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AUTHOR(S) W. L. Talbert, Jr. INC-11
M. E. Bunker, INC-5

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Los Alamos, New Mexico 87545

POSSIBILITIES AT LAMPF FOR STUDYING NUCLEI OF ASTROPHYSICAL INTEREST*

W. L. Talbert, Jr. and M. E. Bunker
Los Alamos National Laboratory, Los Alamos, NM 87545, USA

ABSTRACT

Nuclear data needs in astrophysics range from neutron capture cross sections of a number of stable or near-stable nuclei to decay and neutron binding-energy data for highly neutron-rich nuclei. LAMPF has the potential to contribute significantly to these needs. The new Los Alamos Neutron Scattering Center (LANSCE, aka WNR/PSR) offers world-class capabilities for neutron capture studies up to an MeV or so. The study of nuclei far from stability could be extended into some regions of astrophysical interest using a proposed He-jet coupled mass separator system with a target/production chamber in the LAMPF beam stop area. Specific examples of possible studies at each facility are presented.

INTRODUCTION

Nuclear data needs in astrophysics have recently been outlined by G. J. Mathews,[1,2] some of which appear to be tractable using new and proposed capabilities at LAMPF. Two main approaches are discussed here, the first using the operational characteristics of LANSCE for neutron-capture cross section studies, and the second involving possible studies of highly neutron-rich nuclei at a proposed He-jet coupled on-line mass separator system.

NEUTRON CAPTURE CROSS SECTION MEASUREMENT POSSIBILITIES USING LANSCE

Neutron capture cross sections are unmeasured for a number of stable nuclei of interest in astrophysics for s-process nucleosynthesis calculations. In particular, for ^{66}Zn, ^{72}Ge, ^{73}Ge, ^{77}Se and ^{99}Ru, isotopically-enriched samples are available, but no cross-section measurements have been reported.[2] In addition, very few neutron-induced reactions on long-lived radioactive nuclei near stability have been studied. The neutron burst intensities available at LANSCE are about 10^4 larger than previously available. These intensities will allow the measurement of capture rates in relatively small quantities of stable target material and are sufficient to override the natural decay background associated with long-lived target isotopes.

The layout of LANSCE is shown in Fig. 1, and the surface neutron current is plotted versus energy in Fig. 2 for a split uranium target with the neutron beam line viewing a moderator of water. At the intended operational average current of 100 μA for LANSCE, a neutron intensity for a 10% energy band centered from 100 eV to 1 MeV is about 8×10^6 n/cm^{2}s at a distance of 7 m from the target. The LANSCE delivers pulses at a rate of 12 Hz. Assuming an inverse-velocity-dependent capture cross section for a neutron energy range from 1 keV to 50 keV and a value for the cross section of 1 b at 10 keV, the signal rate is estimated to be 2×10^{-17}Ns^{-1},

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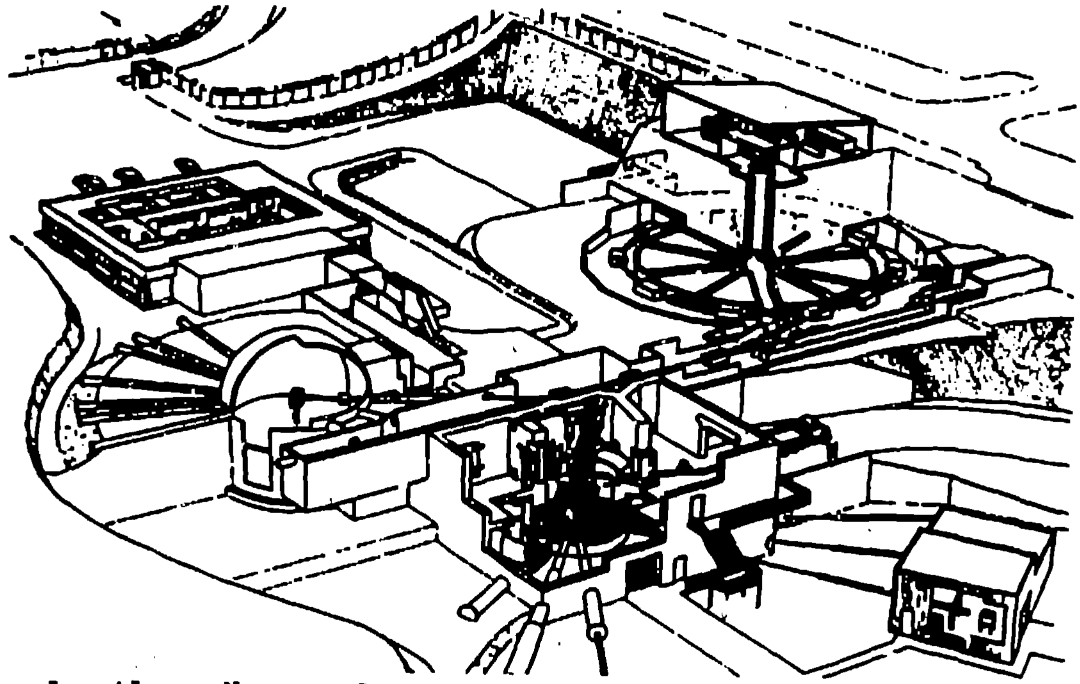

Fig. 1. Los Alamos Neutron Scattering Center layout. Proton storage ring at upper right, high current target area at lower center, low current target area left center, and control and data center at upper left.

where N is the number of atoms in the sample. If 10^4 events/day are required (for a nearly 4π gamma detector), the samples can be as small as 5×10^{15} atoms, or 0.9 μg at A=100. This is a trivially small sample size for stable (isotopically enriched) nuclei. However, for radioactive nuclei, a sample this size is difficult to obtain even for long half-life nuclei.

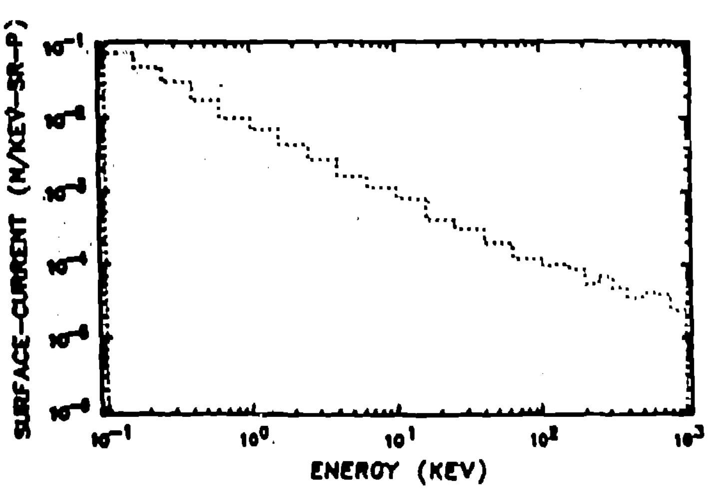

Fig. 2. Calculated neutron leakage spectrum from a water moderator between a split depleted uranium target in the energy range 0.1 to 1000 keV.

The use of smaller samples is feasible if 1) resonance cross sections are measured, or 2) decay characteristics are such that the background in the gamma detector due to target decays does not interfere with the capture gamma-ray signal. Regarding the first condition, in cases where the resonance cross sections are thousands of barns, samples in only the nanogram-size range are required. For radioactive targets, the background rate will depend on the details of the decay.

However, reasonable estimates can be made for the probability that decay gammas will pile up into the capture-gamma energy range. Such estimates indicate that much smaller samples sizes, of the order of 10^{13} atoms would be adequate to obtain signal-to-background ratios of better than 2 to 1, with a corresponding penalty in capture detection rate (the capture rate is linearly dependent on sample size, while the background rate, due to pile-up, has a high power dependence). In practice, we expect to be able to measure capture cross sections for as many as 200 unstable nuclei, pending availability of samples.

POSSIBILITIES TO STUDY NUCLEI FAR FROM STABILITY AT LAMPF

Feasibility studies leading to a proposal of a He-jet coupled on-line mass separator at LAMPF are convincing that such a system would provide unique new capabilities to study ground-state and decay properties of nuclei far from stability. Some of the results of these studies were reported at the TRIUMF-ISOL Workshop.[3] Essentially the only way to produce significant amounts of medium-mass, highly neutron-rich nuclei is through high-energy proton-induced fission. At LAMPF, using our proposed He-jet/ISOL system, we estimate that most of the neutron-rich radionuclides from A=60 to 160 and with $T_{1/2}$ >300 ms could be produced with a yield of >1000 atoms/s. This result is based on our feasibility experiments, reasonable cross-sections estimates (based on systematics), and the following assumptions: 800-MeV protons, 800-μA beam current, two 10-mg/cm^2 uranium targets, 60% activity transport efficiency through the He-jet transport line, and 1% mass-separator efficiency.

Also, with this facility, we estimate that sufficient quantities of mass-separated long-lived activities could be collected for neutron capture studies, assuming cross sections of the order of 10 mb or larger. Collection times of a day or so would provide samples with 10^{13} atoms. The long-lived samples could be collected parasitically during the study of short-lived nuclei through use of a mass separator having adequate mass range at the collector plane. From our analysis of expected cross sections, we predict that many nuclei close to stability in the mass range 90 to 130 could be collected for neutron capture studies.

The mass separator efficiency assumed is very conservative in view of recent experiences at other He-jet coupled systems. The mass separator efficiencies reported recently range from 6% (for aluminum isotopes) at Chalk River[4] to ~10% (for alkali isotopes) at Kyoto.[5] He-jet/ion source coupling studies are continuing at Idaho National Engineering Laboratory (INEL) and at Mainz, and are commencing at Los Alamos. At Mainz, alkaline earth efficiencies of 4-6%, and praseodymium efficiencies of 3-4% have been reported recently,[6] and at INEL, efficiencies have improved[7] over values reported in Ref. 8.

In studying neutron-rich nuclei far from stability of importance to astrophysics, three types of data are desired (in order of decreasing priority): the neutron binding energies (found from beta decay energies, for example), the beta decay half-lives, and the distributions of energies and spins for the lower excited states.[1] For the operating conditions given above, cross sections of under 0.1 μb are expected for the nuclei ^{78}Ni, ^{128}Pd, ^{129}Ag and ^{130}Ag; however, enough activity should be available to make half-life measurements and, possibly, crude beta decay energy determinations. Both decay energy and half-life measurements should be possible for ^{79}Cu, ^{79}Ga, ^{80}Cu, ^{80}Zn, ^{80}Ga, ^{129}Cd, ^{130}Cd, ^{130}Sn, ^{131}Cd, and ^{131}Sn. In addition to decay energy and half-life data, level structure information should be obtainable for the ^{79}Zn, ^{81}Ga, ^{130}In, and ^{131}In decays. These possibilities alone account for nearly all of the nuclei with A<132 singled out by Mathews where critical nuclear data are needed for r-process calculations.[1]

In addition to these specific capabilities, the He-jet coupled mass separator system would provide a general coverage of masses and elements over a major portion of the region of bound nuclei, allowing access to virtually hundreds of nuclei far from stability not available at any other facility. Depending on the property to be determined, the total number of bound nuclei not yet studied, accessible by spallation or high-energy fission of ^{238}U with $T_{1/2}$ > 300 ms, or production cross section greater that 1 μb, ranges from ~360 to over 700 for the basic ground-state properties of half-life and mass. Table I summarizes the enormity of our current ignorance of nuclei far from stability accessible by these high-energy reactions, despite over two decades of prolific on-line studies. Of those nuclei included in Table I, we expect that unique access to about half would come from a He-jet coupled mass separator at LAMPF.

A conceptual layout of the proposed system is shown in Fig. 3. We invite any who are interested in the possibilities for these or related studies to contact us to provide an expression of external interest.

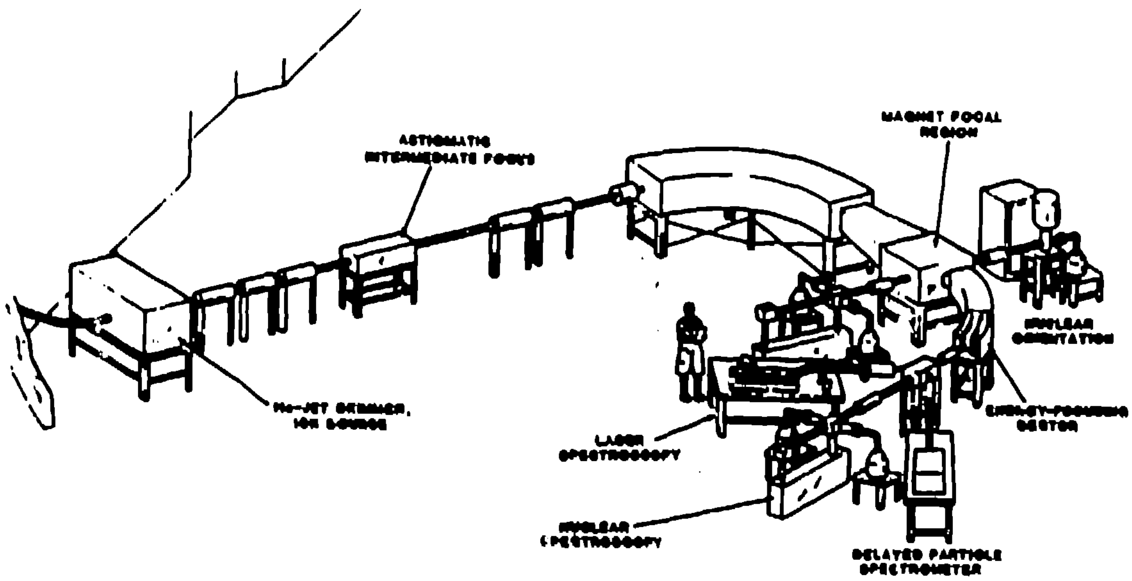

Fig. 3. Layout of the proposed on-line mass separator system at LAMPF, showing conceptual ion optical design for a single magnetic stage.

Table I. Numbers of nuclei with unknown properties between known limits and 300-ms (according to the gross theory of beta decay[9]) or 1-μb cross-section limits; Z=10-90.

Property	Neutron-rich [$^{238}U(p,f)$]	Neutron-deficient [Spallation]
Mass	281	436
Half-life	170	198
Decay scheme	243	630
Spin-parity	300	484

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