

Scientific upgrades at the High Flux Isotope Reactor at Oak Ridge National Laboratory

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A NATIONAL ACADEMIES panel in 1984¹ and a U.S. Department of Energy advisory committee report in 1993² indicated the need for a world-class continuous neutron source (that is, a reactor) and a world-class pulsed neutron source in the United States. The initial plan was to build a 300-MW reactor facility, designated the Advanced Neutron Source, at Oak Ridge National Laboratory, but in the mid-1990s, a decision was made to instead build at ORNL a pulsed neutron source, which became the Spallation Neutron Source (SNS) project (*NN*, Feb. 2006, p. 32).

After the cancellation of the Advanced Neutron Source project, the continuous neutron sources available to address all of the United States' user needs were a 20-MW reactor at the National Institute of Standards and Technology, the 30-MW High Flux Beam Reactor (HFBR) at Brookhaven National Laboratory, the 85-MW High Flux Isotope Reactor (HFIR) at ORNL, and several university reactors. It was recognized at the time that even with new reactor facilities being built in Europe, Japan, South Korea, and other places around the world, there was a growing gap between user needs for continuous neutron beams and available facilities, particularly in the United States. This disparity became even more pronounced when then U.S. Secretary of Energy Bill Richardson announced in 1999 that Brookhaven's HFBR was to

"Cold" neutron beam lines have been added, broadening the HFIR's range as an experimental and testing facility.

close permanently. This reactor had been shut down since the discovery in 1996 of a tritium leak from the spent fuel pool, and it was never again operated following the 1999 announcement.

Even before the shutdown of the HFBR, plans were under way, with support from the DOE, to improve the neutron beam science capabilities at the HFIR. Over the past 10 years, modifications have been made to enhance the thermal beam capabilities and, most important, to add a hydrogen cold source to an existing HFIR beam tube. Most of the planned scientific upgrades to the reactor and many of the planned new neutron scattering instruments are already operational, and other instruments are expected to be functional over the next five years.

History of the HFIR

In March 1959, ORNL submitted a proposal for the construction of the HFIR to the Atomic Energy Commission, which granted approval in July of that year for the lab to proceed with construction. The reactor design was completed in 1960 and construction began in June 1961.³ Initial criticality was achieved on August 25, 1965, and full-power normal operation (100 MW) began in 1966. Since that time, the HFIR has completed 430 fuel cycles. (The length of the fuel cycle is 21–27 days, depending on the power level and experiments loaded in the core region.)

The HFIR was built for the primary purpose of producing transuranium isotopes, but beam tubes were included in the design

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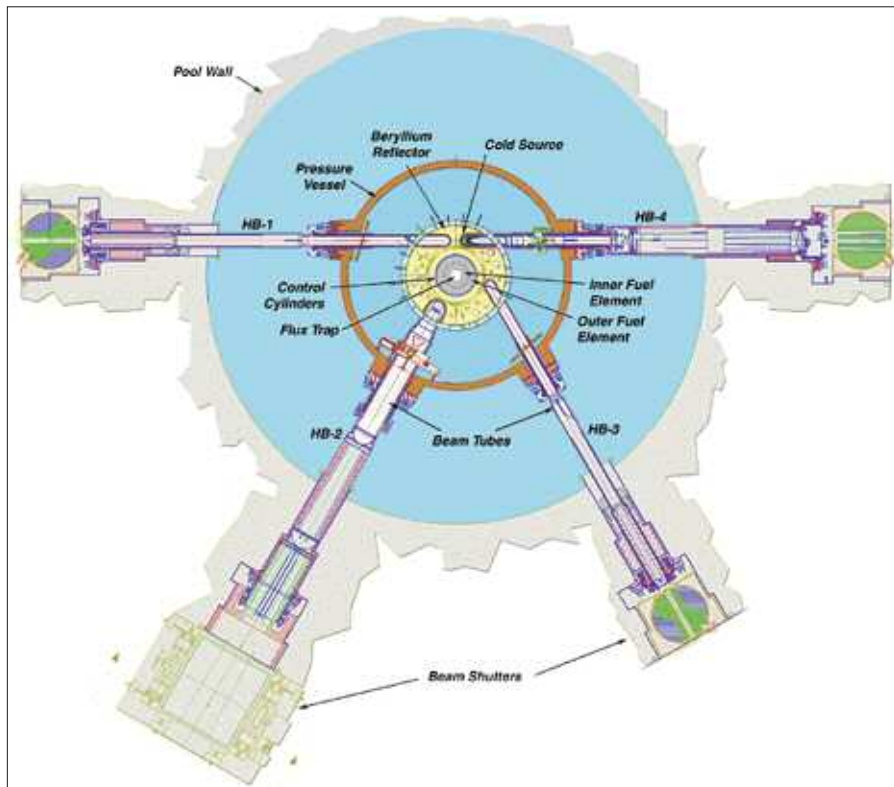


Fig. 1. Layout of the High Flux Isotope Reactor core, reflector, and beam tubes



Fig. 2. The HB-1 Polarized Triple-Axis Spectrometer

in anticipation of a future scientific need for neutrons. In addition, with an under-moderated core and a beryllium reflector, a wide range of neutron spectrum conditions were inherently produced for the incorporation of neutron irradiation capabilities for a multitude of neutron spectra. Although the isotope production capabilities are still important, the primary mission of the reactor has shifted to the neutron scattering science program, which makes use of the neutron beams. Figure 1 provides a layout of the reactor core, the beryllium reflector, and the four beam tubes.

In November 1986, tests on irradiation surveillance specimens indicated that embrittlement of the reactor vessel from neutron irradiation was occurring at a faster rate than had been predicted, and so the HFIR was shut down to allow for extensive review and evaluation of the operation of the facility. The reactor was restarted two and a half years later, following the completion of modifications to extend the life of the reactor, along with upgrades to management practices. One significant modification was a reduction in power level to 85 MW, which is now considered to be the normal full-power operation condition. In January 2006, after Cycle 407, the reactor was shut down for the installation of a new hydrogen cold source, and operation resumed in spring 2007.

The reactor core is water-cooled, with a

beryllium reflector, and the core is composed of involute fuel plates assembled in two compact fuel elements. At the new power level, the peak total neutron flux in the central flux trap for a typical target loading has been measured to be $\sim 4.0 \times 10^{15}$ n/cm²-s with a thermal-to-nonthermal ratio of ~ 1.7 .⁴ The peak thermal flux in the reflector is $\sim 1.4 \times 10^{15}$ and occurs near the tips of the beam tubes.⁵ The neutron thermal-to-nonthermal ratio in the reflector ranges from around 1 to 30. Three tangential beam tubes and one radial beam tube start near the peak flux in the reflector and penetrate the reactor pressure vessel (see Fig. 1). These beam tubes provide holes in the shielding that allow the neutrons to stream to the areas where they can be used by neutron scattering instruments.

It should also be noted that although SNS has become the flagship neutron science facility at ORNL, the capabilities of the upgraded HFIR are equally important to certain portions of the neutron scattering user community and are complementary to the capabilities offered by SNS.

Thermal beam enhancement

The first step in enhancing the thermal neutron beam capabilities at the HFIR was to increase the size of beam tubes HB-1, HB-2, and HB-3. Although the size of the penetrations through the pressure vessel was fixed, it was determined that modifi-

cations could be made to the feed-through designs to increase the size of the beam tube opening for all three thermal beam tubes.

At HB-1 and HB-3, new focusing monochromators and monochromator drums were designed, built, and installed to accommodate the larger beams supporting thermal triple-axis spectrometers (the new HB-1 drum is shown in Fig. 2). In 2001, measurements taken following the modifications indicated an improvement by nearly a factor of three in usable flux at the two instruments fed by the HB-1 beam. At the sample position at HB-3, there was a measured gain in usable flux of nearly a factor of six.⁶ In addition, when this increase in signal is coupled with a proportionally smaller increase in the background for the instruments, the signal-to-noise ratio is greatly increased. These gains are significant and represent a considerable improvement in instrument performance.

HB-2 is the largest beam tube at the HFIR. In order to take full advantage of the size of the neutron beam, the concept of a tunnel structure that would extend into the beam room was developed, allowing instrument access to the neutron beam from three sides. Also, to maximize thermal flux, a beryllium insert was designed for the inside nose of the beam tube that effectively gives the beam tube a tapered geometry, which has been used at other research reac-

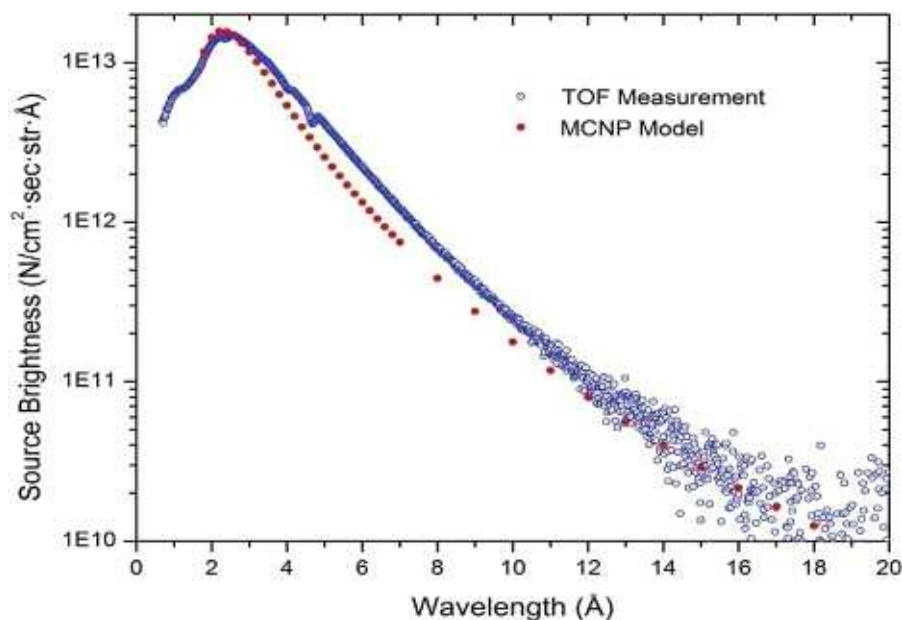


Fig. 3. Comparison of measured HB-4 neutron source brightness with model estimates

tors to enhance the usable neutron current in the beam tube.

Because the HB-2 radial beam tube “views” the reactor core, the very high neutron and gamma flux in the beam presented significant shielding problems since space was limited. The estimated dose on the inside of the shield wall was calculated to be on the order of 100 rem/h, and the requirement was to reduce this to <5 mrem on contact with the outside surface of the shielding. After several design and calculation iterations, a special mixture of steel shot, stearic acid, and paraffin inside a steel container was found to provide the shielding function required. The tunnel was fabricated with four instrument positions fed by four separate monochromators (HB-2A–D). In order to deliver the maximum flux to HB-2D, a section of supermirror thermal neutron guide was installed in the shield tunnel to feed that beamline.

The new cold neutron beams

The most significant upgrade to the scientific capabilities of the HFIR is the addition of a supercritical hydrogen cold source in the HB-4 beam tube. This is a closed-loop forced circulation hydrogen system that maintains the temperature of the hydrogen near 20 K at a pressure of around 15 bar. The neutron energies are moderated by scattering from the half-liter volume of hydrogen located in the nose of the HB-4 beam tube close to the peak flux in the reflector. Each time a neutron collides with a cold hydrogen atom, a transfer of energy occurs that results in a decrease of the neutron’s energy. The result of many neutron collisions with the cold hydrogen atoms is a substantial shift in the energy spectrum of the HB-4 neutron beam. This source feeds four supermirror neutron guides of various sizes that trans-

port the neutrons out to the Cold Neutron Guidehall—a building separate from the reactor that houses the cold neutron instruments—with minimal losses. Figure 3 provides a comparison of the measured source brightness as a function of neutron wavelength versus the model estimates obtained from a Monte Carlo analysis at the start of the guides in the beam room guide tunnel.⁷ These guides transport neutrons to seven cold neutron instrument positions in the guidehall. The cold source began operation in May 2007 and at present has completed 23 reactor cycles.

The Cold Neutron Guidehall

While thermal neutrons are well matched to the length scales of atomic lattices, cold

neutrons are better suited for the studies of larger structures, including aggregates, large molecules, and large unit cells. The cold source at the HFIR provides a new set of tools for studying these “large-scale” structures.

Operationally, one of the advantages of low-energy, or cold, neutrons (<10 meV for this discussion) is that just as fiber optics can be used as a waveguide for light, neutron guides can be used to transport cold neutrons to distances away from the reactor with minimal neutron beam strength loss. Neutron scattering instruments can therefore be located a relatively long distance (30 to 75 meters, in many instances) from the reactor, where there is more space for the instruments’ footprint and supporting equipment. At this increased distance from the reactor, the instruments are less affected by background radiation from the reactor, and with the additional space, it is easier to place shielding to protect neighboring instruments from radiation produced by experiments. In addition, curved neutron guides are used to bend the cold neutron beam, eliminating line-of-sight gammas and higher-energy neutrons (originating in the reactor core) from the beam. These guides have up to hundreds of thin coatings that provide small-angle deflection of the neutrons, allowing the beam to be bent. This makes downstream shielding easier and also reduces the potential for neutron background problems at the instruments due to thermalization of higher-energy neutrons in the shielding.

Figure 4 provides a view from the south end of the HFIR Cold Neutron Guidehall. Shown in the foreground are the two new small-angle neutron scattering (SANS) instrument detector tanks, which are located



Fig. 4. The Cold Neutron Guidehall at the HFIR, looking back toward the reactor

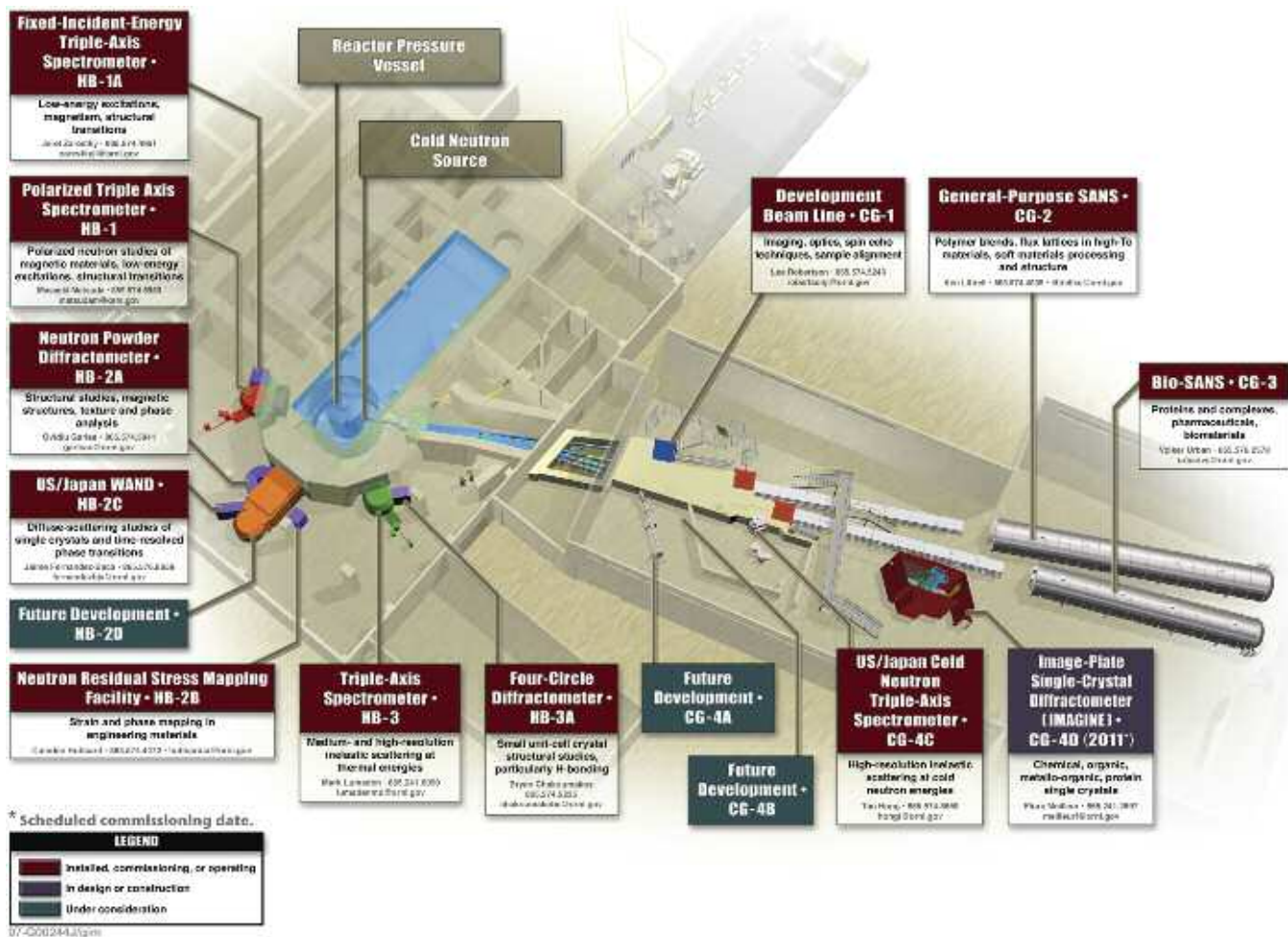


Fig. 5. Model of the HFIR beam room and guidehall showing the neutron instrument systems and their relationship to the reactor (Model: Genevieve Martin, ORNL)

on cold guides 2 and 3 (CG-2 and -3) and have been fully operating with the cold neutron beams for approximately two and a half years. The CG-1 and CG-4 beam lines terminate in the front half of the guidehall, before the yellow walkover (at the rear center of the photograph). Currently, four test station beams are set up at CG-1, and a cold triple-axis instrument has been installed on CG-4. In addition, design work has begun on a single crystal diffractometer instrument that would be located at the end position of CG-4. The performance of the SANS instruments indicates that the objective of providing world-class cold neutron beams with relatively low background levels has been achieved.

Neutron scattering instruments

Fourteen operational neutron instruments are located at the HFIR. Most of these instruments—described below, along with an indication of the types of experiments that can be performed using each—are part of the neutron scattering user program (see page 40). Figure 5 shows the layout of all the instruments and their locations within the HFIR beam room and Cold Neutron Guidehall.

■ HB-1 Polarized Triple-Axis Spectrom-

eter—Of the four triple-axis spectrometers at the HFIR, HB-1 is the only one designed specifically for polarized-beam measurements. The high flux and a wide range of incident neutron energies (between 5 and 120 meV) make this instrument suitable for polarized studies of magnetic excitations in materials exhibiting colossal magnetoresistance (CMR) and high-temperature superconductivity (HTSC) in cuprates. A good example is the study of “resonance” excitations in certain high-temperature superconductors, which are thought to play a crucial role in electron pairing. In the unpolarized mode, HB-1 becomes a state-of-the-art tool for studying various types of excitations and critical phenomena in a variety of materials, from shape memory and superelastic alloys to thin films and quantum materials.

■ **HB-1A Fixed Incident Energy Triple-Axis Spectrometer**—This instrument was constructed by the Ames Laboratory (operated for the DOE by Iowa State University) in collaboration with ORNL scientists. It is used to study excitation spectra of condensed matter systems at high temperatures using neutron energy gain. The very low contamination of the incident beam by higher-order monochromator Bragg reflec-

tions also makes the instrument useful for elastic studies on crystallographic or magnetic structures and transitions.

■ **HB-2A Powder Diffractometer**—This instrument (see Fig. 6) was installed in 2008 and entered the user program in early 2009. Located at the HB-2A beam position, it is now used for structural studies of powdered samples, particularly as a function of sample environment. Materials that can be studied include catalysts, ionic conductors, superconductors, alloys, ceramics, cements, CMR perovskites, magnets, minerals, radioactive waste forms, and zeolites. A full range of ancillary sample environments can be used, including refrigerators (4–800 K), furnaces (up to 1900 K), cryostats (down to 0.3 K), and cryomagnets (up to 7 tesla). The ideal sample size is 1–4 cm³ of material, and typical data collection times range from a few minutes to a few hours.

■ **HB-2B Neutron Residual Stress Mapping Facility**—This instrument uses the penetrating power of neutrons to scan residual stresses in engineering materials. Examples of past work on this instrument include studies of welds, forgings, extrusions, bearings, and materials under applied stress, as well as piezoelectric materials under the influence of electrical fields. Strain scan-

ning studies of co-extruded piping performed on this instrument for the pulp and paper industry's black liquor recovery boilers were instrumental in the selection of alternative cladding alloys for improved boiler performance.⁸ The study of post-weld annealing effects on residual stresses in welded steel plates has been used to provide a nondestructive and detailed delineation of stress pattern changes arising from the heat treatment.

A recent example of the application of HB-2B is the measurement of residual stresses in areas around holes cut in steel railsides for truck frames to help improve truck safety and the economics of truck frame manufacturing.⁸ Two diffractometer setups are available: one for spatial scanning of residual stresses at depths from a millimeter to several centimeters, with spatial resolution at a fraction of a millimeter possible, depending on the material; and the other for strain scanning of large-grained materials and single crystals and for measuring preferred grain orientation in polycrystalline materials. Ancillary equipment that is available for use with this instrument includes a 5000-lb uniaxial (tension or compression) load frame, a Huber Eulerian Cradle, and high-temperature furnaces (vacuum or air).

■ **HB-2C U.S./Japan Wide-Angle Neutron Diffractometer (WAND)**—This instrument is useful for the study of time-resolved phenomena (millisecond time slices) and for the study of diffuse scattering in single crystals. Examples of research performed at the WAND include studies of magnetic structures, precursor structures in martensitic phase transitions, and structural fluctuations of superionic conductors. Other studies have included time evolution in the order-

disorder transition, phase separation, crystallization of amorphous alloys, and phase transformations. More recently, HB-2C has been used to study the hole and charge ordering in CMR materials.⁹ A full range of ancillary sample environments can be used at the WAND, including cryostats and closed-cycle refrigerators (0.3–800 K), furnaces (up to 1900 K), and a 3-tesla cryomagnet. This instrument is operated in collaboration with the Japan Atomic Energy Agency under the U.S./Japan Cooperative Program on Neutron Scattering Research. The WAND Steering Committee is preparing a scientific case for a major upgrade to the WAND instrument in the 2011–2012 time frame.

■ **HB-3 Triple-Axis Spectrometer**—This instrument is a high-flux thermal neutron three-axis spectrometer designed for inelastic measurements on single crystals over a wide range of energy and momentum transfers. While the energy and momentum ranges available at HB-3 are quite large, the instrument is optimized to perform experiments at high-energy transfers. Examples of experiments performed on this instrument are resonance excitations at high energies in high-temperature iron-arsenic superconductors¹⁰ and magnons in materials such as iron or nickel. A wide range of sample environments can be accommodated, including low-temperature (down to a few hundreds of mK), cryomagnets, and furnaces.

■ **HB-3A Four-Circle Diffractometer**—This instrument is primarily used for neutron crystallography of small unit cell crystals ($V < 15,000 \text{ \AA}^3$). It is suitable for a wide range of crystallographic problems, from structure refinement and solution to charge and nuclear density mapping. Locating hy-

drogen atoms in the presence of heavy atoms, as well as problems from chemistry, physics, materials science, and mineralogy, can be addressed with this instrument. It can also be used for more general solid-state physics problems, such as magnetism, diffuse scattering, and ordering phenomena. HB-3A was incorporated into the formal user program during spring 2010.

■ **CG-1 Test Stations**—The cold beam at CG-1 is the most intense cold neutron beam at HFIR. Recently completed was the installation of a system that allows this beam to be split into four separate beams that feed as many as three separate test stations simultaneously. The test stations will be used to develop and test new neutron instrument concepts. Although the test station beams are in a commissioning phase, demonstrations have shown that they can also be used to perform basic research in the field of neutron imaging. According to a recent press release from ORNL, "Scientists and engineers from the United Technologies Research Center are using the neutron imaging available at HFIR's CG-1D development beamline to validate physical models needed for improved design of ejector valves used in the expansion portion of HVAC cooling cycles. Improved multiphase ejectors can improve HVAC efficiency to a point where refrigerants such as CO_2 can be utilized to achieve efficiency levels similar to hydrofluorocarbons, thereby reducing refrigerant contribution to global warming."

■ **CG-2 40-m General Purpose SANS**—This new instrument, located on CG-2 in the HFIR Cold Neutron Guidehall, uses low-energy neutron beams to study soft materials *in situ* to follow structure evolution in industrially relevant equipment, such as extruders. It is also suitable for studying small ($\sim 1\text{-mm}^3$) crystals of high-temperature superconductors to probe flux line lattice melting processes and to undertake kinetic studies of materials, such as the investigation of phase separation kinetics in polymer blends and metallic alloys. Among the many things that SANS is used to study are molecules called dendrimers, which are used in drug casings. Research with SANS is helping scientists develop cancer-fighting drugs that target particular locations in the body. The instrument was introduced into the user program in 2007 and has been heavily subscribed by the user community.

■ **CG-3 35-m Bio-SANS**—This new instrument is located at the end of CG-3 in the HFIR Cold Neutron Guidehall and is primarily used for the study of biological materials, which are often weak neutron scatterers. The high intensity of the cold neutron beam at this instrument allows for smaller samples ($\sim 1 \text{ mg}$) to be probed than could previously be handled at ORNL. This is important for biological materials, where



Fig. 6. The new HB-2A Powder Diffractometer at HFIR

the samples are often difficult to prepare in bulk—for example, with pharmaceuticals, where typically only small amounts are initially available. The Bio-SANS is helping in the development of biofuels by providing highly detailed images of plant sugars, which can help scientists find more cost-effective ways to convert biomass to usable energy, and is also being used for medical studies, including the search for a cure for Huntington's disease. The instrument was added to the user program in 2007 and has been heavily utilized.

■ **CG-4C U.S./Japan Cold Triple-Axis Instrument**—This new instrument has been installed at the CG-4C neutron beam position and is in the commissioning phase. The result of collaboration among the DOE, ORNL, Brookhaven National Laboratory, and the University of Tokyo, CG-4C will focus on the analysis of low-energy excitations in materials and will be useful for studying magnetic effects. Once operational, it is expected to be used to provide advancements in a number of fields, including condensed matter physics, energy, and transportation.

■ **CG-4D IMAGINE**—A project was initiated in 2009 to build a single-crystal neutron diffractometer (IMAGINE) at the CG-4D neutron beam position. This instrument is the result of collaboration among ORNL, the National Science Foundation, the DOE, Middle Tennessee State University, North Carolina State University, and the Hauptman-Woodward Medical Research Institute, and will combine Laue or quasi-Laue geometry and a large cylindrical image plate detector to achieve a gain of up to two orders of magnitude in performance as compared to traditional diffractometers. The program centered around this instrument is expected to have broad scientific impact in the analysis of light atom positions in materials that will be of interest across diverse fields in structural biology, pharmacology, chemistry, condensed matter physics, nanoscience, environmental science, and geosciences. The IMAGINE instrument is scheduled to be approved for start of commissioning in fall 2011.

Plans for new instruments

An effort is under way within the Neutron Sciences Directorate at ORNL, with help from the neutron scattering community, to identify appropriate instrumentation for thermal beam HB-2D and cold beam positions CG-4A and CG-4B. The goal is to have all beam positions filled with operating user instruments within a five-year time frame.

Neutron scattering user program

Users of both the HFIR and SNS neutron scattering instruments include academic, industrial, and government scientists and engineers. The formal user program at HFIR,

begun in March 2003, is now an integrated SNS/HFIR activity that allows access to instruments at both facilities and provides opportunities for attracting new researchers, hosting workshops, seeking collaborations, and organizing the annual National School on Neutron and X-ray Scattering. The allocation of beam time is designed to maximize the scientific output of both facilities as judged through an external peer review process.

A call for beam time proposals is issued twice each year. Information on proposal submission is available on the ORNL Web site at <<http://neutrons.ornl.gov/users/index.shtml>>. The majority of experiments performed within the user program involve open research, with the results published in the open literature. Proprietary experiments can be accommodated, but full cost recovery is required for proprietary work. All proposals are reviewed for feasibility, safety, and scientific merit. More information about the user program is available from the Neutron Scattering User Office at <neutronusers@ornl.gov> or 865/574-4600.

Other capabilities at the HFIR

Although neutron scattering represents the primary mission of the HFIR today, several other activities are performed there that enhance its position as a national resource for scientific research.

■ **Isotope Production**—Although isotope production is no longer considered the primary function of the reactor, it remains an important capability. Isotopes produced through irradiation at the HFIR find uses in technologies for saving lives through nuclear medicine and for supporting U.S. economic competitiveness and homeland and national security. ORNL is currently the Western world's primary supplier of transcurium elements, producing isotopes such as californium-252, einsteinium-253, and berkelium-259 by using the combined capabilities of the HFIR and the Radiochemical Engineering Development Center (REDC) (<www.ornl.gov/sci/nuclear_science_technology/redc/>), which is located adjacent to the HFIR facility. Isotope production feed material targets are fabricated at the REDC, irradiated in the HFIR, and then

processed at the REDC for separation and purification. Other isotopes produced at ORNL that utilize the HFIR's high-flux capabilities include tungsten-188, holmium-166, and lutetium-177, for medical treatment purposes; nickel-63, for the detection of explosives and drugs at airports; and selenium-75 and holmium-166m, for industrial uses.

The HFIR isotope production program made international news recently for its role in the discovery of element 117 (NN, May 2010, p. 73). Over 250 days, the HFIR generated 22 milligrams of nearly pure berkelium for use by Russian researchers in the production of the new element.

For more information on isotope production at ORNL, contact <binderjl@ornl.gov>.

■ **HFIR Gamma Irradiation Facility**—The spent fuel elements from the HFIR core have been used to create the Gamma Irradiation Facility in the reactor spent fuel pool. A cadmium-lined post shields any neutrons from the sample so that it does not become activated. Air supply and off-gas lines are available to the irradiation facility to provide a sweep gas and for temperature control. The present maximum dose rate available in the facility is approximately 1×10^8 rad/h. The facility has been used to study the effects of long-term radiation exposure of materials (such as insulation, electronics, salts, resins, paints, and plastics) for the National Aeronautics and Space Administration and others. In the field of biology, the facility has been used to study the effects of gamma radiation on the AIDS virus. This facility is also used to environmentally qualify commercial-grade equipment for nuclear applications in accordance with the requirements of 10CFR50.49 and IEEE 323. As with the neutron scattering program, there is no charge for the use of this facility for nonproprietary work unless special equipment or staff support is required.

For more information on the Gamma Irradiation Facility and its use, contact <bryancd@ornl.gov>.

■ **HFIR Materials Irradiation Program**—The intense neutron flux and the wide range of neutron spectra accessible in the reactor core and beryllium reflector make the HFIR

HFIR IRRADIATION FACILITY CHARACTERISTICS

	Target	RB Star	Small VXF	Large VXF
Fast Flux, ($E > 0.1$ MeV $\times 10^{14}$ n/cm ² -s)	11	5.3	0.5	0.13
Thermal flux (10^{14} n/cm ² -s)	20	9.7	7.5	4.3
Fast/thermal flux ratio	0.6	0.5	0.7	0.3
Peak dpa/cycle (SS)	1.8	0.67		
Gamma heating (W/g SS)	46	16	3.3	1.7
Typical capsule diameter (mm)	16	43	37	69
Number of available positions	37	8	16	6

dpa = displacements per atom; SS = stainless steel; W/g = watts per gram; VXF = Vertical Experiment Facility

a useful and special tool to study irradiation effects on materials. Since 2003, there have been more than 450 peer-reviewed publications on material irradiation work performed at the HFIR. Facilities for performing irradiation experiments include a wide range of instrumented and uninstrumented positions of various sizes and neutron spectra. A summary of the irradiation positions and their characteristics is provided in the accompanying table.

For more information on irradiation capabilities at the HFIR, visit the ORNL HFIR Web site at <http://neutrons.ornl.gov/hfir/hfir_experiment.shtml>, or contact <burnettese@ornl.gov>.

■ **Neutron Activation Analysis**—Two pneumatic tube facilities are installed in the reactor for conducting neutron activation analysis (NAA). They have thermal neutron fluence rates of 4×10^{14} and 5×10^{13} n/cm²-s and are 97 percent and >99 percent thermal, respectively. NAA is used to measure trace element content in a wide variety of materials nondestructively and with freedom from the “matrix” effects common to chemical methods. NAA at the HFIR supports DOE programs, work for other projects, and educational outreach in radiochemistry and nuclear engineering. These facilities have been used in a wide range of areas, from analyzing trace evidence related to homicides, to the evaluation of bullets from the 1963 assassination of President Kennedy, to refuting the idea that President Zachary Taylor was assassinated by arsenic poisoning.¹¹ The delayed neutron counting array facilitates the rapid, accurate measurement of traces of fissile material for nuclear nonproliferation and forensics efforts. At a sizeable fraction of the HFIR peak fluence rate, the production of research quantities of radioisotopes using the NAA facility has assisted in the measurement of fundamental physics constants such as cross sections, the characterization of advanced materials, and the study of surface phenomena.

For more information on neutron activation analysis at the HFIR, contact <glasgowdc@ornl.gov>.

The HFIR's future

With the continued successful operation of the HFIR cold source, coupled with the addition of new instruments that become quickly oversubscribed, and the continued demand for isotope production and irradiation experiments, the future for the facility looks very bright. In the near term, neutron beam instruments will be built to fill the open beam positions at the HFIR, which will continue to provide research capabilities complementary to those at the SNS.

Plans are also being proposed, as documented in the DOE's 20-year facility plan,¹² to build a second cold source and guidehall

at the HFIR. The cold source would be installed in the HB-2 beam tube, which is the most intense neutron beam available at the HFIR, and could provide at least a factor of four performance improvement over the existing cold beam lines. This new facility could support nine additional neutron instruments. If completed as currently planned, this facility would be available for use in the early 2020s and would ensure significant scientific use of the reactor for many years to come.

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