SNS 00000000-0000-R00

Accelerator Systems Division Commissioning Program Plan

Issued for Review and Comment

October, 2001

A U.S. Department of Energy Multilaboratory Project
SPALLATION NEUTRON SOURCE
Argonne National Laboratory • Brookhaven National Laboratory • Thomas Jefferson National Accelerator Facility • Lawrence Berkeley National Laboratory • Los Alamos National Laboratory • Oak Ridge National Laboratory
SNS

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Accelerator Systems Division
Commissioning Program Plan

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Los Alamos National Laboratory	Oak Ridge National Laboratory

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Accelerator Systems Division
Commissioning Program Plan

October 2001

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1.0 Introduction

1.1 Commissioning Organization

Commissioning of the SNS accelerator requires detailed planning and close coordination of installation, test and check-out, and accelerator system conditioning activities. Commissioning refers specifically to those activities involving the use of the beam. All other activities not using the beam are installation, testing, processing and conditioning etc.

The SNS Accelerator Systems Division (ASD) is composed of approximately 100 physicists, engineers and technicians available to support the effective and efficient commissioning of each accelerator system.

ASD has established a Commissioning Team structure (Fig. 1.a) that will provide day-to-day and weekly coordination of commissioning activities. This group will ensure efficient use of machine resources and time.

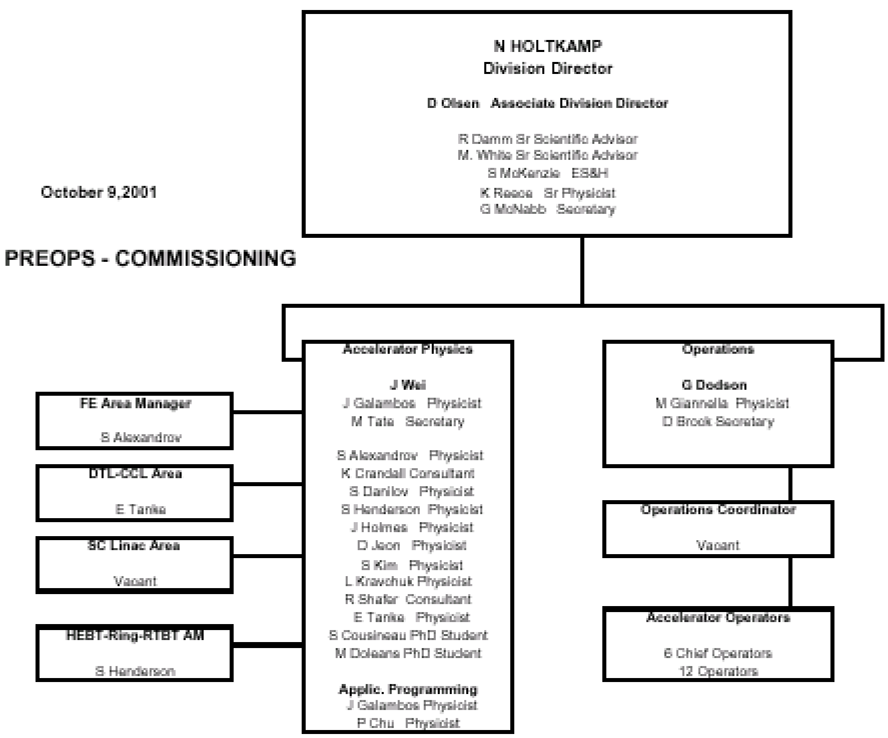


Figure 1.a Commissioning Organization

Each of the ASD technical groups will provide technical leads and specialists to supervise commissioning work, under the guidance and direction of the Commissioning Team.

The SNS Environmental Safety and Health (ES&H) Manager provides guidance and advice pertaining to SNS adherence to Federal and DOE regulations.

1.2 Commissioning

The Accelerator Systems Division Commissioning Program plan was developed over a period of about thirteen months. The process began with one of two SNS Commissioning Workshops held at LANL. These workshops concentrated primarily on the Front End and Linac. In addition to the workshops, a number of conference papers and visits by commissioning team members to partner laboratories added to a basic understanding of the commissioning process. A series of regular Commissioning Team videoconferences were established. These weekly meetings alternated focus between the Front End and Linac. Recently the Ring Commissioning Team was added to the videoconference rotation.

For each of the commissioning teams, an Area Manager (see Fig. 1.a) was named to act as the team coordinator and to assume overall responsibility for the technical commissioning process and beam delivery to the treaty points between systems. The overall goal of the commissioning process is the delivery, to the spallation target, of a beam consistent with the requirements of Critical Decision 4 (CD-4), which defines the successful completion of the SNS project. The CD-4 requirements are listed in the SNS Project Execution Plan, Document SNS_1999_00004 ORNL/M6661/R0A.

The SNS Accelerator Systems Division Commissioning Program Plan is intended to work in concert with the SNS Accelerator Systems Division Installation Plan (document SNS 100000000-PN002-R00) since the installation, test and check out, and conditioning of the accelerator components ("pre-beam") will be interleaved with commissioning ("with beam").

A high level schedule for the installation, testing and commissioning of the SNS accelerator systems is shown in Appendix D.

The commissioning of an accelerator system is a critical step in the transition from the fabrication and installation phases to the operational phase. Accelerator commissioning includes a sequence of accelerator physics measurements, and the test and check-out and tuning of accelerator systems with beam, in order to characterize the actual operational parameters of the accelerator systems. The information gained from commissioning studies is used to endorse the operation of those systems as they were measured, or as a basis by which to modify the systems to provide a beam with different qualities. The sequence of measurements constitutes the Commissioning Program Plan, which is an essential element in the Accelerator Readiness Review (ARR) process as described in DOE O 420.2A.

According to the Draft Guidance for DOE O 420.2A:

> "Commissioning a facility incrementally can be advantageous, particularly if it is desirable to operate portions of the facility while other portions are still under construction. Facilities can be delineated into modules such as the beam particle source, the accelerator, beamlines, accumulator ring, etc. As each module is completed and tested, a commissioning ARR can be conducted for that module. The commissioning activity for each separate module requires DOE approval before it is initiated unless approval from DOE is received for an overall commissioning program. The development of an overall commissioning program plan tends to focus better on the required approval by DOE and lessen the likelihood of delays in obtaining a number of discrete approvals."

In order to proceed as rapidly as possible, it is indeed our plan to commission the SNS accelerator systems as a sequence beginning with the Front End. The accelerator will then be commissioned module by module, as they become available, in coordination with the Installation Plan.

The accelerator consists of the Drift Tube Linac (DTL), the Coupled Cavity Linac (CCL) and the Superconducting Linac (SCL). (See conceptual map in Fig.1.b and detailed layout in Fig.1.c). Following the commissioning of the accelerator we will commission the High Energy Beam Transport (HEBT), the Accumulator Ring (Ring) and the Ring to Target Beam Transport (RTBT). The commissioning of the RTBT will be in two distinct phases. The portion of the RTBT from the Ring to the extraction dump will be commissioned with Ring systems. The dipole magnet, which directs the beam from the first portion of the RTBT into the second portion and to the target, will not be installed until it is needed. Following the installation of this dipole and the completion of the Target commissioning ARR, the beam will be directed to the target straight section of the RTBT.

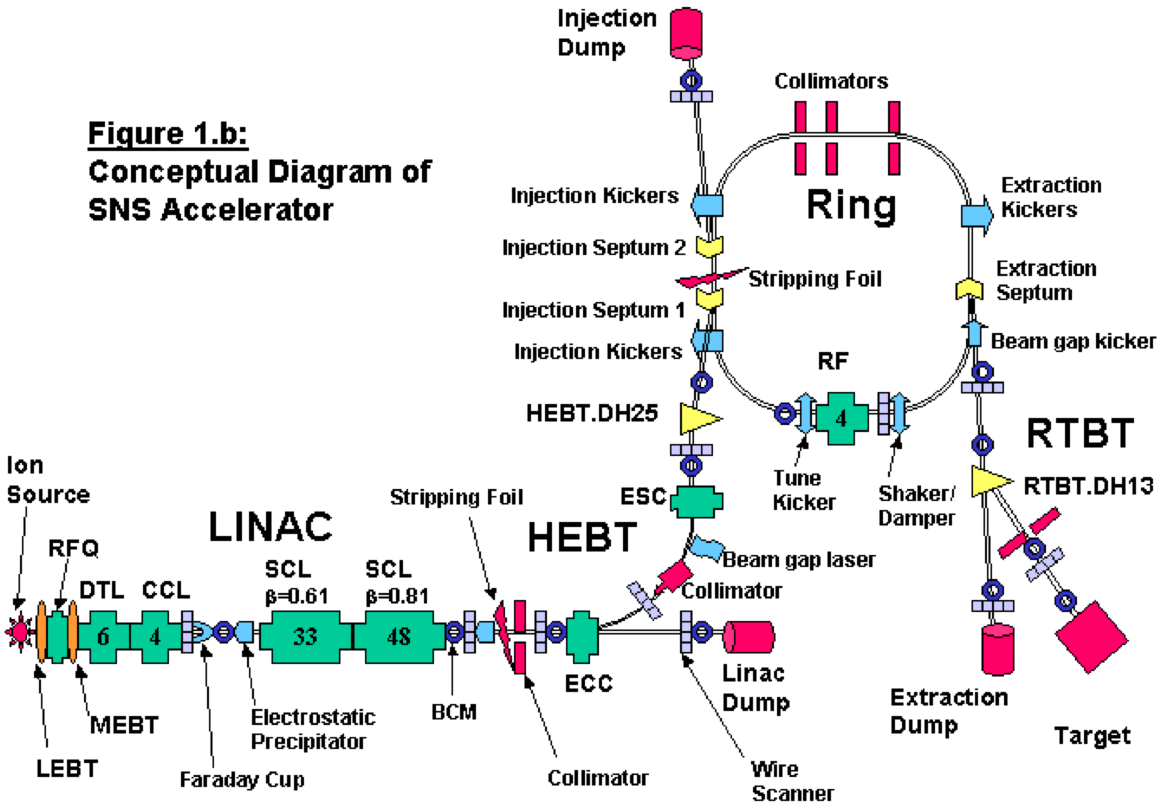
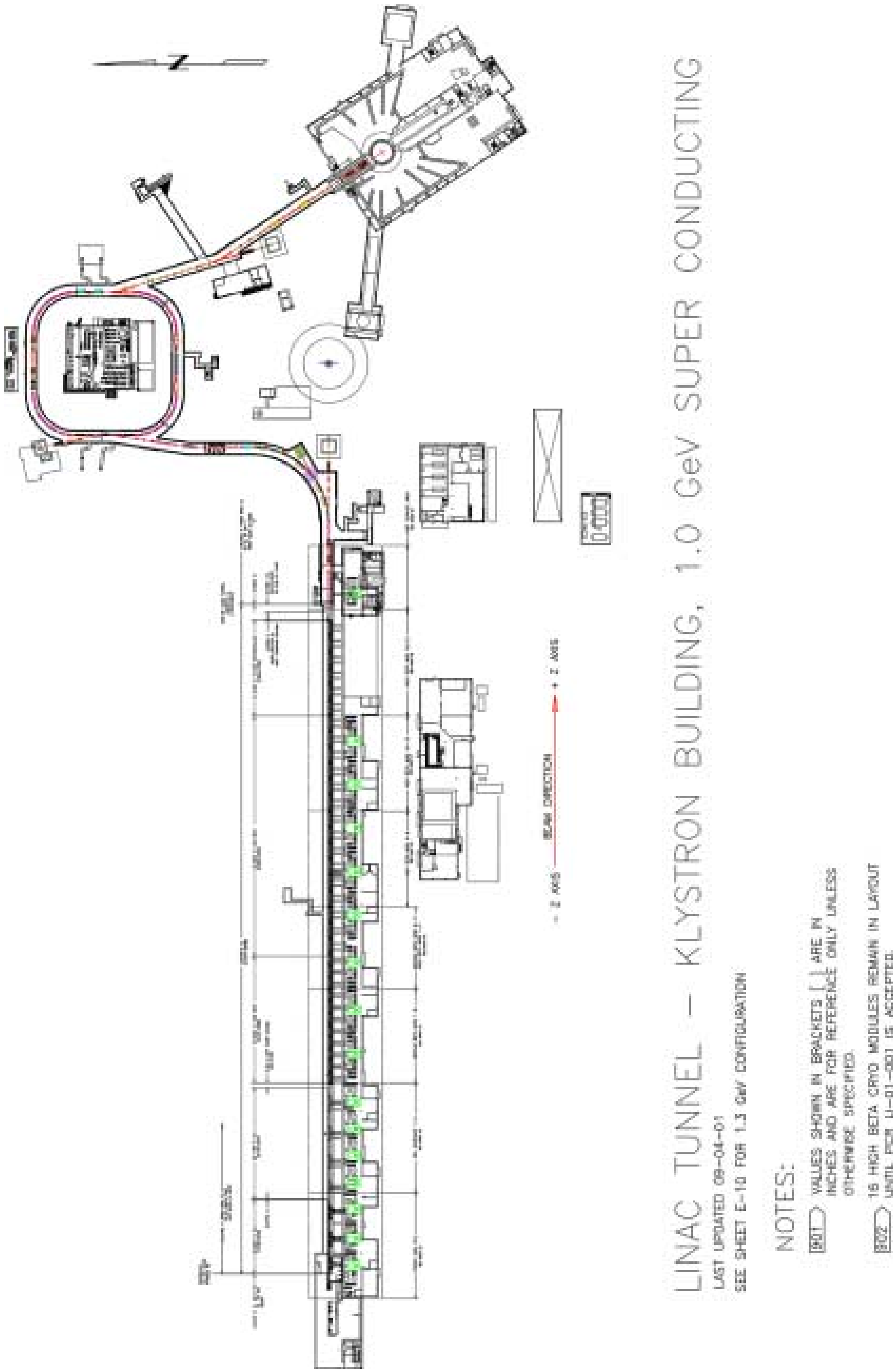


Figure 1.b:
Conceptual Diagram of SNS Accelerator

A visual representation of the SNS approach to the commissioning procedure is shown in Fig. 1.d. We intend to present the overall commissioning plan in a Commissioning Accelerator Readiness Review (ARR). Following this review we will present, system by system, as the systems become available, a Readiness Assessment. These assessments will take place for the Front End, DTL, CCL, SCL, HEBT-Ring-RTBT to the Extraction Dump and lastly, the RTBT to the Target. Prior to Target commissioning there will be a separate ARR for the Target, which will be commissioned under the Accelerator Safety Order DOE O 420.2A as a Radiological Facility. In order for the Accelerator Safety Order to apply, we must maintain a radionuclide inventory in the Target less than the threshold for a Category 3 Nuclear Facility.

Fig. 1.c Overall SNS Facility



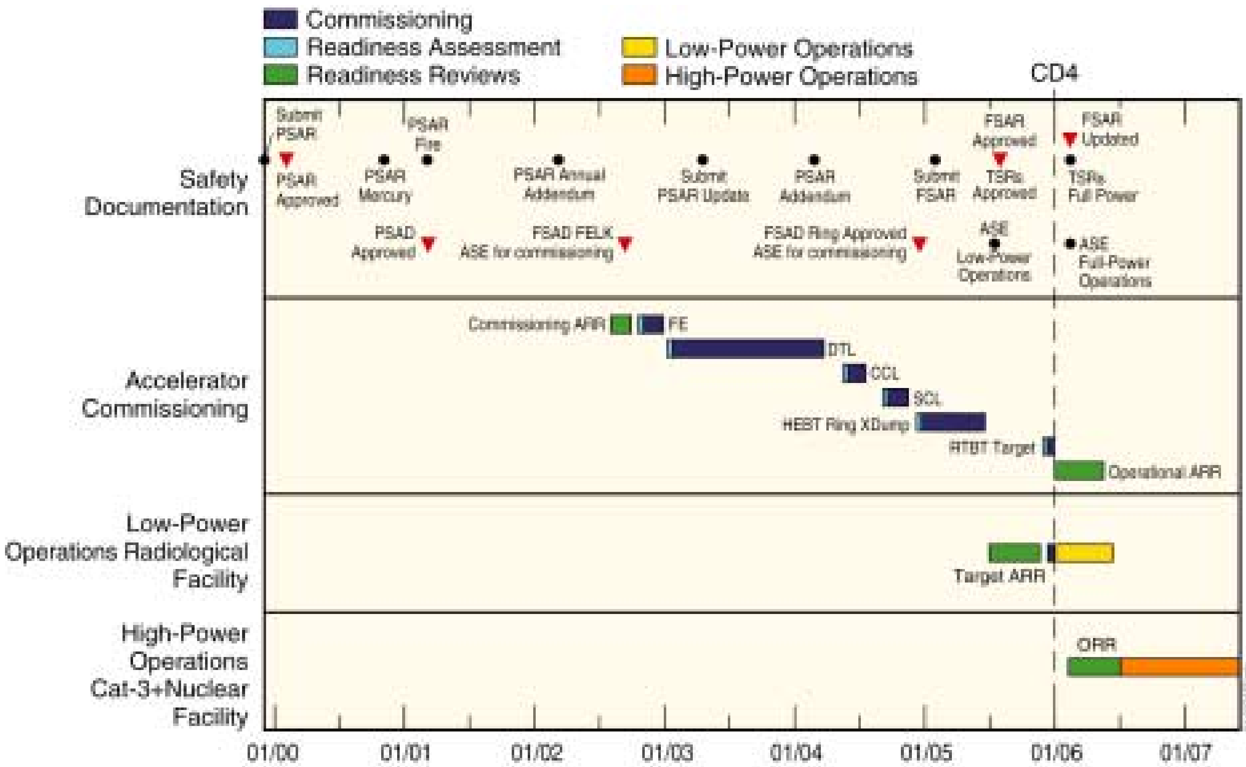


Figure 1.d Schedule for Reviews, Commissioning, and Operations

The commissioning program plan that is presented will include, for each module:

- A technical description.
- A narrative description of the Accelerator Physics activities necessary.
- A listing of the Commissioning Program Plan experimental summary forms – which contain a detailed, task by task breakdown of each Accelerator Physics activity. The actual forms – which specify the measurements and techniques, etc. – are provided in a separate document.
- Identification of any additional administrative and technical controls and contingency plans.
- A description of the content of that portion of the overall facility ARR that is needed.
- The schedule for each module.

2.0 Front End Systems

2.1 System Description

2.1.1 Introduction

The primary function of the Spallation Neutron System Front End System (FES) is to produce an appropriate beam of H^- ions and inject it at 2.5 MeV into the Linac for further acceleration. (See conceptual map in Fig. 1.b and detailed layout in Fig. 2.a). The principal front-end beamline components include:

- H^- Ion source
- Low Energy Beam Transport system (LEBT)
- Radio-Frequency Quadrupole Linac (RFQ)
- Medium Energy Beam Transport line (MEBT)

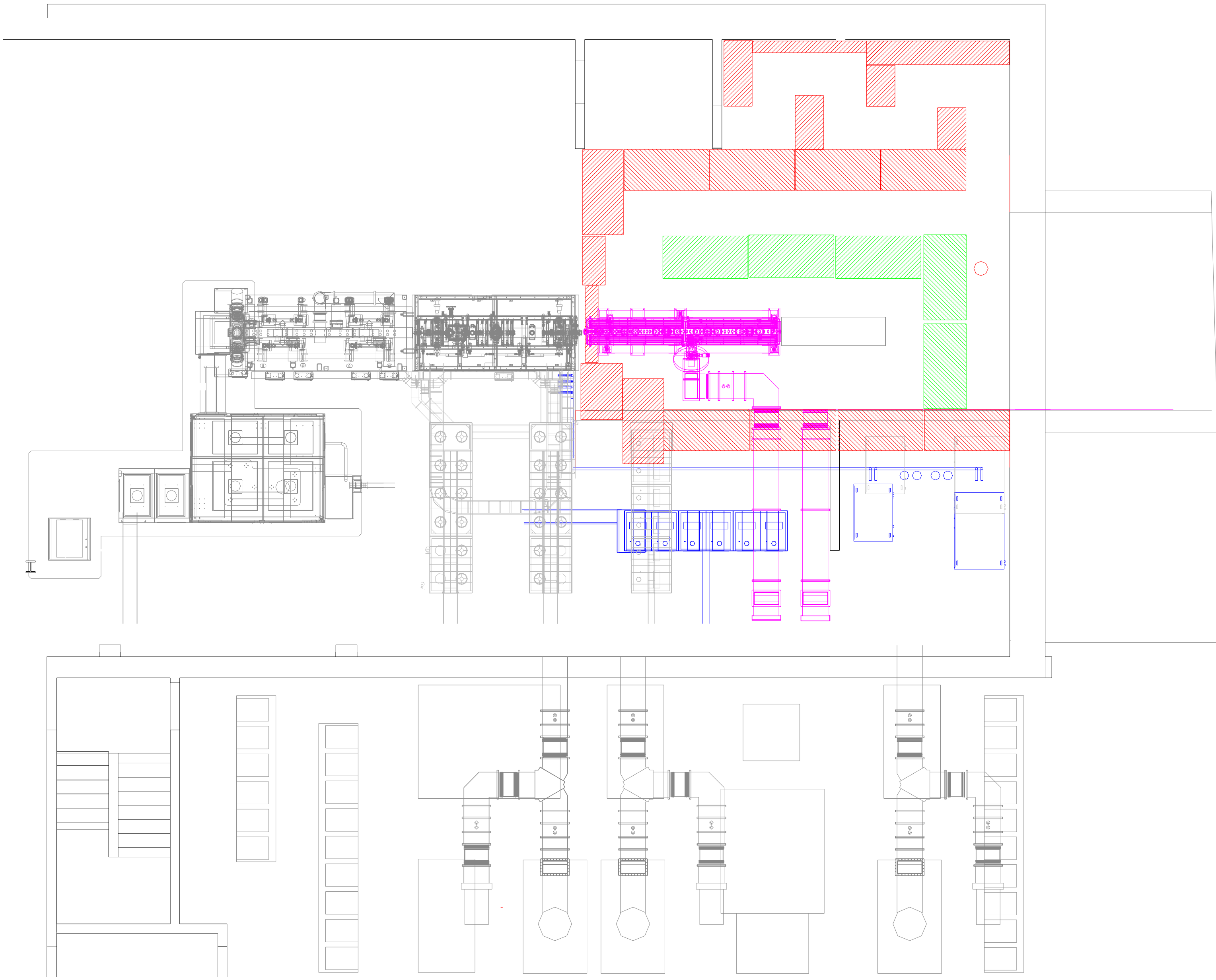


Fig. 2.a Front End and DTL Tank 1

Supporting technical components satisfy the associated instrumentation and control requirements. Also required are local water systems (for cooling and temperature stabilization), vacuum subsystems, and support and alignment capabilities. Beam chopper systems are required in the front end to create a train of 645 nS mini-pulses with gaps of approximately 300 nS in the beam to accommodate the rise time of the extraction kicker in the accumulator ring. Chopping is performed in a distributed fashion with chopping provided in both the LEBT and MEBT.

The Front End Systems will be developed and produced as an integrated package and beam-tested at LBNL prior to delivery and installation at the SNS site.

2.1.2 Front End Performance

The requirements for the front end are established by the 1.5MW overall specification for operation of the neutron source and by the associated requirements of the other major accelerator systems. Operation must be extremely reliable and commensurate with routine operation as part of a major user facility. A summary of these requirements is given in Table 2.1.

The ion source is a multi-cusp, RF-driven, volume source similar to the device successfully developed by LBNL for the Superconducting Super Collider (SSC), but designed and engineered to provide increased peak H^- beam current at the required emittance and duty factor. The LEBT is a compact, split electrode, all-electrostatic transport system. It is required to provide for transverse matching of the beam into the acceptance of the RFQ. The RFQ structure incorporates design concepts developed in earlier LBNL RFQs, but is required to operate at more than 6% duty factor. The RFQ is required to bunch the beam and provide acceleration from 65 keV to 2.5 MeV. The MEBT is required to transport the beam from the RFQ to the drift-tube Linac (DTL) and provide proper beam matching in both transverse and longitudinal phase space. The MEBT incorporates a fast chopper and anti-chopper system developed and built by LANL. The LANL design is based on the traveling wave chopper successfully operated at LANSCE, but designed and engineered to meet the rise/fall time requirement of less than 10 ns for the SNS.

Intensity specifications for the front end are established by the SNS performance baseline, which requires 1.5 MW of average beam power on the spallation target. Allowing for a 6% macro-pulse duty-factor, a 68% mini-pulse duty-factor, and a 4.0% controlled beam loss during injection into the ring, this requirement will be fulfilled by transporting a macropulse consisting of 1060 minipulses each of approximately 38mA peak H^- beam current to the 1 GeV ring injection system. The average chopped macropulse beam current is then 26 mA.

2.2 Narrative Plan For Front End Systems

2.2.1 Introduction

The following is a narrative description of the events and Accelerator Physics measurements needed for commissioning the individual components of the Front End Systems, including the RFQ and the MEBT, into a complete subsystem of the SNS accelerator systems, and for reaching the goal of delivering beam – as characterized by Table 2.1 – to the Linac.

The narrative also contains acceptance criteria for these measurements.

One page summary sheets for each Accelerator Physics activity, the sum of which constitute the Technical Commissioning Plan, are contained in Appendix C.

Table 2.1 Performance requirements for Front End Systems

FRONT END (Ion Source, LEBT, RFQ and MEBT)

Ion type	H minus	
Output energy	2.5	MeV
Length	7.49	m
Beam-floor distance	1.270	m
Output peak current	38.2	mA
ION SOURCE AND LEBT		
Output energy	65	keV
LEBT length	0.12	m
Output peak current	47.8	mA
Ion source type	RF volume	
Electron suppression	magnetic	
LEBT focusing configuration	2 einzel lenses	
Estimated output rms norm H & V emittance	0.20	πmm-mrad
Ion source lifetime	3	weeks
Ion source replacement time	2	hours
RFQ ACCELERATOR		
Output energy	2.5	MeV
Length	3.76	m
Output peak current	38.2	mA
RF frequency	402.5	MHz
Nominal aperture radius	3.51	mm
Rms surface field during macropulse	1.85	Kilpatrick
Rms macropulse structure power	630	kW
Number of 2.5 MW peak power klystrons	1	
Expected output rms norm H & V emittance	0.21	πmm-mrad
Expected output rms L emittance	0.10	πMeV-deg
MEBT		
Output energy	2.5	MeV
Length	3.64	m
Output peak current	38.2	mA
Number of quadrupoles	14	
Quads 1-4 and 11-14 clear bore dia	30	mm
Quads 5 - 10 clear bore dia	40	mm
Maximum integrated quad gradient	2.14/2.31	T
Number of two-plane beam steerers	6	
Number of rebuncher cavities	4	
Rebuncher cavity frequency	402.5	MHz
Maximum rebuncher peak voltage integral	120	kV
Expected output rms norm H & V emittance with errors	0.27	πmm-mrad
Expected output rms L emittance with errors	0.13	πMeV-deg
Expected max rebuncher cavity rms rms field error	2	%
Expected max rebuncher cavity rms phase error	1	deg
Expected max quad rms gradient error	<1	%
Expected max quad rms position error on sub-raft	0.025	mm
Expected max sub-raft rms position error on major support	0.04	mm
Expected max quad rms roll error	0.06	mrad
Expected max quad rms yaw error	0.06	mrad
Expected max quad rms pitch error	0.6	mrad

2.2.2 RFQ Commissioning

The goal of the RFQ commissioning is to bring the RFQ into operation and verify that output beam parameters have not changed after commissioning at LBNL. A full set of RF and vacuum tests without the beam will be carried out during the installation/test/conditioning stage preceding the commissioning stage. The full RFQ output beam characterization is done at LBNL, and it is impossible to repeat it at ORNL. This is due to the fact that the RFQ will be installed as an assembly with the MEBT thus precluding the use of the separate diagnostic line. However, a number of tests will be performed to check the RFQ performance indirectly by comparing the results of the beam measurements with corresponding figures obtained during the commissioning at LBNL. A full power 2.5MeV beam dump will be attached to the MEBT exit flange. We assume that the beam can be completely lost somewhere in the MEBT at the first stage of the commissioning, so to protect the beamline components, a reduced power beam will be used for initial tests. The beam will typically be limited to unchopped 10μs macropulses of 38mA peak current, at 1Hz or pulse on demand.

First, the beam will be transported from the RFQ exit to the beam current monitor BCM1 using beam position corrector #1. Then the LEBT to RFQ matching can be adjusted by looking for the maximum output current while varying the LEBT settings: energy, lens settings and beam position.

LEBT chopper effectiveness and symmetry will be checked by measuring beam off /on ratio using a fast oscilloscope and the wide bandwidth tap of the BCM1 transformer.

Finally the dependence of BCM1 current on the input RFQ power will be measured and compared with the reference curve. If no considerable discrepancy is observed we can assume that the output beam has the same parameters as were measured during commissioning at LBNL.

2.2.3 Beam transport through the MEBT

The goal of beam transport through the MEBT is to bring all of the MEBT elements into operation and find the correct settings to ensure beam transport from the RFQ exit to the beam dump at the end of the MEBT. Diagnostic, vacuum, power and RF systems will be checked and conditioned during the installation/test/conditioning stage preceding the commissioning stage. We assume that the beam can be completely lost somewhere in the MEBT at the first stage of the commissioning therefore reduced power beam will be used for initial tests (unchopped macropulses 38mA, 10μs, 1Hz or pulse on demand) to prevent beam transport line damage. All quads, correctors and rebuncher cavities are initially set to optimal values found during FES commissioning at LBNL.

First, the beam will be transported to BPM #2 using BPM#1,2 measurements and STEER#1 corrector. Then, the phase of the rebuncher cavity #1 will be set using phase scan and/or sum output signal from the BPM#2. Next, the beam will be transported to the BPM#3 using STEER#2 and tweaking STEER#1 if necessary. With the power in the rebuncher cavity #2 set to zero, the phase and voltage of the rebuncher #1 will be corrected by repeating the phase scan using BPM#2,3.

If full transmission through the chopper#1 aperture is not reached at this point correction of the focusing quads Q1-Q4 settings will be done using beam profile measurements at PM#1,2 (second priority). Rebuncher#2 power is then switched on and its phase will be set using phase scan and/or sum output signal from the BPM#3.

The beam will then be transported to BPM #4 using STEER#3 with minor adjustments to STEER#1,2 if necessary. The phase and voltage of the rebuncher #2 will be corrected by repeating the phase scan using BPM#3,4.

The beam will then be transported to BPM #5 using STEER#4 with minor adjustments to STEER#1,2,3 if necessary. The phase of the rebuncher cavity #3 will then be set using a phase scan and/or sum output signal from the BPM#5.

If full transmission through the chopper#2 aperture is not reached at this point, correction of the focusing quads Q5-Q10 settings will be done using beam profile measurements at PM#3,4; however, this activity is a second priority.

At this point, beam transmission through the main part of the MEBT is measured using BCM1 and BCM2. This test provides the best accuracy in transmission measurement because identical current transformers are used. Additional losses in the short part of the MEBT downstream from BCM2 are not expected because the beam has already passed through the small apertures of the choppers.

Then the beam will be transported to BPM #6 using STEER#5 with minor adjustments to STEER#1,2,3,4 as needed.

Then the phase of the rebuncher cavity #4 will be set using a phase scan and/or sum output signal from the BPM#6.

Finally, the beam will be transported to the high power MEBT beam dump using STEER#6 with minor adjustments to STEER#1,2,3,4,5 as needed. The beam dump Faraday cup is used as a detector. The collected charge is measured and compared with the charge calculated from BCM2 measurements.

2.2.4 MEBT tuning and beam characterization

The goal of MEBT tuning and beam characterization stage is to fine tune beam line element settings using global tuning algorithms, to measure output beam parameters using off line diagnostic plate and to map correlation of output beam parameters vs. array of matching elements settings. We assume that beam is transported to the high power dump with minimal losses and higher power beam can be used to provide better signal to noise ratio without danger of damaging transport line elements or excessive activation. However reduced power beam (unchopped pulse 38mA, 10μs, 1Hz or manual) has to be used for beam profile measurements to prevent damage to wire scanners. Peak current should be set to design value of 38mA to ensure that tuned settings are useful for normal operation. Off line diagnostic plate is attached to the MEBT exit (high power jaws of the beam dump are used as a slit for emittance measurement device).

Settings of the focusing quadrupole magnets will be corrected using profile measurements and ‘stimulus/response’ algorithm. Multistage correction is the most effective: quads Q1-Q4 are corrected using data from wire scanners PM1,PM2, quads Q5-Q10 using data from wire scanners PM3,PM4 and quads Q11-Q14 using data from wire scanner PM5. Coupling matrix calculated from PARMILA simulation will be used. If time permits the elements of the coupling matrix will be derived from beam measurements.
Then global trajectory correction will be performed using all 6 BPMs and correctors. Coupling matrix will be derived from beam measurements. Displacement of the quads can be calculated and mechanically corrected to reduce currents in the correctors’ coils.

Horizontal Twiss parameters of the beam will be measured using slit/collector emittance scanner for array of matching quads Q11-Q14 settings. This data will be used for the following matching to the DTL.

Then emittance scanner will be rotated (off line diagnostic box have to be opened) and vertical Twiss parameters of the beam are measured using slit/collector emittance scanner for array of matching quads Q11-Q14 settings.

If time permits global quad setting correction algorithm (all 14 quads and 5 wire scanners are included in the coupling matrix) will be tried and checked against slit/collector measurements in both plains. Coupling matrix calculated from PARMILA simulation or derived from beam measurements (second priority). The main purpose of this algorithm is to provide MEBT to DTL matching in the absence of diagnostic plate during normal operation therefore intentional quad errors and LEBT settings will be introduced and ability of the tuning algorithm to restore nominal settings will be tested.

2.2.5 Choppers commissioning

The goal of the choppers commissioning is to bring the LEBT and MEBT chopper systems into operation, to establish proper timing and verify that they provide design bean-in-gap cleanness. We assume that beam is transported to the high power dump with minimal losses and higher power beam can be used to provide maximum signal to noise ratio without danger of damaging transport line elements or excessive activation.

LEBT chopper effectiveness is measured using wide bandwidth tap of the BCM2 and fast oscilloscope. We expect to find larger beam on/off ratio at this point in comparison with BCM1 measurements due to possible loss of partially chopped and halo particles in the MEBT.

MEBT chopper target will be moved in until it intercepts 1-2% of the beam. With MEBT chop inside LEBT chop window, MEBT waveform will be moved and expand out to sharpen transition at either end. Combined LEBT+MEBT chopper effectiveness and rise time will be measured using wide bandwidth tap of the BCM2 and fast oscilloscope. Note that we do not expect to measure gap cleanness below 10^{-3} level at this point. Specified 10^{-4} extinction ration can be measured only during ring commissioning.

2.2.6 High power beam test

The goal of high power beam test is verify that all FE systems (RF and vacuum systems mainly) operate properly under full beam load and radiation level doesn't exceed specified level. We assume that beam is transported to the high power dump with minimal losses and higher power beam can be used to provide maximum signal to noise ratio without danger of damaging transport line elements or excessive activation. Peak current is set to design value of 38mA, beam power is controlled by changing pulse length and repetition rate.

X-ray and neutron radiation level will be monitored and archived continuously during all high power tests.

Measuring how phase and amplitude stability depend on beam current will test RFQ RF system performance under beam loading. If RF phase deviation during 1ms pulse exceeds 1° and/or RF amplitude deviation exceeds 1% then low level RF feedback system has to be tuned.

Proper rf power coupling under beam loading is established by measuring reflected power during the pulse.

Proper rf power distribution in the RFQ under beam loading is established by measuring changes in field distribution during the pulse. Wall mounted sensing loops and multichannel digitizer are used.

Rebuncher cavity phase and amplitude stability is measured for different beam power and low level RF feedback is tuned if necessary.

Gas desorption stimulated by beam losses can increase load to the vacuum system substantially. Dependence of the vacuum pressure on beam current will be measured during long enough time to allow for selfconditioning.

Dependence of BCM1 current upon beam power will be measured to establish that combined effect of beam loading on RF and vacuum systems doesn't affect total RFQ transmission.

Dependence of BCM2 current and beam dump faraday cup charge upon beam power will be measured to establish that combined effect of beam loading on RF and vacuum systems doesn't affect total MEBT transmission.

LEBT chopper effectiveness for different beam power is measured at the MEBT exit using wide bandwidth tap of the BCM2 and fast oscilloscope.

Combined LEBT+MEBT chopper effectiveness for different beam power is measured at the MEBT exit using wide bandwidth tap of the BCM2 and fast oscilloscope.

2.3 Administrative and Technical Controls and Contingency Plans for Front End Systems

2.3.1 Technical Controls and Safety Systems

Accelerator specific safety systems, which must be in place, tested and certified for operation prior to commencement of commissioning studies for Front End Systems include the Personnel Protection System (PPS) and the Machine Protection System (MPS)

PPS

The Personnel Protection System radiation protection for Front End Systems commissioning includes the following:

The equipment will operate standalone in the PPS Phase 0 mode.
Operating modes provided are:

- Off
- 65 kV power supply on
- RF Plasma power supply on
- Full operation (Ion Source HV, RF and the RFQ)

During commissioning and operation, high radiation levels will be detected by the Fermilab standard ionization chambers (Chipmunks), which will shut off the Ion Source 65 kV power supply and the RF drive to the RFQ at the Transmitter as well as the Transmitter HV supply. High radiation trips will require evaluation and approval by the Chief Operator prior to the manual reset for commissioning restart.

Activation of the Emergency-Stop pushbutton on the operator panel shuts off all critical devices including the Ion Source 65 kV power supply and the RF drive to the RFQ at the transmitter and the transmitter high voltage power supply. Emergency-Stop shutdowns require evaluation and approval by the Chief Operator prior to the manual reset for commissioning restart.

The PPS will be re-certified twice per year and when significant modifications are made.

MPS

The Machine Protection System (MPS) runs in three modes.

- If the High QA system is tripped, the Ion Source 65 kV power supply and the RFQ Transmitter HV power supply are shut down.
- If the MPS Latched system is tripped, the Ion Source 65 kV power supply and the RFQ Transmitter HV power supply are disabled. This will require evaluation and approval by the Chief Operator prior to the manual reset for commissioning restart.
- If the MPS Auto Reset system is tripped, the LEBT Chopper is directed not to allow beam to exit the LEBT and the RFQ RF drive is inhibited for the duration of the macropulse.

The MPS will be re-certified twice per year and when significant modifications are made.

A full description of the MPS can be found at:
http://www.sns.gov/projectinfo/ics/192/1923/MPS_FDR/

Machine Protection software/hardware planned for the Front End commissioning includes:

- EPICS device support for the MPS PMC module.
- Manual mode-mask definitions.
- MPS hardware modules
- Fast Protect Latched shutdown hardware.
- Fast Protect – Auto Reset shutdown hardware
- Differential current monitor
- Integrated current monitor
- Run-permit and Fast-Protect display screens for Source, LEBT, RFQ, and MEBT.
- Beam Power Select Switch
- PPS Inputs to HQA-MPS

Beam Power

During Front End commissioning, the beam power will be limited to an amount less than that which is specified for each system in the Commissioning Accelerator Safety Envelope (Appendix A).

Safety

Radiation Safety during Front End System commissioning is ensured by strict compliance with the relevant policies and procedures of the ORNL Standards Based Management System (SBMS) (http://eshtrain.ct.ornl.gov/SBMS/), specifically:

- ORNL Radiological Protection Management System (RPMS) (http://eshtrain.ct.ornl.gov/sbms/SBMSearch/Msd/RPS/RPS_MSD.cfm)
- ORNL Radiological Control Policy and Radiological Protection Procedures (http://eshtrain.ct.ornl.gov/sbms/SBMSearch/ORNLProc/ORNL-RP-110.htm)
- ORNL ALARA Program (http://eshtrain.ct.ornl.gov/sbms/SBMSearch/ORNLProc/ORNL-RP-138.htm)

which are in compliance with 10CFR835 (Occupational Radiation Protection).

Lockout-Tagout safety during Front End System commissioning is ensured by compliance with the ORNL-SNS LOTO policy, which is OSHA compliant. This policy can be found at:

http://www.internal.sns.gov/esh/standards/lockout_tagout.pdf

Fire safety is ensured during Front End Systems commissioning. A fire alarm system will be in place and operational in the Front End building which is compliant with NFPA Standard 72. A sprinkler system will be in place and operational in the Front End building that is compliant with NFPA Standard 13. Where construction activities prevent a required fire safety feature from being operational, compensatory measures in general accordance with NFPA 241, Standard for Safeguarding Construction, Alteration, and Demolition Operations, will be identified and implemented.

2.3.2 Administrative Controls

Administrative controls are described in **Appendix B, Personnel, Training, Certification, Procedures and Records.**

2.4 The Portion of the Overall Facility ARR Needed for Front End Systems

Portions of the overall ARR that are needed for Front End Systems commissioning include an approved Commissioning Accelerator Safety Envelope (CASE) and an approved Safety Assessment Document (SAD) for Front End Systems.

For Front End Systems the framework for the CASE is listed in Appendix A of this document.

The SNS Preliminary Safety Assessment Document is available at:
http://www-internal.sns.gov/dcrm/docs/102/102030103-ES0003-R00.pdf

2.5 The Schedule for Front End Systems Commissioning

Front End System Systems commissioning is listed in the current Integrated Project Schedule (see Appendix D) to take place from October 29, 2002 through December 31, 2002.

3.0 Linac Systems

3.1 System Description

3.1.1 Introduction

This document establishes the performance, design, development, and test requirements for the Drift Tube Linear Accelerator (DTL). The Linac follows the MEBT and accelerates the H^- beam from an energy of 2.5 MeV to 1 GeV. (See conceptual maps in Fig.1.b and Fig.3.a and the more detailed layout in Fig.3.b). Four types of RF structures, two normal conducting and two superconducting, perform this task. The first structure is a 402.5-MHz DTL that accelerates the beam to 86.8 MeV. Figure 3.a shows a general schematic of the Spallation Neutron Source (SNS) Front End and Linac System Layout.

Figure 3.a SNS Front End and Linac System Layout

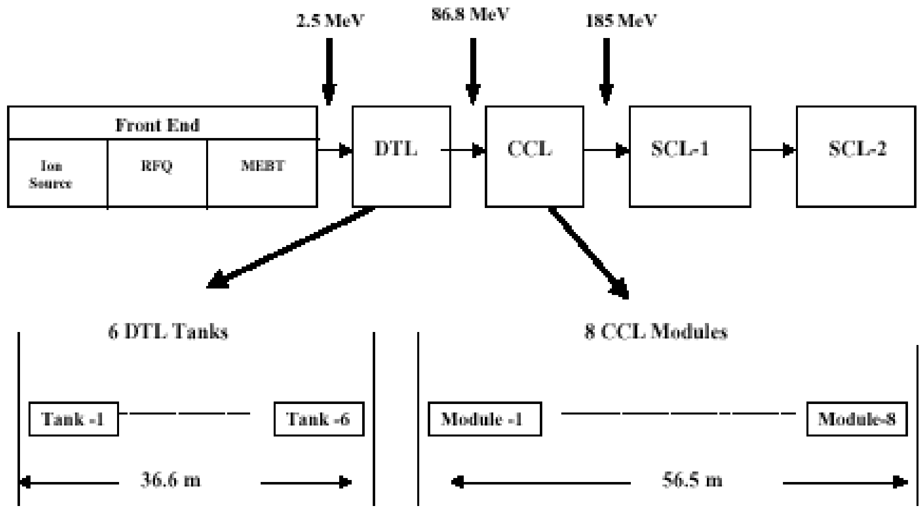
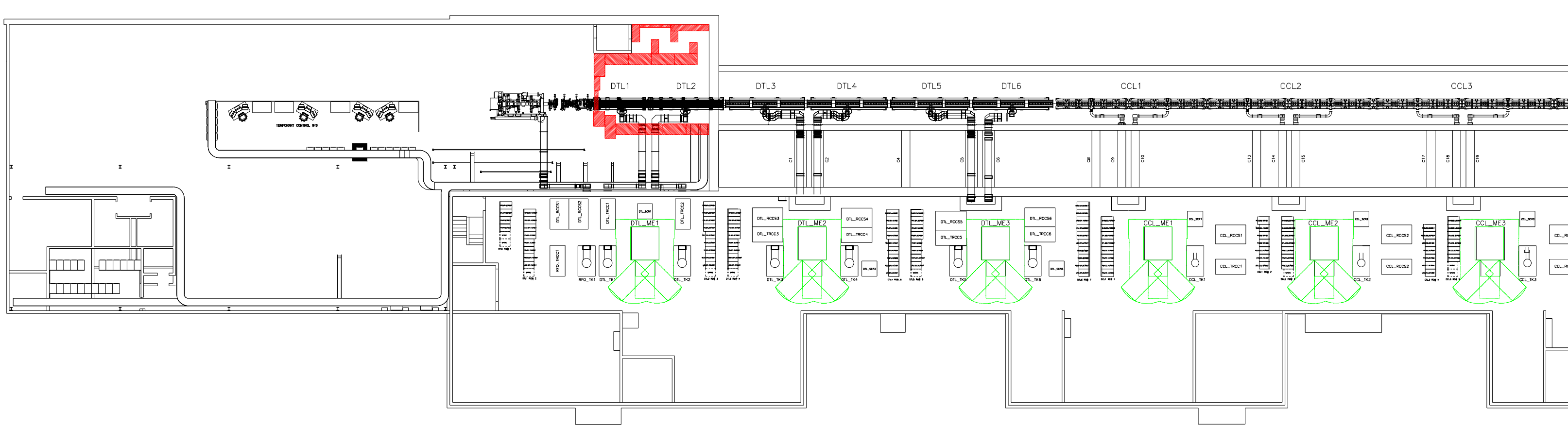


Figure 3.b Detailed Layout of DTL and CCL



3.1.2 The DTL

The DTL is the first of two normal conducting accelerators that comprise the Linear Accelerator of SNS. It accelerates the beam from 2.5 MeV to 86.8 MeV. The DTL RF system is composed of six modules each powered by a 2.5 MW klystron. The accelerating structure is based on the TM_{010} Alvarez design. Cells are of length $\beta\lambda$ and the transverse focusing period is 6βλ. in length. Focusing is accomplished with permanent magnet quadrupoles (PMQs) positioned within specific drift tubes. The focusing lattice is FFODDO, i.e. consisting of two drift tubes containing focusing magnets followed by an empty drift tube followed by two drift tubes containing defocusing magnets ending with an empty drift tube. Some empty drift tubes will incorporate electromagnet dipoles (EMDs) for beam steering or beam position monitor (BPM) diagnostics. In some cases the empty drift tubes will incorporate EMDs in the last four empty drift tubes of each DTL tank. Beginning with DTL tank 2 the first two empty drift tubes in each tank will incorporate a BPM. See the physics design criteria document SNS-104050000-DC-R00 for general magnet locations. The DTL will have post couplers to stabilize and tune the longitudinal field distribution. Performance requirements for the DTL are summarized in Table 3.1.

Table 3.1 Performance requirements for the DTL

DTL ACCELERATOR		
Output energy	86.8	MeV
Length	36.569	m
RF frequency	402.5	MHz
Average synchronous phase	-37 to -26	deg
Number of tanks	6	
Maximum field	1.3	Kilpatrick
Bore radius	12.5	mm
Focusing structure	FFODDO	
Focusing period	6	beta-lambda
Number of quads	145	
Quadrupole type	permanent mag	
Integrated quad gradient	1.295	T
Quad location	inside DTs	
Number of steering dipoles	24	
Average operating vacuum pressure	1.8E-07	Torr

3.1.3 The CCL

The Coupled Cavity Linac (CCL) is the second of two normal conducting sections of accelerator that comprise the SNS Linear Accelerator. It accelerates the beam from 86.8 MeV to 185.6 MeV. The CCL RF system is composed of four klystrons, each of 5 MW, 805-MHz RF capacity. It is a conventional side coupled cavity structure having 8 cells per segment and 12 segments per module. Each module is assembled onto a steel support structure with the segments supported by the steel structure, the bridge couplers and electromagnetic focusing quadrupoles located between the segments. The 8-cell segments are of length 4 βλ and the 3-cell bridge couplers are of length 2.5 βλeach. The spacing between successive quadrupole focusing elements is thus 6.5 βλ, which gives a focusing period of 13βλat 805 MHz for the FODO array. A focusing period spans two segments and two bridge coupler sections. The electromagnet quadrupoles have integral dipole steering coils for steering correction of the beam as required. The spaces between accelerator segments also contain beam diagnostic elements to determine beam centroid position, current and profile. Performance requirements for the CCL are summarize in Table 3.2.

The CCL RF structure consists of all items that will see RF fields (accelerating cavities, side coupling cavities, bridge coupler cells, and the waveguide transition and iris assemblies). The RF Structure is composed of two main types of components, the segment assemblies and the bridge coupler assemblies. The segments provide the basis of RF focusing and acceleration of the beam. The bridge couplers provide a mechanism for resonant coupling of the segments to form an RF assembly that can be powered with a single RF amplifier. The four SNS CCL modules are powered by 5 MW RF amplifiers split into two WR-975 feeds that connect to each module at roughly the one-quarter and three-quarter points along the assembly. Power flows through and fills the resonant structure and the resonant coupling between components is sufficient to prevent unacceptable field variation along the structure between the RF feed points. All powered components are actively water-cooled to control the RF resonance frequency to 805 MHz. Each module has a common water cooling system (Resonance Control System, RCS) and a vacuum pumping system. All RF cavities are connected to a common vacuum plenum running the length of the module. The plenum is actively pumped during operation to maintain the cavities at or below a specified pressure as required to prevent beam stripping and activation of the components.

Table 3.2 Performance requirements for the CCL

CCL ACCELERATOR		
Output energy	185.6	MeV
Length	55.119	m
RF frequency	805	MHz
Number of accelerating cells per segment	8	
Number of segments per module	12	
Number of RF modules	4	
DTL to CCL physics distance	0.248	m
Max field	1.3	Kilpatrick
Bore radius	15	mm
Focusing structure	FODO	
Focusing period	13	beta-lambda
Number of quadrupoles	49	
Quad type	EM	
Quad integral gradient, entry-exit	2.51 - 0.77	T
Quad location	between segs.	
Number of steering dipoles	16	
Average operating vacuum pressure	0.9E-7	Torr

A map of the CCL beam diagnostics layout is at:
http://www.sns.gov/APGroup/refTables/drawings/B_CCL_ideogram.pdf

3.1.4 The SCL

The Super Conducting Linac (SCL) makes up the third and fourth sections of the SNS Linear Accelerator. It consists of a Medium Beta part, taking the beam energy from 185.6 MeV to 387 MeV, followed by a High Beta part, further accelerating the beam to 1 GeV. The 805 MHz SCL design is based on elliptical Niobium six-cell cavities with warm sections between a total of 23 cryomodules. These warm sections house quadrupoles in a doublet focusing arrangement. The cryomodules are based on the CEBAF CM with improvements borrowed from LHC, TESLA, and the JLab 12 GeV upgrade and uses the frequency scaled KEK fundamental power coupler (FPC).

The Medium Beta part consists of 11 cryomodules containing three cavities each and achieving peak electric fields of 27.5 MV/m (± 2.5 MV/m). Cavities are powered by individual klystrons, rated at 0.55 MW peak power. With an average macro pulse beam current of 26 mA, this allows for a 33% margin in view of issues such as Lorentz force detuning, microphonics and uncertainty in peak field.

The High Beta part consists of 12 cryomodules containing four cavities each and achieving peak electric fields of 35 MV/m (+ 2.5 / -7.5 MV/m). This higher gradient, with respect to the Medium Beta, might be obtained through electro-polishing of the cavities. Also the High Beta cavities are powered by individual klystrons, rated at 0.55 MW peak power, but with a 40% margin for an average macro pulse beam current of 26 mA. The output average beam power thus obtained would be 1.56 MW.

Behind the SCL, space is left for 9 more cryomodules, intended for a possible future upgrade in beam energy from 1 GeV to 1.3 GeV. As there is some uncertainty to what extent electro-polishing will be successful, part of this space can be used to install 3 extra cryomodules. In this back-up plan, the High Beta cavities would all operate at 27.5 MV/m, thus obtaining a beam energy of 975 MeV and an average beam power of 1.85 MW at the output. The performance requirements for the SCL are summarized in Table 3.3.

Apart from quadrupole doublets, each warm section also contains a beam position monitor and a wires scanner for beam diagnostics as well as a vacuum gate valve. Beam loss monitors will be positioned near each warm section and each cryo-module.

Table 3.3 Performance requirements for the SCL

SUPERCONDUCTING RF LINAC		
Output energy	1	GeV
Length	157.321	m
RF frequency	805	MHz
Transition energy between sections	387	MeV
Focusing structure	Doublet	
Number of quad doublets	32	
Number of quads with H&V dipole windings	64	
Quad type	EM	
Peak med beta cavity surface field	27.5	MV/ m
Peak high beta cavity surface field	35.0	MV/ m
Medium beta cavity geometrical beta	0.61	
High beta cavity geometrical beta	0.81	
Number of med beta cryomodules	11	
Number of high beta cryomodules	12	
Warm space between cryomodule valves	1.6	m
Period length med beta	5.839	m
Period length high beta	7.891	m
Length of 186 MeV differential pumping section	2.35	m
Length for nine additional high beta cryomodules	71.019	m
Warm beam pipe vacuum	1.E-09	Torr

A map of the SCL beam diagnostics layout is at:
http://www.sns.gov/APGroup/refTables/drawings/B_SCL_ideogram.pdf

3.2 Narrative Plan for Linac Systems

3.2.1 Introduction

The following is a narrative description of the events and Accelerator Physics measurements needed for commissioning the individual components of the Linac Systems, which include the DTL, CCL and SCL, into a complete subsystem of the SNS accelerator systems, and for reaching the various beam current goals stated in Attachment B.

The narrative also contains acceptance criteria for these measurements.

One page summary sheets for each Accelerator Physics activity, the sum of which constitute the Technical Commissioning Plan, are contained in Appendix C.

3.2.2 Overall Sequence

From experience it is known that the matching into and commissioning of the first tank of a DTL is most critical; therefore commissioning (and intermediate installation) will follow these steps, whereby appropriate time is given to commission DTL tank 1:

- **Commission DTL input beam with MEBT offline and inline diagnostics.**
- **Commission DTL tank 1 with Diagnostics or D-plate, up to full beam power.**
- During DTL Tank 1 commissioning, complete the installation of the remaining DTL tanks and the CCL modules 1-4

Following the DTL Tank 1 commissioning, reposition the personnel protection, full-power bulk shielding to downstream of the CCL.

- **Commission DTL tanks 2-6** using only Faraday cup (FC), wire scanner (WS), and BPM in DTL 1-5 beam boxes, plus the FC/WS beam box designed for after CCL Module 1 / Segment 4 is attached to the end of DTL tank 6 with a short spool piece on top of CCL Module 1 support.
- Install CCL to SCL inter-segment region with its beam stop while continuing with above.
- Install 3 SCL cryo-modules (total length about 15 m) and warm inter-segment regions while continuing with above.
- Reposition personnel protection, full-power bulk shielding to downstream of above SCL cryo-modules.
- **Commission CCL modules 1-4** using BPMs and wire scanners in CCL and SCL inter-segment regions (needed for delta t of CCL module 4). Note: SCL cavities must be de-tuned for delta-t measurement.

- Install remainder of cryo-modules, and inter-segment regions, and beam line up to Linac dump while continuing with above (except for cryo-module destined for the bulk shielding location).
- Install last SCL cryo-module after removing shielding needed for CCL commissioning.
- **Commission SCL** using Linac beam dump and all diagnostics in Linac.

An example of a generic commissioning procedure, which can be applied to the DTL, but also the CCL and SCL is given in Attachment A.

A schedule for the beam tests and measurements needed for commissioning can be found on the commissioning web page:
http://www.sns.gov/projectinfo/operations/commissioning.htm

A draft detailed description of the objectives and requirements for each of these measurements is currently available on the above web page.

3.2.3 Testing and Conditioning Previously Required ("pre-beam")

It is essential that, prior to commissioning of each of these systems with beam, the following has been achieved:

- All subsystems are installed, checked out in stand-alone mode and integrated with other associated subsystems.
- Tanks have been RF conditioned and will hold the design fields plus 10% at the design duty factor
- The low level RF controls lock and hold the fields within design tolerance
- RF fault recovery procedures have been completely debugged
- Temperature/resonance control works properly at different power levels and duty factors
- The control system can provide adequate data acquisition and control of specified equipment and parameters
- All diagnostics have been checked out from the pick-up to the control console with test signals
- All quadrupoles have been checked for correct polarity

3.2.4 Testing of equipment with beam

Nevertheless, time has been reserved for testing various systems with beam (like RF, diagnostics, controls etc.). For instance, one may wish to adjust RF feedback systems, which act on beam loading. Some of these tests can be done in parallel and some maybe done whilst other systems are being debugged or even whilst beam commissioning has started. There is no order or priority given for these tests in the Linac commissioning plan on the web: the order will highly depend on the order in which these systems will be available after initial testing; the order and priority can be made up then.

A separate test, not mentioned in the Linac commissioning plan on the web, pertains to shielding. Dose rates will be measured outside the tunnel during commissioning, including rates caused by RF sources, controlled and uncontrolled beam loss. Such tests using portable radiation detection instruments can be made in parallel with the ongoing commissioning. Fixed location radiation measuring instruments will also be placed in locations surrounding the active Front-End/Linac areas prior to operations in anticipation of worst-case radiation

3.2.5 Commissioning of the DTL

Upon starting the commissioning of DTL tank 1, it is assumed that the beam entering the Linac is characterized and reproducible as verified with the available diagnostics. To assure this characterization, the **DTL input beam properties** will be briefly re-measured with the **off line diagnostics** and cross calibrated **with the MEBT inline diagnostics**

Subsequently **DTL tank 1** will be commissioned **with a dedicated D-plate** downstream of it, and up to full beam power. After finding the RF set-point of this tank by using a so called phase scan, a pencil beam aperture limitation (passing 10% of nominal beam) will be inserted upstream of 2 dipole correctors in the MEBT. (In reality MEBT quads, rewired as steerers in order to obtain sufficient steering power for this measurement). Using the D-plate current monitor as a diagnostic for beam transmission, this will enable a systematic scan of the DTL tank aperture and related input acceptance. Preliminary matching may be obtained using beam profile monitors, which can be checked against an emittance scan at 7.5 MeV. The mean beam energy will be verified using a time-of-flight method. One may need to iterate on the above process to fine tune the beam to the model, including for the full power beam test.

DTL tanks 2-6 will be commissioned with limited beam power**.** Typical beam power requirements are given in the attachment A. These tanks will be commissioned one after the other, the sequence of steps being very similar for each tank: The RF set-point will be found by using a phase scan, acceptance scan or other similar techniques. Then the beam will undergo steering using BPMs and beam profile monitors. After checking the transmission and possibly the average beam energy (using a time of flight measurement), one may wish to fine tune settings by repeating the above measurement sequence.

3.2.6 Commissioning of the CCL

The CCL will be commissioned one module at the time, starting with module 1. After finding the RF set-point using a delta-t measurement, the beam will be brought on axis using the BPMs, transmission will be optimized with BPMs and wire scanners. Finally, the mean energy will be verified also using a time-of-flight method. One may need to iterate on the above process to fine tune the beam to the model.

3.2.7 Commissioning of the SCL

In the SCL one will proceed cavity by cavity. The beam will be steered through each cavity by varying each corrector in the SCL region to the Linac dump and observing the effect on the positions at each BPM and Wire Scanner.

Subsequently, the RF set-point will be found by a procedure described in [1], followed by transverse matching using wire scanners. At this point the average beam energy will be measured using a time of flight measurement. One may need to iterate on the above process due to the variation in the cavity field amplitudes to optimize the beam.

Attachment A: Generic Linac Beam Commissioning Procedure

1) RF phase and amplitude
   a This involves using the beam in various ways to identify the RF set-points for each tank, module or cavity
   b The techniques include the following measurements
      i) Output beam phase vs. cavity phase and field
      ii) output beam energy vs. cavity phase and field
      iii) accelerated beam current vs. cavity phase and field
      iv) exciting cryo-modules with the beam to calibrate field loops
   c Diagnostics include Faraday cups and energy degraders and BPMs to measure beam phase and time of flight

2) Steering
   a This initially involves threading a low current beam through a tank, module or collection of cryo-modules.
   b In some cases one may want to use a so called "pencil beam"
   c The objective here is to find a steering solution that minimizes spill or, assuming no spill, places the beam in the center of the transverse acceptance
   d Diagnostics will include beam current transformers, Faraday cups, BPMs and BLMs and wire scanners
   e This will be done by hand (knobs) and will allow initial testing of steering algorithms

3) Transverse Matching
   a This activity involves operating at full peak current and adjusting quadrupoles to minimize envelope oscillations
   b Techniques to achieve this at low energies are not well defined
   c Diagnostics include wire scanners and BLMs

4) These 3 steps will be carried out sequentially on each powered cavity
   a They will be repeated and iterated several times at increasing peak beam current

5) In addition to these basic commissioning steps we will want to pursue additional experiments
   a Some fall into the category of calibrations such as calibrating quads or dipoles using the beam and BPMs
   b Some fall more in the category of machine physics such as cause and effects of beam halo

Attachment B: preliminary Linac Beam Commissioning Requirements

DTL Tank 1:

- 7.5 MeV beam stop, Full beam power, unchopped: 38 mA, 1 ms, 60 Hz, 7.5 MeV = 17.1kW

- Energy-degrader and Faraday cup, 38 mA, 50 μs, <= 10 Hz, 7.5 MeV = 143 watts max. The beam current is actually ramped, so the power is less.

DTL tank 6:

- Energy degrader and beam stop, 38 mA, 50 μs, 1 Hz, 87 MeV = 164 watts. The final DTL tank #6 energy degrader and Faraday cup are located after CCL segment #4, so a temporary one will have to be used for initial commissioning.

CCL module 4:

- Beam stop/Faraday cup, mounted between CCL and SRF, 38 mA, 34 μs, 1 Hz, 186 MeV = 240 watt. This permanent unit is not suitable for initial commissioning using the delta-t method. To carry out the delta-t commissioning, we will need to have a beam stop about 15-m downstream of CCL module 4. This will require that cryo-modules 1, 2, and 3 be installed after CCL commissioning is completed.

SCL:

- Drift the beam to the Linac beam stop (beam debunching is not an issue above 186 MeV). It is believed that the beam current ramp has to be lengthened to 100 μs for the SCL commissioning, 38 mA, 100 μs, 1 Hz, 186 to 1000 MeV = 3.8 kW max.

References

[1] L.M.Young, "A Procedure to Set Phase and Amplitude of the RF in the SNS Linac's Superconducting Cavities", Proc. International PAC2001 (Chicago, June 18-22, 2001)

3.3 Administrative and Technical Controls and Contingency Plans for Linac Systems

3.3.1 Technical Controls and Safety Systems

Accelerator specific safety systems that must be in place, tested and certified for operation prior to commencement of commissioning studies for Linac Systems include the Personnel Protection System (PPS) and the Machine Protection System (MPS).

PPS

The Personnel Protection System radiation protection for Linac Systems will evolve through a number of phases as Linac commissioning proceeds.

The DTL Tank 1 will be commissioned with a variation of the standalone PPS Phase 0 design that was used in the Front End commissioning. DTL Tank 1 is expected to produce significant dark current X-ray radiation during conditioning and commissioning. Additionally, the 7.5 MeV beam is directed to the Diagnostic Plate beam dump, as well as any beam scraped off and not reaching the full energy, will produce significant neutron radiation. DTL Tank1, the Diagnostic Plate and the Diagnostic Plate beam dump will reside in a shielded enclosure with shielding sufficiently thick so that installation work can proceed in the Linac while low intensity beam commissioning activities are ongoing. This version of the PPS will include a minimum of five Chipmunk radiation detectors outside the DTL shielding hut. The hut will have an interior search station, a beam shutdown station and a stack light status indicator. A search zone door will be used to secure the hut. All interlocks will be applied to the 65 kV In Source high voltage supply as well as the RF for the RFQ. The RFQ RF interlock also controls the high voltage supply for the RFQ and DTL Tanks 1 and 2.

For DTL Tanks 2-6 commissioning, the shielding enclosure around DTL Tank 1 will be disassembled and a shielding wall will be fabricated downstream of the CCL. During this mode the beam will be dumped on the internal diagnostic Faraday cups in the DTL tanks. The equipment will operate in PPS Phase 1 mode, i.e. equipment will be installed to secure the warm Linac. The normal PPS operating modes will be available, i.e.

- Restricted Access (RWP Access, Magnets and RF OFF)
- Controlled Access (Magnets and RF OFF)
- Controlled Access (Magnets Off)
- Controlled Access (Magnets On)
- Power Permit (Magnets and RF On)
- Beam Permit (Full Operation)

During commissioning and operation, high radiation levels will be detected by the Fermilab standard ionization chambers (Chipmunks), which will shut off the Ion Source 65 kV power supply and the RF drive to the RFQ at the Transmitter as well as the Transmitter HV supply. High radiation trips will require evaluation and approval by the Chief Operator prior to the manual reset to restart commissioning.

During Linac Systems commissioning, a radiation producing beam is only allowed in the "Beam Permit" mode. The detection of an open PPS interlocked door will terminate the "Beam Permit" operating mode, and will shut down two independent critical devices necessary to create the radiation producing beam, i.e.

- The Ion Source (via the 65 kV power supply) and
- The RFQ (via the RF drive to the transmitter and the transmitter high voltage power supply).

In addition, the PPS operating mode will drop down to "Restricted Access", removing the "Power Permit" and thus turning off both the Magnet and RF Power within the violated PPS area(s). Such PPS area(s) violation will require evaluation by the Chief Operator, and a sweep and reset of the area(s) before commissioning restart.

Activation of the Emergency-Stop pushbutton on the operator panel or the Beam Shutdown Station (BSS) shuts off all critical devices including off the Ion Source 65 kV power supply and the RF drive to the RFQ at the transmitter and the transmitter high voltage power supply. Emergency-Stop or Beam Shutdown Station (BSS) shutdowns require evaluation and approval by the Chief Operator prior to the manual reset for commissioning restart.

During CCL commissioning, the PPS Phase 1 will be extended to the end of the Linac. Appropriate shielding will already be in place at the downstream end of the CCL to protect SCL components immediately downstream and personnel in the HEBT.

During SCL commissioning, the equipment will operate in the PPS phase 2 mode, i.e. equipment will be installed to secure the Linac and the HEBT. The beam will be directed into the Linac beam dump. The normal PPS operating modes will be available, i.e.

- Restricted Access (RWP Access, Magnets and RF OFF)
- Controlled Access (Magnets and RF OFF)
- Controlled Access (Magnets Off)
- Controlled Access (Magnets On)
- Power Permit (Magnets and RF On)
- Beam Permit (Full Operation)

The PPS will be re-certified twice per year and when significant modifications are made.

MPS

The Machine Protection System (MPS) runs in three modes.

- If the High QA system is tripped, the Ion Source 65 kV power supply and the RFQ Transmitter HV power supply are shut down.
- If the MPS Latched system is tripped, the Ion Source 65 kV power supply and the RFQ Transmitter HV power supply are disabled. This requires evaluation and approval by the Chief Operator prior to the manual reset for commissioning restart.
- If the MPS Auto Reset system is tripped, the LEBT Chopper is directed not to allow beam to exit the LEBT and the RFQ RF drive is inhibited for the duration of the macropulse.

The MPS will be re-certified twice per year and when significant modifications are made.

A full description of the MPS can be found at:
http://www.sns.gov/projectinfo/ics/192/1923/MPS_FDR/

Additional Machine Protection software/hardware that should be in place for the Linac commissioning includes:

- Automatic file creation from Oracle Database.
- Configuration verifier.
- High QA Linac Dump Protection
- 2 MHz, RFQ RF Vetoing circuits
- All PS, Vacuum, RF, Beam Loss Monitors, Differential current loss monitors, Diagnostic MPS Inputs
- Run-permit and Fast-Protect display screens for DTL, CCL, SRF, and Linac Dump.

Beam Power

During Linac commissioning, the beam power will be limited to an amount less than that which is specified for each system in the Commissioning Accelerator Safety Envelope (Appendix A).

Safety

Radiation Safety during Linac Systems commissioning is ensured by strict compliance with the relevant policies and procedures of the ORNL Standards Based Management System (SBMS) (http://eshtrain.ct.ornl.gov/SBMS/), specifically:

- ORNL Radiological Protection Management System (RPMS) (http://eshtrain.ct.ornl.gov/sbms/SBMSearch/Msd/RPS/RPS_MSD.cfm)
- ORNL Radiological Control Policy and Radiological Protection Procedures (http://eshtrain.ct.ornl.gov/sbms/SBMSearch/ORNLProc/ORNL-RP-110.htm)
- ORNL ALARA Program (http://eshtrain.ct.ornl.gov/sbms/SBMSearch/ORNLProc/ORNL-RP-138.htm)

which are in compliance with 10CFR835 (Occupational Radiation Protection).

Lockout-Tagout safety during Linac Systems commissioning is ensured by compliance with the ORNL-SNS LOTO policy, which is OSHA compliant. This policy can be found at:
http://www.internal.sns.gov/esh/standards/lockout_tagout.pdf

Fire Safety is ensured during Linac Systems commissioning. A fire alarm system will be in place and operational in the Linac building which is compliant with NFPA Standard 72. A sprinkler system will be in place and operational in the Front End building that is compliant with NFPA Standard 13. Where construction activities prevent a required fire safety feature from being operational, compensatory measures in general accordance with NFPA 241, Standard for Safeguarding Construction, Alteration, and Demolition Operations, will be identified and implemented.

3.3.2 Administrative Controls

Administrative controls are described in **Appendix B, Personnel, Training, Certification, Procedures and Records.**

3.4 The Portion of the Overall Facility ARR Needed for Linac Systems

Portions of the overall ARR that are needed for Linac Systems commissioning include an approved Commissioning Accelerator Safety Envelope (CASE) and an approved Safety Assessment Document (SAD) for Linac Systems.

For Linac Systems the framework for the CASE is listed in Appendix A of this document.

The SNS Preliminary Safety Assessment Document is available at:
http://www-internal.sns.gov/dcrm/docs/102/102030103-ES0003-R00.pdf

3.5 The schedule for Linac Systems Commissioning

Linac Systems commissioning is listed in the current Integrated Project Schedule (see Appendix D) and scheduled to take place as follows:

- DTL Tank 1: from February 21, 2003 to September 30, 2003.
- DTL Tank 2-6: from December 1, 2003 to April 1, 2004.
- CCL: from May 17, 2004 to August 18, 2004.
- SCL: from October 1, 2004 to December 21, 2004

4.0 HEBT- Ring-RTBT-Systems

4.1 System Description

4.1.1 Introduction

Three major accelerator systems are included in WBS 1.5. The first is the High Energy Beam Transport (HEBT) system (Fig.4.a), the second is the Accumulator Ring (AR) system (Fig.4.b), and the third is the Ring to Target Beam Transport (RTBT) system (Fig.4.c). (See also conceptual map in Fig. 1.b). The purpose of the Beam Transport and Ring system is to convert the incoming Linac beam of about 1 ms length into a beam of 695ns length and transport this final beam onto the neutron target. The initial rms un-normalized emittance of the Linac beam is 0.14 π mm mrad in both horizontal and vertical dimensions. The final emittance of beam on the target is 120 π mm mrad in full size. Table 4.1 outlines the evolution of the beam emittance from the Linac through the accumulator ring to the target.

Figure 4.a Detailed Layout of HEBT

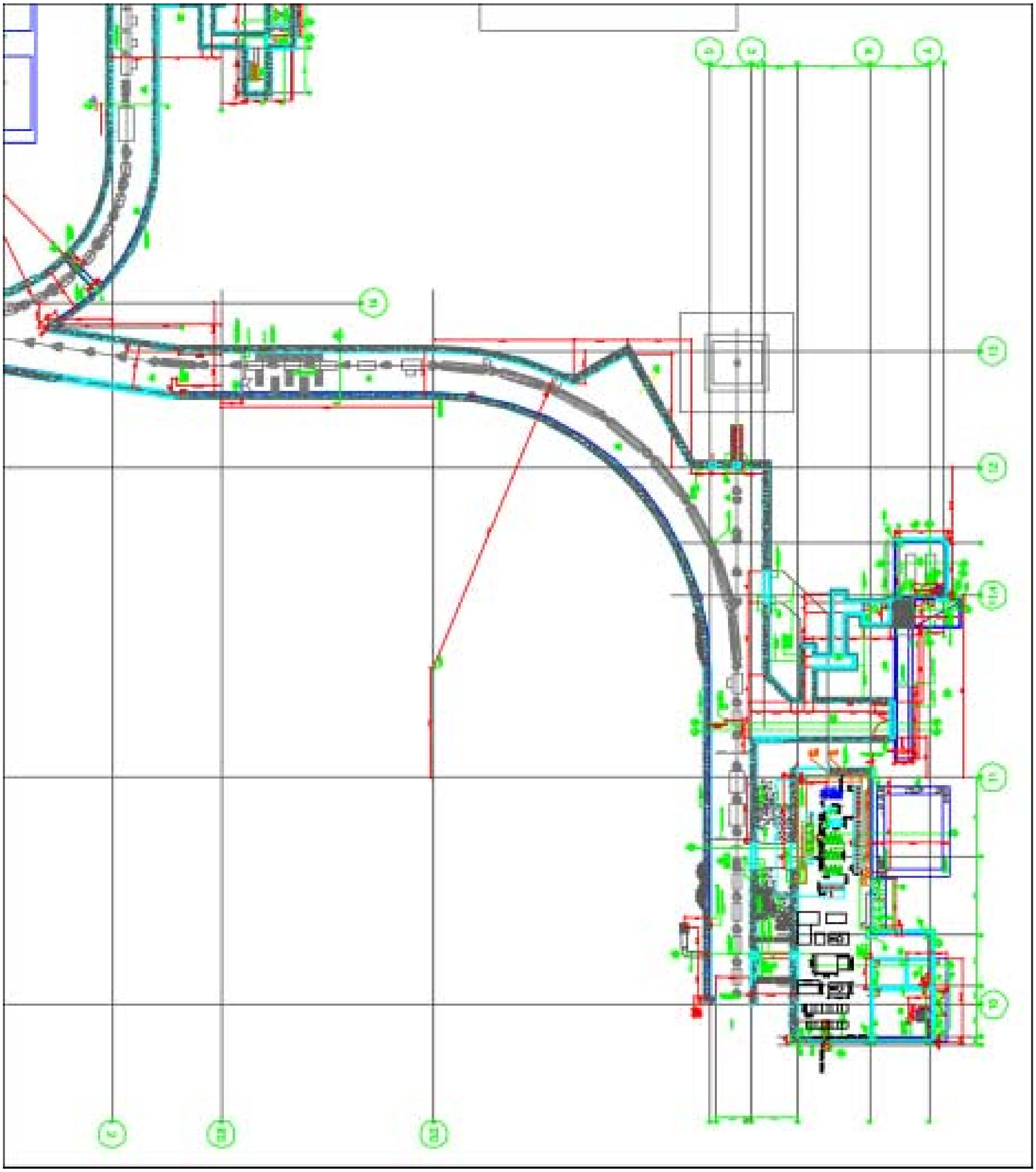


Figure 4.b Detailed Layout of Ring

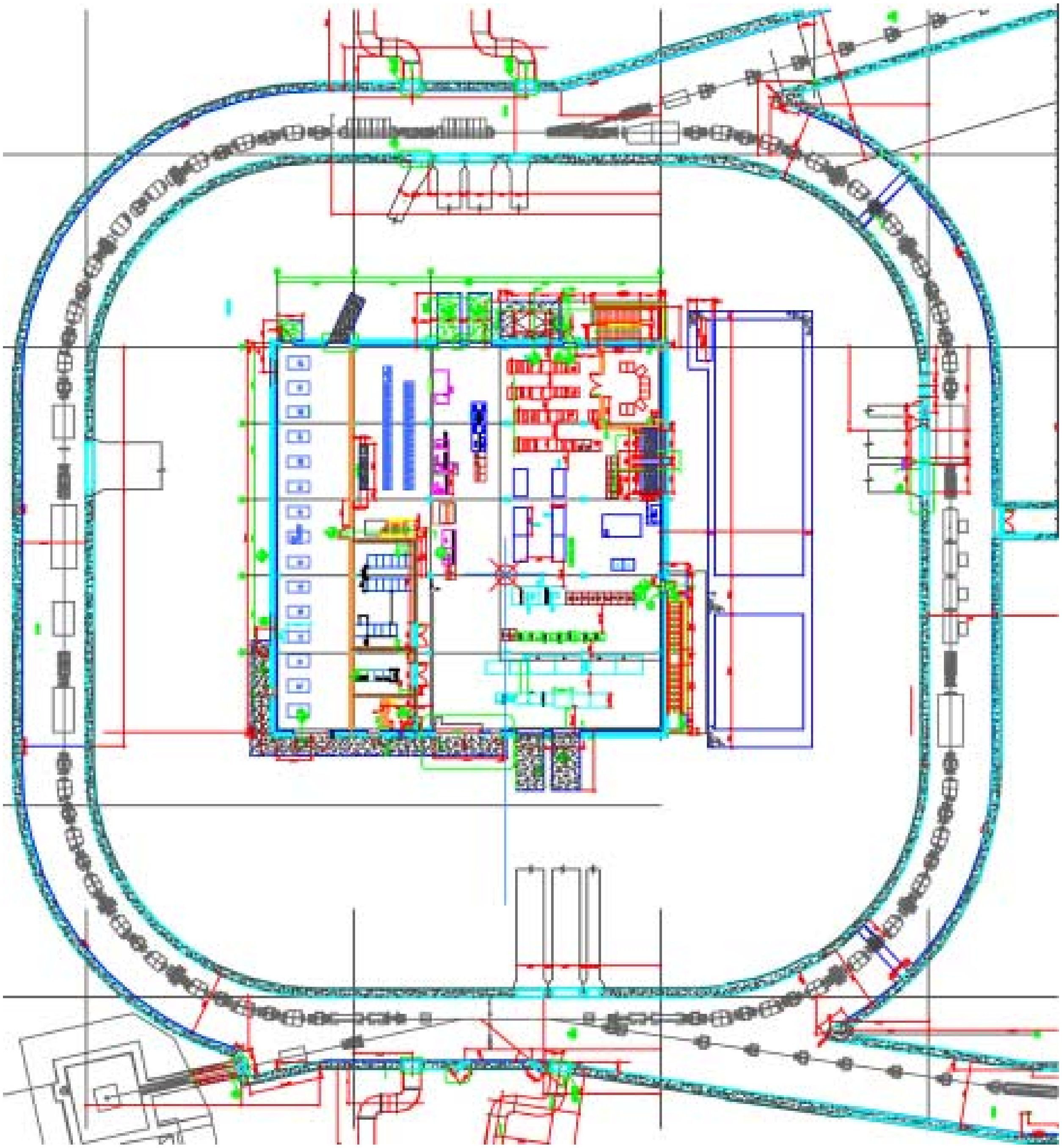
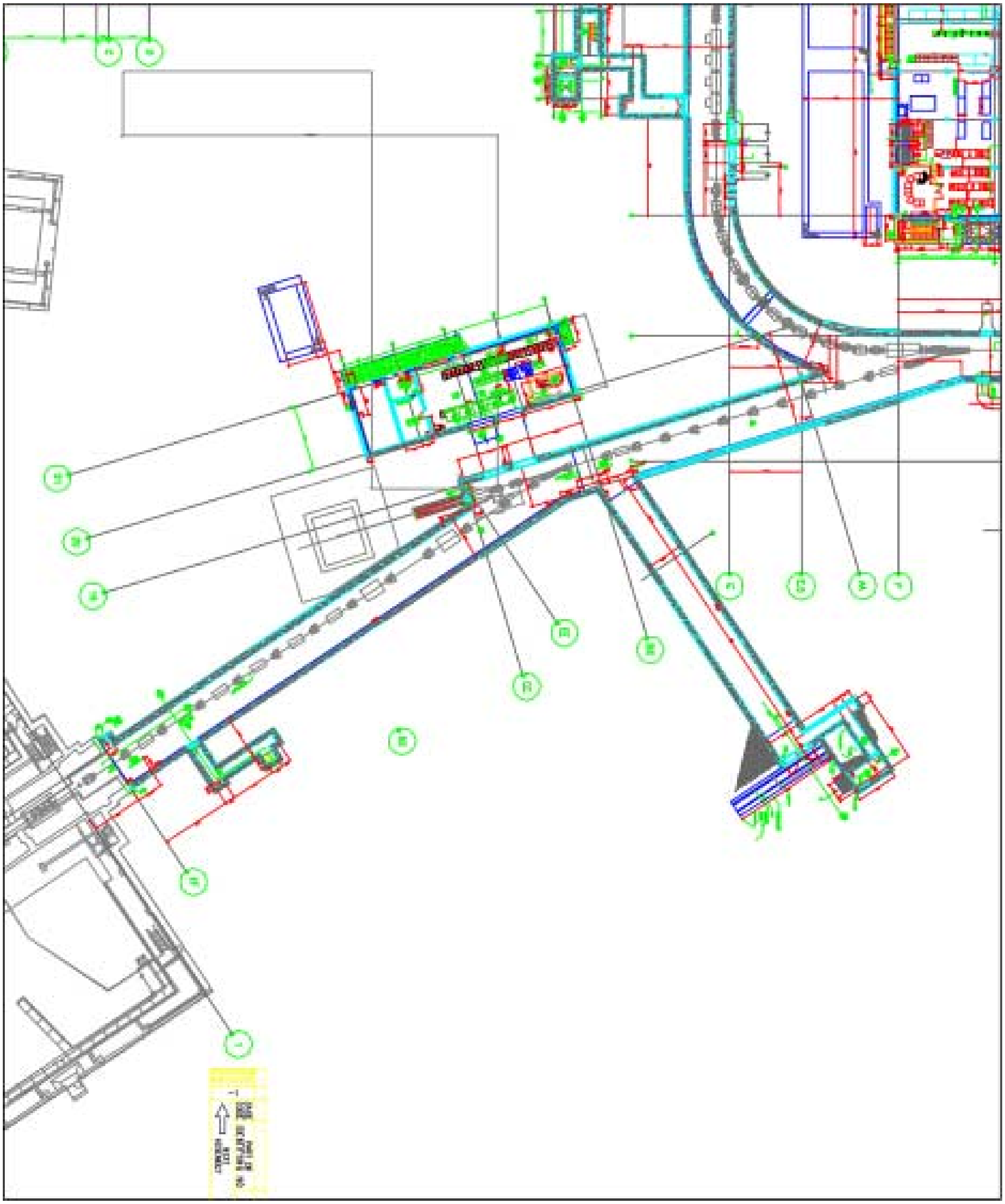


Figure 4.c Detailed Layout of RTBT



To maximize the performance and lifetime of the neutron target, a beam spreading system will create a beam on target of 20 cm (H) x 7 cm (V) size with the ratio of peak density to that of the average density no larger than two. Another major performance requirement will be to hold the average uncontrolled particle loss during the accumulation time to less than 2 x 10^{-4} of total protons. This stringent requirement will hold down the residual radiation to a level that will permit hands-on maintenance except in a few localized areas, such as the injection, extraction, and collimation systems. To achieve this goal, special care has been exercised in the design of the H^- stripping, the RF stacking, and the collimator systems. Ongoing accelerator R&D and computer tracking studies of the space-charge effects and halo formation will ensure the achievement of this performance goal.

Table 4.1 Performance requirements for the HEBT

HEBT BEAM LINE			
Ion type	H minus		
Output energy	1	GeV	
Length	169.49	m	Diff pumping to injection septum center
Beam-floor distance	1.270	m	50.0 in
Length of additional Linac dump beam line	42	m	
Length of Linac to achromat matching section LAMS	40	m	
Number of LAMS FODO cells	5		8.0 m per FODO cell
Length of achromat	59	m	
Number of achromat FODO cells	4		14.0 m per FODO cell
Achromat total bend angle	90	deg	
Achromat maximum dispersion	6.8	m	
Length of achromat to ring matching section ARMS	70	m	
Number of ARMS FODO cells	7.5		8.0 m per FODO cell
Number of Ludewig betatron collimators	2		
Number of betatron foil collimators	4		
Location of momentum collimator	achromat center		
Rms energy spread at achromat center	0.72	MeV	
Energy scrape with momentum collimator	+/- 3.0	MeV	
Energy total jitter before energy corrector	+/- 1.5	MeV	
Energy total jitter after energy corrector	+/- 0.2	MeV	
Total time ave energy spread at foil	+/- 4.0	MeV	
Number of energy sweeps per macropulse	100		
Expected output HandV rms norm emittance w/ errors and wo/ jitter	0.41	πmm-mrad	
Extected output transverse centroid jitter	+/- 0.2	mm	
Expected output HandV rms norm emittance w/ errors and w/ jitter	0.50	πmm-mrad	
Operating vacuum pressure	5E-8 to 1E-8	Torr	From SRFL to Ring

4.1.2 High Energy Beam Transport (HEBT)

The HEBT system provides the link between the Linac and the accumulator ring. The beam coming out of the Linac is a 1 GeV H^- beam, approximately one ms long, with a 805-MHz microstructure, chopped into minipulses of length 645ns with 300ns gaps, each of peak current 38 mA. The transverse rms un-normalized emittance of the Linac beam will be 0.14 π mm mrad in both planes, and the longitudinal emittance will be 300 p keV degrees. The total length of the HEBT line will be 170 m (excluding the beam dumps), and the total bending angle will be 90°. The line will provide locations for beam scraping of the halo particles from the Linac in both betatron and momentum phase space. A debuncher system will be provided for the proper control of the momentum spread of the beam injected into the accumulator ring. At the injection point, the Linac beam will be matched to the ring lattice for the H^- injection process.

A map of the HEBT beamline layout is at:
http://www.sns.gov/apgroup/refTables/drawings/HEBT.pdf

4.1.3 Accumulator Ring (AR)

The proton accumulator ring is one of the major systems in the design of the SNS. The primary function of the AR is to take about 1 ms long 1GeV H^- beam from the Linac and compress it into a 695 ns long beam by accumulating it in the AR in ~1200 turns. The final beam will have ~1.5 x 10^{14} protons per pulse, meeting the design specification of 1.5-MW design average beam power at a 60-Hz repetition rate. Provisions have been reserved for a future upgrade to run the ring with up to 1.3 GeV injection energy with only a minimal change of hardware; namely, two dipoles in the injection straight. The lattice structure of the AR is a fourfold symmetric hybrid of FODO lattice arc with a matching doublet straight section. The betatron phase advance for the arc is adjusted so that the straights are dispersion free. The total circumference of the ring will be 248 meters. The transition gamma is about 4.95, much higher than the operating energy of 1 GeV. Table 4.2 summarizes the performance requirements for the Ring.

Table 4.2 Performance requirements for the Ring

ACCUMULATOR RING

Ion type	proton		
Output energy	1	GeV	
Ring circumference	248.0	m	
Beam-floor distance	1.224	m	48.2 in
Average beam power	1.5	MW	Average power in ring
Peak bunched beam current	52	A	
Proton magnetic rigidity	5.6575	Tm	
Max uncontrolled beam loss	1	W/m	
Unnormalized 99% total emittance (ε_x+ε_y)	240	πmm-mrad	434 πmm-mrad normalized
Ring betatron acceptance	480	πmm-mrad	
Adjustable scraper acceptance	240-300	πmm-mrad	
Collimator acceptance	300	πmm-mrad	
Longitudinal rf bucket area	19	eV-sec	
Expected longitudinal bunch area (99%)	13	eV-sec	
Total Injected energy spread	+/- 4	MeV	
Total extracted energy spread	+/- 10	MeV	
RF system momentum acceptance	+/- 1.0	%	
Vacuum chamber full-beam momentum acceptance	+/- 2.0	%	
Zero betatron amplitude momentum acceptance	+/- 3.8	%	
Bunching factor	0.48		Dual harmonic RF
Expected space charge tune shift	0.15		Uniform-beam tune shift 0.1
Lattice superperiods	4		
Max dispersion in straight sections	<0.3	m	Dominated by injection chicane/bump
Arc lattice	4 FODO cells		
Arc FODO cell length	8	m	
Straight section lattice	2 doublets		
Short drift in long straights	2X6.85	m	
Long drift in long straights	12.5	m	
Phase advance per arc FODO cell	90	deg	
Nominal betatron H tune	6.4		Adjustable range 6 – 7
Nominal betatron V tune	6.3		Adjustable range 4 – 7
Transition gamma	5.23		
Frequency slip factor	-0.198		
Natural H chromaticity	-8.1		Nominal tunes
Natural V chromaticity	-7.0		Nominal tunes
Maximum dispersion function	3.9	m	Nominal tunes
Maximum H/V β function	27.0/14.9	m	Nominal tunes
Ring V beamline offset wrt HEBT beamline	-46	mm	
Offset for injection H static bump	100	mm	
Number of injected turns	1060	turns	
Revolution period	945	ns	
Ring injection pulse length	645	ns	
Ring injection gap length	300	ns	
Ring extraction pulse length	695	ns	
Ring extraction gap length	250	Ns	
Space charge longitudinal impedance iZ/n	-196	Ω	
Expected resistive wall longitudinal impedance Z/n	(1+i)0.7	Ω	At revolution frequency
Expected resistive wall transverse impedance Z	(1+i)6.2	kΩ/m	At revolution frequency
Expected broad band longitudinal impedance |Z/n|	8	Ω	
Expected broad band transverse impedance |Z/n|	94	kΩ/m	
Expected kicker longitudinal impedance |Z/n|	<50	Ω	
Expected kicker transverse impedance, Re(Z/n), Im(Z)	20, 200	kΩ/m	Below 10 MHz
Expected kicker transverse impedance, Re(Z), Im(Z)	12,080	kΩ/m	At 50 MHz

4.1.4 Ring to Target Beam Transport (RTBT)

The Ring to Target Beam Transport system will take the extracted beam from the AR and transport it to the neutron target. The extraction starts with two 7 module kicker arrays to deflect the circulating beam vertically by 16.8 mrad followed by a Lambertson magnet to bend the beam horizontally out of the ring. A small vertical dipole magnet brings the beam back to the horizontal resulting in a beam height about 9 inches below the ring beam height. The magnet apertures in this line will be sized to allow for malfunctions of one of the eight extraction kickers, protecting the line against excessive losses. A beam shape control section will be provided for the final beam profile 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 150 meters (excluding the beam dump line) and the total horizontal bend angle will be 16.8 degrees. Table 4.3 summarizes the performance requirements for the RTBT.

Table 4.3 Performance requirements for the RTBT

RTBT BEAM LINE			
Ion type	Proton		
Output energy	1	GeV	
Length	150.75	M	Lambertson center to target
Beam-floor distance	0.996 to 1.041	M	Start at 39.2 in and end at 41.0 in
Output beam power	1.5	MW	Average power
Beam spot size on target H x V	200 x 70	Mm	
Number of Ludewig betatron collimators	2		
Number of 11.6 m FODO cells	15		
Ring extraction dump beam line length	28	M	
RTBT elevation wrt ring	-0.183	M	
Operating vacuum pressure	1E-8 to 1E-7	Torr	From ring to target

4.2 Narrative Plan for HEBT-Ring-RTBT Systems

4.2.1 Introduction

The following is a narrative description of the events and Accelerator Physics measurements needed for commissioning the individual components of the High-Energy Beam Transport Line (HEBT), the Accumulator Ring (AR), the Ring to Target Beam Transport Line (RTBT) into a complete subsystem of the SNS accelerator systems, and for reaching the CD-4 goal of delivering 10^{13} protons to the target in a single pulse.

The narrative also contains acceptance criteria for these measurements.

One page summary sheets for each Accelerator Physics activity, the sum of which are the Technical Commissioning Plan are contained in Appendix C.

For the initial beam commissioning of the transfer lines and ring, the smallest practical beam intensity at the lowest practical repetition rate will be used in order to minimize losses and activation. The minimum practical beam pulse-length, which may be as short as one mini-pulse (680 ns), will be utilized. The ion source intensity, depending on performance at the time, may be reduced (with some subsequent Linac re-tuning) to further minimize the beam intensity. Finally, the beam will be delivered at low repetition-rate, typically in a single-shot, "pulse-on-demand" mode.

Once the losses are minimized and the beam is transported safely to one of the dumps, the pulse-length or the repetition rate, or perhaps both, will be increased for particular measurements or operations. The three beam dumps have design power limits of 7.5 kW (Linac dump and extraction dump) and 200 kW (injection dump). The target will be capable of handling up to 100 kW of beam power for a short duration, and 3-4 kW of power continuously through the RTBT and Target portion of the commissioning program. As a point of reference, for an ion source current of 38 mA, a single mini-pulse at 1 Hz repetition rate provides a beam power of 25 W.

4.2.2 Linac Dump Commissioning

The objectives of this phase of commissioning are to bring into operation the transport line which takes the accelerated Linac beam to the passive Linac dump, and to establish the operability of the dump and bulk shielding up to the design beam dump limit of 7.5 kW. The Linac beam is transported to the dump via the Linac to Achromat Matching Section (LAMS) of the HEBT transport line, which will have been installed and tested prior to the superconducting Linac commissioning. The Linac dump commissioning proceeds by transporting a beam to the dump, commissioning the diagnostic devices, establishing the proper dump trajectory and beam profiles and verifying the performance of the dump and shielding. Once this has been achieved, measurements of the Linac beam parameters, and collimation studies, will be performed.

For the first transport of a beam from the Linac to the dump, a beam of the minimum practical pulse length will be used. The beam will be delivered on a "pulse-on-demand" basis. The progress of the beam transport will be tracked with Beam Loss Monitors (BLMs) located on each quadrupole in the LAMS and Linac dump lines. The beam will be steered with the horizontal and vertical dipole correctors as necessary to minimize losses. Three beam current monitors are available in the line: HEBT_Diag:BCM01 (after the first HEBT quad), HEBT_Diag:BCM09 (before the achromat) and Ldump_Diag:BCM06 (at the last quadrupole before the Linac dump). These monitors will be "timed-in" as beam transport progresses, and used to measure and "tune-up" the transport efficiency. A gross check of the dump shielding is obtained by observing the radiation monitor response in the dump cave.

The Beam Position Monitors (BPMs) are then "timed-in" and the trajectory measurement systems are debugged with beam. As part of the BPM testing, horizontal and vertical correctors are adjusted to displace the beam in the BPMs in order to provide a check of the BPM cabling and calibration. At the same time, the corrector polarity is checked and an approximate corrector strength calibration is obtained. When the BPM system is operational, the trajectory to the dump is measured and corrected. The automated transfer-line trajectory correction algorithms and applications software are tested with beam. The Linac dump profile-measuring device is then commissioned and the beam profile is measured.

Once the beam profile on the dump wire scanner is verified, the beam intensity is increased in order to verify the performance of the dump. The beam power is raised by gradually increasing the pulse length and minimizing losses. (The 7.5 kW Linac dump power limit corresponds to a 290 μs pulse at 1 Hz for 26mA chopped macropulse current.) The transport efficiency is improved with the set of three BCMs and the losses are minimized with dipole corrector adjustments. The beam position on the dump is inferred by observation of the dump thermocouple array. Adjustments to the last horizontal and vertical correctors in the Linac dump line are made if necessary to position the beam on the dump. Proper shielding of the dump and dump line is verified by observation of the radiation monitors in the dump cave and by measuring the prompt radiation external to the dump cave and dump line.

At this point, measurement of the Linac beam parameters and lattice functions in the LAMS may proceed. The Time-of-Flight (TOF) system is commissioned and the beam energy is measured. The HEBT energy is adjusted in order to match the Linac beam energy. The wire scanner array (HEBT_Diag:WS01-04 and HEBT_Diag:WS09) is then commissioned and beam profiles are obtained. The emittance and twiss parameters are estimated from the wire scanner array data, and the beam profile at the entrance to the achromat and at the Linac dump are measured and compared with expectations. If necessary, the matching section quadrupoles will be adjusted to improve the optics match to the achromat and Linac dump. A transfer-line optics model will be used to calculate the quadrupole strengths necessary to achieve the proper Linac to achromat matching, using the measured emittance and twiss parameters as initial conditions. If necessary, the Linac dump line quadrupoles are adjusted with the aid of the transfer-line optics model to achieve the desired beam profile at the Linac dump.

The commissioning program continues with investigations of the HEBT transverse collimation system. Up to this point, the HEBT collimator stripping foils have been fully retracted for transport to the dump. The BLM system, including both the fast and slow monitors, and the display software are fully functional at this stage. The beam loss rates and distribution are measured as functions of the horizontal and vertical stripping foil positions. The BLMs near the collimators should show higher losses as the stripping foils are moved in, while the loss monitors further downstream should show decreasing loss rates. As the foils are inserted beyond their optimal setting, the loss rates increase dramatically as the foils approach the beam core.

The Energy Corrector Cavity (ECC) is then commissioned. Although a direct measurement of cavity parameters is not possible since the dispersion in the line is zero, it may be possible to observe a change in beam centroid with an "on-off" measurement in which correctors are powered to generate a small residual dispersion at the profile monitor.

4.2.3 HEBT Transport and Optics Commissioning

The objectives of this phase of commissioning are to bring into operation the High-Energy Beam Transport line (HEBT), transport a beam to the injection dump, verify the performance of the dump and bulk shielding, and transport a pulse of 10^{13} protons to the injection dump at low repetition rate . The HEBT consists of three sections, the Linac to Achromat Matching Section (LAMS), the Achromat, and the Achromat to Ring Matching Section (ARMS). Previously, during the Linac Commissioning, the LAMS, Linac dump line and Linac dump will have been commissioned. In this phase, the Achromat, ARMS, ring injection region and injection dump are commissioned.

Commissioning proceeds by transporting a beam through the HEBT line, the ring injection region, the injection dump line and to the injection dump. The dump is verified to function properly at low power. The diagnostic devices are commissioned, and the trajectory and optics are measured and corrected as needed. Linac beam parameters are measured. The ECC and ESC cavities are commissioned and their setpoints established. Fault scenarios are explored to qualify the bulk shielding and dump performance. The beam intensity is increased to 10^{13} protons/pulse and is transported to the injection dump. The beam power is increased and the dump functioning at higher power is verified. As the intensity is increased, the HEBT collimation system is optimized to reduce losses.

Commissioning of the HEBT line begins by transporting a low-power beam to the Linac Dump. The LAMS diagnostics, having been commissioned earlier during the Linac Commissioning, will allow an immediate measurement of the trajectory, transport efficiency and losses, beam energy, emittance and optical functions at the wire scanner array. The HEBT beam line energy is adjusted in accordance with the measured beam energy.

For the initial transport of a beam through the HEBT, the minimum practical pulse-length will be used. The beam will be delivered on a “pulse-on-demand” basis. The progress of the beam transport will be tracked with the BLMs located on each quadrupole in the HEBT and injection dump line. The beam will be steered with the horizontal and vertical dipole correctors as necessary to minimize losses. There are four BCMs in the HEBT line (HEBT_Diag:BCM01,09,20,26) and one in the injection dump line. Two are located before the Achromat, one just after, and the last is located after the final dipole in the line (HEBT_MAG:DH25). These monitors will be “timed-in” as transport progresses, and used to measure and “tune-up” the transport efficiency. The beam is transported to the injection region by tuning on the BLMs, adjusting the achromat dipole field, adjusting the HEBT_MAG:DH25 field and horizontal and vertical correctors.

The beam is transported to the injection foil. A phosphor screen mounted on the stripping foil actuator will be inserted in order to observe the image of a low intensity beam with the video foil monitor. When the beam strikes the phosphor, losses should be observed both in the ring and injection dump BLMs. Adjustments are made to the injection septum (INJSEPTM1) and the chicane amplitude to position the beam horizontally. After replacing the phosphor with a stripping foil, adjustment of the injection dump septum (INJSEPTM2) will take the beam into the injection dump line where it should be observable on the BLM and injection dump BCM. After minimizing losses on the last BLM in the dump line, a gross check of the dump shielding is obtained by observing the radiation monitor response in the dump cave.

The beam pulse-length is increased to aid commissioning of the HEBT diagnostics. The Beam Position Monitors (BPMs) in the HEBT and injection dump line are then "timed-in" and the trajectory measurement systems are debugged with beam. As part of the BPM testing, horizontal and vertical correctors are adjusted to displace the beam in the BPMs in order to provide a check of the BPM cabling and calibration. When the BPM system is operational, the HEBT trajectory is measured and corrected. The HEBT corrector polarities and strengths are checked with beam by observation of the trajectory amplitude as a function of the corrector strength. The automated transfer-line trajectory correction algorithms and applications software are tested with beam. After correction, transfer efficiency and losses are reoptimized.

The injection dump profile-measuring device is then commissioned and the beam profiles observed in the dump line and on the foil video (observing the phosphor screen) are compared with lattice predictions.

With a functioning trajectory measurement system, the dispersion in the HEBT line is measured by adjusting the Linac energy via the accelerating phase of the last cavity and recording the trajectory. The achromatiticy of the bend is measured by noting the residual dispersion in the ARMS, and may be adjusted by tuning the horizontal phase advance through the achromat. The beam motion observed on the foil video as the beam energy is changed measures the dispersion at the injection point.

The remaining HEBT wire scanners (HEBT_Diag:WS20,21,22,23 and HEBT_Diag:WS16) are then commissioned and beam profiles are obtained. The emittance and twiss parameters are estimated from the wire scanner array profiles, and the beam profiles at the entrance to the achromat, within the achromat, and in the injection dump line are measured and compared with expectations. If necessary, the Linac to Achromat Matching Section quadrupoles will be adjusted to improve the optics match to the achromat. The Achromat to Ring Matching Section quadrupoles will be adjusted to properly match the HEBT optics to those of the ring at the injection point. A transfer-line optics model will be used to calculate the quadrupole strengths necessary to achieve the desired twiss parameters, using the measured emittance and twiss parameters as initial conditions, and the beam profiles as constraints.

When the optical functions and beam profiles are well understood, Linac beam parameters may be measured by making use of the finite dispersion within the achromat. The Linac beam energy may be estimated from the achromat dipole field, providing a cross-check with the TOF measurement. The combined energy spread due to beam energy jitter and natural energy spread may be estimated by observing the beam profiles at the wire scanners within the achromat at points of large dispersion.

The Energy Corrector Cavity is brought into operation, and the phase and amplitude controls and stability are checked with beam. The beam position is observed in the achromat at a high-dispersion point. The ECC phase is adjusted and beam motion is observed to verify the phase control. Likewise, the amplitude is adjusted while observing the beam position to verify amplitude control. The beam profile is measured in the achromat with the ECC off and on to verify that the ECC is functioning, and to determine the resulting energy jitter.

The Energy Spreader Cavity (ESC) is then brought into operation. The phase and amplitude controls and stability are checked with beam. The energy is measured with the TOF system following the ESC.

Once the HEBT optics are understood and the proper beam profiles are verified, fault studies in the HEBT and injection dump are performed, as outlined in SNS-OPM Chapter 6, Section J. These studies include confirming the attenuation of the HEBT plug door and man-labryinth with controlled beam loss on the HEBT collimators and first HEBT achromat dipole, as well as verification of the bulk shielding and injection dump shielding with prompt radiation measurements external to the dump and injection dump line.

Once the beam profile in the injection dump has been verified and the fault studies completed, it is safe to raise the beam power transported to the dump. For higher power dump studies, the injection foil is removed and replaced with a blank, so that unnecessary irradiation of the nearby ring components is avoided. The pulse-length is gradually increased and the losses are minimized with corrector adjustments and injection septa and chicane adjustments.

The HEBT collimator foils are then adjusted to minimize losses. Four pairs of foils (two for horizontal and two for vertical) must be properly positioned for the transverse collimation, and one pair is positioned for the momentum collimation. The BLM system, including both the fast and slow monitors, and the display software are fully functional at this stage. The beam loss rates and distribution are measured as functions of the horizontal and vertical stripping foil positions. The BLMs nearest the collimators should show higher losses as the stripping foils are moved in, while the loss monitors further downstream should measure decreasing losses. As the foils are inserted beyond their optimal settings, the loss rates increase dramatically as the foils begin to reach the beam core. The momentum scrapers are optimized by observing fast BLMs near the momentum dump.

The beam pulse is gradually lengthened in order to transport 10^{13} protons per pulse to the injection dump. (For a macropulse current of 26mA, a 62μs pulse provides 10^{13} protons.) Losses are minimized by optimization of correctors and injection region dipoles and optimization of the HEBT collimation system. Beam pulses are delivered on a “pulse-on-demand” basis to minimize the activation.

4.2.4 Ring Transport and Closed Orbit

The objectives of this phase of commissioning are to bring the ring magnets into operation, transport a low-intensity beam around the ring, commission the basic ring diagnostics, and measure and correct the closed-orbit.

The initial ring commissioning will use a beam of the minimum practical pulse-length delivered on a "pulse-on-demand" basis to minimize activation. At low beam power in the ring, it is not necessary to extract the beam to the passive extraction dump, since the collimators are designed to handle steady-state power deposition of several kW. The primary collimators will be retracted for first beam commissioning, so the collimation efficiency may be as low as 50%, even though the collimators themselves are the limiting aperture in both planes. The remaining beam power will likely be absorbed at one or at most a few specific locations in the ring until the closed-orbit is corrected.

Ring commissioning begins by transporting a beam of the minimum practical pulse-length to the injection dump. The beam energy is measured with the TOF system in the HEBT, and the ring energy is set accordingly. The beam is observed on the foil video with the phosphor in place. The beam is positioned on the foil with the injection septum (INJSEPTM1) and chicane if necessary. The primary foil is then moved in place, and losses are observed in the nearby ring BLMs, and the injection dump current will be reduced.

In order to first transport a beam in the ring, the dynamic injection bumps will be powered with a waveform that corresponds to placing the closed orbit in the injection foil at injection time. The bump amplitude will be available as a tuning-knob, as will the injection chicane amplitude.

The progress of the beam transport will be tracked with the BLMs located at each quadrupole. In addition, raw digitized ring BPM signals will be available in the control room for tuning purposes, and to provide another signal with which to track the beam around the machine. The beam will be steered with the horizontal and vertical dipole correctors as necessary to minimize losses. The horizontal and vertical dynamic injection bump amplitudes, as well as the chicane amplitude will be adjusted. There is a single BCM in the ring, located ¾ of a turn from the injection point (Ring_Diag:BCMD13). This monitor will be "timed-in" once the beam reaches the monitor.

A short pulse is then transported for as many turns in the ring as possible by optimizing the horizontal and vertical corrector settings, the dynamic injection bump amplitudes, and the beam position on the injection foil. Both the loss monitors and the BCM are used to improve the injection efficiency. For this stage of commissioning, the BLM calibration should be known, and the BLM display software must be functional in order to quantify losses on an absolute scale. The ring timing signals are checked to ensure proper synchronization of ring diagnostic timing and RF timing signals with the Linac systems.

The beam pulse-length is increased as necessary to obtain sufficient signals for commissioning the ring BPM system. The losses are minimized, and if necessary, the repetition rate is decreased to minimize activation. The BPMs are then "timed-in" and the orbit measurement software is checked with beam. The turn-by-turn BPM analysis software is checked. The horizontal and vertical dynamic injection bump may be closed empirically by tuning the individual kicker strengths to minimize the bump ripple as observed on a BPM signal.

The closed-orbit is then measured by injecting a single mini-pulse, and averaging the turn-by-turn position recorded at each BPM. The ring-corrector polarities and strengths are checked by measuring the closed-orbit error as a function of corrector setting. The closed-orbit is corrected either by a harmonic method, or by a minimization algorithm which adjusts correctors in the ring accelerator model to minimize the orbit deviation. The fixed chicane closure and the dynamic injection bump closure are checked and corrected in a similar way. A set of three and four-element DC bumps are then loaded and their closure is checked.

After chicane and dynamic bump closure and closed-orbit correction, the injection conditions are re-optimized to maximize the transmission and minimize losses by adjusting the injected beam position and angle on the foil and the bump amplitude. The beam is transported as many turns as possible by optimization of injection conditions and adjustments to correctors if necessary.

The tunes are measured from the turn-by-turn BPM data and compared to design. As the closed-orbit studies proceed, the tune measurement system and the wall-current monitor (WCM) are commissioned.

4.2.5 Ring RF System Commissioning

The goal of this phase of commissioning is to verify the proper operation of the RF system with beam and to establish RF system operating conditions.

Beams of short pulse-length, delivered on a "pulse-on-demand" basis will be used for initial RF system commissioning. The revolution frequency is measured with the wall current monitor. The RF cavity resonant frequencies are set to the revolution frequency. The synchronization of ring RF timing signals with the Linac systems is checked. The cavities are individually powered, and the phase and amplitude loop stability is checked with beam.

RF System commissioning begins by finding the cavity phase setpoints. An unchopped CW beam of a few ring turns is injected. One of the three h=1 cavities is powered, and the longitudinal profile obtained from the WCM is recorded. The other h=1 cavities are powered in turn, and their phases adjusted to match the profile obtained with the first cavity. The h=2 cavity is then "phased-in" in a similar way. Finally, all cavities are powered simultaneously, and the overall ring RF phase is adjusted by observing the WCM response of a chopped-beam. The relative phase jitter of the chopper and ring RF is measured.

The synchrotron tune may be measured by observation of the longitudinal oscillations of a bunch stored for several msec. Alternatively, the modulation of the turn-by-turn orbit of a bunch undergoing synchrotron motion may be used to obtain the synchrotron tune. If necessary, RF phase adjustments will be made to obtain the desired synchrotron tune.

The RF System diagnostics are then commissioned. These include the RF vector sum, which provides the combined RF waveform produced by the RF system.

4.2.6 Ring Optics Measurement and Correction

The objectives of this phase of commissioning are to measure and restore the nominal betatron tunes, measure and correct the linear optics, measure the natural chromaticity, power the sextupoles, measure and correct the chromaticity, and measure the transverse coupling. Finally, the working point is adjusted to correct nearby resonance. This phase of commissioning requires a fully functional BPM system and an operational tune-measurement system. The basic optics measurements are performed with the beam intensity necessary for observation on the BPM system.

The tunes are measured in two ways. In the first, the beam is injected off-axis, and turn-by-turn BPM data is accumulated and Fourier analyzed to provide the tune. In the second, the tune measurement system, consisting of a dedicated kicker measures the tunes. The tune adjustment software is commissioned and the tune controls are calibrated. The tunes are restored to the design operating point.

The linear optics may be measured and corrected in several ways. First, the optics are measured by injecting one mini-pulse off-axis and recording the beam positions on a turn-by-turn basis. At each BPM, the sinusoidal turn-by-turn data is fitted to extract the phase of the oscillation. The difference in oscillation phase from BPM to BPM provides the betatron phase advance. The linear optics are corrected with the aid of an algorithm in which the quadrupole strengths are adjusted in a model of the ring lattice in order to fit the measured phase advances. Alternatively, a measurement of the beta-function may be obtained by measuring the oscillation envelope for the off-axis beam. A third method uses the closed-orbit response matrix to obtain the beta-functions. Finally, the linear optics may be corrected by minimizing the half-integer and integer harmonics observed in the fourier spectrum of a kicked beam.

The dispersion is measured by injecting an off-momentum beam and recording the closed orbit. The sextupoles are turned off and the natural chromaticity is measured by recording the tuneshift for a small change in main dipole field (or alternatively, RF frequency). The sextupoles are powered, and the chromaticity is measured. The sextupole polarities are checked by measuring the tuneshift versus the displacement in each sextupole (provided by a DC bump peaked in the adjacent quadrupole). The chromaticity adjustments are then checked and calibrated and the chromaticities are set slightly negative.

The global coupling is measured by placing the machine tunes on the coupling resonance and measuring the normal-mode tunesplit with the tune measurement system. The global coupling is minimized by empirical skew quadrupole adjustments. The local coupling is determined from the turn-by-turn BPM data by exciting the beam horizontally, and observing the out-of-plane response at each detector. A correction is obtained with the aid of an algorithm in which the available skew quadrupole adjustments are varied in a model to best reproduce the data.

The tunes are moved in the vicinity of the nominal working point to explore nearby resonances. The stopband widths are measured by recording the injection efficiency as measured by the BCMs as a function of the working point. The stopbands are minimized by adjustment of the various correctors to produce the appropriate azimuthal harmonics required to compensate the magnetic field errors.

After the optics measurement and correction is complete, the machine conditions are re-optimized. The injection conditions are retuned, the working point, and the chromaticities are adjusted to minimize losses. The orbit correction is repeated if necessary. The pulsed bump closure is checked again after the optics correction. The horizontal and vertical DC bumps are checked to ensure closure.

4.2.7 Ring Extraction and Extraction Dump Commissioning

The objectives of this phase of commissioning are to extract a beam from the ring, transport the beam to the extraction dump, commission the diagnostics in the RTBT line up to the dump and verify the proper functioning of the dump and bulk shielding.

Proper operation of the extraction kicker is verified initially by kicking the beam at small amplitude to observe the betatron oscillations. The polarity of each extraction kicker module is checked by independently triggering the module and observing the betatron oscillation. The extraction kicker timing is then adjusted with respect to the ring RF. The beam energy is measured and the RTBT energy is adjusted appropriately.

For the initial extraction and transport of a beam into the RTBT, a beam of the minimum practical pulse-length, delivered on a “pulse-on-demand” basis will be used. The progress of the extraction and transport will be tracked with the BLMs located on each quadrupole in the ring and RTBT. Extraction conditions are established by adjusting the kicker amplitudes and extraction septum amplitude while observing losses in the RTBT. A current monitor (RTBT_Diag:BCM02) is available at the entrance to the extraction line. This monitor is “timed-in” as soon as a signal is observed, and used to adjust, along with the BLMs, the extraction conditions. The timing is adjusted while observing the ring and RTBT BCMs and BLMs to ensure complete extraction.

Once extracted, the beam is transported through the RTBT by adjusting vertical and horizontal correctors while observing the BLMs. The remaining two BCMs in the line (RTBT_Diag:BCM11 and EDmp_Diag:BCM02) are “timed-in” and are used to maximize the transport efficiency. Using the loss monitors in the ring and RTBT, the extraction and transport conditions are optimized. The gross shielding performance of the dump is verified from the radiation monitor response in the dump cave at low beam power.

The BPMs are then "timed-in" and the trajectory measurement systems tested with beam. The polarity and strength of the horizontal and vertical correctors are checked with beam and the trajectory is measured and corrected with procedures used in the HEBT commissioning.

The profile measuring devices (RTBT_Diag:WS02 and Edmp_Diag:Harp02) are commissioned and the profile in the dump line is measured and compared with expectations. Fault studies as outlined in SNS-OPM Chapter 6, Section J are performed. These include measurements of the prompt radiation external to the extraction dump and dump line.

Once the dump performance is verified and fault studies completed, it is safe to increase the beam power.

The measured beam profiles in the RTBT are compared to expectations. The matching quadrupoles in the RTBT are adjusted, if necessary, with the aid of an optics model to achieve the desired beam profile at the extraction dump. The optics matching between the HEBT, Ring and RTBT may be checked by injecting a single mini-pulse into the ring, and extracting the beam on successive turns. The extracted beam profile is then measured in the RTBT. A perfect optical match results in an extracted beam profile which is the same regardless of the number of turns that the beam makes in the ring. A matching error manifests itself as different beam profiles depending on the number of ring turns. Such profile measurements may be used to empirically tune the matching conditions.

4.2.8 Injection Painting and Multi-turn Injection

The objective of this phase of commissioning is to establish conditions for multi-turn injection by phase-space painting. The injected beam is characterized, multi-turn injection, accumulation, extraction and transport to the extraction dump of 10^{13} protons/pulse is demonstrated at low repetition rate, and the resulting beam parameters are measured. With an ion source current of 26 mA, accumulation of 62 turns provides 10^{13} protons. During these studies, the beam is extracted and transported to the extraction dump, which sets a limit of 7.5 kW in beam power. At a 0.2 Hz repetition rate, 320 W of beam power is brought to the extraction dump.

First, the injected beam parameters are characterized with a single mini-pulse at low repetition rate, which is delivered to the extraction dump. The injected beam momentum spread is estimated from a measurement of the spread in revolution frequencies obtained from the WCM signal with the RF off. A second estimate is obtained from a measurement of the decoherence time as a function of the (measured) chromaticity. The momentum spread is measured as a function of the ESC amplitude. The energy jitter is measured as a function of the ECC amplitude. The momentum deviation is measured by minimizing the synchrotron tune signal observed over several thousand turns. The ring energy and RF frequency are adjusted as necessary to achieve on-energy injection. Finally, the injected beam emittance is measured.

The injected beam controls are established. Knobs are commissioned which control the injected beam position and angle in x and y at the injection foil. The dynamic bump closure is checked and corrected if necessary.

The correlated dynamic bump profiles are loaded, and multi-turn injection studies begin. The injection efficiency of a single mini-pulse at varying injection amplitudes is measured by adjusting the dynamic bump timings. The entire range of amplitudes from peak dynamic bump to bump-off are measured. The losses are minimized and the injection conditions optimized.

Pulses of successively greater length are injected in a "pulse-on-demand" basis with adjustments made to the closed orbit, ring tunes, chromaticities, momentum spread, etc., as necessary to minimize losses. It will likely be necessary to optimize the primary collimators (as outlined in the following section) in order to minimize losses. As the beam intensity is increased, losses throughout the HEBT, Ring and RTBT are continually optimized. The pulse-length is increased and the machine conditions optimized until more than 10^{13} protons are accumulated, extracted, and transported to the extraction dump.

Once multi-turn injection has been accomplished, the beam parameters are measured. The extracted beam profiles are measured as functions of the dynamic bump time constant. The orbits and tunes are measured during the accumulation cycle. Longitudinal beam profile measurements are obtained as functions of momentum spread and RF conditions. The betatron tune variation along the bunch is measured with a high bandwidth pickup.

4.2.9 Ring Collimation and Beam-in-Gap

The objectives of this phase of commissioning are to explore the ring aperture, establish primary collimator settings for optimum cleaning, commission the beam-in-gap kicker system and establish operating conditions for beam-in-gap cleaning.

The ring aperture will be explored by powering local horizontal and vertical DC bumps and observing the transmission of a low-intensity beam as a function of bump settings. The beam is injected off-axis and the losses are recorded. To explore to larger aperture, the extraction kicker is fired after injection while a bump is at the maximum displacement.

The primary collimator settings are then established. The closed-orbit is corrected with particular attention paid to the collimation region. The losses at the BLMs are measured as functions of the primary collimator settings for a particular set of phase-space painting conditions. As the scrapers are moved in, the losses near the collimators should increase and the losses around the rest of the ring should decrease. As the primary collimators are inserted beyond their optimum position, losses near the collimators become large and the transmission is reduced. Horizontal and vertical orbit bumps in the primary and secondary collimators are explored and optimized. Optimum cleaning conditions are obtained by primary collimator adjustments, orbit manipulation and optimization of injection conditions. The collimator efficiency is estimated from the BLM analysis.

The beam-in-gap kicker system is then commissioned. At low beam intensity, the kicker polarity sequence is established by first exciting the bunched beam. The tune is measured, and the corresponding kicker polarity sequence is loaded. The beam is then resonantly excited by increasing the kicker amplitude and the tune is observed. The kicker amplitude is adjusted until particle loss is observed on the collimators. The beam loss distribution is measured.

Once resonant excitation is demonstrated, the kicker timing is adjusted to excite particles in the beam gap. The beam-in-gap losses are measured as a function of RF voltage and momentum spread. Finally, optimal beam-in-gap conditions are established by empirically adjusting the kicker polarity sequence to obtain optimum cleaning.

4.2.10 Machine Protection and Fault Studies

The objectives of this phase of commissioning are to verify the performance of the Machine Protection System (MPS) and to explore various fault scenarios.

As each line is commissioned, the BLM thresholds are adjusted and the MPS is checked with intentional controlled loss near each location. The Harps are calibrated and their MPS outputs are checked. The MPS response times are measured.

The injection foil loss system is commissioned. The BCM, Harp and BLM in the injection dump line are incorporated into the MPS, and their thresholds for normal operation are established. The performance of the system for detecting foil failure is measured.

Various ring fault scenarios as outlined in SNS-OPM Chapter 6, Section J and the MPS document are investigated. These include loss measurements for injection kicker failures and various extraction kicker failure modes.

4.2.11 Studies Related to High-Intensity and High-Power Operation

If time permits, following the successful accumulation and extraction of 10^{13} protons per pulse, studies related to high-intensity and high-power operation of the ring will be performed. The objective of these studies is to understand the accelerator physics issues which are essential for operation at beam intensities approaching the design intensity. With multi-turn injection commissioned, it will be possible, in principal, to accumulate the large beam intensities necessary for these studies, albeit at low repetition rate (e.g. 10^{14} protons/pulse at 0.2 Hz corresponds to 3.2 kW beam power).

Conditions are established for high-intensity bunches. The pulse length is gradually increased to accumulate greater proton intensities and the beam is injected on a "pulse-on-demand" basis. Multi-turn injection conditions are optimized to minimize losses. The primary collimator settings, beam-in-gap kicker, energy spreader cavity, machine tunes, chromaticities, closed orbit and injection conditions are re-optimized. The extraction conditions and RTBT transport are re-optimized to minimize losses. The beam position on the extraction dump is inferred from the thermocouple array, and the performance of the extraction dump is verified.

Tests of the RF system beam-loading compensation at higher intensity will be studied. First, the dynamic tuning of the RF system will be investigated. For the low-intensity commissioning, the ring-RF resonant frequency is held fixed, but at higher intensities the cavity resonant frequency will ramp through the accumulation cycle to compensate beam-loading while minimizing the RF power required. The tuning angle, phase and amplitude loops are checked with beam over the range of intensities which is practical at the time. A further refinement of the beam loading compensation uses the beam current measured by the WCM in a feedforward approach. A final variant, an adaptive feedforward method, is investigated.

The ring losses are studied with the goal of identifying the loss mechanisms and understanding the importance of the various adjustable parameters. The ring losses are measured as a function of the working point, chromaticity, energy spread, RF conditions and painting scheme. The measurements are performed at various beam intensities.

The beam stability is investigated at the highest intensity possible. The extraction will be delayed in order to observe the growth of unstable modes. Central to these experiments are high bandwidth BPM measurements to identify the frequency and growth rates of the most unstable modes.

Impedance-related measurements are performed. The coherent tune-shifts of the various harmonics are measured as a function of beam intensity. The coherent tune along the length of the bunch is measured with a high-bandwidth BPM system. The head-tail growth rates are measured as a function of the chromatiticies. If unstable modes are observed, measurements of the growth rate as a function of transverse position in the extraction kicker and RF cavities will be performed.
Measurements which bear on the e-p instability are performed. The electron detector system is commissioned and the secondary electron rates, time dependence and beam intensity dependence are measured near the stripping foil, collimators, bellows and extraction kicker ferrite. The correlation of these signals with high bandwidth BPM signals, in the event that an instability is observed, will aid in the identification of the impedance responsible for the instability.

Measurements which bear on space-charge effects are performed. Among the experiments are beam profile measurements as functions of the beam intensity.

Finally, tests of a prototype transverse feedback system, based on the tune-measurement kicker, are performed.

4.2.12 RTBT to Target Commissioning

The objectives of this phase of commissioning are to transport a beam to the target, commission the RTBT/target diagnostics and protection systems, measure and correct the trajectory and transfer line optics, investigate potential fault scenarios, and deliver 10^{13} protons to the target in a single pulse. A secondary objective is to deliver bunches of 10^{13} protons at 60 Hz to establish 100 kW operating conditions throughout the facility.

For the initial RTBT and Target commissioning, a low-intensity “pulse-on-demand” beam will be utilized to minimize activation. The initial conditions are established by measuring the beam energy, adjusting the RTBT energy, and transporting a beam to the extraction dump. The RTBT trajectory is measured and corrected if necessary, and the beam profile in the dump is measured and verified.

The dipole RTBT_MAG:DH13 is powered to deliver beam to the target. The beam is transported down the remainder of the line and the progress is tracked with the BLMs. Adjustments to the horizontal and vertical correctors and final dipole are made to minimize the losses. Five BCMs are available in the RTBT, two before the final dipole, two after, and one in the extraction dump line. These monitors are “timed-in” once beam signals are available, and used to maximize the transport efficiency. The beam is transported to the target and observed on the SEM system.

The Beam Position Monitors (BPMs) in the RTBT are then “timed-in” and the trajectory measurement systems are debugged with beam. As part of the BPM testing, horizontal and vertical correctors are adjusted to displace the beam in the BPMs in order to provide a check of the BPM cabling and calibration. When the BPM system is operational, the RTBT trajectory is measured and corrected. The RTBT corrector polarities and strength are checked with beam by observation of the trajectory amplitude as a function of the corrector strength. The automated transfer-line trajectory correction algorithms and applications software are tested with beam. After correction, transfer efficiency and losses are reoptimized.

The profile measurement devices are commissioned, beginning at the target. The beam profile nearest the target is measured and compared with expectations. Profile measurements from the four-wire-scanner array are use to obtain the emittance and twiss parameters. A complete set of profiles in the RTBT are obtained and compared with expectations. The matching from the Ring to the RTBT is adjusted, if necessary, with the matching quadrupoles. A transfer line optics model in which the measured twiss parameters are taken as input is used to calculate the matching quadrupole strengths required to yield the desired beam profile. The dispersion in the RTBT is measured and corrected, if necessary. After any optics corrections, the trajectory is corrected and the losses are re-optimized.

The target related machine protection systems are then commissioned. The BLM and Harp MPS signals are tested with beam. The target and upstream HARP profiles are measured and verified to fit the optics model. Using the upstream profile measurements and the quadrupole strengths in the beam spreader region, the profile at the target is calculated and compared to that which is measured, in order to verify the MPS protection based on profiles and quadrupole current windows.

Various fault scenarios are then investigated. The beam position on the target is measured for various extraction kicker failure modes. The beam position and losses are measured for various injection kicker failures.

The pulse-length is then increased and injection painting conditions are optimized to deliver 10^{13} protons in a single pulse to the target. Losses in the HEBT, Ring and RTBT are minimized as outlined previously.

Once acceptable low-loss conditions for the accumulation and transport of 10^{13} protons to the target are obtained, the repetition rate is increased in order to deliver 100 kW to the target. The full beam is taken initially to the injection dump by inserting a blank foil. The Linac and HEBT conditions are tuned to minimize losses. The performance of the injection dump at 100 kW is verified by observation of the dump cooling water inlet and outlet temperatures as the beam power is increased.

The repetition rate is reduced, the injection foil inserted, and the repetition rate slowly increased while machine conditions are tuned to minimize the losses. The stripped electron catcher position and heat load are checked. The power is increased to deliver 100 kW to the target. The target monitoring systems are checked and verified.

4.2.13 Operational Measurements

A few measurements relate to the operation and stability of the transfer lines and ring. The stability of the HEBT and RTBT trajectories and the Ring orbit are studied by measuring the orbits before and after a magnet standardization cycle. The beam position on the target is measured before and after magnet standardization. Likewise, the machine tunes and linear optics and chromaticities are measured before and after magnet standardization.

A study is performed to investigate the recovery from the failure of an extraction kicker module. One kicker at a time is shut off, and the beam trajectory and position at the target is observed. Adjacent kickers are adjusted to compensate, and a table is produced which provides the kicker configuration which recovers the beam position in the event of a failure.

4.3 Administrative and Technical Controls and Contingency Plans for HEBT-Ring-RTBT Systems

4.3.1 Technical Controls and Safety Systems

Accelerator specific safety systems that must be in place, tested and certified for operation prior to commencement of commissioning studies for HEBT-Ring-RTBT Systems include the Personnel Protection System (PPS) and the Machine Protection System (MPS)

PPS

The Personnel Protection System radiation protection for HEBT-Ring-RTBT Systems commissioning includes the following:

The equipment will operate in the fully operational PPS mode with equipment installed to secure the Linac and the HEBT-Ring-RTBT. The normal PPS operating modes will be available, i.e.

- Restricted Access (RWP Access, Magnets and RF OFF)
- Controlled Access (Magnets and RF OFF)
- Controlled Access (Magnets Off)
- Controlled Access (Magnets On)
- Power Permit (Magnets and RF On)
- Beam Permit (Full Operation)

During commissioning and operation, high radiation levels will be detected by the Fermilab standard ionization chambers (Chipmunks), which will shut off the Ion Source 65 kV power supply and the RF drive to the RFQ at the Transmitter as well as the Transmitter HV supply. High radiation trips will require evaluation and approval by the Chief Operator prior to the manual reset to restart commissioning .

During HEBT- Ring-RTBT Systems commissioning, a radiation producing beam is only allowed in the “Beam Permit” mode. The detection of an open PPS interlocked door will terminate the “Beam Permit” operating mode, and will shut down two independent critical devices necessary to create the radiation producing beam, i.e.

- The Ion Source (via the 65 kV power supply) and
- The RFQ (via the RF drive to the transmitter and the transmitter high voltage power supply).

In addition, the PPS operating mode will drop down to “Restricted Access”, removing the “Power Permit” and thus turning off both the Magnet and RF Power within the violated PPS area(s). Such PPS area(s) violation will require evaluation by the Chief Operator, and a sweep and reset of the area(s) before commissioning restart.

Activation of the Emergency-Stop pushbutton on the operator panel or the Beam Shutdown Station (BSS) shuts off all critical devices including off the Ion Source 65 kV power supply and the RF drive to the RFQ at the transmitter and the transmitter high voltage power supply. Emergency-Stop or Beam Shutdown Station (BSS) shutdowns require evaluation and approval by the Chief Operator prior to the manual reset for commissioning restart.

The PPS will be re-certified twice per year and when significant modifications are made.

MPS

The Machine Protection System (MPS) runs in three modes.

- If the High QA system is tripped, the Ion Source 65 kV power supply and the RFQ Transmitter HV power supply are shut down.

- If the MPS Latched system is tripped, the Ion Source 65 kV power supply and the RFQ Transmitter HV power supply are disabled.
- If the MPS Auto Reset system is tripped, the LEBT Chopper is directed not to allow beam to exit the LEBT and the RFQ RF drive is inhibited for the duration of the macropulse.

The MPS will be re-certified twice per year and when significant modifications are made.

A full description of the MPS can be found at:
http://www.sns.gov/projectinfo/ics/192/1923/MPS_FDR/

Additional Machine Protection System software/hardware that will be in place for the HEBT-Ring-RTBT commissioning includes:

- Automated run-permit checker.
- Run-permit and Fast-Protect display screens for HEBT, Injection Dump, Ring, RTBT, and extraction dump.
- High QA Injection, Extraction and Target Systems
- All PS, Vacuum, RF, Diagnostic MPS Inputs
- Foil, Injection Kickers, Extraction Kickers, Ring RF, Collimator protection inputs.

Beam Power

During HEBT-Ring-RTBT commissioning, the beam power will be limited to an amount less than that specified for each system in the Commissioning Accelerator Safety Envelope (Appendix A).

Safety

Radiation Safety during HEBT-Ring-RTBT Systems commissioning is ensured by strict compliance with the the relevant policies and procedures of the ORNL Standards Based Management System (SBMS) (http://eshtrain.ct.ornl.gov/SBMS/), specifically:

- ORNL Radiological Protection Management System (RPMS) (http://eshtrain.ct.ornl.gov/sbms/SBMSearch/Msd/RPS/RPS_MSD.cfm)
- ORNL Radiological Control Policy and Radiological Protection Procedures (http://eshtrain.ct.ornl.gov/sbms/SBMSearch/ORNLProc/ORNL-RP-110.htm)
- ORNL ALARA Program (http://eshtrain.ct.ornl.gov/sbms/SBMSearch/ORNLProc/ORNL-RP-138.htm)

which are in compliance with 10CFR835 (Occupational Radiation Protection).

Lockout-Tagout safety during HEBT-Ring-RTBT Systems commissioning is ensured by compliance with the ORNL-SNS LOTO policy, which is OSHA compliant. This policy can be found at:
http://www.internal.sns.gov/esh/standards/lockout_tagout.pdf

Fire Safety is ensured during HEBT-Ring-RTBT Systems commissioning. A fire alarm system will be in place and operational in the Front End building which is compliant with NFPA Standard 72. A sprinkler system will be in place and operational in the HEBT-Ring-RTBT buildings that is compliant with NFPA Standard 13. Where construction activities prevent a required fire safety feature from being operational, compensatory measures in general accordance with NFPA 241, Standard for Safeguarding Construction, Alteration, and Demolition Operations, will be identified and implemented.

4.3.2 Administrative Controls

Administrative controls are described in **Appendix B, Personnel, Training, Certification, Procedures and Records.**

4.4 The Portion of the Overall Facility ARR Needed for HEBT-Ring-RTBT Systems

Portions of the overall ARR that are needed for HEBT-Ring-RTBT Systems commissioning include an approved Commissioning Accelerator Safety Envelope (CASE) and an approved Safety Assessment Document (SAD) for Linac Systems.

For HEBT-Ring-RTBT Systems the framework for the CASE is listed in Appendix A of this document.

The SNS Preliminary Safety Assessment Document is available at:
http://www-internal.sns.gov/dcrm/docs/102/102030103-ES0003-R00.pdf

4.5 The schedule for HEBT-Ring-RTBT Systems Commissioning

HEBT-Ring Systems commissioning is listed in the current Integrated Project Schedule (see Appendix D) as follows: HEBT-Ring commissioning is scheduled to take place from December 22, 2004 through June 17, 2005. This commissioning will include the first half of the RTBT up to the Extraction Dump, but not including DH-13, which will not be installed for the safety of personnel in the Target building. Although commissioning is not scheduled to take place from June 17, 2005 through October 31, if there is no reason to stop commissioning studies, the studies can continue.

From November 1, 2005 to November 31, 2005, DH13 will be installed and the movable shielding that protected the Target building personnel will be removed. RTBT to Target commissioning is scheduled to take place from December 1, 2005 through December 30, 2005

Appendix A

Commissioning Accelerator Safety Envelopes

1. Introduction

The Commissioning Accelerator Safety Envelope must define the set of physical and administrative bounding conditions for safe operations based on the safety analysis documented in the SAD. It should include:

a) Limits on operating variables (such as currents, voltages, energy potentials, beam power, pressures, temperatures, flows) needed to preserve physical barriers or to otherwise prevent excessive short-term or long-term risk to persons;

b) Immediate mitigative actions to be taken if the accelerator safety envelope is exceeded;

c) The adopted radiation shielding criteria for different operational modes and resulting radiological conditions;

d) Requirements related to the calibration, testing, maintenance or inspection of safety-related systems to ensure their continued reliability;

e) Monitoring, release control of ventilation effluent and mitigation measures for the protection of the environment; and,

f) Administrative controls such as minimum staffing levels, qualification, and training for operation, minimum operable equipment, critical records to be retained, and currency of procedures.

2. Front End Systems

a) Beam Power Limits

The Ion Source and RFQ are designed to accelerate the beam to fixed voltages, 65 kV and 2.5 MeV respectively. They will only be operated at these voltages. Similarly, the peak operating current of the Front End will typically not exceed 48 mA. It may be operated at lower peak currents. We will place limits on the operating average currents, and consequently the beam power needed to preserve physical equipment. The highest anticipated operation is a "full power" measurement of the chopped beam to the Front End Dump. The Front End Dump is limited to 8.5kW. Therefore the Front End Commissioning Power Envelope is 8.5kW.

b) b. Mitigative Actions to be Taken if the Commissioning Safety Envelope is Exceeded

Upon determination that approved ASE limitations have been exceeded, the Operations staff will terminate activities impacted by or causing the violations at the earliest time it is safe to do so. The Operations Manager will be notified of the violation as soon as possible. The Accelerator Systems Division Director, the ES&H Manager and the SNS Project Director will be notified as soon as possible. The local DOE authority will then be notified by a designated member of the SNS staff. An investigation into the cause and consequences of the activity causing the ASE limits to be violated will begin. A report outlining the cause of the incident and describing actions taken to mitigate future occurrences will be completed. DOE will be notified before activities associated with the ASE violation are resumed. Upon determination that an approved ASE limitation has been exceeded the Operations staff will:

- Stop beam related activities
- Notify the SNS management of the violation
- Evaluate the cause of the violation
- Identify corrective action
- Implement corrective action
- Verify that the corrective action is appropriate and effective
- Request permission to restart from SNS Management

c) Radiation Shielding

The adopted shielding criteria for all operational modes and resulting radiological conditions is the same. There is no anticipated radiation from the Ion Source, RFQ or MEBT anticipated in excess of the 10CFR835 limits, consequently, no external shielding is required. This will be verified during the phase of commissioning carried out at Lawrence Berkeley National Laboratory (LBNL). Once those results have been obtained the shielding plan can be modified as needed.

d) Safety Systems

Critical accelerator specific safety systems, that must be in place, tested and certified for operation before commencement of commissioning studies for Front End Systems include the Personnel Protection System (PPS) and the Machine Protection System (MPS).

PPS

The Personnel Protection System radiation protection for Front End Systems commissioning includes the following:

The equipment will operate standalone in the PPS Phase 0 mode.

Operating modes provided for PPS Phase 0 are:

- Off
- 65 kV power supply on
- RF Plasma power supply on
- Full operation (Ion Source, RF and the RFQ)

During commissioning and operation, high radiation levels will be detected by the Fermilab standard ionization chambers (Chipmunks), which will shut off the Ion Source 65 kV power supply and the RF drive to the RFQ at the Transmitter as well as the Transmitter HV supply. High radiation trips will require evaluation and approval by the Chief Operator prior to the manual reset to restart commissioning.

Activation of the Emergency-Stop pushbutton on the operator shuts off all critical devices including the Ion Source 65 kV power supply, the RF drive to the RFQ at the transmitter and the transmitter high voltage power supply. Emergency-Stop will require evaluation and approval by the Chief Operator prior to the manual reset to restart commissioning.

The PPS will be re-certified twice per year and when significant modifications are made.

MPS

The Machine Protection System (MPS) runs in three modes.

- If the High QA system is tripped, the Ion Source 65 kV power supply and the RFQ Transmitter HV power supply are shut down.
- If the MPS Latched system is tripped, the Ion Source 65 kV power supply and the RFQ Transmitter HV power supply are disabled.
- If the MPS Auto Reset system is tripped, the LEBT Chopper is directed not to allow beam to exit the LEBT and the RFQ RF drive is inhibited for the duration of the macropulse.

The MPS will be re-certified twice per year and when significant modifications are made.
A full description of the MPS can be found at:

http://www.sns.gov/projectinfo/ics/192/1923/MPS_FDR/

Machine Protection software/hardware that will be in place for the Front End commissioning includes:

- EPICS device support for the MPS PMC module.
- Manual mode-mask definitions.
- MPS Hardware modules
- Fast Protect Latched shutdown hardware.
- Fast Protect – Auto Reset shutdown hardware
- Differential current monitor
- Integrated current monitor
- Run-permit and Fast-Protect display screens for Source, LEBT, RFQ, and MEBT.
- Beam Power Select Switch
- PPS Inputs to HQA-MPS

Safety Regulations

Radiation Safety during Front End System commissioning is ensured by strict compliance with the relevant policies and procedures of the ORNL Standards Based Management System (SBMS) (http://eshtrain.ct.ornl.gov/SBMS/), specifically:

- ORNL Radiological Protection Management System (RPMS) (http://eshtrain.ct.ornl.gov/sbms/SBMSearch/Msd/RPS/RPS_MSD.cfm)
- ORNL Radiological Control Policy and Radiological Protection Procedures (http://eshtrain.ct.ornl.gov/sbms/SBMSearch/ORNLProc/ORNL-RP-110.htm)
- ORNL ALARA Program (http://eshtrain.ct.ornl.gov/sbms/SBMSearch/ORNLProc/ORNL-RP-138.htm)

which are in compliance with 10CFR835 (Occupational Radiation Protection).

Lockout-Tagout (LOTO) safety during Front End System commissioning is ensured by compliance with the ORNL-SNS LOTO policy, which is OSHA compliant. This policy can be found at:
http://www.internal.sns.gov/esh/standards/lockout_tagout.pdf

Fire Safety is ensured during Front End Systems commissioning. A fire alarm system will be in place and operational in the Front End building which is compliant with NFPA Standard 72. A sprinkler system is planned to be operational in the Front End building that is compliant with NFPA Standard 13. Where construction activities prevent a required fire safety feature from being operational, compensatory measures in general accordance with NFPA 241, Standard for Safeguarding Construction, Alteration, and Demolition Operations, will be identified and implemented.

e) Environmental Protection

Prior to Front End commissioning, a determination will be made on whether the monitoring of the release of ventilation effluent will be necessary. This determination will be based on the dust loading in the area and the radioactive source term. A dispersion model using input from these factors will determine the necessity of monitoring. As the Front End has been designed to operate without shielding, we anticipate that the source term should be close to zero and monitoring will not be necessary.

f) Administrative Controls

Administrative controls are described in **Appendix B, Personnel, Training, Certification, Procedures and Records.**

3. Linac Systems

a) Beam Current and Power Limits

The warm Linac systems are designed to accelerate the beam to fixed voltages. We will place limits on the operating average currents, and consequently beam power needed to preserve physical barriers. Superconducting Linac (SCL) systems do not accelerate the beam to fixed voltages. For these systems we will use a calculated, expected beam voltage maximum. During SCL commissioning we will transport the beam to the Linac beam dump, which is rated for an average beam power of 7.5 kW. We will not exceed the 7.5 kW limit of the Linac dump for a time averaging period of one (1) hour. This will be accomplished by limiting the average current to the Linac dump

DTL Tank 1 will be commissioned at low power to preserve and protect equipment during those periods in which the beam is being steered, focused or when intercepting monitors are being used. Following these studies, we intend to operate DTL Tank 1 to a high power level consistent with the maximum operating power rating of the Diagnostic plate beam dump (16 kW). A beam power of 17.1 kW corresponds to 7.5 MeV at 38 mA at a 6% duty cycle. Therefore the maximum beam power of the DTL Tank 1 CASE is 26kW.

DTL Tanks 2-6 will be commissioned using the internal diagnostics in the DTL Tanks. The diagnostics include wire scanners and Faraday cups that will be damaged if a high power beam is present during commissioning. A beam power of 165 W corresponds to 87 MeV at 38 mA for 50μs at 1Hz. The maximum of the CASE for DTL Tank 2-6 commissioning is 250 W.

CCL Modules 1-4 will be commissioned using the internal diagnostics in the CCL Modules and an internal Faraday cup following CCL Module 4. These diagnostics include wire scanners and Faraday cups which will be damaged if full power beam is present during commissioning. A beam power of 240 W corresponds to 186 MeV at 38 mA for 34 μs at 1Hz. The maximum of the CASE for CCL commissioning is 360 W.

The SCL will be commissioned into the Linac Dump. The maximum power rating of the Linac Dump is 7.5 kW. Therefore the maximum of the CASE for the SCL commissioning is 7.5 kW averaged over one hour.

b) Mitigative Actions to be Taken if the Commissioning Safety Envelope is Exceeded

Upon determination that approved ASE limitations have been exceeded, the Operations staff will terminate activities impacted by or causing the violations at the earliest time it is safe to do so. The Operations Manager will be notified of the violation as soon as possible. The Accelerator Systems Division Director, the ES&H Manager and the SNS Project Director will be notified as soon as possible. The local DOE authority will then be notified by a designated member of the SNS staff. An investigation into the cause and consequences of the activity causing the ASE limits to be violated will begin. A report outlining the cause of the incident and describing actions taken to mitigate future occurrences will be completed. DOE will be notified before activities associated with the ASE violation are resumed. Upon determination that an approved ASE limitation has been exceeded the Operations staff will:

- Stop beam related activities
- Notify the SNS management of the violation
- Evaluate the cause of the violation
- Identify corrective action
- Implement corrective action
- Verify that the corrective action is appropriate and effective
- Request permission to restart from SNS Management

c) Radiation Shielding

The adopted shielding criteria for DTL commissioning modes and resulting radiological conditions will take place at different times, so they are easily separated into two periods. In the first period, DTL Tank 1 will be commissioned. DTL Tank 1, which accelerates the beam to 7.5 MeV, will be operated with the Phase 0 PPS in “stand-alone” mode as was the case with the Front End. Sufficient shielding will be in place with sufficient radiological monitoring so that the DTL Tank 1 can be run into the LANL Diagnostic Plate beam dump at the full 6% duty cycle at a peak current of 38 mA, resulting in a beam power of 17.1 kW. The DTL Tank 1 will be commissioned with a variation of the PPS Phase 0 design that was used in the Front End commissioning. DTL Tank 1 is expected to produce significant dark current X-ray radiation during conditioning and commissioning. Additionally, the 7.5 MeV beam which is directed to the Diagnostic Plate beam dump, as well as any beam scraped off and not reaching the full energy, will produce significant neutron radiation. DTL Tank1, the Diagnostic Plate and the Diagnostic Plate beam dump will reside in a shielded hut with shielding sufficiently thick so that installation work can proceed in the Linac while low intensity beam commissioning activities are ongoing. This version of the PPS will include a minimum of five Chipmunk radiation detectors outside the DTL shielding hut. The hut will have an interior search station and stack light status indicator. A search zone door will be used to secure the hut. All interlocks will be applied to the 65 kV In Source high voltage supply as well as the RF for the RFQ. The RFQ RF interlock also controls the high voltage supply for the RFQ and DTL Tanks 1 and 2.

For DTL Tanks 2-6 commissioning, the shielding hut around DTL Tank 1 will be disassembled and a shielding wall will be fabricated downstream of the CCL. During this mode the beam will be dumped on the internal diagnostic Faraday cups in the DTL tanks.

For administrative purposes, beginning with SCL commissioning, the shielding requirements for commissioning activities are identical with those for full power operation. Although allowed commissioning power levels are significantly less than operating power levels, we intend to require full shielding. These requirements are listed in the SNS Shielding Policy, which is contained in the SNS PSAD Chapter 4.2. Passive shielding is inadequate for full power operation. An active system comprised of Chipmunks and the PPS High Radiation Detection shutdown system is required to be operational during commissioning activities. This system is described in Section d) PPS.

d) Safety Systems

Critical accelerator specific safety systems, which must be in place, tested and certified for operation prior to commencement of commissioning studies for Linac Systems include the Personnel Protection System (PPS) and the Machine Protection System (MPS).

PPS

The PPS will operate in Phase 1 for DTL commissioning. In Phase 1 PPS Phase equipment will be installed to secure the warm Linac only. The normal PPS operating modes will be available, i.e.

- Restricted Access (RWP Access, Magnets and RF OFF)
- Controlled Access (Magnets and RF OFF)
- Controlled Access (Magnets Off)
- Controlled Access (Magnets On)
- Power Permit (Magnets and RF On)
- Beam Permit (Full Operation)

During commissioning and operation, high radiation levels will be detected by the Fermilab standard ionization chambers (Chipmunks), which will shut off the Ion Source 65 kV power supply and the RF drive to the RFQ at the Transmitter as well as the Transmitter HV supply. High radiation trips will require evaluation and approval by the Chief Operator prior to the manual reset to restart commissioning.

During Linac Systems commissioning, a radiation producing beam is only allowed in the "Beam Permit" mode. The detection of an open PPS interlocked door will terminate the "Beam Permit" operating mode, and will shut down two independent critical devices necessary to create the radiation producing beam, i.e.

- The Ion Source (via the 65 kV power supply) and
- The RFQ (via the RF drive to the transmitter and the transmitter high voltage power supply).

In addition, the PPS operating mode will drop down to "Restricted Access", removing the "Power Permit" and thus turning off both the Magnet and RF Power within the violated PPS area(s). Such PPS area(s) violation will require evaluation by the Chief Operator, and a sweep and reset of the area(s) before commissioning restart.

Activation of the Emergency-Stop pushbutton on the operator panel or the Beam Shutdown Station (BSS) shuts off all critical devices including off the Ion Source 65 kV power supply and the RF drive to the RFQ at the transmitter and the transmitter high voltage power supply. Emergency-Stop or Beam Shutdown Station (BSS) shutdowns will require a Chief Operator evaluation and approval prior to the manual to restart commissioning.

During CCL commissioning, the PPS Phase 1 will be extended to the end of the Linac. Appropriate shielding will already be in place at the downstream end of the CCL to protect SCL components immediately downstream and personnel in the HEBT.

During SCL commissioning, the PPS will be fully operational. The Linac and the HEBT must be secured. The beam will be directed into the Linac beam dump. The same operating modes as the Phase 1 implementation will be available during SCL commissioning.

The PPS will be re-certified twice per year and when significant modifications are made.

MPS

The Machine Protection System (MPS) runs in three modes

- If the High QA system is tripped, the Ion Source 65 kV power supply and the RFQ Transmitter HV power supply are shut down.

- If the MPS Latched system is tripped, the Ion Source 65 kV power supply and the RFQ Transmitter HV power supply are disabled.
- If the MPS Auto Reset system is tripped, the LEBT Chopper is directed not to allow beam to exit the LEBT and the RFQ RF drive is inhibited for the duration of the macropulse.

The MPS will be re-certified twice per year and when significant modifications are made.
A full description of the MPS can be found at:
http://www.sns.gov/projectinfo/ics/192/1923/MPS_FDR/

Additional Machine Protection software/hardware that should be in place for the Linac commissioning includes:
- Automatic file creation from Oracle Database.
- Configuration verifier.
- High QA Linac Dump Protection
- 2 MHz, RFQ RF Vetoing circuits
- All PS, Vacuum, RF, Beam Loss Monitors, Differential current loss monitors, Diagnostic MPS Inputs
- Run-permit and Fast-Protect display screens for DTL, CCL, SRF, and Linac Dump.

Safety Regulations

Radiation Safety during Linac System commissioning is ensured by strict compliance with the relevant policies and procedures of the ORNL Standards Based Management System (SBMS) (http://eshtrain.ct.ornl.gov/SBMS/), specifically:
- ORNL Radiological Protection Management System (RPMS) (http://eshtrain.ct.ornl.gov/sbms/SBMSearch/Msd/RPS/RPS_MSD.cfm)
- ORNL Radiological Control Policy and Radiological Protection Procedures (http://eshtrain.ct.ornl.gov/sbms/SBMSearch/ORNLProc/ORNL-RP-110.htm)
- ORNL ALARA Program (http://eshtrain.ct.ornl.gov/sbms/SBMSearch/ORNLProc/ORNL-RP-138.htm)

which are in compliance with 10CFR835 (Occupational Radiation Protection).

Lockout-Tagout safety during Linac System commissioning is ensured by compliance with the ORNL-SNS LOTO policy, which is OSHA compliant. This policy can be found at:
http://www.internal.sns.gov/esh/standards/lockout_tagout.pdf

Fire Safety is ensured during Linac Systems commissioning. A fire alarm system will be in place and operational in the Linac building which is compliant with NFPA Standard 72. A sprinkler system is planned to be operational in the Linac and Klystron Buildings building that is compliant with NFPA Standard 13. Where construction activities prevent a required fire safety feature from being operational, compensatory measures in general accordance with NFPA 241, Standard for Safeguarding Construction, Alteration, and Demolition Operations, will be identified and implemented.

e) Environmental Protection

Prior to Linac commissioning, a determination will be made on whether the monitoring of the release of ventilation effluent will be necessary. This determination will be based on the dust loading in the area and the radioactive source term. A dispersion model using input from these factors will determine the necessity of monitoring. The Linac commissioning envelope requires limited power operation except during a relatively short DTL Tank 1 run. We anticipate that the source term should be small and monitoring will not be necessary.

f) Administrative Controls

Administrative controls are described in **Appendix B, Personnel, Training, Certification, Procedures and Records.**

4. HEBT - Ring - RTBT Systems

a) Beam Power Limits

The HEBT – Ring – RTBT systems designed to operate within a narrow band of beam voltages, so we will place limits on the operating currents, and consequently the beam power needed to preserve physical barriers;

HEBT commissioning will take place with the beam directed into the Injection Beam Dump. The Injection Beam Dump is rated for 200kW. Therefore the maximum power level of the HEBT CASE is 200kW, averaged over one hour.

Ring commissioning, which includes the RTBT up to the Extraction Dump, will take place with the beam dumped in internal collimators in the ring or the extraction beam dump. Although the ring collimators are designed to absorb beam power of 20 kW, for reasons related to the ALARA principal, we will not operate the Ring commissioning program at these power levels. The power limit of the Extraction Dump is 7.5 kW, the same as the Linac Dump. The Maximum average power level of the Ring CASE is 7.5 kW averaged over one hour.

The RTBT from the Extraction Dump (DH13) to the Target will be commissioned at power levels with constraints on the average power per shift. The Target is designed for 2MW operation, which is well beyond the scope of the commissioning program. During the commissioning program we have committed to maintain radionuclide levels in the target to those of a Radiological Facility, below the threshold of a Category 3 Nuclear Facility. Calculations and measurements are ongoing to establish the power limits for this activity.

The beam power will typically be limited to 100 kW on Target. The Maximum average power level of the Target CASE is 150 kW averaged over one hour.

b) Mitigative Actions to be Taken if the Commissioning Safety Envelope is Exceeded

Upon determination that approved ASE limitations have been exceeded, the Operations staff will terminate activities impacted by or causing the violations at the earliest time it is safe to do so.

The Operations Manager will be notified of the violation as soon as possible. The Accelerator Systems Division Director, the ES&H Manager and the SNS Project Director will be notified as soon as possible. The local DOE authority will then be notified by a designated member of the SNS staff. An investigation into the cause and consequences of the activity causing the ASE limits to be violated will begin. A report outlining the cause of the incident and describing actions taken to mitigate future occurrences will be completed. DOE will be notified before activities associated with the ASE violation are resumed. Upon determination that an approved ASE limitation has been exceeded the Operations staff will:

- Stop beam related activities
- Notify the SNS management of the violation
- Evaluate the cause of the violation
- Identify corrective action
- Implement corrective action
- Verify that the corrective action is appropriate and effective
- Request permission to restart from SNS Management

c) Radiation Shielding

For administrative purposes, during HEBT-Ring-RTBT commissioning, the shielding requirements for commissioning activities are identical with those for full power operation. Although allowed commissioning power levels are significantly less than operating power levels, we intend to require full shielding. These requirements are listed in the SNS Shielding Policy, which is contained in the SNS PSAD Chapter 4.2. Passive shielding is inadequate for full power operation. An active system comprised of Chipmunks and the PPS High Radiation Detection shutdown system is required to be operational during commissioning activities. This system is described in Section d) PPS.

d) Safety Systems

Critical accelerator specific safety systems, which must be in place, tested and certified for operation prior to commencement of commissioning studies for the HEBT-Ring-RTBT Systems commissioning include the Personnel Protection System (PPS) the Machine Protection System (MPS), and the Target Protection System (TPS).

<u>PPS</u>

For HEBT-Ring-RTBT operation, passive shielding is insufficient to assure that the 10CFR835 limits are not exceeded in non-beam enclosures. A fully functional PPS will be operational during commissioning to assure compliance. The normal PPS operating modes will be available, i.e.

- Restricted Access (RWP Access, Magnets and RF OFF)
- Controlled Access (Magnets and RF OFF)
- Controlled Access (Magnets Off)
- Controlled Access (Magnets On)
- Power Permit (Magnets and RF On)

- Beam Permit (Full Operation)

During commissioning and operation, high radiation levels will be detected by the Fermilab standard ionization chambers (Chipmunks), which will shut off the Ion Source 65 kV power supply and the RF drive to the RFQ at the Transmitter as well as the Transmitter HV supply. High radiation trips will require evaluation and approval by the Chief Operator prior to the manual reset to restart commissioning.

During HEBT-Ring-RTBT Systems commissioning, a radiation producing beam is only allowed in the "Beam Permit" mode. The detection of an open PPS interlocked door will terminate the "Beam Permit" operating mode, and will shut down two independent critical devices necessary to create the radiation producing beam, i.e.

- The Ion Source (via the 65 kV power supply) and
- The RFQ (via the RF drive to the transmitter and the transmitter high voltage power supply).

In addition, the PPS operating mode will drop down to "Restricted Access", removing the "Power Permit" and thus turning off both the Magnet and RF Power within the violated PPS area(s). Such PPS area(s) violation will require evaluation by the Chief Operator, and a sweep and reset of the area(s) before commissioning restart.

Activation of the Emergency-Stop pushbutton on the operator panel or the Beam Shutdown Station (BSS) shuts off all critical devices including off the Ion Source 65 kV power supply and the RF drive to the RFQ at the transmitter and the transmitter high voltage power supply. Emergency-Stop or Beam Shutdown Station (BSS) shutdowns will require a Chief Operator evaluation and approval prior to the manual to restart commissioning.

The PPS will be re-certified twice per year and when significant modifications are made.

MPS

The Machine Protection System (MPS) runs in three modes

- If the High QA system is tripped, the Ion Source 65 kV power supply and the RFQ Transmitter HV power supply are shut down.
- If the MPS Latched system is tripped, the Ion Source 65 kV power supply and the RFQ Transmitter HV power supply are disabled.
- If the MPS Auto Reset system is tripped, the LEBT Chopper is directed not to allow beam to exit the LEBT and the RFQ RF drive is inhibited for the duration of the macropulse.

The MPS will be re-certified twice per year and when significant modifications are made.

A full description of the MPS can be found at:
http://www.sns.gov/projectinfo/ics/192/1923/MPS_FDR/

Additional Machine Protection System software/hardware that will be in place for the HEBT-Ring-RTBT commissioning includes:

- Automated run-permit checker.

- Run-permit and Fast-Protect display screens for HEBT, Injection Dump, Ring, RTBT, and extraction dump.
- High QA Injection, Extraction and Target Systems
- All PS, Vacuum, RF, Diagnostic MPS Inputs
- Foil, Injection Kickers, Extraction Kickers, Ring RF, Collimator protection inputs.

TPS

Note that the RTBT will be commissioned in two phases:

1. The first half of the RTBT up to the Extraction Dump, but not including DH-13. DH-13 will not be installed for the safety of personnel in the Target building.
2. The second half of the RTBT to the Target, after DH-13 is installed.

For the second phase of the RTBT commissioning, the Target Protection System (TPS) must also be in place.

A full description of the TPS can be found in DESIGN CRITERIA DOCUMENT WBS 1.6.8 & WBS 1.9.6 SNS TARGET CONTROLS, SNS-106080000-DC0001-R00.

Safety Regulations

Radiation Safety during HEBT-Ring-RTBT System commissioning is ensured by strict compliance with the relevant policies and procedures of the ORNL Standards Based Management System (SBMS) (http://eshtrain.ct.ornl.gov/SBMS/), specifically:

- ORNL Radiological Protection Management System (RPMS) (http://eshtrain.ct.ornl.gov/sbms/SBMSearch/Msd/RPS/RPS_MSD.cfm)
- ORNL Radiological Control Policy and Radiological Protection Procedures (http://eshtrain.ct.ornl.gov/sbms/SBMSearch/ORNLProc/ORNL-RP-110.htm)
- ORNL ALARA Program (http://eshtrain.ct.ornl.gov/sbms/SBMSearch/ORNLProc/ORNL-RP-138.htm)

which are in compliance with 10CFR835 (Occupational Radiation Protection).

Lockout-Tagout safety during HEBT-Ring-RTBT System commissioning is ensured by compliance with the ORNL-SNS LOTO policy, which is OSHA compliant. This policy can be found at:
http://www.internal.sns.gov/esh/standards/lockout_tagout.pdf

Fire Safety is ensured during HEBT-Ring-RTBT Systems commissioning. A fire alarm system will be in place and operational in the Linac building which is compliant with NFPA Standard 72. A sprinkler system is planned to be operational in the Ring building that is compliant with NFPA Standard 13. Where construction activities prevent a required fire safety feature from being operational, compensatory measures in general accordance with NFPA 241, Standard for Safeguarding Construction, Alteration, and Demolition Operations, will be identified and implemented.

e) Environmental Protection

Prior to HEBT-Ring-RTBT commissioning, a determination will be made on whether the monitoring of the release of ventilation effluent will be necessary. This determination will be based on the dust loading in the area and the radioactive source term. A dispersion model using input from these factors will determine the necessity of monitoring. The HEBT-Ring-RTBT commissioning envelope requires limited power operation, so we anticipate that the source term should be small and monitoring will not be necessary.

f) Administrative Controls

Administrative controls are described in **Appendix B, Personnel, Training, Certification, Procedures and Records.**

5. Summary of Beam Power Limits

System	Typical Energy	Typical beam currents	Typical beam power	Maximum (CASE)
FES (into Front End dump)	2.5 MeV	38 mA, 1 ms at 60 Hz	5.7 kW	8.5 kW
FES DTL Tank 1	7.5 MeV	38 mA, 1 ms at 60 Hz	17 kW	26 kW
DTL Tanks 2-6	87 MeV	38 mA, 50 μs at 1Hz	165 W	250 W
CCL Modules 1-4	186 MeV	38 mA, 34 μs at 1Hz	240 W	360 W
SCL (into Linac dump)	1 GeV	(various)	5 kW	7.5 kW, 1 hr avg.
HEBT (into Injection dump)	1 GeV	(various)	133 kW	200 kW, 1 hr avg
Ring (into Extraction dump)	1 GeV	(various)	5 kW	7.5 kW, 1 hr avg.
Target	1 GeV	(various)	100 kW	150 kW, 1 hr avg

Appendix B

Personnel, Training, Certification, Procedures and Records

1. Current Procedures

Only current, approved operating procedures are to be used in the Linac commissioning program. A copy of the current, approved Operations Procedures Manual can be found at:
http://www-internal.sns.gov/operations/SNS-OPM_Folder_Tree/TOC.html

2. Personnel, Staffing, Training and Certification

Operation of Linac Systems during commissioning will proceed with the chain of command and the personnel specified in the SNS Operations Procedures Manual, SNS-OPM Chapter 6, Section A-2.

It is the responsibility of the Operations Coordinator, as Group Leader of the CCR, to direct and supervise the Chief Operators - providing guidance, reviewing and proposing procedures, and resolving any conflicts in operational judgment among the Chief Operators - following the directives and approved procedures by the Operations Manager.

It is the responsibility of the Operations Manager to review and approve all operational procedures and work planning, and to direct operational efforts for quality assurance, reliability and safety.

It is the responsibility of the on-shift operating crew to safely operate the accelerator through adherence to written procedures and sound operating practices. The authority for accelerator operations is vested in the on-duty Chief Operator (CO) and transferred only through formal turnover to a qualified Chief Operator. If a special test, or abnormal condition arises, accelerator personnel shall be aware that the responsibility and authority to determine corresponding operating conditions, system alignments, or equipment manipulations rests fully with the on-duty Chief Operator. The CO shall not permit any individual to bypass or overrule their operational judgment. If this happens, the CO shall bring the matter to the attention of higher line authority for operations.

A minimum of three persons will be present during commissioning. Of these there will be one Chief Operator (CO), at least one accelerator operator (AO) and a Health Physics representative (HP).

Chief Operators and Operators will be trained and certified in accordance with the SNS Operations Procedures Manual Chapter 4, Training and Certification.

3. Critical Records

Critical records will be maintained and kept current in accordance with

- DOE O 200.1 (Information Management Program),
- Code of Federal Regulations, Title 36 (Parks, Forests, and Public Property), Chapter XII (National Archives and Records Administration), Subchapter B (Records Management), and
- US Code, Title 44 (Public Printing and Documents), Chapter 31 (Records Management by Federal Agencies).

These include:

- Training and Certification
- Radiation Dose
- PPS/MPS Design, Calibration, Maintenance and Test
- Fire protection evaluation
- Operations and Health Physics Logbooks, see SNS-OPM Chapter 1, Section B-1

Appendix C

Commissioning Program Plan Summary Forms

The following is a listing of Commissioning Program Plan experimental summary forms. The actual forms are provided in a separate document.

Front End Systems

	Front End Commissioning Plan			
		Priority	**ORNL/SNS**	**Duration**
Task			**Contact**	
1	Ion source is ready	0	M.Stockli	
	Short unchopped pulse 20mA, 10µs, 1Hz or manual, D-plate			
1.1	**RFQ recommissioning**			
1.1.1	Beam transport to BCM1	1	A.Aleksandrov	
1.1.2	RFQ transmission vs. preinjector voltage	1	A.Aleksandrov	
1.1.3	Input match from LEBT to RFQ	1	A.Aleksandrov	
1.1.4	LEBT steering	1	A.Aleksandrov	
1.1.5	LEBT chopper effectivness	1	A.Aleksandrov	
1.1.6	Chop symmetry at low chop voltage	2	A.Aleksandrov	
1.1.7	RFQ transmission vs. exitation	1	A.Aleksandrov	
1.2	**Beam transport through MEBT**			
1.2.1	Beam transport to BPM2	1	A.Aleksandrov	
1.2.2	Phase set of rebuncher 1	1	A.Aleksandrov	
1.2.3	Beam transport to BPM3	1	A.Aleksandrov	
1.2.4	Correction of voltage/phase set of rebuncher 1	1	A.Aleksandrov	
1.2.5	Q1-Q4 quad setting correction	2	A.Aleksandrov	
1.2.6	Phase set of rebuncher 2	1	A.Aleksandrov	
1.2.7	Beam transport to BPM4	1	A.Aleksandrov	
1.2.8	Correction of voltage/phase set of rebuncher 2	1	A.Aleksandrov	
1.2.9	Beam transport to BPM5	1	A.Aleksandrov	
1.2.10	Phase set of rebuncher 3	1	A.Aleksandrov	
1.2.11	Q5-Q10 quad setting correction	2	A.Aleksandrov	
1.2.12	Transmission measurement	2	A.Aleksandrov	
1.2.13	Beam transport to BPM6	1	A.Aleksandrov	
1.2.14	Phase set of rebuncher 4	1	A.Aleksandrov	
1.2.15	Beam transport to the beam dump	1	A.Aleksandrov	
1.3	**MEBT tuning and beam characterization**			
1.3.1	Q1-Q4 quad setting correction	1	A.Aleksandrov	
1.3.2	Q5-Q10 quad setting correction	1	A.Aleksandrov	
1.3.3	Q11-Q14 quad setting correction	1	A.Aleksandrov	
1.3.4	Global orbit correction algorithm check	2	A.Aleksandrov	
1.3.5	Global Q1-Q10 correction algorithm check	2	A.Aleksandrov	

1.3.6	Amplitude/phase scan for rebunchers 1-3	3	A.Aleksandrov	
1.3.7	TOF energy measurements	2	A.Aleksandrov	
1.3.8	BCM1 to BCM2 transmission measurement	1	A.Aleksandrov	
1.3.9	D-plate energy spread vs. reb. 3-4 voltage	3	A.Aleksandrov	
1.3.10	D-plate horizontal emittance vs. Q11-Q14	1	A.Aleksandrov	
1.3.11	Global quad algorithm vs. D-plate	2	A.Aleksandrov	
1.3.12	D-plate vertical emittance vs Q11-Q14	1	A.Aleksandrov	
1.3.13	Global quad algorithm vs. D-plate	2	A.Aleksandrov	
1.4	**Choppers commissioning**			
1.4.1	LEBT chopper effectivness	1	A.Aleksandrov	
1.4.2	Initial MEBT chopper target position measurement	1	A.Aleksandrov	
1.4.3	MEBT Chopper timing	1	A.Aleksandrov	
1.4.4	LEBT+MEBT choppers effectivness	1	A.Aleksandrov	
1.4.5	Chopper – antychopper phase advance check/set	2	A.Aleksandrov	
1.4.6	Antychopper effectivness	2	A.Aleksandrov	
1.5	**High power beam**			
	Short unchopped pulse 38mA, 10µs - 1ms, 1Hz-60Hz, beam dump			
1.5.1	RFQ amplitude stability vs. beam loading	1	A.Aleksandrov	
1.5.2	RFQ phase stability vs. beam loading	1	A.Aleksandrov	
1.5.3	Reverse RF power vs. beam loading	1	A.Aleksandrov	
1.5.4	RF field tilt vs. beam loading	1	A.Aleksandrov	
1.5.5	Rebunchers amplitude stability vs. beam loading	1	A.Aleksandrov	
1.5.6	Rebunchers phase stability vs. beam loading	1	A.Aleksandrov	
1.5.7	Vacuum vs. beam duty factor	1	A.Aleksandrov	
1.5.8	Radiation level vs. beam duty factor	1	A.Aleksandrov	
1.5.9	RFQ transmission vs. beam duty factor	1	A.Aleksandrov	
1.5.10	MEBT transmission vs. beam duty factor	1	A.Aleksandrov	
1.5.11	LEBT chopper efficiency vs. beam duty factor	1	A.Aleksandrov	
1.5.12	LEBT+MEBT chopper efficiency vs. beam duty factor	2	A.Aleksandrov	

LINAC Systems

LINAC COMMISSIONING PLAN				**Date :**	**01-Oct-2001**	**Version:**	**1.4**
Commissioning with beam		**DTL**	**Duration: 150 days* (or 450 shifts of 8h)**				
* from the 7/19/01 schedule by R.Martineau, which has no longer commissioning with D-plate behind							
tank 3 as in PCR LI 01 049							
Major Category	**Task**	**Order**	**Priority**	**Duration (8h shifts)**	**SNS/ORNL contact**	**Partner lab contact**	**Total of shifts available**
Matching to DTL input plane**	**2.1**			**12**			**14**
Beam Sub-category	2.1.1			12			14
RF set-point (rebunchers) (t.b.d.)	2.1.1.1	1	high	2	A.Aleksandrov D.Jeon	J.Stovall	
Beam profiles <-> emittance scan	2.1.1.2	2	high	10	A.Aleksandrov D.Jeon	J.Stovall	
** Match as calculated							
Major Category	**Task**	**Order**	**Priority**	**Duration (8h shifts)**	**SNS/ORNL contact**	**Partner lab contact**	**Total of shifts available**
DTL Tank1 + D-plate	**2.2**			**131**			**256**
Equipment Sub-category	2.2.1			45			90
RF	2.2.1.1			10	M.Champion		
Diagnostics	2.2.1.2			12	S.Assadi	M.Plum	
Controls	2.2.1.3			10	C.Sibley	B.Dalesio	
Timing	2.2.1.4			8	C.Sibley	B.Oerter	
MPS	2.2.1.5			3	C.Sibley	not appl.	
Quad polarity / Steerers	2.2.1.6			1	T.Hunter	not appl.	
PPS	2.2.1.7			1	P.Wright	not appl.	
Beam Sub-category	2.2.			86			166
RF set-point	2.2.2.1	1	high	24	D.Jeon	J.Stovall	
Aperture scan/Steering	2.2.2.2	2	high	6	J.Galambos	J.Stovall	
Beam profiles	2.2.2.3	3	high	12	D.Jeon	J.Stovall	
7.5 MeV Emittance scan	2.2.2.4	4	high	24	D.Jeon	J.Stovall	
TOF energy centroid	2.2.2.5	6	low	9	D.Jeon	J.Stovall	
Transmission	2.2.2.6	5	high	6	E.Tanke	J.Stovall	
Full beam commissioning	2.2.2.7	7	high	5	E.Tanke	J.Stovall	

Major Category	Task	Order	Priority	Duration (8h shifts)	SNS/ORNL contact	Partner lab contact	Total of shifts available
DTL Tank2-6* **	**2.3**			**165**			**180**
Equipment Sub-category	2.3.1			45			60
RF	2.3.1.1			25	M.Champion		
Diagnostics	2.3.1.2			5	S.Assadi	M.Plum	
Controls	2.3.1.3			5	C.Sibley	B.Dalesio	
Timing	2.3.1.4			2	C.Sibley	B.Oerter	
MPS	2.3.1.5			2	C.Sibley	not appl.	
Quad polarity / Steerers	2.3.1.6			5	T.Hunter	not appl.	
PPS	2.3.1.7			1	P.Wright	not appl.	
Beam Sub-category (for DTL Tank 2)	2.3.2			24			24
RF set-point	2.3.2.1	1	high	11	D.Jeon	J.Stovall	
Steering	2.3.2.2	2	high	2	J.Galambos	J.Stovall	
Beam profiles	2.3.2.3	3	high	3	D.Jeon	J.Stovall	
Transmission	2.3.2.4	4	high	2	E.Tanke	J.Stovall	
TOF energy centroid	2.3.2.5	5	low	6	D.Jeon	J.Stovall	
Beam Sub-category (for DTL Tank 3)	2.3.3			24			24
RF set-point	2.3.3.1	1	high	11	D.Jeon	J.Stovall	
Steering	2.3.3.2	2	high	2	J.Galambos	J.Stovall	
Beam profiles	2.3.3.3	3	high	3	D.Jeon	J.Stovall	
Transmission	2.3.3.4	4	high	2	E.Tanke	J.Stovall	
TOF energy centroid	2.3.3.5	5	low	6	D.Jeon	J.Stovall	
Beam Sub-category (for DTL Tank 4)	2.3.4			24			24
RF set-point	2.3.4.1	1	high	11	D.Jeon	J.Stovall	
Steering	2.3.4.2	2	high	2	J.Galambos	J.Stovall	
Beam profiles	2.3.4.3	3	high	3	D.Jeon	J.Stovall	
Transmission	2.3.4.4	4	high	2	E.Tanke	J.Stovall	
TOF energy centroid	2.3.4.5	5	low	6	D.Jeon	J.Stovall	
Beam Sub-category (for DTL Tank 5)	2.3.5			24			24
RF set-point	2.3.5.1	1	high	11	D.Jeon	J.Stovall	
Steering	2.3.5.2	2	high	2	J.Galambos	J.Stovall	
Beam profiles	2.3.5.3	3	high	3	D.Jeon	J.Stovall	
Transmission	2.3.5.4	4	high	2	E.Tanke	J.Stovall	
TOF energy centroid	2.3.5.5	5	low	6	D.Jeon	J.Stovall	
Beam Sub-category (for DTL Tank 6)	2.3.6			24			24
RF set-point	2.3.6.1	1	high	11	D.Jeon	J.Stovall	
Steering	2.3.6.2	2	high	2	J.Galambos	J.Stovall	
Beam profiles	2.3.6.3	3	high	3	D.Jeon	J.Stovall	
Transmission	2.3.6.4	4	high	2	E.Tanke	J.Stovall	
TOF energy centroid	2.3.6.5	5	low	6	D.Jeon	J.Stovall	

*** Prior to commissioning, 60 days of installation, testing and conditioning of tank 2

Priority:
1 - Essential for 100 kW Commissioning
2 - May not be essential for 100 kW Commissioning - Importance determined by measurement/performance
3 - Not essential for 100 kW Commissioning

Duration is the number of scheduled

shifts

	Task	Duration	Priority
Linac Dump Commissioning	1	34	
Transport to Dump	1.1	3	
Transport through LAMS using BLM	_____		1
Verify Dump Functioning at Low Power	_____		1
Commission LAMS Diagnostics	1.2	5	
Commission BLM System	_____		1
Commission BCM System	_____		1
Commission BPM System	_____		1
Check Dump Trajectory and Profile	1.3	5	
Measure Beam Trajectory	_____		1
Check corrector polarity/strength	_____		1
Correct Beam Trajectory/check software	_____		1
Commission Linac Dump Wire Scanner	_____		1
Measure/Verify Beam Profile on Dump WS	_____		1
Check Dump Performance and Fault Scenarios	1.4	5	
Investigate Fault Scenarios	_____		1
Check dump performance up to 7.5 kW	_____		1
Center beam on dump with TC array	_____		1
Measure Linac Beam Parameters	1.5	6	
Commission TOF System	_____		1
Commission Remaining Wire Scanners	_____		1
Measure Beam Energy with TOF	_____		1
Measure Emittance with WS01-04	_____		1
Measure and Correct Optical Parameters	1.6	5	
Set HEBT energy to beam energy	_____		1
Measure profiles with WS01-04,09	_____		1
Match Linac to Achromat Optics	_____		2
Setup HEBT Collimators	1.7	4	
Measure Loss vs. foil positions	_____		2
Optimize Foil Positions	_____		2
Optimize transmission/losses	_____		2
Operate Energy Corrector Cavity	1.8	1	
Observe trajectory On vs. Off	_____		3

	Task	Duration	Priority
HEBT Transport	2	21	
Establish Initial Conditions	2.1	3	
Transport beam to linac dump	_____		1
measure and correct trajectory	_____		1
measure linac beam parameters (E,emit)	_____		1
Set HEBT energy	_____		1
HEBT Beam Transport	2.2	5	
Transport beam through LAMS/achromat	_____		1
Transport beam through ARMS	_____		1
Commission BCMs/BLMs as necessary	_____		1
Transport to Injection Dump	2.3	3	
Install phosphor, observe video	_____		1
Position beam on phosphor w/sept, chicane	_____		1

Transport to Dump w/septum, chicane	_____		1
Gross check of dump shielding	_____		1
Measure and Correct Trajectory	2.4	6	
Commission BPM System and Aps Soft	_____		1
Measure Trajectory	_____		1
Correct Trajectory	_____		1
Calibrate BPM Offsets/Iterate Trajectory	_____		2
Run Automated Steering Check	_____		1
Re-optimize transport/minimize losses	_____		1
Commission Injection Dump	2.5	4	
Commission Dump Harp/Measure profile	_____		1
Check/correct Dump Trajectory	_____		1
Check dump cooling system	_____		1

	Task	Duration	Priority
HEBT Optics and 10^13 protons/pulse	3	27	
HEBT Optics Measurement/Correction	3.1	8	
Commission HEBT Wire Scanners	_____		1
Measure dispersion/correct achromaticity	_____		1
Measure emit,beta,alpha with WS	_____		1
Measure profiles in achromat and dump	_____		1
Match linac to achromat optics	_____		1
Match Achromat to Ring optics	_____		2
Match injection dump line	_____		2
Iterate Trajectory and dump transport	_____		2
Measure Linac Beam Parameters	3.2	3	
Measure Linac Energy, Spread, Jitter	_____		1
Setup Energy Corrector Cavity	3.3	3	
Check/Set Phase and Amplitude Controls	_____		1
Measure Energy Jitter in Arc	_____		1
Measure Energy swing and dispersion	_____		1
Setup Energy Spreader Cavity Operation	3.4	2	
Check/Set amplitude and phase	_____		1
Verify ESC operation	_____		1
Injection Dump Fault Studies	3.5	4	
Confirm bulk shielding/attenuation	_____		1
Measure profiles vs. PS trips/etc.	_____		1
Optimize HEBT Collimation	3.6	3	
Optimize transverse collimators	_____		1
Optimize momentum scrapers	_____		2
Optimize transport/minimize losses	_____		1
Transport 10^13 protons/pulse to dump	3.7	4	
Transport 10^13 beam with low losses	_____		1

	Task	Duration	Priority
Ring Transport and Closed Orbit	4	29	
Establish Initial Conditions	4.1	1	
Check beam on phosphor/install primary foil	_____		1
Tuneup injection dump trajectory if need	_____		1
Transport mini-pulse one-turn in ring	4.2	5	
Measure Linac Energy/Set Ring Energy	_____		1
Setup Dynamic H,V bumps for full amp	_____		1

Transport a single-turn with BLM/BPM	_____		1
Commission full BLM hardware and softw	_____		1
Commission Ring BCM	_____		1
Check Ring Timing System/Phase lock	_____		1
Multi-turn mini-pulse transport	4.3	3	
optimize fixed chicane/injection bumps	_____		1
Minimize losses with H,V correctors	_____		1
Several mini-pulse injection and transport	4.4	5	
optimize injection and transport	_____		1
Commission BPM System	4.5	4	
Commission BPM System	_____		1
Test orbit measurement software	_____		1
Test Turn-by-turn software	_____		1
Closed Orbit Correction	4.6	5	
Measure closed orbit	_____		1
Run automated Steering Check	_____		1
Correct Closed Orbit	_____		1
Correct Chicane Closure	_____		1
Close H, V injection dynamic bumps	_____		1
Install, Close H,V DC bumps	_____		1
Calibrate BPM Offsets/iterate trajectory	_____		2
Transport Beam to End of Cycle	4.7	3	
Optimize injection conditions	_____		1
Optimize transmission/loss through cycle	_____		1
Measure orbit through cycle	_____		2
Commission Ring Diagnostics	4.8	3	
Commission Tune System/Measure Tune	_____		1
Commission Wall-Current-Monitor	_____		1

	Task	Duration	Priority
Commission RF System	5	12	
Set Cavity Resonant Frequency	5.1	3	
Measure Energy/Revolution Frequency	_____		1
Tune Cavity Resonant Frequency	_____		1
Check Phase and Amplitude Loops w/Beam	5.2	2	
Check phase and amplitude loops	_____		1
Set Amplitude and Phase	5.3	4	
Phase-in h=1 cavities with CW beam	_____		1
Phase-in h=2 cavity	_____		1
Measure chopper/RF phase jitter	_____		1
Measure Synchrotron Tune	_____		2
Commission RF Diagnostics	5.4	3	
Verify RF Vector Sum	_____		1
Phase/Amplitude/Forward and Refl Power	_____		1

	Task	Duration	Priority
Ring Optics Measurement and Correction	6	23	
Measure and Correct Linear Optics	6.1	6	
Measure Tunes	_____		1
Commission/Calibrate Tune Adjustment Software	_____		1
Correct Tunes	_____		1

Measure Linear Optics	_____		1
Measure Dispersion	_____		1
Correct Optics and Iterate	_____		2
Measure and Correct Chromaticity	6.2	3	
Measure Natural Chromaticity	_____		1
Power Sextupoles/Measure Chromaticity	_____		1
Check sextupole polarities with bumps	_____		1
Check/Calibrate Chromaticity Adjustment	_____		1
Set Chromaticities	_____		1
Measure and Correct Coupling	6.3	3	
Measure global coupling/tune split	_____		1
Measure local coupling	_____		2
Correct global/local coupling if necessary	_____		2
Resonance Correction	6.4	4	
Explore tunes/measure stopbands	_____		2
Minimize stopbands with resonance corr.	_____		2
Reestablish Machine Conditions	6.5	4	
Retune injection conditions	_____		1
Correct orbit	_____		1
Check closure of pulsed/DC bumps	_____		1
Optimize transmission/minimize losses	_____		1
Check corrector polarities with beam	6.6	3	
Check skew quadrupole polarities/strength	_____		2
Check skew sext polarities/strength	_____		2
Check octupole polarities/strength	_____		2

	Task	Duration	Priority
Ring Extraction and Dump Commissioning	7	24	
Verify Extraction Kicker Operation w/Beam	7.1	2	
Check polarity of each kicker module	_____		1
Observe turn-by-turn orbit	_____		1
Excite/Measure tune	_____		1
Measure ext. kicker to RF jitter	_____		1
Establish Extraction Conditions	7.2	3	
Set Extraction Kicker Timing	_____		1
Measure Energy/Set RTBT Energy	_____		1
Establish Kicker/Septum Conditions	_____		1
Scan Septum Aperture	_____		1
Commission BCM	_____		1
Adjust timing for complete extraction	_____		1
Transport Beam to Extraction Dump	7.3	4	
Adjust kicker/septum/vertical corr	_____		1
Transport to dump using BLM/correctors	_____		1
Verify gross dump shielding	_____		1
Correct Extracted Beam Trajectory	7.4	2	
Commission BPM system/software	_____		1
Check corrector polarity/strength	_____		1
Measure and Correct Trajectory	_____		1
Optimize extraction efficiency/mini losses	_____		1
Commission Extraction Dump	7.5	3	
Check/correct trajectory to dump	_____		1
Commission dump Harp/measure profile	_____		1
Check dump functioning	_____		1
Extraction Dump Fault Studies and Performance	7.6	4	

Measure profiles vs. PS trips/etc.			1
Verify shielding performance			1
Measure/Correct Extracted Beam Params	7.7	6	
Commission profile measuring devices			1
Measure profiles in RTBT and Dump			1
Tune HEBT/Ring/RTBT Matching			2

	Task	Duration	Priority
Injection Painting and Multi-turn Injection	8	22	
Characterize Injected Beam Conditions	8.1	6	
Measure momentum spread			2
Measure momentum spread vs. ESC amp			2
Measure Energy stability/jitter vs. ECC			1
Measure Transverse Jitter/Stability			1
Relative and Absolute Energy Meas			2
Measure Injected Beam Emittance			2
Establish Injected Beam Controls	8.2	2	
Load H,V dynamic bump profiles			1
Measure dynamic bump closure/correct			1
Install/check x, x-prime, y, y-prime adjs.			1
Achieve Multi-turn injection of 10^13 protons	8.3	10	
Optimize beam losses/maximize trans.			1
Optimize injection/extraction conditions			1
Measure Beam Parameters	8.4	4	
Profiles vs. painting conditions			1
Measure beam losses vs. time			1
Measure orbit vs. time			2
Measure tune vs. time			2
Measure longitudinal profile vs. ESC/RF			2

	Task	Duration	Priority
Ring Collimation and Beam-in-Gap	9	12	
Measure Ring Aperture	9.1	3	
Aperture Scan with bumps and ext. kicker			2
Measure losses vs. local bumps			2
Establish Primary Collimator Settings	9.2	3	
Measure beamloss vs. scrapers			1
Optimize scraper settings			1
Investigate Orbit Bumps in Collimators	9.3	1	
Install offset and angle bumps in colls			2
Measure beamloss vs. bumps			2
Setup Beam-In-Gap Kicker System	9.4	5	
Measure Beam in Gap with Ext Kicker			2
Setup kicker polarity sequence			1
Excite beam/observe tunes			1
Set timing for gap cleaning			1
Measure Beam-in-Gap			1
Measure BIG vs. RF settings			1
Establish optimum BIG conditions			1

	Task	Duration	Priority

	Task	Duration	Priority
Machine Protection and Fault Studies	10	13	
Check MPS Inputs	10.1	4	
Set BLM Thresholds			1
Check BLM with local controlled loss			1
Check Harp calibration/outputs			1
Check Response Time (within pulse)			1
Setup Injection Foil Loss	10.2	3	
Set thresholds for nominal conditions			1
Check Fault Scenarios at Low Power	10.3	6	
Extraction Kicker Failures			1
Injection Kicker Failures			1
Controlled losses			1

	Task	Duration	Priority
Studies Related to High-Intensity Operation	11	46	
Establish High-Intensity Conditions	11.1	10	
Tuneup Injection and losses			3
Reoptimize Collimators and BIG			3
Check Extraction Dump Position/Verify			3
Resonance Measurement and Correction	11.2	4	
Measure Phase-Space Motion			3
Measure Tune vs. Amplitude			3
Correct Sext/Skew Sext/Octupole Res			3
Test Dynamic RF Tuning	11.3	6	
Close Tuning Angle Loop/Check Dynamic			3
Study Feedforward Operation			3
Study Adaptive Feedforward Operation			3
Ring Loss Study	11.4	5	
losses vs. working point			3
losses vs. chromaticity			3
Losses vs. intensity			1
losses vs. painting scheme			3
losses vs. momentum spread			3

Beam Stability Measurements	11.5	5	
Commission high-bandwidth BPM			3
Delay extraction to observe unstable modes			3
Measure mode frequencies/growth rates			3
Impedance Measurements w/beam	11.6	5	
Coherent tune-shift vs. intensity			3
Head-tail growth rates vs. chromaticity			3
Growth rates vs. bumps in Ext Kicker			3
Growth rates vs. bumps in RF Cavities			3
e-p instability measurements	11.7	4	
Commission electron detector system			3
Secondary Electron Measurements			3
Correlate electron and high-BW BPM data			3
Space-Charge Experiments	11.8	4	
Beam profiles vs. intensity			3
Ring loss from SC and working point			3
Prototype Transverse Feedback Tests	11.9	3	
Use Tune System for Feedback			3

	Task	Duration	Priority
RTBT to Target Commissioning	12	42	
Setup Initial Conditions	12.1	5	
Set RTBT Energy			1
Tranport beam to Extraction Dump			1
Verify Extraction Dump Functioning			1
Transport Beam to Target	12.2	5	
Power RTBT_MAG:DH13			1
Transport to Target with BLM			1
Commission BCMs			1
Observe Beam on Target			1
Measure and Correct Trajectory	12.3	5	
Commission BPM System			1
Measure RTBT Trajectory			1

Correct Trajectory			1
Run automated Steering Check			1
Calibrate BPM offsets/iterate trajectory			2
RTBT Optics Measurement/Correction	12.4	5	
Commission Wire Scanners			1
Measure emit, beta, alpha at WS			1
Measure dispersion			1
Correct optics/matching to target			2
Correct trajectory to target/iterate			2
Setup Machine Protection Systems	12.5	4	
Verify Upstream and Target HARPs			1
Verify Tcouple or SEM Target monitor			1
Investigate Fault Scenarios	12.6	5	
Measure profiles at target with P.S. trips			1
Investigate Extraction Kicker Failures			1
Investigate Injection Kicker Failures			1
Transport 10^13 protons/pulse to target	12.7	5	
Optimize injection/extraction/losses			1
Optimize collimators and BIG			1
Deliver 100 kW to the Target	12.8	8	
Take 100 kW to injection dump			1
Verify Injection Dump Performance			1
Check e- collector heating/position			1
Verify Target Performance			1

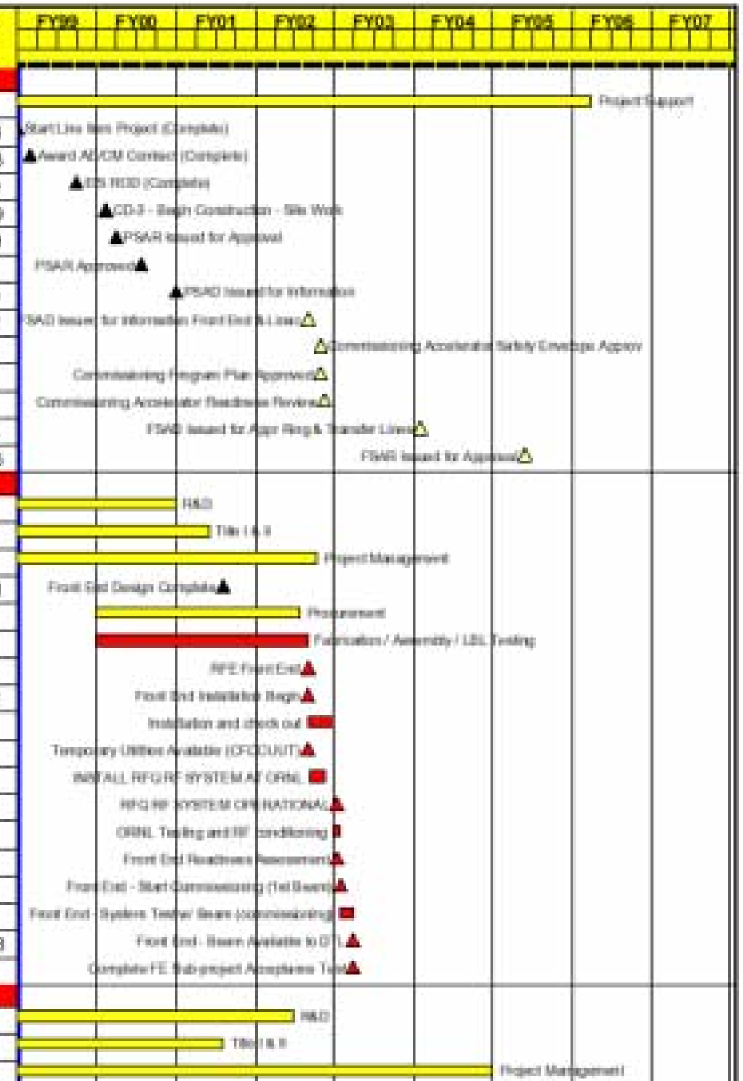
	Task	Duration	Priority
Operational Measurements	13	9	
Orbit and Trajectory Reproducibility	13.1	3	
Meas Ring Orbit b/a mag standardization			1
Meas HEBT Traj b/a mag standardization			1
Meas RTBT Traj and Target Pos b/a mag			1
Optics Reproducibility	13.2	3	

Meas Ring Tunes b/a mag standardization	_______		1
Meas Chromaticity b/a mag stand.	_______		1
Meas lattice function b/a/ mag stand.	_______		1
Extraction Kicker	13.3	3	
Recovery from kicker failures	_______		1

Appendix D

Integrated Project Schedule (IPS)

Activity ID	RESP	PEP ID	Activity Description	Early Start	Early Finish	PEP Date
Project Support						
PSPM	PS		Project Support	01OCT98	30DEC05	
PS104	PS	1A-01	Start Line Item Project (Complete)		01OCT98A	01OCT98
PS109	PS	1B-01	Award AE/CM Contract (Complete)		25NOV98A	25NOV98
PS105	PS	0-3	EIS ROD (Complete)		30JUN99A	30JUN99
PS122	PS	1A-03	CD-3 - Begin Construction - Site Work		12NOV99A	12NOV99
PS115	PS	1B-02	PSAR Issued for Approval		31DEC99A	31DEC99
PS120	PS		PSAR Approved		01MAY00A	
PS116	PS	2-01	PSAD Issued for Information		29SEP00A	29SEP00
PS140	PS	2-03A	FSAD Issued for Information Front End & Linac		03JUN02*	29SEP02
PS150	PS		Commissioning Accelerator Safety Envelope Approv		01AUG02*	
PS155	PS		Commissioning Program Plan Approved		01AUG02	
PS160	PS		Commissioning Accelerator Readiness Review		15AUG02	
PS175	PS	2-03B	FSAD Issued for Appr Ring & Transfer Lines		03NOV03*	27FEB04
PS121	PS	2-04	FSAR Issued for Approval		01MAR05*	31AUG05
Front End						
FERD	FE		R&D	01OCT98	29SEP00	
FEEN	FE		Title I & II	01OCT98	01MAR01	
FEPM	FE		Project Management	01OCT98	15JUL02	
FEEN5	FE	2-05	Front End Design Complete		10MAY01A	31MAY01
FEPR	FE		Procurement	04OCT99*	01MAY02	
FEFB	FE		Fabrication / Assembly / LBL Testing	04OCT99*	31MAY02	
FERFE	CF		RFE Front End		03JUN02*	
FEIN05	AS	2-06	Front End Installation Begin	03JUN02*		30SEP02
FEIN	AS		Installation and check out	03JUN02	25SEP02	
FEIN10	CF		Temporary Utilities Available (CFCCUUT)		03JUN02	
FETE10	LN		INSTALL RFQ RF SYSTEM AT ORNL	14JUN02*	15AUG02	
FETE20	AS		RFQ RF SYSTEM OPERATIONAL		15OCT02	
FETE	AS		ORNL Testing and RF conditioning	26SEP02	28OCT02	
FETE5	AS		Front End Readiness Assessment		15OCT02	
FE110	AS		Front End - Start Commissioning (1st Beam)	29OCT02		
FE115	AS		Front End - System Test w/ Beam (commissioning)	29OCT02	31DEC02	
FE120	AS	1B-06	Front End - Beam Available to DTL		31DEC02	31MAR03
FE125	AS		Complete FE Sub-project Acceptance Test		31DEC02	
Linac - DTL						
CCLRD	LN		R&D	01OCT98	29MAR02	
DTLEN	LN		Title I & II	01OCT98	08MAY01	
LINACPM	LN		Project Management	01OCT98	30SEP04	



Start Date 01OCT97
Finish Date 01JUL06
Data Date 01OCT98
Run Date 01NOV01 13:28

Proposed
Progress Bar
Critical Activity

OBR5

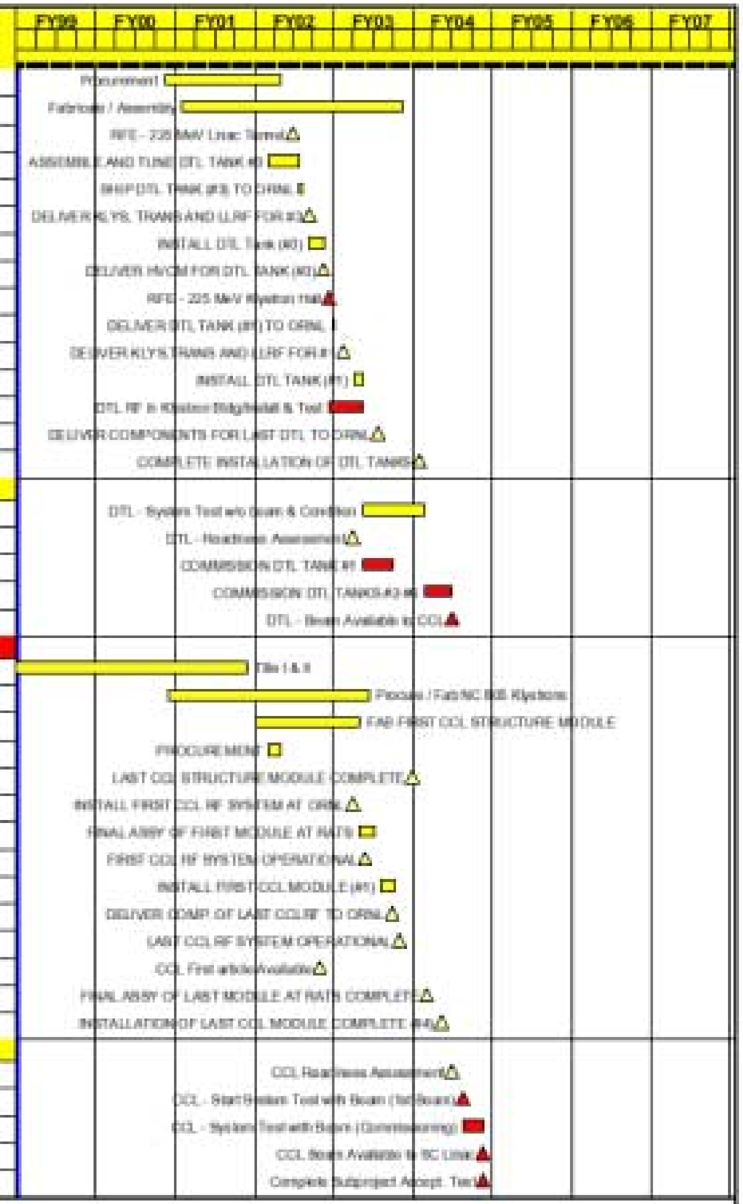
Sheet 1 of 8

Integrated Project Schedule (IPS-08)
November
DOE Review

Reviewed version
dtd
01 November 2001

SNS SPALLATION NEUTRON SOURCE

Activity ID	RESP	PEP ID	Activity Description	Early Start	Early Finish	PEP Date
DTLPR	LN		Procurement	11AUG00*	31JAN02	
DTFB	AS		Fabricate / Assembly	07NOV00*	19AUG03	
DTLRFE	CF		RFE - 225 MeV Linac Tunnel	29MAR02*		
DTLRFE10	LN		ASSEMBLE AND TUNE DTL TANK #3	07DEC01*	02MAY02	
DTFB20	LN		SHIP DTL TANK (#3) TO ORNL	02MAY02	07MAY02	
DTLIN10	LN		DELIVER KLYS, TRANS AND LLRF FOR #3		14JUN02*	
DTL045	LN	2-09	INSTALL DTL Tank (#3)	14JUN02	14AUG02	30SEP02
DTLINK11	LN		DELIVER HVCM FOR DTL TANK (#3)		15AUG02*	
DTKRFE	CF		RFE - 225 MeV Klystron Hall	09SEP02*		
DTL055	LN		DELIVER DTL TANK (#1) TO ORNL	01OCT02*	04OCT02	
DTLINK21	LN		DELIVER KLYS,TRANS AND LLRF FOR #1		15NOV02*	
DTLINK31	AS		INSTALL DTL TANK (#1)	09JAN03	20FEB03	
DTLINK36	AS		DTL RF in Klystron Bldg/Install & Test	09SEP02	14FEB03	
DTFB30	LN		DELIVER COMPONENTS FOR LAST DTL TO ORNL		21APR03*	
DTLIN	AS		COMPLETE INSTALLATION OF DTL TANKS		30OCT03*	
DTL Commissioning						
DTL080	AS		DTL - System Test w/o beam & Condition	17FEB03	26NOV03	
DTL090	AS		DTL - Readiness Assessment		31DEC02	
DTL100	AS		COMMISSION DTL TANK #1	21FEB03	30JUN03	
DTL130	AS		COMMISSION DTL TANKS #2-#6	01DEC03*	01APR04	
DTL120	AS		DTL - Beam Available to CCL		01APR04	
Linac - CCL						
CCLEN	LN		Title I & II	01OCT98	28AUG01	
CCLFB10	LN		Procure / Fab NC 805 Klystrons	31AUG00*	17MAR03	
CCLFB60	LN		FAB FIRST CCL STRUCTURE MODULE	01OCT01*	03FEB03	
CCLPR	LN		PROCUREMENT	11DEC01*	31JAN02	
CCLFB20	LN		LAST CCL STRUCTURE MODULE COMPLETE		29SEP03*	
CCLFB90	LN		INSTALL FIRST CCL RF SYSTEM AT ORNL		31DEC02*	
CCLFB70	LN		FINAL ASSY OF FIRST MODULE AT RATS	04FEB03	07APR03	
CCLFB100	LN		FIRST CCL RF SYSTEM OPERATIONAL		27FEB03	
CCLFB110	LN		INSTALL FIRST CCL MODULE (#1)	15MAY03	11JUL03	
CCL245	LN		DELIVER COMP. OF LAST CCLRF TO ORNL		30JUN03*	
CCL275	AS		LAST CCL RF SYSTEM OPERATIONAL		30JUL03	
CCLFB130	LN		CCL First article Available		01AUG02*	
CCLFB80	AS		FINAL ASSY OF LAST MODULE AT RATS COMPLETE		03DEC03	
CCLFB120	AS		INSTALLATION OF LAST CCL MODULE COMPLETE (#4)		09FEB04	
CCL Commissioning						
CCL230	AS		CCL Readiness Assessment		01APR04	
CCL235	AS		CCL - Start System Test with Beam (1st Beam)	17MAY04		
CCL240	AS		CCL - System Test with Beam (Commissioning)	17MAY04	18AUG04	
CCL255	AS		CCL Beam Available to SC Linac		18AUG04	
CCL265	AS		Complete Subproject Accept. Test		18AUG04	



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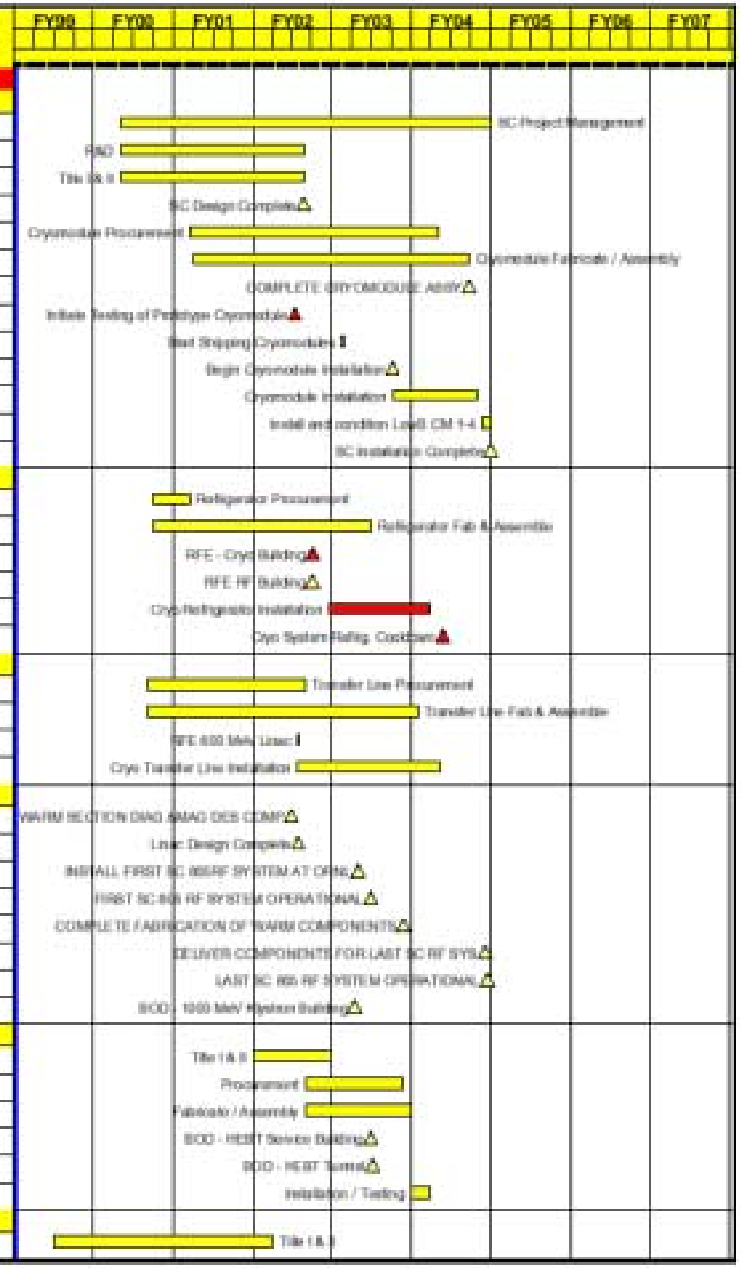
Activity ID	RESP	PEP ID	Activity Description	Early Start	Early Finish	PEP Date
Linac - SC						
SC						
SC00	SL		SC Project Management	01FEB00*	29SEP04	
SC01	SL		R&D	01FEB00*	28MAY02	
SC05	SL		Title I & II	01FEB00*	28MAY02	
SC10	SL	1B-03	SC Design Complete		28MAY02	08SEP02
SC15	SL		Cryomodule Procurement	15DEC00*	04FEB04	
SC20	SL		Cryomodule Fabricate / Assembly	02JAN01*	22JUN04	
SC31	SL		COMPLETE CRYOMODULE ASSY		22JUN04	
SC21	SL	2-30	Initiate Testing of Prototype Cryomodule	11APR02*		03MAY02
CCL351	SL		Start Shipping Cryomodules	19NOV02*	27NOV02	
CCL353	AS		Begin Cryomodule Installation	08JUL03*		
SC23	AS		Cryomodule Installation	08JUL03	03AUG04	
SC40	AS		Install and condition LowB CM 1-4	19AUG04	30SEP04	
SC30	AS		SC Installation Complete		30SEP04	
Refrigerator						
SC75	SL		Refrigerator Procurement	30JUN00*	19DEC00	
SC90	SL		Refrigerator Fab & Assemble	05JUL00*	31MAR03	
SCRFE	CF		RFE - Cryo Building		05JUL02*	
SCRFE10	CF		RFE RF Building		05JUL02*	
SC25	AS		Cryo Refrigerator installation	18SEP02*	30DEC03	
SC35	AS		Cryo System Refrig. Cooldown		01MAR04	
Transfer Lines						
SC80	SL		Transfer Line Procurement	06JUN00*	31MAY02	
SC100	AS		Transfer Line Fab & Assemble	07JUN00	03NOV03	
SC110	CF		RFE 600 MeV Linac	01MAY02*	01MAY02	
SC65	AS		Cryo Transfer Line Installation	02MAY02	13FEB04	
LANL Warm Items						
LAN01	LN		WARM SECTION DIAG.&MAG DES COMP		29MAR02*	
CCLEN5	LN	1B-03	Linac Design Complete		30APR02	08SEP02
LAN21	LN		INSTALL FIRST SC 805RF SYSTEM AT ORNL		29JAN03	
LAN31	LN		FIRST SC 805 RF SYSTEM OPERATIONAL		01APR03	
LAN11	LN		COMPLETE FABRICATION OF WARM COMPONENTS		29AUG03*	
LAN41	LN		DELIVER COMPONENTS FOR LAST SC RF SYS		01SEP04*	
LAN51	AS		LAST SC 805 RF SYSTEM OPERATIONAL		15SEP04*	
CCL343	CF		BOD - 1000 MeV Klystron Building	14JAN03		
LAMS						
LAMSEN			Title I & II	01OCT01*	01OCT02	
LAMSPR			Procurement	03JUN02*	27AUG03	
LAMSFB			Fabricate / Assembly	03JUN02*	26SEP03	
CCL329			BOD - HEBT Service Building	28MAR03		
CCL327			BOD - HEBT Tunnel	10APR03		
LAMSIN			Installation / Testing	29SEP03	29DEC03	
Linac Dump						
LDEN	TG		Title I & II	01APR99*	31DEC01	



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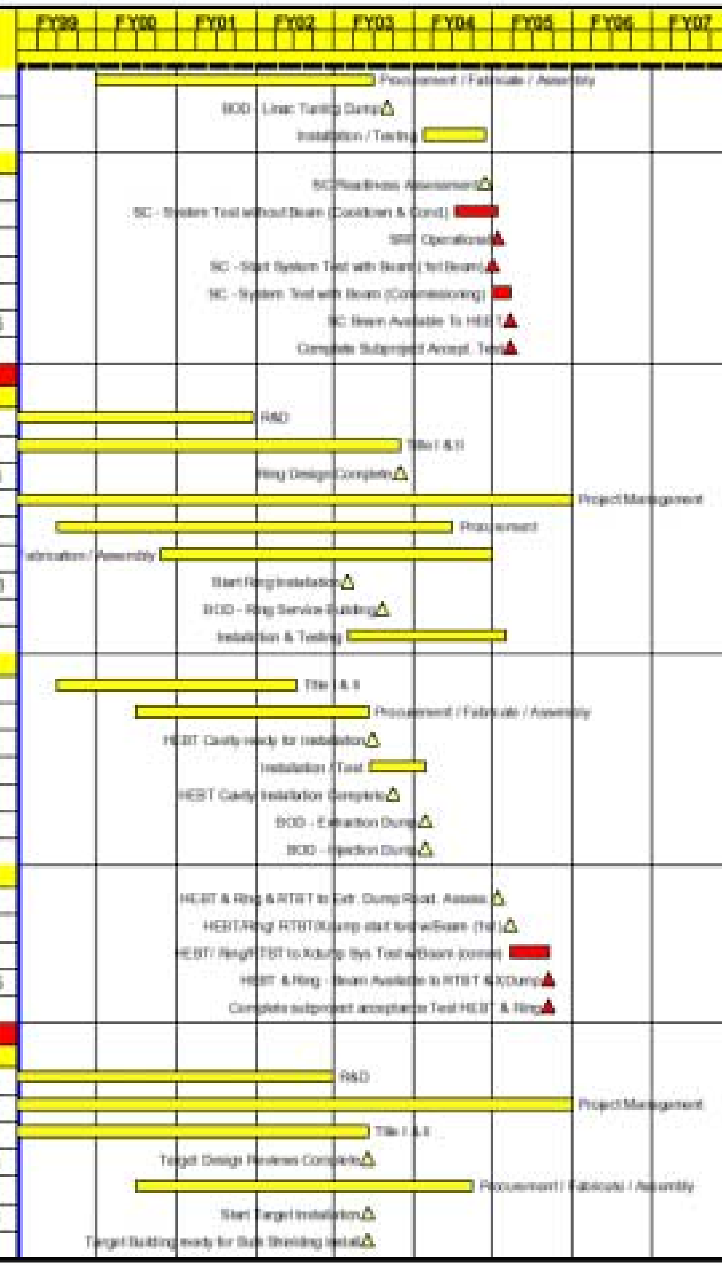
Activity ID	RESP	PEP ID	Activity Description	Early Start	Early Finish	PEP Date
LDPR	TG		Procurement / Fabricate / Assembly	01OCT99*	28MAR03	
CCL330	CF		BOD - Linac Tuning Dump	02JUN03		
LDIN	TG		Installation / Testing	21NOV03*	30AUG04	
SC Commissioning						
SC300	AS		SC Readiness Assessment		30AUG04	
SC310	AS		SC - System Test without Beam (Cooldown & Cond.)	15APR04	21OCT04	
SC315	AS		SRF Operational		21OCT04	
SC320	AS		SC - Start System Test with Beam (1st Beam)	01OCT04		
SC325	AS		SC - System Test with Beam (Commissioning)	01OCT04	21DEC04	
SC330	AS	1B-09	SC Beam Available To HEBT		21DEC04	31MAY05
SC340	AS		Complete Subproject Accept. Test		21DEC04	
Ring - HEBT to Ring						
HEBT & Ring						
RINGRD	RI		R&D	01OCT98	28SEP01	
RINGEN	RI		Title I & II	01OCT98	31JUL03	
RINGEN5	RI	2-11	Ring Design Complete		31JUL03	31OCT03
RINGPM	RI		Project Management	01OCT98	30SEP05	
RINGPR	RI		Procurement	01APR99*	29MAR04	
RINGFB	RI		Fabrication / Assembly	01AUG00*	29SEP04	
RINGIN5	AS	2-12	Start Ring Installation	02DEC02*		28MAR03
HEBT532	CF		BOD - Ring Service Building	09MAY03		
RINGIN	AS		Installation & Testing	02DEC02	01DEC04	
Injection & Extraction Dumps						
TGIEDEN	TG		Title I & II	01APR99*	15APR02	
TGIEDPR	TG		Procurement / Fabricate / Assembly	03APR00*	07MAR03	
HEBTCA	LN		HEBT Cavity ready for Installation	01APR03*		
TGIEDIN	TG		Installation / Test	14MAR03*	28NOV03	
HEBTCA1	AS		HEBT Cavity Installation Complete		01JUL03*	
EDUMP526	CF		BOD - Extraction Dump	01DEC03		
IDUMP508	CF		BOD - Injection Dump	01DEC03		
Commissioning						
HEBT157	AS		HEBT & Ring & RTBT to Extr. Dump Read. Assess.		22OCT04	
HEBT170	AS		HEBT/Ring/ RTBT/Xdump start test w/Beam (1st)		21DEC04	
HEBT290	AS		HEBT/ Ring/RTBT to Xdump Sys Test w/Beam (comm)	22DEC04	17JUN05	
HEBT295	AS	1B-10	HEBT & Ring - Beam Available to RTBT & XDump		17JUN05	18NOV05
HEBT305	AS		Complete subproject acceptance Test HEBT & Ring		17JUN05	
Target - RTBT to Target						
Target						
TARGRD	TG		R&D	01OCT98	30SEP02	
TARGPM	TG		Project Management	01OCT98	30SEP05	
TARGEN	TG		Title I & II	01OCT98	05MAR03	
TARGEN5	TG	1B-07	Target Design Reviews Complete		05MAR03*	30JUN03
TARGPR	TG		Procurement / Fabricate / Assembly	03APR00*	29JUN04	
TARGIN5	TG	2-15	Start Target Installation	04MAR03		01JUN03
RTBTRFE1	TG		Target Building ready for Bulk Shielding install		03MAR03*	



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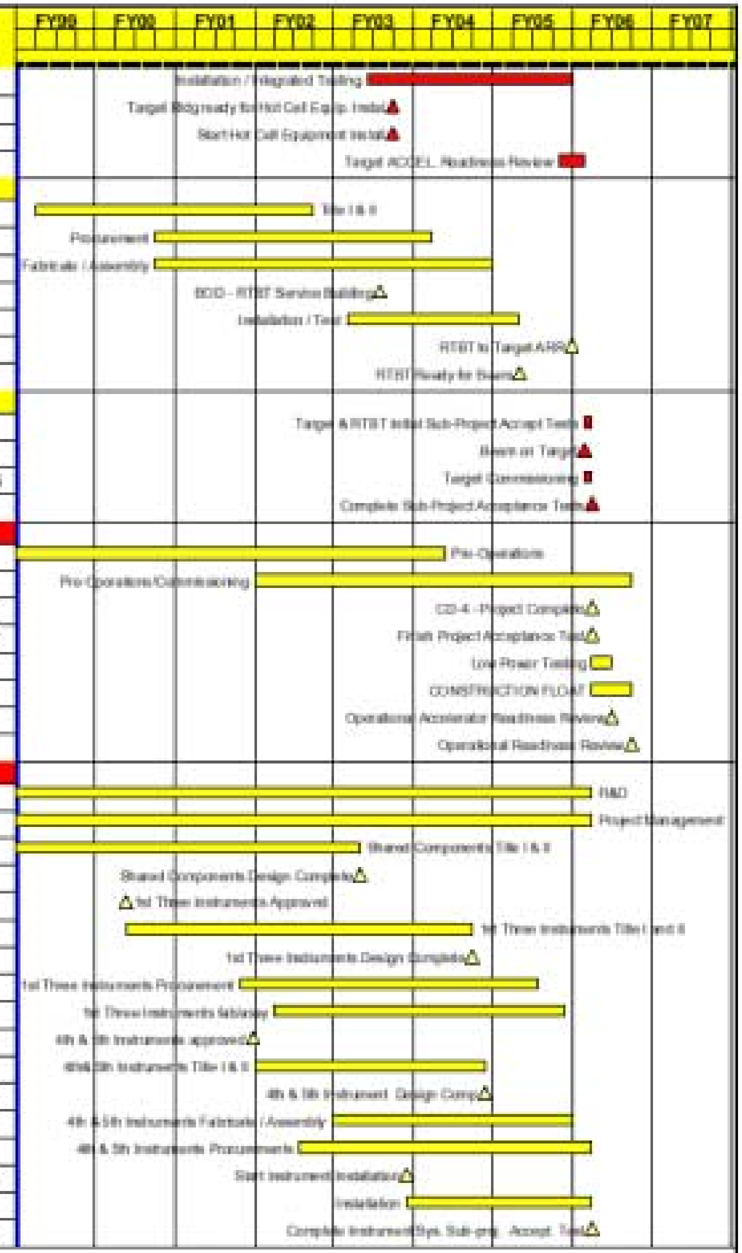
Activity ID	RESP	PEP ID	Activity Description	Early Start	Early Finish	PEP Date
TARGIN	TG		Installation / Integrated Testing	04MAR03	30SEP05	
RTBTRFE2	TG		Target Bldg ready for Hot Cell Equip. Instal		01JUL03*	
RTBT308	TG		Start Hot Cell Equipment Install	02JUL03		
RTBT318	TG		Target ACCEL Readiness Review	08AUG05*	30NOV05	
RTBT						
RTBTEN	RI		Title I & II	04JAN99*	28JUN02	
RTBTPR	RI		Procurement	05JUL00*	30DEC03	
RTBTFB	RI		Fabricate / Assembly	05JUL00*	30SEP04	
RTBT302	CF		BOD - RTBT Service Building	30APR03		
RTBTIN	AS		Installation / Test	02DEC02	04FEB05	
RTBT410	AS		RTBT to Target ARR		03OCT05	
RTBTIN5	AS		RTBT Ready for Beam		04FEB05	
Commissioning						
RTBT337	TG		Target & RTBT Initial Sub-Project Accept Tests	01DEC05	30DEC05	
RTBT411	TG		Beam on Target		01DEC05	
RTBT315	TG	1A-04	Target Commissioning	01DEC05	30DEC05	01MAY06
RTBT342	TG		Complete Sub-Project Acceptance Tests		30DEC05	
Pre-Operations						
OPCO1	OP		Pre-Operations	01OCT98	25FEB04	
OPCO2	OP		Pre-Operations/Commissioning	01OCT01*	30JUN06	
PS130	ALL	0-4	CD-4 - Project Complete		30DEC05	30JUN06
PS170	ALL	1A-05	Finish Project Acceptance Test		30DEC05	30JUN06
OPCO7	ALL		Low Power Testing	03JAN06	30MAR06	
PS135	ALL		CONSTRUCTION FLOAT	03JAN06	30JUN06	
OPCO8	AS		Operational Accelerator Readiness Review		30MAR06	
PS165	ALL		Operational Readiness Review		01JUL06*	
Instrument Systems						
EXPERD	IS		R&D	01OCT98	30DEC05	
EXPEPM	IS		Project Management	01OCT98	30DEC05	
EXPEEN	IS		Shared Components Title I & II	01OCT98	31JAN03	
EXPEPM15	IS		Shared Components Design Complete		31JAN03	
EXPEPM5	IS		1st Three Instruments Approved		24FEB00*	
EXPEEN1	IS		1st Three Instruments Title I and II	25FEB00*	30JUN04	
EXPEEN2	IS		1st Three Instruments Design Complete		30JUN04	
EXPEPR	IS		1st Three Instruments Procurement	01AUG01*	29APR05	
EXPEFB	IS		1st Three Instruments fab/assy	03JAN02	29AUG05	
EXPEEN3	IS		4th & 5th Instruments approved	28SEP01*		
EXPEEN4	IS		4th& 5th Instruments Title I & II	01OCT01*	31AUG04	
EXPEEN5	IS	1B-08	4th & 5th Instrument Design Comp		31AUG04	27OCT04
EXPEFB1	IS		4th & 5th Instruments Fabricate / Assembly	01OCT02*	29SEP05	
EXPEPR1	IS		4th & 5th Instruments Procurements	01MAY02*	30DEC05	
EXPEIN5	IS	2-17	Start Instrument Installation	02SEP03		31DEC03
EXPEIN	IS		Installation	02SEP03	30DEC05	
EXPEIN10	IS	2-18	Complete Instrument Sys. Sub-proj. Accept. Test	30DEC05	30DEC05	30JUN06



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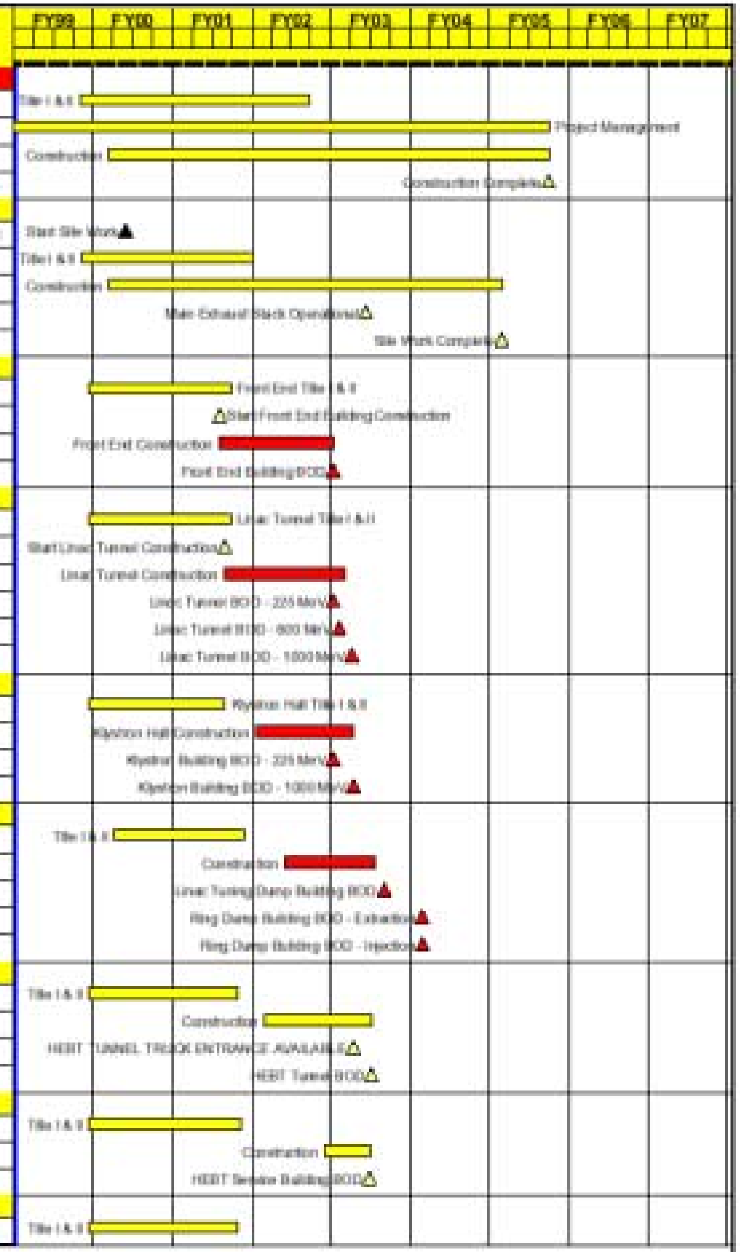
Activity ID	RESP	PEP ID	Activity Description	Early Start	Early Finish	PEP Date
Conventional Facilities						
CFEN	CF		Title I & II	02AUG99*	28JUN02	
CFPM	CF		Project Management	01OCT98	30JUN05	
CFCN	CF		Construction	16DEC99*	30JUN05	
CFCN5	CF	2-24	Construction Complete		30JUN05	30NOV05
Site Prep						
CFSPEN5	CF	2-19	Start Site Work	01MAR00A		07MAR00
CFSPEN	CF		Title I & II	11AUG99*	01OCT01	
CFSPCN	CF		Construction	16DEC99A	30NOV04	
CFSPEN10	CF		Main Exhaust Stack Operational		14MAR03*	
CFSPCN5	CF		Site Work Complete		30NOV04	
Front End Building						
CFFEEN	CF		Front End Title I & II	16SEP99*	27JUN01	
CFFEEN5	CF		Start Front End Building Construction	04MAY01*		
CFFECN	CF		Front End Construction	04MAY01	14OCT02	
CFFEBOD	CF	2-20	Front End Building BOD	14OCT02		31DEC02
Linac Building						
CFLNEN	CF		Linac Tunnel Title I & II	16SEP99*	27JUN01	
CFLNEN5	CF		Start Linac Tunnel Construction	04JUN01*		
CFLNCN	CF		Linac Tunnel Construction	04JUN01*	02DEC02	
CFLNBOD	CF		Linac Tunnel BOD - 225 MeV		14OCT02*	
CFLNBOD2	CF		Linac Tunnel BOD - 600 MeV		05NOV02	
CFLNBOD5	CF	1B-04	Linac Tunnel BOD - 1000 MeV		02JAN03	30APR03
Klystron Building						
CFKLEN	CF		Klystron Hall Title I & II	16SEP99*	01JUN01	
CFKLCN	CF		Klystron Hall Construction	22OCT01*	14JAN03	
CFKLBOD	CF		Klystron Building BOD - 225 MeV		14OCT02*	
CFKLBOD5	CF		Klystron Building BOD - 1000 MeV		14JAN03	
Dump Buildings						
CFDUEN	CF		Title I & II	10JAN00*	30AUG01	
CFDUCN	CF		Construction	01MAR02*	24APR03	
CFDUBODLN	CF		Linac Tuning Dump Building BOD	02JUN03		
CFDUBODEX	CF		Ring Dump Building BOD - Extraction	01DEC03		
CFDUBODIN	CF		Ring Dump Building BOD - Injection	01DEC03		
HEBT Tunnel						
CFHEBTEN	CF		Title I & II	15SEP99*	02AUG01	
CFHEBTCN	CF		Construction	30NOV01*	10APR03	
CFHEBTCN10	CF		HEBT TUNNEL TRUCK ENTRANCE AVAILABLE		14JAN03	
CFHEBTBOD	CF		HEBT Tunnel BOD	10APR03		
HEBT Service Building						
CFHESVEN	CF		Title I & II	16SEP99*	17AUG01	
CFHESVCN	CF		Construction	03SEP02*	28MAR03	
CFHESVBOD	CF		HEBT Service Building BOD	28MAR03		
Ring Tunnel						
CFRIEN	CF		Title I & II	15SEP99*	01AUG01	



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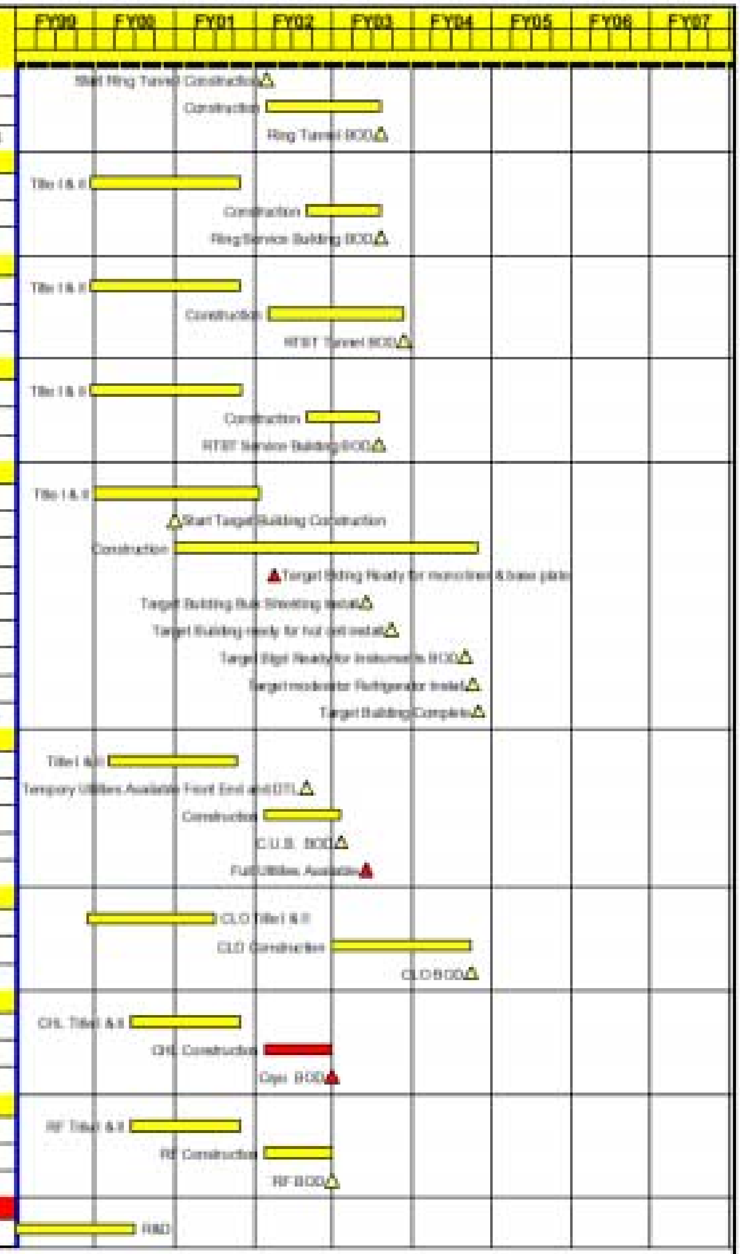
Activity ID	RESP	PEP ID	Activity Description	Early Start	Early Finish	PEP Date
CFRIENS	CF		Start Ring Tunnel Construction	30NOV01*		
CFRICN	CF		Construction	30NOV01	08MAY03	
CFRIBOD	CF	1B-05	Ring Tunnel BOD	08MAY03		01AUG03
Ring Service Building						
CFRISVEN	CF		Title I & II	15SEP99*	02AUG01	
CFRISVCN	CF		Construction	06JUN02*	09MAY03	
CFRISVBOD	CF		Ring Service Building BOD		09MAY03	
RTBT Tunnel						
CFRTBTEN	CF		Title I & II	15SEP99*	02AUG01	
CFRTBTCN	CF		Construction	11DEC01*	29AUG03	
CFRTBTBOD	CF		RTBT Tunnel BOD	29AUG03		
RTBT Service Building						
CFRTSVREN	CF		Title I & II	15SEP99*	06AUG01	
CFRTSVRCN	CF		Construction	06JUN02	30APR03	
CFRTSVRBOD	CF		RTBT Service Building BOD	30APR03		
Target Building						
CFTGEN	CF		Title I & II	05OCT99*	26OCT01	
CFTGENS	CF		Start Target Building Construction	02OCT00*		
CFTGCN	CF		Construction	02OCT00	06AUG04	
CFTG	CF		Target Blding Ready for mono liner & base plate	02JAN02*		
CFTGRFE1	CF		Target Building Bulk Shielding Install		03MAR03*	
CFTGRFE2	CF		Target Building ready for hot cell install		01JUL03*	
CFTGBOD3	CF		Target Bigd Ready for Instruments BOD	04JUN04*		
CFTGRFE3	CF		Target moderator Refrigerator Install		05JUL04*	
CFTG1	CF	2-23	Target Building Complete	06AUG04		31DEC04
Central Utilities Building						
CFCUBEN	CF		Title I & II	07DEC99*	13JUL01	
CFCOUUT	CF		Tempory Utilities Available Front End and DTL		03JUN02*	
CFCUBCN	CF		Construction	28NOV01*	06NOV02	
CFCUBBOD	CF		C.U.B. BOD		06NOV02*	
CFCUB1	CF		Full Utilities Available		06MAR03	
Central Lab & Office Building						
CFCLOEN	CF		CLO Title I & II	01SEP99*	02APR01	
CFCLOEN10	CF		CLO Construction	01OCT02*	30JUN04	
CFCLOEN15	CF		CLO BOD		30JUN04	
CHL Building						
CFCRYEN	CF		CHL Title I & II	14MAR00*	27JUL01	
CFCRYCN	CF		CHL Construction	28NOV01*	24SEP02	
CFCRYBOD	CF		Cryo BOD		24SEP02	
RF Building						
CFSRFEN	CF		RF Title I & II	14MAR00*	27JUL01	
CFSRFCN	CF		RF Construction	28NOV01*	24SEP02	
CFSRFBOD	CF		RF BOD		24SEP02	
Global Controls						
CTRD	CO		R&D	01OCT98	30MAR00	



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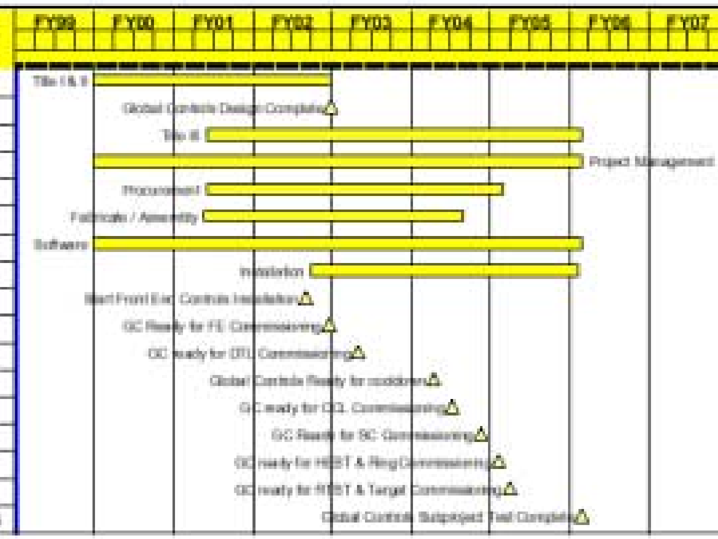
Activity ID	RESP	PEP ID	Activity Description	Early Start	Early Finish	PEP Date
CTEN	CO		Title I & II	01OCT99*	01OCT02	
CTEN5	CO	2-25	Global Controls Design Complete		01OCT02	31JAN03
CTT3	CO		Title III	01MAR01*	30NOV05	
CTPM	CO		Project Management	01OCT99*	30NOV05	
CTPR	CO		Procurement	01MAR01*	30NOV04	
CTFB	CO		Fabricate / Assembly	22FEB01*	28MAY04	
CTSW	CO		Software	01OCT99*	30NOV05	
CTIN	CO		Installation	28JUN02	09NOV05	
CTIN15	CO	2-26	Start Front End Controls Installation	03JUN02		31OCT02
CTIN02	CO		GC Ready for FE Commissioning	17SEP02		
CTIN04	CO		GC ready for DTL Commissioning	30JAN03		
CTIN18	CO		Global Controls Ready for cooldown		16JAN04	
CTIN06	CO		GC ready for CCL Commissioning	05APR04		
CTIN08	CO		GC Ready for SC Commissioning	19AUG04		
CTIN10	CO		GC ready for HEBT & Ring Commissioning	08NOV04		
CTIN12	CO		GC ready for RTBT & Target Commissioning	30DEC04		
CTIN5	CO	2-27	Global Controls Subproject Test Complete		30NOV05	01MAY06



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