CCRI(III)/07-12

IONIZING RADIATION DIVISION
Neutron Interactions & Dosimetry Group
Technical Activities
2006

Active Interrogation Standards: A cargo container test bed with three massive cargo regions as needed for testing under ANSI N42.41, Minimum Performance Criteria for Active Interrogation Systems used for Homeland Security, has been set up for use at the NIST site in Gaithersburg, with the capability of mobility to other locations. Active interrogation involves directing nuclear radiation into a closed container and measuring secondary radiations to gain information about the contents of the container and has the potential for detection of smaller quantities of Special Nuclear Material than by passive detectors.

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Neutron Standards and Measurements: Background and Intended Outcomes

Strategic element: Develop and provide neutron standards and measurements needed for worker protection, nuclear power, homeland security, and fundamental applications.

The Neutron Interactions and Dosimetry (NI&D) group, located at the NIST Center for Neutron Research (NCNR), maintains and supports the nation's premier fundamental neutron physics user facilities, including a weak interactions neutron physics station, Neutron Interferometry and Optics Facility (NIOF), Ultra Cold Neutron Facility (UCNF) and a ^{3}He based Neutron Polarizer development facility, and have developed the nation's only high-resolution neutron imaging user facility (NIF) for fuel cell research. We maintain, and disseminate measurement standards for neutron dosimeters, neutron survey instruments, and neutron sources, and improve neutron cross-section standards through both evaluation and experimental work.

The group is at the forefront of basic research with neutrons. Experiments involve precision measurements of symmetries and parameters of the "weak" nuclear interaction, including measurement of the lifetime of neutrons using thermal and ultra-cold neutrons, improved cold neutron counting techniques, setting a limit on the time-reversal asymmetry coefficient and radiative decay of the neutron. The neutron interferometry program provides the world's most accurate measurements of neutron coherent scattering lengths important to materials science research and modeling of nuclear potentials; in 2006, new interferometry experiments to determine the charge distribution of the neutron, and reciprocal space imaging, were being carried out. We are developing and promoting the applications of efficient neutron spin filters based on laser-polarized ^{3}He, and are pursuing applications for these filters at the NCNR, the Intense Pulsed Neutron Source at Argonne National Laboratory, and the Los Alamos Neutron Science Center.

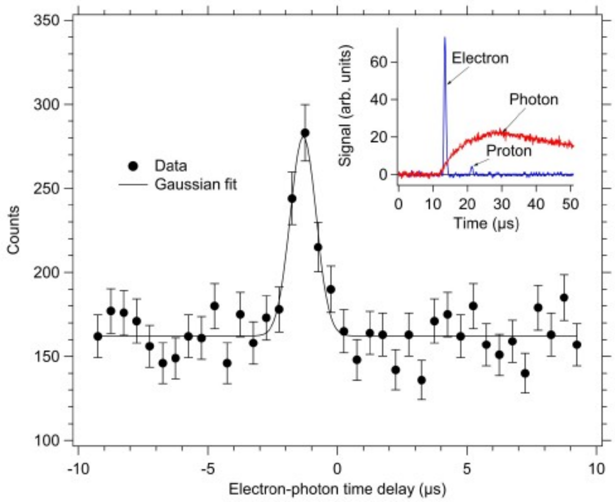
We are developing the necessary technical infrastructure to support neutron standards for national security needs. In addition, we are developing advanced liquid scintillation neutron spectrometry techniques for characterization of neutron fields and for detection of concealed neutron sources with low false-positive rates. We are planning to organize and lead a Consultative Committee for Ionizing Radiation (CCRI) comparison of thermal neutron fluence rate measurements, characterizing four different beam qualities at the NCNR, and carry out comparisons of NIST standard neutron sources and we are leading an effort that will result in a new international evaluation of neutron cross-section standards.

We are applying neutron-imaging methods for industrial research on water transport in fuel cells and on hydrogen distribution in hydrogen storage devices. This facility has provided critical services to major automotive and fuel cell companies during 2006. This is a high demand and high profile nationally recognized program.

In summary, the NI&D group provides measurement services, standards, and fundamental research in support of NIST's mission as it relates to neutron technology and neutron physics. The national interests served include industrial research and development, national defense, homeland security, higher education, electric power production, and, more specifically, neutron imaging, scientific instrument calibration and development, neutron source calibration, detection of concealed nuclear materials, radiation protection, nuclear data, and particle physics data.

Fundamental Neutron Physics

First Observation of the Radiative Decay Mode of the Neutron Beta decay of the neutron into a proton, electron, and electron antineutrino is occasionally accompanied by the emission of a photon. An experiment to study the radiative beta-decay of the neutron was completed at the NG-6 fundamental physics end station. The experiment employed the magnet previously used for the NIST Penning trap neutron lifetime apparatus, with the addition of a detector for photons above 15 keV. A photon detector that operates efficiently in the high magnetic field, low temperature environment of the magnet was developed and implemented. This apparatus allowed half of the available electrons and all of the available protons from neutron beta-decay to be detected, which provided a high-rate, background-rejecting trigger for the observation of radiative decay photons. In this first-generation experiment, the photon detector consisted of a single 12 mm by 12 mm by 200 mm scintillating crystal coupled to the an avalanche photodiode.



The electron-photon timing spectrum for a three-day run with the mirror reflecting all protons. The peak shows the photons associated with neutron decay. The spectrum shows all photons in a 20 microsecond window for which the electron start pulse was accompanied by a delayed proton event. In the inset, the blue line shows the SBD signal for an electron event followed by a delayed proton; the red line shows the much slower preamplified output of the APD for a photon event occurring in coincidence with the electron.

The data run was completed in January of 2006, and the data analysis was finished at the end of the summer. We observed electron-proton-photon coincidences that were unambiguously due to the radiative decay of the neutron. We reported the first observation of the radiative decay mode, and a manuscript detailing the measurement was published in the journal Nature.

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Measurement of the Parity Violating Neutron Spin Rotation in Liquid Helium The spin-rotation experiment is based on the principle that a transversely polarized neutron beam will experience a PNC rotation of its polarization vector about its momentum axis in the target due to the weak interaction component of the forward scattering amplitude. To measure the small PNC rotation, a neutron polarimeter is used in which the horizontal-component of the neutron beam polarization is measured for a neutron beam initially polarized along the vertical axis and traveling in the z direction. The challenge is to distinguish small PNC rotations from rotations that arise from residual magnetic fields. The goal of the run at NIST is a statistical precision of 3×10^{-7} rad/m with an anticipated 10^{-7} rad systematic error.

Photograph of target chamber for measuring parity-violating spin rotation angles in room temperature targets. A Sn target is mounted in the foreground, and the pi-coil (for rotating the neutron spins 180 degrees) is shown behind it. A second Sn target is behind the pi-coil (not visible). Nonmagnetic pneumatic pistons drive the two targets between two physically separated beams to minimize systematic effects.

The apparatus includes an adiabatic RF neutron spin flipper, input and output guides made from float glass, magnetic shielding, system for moving room target targets, a data acquisition system, and a new segmented ion chamber. The cryogenic liquid helium target is still under construction at

Indiana and is expected to be delivered to NIST early in 2007. The apparatus has been assembled on NG-6 and undergone several months of beam characterization. The fluence rate, neutron wavelength spectrum, and beam profile are as expected for the experiment. The polarization product is slightly lower than predicted (approximately 10%) and investigations are in progress to improve that quantity. The chamber for manipulating room temperatures targets was constructed and tested. The first stage of the experiment uses room temperature targets with comparatively large parity-violating spin rotations to study both systematic effects from the apparatus as well as to measure their rotation angles. We have constructed targets using solid La, Pb, and Sn. Designs are in progress for room temperature liquid targets of Br, Cl, and D_2O.

In addition, we constructed two targets of aluminum, which do not produce any parity-violating signal. The first run of the apparatus used these two targets as null tests of both the apparatus and the analysis code. The figure shows preliminary data taken in 2006 that shows the null result for a one-day run. Efforts are currently directed toward measuring the rotation angles of some of the room temperature targets and completion the construction of the liquid helium target, which is expected to run in 2007.

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Magnetically Trapped Neutron Lifetime Experiment This experimental program is designed to substantially improve the measurement of the neutron lifetime τ_n using a technique with completely different systematic uncertainties than earlier measurements. It is an NSF sponsored project currently based at NIST, but the collaboration plans to eventually move this experiment to the SNS in order to utilize the new higher flux, lower background fundamental neutron physics facility. In brief, UCN are produced by inelastic scattering of cold (0.89 nm) neutrons in a reservoir of superfluid ^{4}He (the "superthermal" process). These neutrons are then confined by a three dimensional magnetic trap. As the trapped neutrons beta decay, the energetic electrons produced generate scintillations in the liquid helium which should potentially be detectable with nearly 100% efficiency. Unlike most earlier measurements, τ_n can be directly determined by measuring the scintillation rate as a function of time. Recently a first generation demonstration of this technique has been completed, yielding a measurement of the neutron lifetime of 833 +74 -63 s. This present apparatus is currently undergoing a major upgrade to a larger magnet which should ultimately allow a measurement of the neutron lifetime at the 10^{-3} level. We expect to begin taking data in late FY07. The uncertainty in the neutron lifetime currently limits predictions of the primordial ^{4}He abundance. Precise measurements of the neutron lifetime should improve our understanding of Big Bang Nucleosynthesis. In addition, the neutron lifetime, combined with experiments currently planned at NIST, will improve determinations of the V_{ud} element of the quark mixing matrix and allow stricter tests of unity. Recently, a new measurement of the neutron lifetime, six sigma from the world average, was reported. The NIST measurement is thus all the more important as it will help to clarify this situation. In addition, because the isotopic purity of the ^{4}He is critical to the success of this experiment, we are involved in pioneering methods of measuring ^{3}He/^{4}He ratios on the level of 10^{-13}. Finally, many of the techniques developed in this work have applications for other experiments such as the neutron EDM search and low energy neutrino and dark matter detection.

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Alpha gamma counting for High Accuracy Fluence Measurement Neutron fluence is measured by counting gamma-rays from the reaction $n+{}^{10}B \rightarrow {}^{4}He + {}^{7}Li + \gamma(478\,keV)$ with a calibrated gamma detector. The gamma detector is calibrated in a multi-step procedure that uses a precisely calibrated Pu alpha source (re-calibrated in 2006), an integrated alpha particle detector (the alpha-gamma counter was restored to operation in 2006), a neutron beam, and a thin ^{10}B target. In regular operation, the thin target is replaced with a thick one and the detector operates as a black detector counting the number of neutrons impinging on the target per second. The goal of the calibration is 0.1% relative uncertainty.

This is a new primary calibration method. It is being used to calibrate the fluence monitor that was used in our beam-type neutron lifetime measurement. It has demonstrated the potential to reduce the uncertainty in the monitor efficiency by more than a factor of three. This would reduce the uncertainty on our beam-type lifetime measurement by 32%. It can also be used to recalibrate the national neutron standard NBS-1 and to measure the ^{6}Li and ^{10}B thermal neutron cross sections.

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Neutron Science, Applications and Standards

^{3}He spin filters for a triple axis spectrometer We have developed and employed ^{3}He spin filters to provide full polarized beam capability on the NCNR's new thermal energy triple-axis spectrometer, BT7. ^{3}He spin filters have several advantages as compared to the traditional use of Heusler alloy to polarize and analyze thermal energy neutron beams, including the decoupling the energy and polarization selection, simplicity and reduced cost for a focusing beam geometry, versatility, and improved transmission. Newly developed large area, long relaxation time, glass cells were polarized off-line to > 70 % ^{3}He polarization using hybrid spin-exchange optical pumping (see below) and installed on the instrument in magnetically shielded solenoids. One cell was used to polarize the beam and another to analyze the beam. We have assisted the NCNR in constructing spin-exchange optical pumping stations that will be used to supply polarized gas for routine user operation on BT7. Based on our work developing cells for BT7, we have also provided ^{3}He cells for the magnetism reflectometer at the Spallation Neutron Source. We are currently assisting them in the construction of their own system for fabricating ^{3}He cells.

The BT7 thermal triple-axis spectrometer with ^{3}He spin filters to polarize and analyze the neutron beam. After exiting the monochromator drum (green structure on the left), the neutron beam passes through the polarizer solenoid (small black cylinder) to the sample; the scattered beam passes through the analyzer solenoid (larger black cylinder) to the detector (aluminum cylinder on the right).

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Spin-exchange optical pumping of ^{3}He with Rb/K mixtures and pure K: We have successfully employed Rb/K mixtures and pure K for spin-exchange optical pumping (SEOP) of ^{3}He and carried out a detailed study of the expected and observed increase in efficiency as compared to the conventional use of pure Rb. Rb/K mixtures and pure K yield higher optical pumping efficiency as compared to pure Rb because of the lower electronic spin-destruction rate for potassium. For Rb/K mixtures our existing capability for optical pumping at the 795 nm optical pumping wavelength for rubidium was employed, whereas for pure K we constructed spectrally narrowed lasers using newly available diode bars at 770 nm. In the past, practical studies of SEOP with pure K have not been possible with commercial broadband diode lasers due to the small fine structure in K. We found that the use of either Rb/K mixtures or pure K yield improvements in optical pumping efficiency, but the best results were obtained with Rb/K mixtures. This increased efficiency, typically a factor of two, has proved to be essential for polarizing the large volume spin filters for the BT7 and SNS instruments discussed above. The use of hybrid cells has allowed us to rapidly optically pump large volume cells to the highest possible polarization for applications. Our analysis indicates that for higher pressure cells, the gains from hybrid and/or pure K SEOP will be even greater. Such cells would be employed for rapid production of polarized gas from an SEOP-based centralized filling station.

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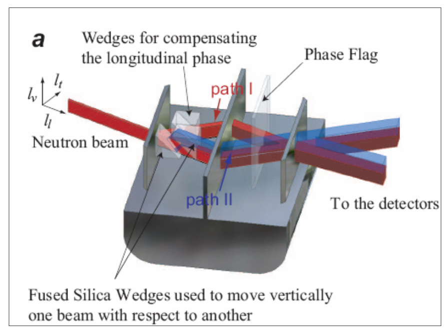
Measurements of the Neutron vertical coherence We have measured the vertical coherence function of a single crystal neutron interferometer via path separation and for different vertical beam distributions. We extended this measurement to 1000 Å. Having a single crystal neutron interferometer with a long coherence length provides new opportunities for experiments such as Fourier Spectroscopy and coherence scattering over scales that are not easily accessible by other approaches. We introduce a path separation via a pair of prisms placed in the legs of interferometer and measure the loss in contrast as this separation is increased. We show that the measured coherence length is consistent with the experimental distribution of the incoming neutron beam momentum in the vertical direction. Finally, we demonstrate that the loss in contrast with beam displacement in one leg of the interferometer can be recovered by introducing a corresponding displacement in the second leg of the interferometer.



A schematic diagram of the coherence length experiment. The phases which neutron accumulates over each path are experimentally controlled by rotating the phase flag. In one of the paths we install two 45° prisms, which at 0 distance separation form a cube. By separating the prisms we shift the neutron beams in path I and II vertically with respect to each other. We observe a loss in contrast with displacement, which we measure with the help of phase shifter (shown on the figure)

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The spin-dependent neutron - ^{3}He scattering length The four-nucleon systems are the frontier for studying the nuclear force. The n + ^{3}He system in particular is very interesting. It is strongly spin-dependent and influenced by the resonance associated with formation of a tightly-bound ^{4}He nucleus. The most important experimental observable for few-body nuclear interactions is the scattering amplitude, which is in general complex and spin dependent.

The neutron scattering amplitude describes the s-wave scattering of a neutron by a free nucleus with spin 1:

$$a_{\pm} = a_{\pm}' - i a_{\pm}''$$

where the ± subscript refers to the interaction channel associated with the compound spin J = 1 ± 1/2. Theoretical calculations of the real parts $a_{\pm}'$ for the n + ^{3}He system have been carried out by a number of theorists. Experimentally, the imaginary parts $a_{\pm}''$ are known very precisely because they can be obtained by spin-dependent neutron absorption in ^{3}He. The real parts have been more challenging because they require a neutron optical measurement (*e.g.* interferometry) using a highly polarized ^{3}He sample, and until recently were only known at the 10% level, which is inadequate for comparison with theoretical calculations. The apparatus for the measurement is shown in the figure below. A neutron spin polarizer and adiabatic spin flipper provide a longitudinally polarized neutron beam with alternating direction to the interferometer. In addition to the usual phase flag, one leg of the interferometer contains a glass cell containing spin polarized ^{3}He, with a polarization in the range 30–50%. The phase shifts corresponding to the two polarization directions, due to coherent forward scattering in the ^{3}He sample, are determined from the interferogram produced by detectors 2 and 3. We simultaneously measure the asymmetry of counts in detector 4 for the two spin flip states. These measurements, combined with the neutron polarization which can be precisely determined in a separate measurement, yield a precise value for the difference $a_+' - a_-'$. This experiment has been set up and is now running at the NIST interferometer.

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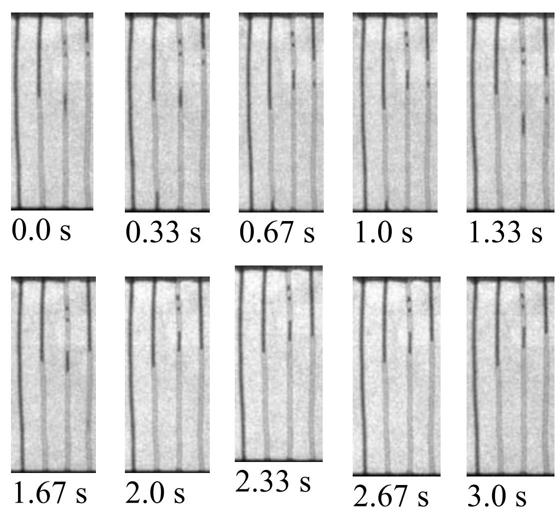
Visual Observation of Oscillating Heat Pipes Using Dynamic Neutron Imaging One of many applications for heat pipes have been in modern computer systems to move heat away from components such as CPUs and GPUs to heat sinks where thermal energy may be dissipated into the environment. Heat pipes have no mechanical components; instead they are closed systems of liquid and vapor phases that rely on the process of vaporization and condensation to drive the system. Liquid absorbs heat in the evaporator and vaporizes. The vapor expands and pushes liquid from the connected condenser back into a second evaporator. The newly created vapor then expands into the condenser where it cools rejecting heat back into the local environment and condensing back into the liquid state. Meanwhile the liquid driven into the second evaporator vaporizes. This second vaporization then drives the liquid (from condensed vapor) back to the first evaporator where the cycle starts all over again. This cycle or oscillation continues back and forth as long as heat is being generated (in this case the heat is created by a CPU). This system is known as an Oscillating Heat Pipe (OHP). Previous experiments performed to visualize the oscillation have had to modify the metal pipe system to use glass or plastic to provide a visible window. Since these systems are all usually made of copper, the use of glass or plastic changes the thermal transfer properties of the system in turn affecting the performance of the system. Neutron imaging allows researchers the opportunity to study the liquid flow in these systems in-situ using



Fluid movement in the center turns of the 12-turn nanofluid OHP at 50.5 Watts and an operating temperature of 20 °C the actual hardware. Due to the high intensity of neutron beam available at the NNIF it is possible to quickly capture dynamic images at 1/30th of a second. To do this the facility utilizes an advanced amorphous silicon imaging system that is capable of capturing neutron images at this extremely high rate. Recently the University of Missouri-Columbia collaborated with NIST to utilize this capability to visualize the oscillation in the flow of nanofluids through heat pipes. The nanofluid in this case is composed of diamond nanoparticles suspended in water. These particles change the thermal properties of the water allowing for better heat conduction.

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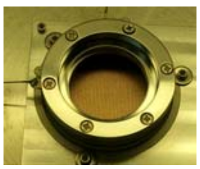
High Resolution Neutron Imaging Neutron radiography was pioneered in 1950's using film and revolutionized in the 1990's by digital imaging. However, all this time efficient high resolution neutron imaging devices have been limited to a minimum spatial resolution of about 0.250 mm. During 2006 a new technology was tested at the NIST NIF that improves this spatial resolution by an order of magnitude (0.025 mm) with the same (or potentially higher) detection efficiency. This revolutionary development is expected to impact areas of research such as PEM fuel cells, and water transport in porous rock structures.



25mm cross delay line anode detector

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Neutron Source Strength Calibrations We operate a facility to calibrate the neutron emission rate of radioisotope neutron sources. Allowable rates range from $1\times10^5\,s^{-1}$ to $1\times10^{10}\,s^{-1}$. They are determined by the manganous sulfate bath method in which the emission rate of the source to be calibrated is compared to the emission rate of NBS–1, the national standard Ra–Be photo-neutron source. Neutron source calibrations typically have a relative expanded uncertainty of about 3.4%, depending on the details of the source encapsulation. During the past year, 6 external vendor neutron sources and 2 Department of Homeland Security neutron sources were calibrated. In support of these measurements, our own standard neutron sources (NBS–1, BIPM) were measured several times.

Picture of the Mn Bath

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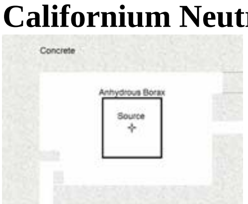
Californium Neutron Irradiation Facility NIST provides an exposure facility for high neutron fluence. A Cf-252 source is housed in a large (approximately 15 m x 10 m x 10 m high) room with concrete walls, floor, and ceiling. Inside the concrete is a 5.4 cm thick shell (5.3 m x 5.3 m x 5.9 m high) of anhydrous borax. The anhydrous borax prevents neutrons scattered by the



Simplified view of the low scatter neutron calibration facility concrete from returning to the source. Typical irradiations include sample activation experiments, electronic damage studies, and other special tests requiring high neutron fluence and a low-room-scatter environment. Interference between successive calibrations through sulfur activation has been identified and eliminated by appropriate scheduling.

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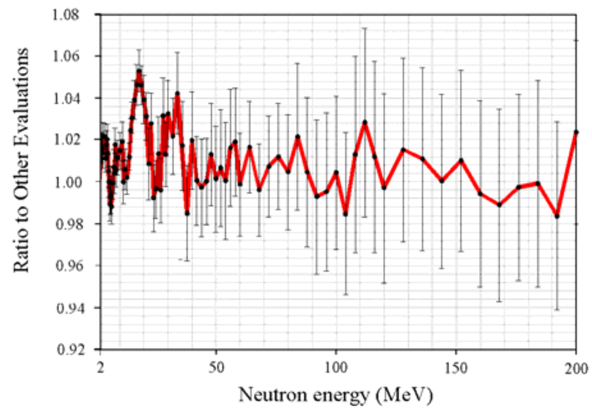
Neutron Cross-section Standards The international evaluation of the neutron cross section standards has been completed. The standards that have been evaluated are the H(n,n), ^{6}Li(n,t), ^{10}B(n,α), ^{10}B(n,α$_1$γ), Au(n,γ), ^{235}U(n,f), and ^{238}U(n,f) cross sections. In addition, the ^{238}U(n,γ) and ^{239}Pu(n,f) cross sections, that are not standards, were evaluated as a result of the evaluation process. The data obtained from this evaluation were used to produce the standards for the new ENDF/B-VII library. A new standards sublibrary was established for ENDF/B-VII. The ^{3}He(n,p) and C(n,n) standards, that were not re-evaluated, were carried over directly from the ENDF/B-VI library into the new ENDF/B-VII standards sublibrary. For this sublibrary, descriptive files, cross section files and covariance files for the data obtained from the international evaluation were written for each of the ENDF/B-VII standards.



Comparison of the ^{238}U(n,f) cross section from this evaluation with the ENDF/B-VI evaluation up to 20 MeV and with updated IAEA values above 20 MeV.

They are available at http://www.nndc.bnl.gov/exfor7/endf00.htm. The fission cross section standards, ^{235}U(n,f) and ^{238}U(n,f), have been extended from the 20 MeV maximum energy of the ENDF/B-VI evaluation to 200 MeV, in order to provide the standards needed for the cross section measurements being made in this higher energy region. The ^{238}U(n,f) cross section is a new U.S. standard that is especially convenient for applications where low energy background is a problem since its cross section in that energy region is negligible. In Figure 1, this cross section is shown. NIST collaborative measurements have had a significant impact on the quality of this standard. The larger uncertainties above 20 MeV indicate the need for additional high quality measurements of this standard in this higher energy region. The international evaluation has been supported by an International Atomic Energy Agency Coordinated Research Project, a Nuclear Energy Agency Nuclear Science Committee Subgroup and a U.S. Cross Section Evaluation Working Group Task Force. NIST has had a major leadership role in each of these activities. Participants in the evaluation process are affiliated with Austria, Belgium, China, Germany, Japan, Russia, South Korea, and the U.S.A. The evaluation was produced from a combining of R-matrix and generalized least squares evaluation procedures. Many types of data were used in this evaluation that uses charged-particle in addition to neutron measurements. It is then possible to include angular distribution, polarization and integral cross section measurements to improve the quality of the evaluation. Detailed correlation information was used in the evaluation.

A detailed document has been written describing the standards evaluation process. It will be published as an IAEA Technical Report. The topics in this report include: methods used for the evaluation, the experimental database, Peelle's Pertinent Puzzle, the combining procedure, comparisons of the results and justification for the recommended uncertainties.

In addition to the evaluation effort, NIST maintains a limited experimental effort focused on improvements to the database of the standards. Recent NIST collaborations have produced measurements of coherent neutron scattering lengths that were available for use in the standards evaluation. Also measurements are nearly finished at Ohio University of the important hydrogen scattering angular distribution standard at 15 MeV neutron energy in an NIST-Ohio University-LANL collaborative experiment. Also measurements to improve low energy standard cross sections are planned at the NIST monochromatic beam facility on NG6.

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Homeland Security

Active Interrogation Standards Active interrogation involves directing nuclear radiation into a closed container and measuring secondary radiations to gain information about the contents of the container. Typically, but not always, neutrons are used as the impinging radiation. Active interrogation has the potential for detection of smaller quantities of Special Nuclear Material than by passive detectors. It also holds the promise of detection of non-nuclear materials, hazardous chemicals and explosives. NIST has organized a drafting committee and held four meetings to prepare a draft of a new ANSI Standard: ANSI STANDARD N42.41 - **Minimum Performance Criteria for Active Interrogation Systems used for Homeland Security**. Comments on the draft have been received from ANSI committee members, commercial systems vendors, universities, and national laboratories. Balloting is expected to begin in early 2007.

A cargo container test bed with three massive cargo regions as needed for testing under ANSI N42.41 is being set up for use at NIST in Gaithersburg or at other sites

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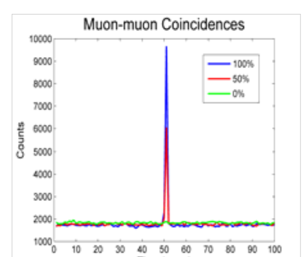
Neutron Background Reduction Cosmic ray showers are initiated by high-energy particles entering the earth's atmosphere. A single initiator particle produces a cascade of particles at ground level. Measurements of muon/neutron and neutron/neutron coincidences have shown insufficient density to significantly reduce background through this technique. Result from this experiment rules out one possibility for reduction of background and false positives in passive detection of Special Nuclear Materials.



Muon-muon coincidences as measured with various geometries of muon paddles

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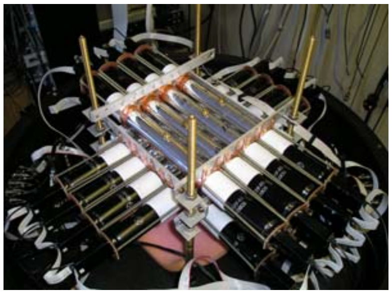
High-efficiency Neutron Detector and Spectrometer The detection of low neutron fluence requires a highly efficient detector. NIST NI&D group is developing a neutron spectrometer using a large volume of liquid scintillator which can intercept all neutrons which pass through a large surface area, and measure almost all neutrons which enter. A confirming signal from thermal neutron capture is required to ensure that the neutron deposits all of its energy within the scintillator. The thermal neutron capture also serves to discriminate against background non-neutron events. The ability to mix an enriched ^{6}LiCl solution in liquid scintillator and detect both Cf-252 and 14 MeV neutrons with good efficiency using the delayed coincidence technique was demonstrated. The 16-channel spectrometer being developed with the Institute for Nuclear Research of the Russian Academy of Science is nearing completion. The same delayed-coincidence technique is also being evaluated for use in a large, low-resolution, but very high efficiency neutron detector. Pulse-shape discrimination techniques have also been studied for use in these spectrometer and detector developments.



Channel neutron spectrometer

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Neutron Detection Standard The detection of Special Nuclear Material and other neutron sources is required to prevent nuclear terrorism. NIST has the lead in the development of a new ANSI standard: *N42.39 Standard for Performance Criteria for Neutron Detectors for Homeland Security*. This will serve as a guide for the development of new detectors and a tool for ensuring consistency in the detection of nuclear materials. The new standard will provide specific criteria to ensure that new detectors meet DHS needs.

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GROUP PUBLICATIONS SINCE 2001

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Black, T.C., Huffman, P.R., Jacobson, D.L., Snow, W.M., Schoen, K., Arif, M., Kaiser, H., Lamoreaux, S.K., Werner, S.A *Precision Neutron Interferometric Measurement of the n-d Coherent Neutron Scattering Length and Consequences for Models of Three-Nucleon Forces* Phys. Rev. Lett. 90, 192502 (2003)

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Coakley, K.J., Chowdhuri, Z., Snow, W.M., Richardson, J.M., Dewey, M.S. *Estimation of Neutron Mean Wavelength from Rocking Curve Data* Meas. Sci. Tech. 14, 131 (2003)

Dewey, M.S.; Gilliam, D.M.; Nico, J.S.; Snow, W.M.; Wietfeldt, F.E. *NIST Neutron Lifetime Experiment* Proceedings of 10th International Seminar on Interaction of Neutrons with Nuclei: Neutron Spectroscopy, Nuclear Structure, Related Topics (Dubna, Russia) (2003)

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Gilliam, D.M., Thompson, A.K., Nico, J.S. *A Neutron Sensor for Detection of Nuclear Materials in Transport* AIP Conference Proc. 632, Unattended Radiation Sensor Systems for Remote Applications Workshop, April 15-17, 2002, Washington, DC, ed. by J.I. Trombka, D.P. Spears, and P.H. Solomon (AIP, College Park, MD, 2002), pp. 291-294.

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Dewey, M.S., Gilliam, D.M., Nico, J.S., Wietfeldt, F.E., Snow, W.M., Greene, G.L. *Measurement of the Free Neutron Lifetime* NIST IR, 6798 (2001)

Mildner, D.F.R., Arif, M., Werner, S.A. *Neutron transmission through pyrolytic graphite monochromators* J. Appl. Cryst. 34, 258-262 (2001)

GROUP INVITED TALKS 2006

Arif, M., “Neutron Imaging Study of the Water Transport in Operating Fuel Cells“, DOE Program Review, Washington D.C., May 2006

Arif, M., “Neutron Imaging for Fuel Cell Research“, Imaging and Neutrons Workshop, Oak Ridge, Tennessee, October 2006

Arif, M., “Imaging with Neutrons“, Ohio University, Athens, Ohio, November 2006

Carlson, A.D., “The Neutron Cross Section Standards,” Triangle Universities Nuclear Laboratory Seminar Series, Durham, NC, December 2006.

Carlson, A.D., “Final Report on the ENDF/B-VII Evaluation of the Neutron Cross Section Standards,” Brookhaven National Laboratory, Upton, NY, November 2006

Carlson, A.D., “Nuclear Data Standards,” Working Party on International Evaluation Cooperation, Nuclear Energy Agency, Paris, France, May 2006

Dewey, M. S., “Neutron Binding Energy Measurements for a Direct Test of E=Mc^2”, Institut Laue-Langevin, France, October 2006.

Dewey, M. S., “Neutron Binding Energy Measurements for a Direct Test of E=mc^2”, Tulane University, November 2006.

Gentile, T.R., “Polarized 3He Spin Filter Development in the U.S.”, Polarized Inelastic Neutron Scattering conference, Brookhaven National Laboratory, April 2006

Gentile, T.R., “Observation of the Radiative Decay Mode of the Free Neutron”, American Physical Society Division of Nuclear Physics Meeting, Nashville, Tennessee, October 2006.

Gilliam, D.M., “Calibration of a Manganese Bath Relative to Cf-252 Nu-bar”, China Institute for Atomic Energy, Beijing, China, October 2006

Gilliam, D.M, “Calibration of a Manganese Bath Relative to Cf-252 Nu-bar”, China Institute for Atomic Energy, China, October 2006

Gilliam, D.M. "The Use of Polyimide Films to Prevent Self-Sputtering of Cf-252 in High Accuracy Fission Counting," 23rd World Conference of the International Nuclear Target Development Society, Tsukuba, Japan, October, 2006.

Hussey, D.S, “In Situ Fuel Cell Tomography at The New NIST Neutron,” 2006 American Conference on Neutron Scattering, St. Charles, IL, June 2006

Hussey, D.S, “Tomographic Imaging of an Operating Proton Exchange Membrane Fuel Cell,” 8th World Conference on Neutron Radiography, NIST, Gaithersburg, MD, October 2006

Jacobson, D. L., “Neutron Radiography and Tomography Facilities at NIST to Analyze In-Situ PEM Fuel Cell Performance,” 8th World Conference on Neutron Radiography, NIST, Gaithersburg, MD, October 2006

Jacobson, D. L., “Neutron Radiography and Tomography Facilities and Experiments to Analyze In-Situ PEM Fuel Cell Performance,” 2006 Joint International Meeting, 210th Meeting of The Electrochemical Society, Cancun, Mexico, October 29 through November 3, 2006

Nico, J.S., "Neutron Physics at NIST," Nuclear Physics Seminar at the California Institute of Technology, Pasadena, CA, February 2006.

Nico, J.S., "Recent Neutron Lifetime Measurements," Plenary talk at the Conference on Intersections of Particle and Nuclear Physics (CIPANP 2006),Puerto Rico, June 2006.

Nico, J.S., "Neutron Lifetime Experiments," First Summer School on Fundamental Neutron Physics, Knoxville, TN, June 2006.

Nico, J.S., "Measuring the Neutron Lifetime with a Proton Trap," NCNR Expansion Initiative, Bethesda, MD, July 2006.

Nico, J.S., "Neutron Facilities at NIST," Neutron Physics and Fundamental Symmetries Pre-Town Meeting, Pasadena, CA, December 2006.

GROUP STAFF CURRICULA VITAE

ARIF, MUHAMMAD, PHYSICS, BS, Dacca Univ., Bangladesh, 76; MS, Ohio Univ., 80; Ph.D., Univ. of Missouri-Columbia, 86; Univ. of Missouri; Post Doc. Fellow, 86-88; Physicist, NIST, 88-03; Group Leader, 03-present. Mem., American Physical Society. Res: Neutron and X-ray scattering, x-ray and neutron interferometry, neutron imaging.

DEWEY, MAYNARD S., PHYSICS. BS, State University of New York at Stony Brook, 78; Ph.D., Princeton University, 84; Research Associate, Princeton University, 86; Physicist, NIST 86-present. Mem: American Physical Society. Res: Neutron lifetime measurement, neutron fluence measurement, ultra-high resolution gamma-ray measurements.

GENTILE, THOMAS R., PHYSICS. BS, State University of New York at Stony Brook, 79; Ph.D., Massachusetts Institute of Technology, 90; Research Fellow, California Institute of Technology, 90-92; NIST 93-present. Member: American Physical Society. Res: Neutron polarization based on polarized ^{3}He, neutron tomography.

GILLIAM, DAVID M., NUCLEAR ENGINEERING, PHYSICS; BA, Rice Univ. 64; MS, Rice Univ., 66; Ph.D., U. Michigan, 73; NBS/NIST Neutron Interactions and Dosimetry Group, 73-present; National Measurement Laboratory Analyst, 85; Associate Division Chief, 86-87; Group Leader, 94-03, Physicist, 03-present. Mem. American Physical Society, American Nuclear Society, ASTM E10.05, ANSI E 13.3, Comité Consutatif pour les Étalons de Mesure des Rayonnements Ionisants, Section III, Mesures neutroniques. Res: Absolute neutron reaction rate measurements.

HEIMBACH, CRAIG R., PHYSICS, BS, Rensselaer Polytechnic Institute, 68; MS, Nuclear Physics, Purdue University, 70; Ph.D., American University, 76. Nuclear Physicist, Harry Diamond Labs., 72-78; Nuclear Physicist, Aberdeen Test Center, US Army, 78-00; Director, Army Pulse Radiation Facility, 00-03, Aberdeen Test Center, US Army; Physicist, NIST, 03-present. Res: Neutron dosimetry and spectroscopy, radiation transport, radiation shielding, radiation effects on electronics.

JACOBSON, DAVID L., PHYSICS, BA, Westminster College, 90; Ph.D., University of Missouri-Columbia, 96; Post Doctoral Fellow, University of Missouri-Columbia, 96; NRC Post Doctoral Fellow, NIST, 96-98; Physicist, NIST 98-present. Res: Neutron optics and neutron interferometry, neutron imaging.

NICO, JEFFREY S., PHYSICS, BS, Michigan State Univ., 83; MS, U. of Michigan, 90; Ph.D., U. of Michigan, 91; Postdoctoral Fellow, U. of Michigan, 91 and Los Alamos National Laboratory, 91-94; Physicist, NIST, 94-present. Res: Absolute neutron reaction rate measurements, weak interactions, neutron dosimetry.

SHANKLE, ROBERT L., Engineering Science Technician. Frederick High School, Machining 1, 2&3., 1983-1986, Welding 1,2&3., 1983-1986. Frederick Community College, Machine Shop 1., 2001. Res. NIST 2006 – Present Engineering Science Technician, Ionizing Radiation Division, Neutron Interactions and Dosimetry Group.

THOMPSON, ALAN K., PHYSICS, BA, Rice U., 86; Ph.D., Mass. Inst. Tech., 91; Research Associate, Harvard U., 91-93; Physicist, NIST, 93-present, Mem: American Physical Society, Res: ^{3}He polarization, neutron polarization, tests of fundamental symmetries, structure of the neutron, weak interactions, neutron dosimetry.

GROUP ASSOCIATES 2006

Neutron Interactions and Dosimetry Group

NAMES	SPONSORS	PROJECT
Black, Timothy C.	University of North Carolina	Neutron Interferometry
Carlson, Allan D.	Self	Neutron cross section standards
Cooper, Robert L.	Univ. of Michigan	Fundamental Physics
Eisenhauer, Charles	Self	Neutron transport calculations and dosimetry studies
Fisher, Brian M.	DHS Post Doc	Homeland Security
Gagliardo, Jeffrey J.	General Motors	Neutron Imaging
Gan , Kangfei	George Washington University	Fundamental Physics
Greene, Geoffrey L.	University of Tennessee	Fundamental Physics
Grundl, James A.	Self	Neutron fluence measurement
Huber, Michael G.	Tulane University	Neutron Interferometry
Huffman, Paul	North Carolina State University	Ultra Cold Neutron
Laptev, Alexander B.	Tulane University	Fundamental Physics
Lee, Seung W.	Korea Atomic Energy Research Institute	Neutron Imaging
Luo, Da	Indiana University	Fundamental Physics
Micherdzinska, Anna	University of Winnipeg	Fundamental Physics
Mumm, Hans P.	University of Maryland	Ultra Cold Neutrons
Opper, Allena	George Washington University	Fundamental Physics
O’Shaughnessy, Chris	North Carolina State University	Ultra Cold Neutron
Owejan, Jon P.	General Motors	Neutron Imaging

Pushin, Dmitry	Massachusetts University of Technology	Neutron Interferometry
Rich, Dennis R.	Indiana University	He-3 Polarization
Schrack, Roald A.	Self	Neutron Cross Section Standards/Data
Schwartz, Robert	Self	Radiation Protection Dosimetry
Snow, Michael	Indiana University	Fundamental Physics
Trabold, Thomas A.	General Motors	Neutron Imaging
Trull, Carroll A.	Tulane University	Fundamental Physics
Werner, Samuel	Self	Neutron interferometer and optics
Wietfeldt, Fred	Harvard University Cambridge, MA	Fundamental physics experiments
Yang, Liang	Harvard University Cambridge, MA	Ultracold neutron research
Yew, Andrew	University of Tennessee	Neutron Radiometry

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Bold: Arrived in 2006