TESTING SOLAR PROTON IRRADIATION MODELS FOR ^{10}Be: CORRELATION WITH ^{138}La. D. S. Burnett[1,3], M.-C. Liu[2], J. M. Paque[1], K. D. McKeegan[2], J. R. Beckett[1]. [1]California Institute of Technology, Pasadena, CA 91125, [2]Department of Earth, Planetary and Space Sciences, University of California, Los Angeles, CA 90095, [3]burnett@gps.caltech.edu.

Introduction: Short-lived radionuclides potentially provide unique views of the local stellar neighborhood, specifically the environments and processes and their timing. ^{10}Be is special in being solely the product of high energy spallation reactions (i.e., it cannot be produced by stellar nucleosynthesis) but the sourcing is, nevertheless, a matter of model-dependent debate hinging primarily on whether spallation occurred via cosmic rays or irradiation from the early sun (e.g., [1-6]). Here, we consider solar proton irradiation of CAI "precursors," either as primary condensates or an earlier generation of CAIs [3-6]. Extant CAIs are not themselves the irradiated objects because proton fluences required to synthesize ^{10}Be would have left many isotopic signatures that are not observed, such as large amounts of co-produced spallation ^{6}Li and noble gases. To account for this, solar irradiation models must assume the loss of volatile elements (including Li and B, but not Be) during or after irradiation. These fractionations complicate testing solar proton irradiation models, in part, because the nature and history of the original target material becomes ambiguous and this can have substantial effects on computed isotopic compositions. For example, initial (^{10}B/^{11}B) of CAIs can be determined from ^{10}Be isochrons and several studies report enhanced (^{10}B/^{11}B) ratios, which are generally interpreted as arising from a mixture of solar and spallation B. If the precursors were chondritic, irradiation models show that producing required amounts of spallation B would produce too much ^{10}Be. Using a CAI bulk composition leads to a more plausible concentration of ^{10}Be [3].

One way to avoid dealing with complications associated with the high volatility of many light elements produced in spallation reactions is to instead measure the isotopic variations of *refractory* elements subjected to the same irradiation that produced ^{10}Be. The best candidate is probably ^{138}La, which is produced by the low energy reaction ^{138}Ba(p,n) and, to a lesser extent, by ^{140}Ce spallation. For ^{138}Ba(p,n), we adopt the measured cross sections from ^{140}Ce(p,n) ([7], reasonable since ^{140}Ce is an N=82 closed shell nucleus like ^{138}Ba), and a proton energy spectrum of the form E^{-a} p/(cm^2-MeV). We set the p fluence (>50 MeV) to produce ^{10}Be/^{9}Be = 5×10^{-4} for a CAI with a 20× CI chondrite enrichment in refractory elements (Be, Ba, La). Table 1 shows that large excesses in ^{138}La over the natural abundances would be expected for the proton fluences necessary to produce ^{10}Be. We also note that predicted ^{138}La excesses are very sensitive to the proton E spectrum because ^{138}La production occurs primarily between 7 and 20 MeV proton energy.

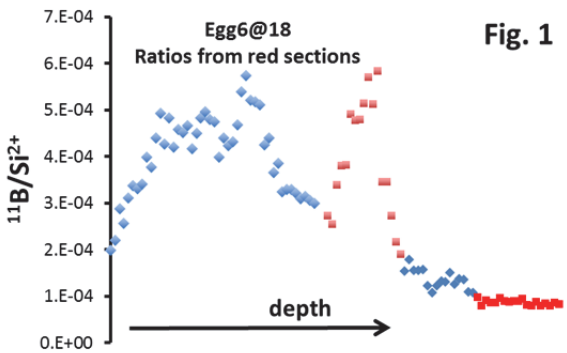
Table 1. Irradiation Model Results

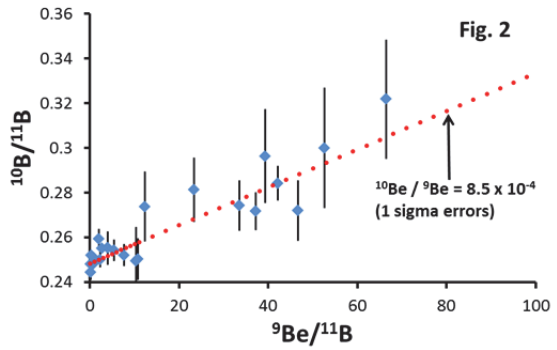
Exponent, a	p fluence/cm^2	δ^{138}La
2	1.3 x 10^{18}	21 ‰
3	1.9 x 10^{18}	270 ‰

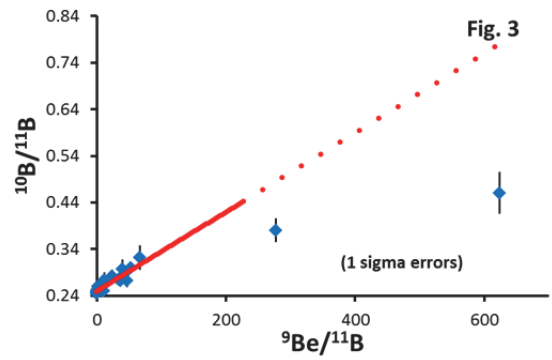
Shen and Lee [8] measured excesses of ^{138}La in four CAIs that ranged from 0 to 6‰. Although excesses were statistically different from zero for three of the four CAIs, all of the excesses were considerably less than values shown in Table 1. Shen and Lee interpreted the measured ^{138}La excesses to indicate UN anomalies since they correlate with ^{50}Ti enrichments in the same CAIs. If, however, the ^{138}La excesses are produced by Solar System irradiation, a correlation of excess ^{138}La and ^{10}Be is expected. Comparison of the ^{138}La excesses of [7] with literature ^{10}Be for the same CAIs gives equivocal results for a correlation because the errors in both ^{10}Be and ^{138}La are large. The CAI Egg 6 is, however, unique in that it shows no excess ^{138}La, so there is a clear prediction that Egg 6 should have no measurable ^{10}Be. We report here Li-Be-B isotopic measurements of Allende Egg 6.

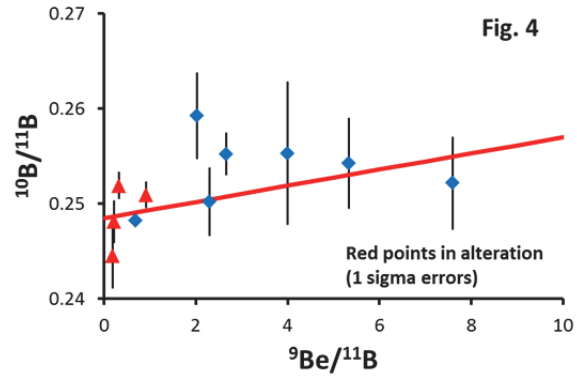
Sample and Analyses: Egg 6 is a type B1 CAI, originally studied because of the presence of large Fremlindge [9]. A section was kindly provided to us by G.J. Wasserburg. Melilite Åk values vary from Åk$_{11}$ at the rim to Åk$_{60}$ in the core. Melilite Na_2O contents increase rapidly beyond Åk$_{50}$ indicating secondary core melting, typical of Type B1 CAIs. Following the approach of [10], we made isotopic and elemental abundance analyses using the UCLA IMS 1270, primarily on melilite, of Li, Be, and B isotopes, normalizing to $^{28}Si^{++}$ as a matrix reference ion. The number of cycles varied depending on the B signals; 5/21 profiles were rejected as showing only B surface contamination.

Results: Considerable structure was observed in some B profiles because of B-rich inclusions, probably alteration veins. For 7 such profiles (e.g., Fig. 1), ^{10}B/^{11}B was calculated for regions selected to avoid or to isolate contributions from the inclusions. For the other 9 profiles, the ratio was calculated based on the deepest region of the profile, after sputtering away surface contamination. Fig. 2 shows that, over most of the range of ^{9}Be/^{11}B, a respectable isochron is









observed which agrees with a reference isochron corresponding to an initial $^{10}Be/^{9}Be = 8.5\times10^{-4}$, comparable to previous literature data. Fig. 3 shows that two highly radiogenic points were encountered, but these lie significantly below the isochron defined by the remainder of the data, most simply explained by a redistribution of radiogenic ^{10}B. The analyses with the lowest $^{9}Be/^{11}B$ are consistent with excess radiogenic ^{10}B compared to the reference $^{10}Be/^{9}Be = 8.5\times10^{-4}$ isochron (Fig. 4), although there is sufficient scatter such that a precise initial $^{10}B/^{11}B$ is not obtained.

Discussion and Conclusions: Egg 6 has clear evidence for ^{10}Be, but no measurable excess ^{138}La. This would be consistent with ^{10}Be not being a product of solar proton irradiation. However, products from such an irradiation depend on details of the assumed irradiation conditions and targets. In particular, ^{10}Be is produced primarily by high energy protons (>50MeV), whereas ^{138}La production from ^{138}Ba would reflect the flux of protons in the 7-20 MeV range. To use solar protons efficiently and to have a sufficiently high temperature for condensation of CAI precursors, production near the Sun is indicated. Nevertheless, a relatively small amount of matter between the Sun and the CAI precursor dust could absorb the lower energy protons that produce ^{138}La but have little effect on the >50 MeV protons that produce ^{10}Be. For example a shell of H_2 gas of 0.4 g/cm^2 between the Sun and the CAI precursor cloud would block passage of protons less than 30 MeV [11]. The rate of p energy loss decreases rapidly with increasing energy in this energy range and ^{138}La production from protons greater than 30 MeV slowing down into the 7-20 MeV range would be inefficient, although we have yet to do detailed modeling of this effect. The thickness of such an absorbing gas cloud depends on the pressure and temperature, but for 1000K, and pressures ranging from 10^{-3} to 10^{-6} atm, gas cloud thicknesses in the range of 10^{-1} to 10^{-4} solar radii are indicated, which seem plausible. An alternative model is synthesis in a thick, well-stirred "thick target" of CAI dust for which ^{138}La would be synthesized only in roughly the outer 0.4 g/cm^2. It is possible that additional measurements would reveal large ^{138}La excesses in other CAIs and that these could be used to refine any connections to ^{10}Be.

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