The Reactor and Cold Neutron Research Facility at NIST

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ABSTRACT

The NIST Reactor (NBSR) is a 20 MW research reactor located at the Gaithersburg, MD site, and has been in operation since 1969. It services 26 thermal neutron facilities which are used for materials science, chemical analysis, nondestructive evaluation, neutron standards work, and irradiations. In 1987 the Department of Commerce and NIST began development of the CNRF--a $30M National Facility for cold neutron research--which will provide fifteen new experimental stations with capabilities currently unavailable in this country. As of May 1992, four of the planned seven guides and a cold port were installed, eight cold neutron experimental stations were operational, and the Call for Proposals for the second cycle of formally-reviewed guest-researcher experiments had been sent out. Some details of the performance of instrumentation are described, along with the proposed design of the new hydrogen cold source which will replace the present D_2O/H_2O ice cold source.

Introduction

Since the last IGORR meeting, progress on several fronts has continued at the NIST Reactor. This includes the installation of new instruments, near completion of other instruments, the initial use of the Cold Neutron Research Facility (CNRF) as a National Facility, and some positive and negative facilities developments. These, with some performance measurements, are described in this paper. Complete details for each instrument are given in Ref. [1], and in a set of review articles soon to be published [2].

Facilities Developments

Cold Ports

Guide Performance. The neutron guides are straight tubes of rectangular cross-section (either 120 by 50 or 150 by 60 mm^2), made from boron containing glass, polished on the inside to an rms surface roughness of 2 nm and a flatness equivalent to 10^{-4} radians, coated with approximately 80 nm of ^{58}Ni, and evacuated most of their length. The guides are manufactured commercially by Cilas-Alcatel[1]. In order to maintain the integrity of the reactor building containment, a "shutter"--which closes automatically by gravity whenever the reactor is shut down, providing a complete seal of the building--is inserted at the wall for each guide. These shutters also serve to interrupt the neutron

[1] Name brands or company names are given for purposes of clarity and do not imply an endorsement by NIST.

beams when desired, so that work can be performed in the experimental hall while the reactor is operating. The first four guides and a cold "port" (in the confinement building) have now been installed as shown in Figure 1. Overall, the performance of the guides has met expectations--typically 15% intensity loss at 40 m distance from the source. Measured fluence rates at certain instruments are provided later in the text.

For several years, coatings with larger critical angles have been sought, and in fact so-called super-mirrors have been developed which consist of many layers of materials with different neutron properties, arranged in a particular sequence. Researchers at NIST, in collaboration with Oak Ridge and Brookhaven National Laboratories, and with two small industrial firms, have recently demonstrated that these devices can be made with the requisite reflectivity for use in guides, at least on the laboratory scale [3]. Use of these coatings is planned for at least the tops and bottoms of the three remaining guides.

Guide Failure. It has been known for some time, as a result of observations at the Institut Laue Langevin, that the borosilicate glass used in normal neutron guides suffers radiation damage in a thermal or cold neutron field, primarily as a result of neutron capture in boron, followed by emission of an alpha particle. Accordingly, the first section of guides in the CNRF installation, which is almost wholly within the reactor biological shield, is made of non-borated glass, and is not evacuated, but rather is both filled with and surrounded by helium gas at one atmosphere (the helium filled section is indicated by dashed cross-hatching in Figure 2). However, the downstream guides are made of borosilicate glass, and were evacuated since their installation in 1990.

This design was chosen after discussions with the vendor, based upon experience at the Saclay reactor, which has fluence rates comparable to the NIST reactor. The installation at Saclay had successfully operated for more than six years when the NIST design was first begun. In approximately September of 1991, it was learned that the Saclay guide installation had suffered two successive guide implosions, presumably as a result of radiation damage, after more than 8 years of continuous operation. Upon receipt of this information, a plan was made to add an additional aluminum window in the guides at 5 m further out ("removable sections" of Fig. 2) in February, 1992, so as to allow filling of this section with helium, thereby removing the stress from them. However, before this could be done, the first element in NG-6 failed on December 1, 1991, in the area shown in the insert in Figure 2.

It appears from the reconstruction of the occurrence, using fragments recovered from the floor beneath the failed section, that one of the side plates failed over a 25 cm length. Based upon all previous experience, and the known total neutron fluence on this section, this failure occurred at a fluence five to ten times less than should have been expected. Preliminary analysis indicates that there may have been a defect in the glass, perhaps as a result of faulty annealing.

When the side plate failed, air entered the guide at high velocity, and carried about 700 g of glass consisting of particles ranging in size from dust to 1 cm radius, down the 80 m length of the guide into the guide hall. There was no release of radioactivity, no effect on the reactor, no personnel were endangered, and no compromise of reactor safety resulted from this occurrence. The NBSR resumed operation in April after modification of NG-5, 6, and 7 for He filling in the 5 m sections indicated.

Cold Sources

A schematic diagram of the existing cold neutron source is shown in Figure 2, with the neutron guides installed (for scaling, the O.D. of the D_2O Ice Moderator is 34 cm). The main components are the lead/bismuth shield lining the beam port (required to reduce γ-ray heating in the moderator), a cryostat containing the D_2O ice (which is surrounded by an insulating vacuum and a helium blanket), and the cooling tubes (which carry helium gas at 30 - 40 K to cool the source). The other main component (which is not shown) is a helium gas refrigerator which supplies 1.0 KW of cooling at a helium mass flow rate of 28 g/s. The cryostat is fabricated of a magnesium alloy (AZ31B), in order to reduce the heat load on the system and increase the neutron efficiency. With the reactor operating at 20 MW, the helium gas enters the cryostat at 32 K and exits at 40K, giving an average temperature in the ice (as a result of thermal conductivity) of approximately 45 K.

The gain which this moderator provides for cold neutrons is of the order of 10, measured as the ratio of the number of cold neutrons produced with the moderator filled with D_2O ice at low temperature to the number produced with the moderator filled with D_2O at 300 K. By direct experiment (as well as calculation), we have determined that this ratio is maximized by the addition of 7% H_2O, and the moderator is operated this way. This moderator has been in service since 1987, and system reliability is now quite good (> 98% availability). As a result of radiation damage in the solid ice, the moderator is warmed up to approximately 80-100 K every two days to allow recombination of the constituents produced by radiolysis.

With this source in operation, we have turned our attention to a second generation source which will utilize liquid hydrogen. A schematic drawing of the proposed hydrogen source is shown in Figure 3, from which several features should be noted. First, as a result of the lower density of hydrogen, the lead/bismuth shield can be left out, with a resultant gain in intensity and simplicity. Second, the source itself is much thinner, as a result of the high scattering power of hydrogen. The moderator chamber is a 2 cm thick, spherical shell with an outside diameter of 32 cm, containing about 5 liters of liquid hydrogen. A 20 cm diameter reentrant hole fully illuminates the guides with cold neutrons from the flux-trap in the interior of the sphere. A large buffer volume is open to the moderator chamber so that the entire liquid hydrogen inventory can vaporize and expand into the buffer without over-pressurizing the system. The cooling mechanism is a gravity fed flow of liquid into the moderator chamber, where evaporation removes the heat produced by the radiation. The hydrogen is in a cooled loop, reliquified outside the beam port, completing the naturally circulating thermosyphon requiring no pumps or moving parts.

The entire hydrogen system is surrounded by an insulating vacuum, which is in turn surrounded by gaseous helium (not shown in the figure) in order to prevent the entry of oxygen into any volume containing hydrogen. This is a central part of the safety philosophy--namely, to limit the oxygen available for combination with hydrogen. The liquefaction is done in the hydrogen condenser, with cooling provided by a 3.5 KW helium gas refrigerator. The first engineering tests of the proposed new source will take place this summer, and a full safety analysis is being prepared for submission to the Nuclear Regulatory Commission this year. Calculations of the performance of this source (performed both by analytical and Monte Carlo methods) indicate a further gain of cold neutrons available for experiments of at least a factor of two over the existing source, with somewhat larger gains at the lower energies.

Instrument Development

Operational

8-m SANS Spectrometer [1,4]. This SANS spectrometer is installed on NG-5. The instrument utilizes a mechanical velocity selector and pinhole collimation to provide a continuous incident beam whose wavelength is variable from 0.5 to 2.0 nm. The neutron detector is a 65 x 65 cm^2 position-sensitive proportional counter which pivots about the sample position to extend the angular range of the spectrometer. The low-Q limit of the instrument (0.025 nm^{-1}) is achieved with a multiple-beam converging pinhole collimation system. A 50-cm diameter sample table accepts standard cryostats, furnaces and electromagnets as well as a sample chamber which houses a temperature-controlled multiple sample changer. The instrument has a dedicated microcomputer which is networked to an interactive color graphics terminal with specialized software to provide rapid imaging and analysis of data from the two-dimensional detector. The instrument is suitable for the study of structural and magnetic inhomogeneities in materials in the 1 to 100-nm range. Intensity characteristics are listed in Table 1.

Table 1. Intensity Characteristics of the 8-m SANS Instrument.

Neutrons on Sample vs Q_{min}	Q_{min} (nm^{-1})	I_s [a] (n/sec)
	0.04	6×10^3
	0.10	3×10^5

[a] measured on 1.5 cm diam. sample, present cold source, with $\Delta\lambda/\lambda \approx 25\%$.

The NIST/Exxon/University of Minnesota 30-m SANS [1,4]. This instrument, developed jointly by NIST, the Exxon Research and Engineering Co., and the University of Minnesota, extends the measurement range and sensitivity of the NIST 8-m SANS instrument in both the small and intermediate angle regions, and, in addition, provides exceptional flexibility in optimizing beam intensity and resolution to meet the requirements of a particular measurement. The Q-range of the instrument extends from 0.01 nm^{-1} to nearly 10 nm^{-1} which enables structural features in materials ranging from roughly 0.5 to nearly 500 nm to be studied. This wide Q-range is achieved through the use of two large 2D position-sensitive detectors (see Fig. 4): a primary detector that moves axially within the cylindrical portion of the evacuated post-sample flight to vary the sample-to-detector distance continuously from 3.5 to 15 m, and a second detector (not yet installed) that will move along a circular arc (over a 40° range) at a fixed distance of 2 m from the sample. Flexibility in beam collimation is achieved by incorporating eight neutron guide sections in the 15-m long pre-sample flight path that can be easily shifted in or out of the beam to change the effective source-to-sample distance in 1.5 m increments from 3 to 15 m. A mechanical rotating velocity selector with variable speed and pitch provides the capability to vary both the wavelength and wavelength resolution of the beam over a wide range.

This instrument began operation using pinhole collimation and the primary detector in the spring of 1991. Development work continues on two novel components for this instrument, which if successful will significantly expand its measurement capabilities. These are a Fe/Si supermirror array for polarizing the incident beam, and a doubly curved, grazing incidence mirror (to replace the pinhole collimation and increase the flux on the sample) to focus the beam onto the detector. Performance is indicated in Table 2.

Table 2. NIST/Exxon/U. of Minn. 30-m SANS Spectrometer

Neutrons on Sample vs Q_{min}	Q_{min} (nm^{-1})	I_s [a] (n/sec)
	0.01	2.5×10^3
	0.02	3×10^4
	0.04	3×10^5
	0.10	1×10^6

[a] measured on 1.5 cm diam. sample, present cold source, with $\Delta\lambda/\lambda \approx 25\%$.

Medium Resolution Time-of-Flight Spectrometer [1,5]. Two time-of-flight spectrometers are planned for the guide hall of the CNRF. The first of these instruments, which is primarily designed for medium resolution applications, is located on guide NG-6. The second instrument, to be located on guide NG-1, uses a number of disk choppers, and is intended for high resolution measurements but may also be operated with relaxed resolution when required. Installation of the latter is expected in 1993.

In the medium-resolution spectrometer, the incident beam wavelength (0.23-0.61 nm) is determined using a double monochromator. The principle of this device is similar to that of a single monochromator, but an important advantage is that the selected neutron wavelength can be changed without having to move the sample (and everything downstream of the sample). This significantly simplifies the design of the instrument. The monochromators are made of individually aligned pyrolytic graphite (PG(002)) crystals. A 60′ Soller collimator is located between the monochromators. The first monochromator is flat, whereas the second monochromator is vertically curved in order to focus intensity at the sample position. Each monochromator is made of two layers of crystals, each layer possessing a 25′ mosaic, but staggered horizontally with 25′ angular offset. This effectively yields a more desirable anisotropic mosaic distribution, 25′ vertically and 50′ horizontally.

The neutron beam leaving the second monochromator is filtered, using pyrolytic graphite or liquid-nitrogen-cooled beryllium, in order to remove higher order contamination, as well as epithermal neutrons. It is then pulsed using a "Fermi chopper". The curvature of the slots and the speed of the chopper determine the optimum transmitted wavelength of the chopper. Two slot packages are available, corresponding to optimum transmitted wavelengths of 0.4 and 0.15 nm, respectively, at close to the maximum chopper speed.

The sample chamber can accommodate a wide variety of cryostats and furnaces. An oscillating radial collimator between the sample and the detectors blocks most of the scattering from material components which surround the sample (e.g. heat shields of cryostats). The evacuated sample-to-detector flight path contains an array of ^{3}He neutron detectors covering a scattering range of 5-140°. Some instrument parameters are given in Table 3.

Table 3. Characteristics of the Medium-resolution TOF Spectrometer

Incident Wavelength Range:	$0.23 < \lambda < 0.61$ nm (÷2 for PG(004))
Incident Energy Range:	$15.5 > E > 2.2$ meV (x4 for PG(004))
Elastic Momentum Transfer Range:	$1 < Q < 50$ nm^{-1} (x2 for PG(004))
Flux on Sample[a]:	~1 x 10^4 n/cm^2/s at $\lambda = 0.24$ nm
	~5 x 10^3 n/cm^2/s at $\lambda = 0.40$ nm
Elastic Energy Resolution[a]:	40 μeV at $\lambda = 0.60$ nm
	150 μeV at $\lambda = 0.40$ nm
	600 μeV at $\lambda = 0.24$ nm
Q Resolution[a] :	$\Delta Q/Q < 3\%$

[a] Expected performance.

Cold Neutron Depth-Profiling (NDP) Facility [1,6]. NDP determines distribution of isotopic concentrations vs. depth within the first few micrometers of a surface. This is achieved by energy analysis of the prompt charged particles emitted following neutron capture--for which energy loss vs. path length is known. The instrument is operational on NG-0 in the reactor hall with a beam filtered by 13.5 cm of single-crystal sapphire. It includes a new 61 cm diam stainless-steel sample chamber, vacuum system, detectors, electronics, and data acquisition system. The new depth-profiling chamber is capable of operating at

UHV pressures and incorporates many design features that enhance the capabilities that currently exist at the thermal depth-profiling instrument in the reactor hall. The chamber has an X-Y positioning system that will allow computer-controlled scanning of up to 15 x 15 cm^2 samples. The computer is also capable of rotating both the sample and the detectors to adjust the sensitivity for depth-profiling. The ability to use time-of-flight depth profiling techniques has also been incorporated into the chamber design. An electron gun for in-situ surface etching of samples will also be available. Pancake type uranium fission chambers are used for monitoring the neutron fluence. A comparison with the BT-3 facility is given in Table 4.

Table 4. Neutron Depth-Profiling Facilities at the NBSR.

	BT-3	Cold Beam
Fluence rate[a]	4 x 10^8	1.2 x 10^9 $n\text{-}cm^{-2}\text{-}s^{-1}$
Peak energy	22.5 meV	~8 meV
^{10}B sigma	3404 barns	~5700 barns
Rel. sens.	1	3
Gamma dose	400 mR/h	~400 mR/h

[a] Thermal neutron equivalence.

Prompt-Gamma Activation Analysis (PGAA) Spectrometer [1,7]. PGAA gives simultaneous nondestructive determination of many major, minor, and trace elements in a variety of bulk matrices. The sample is irradiated with a beam of neutrons. The constituent elements of the sample absorb some of these neutrons and emit prompt gamma rays which are measured with a high-resolution gamma-ray spectrometer. The energies of these gamma rays give qualitative identification of the neutron-capturing elements, and the intensity is proportional to their concentrations.

Design of the facility has focused on three related topics. First, the high quality of the neutron beam and the low level of environmental background in the guide hall allow closer sample-detector spacing, resulting in higher counting efficiency and better sensitivity. Second, the high count rates possible with this high efficiency (> 50k counts per sec) can be measured without loss of quality with recent advances in instrumentation. Finally, the improved efficiency makes attractive the use of γ-γ and γ-conversion electron coincidence counting in analytical measurements, with considerably improved specificity in some cases. Also, the counting system is designed to handle multiple gamma detectors with Compton suppression. Future modifications will include multiparameter coincidence counting.

Structural and shielding materials for this and neighboring instruments have been chosen as far as practicable to avoid generating a background of capture and decay gamma rays. Hydrogenous absorbers are avoided. The section of the beam tube adjacent to the sample position is made of boron-free glass. ^{6}Li is used wherever possible for collimators and absorbers, and antimony-free lead is used for gamma shielding. As a result, the sensitivity for most elements is expected to be at least tenfold better than any with any thermal beam in existence. The detection limit for hydrogen is calculated to be about 1 μg. Characteristics are summarized in Table 5.

Table 5. PGAA Characteristics

Measured reaction rate per atom at sample position:	$1.4 \times 10^8\ \sigma_0$, where σ_0 is the thermal neutron cross section.
Maximum sample size:	5x5 cm^2
Measured gamma rate:	< 1 mR/hr

Center for High Resolution Neutron Scattering (CHRNS) [1,4]. Two of the new CNRF instruments that will begin operation in 1992, a 30-m, high resolution small angle neutron scattering (SANS) instrument and a cold neutron polarized beam triple-axis spectrometer (see below), have been constructed with support from the National Science Foundation. The 30-m CHRNS SANS instrument and its dedicated guide, NG-3, are nearly complete. Up to 85% of the time on the CHRNS 30-m instrument will be allocated by the Program Advisory Committee (see section on Researcher Program, below) compared to 25% for the PRT-developed NIST/Exxon/U. Minnesota SANS instrument.

The performance characteristics of the single-detector CHRNS SANS instrument are very similar to the NIST/Exxon/U. of Minn. 30-m SANS spectrometer. It will, however, be the first in the United States to utilize a 2-d detector of the ILL-type, capable of counting rates in excess of 20,000/sec. To take full advantage of this high count rate capability, the instrument's post-sample vacuum flight path has been designed to allow the detector to approach within 1.2 m of the sample. As a result the instrument will not only be able to perform high resolution (low-Q) measurements, but will also cover a wide Q-range (0.01 to 6 nm^{-1}) and significantly improve current capabilities for time-resolved SANS measurements.

The Neutron Lifetime Experiment [8]. The end position on the NG-6 beam line at the CNRF is devoted to experiments in the field of fundamental neutron physics. In contrast to the CNRF neutron interferometry facility, there is no permanently installed instrumentation; the properties of the beam must be matched to the requirements of each experiment individually. Aside from the beam shutter and a beam stop, the only other permanent equipment on the beamline is a filter cryostat to remove fast neutrons and gamma rays. A variety of collimators, polarizers, spin flippers, and transport tubes can be made available for individual experiments. The capture flux at the end of the 15 x 6 cm^2 NG-6 guide has been measured to be about $4x10^8$ $n/cm^2/s$, which is about a factor of nine lower than the 3 x 5 cm^2 SN-7 guide at the ILL. This flux will increase significantly after the installation of the hydrogen cold source.

The first experiment at the end of NG-6, a measurement of the lifetime of the neutron, is currently underway. This experiment is a collaboration between NIST, the University of Sussex and the Scottish Universities Research and Reactor Center, with related work on advanced methods of neutron flux measurements performed by NIST, the Central Bureau for Nuclear Measurements, the Scottish Universities Research and Reactor Center, Harvard University, and Los Alamos National Laboratory. A more detailed description than that given here can be found in Ref.[9].

The strategy of the experiment is to measure the neutron decay rate N_{decay} and the mean number of neutrons N_n within a well-defined volume traversed by a cold neutron beam. The decay rate is related to these quantities by the differential form of the exponential decay law $N_{decay}=N_n\tau_n^{-1}$. Figure 5 shows a schematic outline of the method. N_{decay} is measured in the experiment by trapping the protons produced in the decay with a Penning trap and counting the trapped protons. N_n is measured by requiring the neutrons leaving the decay volume to pass through an accurately calibrated neutron monitor.

The first experiment using this apparatus, performed at the ILL, measured a neutron lifetime of 893.6 seconds with a 1σ error of 5.3 seconds. This result is in excellent agreement with other recent direct measurements of the neutron lifetime using completely different techniques. In the next experiment, to be conducted at the NIST CNRF, we hope to reduce the 1σ error to 1.5 seconds. Most of the improvement in the anticipated error comes from better counting statistics and improvements in the calibration of the neutron monitor detector efficiency. If the uncertainty in ϵ_o, the efficiency at a single neutron velocity, can be reduced by calibration with the black detectors, the neutron lifetime measurement at the NIST CNRF may turn out to be the most accurate measurement of the neutron lifetime.

Also on NG-6, test runs for an experiment to search for time reversal invariance violation in neutron beta decay are underway. Other experiments in the near future may include searches for parity violation in neutron-nucleus scattering and studies of polarized neutron interactions with polarized nuclei.

Near-Operational Instruments

The CHRNS Spin-Polarized Inelastic Scattering Spectrometer ("SPINS") [1,10]. The installation of the SPINS spectrometer has begun on an NG-5. Assembly and testing of this instrument will continue through the summer with the first experiments expected to commence by year's end. It will initially be configured as a cold neutron triple-axis spectrometer with focusing pyrolytic graphite monochromator and analyzer crystals. Polarizing the incident beam, and analyzing its polarization after scattering, will be provided by iron-silicon supermirrors used in transmission geometry. The development of these polarizers has now reached the stage where the first set of wide-beam polarizers is about to go into production. Also under development for this instrument is a Drabkin-type, energy-dependent spin flipper. Used in conjunction with the polarizers, this device partially decouples the momentum and energy resolution of the instrument making it possible to achieve an energy resolution of 10 μeV under conditions of moderately relaxed momentum resolution.

Neutron Interferometer [8]. With the installation of the primary base slab for a sophisticated vibration control system in early November 1991, construction of the neutron interferometry facility on NG-7 has passed a major threshold. This experimental station will be devoted to a wide variety of investigations concerned with advanced neutron optics, matter wave interferometry, sensitive tests of quantum mechanics and other fundamental theories as well as measurements of the basic parameters describing the interaction between neutrons and matter.

When operational, neutrons extracted by a pyrolytic graphite monochromator mounted inside NG-7 will be directed into an environmentally controlled room containing a perfect crystal interferometer. The monochromator and its control system have recently been installed and tested, and work very well. Due to the extreme sensitivity of such interferometers, very stringent precautions against seismic, acoustic and thermal "noise" are being taken. Internal vibrational modes or bulk displacements at sub-Angstrom levels are sufficient to destroy the interference signal or to render the interferometer insensitive. For this reason, the neutron interferometry station at the CNRF will be equipped with a sophisticated vibration isolation system to reduce the effect of seismic and acoustic perturbations. This system will include both passive and active vibration isolation technology to achieve sufficiently low levels of disturbance so that interferometers of comparatively large dimension (tens of centimeters) may be employed. The prospect of such "long baseline" interferometry offers the possibility of a very significant increase in the sensitivity of this technique.

The initial scientific program planned for this facility includes a the detailed study of a variety of quantum mechanical effects. Recent measurements carried out at the University of Missouri concern a very novel electromagnetic interaction between the neutron magnetic moment and a static electric charge distribution. This so-called Aharanov-Casher effect represents a geometrical phase, which while analogous to effects seen with charged particles has not previously been observed. Detailed studies of this effect are planned at the CNRF. Neutron interferometry is sufficiently sensitive to detect the quantum mechanical phase shift which arises from the difference in the gravitational potential corresponding to a height difference of less than a millimeter. The current best measurements of such quantum mechanical gravitational phase shifts are inconsistent with theoretical expectations. Several measurements with improved sensitivity and increased immunity to possible systematic effects are planned. A wide variety of other investigations are also anticipated.

Construction of this facility is being carried out by NIST staff from the Physics Laboratory and the Materials Sciences and Engineering Laboratory. This project is supported by NIST and the National Science Foundation through a grant to the University of Missouri (Columbia). Included among the institutions which are anticipated to participate are the University of Innsbruck (Austria), Atom Institute (Austria), Hampshire College, University of Melbourne (Australia).

High-Resolution 32-Detector Powder Diffractometer [11]. The new high-resolution powder diffractometer is ready for installation at BT-1 in the reactor hall. A schematic of the instrument is shown in Figure 6. The provision for the selection of one of three monochromators--arranged in series, at take-off angles to produce 0.154 nm neutrons--will allow an instrumental resolution to be selected in which the d-spacing range of maximum interest can be examined at optimum conditions. For 7'-40'-7' collimation, a minimum FWHM of ~0.18° is calculated for d's of~ 0.133, ~0.113, and ~0.091 nm for the three monochromators. Additionally, according to the angle range they cover, different vertical divergences (up to 9°) for different detectors are provided for. The detector array subtends an angular range of 155° and can reach a maximum scattering angle of 167°.

Other New Capabilities

In addition to the instruments described in the previous sections, several other instruments are in detailed design or fabrication stages:

NIST/IBM/U. Minn. cold neutron reflectometer. This instrument is planned for installation on NG-7 in the guide hall in mid-1992. It will have horizontal sample geometry, counters for both small-angle and large-angle scattering--for specular reflection and grazing-angle diffraction measurements, respectively--each with polarized-beam capabilities. Reflectivities less than 3 x 10^{-7} are expected to be measurable, with a Q-resolution, $\Delta Q/Q$, of 0.02 to 0.1—depending on the choice of collimating slits.

Residual stress, texture, and single crystal diffractometer. This instrument is in the final design stage with installation on BT-8 in the reactor hall expected by early 1993. It will feature a monochromator take-off angle of up to 120°, a vertically-focusing monochromator, a large full-circle goniometer, and a PSD or multi-detector.

Researcher Program

The first guest researcher experiments scheduled through the formal review system of the CNRF were performed in November. In response to the limited first call for proposals, the CNRF received 40 proposals, of which 23 were accepted and allotted beam time after a thorough review process. For the 30-m NIST/Exxon/U. of Minn. SANS instrument, one of three stations available through the guest researcher program for the first cycle, the beam time requested (160 days) exceeded that available by a factor of three. In the next proposal cycle, it will be possible to accommodate many more guest researcher experiments when a second 30-m SANS machine and other instruments become operational.

The review of the proposals submitted in response to the first call was accomplished through a system whose basic features were proposed by the Program Advisory Committee (PAC)--and described in the April 1991 NEUTRON STANDARD. The proposals were first peer reviewed by mail, resulting in several written reviews for each proposal. The proposals with their reviews were then scrutinized and rank-ordered for scheduling by the PAC. Actual scheduling is taking place on an ongoing basis through June of 1992.

For the future, it is expected that the number of proposals and the number of guest researcher experiments at the CNRF will increase dramatically over the next few years, and will involve hundreds of scientists from all over the world.

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Figure Captions

1. NBSR reactor and guide hall with completed guides shown.

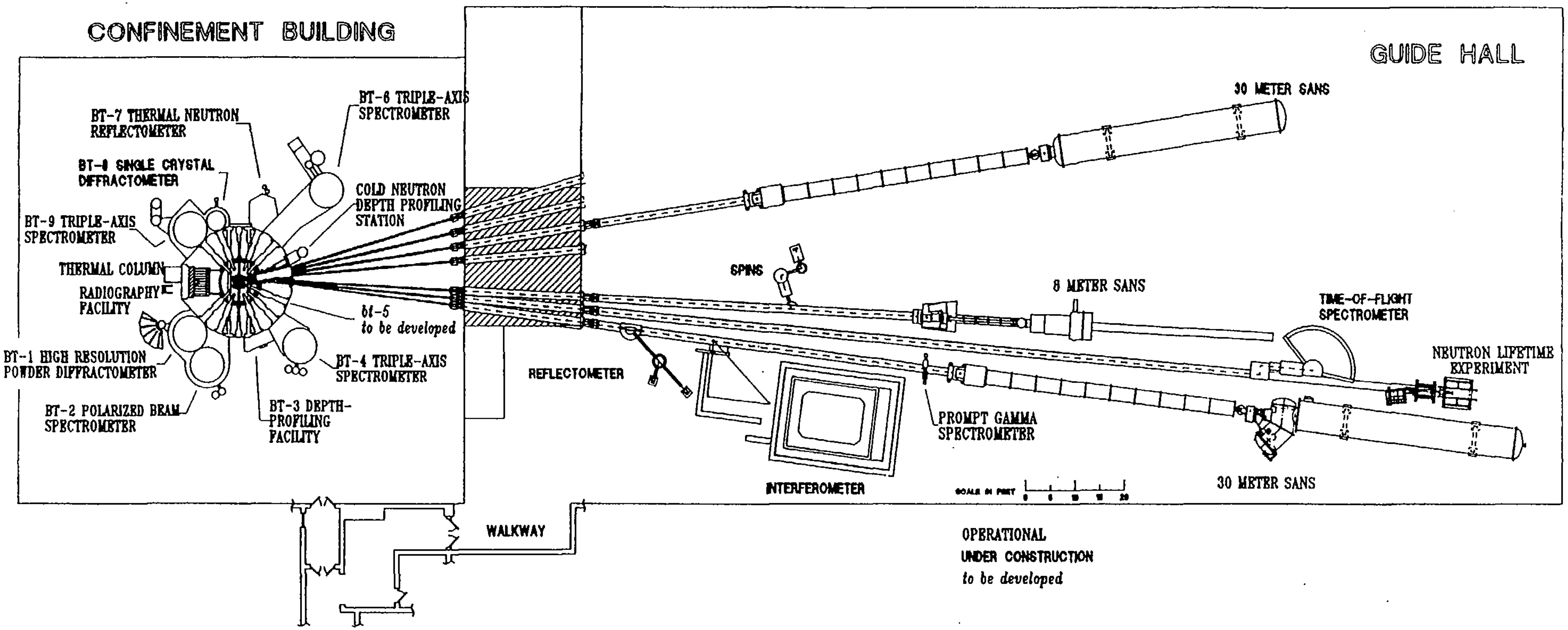
2. Present cold source and guide failure detail.

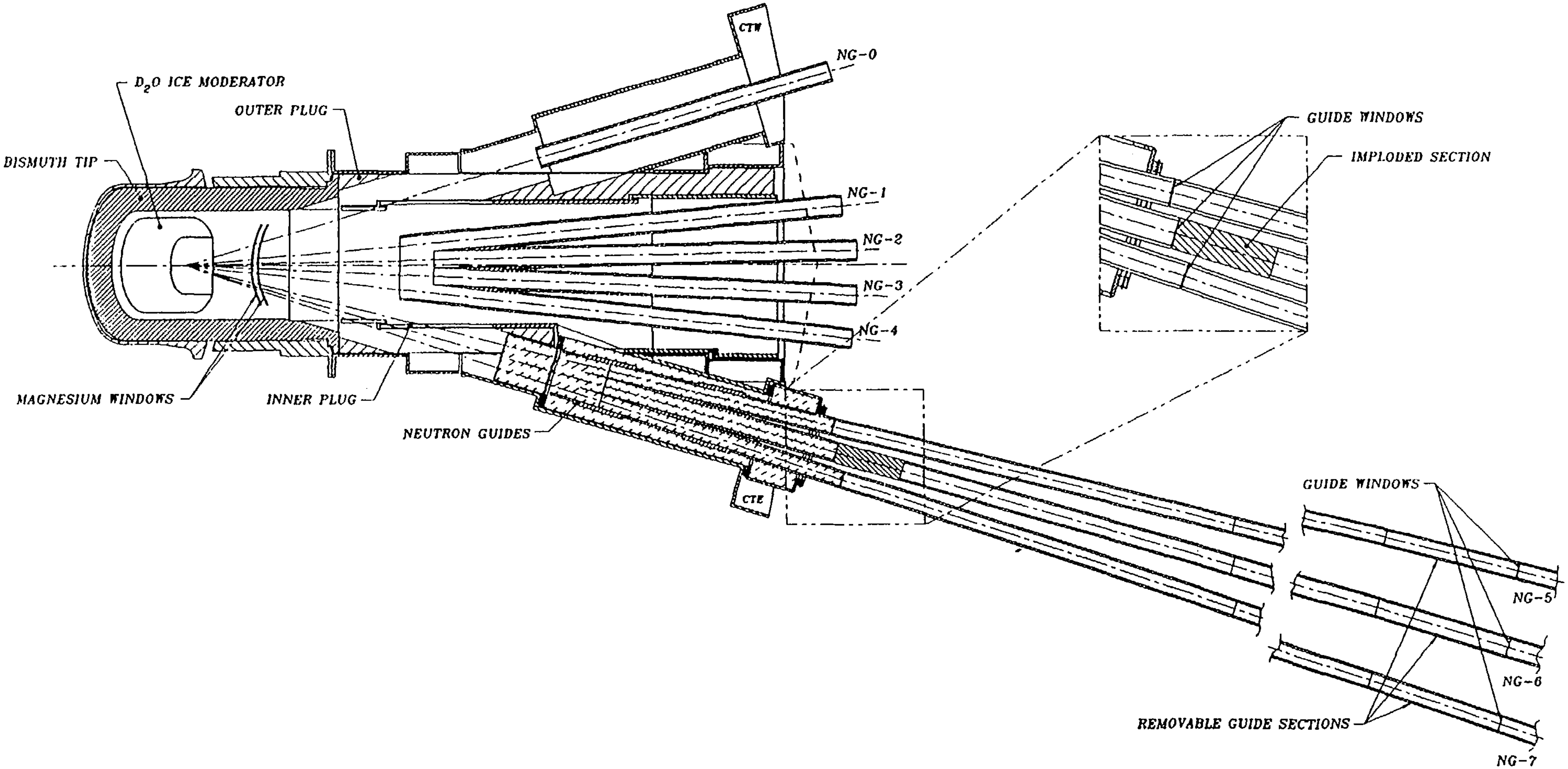
3. New cold source.

4. NIST/Exxon/U. of Minn. 30-m SANS spectrometer schematic.

5. Schematic of neutron lifetime experiment.

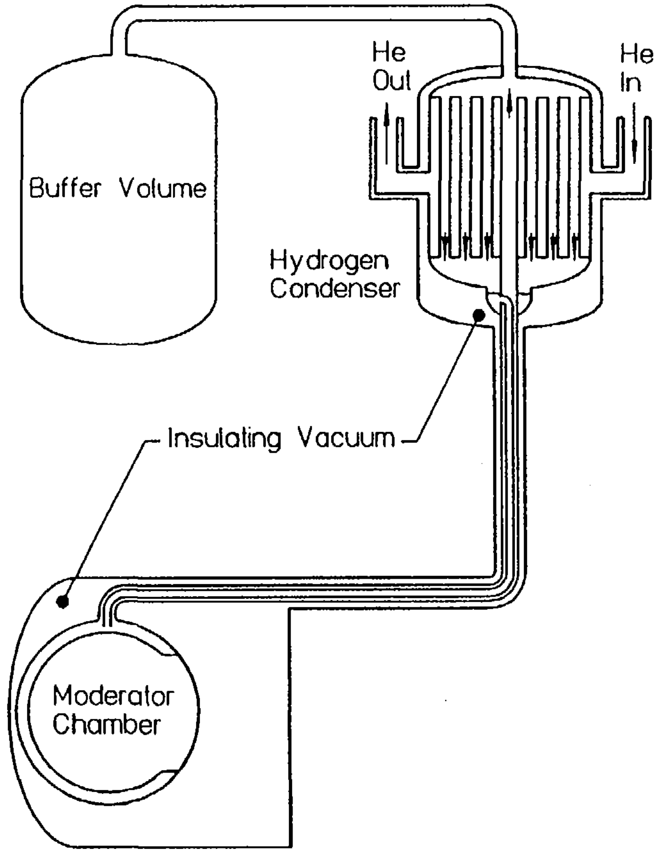
6. High-resolution 32 detector powder diffractometer.


CONFINEMENT BUILDING
GUIDE HALL
BT-6 TRIPLE-AXIS SPECTROMETER
BT-7 THERMAL NEUTRON REFLECTOMETER
BT-8 SINGLE CRYSTAL DIFFRACTOMETER
COLD NEUTRON DEPTH PROFILING STATION
BT-9 TRIPLE-AXIS SPECTROMETER
THERMAL COLUMN
RADIOGRAPHY FACILITY
bt-5 to be developed
BT-1 HIGH RESOLUTION POWDER DIFFRACTOMETER
BT-4 TRIPLE-AXIS SPECTROMETER
BT-2 POLARIZED BEAM SPECTROMETER
BT-3 DEPTH-PROFILING FACILITY
30 METER SANS
SPINS
8 METER SANS
TIME-OF-FLIGHT SPECTROMETER
NEUTRON LIFETIME EXPERIMENT
REFLECTOMETER
PROMPT GAMMA SPECTROMETER
30 METER SANS
INTERFEROMETER
WALKWAY
OPERATIONAL
UNDER CONSTRUCTION
to be developed

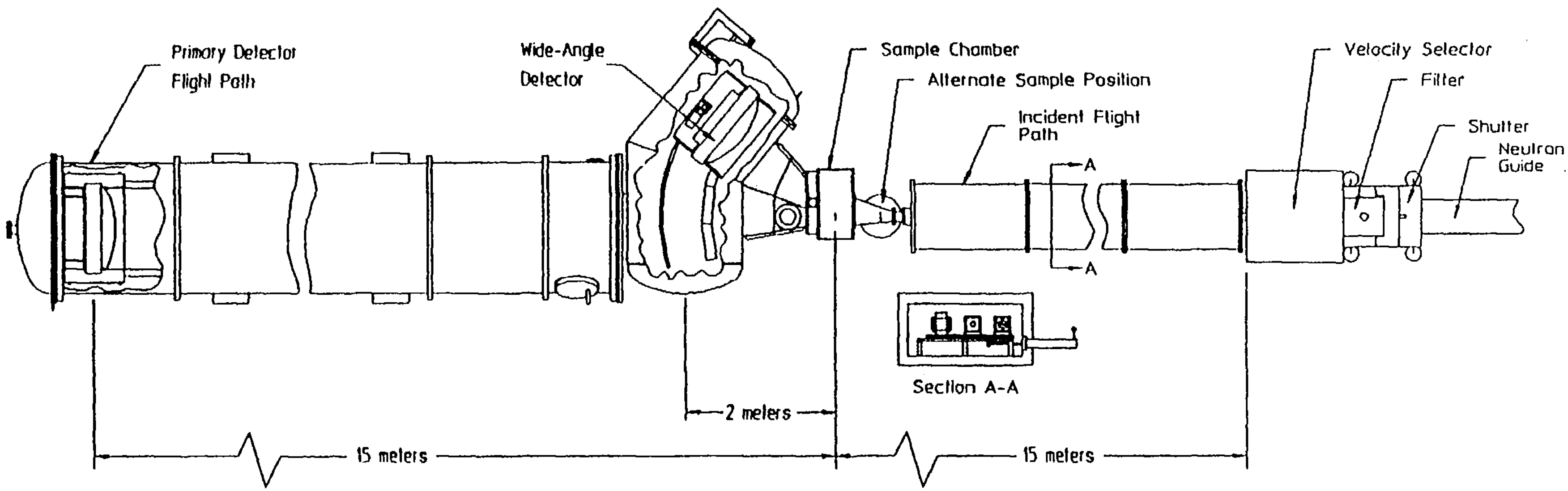


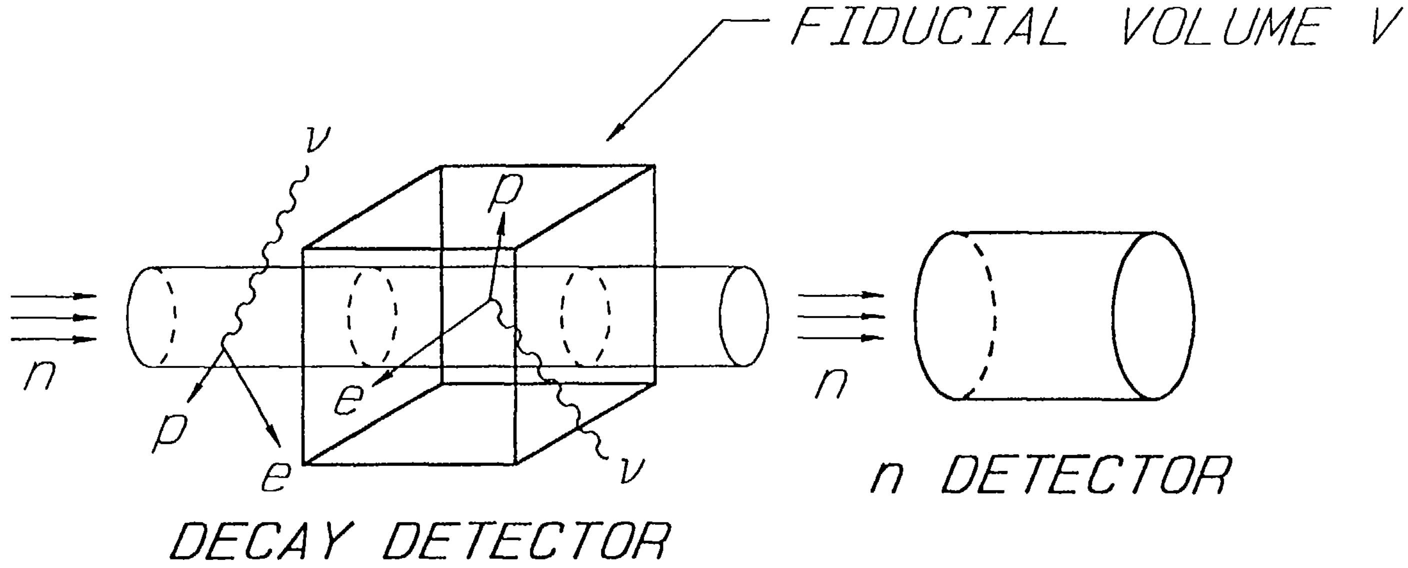
PLAN VIEW - NBSR COLD SOURCE & GUIDES

HYDROGEN COLD SOURCE THERMOSYPHON



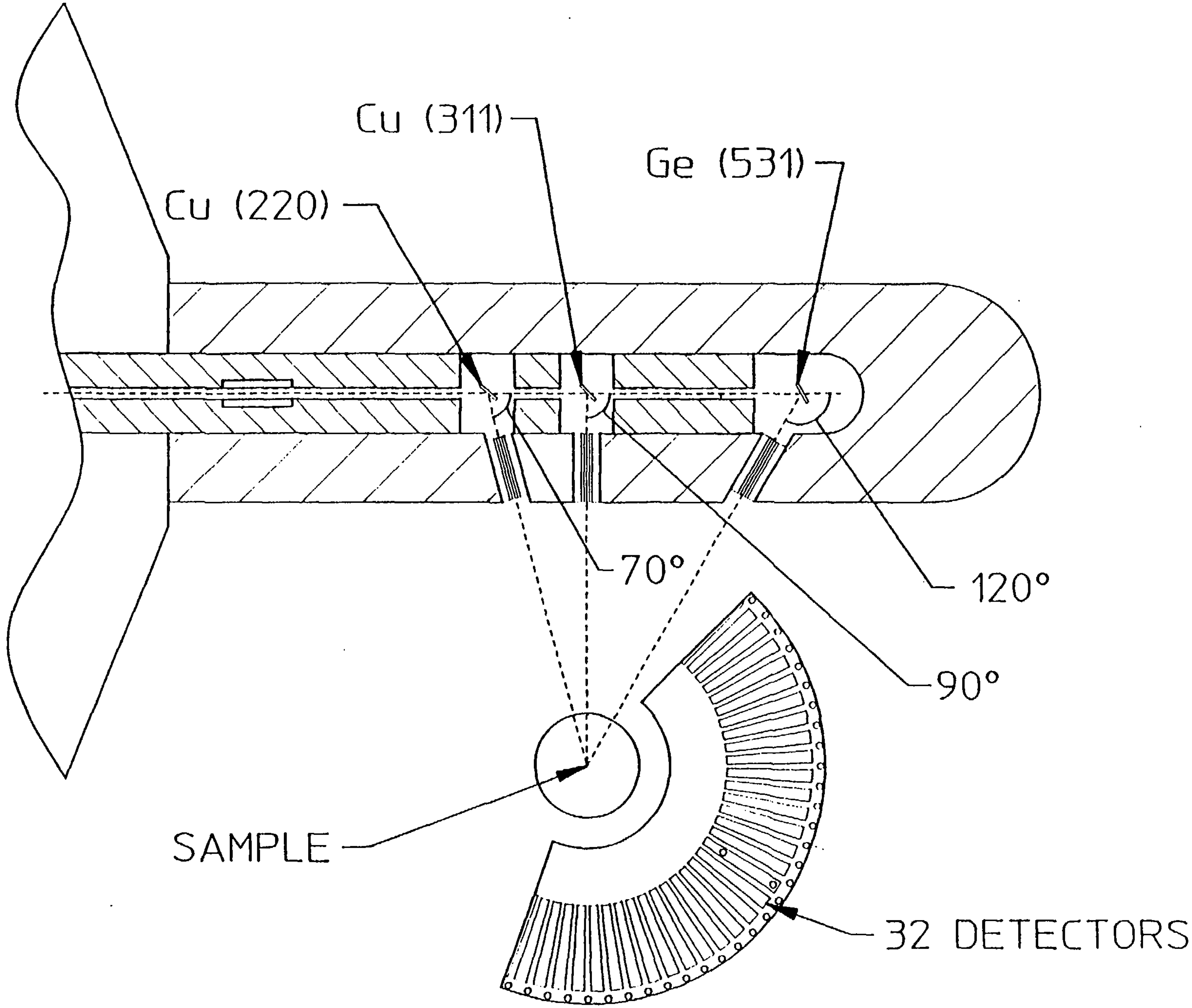
NIST / EXXON / UNIVERSITY OF MINNESOTA
SANS SPECTROMETER





$$\dot{N}_{decay} = \rho_n V \tau^{-1}$$

$$\dot{N}_{decay} = \frac{\dot{N}}{\bar{v}} V \tau^{-1}$$



Cu (311)
Ge (531)
Cu (220)
70°
120°
90°
SAMPLE
32 DETECTORS

NBSR STATUS REPORT:
NAT'L. INST. OF STANDARDS & TECHNOLOGY
GAITHERSBURG, MD

H. Prask, Reactor Radiation Division

HISTORY

Dec. 1967	Criticality achieved
Feb. 1969	10 MW
Feb. 1985	20 MW
Oct. 1986	Cold Neutron Research Facility approved
Jul. 1987	Cold source installed
Nov. 1987	Guide hall "Ground Breaking"
Jan. 1989	Guide hall dedicated
Jun. 1989	Shutdown for guide penetrations
Mar. 1990	Startup
Jun. 1991	Call for CNRF proposals
Nov. 1991	Begin National User Facility operation

NBSR Specifications

Power	20 MW
Peak Thermal Neutron Flux	4×10^{14} n/cm^2-s
Peak Fast Neutron Flux	10^{14} n/cm^2-s
Neutron Ports	
Beam tubes:	11
Cold source ports:	8
Thermal Column	137x132x94 cm^3 graphite
Vertical Thimbles:	17
Rabbit Tubes	4
Operating Cycle	30 days on, 7 days off

RESEARCH PROGRAMS AT THE NBSR

Neutron Scattering
- molecular solids
- magnetic materials
- H in metals
- bonding to catalysts and surfaces

Neutron Diffraction
- powder and crystal technique development
- structure determinations of
  - -ceramics, ionic conductors, alloys,
  - -zeolites, minerals, molecular solids,
  - -magnetic materials, biological materials
- phase transition mechanisms

SANS and Reflectometry
- polymer and bio-molecule structures
- suspensions under shear
- void and microstructure evolution in metals
- internal structure of thin films

Neutron NDE
- radiography and autoradiography
- residual stress & texture

Chemical Analysis
- trace analysis & depth profiling

Neutron Standards Development

Fundamental Neutron Physics
- interferometry
- lifetime of neutron

Irradiations and Isotope Production

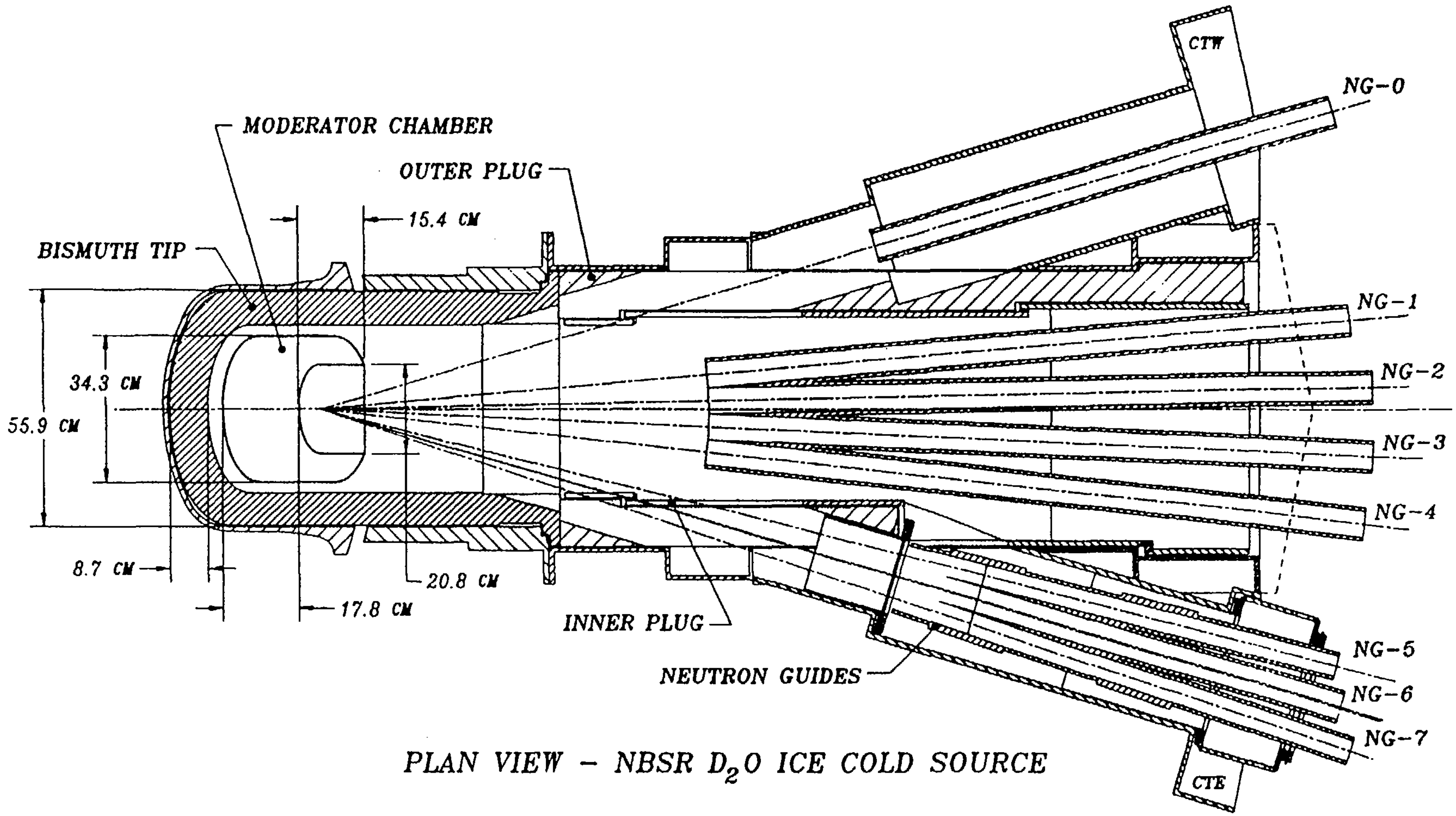
Cold Neutron Research Facility (CNRF)

- Construction continuing of $30M Facility
  - To be completed in 1993
  - 14 to 15 new experimental stations
- National User Facility
  - 1/3 of instruments funded and operated by non-NIST organizations (PRTs)
  - Program Advisory Committee allocates time on non-PRT instruments, following mail review of proposals.

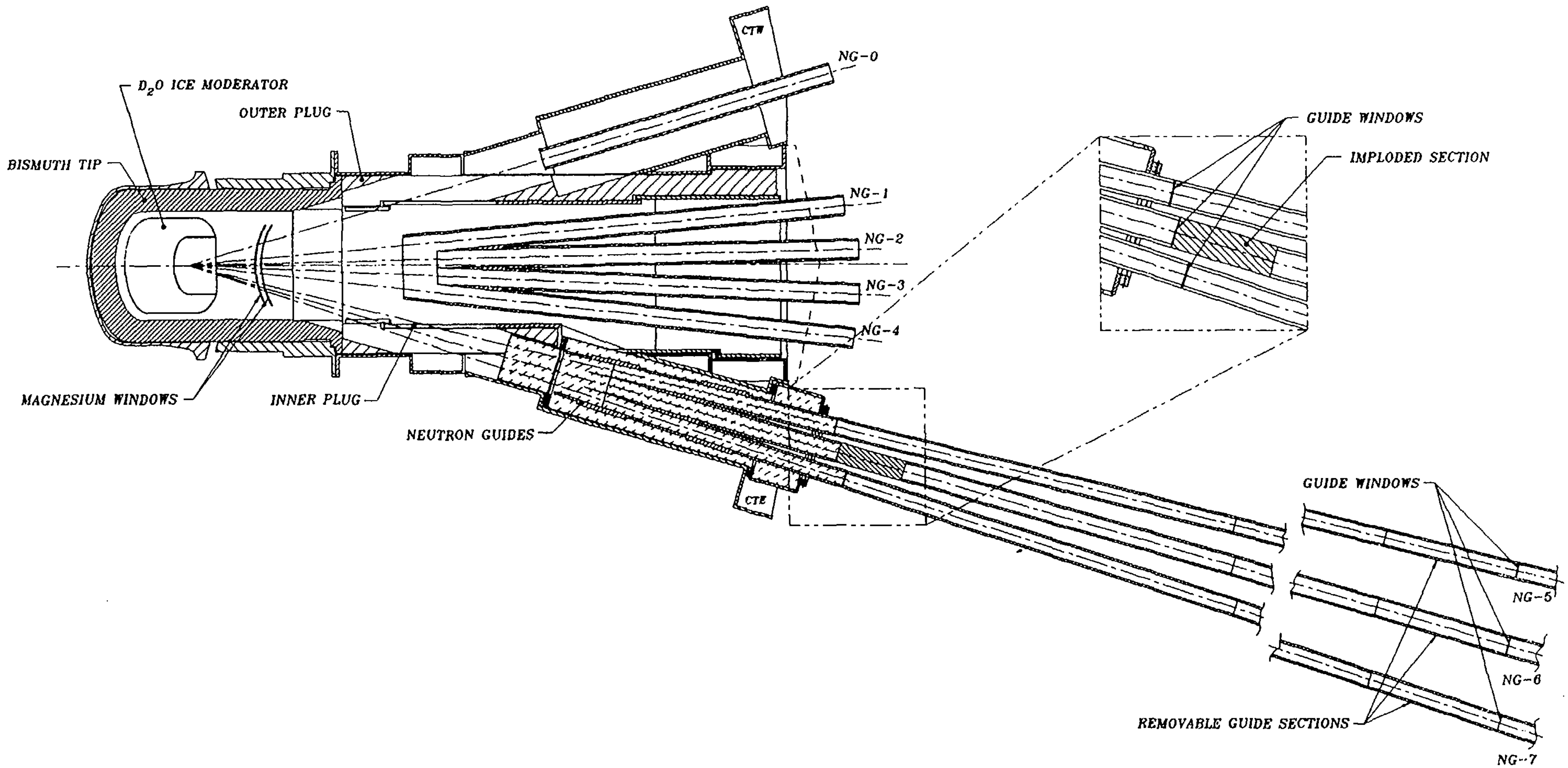
CNRF Instrumentation[1]

MATERIALS STRUCTURE			
•**NG7**	**30m-SANS**	NIST/EXXON/U.MINN.	**oper.**
•**NG3**	**30m-SANS**	NSF	1992
•**NG5**	**8m-SANS**	NIST (POLYMERS)	**oper.**
•**NG7**	**REFLECTOMETER**	IBM/U. MINN.	1992
•NG2[2]	Grazing-angle diff.		1993
MATERIALS DYNAMICS			
•**NG5**	**3-AXIS SPECTROMETER**	JOHNS HOPKINS	1992
•**NG4**[2]	**SPINS**	NSF/NIST	1993
•**NG6**	**MEDIUM-RESL. TOF**		**oper.**
•**NG1**[2]	**HIGH-RESL. TOF**	SANDIA N.L.	1993
•NG2[2]	Backscatter spect.	SANDIA N.L.	1993
•NG4[2]	Spin-echo spect.		1993
CHEMICAL ANALYSIS KODAK/IBM/INTEL			
•**NG0**	**NEUTRON DEPTH PROFILING**		**oper.**
•**NG7**	**PROMPT-γ ACT. ANALYSIS**		**oper.**
FUNDAMENTAL NEUTRON PHYSICS			
•**NG7**	**NEUTRON INTERFEROMETER**		1992
•**NG6**	**FUNDAMENTAL NEUTRON PHYSICS**		**oper.**

[1]Hydrogen cold source to replace D_2O/H_2O source 1992.
[2]NiTi supermirror guides [$\gamma_c=3\gamma_c$(Ni)] planned.



PLAN VIEW - NBSR D_2O ICE COLD SOURCE



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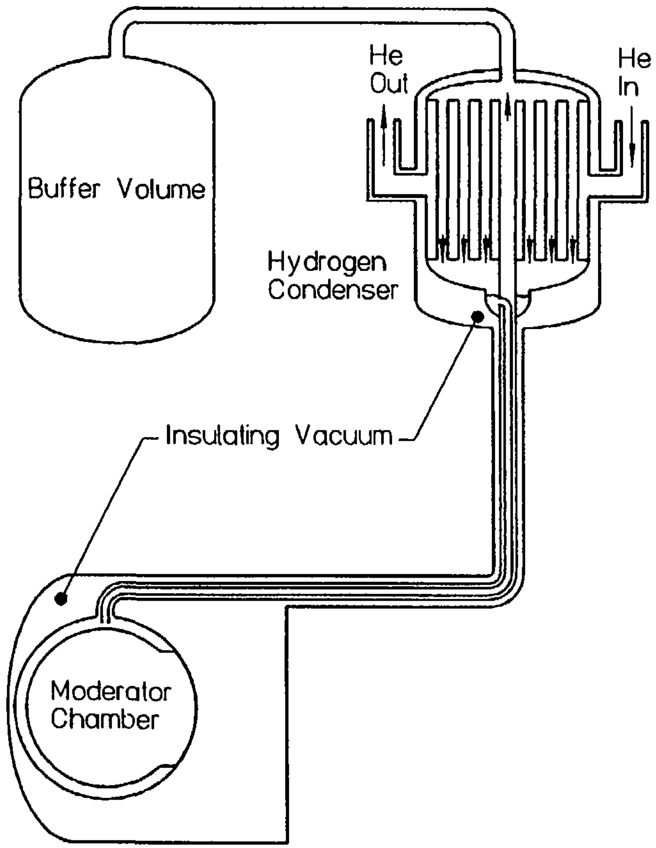
HYDROGEN COLD SOURCE THERMOSYPHON



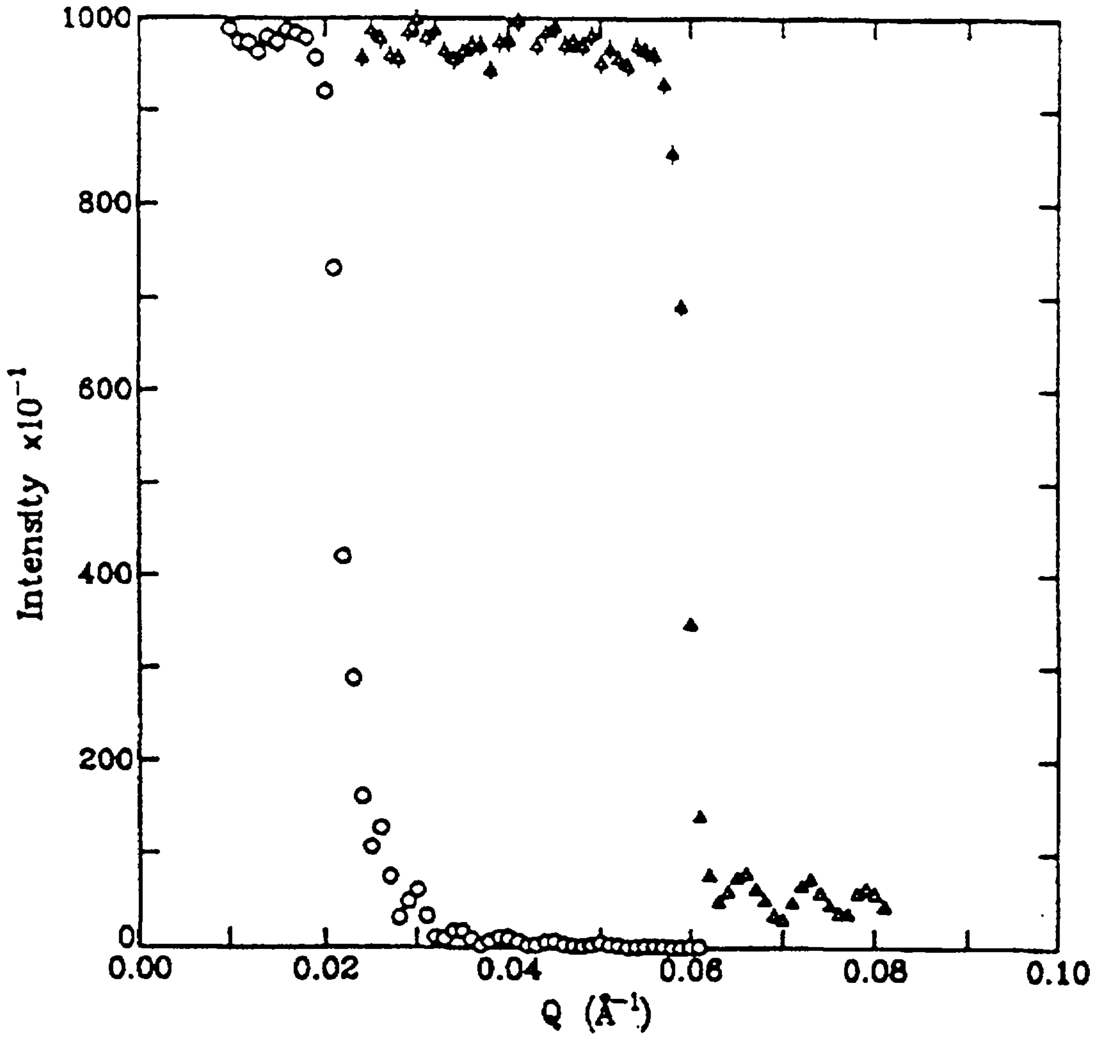
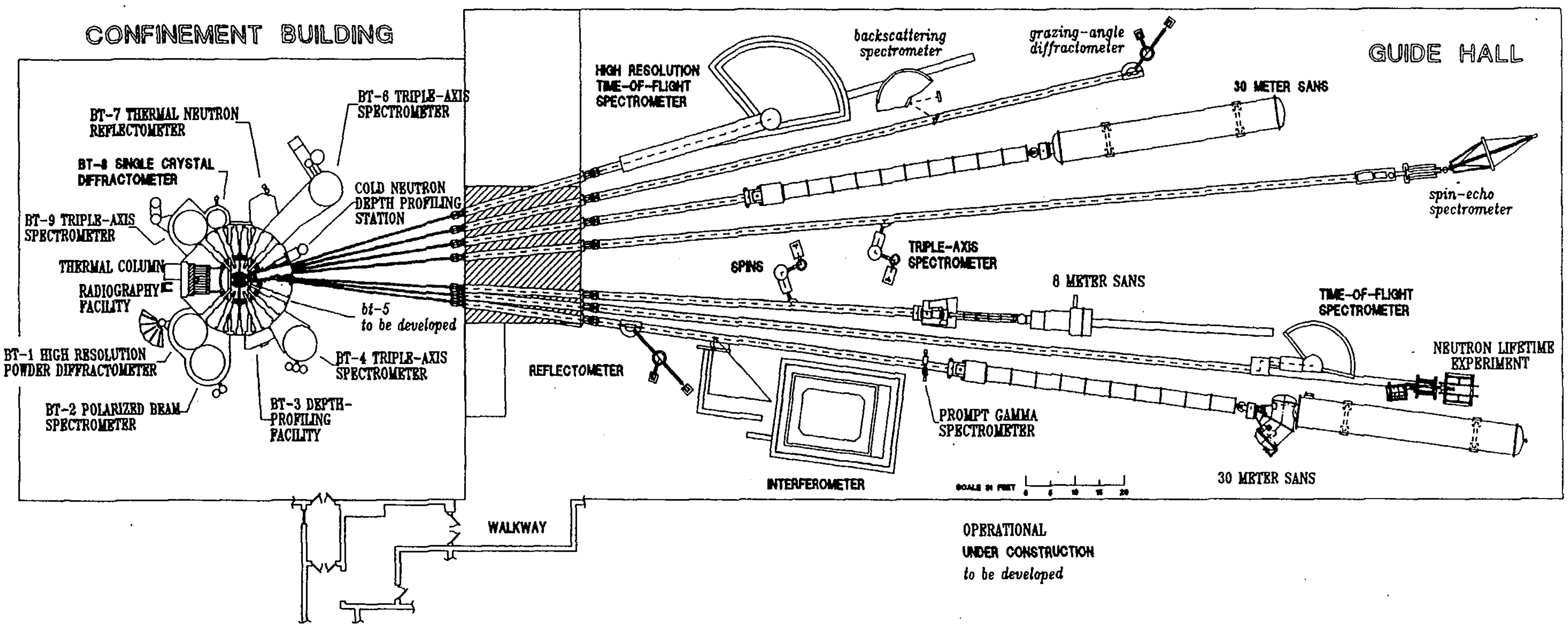


Figure 5. Neutron reflectivity as a function of wavevector transfer for a Ni-C-Ti supermirror superimposed on the reflectivity profile of a 1000-A thick Ni film. This supermirror has an effective critical angle about three times that of the Ni film and a nearly uniform reflectivity of better than 95%. This supermirror is composed of discrete sets of bilayers of different thicknesses as described in the text.

SUPERMIRROR GUIDE COATINGS

- Ovonics Corp., Optoline Corp. are developers
- NIST, ORNL, and MURR have participated
- Ovonics: carbon buffer layer between between alternating polycrystalline Ni and Ti layers
  <u>or</u> alternating Ni/C alloy -- Ti layers
- Optoline: amorphous Ni(x)C(1-x)-Ti(y)Mn(1-y)
- RFP out



CONFINEMENT BUILDING
GUIDE HALL
BT-7 THERMAL NEUTRON REFLECTOMETER
BT-6 TRIPLE-AXIS SPECTROMETER
BT-8 SINGLE CRYSTAL DIFFRACTOMETER
COLD NEUTRON DEPTH PROFILING STATION
BT-9 TRIPLE-AXIS SPECTROMETER
THERMAL COLUMN
RADIOGRAPHY FACILITY
bt-5 to be developed
BT-1 HIGH RESOLUTION POWDER DIFFRACTOMETER
BT-4 TRIPLE-AXIS SPECTROMETER
BT-2 POLARIZED BEAM SPECTROMETER
BT-3 DEPTH-PROFILING FACILITY
HIGH RESOLUTION TIME-OF-FLIGHT SPECTROMETER
backscattering spectrometer
grazing-angle diffractometer
30 METER SANS
spin-echo spectrometer
SPINS
TRIPLE-AXIS SPECTROMETER
8 METER SANS
TIME-OF-FLIGHT SPECTROMETER
NEUTRON LIFETIME EXPERIMENT
REFLECTOMETER
PROMPT GAMMA SPECTROMETER
INTERFEROMETER
30 METER SANS
WALKWAY
OPERATIONAL
UNDER CONSTRUCTION
to be developed

NBSR - Thermal Beams

BT1	5-det. Powder diff. ---> **32 det.powder diff.**
BT2	pol. beam 3-axis
BT3	Neutron depth-profiling
BT4	3-axis or inv. filter spect.
BT5	(to be developed)
BT6	3-axis (tex./res. stress)--->3-axis
BT7	**pol. Reflectometer**
BT8	-----------> **1-crystal diff./texture/res. stress**
BT9	3-axis