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Abstract. The Detector for Advanced Neutron Capture Experiments (DANCE) is a 159-element 4π barium fluoride array designed to study neutron capture on small quantities, 1 mg or less, of radioactive nuclides. It is being built on a 20 m neutron flight path which views the "upper tier" water moderator at the Manuel J. Lujan Jr. Neutron Scattering Center at the Los Alamos Neutron Science Center. The detector design is based on Monte Carlo calculations which have suggested ways to minimize backgrounds due to neutron scattering events. A data acquisition system based on fast transient digitizers is being implemented.

INTRODUCTION

The precise measurement of neutron capture cross sections in the electron-volt and kilo-electron-volt regions on radioactive isotope targets is needed for several applications, including nuclear astrophysics, stockpile stewardship, and waste transmutation studies. Capture cross sections are difficult to calculate accurately because they depend on fine details of nuclear structure and level densities at 5 to 10 MeV in excitation. A recent compilation of "Maxwell-averaged" capture cross section calculations made using the "Non-Smoker" statistical model code [1] showed that the calculated cross sections differed from measured cross sections by +/- a factor of 2 for masses between 25 and 210. While there are capture measurements on most stable nuclides, there are very few measurements on unstable nuclides

One of the main applications for capture cross sections is in understanding s-process nucleosynthesis [2]. The s process occurs by sequential neutron capture along the line of beta stability. When the capture sequence produces an unstable nuclide, the process can branch. The competition between beta decay and neutron capture at the branch nuclide depends on its stellar beta-decay half life, the stellar neutron density, and the capture cross section. Combined with observed nuclear abundances, the capture cross section and beta-decay rate can be used to infer the temperature and neutron density at the stellar s-process site. The interesting energy range for these cross sections is over Maxwell distributions centered at 25 keV and at about 10 keV. A second application is in Stewardship Science, where capture cross sections on unstable nuclides are needed to interpret "radio-chemical" diagnostics from past nuclear tests.

Three separate experimental components are needed to make these measurements: An intense neutron source, facilities to fabricate and handle radioactive targets, and an efficient, well characterized gamma detector. The neutron source and the Detector for Advanced Neutron Capture Experiments (DANCE) are discussed in this paper; target preparation is done using the facilities of the Isotope and Nuclear Chemistry Group at Los Alamos.

NEUTRON SOURCE

The DANCE has been constructed on Flight Path 14 at the Manuel J. Lujan, Jr. Neutron Scattering Center at LANSCE [3]. Flight Path 14 views the upper-tier "backscatter" water moderator. This moderator is 13 cm square by 4 cm thick and is surrounded by a Be and Pb neutron reflector. This "partially coupled" configuration maximizes the thermal neutron flux at the expense of a broadened time distribution. At energies of a few eV and above this broadening becomes increasingly less significant. The backscatter configuration is believed to reduce the beam contamination from high-energy (greater than 1 MeV) neutrons, charged particles, and gamma rays. The Lujan moderators are discussed in detail in Ref. 4.

The bulk shielding surrounding the spallation target is 4.72 m in radius. The sample is positioned 20 m from the moderator and the beam stop is at 30 m. A box for remotely inserting various filters is at 7 m. Filters in use are Bi and S for black resonances and Cd to reduce the thermal neutron flux. Four discrete collimators are located outside the bulk shield, each constructed of about a meter of copper, brass, and 5% borated polyethylene. The collimation was designed to produce a uniform 1 cm diameter beam spot at the target location with minimal penumbra outside the central beam. The last collimator has a r = 0.3 cm opening with the downstream edge at 18.88 m. This tight collimation limits the beam intensity, which depends on the area of the moderator that is viewed. To reduce gamma backgrounds, the beam pipes and flanges were constructed of aluminum and the use of iron in components outside of the bulk shield was kept to a minimum.

The flight path shielding was designed to limit the total gamma plus neutron dose to less than 1.0 mrem/hr along the first 10 m of the flight path and 0.5 mrem/hr beyond 10 m. Magnetite-loaded concrete blocks were used to shield the beam pipes and target area. Only polyethylene and borated polyethylene were used for shielding the roof of the target area. The Monte Carlo shielding calculations predicted significant high-energy gamma-ray production from neutron capture in the polyethylene and concrete, and the interior walls of the target area were faced with 2.54 cm thick 5% borated polyethylene which yields lower energy gamma rays following neutron absorption..

Flight-path characterization was done during the 2001 run cycle. The spallation source was operated at 55 μA. The neutron flux on FP14 was measured with three different techniques. First, a standard ^{3}He tube was used [5]. Next, a fission chamber with 286 μg/cm^2 of ^{235}U was used. Lastly, a neutron monitor consisting of 5.45 X 10^{18} atoms of ^{6}Li in a 1 cm diameter deposit of ^{6}LiF (approx 288 μg/cm^2) on an Al foil backing and viewed by a Si surface barrier detector, was employed to detect neutrons via the ^{6}Li(n,αt) reaction.

The measured flux is shown in Fig. 1. The three measurements were each made at a different flight path location, and were converted to moderator surface current to correct for this geometric difference. The ^{3}He measurement is not consistent with the others, but all were considerably below the anticipated flux. This discrepancy is not understood and will be investigated further during the next run cycle. The ^{235}U and ^{6}Li measurements can be fit to a surface current of the form I = A/E with E in eV and A = 2.58 x 10^9 N/cm^2/sr/eV/sec at 55 uA. At 20 m, this yields a flux of Φ = (8.67 x 10^3 N/cm^2/eV/sec)/E.

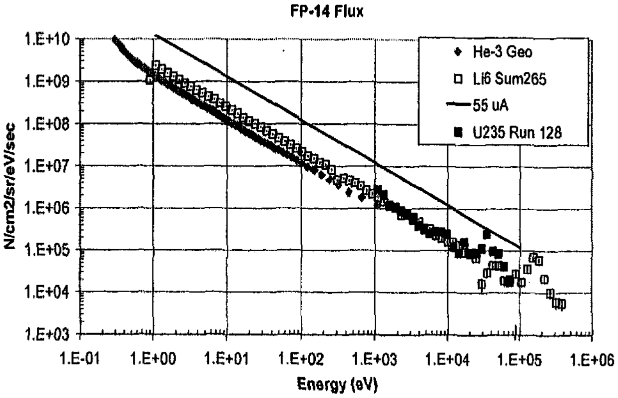

FIGURE 1. Moderator surface current for FP14 at the Lujan Center, measured at 55 μA proton current. The predicted surface current is shown as the solid line.

DANCE DESIGN

The advanced gamma detector is being built to provide a high and well-determined gamma-ray detection efficiency, and also to provide good background rejection. Backgrounds are due both to neutron capture in material surrounding the target and to capture reactions in the detector from neutrons scattered in the target. The neutron scattering cross section is greater than the capture cross section for many materials in the kilovolt region. Three criteria were established for the detector:

- Calorimetric to measure the total gamma ray energy emitted
- Insensitive to neutrons
- Segmented and fast to handle radioactive targets (one Curie is 37 decays/ns)

Of the commonly available scintillator materials, BaF_2 was chosen because it had the smallest neutron capture cross section and a very fast (0.6 ns) component of light. It suffers from an internal alpha particle background due to decay of Ra and its decay chain products, but pulse-shape discrimination can be used if needed.

The crystal array should completely cover 4π steradians with no gaps, and each crystal should have equal area and volume. The analysis of Habs [6] showed that 162 elements with 4 different shapes will meet this requirement. After allowing room for the beam pipe and a target-changing mechanism, only 159 crystals will be used. The inner radius of the array is 17 cm and each crystal is 15 cm deep, 734 cm^3 in volume, and has an inside area of 22.9 cm^2. Each crystal is coupled to an Electron Tubes 9921 7.5 cm phototube with quartz window using RTV-615 for maximum UV transmission.

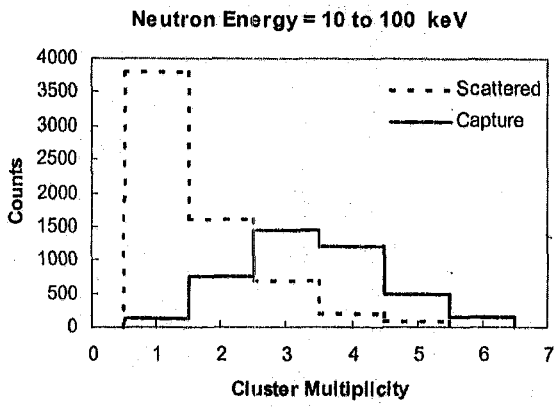

FIGURE 2. Cluster multiplicity (see text) for events due to true capture in the target and capture of neutrons scattered into the BaF_2 array.

Extensive Monte Carlo calculations were made using GEANT-3 to design the detector [7,8]. The calculations indicated that scattered neutrons would contribute a significant background, especially in the 10 to 100 keV range of interest. The calculations also indicated several methods which will be employed to reduce this background. First, the measured reaction Q value can be used in many cases to discriminate between true capture events and events induced by scattered neutrons [7,8]. Next, the calculations predict that an 8 cm thick ^6LiH shell inside the array will reduce the scattered neutrons to 42% of the unattenuated number in the 10 to 100 keV energy range[8]. However, because of space limitations we will use a 6 cm thick ^6LiH sphere surrounding the target. Finally, a "hit pattern" analysis of the event will also be tried. This is illustrated in Fig 2. which shows the calculated number of crystal clusters for events due to neutron scatter and true capture in the target [8]. A cluster is a set of adjacent crystals that give a signal above threshold. True capture events produce several clusters, each due to an individual gamma ray from the decay cascade, while events due to neutron capture in the BaF_2 tend to be grouped primarily into one cluster.

DATA ACQUISITION

A fast data acquisition system is required for the detector. The Lujan center beam rate is 20 pulses/second and 1 eV neutrons arrive at about 1.6 msec. One hundred or more real capture events are expected in each beam burst, depending on neutron flux, along with an estimated 100 background events.

The data acquisition system will consist of two Acqiris DC-265 8-bit waveform digitizers on the anode signal of each phototube. The digitizers sample at 500 MHz and are operated in "segment" mode, with each segment consisting of about 2 to 3 microseconds of data. This has the disadvantage of introducing a 300 ns deadtime for re-arming the digitizer, but the advantage of a short waveform for each event. The digitizers have two different voltage gains to give an appropriate dynamic range for the fast and slow components of the scintillation light. The slow component contains about 85% of the light, and has a decay time of 630 ns. The fast component, while providing only 15% of the light, has a decay time of 0.6 ns and is the dominant feature of the waveform.

The complete data acquisition system consists of 14 compact PCI crates each containing 24 digitizer channels and one 500 MHz front-end computer. The front-end computer will read the waveforms from each digitizer card that contains data and analyze the waveforms for time and pulse height. Only these quantities, along with bookkeeping information, will be sent to a central computer by ethernet for histogramming, analysis, and logging. This procedure both distributes the pulse-height analysis processing and reduces the network activity. The MIDAS program [9] is being used for data acquisition, and the ROOT [10] package for data display and analysis.

Figure 3 shows a typical pulse from a completed crystal assembly, acquired with an Acqiris DC-270 1 GHz digitizer. The fast and slow components of the pulse are easily recognized. Fig 4 shows a ^{60}Co spectrum obtained by simply adding the counts in a waveform from 10 ns before the trigger time to 1790 ns after. The resolution of the 1173 keV peak is 9.0% fwhm.

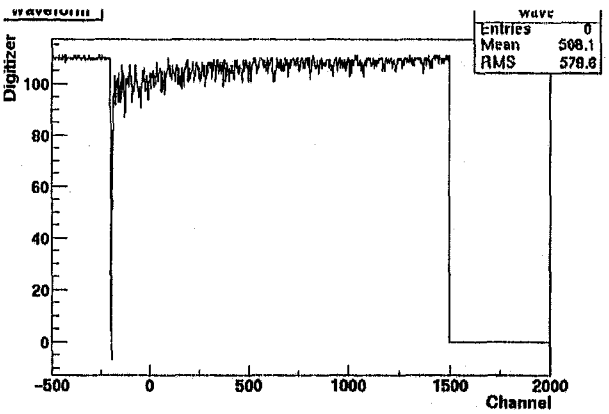

FIGURE 3. Typical waveform from a completed BaF_2 crystal assembly using a DC-720 1 GHz digitizer. The fast and slow components are easily recognized. The x-axis scale is 1 ns/channel.

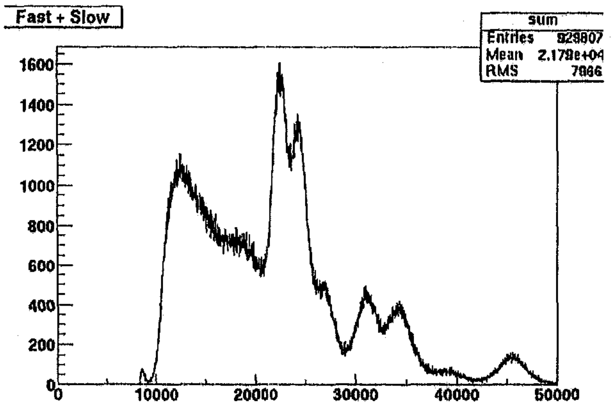

FIGURE 4. ^{60}Co spectrum obtained by simply summing waveforms from a 1GHz digitizer. The peaks from the alpha-decay background in the crystal are readily seen at channel 26000, 31000, and 34000.

SUMMARY AND FUTURE PLANS

The DANCE array is nearly complete, with 140 of the 159 crystals installed and the remainder scheduled for delivery in Fall, 2002. A multi-year program of radioactive targets to be measured for stockpile stewardship and s-process branch point studies has been mapped out. Preliminary experiments using C_6D_6 detectors have confirmed that measurements can be made on 1 mg quantities. Initially, targets that can be chemically purified have been chosen. Samples of ^{146}Nd, ^{154}Sm, and ^{170}Er were irradiated at the ILL in spring, 2002, to produce 4 to 10 mg samples of ^{147}Pm, ^{155}Eu, and ^{171}Tm. It is expected that these isotopes will be studied using the DANCE array during the current 2002-2003 run cycle, along with a new measurement of ^{151}Sm.

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REFERENCES

1. T. Rauscher and F.-K. Thieleman. in *Atomic and Nuclear Astrophysics*, A. Mezzacappa, *ed.*, IOP, Bristol, (1998), p. 519.
2. F. Kaeppeler. Prog. Part. Nucl. Phys. **43**, 419-483 (1999).
3. For more information see http://lansce.lanl.gov.
4. G.J. Russell, et al., in *Fundamental Physics with Pulsed Neutron Beams*, C.R. Gould, et al., *ed.*, World Scientific, Singapore, pp 19-48 (2000).
5. L. Daemen, private communication.
6. D. Habs, F.S. Stephens, and R.M. Diamond, Lawrence Berkeley Laboratory Report LBL-8945, (1979).
7. M. Heil, et al., Nucl. Instr. Meth. **A459**, 229-246 (2001). M. Heil, et al., Los Alamos National Laboratory report LA-UR-99-4046, (1999).
8. R. Reifarth et al., Los Alamos National Laboratory Report LA-UR-01-4185,(2002).
9. See http://midas.triumf.ca, http://midas.psi.ch
10. See http://root.cern.ch