# ABUNDANCES OF 'SECONDARY' ELEMENTS AMONG THE ULTRA HEAVY COSMIC RAYS - RESULTS FROM HEAO-3

J. Klarmann[a], S. H. Margolis[a], E. C. Stone[b], C. J .Waddington[c], W. R. Binns[a], T. L. Garrard[b], M. H. Israel[a] and M. P. Kertzman[c]

[a]Department of Physics and the McDonnell Center for the Space Sciences, Washington University, St. Louis MO 63130, USA.
[b]George W. Downs Laboratory, California Institute of Technology, Pasadena CA 91125, USA.
[c]School of Physics and Astronomy, University of Minnesota, Minneapolis MN 55455, USA.

**1.Introduction.** This paper discusses observations of the abundances of elements of charge $62 \leq Z \leq 73$ in the cosmic radiation from the HEAO-3 Heavy Nuclei Experiment (HNE). These elements, having solar, and presumably source, abundances much less than the heavier Pt and Pb groups, are expected to be largely products of spallation. Thus they are indicators of the conditions prevailing during the propagation of cosmic rays. The abundances have changed from those reported previously (Klarmann et al., 1983) due to a different data selection (Binns et al., 1985). This resulted in better charge resolution and in a higher mean energy for the particles. All the particles we have included in this paper were required to have had a cutoff rigidity $R_c > 5$ GV. This allowed the charge determination to be based solely on the Cherenkov measurement. For a description of the detector see Binns et al., (1981).

**2. Analysis.** The data selection in this paper is identical to that of Waddington et al., (1985, OG4.4-7). We have considered only the following physically significant groups of charges:

| Name | Abbreviation | Range | Number observed |
|---|---|---|---|
| Lead and Platinum | PbPt | $74 \leq Z \leq 86$ | 52 |
| Heavy secondary | HS | $70 \leq Z \leq 73$ | 10 |
| Light secondary | LS | $62 \leq Z \leq 69$ | 34 |

Our discussion will be in terms of the ratios: HS/PbPt and LS/PbPt. In the table, column a) shows the results observed in the detector. The correction factor to outside the detector was derived by propagating eight different plausible theoretical abundances outside the detector through slabs of hydrogen approximating the distribution of aluminum traversed by the particles going into and through the detector. The change of the abundance ratios from outside the detector to inside was nearly independent of the original ratios and is given as a multiplicative correction factor in column b). The abundance outside the detector, column c) is the product of columns a) and b).

| Ratio | HEAO Results | | | Ariel | HEAO/Ariel |
|---|---|---|---|---|---|
| | Inside Detector a) | Correction Factor b) | Outside Detector c) | Outside Detector d) | Outside Detector e) |
| HS/PbPt | 0.19±0.07 | 0.85±0.02 | 0.16±0.06 | 0.27±0.07 | 0.59±0.27 |
| LS/PbPt | 0.65±0.14 | 0.87±0.02 | 0.57±0.12 | 0.88±0.15 | 0.65±0.18 |

Results from the Ariel-6 UH-nuclei detector which was exposed in a 55° inclination orbit (Fowler et al., 1984) are given in column d), while column e) gives the ratio of our HEAO results to those of Ariel. It is seen that for both ratios our result is about 60%

to 65% that of Ariel's. While these differences are only significant at a level of 1.5 to 2.0 standard deviations, it is unlikely that they are just statistical fluctuations. The data of Ariel extend to significantly lower energy than ours. At lower energies the abundance of secondaries is expected to be greater since both the interaction cross sections and the escape length are larger. We cannot tell yet whether this energy dependence is sufficient to explain the difference.

**3. Comparison with Models.** The abundance ratios can be compared with predictions of various models. The source abundance used was either the solar system abundances of Anders and Ebihara (1982) (No FIP) or the same adjusted for an exponential dependence (Brewster et al., 1983a) on the first ionization potential (FIP). These were then propagated through the interstellar medium, assuming a leaky-box model, and using the revised code of Brewster et al., (1983a, 1985) with a rigidity dependent escape length (Ormes and Protheroe, 1983) that is 6.21 g/cm of hydrogen at 7 GV. The calculated values are for approximately the same mix of rigidities as the HEAO data. A different model of FIP fractionation (Cook et al., 1979; J. P. Meyer, 1981), in which the cosmic ray source is suppressed by a constant factor relative to solar abundances for elements with ionization potential above 9 eV, yields propagated abundance ratios which in, this charge range, are indistinguishable from those of the unfractionated source. Similarly, propagation of an r-process source abundance yielded ratios which in this charge region were close to those from a solar system source. Neither of the last two results is plotted in figure 1.

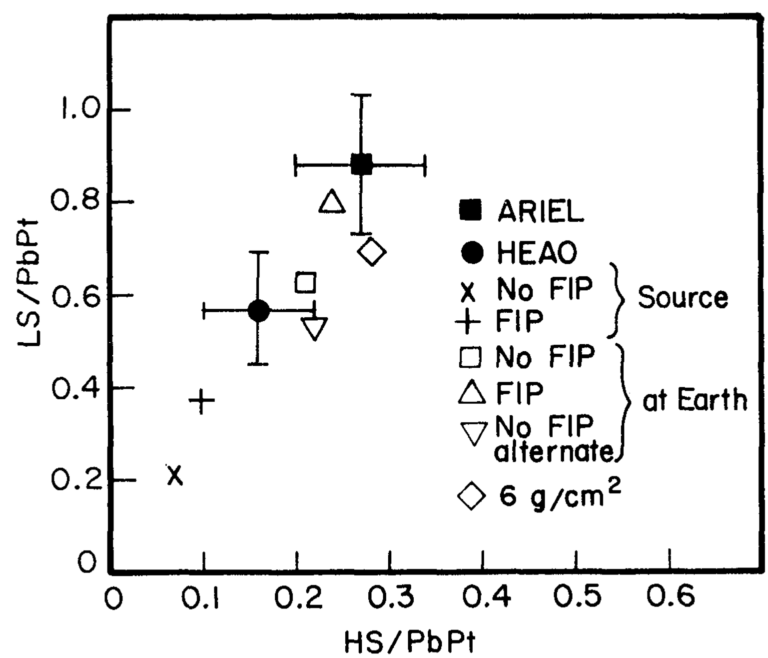


**Figure 1: Comparison of the observed and predicted abundance ratios.**

In the 'No FIP alternate' propagation an independent code was used (Margolis, 1983) to predict the abundance ratios after propagation through leaky boxes of various escape lengths. The results were then combined using the same rigidity dependent escape length distribution as above to yield the inverted triangle point in figure 1. With this rigidity dependent distribution the mean escape length encountered by the observed particles is $\sim 3 g/cm^2$. This point, when compared to the other No FIP point, is an indication of the variation possible in the propagation calculation. The point labeled '6 g/cm$^2$' in figure 1 is the result of the same propagation through a leaky box with a single escape length of 6 g/cm$^2$ of hydrogen. The difference between this point and the 'alternate' point shows the dependence of the results on the escape-length distribution. In figure 1 experimental values are solid with error bars.

The dependence of the abundance ratio on propagation can also be demonstrated in a different way. Every point in figures 2 and 3 (Margolis and Blake, 1985) corresponds to the calculated ratio after propagation of a solar system source without FIP through hydrogen with a mean free path distribution rising linearly from zero to the desired 'truncation' then falling exponentially with the given 'escape length'(Margolis, 1983).

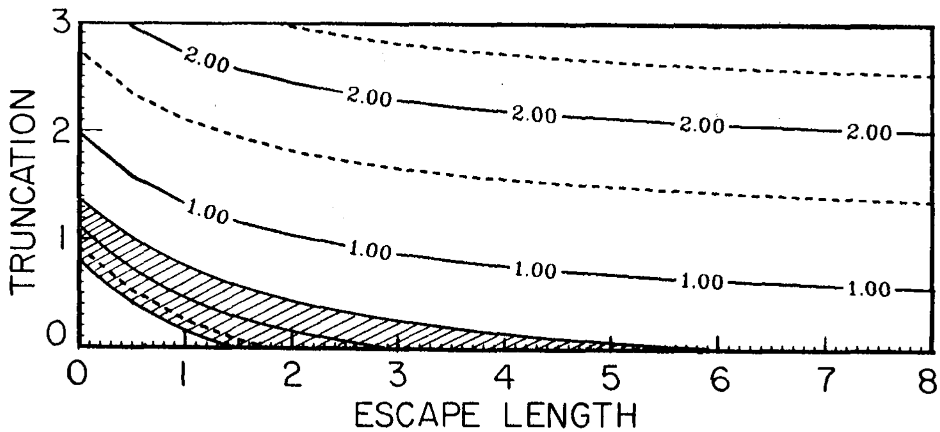


**Figure 2: LS/PbPt**

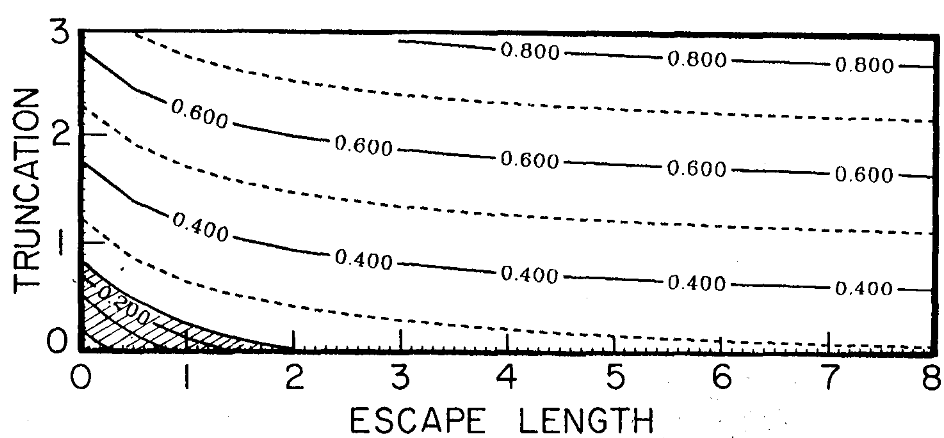


**Figure 3: HS/PbPt**

In contrast to the data in figure 1, these figures assume that all particles traverse the same path length distribution. Our results are represented by the cross-hatched region yielding possible combinations of escape length and truncation.

As expected the predictions in this charge region are nearly independent of escape-length since the interaction mean free path is so short. However the results do not agree with more than a minute amount of truncation of short path lengths. The fact that at zero truncation an escape length of $\sim 2 g/cm^2$ is indicated seems to support the rigidity dependent escape length proposed by Ormes and Protheroe, (1983).

**4. Discussion.** Our observed values of the secondary ratios are in reasonable agreement with the prediction based on a model without FIP fractionation or with a step function FIP fractionation at the source; however, our observations are in distinct disagreement with the models that include exponential FIP fractionation. This is contrary to the conclusions found at lower charges (Binns et al., 1982, 1983) where observed abundances agreed better with those expected from a solar system source with FIP fractionation than without. Thus other representations of source fractionation may be involved.

Our results do fit the predictions obtained using the standard leaky box model in this energy range. The applicability of this model to lower energies requires further investigation.

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**6. References:**

Anders, E., and Ebihara, M., 1982, Geochimica et Cosmochimica Acta, **46**, 2363.
Binns, W. R. et al., 1981, Nucl. Inst. Meth., **185**, 415.
_______., 1982, Ap.J. (Letters), **247**, L115.
_______., 1983, Ap.J. (Letters), **267**, L93.
_______., 1985, Ap.J. **297**, in press.
Brewster, N. R., Freier, P.S. and Waddington, C.J., 1983a, Ap.J., **264**, 324
Brewster, et al., 1983b, 18th ICRC, Vol. 9, p. 259.
Brewster, N.R., Freier, P. S. and Waddington, C. J., 1985, Ap.J. **294** in press.
Cook, W. R., et al., 1979, 16th ICRC, Vol. 12, p. 265.
Fowler, P. H. et al., 1984, 9th European Cosmic Ray Symposium.
Klarmann, J. et al., 1983, 18th ICRC Vol. 9, p.279.
Margolis S. H., 1983, 18th ICRC, Vol. 9, p. 267.
Margolis, S. H. and Blake, J. B., 1985, Ap. J. (in press).
Meyer, J. P., 1981, 17th ICRC, Vol. 2, p. 281.
Ormes, J. F., and Protheroe, R. J., 1983, Ap.J. **272**, 756.
Silberberg, R., and Tsao, C. H. 1983, Ap.J. Supp. **25**, 315 and 335.
Waddington, C. J. et al., 1985, this conference, paper OG 4.4-7.