Fundamental Neutron Physics Beamline Review Panel Report
31 October 2002

The Fundamental Neutron Physics Beamline Review Panel met at the SNS Headquarters on October 17, 2002. We received presentations that described a set of neutron experiments that were designed to measure the fundamental properties of the neutron with a dedicated SNS neutron beam. The ORNL Directorate and the ORNL Physics Division presented their perspectives of the proposed program with this neutron beam. The ORNL Physics Division also presented its plans for the organization and implementation of the physics program and the SNS presented its plans for the design and construction of the beam. The Charge to the Committee and the meeting agenda are contained in enclosures 1 and 2 respectively. Prior to the meeting we received the proposal for this facility (Proposal for a Fundamental Physics Beamline at the Spallation Neutron Source, February 25, 2002), which presented five representative experiments that could be done at the SNS. We are happy to thank you, Geoff Greene and all of the presenters for their concise and informative presentations, since they allowed us to respond to your charge promptly.

We were asked us whether one of the twenty-four SNS beams should be devoted to fundamental neutron physics. On the basis of the program that was presented our answer is an enthusiastic yes. We are persuaded that the proposed science program for the spallation neutron beam is superb and justifies the use of a dedicated beam. The neutron lifetime and decay asymmetry experiments will make significant improvements to the precision of the fundamental nucleon weak couplings, g_A and g_V. These experiments will produce the best measurements of V_{ud} and thus provide a significant test of the unitarity of the CKM matrix for three generations of quarks. If these measurements establish a violation of unitarity then it will provide an important clue to the physics beyond the Standard Model of Particle Physics. The proposed measurement of the neutron electric dipole moment will either place a theoretically significant limit on its magnitude or measure its value for the first time. A definitive, nonzero measurement of this parameter at the proposed level of sensitivity will provide a profound insight into CP violation and could provide an understanding of the matter-antimatter asymmetry of the universe. The measurement of parity violation in the strong interactions of light nuclei will improve the understanding of the strong interactions of the neutron and proton.

We recognize that these experiments are only intended to represent a possible program of experiments that could be ready for beam during the initial period of SNS operation, but we wish to point out that it is very likely that they will be of great interest when operation begins. We comment on each experiment in the following paragraphs.

Neutron Lifetime

The neutron lifetime plays a fundamental role in nuclear and particle physics. Used together with g_A, it is a critical ingredient for primordial nucleosynthesis studies and astrophysics calculations such as the solar neutrino flux. Those quantities are also used in efforts to precisely determine V_{ud}, the cornerstone of the CKM matrix. For some years, there were major discrepancies in experimental measurements of the neutron lifetime. Now a consensus value exists with an error of about 0.1%. However, to compete with nuclear beta decays in the determination of V_{ud}, one should further reduce the uncertainty, with 0.01% a good benchmark goal. The neutron is theoretically cleaner for extracting V_{ud} because it is free of the nuclear theory uncertainties that enter into the traditional superallowed 0+ -> 0+ beta decay analyses. Currently, there is some discrepancy between the values of V_{ud} obtained from nuclear and neutron beta decays. In both cases, V_{ud} when used with V_{us} from K decays and V_{ub} from B

decays indicates some deviation from unitarity, which if verified would be a signal of "New Physics".

Several next generation neutron lifetime measurements are planned. A novel feature of the proposed SNS measurement is the use of magnetic trapping, a technique that is undergoing preliminary testing at NIST. A recent test run at NIST with an upgraded apparatus and increased flux gave an anomalously short lifetime suggesting a possible systematic effect, perhaps caused by a background. Alternatively, there may be a loss mechanism in the liquid He, such as spin-spin relaxation with free electrons. However, the use of liquid He during the measurement phase is not essential and if necessary it can be removed while the neutrons decay.

While the experiment is run CW without using the SNS beam structure directly, the choppers are used to remove shorter-wavelength neutrons and reduce backgrounds. Operation at lower-flux spallation sources or reactors would be problematic.

A small but talented collaboration has been working effectively on this project. The proposed level of accuracy for V_{ud} is competitive with that obtainable from nuclear beta decay. Having different methods competing for a 0.01% measurement should guarantee a precise determination of this important parameter.

Asymmetry measurement: a, b, A, and B

The parity violating asymmetry parameters A, a, and B provide independent measures of λ, the ratio of the axial-vector weak-interaction coupling constant. In the Standard Model, g_v is the cosine of the Cabibbo angle, and g_A, is about 1.27 times larger. The neutron lifetime also depends on g_v and λ, and, when combined with the asymmetry parameters, allows g_v and g_A to be determined separately. The value of g_v which can also be derived from nuclear $0^+ \rightarrow 0^+$ beta decays, when compared to the muon decay constant, determines V_{ud}. The value of λ has also changed significantly over the years and, today, values from different experiments are not consistent. Those discrepancies should be addressed by next-generation experiments that must also aim for higher precision in order to provide a competitive value of V_{ud}. Measuring A to 0.1%, as proposed for the SNS, is a good benchmark. At that level the neutron will provide the best determination of V_{ud}, and the unitarity of the CKM quark-mixing matrix will be tested down to the level of uncertainties in radiative corrections. In the search for "New Physics" it is also interesting to measure b, which is sensitive to tensor interactions that might exist in theories beyond the standard model. No measurement of this parameter in neutron beta decay has yet been attempted.

The proposed asymmetry measurements at the SNS would take advantage of the pulse structure to carry out time-of-flight measurements that would allow a very precise determination of the neutron polarization, the most important systematic uncertainty. The experiment would carry out simultaneous measurements of all three asymmetry parameters, each of which yields a separate determination of λ. Determining all the asymmetries in one experiment offers an important consistency check. As in the case of the neutron lifetime, it is important to have several efforts worldwide competing for a precise measurement of g_A, if we are to have confidence in the final result.

We note that a strong and experienced collaboration has been assembled.

Parity Violations in Hadron Interactions

Despite nearly fifty years of effort, the field of hadronic parity violation remains confused, because of differing indications about the size of the basic weak couplings arising from experiments on different nuclear systems. Such couplings are of interest not only in their own right but also as input to experiments in other fields such as parity violating electron

scattering. Some of the present difficulties may arise on the experimental side - these are difficult measurements - but some may be due to the feature that present analyses are performed with the so-called DDH picture, which is model-dependent. In order to resolve these problems, what is needed is a series of experiments in very light (A<5) nuclear systems wherein reliable structure calculations are feasible together with a theoretical framework that analyzes them in a model-independent fashion. The latter is underway, with an effective field theory approach under active development, while the proposed SNS measurements of both asymmetries and spin rotation parameters in light systems offer an opportunity to provide critical input for the former. The pulsed structure of the SNS beam is particularly useful in that it makes possible an exact spin reversal between the "rotator" and "analyzer" cells of the apparatus for all neutron energies. This feature is not available with continuous beams. It should be noted that the teams proposing these experiments have a long and proven track record in performing such experiments. This combination of precise experiments together with reliable theory should permit a final resolution of the present disagreements.

Neutron Electric Dipole Moment

The proposed measurement of the neutron electric dipole moment (EDM) is the flagship experiment of neutron particle physics. It attempts to nail down the origin of CP violation, and with it the origin of the manifest matter-antimatter asymmetry of the universe. Today, there is only one such experiment running, namely at the Institut Laue-Langevin (ILL) in Grenoble, France. There, the ultra cold neutrons (UCN) used for the EDM detection are being produced in a so-called UCN-turbine.

Today there is a new rush to develop alternative types of UCN-sources, based on widely varying methods. The reason for this is that the number of stored UCN is the most important parameter for progress in this field. ['Mini-spallation', 'solid D_2', 'ultra-cold nano-particles', and 'super-thermal ^{4}He' are the names of UCN sources being tested today by various groups.] At present there is no firm indication yet of what will be the UCN source of the future. However, the super-thermal ^{4}He method as proposed here has promising preliminary results both from LANL and ILL, and large gains of up to 10^4 are being expected.

The proposed EDM apparatus has a number of interesting and novel features. Firstly, the new signal detection method will suppress instabilities due to magnetic-field variations. The method is based on the simultaneous spin precession of polarized UCN and polarized ^{3}He nuclei, whose difference-frequency modulates the neutron capture in ^{3}He, which in turn can be detected by the scintillations it produces in ^{4}He, while the ^{3}He-precession signal is monitored in a SQUID-magnetometer. Secondly, the loss-free separation of spin-up from spin-down UCN within the neutron guide, which feeds two separate UCN storage chambers, is proposed. Thirdly, the remote measurement of the electric field by the optical Kerr effect and internal multiplication of the electric field, which relies on the variation of the gap of the high-voltage electrodes, increase the sensitivity.

The use of superfluid liquid He at 300 mK to cool and trap the neutrons offers another advantage that goes beyond the much increased neutron density. Liquid He has a high dielectric strength, permitting large electric fields to be used in order to enhance the sensitivity to an electric dipole moment. However, the committee noted with concern that, in the presence of the neutrons at the proposed density, radiation-induced currents of tens of nA would flow, creating significant magnetic field perturbations that switch with the electric field and making it difficult to use the proposed technique for internal voltage multiplication. In addition, Joule heating of tens of mW will overwhelm the refrigeration capacity. Similar concerns arise from radioactivity and the presence of an intense beam during cell loading. These problems will require significant

R&D before the design is viable. However, the experimental group has a strong track record of overcoming experimental difficulties.

While all of the aforementioned experiments incorporate ingenious new features and are therefore technically challenging, the proponents have plans either to carry out subsidiary measurements that will allow them to understand how to build the instruments or to begin measurements with the prototype instruments at LANL and NIST. In some instances, the proponents plan to use measurement techniques that are quite new and in other instances they plan to significantly reduce the systematic errors using established techniques. These pre-SNS measurements are crucial since they will undoubtedly expose systematic errors that can be addressed before the SNS versions of the experiments begin in 2006 and beyond. Because it is certain that these pre SNS measurements will not achieve the precision goals of the SNS experiment, the experiments will continue to be important when SNS operation begins as they are today. The SNS offers the best experimental environment to tackle these difficult measurements and with the exception of the EDM experiment the precision of these measurements will not be achieved elsewhere. While a measurement of comparable precision will undoubtedly be mounted at ILL and if either experiment makes a statistically significant non-zero measurement of the EDM it will be essential to have a confirmation. Given the importance of this measurement neither experiment is likely to provide the last measurement of the EDM.

The proposed program engages the best people in this field of science and their commitment to this program, which will not provide a payback until after 2007, is significant testimony of the importance of the experiments.

The organization within the SNS that was proposed to construct and manage the facility appears to be well suited to the task. While the committee did not have the opportunity to review the technical details of the beam line project, we are confident that these can be carried out with the proposed team and organization. The committee notes that there are technical challenges to reach the beam performance that deserve attention.

We learned from the presentations that the ORNL Physics Division plans to support the new facility with enthusiasm. The facility will also complement both the broad SNS science program and strengthen the nuclear physics program at ORNL. The user-centered organization that the ORNL Physics Division proposed to create for the physics program is well conceived and should be very successful, given the Division's history in serving user communities. Acting as a review panel we did not have time to examine all of the details that will make a successful user facility, but as individuals we note that these details deserve careful consideration. In particular, we ask the ORNL management to carefully consider the role of the program advisory committee in the oversight of the scientific program of the facility and the frequency of its meetings. We also ask that the ORNL management carefully define the role of the users executive committee in the management of the facility. On the basis of our discussions with the management of the ORNL Physics Division during the meeting we learned that they are sensitive to these issues.

In concluding our report, the committee notes that most of these experiments use the special capabilities of the Spallation Neutron Source. We also note that the opportunity to build a dedicated facility for these experiments will permit a much greater control of experimental backgrounds than is possible at existing facilities. The committee did not hear anything during the presentations that would lead us to believe that there would be a negative impact on the SNS science program. Therefore, in summary, the committee strongly recommends that ORNL management pursue the creation of this facility vigorously. The Committee further recommends

the SNS and the ORNL Physics Division take the next steps toward the construction of the facility and the instruments that would exploit the facility.

Submitted by the Fundamental Neutron Physics Beamline Review Panel:
John Peoples, Chair, Dirk Dubbers, Barry Holstein, Bill Marciano, Michael Pendlebury, and Hamish Robertson

Enclosure 1

Charge to the Fundamental Neutron Physics Beamline Review Panel

The Review Panel has been convened to assist the Spallation Neutron Source Project in evaluating a proposal to construct a "Fundamental Neutron Physics Beamline" at the Spallation Neutron Source (SNS) by a consortium of researchers with interests in a wide variety of investigations that shed light on important issues in nuclear, particle, and astrophysics; in the determination of fundamental constants, and in the study of fundamental symmetry violation.

The purpose of this review is to evaluate the science that would be performed using a Fundamental Physics Beamline in the broadest context. It is expected that the funding bodies (primarily DOE nuclear physics and NSF) will evaluate the merit relative to other priorities within the fields under their purview as they prioritize their allocation of funds. The question which SNS as a user facility must address is whether to devote one of 24 beamlines to this endeavor. While SNS is a facility primarily devoted to the study of the structure and dynamics of materials using neutron scattering, we are open to other uses provided they do not impact our main mission negatively and the scientific merits warrant allocation of a beamline with the attendant opportunity cost. The allocation of a beamline represents a resource valued in excess of $50 M and we must insure that this resource will be devoted to science of the highest caliber. Understanding that the proposal is still at a conceptual stage and the detailed designs would be subject to further review as required for all SNS instruments provide your assessment of the following:

- Evaluate the importance of the scientific issues which the proposed facility and experiments will address.
- Evaluate the quality and capability of the beamline project team as well as the researchers engaged in the individual experiments.
- Evaluate the importance and quality of the proposed experiments with respect to technical approach, timeliness, and feasibility. Is the science feasible given the proposed instrumentation and source performance?
- Evaluate the suitability of the proposed facility to accommodate the proposed experiments as well as other possible experiments. Is there a compelling need for the special capabilities of the SNS or could the research be performed elsewhere?

Enclosure 2

SNS Science Advisory Sub-Committee Review of the SNS Fundamental Physics Beamline

17 October 2002

AGENDA

08:00	Continental Breakfast/Executive Session	(closed)
08:45	ORNL perspective	Lee Riedinger
09:00	Role of ORNL Physics Division	Glenn Young
09:15	Project Overview	Geoff Greene
09:45	Neutron Beta Decay in Context	Dinko Pocanics
10:05	Break	
10:20	Determination of Correlations in Neutron Decay using Pulsed Neutron Beams	David Bowman
10:50	Determination of the Neutron Lifetime with magnetically trapped UCN	John Doyle
11:20	Hadronic Parity Violation with Pulsed Cold Neutrons	Mike Snow
11:50	Lunch	
13:00	Neutron Electric Dipole Moment	Martin Cooper
13:30	Overview of Project Planning and Organization	Vince Cianciolo
14:00	Executive Session	(closed)
16:00	Out-Brief	Committee
16:30	Adjourn	