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Preconceptual Design of a Long-Pulse Spallation Source (LPSS) at the LANSCE Facility

Target System, Facility, and Material Handling Considerations

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Preconceptual Design of a Long-Pulse Spallation Source (LPSS) at the LANSCE Facility

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ABSTRACT

This report provides a summary of a preconceptual design study for the proposed Long-Pulse Spallation Source (LPSS) at the Los Alamos Neutron Science Center (LANSCE). The LPSS will use a 0.8–MW proton beam to produce neutrons from a tungsten target. This study focuses on the design of the target station and changes to the existing building that would be made to accommodate the LPSS. The LPSS will provide fifteen flight paths to neutron scattering instruments. In addition, options for generating ultracold neutrons, pions, and muons will be available. High-energy, forward-scattered neutrons on the downstream side of the target will also be available for autoradiography studies. A Target Test Bed (TTB) is also proposed for full-beam tests of component materials and advanced spallation neutron sources. The design allows for separation of the experiment hall from the beam line, target, and flight paths. The target and moderator systems and the systems/components to be tested in the TTB will be emplaced and removed separately by remotely operated, shielded equipment. Irradiated materials will be transported to a hot cell adjacent to the target chamber for testing by remotely operated instruments. These tests will provide information about how materials properties are affected by proton and neutron beams.

EXECUTIVE SUMMARY

A preconceptual design study of the facility-related aspects of a 1-MW Long-Pulse Spallation Source (LPSS) at the Los Alamos Neutron Science Center (LANSCE) has been completed. The LPSS would use the LANSCE accelerator and experimental areas. This design is based on the more than 20 years of successful operation of a 0.8-MW proton beam at LANSCE and several years of operating the Manuel Lujan Jr. Neutron Scattering Center (MLNSC). The design emphasizes reliability, serviceability, and maintainability of components needed to provide proper neutron beams to instruments. Optimization of the target system thermal hydraulics and mechanical design, vacuum system, shielding, collimation, and remote handling techniques are not part of this study.

After completion of the nuclear physics program at LANSCE in September 1995, the accelerator and experimental areas become available for use by new programs. The proposed LPSS will be located in the present LANSCE Area A, following removal of the nuclear physics instruments. Cost estimates indicate that the reuse of Area A represents a substantial savings over the construction of a new beam transport system and new building.

Fifteen flight paths will be available to provide beams to neutron scattering instruments. In addition, means for generating ultracold neutrons from a solid deuterium moderator will be available. A flight path that views the downstream side of the target and transports high-energy, forward-scattered neutrons for autoradiography studies will also be available.

Development of target systems for advanced spallation neutron sources will benefit from the Target Test Bed (TTB) proposed for the LPSS. The TTB is placed upstream of the LPSS target system to allow full beam studies of prototypical spallation neutron source concepts, including liquid metal targets. Studies using the TTB will be of short duration, about one week, and are expected to be nearly full-scale installations.

The LPSS target is made of tungsten rods enclosed in a cladding material. The engineering design of this type of target is presently being developed for the upgrade of the MLNSC facility. Both room temperature water moderators and liquid hydrogen moderators are used in the target system. The target is supported and serviced separately

from the moderators; this design permits flexibility in the moderator configuration and allows configuration changes to be made relatively rapidly.

Central to the layout of the facility is the ability to isolate the experiment floor from the areas for remote handling of heavily irradiated components. Contamination control is ensured through use of a sealed transfer cask that remotely removes components from their in-service position and places them in a hot cell for reconfiguration activities. Air pressures in the facility are controlled to ensure that any radioactive contamination does not migrate into occupied areas. The handling philosophy for servicing radioactive materials and components embraces the ALARA principle: to keep radiation As Low As Reasonably Achievable (ALARA).

INTRODUCTION

Following the completion of the nuclear physics program at the Los Alamos Neutron Science Center (LANSCE), the 800-MeV accelerator and the Area A building, which houses nuclear physics instruments, will be available for use by new initiatives. One such initiative is a Long-Pulse Spallation Source (LPSS), a project that will require some modifications to the accelerator and the development of a target station and instrumentation hall in Area A. This report provides a summary of the design philosophy for the target station and a description of the modifications necessary to the Area A experiment hall to accommodate an LPSS.

1. DESIGN PHILOSOPHY

The preconceptual design for the LANSCE-based LPSS contains several specific design parameters considered absolutely necessary for reliable, high-availability operation of the LPSS. Separation of the experiment hall from the areas where radioactive components are serviced was established as a criterion to ensure that radioactive contamination will be controlled and that work during reconfiguration periods will proceed in both areas simultaneously. A system will be implemented that contains remotely operable bottom-entry shields, into which activated target cell components are placed and transported to a hot cell. Inserts holding targets, moderators, diagnostic devices, irradiation experiments, and materials surveillance coupons will be designed for rapid removal and installation. Shutters capable of shielding against the neutron flux in a beam line will be provided to allow access to a single instrument while the remainder of the facility is in operation. Framing (T_0) and pulse-forming choppers will be included on each beam line. The system for handling activated target cell components will be designed to ensure that worker exposure to radiation is as low as reasonably achievable. The target and moderator components and systems will be designed in a conservative and robust manner. Simplicity, reliability, maintainability, and serviceability were considered in all aspects of the design to be attributes necessary for ensuring high beam availability for periods up to nine months per year.

1.A. LANSCE Area A

The Area A building is constructed of metal beams with a sheet metal skin. The available floor space is approximately 55 m square, and the usable building height is about 14 m.

Instrumentation cable plants are in place connecting the experiment instruments with a central control room that is used for data acquisition and accelerator control. Systems for protecting personnel (Radiation Safety System [RSS]) and equipment (Fast Protect [FP]) are in place. The building is equipped with two 30-ton lifting devices that travel over the floor area on a bridge at the ceiling. An air exhaust system capable of providing a negative pressure in the proton beam transport channel transports activated air products through a filter system to a monitored emissions stack. A substantial level of electrical power is available for operating electromagnets used for proton beam transport in the present configuration. Closed-loop water systems used as heat sinks for the electromagnet power, beam line equipment, and power deposited by the proton beam are in place. Five beam lines and seven experiment stations with spectrometers and other instruments allow viewing of the pions and muons produced in two graphite targets. The beam transport line is shielded with iron and concrete to maintain acceptable neutron flux levels in the experiment area, which is continuously occupied by personnel even when the proton beam is operating.

1.A.1. Removal of Nuclear Physics Instruments, Shielding, and Beam Transport Equipment

The LPSS design for the beam transport line, shielding, target system, and instruments will require removal of all present beam transport systems, nuclear physics instruments, and associated equipment. Sufficient crane capacity exists in the building to accomplish this task.

Instruments and equipment that are currently located outside the main shield are either not activated or are activated to very low levels. This equipment will be removed and stored on site.

Some material that is now located on the outer boundary of the beam line shielding may be used again for the LPSS. A large amount of the shielding and all of the beam line components are activated and therefore could cause contamination. Suitable techniques have been developed so that these components can be removed, decontaminated, packaged, and transported to a permanent storage area. Variations of these techniques were used to estimate the costs associated with preparing the area for installation of the LPSS.

The concrete floor area under the existing two target stations and the proton beam transport line is activated. After the shielding is removed, a layer of iron will be placed over this area to produce a radiation-free environment for the LPSS installation.

1.A.2. Upgrade of Instrumentation, Mechanical, Electrical, and Air Handling Services

The basic instrumentation system and the run-permit system will be modified to meet the needs of the LPSS. Upgrades to the radiation safety system will likely be necessary.

The 30-ton cranes have received extensive use over the past 25 years. Maintenance and refurbishing of these units is necessary before the cleanup activities can begin. These cranes are essential to the eventual installation and maintenance of the experiment instruments.

Adequate electrical power exists in the facility. A power distribution system, specific to the final placement of components such as instruments, cryogenic systems, and other facility-related equipment, will be necessary.

The existing high-efficiency particulate air (HEPA) filter system used in the radioactive air handling system will be upgraded. Appropriate air ducting systems for the LPSS will be necessary. Three levels of negative pressure are required to ensure that any possible contamination is controlled and contained in the proper area. Containment of activated air will be emphasized to minimize the presence of radioactive air in the building and emissions from the building.

1.B. Contamination Control

The components within the target system provide the highest potential for producing activated materials that may lead to contamination. The most heavily activated components are contained within the target vacuum vessel (Figure 1). The hot cell and the activated materials transfer area (Figure 2) will be subject to possible contamination during procedures that expose activated components in these rooms. Radioactive contamination in the beam transport area (Figure 3) will be possible, but will likely be at a low level. The experiment hall will be isolated from the potentially contaminated areas whenever active components are being handled, except possibly when the beam shutters are being serviced. Special sealed shield containers and special procedures will be necessary for work on the beam shutters. Expected activation levels for the shutters are much lower (a few hundred mrem/hr) than those expected for target system components (several rem/hr).

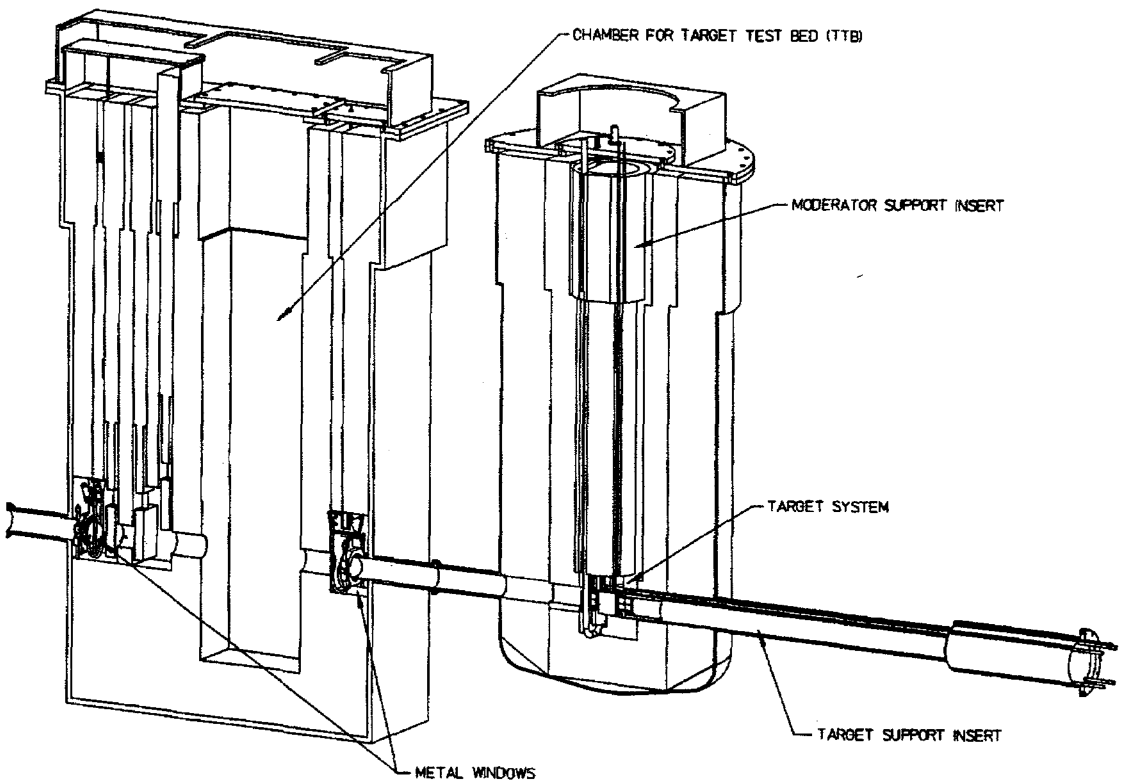

Figure 1. Target system vacuum vessel.

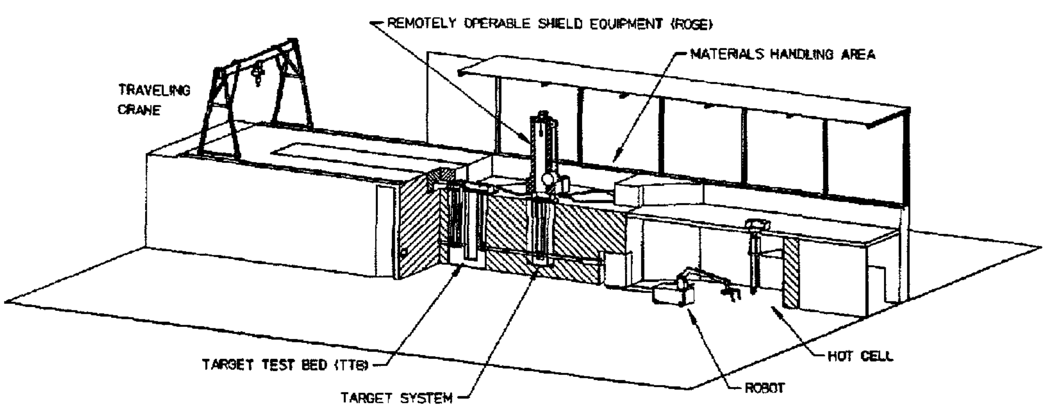

Figure 2. Hot cell and materials transfer area.

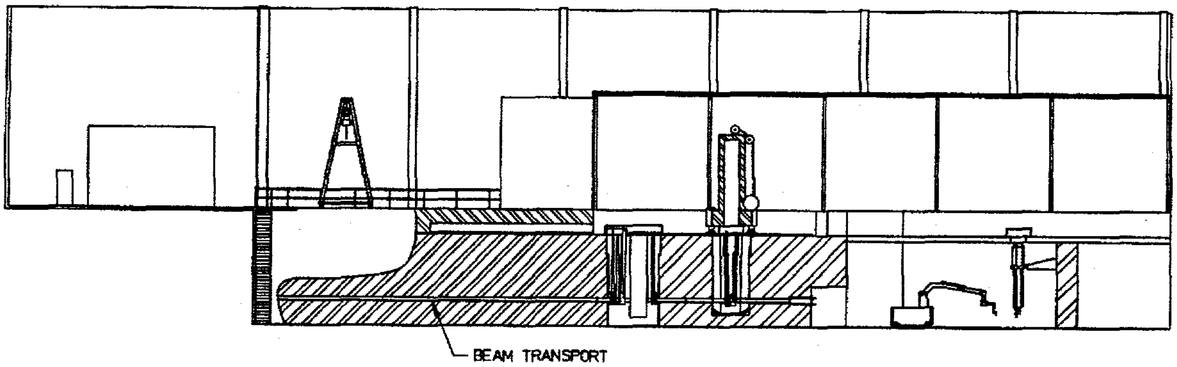

Figure 3. Beam transport area.

Building air pressures must be controlled so that any contaminants will be transported toward the region with the highest probability for contamination. The vacuum vessel surrounding the target system components and the target test bed and diagnostic cell (Figure 1) are maintained at a pressure (vacuum) < 10^{-6} torr. Pumps used to produce the vacuum will be exhausted through the HEPA filters in the radioactive air handling system. Pumps that maintain the vacuum pressure (Figure 4) in the flight paths that connect the target system to the instruments will be treated in the same manner. Note that there is one metal window on the vacuum chamber on each flight path (Figure 5).

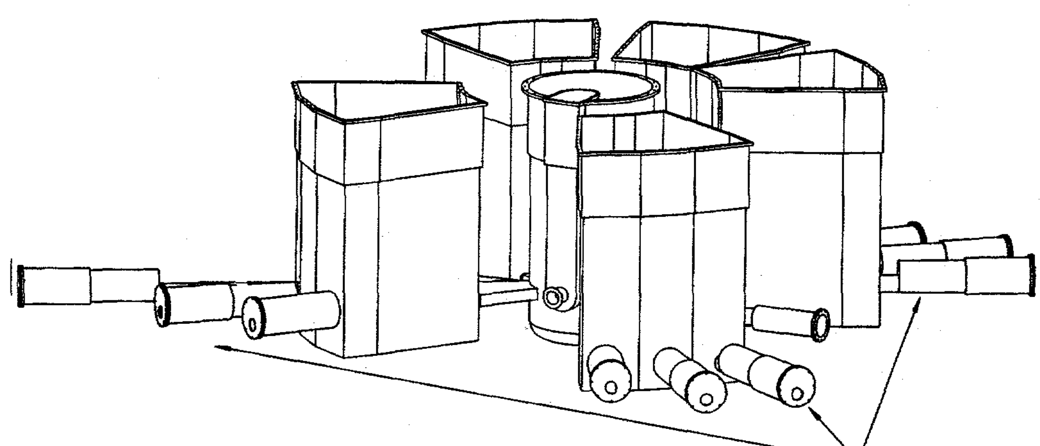

Figure 4. Flight paths maintained at vacuum pressure, or perhaps backfilled with an atmosphere of helium gas.

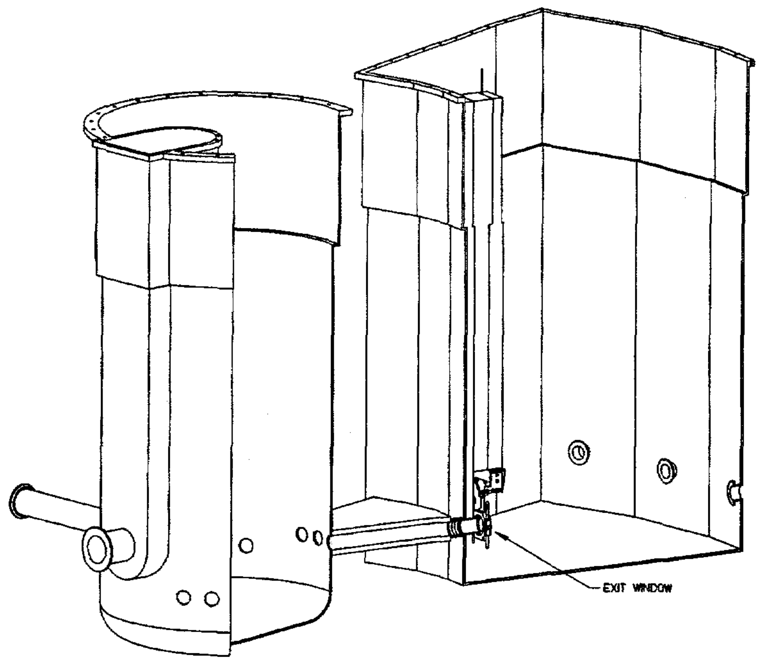

Figure 5. Metal exit windows from the target system vacuum chamber.

An air-tight enclosure is planned for the outer boundary of the bulk biological shield (BBS) (Figure 6). The pressure within this region will be below atmosphere and possibly will be filled with helium to minimize production of tritium and beryllium isotopes, which would be produced in an air atmosphere.

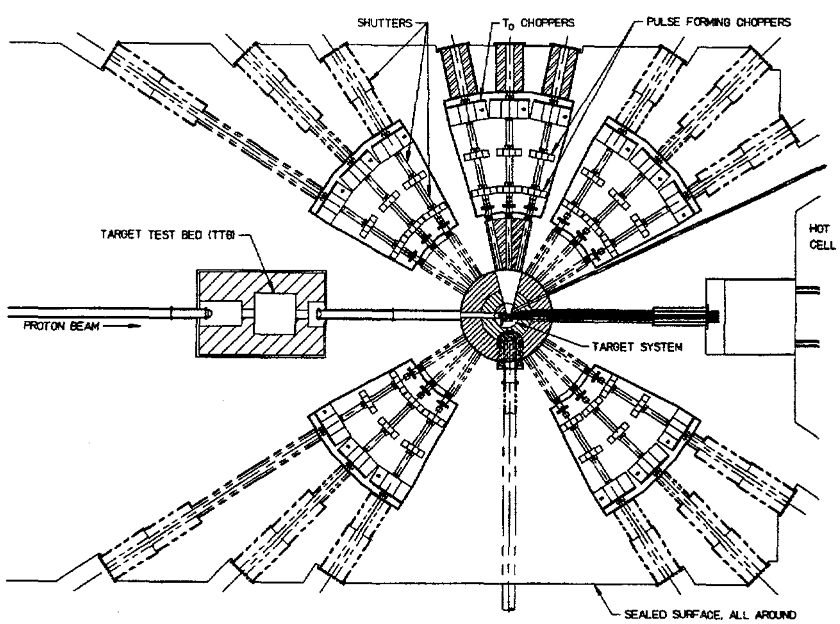

Figure 6. The Bulk Biological Shield (BBS) sealed to the experiment area.

Hot cells have a large potential for radioactive contamination, particularly during cutting and welding operations on radioactive materials. The cells will be maintained at a negative pressure. The exhaust from these cells will be taken through the HEPA-filtered radioactive air system. All equipment and components that are removed from this area will be subjected to a monitoring and decontamination procedure.

The experiment hall will also be maintained at a pressure below atmosphere. Procedures for handling targets exposed to the neutron beam, and thus activated at generally low levels (a few mrem/hr), will be established to minimize any possible contamination of this area. As mentioned above, activities that involve moving the beam shutters and the T_0 choppers will also be closely governed by procedures aimed at minimizing the possibility for contamination.

Transfer of radioactive equipment anywhere in the facility will be accomplished using sealed shielding containers. Special docking rings will be used with the Remotely Operable Shield Equipment (ROSE) to maintain contamination control during maintenance and transfer operations on the radioactive target components. These procedures are described in more detail in the following sections of this document.

1.C. Remote Handling and Hot Cells

In concert with ALARA principles and because of the need to control any possible radioactive contamination, all activities involving handling of activated components will use specially designed and remotely operated shield casks. Figure 7 is a drawing of a cask, referred to as the ROSE, in position over the target system. The ROSE mates to a docking ring that incorporates a remotely operable door to ensure containment of potentially contaminated materials. Figure 8 shows identical docking rings on the Target Test Bed (TTB) and on the roof of the hot cell. Figure 9 depicts a moderator insert positioned in the hot cell for maintenance or disassembly activities.

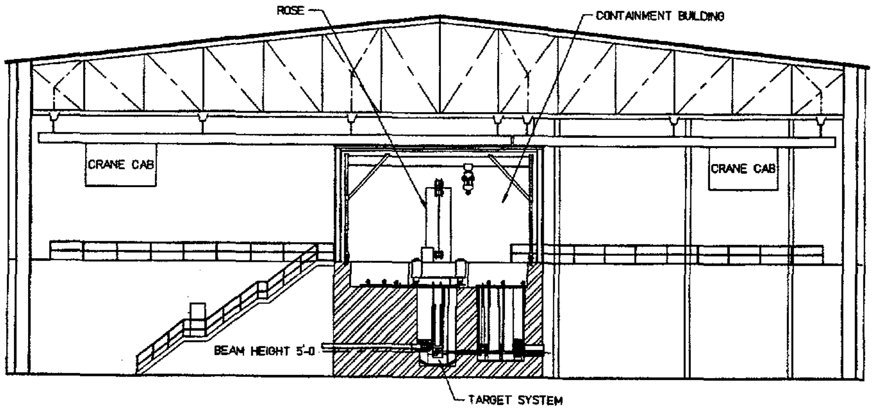

Figure 7. The Remotely Operable Shield Equipment (ROSE) in position over the target system.

The conceptual design criteria placed on handling the active components require that the ROSE mate to the docking rings in a manner that precludes contact of potentially contaminated components with the atmosphere in the containment building, which is used also as a secondary containment area. Hooking and lifting of a component will be performed remotely inside the ROSE. The motor-powered ROSE travels from the target and TTB to the hot cell on a track. The shielding integrity of the ROSE will be adequate to allow radiation workers access to the unit in case of a system failure in the lifting and drive mechanisms.

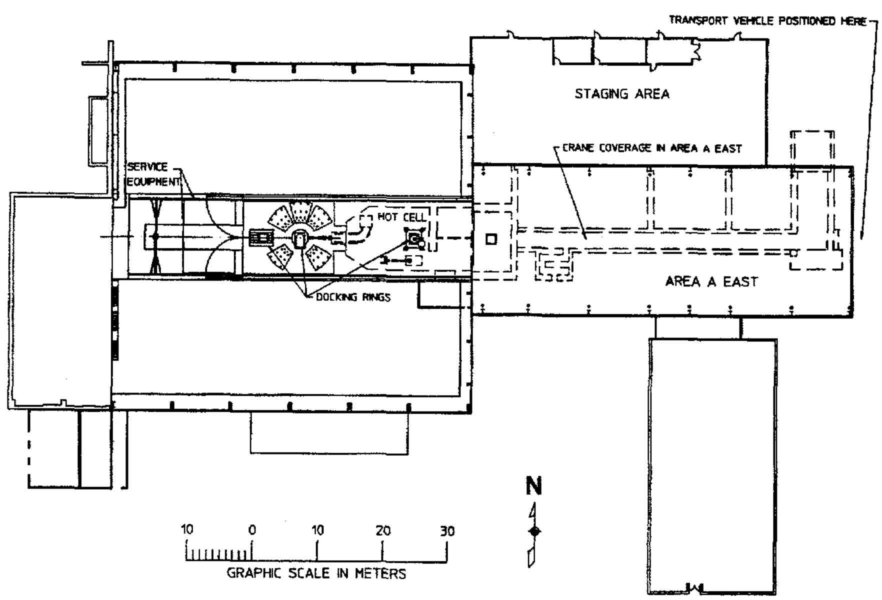

Figure 8. Docking rings for the ROSE on the Target Test Bed, the target system, and the hot cell. Area A East is the route for moving activated components from the LPSS to a transport vehicle and then to a permanent storage facility.

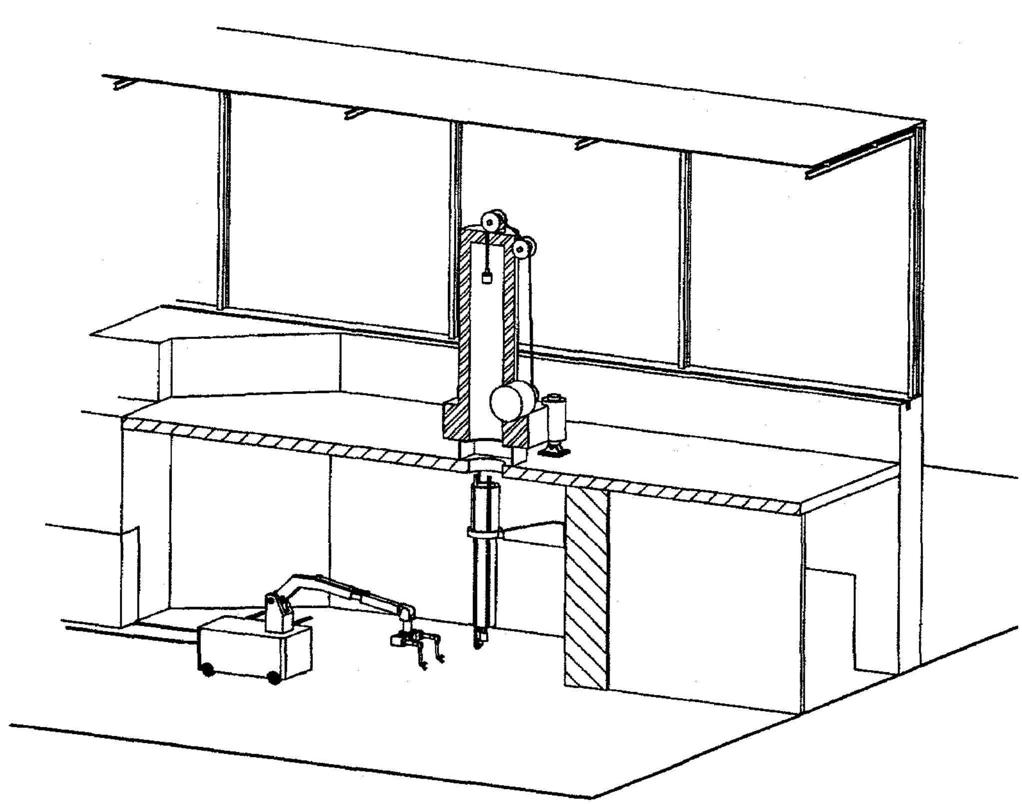

Figure 9. A moderator insert placed in the hot cell for maintenance or reconfiguration uses a robot and closed-circuit television for handling radioactive components.

Activated components from the target area and the TTB may be placed in the hot cell for modification, repair, or packaging for transport to a permanent storage facility. Operations in the hot cell will be performed with a generalized robot using television for vision (Figure 9). The in-cell robot system will be based on a similar system that has been used for several years to maintain the highly activated beam line areas at LANSCE. Specialized fixtures will be developed for handling and supporting the target cell and other components during activities in the hot cell. When components need to be taken to a permanent storage facility, they are taken from the hot cell through the roof docking ring and transported through Area A East (Figure 8), and then placed on a transport vehicle by an existing bridge crane.

As can be seen in Figure 10, the insert that positions the neutron-producing target between the moderators will be emplaced and extracted within the hot cell. This approach ensures that the most highly activated component in the system will always be shielded and contained. Special fixtures inside the hot cell will be necessary to handle this insert.

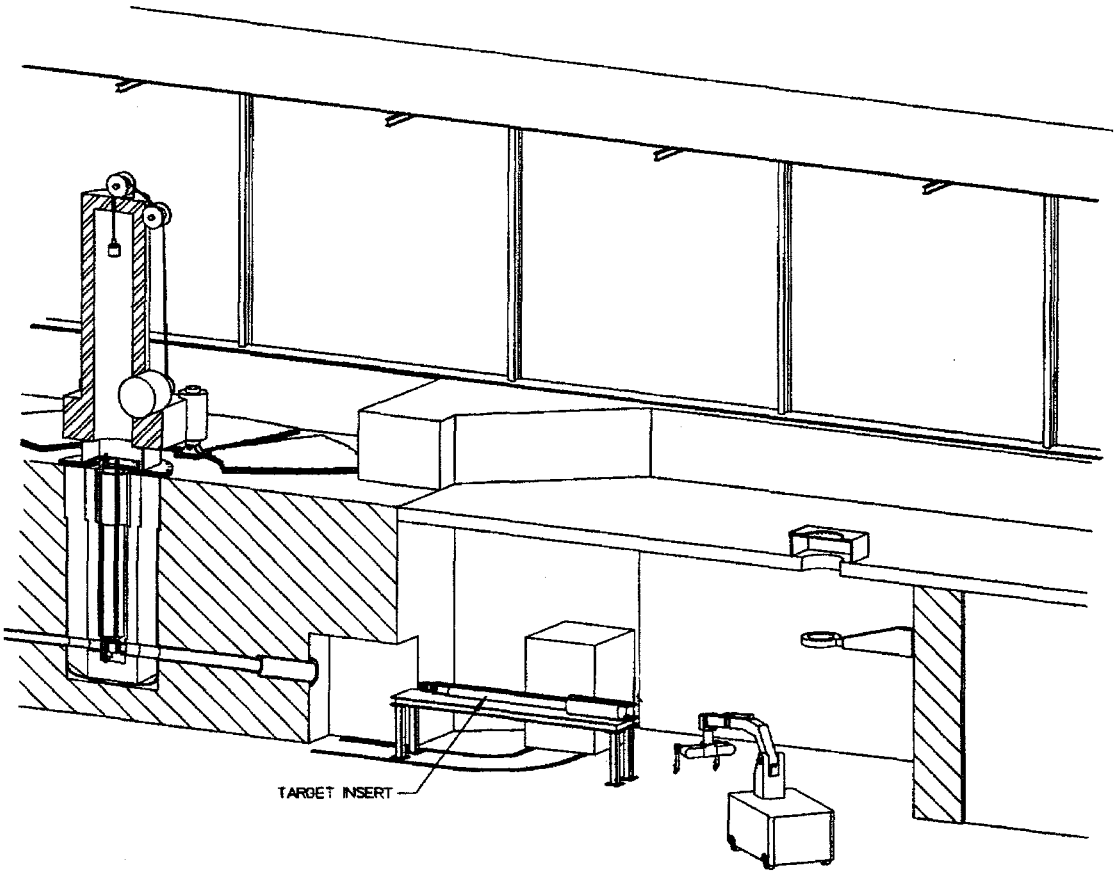

Figure 10. The insert that supports the LPSS target.

Materials properties following radiation exposure will be studied using mechanical and physical properties testing equipment placed in the hot cell. These tests will be performed on materials used for the components in the target system and the TTB. There will also be space in front of the target system reserved for specially designed tests on candidate materials for advanced spallation neutron sources (Figure 11). Studies of the basic aspects of radiation damage effects to materials exposed to high-energy particles will also be possible. Testing equipment for these studies will necessarily be placed in the hot cells because of the high radioactivity levels following irradiation.

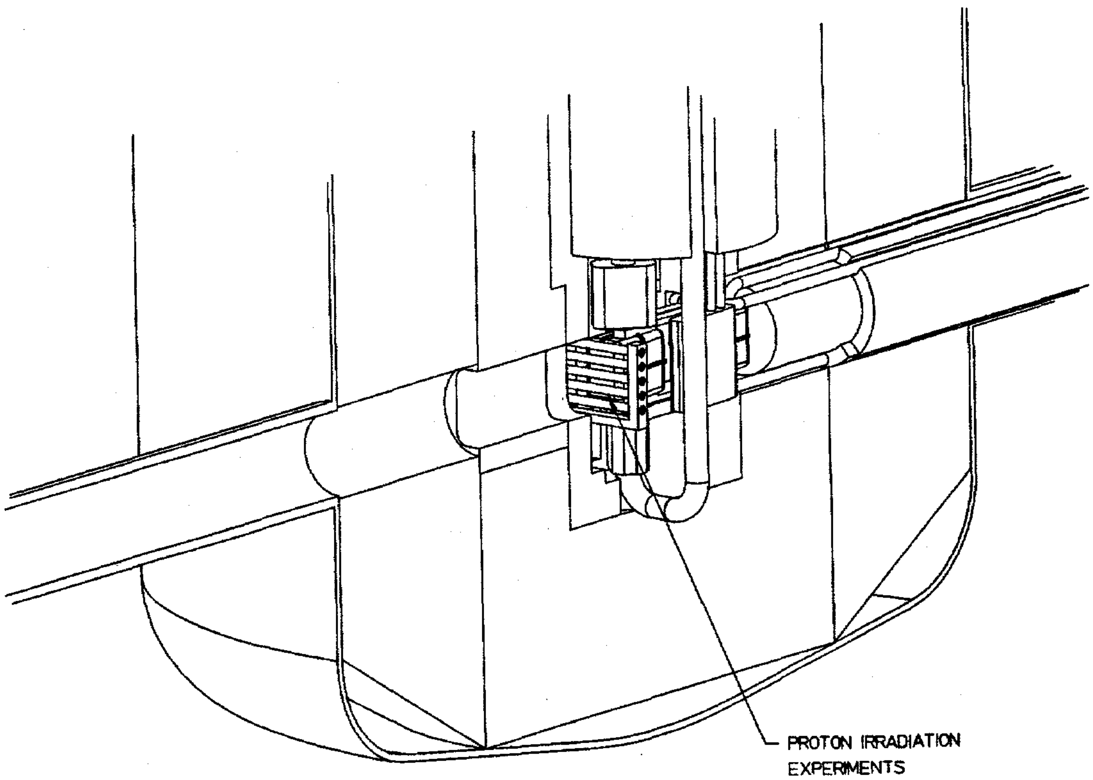

Figure 11. Proton irradiation experiments in front of the LPSS target system.

1.D. Shielding

An extensive shielding study using neutron transport codes is underway. This study considers allowable radiation levels at the surface of the shield, radiation levels in a flight path when the beam is on and a shutter is in place, and radiation levels at the hot cell wall. A separate report on this shielding study will be prepared in early 1996.

1.E. Facility Layout

A basic feature of the facility will be separation of the experiment area from the service area, where highly radioactive materials are handled. Figure 12 shows the overall floor plan. It will be possible to transport the proton beam from the beam switchyard area to the TTB and LPSS target system without any beam line magnet elements under the shielding from the switchyard to the TTB. This design thus eliminates the need for magnet servicing access and water coolant services from the switchyard to the TTB.

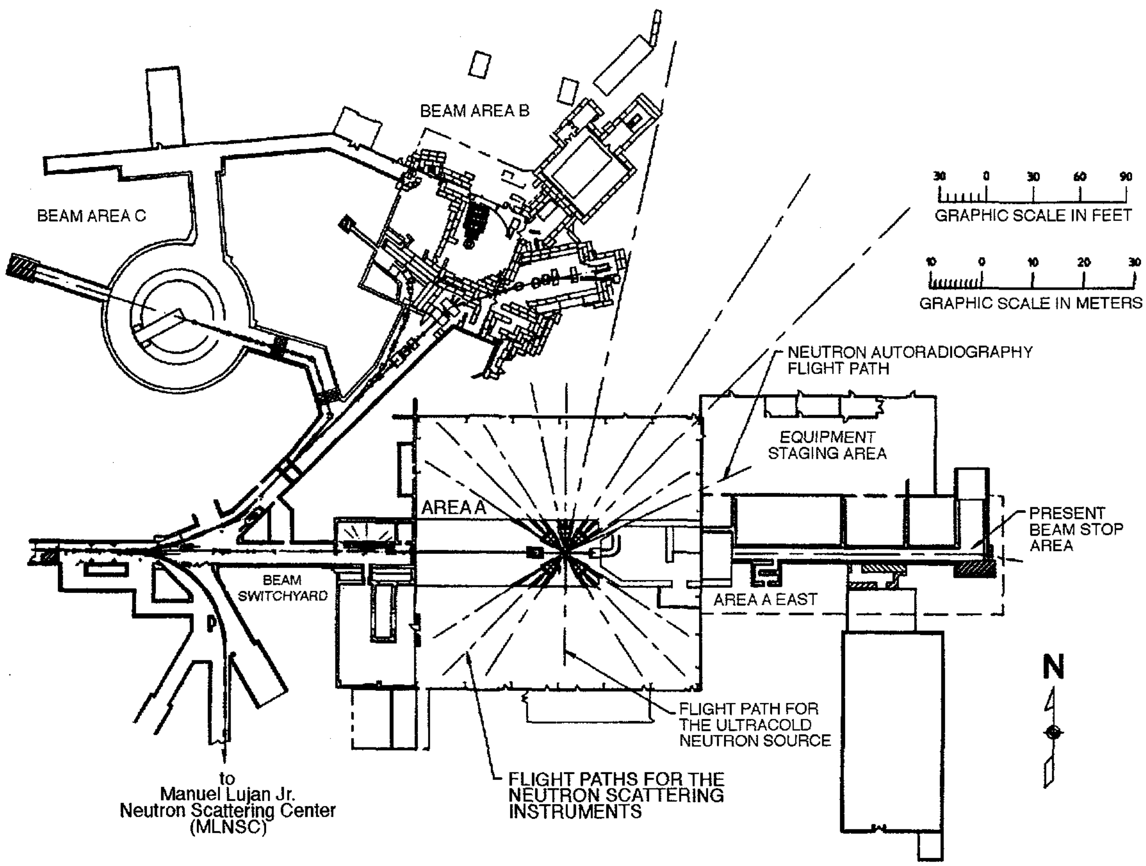

Figure 12. Overall layout of the facility showing the separation of the experiment area from the service areas.

The floor of the experiment area will be available for instruments and shielding. Some of the 15 flight paths (Figure 12) may penetrate the building to achieve the needed flight path length. The three flight paths due south of the target system will service the ultracold neutron (UCN) source.

The area above the BBS (Figures 6 and 8) will be designed to accommodate activities that involve handling radioactive components from the beam diagnostics and TTB chamber, the materials testing and LPSS chamber, and the hot cell using docking rings (Figure 8). The ROSE that extracts and shields the TTB, diagnostics, materials testing, and target moderator components will travel on a track, as will a traveling bridge crane used for moving shielding and service equipment. Services such as cooling water heat exchangers and associated filters and controls (D_2O and H_2O systems), cryogenic helium and hydrogen systems for the moderators, and vacuum pumps and associated equipment will be housed in this area.

The hot cell is located directly downstream from the target system. This arrangement will allow emplacement, retrieval, and handling of the neutron-producing target from within the hot cell. From the hot cell, materials will be transported to Area A East, where a crane will place shielded radioactive materials on a vehicle for transfer to a permanent storage/disposal facility.

Two 30-ton bridge cranes will be available to service the experiment hall. The containment building will be sized to ensure that materials and components can be transported over the beam line from north to south.

2. TARGET SYSTEM

The preconceptual design for the target system closely follows the recently completed work on a 1-MW Short-Pulse Spallation Source (SPSS) entitled "Los Alamos Next-Generation Spallation Source." [1]

2.A. Mechanical Layout of the Target System and Inserts

Figure 13 shows the arrangement of a split target, two liquid hydrogen moderators in wing geometry, and a hybrid water moderator viewed both in transmission geometry from one side and in backscattering geometry from the opposite side. The lower liquid hydrogen moderator is viewed in wing geometry by three flight paths directed to the southeast and by three flight paths to the northwest. The top liquid hydrogen moderator is viewed in wing geometry by three flight paths directed to the southwest and three flight paths to the northeast. The water moderator will be viewed in transmission geometry by three flight paths directed to the south and in backscattering geometry by three flight paths directed to the north.

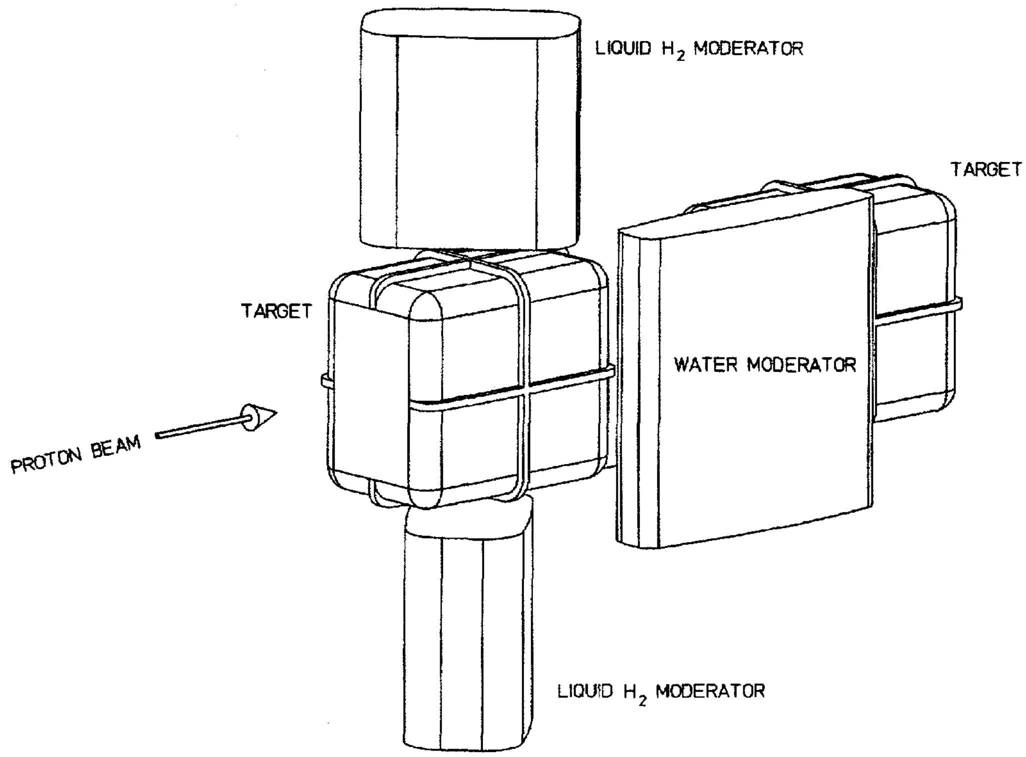

Figure 13. Geometry of the target and moderator system.

A solid deuterium moderator may also be included in this facility to supply UCNs. The deuterium portion of the moderator will likely be attached to the transmission geometry side of the water moderator, so that the water moderator is used as a premoderator.

The target will be split to produce the "flux-trap" geometry used successfully at the Manuel Lujan Jr. Neutron Scattering Center (MLNSC) at LANSCE and will be attached to an insert that penetrates the BBS horizontally from the hot cell. Coolant services and instrument cables, such as thermocouples, are routed through the insert so that its function as a shield is not compromised. The target is essentially inserted into the moderator assembly, thus when the moderators need to be moved, the target must be moved first. The target will be cooled with heavy water to minimize parasitic capture of moderated neutrons.

The moderators will be placed on a single insert that penetrates the BBS from the top. Service equipment such as instrumentation, heavy water coolant lines, and cryogenic fluid transfer lines will be routed through the insert in a manner that does not compromise the shielding integrity of the BBS.

2.B. Remote Handling

The neutron-producing target will be the most activated component in the system following an operating period. For this reason, and to allow as much space as possible for the large number of service lines needed for the moderator insert, the target will be taken directly into the hot cell. Repairs will be made in the hot cell, if warranted. When a used target must be transferred to a permanent storage facility, the target will be removed from the insert to minimize the volume of very active material that needs to be handled. In some cases the insert will be reused. In any case, a spare target and insert will be available in the hot cell to allow rapid recovery from a target failure. The target design is conservative, and data on the radiation performance of the target materials after a prototypic proton fluence (but not pulsed flux level) will be available by the time this facility becomes operational. A surveillance program for monitoring materials performance during operation will also be in place. An emergency repair will not likely be necessary; however, the inclusion of equipment to perform rapid repair ensures that neutron availability will not be compromised by the target.

The moderators are serviced by drawing them vertically into the ROSE and then transporting them to, and inserting them in, the hot cell. As with the target, a spare insert will be available for rapid recovery from any component failure, or for a configuration change required by a specific experiment. A surveillance program on irradiated materials performance for moderator components will also be in place. As with the target materials, the design of the moderator will be conservative and data on materials performance to prototypic fluence levels will be available before the facility becomes operational. The insert design will allow modification of one or more of the moderators in the hot cell. If removal of components to a permanent storage facility is necessary, the insert will be disassembled so that the activated materials can be packaged more easily.

Some of the beryllium reflector and the decoupling materials (Figure 14) will be attached to the moderator insert and withdrawn with this unit for replacement. An additional beryllium reflector and the nickel reflector-shield (Figure 14) surround the moderator insert and will require water coolant to remove the radiation-induced heat. These additional units will be placed in the facility as a series of truncated-wedge segments designed to fit the ROSE in both size and weight. It is unlikely that these units will need replacement during the life of the facility, but provisions will be made to allow their transport to the hot cell for replacement or repair. Another set of truncated-wedge segments surrounds the nickel reflector shield (Figure 14)—these are essentially iron shielding with cutouts for the neutron flight paths. These units will also be sized so that the ROSE can remove the activated materials, though it is very unlikely that these units will require replacement or repair during the lifetime of the facility.

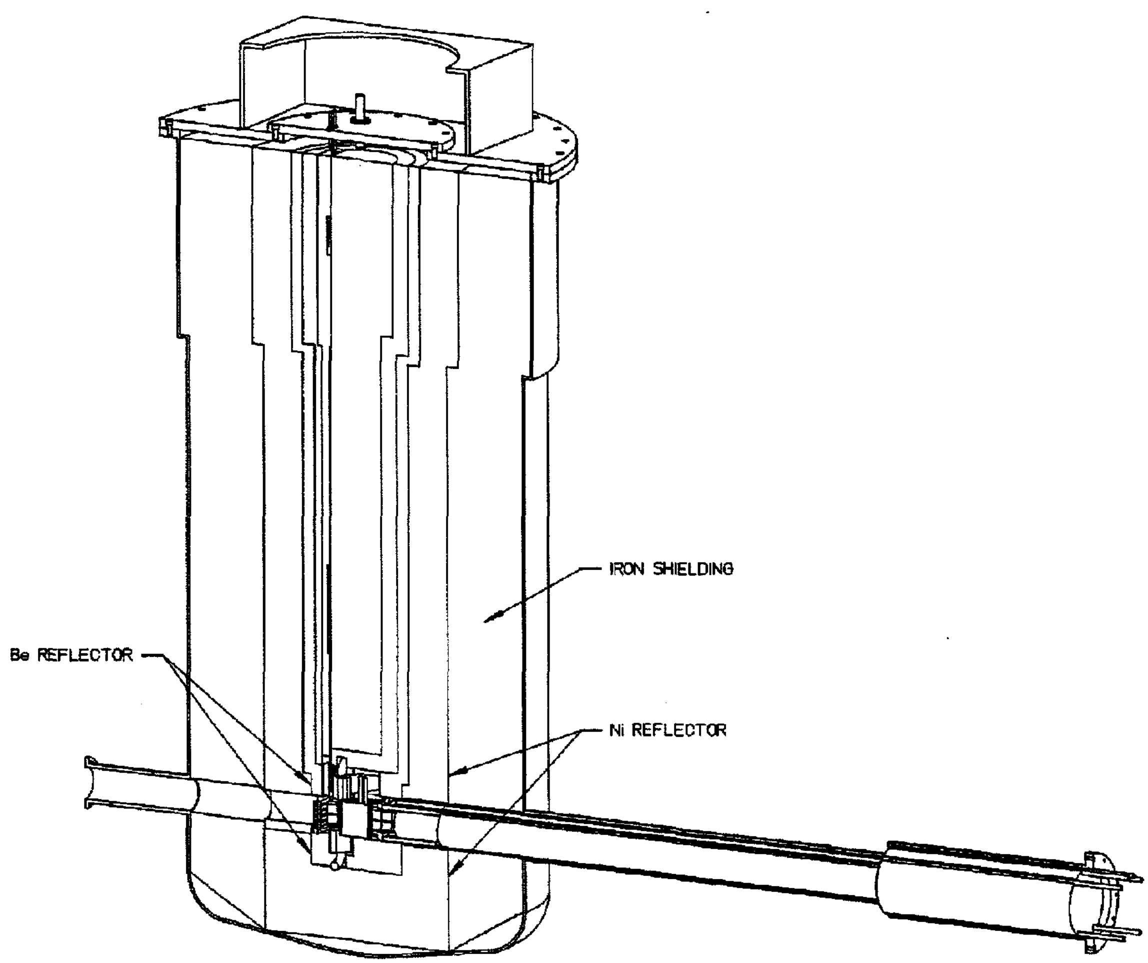

Figure 14. Arrangement of the beryllium and nickel reflector and iron shield segments surrounding the target system.

2.C. Target Design

The MLNSC "flux trap" geometry will be adapted to this proposed design. A box configuration with flat sides will be used to facilitate coupling the moderators to the target (Figure 15). The neutron-producing materials will be tungsten in rod form, enclosed by a tube made of alloy Inconel 718 (Figure 16). Previous design work on a 1-MW tungsten target for a Short-Pulse Spallation Source (SPSS) determined that 4-mm-diameter tungsten rods enclosed with 0.25-mm-thick alloy Inconel 718 tube set on a 1.01 pitch-to-diameter ratio in a close-packed configuration would perform well, considering both thermal hydraulics performance and mechanical stresses. The heavy-water coolant used in this design will be supplied at a pressure of about 1 MPa (150 psia), which requires a flow rate of less than 4 kg/s in the upstream target tier and less than 1 kg/s in the downstream target. The pressure boundary for the tungsten target rod array will be alloy Inconel 718. The flat plate design will require some stiffening ribs to maintain acceptable stress and deflection levels. A report including a detailed description of the design of a 1-MW spallation target with the features given above has been prepared [1].

The target will be supported on the end of an insert that penetrates the BBS horizontally from the hot cell. The instrumentation cables and the heavy-water coolant will be supplied from a station in the hot cell through an insert that avoids compromising the integrity of the shielding.

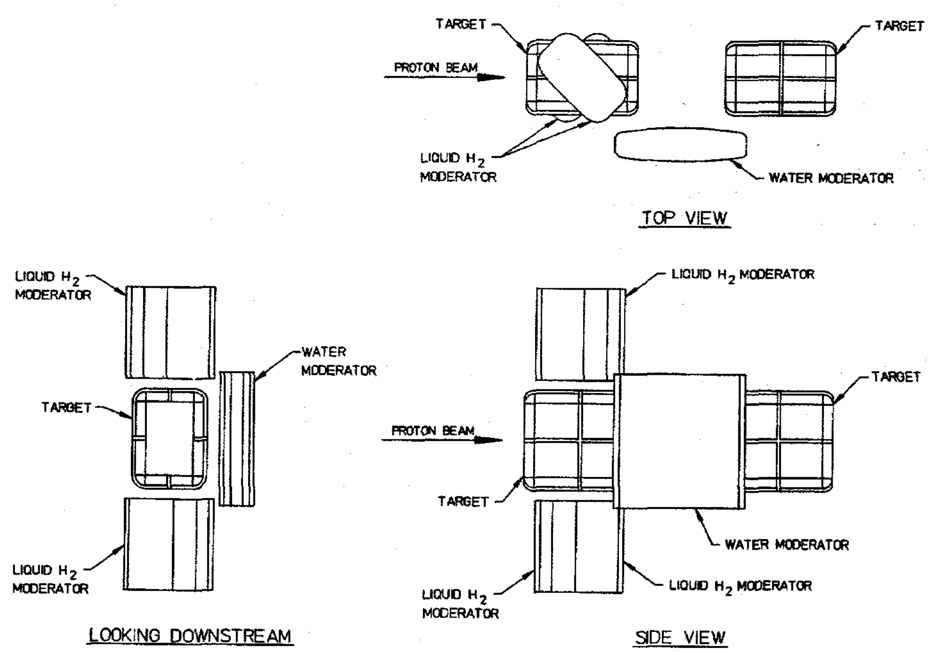

Figure 15. Target enclosure.

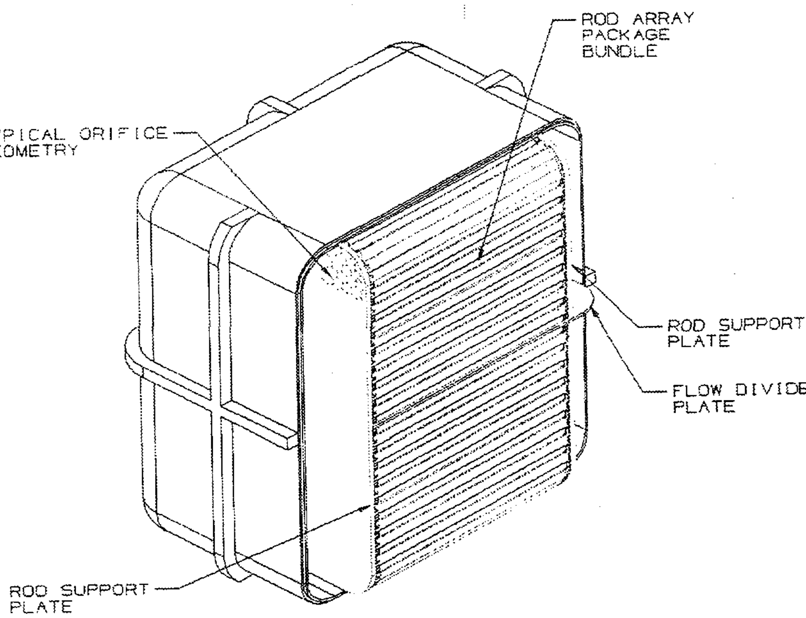

Figure 16. Enclosed tungsten rod material for the target unit.

2.D. Moderator Design

In the base-case preconceptual design, two types of moderators will be considered. Referring back to Figure 13, the two moderators in wing geometry contain liquid hydrogen and will each be viewed by six flight paths. The single moderator in the "flux trap" will be viewed in transmission geometry by three flight paths and in backscattering geometry by three flight paths.

A preliminary mechanical design for the moderators used in our concept was completed during the conceptual design stage for an SPSS source. Consideration was given to energy deposition, mechanical stresses, and geometrical requirements. Figure 17 shows schematically the resulting design of a water moderator and Figure 18 shows schematically the design of a liquid hydrogen moderator. The SPSS study determined that each liquid hydrogen moderator will require about 1 kW of refrigeration power.

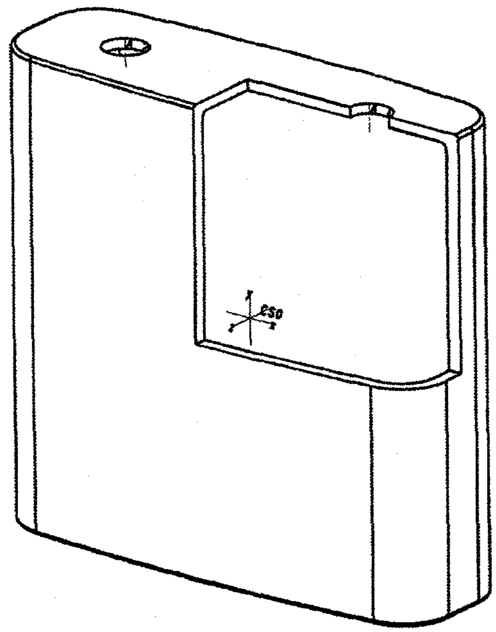

Figure 17. Water moderator design.

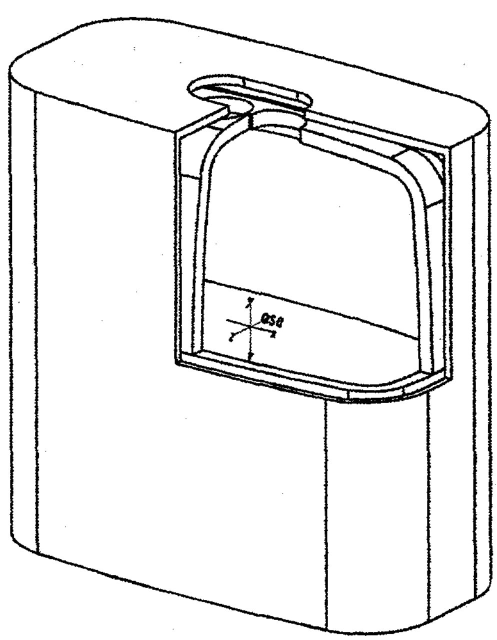

Figure 18. Liquid hydrogen moderator design.

In addition to the base-case moderator configuration, consideration will be given to producing a solid deuterium moderator resulting in an ultracold neutron source. The solid deuterium (D_2) moderator will be placed south of the water moderator, thereby using the water moderator as a premoderator. The arrangement of these units is shown schematically in Figure 19.

Services such as coolant water lines and cryogenic fluid transfer lines will be routed through the insert that supports the moderators so that the integrity of the shield is not compromised. Control units for these services will be located above the target system in rooms that are equipped with adequate shielding and remote handling capabilities to ensure that ALARA principles are followed in servicing the filters and other components.

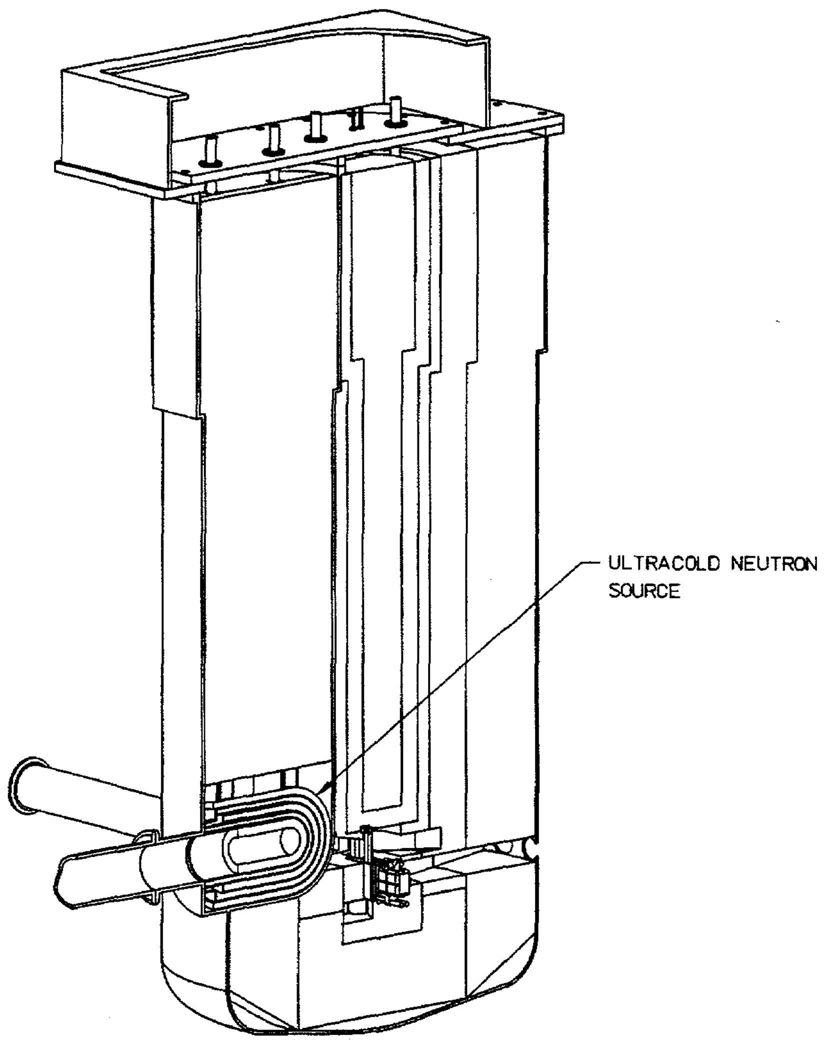

Figure 19. Moderator arrangement for the ultracold neutron source.

2.E. Beryllium Reflector Design

The beryllium reflector components are located inside the vacuum vessel and surround the moderators and target enclosures. These reflector components will be made of rod- and bar-form beryllium material enclosed in thin stainless steel cladding; these individually clad bars will be enclosed within a number of larger canisters that are sized to fit the irregular volumes surrounding the target, moderators, and flight path openings. The canisters will be supplied with a flow of heavy water to cool the material through the interstitial voids between the clad bars. Energy absorption by the beryllium and its thin cladding will be modest. The circuit that provides the coolant will be housed in a shielded room equipped with appropriate remote handling equipment. The lines supplying the coolant to reflector canisters will be routed through the moderator insert along with the service lines for the moderators.

2.F. Nickel Reflector and Shield Design

The fast-neutron reflector and high-energy neutron shield will consist of a group of interlocking containers filled with nickel in plate and rod form. The containers will be placed at the bottom of inserts that extend to the top of the BBS; the inserts will be sized to be convenient for the required geometry and within weight limitations for installation and removal. In our preconceptual design, the inserts and the nickel reflector material reside in the vacuum vessel. Water coolant is provided to the containers housing the nickel material in the same manner as described above for the beryllium reflector. Coolant requirements are modest for the entire reflector and shield unit.

2.G. Vacuum Chamber

Several features will be required for the vacuum chamber for the LPSS target system (Figure 20). The primary chamber will be a cylinder 2 m in diameter that extends from below beam centerline to the top of the BBS. The chamber will be large enough to contain the target, moderators, reflectors, shields, and inserts. A tube will be attached to the upstream side to allow entrance of the beam; this tube is attached to the target test bed chamber and perhaps also to a beam entry window. Another tube will be attached to the downstream side of the chamber to house the insert carrying the target. Neutron flight path chambers that form the front end of the neutron flight paths will be attached to the main chamber at beam line elevation. Metal vacuum windows will be attached to the neutron flight path chambers through a remotely operable clamp; the windows and clamp will be attached to inserts that reside in another chamber that is part of the neutron flight path enclosure.

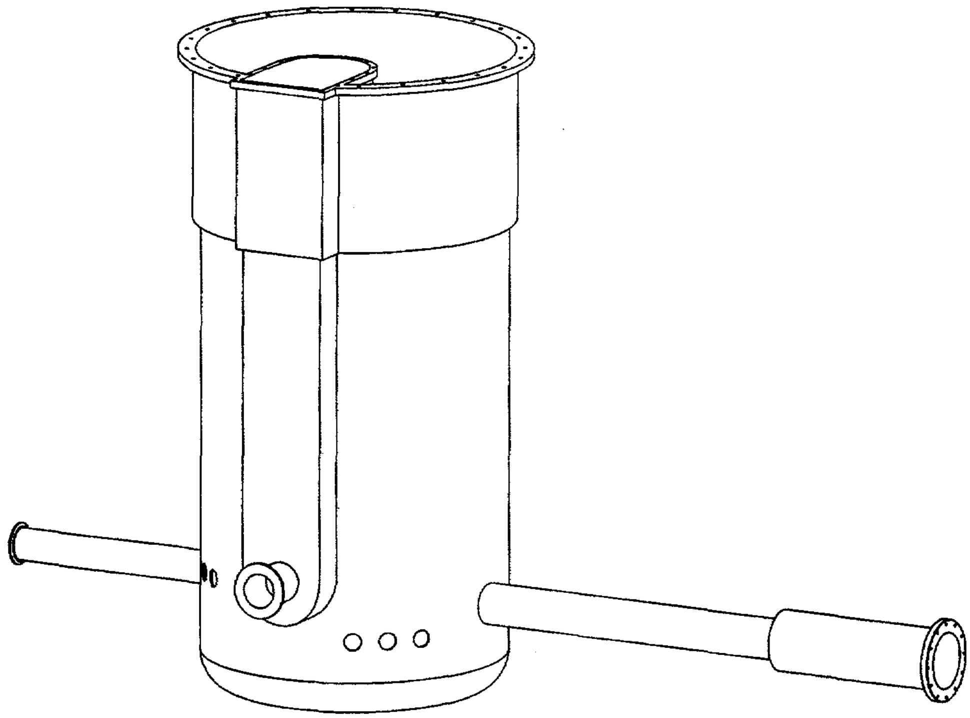

Figure 20. The primary vacuum chamber for the LPSS target system.

The vacuum vessel will be constructed from stainless steel alloy 304L, a material with excellent welding characteristics and performance. The design of weldments will be conservative, employing doubler plates to ensure that stresses during assembly, installation, and operation are very low. The radiation levels and heat deposition levels are expected to be very low and the vacuum chamber is expected to serve the lifetime of the facility.

2.H. Proton Beam Entry Windows

When it becomes necessary to isolate the target chamber and the TTB from the beam line vacuum chamber, or from each other, or to isolate the TTB, provision will be available to attach metal windows in the locations shown in Figure 5. These windows will be identical to those used successfully at LANSCE for several years. As in the LANSCE design, the windows will be constructed from alloy Inconel 718. The windows will be placed and removed remotely using technology developed at LANSCE. The activated units will use the ROSE transfer cask for transport to the hot cells for repair or for packaging prior to removal to a permanent storage facility.

2.I. Gas Containment

Activation of air is minimized in our design because the beam transport is accomplished in a vacuum. The exhaust from the vacuum pumps will be transported to the HEPA-filtered, radioactive air handling system. The flight paths for the neutron beams in the BBS will be filled with helium gas to minimize neutron interactions. When it is necessary to remove the gas from the flight paths, a pumping system will be used that exhausts directly into the HEPA-filtered air system connected to the emissions stack.

The BBS will be sealed with a membrane over its entire external surface. This seal will capture any radioactive gas or particulate formed in the shield materials and void areas.

2.J. Bulk Shield Flight Path Enclosure Design

The flight path enclosures provide paths through the BBS and structures for placing beam-defining apertures. In our design the enclosures (Figure 6) also provide access for attaching the beam exit windows on the flight paths and access for placing the pulse-forming choppers. The enclosures will be filled with helium and will require a thin window at the exit of the enclosure. Instruments that attach to the ends of these enclosures require varying features that will be accommodated as these features become defined in detail.

2.K. Shutter Design

Rotating cylinders with apertures (Figure 21) will be used to provide a collimated flight path during operation and a shield during periods when the beam line requires service or reconfiguration during operation of the remainder of the flight paths. The shield is obtained by rotating the cylinders so that the flight paths are not aligned. High atomic number materials such as tungsten and low atomic number elements such as hydrogen and boron are integrated into the structure to ensure that dose levels are kept at permissible levels. Shutters employing this design philosophy have been used successfully at the MLNSC facility for a number of years.

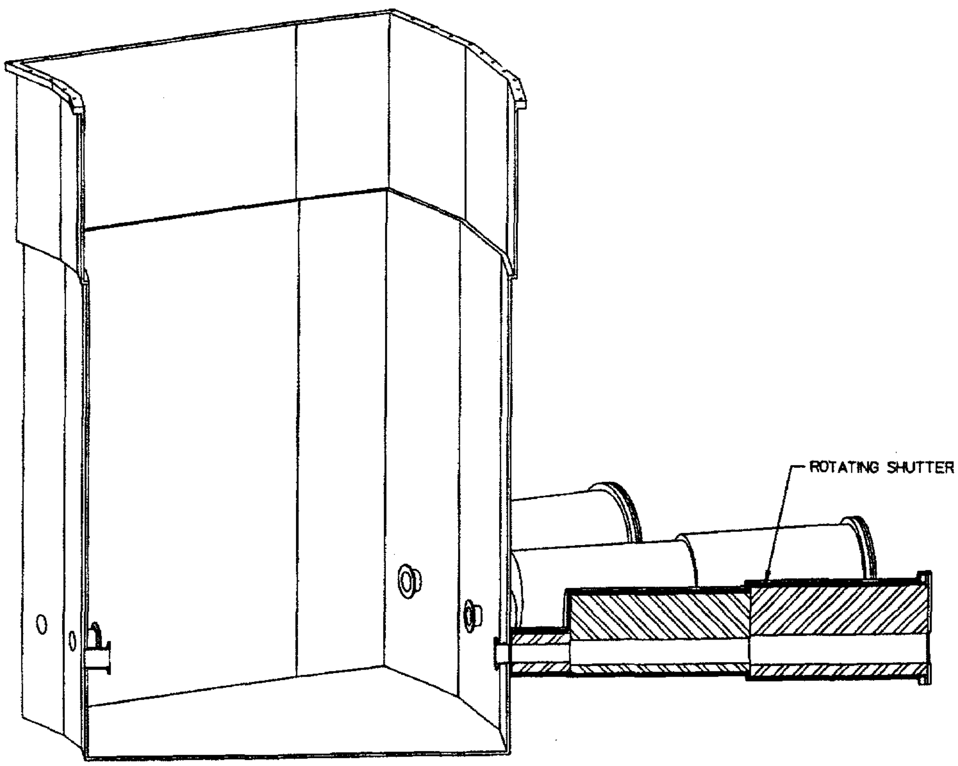

Figure 21. Rotating shutters and apertures used in some of the flight paths.

In addition to the rotating shutters in the outer part of the flight paths, a blade shutter (Figure 22) will be provided in the chamber that extends to the top of the BBS.
The design of this shutter will accommodate the needs of the pulse-forming chopper that must also reside in this space.

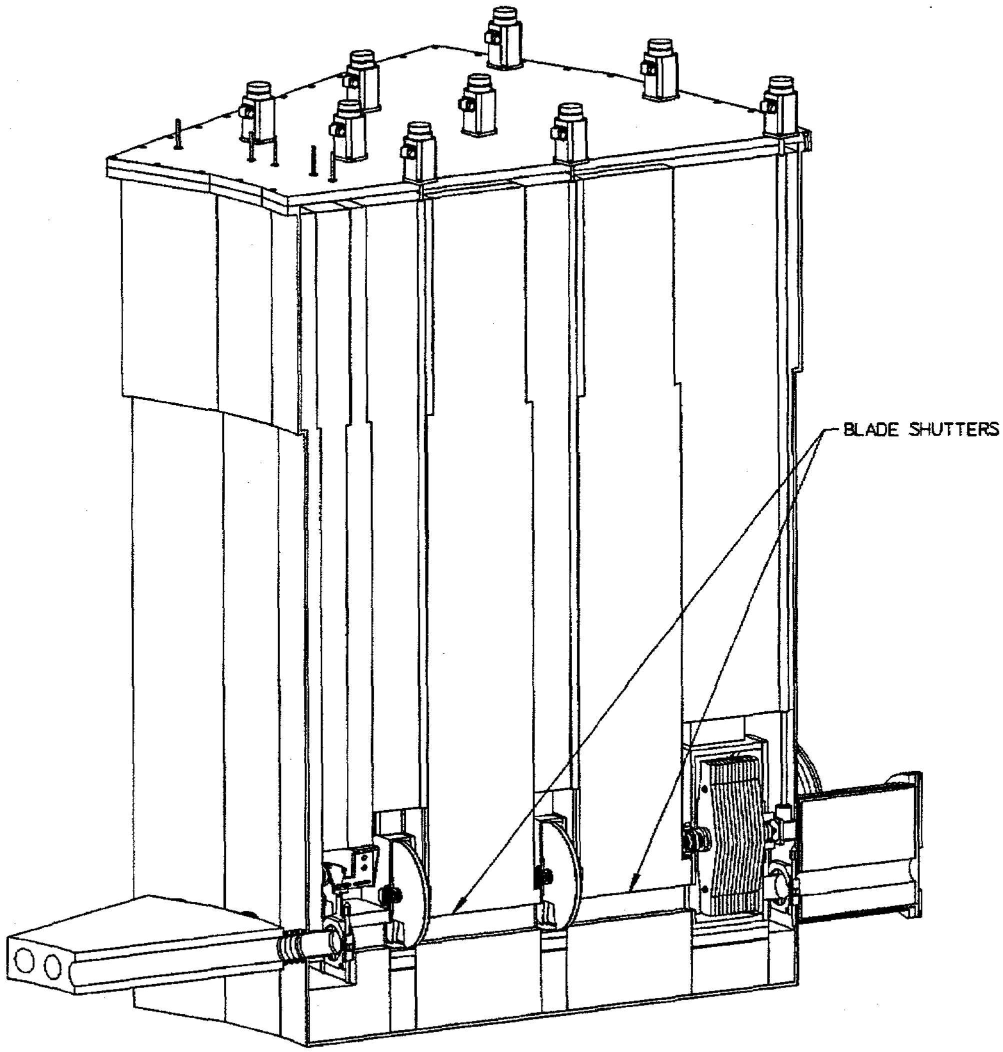

Figure 22. Blade-type shutters used in conjunction with the choppers.

2.L. Choppers and Chopper Chamber

The LPSS requires a T_0 chopper for stopping high-energy neutrons and one or two pulse-forming choppers to eliminate certain low-energy neutrons. The T_0 chopper consists of several centimeters of a heavy material such as a nickel alloy, while the pulse-forming choppers are light-weight, generally using thin foils on a light frame. The arrangement of these choppers will depend on the specific design of the flight path instrument.

Figures 6 and 23 show the arrangement of the flight paths and the placement of the choppers used on the flight paths. The chamber that houses the choppers extends from a distance of 2.5 m to 5.5 m from the target centerline. The chamber is used for access for placing the vacuum windows and for placing the chopper and blade shutters in position. The units are placed on the bottom of inserts that also carry necessary services to the units. Magnetic, gas, and conventional bearings will be considered for the choppers. Material selection will depend on the atmosphere placed in the flight paths and the results of a chopper development program.

3. TARGET TEST BED (TTB) FOR SPALLATION NEUTRON SOURCE DEVELOPMENT

The rationale for including a TTB for spallation neutron source target systems and materials studies is given in Reference 2. The basic requirements for an effective TTB include access to the proton beam; sufficient space to install prototypical-sized targets, moderators, and blankets; and access for necessary diagnostic instrumentation. In anticipation of very-high-power targets in the future, provision will also be made to include liquid metal targets. In anticipation of future blankets using molten salts, the test bed will be constructed to accommodate studies for accelerator-driven subcritical power-producing assemblies.

3.A. Component Access through Vertical Inserts

Figure 23 shows a chamber for the TTB, which will be placed upstream of the LPSS target system. This chamber will be held at vacuum and isolated through metal windows (when necessary) from the upstream vacuum system and the chamber housing the LPSS target system (Figure 24). Target system components being tested are placed on vertical inserts in a manner similar to the moderator insert used in the LPSS target system. Here also the insert serves as shielding and provides access for instrumentation and services lines. Repair, modification, and disassembly of TTB components will be accomplished in the hot cell with transport through a docking ring using the ROSE in a manner similar to that used for the LPSS target system components. Transport of activated components to a permanent storage facility will also follow the procedures established for the LPSS components.

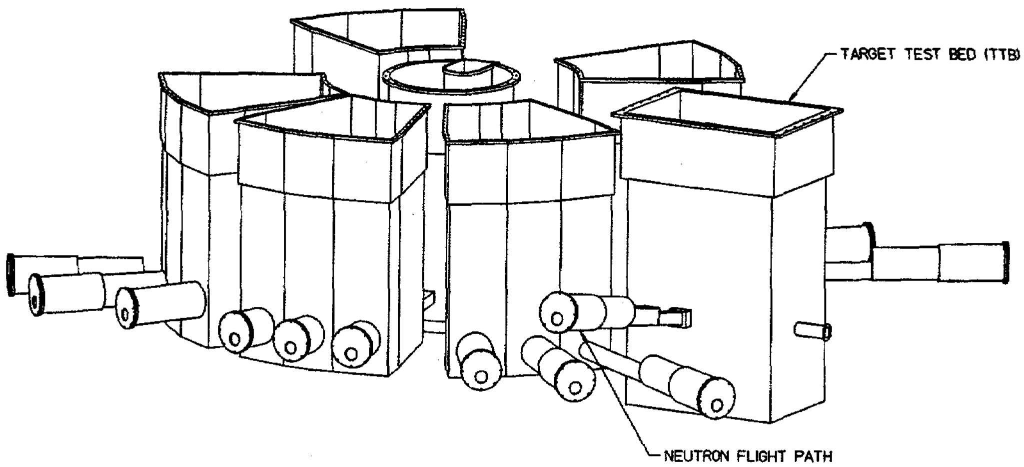

Figure 23. The chamber for the Target Test Bed (TTB).

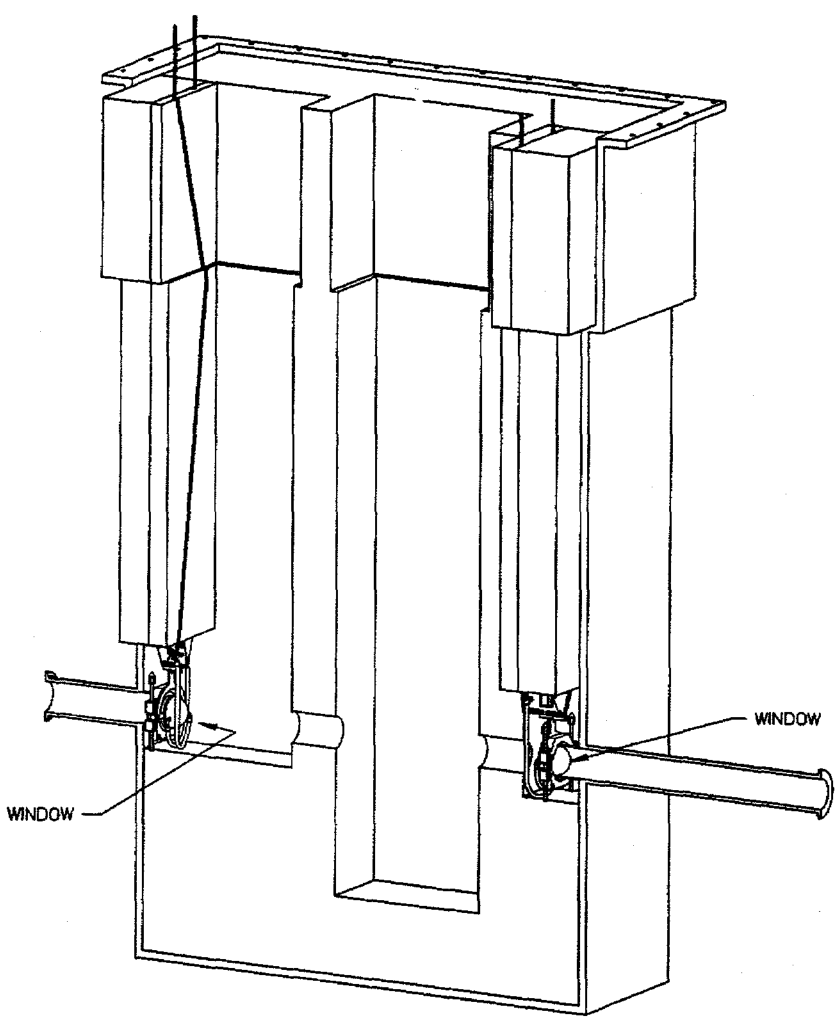

Figure 24. Metal windows used to isolate the TTB.

Secondary containment of liquid metal targets and molten salt blankets will be necessary when these advanced concepts are being tested. The design of the containment systems will be unique to a specific system; the facility will be built large enough to provide the necessary containment.

Services for cooling test bed components, including those necessary for the liquid metal and molten salt applications, will be housed in shielded spaces above the TTB chamber. ALARA principles will be observed when components are serviced.

In summary, the TTB will be designed for maximum flexibility to allow study of a wide variety of new target system concepts. The specific design of the inserts, cooling systems, shielding, and containment for a test must await definition of a target system to be tested in the TTB. Figure 25 is a schematic representation of a possible test target system installation in the test bed.

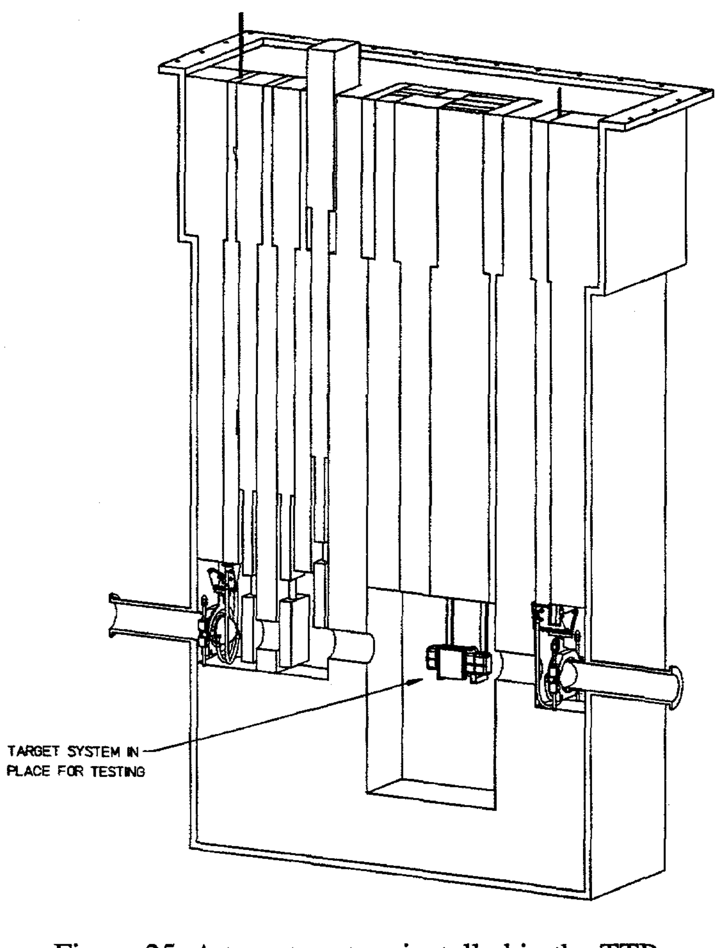

Figure 25. A target system installed in the TTB.

3.B. Flight Path for Neutron Flux and Spectrum Measurements

Figure 23 also depicts a flight path that views a portion of the test assembly in the TTB. The flight path will be configured to allow measurements of target system parameters including neutron flux and spectrum. Through use of the ROSE and the hot cells, it will be possible to reconfigure the target, moderator, and blanket assemblies to systematically refine the flux and spectrum. The independence between the TTB and the LPSS will likely result in a schedule that features a few hours of operation at the TTB followed by sustained operation of the LPSS, during which time refinements to the TTB assembly will be made in preparation for another short operation of the TTB.

4. MATERIALS IRRADIATION TESTS AND SURVEILLANCE PROGRAM

Spallation neutron systems development will benefit from an understanding of materials behavior in prototypic proton and spallation neutron radiation environments. Provision will be made to expose spallation neutron source candidate materials to the proton beam in a position directly in front of the LPSS target, as shown in Figure 26. Capsules will also be placed in regions of the target system where prototypic neutron (and charged particle) environments are present. Both types of irradiation capsules will have provisions for temperature control and in some cases, stress state, as well as provisions for continuous monitoring of performance. These capsules will stay in place over several operating periods and will provide data on the high-fluence performance of candidate materials. As described below, materials properties testing will be done in the hot cells after the units have been transferred to the hot cell using the ROSE.

In addition to long-term tests on candidate materials, provision will be made in the target and moderator inserts to place and retrieve test specimens of the identical materials being used in the LPSS target system. To the largest extent possible, the specimens will be subjected to the identical stress and radiation histories as the operating components. By including a number of specimens at the beginning of the operation of a target system and then extracting and testing specimens as the operating time on a target system increases, the performance of each material can be determined as a function of fluence. Because the limits on allowable radiation deterioration of materials properties will have been established, intelligent decisions on component replacement methodology will be possible. As with the longer term and more general materials irradiations described above, the test specimens will be transported to the hot cell for evaluation.

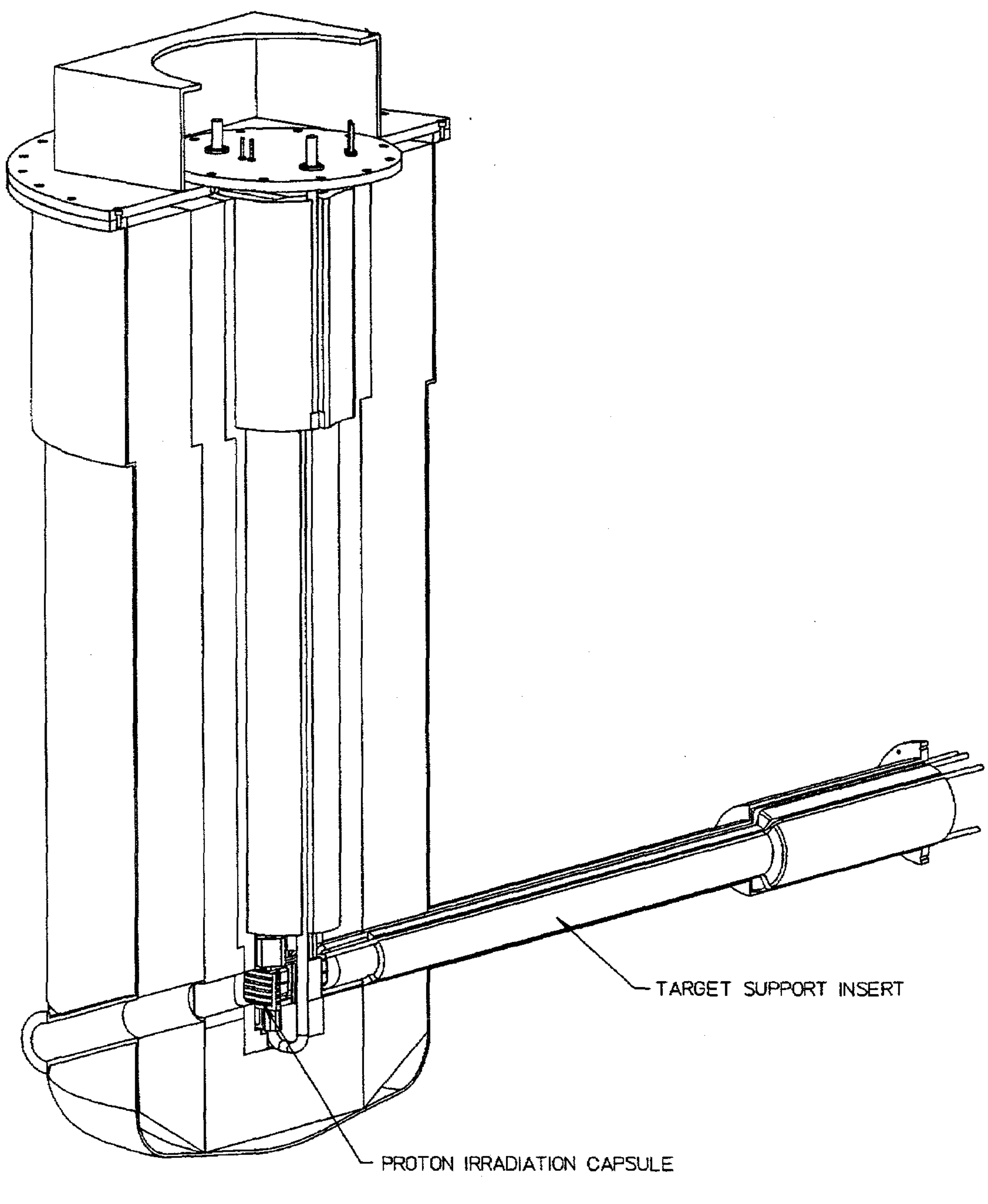

Figure 26. Arrangement of a test capsule for irradiating materials in the proton beam, in front of the LPSS target.

5. SERVICES

5.A. Cranes and Prime Movers

A number of specialized lifting devices will be used to move and service the equipment at the LPSS. Because there will be very high levels of activity during reconfiguration periods, several lifting devices for the experiment floor will be supplied, and the large facility cranes will be reserved for special, very heavy lifts.

5.A.1. Traveling Cask—Remotely Operable Shield Equipment (ROSE)

The ROSE is a key part of our design for properly handling radioactive components and for controlling contamination. A diagram illustrating the basic features of the ROSE is shown in Figure 27. The main winch is a commercially produced and certified unit. The hook and the mating pin on inserts will be designed to allow remote connection and disconnection.

The ROSE travels on rails from docking rings on the TTB and diagnostics instrument chamber, the LPSS chamber, and the hot cell. The docking rings will be fitted with a sealing door, as will the ROSE, to isolate the radioactive and potentially contaminated components from the containment building atmosphere and personnel performing the activities. The ROSE will be designed for compatibility with a transport vehicle used to move radioactive components to a permanent storage facility.

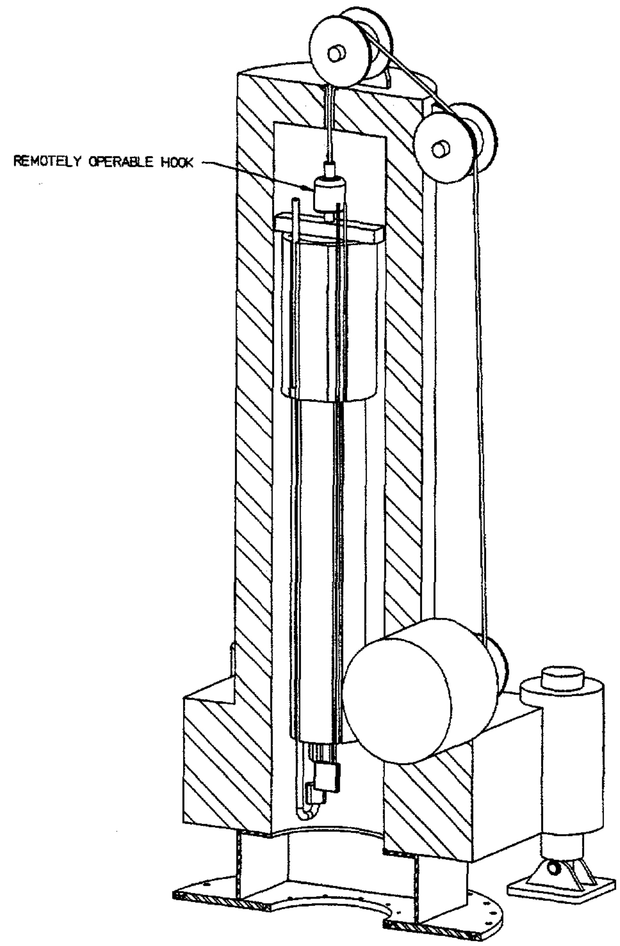

Figure 27. The Remotely Operable Shield Equipment (ROSE).

5.A.2. Cranes for Instruments

Because of the high level of activity during reconfiguration periods, each instrument will be supplied with one or more jib or A-frame lifting devices suitable for specific needs. The large 30-ton overhead bridge crane will be used for infrequent, large-scale installations and modifications to the instruments.

5.A.3. Crane for Handling Target Services Equipment

A traveling A-frame (Figure 28) will be used to lift and move equipment that services the TTB, the LPSS target system, and materials experiments. The equipment will include such items as power supplies, water and vacuum pumps, filters, transport lines, and shielding. In some cases the equipment will require special shielding and will be placed in the hot cell.

The traveling A-frame will also be used in service activities associated with the pulse-forming choppers and the metal windows that isolate the target system vacuum chamber from the neutron flight path. Here also special shielding will be used to ensure adherence to ALARA principles and to eliminate the possible spread of contamination.

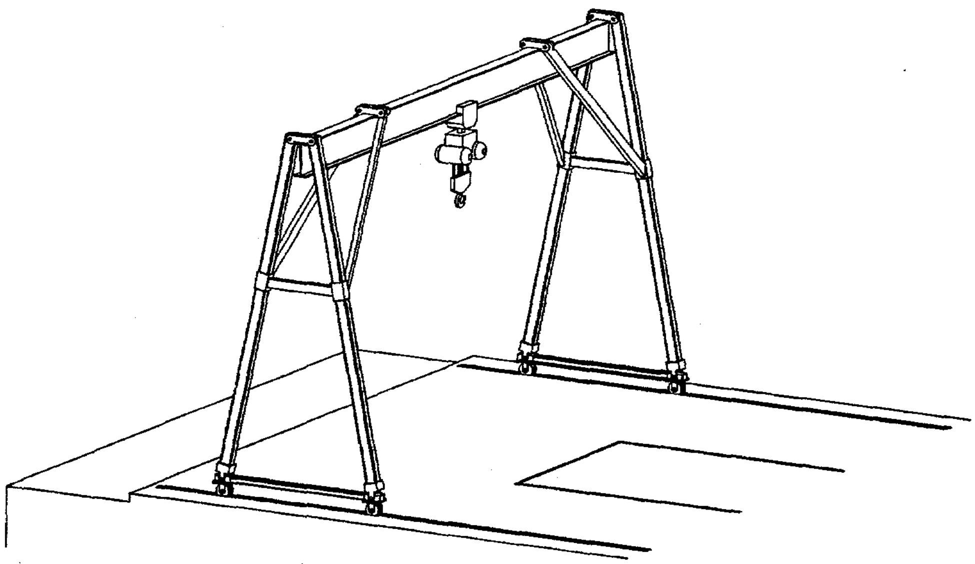

Figure 28. Traveling A-frame and crane used for lifting service equipment above the BBS.

5.A.4. Crane in Area A East for Handling Radioactive Materials Shipments

An existing crane in Area A East will be used to transport the shields containing radioactive components to the east of the facility where they will be loaded on a transport vehicle. The ROSE will be used for the most active components, such as those from the LPSS target system. Other shield containers will be used for smaller and less radioactive components, as appropriate.

5.B. Cooling Water

One megawatt of power will be deposited in the LPSS or TTB. Conventional and heavy-water coolant systems will be used as a heat sink for this power.

5.B.1. Upgrade of Existing System

Substantial cooling towers, heat exchanger equipment, and pumping capacity already exist in LANSCE Area A. This equipment will be upgraded to ensure a reliable operation with high availability. A new system capable of properly handling heavy water coolant is needed; the heavy water is used to cool the target and reflectors to minimize parasitic neutron capture. The heavy water system will use the regular water coolant system as a heat sink through heat exchangers.

5.B.2. Routing, Instrumentation, Filtration, Shielding, and Control

The space above the LPSS and TTB will house a number of service facilities. Personnel in the service area must be shielded from the coolant lines, even when the beam is off. A robust shield will be placed around the water filters and other equipment where radioactive spallation products and corrosion products are known to accumulate. Instrumentation for monitoring water flow rates, water temperature, water quality, and system status will be provided, and some elements will be placed in the run-permit system.

5.C. Electrical Services

A full complement of electrical power services will be distributed throughout the service and experiment areas. Instruments will require power serviced from isolation transformers that ensure minimal electrical noise. The routing of the electrical services will be isolated from the instrumentation cable trays.

5.D. Facility Instrumentation

The performance of the facility equipment, including vacuum systems, cryogenic fluid systems, target and moderator temperature and coolant systems, and interlocks, will be continuously monitored. Performance level limits will be preset and monitored; proper signal levels will be required for a condition that allows beam-on-target. Off-normal conditions that cause a beam-off condition will be mitigated by following a prescribed set of procedures.

All instrumentation systems used to monitor facility performance will be subjected to a quality assurance program as well as a surveillance and testing program to ensure that signals are representative of the condition being monitored. Instruments used in radiation fields will be calibrated at proper intervals to ensure the signal quality. A preventative maintenance program will be established to minimize downtime caused by faulty instruments.

5.E. Vacuum System

The beam transport line from the switchyard area to the target system vacuum chamber will be maintained at a vacuum pressure < 10^{-6} torr. Mechanical pumps, turbomolecular pumps, cryogenic fluid pumps, and ion pumps will be used to provide the vacuum environment. The exhaust from these pumps will be filtered and then placed in the radioactive air handling ducting to ensure proper transport through the HEPA filter system.

The pumps for the target system will be housed in a shielded room. Entry into this area will require surveillance to ensure that radiation levels are acceptable and that no contamination exists in the area. Filters have the potential for contamination and will be shielded during maintenance activities.

5.F. Compressed Air System

Pneumatic actuators will likely be used to provide functions such as operation of valves. A centralized compressed air system will be maintained for these purposes. Because some of the functions provided by the compressed air system will be critical to the facility operation, its status will be a part of the run-permit logic.

5.G. Ventilation System

The movement of air into and out of the facility must be carefully controlled to ensure that any possible contamination is controlled. The entire facility will be maintained at a pressure below atmospheric pressure. The target system will be at vacuum. The hot cells will be at a pressure below that of the service area. The service area will be maintained at a pressure below that of the experiment area and the experiment area will be at a pressure below atmospheric pressure. Air-lock entrance doors will be used to ensure that the proper pressures are maintained.

5.H. Radioactive Air Removal System

Interactions between energetic particles and the components of air lead to production of radioactive isotopes. Also, activated surfaces of vacuum pipes and other structures in the beam transport and target systems can produce particulates that may become airborne. As mentioned above, the areas where air has the potential for activated components will be maintained at a pressure below those areas occupied by workers. The air and particulates will be taken through the HEPA filter system before being exhausted. The radiation levels of the exhaust will be continuously monitored to ensure compliance with the emissions limits set by the Environmental Protection Agency.

5.I. Cryogenic Fluid Plant

A helium refrigeration system will be provided to maintain liquid hydrogen for two moderators in the target system. The equipment will be housed in a specially prepared and shielded room above the BBS. Monitoring equipment will be provided to ensure that an acceptable atmosphere is maintained that is free of hydrogen and has adequate oxygen. No appreciable activation of this equipment is expected.

6. STRUCTURES

6.A. Bulk Biological Shielding

The beam transport line will be covered with steel and other shielding adequate to maintain an acceptable radiation dose level if an accident occurred where beam control was lost and the beam impinged on metal components in the transport line, producing neutrons. Under normal operating conditions, the radiation dose levels at the beam transport shield surface will be at building background levels.

The BBS (Figure 6) will be designed for a dose level of 0.1 mrem/hr during operation at 10 MW. Most of the shield will be made of steel. An outer ring of concrete containing boron will be provided for moderation and capture of low-energy neutrons. The BBS will include large chambers for housing the choppers; these chambers will be filled with "inserts" that provide shielding and access to the choppers for service activities.

The flight paths will penetrate the BBS. Close mechanical fits will be maintained between the BBS materials, the flight path liners, and the shutters and collimators in the flight path to eliminate neutron streaming.

The BBS will be built with sufficient structural strength to support the heavy shield equipment (ROSE and others) used for servicing the target system, the TTB, and the beam diagnostics inserts. The outer surface of the BBS will be enclosed by a membrane that will contain any activated air components produced by neutrons interacting with air in the void spaces in the shield.

6.B. Containment Building

Service activities on the target system, the TTB, and beam diagnostics will begin by removing components from above the BBS and beam transport line shielding. This area will be enclosed in a building (Figure 7) maintained at a pressure lower than the experiment area. The major purpose of this building is to contain and control any contamination from activated components.

The building will be constructed of metal girders and a metal skin capable of supporting the needed air pressure differentials. Air-lock entrance doors will be provided for contamination control. Although normal operation will not require anticontamination clothing, provision will be made to institute proper control if the area does become contaminated and work must proceed.

6.C. Hot Cell

The hot cell (Figure 2) will be used for servicing the LPSS target directly and the other target system components (e.g., moderators, reflectors) after those components are placed in the cell by the ROSE. Components from the TTB as well as materials irradiation experiments and proton beam diagnostics components will be handled in the hot cell.

The hot cell will be constructed of magnetite concrete. No leaded-glass windows will be used because closed circuit television will provide a view of the cell. A docking ring will be provided in the roof of the cell to prevent contamination from activated components. Identical docking rings will be provided for the test bed at the proton beam diagnostics port.

7. TEST FACILITIES

The primary purpose of the LPSS is to produce low-energy neutrons used for a variety of studies on the structure of matter. The LPSS may also produce ultracold neutrons. The high-energy neutrons produced in the forward direction will also be useful for neutron autoradiography. The details of the science that will be pursued are described in the document "A Long-Pulse Spallation Source at Los Alamos National Laboratory" [3].

The ability to irradiate materials samples in both the direct proton beam and in the neutron flux at the LPSS target system will provide a unique opportunity to study the effects of spallation radiation damage to materials. Examination of surveillance coupons and complete components from the operating systems will also be highly useful. Examination of diagnostic equipment will also provide information leading to improvements in these components. The hot cell will be equipped with testing equipment to evaluate changes in mechanical and physical properties of materials following exposure to energetic particle radiation.

7.A. Post-Irradiation Testing of Materials—Mechanical Test Equipment in the Hot Cell

The hot cell will be equipped with a load frame and fixtures that allow characterization of mechanical properties such as strength, ductility, and toughness. Tooling for sample handling using remotely operable manipulators will be provided. Also, tooling suitable for sample preparation from used and activated components will be developed and made available.

7.B. Post-Irradiation Testing of Materials—Physical Properties Testing Equipment in the Hot Cell

Equipment capable of physical properties measurements such as electrical, thermal, and magnetic properties will be provided in the hot cell. Here also remote handling methods will be used for sample preparation and handling.

Additional equipment for preparing samples for optical and electron microscopy will be placed in the hot cell. Special remote handling tooling will be provided to accomplish the required tasks.

7.C. Radioisotope Measurements after Materials Exposure to Radiation—Integral with the Hot Cell

Many of the irradiated components and test samples available for study will be highly radioactive (1 to > 1000 rem/hr). Benchmarking of the Monte Carlo codes used to predict proton and neutron interaction with matter would benefit from a complete measurement of the radioisotopes present in the irradiated materials. A system will be placed in the hot cell that allows accurate placement of active materials and measurement of decay gamma spectra using the normal Ge-Li detector systems. The highly activated materials will require that the detector be placed outside the hot cell and the electromagnetic radiation be transmitted through the cell wall through a collimated, shielded, and calibrated port.

7.D. Chemical Composition Measurements after Materials Exposure to Radiation—Integral with the Hot Cell and Including a Mass Spectrometer

In conjunction with the gamma spectrum measurements, it will be possible to provide validation data for the Monte Carlo codes from measurements that determine isotopically stable transmuted elements. A mass spectrometer and equipment suitable for preparing gaseous and liquid samples will be required in the hot cell.

7.E. Measurements of Water Chemistry in Corrosion Experiments in Conjunction with the Test Bed Facility

Systems studies on chemistry and corrosion of target system components will require measurements of the composition of water and other fluids after exposure to radiation. The mass spectrometer used for the chemical analysis of irradiated materials will also be used for these measurements. Additional corrosion-related measurement equipment for determining such parameters as corrosion potentials following irradiation will also be provided.

8. MATERIALS PERFORMANCE ISSUES

When protons strike a tungsten target, neutrons are produced through spallation reactions followed by evaporation processes. These neutrons are moderated in energy as they pass through media such as water and liquid hydrogen. These moderated neutrons are then viewed by flight paths that transport them to a variety of instruments.

Materials used in a spallation neutron environment will experience the effects of penetrating particle radiation. These effects include atom displacement, impurity atom production, and ionization. These effects will cause corrosion at varying rates. As the design for this facility proceeds, materials will be evaluated to determine expected lifetimes, based on data from fission power reactors (bearing in mind the effect of different neutron energy spectra at a spallation source) and high-power accelerators such as LANSCE and the Swiss Institute for Nuclear Research (SIN). The LANSCE and SIN experience, as well as experience with spallation target operation at MLNSC and ISIS (Rutherford-Appleton Laboratory in the United Kingdom), is useful in beginning the selection process for materials subjected to the high-energy proton beam and a neutron flux that includes particles with energies above 20 MeV. The physics of the radiation damage processes must be evaluated and tests executed in prototypic radiation environments that will determine component lifetime. A surveillance program that allows withdrawal of test specimens exposed to the identical irradiation history as the facility components will be implemented to allow intelligent decisions to be made regarding component replacement.

The following sections describe candidate materials for the components of the target system.

8.A. Neutron-Producing Target

Materials with high atomic numbers are used for neutron-production targets because the yield of neutrons per incident proton increases as the atomic number increases. MLNSC has successfully used unclad tungsten cooled by water for a number of years. ISIS has employed α phase uranium, clad in a zirconium alloy and cooled by water, with some success, although at the higher beam currents used recently, material swelling has caused some difficulty. Our preconceptual design uses tungsten, also the preferred material in the conceptual design study for the SPSS. Because the total power is substantially greater than that at the present MLNSC, the simple solid cylinder design used successfully at MLNSC must be changed to provide adequate surface for heat transfer.

Outstanding issues concerning the use of tungsten include:

***1. Lifetime*:** One tungsten target at MLNSC was exposed to a proton fluence approaching 10^{21} protons/cm^2. In our design, at a 1-MW power level the current density in the center of the beam will be 65 mA/cm^2 (parabolic beam profile with a diameter of 7 cm). This is a particle flux of about 4.1×10^{14} protons/cm^2, leading to a fluence of about 10^{22} protons/cm^2 in a full power year. This limited experience base is not adequate for a schedule that would plan only one target change each year.

***2. Ductile-to-Brittle Transition Temperature for Tungsten and Tungsten Alloys as a Function of Radiation Fluence*:** Tungsten and its alloys were considered as the target elements for the proposed German Spallation Neutron Source (SNQ) [4]. Tungsten and two of its alloys were irradiated in a fission reactor to a fluence of 10^{21} neutrons/cm^2 (E > 0.1 MeV), and the results [4,5] are given in the tablebelow.

Ductile-to-Brittle Transition Temperature for Tungsten and Tungsten Alloys Exposed to a Neutron Environment at a Fission Reactor

Material	Irradiation State	Ductile-to-Brittle Transition Temperature (°C)
Densimet 18	Before	< Room Temperature
	After	> 800
W-10%Re	Before	30
	After	85
Tungsten	Before	75
	After	240

These data indicate a strong radiation effect on the mechanical properties of tungsten. In support of the Accelerator Production of Tritium (APT) project, tungsten and three alloys including 97% W-Ni-Cu, 90% W-Ni-Cu, and W-25%Re were irradiated in the proton beam at LANSCE to several fluences up to 3.4×10^{20} protons/cm^2 (E_p~ 760 MeV).

Post-irradiation tests [6] of the samples in bending showed that all the materials were brittle. The pure tungsten samples showed the least effect from the radiation. The 97% W-Ni-Cu and W-25%Re materials were so brittle that it was not possible to prepare a suitable specimen for testing in bending. The 90% W-Ni-Cu retained some toughness after irradiation, but it was also difficult to obtain a suitable sample.

Tantalum is also considered a candidate for the spallation neutron-producing targets. A target made of tantalum has been used at ISIS with success to a relatively high dose. Only phenomenological results are available to date; the target has presumably operated to fluences greater than 10^{21} protons/cm^2. Mechanical properties testing of this material is planned.

*3. **Operating Stress Level:*** Although material such as tungsten and its alloys may be brittle even at room temperature, it may be possible to operate the LPSS at temperatures high enough to ensure ductile behavior. The concern then is the effect of rapid temperature quenches of the target system when the accelerator turns off after having been at full power. In general, the strength of a brittle tungsten or tungsten alloy can be expected to be high and adequate; it is prudent, however, to design the system so that plastic deformation does not occur. Our design encloses the tungsten material in a tube made of alloy Inconel 718. The tube will provide the needed structural integrity for the target pin assembly.

4. Corrosion and the Need for Cladding: Operating experience at MLNSC gives no indication of any severe problems with corrosion caused by contact of the irradiated material with the water coolant. Studies of the particulate found in the cooling system filters do indicate the presence of spallation products [7]. The corrosion rate of pure tungsten in water should be very low at room temperature [8]. Unclad tungsten material exposed to water coolant and a proton should be kept at a temperature well below 500°C.

5. Stability of Physical Properties Such as Thermal Conductivity, as a Function of Radiation Fluence: Irradiation of materials with 800 MeV protons leads to copious production of transmutation products, through spallation reactions, that serve as impurities [9]. These impurities may be effective in decreasing thermal conductivity, especially at high dose when the impurities such as helium decorate grain boundaries. This possibility must be considered during the design and should be confirmed by experiment in prototypic environments.

8.B. Thermal Neutron Reflector

The present MLNSC facility uses beryllium as a thermal neutron reflector to prevent those neutrons that have been thermalized from returning to and being absorbed by the high-Z target material. The material has performed without problems to a neutron fluence estimated to be 2.5×10^{20} neutrons/cm^2 (E > 0.1 MeV). Beryllium has a hexagonal close-packed crystal structure and is susceptible to embrittlement. Because components made of this material serve no structural function, the stress and necessary plastic deformation can be kept to a low level, which reduces the probability of failure. The exception would be stress resulting from coolant flows and pressures. In our design, the beryllium will be enclosed with a tough material such as alloy 304L stainless steel to provide the necessary structural integrity.

Beryllium has been used as a moderator since the beginning of fission reactor operations. Early studies indicated severe radiation effects resulting largely from the formation of helium from (n,α) reactions resulting from fast neutrons [10]. In the MLNSC application there may be additional helium caused by spallation if high-energy neutrons (> 50 MeV) are also incident on the material. The general findings in the early studies [11] are quoted below. Test conditions were a fast fluence of 7.6×10^{21} neutrons/cm^2 with the irradiation temperature at about 70°C in the Materials Testing Reactor:

> "1. Considerable embrittling effect due to atom displacement by fast neutrons;
> 2. Helium produced by fast neutrons remains in solution at temperatures < than 500°C;
> 3. Helium will tend to precipitate at temperatures above 500°C and form bubbles causing a volume increase that did not exceed 30% in these studies;
> 4. The presence of bubbles at grain boundaries will cause the beryllium to embrittle and become permeable to gases."

The fusion reactor community has also considered beryllium in the tritium-producing blanket portion of the first wall. Some progress has been made in understanding the irradiation behavior of beryllium. Tests done at the Engineering Breeder Reactor showed that material irradiated to a fluence of 10^{22} neutrons /cm^2 lost ductility from 30% to 3% when tested at room temperature. When tested at 450°C after irradiation the ductility was better at 14%. When first annealed at 900°C and then tested at 450°C, the ductility was 30%. The unirradiated room temperature ductility of this material is about 30%.

The corrosion resistance of beryllium in water is influenced strongly by purity; high-purity material is not susceptible to the pitting corrosion that results from impurities that form cells with pure beryllium areas on the surface [12]. A ten-year operation in a nuclear rocket environment using demineralized water coolant, slightly acidified, showed good performance [13]. This high-purity water environment showed no galvanic corrosion when coupled with stainless steel and aluminum. In our design, beryllium will be enclosed not only to provide strength to the assembly but also to ensure that material is not spalled into the coolant water and transported around the facility. The enclosure also acts to mitigate beryllium corrosion.

8.C. Fast Neutron Shield-Reflector

Shield material should be placed as near the target and moderator as possible to prevent leakage of fast neutrons through the bulk biological shield and into the experiment hall. The MLNSC uses close-packed nickel rods arranged to form an annular right-circular cylinder with penetrations for the flight paths. This unit is cooled by flowing water; no difficulties have been encountered in this system during more than five years of operation. The neutron fluence is not known but can be expected to be about 10^{20} neutrons/cm^2.

The LPSS will employ a similar design to that used at MLNSC. Stresses should be low, depending on the specific coolant pressure design. Irradiations of nickel in fission reactors to a dose of 10^{20} neutrons/cm^2 lead to yield strength increases up to 77%, tensile strength increases up to 25%, and although not reported, an expected, attendant decrease in ductility [14]. The LPSS reflector is expected to operate for the life of the facility.

Nickel and its alloys are generally very corrosion resistant in atmosphere, natural water, deaerated nonoxidizing acids, and caustic alkalis [15]. Difficulties with nickel corrosion are not expected at the LPSS.

8.D. Proton Beam Entry Window

The proton beam entry window at LANSCE is a hemispherical shell, cooled with water in a 2-mm gap between two 2-mm-thick shells made of alloy Inconel 718. No failures of this window have occurred since the spherical design was adapted. The windows are changed after a service of two years or so, corresponding to a fluence of 0.5 to 1.0×10^{21} protons/cm^2. It is generally accepted that the windows are capable of much longer life; however, easy access for change-out and relatively low cost dictate replacement during scheduled refit periods.

A flat plate window made of alloy Inconel 718 is used on the front face of the LANSCE copper beam stop. One such window survived a fluence in excess of 10^{21} protons/cm^2 before it was replaced [9]. Another hemispherical window made of alloy Inconel 718 and used as a beam degrader successfully performed to a fluence of 7×10^{21} protons/cm^2. The flux at LANSCE is comparable to that expected at the LPSS: 30 to 40 μA/cm^2 at LANSCE and 65 μA/cm^2 at the LPSS.

In support of the target development program at the spallation neutron source at SIN, two scale windows made of a Fe-10.5%Ni alloy have been irradiated at LANSCE. These, along with those made of alloy Inconel 718 used at LANSCE, will soon be tested for mechanical property changes and microstructural evolution to better determine expected lifetimes. These tests will be very valuable in establishing the safety margin available for this crucial component.

8.E. Moderator Enclosures

A major consideration for moderator enclosure materials is that they have a low thermal neutron absorption cross section. This requirement has led to the use of aluminum and zirconium alloys for almost all applications at accelerators and at fission reactor neutron sources. Some of the experiences are summarized in Reference 16. Zirconium has a slightly lower thermal neutron cross section than aluminum, but has a relatively large resonance integral that may point to use of aluminum, depending on the details of the energy spectrum.

Zirconium-based alloys (zircaloy) have performed well as fuel cladding in high neutron flux and to high fluence levels. The performance of these materials is tied, to a large extent, to the process used to make a specific shape and thus to the final texture. Because this material is hexagonal-close-packed, easy deformation is limited to the close-packed basal plane. Extensive deformation can lead to formation of microcracks, which makes the material susceptible to hydrogen-assisted cracking and embrittlement. Careful control of drawing parameters such as rate and temperature has allowed production of tubular products with excellent radiation resistance.

Aluminum alloys have performed well to high dose in fission reactors [17,18], showing an increase in strength with adequate ductility at fluences approaching 10^{23} neutrons/cm^2. A recent study [19] has evaluated the use of aluminum alloys in the APT project. Aluminum alloys 6061 and 5052 were exposed to the spallation neutron environment at LANSCE to a dose >10^{20} neutrons/cm^2. The irradiation temperature was 90° to 120°C. Results indicate little effect on material properties from this exposure. Alloy 6061 in T6 temper has been used successfully at MLNSC as an enclosure structure for the water moderator system. The dose on these components is not known but is estimated to be near 10^{21} neutrons/cm^2.

Exposure of both aluminum alloys 6061 and 5052 to the direct proton beam at LANSCE resulted in a drastic softening of these alloys at a dose approaching 4×10^{20} protons/cm^2 [20]. Irradiation temperature was estimated to be less than 100°C but could not be confirmed by measurements because the facility used did not allow access for thermocouples. Additional investigations of this effect in support of APT [19] showed little effect on the mechanical properties of these alloys when irradiated at LANSCE to a fluence near 4×10^{20} protons/cm^2, when the irradiation temperature was 50°C. When the irradiation temperature was > 200°C, the material after irradiation exhibited mechanical properties similar to those of annealed material.

8.F. Structural Components

Neutron absorption is also important in the selection of structural components. Aluminum and zirconium alloys are again favored, for the same reasons given above.

8.G. Vacuum Enclosure

The vacuum enclosure must perform for the life of the facility. Stainless steel alloy 304L has been in service as water-cooled shielding in the beam stop area at LANSCE for an estimated fluence of high-energy spallation neutrons approaching 10^{22} neutrons/cm^2 with no apparent corrosion or mechanical property difficulties. This alloy is also an excellent material for vacuum systems. The fluence at the LPSS is not expected to exceed that already achieved at LANSCE.

9. FUTURE FACILITY DEVELOPMENTS

The LPSS will be constructed with the maximum flexibility possible to accommodate future experiment needs. The target system can be completely reconfigured because of the large space provided in the vacuum vessel and the ease with which components can be removed and replaced. The neutron flight paths will be built to allow changes in collimation and chopper configurations. The TTB will be large enough and have adequate services to accommodate a variety of target system assemblies.

9.A. Ultracold Neutron Source

A schematic drawing of a possible ultracold neutron source based on a solid deuterium moderator is shown in Figure 19. The moderator unit will be placed and serviced from above using the ROSE unit. The flight path containing the ultracold neutrons will not have a window.

9.B. Pion and Muon Source

A graphite target upstream of the LPSS target system and the TTB would be necessary to produce pions and muons, and a flight path viewing the target would be necessary. Adequate space exists for inclusion of this capability. Priority and importance will determine the extent to which this capability will be developed.

9.C. Neutron Autoradiography Capabilities

High-energy neutrons produced in the forward direction from the tungsten target are considered useful for neutron autoradiography of heavy materials and components. A possible flight path and position for equipment are shown in Figure 12. The beam line will require adequate shielding to ensure compliance with the dose limits of 0.1 mrem/hr set for the facility.

10. REFERENCES

1. N. Bultman, A. Jason, E. Pitcher, G. Russell, W. Sommer, D. Weinacht, R. Woods, "Los Alamos Next-Generation Spallation Source," Los Alamos National Laboratory report LA-UR-95-4300 (December 1995).

2. Walter F. Sommer, "Rationale for a Spallation Neutron Source Target System Test Facility at the 1-MW Long-Pulse Spallation Source," Los Alamos National Laboratory report LA-13079-MS (December 1995).

3. "A Long-Pulse Spallation Source at Los Alamos National Laboratory," Los Alamos National Laboratory report LA-UR-95-2760 (October 1995).

4. W. Lohmann (Editor), "Materials Investigations for the SNQ Target," SNQ 3 JA/BH 12 01 84 (January 1984).

5. W. Lohmann (Editor), "Materials Investigations for the SNQ Target Station - Progress Report 1985," Jul 2061, ISSN 0366-0885 (May 1986).

6. Walter F. Sommer, et al., "Tungsten Materials Analysis," Los Alamos National Laboratory report LA-UR-95-220 (January 1995).

7. G. Russell, "Radioactive Inventory of the LANSCE Tungsten Target," Los Alamos National Laboratory internal memorandum, Russell to Torben Brun, dated February 5, 1991.

8. *Metals Handbook*, Ninth Edition, Volume 2, *Properties and Selection: Non-Ferrous Alloys and Special Purpose Materials* (ASM International, Metals Park, Ohio, 1987), p. 579.

9. Walter F. Sommer et al., "Experience at the Los Alamos Meson Physics Facility with the Use of Alloy Inconel 718 as an Enclousure for a Beam Degrader and as a Proton Beam Entry Window," Los Alamos National Laboratory report LA-UR-94-2809 (August 1994).

10. J. B. Rich, G. B. Redding, and R. D. Barnes, "The Effect of Heating Neutron Irradiated Beryllium," United Kingdom Atomic Energy Authority, AERE-M/R 2685 (September 1958).

11. J. M. Beeson et al., "Comparison of Compression Properties and Swelling of Beryllium at Various Temperatures," J. Nucl. Mater. **122** & **123**, 802–809 (1984).

12. *Metals Handbook*, Ninth Edition, Volume 13, *Corrosion* (ASM International, Metals Park, Ohio, 1987), p. 809.

13. *Metals Handbook*, Ninth Edition, Volume 13, *Corrosion* (ASM International, Metals Park, Ohio, 1987), p. 811.

14. John F. Kircher and Richard E. Bowman, *Effects of Radiation on Materials and Components* (Reinhold Publishing Corporation, New York, 1964), p. 451.

15. *Metals Handbook*, Ninth Edition, Volume 13, *Corrosion* (ASM International, Metals Park, Ohio, 1987), p. 641.

16. M. S. Wechsler, J. F. Stubbins, W. F. Sommer, P. D. Ferguson, and E. H. Farnum, "Selection and Qualification of Materials for the Accelerator Transmutation of Waste Project," Los Alamos National Laboratory report LA-UR-92-1211 (June 1992).

17. John R Weeks, Carl J. Czajkowski, and Paul Tichler, "Effects of High Thermal and High Fast Fluences on the Mechanical Properties of Type 6061 Aluminum at HFBR," ASTM STP 1046 (1990), pp. 441–452.

18. K. Farrell and R. T. King, "Tensile Properties of Neutron-Irradiated 6061 Aluminum Alloy in Annealed and Precipitation-Hardened Conditions," ASTM STP 683 (1979), pp. 440–449.

19. Walter F. Sommer, et al., "APT Materials Safety Experiments Technical Report," Los Alamos National Laboratory report LA-UR-93-2850, submitted to the US Department of Energy, Defense Programs Office, September 1993.

20. W. Lohmann, A. Ribbens, W. F. Sommer, and B. N. Singh, "Microstructure and Mechanical Properties of Medium Energy (600–800 MeV) Proton-Irradiated Commercial Aluminum Alloys," *Radiation Effects*, **101**, 283–299 (1986).

11. ACRONYM LIST

ALARA	as low as reasonably achievable
APT	Accelerator Production of Tritium
BBS	bulk biological shield
FP	fast protect (equipment)
HEPA	high-efficiency particulate air (filter)
ISIS	Rutherford-Appleton Laboratory (United Kingdom)
LANSCE	Los Alamos Neutron Science Center (formerly known as LAMPF)
LPSS	Long-Pulse Spallation Source
MLNSC	Manuel Lujan Jr. Neutron Scattering Center
ROSE	Remotely Operable Shield Equipment
RSS	Radiation Safety System
SIN	Schweizerisches Institute für Nuklearforschung (Swiss Institute for Nuclear Research)
SINQ	Schweizerisches Institute für Nuklearforschung Quelle (Swiss Spallation Neutron Source)
SNQ	German Spallation Neutron Source
SPSS	Short-Pulse Spallation Source
TTB	Target Test Bed
UCN	ultracold neutron