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ALARA Review of the Spallation Neutron Source Accumulator Ring and Transfer Lines

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ALARA REVIEW OF THE SPALLATION NEUTRON SOURCE ACCUMULATOR RING AND TRANSFER LINES

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ACRONYMS

AGS	advanced gradient synchrotron
ALARA	as low as reasonably achievable
ASRC	Accelerator Safety Review Committee
BNL	Brookhaven National Laboratory
CCDTL	cavity coupled drift-tube linac
CCL	cavity coupled linac
DOE	U.S. Department of Energy
DTL	drift-tube linac
ES&H	environment, safety, and health
FODO	Focus Zero Defocus Zero
FSAR	final safety analysis report
HEBT	high-energy beam transport
LANL	Los Alamos National Laboratory
LINAC	linear accelerator
ORNL	Oak Ridge National Laboratory
ORR	Oak Ridge Reservation
OSSD	Operational Safety Services Division
PLC	programmable logic controllers
PPS	personnel protection systems
rf	radio frequency
RTBT	ring-to-transfer beam transport
RWP	radiological work permit
SNS	Spallation Neutron Source
SRD	System Requirements Document

EXECUTIVE SUMMARY

The Spallation Neutron Source (SNS) is designed to meet the growing need for new tools that will deepen our understanding in materials science, life science, chemistry, fundamental and nuclear physics, earth and environmental sciences, and engineering sciences. The SNS is an accelerator-based neutron-scattering facility that when operational will produce an average beam power of 2 MW at a repetition rate of 60 Hz. The accelerator complex consists of the front-end systems, which will include an ion source; a 1-GeV full-energy linear accelerator; a single accumulator ring and its transfer lines; and a liquid mercury target. This report documents an as-low-as-reasonably-achievable (ALARA) review of the accumulator ring and transfer lines at their early design stage.

An ALARA working group was formed and conducted a review of the SNS ring and transfer lines at the - 25% complete design stage to help ensure that ALARA principles are being incorporated into the design. The radiological aspects of the SNS design criteria were reviewed against regulatory requirements and ALARA principles. Proposed features and measures were then reviewed against the SNS design criteria. As part of the overall review, the working group reviewed the design manual; design drawings and process and instrumentation diagrams; the environment, safety, and health manual; and other related reports and literature. The group also talked with SNS design engineers to obtain explanations of pertinent subject matter.

The ALARA group found that ALARA principles are indeed being incorporated into the early design stage. Radiation fields have been characterized, and shielding calculations have been performed. Radiological issues are being adequately addressed with regard to equipment selection, access control, confinement structure and ventilation, and contamination control. Radiation monitoring instrumentation for worker and environment protection are also being considered—a good practice at this early design stage.

The ring and transfer lines are being designed for hands-on maintenance. The SNS beam loss criteria, which determine radiation dose design, are a factor of ~30 lower than the lowest that has been achieved at any existing proton synchrotron and accumulator rings. This demonstrates that ALARA considerations are an important part of SNS design.

A noteworthy example of the ALARA principal being incorporated into the SNS is the hybrid ring lattice design recently approved by the SNS change control process. The new lattice design increases calculated acceptance by about 50% and improves the expected collimator efficiency from 80 to 95%. As a result, the expected calculated beam loss rate, and resulting radiation dose rates, are significantly improved.

Another major design change with ALARA implications was the change from an alpha to an omega configuration for the high-energy beam transport (HEBT) system, ring, and ring-to-target beam transport (RTBT) system. Because of this change, the ring and transfer lines will have crane coverage, eliminating the need for personnel to be near activated equipment for repair and removal. By using the crane, extensive shielding can be placed around highly radioactive equipment (e.g., collimators), and the equipment can be moved by remote control. As part of the change from an alpha to omega configuration, the tunnel width was increased by 2 ft. This increased width will allow easier access to failed equipment, reducing radiation exposure time to workers during maintenance and repair. In addition, a personnel entrance was added to the ring between the HEBT and RTBT so that personnel will not have to enter this area directly through the HEBT or RTBT. This addition will shorten the travel distance, and therefore the time, that personnel performing maintenance work on radioactive equipment will need to be in the area, reducing potential dose. In the RTBT beam line, a hatchway will be placed above the collimators and quad doublet magnets near the target to facilitate their removal. This design was chosen in lieu of a track system that would require removal of all equipment near the target when replacing collimators or quads.

This report describes many other examples where ALARA principals have been applied to the SNS design. The strongest, clearest indication that ALARA principles are being incorporated into the design is that knowledgeable, experienced individuals who are conscious of ALARA issues participate at every design review and at all levels of design.

1. INTRODUCTION

The Spallation Neutron Source (SNS) is a new accelerator-based neutron-scattering research facility under construction in Oak Ridge, Tennessee. The SNS will serve the needs of scientists and researchers from universities, industry, and private and federal laboratories from the United States and beyond. Neutron-based research is becoming an increasingly essential tool in the physical, chemical, and biological sciences. To produce the neutrons needed for such research at SNS, an accelerator system will be used to deliver short (microsecond) pulses of high-energy protons that will be accumulated in a ring and delivered onto a liquid mercury target. The impact of protons onto the neutron-dense mercury "spalls off" neutrons, which are guided to various specially designed experiment stations. The SNS is scheduled to be completed in 2006 at a cost of $1.4B.

This report documents an as-low-as-reasonably-achievable (ALARA) working group's review of the SNS accumulator ring and transfer lines to ensure that ALARA principals are being incorporated. The radiological aspects of the design criteria for normal operations, maintenance, and anticipated upset conditions were reviewed against regulatory requirements and ALARA principles. The corresponding proposed features or measures for SNS were then reviewed against the design criteria.

As part of the review, the ring ALARA working group became familiar with key elements of the SNS accumulator ring and transport lines and the basis of design for them. The group reviewed the design manual; drawings and process and instrumentation diagrams; environment, safety, and health (ES&H) manual; and related reports and literature. The group also talked with SNS design engineers to obtain explanations of pertinent subject matter. Numerous discussions were also held with SNS personnel from Brookhaven National Laboratory, where the primary ring design is being conducted.

The SNS is designed for hands-on maintenance, as opposed to remote maintenance. This design philosophy requires that the average uncontrolled beam loss be limited to ~1 W of beam power per tunnel meter. For an accumulator ring with a circumference of 220 m, this corresponds to an average fraction beam loss of $\sim 10^{-4}$ at 1 GeV beam energy. The lowest achievable beam loss, among existing proton synchrotrons and accumulator rings, is about 3 H 10^{-3} at the Proton Storage Ring at Los Alamos National Laboratory (LANL). However, SNS is designed with an estimated beam loss of 10^{-4}. SNS is committed to ALARA principles as demonstrated by this low beam loss design criterion.

2. DESCRIPTION OF THE SNS SITE, FACILITIES, EQUIPMENT, AND RADIOLOGICAL CONTROLS

This section provides a description of the SNS site characteristics and facilities, including the location of major buildings and their projected occupancy levels. Descriptions of radiological control policies, ALARA organizations, and administration are also included.

2.1 SITE DESCRIPTION

The SNS site is located atop Chestnut Ridge on the X-10 portion of the Oak Ridge Reservation (ORR), -1.75 miles (2.8 km) northeast from the center of Oak Ridge National Laboratory (ORNL). The site is accessed via Chestnut Ridge Road, across from the 7000 area at ORNL. The SNS buildings will be built on Chestnut Ridge about 1,030 to 1,050 ft above sea level. The footprint for the project extends along a long, wide ridge top at the eastern end of Chestnut Ridge. The major buildings needed for the operational part of the facility—the linear accelerator (LINAC), transport line, ring, and target—are notched into the south side of the ridge.

The ORR consists of about 37,000 acres, with three major industrial complexes located in adjacent valleys: the K-25 site (East Tennessee Technology Park), the X-10 site (ORNL), and the Y-12 Plant site. The ORNL site is about 6 miles southwest of the commercial and population center of the city of Oak Ridge and about 23 miles west of the center (downtown) of the city of Knoxville. The location of the SNS within the ORR is shown on Fig. 2.1.

The closest ORR boundary to the SNS site is about 7,500 ft to the northwest on the south side of East Fork Ridge. The closest point where private residences can be built (some already exist in this area) is about 7,500 ft to the northwest. The general public is allowed routine access to several ORR locations, and several unrestricted roads traverse the reservation. The public road closest to the SNS site is Bethel Valley, which runs in an east-west direction about 1 mile to the south. Because Bethel Valley Road is closer to the SNS site than the ORR boundary and any other locations on the reservation where the public is allowed routine access, it is the point where the consequences to the public of short-term airborne normal operation and accident releases are evaluated. The point of closest approach on Bethel Valley Road is about 4,600 ft (1400 m) to the south of the SNS site.

Access to ORNL is from Bethel Valley Road to the south and Tennessee State Highway 95, which runs in a north-south direction west of ORNL. All access roads that lead directly onto the ORNL site are posted and are closed to the general public. ORNL has the authority to control access to Bethel Valley Road and Highway 95 in the event of an emergency.

The average temperatures recorded vary from about 37EF in January to 77EF in July. Temperatures above 100EF (105EF maximum) have been experienced from June through September. Temperatures of 5EF or below (-17EF minimum) have been experienced from November through March.

The average annual precipitation recorded is about 54 in., with a maximum annual of 76.33 in. and a minimum annual of 37.43. The greatest monthly total has been 19.27 in., with a maximum of 7.48 in. during a 24-h period. The normal season snowfall recorded at the City of Oak Ridge station is 11.1 in., with a single season maximum of 41.4 in.

The wind direction above the ridge tops and within the valleys at ORNL tends to be aligned with the orientation of the valleys. The prevailing wind is from the southwest, with a secondary maximum from the northeast during the winter, spring, and summer months. This situation is reversed in the fall, with the prevailing wind coming from the northeast. Flow across the valleys is infrequent. The average wind speed recorded at the 10 m height on the ORNL Bethel Valley area meteorological tower-2 during the period of record from 1984 through 1996 was also 4.4 mph.

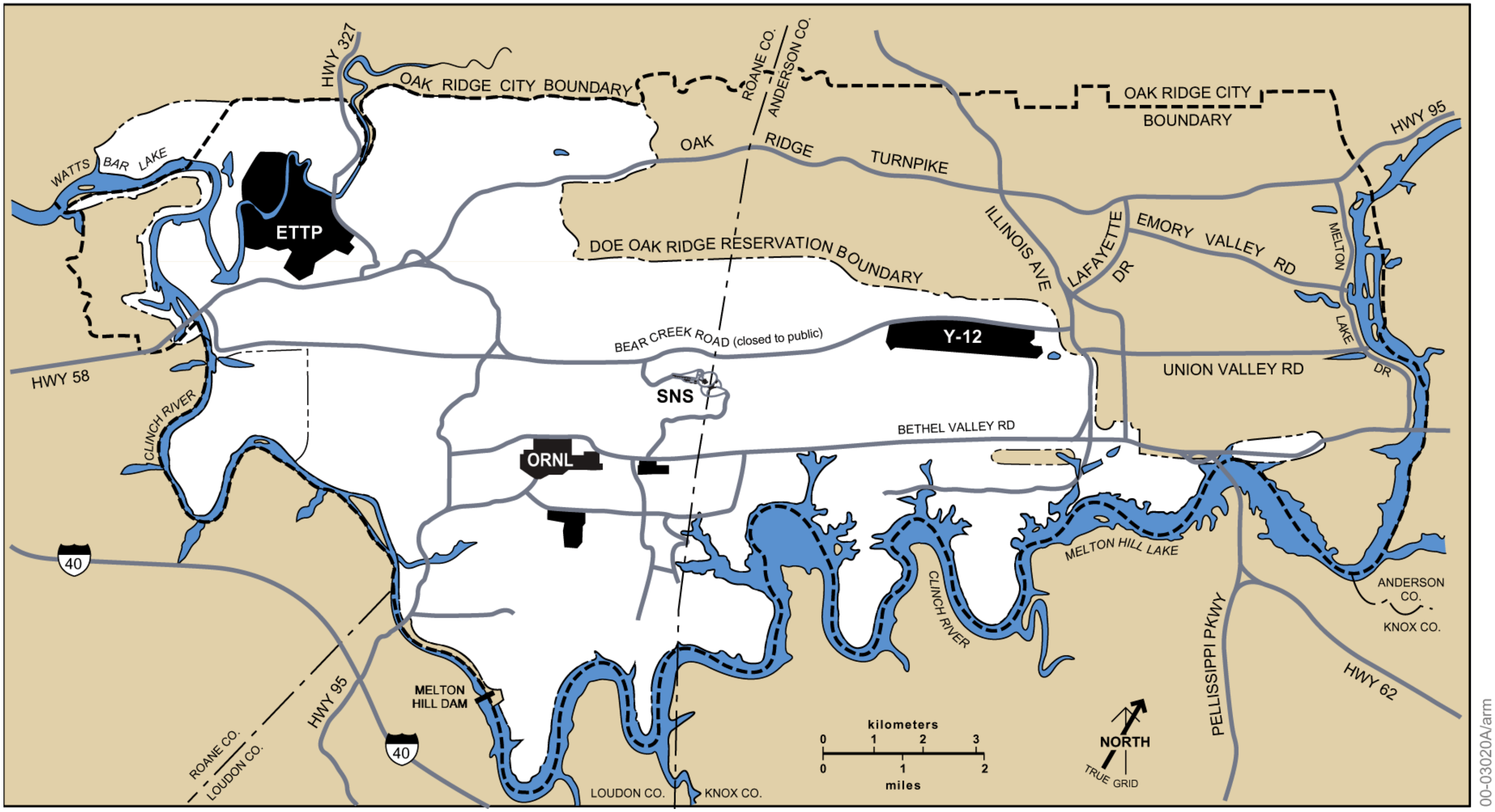

Fig. 2.1. Location of SNS site within the Oak Ridge Reservation.

Surface water at the SNS site consists of a small perennial stream that acts as headwater to White Oak Creek. This unnamed tributary flows southeast from the valley below the SNS footprint on Chestnut Ridge into the ORNL main plant area. Flow diminishes to zero at the elevation of the proposed SNS site. Two additional drainages northeast and southwest of the site dissect the scarp face of Chestnut Ridge and flow northwesterly into Bear Creek. While these drainages may receive runoff from the SNS footprint area, the footprint does not overlay the actual stream channels.

The SNS site is not within a floodplain, and widespread flooding is unlikely for a site several hundred feet above the valley floor. The site development plans include a basin to retard runoff from graded areas during a severe rain event.

No significant undesired local ponding would occur on the immediate SNS site since the site is located on a ridge top and will be graded to preclude undesired water accumulation. A drainage basin will be provided to control rainwater drainage from the site. Because of the site's location atop Chestnut Ridge, significant local site flooding is not credible.

Groundwater at the site is observed at a depth of >60 ft (18 m). Note that groundwater levels vary significantly at the site depending on height above the valley floor and seasonal and climatic conditions.

The hydrology of the ORR has been described by Moore (1989). A detailed environmental description is contained in Fitzpatrick (1982) and Boyle et al. (1982). A detailed site description is contained in LMER (2000), Fitzpatrick (1982), and Boyle et al. (1982).

2.2 SNS FACILITIES AND EQUIPMENT

The facilities that comprise the SNS are shown in Fig. 2.2 and are identified in Table 2.1, along with the approximate closest distances from other buildings.

2.2.1 Front-End Systems

The 2.5-MeV beam from the radio-frequency (rf) quadrupole is transported through the medium-energy beam transport for matching and injection into the drift-tube LINAC (DTL).

2.2.2 Linac Systems

The LINAC receives 2.5 MeV of H ! injected from the front-end systems and accelerates the negative ions to 1.0 GeV for delivery to the high-energy beam transport (HEBT) system. The LINAC consists of three types of rf accelerating structures: the DTL, coupled-cavity DTL (CCDTL), and coupled-cavity LINAC (CCL). The DTL operates at 402.5 MHz and accelerates the beam from 2.5 MeV to 20 MeV. The remaining lattice structures, the CCDTL and CCL, operate at 805 Hz. The CCDTL takes energy to 95 MeV, where the transition to CCL takes place. The bulk of the acceleration takes place in the CCL. The low-energy component of the CCL (95 to 165 MeV) consists of eight cells per segment, where "segment" refers to a contiguous section of accelerating cavities between two quadrupole focusing magnets. The high-energy component of the CCL (165 Mev to 1 GeV) consists of 10 cells per segment.

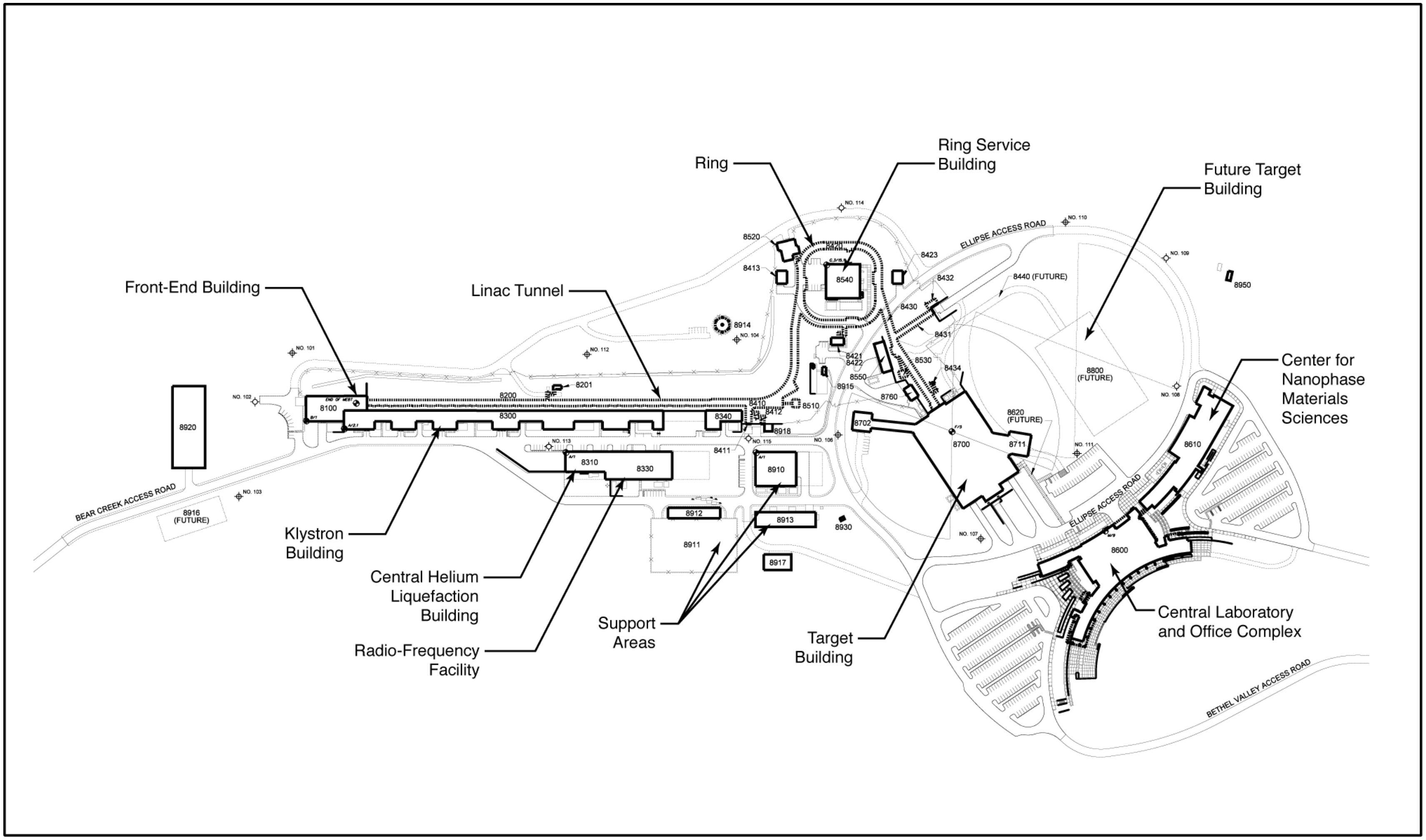

Fig. 2.2. SNS footprint.

Table 2.1. SNS facilities and distances

Facility description	Approximate separation distance (ft)				
	LINAC to	HEBT to	Ring to	Ring-to-target beam transport (RTBT) to	Target to
Electrical switchyard	250–1,730	1,960	2,000	2,230	2,340
Front-end building	0–1,500	1,750	1,750	2,030	2,100
Outdoor storage yard	230–1,600	1,850	1,900	2,140	2,160
Central utility building and cooling tower area	140–1,150	1,600	1,625	1,870	1,920
LINAC tunnel and klystron building	-----	0–1,560	350–1,750	530–1,810	420–2,200
HEBT	0–1,560	-----	0–325	200–510	420–600
Ring service building	410–1,820	25–360	(25)	25–450	465
Ring	350–1,750	0–325	-----	0–400	390–610
Ring injection dump	460–1,585	350–530	0–250	280–640	660
LINAC dump	250	50–250	175	250–400	360
Ring extraction dump	540	350–530	225	10–380	165
RTBT	530–1,810	200–650	400	-----	0–400
Target	420–2,200	420–600	390–610	0–400	-----
Central lab and office building	1,180–2,630	1,100	950	650–1,040	220–630
Conference center	1,220–2,600	1,200	1,075	680–1,090	390-750

2.2.3 Ring and Beam Transport Systems

The SNS consists of three major ring systems: the HEBT system, the accumulator ring itself, and the RTBT system. Three support buildings—the HEBT services and support building, the ring support building in the center of the ring, and the RTBT support building—will house power supplies, monitoring devices, rf equipment, etc., for the major systems. These facilities are shown in Fig. 2.2. The HEBT provides the link between the LINAC and the accumulator ring. The beam coming out of the LINAC is a 1.0-GeV H! beam, with a peak current of 28 mA. The total length of the HEBT line will be 192 m, and the total bending angle will be 90E. The line will provide locations for beam scraping of the halo particles (i.e., collimators).

The primary function of the proton accumulator ring is to take a 1-ms, 1.0-GeV H! beam from the LINAC and compress it to a 0.5-Fs pulse by accumulating 1,158 turns in the ring. The final beam will have 2 H 10^{14} protons per pulse, meeting the specifications of a 1-MW design average beam power at a 60-Hz repetition rate. A missing magnet design is used to reduce the dispersion function to zero in the straight sections of the ring.

The RTBT system takes the extracted beam from the ring and transports it to the target. The extraction starts with an eight-module kicker magnet array to deflect the circulating beam, followed by a Lamberston magnet to bend the beam vertically out of the ring (????). A small dipole magnet brings the beam back to a horizontal direction, resulting in a beam height of ~1 ft above the ring beam height. The magnet apertures in this line will be sized to allow for malfunctions of one of the eight extraction kicker magnets, protecting the line against excessive beam losses. A beam shape control section will be provided for the final beam shape tuning for the target. Additional focusing control will provide compensation for the window scattering before the target. The total length of the RTBT line will be 180 m, and the total horizontal bend angle will be 15E.

2.2.4 Target Systems

The target systems primary function is to provide short pulses of low-energy neutrons to neutron-scattering instruments. This is achieved through the high-energy spallation reactions from the incoming proton beam from the RTBT and the liquid mercury target. A secondary function is to safely contain the target material in a system that can transport the proton beam power and resulting radiation to a secondary cooling system.

The target module consists of the mercury target vessel, water-cooled shroud surrounding this vessel, and the plug that contains mercury and the water feed and return lines. Target modules are designed to handle a reference beam profile that has a width of 200 mm and a height of 70 mm. The peak intensity of the beam over this area is #0.18 A/m^2. For normal operating conditions, the peak temperature of the stainless steel target vessel is maintained at <200EC (392EF). The module extends from the center of the target shielding monolith to the inside of the target cell. Because it is directly in line with the proton beam, it includes passive shielding provisions, which incorporate dog-legs in the piping to prevent generation of excess radiation in the target cell in the event of mercury loss. The modules also include wheels to facilitate retraction into the hot cell. Expectations are that the target module will be replaced twice a year. Because of the effects of interaction with the proton beam, the target module structure will be replaced at least every four operating months.

The target plug is the structure that spans the region from the target module to the flange that interfaces with the process equipment located in the target cell. The target plug contains the feed and return lines for the mercury and water systems and shielding. A vertical offset in the plug is provided to control neutron streaming through the 5-mm clearance gaps between the plug and the surrounding vessel that contains the bulk shielding. The offset also provides shielding in the unlikely event that mercury is lost from the piping while the beam is on. A target transport system is provided to facilitate remote replacement of the target plug within five 8-hour working shifts.

The target process systems include the liquid mercury process equipment and water process systems used to cool the shroud surrounding the mercury vessel. The mercury flow loop used to feed the target and the water flow loop used to cool the shroud surrounding the mercury target are required to transport the power deposited in the target module structures. The transport includes removable shielding. This equipment includes the mercury pump, heat exchanger, mercury storage tanks, valves, etc.

The target station includes four moderators to slow spallation neutrons to energy levels needed in experiments, beam ports in the biological shield, and beam shutters capable of blocking each of these beam ports. The beam ports are large enough to accommodate a range of beam-defining inserts: apertures, guides, collimators, and the associated shielding immediately surrounding the beam. These inserts are used to define the size and shape of the neutron beam required for specific instruments in the experiment systems.

The target station also includes neutron beam shutters, which are designed to accommodate a wide variety of beam-defining inserts. This accommodation is accomplished by providing a large, stepped passage through the shutter to be filled by components provided as part of the experimental instrument. Some instruments will require guides that pass through the shutters, so the shutters must be capable of small rotations about the vertical axis and of vertical and horizontal adjustments necessary to optimize guide alignment.

2.2.5 Experiment Facilities

Experimental facilities include the neutron-scattering instruments located on the neutron beam radiating from the target station. The target station will provide at least 18 neutron beams, and the associated experiment hall is sized to accommodate the neutron-scattering instruments for these beams. Most of the neutron-scattering instruments fit entirely within this experiment hall, but a few long-flight-path instruments will be on beam lines that extend through the walls of the experiment hall. The experiment facilities also include facilities to support operation of the instruments. These support facilities will include offices, shops, and laboratories that are housed in an experiment support building adjacent to the experiment hall.

2.3 RADIOLOGICAL CONTROLS

SNS personnel exposed to standard industrial hazards will use the same ORNL support organizations, controls, and mechanisms as other ORNL organizations. Controls for a wide range of hazards and conditions are identified in SNS system requirements documents (SRDs), which also document ORNL's radiological control policies and administrative levels for action. SNS management expectations for radiological protection are documented in SNS management and quality assurance plans.

General rules for training are provided by ORNL directives for training and qualifications. All applicable SNS personnel will receive appropriate training on the SRDs.

SNS is committed to the Integrated Safety Management System precept of continuous improvement. SNS intends to continue to improve its management programs, including those for ES&H, and to continually search for the most meaningful metrics and indicators for feedback.

SNS management has developed mechanisms to involve the following three committees in radiation safety review activities: the Radiation Safety Committee, ALARA Committee, and the Accelerator Safety Review Committee. Effective interaction and communication, including periodic reviews, with these committees will help ensure that the SNS is designed, built, and operated according to the highest radiation safety standards.

2.3.1 Radiation Safety Committee

The Radiation Safety Committee was charged with the responsibility for resolving radiation safety issues as they arise during day-to-day design. The chairman of the committee reports to the SNS administrative director. Committee membership is listed in Table 2.2. Note that membership will change as the project evolves.

Table 2.2. Radiation Safety Committee membership

Name	Title
Frank Kornegay	Chairman
Paul Wright	SNS Personnel Protection System (PPS)
Jonathan Haire	SNS radiological support
Ken Reece	SNS Accelerator Division
Don Gregory	ORNL Operational Safety Services Division (OSSD)