NCSX

System Requirements Document (SRD)

For the

Liquid Nitrogen Distribution System (WBS 161)

NCSX-BSPEC-161-dB

DRAFT

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Record of Revisions

Revision	Date	ECP	Description of Change
Rev. 0		-	Initial issue

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1 Scope

The National Compact Stellarator Experiment (NCSX) is an experimental research facility that is to be constructed at the Department of Energy's Princeton Plasma Physics Laboratory (PPPL). Its mission is to acquire the physics knowledge needed to evaluate compact stellarators as a fusion concept, and to advance the understanding of 3D plasma physics for fusion and basic science.

Among the primary core components of the facility are the Modular Coils (MC) and the conventional coils, an assembly of Poloidal Field Coils (PF), and Toroidal Field Coils (TF). These three sets of coils provide the magnetic field required for plasma shaping and position control, and inductive current drive, and are actively cooled by liquid nitrogen supplied by the Liquid Nitrogen Distribution System (LN2 System).

This specification addresses the design requirements for the LN2 System.

1.1 Document Overview

This document, the System Requirements Document (SRD) for the Liquid Nitrogen Distribution System (WBS 161), is the complete development specification for this subsystem. Performance requirements allocated to this subsystem in the system specification, the General Requirements Document (NCSX-GRD-XX), have been incorporated in this document. In this document, the term "the system" refers to the overall device and facility and the terms "the subsystem" and refers to the LN2 System (WBS 161)."

The specification approach being used on NCSX provides for a clear distinction between performance requirements and design constraints. Performance requirements state what functions a system has to perform and how well that function has to be performed. Design constraints, on the other hand, are a set of limiting or boundary requirements that must be adhered to while allocating requirements or designing the system. They are drawn from externally imposed sources (e.g., statutory regulations, DOE Orders, and PPPL ES&H Directives) as well as from internally imposed sources as a result of prior decisions, which limit subsequent design alternatives.

1.2 Incomplete and Tentative Requirements

Within this document, the term "TBD" (to be determined) indicates that additional effort (analysis, trade studies, etc) is required to define the particular requirement. The term "TBR" (to be revised) indicates that the value given is subject to change.

2 APPLICABLE DOCUMENTS

NCS X-ASPEC-GRD	NCSX General Requirements Document
NCSX-CRIT-CRYO	NCSX Structural and Cryogenic Design Criteria Document
NCSX-CRIT-SEIS	NCSX Seismic Design Criteria Document

3 REQUIREMENTS

3.1 Subsystem Definition

The LN2 System consists of a set of supply and return distribution manifolds and branch lines (flexible hosing) mounted in each of the three field periods. The purpose of this system is to provide single phase liquid nitrogen cooling to maintain the MC and conventional coils at 77-80 K during operation of the NCSX device and return the temperature back to this operating regime in the allotted time after operational shots. The LN2 System must be compatible with chilled nitrogen gas flow as well. Gas flow may be used in the system to aid in initial cool down of the coils and then switch over to LN2 flow. This system is the responsibility of Cryogenics System (WNS 62) and not part of WBS 161.

3.1.1 Subsystem Diagrams

A functional flow block diagram (FFBD) is provided in

Figure 3-1.

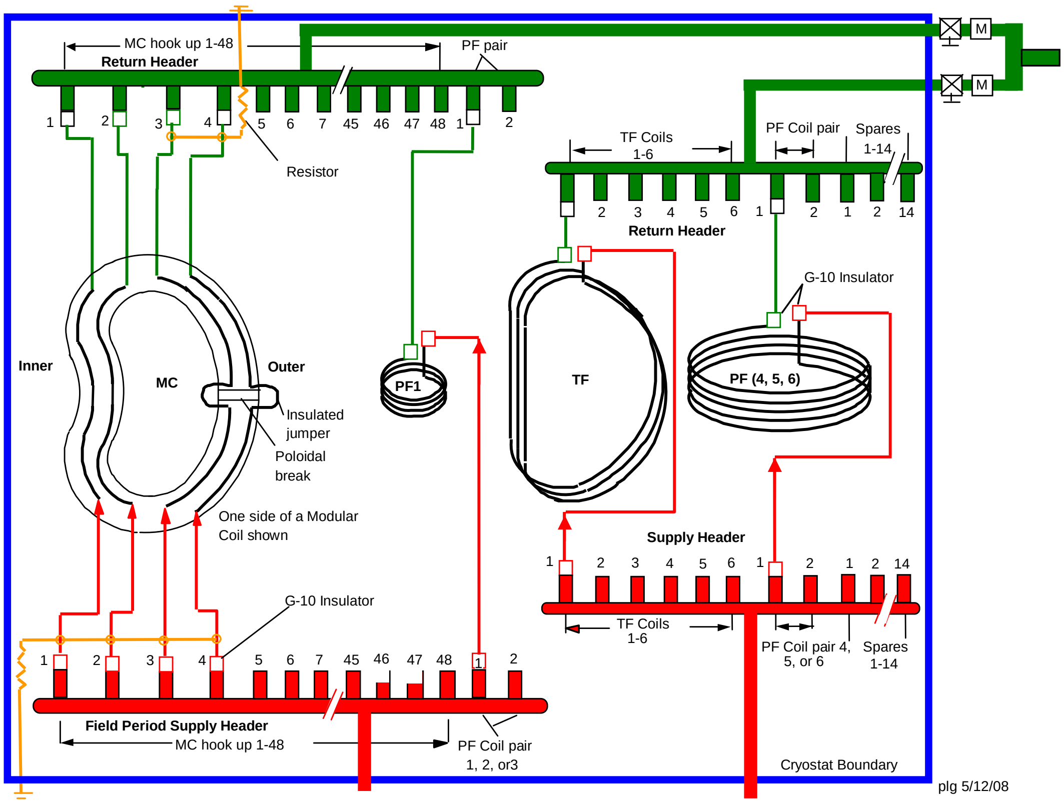

Figure 3-1 Functional flow block diagram

3.1.2 Interface Definition

3.1.2.1 Vacuum Vessel (WBS 12)

There is no interface with WBS 161 that needs to be managed.

3.1.2.2 TF Coils (WBS 131)

Physical: LN2 supply and return lines connect directly to TF coil cooling tubes.

Functional: The LN2 distribution system supplies/returns liquid nitrogen to/from the TF coils for the purpose of cooling the coils during cool down from room to operating temperature, maintaining coil operating temperature during bakeout, maintaining coil operating temperature between pulses, maintaining continuous liquid nitrogen flow during a pulse, and returning the coils to operating temperature after a pulse.

The LN2 distribution system supplies/returns chilled nitrogen gas to/from the TF coils for the purpose of cooling the coils during parts of the cool down and warm up cycles.

Heat loads and operating scenarios are summarized in NCSX-CALC131-001-XX Thermal Analysis TF Coil Cooling.

3.1.2.3 PF Coils (WBS 133)

Physical: LN2 supply and return lines connect directly to PF coil cooling tubes.

Functional: The LN2 distribution system supplies/returns liquid nitrogen to/from the PF coils for the purpose of cooling the coils during cool down from room to operating temperature, maintaining coil operating temperature during bakeout, maintaining coil operating temperature between pulses, maintaining continuous liquid nitrogen flow during a pulse, and returning the coils to operating temperature after a pulse.

The LN2 distribution system supplies/returns chilled nitrogen gas to/from the PF coils for the purpose of cooling the coils during parts of the cool down and warm up cycles.

Heat loads, coolant flow, and operating scenarios are summarized in NCSX-CALC-132-001-XX PF-4, 5, & 6 Thermo-Hydraulics Calculations.

3.1.2.4 Modular Coils (WBS 14)

Physical: LN2 supply and return lines connect directly to modular coil cooling tubes.

Physical / Functional: The LN2 manifolds and hoses connect to and are (partly) mechanically supported by the modular coil shell. *Check that this is true.*

Functional: The LN2 distribution system supplies/returns liquid nitrogen to/from the modular coils for the purpose of cooling the coils during cool down from room to operating temperature, maintaining coil operating temperature during bakeout, maintaining coil operating temperature between pulses, maintaining continuous liquid nitrogen flow during a pulse, and returning the coils to operating temperature after a pulse.

The LN2 distribution system supplies/returns chilled nitrogen gas to/from the modular coils for the purpose of cooling the coils during parts of the cool down and warm up cycles.

Heat loads, coolant requirements, and operating scenarios are summarized in NCSX-CALC-14-001-XX Modular Coil Thermal Anaysis.

3.1.2.5 Coil Support Structures (WBS 15

Physical / Functional: The LN2 manifolds and hoses connect to and are mechanically supported by the coil support structures.

3.1.2.6 Cryostat (WBS 171)

Comment [wtr1]: This is fine but we ought to consider if there is an interface wit h the cryostat cooling system (the system that regulates the temperature inside the cryostat). If that system needs LN2 inside the cryostat, we might want to take it from 161. Also, we might want to run the return flow through a "baseboard heater" to help keep the cryostat interior cool.

At this point, the interface is unknown. We will need to take this up after the cryosystems are defined. Phil

Physical: The supply and return lines carrying LN2 to/from the supply/return headers, and leads from local I&C sensors, penetrate the cryostat wall.

3.1.2.7 Electrical Power Systems (WBS 4)

Physical / Functional: Grounding shall meet the requirements set forth in grounding specification NCSX-CSPEC-411.

3.1.2.8 Central I&C (WBS 5)

Physical:

Local I&C sensor leads are brought to terminal boxes outside the cryostat. *How are they supported?*

Leads connect from the WBS 16 terminal boxes to WBS 5, which hosts the signal conditioning electronics for sensor signals and the drivers for control actuators such as valves.

Functional:

WBS 5 displays and stores the data, and uses it for various control functions (e.g., coil protection, coil cooling) during all phases of operation

Central I&C (WBS 5) generates control signals which controls the operation of LN2 distribution system control actuators (e.g. valves) during all phases of operation

3.1.2.9 Cryogenic Systems (WBS 62)

Physical: The supply and return lines carrying LN2 to/from the supply/return headers connect to the LN Supply System (WBS 62) outside the cryostat wall and outboard of the WBS 161 LN2 valves and pressure gauges.

Functional: The LN2 Supply System (WBS 62) supplies/returns liquid nitrogen to/from the LN2 distribution system (WBS 16) during all phases of operation.

The LN2 Supply System (WBS 62) supplies/returns chilled nitrogen gas to/from the LN2 distribution system (WBS 16) during parts of the cool down and warm up cycles.

3.1.3 Major Component List

There are no major components for which additional development specifications are planned.

3.1.4 Characteristics

3.2 Characteristics

3.2.1 Performance

3.2.1.1 Perform Initial Verification

a. Initial Facility Startup

Background

Initial facility startup includes all activities required to verify safe operation of NCSX systems after their initial assembly and installation, or after a major facility reconfiguration, and before plasma operations. Initial facility startup activities would be performed prior to First Plasma and will include subsystem pre-operational test procedures (PTPs) and an Integrated System Test Program (ISTP) to verify that the system operates safely and as expected prior to plasma operation. The ISTP will also include verification that, at First Plasma, the system demonstrates a level of system performance sufficient for the start of research operations, as specified in the Project Execution Plan (NCSX-PLAN-PEP-01). A subset of the ISTP will be conducted before the start of a run.

b. Initial Verification of Operability

The subsystem shall provide the capability to perform subsystem PTPs and support a comprehensive ISTP, to verify, prior to plasma operation that the system is properly configured, functioning correctly, and can be operated safely. [Ref. GRD Section 3.2.1.1]

c. Design Verification

The subsystem shall be instrumented such that key performance parameters (temperatures, pressures, etc.) can be measured and compared to calculated values to assure that the subsystem is performing consistent with the design intent prior to First Plasma.

3.2.1.2 Pre-Run Facility Startup

Background

Pre-run facility startup includes all activities required to verify safe operation of the NCSX subsystems after a major maintenance outage or a minor facility reconfiguration (one affecting a small number of subsystems). Pre-run facility startup activities would typically be performed prior to the start of a run period and would include a subset of the full PTP and ISTP activities referred to in Section 0.

Requirement

The subsystem shall support the capability to perform a controlled startup of the facility, and verify that the subsystem is properly configured, functioning correctly, and can be operated safely. [Ref. GRD Section 3.2.1.2]

3.2.1.3 Prepare for and Support Experimental Operations

a. Subsystem Verification and Monitoring

Background

Pre-operational initialization and verification activities would generally cover those activities required prior to the start of an operating day following an overnight or weekend shutdown. Pre-pulse initialization and verification activities cover those activities required prior to the start of each pulse (plasma discharge). The LN2 System should be monitored to verify that the subsystem is functioning correctly and configured properly at the start of an operating day and prior to the start of each pulse.

Requirement

The subsystem shall provide the capability to verify that the subsystem is properly configured, functioning correctly, and can be operated safely prior to the start of an operating day and prior to the start of each pulse (plasma discharge). [Ref. GRD 3.2.1.3 and GRD 3.2.1.4]

b. Coil Cool-down

Background

Prior to experimental operations, the cryo-resistive coils must be cooled down from room temperature to a pre-pulse operating temperature of about 80K. The coils are located in a dry nitrogen environment that is provided by the cryostat, which surrounds the coils. In order to gain access to the interior of cryostat, the coils must be warmed up from operating temperature to room temperature. The anticipated operational plans are expected to result in no more than 150 cool-down and warm-up cycles between room temperature and operating temperature over the lifetime of the machine.

c. Coil Cool-down Timeline for to Cryogenic Temperature

The LN2 system shall be capable of cooling down the conventional coils from room temperature (293K) to their pre-pulse operating temperature (<85K) within 96 hours with the vacuum vessel at room temperature (20°C). [Ref. GRD Sections 3

3.2.1.4 Shut Down Facility

Background

Facility shutdown involves the shutdown of NCSX equipment following the termination of a discharge (per Section 4.3.1.2.j) preparation for a brief (overnight or weekend) or extended (between run periods) shutdown.

Requirement

The NCSX system shall provide the capability to perform a controlled shutdown of the LN2 System. [Ref. GRD Section 3.2.1.6]

3.2.1.5 Bakeout

Background

The temperature of the vacuum vessel shell will be capable of being elevated to a nominal temperature of 350ºC for vacuum vessel bakeout operations. The capability to bake the vessel with the cryo-resistive coils at cryogenic temperature is required.

a. Coil Temperatures during Bakeout

The LN2 system shall supply the capability to maintain the Conventional Coils below 90K during bakeout of the vacuum vessel. The Conventional Coils shall return to their pre-pulse operating temperatures (<95K) within the 24 hours following completion of bakeout. [Ref. GRD Section 3.2.1.2.3.3]

b. Bakeout Cycles

The device shall be designed for at least 1000 bakeout cycles over the life of the machine. [Ref. GRD Section 3.2.1.2.3.6]

3.2.1.6 Pre-Pulse Temperature

The LN2 system shall return the Conventional Coils to a pre-pulse temperature of less than 95K, so as to prevent overheating during repeated operation, with a vacuum vessel shell temperature in the range of 40ºC to 210 C. [Ref. GRD Section 3.2.1.4.2]

3.2.1.7 Plasma Magnetic Field Requirements

Background

Reference scenario definitions are provided in Section 3.2.1.5.3.3.1 of the GRD. Reference waveforms of engineering parameters such as coil currents, voltages, power dissipation, etc. are derived from the scenario specifications and are documented in Appendix A of the GRD.

Requirement

The LN2 system shall be designed to withstand electromagnetic forces resulting from major disruptions characterized by instantaneous disappearance of the plasma at the maximum plasma current of 320 kA [Ref. GRD Section 3.2.1.5.5]

3.2.1.8 LN2 Temperature and pressure

a. LN2 operating parameters shall be based on the peak temperature and the minimum cool down time required for the MC and conventional coil operation. The LN2 shall be maintained at a sufficient pressure and flow rate to maintain single phase liquid flow at all times, i.e. the saturation temperature of the LN2 shall not be exceeded anywhere in the flow circuit. The rated LN2 flow shall be maintained before, during, and, after operational shots.

b. The installed LN2 system including, all manifolds, headers, hoses, and fittings, shall be leak checked per the requirements in the applicable Engineering Drawings and Procurement Specifications.

3.2.1.9 Pulse Repetition Rate

The LN2 system shall be designed to cool the Conventional coils after 2 second pulses to be initiated at intervals not exceeding 15 minutes. [Ref. GRD Section 3.2.1.5.10]

3.2.1.10 Warm-up Timeline

The LN2 system shall be capable of being warmed up from operating temperature (80K) to room temperature (293K) within a period of 96 hours. [Ref. GRD Section 3.2.1.6.1]

3.2.2 System Physical Characteristics

Background

The system is located in a dry nitrogen environment that is provided by the cryostat. Cool down is the responsibility of Cryogenic Systems. LN2 operation does not begin until cool down is completed.

3.2.2.1 Local I&C

The supply and return lines of every cooling circuit shall be provided with sensors to confirm the presence of flow in the lines and that the temperature meets the pre-shot requirements.

3.2.2.2 Voltage Stand-off Requirements

The conventional coil supply/return hosing shall be electrically isolated from the conventional coils and supply/return manifolds by electrical breaks which provide 2 kV standoff.

The MC coil supply/return hoses shall be electrically isolated from the supply/return manifolds by electrical breaks which provide 2 kV standoff and shall be provided with a path to ground through resisters as defined in Grounding Plan.

The supply/return ring manifolds shall be electrically isolated from their mounting structure and from each other by insulation which provides 2kV standoff.

3.2.2.3 Flow balancing

The LN2 System shall provide hardware (valves) to balance the flow in the circuits and provide instrumentation (gauges) to confirm the balance.

3.2.2.4 Manifold Mounting

The manifold mounting and brackets shall provide for differential thermal growth during cool down and heat up of the LN2 system and shall be designed to withstand the deflection of the coil support structural components they are attached to during EM pulses & faults.

3.2.2.5 Symmetry and Alignment

LN2 components shall be up-down symmetric with respect to the horizontal mid-plane of the modular coils and branch line run lengths, that is the sum of the supply and return, within each system (MC, PF, and TF) shall be made equal in length to within $\pm$ 3 feet.

3.2.2.6 Supports

The LN2 System will have custom designed brackets which will be mounted to the Coil Support Structures (WBS 15).

3.2.3 System Quality Factors

3.2.3.1 Reliability, Availability, and Maintainability

General

<u>Background</u>

The overall objective is to provide a device with high operational availability, meaning that the number of plasma discharges achieved in a run period is a large percentage (greater than 75%) of the number planned after the initial shakedown and commissioning phases of the facility. Bottoms-up reliability predictions are difficult to perform and have large uncertainties for first-of-a-kind experimental devices such as NCSX. Therefore, quantitative RAM requirements on NCSX will be few. Rather, NCSX will rather rely on sound engineering practice to assure high availability in NCSX, which has been the tried-and-true approach on similar scale fusion devices. Sound engineering practices include:

- Applying design principles that promote reliability (e.g., employing an adequate factor of safety on mechanical and electrical stresses, avoiding unnecessary complexity, using proven design approaches and well characterized materials, etc.)
- Optimizing designs for reliability and maintainability through systematic evaluation of design options,
- Performing failure modes, effects and criticality analysis (FMECAs) for RAM design improvement and verification, and
- Employing peer reviews as a mechanism to enhance the design process.

The NCSX RAM Plan defines the processes that will be used by the Project to achieve a device with high availability.

Requirements

- The LN2 System shall incorporate reliability and maintainability features in the design that are consistent with achieving a high (greater than 95%) operational availability.
- Provisions for recovery shall be made for every credible failure mode.
- The LN2 System shall be capable of being disassembled and reassembled to permit replacement of any part or machine reconfiguration that would require disassembly.

[Ref. GRD Section 3.2.4.1]

3.2.3.2 Design Life

The LN2 System shall have a design life of >10 years.

3.2.3.3 Seismic Criteria

Background

NCSX systems shall be designed in accordance with seismic design and evaluation criteria for Performance Category 1 (PC1) facilities, per DOE-STD-1020-2002, "Natural Phenomena Hazards Design and Evaluation Criteria for Department of Energy Facilities." The NCSX Seismic Design Criteria provides an NCSX-specific interpretation of those requirements

Requirement

The LN2 System shall be design in accordance with the NCSX Seismic Design Criteria. [Ref. GRD Section 3.3.1.5]

3.2.4 Transportability

The LN2 System and components shall be transportable by commercial carrier via highway, air, sea, or railway. [Ref. GRD Section 3.2.5]

3.3 Design and Construction

3.3.1 Materials, Processes, and Parts

3.3.1.1 Magnetic Permeability

All materials (including weld materials) used in the LN2 System must have a relative magnetic permeability as calculated by the formula in the GRD but will not be required to be less than 1.02 unless otherwise authorized by the Project. [Ref. GRD Section 3.3.1.1]

3.3.1.2 Structural and Cryogenic Criteria

The LN2 System shall be designed in accordance with the NCSX Structural and Cryogenic Design Criteria. [Ref. GRD Section 3.3.1.3]

3.3.1.3 Corrosion Prevention and Control

Materials, processes, and protective surface treatments or finishes shall be provided to ensure that equipment capability during its service life is not degraded due to corrosion. Where possible, contact between dissimilar metals shall be avoided. [Ref. GRD Section 3.3.1.4]

3.3.2 Electrical Grounding

The LN2 System within the WBS 161 interface will not have a ground plane surface. LN2 System shall be connected via a single point ground provided by the Electrical Power Systems (WBS 4) where appropriate. [Ref. GRD Section 3.3.2]

3.3.3 Nameplates and Product Marking

3.3.3.1 Labels

Equipment and any parts of that equipment to be used by personnel shall be identified with appropriate labels. Labels shall indicate clearly and concisely the function and purpose of the item being labeled. Hierarchical labeling shall be used to facilitate component location on control panels. The terminology used for equipment, procedures, and training materials shall be the same for each case. Label design shall be consistent to promote simplicity and avoid clutter. The use of abbreviations and acronyms shall be minimized. Permanent labels shall be attached to the specific component or equipment in such a manner that environmental conditions or usage by personnel will not remove or destroy the label. Temporary labels shall be used only when necessary and shall not obscure other information or equipment. If a temporary label is to designate a device that is out of service, the label shall be applied so that it prevents the use of that device. Labeling shall be legible and conform to human visual capabilities and limitations in regard to physical characteristics. The labels for the LN2 System will be in the vicinity of the leads for ease of identification of lead polarity and winding direction. [Ref. GRD Section 3.3.3.1]

3.3.4 Workmanship

During LN2 System fabrication and finishing, particular attention shall be given to freedom from blemishes, defects, burrs, and sharp edges; accuracy of dimensioning radii of weld fillets; making of parts; thoroughness of cleaning; quality of brazing, welding, riveting, painting, and wiring; alignment of parts; and tightness and torque of fasteners. [Ref. GRD Section 3.3.4]

3.3.5 Interchangeability

Design tolerances shall permit parts and assemblies of the same part number to be used as replacement parts without degrading the specified performance of the parent item. [Ref. GRD Section 3.3.5]

3.3.6 Environmental, Safety, and Health (ES&H) Requirements

3.3.6.1 General Safety

- When utilized within its intended use and within specified environments, the safe operation, test, handling, maintenance and storage of the LN2 System shall be provided.
- The LN2 System shall not present any uncontrolled safety or health hazard to user personnel.

3.3.6.2 Personnel Safety

The LN2 System shall meet all applicable OSHA requirements in accordance with 29CFR1910. The system shall limit personnel exposure to hazardous materials to below their OSHA permissible exposure limit (PEL). [Ref. GRD Section 3.3.6.3]

3.3.6.3 Flammability

The use of flammable materials shall be minimized. [Ref. GRD Section 3.3.6.4]

3.4 Documentation

3.4.1 Specifications

Specifications shall be developed for the items configured in Figure 1 and procured from commercial vendors, i.e. hoses, manifolds, electrical breaks.

3.5 Logistics

3.5.1 Maintenance

The LN2 System shall be maintained using, to the extent possible, standard/common tools and existing multi-purpose test equipment. Use of new/special tools and the number of standard/common tools shall be minimized through maximum commonality of fasteners, clamps, adapters, and connectors.

3.5.2 Standardized Parts

Standardized parts shall be used in all coil systems (including the Trim Coil System) to the extent practicable. Specifically, standardization shall be considered for electrical leads, coil I&C, and epoxy formulation.

4.0 Quality Assurance Provisions

4.1 General

This section identifies the methods to be used for verification of requirements in Section 0 of this specification. General definitions of basic verification methods are outlined in Section 4.2 Verification of subsystem requirements will require additional testing in operational or near-operational environments.

4.2 Verification Methods

Verification of qualification shall be by analysis, demonstration, inspection, or test. Definition of analysis, demonstration, inspection, and test is as follows:

Analysis: Verification of conformance with required characteristics by calculation or simulation, including computer modeling based on established material or component characteristics.

Inspection: Verification of conformance by measuring, examining, testing, and gauging one or more characteristics of a product or service and comparing the results with specified requirements.

Test: Verification by physically exercising a component or system under appropriate loads or simulated operating conditions, including measurement and analysis of performance data.

4.3 Quality Conformance

This section establishes the specific evaluation criteria for verification of the subsystem performance requirements in Section 0. In general, all requirements shall be verified under operational or near-operational conditions as possible given test constraints.

4.3.1 Performance

4.3.1.1 Perform Initial and Pre-run Verification

a. Initial Facility Startup

b. Initial Verification of Operability

Initial verification of operability (ref. Section 0) shall be assured by inspection of the subsystem PTPs and the ISTP.

c. Design Verification

The adequacy of the design to determine key performance parameters (ref. Section 0) shall be assessed during final design.

Functionality shall be tested during integrated systems testing.

d. Pre-Run Facility Startup

The adequacy of the design to support a controlled startup of the facility (ref. Section 0) shall be assessed during final design.

Functionality shall be tested during integrated systems testing.

4.3.1.2 Prepare for and Support Experimental Operations

a. Subsystem Verification and Monitoring

The adequacy of the design to verify that the subsystem is properly configured, functioning correctly, and can be operated safely prior to the start of an operating day and prior to the start of each pulse (ref. Section 0) shall be assessed during final design.

Functionality shall be tested during integrated systems testing.

b. System integrity

The system shall be leak checked per the requirements referenced in Section 3.2.1.8.

c. Coil Cool-down

The ability to meet the maximum temperature specified in Section 3.2.1.2 shall be demonstrated by analysis during final design, testing upon manufacture to measure key parameters such as coil resistance, and by testing during integrated systems testing.

d. Timeline for Coil Cool-down to Cryogenic Temperature

The ability to cool down the LN2 System is the required time (ref. Section 3.2.1.2) shall be verified by analysis during final design.

The actual cool down time shall be demonstrated during integrated systems testing.

e. Bakeout

The ability to bakeout the vacuum vessel with the LN2 System below 90K shall be verified by analysis during final design (ref. Section 3.2.1.5).

The ability to accommodate the required number of bakeout cycles shall be verified by analysis during final design.

f. Pre-Pulse Temperature

The ability to return to the specified pre-pulse temperature (ref. Section 3.2.1.3) shall be verified by analysis during final design.

The ability to return to the specified pre-pulse temperature shall be demonstrated during integrated systems testing.

g. Disruption Handling

The ability of the LN2 System to withstand electromagnetic forces due to major disruptions per Section 3.2.1.7 shall be verified by analysis during final design.

h. Pulse Repetition Rate

The ability of the LN2 System to meet the pulse repetition rate specified in Section 3.2.1.9 shall be verified by analysis during final design, testing upon manufacture to measure key parameters such as coil resistance, and by testing during integrated systems testing.

i. Voltage Stand-off Requirements

The design voltage standoff in Section 3.2.2.2 for the LN2 System shall be determined by analysis during final design.

The ability to accommodate the manufacturing test voltage shall be verified by test following coil manufacture

4.3.1.3 Shut Down Facility

a. Controlled shutdown of the LN2 System (Section 3.2.1.4) will be demonstrated during integrated systems testing.

b. The capability to warm up the LN2 System in the required time period (Section 3.2.1.10) shall be demonstrated during integrated systems testing.