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Publication Date

1988-12-01

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This work was supported by the Director, Office of Energy Research,
Division of Nuclear Physics of the Office of High Energy and Nuclear
Physics of the U.S. Department of Energy under Contract DE-AC03-76SF00098.

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ABSTRACT

A target chamber was developed which allows the use of up to 25 heavy element targets concurrently for light ion bombardments, compensating for the low recoil range of the compound nuclei. A KCl-aerosol/He-jet transport system transports the recoiling compound nucleus activities away from the target system with greater than 90% yield. The target system is designed so that the gas-jet yield of unwanted fission products is very low, which strongly suppresses the β - γ interference associated with fission fragments. The target system can accept high beam fluxes safely.

The production of neutron-deficient actinide nuclei by light-ion bombardments has a number of advantages over bombardments using heavy ions. Highly asymmetric nuclear reactions generally have much higher production cross-sections than the less asymmetric heavy ion reactions. The Coulomb barrier for the reaction is lower, increasing the scope of reactions that can be carried out with a single accelerator. Most accelerators can give much higher beam fluxes of light ions than heavy ones. The $\frac{dE}{dx}$ for light ions is considerably lower than that of heavy ions [1], thus reducing the problem of thermal damage to targets and vacuum windows. When a helium-jet technique is used to extract the product nuclei quickly, the helium carrier gas can provide cooling to the targets and windows as a beneficial side effect.

Disadvantages of light-ion reactions are few, but significant. Light ions by definition have small masses, hence they have small momenta for a given energy. This means the heavy compound nucleus will have a very small recoil energy, which limits the effective thickness of the target material to approximately the recoil range of the compound nucleus in the target material. For a typical actinide oxide target, the recoil range is on the order of tens of micrograms per square centimeter [1]. Also, the lower Coulomb barrier for light-ion reactions and the higher available fluxes lead to an increase in the production of fission products and activation products from charged-particle reactions and capture of stray neutrons.

With this in mind, we sought to design a target system which would allow us to use all the advantages discussed above while minimizing the

effect of the disadvantages. Since light ions lose very little energy while passing through thin ($\sim 100 \mu\text{g}/\text{cm}^2$) targets and target backings, multiple targets can be bombarded concurrently with only a small spread in incident beam energy. A system using up to three light-heavy atom targets (e.g., magnesium) has been reported [2], but this has never been done with a large number of heavy targets where the recoil range becomes very small. If an incident energy spread of a few MeV were acceptable, ten or more actinide oxide targets on 0.025-mm beryllium backings could be bombarded with the same beam. This multiplication of the targets compensates for the low recoil range of the compound nucleus, yielding effectively a thick target.

The low recoil range of the compound nucleus can also be exploited to suppress the collection efficiency of fission products. For example, the recoil range in helium of $^{241}\text{Am}^*$ produced by the bombardment of ^{237}Np with 100-MeV alpha particles can be estimated from Figure 1 to be about $70 \mu\text{g}/\text{cm}^2$, or about 4 mm at atmospheric pressure. Typical fission fragments, with energies of about 1 MeV/A, have recoil ranges [1] in helium of about $2500 \mu\text{g}/\text{cm}^2$, or about 140 mm. Hence, by arranging the spacing between the targets to be greater than the recoil range of the compound nucleus but much less than that of fission fragments, most of the fission fragments will embed in the next target backing rather than attach to aerosols. This severely decreases the gas-jet extraction yield of the fission products, and hence greatly reduces the β - γ background resulting from fission products.

The use of high beam fluxes is often desirable, so the target system

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Figure 1: Estimation of low-energy recoil ranges for americium in helium by extrapolation of range data from Northcliffe and Schilling [1] to zero recoil energy.

design had to incorporate two primary safety features. First, the system had to accept high fluxes without suffering design failures due to the large amount of heat generated. Secondly, the amount of induced radioactivity, primarily in the beam stop, had to be minimized to reduce the hazards of handling the system following a bombardment. These criteria led to the use of a thick beryllium plug in a water-cooled copper heat sink as a beam stop. A large diameter collimator allowed large diameter targets (12.7 mm) to be used, hence reducing the risk of target failure due to localized heating. Fortunately, the energy deposition in the targets can be kept low enough by using suitably thin target backings so that the flow of helium in the KCl/He-jet provides adequate cooling.

The Light Ion Multiple Target System (LIM target system) we designed is shown schematically in Figure 2. The target material is electrodeposited onto 25.4- μ m beryllium foils by a standard technique [4,5,6,7]. These foils are attached to square target holder cards by epoxy. The target holder cards are then placed in the recoil chamber with the gas vents alternating so that the aerosol-laden helium gas has to pass behind each target. This configuration is shown in Figure 3. The number of targets, their composition, and their spacing can be varied in the target system. The beam, after passing through all the targets and the volume limiting foil after the last target, impinges on a 25-mm thick beryllium plug. This plug is press-fitted into a water-cooled copper jacket to dissipate the heat generated in a high-flux bombardment.

The transport efficiency of the gas jet through the target system was

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Figure 2: Schematic Representation of the LIM Target System.

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Figure 3: Horizontal cross-sectional view of the LIM target system. Note the alternating arrangement of the open gas vents, forcing the gas jet to sweep out the volume behind each target. The gas jet is extracted after the last target position through a single 1.4-mm i.d. polyethylene capillary tube.

measured with an ^{225}Ac ($t_{1/2} = 10.0$ days) recoil source by measuring the 4.8-minute daughter ^{221}Fr . The yield was measured as the ratio of ^{221}Fr collected per unit time after passing through the system to the amount of ^{221}Fr collected per unit time bypassing the target system. This ratio was consistently 90% or better. Of course, the overall gas-jet yield is the product of the attachment efficiency, the transport efficiency, and the collection efficiency. In an on-line measurement using 100-MeV $^4\text{He}^{2+}$ to bombard ^{237}Np , we measured a ten-fold increase in the ^{232}Am activity collected when switching from a single target with a large recoil volume ($\sim 100\text{ cm}^3$) to a ten target arrangement in the LIM target system with the targets spaced 8.6 mm apart. This implies that the attachment efficiency in the LIM target system is as least as good as that of the traditional one-target, one-capillary system. The collection efficiency should remain constant since the same apparatus was used to collect the transported aerosols in each case. Comparison of our measured fission rate for this isotope with the published cross section [3] gives an overall gas-jet yield of 70–95%.

In conclusion, we have constructed a target system capable of accepting up to 25 targets at one time. The system is specifically designed to allow the safe use of high beam fluxes. Nuclei produced in reactions can be selected according to their recoil ranges by the appropriate spacing of the targets to suppress long-range activities. Range-selected products are transported away from the system via a KCl/He-jet with high efficiency. The helium also serves to cool the targets. The LIM target system has already been used in several nuclear physics experiments, and has been shown to greatly

enhance the effective yield of desired products in light-ion bombardments of heavy targets.

Acknowledgements

The authors would like to thank Albert Ghiorso for many helpful suggestions and valuable discussions.

This work was supported by the Director, Office of Energy Research, Division of Nuclear Physics of the Office of High Energy and Nuclear Physics of the U.S. Department of Energy under Contract DE-AC03-76SF00098.

This work was supported in part by a National Science Foundation Graduate Fellowship. The results, views, and findings of this work are those of the authors only and do not necessarily reflect those of the National Science Foundation.

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