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Title: Recent Research with the Detector for Advanced Neutron Capture Experiments (DANCE) at the Los Alamos Neutron Science Center.

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RECENT RESEARCH WITH THE DETECTOR FOR ADVANCED NEUTRON CAPTURE EXPERIMENTS (DANCE) AT THE LOS ALAMOS NEUTRON SCIENCE CENTER

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The DANCE detector at Los Alamos is a 160 element, nearly 4π BaF_2 detector array designed to make measurements of neutron capture on rare or radioactive nuclides. It has also been used to make measurements of gamma-ray multiplicity following capture and gamma-ray output from fission. Several examples of measurements are briefly discussed.

1. Introduction

Neutron capture cross sections are important for basic science and for many applications of nuclear science, including defense and global security, reactor design, and astrophysics. Careful cross section measurements have been made on most stable nuclei. Hauser-Feshbach calculations can reproduce the measurements, but must usually be normalized to the experimentally determined average gamma decay width. If calculations are not properly constrained, the predictions can differ from the experimental value by a factor of two or more [1]. For rare or radioactive nuclei, the available data for normalizing the calculation are poor. DANCE was designed to make capture cross-section measurements on small quantities of material, on the order of tens of milligrams or less, while most previous measurements required 100's of milligrams or more. For radioactive targets, this resulted in a radiation hazard as well as requiring self-shielding and multiple-scatter corrections.

This paper will briefly describe some recent capture measurements, and also describe other measurements made with DANCE, including fission gamma ray emission, capture gamma-ray spectra, and using gamma-ray multiplicity as a "spin meter" for neutron resonances.

2. The DANCE spectrometer

DANCE is a nearly 4π BaF_2 array consisting of 160 BaF_2 crystals, each about 0.75 liters in volume. Four different crystal shapes are needed to allow equal solid angles for each crystal. The distance from target to the inner surface is 17 cm. The target position is surrounded by a ^{6}LiH sphere to absorb scattered neutrons. A total of 324 fast transient digitizers are used for data acquisition (two channels per crystal plus neutron monitors.)

The array is centered at 20.25 m from the “upper tier” room-temperature water moderator at the Manuel J. Lujan, Jr. Neutron Scattering Center. Three neutron monitors are located downstream of the target location at about 20.75 m. The monitors use the ^{6}Li(n,αt), ^{3}He(n,p), and ^{235}U(n,f) reactions. Earlier measurements used a BF_3 counter instead of the ^{3}He detector. The neutron flux spectrum consists of a thermal peak at 0.025 eV, and a tail above about 0.3 eV that is described roughly as $\Phi = 547\ E^{-1.04}$ n/cm^2/eV/To at the monitor location, with 100 μA of protons incident on the neutron production target, and where To is the number of beam bursts which occur at 20 Hz.

DANCE is a calorimetric detector which measures the total gamma-ray energy released in a reaction, with about 15% FWHM on the total energy spectrum. This permits a measurement of the Q-value of the capture reaction and the ability to gate on the target nucleus. Neutrons that are scattered from the target capture on the barium in the detector with a distinct Q value, and their contribution can therefore be minimized in the analysis.

3. Neutron Capture Measurements

3.1 . *Capture Measurements on Actinides*

The capture cross section in the keV region is known with surprisingly poor accuracy for many fissile actinides due to the gamma background from fission. Fission-tagging detectors can be used, but the thin targets required often compromise the statistical uncertainties in the capture measurement. Recent measurements at DANCE using a fission-tagging parallel-plate avalanche counter and an innovative thick/thin target technique have resolved some discrepancies in the ^{235}U(n,γ) evaluations [2]. More information on this and some preliminary results on ^{239}Pu(n,γ) are given in the contributions by M. Jandel and S. Mosby to this conference.

The cross section for ^{238}U(n,γ) is thought to be understood in the keV region, and so provides a test of the DANCE detector. Figure 1 shows the results of a measurement at DANCE using a 48 mg/cm^2 ^{238}U target. The data is binned in bins of dE/E = 0.05, and was normalized to low-lying resonances. The calculated cross section [3] was obtained using the CoH code, and required a value of the average gamma width $<\Gamma_\gamma>$ = 17 meV to normalize the calculation. The tabulated value of $<\Gamma_\gamma>$ is 23.6 meV [4]. This discrepancy is also seen in other actinides.

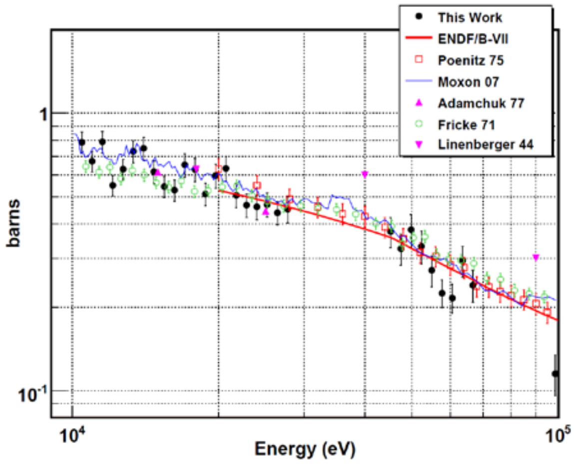

Figure 1. The $^{238}U(n,\gamma)$ cross section measured at DANCE in the 10 – 100 keV region compared to previous measurements and a Hauser-Feshbach calculation [3].

3.2 . *Astrophysical s-Process*

Measurements of the capture cross section from 0.5 to 100 keV are important for understanding slow ("s") process nucleosynthesis, which proceeds by capture along the valley of stability. Of particular interest is the measurement on unstable "branch point" nuclei, where the ratio of capture to beta decay is sensitive to the physical conditions at the stellar s-process site. Many unstable nuclides could be studied at DANCE [5].

An interesting DANCE measurement of $^{62}Ni(n,\gamma)$ for neutron energies from 0.05 to 50 keV was made by Alpizar, et al. [6]. The 30 keV Maxwellian-averaged cross section determined from this measurement was 25.8 ± 2.6 mb, confirming the activation result of 26.1 ± 2.6 mb [7], but twice as high as the expected value of 12.5 mb. This new value has had important implications for the s-process in the mass 60 region.

3.2 . *Gamma-ray spectra*

Additional insight into the capture mechanism can be gained by looking at the emitted gamma-ray spectrum for selected gamma-ray multiplicities. Figure 2 shows the measured energy spectrum from $^{238}U(n,\gamma)$ for two-gamma emission, also gated by a Q-value window on the total gamma energy spectrum. Data from two capture resonances are shown. Calculations of the spectra were made with two codes, the CGM code of T. Kawano [8] and the DICEBOX code of F. Becvar [9], and propagated through a GEANT4 model of DANCE [10]. Both codes are dependent on level densities and radiative strength functions. The calculations of both codes without low-lying M1 strength in the radiative strength function fail to reproduce the shape of the data, while inclusion of M1 strength at 2.0 and 7.0 MeV produced an enhancement from 2 to 3 MeV that mimics the data. It should be noted that the strength and location of the M1 strength was adjusted to fit the data, and that a more systematic approach is needed to fully justify it's inclusion.

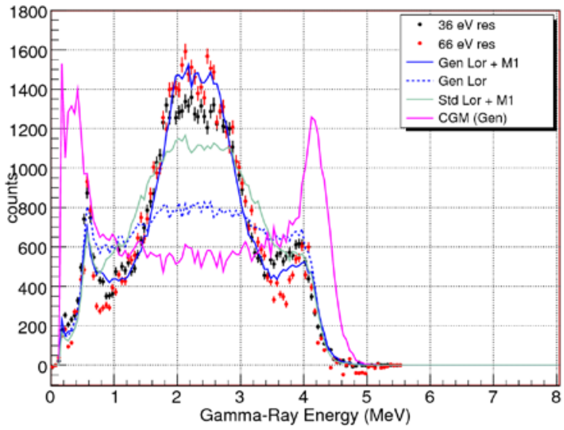

Figure 2. Gamma-ray spectrum from $^{238}U(n,\gamma)$ gated on capture resonances at 36 and 66 eV. The results of various calculations, as discussed in the text, are shown.

4. Other Measurements

4.1 . *Spin assignment of neutron resonances*

There are many techniques used for assigning the spin of neutron resonances, but in a number of nuclei many spins are still undetermined or ambiguous. The number of gamma-rays in the de-excitation cascade following capture can be used to determine the spin of a capture resonance. The high segmentation of DANCE makes it ideal for these studies. However, a single gamma-ray may produce a signal in several adjacent crystals, and it is the number of these clusters that is proportional to the gamma-ray multiplicity. For the simple case of s-wave capture, the final spin is J±½. Assuming that the gammas are E1 or M1, the minimum number of gammas emitted is roughly equal to the difference in spin between the capture state and the ground state. Of course, reality is more complicated, but in favorable cases the average number of emitted gamma rays provides a clean signature of the spin.

This was shown in a study of ^{95}Mo(n,γ) by Sheets, et al., [11] which resolved many uncertain spin assignments in ^{96}Mo. This method was refined to compare the multiplicity distribution with known "prototype" distributions for resonances in ^{147}Sm(n,γ) [12]. Finally, an elegant method of spin determination using the statistical pattern recognition technique of Expectation Maximization was developed by Baramsai to determine spins in ^{155}Gd(n,γ)^{156}Gd [13]. This approach has the benefit of determining the probability of each available spin.

4.1 . *Fission Gamma-ray spectra*

DANCE is an ideal detector for studying the gamma-ray output following fission, due it's nearly 4π solid angle and high segmentation. Measurements were recently done on ^{252}Cf spontaneous fission, and ^{235}U, ^{239}Pu, and ^{241}Pu neutron-induced fission, with the target material in a small parallel-plate avalanche counter inserted into the center of the DANCE array to tag fissions. The quantities measured were the individual gamma-ray emission spectrum, the distribution of number of gamma-rays emitted per fission, and the total emitted energy spectrum. Results from this measurement are discussed in the contributions of Chyzh and Jandel at this conference, and in several reports. [14].

5 . Summary

The DANCE array has been proven to be a versatile tool for measuring neutron capture cross sections, gamma-ray emission spectra, and gamma-ray multiplicities. Many experiments have been completed, and others are still being analyzed. The addition of two newly-acquired HPGe detectors, replacing two of the BaF_2 crystals, will give additional high-resolution information.

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