SPALLOGENIC PRODUCTION RATES IN INTERSTELLAR GRAINS. J. Ray and H.J. Völk, Max-Planck-Institut für Kernphysik, Heidelberg, FRG.

Since the early suggestion by Black (1), there have been many speculations regarding the possibility of finding in meteorites relic noble gas records originally carried by progenitor interstellar grains (ISGs) (e.g., 2,3). It is natural, given such an hypothesis, to inquire into the nature of the accompanying cosmic ray spallation spectrum that would be expected due to a presumably lengthy irradiation interval during residence in the interstellar medium. Various, conflicting opinions on this subject exist in the literature (3,4). Recently, the issue has assumed added interest in the context of proposed explanations for the apparent presolar ages of some Allende white inclusions (5). If these anomalous $^{39}$Ar-$^{39}$Ar ages are ascribed to $^{40}$K decay in ISGs beginning long before their incorporation into meteoritic inclusions (6), then the degree of spallogenic gas retention becomes a crucial component of any test for the role of presolar dust. We have been motivated by these issues to consider in some detail the question of the retention against recoil loss of spallation products formed inside ISGs, using detailed nuclear data on recoil momenta (7).

Assuming the ISGs to form a collection of uniform and homogeneous spheres with a size distribution given by $n(a)$ ($a =$ radius), then the effective production cross section for a spallogenic species is

$$
\sigma_{\text{eff}} = \int_{-\infty}^{+\infty} \frac{d\sigma}{dp} R(p) \, dp
$$

where $R(p)$ is the fractional retention at momentum $p$ found from

$$
R(r) = \frac{\int_{0}^{r} n(a) f_{a}(r) \left(\frac{4}{3} \pi a^{3} da\right)}{\int_{0}^{\infty} n(a) \left(\frac{4}{3} \pi a^{3} da\right)}
$$

and an empirical relation for recoil range $r$ in terms of momentum $p$. The quantity $f_{a}(r)$ gives the fractional retention for recoil range $r$ inside a spherical grain of radius $a$, considering geometrical effects and range straggling. We have adopted the empirical results of Greiner et al. (7) for $d\sigma/dp$, the ISG size distribution of Mathis et al. (8) and evaluated the above equations numerically to find $\sigma_{\text{eff}}$. Of all the rather uncertain ISG parameters, it is found that the grain material density is the most important in its effect upon the calculated retentivity. Results are given in Table 1 for production of $^{38}$Ar, where the error bars express the range of variation associated with allowing a factor 5 uncertainty in grain density ($\sim 0.7$ to $\sim 3.5$ g cm$^{-3}$).

Assuming two main chemical forms for ISGs (i.e., carbonaceous and oxide) and that the target nuclides for $^{38}$Ar production reside entirely in the oxide fraction, with a major element form $\text{MgO SiO}_{2} \text{FeO}$, yields a production rate $P^{(38}\text{Ar}) = (0.26 \pm 0.09) \times 10^{-8} \text{cm}^{3} \text{ STP g}^{-1}(10^{8} \text{y})^{-1}$.

It should be emphasized that this rate applies only to production by high energy spallation reactions, corrected only for recoil losses. Possible contributions by low-energy reactions have not been included so that the rate above must be regarded as a lower limit. While the amounts of cosmogenic $^{38}$Ar indicated, for ISM residence times of $10^{8}$-$10^{9}$y, are significant relative to the concentrations measured in Allende white inclusions or bulk CI chondrites, the values are not so large as to render implausible the hypothesis of non-redistributed presolar gas. Arguments which attempt to exclude this possibility on the basis of bulk spallogenic gas concentrations (e.g., 4) have assumed that the production spectra for ISGs are the same as for whole rock meteorites,
a circumstance which we would not expect to be true. Until low energy, thin target calculations are performed for ISGs, the argument of Wasson (4) cannot be accepted as strictly valid.

TABLE 1: Spallation cross section for production and retention (against recoil) of $^{38}$Ar in ISGs

<table>
<thead>
<tr>
<th>Target Nuclide</th>
<th>$\sigma_{total}$ a (mb)</th>
<th>$\sigma_{eff}$ b (mb)</th>
<th>Fractional Retentivity c</th>
</tr>
</thead>
<tbody>
<tr>
<td>$^{56}$Fe</td>
<td>12</td>
<td>2.3±0.8</td>
<td>0.19±0.07</td>
</tr>
<tr>
<td>$^{48}$Ti</td>
<td>30</td>
<td>6.9±2.4</td>
<td>0.23±0.08</td>
</tr>
<tr>
<td>$^{40}$Ca</td>
<td>32</td>
<td>13.4±4.2</td>
<td>0.42±0.13</td>
</tr>
<tr>
<td>$^{38}$K</td>
<td>50</td>
<td>27.0±7.5</td>
<td>0.54±0.15</td>
</tr>
<tr>
<td>$^{55}$Mn + $^{52}$Cr</td>
<td>12</td>
<td>2.4±1.0</td>
<td>0.20±0.08</td>
</tr>
</tbody>
</table>

a Thin-target cross sections (mb) for 600 MeV protons as reported by Stoenner et al. (9). Absolute errors are given as 5-10%.
b Calculated using $n(a) = a^{-3.5}$ for grain radius between $a_\text{min} = 250 \AA$ and $a_\text{max} = 2500 \AA$ (see (8)); using a Gaussian distribution of ranges about a projected range $r_0$ with a standard deviation $\Delta r = 0.40 r_0$; and using a scaling relation for the projected range in terms of momentum

$$r_0 = \bar{r}_0 \left[ \left( \frac{E}{Zm} \right)^{0.5} \right]$$

where $\bar{r}_0$ is the range inside ISGs of $^{38}$Ar with mass $m$ at the normalizing kinetic energy of 0.1 MeV. For $\bar{r}_0$ we have used the two values of 750 $\AA$ and 3750 $\AA$ which consider the possible uncertainty in grain density; the error limits are fixed by the two density extremes.
c The fractional retentivity is $\sigma_{eff}/\sigma_{total}$.

References: