

CLS Cryogenic System Specification

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1 INTRODUCTION

1.1 Purpose

This document specifies the requirements for the Canadian Light Source (CLS) cryogenic system needed to supply liquid helium (L He) for use with the CLS superconducting RF cavity.

The Canadian Light Source requires a cryogenic system to supply L He to the superconducting acceleration module for the CLS storage ring. The cryogenic system is to be designed, fabricated, delivered to the CLS site, tested, and installed for use with the storage ring. The cryogenic system shall be designed with the flexibility to allow for expansion of its capacity in the future.

1.2 Scope

The cryogenic system includes the refrigerator/liquefier with a helium purifier(s), compressor(s), oil-removal/filter system, L He storage dewar, buffer tank (if required), gas storage tank, cryogenic distribution system, He gas purity monitoring system, He gas inventory (option), and emergency power system (option) required to deliver the cryogenes to the cavity location and recover the evaporates. The Proponent shall also supply any other components required to meet the requirements outlined in this specification or required to provide a complete and operating system.

This specification details the requirements for the design, fabrication, supply, and testing of the amplifier system. This work includes, but is not limited to:

- Materials
- Equipment
- Commercial components
- Detailed drawings
- Fabrication
- Assembly
- Testing and Inspections
- Quality Assurance /Quality Control documentation
- Delivery to site
- Installation
- Commissioning and Owner Training
- Initial Operation

1.3 Background

The Canadian Light Source, CLS, is a national facility under construction on the University of Saskatchewan campus in Saskatoon, Saskatchewan. This facility will be a 3rd generation synchrotron light source, which will produce a high intensity source of infrared, visible, ultraviolet and x-ray radiation.

This facility will use a 500 MHz superconducting (SC) RF acceleration module installed into the CLS storage ring. The RF acceleration module uses a SC niobium cavity immersed in a bath of L He at 4.5 K to supply sufficient power to the electron beam to make up for power losses to synchrotron light in the

dipoles and insertion devices, as well as power that is coupled through the ring impedances and dissipated in the walls of the vacuum chamber. The design current for the CLS storage ring is 500 mA.

The storage ring will be capable of circulating electrons with energies of up to 2.9 GeV. At this energy, the expected power loss of the beam will be approximately 110 kW per 100 mA of circulating current. The CLS has decided to meet its design current through a two-stage approach. All systems, excluding the RF system and the associated refrigeration plant, will be designed for operation in excess of 500 mA. In phase one, the RF system will be sized to allow for a minimum of 200 mA of circulating beam. Currently, the SC cavity design that is to be used at the CLS, has been demonstrated to deliver in excess of 260 kW of power to the beam, with a concerted effort underway to reach higher power levels. Thus, the phase one design goal can be accomplished with one SC acceleration module installed, but phase two may require two modules. It may be possible in the future to approach phase two current goals with only one SC acceleration module. The CLS is looking to install enough refrigeration capacity to easily service one SC acceleration module running at high fields with a large dynamic heat load. The design should be kept flexible enough to easily expand its capacity in the future to service two cavities operating at slightly lower dynamic heat loads.

Inside the SC acceleration module is a niobium RF cavity that operates immersed in a liquid helium (L He) bath surrounded by a liquid nitrogen (L N₂) heat shield. Nominally, the helium vessel is full at 550 litres of helium, although 410 litres of helium is all that is required to fully cover the niobium cavity. The L He level is controlled to a level fluctuation of less than +/- 1%. Layers of super-insulation are wrapped around the L He vessel and the heat shield to reduce the static cryogenic heat losses below those obtainable by vacuum isolation alone. Stainless steel thermal transitions are attached to each side of the cavity along the beam axis. The thermal transition cross sections are round and fluted, matching the cross section of the niobium cavity where they are attached. L N₂ flow of up to 15 l/hr is used to cool the intercepts on all the thermal transition pieces between the L He system and the room temperature components. Cold helium boil-off gas is used to cool the waveguide's thermal transition heat exchanger section at a nominal flow rate of 0.18 g/s. The waveguide heat exchanger is connected to an in-vacuum, double-elbow bend of waveguide.

External to the cryostat, the beam axis consists of two RF higher-order-mode (HOM) absorbers attached to the longitudinal thermal transition pieces. The HOM damper on the fluted-beam-tube side is connected to a sliding joint, a transitional taper, and a vacuum gate valve. The round-beam-tube side is connected to a transitional taper and another vacuum gate valve. Vacuum pumps are located at the location of the transitional tapers.

Bellows are used to allow for the differential expansion of the niobium and stainless steel and dimensional tolerances, and provide the flexibility for assembly and for frequency tuning of the cavity. Attached to the fluted end of the RF cavity module is a tuner, which varies the resonant frequency of the cavity by mechanically stretching it. A pressure compensation arrangement is used to minimize any variations of the cavity resonant frequency due to helium vapour pressure fluctuations. The He vapour pressure is maintained to better than +/-300 Pa. It is very important that the steady state suction pressure of the compressor be with well within this limit (+/-300 Pa).

Further background information can be seen in the attached report "CLS RF Design Note" [1]

2 CRYOGENIC SYSTEM GLOBAL REQUIREMENTS

2.1 Functional Requirements

- 2.1.1 The Proponent shall supply one complete “turn-key” cryogenic system used to produce L He to be delivered to the location of the RF cavity located in the CLS storage ring.
- 2.1.2 All large components of the cryogenic system shall be equipped with crane attachments for lifting the components. The gravitational centre of all large components shall be marked.
- 2.1.3 If required, the Proponent shall supply all cooling water supply and return manifolds for the system.
- 2.1.4 Unless otherwise stated, the Proponent shall supply all monitoring transducers (e.g., temperature, flow, pressure and fluid levels) required for adequate monitoring of the system.
- 2.1.5 Provisions shall be made for remote control and monitoring by the CLS control system. The Proponent shall allot a minimum of 10 % spare space for additional monitoring points that may be required in the future operation of the cryogenic system. The spare space allocated for future expansion shall be stated by the Proponent.
- 2.1.6 The cryogenic control system shall be designed to interface with the CLS Distributed Control System (DCS). The interface may use EPICS communication protocols, RS-232, RS-485, Modbus Plus, or Profibus. The interface shall be reviewed and accepted by the CLS before being implemented.
- 2.1.7 If a Programmable logic controller (PLC) is used, it should be based on a Modicon Momentum, Siemens S7/300 or Siemens S7/400 controller. All PLC control software programs shall be provided by the Proponent, in source form as well as installed on the PLC hardware.
- 2.1.8 Controller hardware and software must be reviewed and accepted by the CLS to verify adherence to the CLS standard control protocols and standards.
- 2.1.9 The cryogenic system shall be configured to allow for convenient purging and testing of the system.
- 2.1.10 The cryogenic system shall be designed with the flexibility to allow for future expansion of its capacity.
- 2.1.11 A local emergency off switch with mechanical latching shall be provided for the cryogenic system. This system shall employ redundant and independent means of shutdown. The cryogenic system shall have a small number of clearly defined operational states. These states shall allow for monitoring of interlock status through all states.
- 2.1.12 The cryogenic system shall remain safe for all personnel and equipment under the conditions of a system power failure. The Proponent is strongly encouraged to base its design on the likelihood of more than 3 full system power failures per year. The Proponent shall make specific reference to the CLS as to the limitations/strengths of the proposed system under power failure conditions, and recommend enhancements that may be implemented to minimize problems.

2.2 Performance

- 2.2.1 The cryogenic system shall be designed to be capable of continuous operation at the maximum installed cooling power.
- 2.2.2 The cryogenic system shall be capable of delivering a minimum of 235 W of cooling via the delivery of L He to the location of the SC RF cavity in the storage ring. Extra capacity will be required to make up for heat losses in the distribution lines and neck cooling losses of any dewars. This is based on the following assumptions:
 - 1. Q_0 of the cavity is $> 6 \times 10^8$.
 - 2. Q_{external} of the cavity is 2×10^8 .

3. Cavity voltage is 2.8 MV to permit 400 mA operation with one cavity with a Q_{external} of 2×10^8 .
4. 1), 2), and 3) above yield a dynamic heat load of the cavity of 147 W.
5. The static heat leak is 35 W.
6. The valve box and flexible VJ piping near the location of the cavity adds 30 W of cooling required.
7. About 0.18 g/s of boil-off gas is used to cool down the L He heat exchanger portion of the waveguide run into the cryostat. The cooling requirements required to supply the L He heat exchanger gas is an additional 20 W.

The cooling requirements are strongly influenced by the Q_0 of the cavity, and the RF voltage of the cavity. As an example, operation at 2.4 MV results in a dynamic heat load of 108 W. If the Q_0 of the cavity is $> 1 \times 10^9$, the dynamic heat load will fall further to 65 W. If future expansion of the cryogenic system is required to facilitate the installation of a second RF cavity (see section 1.3), the two cavities will run at lower fields. Safely we can assume both cavities running with dynamic heat loads of 90W in this case.

- 2.2.3 The cryogenic system shall be capable of accumulating and of storing a minimum of 2000 litres of L He to be delivered to the RF cavity cryostat. The delivery system shall be capable of transporting a minimum of 300 litres/hour of L He from storage to the location of the RF cavity. Typically a L He transfer rate of 200 to 250 litres/hour for a duration of 6 hours is required to rapidly cool down the niobium cavity and avoid the "Q-virus". The Q of the cavity can be drastically degraded by allowing the cavity to remain at a temperature range between 60 and 150K for a period of over an hour or more if there is any hydrogen dissolved in the niobium.
- 2.2.4 To ensure a rapid cool-down time for the niobium cavity to avoid the effects of the "Q-virus" mentioned above, the refrigerator/liquefier should have a liquefying capacity of greater than 75 litres/hour as measured by a liquid helium level sensor in the main storage dewar.
- 2.2.5 The system shall be able to operate continuously at output capacity levels ranging from 0 to 100% of the installed cooling power level.
- 2.2.6 The cryogenic system shall be equipped with a He gas recovery system with a recovery gas purity of 99.995% or better.
- 2.2.7 Unless explicitly stated, all control and monitoring of the cryogenic system shall conform to the "CLS Design Specification Control System Overview" [2].
- 2.2.8 The design floor load under any component should not exceed the following values:
 1. The floor slab in the Cryogenic room: 4788 Pa (100 lbs/sqft)
 2. The main hall floor slab: 28730 Pa (600 lbs/sqft)
 3. The perimeter main hall slab: 4788 Pa (100 lbs/sqft)
 4. Main hall area over the basement: 3830 Pa (80 lbs/sqft)
 5. Roof of the storage ring shielding tunnel: 4788 Pa (100 lbs/sqft)
 6. The "Gas Farm" slab external to the building has a varying load capacity due to the pile configurations underneath it. The east half of the slab (nearest the building) has a load capacity of 90 tonnes, while the west half of the slab (furthest away from the building) has a load capacity of 110 tonnes.

Floor loading in excess of these values shall be subject to review and acceptance by the CLS.
- 2.2.9 All control and interlock signal inputs shall be 24 V DC and shall require less than 50 mA drive. Interfaces with CLS equipment shall be designed to work with external optical isolators.
- 2.2.10 All control and interlock signal outputs shall be 24 V DC and shall be able to switch a minimum of 50 mA and use optical or some other form of isolation.

2.3 Safety and Environmental

- 2.3.1 The general layout of the main floor of the CLS can be seen in the diagram: 2D General Plan View Technical Details, BLDG/ME/0035100 REV. O. The space available for a remotely located cryogenic system and the space available on the surface of the storage ring tunnel can be seen in the diagram: Cryogenic Layout Proposal, BLDG/PPL/CRYO/0038300 Rev. C and its associated drawings (see section 6.1).
- 2.3.2 The cryogenic system shall be capable of operation in an ambient temperature range of 10°C to 40°C. The Proponent shall provide an estimate as to the amount of heat that the proposed system will supply into the main cryogenic room, which is equipped with very limited cooling. The normal ambient temperature of the main floor area at the CLS is 23°C. The expected temperature stability of the main floor will be +/- 1° C during normal operation.
- 2.3.3 The main CLS building and the cryogenic room are equipped with an overhead sprinkler system. All components of the cryogenic system shall be installed in a "weather-resistant" condition or housed in "weather-resistant" cabinets that are capable of withstanding modest exposure to water or other fluids.
- 2.3.4 The components shall be able to withstand a relative humidity range of 0 % to 90%. The expected relative humidity limits under operation are from 25% during the winter months and a maximum of 50% during the summer months. The expected relative humidity range for components under storage will be the same as those for operation.
- 2.3.5 Any equipment located external to the building envelope will be designed for "outside" use. Over the course of one calendar year, the CLS may encounter temperatures ranging from -40°C to 40°C. All equipment that is to be used outside shall be designed to operate in a temperature range of -50°C to 60°C.
- 2.3.6 No components of the cryogenic system shall induce a vibration source to the floor greater than 0.4 microns at frequencies less than 100 Hz. All equipment/structures shall conform to the BKL report "Vibration Isolation Mechanical Equipment" [3]. The Proponent shall be responsible for the correction of any vibration problems resulting from its equipment for a period of up to 6 months after final acceptance.
- 2.3.7 If required, low conductivity cooling water (LCW) will be supplied by the CLS. The supply water will have a conductivity of less than 600 $\mu\text{S}/\text{m}$.
- 2.3.8 The Proponent shall specify the expected consumption of low conductivity water for the normal operation of the cryogenic system. The Proponent shall supply the CLS with its LCW consumption requirements within 80 days of the award of the contract.
- 2.3.9 The Proponent should limit the consumption of low conductivity water to less than 2000 l/hr.
- 2.3.10 Where water-cooling is required, the cooling system shall operate at an input pressure of 1 MPa.
- 2.3.11 The pressure drop to achieve the required flows in the cooling water circuits shall not exceed 800 kPa.
- 2.3.12 Any cooling circuits should be designed so that under normal operation the velocity of the cooling water is maintained in the transition zone between laminar and turbulent flow. This corresponds to roughly 1.5 to 2 m/s.
- 2.3.13 Supply temperature of the LCW will be nominally between 27°C to 33°C. The maximum water inlet temperature is 40°C and the minimum water inlet temperature is 10°C.
- 2.3.14 The maximum temperature rise in the water-cooling circuits should be kept below 20 K.
- 2.3.15 The Proponent shall notify the CLS of any special cooling water requirements at the time of the bid. The Proponent shall supply, in detail its cooling water requirements at the time of the bid. This

shall include, but not be limited to, acceptable inlet temperature ranges, expected temperature rises and pressure drops of all cooling circuits

- 2.3.16 All small tubing water connections shall be American standard Swagelok fittings. All large water tubing shall use NPT threads.
- 2.3.17 Liquid nitrogen (L N2) will be supplied by the CLS. The CLS will install a supply point near the location of the refrigerator/liquefier cold box. The L N2 interface shall be agreed upon between the CLS and the successful Proponent.
- 2.3.18 The Proponent shall specify the expected consumption of L N2 for the normal operation of the cryogenic system. These estimates should cover the initial installation and the expected consumption after a cryogenic upgrade to service two acceleration modules. As an example, L N2 supply to the refrigerator/liquefier may be added at a later date to allow for a system upgrade
- 2.3.19 The Proponent should limit the consumption of L N2 to less than 200 l/hr.
- 2.3.20 The Proponent shall supply the CLS with its L N2 consumption requirements within 80 days of the award of the contract.
- 2.3.21 The cryogenic system shall be designed such that no component damage or personnel hazard shall result from any combination of a loss of instrument air, cooling water, L N2 supply or a power failure.
- 2.3.22 AC input power will be supplied through a CLS-installed, external, manually operated disconnect switch, which is normally closed.
- 2.3.23 All power supplies with an input supply requirement exceeding 2.5 kVA shall incorporate circuitry to reduce harmonic current components on the supply lines. As a minimum, this circuitry shall include the equivalent of 12 pulse rectification.
- 2.3.24 The electrical power supplied by the CLS will be 60 Hz AC. Each load connection shall be one of the voltage levels listed below and not exceed the current limits given in Table 1.

Table1: Load Connections

RMS voltage (V,+/- 10 %)	Single or Three Phase	Maximum RMS current (A)
120	Single	15
208	Single	15
208	Three	30
600	Three	1900

Line voltage will exhibit instantaneous (faster than one millisecond) fluctuations of +/- 1.5 % and gradual variations of +/- 10 %. Brownout conditions involving instantaneous drops and restorations of 10 % are also observed.

- 2.3.25 The Proponent shall describe in detail the electrical power requirements at the time of the bid.
- 2.3.26 Every effort shall be made through careful design to keep the acoustic noise levels well below 60 dB. Noise levels above 60 dB limits effective communication and warning sounds such as sparking are masked. In instances where these noise specs cannot be reached, the Proponent shall state this to the CLS in the proposal. The Proponent may quote on the cost of additional noise abatement as an option.
- 2.3.27 In general, the cryogenic system can be set up and operated according to standard industrial practices. However, maintenance and testing in some cases may be expedited by deviating from standard practices provided extra precautions are taken to reduce hazard to an acceptable level before these deviations are permitted.

- 2.3.28 All volumes that have the ability to be isolated and contain liquid cryogenics, or have the potential to result in over-pressures, shall be equipped with suitable relief valves. All such valves shall be easily accessible for inspection and resetting.
- 2.3.29 All relief valves looking at an area containing super-insulating materials shall be properly screened to protect from possible blockage.
- 2.3.30 All equipment must be housed in a suitable enclosure to prevent contact by personnel with high voltage or other dangerous components. These enclosures may be one of the following:
1. Permanent completely enclosed cabinets
Permanent cabinets should be constructed of metal panels with plastic or safety glass for windows when necessary. They should be constructed so that it is impossible to touch high voltage from the outside with a thin conductor of reasonable length. These cabinets must provide protection for uninformed personnel and be suitable for unattended operation. Doors must be fitted with redundant and independent interlocks.
 2. Permanent walk-in enclosures
Walk-in enclosures may be used for equipment that occupies large areas. The walls of such enclosures must be a minimum of 2 m high and should be higher than the equipment. They may be constructed of perforated metal with openings smaller than 1 cm or have solid walls with safety glass or plastic windows to allow for a clear view of the inside. Access doors must be fitted with redundant and independent interlocks. Local control panels are required outside the enclosure but close to it so that the operator can readily check that no one is inside during operation. They must provide protection for uninformed personnel and be suitable for unattended operation.

Where exposed high voltage is present, cabinets or walk-in enclosures shall be equipped with grounding hooks to allow for the safe discharge of high voltage on equipment that may retain a charge. These grounding hooks should be positioned to prevent access without the hooks being moved.

2.4 Applicable Codes, Standards and Procedures

- 2.4.1 The following documents can be considered as part of this specification. All equipment shall be built in strict accordance with the following standards:
1. CSA Canadian Electrical Code 1998 Safety Standards for Electrical Installations [4]
 2. B51-97 Boiler, Pressure Vessel, and Pressure Piping Code (CSA) [5]
 3. ASME Boiler and Pressure Vessel Code Section VIII divisions 1 2 and 3 [6]
 4. B52-99 Mechanical Refrigeration Code [7]
 5. IEC 61508-Functional Safety of Electrical/Electronic/Programmable Electronic Systems – Parts 2 and 3 [8] shall be applied to any computer system performing a personnel safety function.
 6. The Saskatchewan Occupational Health and Safety Act and Regulations [9].
- 2.4.2 Unless otherwise specified, the issue date or revision level shall be that in effect on the date of the Invitation to Quote. Exceptions to these standards shall be reviewed and accepted by the CLS.

2.5 Quality Assurance

- 2.5.1 The Proponent shall maintain and apply a quality assurance program compliant with ISO-9001 for the design, manufacture and testing of all components.
- 2.5.2 The guidelines of ISO-9000-Part 3 shall be followed for software.

2.6 Inspection, Testing and Commissioning

- 2.6.1 The Proponent shall be responsible for the installation of the cryogenic system. The manpower for the installation shall be provided by the Proponent. The Proponent should try and incorporate the use of CLS staff in the installation process during tasks that will be related to the long-term maintenance of the system. The Proponent shall supply a list of the CLS personnel (along with their required skills) it feels should be made available to participate in the installation process at the time of the bid.
- 2.6.2 The CLS main hall is equipped with a 10 tonne overhead crane. The crane has coverage extending from the loading area to drop areas above the booster ring and storage ring tunnels. The CLS has a pallet jack rated for 2000 kg (4500 lb). The Proponent must advise the CLS if additional handling equipment is required.
- 2.6.3 Installation and testing shall conform at all times to the local safety codes, including the Saskatchewan Occupational Health and Safety Act and Regulations and the CLSI Policies and Procedures.
- 2.6.4 The CLS reserves the right to have access to the Proponent's facility at any time during the fabrication and testing procedures. The CLS shall have the right to witness any manufacturing or testing procedures upon request. When requested, the Proponent shall provide a minimum of 21 days notice in advance of any test date to allow for the CLS to make the necessary travel arrangements.
- 2.6.5 The CLS reserves the right to require additional or more extensive tests to be conducted in the event of marginal design or performance.
- 2.6.6 The Proponent shall formulate acceptance test procedures for all components and will provide the facility and instrumentation to perform all relevant tests to ensure compliance with this specification. The acceptance test procedures shall include but not be limited to all of the testing procedures specifically outlined in this document.
- 2.6.7 All items purchased or manufactured by a subcontractor used in the work shall be clearly identified to the CLS.
- 2.6.8 Review and acceptance of the CLS shall not release the Proponent from its responsibility to correct errors, oversights and omissions to ensure conformance to the specifications in this document.
- 2.6.9 Refer to Section 5 for Cryogenic Acceptance Tests

2.7 Reliability and Maintainability

- 2.7.1 All elements of the cryogenic system shall be designed and manufactured with strong consideration for both reliability and serviceability. Access to all external connection points must be incorporated into the overall design.
- 2.7.2 The Proponent shall supply documentation to the CLS outlining the expected maintenance requirements and schedules for all major subsystems of the cryogenic system. A list of recommended spare parts, along with cost information, shall be supplied by the Proponent.
- 2.7.3 The cryogenic system shall be designed and constructed to be in continuous use with very limited maintenance periods throughout the year. Major maintenance periods will be scheduled twice a year and have a duration of approximately 10 working days. Weekly maintenance periods will likely be scheduled to last for one 8 hour time period. Weekly maintenance should not be required for the cryogenic system. The total maintenance time annually should not exceed 6 man-days.
- 2.7.4 All components shall have a minimum mean time between failure (MTBF) of 40,000 hours in the operational environment at the CLS as outlined in this specification.
- 2.7.5 The cryogenic system shall be designed and constructed in such a way as to supply access to any system components that are expected to fail in the normal operating environment. This will facilitate easy and timely replacement of such components upon failure or during scheduled

maintenance periods. Any units that need to be removed from cabinets or racks for service shall be mounted on slides. The Proponents drawings shall show the positions of the major components in each subsystem.

- 2.7.6 The cryogenic system shall be designed and constructed with an expected operational lifetime of greater than 20 years.
- 2.7.7 All threaded mechanical fasteners should be American Standard Thread. The use of metric standards is negotiable with the CLS. If metric standards are used, additional spare nuts and bolts shall be provided by the proponent.

2.8 Layout

- 2.8.1 The area available for installing the cryogenic system can be seen in the attached diagram Cryogenics Layout Proposal, BLDG/PPL/CRYO/0038300 Rev. C and its associated drawings. Deviations from this specification shall be subject to review and acceptance by the CLS. Access to the cryogenic room is limited and will require appropriate equipment sizing. Current access is restricted by existing equipment to a corridor measuring roughly 1200 mm wide by 2100 mm high. Access to the cryogenic room may be enhanced through partial demolition of an existing wall. A corridor of roughly 2150 mm width by 2400 mm height could be established by this method. Entering the Cryogenic room by this method requires an elevation drop of 400 mm. The Proponent shall identify its access needs to the CLS at the time of the bid.
- 2.8.2 The location and details of the connections to the valve box can be seen in diagrams 1) SR1 RF Straight Section General Plan View, SR1/ME/RF/0037100 Rev. E, 2) SR1 RF Cavity Tunnel Cross Section, SR1/PPL/RF/0034304 Rev. G, 3) Cold Valve Box for 1 Cavity Cryostat, 1130-40.00.01 Rev. B, 4) Flange Connections Mc-Transfer Line/GHe,warm Cold Valve Box, 1130-40.00.03, 5) Details Mc-Transfer Line/GHe,warm Cold Valve Box, 1130-40.00.04.

2.9 Other Requirements and Constraints

- 2.9.1 The Proponent shall supply complete documentation of all components and subsystems contained in the cryogenic system. This documentation shall include but be not limited to the following:
 - 1. Users/operation manual for the cryogenic system. These manuals shall contain, but not be limited to: specifications, operating instructions, hook-up instructions, circuit diagrams, block diagrams, PLC programs (also provided on CD-ROM), maintenance procedures (both operational and preventative), component data sheets, normal adjustments and calibration set up procedures.
 - 2. A final parts list along with a list of recommended spare parts and their cost information.
 - 3. A complete set of electrical and mechanical as-built drawings shall be supplied for each subsystem.
 - 4. Layout diagrams of the full cryogenic system.
 - 5. Mechanical layout diagram of all distribution lines including cryogenic lines and He gas lines to the gas storage area.All documentation should conform to the "CLS Documentation Specification" [10]. Electrical diagrams should be presented in Orcad® 9.2 or Autocad® R14 or Autocad® 2000 or Cadsoft Eagle 3.5. Hardcopies shall be provided of all documentation along with copies on CD-ROM.
- 2.9.2 The Proponent shall provide the CLS with electronic copies of all custom developed source code, PLC programming and embedded logic in source and binary format on CD-ROM or equivalent media.
- 2.9.3 All measurement results shall be filed in hardcopy, on magnetic or optical media, and archived at the Proponent's location in duplicate.
- 2.9.4 One set of measurements in hardcopy and an electronic copy on magnetic media or optical (CD-ROM) shall be sent to CLS after all major assembly and measurement procedures. Frequent data transfer is encouraged.

- 2.9.5 The implementation of this specification is subject to a design review. The CLS reserves the right to hold this design review at the Proponent's facility prior to the start of fabrication. At this time, an agreement will be reached on drawings, data sheets, component specifications, manufacturing procedures, testing procedures, and production schedules. The CLS shall be notified by the Proponent of any changes, and all changes are subject to subsequent review and acceptance by the CLS.
- 2.9.6 The Proponent shall provide a detailed schedule for completing the work that is outlined in this specification. The CLS requires monthly updates to this schedule to track the Proponents progress. This schedule shall be accompanied by a monthly progress report to be received within the first 5 working days of each calendar month.
- 2.9.7 All equipment/structures shall be labelled with a unique serial number with details to be worked out with the CLS.
- 2.9.8 The Proponent shall assume the responsibility to evaluate and verify the feasibility of the proposed system before signing the contract with the CLS.
- 2.9.9 The Proponent shall supply adequate training for the operation and servicing of the proposed cryogenic system. This training shall include the following:
1. Supply of an operating manual (minimum 6 copies).
 2. Training to a minimum of 3 CLS staff on Cryogenic operation through all operating modes outlined in section 4. During this training, the Proponent shall demonstrate operation of the cryogenic plant following the procedures outlined inside the operation manual.
 3. Maintenance lists.
 4. Training of CLS technical staff on the replacement of common maintenance items. When possible, the Proponent shall allow for CLS staff to replace parts under the Proponents supervision as part of the training.
 5. Supply of trouble shooting checklists and instruction of its application during abnormal plant operation.

3 CRYOGENIC SYSTEM COMPONENT REQUIREMENTS

3.1 Functional Requirements

REFRIGERATOR/LIQUEFIER:

- 3.1.1 The refrigerator shall be a turbine-based refrigerator due to its increased reliability and vibration characteristics over a piston-based refrigerator.
- 3.1.2 The Proponent shall supply and implement all interlocks required by the refrigerator/liquefier manufacturer.
- 3.1.3 The refrigerator/liquefier cold box should be equipped with a cryogenic purifier(s), to freeze contamination in the impure gas stream. This will also allow for back flushing of contaminants without warming of the entire refrigerator.
- 3.1.4 The Proponent should consider using dual full-flow cryogenic absorbers in its cryogenic purifier system to allow for switching over from one absorber to the other without disrupting the cold-box operation. In this configuration, the cryogenic plant shall be able to automatically switch from using a saturated to a non-saturated absorber while the system remains online. The operational state of the absorbers shall be relayed to the user. The Proponent shall outline the re-generation procedures for the cryogenic absorbers. The Proponent should also consider implementing automatic regeneration of the off-line absorbers.
- 3.1.5 The cryogenic purifier system shall be subject to review and acceptance by the CLS.
- 3.1.6 All high-pressure piping and equipment in the refrigerator/liquefier shall meet or exceed the pressure rating of the main compressor set.

- 3.1.7 All valves shall be low heat loss valves designed for use with L He.
- 3.1.8 All valve seals shall be easily replaceable without breaking vacuum of the refrigerator/liquefier cold box.
- 3.1.9 A removable mechanical filter shall be installed in front of the refrigerator/liquefier high-pressure inlet.
- 3.1.10 The vacuum vessel of the refrigerator/liquefier cold box shall be equipped with a relief device capable of handling the full compressor flow in the case of failure of any high-pressure or low-pressure component. Under such a failure, the internal components of the cold box shall not collapse.

TRANSFER LINES:

- 3.1.11 The main transfer line shall be a multi-channel transfer line that contains channels for L He supply, L N₂ supply, and cold He gas return. This line shall attach to a valve box located on the roof of the storage ring shielding tunnel above the location of the superconducting acceleration module. Details of the valve box and the valve box location are shown in the diagrams figures 1) SR1 RF Straight Section General Plan View, SR1/ME/RF/0037100 Rev. E, 2) SR1 RF Cavity Tunnel Cross Section, SR1/PPL/RF/0034304 Rev. E, 3) Cold Valve Box for 1 Cavity Cryostat, 1130-40.00.01 Rev. B, 4) Flange Connections Mc-Transfer Line/GHe,warm Cold Valve Box, 1130-40.00.03, 5) Details Mc-Transfer Line/GHe,warm Cold Valve Box, 1130-40.00.04, 6) Flow Diagram with Diagnostic Elements for Valve Box, 1130-40.00.02 Rev. A.
- 3.1.12 All transfer lines shall be equipped with adequate “keep-cold” devices or “phase separators” to eliminate the flow of slugs of gas in the transfer lines. The Proponent shall supply one “keep-cold” device to be located on the top of the valve box. The bayonet connections shall be coordinated between the Proponent and the CLS.
- 3.1.13 The Proponent should use reusable gaskets on the outer vacuum jacket. This will avoid the problem of having to disconnect all inner lines to insert a new gasket for the outer vacuum jacket.
- 3.1.14 The Proponent shall work together with the CLS to establish the routing of the multi-channel transfer line used to transfer L He and L N₂ from the main He dewar to the cryogenic valve box for distribution to the SC RF module and to return the cold He return gas from the valve box.
- 3.1.15 All He gas transfer lines should be high quality stainless steel.
- 3.1.16 All L N₂ lines should be high quality stainless steel and be vacuum jacketed.
- 3.1.17 The Proponent shall supply all L N₂ transfer lines between the CLS provided cryogenic valve box and the CLS supply point located near the location of the refrigerator/liquefier cold box. The CLS will supply the L N₂ transfer line from the valve box to the SC RF module. Details of the supply point shall be worked out between the Proponent and the CLS.
- 3.1.18 All piping shall be designed so as to eliminate condensed water and the forming of ice along the piping surfaces.
- 3.1.19 Piping shall be designed to eliminate problems associated with thermal deformation stresses resulting from warming or cooling of pipe runs. The Proponent shall incorporate adequate flex sections or sections of flexible piping so that rigid piping sections are not subject to thermal deformations. The Proponent shall supply flex sections (or other methods of mechanical and vibrational isolation) spanning the concrete isolation joint located between the outer building and the main building floor slab.
- 3.1.20 The Proponent shall do calculations to determine the expected pressure drops on the suction and discharge lines between both the main compressor and the refrigerator/liquefier and the recovery compressor and the refrigerator/liquefier. The Proponent shall provide these to the CLS at the time of the bid.
- 3.1.21 Any connections in the multi-channel transfer line requiring welded connections shall be clearly indicated by the Proponent. The Proponent shall be responsible for all such welds.

- 3.1.22 Transfer lines shall be equipped with spare ports with shut-off valves to allow for future gauges and sensors to be installed. This shall include, but not be limited to, the discharge and suction lines, and the high-pressure lines on the refrigerator/liquefier. The implementation of these extra ports shall be coordinated between the Proponent and the CLS.

CRYOGENIC LIQUID AND GAS STORAGE:.

- 3.1.23 The Proponent shall supply a system to allow for liquid helium storage.
- 3.1.24 The L He dewar shall be super-insulated and vacuum insulated.
- 3.1.25 The outer vessel of the L He dewar shall be equipped with a relief valve and a pump-out port for the insulation vacuum.
- 3.1.26 The Proponent shall supply a pump-out port to the main He vessel. This port shall be equipped with a manual valve.
- 3.1.27 The L He dewar shall be equipped for both remote and local measurement of the He vapour pressure.
- 3.1.28 The L He dewar shall be equipped with a suitable spare port to allow for the transfer of L He from another vessel.
- 3.1.29 The Proponent shall supply the facilities for gaseous helium storage.
- 3.1.30 The gas storage system shall be an all-metal system. The use of a gas bag can allow for diffusion of water and other contaminants into the system, which is not acceptable.
- 3.1.31 The available space for the L He and gaseous helium storage can be seen in the figure Cryogenics Layout Proposal, BLDG/PPL/CRYO/0038300 Rev. C. Space allocation outside the main CLS building can be seen in the figure Hard Landscaping Plan & Details, BLDG/CVL/0025012 Rev. 1. The CLS has located a concrete pad exterior to the building that may be used for the gas storage facilities. This is labelled "Gas Farm" in the figure Cryogenic Layout Proposal. Approximately half of this pad is available for gas storage. A portion of the pad is to be used by the CLS to accommodate a 60,000 litre vertical tank for L N₂ storage. Space is very limited. Dimensions of the pad can be seen in the figure Structural Pile Caps and Grade Beams & Ground Floor Plan—Area 'C', BLDG/STRC/0025203 Rev. 3. Any additional space requirements shall be subject to review and acceptance by the CLS. Preference will be given to designs that can fit into the allotted space.
- 3.1.32 The Proponent shall make arrangements for automatic helium recovery. In the case of a malfunction of the main cryogenic plant, the system shall be able to automatically recover the helium contained in the L He vessel of the SC RF module and the main L He dewar to the gaseous storage tanks.
- 3.1.33 The helium recovery system should use a recovery compressor equipped with an oil removal/filter system.
- 3.1.34 The Proponent shall allocate space for the future expansion of the gas storage facilities (if possible) in the event that a second acceleration module is brought into service in the CLS storage ring. The gas storage system shall be configured to allow for the easy expansion of the storage facilities at a later date if room is available for such an expansion.

MAIN COMPRESSOR SET

- 3.1.35 The Proponent shall supply a main circulation compressor(s) for the cryogenic system. The main compressor set shall be a water-cooled, screw-type compressor.
- 3.1.36 The Proponent shall supply an oil absorber to be used with the main circulation compressor(s) to ensure the purity of the He gas. The oil removal shall be sufficient so as not to effect the long-term operation of the refrigerator/liquefier system. The Proponent shall supply the specifications of the oil contamination in the gas stream at the time of the bid.

- 3.1.37 The main compressor set shall be designed so that no valving errors can result in oil contamination entering the connecting lines, cold box, or gaseous storage tanks.
- 3.1.38 The proponent shall provide a system for the main circulation compressor(s) for energy saving/load matching capability. The adjustable range should be continuous from 50 to 100% of full load capacity. The Proponent shall clearly specify the system used to adjust the excess compressor capacity to match the cryogenic load.
- 3.1.39 The main compressor(s) shall be equipped with both suction and discharge relief valves.

RECOVERY COMPRESSOR

- 3.1.40 The recovery compressor will be of use to recover helium gas returning from the installation, after an unscheduled shutdown. This compressor may in the future be connected to an emergency power generator to facilitate He recovery during a power outage condition. It will also be of use to recover the excess He gas returning from the installation during the SC RF cavity cool down or during a cavity warm up. The recovery compressor should be able to pump the warm-up or shut-down He gas without any losses.
- 3.1.41 The recovery compressor shall be a screw-type compressor. Under the current plans, no water is available under power outage conditions. This compressor should be air-cooled or operate with closed loop water cooling that may be powered by a back-up generator under conditions of power outages.
- 3.1.42 The Proponent shall supply an oil absorber to be used with the recovery compressor to ensure the purity of the He gas. The oil removal shall be sufficient so as not to effect the long-term operation of the refrigerator/liquefier system.

OTHER COMPONENTS

- 3.1.43 The Proponent is encouraged to identify all applicable energy saving solutions.
- 3.1.44 The Proponent shall be responsible for supplying the analogue outputs for all water flow rates associated directly with the amplifier system.
- 3.1.45 The Proponent should provide interlocks and monitoring to ensure the proper operation of any dehydrators, blowers, or electrostatic air filters used in the cryogenic design.
- 3.1.46 Adequate temperature monitoring shall be provided by the Proponent. Non-cryogenic temperature monitoring shall be accomplished with 100 ohm platinum resistive temperature detectors (PRTD) with an $\alpha = 0.00385$ (IEC) temperature coefficient. All temperature measurements shall be 3-wire measurements. The sensor elements should have a ¼ inch diameter stainless steel sheath, six inches long, to be compatible with other CLS sensors. The Proponent shall provide all thermal wells required for temperature measurement. Cryogenic temperature monitoring shall be accomplished with cryogenic linear temperature sensors (CLTS). Cryogenic temperature sensors should read out in kelvins. The method, location, number of temperature monitoring points, and accuracy shall be reviewed and accepted by the CLS. The Proponent shall supply the signal processing for all temperature readings. Provisions shall be made for monitoring by CLS computers. The Proponent shall build in provisions for a minimum of 10 percent additional monitoring points to be added at a later date.
- 3.1.47 The CLS is striving to maintain common vacuum monitoring and vacuum pumping components in use throughout the different systems in the facility. It is the intention of the CLS to have the Proponent provide vacuum pump requirements for the cryogenic system to the CLS and the CLS will either supply the equipment or advise the Proponent as to what equipment is acceptable. The pumps used shall be of an oil-free nature. The cost of the vacuum pumping and vacuum monitoring should not be included in the bid price for the contract. Adequate pressure monitoring points shall be provided by the Proponent to monitor the insulation vacuum in the refrigerator cold box and throughout the cryogenic delivery system. Vacuum monitoring should be accomplished through

2.75 inch Conflat™ flanges supplied by the Proponent. Each vacuum monitor shall have a separate port.

- 3.1.48 The Proponent shall supply the vent tubes from all burst disks and relief valves to connect up with the CLS venting system. The Proponent shall size these tubes to allow for handling of the vaporized gas without back-pressure effects. Any vent tubes that may contain cold gases shall be permanently insulated. The specifics of the venting system shall be worked out as a collaboration between the Proponent and the CLS.
- 3.1.49 The Proponent shall supply the Grade A He (99.995% purity) to facilitate all of the required purging and pumping processes as well as the initial charging of the system. The Proponent shall provide the CLS with the expected amount of He required for all purge and pump down processes, normal operational losses during commissioning and acceptance test procedures, and the initial charge of the system.
- 3.1.50 All tubes, pipes, and vacuum components shall be free of dust, dirt, scale, rust, flux residues, oil residues, solvents, grease, films etc., prior to assembly into the system. The Proponent shall thoroughly clean all components before they are fitted, to adhere to this specification. The Proponent shall outline any additional cleaning procedures that are required after initial assembly. The proposed cleaning procedures shall be made available to the CLS at the time of bid. Cleaning procedures shall be subject to review and acceptance by the CLS.
- 3.1.51 The Proponent shall provide sufficient piping flexibility to absorb equipment vibration. All input and output piping from machinery such as the main compressor and recovery compressor shall be made with flexible hoses and equipped with foundation damping pads. When piping passes through wall, it must not touch any part of the building and be supported by pipe hangers to prevent transmission of vibrations through the building.

3.2 Performance

REFRIGERATOR/LIQUEFIER:

- 3.2.1 The refrigerator/liquefier shall be sized to meet all performance criteria outlined in section 2.2.
- 3.2.2 The refrigerator/liquefier system shall require three different He gas return lines.
 - 1. A warm He gas return line from the location of the SC RF module. This gas will be transported to the compressor suction. This gas will be at, or slightly above ambient temperature.
 - 2. Cold return gas from the SC RF module cryostat, and transported via the cryogenic valve box and the multi-channel transfer line. This gas will be between 4.5 K and ambient temperature. The Proponent shall indicate the return path of this gas through the refrigerator/liquefier as a function of its return temperature.
 - 3. He return gas from the main L He dewar. Under normal operation, this gas will be returning at 4.5 K.
- 3.2.3 When installed, the cold box shall be fixed in its position such that it cannot be moved without removing fasteners.

TRANSFER LINES:

- 3.2.4 The cryogenic transfer lines between the main dewar and the valve box and between the refrigerator/liquefier and the main dewar should obtain heat leak values of less than 0.5 W/m with a goal of less than 0.2 W/m.
- 3.2.5 The He gas lines shall be designed to handle the flows required by the refrigerator/liquefier with only minimal pressure loss of less than 1%.
- 3.2.6 The Proponent shall design the L N₂ transfer lines to accommodate L N₂ flow rates of 20 to 150 litres per hour from the CLS supply point to the refrigerator/liquefier cold box, cryogenic valve box, and the SC RF module.

- 3.2.7 All vacuum vessel surfaces, He transfer lines, and nitrogen transfer lines shall be designed so that these surfaces remain within +/- 5 K of the ambient temperature.

CRYOGENIC LIQUID AND GAS STORAGE:

- 3.2.8 The CLS requires L He storage of 2000 litres or greater to facilitate the accumulation of enough liquid helium to allow for a rapid cool-down of the niobium cavity to avoid the "Q-virus". If in the future a second RF cavity module is used, the L He storage capacity should be expandable to facilitate rapid cool-down of two cavities at the same time. This cool down requires a flow of 250 litres per hour to each cavity for a duration of 6 hours.
- 3.2.9 The gas storage system should be sized to house the entire He gas inventory in the case of a warm-up. This would dictate a minimum gas storage capacity equivalent to 2000 litres of L He.
- 3.2.10 The Proponent shall clearly outline the gas storage system at the time of the bid. This shall include, but not be limited to, the type of storage tanks used, the storage pressures, the storage capacity, and the expected purity of the recovered He gas. The Proponent shall also supply options for expansion of the gas storage facility to increase the storage capacity.
- 3.2.11 The He gas storage system shall be equipped with adequate dual-redundant pressure relief valves set at the maximum system working pressure.
- 3.2.12 The main He dewar shall be designed to operate at a maximum pressure of 200 kPa. The dewar shall be designed to withstand pressure of 400 kPa or greater.
- 3.2.13 Under steady state operations, the main dewar pressure shall operate at between 120 and 160 kPa with a L He level of approximately 1000 litres.
- 3.2.14 The main He dewar shall be equipped with dual removable 500 W heaters (one will act as a spare). One DC power supply with controller shall be provided by the Proponent to allow for load levelling to the cryogenic system. The heater shall be controlled by a PID controller (single loop or PLC) reading the L He level signal. The heater shall be controlled to a resolution of better than 5 W.
- 3.2.15 The heat leak in the main L He dewar including the neck and penetrations should not exceed 5 W.
- 3.2.16 The L He dewar shall be equipped with two SC L He level detectors and one indicator. The resolution of the level detectors shall be better than 0.1 %.
- 3.2.17 The proponent shall provide a graph of the main dewar L He volume versus the L He level indicator.
- 3.2.18 The L He level in the main dewar shall be maintained by a dedicated control system (as per CLS guidelines). The dewar pressure fluctuation shall be controlled to less than +/- 300 Pa. The dewar level fluctuation shall be controlled to less than +/- 1 % of full scale with a goal of less than +/- 0.2 %.
- 3.2.19 The main dewar vacuum space should normally remain sealed off and contain an active getter which will maintain the vacuum pressure at less than 1.0 mPa for a period of greater than 5 years when the dewar is cold.
- 3.2.20 The L He vessel shall be equipped with two sets of dual relief valves and a burst disk to protect against conditions of heater malfunction, loss of insulation vacuum and or fire. The burst disk shall be connected to the CLS venting system. One set of relief valves shall be equipped with a manual valve that can isolate the relief valves from the dewar. This will operate as a low-pressure relief system, nominally set at 2 kPa gauge. The manual valve will be closed under normal operation. The other high-pressure relief valves shall operate at 100 kPa gauge (at the burst disk pressure of the SC RF module).
- 3.2.21 The L He and gaseous storage systems shall be subject to review and acceptance by the CLS.

MAIN COMPRESSOR SET

- 3.2.22 In normal operation, the compressor suction shall be 105 kPa absolute.

- 3.2.23 The instantaneous compressor suction line pressure shall never be higher than 136 kPa at any time. Dual relief valves shall be installed in the compressor suction line with a setting value of 50 kPa gauge.
- 3.2.24 In steady state operation, the fluctuation of the main compressor suction shall be maintained within +/- 300 Pa.

RECOVERY COMPRESSOR

- 3.2.25 The recovery compressor shall be able to pump He gas from a suction pressure of 110 kPa absolute to the designed discharge pressure.
- 3.2.26 The recovery compressor suction pressure shall be controlled to be lower than 136 kPa absolute and higher than 105 kPa absolute at all times. The recovery compressor should be able to reach full capacity as soon as possible after start-up. The Proponent shall provide some system to relieve suction pressure to the maximum allowable working suction pressure to avoid starting problems at high suction pressures following a power failure. Note: If the recovery compressor is operated using a system of back-up power, high suction pressures can occur in the time required for emergency power to be started.
- 3.2.27 It is not good for the recovery compressor to start up and shut down very often. To protect the recovery compressor and the He recovery system, the recovery compressor shall start pumping at 122 kPa absolute or under conditions of a main cryogenic plant shutdown, the recovery compressor shall immediately reduce the suction pressure to below 108 kPa absolute and then reduce the He gas flow to zero. The recovery compressor shall keep running in a standby mode (to avoid numerous start-up and shut-down cycles) for a minimum of 2 hours under the conditions of zero gas flow. If in this 2 hour period the suction line pressure reaches 136 kPa absolute, the recovery compressor shall be able to be switched to a full gas flow mode automatically and the 2 hour timer shall be reset.

OTHER COMPONENTS

- 3.2.28 The water flow meters shall be ELETТА™ flow meters or CLS accepted equivalent with 4-20 mA analogue outputs and either a dry contact, which is closed or a +24 V output when water flow is above an adjustable limit.
- 3.2.29 The Proponent shall identify the emergency power requirements that would be necessary to operate the emergency gas recovery system along with its associated control, under conditions of a power outage.

3.3 Safety and Environmental

- 3.3.1 The Proponent shall be responsible for providing protection from any potentially dangerous mechanical systems or cryogenic hazards that may be encountered in the normal operation of the cryogenic system.
- 3.3.2 The Proponent shall be responsible for the labelling of all potentially hazardous systems or components with standard type labels.
- 3.3.3 All piping and transfer lines shall be clearly labelled with information of the contents and flow direction.

3.4 Applicable Codes, Standards and Procedures

- 3.4.1 See section 2.4.

3.5 Quality Assurance

- 3.5.1 The Proponent shall provide QA/QC manuals for all components.

3.6 Inspection, Testing and Commissioning

- 3.6.1 The refrigeration system shall undergo initial component testing at the Proponents site prior to shipment to the CLS.
- 3.6.2 Refer to Section 5 for Cryogenic Acceptance Tests

3.7 Reliability and Maintainability

- 3.7.1 When assembling any vacuum vessels or the cryogenic transfer lines it is important to assure proper alignment of the flanges to maintain proper continuity across each junction. All assemblies shall follow the procedures recommended by the manufacturer including the use of alignment tools, torque wrenches and the proper tightening sequences. The assembly procedures shall be provided to the CLS prior to equipment arrival at the CLS.
- 3.7.2 The Proponent shall be responsible to eliminate any detected ice spots on the He or Nitrogen lines for a period of up to 6 months after final acceptance test have been preformed. The Proponent accepts that re-piping of lines may be necessary to eliminate surface ice spots.

3.8 Other Requirements and Constraints

- 3.8.1 All equipment supplied will bear the approval of the Canadian Standards Association (CSA). Where CSA approval is not available, the Proponent will secure approval of the Technical Safety Services Branch of the Department of Industry and Labour, Province of Saskatchewan prior to shipment of equipment to site. Evidence of such approval will be presented to the Owner, prior to shipment of the equipment from the factory.
- 3.8.2 The Proponent shall package all components to insure acceptance and safe delivery by a common or other carrier, and so components can be delivered in an undamaged condition.
- 3.8.3 All major components shall have a stainless steel or aluminium nameplate on each unit that shall include the following information:
 - Manufacturer's name and address
 - Equipment type and serial number
 - Input ratings
 - Output ratings
 - Gross weight of the unit
 - Date of manufacture
 - Cooling requirements (if required)
- 3.8.4 All shipping containers shall be marked or tagged with the following information:
 - 1. CLS purchase order number.
 - 2. Shipping address as specified within the contract.
 - 3. Proponent's name.
 - 4. Components contained within each package.
 - 5. "Top-side up" if required.
 - 6. "Fragile" if required.All shipping containers shall contain an accelerometer to register shocks that the equipment was subject to during shipping.

4 OPERATIONAL MODES

4.1 Purging and Initial Start-up

- 4.1.1 The Proponent shall provide, in detail, step-by-step documentation of its pump down and purging procedures for every isolated process volume in the L He system. The Proponent shall be

responsible for performing/supervising the pump down and purge for the initial system clean up and start up. The supplied documentation shall cover any special instructions for a purge to be done at a later date due to contamination of the system after the initial start up has already occurred.

- 4.1.2 The Proponent's pump down and purging procedures shall include evacuating every isolated process volume to a pressure less than 6.7 Pa (50 mtorr) and backfilling the volume with He gas with purity 99.995% pure or better. This process shall be performed twice on each volume.
- 4.1.3 The Proponent shall incorporate convenient connection points to allow for pump down and He gas purging on all the process volumes mentioned above.
- 4.1.4 Once the initial pump down and purging procedures are completed, the Proponent shall pump down the system in isolated sections to demonstrate their final tightness.
- 4.1.5 The system can now be filled and circulated with He gas of a purity 99.995% or better. The Proponent shall provide a gas analyser system with a resolution of 1 ppm or better to monitor the circulating gas purity. The vendor shall circulate He gas through the system until it has demonstrated a contamination level of better than 1 ppm. The Proponent may wish to temporarily install portable, make-up purifiers (in addition to the system purifiers) to purify the circulating He gas in a reasonable amount of time.

4.2 Cool-down Procedures

- 4.2.1 The Proponent shall formulate a procedure to perform a cool-down of the main cryogenic plant, the main liquid helium dewar, and the multi-channel vacuum jacketed distribution lines to verify the performance of the above mentioned items. The Proponent may require additional equipment to be employed such as a test dewar with cryogenic adapters to perform these initial cool-down tests.
- 4.2.2 The Proponent shall formulate a procedure to perform a cool-down of the cryogenic distribution valve box and the flexible cryogenic lines to cavity location immediately following the initial cool-down tests outlined in 4.2.1. This test will be to verify the operation of the CLS supplied valve box and flexible distribution lines. The Proponent may require additional equipment to be employed (such as a test dewar with heater and additional cryogenic adapters) to perform this cool-down test. It may also be necessary to reposition the valve box to allow for easy connection to its flexible distribution lines.

4.3 Normal Operation

The normal cool-down procedure is listed below.

- 4.3.1 The main SC RF module liquid nitrogen shield is used to pre-cool the main SC RF module. The niobium cavity is enclosed by a liquid helium vessel that is thermally isolated by an insulating vacuum, multi-layer insulation, and low heat leak supports. In the liquid nitrogen pre-cooling process, the main SC RF module is indirectly cooled by the serial flow of L N₂ through the cryostat nitrogen shield and the longitudinal heat intercepts. Based on an operating procedure developed at Cornell, this pre-cool-down procedure cools the SC RF cavity body from room temperature to 220-200 K in about 2-3 days. During that time, the Main Cryogenic Plant is operated in the liquefier mode to accumulate a minimum of 1600 litres liquid helium in the 2000 litres main liquid helium dewar. This liquid inventory must be adequate for the main SC RF module cool-down period to follow.
- 4.3.2 When the cavity temperature is at about 200 K, the main SC RF module is ready for further cool down with L He at a high transfer rate. A liquid helium consumption rate of 200-250 l/hr (6.46-8.08 g/s @1.4 bara) is necessary to guarantee a rapid main SC RF module cool-down rate of 40 K/hr to avoid Q-virus. Conversely, the cool-down rate should not be greater than this to avoid any problems due to thermal stress. It will take 5-6 hours to cool the main SC RF module down to 4.5 K. The liquid helium consumption rate will exceed the liquefier capacity of the main cryogenic plant. The excess consumption will reduce the main liquid helium dewar level and the compressor will pump the excess gas to, and build up pressure in, the gaseous helium storage tanks. The

refrigerator/liquefier cold box compressor flow and thus the refrigerator capacity will, at least initially, be reduced. The main cryogenic plant shall guarantee that, during cool down of the main SC RF module at a rate of 40K/hr (i.e. at 250 l/hr) for six (6) hours, that the main L He dewar level, beginning at 1600 litres, is always higher than 200 litres, and the pressure of the gaseous helium storage tanks lower than the maximum allowed operating pressure and higher than the minimum allowed operating pressure of the gas management system, and no helium inventory is lost.

Note that during cool-down of the main SC RF module, the warm He gas goes through the bypass warm return line of the cryogenic distribution valve box back to the compressor suction line, and that the cold return valve in the cryogenic distribution valve box and the HEX port on the main SC RF module will be shut-off.

- 4.3.3 After cool-down of the main SC RF module to L He temperature, more than 30% of the helium vessel (160 litres) will be filled to maintain the SC RF cavity at liquid helium temperature and the liquid helium stored in the main L He dewar shall not be less than 200 litres. Then, more than 500 litres inventory shall be established in the main liquid helium dewar within 12 hours while the L He volume in the He vessel of the main SC RF module is maintained at 30% with a liquid helium supply valve.
- 4.3.4 After re-establishment of the L He level in the main dewar, L He will be filled into the L He vessel of the main SC RF module to its nominal operating level, of 480 litres, in two hours. The main cryogenic plant shall be able to maintain the L He remaining in the main dewar at more than 200 litres during transfer of L He to the main SC RF module.
- 4.3.5 When the L He level of the main SRF module reaches its nominal operating value (nominally 480 litres) the cryostat L He level will be maintained by regulating the L He flow rate into the main SC RF module with a L He supply valve. This supply valve is mounted on the cryogenic distribution valve box and controlled by a PID controller, provided by the CLS. After the L He level has been established and stabilized, and in preparation for operation, the DC heater inside the L He vessel of the main SC RF module will be manually turned on to generate an additional cryogenic load to simulate the dynamic load of the main SC RF module.
- 4.3.6 Finally, the main cryogenic plant resumes collecting L He in the main dewar with its excess capacity. After 1000 litres of L He is accumulated and stored in the main dewar, the main cryogenic plant will turn-down to match the nominal cryogenic load (described in section 2.2.2) by the method prescribed by the Proponent.

4.4 Warm-up Procedures

The cryogenic system shall be capable of performing all of the below mentioned warm-up procedures.

- 4.4.1 The SC RF module may be warmed up to 300 K with the main cryogenic plant continuing to operate and remaining cold. This procedure may be undertaken a few times a year under normal operations. Warming of the niobium cavity and cryostat to room temperature will typically be accomplished over a period of about 7 days. The process starts by boiling off the L He in the cryostat with the use of ~ 200W DC heaters located in the cryostat. This will take roughly 3 hours. The He gas is recovered to the compressor via the cold He gas return line to the cryogenic distribution valve box, through the multi-channel transfer line to the refrigerator/liquefier cold box and finally to the compressor suction. This warm up may also be expanded to include the flexible vacuum-jacketed lines to the cavity cryostat and the cryogenic distribution valve box.
- 4.4.2 The SC RF module will undergo warm-up to a temperature of 10 to 20 K. The method of warm-up will be the same as described in 4.4.1, using the cryostat DC heaters. A warm-up to 10 K is required to eliminate magnetic flux trapping in the Niobium cavity. A warm-up to 20 K is used in the reconditioning of the RF window. In both cases, the L N₂ will continue to circulate through the radiation heat shield.

- 4.4.3 The main cryogenic plant and the SC RF module may both be warmed up to 300K. This may or may not include the warm-up of the main L He dewar.
- 4.4.4 The main cryogenic plant may be quickly warmed up to 300 K and cooled back down while the SC RF module is kept cool by L He accumulated and transferred from the main storage dewar.

4.5 Turn-down and Speed-up and Load Matching Procedures

- 4.5.1 Under normal operation, the cryogenic system shall be automatically turned-down to match the cryogenic load. The cryogenic load shall be determined by sensing the L He level in the main dewar. Gas pressure readings should not be used to determine the cryogenic load to avoid effects resulting from variations in the ambient temperature. The Proponent shall clearly outline its turn-down procedures and supply graphs of cooling capacity versus total consumed electrical power at the time of the bid.
- 4.5.2 The Proponent shall supply a procedure to manually over-ride the automatic turn-down/load-matching system, to allow the cryogenic plant to operate at full capacity.

4.6 Shutdown Procedures

- 4.6.1 The Proponent shall supply complete shut-down procedures of the cryogenic plant. These procedures shall require 100% recovery of the helium inventory.

4.7 Helium Recovery procedures

- 4.7.1 It is the goal of the CLS to have total He inventory recovery to the gaseous He storage facilities under emergency shutdown of the main cryogenic plant. Under a required shut-down of the cryogenic plant, the CLS will be notified by a fail-safe interlock so that the SC RF module can be protected by the following procedures:
 1. The Proponent shall be responsible for making sure that the DC heaters in the L He dewar are turned off.
 2. The L He supply valve in the cryogenic distribution box will be shut off.
 3. The DC heaters in the SC RF module will be shut off.
 4. The RF power to the SC RF module will be shut off.
 5. The HEX gas flow through the SC RF module will be shut off.

4.8 Recovery During Main Power Failure

- 4.8.1 The Proponent shall clearly outline any special procedures required after a main power failure has occurred. The Proponent shall detail any possible effect on the He gas inventory for power outages of varying duration at different stages in the operating conditions outlined in sections 4.2 to 4.5. The Proponent shall indicate the power requirements that would be needed to run such things as the recovery compressor and the cryogenics control system to allow for full or near full recovery of the He inventory under lengthy power outages. The Proponent shall detail the emergency power requirements to the CLS at the time of the bid. The emergency power may be supplied by the CLS, or incorporated at a later date. The Proponent shall design a system that can safely operate without CLS supplied back-up power. The system shall be configured to easily allow the implementation of an emergency He recovery system (as outlined) to be put in place at a later date.

5 CRYOGENIC ACCEPTANCE TESTS

5.1 Tests Off Site

- 5.1.1 The refrigeration system shall undergo initial component testing at the Proponents site prior to shipment to the CLS. This testing shall include but not be limited to the following:
 1. Pressure, vacuum and leak testing shall be performed on the main compressor set, the recovery compressor set, the refrigerator/liquefier cold box, buffer tank (if required), and the

- main L He dewar. All components that function in a vacuum shall be certified as being leak tight at the factory except for the field connections.
2. Leak test shall be performed on the gaseous He storage tank(s). The CLS may require separate test to be performed or accept factory acceptance test depending upon the system proposed.
 3. Where applicable, static water tests shall be done at 2 MPa for a minimum of 1 hour with no indications of leaks.
 4. The CLS shall require factory acceptance tests on all major components including spares. This shall include the compressor(s), refrigerator/liquefier cold box, main L He dewar, gas storage facilities, and the back-up power generator.

5.2 Final Acceptance Test at the CLS Site

- 5.2.1 Final acceptance of the cryogenic system shall require a successful test to be performed at the CLS.
- 5.2.2 Leak Tests:
 1. All He and Nitrogen equipment shall be cleaned and demonstrated He leak tight. All field connections shall be demonstrated as He leak tight.
 2. All cryogenic piping and components shall be leak tight to the insulating vacuum at room temperature and at the mean average working temperature. Leak rates shall be demonstrated to less than $1\text{E-}5$ Pa³/s He for the sealed vacuum and less than $1\text{E-}3$ Pa³/s He for the cold box.
 3. The vacuum shielding of the cryogenic transfer lines shall be leak tight at room temperature to a global leak rate of less than $1\text{E-}4$ Pa³/s He. Individual connections shall have leak rates less than $1\text{E-}6$ Pa³/s He.
 4. All piping that is to be interconnected with the refrigerator/liquefier cold box shall be leak checked to less than $1\text{E-}7$ Pa³/s He at room temperature along all weld seams. This check shall be done before connection the cold box. Testing pressures of the connecting pipes shall be done at least 1.5 times their operating pressure.
 5. The proponent shall demonstrate an insulation vacuum pressure of the refrigerator/liquefier cold box of less than $1\text{E-}2$ Pa at room temperature. After thermal cycling the system a minimum of two times, the insulation vacuum pressure shall again be measure to be less than $1\text{E-}2$ Pa at room temperature and less than $5\text{E-}4$ Pa when cold. All other insulation vacuum pressures shall be measured to be less than $1\text{E-}2$ Pa at room temperature.
- 5.2.3 All mechanical systems shall be checked for proper operation. All valves and actuators shall be stroked and verified to operate normally.
- 5.2.4 All sensors shall be checked for normal operation.
- 5.2.5 All interlock functions shall be checked for proper operation and indications. All fault status indicators shall latch until reset.
- 5.2.6 Control functions shall be exercised through all states.
- 5.2.7 The Proponent shall develop test procedures to verify all the major performance criteria of the cryogenic system. This shall include test to verify the following:
 1. Refrigeration of greater than 235 W obtainable at the CLS interface point.
 2. Liquefying capacity of greater than 75 l/hr as measured in the main He dewar.
 3. Heat leak measurements of the main dewar and multi-channel transfer lines.
 4. Verification of the L N₂ consumption rates.
 5. Verification of system operation stability criteria in the normal operating mode. This shall include main He dewar vapour pressures, L He level, and compressor suction pressures over an operation period of more than 12 hours.
 6. Recovery gas purity of greater than 99.995%.

7. The Proponent shall verify operation of the cryogenic system in all operational modes outlined in Section 4.

The Proponent shall be responsible for any additional equipment that is required to perform these tests. This may include such items as a test dewar equipped with heater and liquid level sensor, additional cryogenic adapters, etc.

6 REFERENCES

6.1 Drawings

1. 2D General Plan View, BLDG/ME/0035100 Rev. O.
2. Cryogenics Layout Proposal, BLDG/PPL/CRYO/0038300 Rev. C
3. SR1 RF Cavity Tunnel Cross Section, SR1/PPL/RF/0034304 Rev. E
4. SR1 RF Straight Section General Plan View, SR1/ME/RF/0037100 Rev. E
5. SR1 RF Cavity Straight Arrangement Study, SR1/PPL/RF/0034300 Rev. G
6. Heating Water System Main Floor, BLDG/ME/0025308 Rev. 1
7. Booster/Storage Ring Top of Shielding Cable Tray Layout, BLDG/EE/0050701 Rev. C
8. Piping Sections, BLDG/PPG/WTR/0025428 Rev. 0 Section E
9. Fluid Coolers & Chiller Room Floor Plan, BLDG/ME/0025325 Rev. 1
10. Architectural Building Sections, BLDG/ARCH/0025121 Rev. 1 Detail #4
11. Hard Landscaping Plan & Details, BLDG/CVL/0025012 Rev. 1
12. Structural Pile Caps and Grade Beams & Ground Floor Plan—Area 'C', BLDG/STRC/0025203 Rev. 3
13. Technical Mechanical HVAC Sections, BLDG/ME/HVA/0025405 Rev. O Section C-C (Looking West)
14. Cold Valve Box for 1 Cavity Cryostat, 1130-40.00.01 Rev. B
15. Flange Connections Mc-Transfer Line/GHe, warm Cold Valve Box, 1130-40.00.03
16. Details Mc-Transfer Line/GHe, warm Cold Valve Box, 1130-40.00.04
17. Flow Diagram with Diagnostic Elements for Valve Box, 1130-40.00.02 Rev. A

6.2 Documents

1. "CLS RF Design Note" 8.2.32.1 Rev. 0 (previously known as 2.1.4 Rev.
2. "CLS Design Specification Control System Overview" 7.4.39.1 Rev. 1
3. "BKL report "Vibration Isolation Mechanical Equipment".
4. CSA Canadian Electrical Code 1998 Safety Standards for Electrical Installations.
5. B51-97 Boiler, Pressure Vessel, and Pressure Piping Code (CSA)
6. ASME Boiler and Pressure Vessel Code Section VIII divisions 1 2 and 3.
7. B52-99 Mechanical Refrigeration Code.
8. IEC 61508–Functional Safety of Electrical/Electronic/Programmable Electronic Systems – Parts 2 and 3.
9. The Saskatchewan Occupational Health and Safety Act and Regulations
10. "CLS Documentation Specification" 0.4.1.1 Rev. 1 (previously known as:2.42.01.001 Rev. 1).