BARIUM ISOTOPE COMPOSITIONS OF ALLENDE REFRACTORY INCLUSIONS: *r*-PROCESS EXCESSES AND EVIDENCE FOR ^{138}La DECAY

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Introduction: Previous work on carbonaceous chondrites and refractory inclusions has shown excesses in the isotopes of Ba that include significant *r*-process contributions (^{135}Ba and ^{137}Ba) [1-5]. This information has been used to help understand isotopic heterogeneity and mixing in the early Solar System [4-6]. In this study, we present the Ba isotope compositions of Allende refractory inclusions for which we have previously reported U isotope compositions [7], and additionally provide evidence of ^{138}Ba excesses produced by the decay of ^{138}La.

Samples and Methods: Material from previously dissolved calcium-aluminum-rich inclusions (CAIs) of the Allende meteorite (as described in [7]) was obtained for Ba isotopic and trace element analysis. This sample set includes several group-II CAIs [7]. Barium was separated from the matrix and interfering elements following the procedure outlined in Carlson et al. [5]. Terrestrial rock standards were prepared and measured using the same procedures as the samples.

Measurement of La/Ba ratios was performed on a ThermoX-SII quadrupole ICPMS at Arizona State University. The Ba isotopic compositions of the samples and standards were measured on a Thermo Triton TI at Lawrence Livermore National Laboratory. A ^{134}Ba/^{136}Ba ratio of 0.3078 was used for internal normalization for correction of instrumental mass bias (we note that ^{134}Ba and ^{136}Ba are generated exclusively by *s*-process nucleosynthesis [8]).

Results and Discussion: Relative to terrestrial standards, CAIs of this study show an average excess of 0.51±0.09 ε (2SD) in ^{135}Ba/^{136}Ba and an average excess of 0.19±0.13 ε (2SD) in ^{137}Ba/^{136}Ba. This is consistent with previous work on refractory inclusions [2, 9], but is slightly higher than reported values for bulk chondrites [3, 5-6]. No resolvable excesses or depletions were detected in the *p*-process isotopes of Ba (^{130}Ba and ^{132}Ba).

Evidence of ^{138}La decay. Lanthanum-138 comprises less than 0.1% of all La, and has a half-life of ~105 Ga. Decay of ^{138}La is branched between ^{138}Ce (33.6%) and ^{138}Ba (66.4%). Given the long half-life of ^{138}La, a large range of La/Ba ratios is required to detect in-growth of ^{138}Ba from ^{138}La. Group-II CAIs have experienced a complex thermal history, resulting in a large elemental fractionation of Ba from La. In our sample set, the La/Ba ratio ranges from as low as ~0.05 (in non-group-II CAIs) up to ~1.3 (in group-II CAIs). This elemental fractionation is correlated with ^{138}Ba/^{136}Ba ratios in these CAIs, which ranges from 0.00±0.16 ε^{138}Ba to 0.47±0.13 ε^{138}Ba (2SD). These data provide evidence for the decay of ^{138}La in refractory inclusions and indicate the possibility of further development of a ^{138}La-^{138}Ba chronometer for early Solar System materials.

References: [1] McCulloch and Wasserburg 1978, *ApJ*. **220**, L15. [2] Harper et al. 1992, *Meteoritics* **27**, 230. [3] Hidaka et al. 2003, *EPSL* **214**, 455. [4] Ranen and Jacobsen 2006, *Science* **314**, 809. [5] Carlson et al. 2007, *Science* **316**, 1125 [6] Andreasen and Sharma 2007, *ApJ*. **655**, 874. [7] Brennecka, G. A. et al. 2010, *Science* **327**, 449. [8] Burbidge et al. 1957, *Rev. Mod. Phys*. **29**, 547. [9] Bermingham et al. 2010, LPSC **41**, 1735.