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A DATABASE OF FRAGMENTATION CROSS SECTION MEASUREMENTS APPLICABLE TO COSMIC RAY PROPAGATION CALCULATIONS

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Abstract

A database of single particle inclusive fragment production cross section measurements has been established and is accessible over common computer networks. These measurements have been obtained from both published literature and direct communication with experimenters and include cross sections for nuclear beams on H, He, and heavier targets, and for H and He beams on nuclear targets, for energies >30 MeV/nucleon. These cross sections are directly applicable to calculations involving cosmic ray nuclear interactions with matter. The database includes projectile, target, and fragment specifications, beam energy, cross section with uncertainty, literature reference, and comment code. It is continuously updated to assure accuracy and completeness. Also available are widely used semi-empirical formulations for calculating production cross sections and excitation functions. In this paper we discuss the database in detail and describe how it can be accessed. We compare the measurements with semi-empirical calculations and point out areas where improved calculations and further cross section measurements are required.

<u>Introduction</u>: The cosmic ray isotope flux observed near Earth contains virtually all known stable and long lived isotopes, reflecting the complex history of primaries and secondaries as they traverse the interstellar medium. The spectrum of a given isotope will include contributions from the cosmic ray source as well as from fragmentation of many different parents that can fragment into the observed isotope. This process of multiple parentage gives each observed isotope a potentially very complex pedigree. The relative importance of any parent depends on the fragmentation probability to the isotope of interest as well as on the relative abundance of the parent in the cosmic ray flux. Many observed isotopes are dominated by the primary flux from the cosmic ray source, such as ^{16}O or ^{12}C. Others are dominated by contribution from a single parent type, such as ^{55}Mn

which has significant energy dependence. An excellent example of this is found in the ^{34}S and ^{30}Si isotopes, which have important contributions from K, Ar, S, Ca, and Fe parents. Interpreting the relative abundances of these isotopes demands detailed knowledge of the fragmentation properties of a wide variety of nuclear species.

In this paper we describe a nuclear fragmentation cross section database for use in cosmic ray propagation calculations. We have established this data base to aid in determining the accuracy to which fragmentation cross sections are measured or calculated. Our intent is to keep this database current and easily accessible by the community. It presently contains over 3000 entries from over 100 references and is easily accessed through FORTRAN subroutine or through interactive programs available on HEPNET or SPAN (Goren et al., 1987).

Description of Database: Data entered into the database has been selected from the published literature wherever possible. Key words used in literature searches include **fragmentation, nuclear, cross section, isotope, spallation** in various logical combinations. Private communications are replaced as the data become published. We have concentrated on entering isotope production rather than element production cross sections since our goal is, at least in part, to understand better the nuclear systematics revealed through the fragmentation process. A coded comment pertaining to experiment type, sensitivity, or quality is entered with each data point.

The database consists of a header record followed by a number of data records stored as simple ASCII characters formatted as shown below:

Database Format

$Z_B, A_B, E_B, Z_T, A_T, Z_F, A_F, \sigma(BT\text{->}F), d\sigma$, ref., comment

where B indicates beam, T target, and F fragment, σ is the cross section and $d\sigma$ is the measurement error. This file can be accessed directly over the HEPNET/SPAN networks and copied from our NASA nodes at LBL or LSU. All references are numbered and refer to the order in a file REFERENCES.REF. That file is also stored in ASCII character format and can be copied or read from either node. The final file of the set is the COMMENTS.DOC file, again stored in ASCII format for ease of use. To gain access to this information, please send a letter on your institutional letterhead requesting access to the area to one of the authors of this manuscript.

The data available includes isotope and element production cross sections over the whole periodic table. Some of this data is from proton and ^{4}He irradiations of nuclear targets in which secondary yield is determined radiochemically. Other data is from nuclear beams interacting with nuclear targets in experiments having only elemental secondary identification capabilities. Most of the data, however, is from nuclear beams interacting with nuclear targets in experiments that have secondary isotope identification capability.

Often the proton target information is extracted from CH_2 - C methods that allow the use of simple solid targets. Our new experimental program will employ liquid hydrogen and helium targets to increase our measurement efficiency for the cosmic ray related problems of fragmentation (Guzik et al., 1990). We welcome additions and corrections to this database supplied by the user community. If you have suggestions, please address them to any of the above authors and we will attempt to include these in subsequent versions of the database.

<u>Comparison to Semi-empirical Models:</u> It is prohibitively expensive in both time and resources to measure every cross section relevant to the cosmic ray propagation problem. Thus, a number of authors have developed semi-empirical formulations that are tuned to fit existing data and used to predict unmeasured cross sections. Most successful among these has been the approach of Silberberg and Tsao (S&T) (Silberberg, R. and T.Tsao, 1987) . We show in Figures 1 and 2 two ways in which the database can be used to check the accuracy of both the data and a prediction formula .

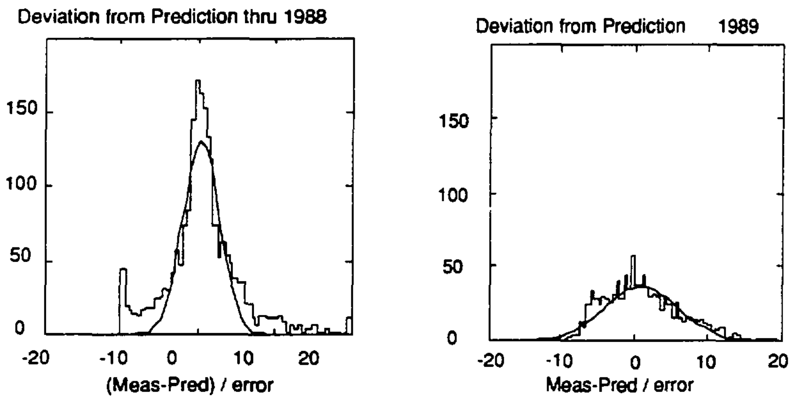
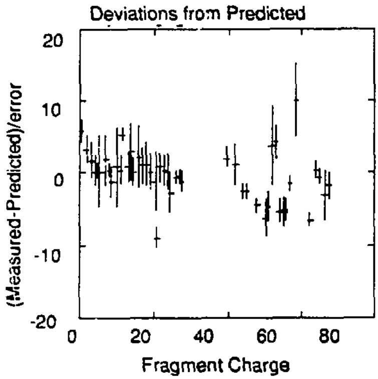


Figure #1

We form a measure of "goodness of fit" using the value of the difference between the measured and predicted cross sections divided by the error, which is found by adding in quadrature the measurement error and a 10% uncertainty in the prediction. In Figure 1 we show two views of the data: in 1a, we compare the semi-empirical prediction with data available at the time of the last modifications to the code; in 1b, we compare predictions to new data, a measure of the accuracy with which "extrapolations" may be made. The average deviation for the new data is 5 units compared to 2 for the older. If all errors were correct and the hypotheses of the predictor rigorous, we would expect these deviations to be 1 unit. For secondaries whose yield is well mapped in energy space, such as ^{7}Be, predictive code is very good indeed.



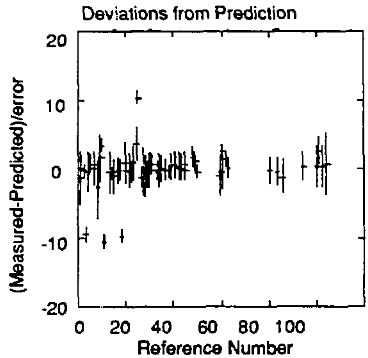


Figure 2a and 2b

In Fig.2a we compare the predictions of the S&T code to both element and isotope data. A number of conclusions can be drawn here, including the fact that the mean and moment of deviations varies greatly with fragment charge In Fig.2b we show the same quality factor only we plot it against reference number to illustrate the fact that the predictive formula is quite good for data from a number of experiments, but that certain reported measurements deviate substantially from the prediction.

Other authors have also developed semi-empirical formulae for predicting fragmentation cross sections, most·recently the New Hampshire-Saclay groups (Webber et al. 1989) and the HEAO collaboration (Binns et al. 1989). The former have fit their model to data from more than 100 secondary elemental production cross sections and over 300 secondary isotope production cross sections from 42 beam-energy combinations on a hydrogen target, and achieved an accuracy of better than 10%. The latter have concentrated on elemental yields from very heavy beams (La and Au) on various targets and incorporated nuclear systematics to convert to isotope production predictions, showing very satisfactory agreement with the data using only seven free parameters.

Conclusions : It is useful to have an easily accessible database for comparing predictions to measured data as a means of developing or verifying semi-empirical approaches to cross section prediction. In addition, the database makes clear where measurements are needed to make interpretation of cosmic ray propagation calculations more reliable.

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