CCRI Activities of the NIST Neutron Interactions and Dosimetry Group

The NIST Neutron Interactions and Dosimetry Group has taken part in the CCRI comparison on neutron emission rate measurements. Our measurements and analysis are complete. M. Scott Dewey has done this work and will send his results to the referee prior to the meeting of Section III in May.

Dr. Dewey is also considering organization of a SIM comparison of neutron survey meter measurements. This possibility will be discussed with SIM participants this summer.

Dr. Alan K. Thompson will lead the NIST participation in the EUROMET 608 exercise.

The planned NIST-led comparison of thermal neutron fluence rate measurements has been postponed much longer than expected. The NIST Neutron Group remains willing to lead and host this comparison. However, since the NIST Group probably will not be able to commit to a firm schedule for this comparison until the next meeting of the Section III (2007), it would be reasonable to consider letting another laboratory take over the lead of this comparison if Section III wishes to avoid further delay in the schedule.

Other Research Activities of the NIST Neutron Interactions and Dosimetry Group

Fundamental Physics Research with Slow Neutrons

1.1 Neutron Physics
1.2 Neutron Interferometry
1.3 Ultra-Cold neutrons
1.4 Polarized ^{3}He Based Neutron Spin Filters

Applied Physics Research for Industry and Homeland Security

2.1 Homeland Security
2.2 Neutron Imaging
2.3 Neutron Calibrations
2.4 Neutron Radiometry
2.5 Neutron Cross-section Standards

Fundamental Physics

1. 1. Neutron Physics

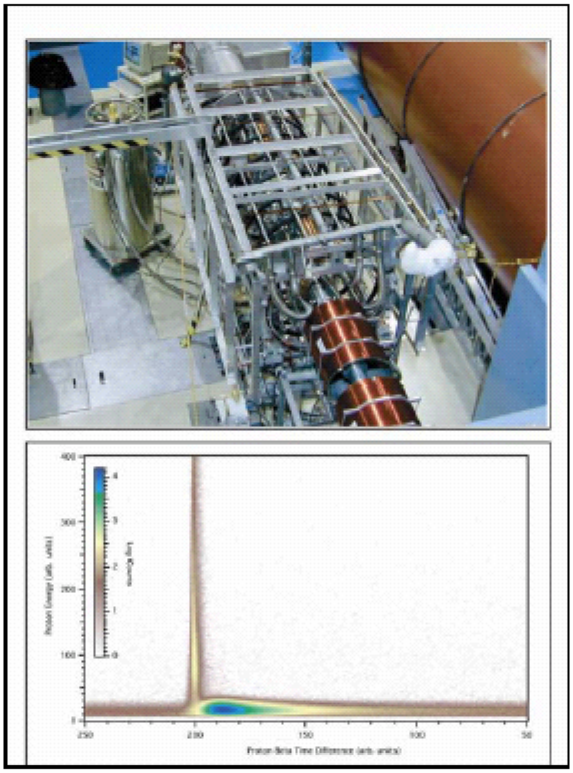


Figure: (Top) The emiT apparatus installed on the end of the NG6 beamline. (Bottom) Histogram of raw proton-electron coincidence data (log scale) showing the peak from neutron decay events. The high signal to background is also readily apparent.

A. Search for Time Reversal Violation in Polarized Neutron Decay (emiT)

Description: The "emiT" experiment recently completed a successful data run on the polychromatic beam NG-6 during 2003. The experiment searches for - or will set an improved upper bound on - the time-reversal asymmetry term in neutron beta decay. It does so by measuring electron-proton coincidence events from the decay of polarized neutrons. An asymmetry in coincidence pairs is formed as a function of the direction of the neutron spin. A measurement of a nonzero asymmetry would be an indication of time-reversal violation. The performance of the detector is dramatically improved over its first run in 1997. The measured electron-proton coincidence rate is a factor of 10 higher than in the first run. In addition, the signal-to-background ratio is two orders of magnitude higher. These improvements were primarily due to better proton detectors, greatly reduced high voltage-induced backgrounds, and improved electronics. Since the experiment is statistics limited, the majority of the running time was devoted to reducing the statistical uncertainty on the asymmetry. A smaller amount of time was spent studying possible systematic effects that may produce false asymmetries. We have collected enough data to improve significantly on the limit from emiT in 1997, presently the most stringent limit in the world. We anticipate the completion of a successful run early in FY04 with a result that is almost a factor of 10 better than the current limit.

Impact: CP violation has been observed so far only in the decays of neutral kaons and B mesons. Recently evidence for the implied T violation in the neutral kaon system has been reported. These effects could be due to the phase in the Standard Model, or these observations could also be due to new physics. It is well established that new sources of CP violation are required by the observed baryon asymmetry of the universe. The emiT experiment searches for CP violation in one such observable, a T-odd correlation in the decay of free neutrons.

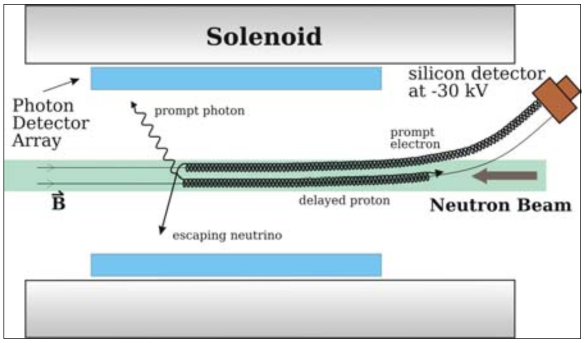
Institutions / people:

NIST - H.P. Mumm, M. S. Dewey, J. S. Nico, and A. K. Thompson
University of Washington, Seattle - A. Garcia, R.G. H. Robertson, and J. F. Wilkerson
University of California at Berkeley - S. J. Freedman, B. K. Fujikawa, and L. J. Lising
University of Michigan - T. E. Chupp, R. L. Cooper, and K. P. Coulter
Tulane University - L. J. Broussard, C. A. Trull and F. E. Wietfeldt
Hamilton College - G. L. Jones

Current Projects

A. Measuring the Radiative Decay Mode of the Neutron

Description: 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 is currently being developed for the NG-6 fundamental physics end station. The experiment will make use of the existing apparatus for the NIST proton-trap lifetime experiment, which can provide substantial background reduction by providing an electron-proton coincidence trigger. The need for a large solid-angle gamma ray detector that can operate in a strong magnetic field and at low temperature has led us to consider scintillating crystals in conjunction with avalanche photodiodes. Tests and design of a detector for gamma-rays in the 10 keV -200 keV range are in progress. We hope to definitively detect and measure the spectrum in 2005.



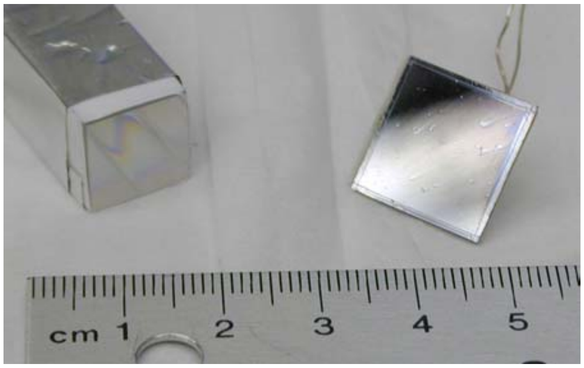


Figure: *(TOP) A schematic diagram of the radiative decay experiment showing the delayed electron-proton coincidence and the photon detector array. (BOTTOM) A photograph of a BGO crystal and an avalanche photodiode, 12 of each which will make up the photon detector array.*

Impact: Like all elementary particle decays to charged particles in the final state, the beta-decay of the free neutron has a radiative mode: n -> p + e + antineutrino + photon. In spite of decades of detailed experimental studies of neutron beta-decay (including very precise measurements of the neutron lifetime and beta-decay correlation coefficients), this rare decay branch has never been observed, while it has been extensively investigated in more exotic systems. Recently, theoretical investigations of this process have been underway in both US and Russia. Their predictions show that the radiative decay mode of the neutron, while a rare process, should be observable in the laboratory. Indeed, a recent experiment attempting to measure this branching ratio was been performed at Institut Laue-Langevin (ILL) in Grenoble, France. Due to experimental difficulties that produced very large backgrounds, this decay mode was not seen, and the result published was an upper limit.

Institutions / people:

Tulane University - B. M. Fisher and F. E. Wietfeldt,
NIST -M. S. Dewey, T. R. Gentile, J. S. Nico, A. K. Thompson and K. J. Coakley
University of Maryland, College Park - E. J. Beise and K. G. Kiriluk
University of Sussex, UK - J. Byrne

1.2 Neutron Interferometry

A. Reciprocal encoding of spatial information for neutron imaging

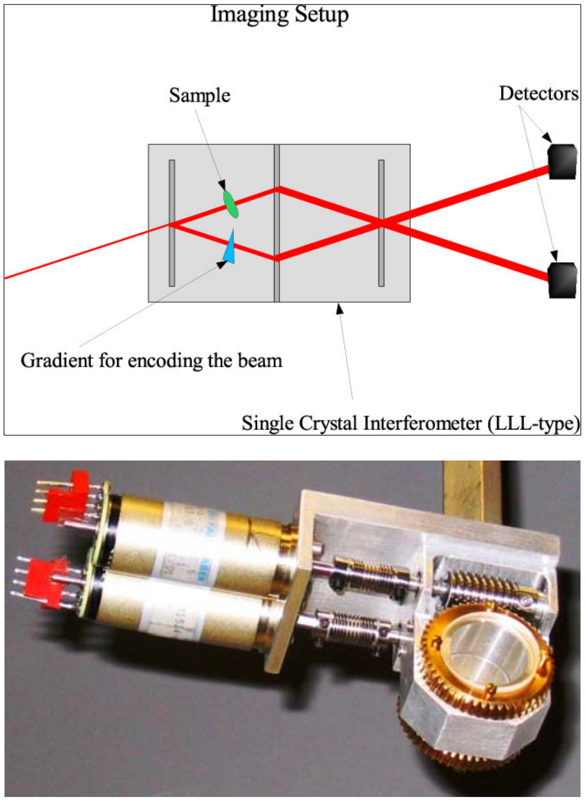


Figure: (Top) Schematic diagram of the reciprocal space neutron imaging setup. The neutron beam enters into interferometer from left, slits by the first blade, passes through the sample and phase gradient region, recombines and interfere on the third blade and comes to the neutron detectors.(Bottom) Image of the wedge assembly setup.

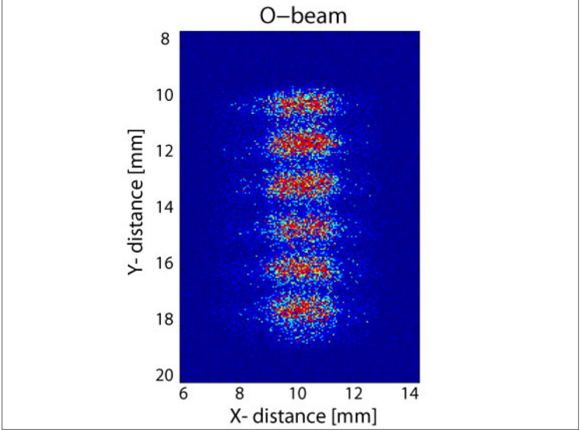
Description: The experimental setup is based on a Single Crystal Neutron Interferometer where one of the interfering paths includes the sample and the other is partially encoded with a gradient in the neutron phase. This experiment implements a spatial encoding similar to that used in Nuclear Magnetic Resonance (NMR) imaging and Neutron Fourier Spectroscopy. Spatial information is encoded in the phase of neutrons. Fourier components are directly measured:

$$I(\vec{k}) = \int P(x,y)e^{i\vec{k}\vec{r}}d^2\vec{r}\,.$$

Where *P(x,y)* is the scattering function of the sample. The real space image can be reconstructed via Fourier transform:

$$P(x,y) = \int I(\vec{k})e^{-i\vec{k}\vec{r}}d^2\vec{k}$$

Impact: The idea of experiment is to overcome the limitation of spatial resolution of present neutron detectors. There have been other experimental setups for neutron imaging. The image resolution of these depends on the spatial resolution of the neutron detectors. In modern days such detectors have demonstrated a resolution of 25 *μm*. The proposed method allows one to improve spatial resolution in principle up to Rayleigh limit which in our case may be of the order of several Ängstroms. In practice the resolution will be limited by signal to noise constraint. Therefore, one can improve in study density fluctuation due to inhomogeneities caused by hydrogen in metals, density of polymeric overlayers, formation of water in hydrogen fuel cells, crystallography for structural biology, tomography of magnetic domains and so on.



Picture of the interference produced by coded beam with a reference beam during reciprocal imaging experiment.

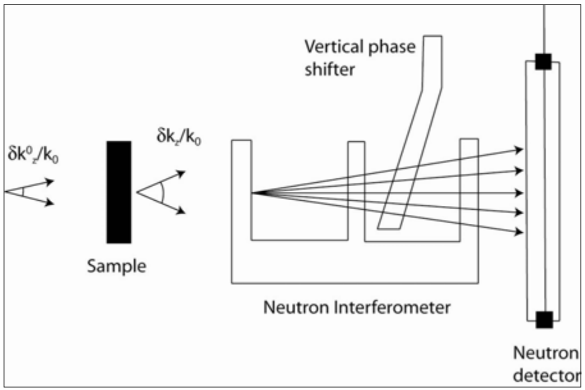


Figure: Schematic diagram of the neutron Fourier spectroscopy setup.

B. Neutron Fourier Spectroscopy

Description: In the neutron interferometry the phase of the neutron wave is an observable which is influenced by any momentum and energy change that the beam experienced during interaction with the sample. The phase shift is measured by coherent superposition of the affected with reference (undisturbed) beam. A sample placed in front of the interferometer changes the momentum distribution ($g(\mathbf{k}) \rightarrow g_s(\mathbf{k})$), which is convolution of the resolution function with the scattering function ($S(\mathbf{Q})$) . The scattering function is the Fourier transformof the normalized scattering-length density in he sample.

Impact: Small-angle scattering phenomena and structural investigations can profit from this new technique. Also a very interesting application can be a direct measurement of the surface profile in neutron reflectometry.

Institutions / people:

NIST - M. Arif, David L. Jacobson
MIT - D. Cory, D. Pushin, C. Do
Tulane University – F. Wietfeldt, M. Huber
Indiana University – Helmut Kaiser

1.3. Ultra-Cold Neutrons

A. Magnetically Trapped Neutron Lifetime Experiment

Description: This experimental program is designed to substantially improve the measurement of the neutron lifetime τ_n using a technique with completely different systematic effects 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. 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 allow a measurement of the neutron lifetime at the 10^{-3} level.

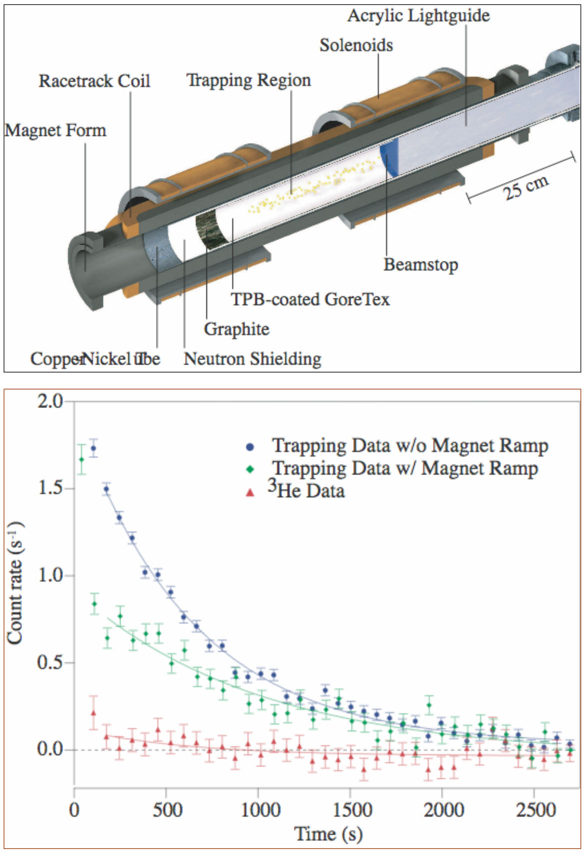


Figure: (Top) Ultracold neutron trap.(Bottom) Data from neutron lifetime determination runs. The upper curve is a normal trapping run. The middle curve represents data taken by ramping the trap magnet to remove marginally trapped neutrons. The lower curve represents data taken with natural helium in the trapping region where one would expect no trapped neutrons.

Impact: 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 currently planned experiments, will improve determinations of the V_{ud} element of the quark mixing matrix and allow stricter tests of unitarity. Because the isotopic purity of the ^{4}He is critical to the success of this experiment, we are also 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.

Institution / people

Harvard University -J. Olson, L. Yang, and J. M. Doyle -
North Carolina State University -P. Huffman, R. Golub and E. Korobkina
NIST -P. Mumm, A. K. Thompson, K. J. Coakley
Los Alamos National Laboratory -S. K. Lamoreaux -

1.4. Polarized ^{3}He based neutron spin filters

A. An in-situ compact ^{3}He based neutron polarizer

Description: A ^{3}He spin filter was employed as a continuously operating compact neutron polarizer to polarize thermal neutrons on the Single Crystal Diffractometer at the Intense Pulsed Neutron Source (IPNS) at Argonne National Laboratory.

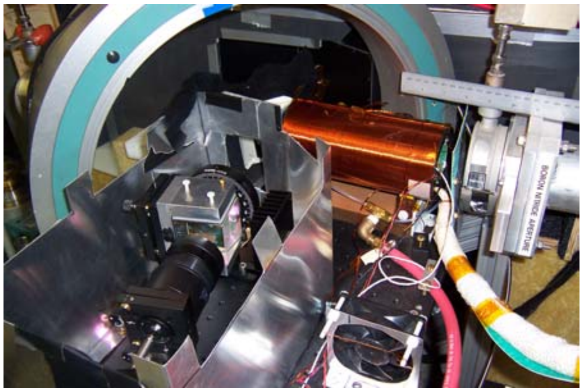


Figure: In-situ compact 3He polarizer at the IPNS (at the Argonne National Laboratory) Single crystal diffractometer

Impact: This work was the first demonstration of a continuously operating neutron polarizer for neutron scattering.

List of institutions / people:
NIST - T.R. Gentile, W.C. Chen
Hamilton College - G.L. Jones and students
Argonne National Laboratory - A.J. Schultz, T. Koetzle
Spallation Neutron Source – W.T. Lee, C. Hoffmann

B. Studies of the current limits of spin-exchange optical pumping

Description: Following the implementation of spectrally narrowed lasers, we now routinely obtain record high values of ^{3}He polarization (75%), which substantially improves the efficiency of ^{3}He spin filters. However, in collaboration with the Univ. of Wisconsin, we have shown that this apparent limit is not consistent with the traditional theory of spin-exchange optical pumping, but rather is due to an unexplained form of temperature-dependent relaxation that varies from cell to cell.

Impact: After nearly 45 years since its first demonstration and 20 years of focused development, the dominant mechanism limiting the ^{3}He polarization for spin-exchange has finally been identified. The observation of a form of relaxation that scales with alkali density was completely unexpected. This results points the direction for what needs to be understood and eliminated to make further improvement.

Institutions / people:

NIST -T.R. Gentile, W.C. Chen
Univ. of Wisconsin at Madison, Madison, Wisconsin - T.G. Walker, E. Babcock

C. Development of diffuse reflectometry on the NCNR Advanced Neutron Diffractometer / Reflectometer (AND/R)

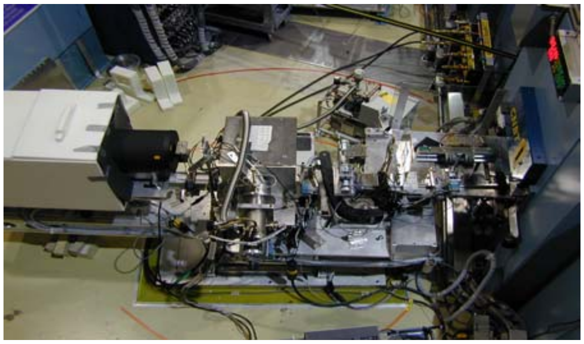


Figure: Diffuse refelectometry with a ^{3}He analyzer and a position sensitive detector at the NCNR AND/R reflectometer

Description: The NCNR has recently commissioned a new instrument, AND/R, that is equipped with a position sensitive detector (PSD). A PSD is needed to make use of the full solid angle coverage of a ^{3}He spin filter. With our NCNR collaborators, we recently set up a polarized beam option on AND/R and used a new ^{3}He spin filter analyzer for preliminary studies of a magnetic film samples. In this work, we obtained record high ^{3}He polarization values (76%) and relaxation times on the beam line (260 hours), which have captured the interest of NCNR staff for further applications. In the near future, we will employ 3he spin filters for experiments in diffuse reflectometry on AND/R.

Impact: Neutron scatterers can now consider consider polarization analysis for diffuse reflectometry to be an available tool for the study of magnetic materials. In collaboration with MSEL, we have plans to study several materials.

List of institutions / people:

NIST - T.R. Gentile, W.C. Chen, J.A. Borchers, C.F. Majkrzak, K.V. O'Donovan, P. Mangin

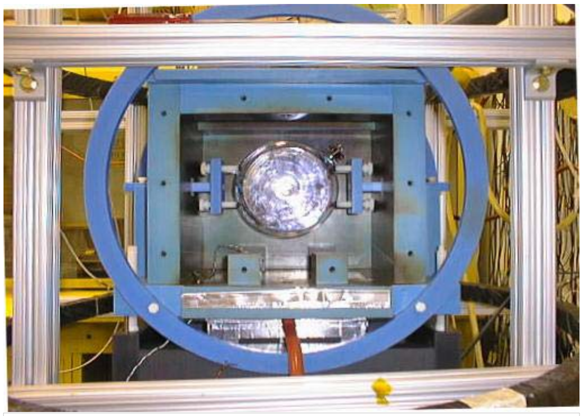


Figure: A large are ^{3}He spin filter for the "npdγ" experiment at the Los Alamos Neutron scattering center.

D. A ^{3}He polarizer for the "npdγ" experiment

Description: An experiment to measure the parity violating asymmetry in the emission of gamma rays from the absorption of neutrons by hydrogen has recently been commissioned at the Los Alamos Neutron Science Center. There has been recent controversy regarding the value of "H_π", one of the fundamental parameters of the weak interaction between nucleons. The value extracted from a recent atomic physics determination is in conflict with an earlier value that is based on an earlier value determined in a nuclear system. In the "npdγ" experiment, this parameter will be directly measured in the neutron system, which allows for a direct measurement free of nuclear effects. The ^{3}He polarizer for this experiment , which operated successfully for several weeks during the commissioning run, employs unique, large area, long lifetime cells that were developed, fabricated and tested at NIST. In the next year, we will contribute to the improvement of the polarizer and its operation.

Impact: This experiment will the first fundamental neutron physics experiment to employ a continuously operating polarized ^{3}He spin filter. The success of this device will affect the future program of fundamental neutron physics at the NCNR and the upcoming Spallation Neutron Source. The success of the "npdγ" experiment will increase our knowledge of the force between nucleons.

Institutions / people:

NIST -T.R. Gentile, W.C. Chen
The npdγ collaboration - J.D. Bowman (spokesman), S. Penttila (project leader), T.E. Chupp (3He polarizer subsystem leader), and others

E. Efficient production of highly polarized ^{3}He gas using hybrid SEOP

Description: For traditional SEOP with rubidium, the laser power demands are large and present issues for scaling to higher gas production, and the relaxation time requirement puts constraints on the fabrication of the polarized gas storage vessels. In principle the use of other alkalis could substantially increase the optical pumping rate, but atomic structure, laser availability, and temperature requirements are issues for practical application. Recently a hybrid scheme that employs mixtures of rubidium with either potassium or sodium has been demonstrated at the Univ. of Wisconsin. We have recently fabricated our first hybrid cells. In collaboration with Wisconsin, we will investigate the utility of hybrid SEOP for practical application to neutron spin filters. We also plan to spectrally narrow a new laser to test SEOP with pure potassium. An unanticipated observation in our first cells containing sodium is the possibility that a heat treatment with sodium may allow for improved relaxation times.

Impact: Successful demonstration of hybrid SEOP will allow high ^{3}He polarization under conditions in which relaxation mechanisms cannot be avoided, and high volume production of polarized ^{3}He for large spin filters and other applications. In addition, the use of other alkalis will explore new regimes, which could have unanticipated results in the study of both traditional room-temperature and temperature-dependent relaxation.

Institutions / people:

NIST -T.R. Gentile, W.C. Chen
Univ. of Wisconsin at Madison, Madison, Wisconsin - T.G. Walker, E. Babcock

Applied Physics

2.1. Homeland Security

A. Calibrated Neutron Sources

Description: ANSI N42.35 requires Cf-252 neutron sources encapsulated in 1 cm of steel with a fluence of 2E4 n/s ±20%. NIST designed a compliant source. NIST acquired, calibrated and delivered several such sources for DOE laboratories. They were used to evaluate potential neutron detectors for Homeland Security. Additional sources will be supplied as needed.

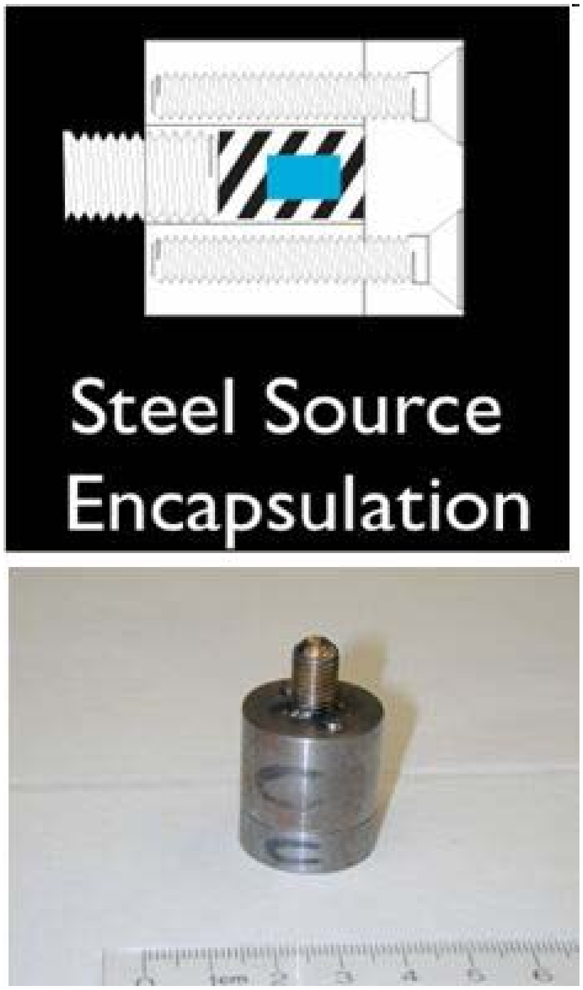


Figure. Neutron Sources for Homeland Security. Californium-252 sources spontaneously emit fission neutrons. These sources were embedded in a 1-cm thick steel shell. This has the effect of suppressing gamma rays and providing a rugged container for field use.

Impact: Calibrated sources were delivered for the DOE laboratories to perform equipment testing as required by ANSI standards.

List of institutions/people:
NIST – David M. Gilliam, Alan K. Thompson and Maynard S. Dewey

B. Neutron Detectors

Description: DHS has solicited research and development programs for better methods of detecting Special Nuclear Material. Potential respondents requested a list of existing detectors. DHS, in turn, request NIST to supply such a list. This list was supplied to DHS.

Impact: A list of existing neutron detectors allows DHS to better match existing detector capabilities versus their requirements. It allows potential developers to avoid duplication of existing systems.

Institutions/people:

NIST: Alan K.Thompson, David M. Gilliam

B. ANSI standard support

Description: One of Homeland Security's immediate priorities was the development of a set of ANSI standards for radiation detectors. Four standards were developed: N42.32, *Performance Criteria for Alarming Personal radiation Detectors for Homeland Security*, N42.33, *Portable Radiation Detection Instrumentation for Homeland Security*, N42.34, *Performance Criteria for Hand-held Instruments for the Detection and Identification of Radionuclides*, and N42.34, *Evaluation and Performance of Radiation Detection Portal Monitors for Use in Homeland Security.* Each standard was reviewed to ensure that it met DHS requirements in the detection of neutrons. Each standard was also reviewed to ensure that NIST was capable of supporting calibration efforts required by the standard. NIST continues to review these standards in light of its own and user experience.

Impact: Four ANSI standards were published in a timely manner.

Institutions/people:

NIST – Alan K. Thompson, David M. Gilliam

C. New Manganese Sulfate Bath

Description: Many neutron sources required by Homeland Security have a lower neutron emission rate than is appropriate for the NIST calibration facility, a Manganese Sulfate Bath system. The Manganese Sulfate Bath uses a sphere of neutron-absorbing material which surrounds a neutron source. The induced radioactivity is a measure of the neutron source strength. The lower intensity of the DHS sources provides less manganese activation, resulting in a reduced signal over background. NIST developed a smaller bath so that more of the manganese is close to the source and therefore induces higher manganese activity. Unfortunately, the smaller bath also has a higher neutron leakage. The fraction of neutron leaking from the sphere depends on the neutron spectrum. NIST uses the new bath only as a means to compare one Californium source against another so that the spectrum remains constant. High-fluence Californium sources calibrated in the existing Manganese Sulfate Bath will be used to calibrate the new bath.

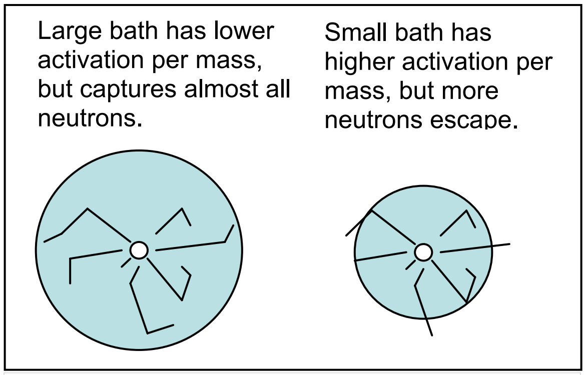


Figure. The Manganese Sulfate Bath in use at NIST was designed for intense sources. The low-level sources required for Homeland Security provide a much reduced activation. NIST designed a developed a smaller Bath specifically for Homeland Security Sources

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Impact: The tight neutron fluence specification required by ANSI standards requires new sources approximately every nine moths. A new calibration facility is required to meet the demand.

Institutions/people:

NIST - David M. Gilliam /Maynard S. Dewey

D. Active Interrogation Standards

Description: Active interrogation involves directing nuclear radiation into an object and measuring reaction products to gain information about the material composition of the object. 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 is currently possible. It also holds the promise of detection on non-nuclear materials, such as hazardous chemicals and explosives. NIST has the lead for developing a new standard: ANSI STANDARD N42.41 - Evaluation and Performance of Active Interrogation Systems for Detection of Threat Substances of Concern in Homeland Security.

Figure: *A car passing a neutron/gamma detection portal at the Illicit Traffiking Radiation Assessment Program (ITRAP). The International Atomic Energy Agency (IAEA) conducts tests of radiation detectors at border areas.*

Impact: Active interrogation is a highly active area of research and development. The selection of correct techniques for further development, and, ultimately, the selection of appropriate systems, requires a consistent set of standards for comparing the various techniques.

Institutions/people:

NIST - David M. Gilliam

E. Neutron Detection Standard

Description: 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: *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.

Impact: Neutron detectors are being developed for Homeland Security. The new standard will provide specific criteria to ensure that new detectors meet DHS needs.

Institutions/people:

NIST - Alan K. Thompson

F. Neutron Background Reduction

Description: Cosmic ray showers are initiated by high-energy particles entering the earth's atmosphere. A single initiator particle collides with a nucleus in the air, generating secondaries. These secondaries in turn collide with other nuclei, and so on, to produce a cascade of particles at ground level. Ultimately, neutrons detected at ground level are in coincidence with the other cascade particles. NIST is investigating using anti-coincidence techniques to separate neutrons which come from a cosmic ray cascade from neutrons emitted from a contraband source.

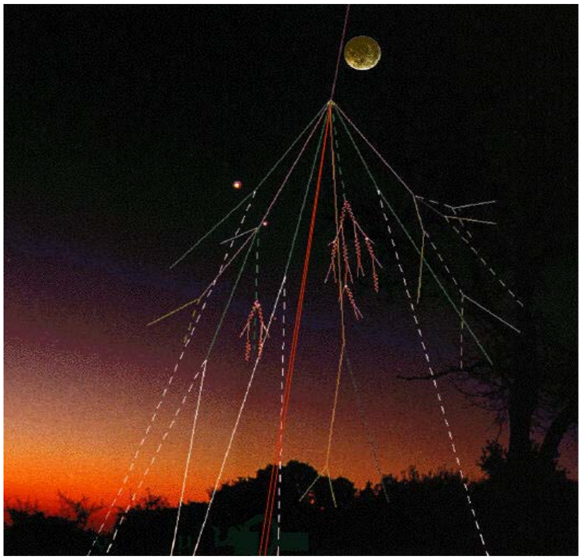

Figure: A high-energy cosmic ray scatters of nuclei in the air. The secondaries, in turn, collide with other nuclei. The net result can be a cosmic ray shower of particles arriving together at the surface of the earth.

Impact: Allow detection of Special Nuclear Material with lower background and fewer false positives.

Institutions/people:

NIST - Craig. R. Heimbach, Alan K. Thompson

G. COTS and GOTS Evaluation of Neutron Spectrometers

Figure: Rotating Spectrometer (ROSPEC). ROSPEC combines several neutron detectors into a single system to measure the neutron spectrum from thermal neutron energy to 18 MeV. The detectors rotate so that all detector sample the same volume.

Description: It is highly desirable to be able to discriminate neutrons emitted from contraband sources from neutrons emitted from legitimate sources and from background. Also, the neutron spectra emitted from contraband will depend on its shielding. A terrorist may attempt to shield a source with various materials in order to escape detection. NIST is evaluating the abilities of Commercial Off-The-Shelf (COTS) and Government Off-The-Shelf (GOTS) neutron spectrometers to distinguish Special Nuclear Material in a background of thermal and high-energy neutrons. These detectors will have the additional benefit of providing better information on NIST standard neutron fields.

Impact: Determine the ability of current techniques to locate special nuclear material. This material may either be unshielded, in containers, or with shields designed to disguise the nature of the material.

List of institutions/people:

NIST – C. R. Heimbach

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H. High-efficiency Neutron Spectrometer

Description: The detection of low neutron fluence requires a highly efficient detector. NIST 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 ev ents. A major difficulty in the development is the ability to add a thermal-neutron detection agent, such as boron or lithium, to the scintillator while maintaining transparency to light.

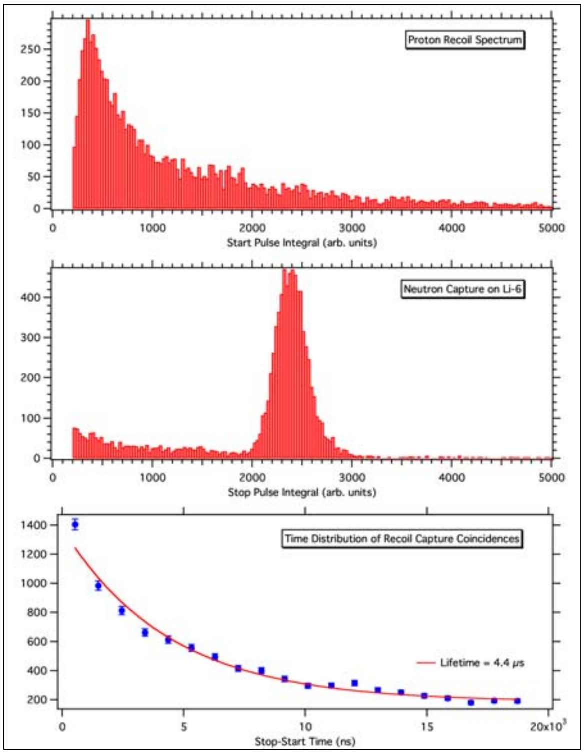

Figure: Spectra from fast-neutron spectrometry in "pulse height mode". The top plot is a histogram of proton recoil (start) pulses, the middle plot is a histogram of ^{6}Li capture (stop) pulses. This delayed coincidence is a very good method for background rejection – only neutron whose energy is totally absorbed in the scintilator.

Impact: Make it easier to detect low levels of neutrons from Special Nuclear Material.

Institutions /people :

NIST : Nico, J.S.
Tulane University: Fisher, B.

I. ASTM Committee on Homeland Security

Description: ASTM has initiated a new committee to develop standards related to Homeland Security. Ionizing Radiation personnel are members of two subcommittees: *Chemical, Biological, Radiological, Nuclear, and Explosive (CBRNE) Sensors & Detectors*, and *Decontamination*. The first order of business was to review existing standards and identify gaps. Standards under development include detector requirements for chemical warfare detectors, a method to evaluate biological decontamination agents, procedures to control a contaminated site, and others.

Impact: Standards will ensure adequacy of response to an incident and ensure that all participants in the response have a common set of expectations.

List of institutions/people:

NIST - C. R. Heimbach, D. M. Gilliam

2.2. Neutron Imaging

A. New Imaging Station for Fuel Cell Research

Description: The Neutron Imaging Facility (Figure1) started full time operation in 2003 at Beam Tube 6 (BT-6) at the NIST Center for Neutron Research (NCNR). The facility has a r extremely high fluence rates of 1.8×10^7 cm^{-2} s^{-1} uniformly spread over a 26 cm diameter area with an L/d ratio of 300. This is one of the most advanced neutron imaging facility in the world and is the best of its kind in the USA. Currently this facility has been hosting experiments from industrial fuel cell developers who are interested in looking at the distribution of water in operational fuel cell systems using standard fuel cell hardware. We have pioneered non-destructive imaging technique to map critically important hydrogen and water motion in operating fuel cells. First generation neutron experiments with a major industrial partner shows exciting promise of robust/efficient fuel cell design, substantial reduction in fuel-cell development time and establishment of uniform characterization/performance standards.

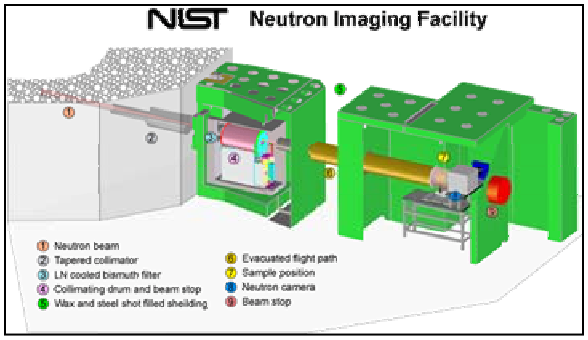

Figure: New neutron imaging station for fuel cell research at the BT-6 beam line at the NCNR

Impact: Allows industrial/academic research to study performance and design of PEM fuel cells. This is the only facility of its kind in the world dedicated primarily to study of fuel cells.

Institution/people:

NIST - M. Arif, D.L. Jacobson, P.R. Hu_man, R.E. Williams, J.C. Cook, I. Schroder, D.S. Hussey

B. Imaging of water transport inside operating fuel cells

Description: Neutron imaging has demonstrated that it is the method of choice for understanding the water management in an operational fuel cell, in situ. As a result, the

NIST Neutron Imaging Facility is being utilized by several industrial users predominantly performing proprietary research. We strive to provide our users with the best possible images by maintaining a world-class facility, pursuing detector development, investigating new imaging methods, and providing any necessary technical support. At the NIF fuel cell researchers can measure laminar water thickness ~0.01 mm, with a spatial resolution of ~0.1 mm at a frequency of 1-0.1 Hz. These capabilities have led to new understanding about the water dynamics of the cathode side of the PEMFC. With a our recent detector upgrade, the time resolution will improve to 30-7.5 Hz, while maintain the high 0.1 mm spatial resolution.

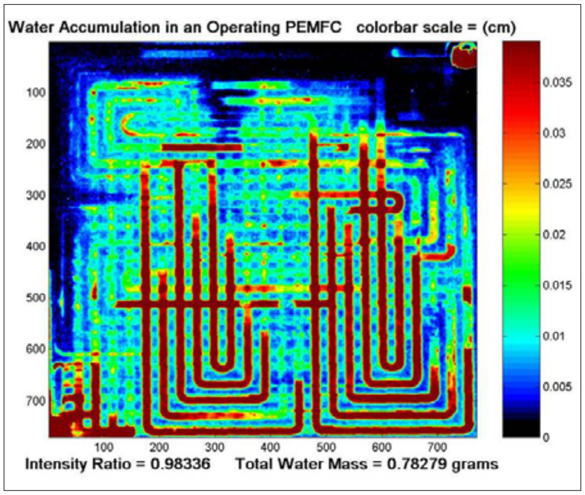

Figure: Neutron image of water distribution inside an operating fuel cell.

Impact: Neutron imaging is the tool for understanding water management issues in PEMFC, and the NIST NIF provides users with the best imaging facility in the world.

Institution / people:

NIST -D.L. Jacobson, M. Arif, D.S. Hussey

C. Coded Source Imaging

Description: In coded source imaging, one uses an array of pinhole, arranged in a specific pattern to illuminate an object. A reconstructed image is obtained by correlating the resulting encoded intensity with a decoding array. We have constructed a coded mask from a 100 m Gd foil with 0.5 mm diameter pinholes based on a MURA pattern. We are currently testing the reconstruction of a coded image using visible to simulate neutrons while the NIST reactor is shutdown. We anticipate taking our first neutron coded source images by the end of2004.

Impact: Coded source imaging may open up the possibility for many new neutron imaging experiments, including phase imaging and acquiring 3 dimensional images from one 2 dimensional image.

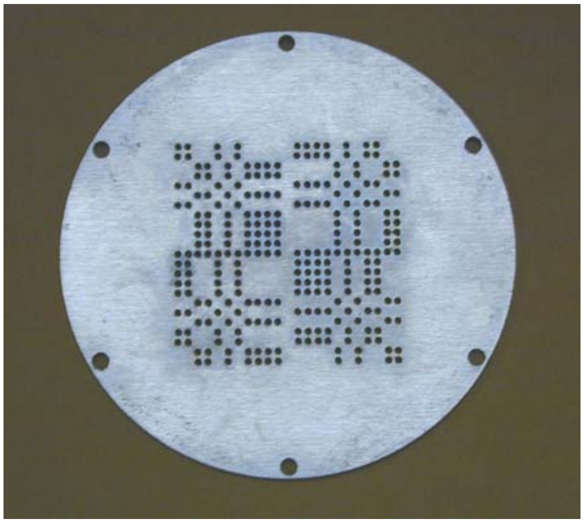

Figure: Photograph of a coded source

Institution/People:

NIST - D.S. Hussey, M. Arif, D.L. Jacobson

D. Permeability of the catalyst and gas difusion layers of proton exchange membrane fuel cells

Description: In order to improve the current understanding of the water management in PEM fuel cells, the permeability of the gas difusion layer (GDL) and the catalyst layer must be measured. Current water transport calculations use permeabilities obtained in rock samples. Using neutron imaging, we will measure the water density along the height of a sample mounted vertically in a water reservoir. Since gravity will balance the capillary force, the permeability can be directly obtained from the water distribution along the height of the sample.

Impact: These permeability measurements will improve numerical models of the operation of the proton exchange membrane fuel cell.

NIST -D.L. Jacobson, D.S. Hussey
University of Kansas -T.V. Nguyen

2.3. Neutron Calibrations

A. Neutron Source Strength Calibrations

Description: We operate a facility to calibrate the neutron emission rate of radioisotope neutron sources. Allowable rates range from 5×10^5 s^{-1} to 1×10^{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.

Figure: Picture of the Mn Bath

Impact: During the past year 4 vendor neutron sources were calibrated, 3 Department of Homeland Security neutron sources were calibrated, and an international round robin neutron source was calibrated. In support of these measurements, our own standard neutron sources (NBS–1, BIPM) were measured several times.

Instinution/People:

NIST -M. S. Dewey, C. Heimbach, D. M. Gilliam

B. Neutron device calibrations

Description: NIST provides the national reference for the calibration of neutron radiation detectors and for neutron personnel dosimeters. The reference sources are bare Californium-252 and Californium-252 moderated with a D_2O sphere. The spontaneous fission neutron spectrum of bare Cf-252 has been extensively studied and is known well enough to have achieved “benchmark” status. The moderated spectrum, with an abundance of low and intermediate energy neutrons, is more characteristic of reactor working environments and is often preferred for that reason. Some personnel dosimeters are sensitive to neutrons scattered off the person wearing the dosimeter, so that a frequent exposure configuration has dosimeters adjacent to an acrylic phantom. In all exposure geometries, corrections are made for air scatter and room return. NIST periodically compares its standard field to those of other national standards laboratories.

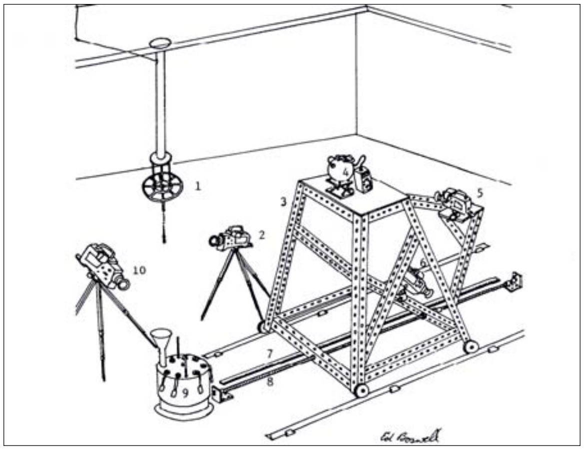

Figure. Simplified view of the low scatter neutron calibration facility

Impact: NIST provides the neutron reference calibrations to ensure the safety of the public and of radiation workers throughout the United States.

List of institutions/people: *NIST:* Alan K. Thompson
PTB, NP

2.4. Neutron Radiometry

A. Neutron Radiometer for High Accuracy Fluence Measurement

Description: Neutron fluence is measured by measuring the heat of reaction in an absorbing target. The target materials are liquid ^{3}He or ^{6}Li in a LiMg alloy. Reactions are $\mathrm{n+{}^3He \rightarrow p+{}^3H + 764\,keV}$ in ^{3}He or $\mathrm{n+{}^6Li \rightarrow {}^4He+{}^3He + 4783\,keV}$ in ^{6}Li. The heat measurement is made in an electrical substitution radiometer (Fig. 1). The target is attached by a weak thermal link to a heat sink, and the temperature of the target and the heat sink are separately controlled with feedback loops controlling electrical heaters. The beam is cycled on and off with a half-cycle period from ten to thirty minutes sufficient to allow the target to reach a steady state after each change. The heater power required to control the target in each state is measured. The difference in heater powers gives the reaction energy, and when divided by the energy per reaction, the neutron fluence.

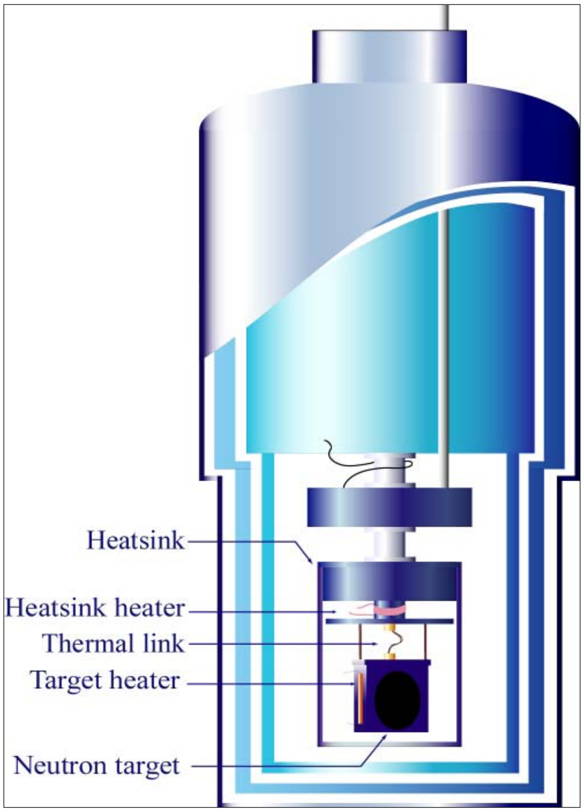

Figure: The neutron radiometer

Impact: 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 significantly reduce the uncertainty on our beam-type lifetime measurement. 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.

Institution / People:
Indiana University: G. L. Hansen, Z. Chowdhuri, V. Jane, C. D. Keith, W. M. Lozowski, and W. M. Snow
NIST: M. S. Dewey, D. M. Gilliam, G. L. Greene, J. S. Nico, and A. K. Thompson
Tulane University: F. E. Wietfeldt

2.5. Neutron Cross-section Standards

Decription: The major standards activity at this time is work on the new international evaluation of the neutron cross section standards. The new evaluation will include the H(n,n), ^{3}He(n,p), ^{6}Li(n,t), ^{10}B(n,α), ^{10}B(n,α_1K), C(n,n), Au(n,Ḳ), ^{235}U(n,f), and ^{238}U(n,f) cross sections. The evaluation is 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 a major leadership role in each of these activities. Participants in the evaluation process are from Austria, Belgium, China, France, Germany, Japan, Russia, South Korea, and the U.S.A. The evaluation will result from the combining of R-matrix and generalized least squares evaluation procedures. A suitable combining procedure has recently been determined. Many types of data are being used in the 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 is being used to generate covariance-variance matrices for use in the evaluation. Comparisons are now being made of several independent least squares codes and several independent R-matrix codes. The comparisons include not only the output cross sections but also the uncertainties and covariances of the results. The objective is to provide standards with well defined uncertainties which can be used for the major international cross section evaluation projects in time for use in their new versions. The major portion of the evaluation effort has been completed with approximately another year being required to finish the effort. Cross section evaluations for the most important standards were recently provided for the new version of the U.S. evaluation library, ENDF/B-VII.

In addition to the evaluation effort, NIST maintains a limited experimental effort focused on improvements to the important standards. NIST collaborations have recently produced ^{3}He total neutron cross section data, measurements of coherent neutron scattering lengths of hydrogen and ^{3}He, and a determination of the ^{6}Li(n,t) cross section at a sub-thermal energy. Also an NIST-Ohio University-LANL collaborative experiment is now underway on measurements of the important hydrogen scattering angular distribution standard at 15 MeV neutron energy. The experiment is being done at the Ohio University accelerator. Also measurements to improve low energy cross sections are planned at the NIST monochromatic beam facility on NG6. (A.D. Carlson, P.R. Huffman)