Observation of the New Nuclides ^{27}Ne, ^{31}Mg, ^{32}Mg, ^{34}Al, and ^{39}P†

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Five new, neutron-rich nuclides, ^{27}Ne, ^{31}Mg, ^{32}Mg, ^{34}Al, and ^{39}P, have been produced by the bombardment of uranium with 800-MeV protons. A time-of-flight method which utilizes the rf structure of the beam was combined with a ΔE-E measurement to identify the nuclides.

In this Letter we report the observation of five new, neutron-rich nuclides, ^{27}Ne, ^{31}Mg, ^{32}Mg, ^{34}Al, and ^{39}P, among the fragments produced by the interactions of 800-MeV protons with a uranium target.[1] The fragment Z was identified with a silicon ΔE-E detector telescope, and the mass number was determined by a time-of-flight method which utilizes the rf microstructure (~0.5-nsec-wide pulses at a frequency of 201.25 MHz) of the primary proton beam at the Clinton P. Anderson Meson Physics Facility (LAMPF) to provide one of the two timing signals. The high beam current (35 μA at the time of this experiment) made it practical to use a very long flight path (4.3 m) to achieve excellent fragment mass resolution. Because the fragment flight times are much longer than the rf period, they are uncertain by an unknown multiple of this period. Thus, an essential component of this method is the simultaneous time-of-flight measurement over a short flight path between the ΔE and E detectors to obtain the fragment velocity with sufficient accuracy to determine the number of rf periods in the flight time over the long flight path. This new technique extends the ΔE-E, time-of-flight method of nuclide identification[2,3] up to a mass number of ~40.

The experiment was carried out in the thin-target area at LAMPF. The 800-MeV proton beam passed through a 3.5-mg/cm^2 uranium target mounted in a scattering chamber which is about 12 m upstream of the first pion-production target. The ΔE and E detectors were in a detector box at the end of a 4-m flight tube which was connected to the scattering chamber at an angle of 45°. A 1-m-thick concrete shield separates the room containing the detector box from the scattering chamber and the primary proton beam line.

The long flight path from the target to the ΔE detector was 433 cm, and the short flight path between the ΔE and E detectors was 39 cm. The distance of the short flight path was chosen to insure a total lack of ambiguity in the calculation of the flight time for the long flight path while minimizing the loss of events due to multiple Coulomb scattering in the ΔE detector. The silicon ΔE detector was 7 mm×7 mm×19 μm, collimated to 5.5 mm×5.5 mm, and the silicon E detector was 13.8 mm diam×87 μm, collimated to 12 mm diam. Both detectors were cooled to 5°C. The fast timing electronics used for the short-flight-path time measurement was similar to that previously described.[2] The aluminum target ladder, which was insulated from the scattering chamber, was used as a beam pickoff. The zero-crossing point of the output of a fast, bipolar amplifier which was dc coupled to the ladder was used to derive the beam pickoff signal. The time measured was the interval between the ΔE fast timing signal and the next following beam pickoff signal.

About 350 000 events of the elements B through Ar were collected during a five-day period. Events for which the residual fragment energy E was between 15 and 60 MeV were selected for analysis. Both the ΔE and E signals were corrected for pulse-height defects[4] and dead layers. The flight time for the short flight path was corrected for discriminator time walk as a function of both the ΔE and the E pulse heights, and that for the long flight path was corrected for time walk as a function of ΔE. A time resolution of 150 psec (full width at half-maximum) was achieved for the short flight path, and the time resolution for the long flight path was 0.5 nsec. The fragment Z was determined by means of a table-look-up method of particle identification[5] with a correction which used the short-flight-path mass measurement to eliminate the mass dependence. Both the fragment Z and A calibrations were verified by the absence of a peak at $A=9$ in the B mass spectrum.

The final fragment mass is calculated from the total flight time for the long flight path and the total kinetic energy: $A=2(E+\Delta E)t^2/d_l^2$, where d_l is is the distance of the long flight path. The total flight time is given by $t=nt_{\mathrm{rf}}-\Delta t_l$, where Δt_l is the measured time from the ΔE signal to the next beam pulse, t_{rf} is the rf period, and n is the number of rf periods in the interval between the creation of the fragment and the beam pulse immediately following the ΔE signal. The integer n is obtained by rounding off the quantity $(t'+\Delta t_l)/t_{\mathrm{rf}}$ in which t' is the estimate of the flight time for the long flight path calculated from the short-flight-path measurement. The accuracy of this estimate is enhanced by using the short-flight-path mass number A' (the mass rounded to an integer): $t'=d_l[A'/2(E+\Delta E)]^{1/2}$.

The background due to random coincidences and other spurious effects was reduced from 0.5 to 0.2 events per nuclide by requiring that the final flight time differ from the estimated flight time by less than 1.5 nsec, and that the final mass differ from the short-flight-path mass by less than 0.4 amu. Only 5% of all of the events were rejected by these requirements. This is because the short-flight-path mass resolution was only 0.3 amu and the long-flight-path time resolution was 0.5 nsec ($\frac{1}{10}$ of the rf period). Thus there was little ambiguity in the determination of n and in the final mass assignments.

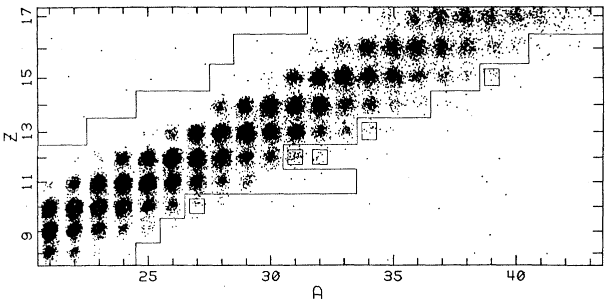

FIG. 1. Distribution in Z and A of fragments detected. Each dot represents one event. The boxes outline the regions of the nuclides ^{27}Ne, ^{31}Mg, ^{32}Mg, ^{34}Al, and ^{39}P. The solid lines enclose the region of previously known nuclei (Ref. 6).

The results are shown in the form of a scatter plot in Z and A in Fig. 1. The good resolution in both parameters is clear, and, more importantly, it can be seen that there is no tailing, in any direction, from an abundant peak into the region of a lightly populated one. All of the stable and known[6] neutron-rich nuclides (except for ^{24}O and the more neutron-rich Na isotopes) are seen. The five previously unobserved neutron-rich nuclides ^{27}Ne, ^{31}Mg, ^{32}Mg, ^{34}Al, and ^{39}P are clearly evident; each of these peaks contains ten or more events. There are five additional nuclides whose existence is suggested by from three to six events each, but we do not consider this evidence to be statistically conclusive. Elemental mass spectra, cuts through Fig. 1 with windows on the Z peaks, are shown in Fig. 2 for the elements Ne, Mg, Al, and P. The five new nuclides appear as peaks, and it can be seen that the yields of these nuclides follow systematic trends from the yields of the known nuclides. The energy spectra of these nuclides were found to be consistent with those of the adjacent known nuclides.

All of these new nuclides have been predicted to be particle stable.[7] Because of the pairing-energy effect, the particle stability of ^{27}Ne and ^{34}Al strongly implies that ^{28}Ne and ^{35}Al should also be particle stable. The nuclide ^{33}Mg is predicted to be bound by only 0.48 MeV,[7] a value which is close to the expected uncertainty of the predictions, and it would thus be of interest, with an order of magnitude more data, to see if it can be observed.

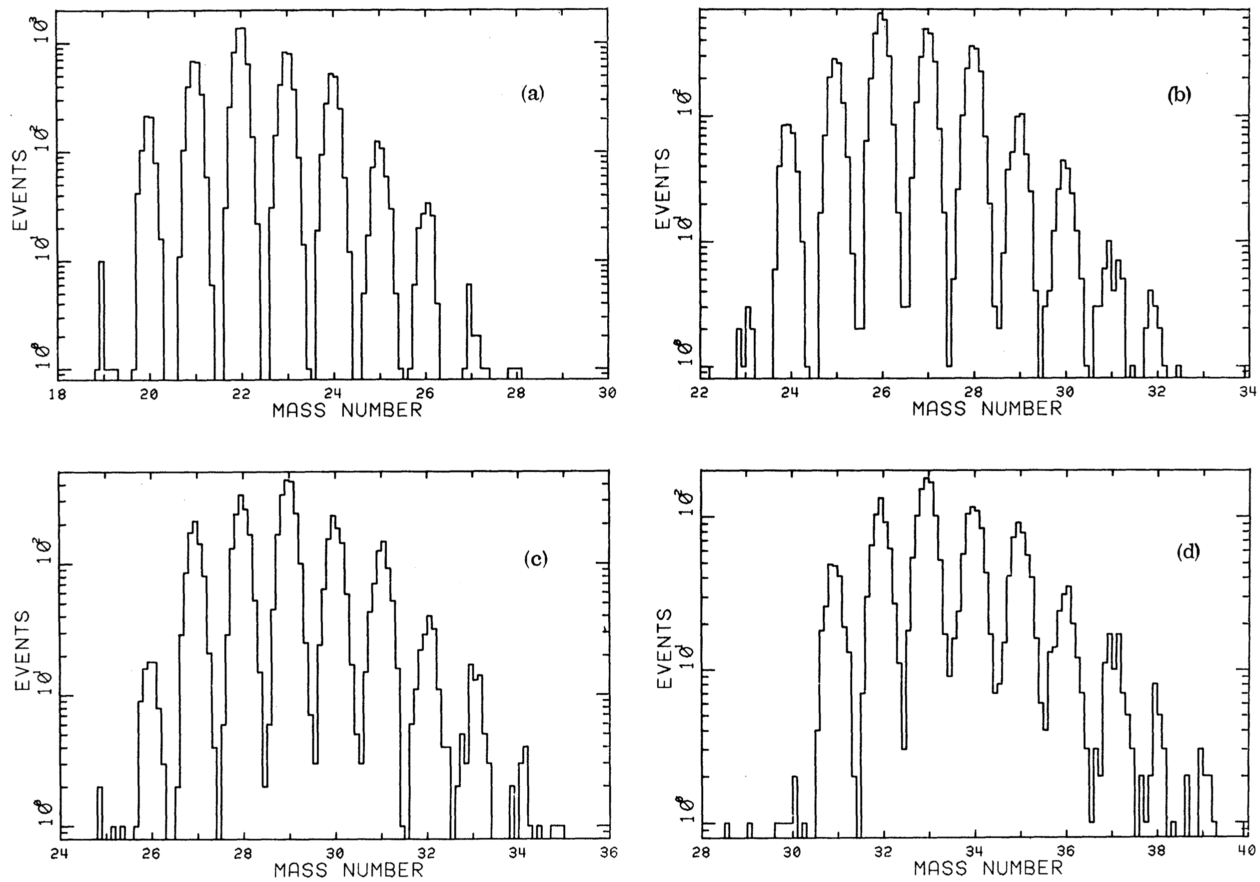

FIG. 2. Mass spectra for the elements (a) Ne, (b) Mg, (c) Al, and (d) P.

The yields shown in Fig. 2 cannot be considered as relative cross sections because of energy windows, multiple-scattering losses, etc., but they are likely to be correct to within a factor of 2. The yield distribution of Na isotopes as far as was measured in this work agreed within a factor of 2 with the cross section distribution of Na isotopes produced by the irradiation of uranium by 24-GeV protons,[8] although the absolute values of the cross sections are considerably lower at 800 MeV. This suggests that at least some aspects of the mechanisms for the production of these light fragments from the proton bombardment of heavy element targets do not change over this range of proton energies. It also shows that the irradiation of uranium by a very intense 800-MeV proton beam is a good method for the production of light, highly neutron-rich nuclides.

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[1]A preliminary report of the observation of ^{31}Mg by this group is given by G. W. Butler, in CERN Report No. 76-13, Proceedings of the Third International Conference on Nuclei far from Stability, Cargèse, France, 1976 (unpublished), p. 15.

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