Measurements of \((n,\gamma)\) Cross Sections for Unstable Nuclei of Interest to s-Process Nucleosynthesis


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Abstract

This is the final report of one year of a Laboratory-Directed Research and Development (LDRD) project at the Los Alamos National Laboratory (LANL) that was originally planned for three years. After one year, the project was terminated due to the laboratory-wide reduction in LDRD funding. The goal of the project was to make measurements of the capture of neutrons by unstable nuclei to learn more about the basic process as it relates to the formation of elements in the stars. Detailed measurements on unstable nuclei, of the sort we would make, have not yet been made before, and Los Alamos is presently unique in the world for being able to make them. A flight path was built and the experimental environment was characterized.

Background and Research Objectives

The process known as neutron capture has been studied for 50 years and from this research a great deal has been learned about the structure of the atomic nucleus. The capture process consists of a neutron striking and sticking to a target nucleus (becoming captured), followed by the new nucleus emitting characteristic gamma rays. Because facilities that could readily study unstable nuclei did not exist, nearly all experiments to date have studied stable nuclei, and there is very little experimental information on neutron capture by radioactive nuclei. Applications that require capture reaction probabilities (known as cross sections) for radioactive nuclei must rely on calculated values.

Capture reactions are crucial to the study of the synthesis of elements that takes place in stars. About half of the nuclei heavier than iron are believed to have been produced by a "slow process" (s-process) of sequential neutron capture along the line of stable isotopes. This is thought to take place in low- to medium-mass stars at a certain stage of their evolution, or in red giant stars.

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The basic mechanism of the s-process appears to be understood, but the branching of the capture path that occurs at radioactive isotopes is of particular interest in understanding nucleosynthesis and the stellar environment in which it occurs.

Measurements on unstable nuclei are complicated by the need to prepare radioactive targets and handle them safely. The Los Alamos National Laboratory offers several experimental facilities that individually and collectively combine to give it a capability that is unique in the world to make these measurements. First, there is the intense neutron source of the Manuel Lujan Jr. Neutron Scattering Center. This allows us to measure samples weighing about one milligram; other experimental facilities require 100 to 1,000 times as much material, sometimes even more. Next, there is the ability to produce and handle radioactive targets by the Nuclear and Radiochemistry Group of the Chemical Science and Technology Division. In addition to radiochemistry expertise, this group has recently built the Radioactive Species Isotope Separator, a magnetic isotope separator specifically designed to separate highly radioactive isotopes. Finally, the planned DANCE detector [1] will offer detection sensitivity and background rejection far superior to detectors used at other laboratories.

The study of nuclear reactions relevant to processes taking place in the stars and in the cosmos is currently an area of intense interest for research in nuclear science, as evidenced by a recent White Paper. [2]. The objective of this research was to make neutron capture measurements on selected important unstable nuclei over a continuous range of neutron energies relevant to understanding these reactions in stars. These experiments can currently only be done using the unique capabilities at Los Alamos.

**Importance to LANL's Science and Technology Base and National R&D Needs**

This experiment contributes directly to the laboratory's Nuclear Science core competency, and provided the basic science portion of a larger program to make measurements of neutron capture in support of the Nuclear Weapons Science core competency. The larger program would measure capture cross sections on unstable targets that are needed to correctly interpret archived nuclear test data.

**Scientific Approach and Accomplishments**

The experiment that was built in FY99 was intended to be an interim experiment to obtain data on the astrophysically interesting isotope \(^{151}\text{Sm}\), while an advanced gamma-ray detector was being designed and built. The FY99 experiment used deuterated benzene, \(\text{C}_6\text{D}_6\), gamma ray detectors that had been used in previous experiments.
A new flight path, which included neutron collimation and radiation shielding, was built on Flight Path 2 at the Manuel J. Lujan Jr. Neutron Scattering Center at the Los Alamos Neutron Science Center (LANSCE). After constructing the flight path, most of the beam time was used to characterize and understand experimental backgrounds. It was learned that considerable upstream shielding is needed to reduce the background count rate from scattered neutrons and gammas, and that neutrons scattering from the thin Be target backing was a source of considerable background. The apparatus had been characterized and optimized when beam operations were prematurely curtailed, and no cross-section data for $^{151}$Sm were obtained.

The full attention of the experimenters was then directed towards the planning and design of an advanced gamma ray detector for neutron capture measurements. The work, although yielding no cross section data of astrophysical interest, provided important information for the design of the new flight path and the new DANCE detector.
Publications


References
