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(n, γ) measurements on radioactive isotopes with DANCE

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Abstract

The Detector for Advanced Neutron Capture Experiments (DANCE) at the Los Alamos National Laboratory (LANL) is designed as a high efficiency, highly segmented 4π BaF2 detector for calorimetrically detecting gamma rays following a neutron capture. Coupled with the neutron spallation source at the Los Alamos Neutron Science Center (LANSCE), DANCE measurements on unstable isotopes in the energy range between 10 meV and 500 keV will provide many of the missing key reactions that are needed to understand the nucleosynthesis of the heavy elements and will also provide vital information for the design of future reactor concepts.

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1. Introduction

In astrophysics the neutron energy range between 1 keV and 1 MeV is the most important, because it corresponds to the temperature regimes of the relevant sites for synthesizing all nuclei between iron and the actinides. In this context neutron capture cross sections for unstable isotopes are required for a quantitative understanding. There is also continuing interest on neutron cross sections for technological applications, i.e. with respect to the neutron balance in advanced

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reactors, which are aiming at high burn-up rates, as well as for concepts dealing with transmutation of radioactive waste.

Except for the stable isotopes, very few neutron-induced reactions in the energy range of interest have been measured to date. The detector for advanced neutron capture experiments (DANCE) at the Los Alamos National Laboratory (LANL) is able to perform (n,γ) experiments with samples sizes of about 1 mg. DANCE measurements on unstable isotopes will provide many of the missing key reactions that are needed to understand the nucleosynthesis of the heavy elements and will also provide vital information for the design of future reactor concepts.

1.1. DANCE

The detector for advanced neutron capture experiments (DANCE) is designed as a high efficiency, highly segmented 4π BaF_2 detector array to calorimetrically detect γ-rays following a neutron capture. DANCE is located on the 20 m long neutron flight path 14 (FP14) at the Manuel Lujan Jr. Neutron Scattering Center at the Los Alamos Neutron Science Center (LANSCE) [1]. The initial design work is described in [2]. The design of the detector is such that a full 4π array would consist of 162 crystals of four different shapes, each shape covering the same solid angle [3]. Two of the 162 crystals are left out in order to leave space for the neutron beam pipe. Depending on the experiment, one crystal can be replaced by a sample changer mechanism, which makes it possible to exchange up to 3 samples without closing the beam shutter and breaking the vacuum of the beam pipe. Thus, the full array is designed to host 159 or 160 out of 162 possible BaF_2 crystals, which corresponds to a solid angle coverage of about 3.5π. The dimensions of the bare crystals are designed to form a BaF_2 shell with an inner radius of 17 cm and a thickness of 15 cm. Thanks to the fairly low repetition rate of 20 Hz, measurements can be carried out over the whole energy range from 10 meV to 500 keV. This combination of a strong neutron source and a high efficiency γ-ray detector allows the measurement of (n,γ) cross section of radioactive isotopes down to a few hundred days half-life. Further details on the overall performance of the array can be found in [4].

The BaF_2 signals are digitized for software pre-processing using 320 channels of Acqiris model DC265 transient digitizers (Acquiris SA, Geneva, Switzerland). The DC265 has a maximum sampling rate of 500 MS/s (million samples per second), or 2 ns per sample. The configuration for DANCE has a dedicated storage capacity of 128 KS (1024 samples) per channel. The digitizer cards were mounted in 14 Acqiris model CC108 CompactPCI crates, consisting of six digitizer cards plus one single board computer for digitizer control and readout per crate. One Acqiris crate supports 12 detectors, since each detector signal was split into high and low gain. The total available memory per channel can be configured as a single contiguous block (up to 250 μs), or as several smaller regions of memory, each of which can store a single acquired waveform. In the latter case it is possible to perform several independent "sequential" acquisitions, each with its own associated trigger, before stopping the acquisition to read out the stored waveforms. Memory and processing limitations, as well as dead time and total run time concerns eventually lead to the development of two distinct operating modes based on these two extremes. These two modes were aptly named continuous mode (one trigger per neutron spill) and segmented mode (one trigger per signal). During the run cycle 2003/2004 the neutron energy range from 10 meV to 10 keV was investigated with the segmented mode and the energy range above 1 keV with the continuous mode. It is therefore possible to measure keV cross sections relative to the usually well known thermal neutron capture cross sections.

The intrinsic radioactivity of the BaF_2 crystals originates from the α-decay chain of the chemical homologue ^{226}Ra, see Fig. 1. Typical activities are 0.2 Bq/cm^3 material [5]. Most of the crystals used for DANCE show an intrinsic α-activity between 150 and 250 Hz. The scintillation light of BaF_2 crystals has a short ($\sim$0.6 ns) and a long ($\sim$0.6 μs) component. The intensity ratio between the two components is radiation type dependent, which allows for particle identification if both components are measured. While the emitted α-particles deposit their energy almost exclusively through