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Yields of medium mass nuclear fragments: Statistical emission

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The results of a calculation using a newly developed statistical emission formalism are compared with the recently published data of Finn *et al.* for nuclear fragment yields from high energy proton-nucleus interactions on ^{132}Xe. Good agreement is noted.

[NUCLEAR REACTIONS Statistical emission, heavy mass fragments from high energy reactions.]

In a recent Letter Finn *et al.*[1] and Minich *et al.*[2] present intriguing data on nuclear fragmentation following high energy (80–350 GeV) proton bombardment of Xe and Kr. They report isotope-separated multiplicity measurements of nuclides of mass up to 30 and show a spectra of ^{12}C from Xe. The mechanism underlying the production of this range of fragments remains unclear.

We wish to report here the results of a calculation performed with a statistical emission formalism designed to integrate the time evolution of an ensemble-averaged system as it deexcites through the emission of particles. We allow for the emission of all particle-stable nuclides for mass less than 21 and for those particle-unstable resonances when the lifetime is long compared with the emission time. The statistical emission is governed by a phase space for the excited system which we take as that of a Fermi gas of neutrons and protons with a density of nuclear matter. Separation energies are provided by a conventional liquid drop model which ignores pairing and shell effects. The formalism provides the integrated multiplicities and spectra of each species for a nuclear system of given mass and charge which deexcites from an initial temperature (or excitation energy). Further details of the formalism are discussed in Ref. 3.

We show here the results of a calculation done on ^{132}Xe for comparison with the data of Ref. 1. We have taken the initial temperature for the ^{132}Xe nucleus to be 15 MeV, which corresponds to an initial excitation of 1.47 GeV. The details of this excitation process are not our concern here. However, we point out that the assumed excitation energy is very small compared with the incident proton energy, and if the primary proton undergoes, on average, five collisions while passing through the ^{132}Xe nucleus (corresponding to a mean free path of 2.5 fm) the 1.47 GeV excitation amounts to the transfer of about 300 MeV with each collision. By assuming 15 MeV as the initial temperature we obtain the spectrum for ^{12}C shown in Fig. 1 where a comparison with the data of Ref. 1 is indicated. The location of the peak and the shape of this spectrum is influenced by the complicated time evolution of the decay process, since the formalism predicts the ^{12}C to be emitted principally at later stages after the system has cooled to temperatures of about 7 MeV. At this point in the process the Coulomb barrier has been reduced from its initial value of near 40 MeV, and the decaying system has acquired a substantial (random) recoil velocity. The agreement in Fig. 1 is excellent.

The same calculation predicts that the mean number of charged primary fragments is 22.8, which must be augmented by about 1.4 additional particles arising from the decay of resonant states. This number is in good agreement with reported observation of an average of 20 tracks of charged particles equal to or heavier than the proton mass. The emission calculation provides, after the decay of resonances, about 8.1 proton and 23.3 neutron. This is a yield of about 2.9 neutrons for each proton rather than the 1.3 neutron contribution assumed in Ref. 1. We thus find 31.3 mass-1 particles compared with 18.6 mass-1 particles, which would result from the assumed 1.3 ratio of Ref. 1 given a mean yield of 8.1 protons.

In Fig. 2 we show the predicted yield of particles as a function of fragment mass which results from the same calculation that provides spectra in Fig. 1. For comparison with Ref. 1 we provide a mass-1 point following the neutron assumption of that paper and indicate the curve $A^{-2.64}$ passing through that point for comparison. The agreement between experiment and calculation for mass yields 12 to 20 is excellent. Our calculation provides substantially greater yields of particles in the mass 6 to 10 region. It is noted in Ref. 1 that the yield of the specific isotope ^{8}Li provides approximately 7% of all fragments of lithium or heavier. For

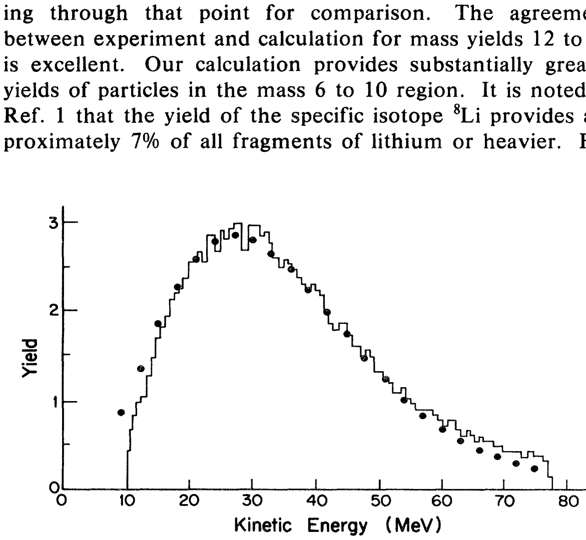

FIG. 1. Spectrum of ^{12}C fragments from ^{132}Xe. Histogram: data from Ref. 1. Points: statistical emission calculation with maximum temperature 15 MeV.

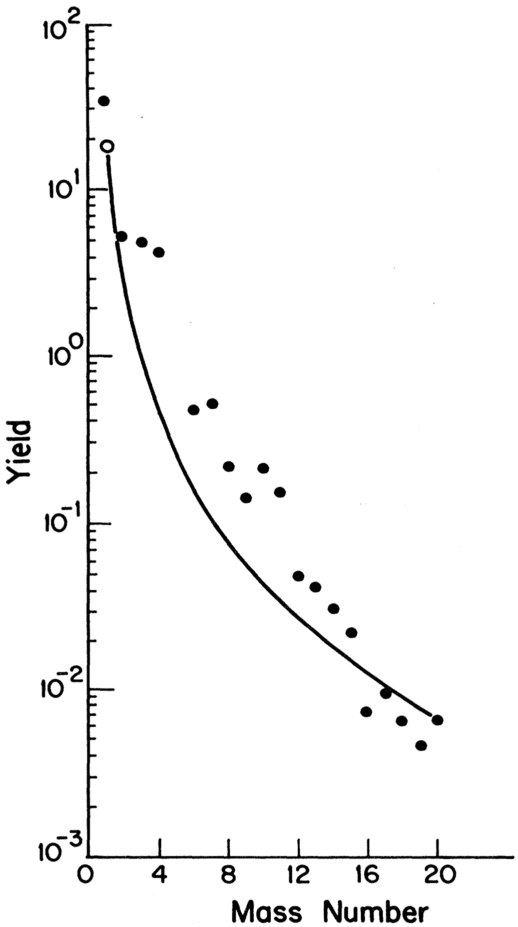

FIG. 2. Yield of fragments by mass from ^{132}Xe. Points: statistical emission calculation as in Fig. 1. Curve: $A^{-2.64}$ passing mass-1 point (open circle) obtained according to Ref. 1.

this isotope (^{8}Li) our calculation provides a yield, including all particle-stable states, which represents 10.9% of the fragments with charge greater or equal to 3. (The yield of ^{8}Li in its *ground state* represents 7.1%.)

Finally, we show, in Fig. 3, the calculated multiplicities for isotopes of C, N, and O resulting from the same calculation for ^{132}Xe. The separation energies for these isotopes were computed using a standard liquid drop model without shell corrections, and some inaccuracies may result from this procedure. We have, however, attempted to include quantitatively the particle-stable states of each nuclide in determining the statistical yields. The calculation illustrates the effectiveness of the statistical evaporation process for producing isotopes far from the "valley of stability."

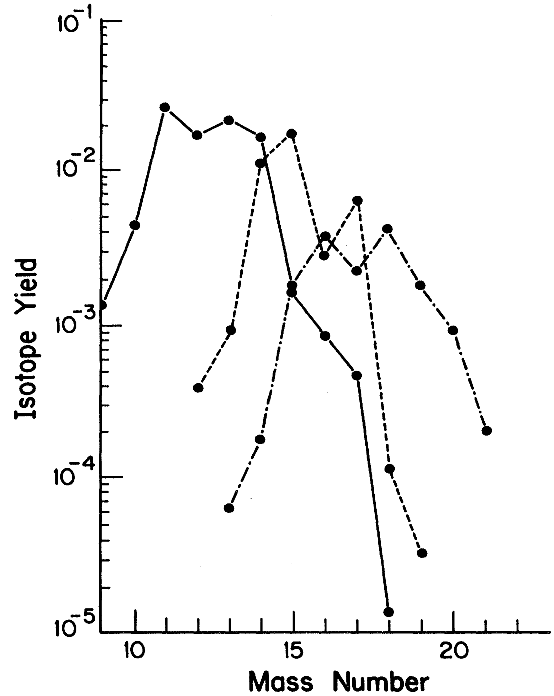

FIG. 3. Isotope yields from ^{132}Xe from statistical emission calculation as in Fig. 1. Solid line: isotopes of C; dashed line: isotopes of N; dot-dashed line: isotopes of O.

In summary, we have reported a single calculation for the statistical fragment yield from ^{132}Xe excited to an initial temperatue of 15 MeV. We observed striking agreement in the following features: (a) calculated spectra of ^{12}C; (b) the average multiplicity of charged particles; and (c) the mass dependence of multiplicity for mass 12 to 20 normalized to charge 1. In addition, we present the calculated isotope yields for three elements C, N, and O.

While the mechanism for these yields cannot be definitely determined by the agreement we have shown, our results suggest that the statistical emission process may be able to account for the observed features.

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[1]J. E. Finn, S. Agarwal, A. Bujak, J. Chuang, L. J. Gutay, A. S. Hirsh, R. W. Minich, N. T. Porile, R. P. Scharenberg, B. C. Stringfellow, and F. Turkot, Phys. Rev. Lett. 49, 1321 (1982).

[2]R. W. Minich, S. Agarwal, A. Bujak, J. Chuang, J. E. Finn, L. J. Gutay, A. S. Hirsch, N. T. Porile, R. P. Scharenberg, B. C. Stringfellow, and F. Turkot, Phys. Lett. 118B, 458 (1982).

[3]W. A. Friedman and W. G. Lynch, Phys. Rev. C 28, 16 (1983).