Opportunities for research program development at LANSCE

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ABSTRACT: The availability of intense neutron beams from facilities associated with the Proton Storage Ring and LANSCE has stimulated the development of neutron research well beyond the mainstream of neutron scattering. A description of this extended program is given along with prospects for further growth.

Introduction

The Proton Storage Ring (PSR) project originally was launched for nuclear physics research. As the opportunities for neutron scattering research were recognized, capabilities were included in the PSR design to accommodate both programs. However as the scope of both programs grew it became clear that the PSR could not be satisfactorily multiplexed between them. As a result, the PSR was finally constructed with a several hundred nanosecond pulse width which was most suitable for neutron scattering research, and other means were devised to obtain a sub-nanosecond pulse width for MeV neutron nuclear physics at a different target station. These two modes also could be readily multiplexed allowing both programs to run simultaneously and thereby greatly enhancing the research output across the full energy spectrum of neutron spectroscopy. Upon completion of the PSR, its powerful capabilities for nuclear physics research were also recognized. The success of this extended neutron research program[1] has provided the base for suggesting in this paper further major augmentation of the facilities by adding an experimental cell capable of receiving a small fraction of the PSR beam and arranged so that the PSR proton pulse can be brought directly to experimental apparatus. The views expressed here regarding prospects for the future are my own and do not necessarily represent those of the Laboratory.

Neutron Nuclear Physics at the LANSCE Complex

The scope of the neutron nuclear physics program at the LANSCE complex is perhaps best illustrated by the following list of experiments approved by the Internal Program Advisory Committee for Neutron Research (IPAC) for 1988.

Gamma Ray Production Measurements by keV and MeV Neutrons.

Neutron-Induced Fission Cross Section From 1 to 400 MeV.

Neutron-induced Pion and Photon Production from Nuclei.

Charge Exchange Reactions in Neutron Physics.

Giant Resonance Studies Using Neutron Capture Gamma Rays.

Neutron-Proton Bremsstrahlung.

Accurate ^{235}U Fission Cross Section from 1 to 200 MeV.

Nuclear Level Density through (n,p) and (n,alpha) Reactions.

Response of BGO to neutrons from 1 to 200 MeV.

Differential Cross Sections for (p,xn) Reactions at 800 MeV.

Continuum Excitation by the (p,n) Reaction at 800 MeV.

Neutron Cross Sections on Radioactive Nuclei.

Fundamental Symmetry Experiments using Resonance Neutrons.

Electric Polarizability of the Neutron Using eV Neutrons.

Neutron-induced Optical Photon Emission.

Benchmark Neutron Transport Experiments.

The substantial Los Alamos staff which participated in this program in 1988 is listed in Table I. The P-3 staff devoted essentially full time to the program while most of the other staff members worked part time. The many other institutions which contributed to these experiments are listed in Table II.

A. MeV Neutron Nuclear Physics Facilities

The key to MeV neutron nuclear physics at LANSCE was the realization[2] that a world class MeV neutron source could be developed at LANSCE at very modest cost by directing single micropulses, with width as small as 0.3 nanosecond at a small tungsten target and energy analyzing the white-spectrum neutrons by nanosecond time-of-flight techniques. The low cost arose from (1) use of the PSR injector for injecting well separated H- beam micropulses into the LAMPF accelerator simultaneously, (2) accelerating them simultaneously with the high current H+ (3) separating the two charges at the end of the accelerator in an existing magnet, and (4) transporting them to the MeV spallation target using much of the same beam line used to transport LANSCE beam.

The main cost in adding this capability, referred to as Target 4, was in constructing the target and associated beam lines. This construction is now complete and is shown in Fig. 1. Neutron drift tubes radiate from two target locations[3]. The dashed-line tubes are located about 2.5 M below and in a plane parallel to the other drift tubes. Altogether there are 14 drift tube locations of which eight have already been brought into frequent use. Each beam line has its own stand-alone Microvax data collection system. This facility provides the world's most intense neutron beams in the 1 to 800 MeV range. By increasing the rate of LAMPF macropulse delivery to Target 4 and improving the H-injection into LAMPF, the neutron intensity could be increased by a factor of three or more. Research on this facility is well established with substantial staff, a large external user group, and an exciting array of research problems.

Presently the major fraction of neutron nuclear physics is conducted at Target 4. However a program using 0.025 to 10,000 eV neutrons has begun at LANSCE with substantial growth potential. Also additional facilities could be added making possible an even broader spectrum of research opportunities. The remainder of this paper will be devoted to a discussion of PSR-based nuclear research and program expansion beyond the confines of conventional pulsed neutron scattering techniques.

B. eV Neutron Nuclear Physics at LANSCE

The width of the proton pulse from the PSR is 0.25 microseconds which corresponds to the moderation time in a water moderator for 15-eV neutrons. Therefore for neutrons with energy below 15 eV the resolution is not appreciably worsened by the beam pulse width. Above that energy effective neutron spectroscopy still can be performed despite some resolution broadening introduced by the PSR pulse width. These properties along with the low repetition rate of 12-15 Hz and very high average intensity make LANSCE a powerful source for eV neutron spectroscopy. We describe here several experiments already performed which illustrate this power.

Table I. Los Alamos Staff Members Participating in Neutron Nuclear Physics Research at LANSCE-related Facilities in 1988.

R. Nelson	P-3 (Facility and Research Program Responsibility
S. Seestrom-Morris	
S. Wender	
J. Ullmann	
P. Lisowski	
P. Koehler	
H. O'Brien	
C. Bowman	
R. Byrd	P-2
G. Morgan	P-15
N. King	
R. Haight	
J. D. Bowman	MP-4
J. Szymanski	
B. Tippins	
D. Lee	
J. Mcgill	MP-5
C. Morris	MP-10
C. Goulding	N-2
C. Moss	
R. Reedy	ESS-8
M. Meier	ESS-9
D. Drake	
J. Wilhelmy	INC-11
M. Fowler	

Table II. Universities and Laboratories Participating in Neutron Nuclear Physics Research at LANSCE-related Facilities in 1988.

University of Colorado

University of Hanover

ORNL

NBS-Washington

Ohio University

University of California-Davis
  -Irvine
  -Los Angeles
  -Riverside

CEBAF

University of New Mexico

Temple University

William and Mary University

Upsalla University

LLNL

KEK

Kyoto University

TRIUMF

University of Technology-Delft

GKSS Research Center-FRG

Princeton

Harvard

AERE-Harwell

TUNL

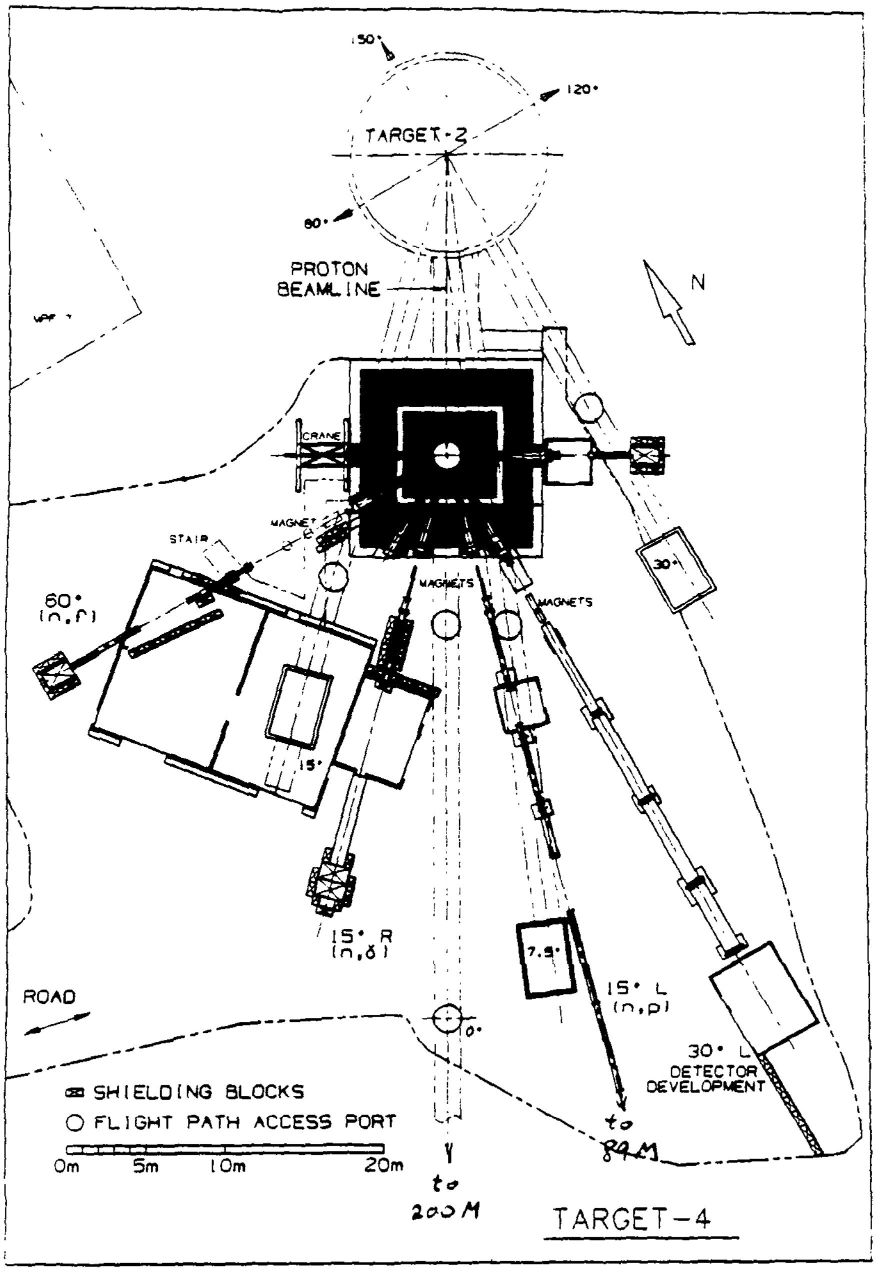

Fig. 1 Facilities for MeV neutron nuclear physics research.

1. Cross Sections on Radioactive Samples

Perhaps the most dramatic example of the power of LANSCE for neutron nuclear physics is in the measurement of reaction cross sections on highly radioactive nuclei. The problem with such experiments in the past has been the decay products which overload the detector and obscure the detector response to the neutron-induced reaction products such as protons, alphas, and gammas. The sheer intensity of the LANSCE eV beam allows the use of samples smaller by about a factor of 1000 than previously practical (i. e. in the nanogram and microgram range) and the low repetition rate at which the neutrons are delivered to the sample produces a high signal-to-noise ratio.

Our first successful measurements[4], conducted on FP-4 when the first LANSCE beam became available in 1986, were done using 100 nanograms of ^{7}Be, which has a 53-day half-life. The measurements extended from thermal to about 50,000 eV. The apparatus shown in Fig. 2 includes a beam line with collimation for a 3-mm diameter beam, an aluminum foil on which the sample is placed, a solid-state charged particle detector to detect the reaction products, and a second detector downstream (not shown) to collect alphas and tritons from a second foil with a small amount of ^{6}Li used as a flux monitor.

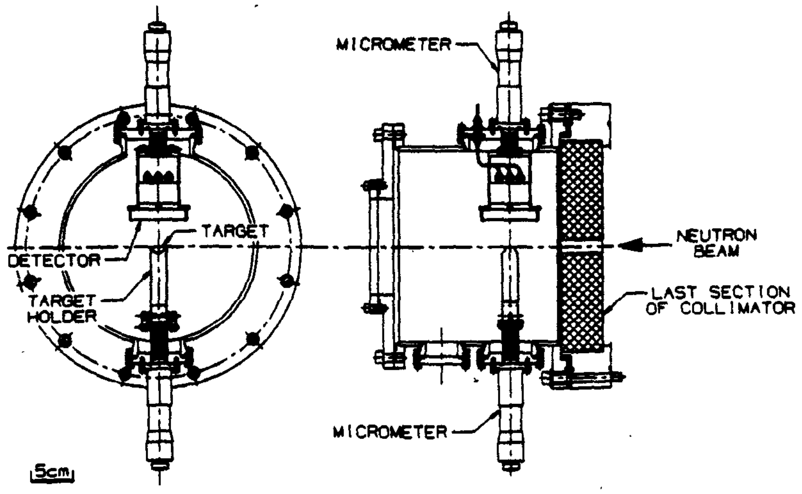

Fig. 2 Arrangement for neutron reaction cross section measurements on highly radioactive targets.

The flight path length is about 7 M. The samples studied to date include ^{7}Be, ^{22}Na, ^{26}Al, ^{35}Cl, ^{36}Cl, and ^{57}Co. The results for ^{36}Cl are shown in Fig. 3. A new detector is under construction which will allow capture cross section measurements on this class of samples by gamma detection. Measurements will become possible on more than 100 nuclei previously inaccessible to study. The primary basic research interest for this work is in nuclear astrophysics.

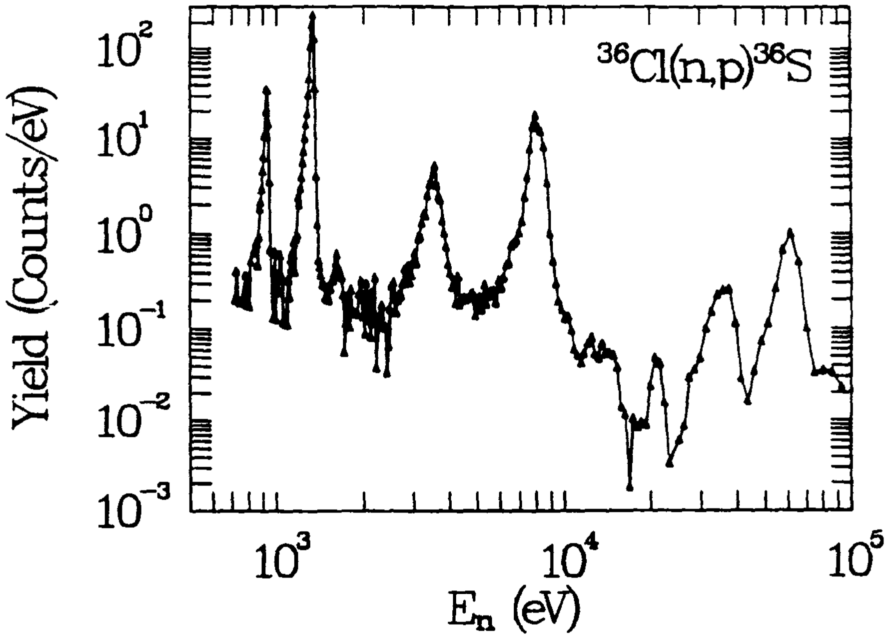

Fig. 3 The ^{36}Cl(n,p)^{36}S yield as a function of neutron energy measured at a 7 meter flight path.

2. Neutron Transport Benchmarks

A facility also has been established on FP-2 at LANSCE for neutron transport studies. The assembly for this study includes a fission neutron detector incorporating detection by proton recoil and the elimination of gamma detection by pulse shape discrimination. It is located at the end of a 60-M flight path. Successful experiments require the presence of fissile material and a neutron life time in the assembly which is short compared to the drift time of the neutron along the flight path. The latter condition is satisfied in small assemblies for neutrons with energy less than 1000 eV. An example of a very simple assembly is shown in Fig.4. A comparison of the results for two thicknesses of ^{235}U is shown in Fig. 5. This particular geometry is highly sensitive to the capture-to-fission ratio and has been used to improve the

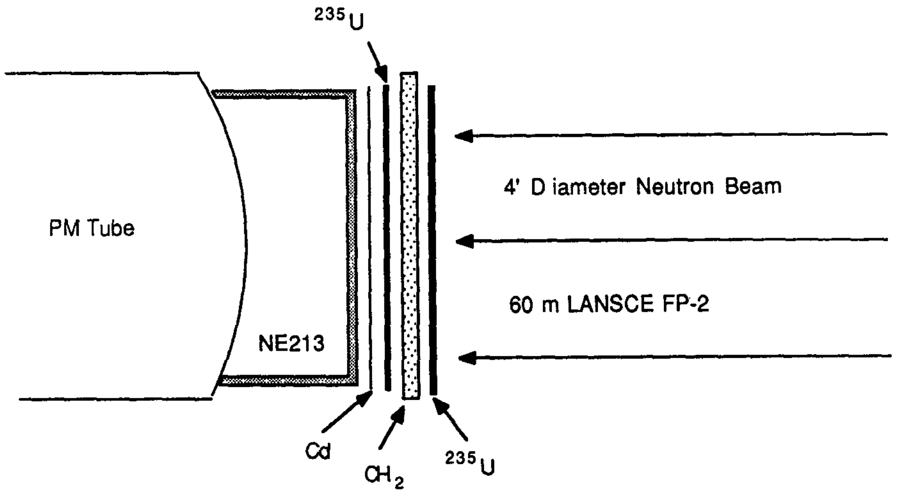

Fig. 4 Benchmark neutron transport assembly. Neutrons impinge from the right on an assembly in this case consisting simply of a layer of ^{235}U and a layer of Cd. Fission neutrons produced in the ^{235}U are detected by proton recoil in the hydrogenous scintillator viewed by the photomultiplier tube. The flight path length is 60 meters.

accuracy of the ^{235}U resonance parameter characterization of the cross section in the energy region below 1000 eV in a joint effort with the Theoretical Physics Division of Los Alamos and the ORELA Group at the Oak Ridge National Laboratory.

3. Polarized Neutrons for Fundamental Symmetry Studies

It is now well established that p-wave resonances in the eV range exhibit parity violation (P-violation) enhanced over the nucleon-nucleon experiments by several orders of magnitude[5]. Similar enhancements are also expected for time reversal invariance violation (T-violation)[6]. Since P-violation is a property of the weak force, detection of this effect as a general phenomenon in neutron resonances would provide the only opportunity for studying systematics of the weak force in nuclei. Among the many ways in which the P-violation experiment might be done, perhaps the simplest is the transmission of longitudinally polarized neutrons. The detection of a difference in transmission for the two helicities is unambiguous evidence for P-violation.

Our first experiments however were done without polarized neutrons[7]. Since in the presence of P-violation the transmission (cross section) depends on the

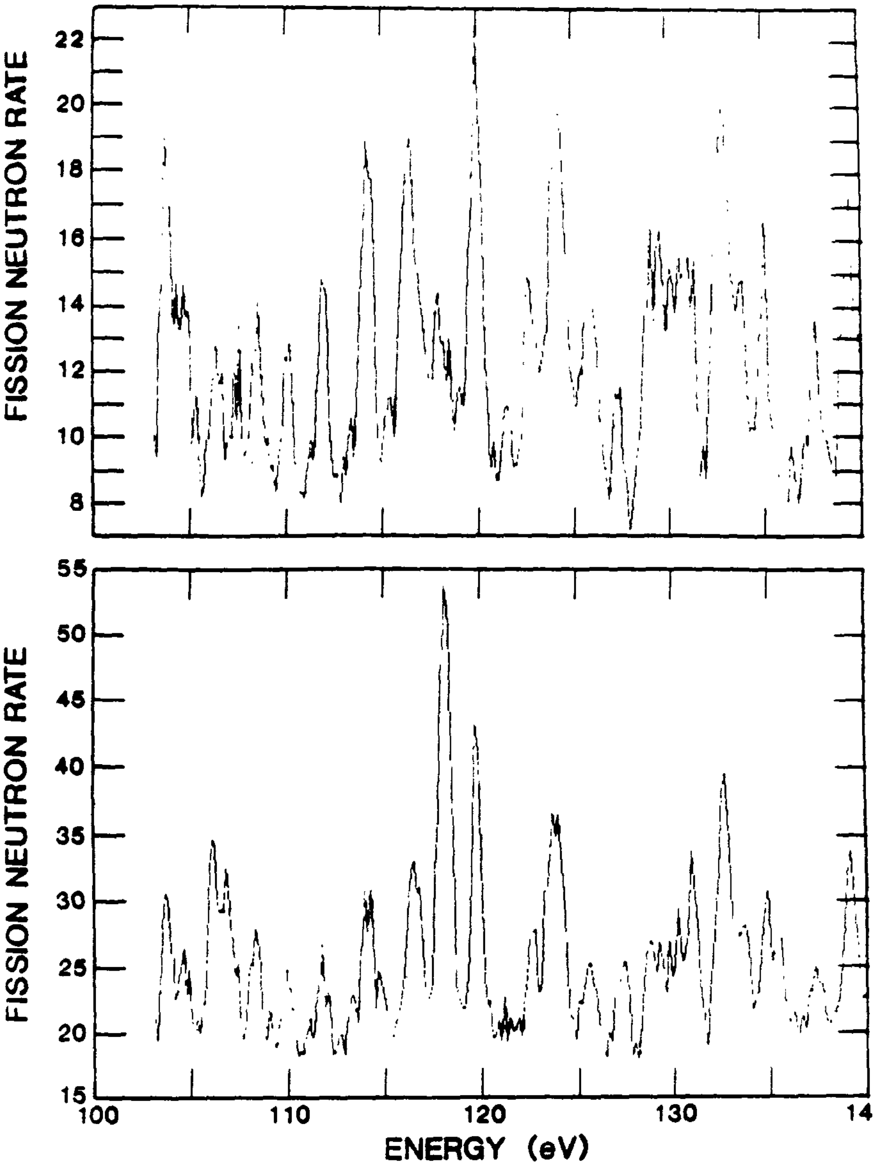

Fig. 5 A comparison of fission neutron rate for two thicknesses of ^{235}U as a function of neutron energy. The measurements, which extended up to 1 keV and required eight hours, illustrate the power in resolution and intensity for eV range neutron spectroscopy at a modern spallation source.

neutron helicity, likewise polarization will be introduced into the beam when an unpolarized beam traverses a sample exhibiting parity-mixed neutron interactions. We demonstrated this effect using the geometry illustrated in Fig. 6. The unpolarized beam was first transmitted through a La sample which has a P-violating resonance at 0.73 eV. It was then passed through a magnetic device which flipped the longitudinal polarization introduced by the resonance in the first sample. The neutron beam was then passed through a second sample of the same material and neutrons detected in a detector at a flight path of 11.3 M. If the detected rate is different for the two states of the flipper, the presence of polarization in the neutron beam after traversing the first sample is established.

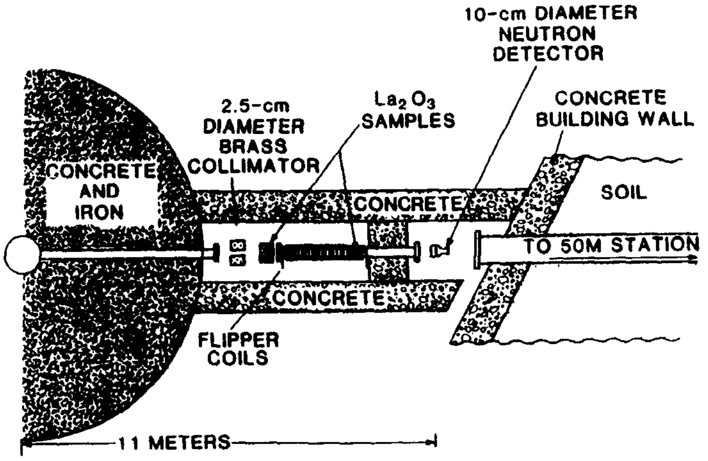

Fig. 6 Plan view of the arrangement for first measurements of parity violation without the use of polarized neutrons.Our next experiments were conducted using polarized neutrons produced by transmission through laser-polarized ^{3}He. The ^{3}He is polarized by bathing a mixture of helium gas and a small amount of vaporized rubidium with polarized laser light[8]. The alkali vapor is polarized in the optical pumping process and the polarization transferred to the helium nuclei by the spin-spin interaction. We typically achieve an 70 % ^{3}He polarization in a 10 atmosphere-cm^3 volume. The area of the cell was 0.75 cm^2 with a length of 4 cm, and a pressure of 3.3 atmospheres. It was located at a flight path distance of 7 meters.

The technique has the advantage over a polarized hydrogen target[9] of little loss in neutron intensity in the polarization process, easy neutron spin flipping by flipping the ^{3}He by adiabatic fast passage, eight-hour polarization decay time in the absence of laser pumping, no cryogenics, and no strong magnetic field. At its present stage the beam area is small and useful neutron polarization experiments are limited to the energy region below 1 eV. Progress in the amount of polarized ^{3}He has moved rapidly and depends primarily on a better understanding of wall depolarization effects and on increasing the laser power. The power on the cell was about 0.5 watts. A comparison of what we have achieved and what should be possible for a 3 cm^2 beam area with an increase in laser power by a factor of ten is shown in Fig. 7. This performance would be of substantial interest to the neutron scattering community. We are also studying the possibility of a laser-polarized ^{3}He detector which would offer interesting advantages for polarized neutron research.

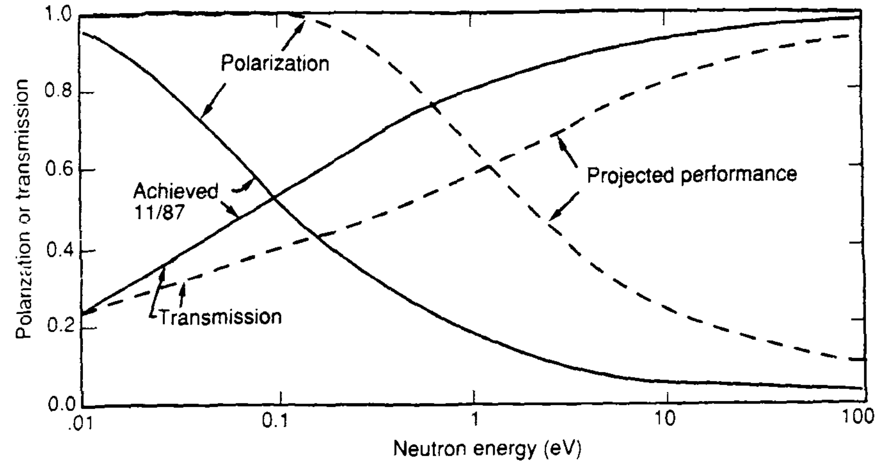

Fig. 7 Performance of the first ^{3}He spin filter in terms of filter transmission and polarization as a function of neutron energy and improvements resulting from a factor ten increase in polarized laser light intensity.

In order to reach polarization of about 60 % over an area of 10 cm^2 and throughout the eV range, we brought on line for 1988 a polarized hydrogen transmission filter of conventional design using lanthanum magnesium nitrate crystals as the filter[9]. The transmission of the neutron beam through the filter was about 0.18. P-Violation data was collected using a 100-cm^2 detector located at 11 M or a 700-cm^2 detector at 60 M. An example of the P-violation data collected on ^{139}La in 1.5 hours is shown in Fig. 8. A spectrum for ^{238}U is shown in Fig. 9. The p-wave resonances are readily seen; a resonance at 89 eV appears to show substantial P-violation. For 1989 we hope to switch over to an organic filter and to improve our beam area by at least a factor of two, make some improvements in polarization, and increase the transmission by perhaps a factor of two.

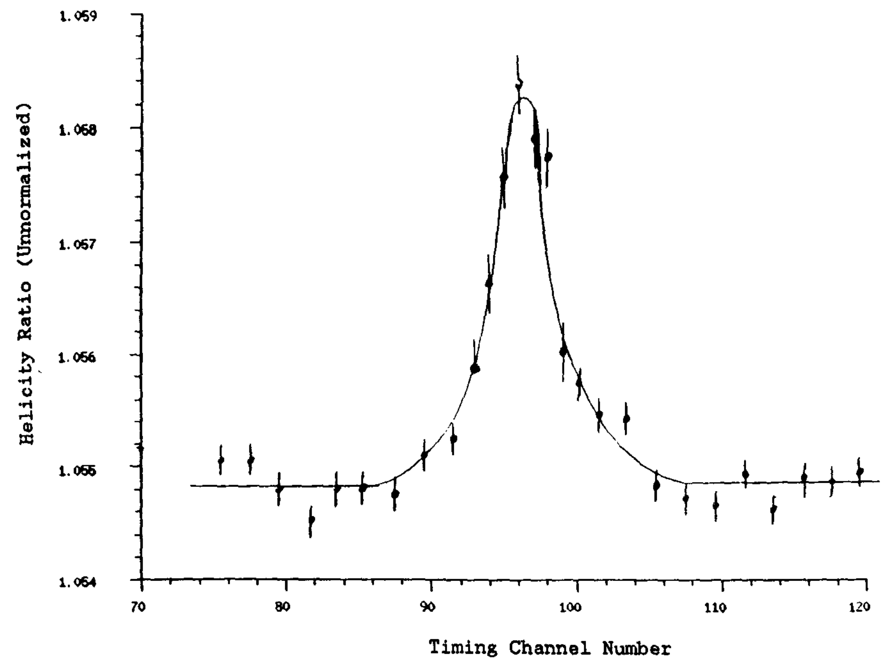

Fig. 8 A measurement of parity violation in a resonance at 0.734 eV in ^{139}La. The ordinate is the ratio of transmission for neutrons polarized along and opposite to the direction of neutron propagation. The measuring time was 1.5 hours.

The counting rate in these transmission experiments exceeds 10^{10} per second and it is therefore not possible to count individual neutrons. We have therefore developed current-mode counting to accommodate the rates. The apparatus and an example of the data is shown in Fig. 10. A 1-cm thick detector of ^{6}Li-loaded glass is attached to the face of a photomultiplier tube with separate high capacity power supplies for each of the higher dynodes to assure that the voltage on these dynodes doesn't sag under high current loading. The signal may be averaged and then fed into a transient digitizer. This unit measures the current 8096 times in one cycle with a dwell time as short as 1/8 microsecond. Each of these 8096 values is added to an 8096-channel summing memory after each beam pulse. The result for three LANSCE beam pulses (1/5 s running time) is shown for transmission on a Ho sample. Note that even weak p-wave resonances in Ho are beginning to appear already in the wings of the much stronger s-wave resonances. Being able to handle these enormously high counting rates might make Bragg-edge diffraction competitive with conventional high resolution powder

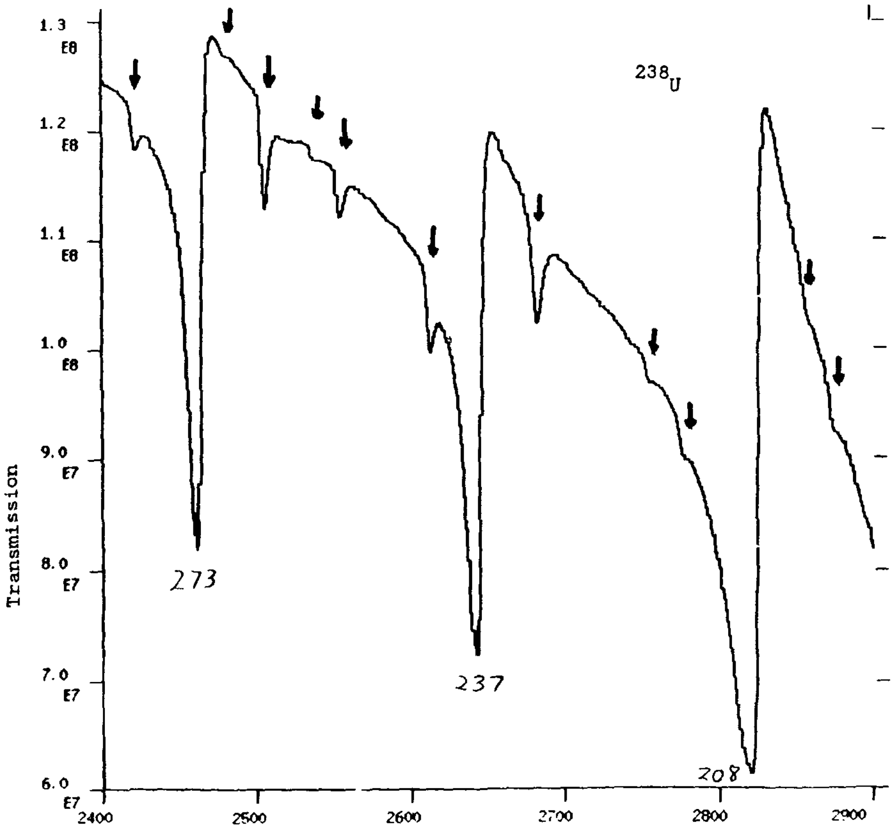

Fig. 9 Transmission measurements on ^{238}U using polarized neutrons for parity violation studies. The ordinate is proportional to transmission and the abscissa is the neutron time of flight channel. The numbers at the dips are the s-wave resonance energies in eV. The arrows indicate the position of the weak p-wave resonances.

diffractometers. This possibility is discussed for some specific experiments below.

Neutron Scattering Science Related to Neutron Nuclear Physics

Both neutron scattering and neutron nuclear physics originated at nuclear reactors. While neutron scattering focused on the exploitation of thermal neutrons and the science possible with them, most of the nuclear physics moved on to higher energies using electron linacs which produce intensities of higher energy neutrons. However the advent of intense spallation sources provides epithermal neutron intensity higher by several orders of magnitude and has begun to attract nuclear physicists back to the lower energy range. One may therefore expect a synergism with nuclear physics which might hasten the exploitation of some parts of the pulsed neutron scattering field. This section gives some examples of prospective condensed matter science growing out of neutron nuclear research.

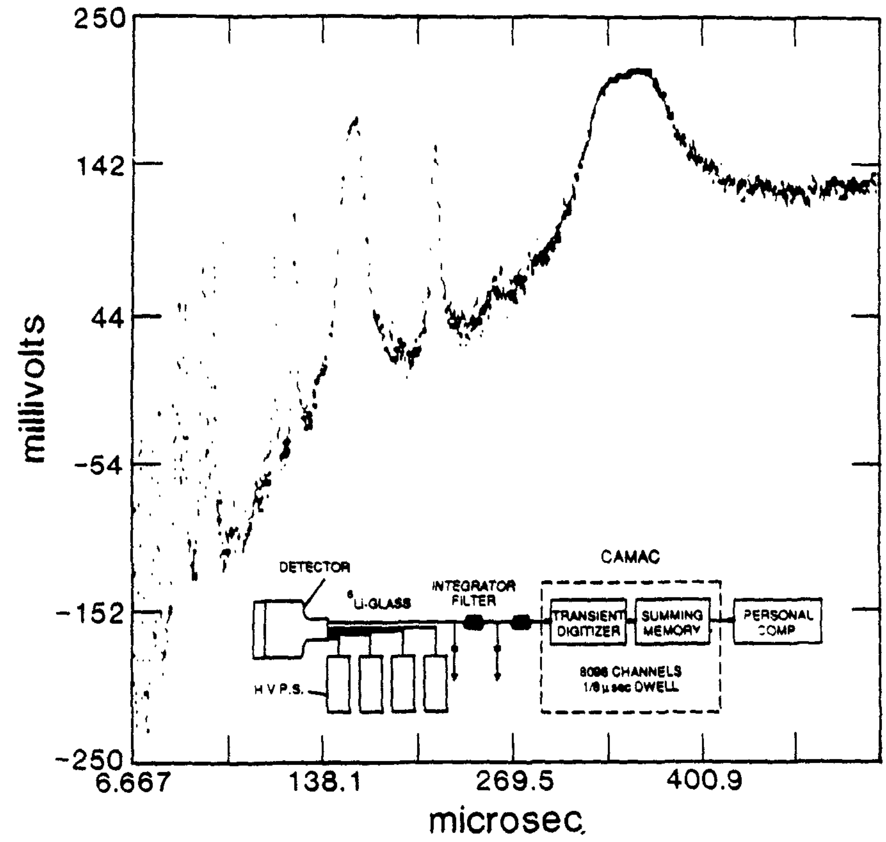

Fig. 10 Current-mode neutron detection. The spectrum shown was collected in about 0.3 seconds. See text for details.

A. Bragg-Edge Diffraction

Several years ago demonstration experiments[10] were reported which suggested the use of Bragg-edge diffraction for extending the power and breadth of neutron diffraction research. Fig. 11 shows an example of such a measurement on a 2-cm thick slab of iron. The sharpness of the peaks allows a measure of the internal stress and the relative sizes allowed a determination of the texture. This approach offers high resolution because of the absence of scattering angle and sample thickness contributions to the resolution. The geometry is simple since it is a straightforward transmission experiment and the angular structure of the detector need not be dealt with in data collection. The transmission geometry also allows the collection of position-sensitive data on the sample so that high resolution position-sensitive stress distributions, etc could be measured. The natural geometry for this experiment is substantially different from the scattering geometry in that the few cm^2 sample should be placed relatively close to the source and a large area detector placed far away for best resolution.

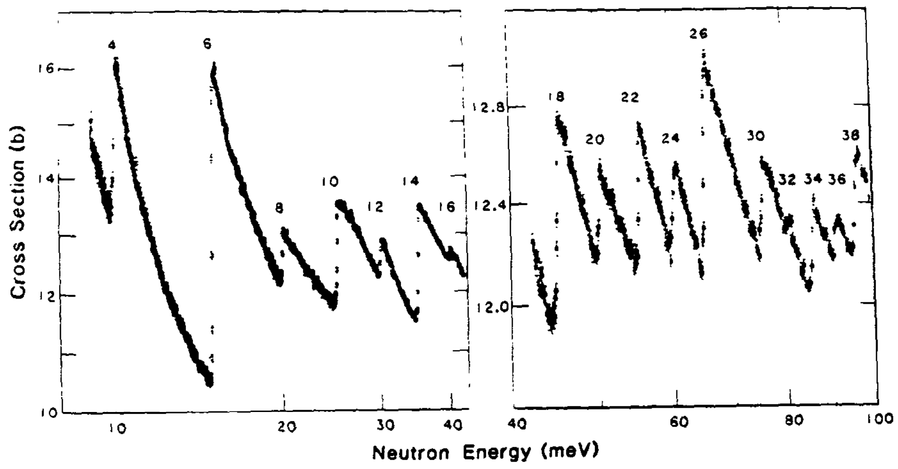

Fig. 11 Bragg-edge diffraction measurement on a 2-cm thickness of natural iron. The numbers at the edges in the figure are the sum of the squares of the Miller indices for the various scattering planes.

1. High Resolution Diffraction

The geometry of the P- violation experiment described above is essentially that required for high resolution Bragg-edge diffraction. The 60-M detector should make possible resolution equivalent to a scattering geometry path length of 120 M. Also the current-mode large area neutron detector is operational and make possible data collection at the high rates necessary for practical diffraction experiments in transmission geometry.

2. Diffraction Using Polarized Neutrons

Polarized neutrons are available on this beam line along with spin flippers and polarization transport apparatus. The LMN transmission filter is not the most effective neutron polarizer for the thermal range. The rising cross section of hydrogen as the energy decreases into the thermal range improves the polarization substantially above the eV range value of about 55%. However the transmission of the neutrons decreases rapidly as the neutron energy decreases. The practicality of polarized neutron diffraction remains to be demonstrated with the present system. Of course planned improvements in the system using filter materials such as butanol could improve the polarized neutron intensity in the thermal range. The full development of the potential of the laser-polarized ^{3}He should make this geometry highly effective for this field of work.

3. Stress Distribution Studies

The Bragg-edge geometry has the feature that the sharpness of the edges is different as a function of position on the sample if the stress distribution varies over the sample. This position information can be measured with either of two position-sensitive detector arrangements. In either case the incident neutron beam should be as nearly parallel as possible and the neutron detector should be located close behind the sample to reduce parallax. Data could be collected at a short flight path by scanning a small current-mode detector across the sample with position resolution determined by the detector size. This geometry would be suitable where low wavelength and position resolution is adequate and high measurement speed is important.

Alternatively a high efficiency position-sensitive detector[11] could be used with resolution as good as 0.5 mm. The data collection rate for this class of detector is usually too low for use in the direct beam at LANSCE unless the sample and detector are placed a long way from the moderator. Therefore this mode would make possible better wavelength and position resolution but with much longer measurement time. Position-sensitive stress measurements could prove valuable for industrial application such as stress distribution in welds.

4. Strong Transient Diffraction

Strong transient diffraction is defined here as the study of the response of a sample to a sudden change in its condition such as would be caused by sudden heating by a strong current pulse or by sudden compression from a hammer blow. Obtaining the time history of a phase transition induced by these means might be the objective of such an experiment. Another might be to study the time history of the stress under such transient conditions. It appears that LANSCE now has the capability to conduct such experiments using a single

PSR pulse. The experiment requires the very high pulsed neutron intensity of the PSR, the Bragg-edge geometry, and current-mode neutron detection.

The idea is to look at the change in position and shape of a sequence of Bragg edges as the transient is imposed upon the sample. Each edge therefore provides both strain and compression information. Since the neutrons arrive at the sample at different times for each Bragg edge, a time sequence of this information can be obtained with a single PSR pulse for a transient which takes the sample to destruction. Table III lists parameters for such an experiment on a 1-cm^2 area by 2-cm thick iron sample located at a flight path length of 6 meters using a collimated beam on a detector which collects all neutrons transmitted through the sample. Counting rate estimates indicate that seven frames could be measured over a time interval (at the sample) extending from 2.2 to 6.2 milliseconds after a particular PSR pulse. The typical size of a Bragg- edge step in transmission is about 0.3 and ten points across each edge could be obtained with a statistical accuracy of 0.01. It is of interest to note that the time required for a sound wave to cross the sample is about 4 microseconds.

Table III. Parameters for Strong Transient Diffraction Experiment.

Target Yield in Thermal Range	0.4 n/p-sr-eV
Solid Angle (1cm^2 at 6 meters)	2.8×10^{-6}
Protons per pulse (12 Hz)	5×10^{13}
Channel Width (eV) (2dL/L)E	2.2×10^{-4}

Incident Neutrons = 1.2×10^4
Statistical Accuracy = 0.01
Transmission Change at 2,1,1 peak of 1-cm iron = 0.65

Multiple Frames per Pulse	Indices	Time microseconds
	3,2,1	2200
	2,2,2	2550
	3,1,0	2800
	2,2,0	3100
	2,1,1	3600
	2,0,0	4350
	1,1,0	6200

B. eV Inelastic Neutron Scattering

The ability to measure energy transfers in the eV range at low momentum transfers would be a powerful addition to the array of experimental techniques available at pulsed sources. Attempts[12] to establish this capability using materials possessing narrow neutron resonances in transmission or capture geometry have not been entirely successful because of both limited intensity and the resolution limit of a few percent. However enough has been learned that it is clear that a resolution of a few tenths percent with adequate intensity would probably have a major impact on condensed matter physics studies.

Two new avenues are available at LANSCE for attempted improvements. The first involves the use of the LANSCE through-tube which makes possible the emplacement of a resonance scatterer near the moderator which would scatter down the flight path only neutrons at the resonance energy. The resolution of the neutron pulse is determined by the resonance shape and not by the time of flight. By appropriately filtering this pulse it might be possible to improve the resolution into the interesting range while maintaining adequate intensity and low background.

The second possibility is the use of polarized beams, spin rotation and polarized detectors to develop a means of high resolution neutron spectroscopy similar in some ways to the spin-echo technique[13]. At LANSCE the ingredients available for testing such an idea include high intensities of eV polarized neutrons, high current spin rotation solenoids, long drift tubes, and prospects for a polarized ^{3}He neutron detector.

C. Resonance Neutron Radiography

Resonance neutron radiography takes advantage of the distinctive resonance properties of materials for quantitative assay of samples in both a chemical and isotopic sense and for distribution assay of samples with a position resolution of 0.5mm. The practicality of resonance neutron radiography has been demonstrated using neutron sources far weaker than modern spallation sources. However the implementation of a facility which can make available the power of the method at a spallation source for a broad spectrum of applications remains to be done. The full development of the potential of the method probably requires the active involvement of staff with extensive experience in neutron nuclear spectroscopy in the eV and keV range.

Extensions for Neutron Nuclear Physics at LANSCE

In this section new experiments in nuclear physics for spallation sources will be described. The power of the polarized beam facility on FP-2 and the unstable target facilities on FP-4 at LANSCE and also the demand for time on these beam lines forecloses the possibility of expanding the scope of the neutron nuclear physics effort at LANSCE for the foreseeable future except through the implementation of at least one new flight path. This flight path should have the potential for extension to 300 M and eventually to 600 M. Apparently

FP-15 at LANSCE is the only unoccupied flight path which can be extended to these distances.

A. Electric Polarizability of the Neutron

In the absence of T-violation the neutron has no static electric dipole moment. However an induced dipole moment appears as the neutron closely approaches the strong field of a heavy nucleus such as lead. The field induces a moment through which the neutron and the nucleus can interact. There is as a result a small contribution to the scattering cross section which in principle can be detected either in the total or the scattering cross section at back angles[14]. The size of this cross section has been estimated[15] using quark models both for the neutron and the proton and the polarizability appears to be measurable for both particles. The proton polarizability is being measured in high energy electron scattering experiments. LANSCE appears to be an excellent neutron source for studying the neutron. Preliminary evaluations of the experiment indicate the need for a flight path of 100- to 150-M length and that a sensitivity three to ten times smaller than the predicted polarizability could be achieved at LANSCE. This would be quark physics using eV neutrons!

B. Neutron Gravitation

Interest continues on a comparison of the value of small g for the neutron compared with that for macroscopic objects. The value of small g has been measured by comparing the value of a scattering length measurement using a reflectometer with that from other methods. An accuracy of 3×10^{-4} is claimed[16] for a value of g, which agrees with the geophysical value. By taking advantage of the high intensity at LANSCE and a flight path of 300 M it should be possible to extend the accuracy to 1×10^{-5}. If the flight path were extended across a 100-meter deep by 200-meter wide canyon to about 600 meters, the first "fifth force" experiment looking for a short range contribution to the gravitational field for an elementary particle might be performed. Both experiments would likely be viewed as milestone experiments in the field of gravitation.

C. Neutron Capture Gamma Ray Spectroscopy

The field of neutron capture gamma ray spectroscopy has been rather well studied with thermal neutrons. However the scope of the experiments in terms of scientific questions is greatly expanded by studies using resonance neutrons. Such studies at electron linacs have been greatly hampered by the low neutron intensity and the intense gamma flash. Both limitations can be resolved by using a LANSCE-class spallation source for studies in the eV and keV range. By working at longer flight paths the duty cycle advantage of the linac is also substantially overcome. It seems likely therefore that this field could be greatly advanced by experiments conducted using 100- to 200-M flight path distances.

D. eV and keV Spectroscopy

The field of neutron resonance spectroscopy advances steadily through a variety of experiments. The research is driven by the interests of basic science and the continuing need for nuclear data for technology. Most experiments could be done better at LANSCE than at the best electron linacs in current use. One could therefore envisage a broad program of eV and keV neutron spectroscopy conducted on a long flight path equipped with several experimental stations. Highlight experiments in neutron electric polarizability and neutron gravitation would be supplemented with applied studies such as resonance neutron radiography.

Experimental Cell for PSR Beam

The PSR now provides the world's most intense bursts of protons and neutrons. When the PSR improvement program reaches design specs, the intensity will be still higher by a factor of three with an instantaneous current of 25 amperes, and a proton power level of 30,000 megawatts. The parameters of the intense pulse are summarized in Table IV.

Table IV. Proton Storage Ring Output Beam Parameters

Proton Energy	800 MeV
Pulse Width	0.27 microseconds
Stored protons	5×10^{13}
Instantaneous Current	25 A
Proton Power Level	30 GW
Neutrons per pulse	10^{15}
Total Proton energy	8 kJ

Presently there is no available experimental area for direct access to this intense proton pulse. Such space would make possible a number of noteworthy experiments which would not be practical anywhere else. These experiments would typically use only a small part of the PSR output and many might fall into the class of single pulse experiments. Frequent and close access to the experimental apparatus by personnel would be a characteristic of the required experimental cell. Some of the experiments which might be conducted are briefly described below.

A. PSR-Driven Neutron Multiplier

Neutron production from spallation reactions can be multiplied by large factors using a fission multiplying assembly. These assemblies range from high repetition rate devices such as the new multiplier at Argonne[17] with modest effective neutron amplification of a factor of three to slower devices with greater amplification and even conceptual designs with multiplication by 1000 which allow for core disassembly during the multiplication process while still maintaining a slow repetition rate capability[18]. Using a spallation driver also provides more control over pulse width and delayed neutron backgrounds, and more flexibility in some aspects of mechanical design for pulsed reactors.

The concept most likely of interest to Los Alamos would be a facility operating at an average power level of less than 1 MW with high multiplication and therefore repetition rate of 1 to 0.001 Hz. The impact on LANSCE neutron production would be negligible while the intensity of the neutron pulses would be much larger than those at LANSCE and close access to the source could be available. One can imagine a broad array of studies in condensed matter and nuclear research, radiation effects, and radiography.

B. Ultracold Neutron Facility

The ultimate storage density of ultracold neutrons depends on the highest instantaneous density of cold neutrons which can be produced. Realization of advantages from pulsed neutron sources requires the use of synchronized reciprocating collectors which have been demonstrated[19]. The collection efficiency also can be enhanced if the facility geometry allows close access to the proton beam line or to a multiplier assembly[20]. Stored neutron quantities substantially exceeding that available at the best reactors are in principal possible if one takes advantage of all the features of the most intense spallation sources and of any associated multiplier assemblies.

A broad array of experiments would be possible with higher densities of ultracold neutrons than presently available including the search for the neutron electric dipole moment, the search for T-violation in neutron decay, improved accuracy for the neutron half-life, more than an order of magnitude improvement on the measurement of small g for the neutron including the search for a gravitational spin dependence, neutron-antineutron oscillations, improving the limit on the neutron charge, and surface studies in condensed matter physics.

C. Lead Slowing-Down Spectrometer

The lead slowing-down spectrometer provides a means of greatly enhancing the neutron intensity available for some classes of neutron spectroscopy in the eV and keV range. A cube of lead usually about 1 meter on a side is driven with a pulse of MeV neutrons. As the neutrons moderate, a correlation develops between the neutron energy in the block and the time after the block was pulsed. The intensity gain over a conventional drift tube experiment at 7 meters can be four orders of magnitude while giving up a factor of ten in resolution. The PSR could drive such an assembly with four orders of magnitude more average or pulsed intensity than has been used up to the present[21]. Such a facility offers its best advantage in measurements of very small neutron reaction cross sections or measurements on very small samples.

D. Neutron-Neutron Scattering

The neutron-neutron (n-n) scattering length has never been directly measured and a value to an accuracy of a few percent is of great interest. Experiments on the edge of practicality have been proposed for steady state thermal neutron sources. Since the scattering rate in an n-n scattering length measurement depends on the square of the neutron flux, the spallation pulsed source has a decided advantage over the steady state reactor.

A cavity could be built close to a spallation source or better yet close to a neutron multiplier assembly containing a gas of thermal neutrons which is viewed by a detector through a collimated path which does not allow the detector to see the cavity walls. With a cavity containing a low pressure of hydrogen gas, the scattering rate will be proportional to the neutron flux so that the flux may be measured. The n-n scattering rate may be separated from residual gas scattering by measurement of the scattering rate for different pulse intensities. Although a calculation has not been done for a spallation source, it has been done for a pulsed reactor[22]. For a flux of 10^{17} n/cm^2-sec, a cavity 10-cm long, and 10-cm in radius, a detector distance of 12 meters, a detector radius of 10 cm, and a pulse width of 6 milliseconds, the detected n-n scattering rate is 30 neutrons per pulse.

E. Optical, X-ray, and Gamma-ray Lasers

The 30,000 megawatt power level of the PSR proton pulse offers substantial potential for use in driving a wide spectrum of laser types. Optical lasers certainly could be driven and an experiment already has begun[23] at LANSCE to do this in front of the tune-up beam dump in the PSR hall. Of greater interest would be driving an x-ray laser through the electron excitation produced by the proton beam or a gamma-ray laser through nuclear excitations created by the protons directly or perhaps through the neutrons generated by the beam.

An x-ray or gamma-ray laser driven by the same facility used in neutron production would be a powerful adjunct to condensed matter physics. Undoubtedly many new experimental techniques not possible with synchrotron radiation could be developed and many conventional experiments could be done better with a super-intense high coherence keV photon beam. It seems likely that many experiments in fundamental physics such as quantum mechanics tests, etc. might also be possible using a beam with such characteristics.

Conclusion

The spectrum of neutron nuclear science, which stretches from 0.01 eV to 800 MeV, is clearly a rich field of research which is ripe for development and facilities are now in place at Los Alamos for studies throughout the energy range. So far, however, no spallation facility includes a cell providing direct access to the intense pulsed proton beams. Such a capability would broaden much further the power of the spallation source for research. Hopefully the ICANS community will encourage exploration of the full spectrum of science which the Advanced Neutron Sources make accessible in order to provide the strongest possible case for the next advance in pulsed neutron intensity.

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