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Basic and applied research at the Weapons Neutron Research facility

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ABSTRACT

The Weapons Neutron Research facility (WNR), is an intense, high energy spallation source, driven by the LAMPF 800 MeV proton linac. We describe below some of the basic and applied research projects which are currently being worked on at this facility.

1. INTRODUCTION

The Weapons Neutron Research facility¹ (WNR) uses the proton beam from the Los Alamos Meson Physics Facility (LAMPF) to produce spallation neutrons. In typical operation, 40 macropulses of proton beam are sent to WNR - each macropulse is $\sim 800 \mu\text{sec}$ long, and the usual micropulse spacing (inside the macropulses) is $1.8 \mu\text{sec}$. In this mode of operation, the average proton beam to WNR is $\sim 1 \mu\text{A}$. This summer, we expect an upgrade to enable us to obtain 100 macropulses, increasing our intensity proportionally. The neutron production target is a tungsten rod, 3 cm in diameter and 7.5 cm long, shielded in a magnetite-concrete crypt. Seven well-collimated beam lines are available, covering angles of 15, 30, 60 and 90 degrees to the proton beam. The difference between spectra in the different beam lines is evident mainly at high energies, i.e., above 100 MeV, and is depicted in figure 1.

Figure 1: WNR Neutron fluence per steradian, per incoming proton, at 15, 30 60 and 90 degrees.

In addition to research at WNR, three beam lines at the Manuel Lujan Jr. Los Alamos Neutron Scattering Center (LANSCE) are dedicated to nuclear science experiments performed by the WNR group.

WNR research can be divided into basic research, applied research and weapons research. Basic research includes experiments concerning neutron-proton bremsstrahlung, parity and time reversal violation in nuclei, determining nuclear viscosity using the fission process, and neutron-proton charge exchange reactions. Applied research involves investigation of upset and latchup phenomena in semiconductor circuits, enhancing superconductor properties by Bi-induced fission, determination of induced radioactivity in tungsten and lead by proton beams, determination of prompt gamma-ray emission induced by neutrons, cross-section measurements for Accelerator Transmutation of Waste (ATW) and more. Weapons research involves detector characterization for test-site measurements, measurement of tritium production from moderated spallation neutrons, neutron radiography and related topics. We will now discuss some details of the basic and applied research aspects of WNR.

2. BASIC RESEARCH AT WNR

2.1. Neutron - proton bremsstrahlung

Neutron - proton bremsstrahlung² (NPB) addresses several physics issues in the 40 to 400 MeV neutron range:

1. A study of the "off-shell" behavior of the nucleon-nucleon interaction, below and above the pion threshold.
2. A study of the contribution to the n-p interaction of the meson exchange currents, including mesons heavier than pions.
3. NPB is the simplest process that involves electromagnetic and nuclear reactions simultaneously.
4. NPB cross-sections are needed for the understanding of high-energy gamma-ray production in heavy-ion reactions.

The goal of the ongoing experiments at WNR is to provide data for testing the largely unverified NPB calculations. One type of measurement that is being performed, uses proton and neutron detectors to measure n-p coincidences, providing a differential measurement. The proton detectors are an array of nine proton phoswich telescopes, placed in three rows of three cubical detectors, positioned on one side of the beam. The phoswich consists of a 3 mm thick fast plastic scintillator, coupled to a 26.7 cm thick slow scintillator. Short and long charge integration times permit the separation of the fast and slow components into dE/dx versus energy, with the consequent identification of proton events in the detector. The neutron detectors (total of six) are 6 inch diameter by 5 inch deep plastic scintillators, attached to a 5 inch phototube. A plastic veto paddle is placed in front to reject charged particles. These data are still being analyzed.

Previous experiments involved the use of a high-energy gamma-ray telescope, to detect photons at angles of 90 and 117 degrees. Above the pion production threshold, other contributions mask the NPB, and most of the valid data is at lower energies. Each telescope consisted of 5 planes of elements: The first plane was a plastic paddle for rejection of charged particles. Next was a BaF_2 plane, 1 cm thick, segmented into 6 paddles, which served to convert photons to electron-positron pairs. A 1 cm thick plane of Cerenkov counters, segmented into three paddles, for identification of fast electrons, and rejection of proton and neutron induced events. Next, a 3 mm thick scintillator provided a ΔE measurement. The last plane consisted of an array of 16 NaI detectors, each $10 \times 10 \times 40$ cm³. The crossing of the sets of paddles defined the solid angle of the telescope. Coincident measurements between the photon detector and the array of 16 phoswich detectors (which registered protons) were taken. Results obtained for $E_n=200$ MeV at 90 degrees, compared to various calculations, are shown in the next figure. One of the important consequences of the experiment and the analysis is the important role the $n+p \rightarrow d+\gamma$ reaction plays in high-energy below the pion production threshold.

2.2 The nuclear fission process

Nuclear viscosity (dissipation) plays a prominent role in fission theory. The Bohr-Wheeler approach to fission cross-section calculation was accepted without challenge for many years. Measurements of particles preceding fission in heavy-ion reactions, led to an improved understanding of the fission process, in which fission is both delayed and inhibited by the viscosity of the fissioning nucleus. Since these measurements pertain to nuclei at high excitation energy and high

Figure 2: Comparison of gamma-ray measurements to various theoretical models.

angular momentum, we embarked on an experimental program to determine the effects of viscosity in neutron induced reactions, where the angular momentum is small. The program included two phases: Phase one - detailed measurements of fission cross-sections of $^{233-236,238}\text{U}$, that enabled us to determine the statistical model parameters used to reproduce the data³; phase two - measurement of the energy spectrum and angular distribution of neutrons emitted in the $^{238}\text{U}(n,f)$ reaction. We have completed the analysis and modeling of the results obtained in phase one. We are able to fit the experimental cross-sections using a statistical model calculation, provided we incorporate the necessary physics. First, we need to incorporate the double humped structure of the actinide fission barrier. Each barrier has different symmetries, giving rise to different level density enhancements at each saddle point. We use level densities generated from single particle levels, thus incorporating shell and pairing effects. The "washing out" of the shell effects with increasing excitation energy is inherently included in this method of calculating level densities. We incorporate preequilibrium particle emission, using the geometry-dependent hybrid model. In addition, we find that in order to fit the data, we need to wash-out the enhancement to the level density at the first saddle-point, that resulted from the axial deformation. This occurs between 6 to 8 MeV above the fission barrier. This is the first time the washing out of the triaxial enhancement to the level density at the first barrier has been determined. Figure 3 shows a comparison between the data (points) and the calculation (full line - calc-1). The dashed line (calc-2) shows the calculation when the effects of preequilibrium emission and axial-enhancement washing out are neglected.

3. APPLIED RESEARCH AT WNR

3.1 Neutron irradiation of semiconductors.

The neutron spectrum at WNR resembles the spectrum of secondary neutrons produced by cosmic rays at high altitudes (approximately 13 km). A comparison of these spectra is presented in figure 4. A collaboration of Boeing aviation and honeywell electronics is using this similarity to examine the effects of neutrons on electronics designed for use in the high- flying Boeing 777 aircraft⁴. At WNR, they can perform tests equivalent to 10^5 hours of flying time, in one hour of

Figure 3: Comparison of measured cross section of ^{235}U to calculations. Calc-2 shows the calculated values when preequilibrium emission and axial-enhancement washing out are excluded.

Figure 4: Comparison of neutron spectrum at WNR (30 degree left flight path), to the spectrum of secondary neutrons at 60,000 feet altitude.

irradiation. Their tests have demonstrated latchup events in addition to single- and multiple-event upsets. New and improved electronics will be tested this summer. Other electronics manufacturers have now expressed their interest in using WNR to test the effect of neutrons on various electronics packages. The current work indicates notable inaccuracies in the presently accepted models for predicting single-event upset rates in an atmospheric environment, and provides an experimental basis for the development of a more accurate model.

3.2 High-temperature superconductor irradiation.

A collaboration between IBM and WNR has irradiated composite tapes of the superconductor $\text{Bi}_2\text{Sr}_2\text{CaCu}_2\text{O}_8$ using the direct 800 MeV proton beam⁵. Fission of the bismuth nuclei creates extended splayed (i.e., dispersed in orientation) tracks in the superconductor. These tracks give rise to a large increase in the current density J , at low temperatures, as well as the ability to extend the persistent current to much higher temperatures. A comparison of the persistent current density before and after irradiation is presented in figure 5. We note the relatively high value of J at large temperatures for the irradiated superconductor. It is believed that the substantial splay in the track directions arrests the creep of vortices from the tracks, thus boosting both J and the size of the irreversible region.

Figure 5: Persistent current density J , vs temperature, before (full line) and after (dashed line) processing with 10^{14} fission fragments/cm³, in a $\text{Bi}_2\text{Sr}_2\text{CaCu}_2\text{O}_8$ superconductor.

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