Remote handling in the Spallation Neutron Source target facility

BY MARK J. RENNICH AND THOMAS W. BURGESS

The Department of Energy offers its latest step in the development of accelerator-based neutron research facilities.

NEUTRONS OFFER UNIQUE advantages for exploring the atomic structure of molecules. Their first use occurred at Oak Ridge National Laboratory (ORNL) in the 1950s under the leadership of Nobel Prize winner Clifford Shull. Since that time, many neutron research facilities have been constructed worldwide, beginning with reactors and later using accelerators in combination with a neutron-generating target. Remote handling has been central to the safe and efficient operation of these facilities.

The Spallation Neutron Source (SNS), a new Department of Energy facility located at ORNL, is the latest step in the development of accelerator-based neutron research facilities. SNS boasts a tenfold increase in neutron production over the most powerful short-pulse spallation facility in existence today, ISIS, located at the Rutherford Appleton Laboratory in the United Kingdom. It will ultimately be powered by a 2-MW, 1-GeV, 1-MHz proton linear accelerator measuring 1100 feet in length. One thousand beam pulses will be bunched in a ring and then directed to a flowing liquid mercury target that will convert the protons to a pulse of approximately 5×10^{15} neutrons. The neutrons will then be slowed to useful energies and guided to 24 instruments where scientists from around the world will have the opportunity to undertake basic research in materials science.

SNS is progressing on schedule to a beam-on-target start date of April 3, 2006. Scientists from around the world will soon begin to submit proposals to perform testing in the completed facility. This success has resulted from a collaboration of six DOE

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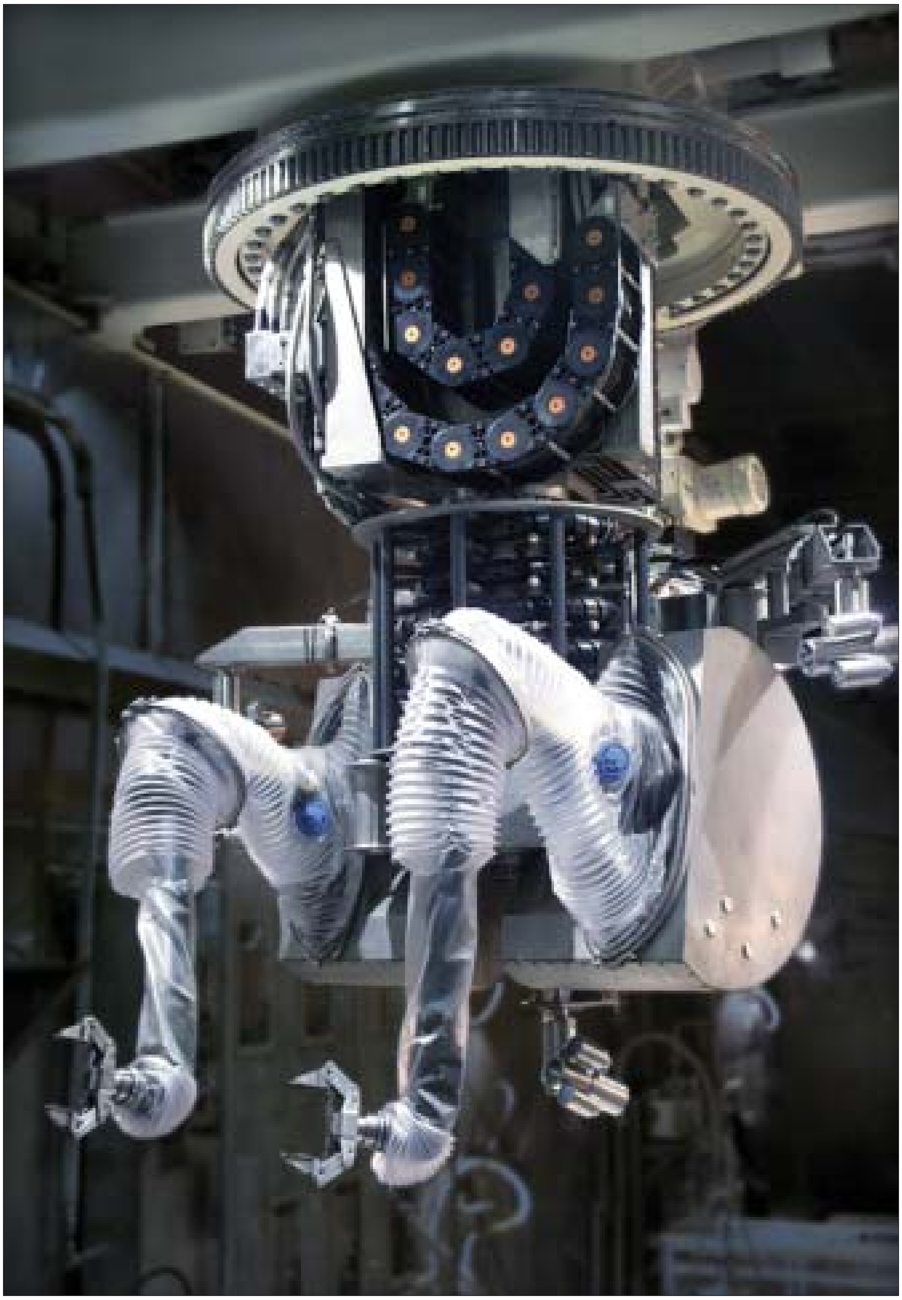


Dual-arm servomanipulators provide dexterous handling capabilities throughout the hot cell. (Photos: ORNL)

The DOE's Spallation Neutron Source, under construction in Oak Ridge, Tenn. The target building is in the foreground.

national laboratories with experience in the segments of the facility for which they were responsible. Consequently, the accelerator was designed and built by laboratories with existing accelerators. ORNL, as the home of SNS, was responsible for conventional facilities, overall coordination, and installation. It was also responsible for the target facility, with its numerous remote-handling challenges.

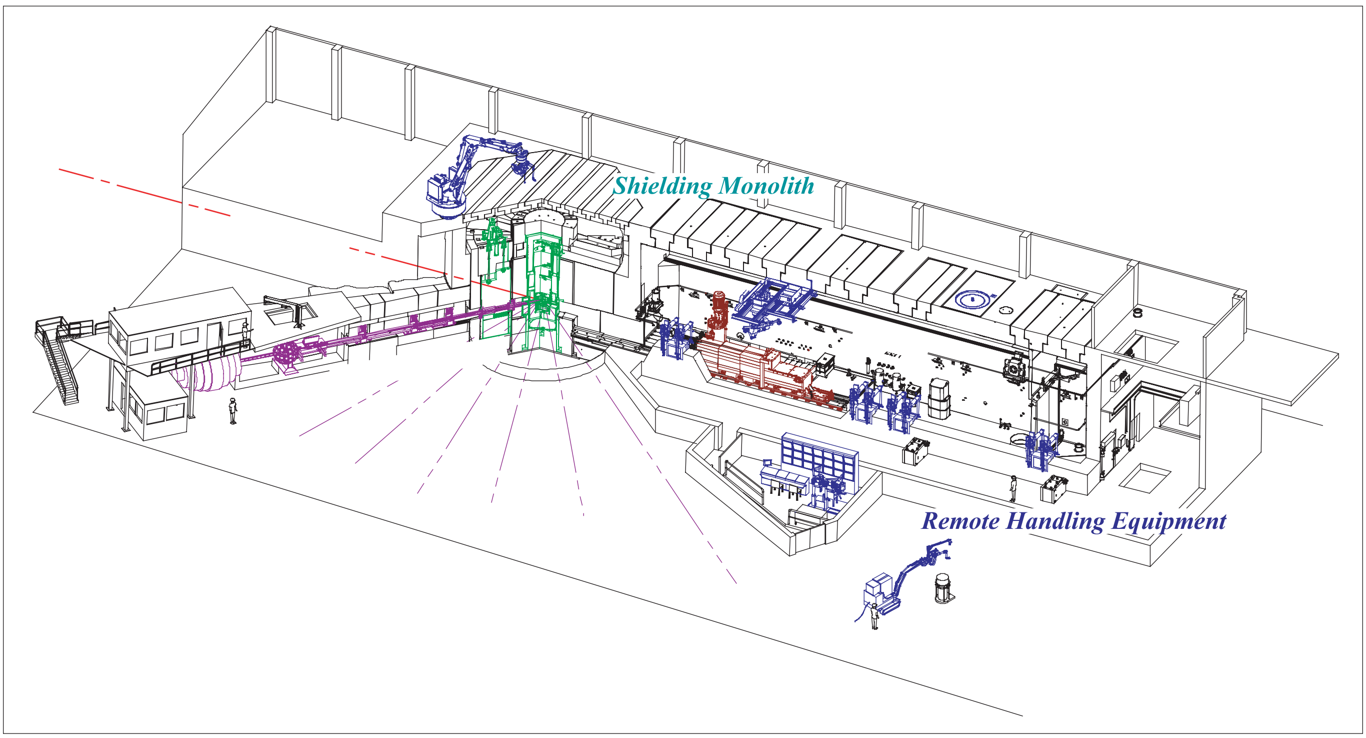
As a user facility in which experiments and user visits are scheduled months ahead, the ultimate success of SNS is based on dependability. The facility is projected to function with a minimum of 90 percent availability during scheduled operations exceeding 5000 hours per year. The twin challenges of forward-looking technology and reliability focused attention on maintenance and planning from the earliest stages of design.

The designers made the SNS accelerator system robust. They also configured the beam line systems to prevent components from becoming activated beyond personnel accessible limits, because the equipment is large and would be complex and costly to repair using remote means. While conservative design techniques were also used in the target system, remote handling could not be avoided because of the inevitable activation of materials where the accelerator beam collides with the mercury target. This problem is amplified by the very high levels of radiation, which accelerate component deterioration. For example, an SNS proton beam window that separates the accelerator beam atmosphere from the target vessel must be replaced annually, while in predecessor facilities this component could be expected to last several years.

Fortunately, the SNS target design team was able to learn from 50 years of neutron science facility development and operation. Early on, experienced designers and operators in the field were consulted, and all existing accelerator-based neutron facilities were visited, with the goal of establishing the most reliable, efficient, and cost-effective configuration. As a result of these consultations, the basic configuration of the ISIS facility was selected for cost, design, and operating reasons. Large shielding components such as the neutron beam line shutter gates, proton beam window, and inner plug are maintained by replacement in the high-bay area above the target shielding monolith. This work is facilitated by a series of shielded containers and a hydraulic boom–mounted manipulator system designed to perform precision work in highly activated areas. Target change out and related process and waste-handling activities are contained in a hot cell referred to as the target service bay.

Challenges of the hot cell

The primary difference between SNS and predecessor facilities is the use of a first-of-a-kind flowing mercury loop to absorb the energy of the proton accelerator beam while efficiently producing neutrons. The mercury introduces long-lived isotopes, conta-



The SNS target building layout, with key remote-handling equipment highlighted in blue

The target service bay, looking toward the mercury process at the west end. The dual-arm servomanipulator is visible at the far end of the cell.

mination, and handling problems. For example, while a solid target becomes highly activated in all facilities, SNS's activated flowing mercury target extends the remote-handling requirements to all the mercury process components. In order to accommodate the mercury process, the entire operation is contained in a hot cell measuring 103 ft long by 14 ft wide by 30 ft high. The mercury process consists of a 60-horsepower centrifugal sump pump, which circulates 360 gallons of mercury through the target container, and a 1.4-MW double-walled heat exchanger. This operation requires about one-third of the length of the cell, with the remaining cell volume needed for storage, waste-handling, and a maintenance cell for the overhead bridge crane and the manipulator system. Forty-in. thick, high-density concrete shielding walls protect personnel during changeout of the 2500-lb spent targets, which have a contact dose rate greater than 10^4 gray/hour (Gy/h; 10^6 rad/hour). Local shielding inside the cell is used to reduce the usual background radiation to roughly 3 Gy/h (300 rad/h) to protect equipment such as cameras and manipulators. Given these dose rates, the design assumes that personnel will not be able to enter the hot cell at any time, and therefore, all processes and equipment are remotely maintained.

While the SNS hot cell design is similar to that of other hot cells, its remote-handling capabilities are significantly different from those of other cells currently in use. Heavy shielding walls, lead-glass windows, mechanical master-slave manipulators (MSM), and large, high-efficiency filtration systems remain fundamental building blocks. Computers, however, have significantly advanced the way that hot cells and hot cell equipment are designed, manufactured, and operated. SNS relied on Internet communication within the larger remote-handling community to keep the internal remote-handling design team small and efficient. With the broad range of electronic tools, particularly solid modeling, this proved to be especially effective. The freedom to exchange ideas quickly allowed for a great deal of creativity and flexibility by all the designers. Most important, solid modeling simplified the resolution of difficult remote-handling design problems, and this in turn reduced the need for expensive mockups and test fixtures.

The size of the SNS mercury process equipment, and the complexity of the tasks within the hot cell, motivated a departure from traditional hot cell design, which is constrained by limited remote-handling dexterity and coverage. With the advent of digitally controlled, force-reflecting "servomanipulators" mounted on robotic overhead bridges, combined with a multicamera viewing system, dexterous handling operations are no longer confined to window work stations. Remote maintenance can now be performed more effectively and quickly throughout the cell. PaR Systems, of St. Paul, Minn., joined with Telerob GmbH, of Ostifildern, Germany, to build the servomanipulator and bridge crane systems that are the primary maintenance tool in the SNS hot cell.

The Telerob EMSM-2B servomanipulator arms each have six positioning degrees of freedom, plus a gripper axis, a 72-in. reach, a 55-lb continuous capacity, and a 100-lb peak capacity. Scaleable force reflection, joint indexing, tool weight cancellation, and other advanced control features minimize operator fatigue and give the teleoperated arms capabilities beyond those of standard MSMs. The servomanipulator package includes a 500-lb auxiliary hoist for assisting in component-handling and tool support. This is particularly important for a system normally operating in areas in which dropped tools can be difficult to retrieve.

The servomanipulator bridge is supplemented by a robotic 7.5-ton bridge crane mounted on an independent set of rails at the top of the cell. Precise robotic position control of the bridges allows the arms or hoist hook to be positioned automatically to within less than 1/8 in. This feature has been shown to speed and simplify operations within the cell in several ways. For example, accurate location of the bridges for known operations such as lift fixture placement can substantially reduce the amount of time required to perform lifting operations by eliminating the tedious process of hook placement. Equally important is the ability to preprogram exclusion areas and safe-passage zones. Operator-actuated 120-VAC and 48-VDC power outlets on the crane hoist block are used for the control of

The target service bay remote-handling systems control room

The pedestal manipulator system provides dexterous remote handling when replacing target region components located outside of the hot cell.

tools suspended from the hook. Of these, the most notable is the compact ZIP-LIFT™ load connector grapple with a capacity of 7.5 tons, from Fastorq Bolting Systems Inc., of Houston, Tex.

A comprehensive video camera system is required for operators to monitor and control the hot cell remote-handling systems. For this, Imaging and Sensing Technology (IST) Corporation, of Horseheads, N.Y., provided a complete, integrated system starting with 11 radiation-tolerant Model R981 video cameras distributed on the hot cell walls, bridges, and servomanipulator package. Images from the cameras are routed through an electronic video matrix that allows the operators to easily switch camera views to any of the 21 monitors. All the cameras have remote-control pan/tilt/zoom capability, and some include microphones and lights. The video system is complemented by an eight-channel DVD recording system that continuously records eight hours of activity on a hard drive. This ensures that notable events are stored for later permanent recording.

The in-cell viewing system can tolerate the 10^4 Gy/h (10^6 rad/h) radiation levels present while changing out a spent target. With a lifetime total absorbed dose rating of 10^6 Gy (1.4 MeV gamma; 10^8 rad), the cameras should function for several years. These limits prompted the installation of local shielding around the mercury process to reduce the general cell background radiation. This was particularly important because the mercury system is not only highly radioactive, but also large.

The integration of the hot cell systems using Internet communications is evidenced throughout the cell. Notable is the incorporation of the video camera system into the overhead bridge systems through a collaboration of IST and PaR Systems. The incorporation of seven cameras and the routing of the video cabling from on-board locations to the hot cell wall made the servomanipulator and bridge crane systems complete packages. The result of the successful interaction of these companies, as well as the designers of the cell lighting and shield door systems, can best be seen in the control room, where an efficient layout of cabinets, video monitors and controls, and transporter manipulator controllers has been achieved.

The integration of the tooling systems carries over to the four window workstations. The window workstations are positioned at key locations in the hot cell to enable the operators to use direct viewing to perform concentrated functions such as target connector handling, waste-handling, and post-mortem target container sampling. Each of the four window workstations is fully integrated with all of the hot cell remote-handling systems to maximize the efficiency of the local operations. As a result, an operator can operate the bridge crane, position the servomanipulator bridge, or take advantage of the in-cell video system through local control of any of these systems. Communication between window workstation and remote-handling control room operators is facilitated by a hardwired audio system linking all of the workstations and the control room. The audio communication and bridge system controllers are also available in the personnel-accessible transfer cell, where the bridge and servomanipulator maintenance activities will take place. This will enable maintenance personnel to safely debug and test systems hands-on.

The SNS hot cell has been equipped with a uniform shield wall penetration configuration. A curved 2 1/2-in. Schedule 40 pipe, sealed with a flange on the outside of the cell and protected with an air block at the midpoint, allows for the external loading of electrical, fluid, or gas service lines, including connectors. Similarly, a uniform two-prong, 1000-lb capacity wall bracket design is used throughout the hot cell to support a large array of equipment such as process service lines, cell lights, and cameras. The standardized bracket simplifies component design and aids operator handling within the cell.

Other proven cell features used in SNS include a bottom-loading hatch for the removal of waste, a ceiling hatch to permit spent components to be loaded from the high bay, and two input enclosures for loading small components into the cell.

High-bay operations

High-bay operations are focused on removing spent, failed, or obsolete components, such as proton beam windows, rather than maintaining them for continued service. Experience at other facilities has shown that this type of component degrades as a result of radiation and use and is not easily repaired. Neutron shutter guides and inner plugs may have to be replaced because of a change in experimental requirements. Consequently, components are designed to be disconnected for removal into shielded transfer casks. Removed components may go into long-term storage, be shipped off site, or moved into the hot cell through a top-loading hatch for inspection, breakdown, or packaging.

Relatively intricate service disconnect and reconnect operations require a dexterous remote-handling capability. In most cases, the service lines, primarily water, are contaminated and are located in highly activated areas. While these operations are not as frequent or intense as those inside the hot cell, special tooling is essential. The purpose-built pedestal manipulator was configured to reach the utility areas in the monolith. A pedestal-mounted hydraulic boom system equipped with a hoist and replaceable with a dual-arm servomanipulator package was specified and procured from TPG Applied Technology (TPG), of Knoxville, Tenn., to perform these operations. The boom system is a modified commercial system that includes four degrees of freedom: pedestal rotation, boom pitch, stick pitch, and tool plate pitch. The system boom has a capacity of 6500 lb and can reach 30 ft horizontally, 32 ft above grade, and 12 ft below grade, giving it access to the pipe fittings and other components located at the top of the shielding plugs. It is configured to be used either to position the servomanipulator arms, or as a crane with a 1000-lb hoist. The Telerob servomanipulator arms are an exact match to the arms used inside the hot cell, and thus provide a rapid replacement capability for this critical system. The servomanipulator package is configured similarly to the in-cell system, with an auxiliary hoist, lighting, and three

The mobile manipulator system will provide remote-handling capabilities throughout the SNS facility.

on-board video cameras. Five pedestal mounting positions have been installed in the SNS high bay to give this system access to all areas in which it may be needed.

The industrial collaboration employed to develop the in-cell servomanipulator system also integrated the Telerob EMSM-2B manipulator arms and IST video cameras with the TPG boom system. The servomanipulator package is attached to the boom via an interface package that provides cable management and +/-340-degree rotation. As with the hot cell bridge-mounted systems, numerous complex mechanical mounting, cable routing, and control system design details were worked out directly between the companies.

Mobile manipulator

A variety of remote maintenance tasks may be performed in areas throughout SNS, including some areas of the accelerator. A mobile vehicle equipped with a servomanipulator, and replaceable with a 500-lb hoist, was procured from TPG to perform some of these operations. The mobile platform is based on a commercial mini-excavator that was converted from diesel to electric power. The system is mounted on tracks that provide versatile positioning capability such as zero-radius turning. The tracks can be retracted for driving through standard doorways as narrow as 39 in. and then extended at the work site to form a more stable base. The boom is similar to the pedestal boom, but with an overall reach of approximately 8 ft horizontally, 10 ft above the floor, and 6 ft below floor level.

The single Telemate servomanipulator arm has a 40-in. reach, a continuous load capacity of 25 lb, and a peak capacity of 33 lb. As with all of the SNS servomanipulators, an auxiliary hoist, cameras, and lights are coupled with the arm to assist with the handling of tools and components. The portable control stations for the vehicle and the manipulator include the vehicle control panel, the servomanipulator master control arm, and man-machine interface.

Startup and operations

The installation of the basic hot cell remote-handling and process systems was completed in May 2005. This cleared the way for the SNS Operations Group to begin testing the fully integrated hot cell systems. From the beginning of testing, the value of the flexible SNS maintenance system has been evident as handling and maintenance operations are effectively performed throughout the cell. Equally important, months of commissioning and operation in this initial startup phase have shown that the handling systems demonstrate the reliability required of remotely operated equipment.

Operational testing has been under way for several months as the intricate task of making SNS a success continues. Remote operation procedures for the hot cell process and cell system components have been fully tested and demonstrated, first with a dry system, and now with mercury. With mercury loaded into the cell, hands-on assistance has been greatly reduced, and operations have successfully shifted to nearly fully remote. Thus, current testing is subjecting the in-cell tooling to the rigors of remote handling well before the equipment is irradiated with “beam-on-target” operation in April 2006.

SNS is preparing to begin scientific operations, the culmination of years of design, R&D, construction, and testing. Significantly, last August the linear accelerator achieved a world’s best performance proton beam energy of 866 MeV. The first scientific instruments are being installed, and experimental proposals are being readied. The target system is on course to be ready to convert the proton beam to neutrons and provide the neutrons to the instruments. More information is available at <www.sns.gov>.