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NUCLEAR SCIENCE RESEARCH AT THE WNR AND LANSCE NEUTRON SOURCES

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ABSTRACT

The Weapons Neutron Research (WNR) Facility and the Los Alamos Neutron Scattering Center (LANSCE) use 800 MeV proton beam from the Los Alamos Meson Physics Facility (LAMPF) to generate intense bursts of neutrons. Experiments using time-of-flight (TOF) energy determination can cover an energy range from thermal to about 2 MeV at LANSCE and 0.1 to 800 MeV at WNR. At present, three flight paths at LANSCE and six flight paths at WNR are used in basic and applied nuclear science research. In this paper we present a status report on WNR and LANSCE, discuss plans for the future, and describe three experiments recently completed or underway that use the unique features of these sources.

I. INTRODUCTION

The most intense broad-spectrum neutron sources in the world used for nuclear science research are LANSCE and WNR, presently in operation[1] at Los Alamos National Laboratory. Those neutron sources are based on proton spallation, and use 800 MeV beam from the Los Alamos Meson Physics Facility as the driver. The result is that there are intense pulsed neutron beams for time-of-flight research over ten decades of energy, from thermal to nearly 800 MeV.

This paper gives a brief description of the facilities as an update to a more comprehensive reference[1]. It is hoped that this work will stimulate scientists with appropriate research projects to submit proposals for research at these facilities.

II. THE WNR NEUTRON SOURCE

The Weapons Neutron Research Facility, presented in Figure 1, shows that there are two experimental areas. At these areas, the proton beam consists of narrow 150-ps bursts, separated from each other by a spacing as small as 360 ns. Each burst, or micropulse has about 3.3×10^8 protons. Because of the linac operating characteristics, micropulses occur over an interval of approximately 800 microseconds, as part of a longer time structure known as a macropulse. Beginning in 1994, it is anticipated that the macropulse rate to the WNR Facility will be increased from 40 Hz to 100 Hz. At a micropulse spacing of 1 microsecond, the beam current will be 4 micro-Amperes, and the micropulse rate will be 80,000/s. Beam energies from 113 MeV to 800 MeV can be provided, although preference is given to experiments running at 800 MeV to avoid beam transport interference with the nearby LANSCE Facility.

A. WNR Target-2

The Target-2 area was designed for experiments requiring protons. It is the only area at LAMPF with an external proton beam in routine use. Previously, the proton beam current incident on stopping-length targets was limited to approximately 100 nano-Amperes because of shielding limitations. When several experiments required higher beam current, a study was initiated using the Los LAHET Code System[2] (LCS) to predict the sources of radiation dose. Adding thermal-neutron shielding reduced the radiation level at the entrance by a factor of ten. Experiments with up to one-micro-Ampere are now routinely conducted in Target-2.

B. WNR Target-4

The Target-4 area was designed to produce a broad spectrum of neutrons using 800-MeV proton-induced spallation reactions on a water-cooled tungsten target. The production target and surrounding biological shield were arranged to optimize the flux for TOF experiments requiring incident neutron energies from about 100 keV to nearly 800 MeV. Target-4 is surrounded by a biological shield constructed for use with up to 20 micro-Amperes of proton beam. Recent radiation tests have verified that at a proton current of 10 micro-Amperes, neutron leakage at the surface of the shield is not detectable above background levels. Because the area surrounding the shield is fenced to prevent close personnel access, it is anticipated that currents as high as 100 micro-Amperes can be delivered to Target-4 without exceeding DOE radiation guidelines.

Since the last report on WNR, several modifications have been made to the time-of-flight experimental area,

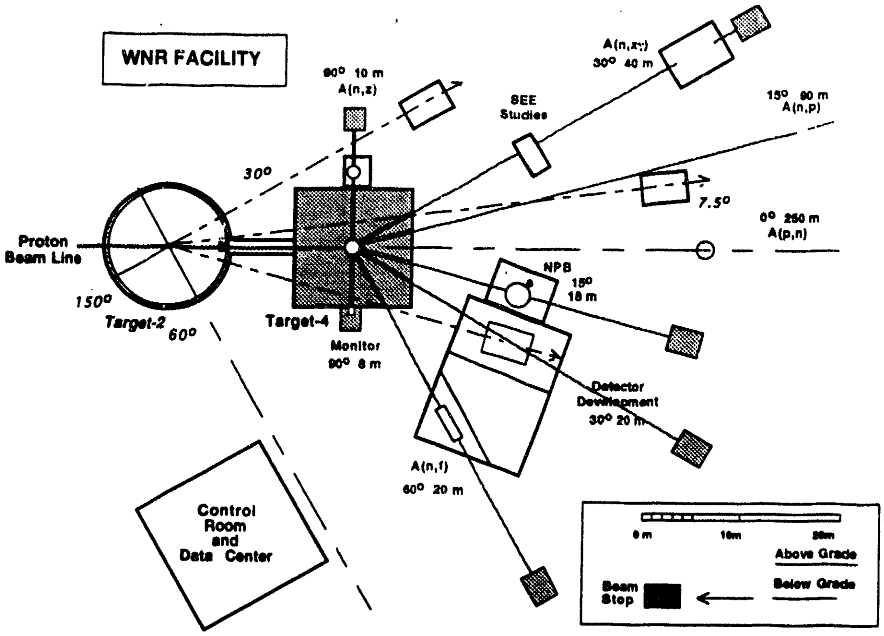

Figure 1 Layout of the WNR Facility. The proton beam enters from the left.

Table I summarizes the present configuration. The 30R and 60R stations extend from 20 to about 30 meters.

TABLE I. WNR Target-4 Neutron Flight Paths

Angle	Station Distance (m)
90L	8
30LA	20
30LB	40
15L	90
15R	11
30R	25
60R	25
90R	7

III. THE LANSCE NEUTRON SOURCE

The Los Alamos Neutron Scattering Center neutron source is optimized to produce thermal and epithermal neutrons using 800 MeV proton beam from LAMPF that is time-compressed by a Proton Storage Ring (PSR). The PSR output consists of a 125-ns (FWHM) triangular pulse containing about 2 x 10^{13} protons. The maximum repetition rate of those pulses is the same as LAMPF, 120 Hz, but beam delivery to LANSCE is limited to 20 Hz to avoid frame-overlap. LANSCE routinely operates with between 60 and 75 micro-Amperes of beam striking a split-tungsten target[3] surrounded by water or liquid-hydrogen moderators. The neutron intensity and time resolution of the present target-moderator system have been studied for the flight paths in use for nuclear science. Figure 2 shows recent results from neutron flux[4] determinations. New measurements[5] of the neutron energy resolution have also been made.

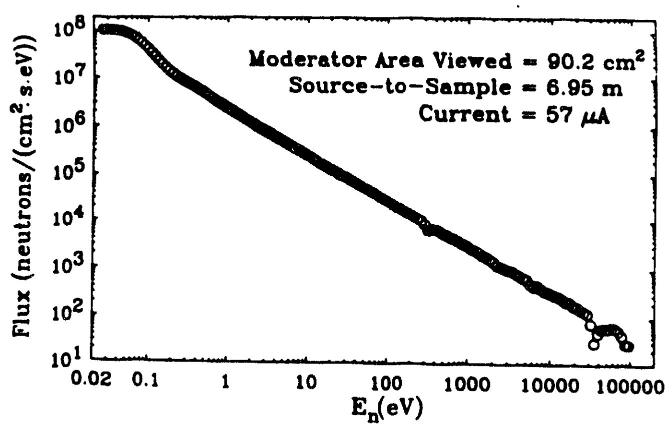

Figure 2 Neutron Flux Measurements for the LANSCE High Intensity Water Moderator.

Because several experiments have expressed an interest in developing a moderator with a narrower neutron output pulse width than is now possible at LANSCE, a study was instituted to determine the effect of lowering the PSR pulse width. In that study, it was found that the output current is linear with output pulse width down to approximately 15 ns (FWHM). However, because the PSR output is limited by beam spill during the filling process, it is possible that reducing the pulse width to about 60 ns will allow a mode of operation with less than proportional loss in beam current compared to operation at 125 ns. That means that it is possible to install a moderator system that can substantially enhance useful neutron intensity in the resonance energy range.

Since the last report on the LANSCE facility, a new flight path has been constructed for nuclear science research. That flight path has stations at about 10-meters and 80-meters and was constructed by boring and installing a 1-meter diameter iron pipe approximately 12-meters below ground level. The 80-meter station is located in the WNR time-of-flight experimental area. Personnel access to the station is by means of a spiral staircase; equipment is lowered from a building at the surface using a crane.

Table II lists the present configuration of the nuclear science flight paths at LANSCE.

TABLE II. Nuclear Science Flight Paths at LANSCE

Flight Path	Station Distance (m)
2	20, 80
4	8
5	8, 80

IV. THE NUCLEAR SCIENCE RESEARCH PROGRAM

Over the past three years[6], there has been a substantial diversification of the research program at Los Alamos. In the following discussion, three diverse examples of experimentation in each of the major areas of effort at Los Alamos will be presented: Nuclear Technology, Defense Science, and Basic Nuclear Physics. In order to put this work in perspective, these examples represent less than 10% of the total number of nuclear science experiments conducted at WNR and LANSCE each year. The entire research program involves about 100 scientists, about half of whom are members of the university and industrial community.

A. Nuclear Technology Example - SEE

The effects of radiation on electronics components in space and military applications has been of interest for many years. At airplane altitudes of 30,000 to 60,000 feet, in contrast to space applications where heavy ions and protons are of major concern, neutrons produced by the interaction of cosmic rays in the atmosphere are the dominant radiation threat, producing Single Event Effects (SEE). SEE include single-event effects, multiple event upsets, and single-event latchup. As integrated circuit technology has become smaller and more densely packed, and as the aircraft manufacturing industry has integrated more sophisticated electronic components into critical features of new aircraft, reliability has become an issue. For example, new airplane technologies such as the European Airbus and the Boeing 777 use "fly by wire" designs that rely on correct functioning of elaborate electronics to maneuver control surfaces on the aircraft. Because simulation codes and nuclear data for high-energy neutrons with electronics components are inadequate, the Boeing Aircraft Company, Honeywell and LSI Logic decided to perform tests of electronics systems in the WNR neutron spectrum. As shown in Figure 3, The WNR neutron flux is 10^5 times the intensity of the cosmic ray neutron flux at 45,000 feet, but with very nearly the same shape.

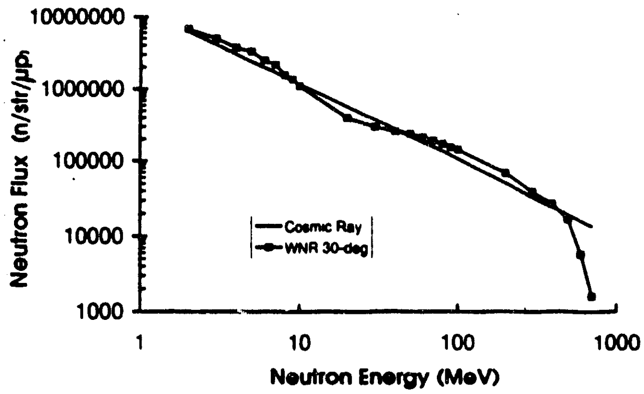

Figure 3 The neutron flux at the 30°L flight path at WNR Target-4 facility and the atmospheric cosmic-ray induced flux at aircraft altitudes. The cosmic ray flux is multiplied by approximately 10^5

The experiments[7] at the WNR Facility showed, for the first time, effects due to energetic neutron-induced SEE. The result is realization of the pressing need to acquire experimental data in order to improve the understanding and accuracy of upset evaluations and to resolve inaccuracies in the presently acceptable models for predicting SEE rates.

B. Defense Science Example - Tritium Production

Because tritium decays at a rate of 5.5% per year, it is the only nuclear material that must be continually produced in order to maintain our defense capabilities.

Spallation neutrons generated by high-energy protons from a linear accelerator can produce the required tritium without the use of any fissile material, greatly minimizing environmental effects. In addition, because there is no energetic material such as uranium present, an accelerator system can shut down almost instantaneously, providing a unique safety advantage. Los Alamos, Brookhaven and Sandia National Laboratory together with Bechtel, Grumman, Babcock & Wilcox and Westinghouse have developed a pre-conceptual design of a 1000 MeV, 200 mA linear accelerator and spallation neutron source using tungsten and lead to produce tritium through thermal neutron capture on ^{6}Li or ^{3}He.

For either system, it is important to quantify the residual radionuclide production in the spallation target. From engineering considerations, it is necessary to understand the short-lived isotopes that may to contribute to the decay heat that must be removed once the beam is turned off, From a safety viewpoint, it is important to understand the radioactivity to properly engineer confinement for an accident and ultimately, to estimate waste disposal problems.

Because the designs use stopping length targets, it is necessary to consider radionuclide production over a wide energy range. For a thick target, calculations involve two processes. The transport of the incident and resultant reaction products must be considered. Second, the probability for production and destruction of a given radionuclide or material in the system must be considered. Presently, the data in use result from an application of the LCS to the target system with burn-up and radioactive decay being predicted by the CINDER90 code[8].

Recently, benchmark tests of the entire sequence of codes were made at the WNR Target-2 facility by bombarding l.rge range-thick targets of tungsten and lead[9] by the 800 MeV proton beam. Particular attention was paid to obtaining information about short-lived nuclei, and to getting information on tungsten, both of which cases have no previous information.

In the measurements, thin foils of the same material as the target were inserted at various locations to sample the radiation environment. The foils were then removed and counted using high-resolution high-purity germanium detectors. Radioisotopes were identified through their characteristic gamma-ray energy spectra. Figure 4 shows a typical gamma-ray spectrum from a tungsten foil at several times after bombardment. This foil was located on the proton beam axis, 10-cm deep within the assembly. Analysis of the experimental results is still underway. Preliminary results show a broad range of agreement with calculations, with predicted results for individual radionuclides generally better than a factor of ten of the data.

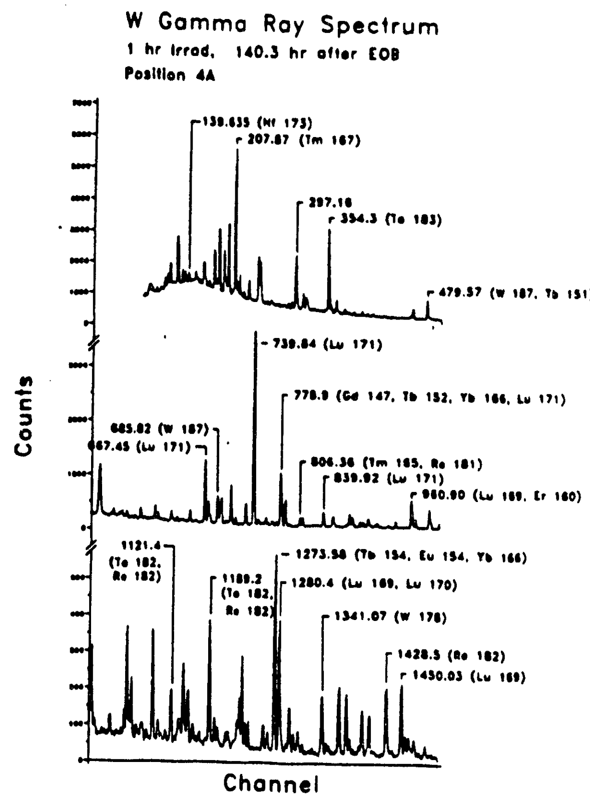

Fig. 4 Gamma-ray spectrum from 800 MeV proton-induced spallation of tungsten This spectrum was from an on-axis foil, 10-cm deep in a stopping-length target, 140 hours after a one-hour bombardment.

This experiment has general applicability to several other accelerator applications. The amount of spallation-induced activity must be understood by programs that are trying to determine how to transmute spent-fuel and weapons plutonium using accelerators, and may be important to the development of intense spallation sources for research purposes.

C. Basic Nuclear Physics Example - P&T Symmetry

Epithermal neutron transmission measurements using polarized neutrons have provided a sensitive testing ground for studies of the fundamental symmetries of parity violation. Signals of parity-violation in nuclear physics are difficult to observe because they are caused by the weak interaction with a strength only about 10^{-7} of that of the strong interaction. It has been known for some time[10] that there are enhancements of parity violating effects when strong s-wave resonances mix with nearby p-wave resonances, producing a helicity dependence in the total cross section. What was need to fully exploit these enhancements was a suitably intense source of neutrons covering a broad energy range. With the implementation of a polarized neutron beam at LANSCE, both of those requirements were fulfilled. In the experiments discussed here, measurements are taken of the counting rate asymmetry that results when polarized neutrons with spin along and opposite to their momenta are transmitted through samples[11]. The experimental arrangement is shown in Fig. 5. Any observed asymmetry indicates a violation of parity. An improved polarized hydrogen target

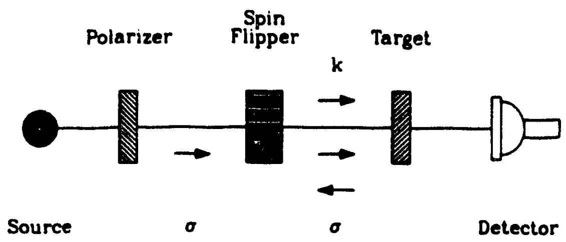

Fig. 5 Schematic layout of the polarized neutron transmission experiment.

installed in 1993 has increased the figure-of-merit [(beam polarization)^2 x neutron intensity)] by a factor of 25, allowing more sensitive parity violation tests on a large number of samples. Results to date have shown many parity violating asymmetries, some as large as 10%, for ^{139}La, ^{238}U, ^{232}Th, In, ^{113}Cd, and Ag, with a number of additional nuclei planned for the next LANSCE operating period in 1995. These studies are the first systematic study of weak interaction physics over a broad range of nuclei and are paving the way for an even more difficult time reversal test now in the planning stages. That test hopes to use similar s-p wave resonance enhancements to make possible time-reversal violations. In the proposed T-violation experiments, it will be necessary to perform a three-fold correlation using both polarized neutrons and a polarized target.

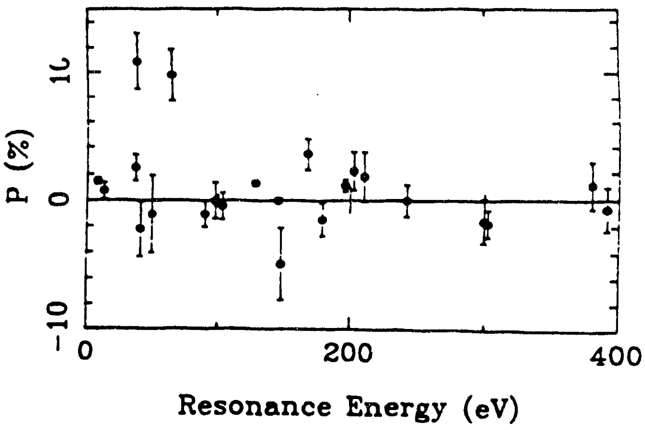

Fig. 6 Parity violating asymetries from ^{232}Th + n measurements as shown in Ref. 12.

V. CONCLUSIONS AND FUTURE PLANS

The three examples of research at the Los Alamos neutron sources are only a small part of the entire program. They represent quite diverse, and until recently, unusual uses of the Los Alamos neutron sources.

Over the past several years, the number of proposed and conducted experiments at WNR and LANSCE has increased, even in the face of steadily declining research budgets. Until very recently, the future of the nuclear science program at Los Alamos was tied to the end of DOE Medium Energy Physics support of the LAMPF accelerator. It now appears promising that the DOE will find alternate means to keep the linac operating in support of a neutron science program that involves a broad range of activities, including condensed matter neutron scattering research, defense science studies, basic nuclear physics with neutrons and applied nuclear technology.

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