# The Detector for Advanced Neutron Capture Experiments at the Los Alamos Neutron Science Center

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**Abstract.** The Detector for Advanced Neutron Capture Experiments (DANCE) is a 160-element, $4\pi$ $BaF_2$ array designed to make neutron-capture cross-section measurements on rare or radioactive targets. This paper presents information on the basic design and performance of the detector as well as some initial results.

## INTRODUCTION

A knowledge of neutron capture cross sections in the energy range of 1 eV to 100 keV is needed for many current applications, including defense programs, studies of stellar nucleosynthesis, advanced nuclear fuel cycles, and nuclear waste transmutation. Capture cross sections are difficult to calculate accurately, and therefore must be measured for many applications. While many precise measurements of capture cross sections for stable nuclides have been made, most have required tens of milligrams or more of sample material. For these reason there are very few measurements of capture on radioactive nuclides, where for isotopes of interest, 1 mg may equal 1 Curie or more of activity. The Detector for Advanced Neutron Capture Experiments (DANCE) was designed to make precise measurements of neutron capture on milligram or less quantities of sample material.

## DETECTOR AND FLIGHT PATH

DANCE was designed to be a calorimetric detector in which the total energy of the gamma-ray cascade following capture is measured. This total energy is roughly equal

to the Q value of the capture reaction, and can be used to help identify the nuclide on which capture occurred. The detector is a sphere of 162 equal-area segments of four different shapes. Two of the segments are empty to allow the beam to enter and exit the detector. The detector segments are 15 cm long $BaF_2$ crystals, coupled to Electron Tubes 9921 75 mm phototubes using Dow-Corning Sylgard-184 silicone elastomer. The crystal faces are 18 cm from the center of the sphere, for a total solid angle of 3.52π. Barium fluoride was chosen to minimize events due to capture of scattered neutrons in the detector itself. A 6 cm thick $^{6}$LiH sphere with inner radius of 10.5 cm is used to further reduce the scattered neutron background. Barium fluoride, however, has an internal radioactivity of about 0.2 Bq/cm$^3$ from the decay chain of $^{226}$Ra, a chemical homologue of Ba. This produces an alpha background of about 150 to 250 counts per in each crystal.

DANCE was constructed on Flight Path 14 at the Manuel J. Lujan, Jr. Neutron Scattering Center at the Los Alamos Neutron Science Center. The flight path views the partially coupled second-tier "backscatter" water moderator. The sample location is at 20.25 m and the beam stop at 30 m from the moderator. Outside of the bulk shield surrounding the neutron production target, the beam pipes are made of aluminum and all collimation is copper. The collimation was designed to provide a small (1 cm dia) beam spot with minimal penumbra at the sample location.

Three neutron monitors are located about 2 m downstream of the sample location. The monitors are a $BF_3$ proportional counter, $^{235}$U fission chamber, and a Si surface-barrier detector viewing a $^{6}$LiF deposit on a mylar film. The absolute integral value of the neutron flux was measured at the sample location by Au activation using a 2 mg/cm$^2$ Au foil with and without Cd according to the Westcotte convention. Figure 1 shows the neutron spectrum measured with $^{6}$Li(n,t) reaction and normalized by the Au activation. Also shown is the flux calculated by Muhrer[1] for the "as built" configuration of the flight path.

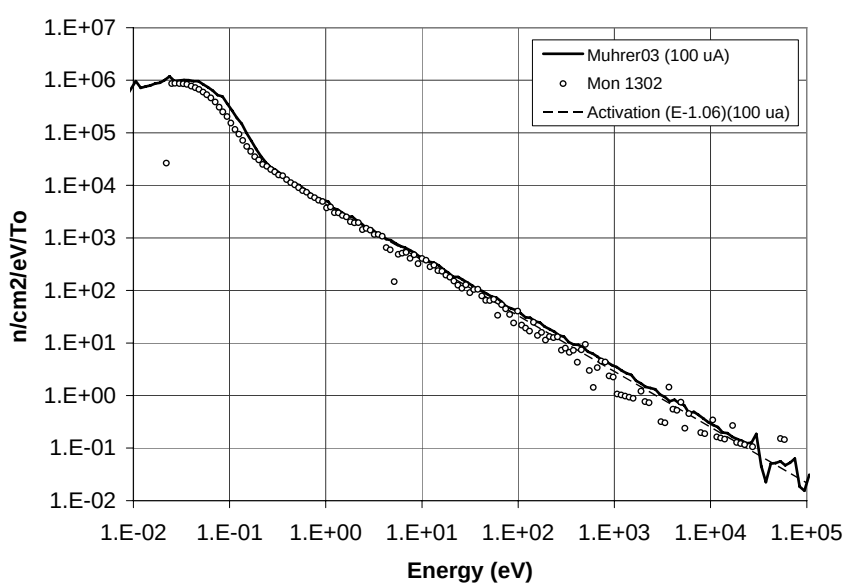


**FIGURE 1.** Neutron flux measured on FP14 and normalized to the DANCE sample location using Au activation. The "activation" curve is a power-law ($E^{-1.06}$) normalized to the activation measurement.

## DATA ACQUISITION

A typical event rate for a 4 mg/cm$^2$ Au target is 400 events in a 2 ms gate. The data acquisition system must handle multiple events per beam burst, fast digitization of the pulse heights, time measurements out to 15 ms with 5 ns or better time resolution, and rapid data transfer times. Fast waveform digitizers were chosen to meet these requirements. DANCE uses the Acqiris DC-265 digitizer[2], which is an 8-bit, 500 megasample/sec, 300 MHZ bandwidth digitizer with 128 kpoints memory per channel. The phototube anode signal is read directly by the digiziters, and two digitizers per crystal are used. The digitizers are configured with 12 detectors (24 digitizers) in a compact PCI crate. A 1.8 GHz single-board computer is mounted in each crate to control the digitizers and perform preliminary pulse-shape analysis and data compression. The acquisition system is described more fully in Ref 3.

Data are acquired in two different modes. In the segment mode, two digitizers are used for each crystal with high and low gains to give the proper dynamic range for the fast and slow light components of the $BaF_2$ crystal. External NIM logic is used to trigger an event when 2 or more detectors fire, and only the "hit" channels are digitized. The digitization range is 2 μsec, and a fixed deadtime of 3.25 μsec is imposed on the trigger circuit. This mode has the advantage of going to long times of flight and providing good fast/slow ratios for alpha discrimination, but the disadvantage of having a rather large fixed deadtime.

The second mode, the continuous mode, all digitizers are triggered on each beam burst and the frontend code strips the peak time and area from the continuous waveform. The two digitizers on each detector are configured with the same gain, but set to take data with different time delays relative to the trigger signal. Two waveforms, each up to 250 microsecond long, can be obtained. The total time is limited by the frontend processing time. In this mode, the fast component saturates at about 3.5 MeV, but this is adequate to provide good alpha-gamma discrimination. This mode has the advantage of having essentially no deadtime, but the disadvantage of having a limited energy range.

## DETECTOR PERFORMANCE

As noted above, the summed energy of the gamma cascade is related to the Q-value of the capture reaction. This is illustrated in Figure 2A, which shows the summed gamma energy peak from an Au target, gated on the neutron energies around the strong 4.91 eV resonance. The solid curve is a GEANT simulation of the peak[4]. The width of the summed peak is sensitive to the threshold of the detectors.

There are several sources of background in the DANCE detector, both beam related and beam-independent. Many of these are easily measured by making blank-target runs, and backgrounds from alpha decays in the $BaF_2$ detectors can be eliminated by pulse-shape discrimination. However, at neutron energies above about 1 keV, events from neutrons scattering in the sample and capturing on Ba isotopes in the detector become an important source of background, even with the $^6$LiH absorber. This is illustrated in Figure 2B, which shows the summed gamma spectrum for neutron

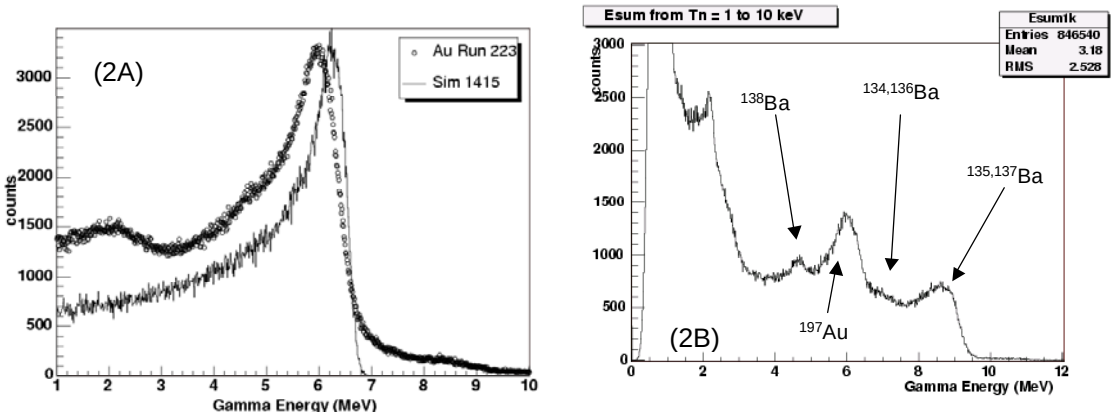


**Figure 2.** Figure 2A shows a comparison of the measured summed gamma energy peak for Au, gated on the 4.91 eV resonance, to a GEANT simulation. Figure 2B shows the summed gamma energy peak for neutrons from 1 to 10 keV. Gamma peaks from scattered neutrons capturing on barium isotopes are clearly seen.

energies from 1 to 10 keV from a 3.92 mg/cm$^2$ Au target. The Au capture peak at Q=6.51 MeV is obvious, as are captures on $^{138}$Ba (4.72 MeV), $^{135}$Ba (9.11 MeV) and $^{137}$Ba (8.62 MeV). The scattering contribution can be estimated using a C target, for which the scattering cross section is much greater than the capture cross section.

Another background comes from gamma rays that are produced in the target/moderator region, or by neutrons capturing along the flight path[5,6]. These gammas interact by Compton scattering or pair production in the target, and are then detected with high efficiency by DANCE. Since the interaction probability goes like Z for Compton scattering and $Z^2$ for pair production, this background is more important for heavy elements. It has been estimated by measuring gammas from a Pb target with a $CH_2$ neutron absorber in the beam.

## RESULTS AND FUTURE PLANS

Assembly of the DANCE array was completed in the fall of 2003, followed by commissioning tests and experiments on several stable and unstable targets. Preliminary results from several of these experiments have been reported at this conference. Measurements were made on several unstable targets, including $^{237}$Np,$^{234,235,236,238}$U, and $^{151}$Sm. These targets were prepared by electroplating small amounts (typically 0.5 mg) of the material on a thin (2 μm) Ti foil, and then gluing two sample foils together with the deposit facing each other. These were then mounted in a secondary container that had 50 μm Kapton windows[7].

As an example of the data obtained at DANCE, Figure 6 shows the cross section measured for $^{237}$Np(n,γ)[6], obtained with a 0.44 mg $^{237}$Np target. The data were normalized to the first resonance at 0.49 eV, for which various evaluations agree. This measurement is in qualitative agreement with the evaluations, but resolves discrepancies between different data sets.

In Fall, 2005, measurements are planned on $^{151,153,155}$Eu and $^{171}$Tm, which are important for fluence measurements by neutron activation, and on $^{240,242}$Pu. In future years, measurements are planned on $^{153}$Gd and $^{152,154}$Eu for understanding s-process nucleosynthesis. The capture-to-fission ratio in both fissile and non-fissile nuclides is also of considerable interest, as is the study of gamma rays following fission. Measurements of these quantities, using a fission-tagging detector, will also be made[8].

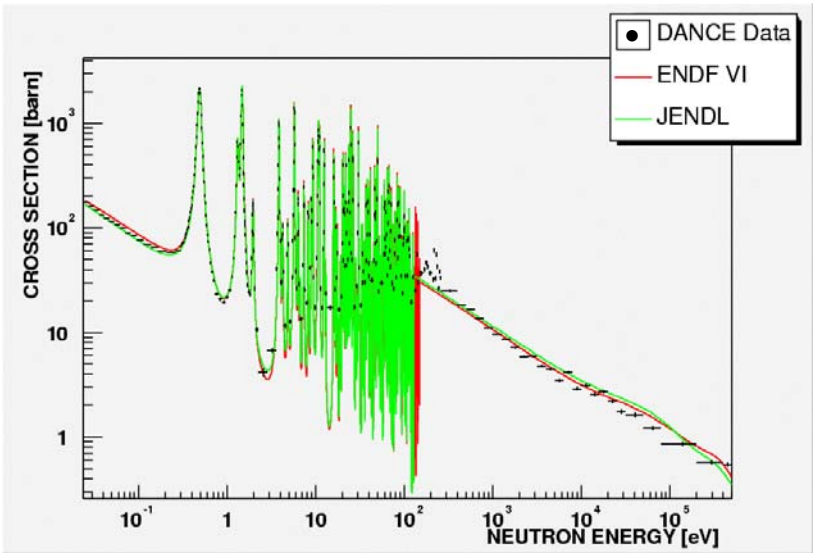


Figure 10. Measurement of $^{237}$Np(n,γ) cross section at DANCE. The measurement is in qualitative agreement with the ENDF-VI and JENDL evaluations. See Ref. 6 for more details.

## ACKNOWLEDGEMENTS

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