ISOTOPIC COMPOSITION OF MOLYBDENUM AND BARIUM IN SINGLE PRESOLAR SILICON CARBIDE GRAINS OF TYPE A+B

M. R. Savina[1], C. E. Tripa[2], M. J. Pellin[1], A. M. Davis[2,3], R. N. Clayton[2,3,4], R. S. Lewis[2], S. Amari[5], [1]Materials Science Division, Argonne National Laboratory, Argonne IL, 60439, [2]Enrico Fermi Institute, [3]Department of the Geophysical Sciences, [4]Department of Chemistry, University of Chicago, Chicago IL, 60637, [5]Laboratory for Space Sciences, Washington Univ., St. Louis, MO 63130.

Introduction: Presolar SiC grains fall into several groups based on C, N, and Si isotopic compositions. Approximately 93% are defined as mainstream, having $10 < {}^{12}C/{}^{13}C < 100$ and ${}^{14}N/{}^{15}N$ ranging from 50 to 20,000. A number of studies have shown that the most likely sources of mainstream grains are low mass asymptotic giant branch stars. Models of nucleosynthesis in AGB stars reproduce the *s*-process enhancements seen in the heavy elements in mainstream SiC grains [1, 2]. Among the less common grains, A+B grains, which comprise ~3-4% of presolar SiC, are perhaps the least well understood. Recent studies by Amari et al. show that A+B grains can be divided into at least 4 groups based on their trace element concentration patterns [3]. Of 20 grains studied, 7 showed trace element patterns consistent with condensation from a gas of solar system composition, while the rest had varying degrees of *s*-process enhancements. Our previous measurements on 3 A+B grains showed Mo of solar isotopic composition, but Zr with a strong enhancement in ${}^{96}Zr$, which is an *r*-process isotope but can be made in an *s*-process if the neutron density is high enough to bridge the unstable ${}^{95}Zr$ ($T_{1/2}$= 64 d). The observation of Mo with solar system isotopic composition in the same grains is puzzling however. Meyer et al. [4] have recently shown that a neutron burst mechanism can produce a high ${}^{96}Zr/{}^{94}Zr$ without enhancing ${}^{100}Mo$, however this model leads to enhancements in ${}^{95}Mo$ and ${}^{97}Mo$ not observed in A+B grains. We report here results of Mo measurements on 7 additional A+B grains, and Ba measurements on 2 A+B grains, and compare these to the previous studies.

Experimental: Molybdenum measurements were made on a mount prepared from Murchison grain size separate KJG in a manner similar that described previously [1]. The grains were analyzed at Washington University for Si, C and N isotopes, and 60 were identified as type A+B. The mount was mapped by SEM at theUniversity of Chicago, and a number of grains were analyzed by resonant ionization mass spectrometry (RIMS) at Argonne National Laboratory using methods described in detail elsewhere [5-7]. Of the 17 grains analyzed by RIMS, 7 had enough Mo for analysis. The Mo RIMS scheme was [Kr]4$d^5$5s (^{7}S) → [Kr]4$d^4$5s5p (^{7}P) at 313.350 nm, followed by a 388.337 nm transition to an autoionizing state.

Two grains from different mounts were analyzed for Ba. The first was from Murchison size separate KJG as described elsewhere [8], and the second was from a mount of Indarch SiC prepared at Washington University [9]. The Ba RIMS scheme was [Xe]6s^2 (^{1}S) → [Xe]6s7p (^{1}P) at 307.247 nm, followed by ionization with a photon at 883.472 nm.

Results: Molybdenum and barium isotopic data (with 2σ errors) are given in Tables 1 and 2. The grains fall into three categories: normal Mo or Ba (7 grains), *p*-enhanced Mo (1 grain) and unique Mo (1 grain). The isotopic compositions of the anomalous grains and the weighted average of the "normal" grains are plotted in Figure 1. Isotopic compositions for the normal grains fall close to solar system values with the possible exception of ${}^{95}Mo$, which may be slightly depleted. We have previously measured 3 other Murchison SiC grains of type A+B for Mo [10]; these all had normal Mo as well, bringing the total to 8 (of 10 ten grains measured in all). Grain 133-1 shows an enhancement in the two *p*-isotopes ${}^{92}Mo$ and ${}^{94}Mo$, while the other isotopes are normal within error. This is, to the best of our knowledge, the first observation of an enhanced *p*-process in any grain. Grain 054-1 has an isotopic composition that has not been seen before, since the mixed *r*, *s* isotopes ${}^{97}Mo$ and ${}^{98}Mo$ show enhancements relative to the *s*-only ${}^{96}Mo$, but the mixed *r, s* isotope ${}^{95}Mo$ is not enhanced within 2σ error and ${}^{100}Mo$ is solar. This is somewhat the opposite of the pattern seen in mainstream grains, where the *s*-only isotope ${}^{96}Mo$ is enhanced relative to all others [1], however in mainstream grains the ${}^{92}Mo$, ${}^{94}Mo$, and ${}^{100}Mo$ show the largest deviations whereas in 054-1 ${}^{97}Mo$ and ${}^{98}Mo$ are the only statistically significant anomalous isotopes.

Discussion: In all, we have now measured Zr in 2 A+B grains [10], Ba in 2 grains, and Mo in 10 grains. Both of our Ba measurements and 8 of our 10 Mo measurements show solar isotopic compositions. This is in keeping with the previous findings [3] that many A+B grains show no *s*-process enhancements in their trace element concentration patterns, however we find a much greater fraction of isotopically normal grains (10/12 vs. 7/20). In contrast to the previous work, our results shows no *s*-process enhancement in any of the 14 grains measured. Both of the previous Zr

Table 1: Mo isotopic composition of A+B presolar SiC from the Murchison meteorite.

	δ^{92}Mo/^{96}Mo	δ^{94}Mo/^{96}Mo	δ^{95}Mo/^{96}Mo	δ^{97}Mo/^{96}Mo	δ^{98}Mo/^{96}Mo	δ^{100}Mo/^{96}Mo
341-1	-52 ± 80	-34 ± 92	-100 ± 74	-39 ± 89	-1 ± 74	-86 ± 86
88-10	-57 ± 102	-133 ± 111	-118 ± 95	50 ± 125	-48 ± 93	-6 ± 120
281-1	123 ± 205	-41 ± 208	-234 ± 150	90 ± 224	94 ± 181	-55 ± 203
297-2	-141 ± 264	-78 ± 319	-215 ± 240	1 ± 332	-5 ± 264	141 ± 364
333-2	28 ± 76	54 ± 88	-11 ± 71	36 ± 85	30 ± 68	39 ± 86
"normal" grains average*	-12 ± 47	-19 ± 53	-86 ± 43	5 ± 53	6 ± 43	-26 ± 52
133-1 (*p*-enhanced)	146 ± 38	168 ± 43	10 ± 33	24 ± 38	-44 ± 29	52 ± 39
054-1	177 ± 229	-46 ± 225	178 ± 224	878 ± 361	431 ± 244	18 ± 231

*Weighted by the measured relative Mo abundances.

Table 2: Ba isotopic composition of A+B presolar SiC from the Murchison and Indarch meteorites

	δ^{134}Ba/^{136}Ba	δ^{135}Ba/^{136}Ba	δ^{137}Ba/^{136}Ba	δ^{138}Ba/^{136}Ba
Murchison 342-1		-19 ± 297	77 ± 163	0 ± 123
Indarch 6	-5 ± 179	-49 ± 126	-86 ± 108	-7 ± 93

measurements showed large enhancements in ^{96}Zr [10], however the Mo isotopes in these same grains were solar within error. Our new results show that isotopically normal Mo is the rule rather than the exception in A+B grains. Thus it appears that a model that is able to reproduce the unusual Zr isotope pattern in A+B grains must also account for isotopically normal Mo.

Among A+B grains with anomalous Mo isotopic compositions, the *p*-enhancement seen in grain 133-1 is particularly interesting. This observation is, as noted above, unique. Further, the *p* and *r*- process isotopes in this grain are decoupled: while ^{92}Mo and ^{94}Mo are enhanced, ^{100}Mo is normal. Candidates for *p*-process astrophysical sites such as Type Ia and Type II supernovae should also produce significant deviaitons in other Mo isotopes. The answer may lie in the details of envelope mixing and grain condensation at these sites. ^{92}Mo and ^{94}Mo are among the very few *p*-process isotopes with significant abundances (the others being ^{96}Ru and ^{98}Ru). Further searches for *p*-process enhancements in Mo and Ru in A+B grains would be extremely valuable in elucidating the astrophysical sites of the *p* process.

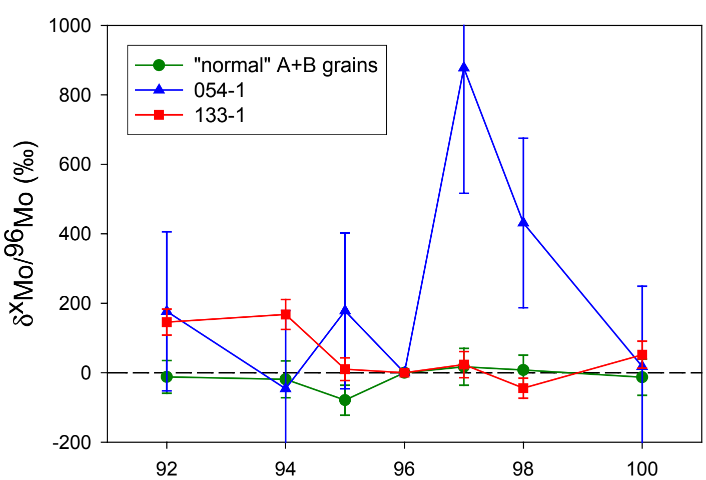

Figure 1: Mo isotopic compositions for grains 133-1 and 054-1, plus the weighted average of the "normal" grains.

Acknowledgements: This work was supported by the Department of Energy, BES-Materials Sciences through Contract No. W-31-109-ENG-38, and by the National Aeronautics and Space Administration through grants NAG5-3986 (RNC) and 9510 (AMD). MJP also acknowledges a NASA grant for this work.

References: [1] Nicolussi, G.K., et al., *Geochim. Cosmochim. Acta*, 1998, **62**(6), 1093-1104. [2] Savina, M.R., et al. *Lunar Planet. Sci. XXXIII*, 2002. abstr. #1962. [3] Amari, S., et al., *Astrophys. J.,* 2001, **559,** 463-483. [4] Meyer, B.S., D.D. Clayton, and L.-S. The, *Astrophys. J.,* 2000, **540**(1), L49-L52. [5] Ma, Z., et al., *Rev. Sci. Instrum.*, 1995, **66**(5), 3168-3176. [6] Nicolussi, G.K., et al., *Anal. Chem.*, 1997, **69**(6), 1140-1146. [7] Savina, M.R., *Geochim. Cosmochim. Acta*, 2002, in press. [8] Amari, S., R.S. Lewis, and E. Anders, *Geochim. Cosmochim. Acta*, 1994, **58,** 459-470. [9] Jennings, C.L., et al., *Lunar Planet. Sci. XXXIII*, 2002, abstr. #1833. [10] Pellin, M.J., et al., *Lunar Planet. Sci. XXXI*, 2000, abstr. #1934.