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SUBMITTED TO: Sixth International Conference on Atomic Masses
September 18-21, 1979
East Lansing, Michigan

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DEPARTMENT OF ENERGY
CONTRACT W-7405-ENG. 36

SEARCH FOR LIGHT NEUTRON-DEFICIENT NUCLEI PRODUCED IN 800 MEV PROTON SPALLATION REACTIONS*

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INTRODUCTION

Defining the limits of particle stability in the light mass region provides a challenge to both the experimentalist and the theorist. The surprising discoveries of the particle stability of the neutron-rich nuclei ^{11}Li (ref. 1), ^{14}Be (ref. 2), ^{19}C (ref. 3), and ^{32,34}Na (ref. 4), which were predicted to be unstable with respect to one or two neutron emission, pointed out significant deficiencies in the understanding of the nuclear mass surface for light nuclei far from the valley of β-stability. Today such measurements of very neutron-rich or very neutron-deficient nuclei remain one of the most critical tests of current nuclear mass theories.

Several recent experiments[5,6,7] have been successful in determining the particle stability of some 23 previously unknown neutron-rich isotopes of the elements nitrogen through chlorine by a positive identification in on-line particle spectra. However, no analogous

*This work supported by the U.S. Department of Energy.

search has yet been undertaken on the neutron-deficient side of β-stability in this region. In this contribution we describe the initial experiments performed at the Clinton P. Anderson Meson Physics Facility (LAMPF) in which time-of-flight (TOF) techniques have been used to search for new neutron-deficient nuclei at the limits of proton stability.

EXPERIMENTAL METHOD

The current LAMPF experiments have concentrated on the neutron-deficient isotopes of Mg to Ar, since the limits of proton stability have previously been determined up through Na. Spallation products resulting from 800 MeV proton bombardments of three medium mass targets have been detected using an improved version of the dE/dx-TOF techniques reviewed by Butler[6].

Fig. 1 shows the Thin Target Area at LAMPF where these measurements were performed. It consists of a scattering chamber with several 5 m flight tubes. In the present experiment, spallation residues produced by the intense (500 μA average current) 800 MeV

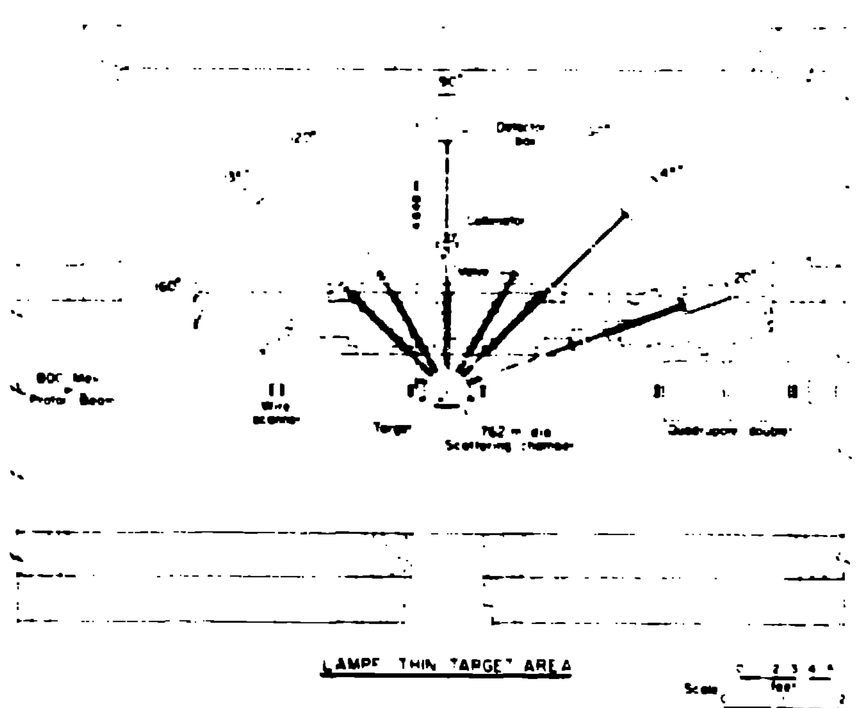


Fig. 1 A schematic diagram of the LAMPF Thin Target Area. The scattering chamber is located 15 m upstream of the first pion production target.

proton beam with targets of $^{nat}CaF_2$, ^{nat}Ni, and ^{92}Mo (thickness ~0.5 mg/cm^2) were detected at 45°. The observed energy distributions of the aluminum residues resulting from the three separate targets are shown in Fig. 2. The Al yields are observed to decrease rapidly with energy and for higher A targets a more gradual energy dependence is found. These features are consistent with the interpretation of spallation being the dominant reaction mechanism.

In order to acquire data where the spallation yields were sufficiently large, a detection system capable of characterizing reaction products to as low an energy as possible was necessary. This system consisted of two fast-timing, secondary-emission channel plate detectors[9] and a standard ΔE-E, gas-Si telescope[10]. A schematic layout of the experimental arrangement is shown in Fig. 3. For each event nine parameters were recorded: the amplitudes of the channel plate signals (CP1 and CP2), the ΔE-E energies of the detector telescope, the pressure and temperature of the gas in the detector telescope, and three time measurements - T_a which measures the TOF between CP1 and CP2, T_b which measures the time difference between CP1 and the next beam pickoff signal, and T_c which measures the TOF between CP2 and the E detector. From these measured para-

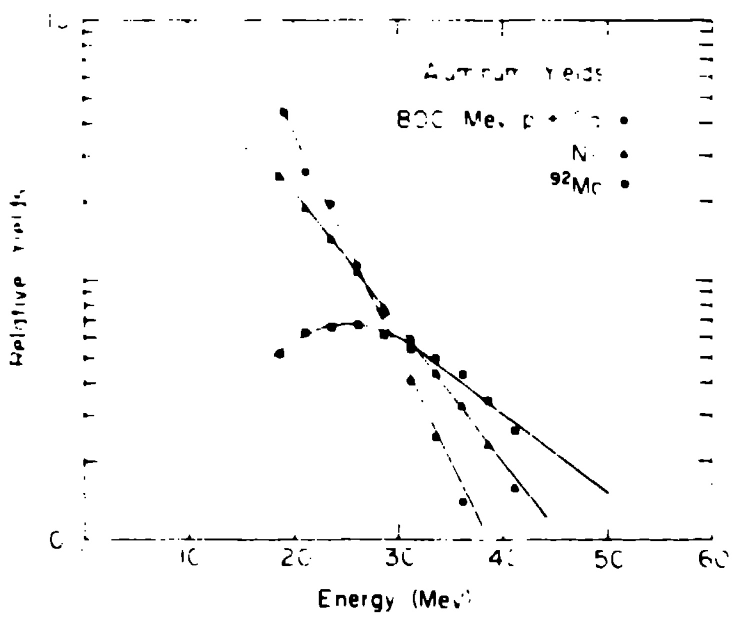
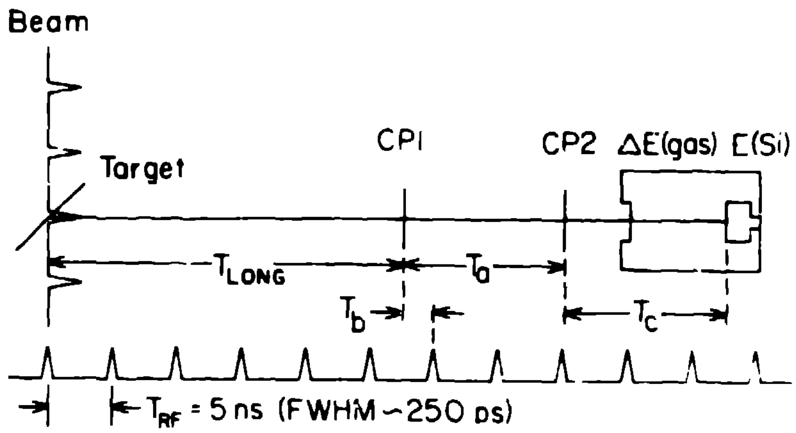


Fig. 2 The relative yields of aluminum (Z=13) observed at 45° (lab) in 800 MeV proton bombardments. The solid lines have been drawn to guide the eye.



$$E_{TOTAL} = \Delta E + E + \Sigma DL's + PHD$$

$$Mass = 2\,E_{TOTAL}\,(T_{LONG}/D_{LONG})^2$$

Fig. 3 Schematic layout of the experimental arrangement, the LAMPF beam microstructure, and the important experimental parameters. See text for a detailed description.

meters the following were determined: 1) the long flight path TOF between the target and CP1 (T_{Long}), 2) the total kinetic energy (E_{total}), 3) the mass (A), and 4) the atomic number (Z) of the spallation residue.

The long flight time is given by

$$T_{Long} = nT_{RF} - T_b \qquad (1)$$

where T_{RF} is the RF period between beam bursts, and n is the number of RF periods in the interval between the creation of the residue and the beam burst immediately following the CP1 signal. The integer n is obtained by rounding off the quantity $(T' + T_b)/T_{RF}$ in which T' is an estimate of the long flight path TOF calculated from the short flight path measurement, T_a. Thus in this technique the long flight path TOF was determined to high precision by combining a coarse time measurement, T_a, which was used to determine the long flight time to the nearest RF period, and a fine time measurement, T_b, which measured the time when the event occurred to a fraction of a RF period. After correcting T_a and T_b for time walk with respect to CP1 and CP2 amplitudes, a time resolution of 0.25 ns (FWHM) was obtained over a short flight path (CP1-CP2) of 50 cm, while the long flight path (target - CP1 = 4.3 m) time resolution was found to be 1.2 ns.

The total kinetic energy of the reaction product was obtained by adding together the pressure and temperature-normalized ΔE-E detector telescope energies. Dead layer corrections for energy losses in the thin carbon foil ($\sim 20\ \mu g/cm^2$) of the channel plate detectors and the polypropylene gas isolation window ($\sim 60\ \mu g/cm^2$) on the detector telescope were made using the dE/dx table lookup method. Due to the lack of an existing dE/dx table of sufficient accuracy in this energy region, we generated our own table from the data itself. This table consisted of ΔE entries for different E and Z values that were determined by a peak finding routine. The use of this ΔE-E table as a dE/dx table enabled good dead layer energy loss corrections to be made over the entire energy and Z region of interest. Finally, an estimate of the pulse height defect (PHD) using the method of Kaufman, et. al.[11] was added to give the total kinetic energy, E_{total}. Once the total kinetic energy and the long flight time were obtained, the calculation of the final mass was straightforward using the second equation given in Fig. 3.

The Z of each spallation residue was determined by two separate methods. In the first method the atomic number was obtained using the ΔE-E table lookup approach which was then followed by a mass correction to remove the mass dependence of the Z determination. The second method used the ΔE-TOF table lookup method, where, in an analogous fashion to the ΔE-E table, a ΔE-TOF table was generated from the data. The latter method has the added attraction of being mass independent in first order[12]. However, when we compared the two methods we found the results to be nearly identical, so in this experiment we arbitrarily chose to use the ΔE-E table lookup method as the final determination of the Z of the reaction product.

Three major requirements were used to avoid any ambiguity in the final mass determination and to reduce background events due to random coincidences and other spurious effects. First, a window of 0.35 ns was placed on the time difference between T_c, the measured TOF between CP2 and the E detector, and the estimated CP2-E flight time that was calculated from T_a and the pertinent energies and distances. Furthermore, the final flight time, T_{Long}, was required to differ from the estimated long flight time, $T' + T_b$, by less than 3.2 ns. Finally, a lower kinetic energy restriction was added. The latter represented a compromise between statistics and adequate charge and mass resolution. At low energies the mass resolution was dominated by energy uncertainties which resulted primarily from energy straggling in the dead layers[13]. The energy straggling accounted for an estimated energy uncertainty of ~ 200 keV out of a total uncertainty of ∿350 keV. The Z resolution was also found to be very energy dependent due to charge neutralization effects which cause adjacent Z values to converge at low energies. In this analysis a total kinetic energy threshold of 26 MeV was chosen, resulting in a mass and charge resolution (FWHM) of 0.4 amu and 0.4 charge units, respectively, for a typical spallation product like ^{26}Al

RESULTS AND CONCLUSION

About ten million events of the elements N through Ca were collected from a Ni target in a one month period. This data was analyzed in the fashion previously described and Fig. 4 shows two of the observed mass spectra. All of the known neutron-deficient isotopes of Al and P are seen out to the currently known limits of particle stability, ^{23}Al and ^{27}P. Beyond these points we find some evidence that ^{22}Al and ^{26}P may be stable, however the statistics are too meager to be convincing. Furthermore, the Al spectrum is confused by five potentially spurious events observed below mass 22. Current predictions using Kelson-Garvey mass relationships predict ^{22}Al to be marginally bound by 250 keV, while ^{26}P is predicted to be proton unbound by 90 keV[14]. Future attempts to define the neutron-deficient limits of particle stability and, in particular, the possible stability of ^{22}Al and ^{26}P are expected.

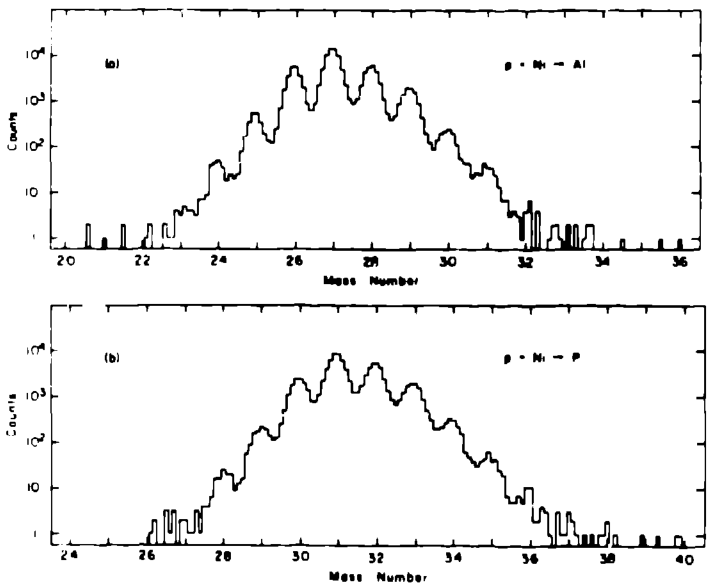


Fig. 4 Mass spectra observed in 800 MeV proton bombardment of ^{nat}Ni for the elements (a) Al and (b) P.

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