IMPLICATIONS OF CROSS SECTION ERRORS FOR COSMIC RAY PROPAGATION

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ABSTRACT

Errors in nuclear interaction cross sections are the single most important limitation on the analysis of cosmic ray composition data. In the 18th International Cosmic Ray Conference, Hinshaw and Wiedenbeck (1983) demonstrated the potential importance of correlations in cross section errors in determining cosmic ray source abundances. In this paper we estimate the magnitude of cross section error correlations. Our analysis suggests that cross section errors are essentially uncorrelated for nuclei with $Z < 29$ and that the actual errors may be less than the nominal 35%.

1. Introduction. Uncertainty in nuclear interaction cross sections is the most important limitation on the analysis of cosmic ray composition. Cosmic ray primaries, such as C, O, and Ne, have 5-20% source abundance uncertainties due to errors in estimating the contribution of fragments of heavier nuclei. These errors have a more profound impact as the contribution of secondaries grows. Thus a more detailed understanding of pre-acceleration atomic selection effects awaits improved source abundances for Na, Al, and Ca. Consistency of the N source abundance remains doubtful because of the uncertain O --> N cross sections. Source abundances of K, Ti, V, Cr, and Mn, though possibly not negligible, are entirely obscured by cross section errors.

Hinshaw and Wiedenbeck (1983) analyzed the uncertainties involved in computing cosmic ray source composition from observed abundances. Their analysis included measurement error, total and partial cross section error, and mean pathlength uncertainty. They demonstrated that cross sections are the dominant source of uncertainty. More importantly, they left open the possibility that cross section errors are strongly correlated, meaning only source abundances of pure primaries can be reliably derived from compositional measurements.

In this paper we show that cross section correlations in the semi-empirical formulas (Silberberg and Tsao, 1973 and Silberberg et al., 1985) are essentially negligible in cosmic ray propagation calculations concerning $Z < 29$. Our conclusion is based on the excellent agreement between secondary abundances measured by the French-Danish experiment on HEAO-3 (Engelmann et al., 1983) at 3.99 GeV/N and a primitive propagation model.

2. Method of Calculation. A standard cosmic ray propagation model (Letaw et al., 1984) with exponential pathlength distribution having a rigidity-dependent mean pathlength of $\Lambda R^{-0.6}$ g/cm^2 was used. Initially the source composition was taken as the solar system abundances of Anders and Ebihara (1982). Semi-empirical cross sections were used throughout. Errors of partials were assumed to be 35%.

For fixed values of Λ a propagation was performed iteratively. Primary and secondary contributions were tracked independently. In each iteration, the required fractional increase in the primary arriving abundance needed to match observed abundances was determined. The source elemental abundances were then corrected by these fractions. Isotopic ratios at the source were left unchanged because experience indicates these have little effect on arriving elemental abundances. Eventually the source abundances stabilize. For each element an abundance is given with uncertainty estimated using uncorrelated and correlated cross sections.

To fix the best value of Λ we analyzed the abundances of 9 secondaries (Be, B, F, P, K, Cl, Sc, Ti, V) for several possible choices. These elements should have nearly zero source abundance. Calculated source abundances are shown in Figure 1 as a function of Λ. Note that all values shown are within one standard deviation of zero. Their deviations from zero were divided by the source uncertainties, squared, and summed. This quantity is a measure of the group's proximity to zero and is shown in Figure 2. It is minimized when $\Lambda = 25$ (with 70% confidence that it is between 23 and 26.5).

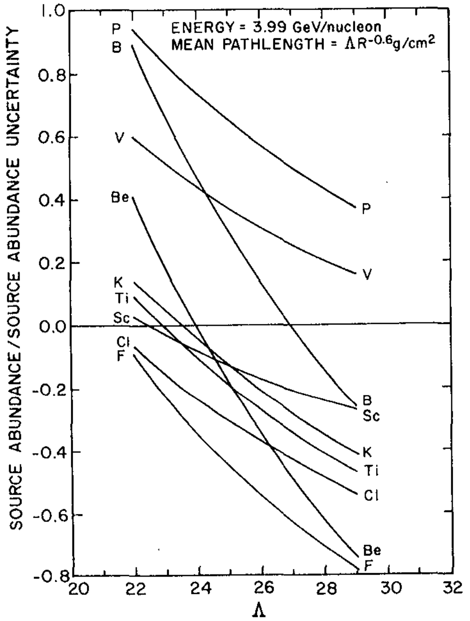

Fig 1. Deviation of some "secondary" source abundances from zero versus pathlength.

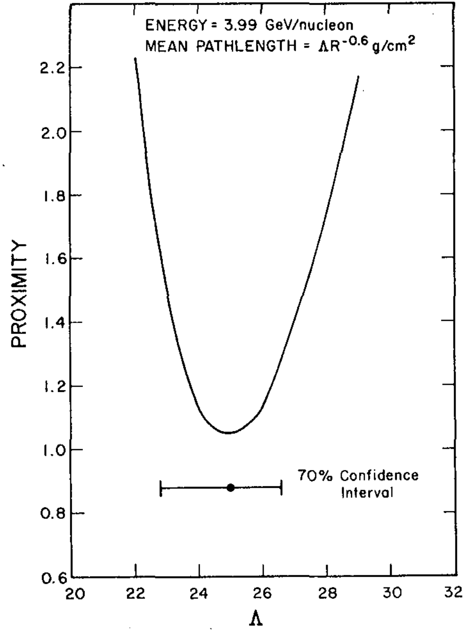

Fig. 2. Proximity of 9 "secondary" source abundances to zero versus pathlength.

There are two important implications of this procedure. First, heavier elements are now allowed to participate in determining the mean pathlength. We believe this approach is advisable when overall source uncertainties of the heavier elements are comparable to those of Li, Be, and B. Second, uncertainty in Λ (i.e., uncertainty in one aspect of the propagation model) should not further increase the computed uncertainties in the source abundances. An indeterminate uncertainty resides in the model. It is not possible to quantify model uncertainties because the model cannot be independently validated.

3. Results. Figure 3 shows some results of the propagation described above. The deviation of computed arriving abundances (with their correlated and uncorrelated uncertainties) from observed arriving abundances of the 9 secondaries are shown. We note first the excellent agreement of this primitive cosmic ray propagation model with the high energy experimental data. Only in one case does the difference amount to more than one standard deviation. This leads us to Conclusion 1: Even simple cosmic ray propagation models provide an excellent representation of the interstellar transport process (with respect to composition).

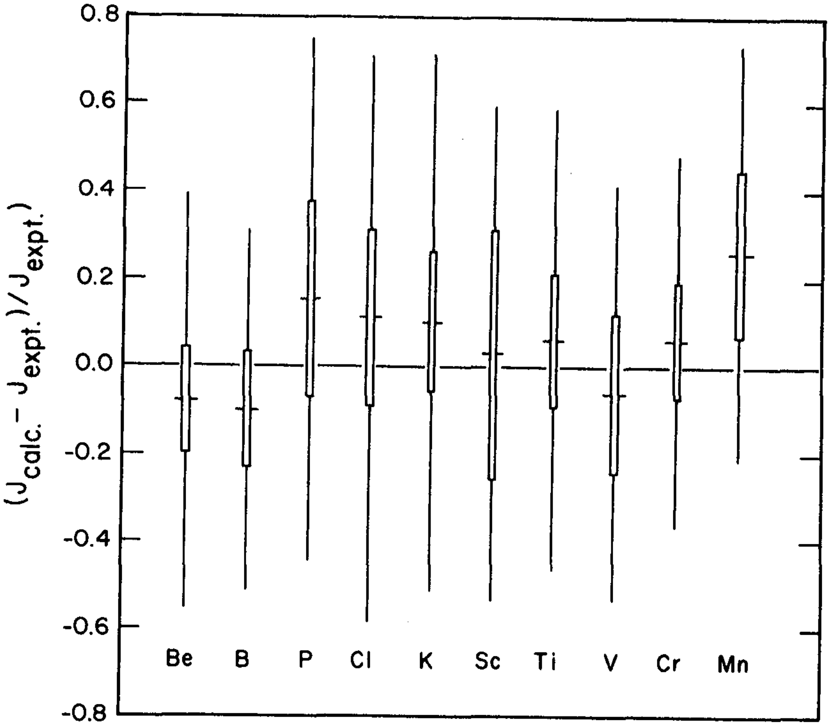

Fig. 3. Comparison of observed and computed source abundances for 9 cosmic ray secondaries. Estimated errors are larger for correlated cross section errors.

A disturbing feature of Figure 3 is that the agreement with experiment is too good. We should expect several of the elemental abundances to differ by more than one sigma. The mean deviation is about 12%. For uncorrelated cross section errors a mean deviation of 18% is expected, while for correlated errors a deviation of 50% is expected. Using the χ^2 test we estimate the probability that agreement with experiment would be so good if uncertainties are properly estimated. In the case of correlated cross section errors (larger uncertainties) the probability appears to be less than 2 in 10^4. For uncorrelated cross sections the probability is about 0.18. Conclusion 2: while we cannot rule out the possibility of error correlations, it appears that cross section error correlations are negligible in cosmic ray propagation. Even with uncorrelated errors the agreement with experiment is improbable suggesting that the nominal 35% cross section uncertainty is too high an estimate for $Z < 29$.

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