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POSSIBILITIES FOR STUDYING SHORT-LIVED NUCLEI PRODUCED AT LAMPF*

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Abstract We present results of a study of the feasibility of using a He-jet coupled on-line mass separator system at LAMPF. He-jet transport-line characteristics, and estimates for the production of nuclei far from stability are given. Some specific areas of interest for potential studies are also presented.

INTRODUCTION

A He-jet coupled on-line mass separator, used in conjunction with a target chamber placed in the LAMPF main beam, offers an especially attractive approach for the study of nuclei far from stability. Such a facility would provide access to isotopes of a number of elements that cannot be efficiently extracted for study at any other type of on-line separator system, and the use of a long capillary transport line would allow the separator ion source to be located outside the accelerator beam-line shielding, greatly reducing the installation cost. The reason such a system has not previously been mounted at a high-energy proton accelerator is lack of a sufficiently intense beam current. The He-jet technique requires thin targets in order for the reaction products to escape, and to produce a sufficient yield of radioisotopes far from stability for detailed nuclear studies, a beam intensity comparable to that available at LAMPF is needed.

The mass-separated ion beams extracted from the proposed system would be directed to various experimental devices that are capable of determining basic nuclear properties such as half-life, spin, nuclear moments, mass, and nuclear structure. The data acquired would have broad application to theories of nuclear matter and to such related topics as nucleosynthesis of the elements. We estimate that several hundred previously unobserved nuclei, both neutron-deficient and neutron-rich, would become available for study. Such a capability would inevitably attract a sizeable international user group.

This report presents a brief summary of the results of our

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He-jet studies, along with estimates of which nuclei would become available with our proposed facility. Specific areas for initial studies are also suggested.

He-JET ACTIVITY TRANSPORT STUDIES

The concerns addressed in our feasibility studies of He-jet activity transport were: 1) Will the He-jet technique work at the beam intensities that exist at LAMPF?; 2) What transport efficiencies can be expected for both fission and spallation products?; 3) What is the time dependence of the activity transported?; and 4) What aerosols and/or aerosol conditions are optimum?

Using both spallation- and fission-product targets in the LAMPF H^- beam, we determined that the He-jet technique should work well at LAMPF beam intensities (~800μA). Absolute efficiencies for transport of refractory-element activities through a 22-m long capillary were found to average about 60%. Transit time measurements appear convincing that activities as short as 300 ms could be made accessible for study. We found that $PbCl_2$ aerosol provided more efficient transport than KCl and NaCl aerosols.

Optimization of the target chamber configuration resulted in a design employing two radially-directed inlets at $\pm 135^\circ$ to a single radially-directed capillary outlet. The time-related performance of the target chamber and He-jet is enhanced for larger-bore capillaries; we have chosen an inside diameter of 2.4 mm as a reasonable compromise between target chamber purge rate and helium flow rate.

Two target chambers have been designed, one for fission targets and one for spallation targets. These chambers, which are designed for remote servicing, will be located at the end of a vertical shield plug near the LAMPF beam-stop. The plug is designed to be remotely raised and lowered to allow the target to be moved in and out of the LAMPF beam. The target chambers incorporate the inlet and outlet geometries determined from our feasibility experiments and will feature double containment to allow use of actinide targets.

One concern remains in our considerations. Despite the considerable experience in coupling a He-jet to a mass separator ion source,[1-2] the reported total efficiencies are characteristically less that those achieved with normal on-line separator systems. Current efforts to improve the He-jet coupling and ionization efficiencies are, however, showing progress.

PRODUCTION ESTIMATES FOR NUCLEI FAR FROM STABILITY

To define more accurately the boundaries of the mass regions that could be accessed with the proposed He-jet coupled mass separator system, production cross sections for both neutron-deficient and neutron-rich nuclei far from stability have been estimated for 800-MeV proton reactions. The spallation-product cross sections were estimated through use of the Rudstam systematics.[3] For estimation of the fission-product cross sections, however, there is no established, similar approach. Thus, an empirical approach was taken in which two overlapping Gaussian distributions were fitted to existing rubidium and cesium isotopic distributions obtained at 156 MeV, 170 MeV, and 1 GeV[4-5]--one Gaussian for the neutron-rich portion of the distribution and one for the neutron-deficient portion. The parameters of the Gaussians were then varied with A and Z to account for the mass-yield variations and other differences between the rubidium and cesium data. Adjustment of the cross-section distributions to 800 MeV was accomplished by interpolation.

If we assume that 1000 atoms/s of a mass-separated radionuclide are needed for spectroscopic measurements and that the mass separator system has only a one-percent overall efficiency, a partial production cross section of about 0.7 μb is required for the nuclide in question, assuming a LAMPF beam intensity of 800 μA. According to our cross-section estimates, essentially all neutron-deficient nuclei with calculated[6] half-lives >300 ms will be produced in 800-MeV spallation with a cross section of >1 μb (assuming the use of at least 10 different target materials). Interesting nuclear regions that could be reached include those near ^{76}Sr and ^{100}Sn. On the neutron-rich side of stability, most nuclei with half-lives >300 ms and mass 60-135 can be produced in high-energy fission of ^{238}U with a cross section of >1 μb. Between A=135 and 160, the 1-μb contour does not reach all the way to the 300-ms limit, but there are many neutron-rich nuclei within this contour that have not yet been observed. In all, we expect to gain unique access to about 200 nuclei with unknown half-lives, 400 nuclei with unknown decay schemes, 350 nuclei with unknown masses, and 300 nuclei for which ground-state spin and parity assignments are unknown. Studies of these nuclei would significantly advance our knowledge of nuclear dynamics.

POSSIBLE SPECIFIC STUDIES

Given the large variety of new nuclei that would become available with the proposed on-line separator system, a focus is needed for possible initial studies. On the other hand, the importance of making systematic studies of nuclear properties over sizeable regions must be recognized. For example, the novel feature of shape coexistence was established only through detailed, systematic studies of nuclear decays. A notable feature of the proposed on-line mass separator system is the capability to make unique systematic studies in several interesting regions.

One such region is that around N=Z=38, postulated to be a region of strong deformation.[7] Although this prediction has some experimental support,[8-10] other theories predict nuclei in this region to be spherical, with some softness toward deformation.[11-12] Recent work in this region suggests an apparent quenching of pairing correlations in ^{84}Zr, resulting in moments of inertia at about rigid-body values.[9]

The neutron-rich nuclei near ^{100}Zr comprise another recently established deformed region.[13-16] Here, the onset of deformation is especially abrupt, and quenching of pairing correlations seems indicated.[17] The He-jet technique offers the capability of mapping the extent of this unusual deformed region in the refractory-element area above A=100 -- a region presently inaccessible at other on-line facilities.

The region around ^{100}Sn also offers exciting possibilities. Studies of nearby nuclei have been unable to determine the applicable coupling scheme or the interplay of the nearly symmetric neutron-proton configurations. Furthermore, heavy-ion reaction cross sections pose a severe limit in extending the previous studies in this region.[18]

Last, but not least, it is important to search for other regions besides the Pt region in which the nuclear structure can be described in terms of supersymmetric boson-fermion theory. The proven existence of several such regions would bring us one step closer to a comprehensive theory of all nuclei.

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