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Addendum II - Cryoplant Technical Requirements

[Technical Specifications and Project Requirements]

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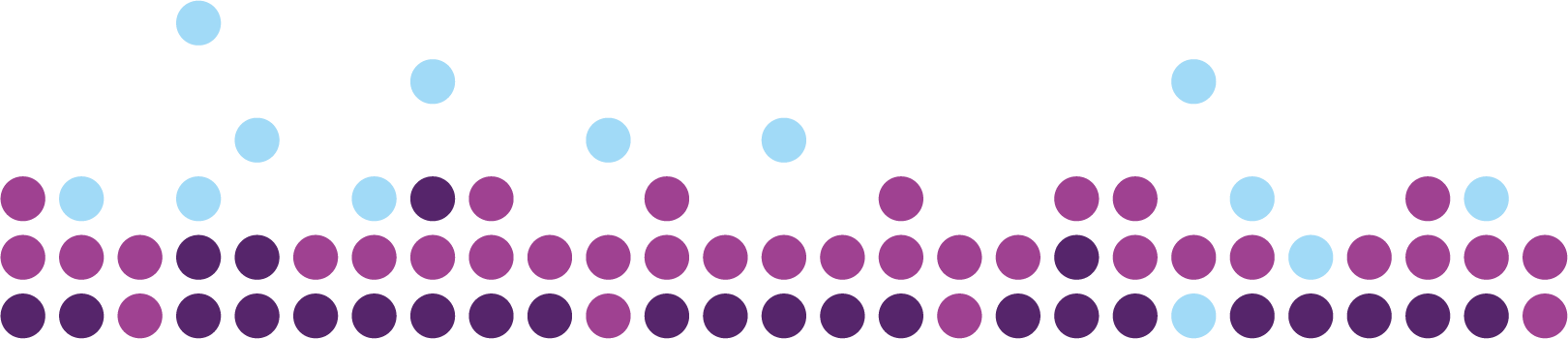
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# Table of Contents

[Table of Contents 3](#_Toc198518286)

[Abbreviations 8](#_Toc198518287)

[Terms and Definitions 10](#_Toc198518288)

[Figure Index 12](#_Toc198518289)

[Table Index 12](#_Toc198518290)

[1 Introduction 13](#_Toc198518291)

[1.1 The LINAC 13](#_Toc198518292)

[1.2 Cryogenic System 13](#_Toc198518293)

[1.3 Cryogenic Users 15](#_Toc198518294)

[1.4 Main Helium Process Interfaces 15](#_Toc198518295)

[1.5 Introduction to CIS 16](#_Toc198518296)

[2 Nature of the Procurement 18](#_Toc198518297)

[2.1 Scope of Work by the Contractor 18](#_Toc198518298)

[2.2 Scope of Supply by the Contractor 18](#_Toc198518299)

[3 Technical Requirements 19](#_Toc198518300)

[3.1 General Requirements 19](#_Toc198518301)

[3.2 Operation Modes and Associated Performances of the Cryogenic System 20](#_Toc198518302)

[3.2.1 Lifetime and annual operation schedule 20](#_Toc198518303)

[3.2.2 Stead state operational scenarios 20](#_Toc198518304)

[3.2.3 Transient operational Scenarios 21](#_Toc198518305)

[Background information 21](#_Toc198518306)

[3.2.3.1 Cool-down 22](#_Toc198518307)

[3.2.3.2 Warm-Up 22](#_Toc198518308)

[3.2.4 Other operational scenarios 23](#_Toc198518309)

[3.2.4.1 Purging and Conditioning 23](#_Toc198518310)

[3.2.4.2 LHe filling and emptying 23](#_Toc198518311)

[3.2.5 QPLANT performance 23](#_Toc198518312)

[3.2.6 Machine self-protection 24](#_Toc198518313)

[3.3 Design and Construction Requirements 25](#_Toc198518314)

[3.3.1 General requirements 25](#_Toc198518315)

[3.3.2 Energy efficiency 25](#_Toc198518316)

[3.3.3 Reliability requirements 26](#_Toc198518317)

[3.3.4 Design, materials and construction requirements 27](#_Toc198518318)

[3.3.4.1 Pressure design 27](#_Toc198518319)

[3.3.4.2 Material requirements 28](#_Toc198518320)

[3.3.4.3 Safety device requirements 28](#_Toc198518321)

[3.3.4.4 Valve requirements 28](#_Toc198518322)

[3.3.4.5 Joints and seals 29](#_Toc198518323)

[3.3.4.6 Bellows 29](#_Toc198518324)

[3.3.4.7 Welding 29](#_Toc198518325)

[3.3.4.8 Cleaning and surface treatment 29](#_Toc198518326)

[3.3.5 Helium guard 29](#_Toc198518327)

[3.3.6 QRB Vacuum system 30](#_Toc198518328)

[3.3.7 Purge requirements 30](#_Toc198518329)

[3.3.8 Leak rate requirements 31](#_Toc198518330)

[3.3.9 Helium Recovery and Helium Inventory management 32](#_Toc198518331)

[OPTION 4 – Dedicated SSC for helium recovery in case of LOOP 32](#_Toc198518332)

[3.3.10 Instrumentation requirements 34](#_Toc198518333)

[3.3.10.1 Sensors used in hard wired component protection 34](#_Toc198518334)

[3.3.10.2 Heaters and electrical measurements 35](#_Toc198518335)

[3.3.10.3 Temperature measurements 35](#_Toc198518336)

[3.3.10.4 Pressure measurements 36](#_Toc198518337)

[3.3.10.5 Liquid level measurements 36](#_Toc198518338)

[3.3.10.6 Flow rate measurements 36](#_Toc198518339)

[3.3.10.7 Impurity measurements in helium flow 37](#_Toc198518340)

[3.3.10.7.1 Pick-ups and sampling main requirements 37](#_Toc198518341)

[3.3.10.7.2 Gas analysis main requirements 37](#_Toc198518342)

[3.3.11 Wiring requirements 37](#_Toc198518343)

[3.3.12 Electrical Requirements 38](#_Toc198518344)

[3.3.13 Identification and labelling 38](#_Toc198518345)

[3.3.14 Valves 39](#_Toc198518346)

[3.3.15 Warm Compressor Station 39](#_Toc198518347)

[3.3.15.1 Technical Specifications of the Warm Compressor Station 39](#_Toc198518348)

[3.3.15.1.1 General requirements 39](#_Toc198518349)

[3.3.15.1.2 Valves requirements 39](#_Toc198518350)

[3.3.15.1.3 Noise level 39](#_Toc198518351)

[3.3.15.1.4 Vibration 40](#_Toc198518352)

[3.3.15.1.5 Heat dissipation to air 40](#_Toc198518353)

[3.3.15.1.6 Heat recovery 40](#_Toc198518354)

[3.3.15.1.7 Compressors requirements 41](#_Toc198518355)

[3.3.15.1.8 Coolers 41](#_Toc198518356)

[3.3.15.1.9 Oil 41](#_Toc198518357)

[3.3.15.2 Oil circulating system 41](#_Toc198518358)

[3.3.15.2.1 Oil-pump units 41](#_Toc198518359)

[3.3.15.2.2 Oil-retention vessel 42](#_Toc198518360)

[3.3.15.2.3 Oil filters 42](#_Toc198518361)

[3.3.15.3 Purge and fill up requirements 42](#_Toc198518362)

[3.3.15.4 Oil Removal System (ORS) 42](#_Toc198518363)

[3.3.15.4.1 Coalescers 42](#_Toc198518364)

[3.3.15.4.2 Charcoal adsorber 43](#_Toc198518365)

[3.3.15.5 Helium dryer 43](#_Toc198518366)

[3.3.15.6 Recovery and purification system for add-hoc user 44](#_Toc198518367)

[3.3.15.7 Gas Filters 44](#_Toc198518368)

[3.3.15.8 Measuring points 44](#_Toc198518369)

[3.3.16 Refrigeration Cold Box (QRB) 45](#_Toc198518370)

[3.3.16.1 General description 45](#_Toc198518371)

[3.3.16.2 General design requirements 46](#_Toc198518372)

[3.3.16.3 Main components 46](#_Toc198518373)

[3.3.16.3.1 Vacuum vessel 46](#_Toc198518374)

[3.3.16.3.2 Heat exchangers 47](#_Toc198518375)

[3.3.16.3.3 Turbines 47](#_Toc198518376)

[3.3.16.3.4 Cold Compressors 47](#_Toc198518377)

[3.3.16.3.5 Helium baths 48](#_Toc198518378)

[3.3.16.3.6 Adsorbers 48](#_Toc198518379)

[3.3.16.3.7 Filters 49](#_Toc198518380)

[3.3.16.3.8 Heaters 49](#_Toc198518381)

[3.3.16.4 Measuring Points 50](#_Toc198518382)

[3.3.17 Warm Storage Helium (Option 1) 51](#_Toc198518383)

[3.3.17.1 General description 52](#_Toc198518384)

[3.3.17.2 Design requirements 52](#_Toc198518385)

[3.3.17.3 Measuring points 53](#_Toc198518386)

[3.3.18 QPLANT Control System 54](#_Toc198518387)

[3.3.18.1 Overview 54](#_Toc198518388)

[3.3.18.2 Reference Architecture 54](#_Toc198518389)

[3.3.18.3 Control System Requirements 59](#_Toc198518390)

[3.3.18.4 General Software and Hardware Requirements 60](#_Toc198518391)

[3.3.18.5 Software development 62](#_Toc198518392)

[3.3.18.6 Software Change Management 63](#_Toc198518393)

[3.3.18.7 Human Machine Interface (HMI) 64](#_Toc198518394)

[3.3.18.8 Network 66](#_Toc198518395)

[3.3.18.8.1 Reference Architecture 66](#_Toc198518396)

[3.3.18.8.2 General 67](#_Toc198518397)

[3.3.18.8.3 Services 67](#_Toc198518398)

[3.3.18.8.4 Infrastructure 69](#_Toc198518399)

[3.3.18.9 Security 69](#_Toc198518400)

[3.3.18.10 Safety 70](#_Toc198518401)

[3.4 Interfaces 70](#_Toc198518402)

[3.4.1 Interfaces to the QLM 70](#_Toc198518403)

[3.4.1.1 Main cryogenic line interfaces 70](#_Toc198518404)

[3.4.1.2 Warm line interfaces 71](#_Toc198518405)

[3.4.2 Interfaces with the site 72](#_Toc198518406)

[3.4.2.1 Compressor room 72](#_Toc198518407)

[3.4.2.2 The cold box room 72](#_Toc198518408)

[3.4.2.3 Storage Area 73](#_Toc198518409)

[3.4.2.4 Site environmental conditions 73](#_Toc198518410)

[3.4.3 Interfaces With Electrical Power Supply 73](#_Toc198518411)

[3.4.4 Interfaces with the Water-Cooling Loop 74](#_Toc198518412)

[3.4.5 Interfaces with instrument air System 75](#_Toc198518413)

[3.4.6 Interfaces with HVAC 75](#_Toc198518414)

[3.4.7 Interfaces with the Vacuum System 76](#_Toc198518415)

[3.4.8 Interfaces with Helium filling 76](#_Toc198518416)

[3.4.9 Interface with LHe (ad-hoc) user and associated helium recovery 76](#_Toc198518417)

[3.4.10 Liquid Nitrogen (LN2) 76](#_Toc198518418)

[3.4.11 Interfaces with MCS 76](#_Toc198518419)

[3.4.12 Interfaces with MIS 76](#_Toc198518420)

[3.4.13 Interfaces with MIT 77](#_Toc198518421)

[3.5 Factory Testing 78](#_Toc198518422)

[3.5.1 Welding, pressure and leak tests 78](#_Toc198518423)

[3.5.2 Tests of components 78](#_Toc198518424)

[3.5.3 Electrical, wiring and control system tests 79](#_Toc198518425)

[3.6 Transport and Storage 79](#_Toc198518426)

[3.7 Installation and Assembly 80](#_Toc198518427)

[3.7.1 Incoming inspection at SCK CEN site 80](#_Toc198518428)

[3.7.2 Test after Mechanical assembly completion 81](#_Toc198518429)

[3.8 Commissioning 81](#_Toc198518430)

[3.8.1 Tests to be done during Commissioning 81](#_Toc198518431)

[3.8.1.1 Preliminary tests 81](#_Toc198518432)

[3.8.1.2 Running tests 81](#_Toc198518433)

[3.9 Site Acceptance testing 82](#_Toc198518434)

[3.9.1 Site acceptance tests 82](#_Toc198518435)

[3.9.1.1 General definition 82](#_Toc198518436)

[3.9.1.2 Leak test and leak rate 83](#_Toc198518437)

[3.9.1.3 WCS functional tests 83](#_Toc198518438)

[3.9.1.4 WCS capacity tests 83](#_Toc198518439)

[3.9.1.5 QPLANT functional tests 84](#_Toc198518440)

[3.9.1.6 QPLANT capacity tests 84](#_Toc198518441)

[Thermal Shield stand-by 85](#_Toc198518442)

[Cold stand-by 85](#_Toc198518443)

[2 K Operation 85](#_Toc198518444)

[QPLANT transition tests 85](#_Toc198518445)

[3.10 Spare Parts (Option 2) 86](#_Toc198518446)

[3.11 After-sales services 87](#_Toc198518447)

[3.12 Documentation 88](#_Toc198518448)

[4 Lifecycle Cost Management and Reliability-Centred Maintenance 90](#_Toc198518449)

[5 Safety, Codes and Standards 92](#_Toc198518450)

[5.1 Safety 92](#_Toc198518451)

[5.2 Codes and Standards 92](#_Toc198518452)

[5.2.1 Pressure Equipment & Safety 93](#_Toc198518453)

[5.2.2 Functional Safety & Control 93](#_Toc198518454)

[5.2.3 Asset & Maintenance Management 94](#_Toc198518455)

[5.2.4 Cleanliness & Purity 94](#_Toc198518456)

[5.2.5 Proof‑Test & Control‑Phase Requirements 94](#_Toc198518457)

[6 Schedule 95](#_Toc198518458)

[6.1 Contractual Phases 95](#_Toc198518459)

[6.2 Preliminary Schedule 96](#_Toc198518460)

[6.3 Hold and Witness Points 96](#_Toc198518461)

[7 Contract Performance 98](#_Toc198518462)

[7.1 General Organization 98](#_Toc198518463)

[7.2 Communication 98](#_Toc198518464)

[7.3 Contract Management 99](#_Toc198518465)

[7.3.1 Progress Dashboard 99](#_Toc198518466)

[7.3.2 Meetings 99](#_Toc198518467)

[7.3.2.1 Progress Meetings 100](#_Toc198518468)

[7.3.2.2 Milestone Meetings 100](#_Toc198518469)

[7.3.2.3 Technical Review Meetings 100](#_Toc198518470)

[7.4 Risk Assessment and Risk Management Plan 100](#_Toc198518471)

[7.5 Factory Access 100](#_Toc198518472)

[8 Quality Assurance and Control 101](#_Toc198518473)

[8.1 Quality Assurance 101](#_Toc198518474)

[8.1.1 General requirements 101](#_Toc198518475)

[8.1.2 Quality Management System 101](#_Toc198518476)

[8.1.3 Quality Assurance Program 101](#_Toc198518477)

[8.1.4 Qualification of personnel 101](#_Toc198518478)

[8.1.5 Document management 102](#_Toc198518479)

[Documents provided by the Contractor to SCK CEN: 102](#_Toc198518480)

[Documents provided by SCK CEN to the Contractor: 102](#_Toc198518481)

[8.1.6 Change Management 102](#_Toc198518482)

[8.1.7 Non-Conformity Management 103](#_Toc198518483)

[8.1.8 Audits 104](#_Toc198518484)

[8.2 Quality Control 104](#_Toc198518485)

[8.2.1 General requirements 105](#_Toc198518486)

[8.2.2 Manufacturing and Inspection Plan 105](#_Toc198518487)

[8.2.3 Declaration of conformity with all requirements 105](#_Toc198518488)

[8.3 Acceptance Tests 106](#_Toc198518489)

[8.3.1 General Requirements 106](#_Toc198518490)

[8.3.2 Factory Acceptance Test (FAT) 106](#_Toc198518491)

[8.3.3 Site Acceptance Tests 107](#_Toc198518492)

[9 Acceptance and Warranty 108](#_Toc198518493)

[9.1 Provisional Acceptance 108](#_Toc198518494)

[9.2 Warranty Period 108](#_Toc198518495)

[9.3 Warranty Conditions 108](#_Toc198518496)

[9.4 Final Acceptance 109](#_Toc198518497)

[10 Appendix 110](#_Toc198518498)

[10.1 Cooling Power for Cool-down 110](#_Toc198518499)

[Cooldown to 50 K 110](#_Toc198518500)

[Cool-down to 4.5 K 111](#_Toc198518501)

[LHe filling 111](#_Toc198518502)

[Cooldown to 2 K 112](#_Toc198518503)

[11 References 113](#_Toc198518504)

[11.1 Applicable Documents 113](#_Toc198518505)

[11.2 Cold masses of Cryogenic Users and Cryogenic Distribution 114](#_Toc198518506)

[11.3 PFD of the QVE (not included in the QPLANT procurement) 115](#_Toc198518507)

[Annexes 116](#_Toc198518508)

## Abbreviations

|  |  |  |
| --- | --- | --- |
| ACC NF | Accelerator Nuclear Facilities (buildings and utilities) |  |
| AD | Applicable Documents |  |
| AH | Atmospheric Heat exchanger |  |
| CAV | Cavity |  |
| CCB | Cryogenic Compressor Building |  |
| CEA | French Alternative Energies and Atomic Energy Commission |  |
| CIS | Control and Interlock system |  |
| CV | Control Valve |  |
| DD | Documentation Deliverables |  |
| DSBT | Low Temperature Systems Department |  |
| EH | Electrical Heater |  |
| FAT | Factory Acceptance Test |  |
| FMECA | Failure mode, effects, and criticality analysis |  |
| FT | Fault Tolerance |  |
| GHe | Gaseous Helium |  |
| HAZOP | HAZard and OPerability |  |
| He | Helium |  |
| HMI | Human Machine Interface |  |
| HP | High Pressure |  |
| HVAC | Heating, Ventilation and Air Conditioning |  |
| HV | Hand Valve |  |
| HX | Heat Exchanger |  |
| KOM | Kick-Off Meeting |  |
| LHe | Liquid Helium |  |
| LN2 | Liquid Nitrogen |  |
| LINAC | Linear Accelerator |  |
| LTU | LINAC Tunnel |  |
| LP | Low Pressure |  |
| LWC | Low Pressure Warm Compressor |  |
| MCS | Control System |  |
| MIP | Manufacturing and Inspection Plan |  |
| MIS | Interlocking System |  |
| MIT | IT System |  |
| MTBF | Mean Time Between Failure |  |
| MTBM | Mean Time Between Maintenance |  |
| MTTR | Mean Time To Repair |  |
| MYRRHA | Multi-purpose hYbrid Research Reactor for Hight-tech Applications |  |
| NA.CP | Cryogenic Supply System |  |
| ORS | Oil removal system |  |
| PFD | Process Flow Diagram |  |
| PID | Piping and Instrumentation Diagram |  |
| PLC | Programmable Logic Controller |  |
| QCELL | Cryogenic Cell = QVB+QM |  |
| QLM | Main Cryogenic Distribution Line |  |
| QM | Cryomodule |  |
| QPLANT | QPLANT |  |
| QPLANT:CS | QPLANT Control System |  |
| QRB | QPLANT Refrigeration Cold Box |  |
| QSYS | Cryogenic System |  |
| QSYS:CS | Cryogenic Control System |  |
| QVB | Cryogenic Valve Box |  |
| QVE | End-box |  |
| RF | Radio Frequency |  |
| SAT | Site Acceptance Test |  |
| SC | Superconducting |  |
| SHe | Supercritical Helium |  |
| ST | Storage |  |
| SV | Safety Valve |  |
| TRO | Technical Responsible Officer |  |
| TRM | Technical Review Meeting |  |
| TS | Thermal Shields |  |
| Tu | Turbo Expander |  |
| UPS | Uninterruptible Power Supply |  |
| VLP | Very Low Pressure |  |
| VP | Vacuum Pump |  |
| WCS | Warm Compressor Station |  |
| WSH | Warm Storage Helium |  |



## Terms and Definitions

|  |  |
| --- | --- |
| CoreShare | SCK CEN’s document management system |
| Conceptual Process Proposal | A preliminary engineering framework that defines the cryogenic helium refrigeration architecture, supporting a range of operational and functional requirements. The Conceptual Process Proposal serves as the foundation for subsequent design stages by detailing the system architecture, proposed configurations, and functional decompositions necessary to meet the overarching System Requirements. It ensures integration of key subsystems and process units while maintaining compliance with operational constraints, safety margins, and performance criteria. It is reviewed and validated as a baseline for the Detailed Design phases |
| Design Stage(s) | |  | | --- | | A self-contained phase within the engineering design process, each focusing on a distinct level of technical maturity and output deliverables. Design Stages are sequenced to transform user requirements into realizable system configurations through increasing levels of fidelity and validation. |   Conceptual Design: A phase in the design process that involves evaluating multiple concepts to determine their ability to fulfil the defined fit-for-purpose requirements. It includes the identification and justification of a reference concept deemed the most suitable and feasible within the specified constraints. The Conceptual Design provides a general understanding of the system's intended purpose, overall structure, operating principles, physical dimensions, and key technical specifications. Once reviewed and approved, the Conceptual Design serves as the foundation for the development of the Detailed Design.  Detailed Design: This stage develops the finalized and exhaustive Design Documentation required for fabrication, inspection, testing, installation, commissioning, operation, maintenance, refurbishment, and decommissioning of the System. Documentation must meet quality, regulatory, and lifecycle expectations. |
| Hold Point | A mandatory verification point beyond which work cannot continue without approval by SCK CEN. The work can only continue provided that SCK CEN has been able to verify the quality of the work completed so far and has confirmed its approval of such work in writing. |
| Fixed Price Offer | A commercial proposal in which the total project price remains unchanged regardless of actual costs incurred. This offer must fully reflect all technical requirements and be supported by traceable cost models aligned with the Scope of Requirements (SoR). |
| Lifecycle Cost Management | The cost optimization approach used during the post-commissioning phase to manage preventive maintenance, replacement strategy, and reliability targets. It is supported by failure forecasting, risk-based planning, and system performance modelling to maintain or reduce lifetime cost without compromising function. |
| Reliability Centred Maintenance | A systematic and structured process to determine the most effective maintenance approach for an asset or system. RCM seeks to ensure that systems continue to do what their users require in their current operating context. It involves identifying failure modes, assessing their consequences, and selecting proactive maintenance tasks to mitigate risk while optimizing cost, safety, and system availability. |
| Risk Register | A formal tool used to systematically document, track, and manage risks throughout a project, with the primary purposes of risk identification, assessment, treatment, monitoring, and communication. |
| System Under Test (SUT) | |  | | --- | |  |  |  | | --- | | A digital or physical representation of the system used for validation during commissioning, including control logic, process response, and layout. The model serves as a reference for virtual sensors, predictive maintenance, and cost optimization decisions related to system operation and lifecycle | |
| Verification | Confirms that the product is built correctly according to the specified requirements, ensuring compliance with regulations and specifications.  Conducted throughout the development lifecycle, including during production or development phases. These activities involve reviews, inspections, and testing to ensure compliance with specifications. |
| Validation | Ensures that the right product is built, confirming that the system meets the needs and expectations of the end-users or stakeholders.  Occur after verification processes, typically at the end of a development phase or project. Validation involves evaluating the final product to ensure it meets the needs of the intended end-user or customer. |
| Terminal Point | A physical interface with CLIENT infrastructure, specifically ACC NF. |
| Warm Compressor station | Composed of LP to HP and VLP to LP compressors, the Oil Removal System, the gas management panel and the necessary electrical cabinets. |
| Witness Point | A point in the process where SCK CEN will verify the quality of the work completed. However, the work may continue meanwhile. |

## Figure Index

[Figure 1 Overall layout of the Cryogenic System. 11](#_Toc195865357)

[Figure 2 QPLANT’s Simplified Process Flow Diagram 12](#_Toc195865358)

[Figure 3 View of the buildings. 13](#_Toc195865359)

[Figure 4 Simplified interface diagram of QPLANT depicting a single representative 'QCELL' as a proxy for all heat load sources 13](#_Toc195865360)

[Figure 5 Main operational transitions for the Cryogenic System. Blue boxes indicate steady states while light blue boxes indicate transients. 20](#_Toc195865361)

[Figure 6 Heat recovery principle. 38](#_Toc195865362)

[Figure 7 Reference Architecture of the Cryogenic Control System 54](#_Toc195865363)

[Figure 8 Software Change Management 61](#_Toc195865364)

[Figure 9 MIT Reference Architecture 65](#_Toc195865365)

[Figure 10 Preliminary arrangement of the pipes in the QLM (see Table 12 for details). 69](#_Toc195865366)

[Figure 11 Overall layout of buildings. 71](#_Toc195865367)

[Figure 12 Cool-down power for Thermal Shields (based on cool-down speed of 4 K/h ~ 72 hours) 111](#_Toc195865368)

[Figure 13 Cool-down power for cold masses < 5 K (based on constant cool-down speed of 4 K/h ~ 72 hours). 112](#_Toc195865369)

[Figure 14 General PFD of the QVE (end box) with interfaces 116](#_Toc195865370)

## Table Index

[Table 1 Main Helium Interfacing Process Lines/Pipes 14](#_Toc195865371)

[Table 2 Operational Scenarios of the Cryogenic System 18](#_Toc195865372)

[Table 3 Heat loads summary for QCELLs and cryogenic distribution 22](#_Toc195865373)

[Table 4 Fluid conditions at the Refrigerator Cold Box interfaces for the different operating scenarios 22](#_Toc195865374)

[Table 5 Leakage requirements 29](#_Toc195865375)

[Table 6 Temperature measurement precision 33](#_Toc195865376)

[Table 7 measuring points for WCS 43](#_Toc195865377)

[Table 8 measuring points for QRB 48](#_Toc195865378)

[Table 9 Helium inventory 50](#_Toc195865379)

[Table 10 Measuring points for gas helium storages. 51](#_Toc195865380)

[Table 11 Instructions for GSHRC 58](#_Toc195865381)

[Table 12 Preliminary pipe diameters for the QLM 69](#_Toc195865382)

[Table 13 Warm lines at room temperature 70](#_Toc195865383)

[Table 14 Documentation Deliverables 90](#_Toc195865384)

[Table 15 Preliminary Schedule and Main Milestones 97](#_Toc195865385)

[Table 16 Cool-down power down to 50 K (4 K/h) 112](#_Toc195865386)

[Table 17 Cool-down power below 50 K (4 K/h) 112](#_Toc195865387)

[Table 18 Applicable Documents (AD) 114](#_Toc195865388)

[Table 19 Cold masses at 4.5 K / 2 K 115](#_Toc195865389)

[Table 20 Cold masses at 40 K / 60 K 115](#_Toc195865390)

1. Introduction

“Phase 1 – Implementation” of the MYRRHA program focuses on the design, construction and commissioning of a 4 mA 100MeV super-conducting CW proton Linear Accelerator (LINAC), a Proton Target Facility (PTF) and a Full Power Facility (FPF). (Phase 2 of the MYRRHA program will be the extension to 600 MeV). Further information about MYRRHA Phase I is provided in reference AD3.

* 1. The LINAC

The LINAC (~100 m length) consists of a normal conducting injector, followed by a superconducting section. The latter section accelerates protons from 17 to 100 MeV using 352.2 MHz single-spoke cavities operating at 2 K. Each Cavity (CAV) is submerged in saturated superfluid helium (He II) within Helium Tanks (HT), organized into pairs inside a Cryomodule (QM). Each QM is connected to a dedicated Cryogenic Valve Box (QVB). The combination of one QM and one QVB is called a Cryo-Cell (QCELL). The full LINAC configuration will comprise sixty CAVs in thirty QMs. Initial deployment includes twenty-four QMs; the remaining six are to be added later.

* 1. Cryogenic System

The Cryoplant (QPLANT), a subsystem of the Cryogenic System (Figure 1), is designed to provide refrigeration to QMs via the Cryogenic Distribution System (QDIST).

|  |
| --- |
|  |
| Figure 1 Overall layout of the Cryogenic System. |

QDIST comprises the QLM, the string of QVBs, and the QVE. The QLM houses the main headers distributing cold helium at multiple temperature levels. The QLM enters the LINAC Tunnel (LTU) via a radiation-protection chicane. Each QCELL regulates its helium mass flow by

tapping from and returning to the distribution headers. Additionally, QVBs include He II conditioning

capabilities. Excess flow is bypassed through the QVE.

The QPLANT includes a WCS connected to helium storage vessels, a

Cold Box for refrigeration processes, and process equipment for drying, oil removal, gas management, and

purification. An indicative Process Flow Diagram of the QPLANT is shown in Figure 2.



Figure 2 QPLANT’s Simplified Process Flow Diagram

The QPLANT is located in different areas as shown in the layout in Figure 3:

* Compressor Room: Location for the Warm Compression Station (WCS)
* Storage Area (outside): Location for helium storage vessels and (if needed) liquid nitrogen storage vessels.
* Cold Box Room: Location for the QRB with the associated warm panel. In addition, if a liquid helium storage is needed for the operation of the cryogenic system, it is in this room.
* Connecting rooms: The Warm lines from the WCS to the QRB cross multiple other rooms.

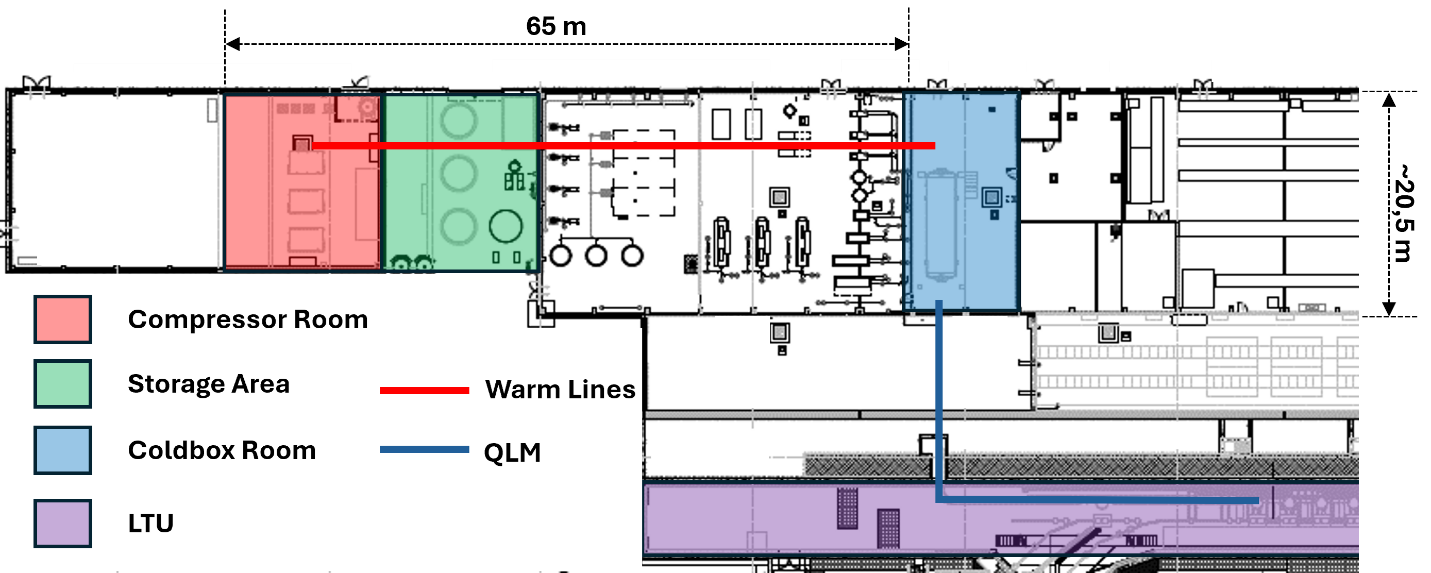


Figure 3 View of the buildings.

* 1. Cryogenic Users

Each Cryogenic User (QCELL), see Figure 4, interfaces with the QPLANT via designated helium lines (**A, B,**

**D, E, W**), which correspond to main helium circulation circuits as detailed in Table 1

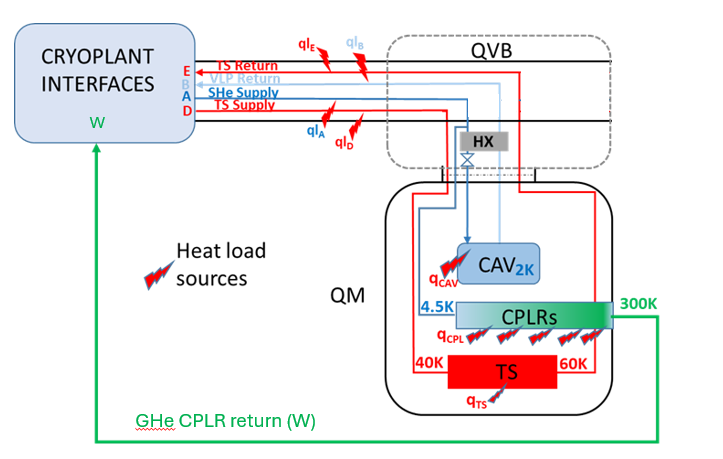


Figure 4 Simplified interface diagram of QPLANT depicting a single representative 'QCELL' as a proxy for all heat load sources

* 1. Main Helium Process Interfaces

Table 1 lists the helium transport paths between QRB, WCS, QCELLs, and other subsystems. Values are indicative and subject to refinement during detailed design.

Table 1 Main Helium Interfacing Process Lines/Pipes

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Name** | **Category** | **Purpose** | **Indicative Flow Rate** | **Role / Notes** |
| A | Cryogenic Line | Supply of Supercritical Helium (SHE) at 4.5 K, 3 bar from QRB | ~50 g/s | Delivers cold helium to user distribution or cryomodules requiring SHE |
| B | Cryogenic Line | Suction/return from QCELL at ~28 mbar, 2 K | ~45 g/s | Managed by QRB for 2 K return flow from cryomodules |
| D | Cryogenic Line | Thermal shield helium supply (30–40 K) | ~80 g/s | Flow matches that of E |
| E | Cryogenic Line | Thermal shield return header (~60 K) | ~80 g/s | Returns helium from the shield circuit to the cold box or WCS |
| U | Warm Piping | 2 bar max, ad-hoc usage for specialized flows | ~10 g/s | - |
| W | Warm Piping | From QDB (via QCELLs) to VLP compression at 300 K | ~5 g/s | Coupler (QPLR) return |
| S | Warm Piping | Safety path from QRB to VLP compression, typically 300 K | ~50 g/s (normal), up to 100–200 g/s (event) | Emergency discharge or vent path |
| HP | Internal Connection WCS↔QRB | High-pressure helium (up to ~15 bara) from WCS (LP→HP stage) | ~350 g/s, 300 K | Supplies high-pressure helium downstream from compressor stage |
| LP | Internal Connection WCS↔QRB | Low-pressure (~1.05 bar) feed for compression | ~300 g/s, 300 K | Acts as suction/feed for compression system |
| VLP | Internal Connection WCS↔QRB | Transfer of very low-pressure helium (~28 mbar to ~500 mbar) from QRB | ~50 g/s, 300 K after warming | Connection to PVPS (Very Low Pressure System) |

* 1. Introduction to CIS

The **Control and Interlock System (CIS)** performs controls and safety related functions on the primary systems. It consists of two main components:

* SCK CEN Control System (MCS):

MCS manages and monitors all devices and processes. It sends commands to operate various parts of the system (e.g. RF generators, magnets, and the QPLANT) and continuously collects data to ensure everything is running correctly. Its focus is on performance and operational efficiency.

* SCK CEN Interlock System (MIS):

MIS works side-by-side with MCS but with a different goal. Its main job is safety. MIS is an independent, fail-safe system that immediately steps in to prevent accidents, such as equipment damage or any risk to personnel, by cutting off or altering operations if something goes wrong.

* Information Technology (MIT):

MIT provides the supporting IT infrastructure for the entire facility. This includes networking, servers, user authentication, data storage, and backup services. Essentially, MIT makes sure that all the systems (primary and secondary) can communicate reliably, and that data is managed securely.

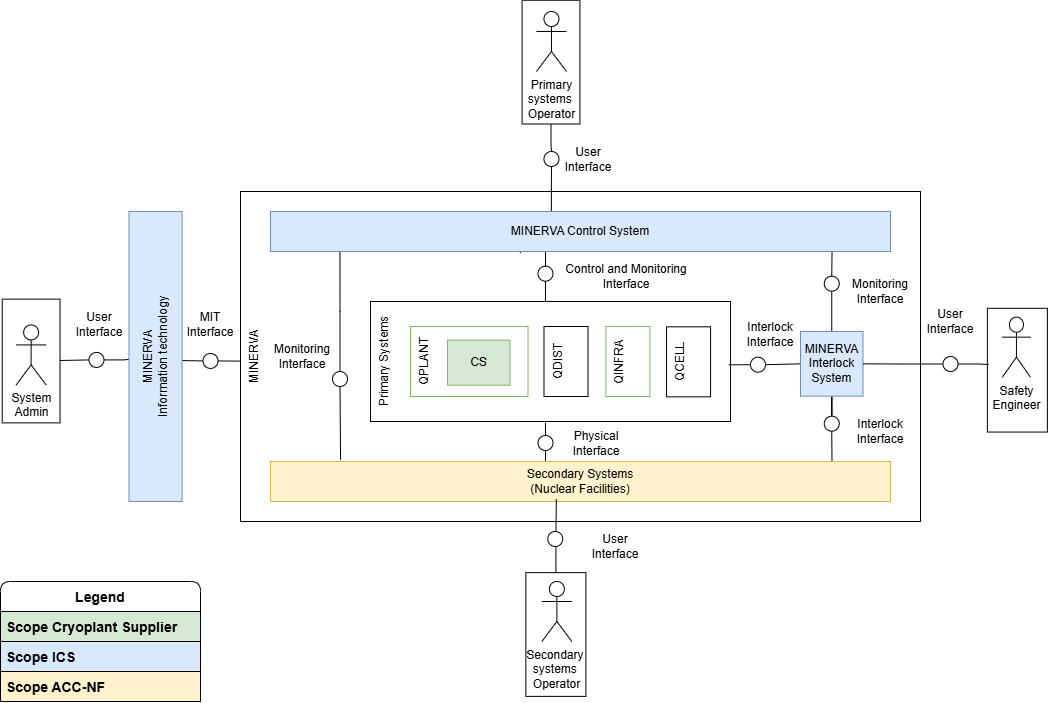


Figure 5 MINERVA Control and Interlock related systems

1. Nature of the Procurement
   1. Scope of Work by the Contractor

The procurement assignment includes all services required to design, build and commission a fully functional QPLANT in compliance with the requirements set forth in this document. This includes the following activities (non-exhaustive list):

* Design of the QPLANT
* Development of the QPLANTs Control system (QPLANT:CS).
* Manufacturing and procurement of all necessary components.
* Transportation and delivery.
* Installation
* Stand-alone commissioning and testing (including QPLANT:CS).
* Activities for integrated commissioning (including the connection to MCS)
* Quality Assurance and Control.
  1. Scope of Supply by the Contractor

The Contractor's scope of supply for the QPLANT includes the delivery of the granted supplies (fixed amount and granted options) as set forth below.

Fixed amount:

* One fully functional QPLANT including, but not limited to:
  + Warm Compression Station (WCS)
  + Refrigeration Cold Box (QRB)
  + All helium required to perform the commissioning and acceptance testing of the stand-along QPLANT
  + Internal piping between the various areas of the QPLANT
  + Vacuum systems
  + Control system
  + Documentation

Options:

* Option 1: Warm Storage Helium (WSH) vessels for full helium inventory
* Option 2: Spare Parts
* Option 3: Service Level Agreement

N.B.: There is no order/preference assumed for the options.

1. Technical Requirements
   1. General Requirements
2. The Contractor shall be fully responsible for ensuring that the Deliverables and Services provided fully meet the specified requirements for the Contract. Therefore, the Applicant shall duly analyse the SCK CEN’s Tender Documents and evaluate whether sufficient information is presented to allow the Applicant to put forward a proposal that ensures that the delivery of the procured items meet the specified requirements.
3. If certain information is found to be lacking, the Applicant must request this information from SCK CEN without undue delay (according to §1.6 of the Main Tender Document). In accordance with §1.7 of the Main Tender Document, the Contractor may no longer rely on information lacking after submission of its offer. If the Contractor would only identify a lack of information during the performance of the Contract, this will not give rise to any basis for a Variation.
4. In the offer, the Applicant shall list the requirements (in addition to the SCK CEN’s requirements) which have been defined by the Applicant (as well as any assumptions made to define such requirements) and which shall be used as a basis for the definition and execution of the Contract.
5. The technical requirements imposed by the SCK CEN (including, but not limited to norms and other standards, processes, and their parameters) applicable to the development, performance, and quality (inspections, tests, etc.) of the procured items are specified in the present document and all other documents referred to herein.

In principle, these requirements are mandatory, unless adjusted in accordance with the principles set forth in the subsequent paragraphs.

1. If certain of these technical requirements are not met (for example: if a requested norm or standard, or a preferred process (parameter), is not implemented by the Applicant), the Applicant shall clearly state this deviation in his offer. The Applicant shall also provide a clear description of the deviation (e.g.: indicating which norm/standard or process (parameter) shall be implemented as an alternative to the requested one) and shall justify this choice.
2. In its offer, the Applicant may suggest modifications vis-à-vis the technical requirements as imposed by the present document, which, in the Applicant’s opinion, would constitute an improvement in terms of cost, reliability, safety, ease of use, or any other improvement of the QPLANT. For each modification, the Applicant shall demonstrate its advantages as well as list the drawbacks (if any).
3. The Applicant shall submit one offer, including all modifications, which in the Applicant’s view constitutes the most optimal solution for the QPLANT. It is not allowed to submit multiple offers covering multiple solutions.

In the offer, the Applicant is to give a clear overview of the main activities that shall constitute the Contract performance. For each activity, the Applicant is to provide information regarding i.a. how the applicable requirements shall be met, the chosen process(es) and technique(s) that shall be implemented, etc. Where applicable, the Applicant is to give at least the details as requested in the present document; if no specific details are requested in the present document, the Applicant is to choose, based on its experience, the appropriate (level of) detail(s) to be provided in relation to the criticality and/or complexity of the activity.

1. During negotiations, if any, the deviations and modifications shall be discussed between SCK CEN and the Applicant. SCK CEN reserves the right, at its sole discretion, to refuse deviations and/or modifications without justification of its decision. Only deviations and modifications for which the Applicant has received SCK CEN’s prior written approval may be implemented.
   1. Operation Modes and Associated Performances of the Cryogenic System
      1. Lifetime and annual operation schedule
2. The QPLANT shall operate in “2K operation” uninterrupted for at least 6 months.
3. The maintenance plan of the QPLANT shall adhere to the following constraints:
   * + every 6 months, no more than 10 days requiring “2K standby”.
     + every 1 year, no more than 20 days requiring “4.5K standby”
     + every 5 years, no more than 60 days requiring “warm stop”
     + every 10 years, no more than 120 days requiring “warm stop”
4. The QPLANT shall have a lifetime of at least 40 years.
5. The QPLANT shall withstand at least 50 warm-up/cool-down cycles (between 300 and 2K) during its lifetime.
   * 1. Stead state operational scenarios
6. The QPLANT shall operate in the operations scenarios given in Table 2

Table 2 Operational Scenarios of the Cryogenic System

|  |  |  |
| --- | --- | --- |
| Operational scenarios | Description | Comments |
| Thermal Shield Standby | all QCELLs at thermal shield temperature |  |
| 4.5K Standby | all QCELLs around 4 K |  |
| 2K Standby | all QCELLs at 2 K | Minimal design point |
| 2K operation | RF-operation allowed | Nominal design point |

1. When in 4.5K standby, the QPLANT shall allow the (partial) stop of the (cold and/or warm) VLP compressors.

For the 2K operation scenario, the operation temperatures and pressures are the nominal ones: it requires cavity bath at 2 K (saturated superfluid helium with 31 mbar), the thermal shields supplied at 40 K and the coupler cooled between 5 K and 300 K. The superfluid helium levels and the bath pressure are controlled for each QCELL. The heat loads dissipated in the helium bath is a function of the RF power in the cavities.

For the 2K Standby scenario, the operation temperatures and pressures are the similar to the 2K operation with the distinction that the stability requirements are relaxed as there is no RF operation. This operation mode may be used in the preparation phase before and after accelerator operations.

* + 1. Transient operational Scenarios

Background information

All QCELL’s will be cooled down in parallel.

During cool-down and warm-up, cavities and cryomodules impose the following requirements and constraints on the QPLANT operation:

* The magnetic shields must reach a temperature T < 70 K before the cavities reach T < 10 K. In order to guarantee this, each QCELL autonomously limits its cool down speed.

For proper interface modeling, the following user-side input data shall be provided by SCK CEN after contract granting:

* The static heat load as a function of temperature, Q\_static = f(T), for each relevant circuit.
* The total energy to be extracted, E\_extract = f(T).
* Although material and mechanical stress due to differential temperature gradients impose some limits, a cooldown speed of up to 20 K/h (equivalent to ~12 hours) is acceptable for the “cooldown to 50 K”. As an example, the required cooling power for a 4 K/h cool-down rate (corresponding to 72 hours) is provided in the appendix.
* There is no constraint imposed on the cool-down speed for the “Cool down to 4.5K”.

QCELLs are equipped with heaters in their 2 K tanks. One of the main functions of these heaters is to accelerate the warm-up process by:

* Evaporating the remaining liquid helium to vapor (isothermal phase) to assist in tank emptying.
* Increasing the enthalpy of the cold mass (reheating the structural material).

The total power of these heaters is 600 Watt. This power may be adjusted to match what the QPLANT can absorb.

SCK CEN does not impose a warm-up rate nor the use of QCELL heaters, particularly during the liquid emptying phase, as part of the operational requirements towards the QPLANT.

1. The QPLANT shall support the transitions given in Figure 6.

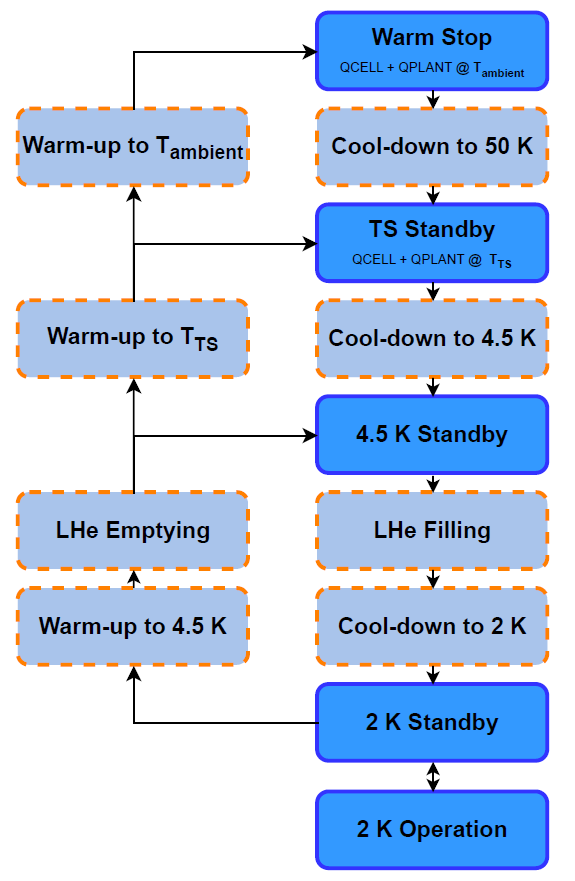


Figure 6 Main operational transitions for the Cryogenic System. Blue boxes indicate steady states while light blue boxes indicate transients.

Cool-down

1. The Contractor shall not drive the design and size of the QPLANT by the cool down requirements.
2. The QPLANT shall perform the cool-down of the QPLANT simultaneously with the cryogenic users.
3. The Contractor shall assume that the TS-circuits (headers “D” to “E”) and cold mass circuits (headers “A” to “B”) are cooled down simultaneously.

In their offer, the Applicant shall indicate and motivate the resulting shortest possible cool down duration and speed of the complete cryogenic system (from 300K to 2K). For this purpose, the Applicant shall use the following information given in Appendix 10.1.

Warm-Up

1. The QPLANT shall be able to cope with a warm-up of the cryogenic users from 2K to 300 K in less than 5 days.
2. The QPLANT shall support the following main phases for the warming-up of the cryogenic users:
   * + Warm-up to 4.5 K by stopping the Very Low Pressure Compressors
     + Emptying of the Liquid helium baths by evaporation with electrical heaters and stop of the level controls.
     + Warm-up from 4.5K to 300K.

In their offer, the Applicant shall indicate the expected duration of the main phases of the warming up of the cryogenic users.

* + 1. Other operational scenarios

Purging and Conditioning

1. The Contractor may implement a manual purging, manual conditioning and manual initial preparation of the QPLANT.
2. If a manual operation for this step is chosen, the Contractor shall provide a detailed procedure.

LHe filling and emptying

1. The Contractor shall assume that the LHe filling and emptying occurs when the cryogenic users are at 4.5K and XXXXX give them header A condition before JT expansion.
   * + Average retention rate of 0.8 g/s LHe per individual QCELL (24 g/s total) during the filling process
2. During LHe filling, the QPLANT shall provide 2900 liters of LHe to the users.

In their offer, the Applicant shall indicate the expected duration of the LHe filling as well as the maximum filling rate the QPLANT can produce.

1. The Contractor shall consider an enveloping range for the warm-up rate, encompassing the following boundary conditions:
   * + The minimum warm-up rate, corresponding to the case where only static heat loads are present.
     + The maximum warm-up rate, corresponding to the case where QCELL heaters are fully utilized to accelerate the process or the maximum flow rate the QPLANT can manage during the emptying phase.

In their offer, the Applicant shall indicate the expected duration of the emptying phase as well as the maximum flow rate that can be accepted while conserving the helium inventory.

* + 1. QPLANT performance

1. The Contractor shall use the simplified heat load deposition sources as indicated in Figure 4.
2. The QPLANT shall be designed for the heat loads defined in Table 3

Table 3 Heat loads summary for QCELLs and cryogenic distribution

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| Operating Scenario | Isothermal Heat Loads (W) | | Non-Isothermal Heat Loads (W) | | | | Indicative Equiv. Refrigeration W@4.5K |
| Bath at 2K (qCAV) | Bath at 4K (qCAV) | VLP return line  3.5K-3.7K (qIB) | SHe return line  4.5K (qIA) | TS (40-60K)  (qTS+ qIE + qID) | Mass Flow (g/s) for couplers 4.5-300K (qCPL) |
| 2K operation:  Nominal Design Point | 900 | 0 | 40 | 20 | 8600 | 2 | 3430 |
| 2K Standby:  Minimal Design Point | 340 | 0 | 30 | 10 | 5100 | 1 | 1490 |
| 4.5K Standby | 0 | 560(\*) | 0 | 11 | 8600 | 2 | 1640 |
| TS Standby | ~0 | ~0 | ~0 | ~0 | 8600 | ~1 (40k-300k) | 720 |

(\*) This is referred to as ‘static heat load’ further in the text

1. The QPLANT shall support the operating fluid conditions at the QRB as listed in Table 4.
2. For the Thermal Shield circuits (header “D” to “E” in Table 4), the Contractor shall optimize the mass flow, temperatures, and pressures (staying within the stated operating window of) to improve the overall efficiency or capital investment.

In the offer, the Applicant shall indicate the mass flow, temperatures, and pressures of the Thermal Shield circuits.

Table 4 Fluid conditions at the Refrigerator Cold Box interfaces for the different operating scenarios

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| Refrigerator Cold Box Interfaces | | A  HP | B  VLP | W  Coupler return | D  TS supply | E  TS return |
| 2 K Operation | Pressure (bar) | ≥3 | ≤0.026 | ~ 1.1 | ~ 14\* | ~ 13\* |
| Temperature (K) | ≤4.5 | ≥3.5 | 300 | ≤40 | ≤60 |
| Mass flow rate (g/s) | ≥47 | ≥45 | ≥2 | 81\*\* | 81\*\* |
| 2 K Standby | Pressure (bar) | ≥3 | ≤0.029 | ~ 1.1 | ~ 14\* | ~ 13\* |
| Temperature (K) | ≤4.5 | ≥4.2 | 300 | ≤40 | ≤60 |
| Mass flow rate (g/s) | 18 | 17 | 1 | 48\*\* | 48\*\* |

\* Pressure value to be defined by the Contractor depending on the compressor HP process value.

\*\* Indicative mass flow rate values (determined for T= 20 K) to be adjusted depending on the process supply and return temperatures to TS to cope with the required heat loads given in Table 3.

* + 1. Machine self-protection

1. The QPLANT shall protect itself from any damage and allow subsequent recovery after these events. The Contractor shall identify all such events including but not limited to:

* loss of utility (electricity, water, compressed air, nitrogen if used)
* loss of vacuum (internal “QRB” or external: cryogenic distribution or users)
* QPLANT trip

1. The abnormal event management shall be included in the failure and safety lifecycle analysis (e.g. HAZOP, FMECA, or equivalent methodology) and shall take into account all identified abnormal events. The Contractor shall develop the resulting risk mitigation strategy covering the entire QPLANT system, its subsystems, and all physical and functional interfaces with external systems or facilities. The strategy shall define mitigation measures, responsible parties, implementation timelines, and the verification and validation methods for each identified risk.

The outcome shall be documented in a dedicated Abnormal Event Mitigation Plan, which shall be reviewed and approved by the Client during the design review phases..

* 1. Design and Construction Requirements
     1. General requirements

1. All pressure values shall be given in absolute pressures using the bar or mbar unit, the zero-value referring to vacuum.
2. All other measurement units (not covered by the previous requirement) shall be given in SI units.
   * 1. Energy efficiency

* Coefficient of Performance (COP) – Cryogenic Refrigeration

The Coefficient of Performance (COP) is defined as the ratio of the net cooling power to the total input power:

Where:

* Inverse Coefficient of Performance (invCOP)

Due to the low efficiency values typical of cryogenic systems, it is standard practice to also express performance using the inverse of COP (Units: W/W or kW/W)

:

1. The inverse COP shall be smaller than 380 under any operating scenario within the defined design envelope.

In the offer, the Applicant shall state the inverse COP for each of the steady-state scenarios they commit to deliver.

In the offer, the Applicant shall provide a substantiated justification via e.g. design configuration, operating assumptions, and calculations, measurements, …

Higher efficiency levels will be considered a technical advantage during bid evaluation.

1. The efficiency value shall be tracked throughout the Contract lifecycle: at design reviews, implementation stages, and final acceptance.
2. Final validation shall be conducted through mutually agreed test protocols, including calorimetric, flow-based, or standardised methods (e.g., ISO 5167, EN 13445, or equivalent).

The Applicant shall include in the Offer the electrical power measurement method they will apply on the QPLANT side, specifying the level of integration (e.g., total plant consumption including auxiliaries, compressors, control systems) and the measurement uncertainty. The Offer shall also specify the corresponding reciprocal measurement methodology expected to be applied by SCK CEN, including temperature, flow, and enthalpy balance, or equivalent performance indicators, to validate claimed energy figures.

1. Any deviation greater than ±5% from the claimed inverse COP at final acceptance shall trigger contractual review, including performance non-conformity, penalties, or corrective actions.
   * 1. Reliability requirements
2. The QPLANT shall apply proven processes and be based on industrially proven technologies in order to reach very high reliability.
3. The QPLANT shall have an MTBF (Mean Time Between Failure) of at least 5 years.

In the offer, the Applicant shall present a preliminary FMEA showing compliance of the proposed design with this MTBF. The Contractor shall continuously update this FMEA during the design process ensuring that the MTBF is maintained.

1. The Contractor shall provide the Mean Time Between Failures (MTBF) values for all major QPLANT components, including but not limited to:

* Equipment and assemblies listed in the main Bill of Materials (BoM)
* Safety-significant or reliability-critical Structures, Systems, and Components (SSC), such as:
  + Sensors and instrumentation
  + Control and shut-off valves
  + Pressure relief devices and bursting disks
  + Actuators, regulators, and any components affecting operational safety or availability

1. MTBF values shall be substantiated by manufacturer data, field performance records, or predictive reliability models. The level of detail shall be proportionate to the component’s criticality in the overall system reliability and availability architecture.

In the offer, the Applicant shall provide a substantiated justification for the proposed MTBF, including:

* Overview of system architecture and major components
* Configuration and applied redundancy (e.g. N+1, 2oo3)
* MTBF values per critical component, with supporting data
* Summary RAMI considerations and lifecycle-impacting design choices
* Outline of RCM strategy supporting availability objectives
* Key failure modes and corresponding mitigation measures

The design shall clearly support the specified system-level reliability and availability targets

1. The Contractor shall provide the detailed maintenance plan for all the QPLANT main components in order to meet the reliability requirements.
2. Operating scenario, minimum turndown or nominal operation shall not influence or impact reliability.
3. The Contractor shall deliver a preventive Functional Test Plan as part of the maintenance plan.
4. The Contractor shall deliver a Reliability-Centered Maintenance (RCM) Plan, defining failure modes, MTBF, inspection/replacement intervals, and spares recommendations for each system component. Specific strategies including but not limited to

* Run to failure
* Do time-based replacement
* Do condition-based maintenance
* Or do functional verification (testing)

1. The QPLANT:CS shall support real-time monitoring of instrument health (drift, dropout, deviation from expected range) with alarms and diagnostic flags for early fault detection.
2. A component-level replacement schedule for 40 years shall be provided by the Contractor, including MTBF data, estimated downtime impact, and cost per intervention.
   * 1. Design, materials and construction requirements
        1. Pressure design
3. Pressure design shall follow general specification (AD 4) for steel piping materials as a minimum requirement.

The operating pressure is defined as the maximum pressure met during all the operation modes.

1. The opening pressure of the safety relief valves and other safety components shall be set at least 10% higher than the operating pressure in the components.
2. The design pressures of components shall be higher or equal to the opening pressure of their safety devices.
3. The Contractor shall take the Cryogenic system user input into account when deciding on the opening pressure of the safety components. e.g. the back pressure in the “S” or “B” header shall never exceed 1.9 bar to protect the users.
   * + 1. Material requirements
4. The general specification (AD 4) for steel piping materials shall be applied by the Contractor.
5. All components shall be new.
6. All materials shall be accompanied by their respective certificates and are part of the documentation deliverables.
   * + 1. Safety device requirements
7. Cold volumes containing helium shall be protected by safety devices according to EN 17527.
8. Any cold volume that can be isolated by valves and all insulation vacuum volumes shall be protected by safety devices.
9. The QPLANT safety valve exhausts shall either be collected or safely discharged to the outside to minimuize.

*For information, the safety valve exhausts of cryogenic users and cryogenic distribution are also collected through the recovery header.*

1. The recovery header shall be protected against over pressures by safety devices and non-return valves with an exhaust to atmosphere at a safe location.
2. The burst disks shall exhaust in a safe way regarding operators and equipment to avoid any risk of cold burn and/or anoxia.
3. The analyses and calculation of safety devices shall be subject to approval by SCK CEN.
4. All safety devices shall be accessible and removable during maintenance period for calibration or replacement.
5. The pipework surrounding the safety devices shall be designed to allow dismounting of safety valves and burst disk.
6. The Contractor shall recommend and guide SCK CEN to define the location of the oxygen deficiency detectors in the QPLANT buildings.
   * + 1. Valve requirements
7. Technical Specification for Safety and Relief Valves (AD 13), shall be applicable to all warm valves unless superseded by more stringent requirement for helium operation based on the Contractor experience. The cryogenic valves inside QRB shall be of the extended-spindle type, sealing by metallic bellows.
8. Cryogenic valves shall be welded to the pipework and preferably to the top plates of the cold box.
9. The control valves at ambient temperature shall follow AD 9 and shall be adapted to the process and to the fluid to be controlled.
10. The shut-off valves shall be ball or butterfly valves depending on size.

* + - 1. Joints and seals

1. Dismountable joints in the QRB below room temperature are not recommended and shall be subject to approval by SCK CEN. At ambient temperature, metal and Viton O-rings are allowed.
   * + 1. Bellows
2. The use of bellows to compensate thermal contraction shall be avoided by appropriate piping design. If the Contractor cannot avoid the use of bellows, location and type of bellows shall be subject to approval by SCK CEN.
   * + 1. Welding
3. All permanent junctions shall be welded; brazing must be exceptional, and its use is subject to approval by SCK CEN.
4. All junctions separating helium and water shall be welded with the weld on the water side.
   * + 1. Cleaning and surface treatment
5. All welding and brazing surfaces shall be cleaned before assembly, using proper solvents and water to remove any trace of acid flux, organic depositions and any other dirt and dust.
6. All metallic surfaces shall be cleaned, pickled and passivated. The completed components shall also undergo cleaning (degreasing, cleaning and drying) prior to helium leak testing.
   * 1. Helium guard
7. Every component operating below atmospheric pressure shall be protected from air ingress by a helium guard filled with pure helium with a pressure higher than 1.05 Bar.
8. In order to detect leaks it shall be possible to isolate each helium guard circuit by means of a hand valve.
9. The helium guard pressure shall be monitored by a pressure transmitter which is accessible by the QPLANT control system.
10. All static seals not completely welded and operating between air and sub-atmospheric helium shall be doubled; the space between the seals shall have a connection to the helium guard system.
    * 1. QRB Vacuum system
11. ~~A mobile vacuum pumping system, integrated on a skid frame with wheels, shall be provided so it can be used for the pumping and conditioning of various components, including storage vessels.~~
12. The Refrigeration Cold Box up to the vacuum barrier with cryogenic distribution system shall be equipped with a dedicated pumping system.
13. The pumping stations shall be able to pump at room temperature the vacuum vessels from atmospheric pressure to less than 10-5 mbar within one week or less.
14. The exhaust of the roughing pump shall be collected and sent outside the building via a dedicated pipe.
15. A fast insulation valve shall be provided on the vacuum port upstream of the secondary pump to protect the vacuum in the cryostat vessel.
16. A dedicated flange shall be provided between the secondary and primary pump for connection of a leak detector.
17. The necessary valve actuators and vacuum gauges shall be provided to allow safe remote automatic operation of the cold box pumping.
    * 1. Purge requirements
18. Necessary purge connections equipped with valves shall be installed for the pumping and filling of the overall helium pipework and volumes. These connections shall be subject to approval by SCK CEN.
19. Each purge valve shall be connected to a purge collector.
20. This purge collector shall allow venting, pumping and filling of all the volumes requiring purge.
21. The helium pumped or vented shall be sent to atmosphere outside the buildings.
22. The purge collector shall have a connection to pure helium supply equipped with a dedicated valve.
23. For the pumping, purging and conditioning of the cryogenic lines and of the cryogenic distribution, necessary purge connections shall exist on the Refrigeration Cold Box.
24. Downstream the vacuum barrier, the vacuum jacket interfacing with the QLM shall be equipped with a pumping port (DN 160).
    * 1. Leak rate requirements
25. The Contractor shall establish a helium leak detection and monitoring program in accordance with EN 13185:2001, Clause 6.2 (Leak Detection Methodology) or equivalent, including routine leak testing and automated isolation mechanisms.
26. The leak rate of the complete QPLANT (including all interconnecting piping, joints and components operating at maximum operating pressure and ambient temperature) shall not exceed the values defined in Table 5. The system shall be qualified for leak-tightness under operational and standby conditions.

In the offer, the applicant shall explicitly quantify and elaborate:

* Expected global and local leak rates, including thresholds for diffusive losses expressed as % loss per year. Estimated number and types of valves and fittings contributing to leak paths.
* Detailing the type of helium leak detection methods, pressure hold test procedures, vacuum decay or rise time methodologies, and long-term monitoring techniques. Acceptance criteria for each method and the calibration procedure for leak detection equipment.
* Post-installation and operational phase monitoring strategy, if applicable, including thresholds and frequency

Table 5 Leakage requirements

|  |  |  |
| --- | --- | --- |
| **Type of components** | **Maximal leak rates** | **Mass flow (g/year)** |
| Individual leakage from helium circuits or welding to vacuum | 1×10⁻⁸ mbar·L/s | **0.050 g/year** |
| Individual leakage from helium and oil circuits to the water circuits | 1×10⁻⁸ mbar·L/s | **0.050 g/year** |
| Individual leakage from LN2 to helium circuits | 1×10⁻⁸ mbar·L/s | **0.050 g/year** |
| Individual leakage from the helium guard to sub-atmospheric circuits | 1×10⁻⁵ mbar·L/s | **5.04 g/year** |
| Individual leakage from helium and oil circuits to atmosphere | 1×10⁻⁵ mbar·L/s | **5.04 g/year** |
| Total leakage from all heat exchangers of the cold boxes to vacuum vessel | 1×10⁻⁵ mbar·L/s | **5.04 g/year** |
| Total leakage of air into the vacuum vessels | 1×10⁻⁵ mbar·L/s | **5.04 g/year** |
| Total leakage from helium circuits to vacuum vessels | 1×10⁻⁵ mbar·L/s | **5.04 g/year** |
| **Max global helium gas losses of the Cryogenic System target** | 1 Nm³/day | **65.335 kg/year** |
| **Valves** | | |
| **Leak Type** | **Leak Rate** | **Mass Flow (g/year)** |
| Individual leak rate through valve seat | 1×10⁻⁴ mbar·L/s | 504 g/year |
| Individual leak rate to atmosphere | 1×10⁻⁵ mbar·L/s | 5.04 g/year |
| Individual leak rate to vacuum | 1×10⁻⁸ mbar·L/s | 0.050 g/year |

* + 1. Helium Recovery and Helium Inventory management

1. The Contractor shall implement a comprehensive helium recovery strategy. This strategy shall cover all credible initiation events, including but not limited to Loss of Offsite Power (LOOP), Loss of Vacuum or Instrument Air (LOCA/LOIA), Cooling Circuit Trip, Turbine Trip, QRB Trip, HP Compressor Trip, and PVPS Trip. For each scenario, the Contractor shall identify at least:

* The operational impact (e.g. compressor trip, loss of containment, or circulation failure),
* The required recovery mechanisms (e.g., buffer storage activation, valve isolation, overpressure protection),
* The stepwise action plan to resume normal helium circulation once the initiated event is resolved, and
* Compliance with applicable standards (e.g., ISO 21014, API 521, or EN 13445, where relevant).

The strategy shall be supported by engineering justifications and include timelines, buffer sizing assumptions, and any control system responses required to mitigate helium losses and protect sub-atmospheric components.

In the offer the Applicant shall present a high level description of the helium recovery strategy including but not limited to a Bill of Materials (BoM) of all recovery components, including low-pressure gas balloon storage and/or high-pressure compressor-driven recovery options and/or dedicated purification system.

1. The helium recovery strategy shall cope with the following He flow from the users:

* 100–200 g/s for full QPLANT shutdown cases
* 20–40 g/s for partial operation (thermal shield cooling only)

1. The Contractor shall ensure that venting of helium to atmosphere is minimized under any defined failure or transition scenarios, unless explicitly triggered by the machine protection system (MPS).
2. The Contractor shall assume that, in the event of a Loss of Offsite Power (LOOP), the following utilities are available after a short interruption (few minutes):

* 350 kW of back-up power supplied by a diesel generator
* 350 kW of cooling water.
* see requirement about pneumatic supply

OPTION 4 – Dedicated SSC for helium recovery in case of LOOP

1. System shall recover and compress helium at a nominal flow range of 3.5–35 g/s. Measurability via Flow measurement logs; control system feedback loop
2. System shall sustain 100 g/s helium recovery for 6 hours under LOOP conditions. Verification via Simulation + integrated testing; VFD power demand log
3. Control system and infrastructure shall support upgrade to 2×100 g/s N+1 redundancy. Verification via Design documentation, scalability matrix, PLC spare I/O validation
4. Pneumatic backup shall ensure actuation of all critical WCS and QRB valves during a 6-hour LOOP scenario. Verification via Endurance test; backup cylinder sizing calculation; pressure decay test
5. Pressure Safety Valves (PSVs) and Burst Disks (BDs) shall comply with PED and API 520 for 1 bar to 200 bar envelope. Verification via Inspection certificates; calibration records; system blowdown test
6. At least two buffer configurations (e.g., 50 bar balloon + 200 bar sphere) shall be available to decouple flow and ensure non-loss transfer. Verification via P&ID confirmation; vessel certification documents
7. Control architecture shall interface with QPALNT:CS, WCS, and HeR:CS with modular integration (future-proof). Verification via I/O mapping; communication protocol tests (Modbus/TCP or OPC-UA)
8. System shall be handed over with 40-year RCM plan, failure diagnostics, spare parts, and validated commissioning package. Verification: RCM deliverables; FMECA; maintenance plan; signed handover form
9. The Contractor shall integrate the recovery system with the QPLANT process systems.
10. The Contractor shall design the system with flexibility to enable implementation of either balloon (including purification and dedicated compression and/or dedicated storage) or compressor-based (existing QPLANT infrastructure) recovery, as per final AFA decision.

* The final design shall be subject to Client review and approval prior to implementation.

1. If a Recovery Balloon is used as part of the strategy, its maximum capacity shall be limited to 200 m³ at ambient pressure, consistent with physical constraints of ~10 m × 10 m × 2 m, as referenced in AD1.
2. In case of balloon use an oil-based air lock shall be installed, preventing ambient air ingress at sub-atmospheric pressures (max differential pressure: 1100 mbar).
3. The passive venting mechanism shall comply with EN 13648 and ISO 21013 standards.
4. The Contractor shall perform a reliability analysis including e.g. failure to start.
5. The He recovery system shall support lifecycle monitoring per RCM principles, including Preventive Functional Diagnostics (PFD) bi-annually.

In the offer, the Applicant shall provide RCM details as per MTBF vs Replacement vs Spares.

1. In the event of a Loss of Offsite Power (LOOP), the Contractor shall provide a dedicated pneumatic backup system to ensure full support of helium recovery operations requiring pneumatic actuation. The system shall satisfy the following minimum requirements:

* The system shall consist of two compressed gas cylinders (Instrument Air or Nitrogen), equipped with an automated switchover manifold to ensure redundancy and continuous supply.
* The pneumatic supply system shall have a minimum autonomy of 2 hours under full helium recovery load conditions
* The switchover and regulation shall be fully automatic, without requiring manual intervention during the LOOP event.
* The initial valve actuation (Fail-Closed or Fail-Open) shall be powered by the Instrument Air and Receiver System supplied by SCK CEN. However, this does not constitute a continuous supply obligation during LOOP.
* **Note:** This requirement supersedes any prior assumptions regarding continuous instrument air supply during LOOP. The Contractor shall design the pneumatic backup to be self-sufficient and operationally integrated within the helium recovery logic
* The Contractor shall be responsible for supplying and integrating any additional pneumatic backup capacity necessary to maintain helium recovery functionality during the LOOP event.
* The pneumatic backup system shall be provided with:
  + Local and remote pressure monitoring,
  + Alarm outputs to the control system for pressure loss or cylinder depletion,
  + Safety relief measures and isolation valves for safe maintenance.

1. The pneumatic backup system be commissioned and functionally tested under simulated LOOP conditions to verify switching, autonomy, and integration with the helium recovery sequence.
   * 1. Instrumentation requirements
2. The QPLANT shall be sufficiently instrumented to allow automatic control of its proper functions and to allow a safe operation.
3. The number, type, accuracy, and positioning of the sensors shall be chosen in a way to Control the components performances and to verify the required performance values during acceptance tests.
4. The Contactor shall prove that all measuring instruments are suitable for their purpose using appropriate references.
5. Location and measurement ranges shall be defined by the Contractor and shall be assessed by SCK CEN during the design phase.
6. Redundancy measurements and heaters shall be provided for inaccessible components and vital for operation and safety.
7. A complete wiring diagram shall be included in Deliverable package **Error! Reference source not found.**.
   * + 1. Sensors used in hard wired component protection
8. Hard wire protection to prevent damage of main components, in particular compressors, turbines, pumps, and heaters shall be provided by the Contractor.
9. The contacts of controlled equipment driven by hard wire (using sensors such as flow, pressure, temperature and level switches, valve end switches, etc.) shall be set as opened in abnormal situations (positive logic).

* + - 1. Heaters and electrical measurements

1. Electrical heaters shall be protected against overheating by temperature sensors acting on the power or the control unit.
2. All heating elements required for control and operation shall be replaceable without breaking the insulation vacuum or redundant elements shall be installed.
3. The power measurement of heaters shall be transmitted to the QPLANT control system. The list of heaters shall be subject to approval by SCK CEN.
4. Heating power of the power control units shall be controllable from the remote control room.
5. Dielectric test shall be carried out and successfully passed during each main phase of the mounting and at the end of the assembly.
   * + 1. Temperature measurements
6. Two twisted pairs of wires shall be used from the temperature element to the signal conditioner.
7. The mounting of temperature elements shall be done in the way to minimize sensor self-heating and to limit the amount of heat brought by the wires using thermalization when necessary. The mounting principle shall be subject to approval by SCK CEN.
8. Temperature elements outside cold boxes shall be mounted directly in the fluid stream, using a protection tube welded on the pipe.
9. For each kind of temperature range to measure, the temperature measurements (including the whole thermometry chain) shall meet the requirement in Table 6.

Table 6 Temperature measurement precision

|  |  |  |  |
| --- | --- | --- | --- |
| Nominal Temperature | < 30 K | 30 K to 120 K | > 120 K |
| Accuracy (trueness) required for standard measurements | ≤ +/- 100 mK | ≤ +/- 500 mK | ≤ +/- 1 K |
| Accuracy (trueness) required for high precision measurements | ≤ +/- 50 mK | ≤ +/- 300 mK | not applicable |
| Long term drift for the whole scale | ≤ +/- 10 mK per year | ≤ +/- 50 mK per year | ≤ +/- 100 mK per year |

1. The choice between standard and high precision measurements shall be subject to approval by SCK CEN.
2. A calibration curve shall be provided for each sensor when relevant.
   * + 1. Pressure measurements
3. Each pressure transmitter shall be installed with at least one isolation valve and at least one connection for calibration, venting with isolation valve.
4. The pressure measurement ranges of the instruments shall be agreed with SCK CEN, with a particular caution for the VLP line instrumentation.
5. All pressure transmitters shall withstand, without de-calibration or damage, any pressure from vacuum to the maximum operating pressure (given by the setting of the relevant safety valve).
6. The long-term drift for pressure measurement shall be less than ±0.5 % of the maximum span per year.
7. The accuracy for absolute pressure measurement shall be better than ±0.5 % of the calibrated span.
8. The accuracy for differential pressure measurement shall be better than ±0.25 % of the calibrated span.
9. In addition to the isolation and calibration valves, the differential pressure shall be equipped with a by-pass valve.
10. Vacuum pressure measurement shall cover the range from to mbar.
11. Each vacuum gauge shall be equipped with at least an isolation valve.
12. Each vacuum gauge shall be able to withstand gas inrush.
    * + 1. Liquid level measurements
13. Liquid helium level shall be measured by differential pressure or using a superconducting level sensor. Any other technology used for liquid level measurements shall be subject to approval by SCK CEN. A conversion curve to the volume shall be provided for each level measurements.
14. The liquid level sensors shall not be disturbed neither by electrical heaters (bubbles) nor by flow turbulence.
15. Liquid level measurements shall be displayed in percentage. Accuracy required for the measured value shall be better than 2% for helium and better than 5 % for other fluids.

* + - 1. Flow rate measurements

1. For helium flow rate measurements at cryogenic temperature, temperature and pressure shall be measured upstream flow measurements for the mass-flow rate calculation by the QPLANT control system. According to the Contractor experience standardized orifices as venturi associated differential pressure measurement shall be used. A calibration curve shall be provided. Accuracy required shall be better than 5% of the full range.
2. For helium flow rate measurements at room temperature and water, other types of the flow meters are allowed. The accuracy required shall be better than 2% of the calibrated span.
3. The display units for mass flow rates shall be g/s for helium flow and l/s or m3/h for water flow.
   * + 1. Impurity measurements in helium flow
          1. Pick-ups and sampling main requirements
4. The location of sampling points shall be agreed with SCK CEN.
5. Two dedicated gas analyser cubicles shall be installed for the QPLANT (one in the compressor room and the second one in the cold box room).
6. All capillaries used for permanent monitoring shall end at the gas analysis. These sampling lines shall be provided with at least a pressure regulator, a proper removable filter element and a manual process isolation valve.
7. Temporary sampling points shall be at least equipped with a manual process isolation valve and proper plug.
8. Each gas analyser shall be equipped with a dedicated calibration line.
9. Gas sampling components and piping shall be in compliance with gas analysers accuracy requirements.
10. The analysed gas samples shall be sent back to the Low Pressure of the WCS.
    * + - 1. Gas analysis main requirements
11. Moisture, nitrogen in helium shall be measured continuously and anomalies shall trigger alarms on the QPLANT control system HMI.
12. Gas analysers will be chosen according to the Contractor experience and shall have at least a measuring range of 0-100 ppm by volume for moisture and nitrogen. Accuracy required shall be better than or equal to ± 1 ppm by volume for the full range, with a long-term drift better than ± 1ppm by volume per year.
13. In the compressor room, the residual hydrocarbons shall be measured with suitable instrumentation.
    * 1. Wiring requirements
14. The Contractor shall propose a solution to be approved by SCK CEN to minimize the Electro Magnetic Interferences effects (AD 7) required for standard measurements (e.g., using suitable shielded cables, twisted pairs, routing properly and separating voltage levels, etc.).
15. In order to ease diagnostic and checking of measurement chains, knife-switch type terminal blocks or similar cabling interface shall be fitted for input and output signals connections with the QPLANT control system.
    * 1. Electrical Requirements
16. All electrical components (cables, cubicles, cable trays, etc.) shall be in accordance with the applicable international electrical standards (IEC including IEC 61508 and IEC 61511 for lifecycle safety aspects) and AD 6.
17. All cable sheathing shall be adapted to their environment (moisture, cable trenches, oil, heat and cold conditions, external environment, EMI effects, etc.).
18. Each electrical and instrumentation cabinet shall have at least 25 % available space to allow later installation of equipment.
19. The Contractor shall install harmonic filtering devices on the major variable frequency drives (for LP-HP compressors) and refer to AD 6 for variable frequency drive requirements.
    * 1. Identification and labelling
20. The naming convention for cryogenic system shall be based on existing reference projects and shall be agreed with SCK CEN.
21. For pressure equipment, vessels and safety devices, the Contractor shall comply with the requirements as detailed AD 5, AD 13, and AD 14.
    * 1. Valves
22. The valve actuators of the QPLANT control valves shall be equipped with an electro-pneumatic positioner and a numerical feedback signal of valve position.
23. Valve position shall be displayed on the QPLANT control system.
24. Based on reliability and safety analyses, some manual process on/off valves shall be at least equipped with two end switches confirming their positions during operation. The list of manual valves that shall be equipped is subject to approval by SCK CEN.
    * 1. Warm Compressor Station

Technical Specifications of the Warm Compressor Station

* + - * 1. General requirements

1. The WCS shall provide helium flows at required pressures to allow the QRB to achieve its required performances.
2. The WCS shall create at least 3 pressure levels (VLP, LP, HP).
3. The design of the WCS shall allow easy accesses for maintenance, repair, and inspection.
4. The WCS shall be connected to the warm gas helium storage.
   * + - 1. Valves requirements
5. At least one by-pass valve shall be installed between VLP, LP and HP levels.
6. By-pass valve size shall allow the maximal flowrate of the compressors to pass.
7. Two controls valves shall link the helium gas storage to the LP suction for the loading and to the HP discharge for unloading.
8. The HP unloading valve shall be installed downstream of the fine dust filter after the oil charcoal adsorber.
9. Connections with the QRB shall be performed via control valves located in the WCS building in order to prevent fast pressure variation.
10. Helium lines connected to the suction and discharge sides of the compressors (for every compressor stage) shall be equipped with non-return valves which close when the compressor stops.
    * + - 1. Noise level
11. Each compressor noise shall not exceed 80 dB(A) at a 1 meter distance.
12. The Contractor shall provide documents including values for the noise level of every compressor and every electrical motor drive according to the international standard for machine noise (Deliverable **Error! Reference source not found.** after manufacturing tests and **Error! Reference source not found.** after acceptance tests).
    * + - 1. Vibration
13. The maximum allowable vibration levels for the compressors and rotating machines shall be in accordance with the ISO 2372 standard.
14. During the design phase, the Contractor shall submit report and calculation basis justifying all the guaranteed vibration levels for SCK CEN’s approval. During commissioning, the vibration level shall be measured by the Contractor using dedicated instruments for measuring vibrations following the ISO 2954 standard.
    * + - 1. Heat dissipation to air
15. The total heat dissipated by the WCS to air shall remain below 120 kW.
16. The WCS shall have a local heat dissipation duct which
    * + - 1. Heat recovery

The heat produced by the LP/HP compressor is to be partially recovered to supply a heating system only operating when there is a need for hot water. Figure 7 illustrates how it could work.

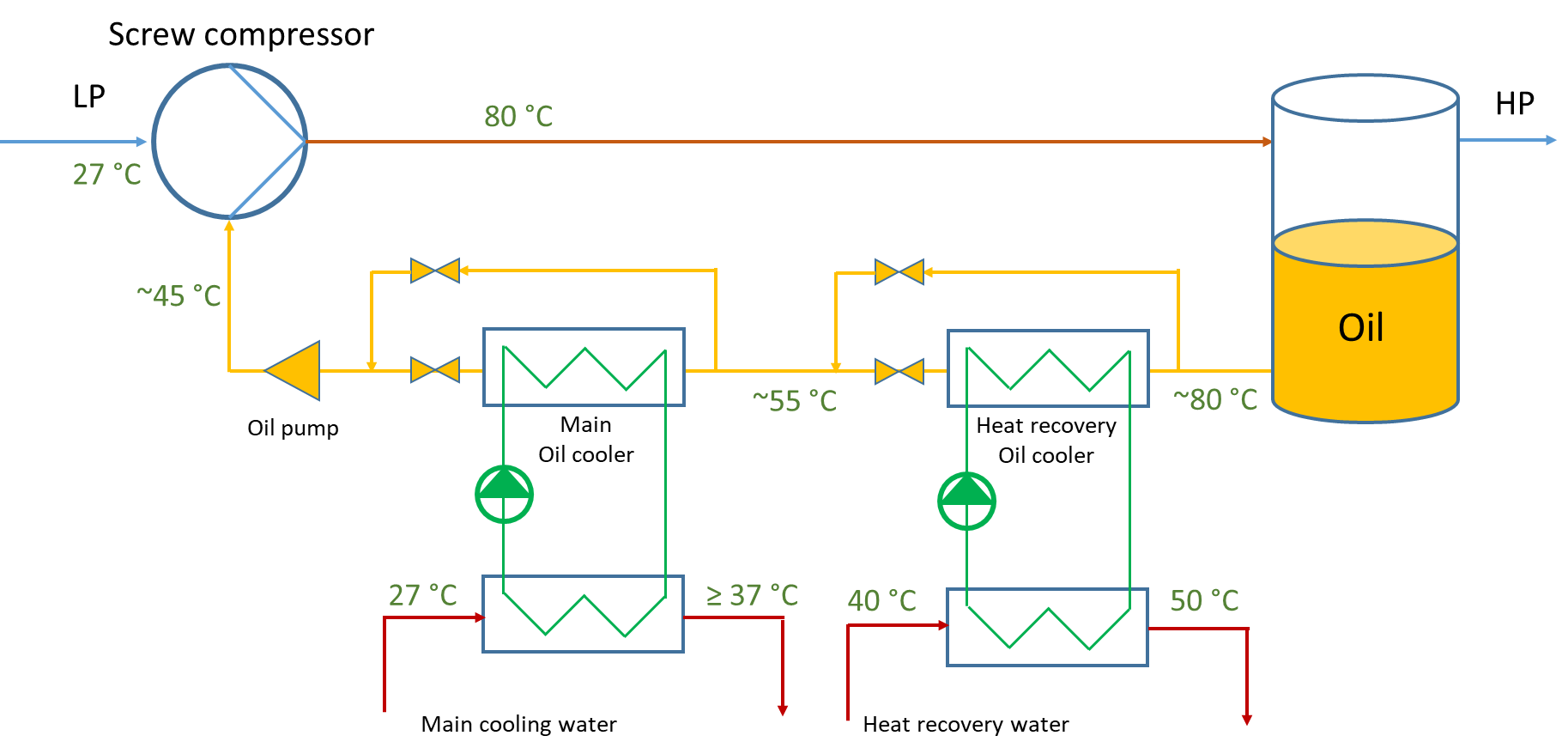


Figure 7 Heat recovery principle.

1. The heat produced by the LP/HP compressors shall be at least 65 % recovered using the appropriate heat recovery water flow given by SCK CEN. The heat recovery system can only operate when needed on SCK CEN site.
2. The Contractor shall confirm the expected values concerning operating temperatures and percentage of possible heat recovery considering 27 °C as cooling water supply (3.4.4).
   * + - 1. Compressors requirements
3. The size and the number of machines (at least three per compressor stage) used for each compressor stage shall be defined by the Contractor in order to allow the best adaptation to the various flows necessary according to the operation modes.
4. The LP/HP compressors shall be all identical to facilitate the maintenance and repair.
5. The supply voltage for the motors shall be 400V, 3Φ, 50 Hz.
6. The drive between motor and compressor shaft shall be direct, with a dismountable shaft coupling.
7. Oil-retention reservoirs shall be incorporated in the base frames of each compressor skid to handle the full oil content of the skid in case of pipe rupture.
8. The compressor flow shall be adjustable by use of integrated slide valves.
9. The compressor flow shall be adjustable by use of variable-frequency drive, with a frequency of 50 Hz to be used at the 2 K nominal operation mode.

In the offer, the Applicant shall state the number of LP/HP compressors.

* + - * 1. Coolers

1. The cooler shall be designed in accordance with the cooling water characteristics described in 3.4.4.
2. A manual or a thermostatic control valve shall be provided at the outlet of each cooler.
3. On the gas side, the coolers shall be equipped with purge valves for rinsing.
4. On the water side, valves to drain the water and to purge air shall be installed.
5. A water manual shut off valve shall be set up at the inlet of each cooler.
   * + - 1. Oil
6. For the first filling, the Contractor shall provide a suitable oil type for the commissioning and acceptance tests. The oil shall have the following purity rate:
   * + no solid particle larger than 25 µm.
     + water content in the oil less than 1 ppm by volume.
7. The Contractor shall give recommendation on oil preparation prior to fill for operation and after major maintenances.

Oil circulating system

* + - * 1. Oil-pump units

1. An autonomous oil-pump shall be provided for each compressor.
   * + - 1. Oil-retention vessel
2. The upper part of the oil-retention vessel shall include a separator for oil droplets allowing to reduce the oil content of the helium at the outlet of each vessel to a level of impurity compatible with the Oil Removal System performance.
3. The suction line of the oil pumps shall not be connected to the lowest point of the vessels.
4. The suction line of the oil purge and filling circuits shall be connected to the lowest point of the vessels.
5. Each retention vessel shall include heater for pre-heating the oil.
   * + - 1. Oil filters
6. The oil pumps providing oil bearing, shaft seals and slide valves shall possess at the suction side, double oil filters mounted in parallel.
7. A fine oil filter shall set up at the injection of the compressor bearings and shaft seals.
8. A wire mesh filter (100 µm) shall be integrated in the oil-supply line for each screw compressor.
9. Manual shut-off valves shall be installed upstream and downstream of each oil filter.

Purge and fill up requirements

1. Each compressor shall be equipped with manual isolation valves in all connecting piping to allow isolation of all circuits for maintenance.
2. The Contractor shall design the purge system and slope piping in order to avoid oil migration to oil-free region.

Oil Removal System (ORS)

* + - * 1. Coalescers

1. Downstream HP primary oil removal system, minimum three coalescing filters shall be installed in series, with dimensions such that sufficiently low gas velocity is achieved through the filter elements for efficient coalescing.
2. The gas velocity shall be determined for the highest possible volumetric flow during the different phases of compressor operation, plus a 20% margin.
3. The coalescer arrangement and its seal construction shall be capable of withstanding compressor vibration.
4. All coalescers shall be equipped with stand pipe on which magnetic level indicator is positioned. Level is monitored locally and from the control system with high level alarms and shutdowns.
5. The oil collected from the first two coalescers is to be re-injected to the suction side of the LP/HP compressors. The automatic flush of oil from coalescer to compressor suction shall be carried out using a motorized valve controlled by the level indicator mentioned above.
6. The coalescers shall reduce the oil content of the stream to less than 40 ppb.
7. The last coalescer operates as guard unit. Any confirmed sign of oil collected therein shall lead to a shutdown of the compressor station.
   * + - 1. Charcoal adsorber
8. The charcoal oil adsorber shall be designed for a flow 20 % higher than the maximum compressor flow going to the cold box.
9. Only charcoal in the form of smooth pellets shall be used as adsorbent filling. No filling consisting of irregularly broken particles shall be accepted.
10. Charcoal shall be cleaned and dried by the Contractor to avoid dust and moisture.
11. The filling shall permit an operation time in the 2 K operation mode of at least 3 years without exceeding the guaranteed maximum outlet impurity of 10 ppb.
12. Contractor shall verify that the filling of the bed is regular and no preferred passages for the helium exist.
13. Contractor shall demonstrate (based on design and previous experiences) that movement of the adsorbent and the carry-over of dust particles is avoided.
14. The flow direction of the gas through the charcoal bed shall be from top to bottom.
15. Any equipment necessary to fill the adsorber without degrading the adsorbent shall be supplied by Contractor.
16. The heating unit necessary for the procedure of drying of the adsorbers shall be supplied by the Contractor.
17. The adsorber vessel shall be equipped with adequate thermal insulation in order to prevent from personal risk of burn on hot surfaces throughout the drying of the adsorber by means of hot nitrogen.

Helium dryer

1. The helium dryer shall be designed for the full helium mass flow (HP total mass flow) contaminated up to 50 ppm by volume of water for a duration of 12 hours before regeneration.
2. The capacity of the dryer shall remove water in the helium to a level of less than 1 ppm.
3. The dryer shall operate at the High Pressure of the WCS without generating a total pressure drop of more than 0.5 bar.
4. The total regeneration time shall not exceed 12 hours.
5. The helium dryer unit shall include inlet and outlet valves and a by-pass circuit. The regeneration shall be performed by circulation of warm and dry nitrogen gas.
6. At the dryer outlet, a wire mesh filter of 30 µm shall be installed in order to trap particles of dryer adsorbent.
7. As adsorbent material, a molecular sieve of alkali alumino-silicate (Zeolite) or equivalent is required. The necessary replacement frequency and associated procedure shall be provided by the Contractor.

Recovery and purification system for add-hoc user

1. The QPLANT shall include a recovery header for helium gas at room temperature and atmospheric pressure collecting safety valves and potentially for future external user.

Envisaged future external user amounts (future external helium users liquid supply by dewar and gaseous return) will be about 200 litres for initial cooldown and 50 litres/day while the relevant experimental setup is operational).

1. This recovery header shall be connected to the LP of the warm compressors.
2. The pressure and mass flow through the recovery header shall be permanently measured.
3. The possibility to connect in the future to a recovery gas bag and external purification system shall exist. The Contractor shall make recommendation on required external purification system, or as a minimum specify the limits (in terms of impurities) to avoid negative impact on the main QPLANT function.

Gas Filters

1. The Contractor shall install at least the following gas filters:

* At the suction side of each compressor with a wire mesh filter of 100 µm of retention ability.
* Downstream of the charcoal adsorber, an adapted wire mesh filter to stop particles of charcoal adsorbent shall be installed.
* Each gas filter shall be equipped by manual shut-off valves to minimize contact with air.

Measuring points

1. The Contractor shall submit to SCK CEN for approval all measuring points necessary for operation and protection of the equipment.
2. At least the measuring points defined by Table 7 shall be exploitable by the QPLANT control system.

Table 7 measuring points for WCS

|  |  |
| --- | --- |
| Helium mass flow rate | WCS mass flow rate for operation and tests at VLP and HP levels. |
| Temperatures | Inlets and outlets of the QRB  Inlet and outlet of each turbine  HP outlet downstream 300 K-80 K precooling  In each adsorber bed  Liquid helium baths |
| Pressure | Suction of each compressor (including VLP)  After each oil-retention vessel  After the charcoal adsorber and the dryer |
| Differential pressure | Across each oil filter  Across the charcoal adsorber and the dryer |
| Moisture | After the charcoal adsorber  Upstream and Downstream the dryer  At 2/3 of the dryer bed |
| Measure of nitrogen content for air detection | After the charcoal adsorber  After the dryer |
| Oil level measurements and switches | In each oil retention vessel (analog and switch)  In the third coalescer (level switch) |
| Water | Mass flow rate at the outlet of the coolers  Water supply pressure |
| Other measurements | Motor temperature  Motor and compressor vibration  Operation-hour counters for each compressor, oil-pumps  Visual oil level in the oil retention vessels, in the third coalescence  Pressure indicators for the main volumes  Oil injection pressure for each compressor skid  Rotational speed for every turbine  Current and voltage of each motor  Compressed air pressure |

* + 1. Refrigeration Cold Box (QRB)

General description

The QRB comprises internal components and external components and produces the refrigeration power necessary to achieve the needs of the cryogenic users. The QRB is coupled to the WCS and distributes the cryogenic flows to the Cryogenic Distribution System.

1. The QRB shall be a horizontal cold box to fit with the building constraints (see AD 1).
2. The QRB shall comprise the following internal components:
   * + Heat exchangers
     + Turbines
     + Cold Compressors
     + Piping
     + 80 K dual bed adsorber
     + 20 K single bed adsorber
     + helium baths at 4.5 K and 2 K
     + Filters
     + Heaters
     + Cryogenic valves
     + Instrumentation
3. The external components of the QRB shall be:
   * + Vacuum pumping system.
     + Warm panel with warm valves and instrumentation.
     + Piping and valves for purging and conditioning all the circuits.
     + Electrical cabinets.
     + Safety valves.
     + Helium guard circuits .
     + Compressed air distribution.
     + Coolers for turbines.
     + A platform for easy access to all the components located at the upper level.
     + Connection port to transfer liquid helium from QRB to external dewar or vice versa.
4. The Refrigeration Cold Box shall be installed in the Cold Box room, as described in 3.4.2.
5. The final location of the QRB in the cold box room shall be agreed with SCK CEN.

General design requirements

1. The QRB can use liquid nitrogen between 300K and 80K, if the Applicant is able demonstrate that this solution has a real benefit in term of capital and operation cost (including delivery logistics and impact on the reliability in terms of logistics) for the QPLANT and such a solution shall be agreed with SCK CEN. In case of liquid nitrogen pre-cooling, the Contractor shall be responsible for all the related components and integration.
2. The Contractor shall demonstrate the possible access to QRB components and instrumentation located in the vacuum vessel.
3. At least a manual shut-off valves shall be installed on each line connected to the WCS.

Main components

* + - * 1. Vacuum vessel

1. The vacuum vessel shall be designed for internal vacuum and for overpressure.
2. The vacuum vessel shall be protected by a suitable safety device sized according to regulations.
3. The design of the passage of every line (cold or warm) connected to the QRB shall avoid any condensation or frost formation at the interfaces during any operation mode or any transition between operation modes of the QPLANT.
4. The ports of the vacuum vessel carrying cold valves, turbines, transfer lines connections and instrumentation feedthrough shall be fabricated from stainless steel. The vacuum vessel may be fabricated from mild steel.
5. The pumping port of vacuum vessels shall be designed to avoid the intake of any loose sheets of superinsulation into the vacuum pumps.
6. The QRB shall be equipped with a vacuum barrier at the Cryogenic Distribution System interface.
   * + - 1. Heat exchangers
7. Aluminium plate fin heat exchangers shall be vacuum brazed. Stainless steel heat exchangers shall be of all-welded construction.
8. For all heat exchangers, the type and origin of materials and transition pieces (Aluminium-Stainless Steel) shall be provided.
9. All heat exchangers operating below 20 K shall be arranged vertically with the warm end at the top.
10. A system on the first heat exchangers (between 300 K and 80 K) is required in order to warm up and regenerate it for frozen water removal in the HP sides. The differential pressure between inlet and outlet of the heat exchanger shall be measured in order to follow the pressure drop evolutions during operation.
11. In case of use of nitrogen for 80 K pre-cooling, a separated heat exchanger between nitrogen and HP helium flow shall be installed to avoid solidification of nitrogen in case of important return of cold helium flow in the LP stream.

* + - * 1. Turbines

1. Only turbines with gas lubricated or magnetic bearings are accepted.
2. The power extracted by the turbines shall be transferred to water cooled heat exchangers. These exchangers shall have high resistance to corrosion. Acceptable materials for the water channels are stainless steel and copper compatible with the water quality as described in 3.4.4. The water side shall give easy access for cleaning.
3. In order to allow the easy exchange of turbine cartridges, the system shall include all the elements needed to isolate, warm up, purge and cool down each turbine. This exchange shall be done in situ without warming up heat exchanger blocks. Heating by circulation of gas is preferred to electrical heating for this application.
4. Duration of the replacement of one turbine cartridge shall not exceed 3 hours.
   * + - 1. Cold Compressors

Cold compressors could be either located in the Refrigeration Cold Box considering as the baseline solution or located in a dedicated Cold Box with separate vacuum

1. To cope with the high reliability requirements, the technology shall be centrifugal compressor with active magnetic bearings.
2. The pressure fields (of the cold compressors) shall be provided by the Contactor. It represents the pressure ratio as a function of the reduced flow for different reduced iso-speeds. The stall and choke lines shall be provided.
3. Mass flow rate of helium shall be easily adjustable via rotation speed regulation using Variable Frequency Drive. Rotational speed of the cold compressor shall include at least 10% speed margin with respect to the maximum value encountered in the different operation modes. The bearing system should allow the rotational speed of each cold circulator be lowered down to 30 % of nominal speed while remaining in the operational window.
4. The cool-down and start-up procedures of the cold compressor shall be detailed and subject to approval by SCK CEN.
5. The supplied system shall allow inspection, maintenance and exchange of cold compressor. The intervention time including the warm-up and cold compressor exchange shall be less than 4 hours.
   * + - 1. Helium baths
6. Two helium phase separators shall be installed in the QRB: one at 2 K pumped by the cold circulators and one at 4.5 K. The phase separators will contribute to the operation for the control of the cold compressor and for restart after a short break.
7. The phase separators shall be sized to cope with the different operating modes and to perform the acceptance tests with stabilized levels. The volume of the phase separators shall subject to approval by SCK CEN.
8. The phase separators shall be equipped with electrical heaters in order to adjust the level of liquid helium, to empty from liquid helium and potentially to perform acceptance tests of the QPLANT.
9. In order to reduce gas velocity, a diffuser shall be installed at the inlet of the fluid coming from the final expansion valve into the phase separators.
10. Inlet and outlet of the phase separators shall be adequately spaced to avoid cross connection of the helium flows. The drawings of the helium baths shall be subject to approval by SCK CEN.
    * + - 1. Adsorbers
11. Two 80 K parallel switchable adsorbers to remove air impurities shall be installed with an operating temperature below 85 K during cold operation modes.
12. Each of these adsorbers shall be sized to purify the full HP compressors flow contaminated up to 50 ppm by volume of air during a time that shall be designed by the Contractor.
13. The adsorption/regeneration time shall be designed by the Contractor in order to guarantee continuous operation.
14. The necessary equipment for fully automatic switching, regeneration and cool-down of the 80 K adsorber beds shall be included. A by-pass between outlet of switchable 80K adsorbers and LP line of the QRB shall be installed which could be used for helium purification.
15. One single 20 K adsorber operating below 25 K during cold operation modes shall be installed to remove from the process cycle the remaining impurities of neon and hydrogen.
16. This 20 K adsorber shall be sized to retain impurities of the full helium flow contaminated up to 1 ppm by volume of hydrogen and neon each, for a duration of at least 200 hours.
17. The necessary equipment for fully automatic regeneration of this 20 K adsorber bed shall be supplied. It shall be possible to regenerate and re-cool the contaminated adsorber with the QRB operating within 12 hours.
18. All adsorbers shall be equipped with a by-pass allowing to pass the full helium mass flow rates relevant for all operating modes.
19. The design of the adsorbers shall allow access for the periodic change of the adsorbent.
20. The design of the adsorbers shall avoid any movement of the adsorbent and any emission of dust. The adsorbent material shall be chemically and mechanically stable under any operating conditions.
21. All adsorbers shall be also equipped with gas analysis ports (cfr. 3.3.16.4).
    * + - 1. Filters
22. Downstream of each adsorber bed, a 10 m wire mesh filter shall be installed. Filters of 10 m retention ability shall be installed at the inlet of turbines. The Contractor shall decide the number and positions of any additional filters required.
23. All filters shall be accessible for cleaning and purging in a way to be proposed by the Contractor considering the operation scenario requirements (3.2.1). On the vacuum vessel, openings shall be installed to allow access to the filters to be changed. All filters are to be designed such that no dust collected can fall into the connected piping during replacement.
    * + - 1. Heaters
24. The Contractor shall install heaters wherever necessary to permit a full warm-up of all the circuits, including cryogenic distribution and the cryomodules as described in 3.2.3.2. Heaters shall also be used to demonstrate the QPLANT performance during the Acceptance Tests.
25. The capacity and the location of the heaters shall be defined by the Contractor and subject to approval by SCK CEN.
26. Heaters and associated electrical wiring shall be designed to minimize the heat loads to cold surfaces using necessary thermalization and optimized wiring diameters.
27. For heaters located in helium phase separators, redundancy and easy replacement shall be considered in line with the requirement Req # 116.

Measuring Points

1. The Contractor shall submit to SCK CEN for approval all measuring points necessary for operation and protection of the equipment.
2. At least the measuring points defined in Table 8 shall be exploitable by the QPLANT control system.

Table 8 measuring points for QRB

|  |  |
| --- | --- |
| Helium mass flow rate | Inlet HP stream of the QRB  Supply SHe from QRB to LINAC |
| Coupler mass flow return |
| Temperatures | Inlets and outlets of the QRB |
| Inlet and outlet of each turbine |
| HP outlet downstream 300 K-80 K precooling |
| In each adsorber bed |
| Liquid helium baths |
| Pressure | Inlets and outlets of the QRB |
| Inlet and outlet of each turbine  Outlet of each cold compressor |
| In each adsorber bed |
| Helium guards if any |
| Liquid helium baths |
| Water cooling circuit |
| Differential pressure | Across each filter or set of parallel filters |
| HP line (300K-80K) first heat exchanger |
| Across each adsorber bed or pressure at inlet and outlet |
| Level measurements | In liquid helium baths and the liquid nitrogen bath (if any) |
| Moisture | At the inlet of the QRB (HP flow) |
| Measure of nitrogen content for air detection | At 2/3 of the 80 K adsorber beds |
| Other measurements | Rotational speed for every turbine |
| Refrigerator cold box vacuum vessel pressure |
| Power of electrical heaters |

* + 1. Warm Storage Helium (Option 1)

Procurement and installation of helium gas storage facilities on the SCK CEN site are part of *Option 1*.

1. The Contractor shall define the total helium inventory required for the entire cryogenic system based on the helium inventory specified for the cryogenic users in Table 9 as well as for the QPLANT, regardless of whether *Option 1* is granted.
2. The helium gas storage on site shall be sized for the full helium inventory, as required by the operation modes and availability.
3. The High Pressure of the WCS shall be used as the maximum storage pressure when calculating the storage volume required to accommodate the full helium inventory.
4. A minimum of three vessels shall be considered to store the full helium inventory of the Cryogenic System.
5. As a contingency to account for potential volume deficiencies and to include operational margins to offset helium loss, a margin of 20% shall be applied to the helium inventories and the corresponding helium storage facilities.
6. To minimize the footprint impact in the storage area, the vertical positioning of the helium storage vessels is currently considered as baseline. However, the final volumes and arrangement shall be validated by SCK CEN.

Table 9 Helium inventory

|  |  |  |
| --- | --- | --- |
| Component | Helium inventory data | Helium Mass (kg) |
| Cryomodules (QM) including QVE. | QM (~ 90 liters of helium per cryomodules)  +QVE ~ 200 liters | 440 |
| Cryogenic distribution:  QVB and QLM for 2K operation | VLP return ~ 2 kg  SHe supply ~ 15 kg  TS supply-return ~ 12 kg  Warm He lines ~ 1 kg | 30 |
| QPLANT | To be determined by the Contractor of the QPLANT | TBD by Contractor |
| Gaseous warm storage | Remaining inventory during operation.  To be determined by the Contractor of the QPLANT | TBD by Contractor |
| TOTAL without margin applied | Without QPLANT and helium gas storages remaining during operation | ~ 470 kg  + QPLANT and helium gas storages |
| TOTAL with margin | Without QPLANT and helium gas storages remaining during operation  20 % Margin shall be applied on each Component | ~ 570 kg  + QPLANT and helium gas storages |

1. The Contractor shall address supply continuity for critical fluids (helium, nitrogen), including:

* Volume forecasts, logistics, buffer tanking
* Vendor reliability and emergency resupply
* LCM-aligned integration (storage, purification, TED/QRB interface)

In the offer, the applicant shall:

If redundancy/diverse routes are offered, the offer shall include Technical justification; Conditional upgrade path pricing; Adjusted flow/control architecture

General description

1. If *Option 1* is granted, the foundation requirements shall be provided by the Contractor at the end of the design phase to SCK CEN. The interfaces will be finalized during the design phase with SCK CEN.
2. The helium storages shall be located outside the building and installed vertically to reduce the footprint (AD 1).
3. If *Option 1* is granted, the Contractor is responsible for the design of the storage vessel and all the necessary mechanical analysis to cope with the site environment.
4. At least an inspection manhole shall be installed on each storage vessel.

Design requirements

1. If *Option 1* is granted, the Contractor shall design, manufacture, inspect and test the storage vessels in conformity with the applicable codes and especially with the European Directive for Pressurized Equipment (PED 2014/68/EU).
2. If *Option 1* is granted, the Contractor shall prepare the technical specification for the storage vessels (see internal SCK CEN reference requirements in AD 14). A particular caution shall be taken concerning the treatment including cleaning of inner surfaces to avoid corrosion, grease, oil, particle and moisture. For the inner surfaces treatment, the use of Rustol (Owatrol) or equivalent treatment is recommended. The outer surface shall receive a coating to withstand with outside condition. The color of the painting shall be decided in agreement with SCK CEN. The technical specification for the storage vessels shall be reviewed and validated by SCK CEN.
3. If *Option 1* is not granted, the Contractor shall review and approve the technical specification for the storage vessel in charge of SCK CEN.
4. The storage vessels shall be equipped with the necessary valves and ports to allow the different operation including purging, conditioning, and gas analysis.
5. The vessels shall be interconnected with valves and also connected to the LP side and the HP side of WCS with automatic valves in order to regulate the process pressures.
6. A gas management warm panel for the storage vessel valves shall be installed in the compressor room to manage the storage vessels.

Measuring points

1. At least the measuring points defined in Table 10 shall be exploitable by the QPLANT control system.

Table 10 Measuring points for gas helium storages.

|  |  |
| --- | --- |
| Temperatures | Temperature of at least one storage vessel |
| Pressure | Helium pressure in each installed helium storage vessel  Helium pressure in the common manifolds |
| Impurity measurements | Pick-ups and capillaries shall be provided for measuring moisture and nitrogen contents in each vessel |
| Local indicative measuring points | Helium pressure indicator for each installed vessel |

* + 1. QPLANT Control System

Overview

The QPLANT Control System (QPLANT:CS) shall be designed specifically for the local control of the QPLANT and the helium storage system, ensuring that all cryogenic processes operate safely and efficiently on site.

The QPLANT:CS is integrated with MCS to

* exchange any information between the QPLANT:CS and the cyrogenic users.
* create a unified operator experience showing the QPLANT:CS data and controls through a single user-friendly interface, allowing the operator to monitor and manage the QPLANT seamlessly alongside other primary systems.

Furthermore, all IT-related services - ranging from network communication and data storage to backup and user authentication - are integrated with the Information Technology (MIT) platform. This integration ensures that all the data and control signals from QPLANT:CS and MCS are supported by a robust and secure IT infrastructure, providing reliability and efficiency across the entire system.

Within the overall safety framework, the QPLANT Control System (QPLANT:CS) is dedicated solely to the local control and protection of the QPLANT. It handles immediate, on-site safety functions, such as local shutdowns or protective actions in response to detected issues. However, when the QPLANT interacts with other systems, the responsibility for ensuring global safety shifts to the Interlock System (MIS).

Reference Architecture

Figure 8 shows the reference architecture of all elements involved in the control of the complete cryogenic system. The QPLANT:CS is a subpart of this.

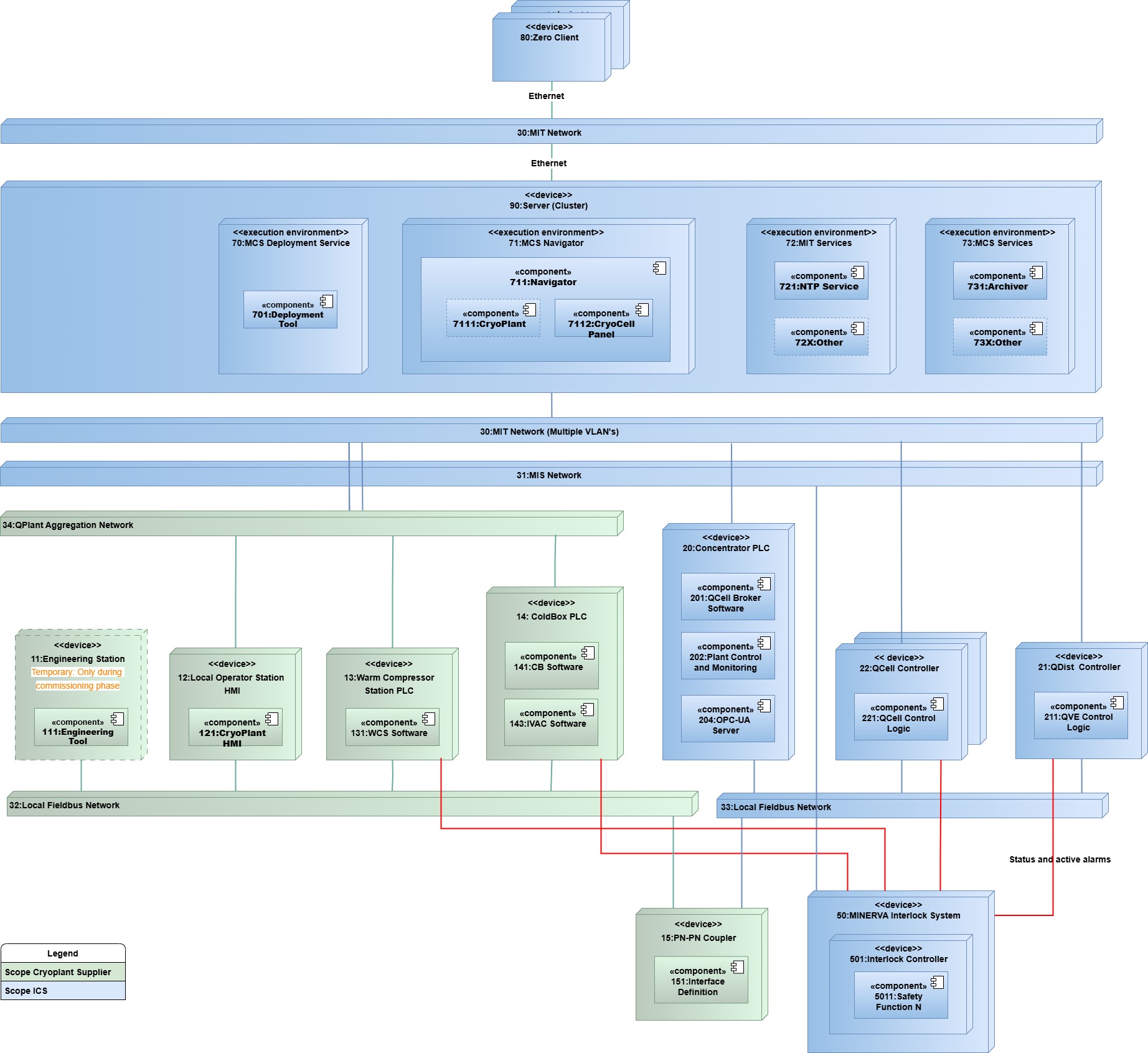


Figure 8 Reference Architecture of the Cryogenic Control System

The Cryogenic Control System, as depicted in Figure 8, includes the following devices/components:

|  |  |  |
| --- | --- | --- |
| No. | Name | Description |
| 11 | Engineering Station | A dedicated **workstation** for running the engineering tools in commissioning stage. |
| 12 | Local Operator Station (HMI) | A touchscreen placed near the cryogenic plant for direct operator interactions, real-time control, and monitoring. |
| 13 | Warm Compressor Station PLC | A **PLC** in charge of warm compressor processes and associated subsystems in the cryogenic plant. |
| 14 | ColdBox PLC | A **PLC** handling cold-related processes (cold box, vacuum insulation, possibly other sub-circuits) in the QPLANT. |
| 15 | PN-PN Coupler | A **Profinet-to-Profinet coupler** device bridging two separate PN networks or segments in ICS/plant architecture |
| 20 | Concentrator PLC | A **PLC** responsible for system level control, integrating the QPLANT with the MCS Navigator and aligning consumers with production plant. |
| 21 | QVE Local Controller | A **PLC** for controlling and monitoring the end valvebox |
| 22 | QCELL Controller | A **PLC** for controlling and monitoring cryogenic cells. |
| 30 | MIT Network | Networks |
| 31 | MIS Network | A dedicated **fieldbus** network for safety related communication |
| 32 | Local Fieldbus Network | A **fieldbus** network in scope of **Contractor** for interconnecting local devices (PLCs, sensors, etc.) |
| 33 | Local Fieldbus Network | A **fieldbus** network in scope of **ICS** for interconnecting local devices (PLCs, sensors, etc.), |
| 34 | QPlant Aggregation Ntw | The **aggregation network** serves as an intermediary between the MIT backbone and the Plant. |
| 41 | Zero Client | MIT backbone upper-level network. |
| 50 | MIS Interlock System | A system responsible for global personal and machine protection |
| 70 | MCS Deployment Service | A **deployment service** for QPLANT, used to distribute or update software components. |
| 72 | MIT Services | Global IT services like NTP, Authentication, etc |
| 73 | MCS Services | Control System shared services like the Navigator, Archiving etc |
| 80 | Zero Client | Used for visualizing MCS Navigator, the zero client displays the user interface generated by the server. All processing, data storage, and updates occur centrally. |
| 90 | Server (Cluster) | Server cluster based on KVM (for Kernel-based Virtual Machine) full virtualization solution for Linux on x86 hardware. |
| 111 | Engineering Tool | A dedicated **engineering software** for configuring, troubleshooting, or programming the QPLANT control system during commissioning phase. |
| 121 | QPLANT HMI | Local HMI |
| 131 | WCS Software | The **software component** or logic running on the Warm Compressor Station PLC. |
| 141 | CB Software | The **software** controlling the cold box, vacuum insulation, etc. |
| 143 | IVAC Software | The **software** dedicated to insulation vacuum, or auxiliary cold systems. |
| 151 | Interface Definition | The definition of the interface used for controlling and monitoring the QPLANT (**Error! Reference source not found.**) |
| 201 | QCELL Broker Software | A software component that mediates the QCell consumers with the QPLANT production |
| 202 | Plant Control and Monitoring | A software component that instructs the QPLANT operation to align with the accelerator needs. |
| 204 | OPC-UA Server | A **server** implementing OPC-UA for data exchange with MCS Navigator |
| 211 | QVE Control Logic | Logic for controlling the end valvebox |
| 221 | QCELL Control Logic | A **software** component implementing the logic for the QCELL control |
| 501 | Interlock Controller | A PLC controller responsible for integrating relevant QPLANT interlocks with the MIS system |
| 701 | Deployment Tool | Tool used for deploying new software versions to the QPLANT:CS |
| 711 | Navigator | The project wide **SCADA system** for controlling/monitoring the accelerator and the cryogenic processes at a higher supervisory level. |
| 7111 | QPLANT | A **control panel** or interface for the QPLANT |
| 7112 | CryoCell Panel | A **control panel** or interface for a cryogenic cell. |
| 721 | NTP Service | A **network time protocol** service for time synchronization across ICS or QPLANT systems. |
| 731 | Archiver | A **data historian** or archiving service used to record historical process data for the accelerator and the **QPLANT** |

* + - 1. Control System Requirements

1. The QPLANT:CS shall incorporate at least the components shown in green in the reference architecture defined in Figure 8. Furthermore, it shall include any additional systems or subsystems required to meet the overall performance, functionality, and safety objectives of the cryogenic plant.
2. The QPLANT:CS shall use a commercially available control system that is industrial-grade and proven in comparable applications, meeting predefined performance, safety, and reliability standards; it shall be procurable off-the-shelf from an approved vendor with documented lifecycle support and compliance with relevant regulatory requirements to ensure long-term system sustainability and minimal vendor dependence.
3. The QPLANT:CS shall enable autonomous operation (without operator intervention) of the QPLANT across all specified scenarios and transitions between them.
4. The Contractor shall deliver of a fit-for-purpose Test System for System Under Test (SUT) which is used during functional testing, validation, and commissioning of QPLANT and QPLANT:CS. This Test System shall:

Represent key operational states (start-up, shut-down, transients, faulted/degraded performance).

Support alarm logic verification, interlock testing, and diagnostics without reliance on a live operational system.

1. The Contractor shall not be required to implement a digital twin per se; however:

* If a validated digital twin or process-control simulation model (e.g., Simulink®, SimCryogenics, RNN, empirical/statistical thermodynamic or reliability models) is proposed, it must be:
  + Based on certified, validated, or standards-compliant toolsets.
  + Configured to support operator training, diagnostics, and maintenance planning.
  + Allow future Integration with instrumentation and control system architecture to enable virtual sensors or diagnostic inference.
* If no model is proposed, the Applicant shall:
  + Explicitly state and justify the exclusion, supported by a cost-benefit or reliability impact rationale.
  + Describe in detail the alternate approach used for initiating event training, commissioning testing, and system diagnostics.
  + Demonstrate how operational reliability, functional verification, and maintenance readiness are ensured in the absence of a digital model.

In the offer, the Applicant shall provide substantiated details: Contractor’s proposed SUT and test system description; Declaration of modelling approach (or exclusion), with justification; Simulation capabilities or testing methodology documentation; Operator training protocols and model/test system interface

1. Controlling mass flow rate and supply temperature: The QPLANT shall supply and regulate the mass flow rate and supply temperature at the QPLANT–QCELL interface (via QINFRA to QRB in the coldbox room), such that the temperature change rate—during both cool-down and warm-up—of each QCELL remains within predefined and controlled limits. The temperature change rate is defined as the maximum allowable rate of change of the internal QCELL temperature, expressed in K/h (e.g., 4 K/h). These limits shall be adjustable via process control, depending on the thermal inertia of each QCELL and the operational mode.
2. The QPLANT:CS shall support bidirectional communication with the Broker, exchanging real-time operational and control signals at an update rate of 1 Hz. This will be used by the Broker system, implemented within MCS, to actively control and enforce this temperature change rate by issuing setpoints and operational constraints to the QPLANT Control System (QPLANT:CS).

General Software and Hardware Requirements

1. GSHRC: The Contractor shall follow the applicable sections from the General Software and Hardware Requirements for Contractors (GSHRC) containing quality and other requirements related to software, firmware and interoperability. The table below contains a specific instruction to the respective requirement §AD 21.

Table 11 Instructions for GSHRC

|  |  |
| --- | --- |
| Req. | Specific instruction |
| GSHRC-1 | **Applicable. Software hardware and firmware** are deliverables**.** |
| GSHRC-2 | **Applicable**. Final **Software Architecture** shall be delivered as part of **Error! Reference source not found.Error! Reference source not found.**. |
| GSHRC-3 | **Applicable**. Final **System Interlock** **Diagram** shall be delivered as part of **Error! Reference source not found.**. |
| GSHRC-4 | **Applicable**. Final **Interface Design Description** shall be delivered as part of **Error! Reference source not found.**. |
| GSHRC-5 | **Applicable**. **Datasheets** shall be delivered as part of **Error! Reference source not found.**. |
| GSHRC-6 | **Applicable**. A **Release Note** shall be delivered as part of **Error! Reference source not found.**. And after any change after acceptance. |
| GSHRC-7 | Applicable. An **Installation Instructions** shall be delivered as part of **Error! Reference source not found.**. |
| GSHRC-8 | Applicable. A **Test Plan** shall be delivered as part of **Error! Reference source not found.**. |
| GSHRC-9 | Applicable. |
| GSHRC-10 | Applicable. An **Interface Test Plan** shall be delivered as part of **Error! Reference source not found.**. and **report** shall be delivered as part of **Error! Reference source not found.**. |
| GSHRC-11 | Applicable. An **Interface Simulator** shall be delivered as part of **Error! Reference source not found.**.  See paragraph Software Change Management for more details. |
| GSHRC-12 | Applicable. A **Test System Description** shall be delivered as part of **Error! Reference source not found.**. |
| GSHRC-13 | Applicable. An **Interlock Test Plan** shall be delivered as part of **Error! Reference source not found.**. |
| GSHRC-14 | Applicable. An **Interlock** **Test Report** shall be delivered as part of **Error! Reference source not found.**. |
| GSHRC-15 | **Not Applicable**. Not a deliverable. See paragraph Software Change Management for more details. |
| GSHRC-16 | **Applicable**. Description of the used internally used test system required by applicant. |
| GSHRC-17 | **Granting a license** for **background** materials is applicable and shall be delivered as part of **Error! Reference source not found.**. |
| GSHRC-18 | Applicable. Delivery of the **background materials** shall be done before **Error! Reference source not found.**. |
| GSHRC-19 | **Updates of Background materials** are applicable up to the end of the Warranty period. |
| GSHRC-20 | **Granting a license** for **foreground** materials is applicable and shall be delivered as part of **Error! Reference source not found.**.. |
| GSHRC-21 | Applicable. Delivery of the **foreground materials** shall be done |
| GSHRC-22 | **Updates of foreground materials** are applicable up to the end of the Warranty period. |
| GSHRC-23 | Applicable. Restrictions on use of specific open-source licenses for SW/HW Materials |
| GSHRC-24 | Applicable. Restrictions on open-source licenses for combined work |
| GSHRC-25 | Applicable. Inventory must be provided with each Release Note |
| GSHRC-26 | Applicable. Sublicense(s) for intended use |
| GSHRC-27 | Applicable: **warranty** |
| GSHRC-28 | Applicable: **Escrow** |
| GSHRC-29 | Applicable. Updates of Escrow Materials must be promptly deposited if changes occur. |
| GSHRC-30 | Applicable. Upkeep of escrow is required, and fees are paid by SCK CEN. |
| GSHRC-31 | Applicable. Description of secure software development must be provided. |
| GSHRC-32 | Applicable. Delivery of secure software is required with no known exploitable vulnerabilities. |
| GSHRC-33 | Applicable. Default configuration must be secure. |
| GSHRC-34 | Applicable. Description of a default configuration must be provided. |
| GSHRC-35 | Applicable. Description of vulnerability management process must be provided. |
| GSHRC-36 | Applicable. Description of policy for Coordinated Vulnerability Disclosure must be provided. |
| GSHRC-37 | **Applicable**. **Known Vulnerabilities** must be listed in Release Notes. |
| GSHRC-38 | **Applicable**. Distribution of patches/updates to mitigate Vulnerabilities is required. |
| GSHRC-39 | Applicable. Description of software defects process must be provided. |
| GSHRC-40 | Applicable. Known software defects must be listed in Release Notes. |
| GSHRC-41 | Applicable. Distribution of patches/updates to address software defects is required. |

1. Autonomous operation: When the MCS is unavailable or a communication loss occurs, the QPLANT:CS shall continue to operate as long as the systems safety as well as personnel safety are guaranteed.
2. Remote parameters access: All the control parameters (like setpoints and thresholds), where manufacturing calibration data is optional, shall be available to the remote control interface with MCS.
3. Interlock thresholds shall not be writable through the remote control interface.
4. The QPLANT Control System should allow every actuator to be controlled manually in the event of a malfunction (for example a motor can have an auto, manual and maintenance mode to accommodate this behaviour).
5. The QPLANT Control System should allow every sensor value to be set by the operator (mode maintenance) to be interpreted by the QPLANT:CS as it is the real value coming from the sensor.
6. Records of all measured values, valve positions, operator actions, log book and alarms shall be accessible in QPLANT Control System.

Software development

1. As part of **Error! Reference source not found.**, the following controls related information shall be provided:

* The detailed documentation of the software architecture, covering all modules, functional blocks, and components, along with their inputs and outputs.
* lists of alarms, protection functions, instruments, events, and parameters.

1. PLCs shall be programmed in accordance with the IEC 61131-3 standard.
2. The use of Instruction List(IL) is highly discouraged. Higher-level languages like Structured Text (ST) are highly recommended for better clarity, maintainability, and portability of PLC programs. Therefore, users and developers are strongly advised to avoid new implementations in IL and to migrate any existing IL-based code to ST or other recommended IEC 61131-3 languages whenever possible.
3. When the Software Component includes human readable information (for example, but not limited to: HMI, logging, source code), it shall be in English.
4. The Contractor shall develop a functional analysis (first version is part of the **Error! Reference source not found.**) and a detailed description of all control scenarios including interfaces. The detailed description shall also include program sequence plan (functions and procedures used in the program).
5. For each software module, functional block, functional component or data block, the Contractor shall provide a description of the conditions to act on the output parameter.
6. Versioning info through MCS interface: Each Software Component and Hardware Node shall include a unique version identifier that uniquely represents the build date and Git commit hash, automatically generated during the build process to ensure traceability; this identifier must be retrievable in a consistent and read-only manner through the MCS control and monitoring interface.

Software Change Management

Prior to deployment in the production environment, software updates shall be rigorously tested in a staging environment. This minimizes risks of integration issues with MCS, MIT, MIS, or any interfacing systems and downtime of the QPLANT.

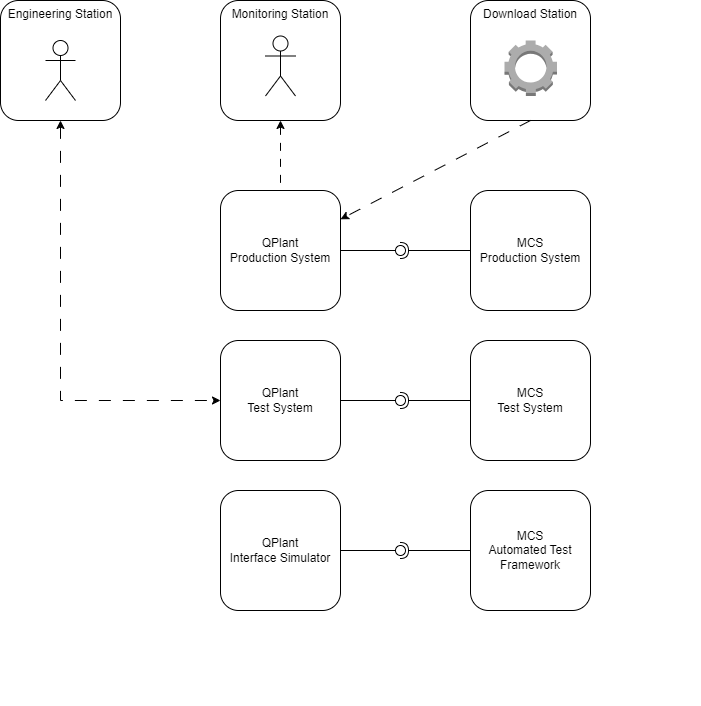


Figure 9 Software Change Management

1. Establishment of a Dedicated Test Environment: The supplier should use a dedicated test environment that replicates the production system's configuration, functionality, and critical interfaces for software changes. This environment may be virtual, physical or a combination.
2. Environment Fidelity: The test environment shall mirror the production system to a level that allows reliable validation of all changes under simulated real-world conditions, including performance, response time and stress scenarios.
3. Comprehensive Testing: All changes shall undergo rigorous functional, integration, and regression testing in the staging environment before deployment to the production system.
4. Approval Before Deployment: No changes shall be implemented on the production system without prior approval based on documented test results and validation in the test environment.
5. Rollback Plan: The supplier shall provide a pre-tested rollback plan to ensure the system can be restored promptly to its previous state in case of issues.
6. Version Control and Audit Trail: All changes shall be tracked in a version control system with an audit trail, providing clear documentation of modifications and approvals.
7. Minimizing Downtime: Changes shall be designed and tested to ensure minimal impact on system availability during deployment, including options for hot-swapping or scheduled maintenance windows.
8. Disruption-Free Testing: The supplier shall guarantee that all testing activities in the staging environment remain completely isolated from production operations to prevent any unintended disruptions.
9. Regulatory Adherence: All regulatory requirements applicable to the delivery of the plant shall also be adhered to for any changes made after delivery, ensuring compliance with safety, environmental, and industry standards.
10. Audit and Monitoring: The contracting authority reserves the right to audit the testing process, staging environment, and changes at any time to ensure adherence to requirements.
11. Continuous Improvement: The supplier shall collaborate with stakeholders to evaluate and improve the testing and change management process based on operational feedback and lessons learned.
12. The Change management should be in place after Factory Acceptance Test and used for changes needed to integrate the consumers.

Human Machine Interface (HMI)

1. Local Operator Station: The Contractor shall deliver local operator stations to provide local data collection and reporting for the QPLANT system to support maintenance activities. As a minimum one is expected in the Compressor Room and one in the Cold Box Room.
2. No Full SCADA System: The Contractor shall not deliver or implement an enterprise level QPLANT SCADA system (multi-user or multi-server architecture) as part of the scope.
3. Temporary SCADA System for Standalone Commissioning:  
   The Contractor shall deliver and implement a temporary QPLANT SCADA system exclusively for use during the standalone commissioning phase. This solution is intended solely to support initial testing, commissioning, and operator training, and should be decommissioned and replaced by the MCS solution once integration is realized. This temporary system shall also be used as reference design for the development of the MCS Navigator therefor sufficient documentation is required.
4. Integration Support: The Contractor shall provide support for integration of the QPLANT Control System with the MCS Navigator. This includes, but is not limited to:

* Providing support in designing the Operator Screen for the Plant.
* Supplying necessary communication protocols (e.g., OPC UA, TCP/IP)
* Coordinating with the project SCADA team to ensure data consistency (e.g., tags, alarms)
* Sharing relevant technical documentation and engineering details to enable seamless integration

1. Industrial-Grade Platform: The Contractor shall ensure that the operator stations (whether HMI panels or dedicated Industrial touch PCs) are based on industrial-grade hardware specifically designed for continuous operation in a production environment. This includes robust construction, compatibility with the QPLANT’s environmental conditions (temperature, dust, vibrations, etc.), and adherence to relevant industrial standards.
2. Long-Term Software Update Support: The platform shall be supported with software updates, firmware updates, and security patches for a minimum of 20 years from the date of commissioning. The Contractor shall provide documentation or official manufacturer statements guaranteeing availability of updates throughout this period.
3. Migration to Newer Hardware: The visualization (HMI) project shall be designed in such a way that it can be migrated to newer hardware of the same manufacturer if the originally delivered hardware becomes obsolete or requires upgrade. This includes ensuring future compatibility of project files and software licenses, and providing guidelines for seamless transfer of project data and configurations.
4. The touchscreen display shall have a minimum diagonal size of 24 inches to ensure sufficient screen space for detailed process graphics and user interaction.
5. The display shall support a resolution suitable for clear viewing of process graphics, text, and trends. A minimum resolution of 1920×1080 (Full HD) is recommended for a 24-inch display.
6. Where the system includes a local Human Machine Interface (HMI) that supports local control, it shall implement a control selection mechanism based on a 3-state principle: Local - Free - Remote. Local or remote control can only be granted when the system is in the "Free" state. If the system is not free, the requester will be denied the requested control, and any write commands from that side will be ignored. However, reading the system state shall always be permitted in any state, allowing either side to retrieve information about the system's status and confirming whether a request was successful. Writing (changing) is only allowed when the request is accepted. It is important to note that this control mechanism only pertains to local versus remote control states. Any other state machines within the system shall remain active, ensuring that, for example, regulation loops continue to function in either state.
7. Release: Once a system is reserved in a specific control mode, it shall automatically transition to the "Free" state if a configurable timeout period (maximum of 5 minutes) of non-activity expires. "Releasing" means transitioning from a specific control state to the "Free" state. Non-activity refers to the absence of local or remote actions.
8. Non-Critical System Role: The Operator Station shall be designed as a non-critical component of the control system. No real-time or safety-critical control functions shall reside in the Operator Station; it is purely for monitoring, visualization, and local interaction.
9. Data Storage & Retention: The Operator Station shall store operational data (e.g., trends, alarms) only for a limited amount of time, sufficient for short-term analysis and troubleshooting. The data stored locally shall not be formally backed up; once data ages out of the configured retention period, it may be overwritten or discarded.
10. The Operator Station shall provide capabilities for plotting curves and trends, enabling real-time and short-term historical visualization of key process variables.
11. The Operator Station shall include graphical process views, providing an intuitive interface for monitoring equipment states and process flows.
12. The Operator Station shall show and log alarms and events for immediate operator awareness without functionality to acknowledge alarm occurrences
13. Graphical process views shall be agreed with SCK CEN.
14. All the sensors and actuators shall be integrated in different graphical views.
15. The Operator Station software shall support a default data acquisition period of maximum two seconds. For critical turbine data an acquisition rate of 100 ms is required.
16. The HMI software shall allow at least two permission levels with different functions available.
17. The HMI software package shall allow to automatically call or e-mail “on call” staff through MIT (see Figure 8).
18. The graphical views shall be in accordance with the Process & Instrumentation Diagrams to easily understand and operate the system.
19. The HMI software package shall be installed on two workstations with large screens (at least height 24 inches monitors) to visualize the useful information during QPLANT operation (see Figure 8).

Network

* + - * 1. Reference Architecture

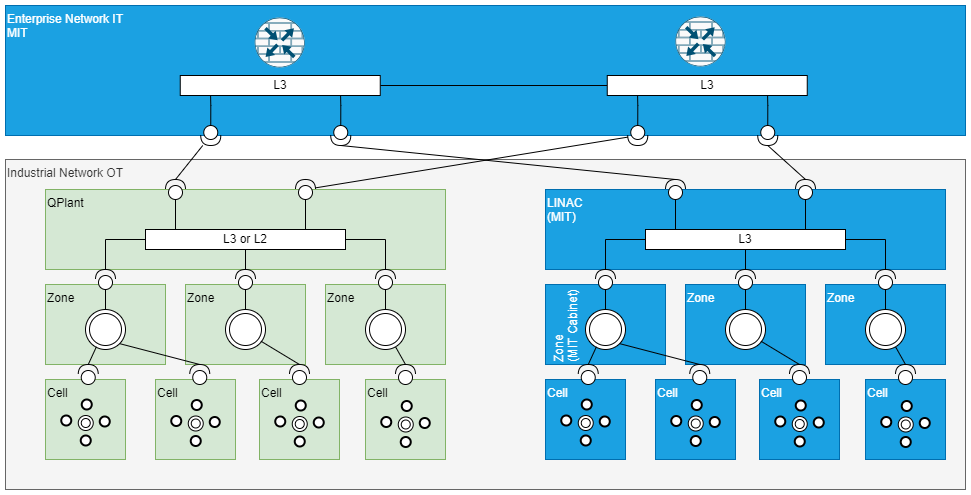
[](https://polarion.sckcen.be/polarion/module-attachment/MYRRHA/CIS/QPLANT%20-%20CIS%20Supplementary%20Requirements/diagram_20241202-1457.47868.mxg.svg?revision=95157)

Figure 10 MIT Reference Architecture

Enterprise Network: Represents the high-level IT network connecting various business operations, services, and systems. It serves as the foundation for communication across the organization.

Industrial Network: Focuses on the network responsible for managing industrial operations and controls, connecting systems such as SCADA, PLCs, and field devices. It ensures reliable data transmission for production and automation processes.

Plant: This is the central infrastructure that interconnects different network segments, providing high-speed data transfer and ensuring scalability and reliability.

Zone: Acts as an intermediary between the cell and the industrial network, handling traffic distribution and optimizing data flow.

* + - * 1. General

1. Internal Inventory for Plant: The Contractor shall maintain and provide an up-to-date internal inventory of all components, equipment, and services delivered as part of the plant. This inventory must include detailed information on internal applications, devices, network interfaces, and communication protocols used within the plant. The internal inventory should be updated and shared with the client whenever any changes or updates occur in the plant.
2. Network Ports and Protocols Requirement: The Contractor shall supply a detailed list of the network ports and protocols necessary for the correct functionality of their system and application. (**Error! Reference source not found.**)
3. Responsibility for Network Configuration: The Contractor shall be responsible for configuring the necessary network elements based on the inventory of network ports, protocols, internal and external applications.
4. IP Address Allocation and Compliance: The Contractor shall use IP address ranges for the QPLANT:CS as provided by the customer. This includes equipment in Level 0 of the Perdue model. These ranges will be pre-assigned by MIT to ensure consistency with the overall network architecture and addressing schemes. The Contractor is responsible for implementing the provided IP ranges without deviation, and any additional IP requirements shall be communicated to and approved by MIT prior to implementation. Additionally, the Contractor shall document the use of the assigned IP ranges for each device and submit this documentation to MIT upon completing the configuration. (**Error! Reference source not found.**) MIT reserves the right to audit the Contractor's implementation to ensure adherence to the assigned IP ranges and network configuration standards.
5. Remote upgrade: Where a Software Component can be upgraded, the QPLANT:CS shall support an upgrade procedure which can be automated as script(s), without the need for an Internet connection. A list of required tools has to be provided. **Error! Reference source not found.**
   * + - 1. Services
6. Backup: Where backup of a system is required, for each system following shall be defined (**Error! Reference source not found.**):
   * + a clear list of all folders, files, databases, etc. that are to be included in a backup
     + a document describing the backup and restore process
     + any script(s) required to perform these backup and restore actions
7. Monitoring systems with OS: Where the system has an operating system, the System shall support monitoring by at least one of the protocols mentioned in the MIT interface catalogue chapter "Monitoring". Ref. SCK\55564083
8. Authorization and security: Where the system has no operating system and requires authorization, the System shall support authorization by at least one of the protocols mentioned in the MIT interface catalogue chapter "Authorization and security". Ref. SCK\55564083
9. Authorization and security systems with OS: Where the System has an operating system, the System shall support authorization by at least one of the protocols mentioned in the MIT interface catalogue chapter "Authorization and security". Ref. SCK\55564083
10. Authentication: Where the system has no operating system and requires authentication, the System shall support authentication by at least one of the protocols mentioned in the MIT interface catalogue chapter "Authentication". Ref. SCK\55564083
11. Authentication systems with OS: Where the System has an operating system which requires authentication, the System shall support authentication by at least one of the protocols mentioned in the MIT interface catalogue chapter "Authentication". Ref. SCK\55564083
12. Network addressing service: The System shall support network addressing service by at least one of the protocols mentioned in the MIT interface catalogue chapter "Network addressing service". Ref. SCK\55564083
13. Network naming service: The System shall support network naming service by at least one of the protocols mentioned in the MIT interface catalogue chapter "Network naming service". Ref. SCK\55564083
14. Automatic IP Address Assignment: The Contractor shall implement a mechanism for automatic IP address assignment based on MAC addresses whenever possible, utilizing DHCP services to ensure efficient and consistent configuration. In scenarios where DHCP is not feasible, the Contractor shall configure static IP addresses in accordance with MIT's assigned IP ranges. All configurations shall align with MIT's network architecture standards to ensure seamless integration and avoid IP conflicts.
15. Device Identification and MAC Address Tracking: The Contractor shall provide a comprehensive list of all devices, including their respective MAC addresses, prior to configuring the network. This list is crucial for tracking and managing devices, especially when configuring static IP addresses or ensuring proper DHCP assignment. (**Error! Reference source not found.**)
16. Procedure for Enabling DHCP on Devices: If a device is DHCP-capable but not configured for DHCP, the Contractor shall provide a detailed procedure for enabling and configuring DHCP on the device. The procedure shall include all necessary steps for ensuring proper DHCP functionality, such as network settings, IP lease time configuration, and alignment with MIT’s DHCP service and network standards. (**Error! Reference source not found.**)
    * + - 1. Infrastructure
17. Aggregation Network Redundancy: The aggregation network shall use a redundant ring topology, with a dedicated redundancy manager and client switches. The network shall automatically reconfigure within 300 ms in case of interruptions. Redundant connections to the backbone shall be established using a master/slave configuration, ensuring failover times under 300 ms. All links within the aggregation network, including connections to the backbone and cell networks, shall support 1 Gbit/s bandwidth. The network design shall incorporate fault recovery mechanisms to reroute traffic in the event of failures, ensuring uninterrupted data flow. Rationale: The aggregation network ensures high reliability and performance by implementing redundancy to minimize downtime and enable fast recovery during faults.
18. Standby Redundancy for Backbone Connections: The QPLANT:CS shall establish redundant connections to the backbone network using standby redundancy. Each connection shall include a master and backup device, with failover mechanisms ensuring that if one device or connection fails, the other takes over seamlessly. The failover time shall be deterministic, with a maximum duration of 300 ms to minimize downtime. Rationale: Redundant connections ensure continuous backbone network availability by enabling quick failover during link failures, minimizing disruptions and maintaining system stability.
    * + 1. Security
19. Contractor Compliance with Customer Security Policy: The Contractor shall comply with the SCK CEN cybersecurity policy, ensuring alignment with the IAEA NSS17 (Nuclear Security Series), ISO 27001 (Information Security Management), and IEC 62443 (Industrial Communication Networks – Network and System Security) standards. This includes implementing required security controls, risk management processes, and incident response protocols as outlined by these frameworks.
20. Security Documentation and Client Approval: Documentation of the system's security features and their alignment with the client's standards must be provided for review and approval before deployment. **Error! Reference source not found.**
21. Integration with Client's Security Infrastructure: The Contractor shall work with the client to verify that the system integrates seamlessly with the client’s existing security infrastructure, including firewalls, VPNs, and any other relevant security tools.
22. Identification of Relevant Products and Digital Elements: The Contractor shall identify all products and digital elements used in the production plant, including Commercial Off-The-Shelf (COTS) materials and custom-built systems, that fall under the scope of the Cyber Resilience Act. These products must be evaluated for compliance with the CRA's cybersecurity requirements.
23. Remote Access to Plant: If the Contractor requires remote access to the plant, he shall utilize the standard solution provided by the customer. Access will be granted with restricted permissions to ensure that only necessary functions are available, safeguarding the integrity and security of the plant's systems. The Contractor is responsible for adhering to the defined access protocols and ensuring compliance with the customer's security policies.
    * + 1. Safety
24. Internal interlocks: The QPLANT shall not rely on the MIS, unless the interlock has to be propagated to or relies on other systems.
25. Interlock status to MCS: The QPLANT shall ensure that the status of each interlock is monitorable through the MCS control interface.
26. Personnel protection standards: When the system has personnel protection, the systems personnel protection shall be designed according to standards IEC 61508 (Functional Safety) or one of the sector-specific derived standards (IEC 62061, IEC 61511) or alternative (e.g. ISO 13849-1).
    1. Interfaces
       1. Interfaces to the QLM

Main cryogenic line interfaces

The QPLANT shall interface to the QLM at the cold end of the QRB.

The QPLANT shall contain the final vacuum barrier and the isolation cryogenic valves.

The QLM contains the following cryogenic lines:

* + - * + “A”: Supply of supercritical helium;
        + “B”: Return of very low pressure helium;
        + “D”: Supply of gaseous helium to the TS;
        + “E”: Return of gaseous helium from the TS.



Figure 11 Preliminary arrangement of the pipes in the QLM (see Table 12 for details).

A preliminary arrangement of the pipes in the Cryoline is shown on Figure 11. The preliminary diameters of the pipes are indicated in Table 12. The final arrangement and pipe diameters shall be defined by SCK CEN in due time.

Table 12 Preliminary pipe diameters for the QLM

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Pipe | DN  (mm) | External diameter (mm) | Thickness (mm) | Indicative operating pressure (bar) |
| A | 150 | 168.3 | 2.77 | ~0.03 |
| B | 25 | 33.4 | 1.65 | ≥ 3 |
| D | 40 | 48.26 | 1.65 | 14 |
| E | 40 | 48.26 | 1.65 | 13 |
| Thermal shield |  | 350 |  3\* | - |
| Vacuum jacket |  | 500 | 4.5 | 10-6 |

1. The welding connection between QRB and QLM shall be done by SCK CEN.
2. For the acceptance tests, the Contractor shall provide the necessary welded caps on pipes on the QRB side.

Warm line interfaces

1. The following warm lines are distributed in the tunnel. The interface with the QPLANT will be located in the cold box room, around the QRB. The final location and pipe requirement shall be defined during the design phase with SCK CEN.

* Warm GHe supply: This line supplies helium to the cryogenic users (300 K – 14 bar). It is high pressure (coming from the HP of the compression station), the interface pipe diameter is DN 25.
* Safety Valves GHe return: to avoid loss of helium and to reduce anoxia risk, the safety devices shall be collected. The diameter of the pipe is DN 150.
  + To cope with a return mass flow rate through the safety valves around 100 g/s (case of utility stop for more than 1 hour), the diameter line shall be at least DN 125. The selection of DN 150 could avoid increase of pressure along this return line from QCELL’s to QPLANT in case of utility stop.
* Coupler return line: This line collects the helium gas at the outlet of the coupler cooling circuits (300 K and 1.1 bar). It shall be connected directly to the LP pressure of warm compressors at 1.05 bar. The selected diameter of this line is DN 25.

Table 13 Warm lines at room temperature

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Pipe | DN  (mm) | External diameter (mm) | Thickness (mm) | Indicative operating pressure (bar) |
| Warm GHe supply (U) | 25 | 33.4 | 1.65 | ~ 14 |
| Safety Valves GHe return (S) | 150 | 168.3 | 2.77 | ~ 1.1 |
| Coupler return line (W) | 25 | 33.4 | 1.65 |  1.1 |

In the LINAC tunnel, a line called “vent collector, Line V” could recover the burst disk of the Cryogenic Cells (QCELL’s) in order to vent helium outside tunnel in case of major failure. This vent collector is out of the present scope and does not have any interface with the QPLANT.

* + 1. Interfaces with the site

Figure 3 gives an overview of the building for the linear accelerator. The cryomodules are in the tunnel (LTU). The Refrigeration Cold Box (QRB) is in the cold box room and the WCS in the compressor room (CCB). The distance between the centres of 2 buildings (rooms inside) dedicated for QPLANT is about 65 meters.

The details of the Auxiliary Buildings are given in AD 1. SCK CEN provides volumes and envelop of the buildings.

1. The QPLANT shall be designed to fulfil the site constraints (buildings, rooms) given in AD 1.
2. For the cryogenic areas, the Contractor shall provide the general assembly drawings with QPLANT components and 3D models. (\*.step files may be used).

Compressor room

1. The compressor room (16 m \* 14 m \* 6.5 m) shall house the WCS. The Contractor shall reserve space in this room for future upgrades (e.g. a dedicated purification system), for spare parts storage as well as for an unloading area.
2. The Contractor shall define the positioning of all equipment in this room in agreement with SCK CEN.
3. The compressor units may be installed and grouped on skids.
4. During the conceptual design phase, the Contractor shall evaluate the need for a crane in the compressor room and shall provide the necessary inputs in the deliverable **Error! Reference source not found.**.
5. The access for the installation of the large components could take place from the road by removal of the wall dismountable panels. SCK will be in charge of the dismountable panels dismounting and mounting.

The cold box room

1. The Cold Box Room (20 m\*10 m~200 m², see details in AD 1) shall host the Refrigerator Cold Box and associated warm panels, the electrical cabinets, the gas analysers and pumping system. The height of the ceiling is around 6.5 meters.
2. During the conceptual design phase, the Contractor shall evaluate the need for crane in the cold box room and shall provide the necessary inputs in the deliverable **Error! Reference source not found.** **Error! Reference source not found.**.

The access for the installation of the large components could take place from the road by removal of the wall dismountable panels. SCK will be in charge of the dismountable panels dismounting and mounting.

The cold box room shall be connected to the compressor room by the different warm lines of the QPLANT.

1. These warm lines of about 60 meters long shall be installed on the roof or below the roof close to the ceiling of the buildings between compressor room and cold box room.

Storage Area

1. The gas helium storages and potentially liquid nitrogen storage shall be installed in the storage area (17 m\*10 m ~170 m²), next to the compressor room. The total helium inventory is detailed in §3.3.17 .
2. The positioning of the different storages shall consider the possibility of the fluid refilling by trailers.

Site environmental conditions

1. The following site operating conditions shall be considered for the design and operation of the QPLANT and auxiliary equipment (see AD 1):

* Winter condition:
  + Winter dry bulb temperature: -9.1 ºC
  + Relative Humidity: 90%
* Summer condition:
  + Summer dry bulb temperature: 33.4 ºC
  + Relative Humidity: 39%
* All technical rooms share the following ambient conditions:
  + Cold box room temperature: 5ºC- 40ºC (range of temperature can be reduced in case of need for cold box components, to be requested by Contractor).
  + Compressor room temperature: 5°C-40°C.
  + Relative Humidity: Not Controlled.
  + Design wind velocity: 49 m/s (~176 km/h, average values on 3 seconds to a height of 25 m) (NBN 460 standard).
  + Rain intensity: 54 mm/h per a period of 1h (return period 100 years).
  + Snow load: 0.50 kN/m2 (return period 100 years).
  + Elevation 27 m above sea level.
  + Coordinates: Latitude - 51°13’50.N ; Longitude - 5°05’24.E.
    1. Interfaces With Electrical Power Supply

SCK CEN site will supply 400 V~50 Hz, 3Φ+N (TN-S) in the compressor room and in the cold box room at one point in each building. The maximum available power is 1.2 MW in the compressor room and 100 kW in the cold box room.

1. The Contractor shall provide the power supply consumption at the end of the Conceptual Design phase.
2. The Contractor shall provide the Low Voltage distribution and associated LV cubicles associated to the QPLANT procurement.
3. The Contractor shall provide routing, cabling, cable trays and connectors for all QPLANT components related to the compressor room, the cold box room and the storage area.
4. The electrical diagrams, cable trays and electrical management shall be subject to approval by SCK CEN. SCK CEN will provide the grounding connections in the compressor room, cold box room and storage area (in compliance with the international standards).
5. The Contractor shall connect all cryogenic equipment to the grounding of their buildings following the IEC standards.
6. The piping (helium, water, air) and Low Voltage cables shall be grouped in a single building feed-through and connected to equipotential bounding in order to reduce the EMI effects. EMC standards and guidelines shall be followed by the Contractor (§AD 7).
7. The Contractor shall provide to SCK CEN a proposal for UPS backup power in case of loss of electricity to supply HMI, PLCs, network, digital inputs. Centrally managed UPS backup power is provided by SCK CEN.
8. A list of sensors and transmitters to be powered by UPS shall be proposed by the Contractor and subject to approval by SCK CEN, based on a risk analysis of the relevant signals by the Contractor. This allows SCK CEN to dimension the centrally managed UPS and to provide the required backup power.
9. Where the QPLANT has high power or high voltage components, the Systems embedded controls electronics shall be powered with a segregated AC power interface.
   * 1. Interfaces with the Water-Cooling Loop

Cooling water (mixture with 40 % of propylene glycol) in the compressor room for the warm compressors and in the cold box room for rotating machines (turbines, cold compressors, pumping system) will be provided by SCK CEN site at one point (supply and return) in each building at the dedicated technical rooms (Compressor Room and Cold Box Room).

According to expected temperature difference of 10°C on cooling water circuits, the associated mass flow rate will be maximum 100 m3/h for compressor cooling and 10 m3/h for cold box cooling.

1. The Contractor shall provide the cooling water expected consumption at the end of the Conceptual Design phase.
2. The Contractor shall distribute the cooling water inside the dedicated technical rooms to the different QPLANT users. The scheme of the cooling water distribution in the buildings shall be subject to approval by SCK CEN.
3. The Contractor shall install the necessary instrumentation and additional control elements where required to measure/control temperature, pressure and mass flow rate of the cooling water loops.
4. The Contractor shall provide local drains considering that the draining of cooling water is a glycol type waste, and therefore needs to be connected to the SCK CEN PS03 system.
   * 1. Interfaces with instrument air System

Instrument air in the compressor room and in the cold box will be provided by SCK CEN site at one point in each building at the dedicated technical rooms (Compressor and cold box room). Instrument air pressure will be around 9 bar with a dew point lower than -40 °C. For the QPLANT, a maximum of 50 Nm3/h of compressed air will be available.

1. The Contractor shall provide the compressed air needs at the end of the Conceptual Design phase.
2. The Contractor shall distribute the compressed air inside the dedicated technical rooms to the different QPLANT users. The scheme of the compressed air distribution shall be submitted to SCK CEN’s approval.
   * 1. Interfaces with HVAC

1. The Contractor shall provide a quantitative analysis of heat dissipation to the HVAC system covering:
   * + - Heat load to room and cooling air (in kW) for steady state (24 and 30 QCELL) operational and standby per room of WCS and QRB.
       - Validation of SCK CEN provided exhaust routing to designated HVAC intake points during commissioning and acceptance testing.
2. The Contractor shall ensure the integration of the HP compressor exhaust ducting with the Compressor Room (WCS in CCB). SCK CEN provides extraction from defined scope boundary.

In the offer, the Applicant shall furnish interface (HP compressor exhaust outlet/terminal points) quantitative data (heat dissipation, flow rates, pressure drop, …)

1. HVAC system to allow for partial by-pass or heat injection during cold ambient conditions. The system shall be designed to minimize energy input while ensuring reliable operation.

In the offer, The Applicant shall quantify flow rates, temperatures (maximum, nominal, minimum), and provide outlet dimensions and fixed interface and terminal point definition. The allowable pressure drop from the compressor to the outside shall be specified.

* + 1. Interfaces with the Vacuum System

1. The exhaust of the vacuum system(s) from the QPLANT process rooms shall be collected and vented outside the building. The location of these exhausts shall be subject to approval by SCK CEN.

In the offer, The Applicant shall quantify the number, size and location of expected roof/wall penetrations.

* + 1. Interfaces with Helium filling

For the commissioning and operation of the QPLANT, SCK CEN will provide pure helium gas (with all impurity levels lower than 50 ppm by volume) in the gas helium storage tanks.

1. The Contractor shall provide the necessary helium to be used during the installation and pre- commissioning phases including leak tests and conditioning of the QPLANT circuits.
   * 1. Interface with LHe (ad-hoc) user and associated helium recovery
     2. Liquid Nitrogen (LN2)
2. If liquid nitrogen is used for the QPLANT precooling, the Contractor shall be responsible for the entire nitrogen equipment including liquid nitrogen tanks, heaters, etc. If the liquid nitrogen is not used for the QPLANT precooling, SCK CEN could provide gas helium for regeneration purpose. SCK CEN will provide the necessary support as required.
3. During installation and commissioning, the Contractor shall be in charge to supply the necessary nitrogen linked to these activities.
   * 1. Interfaces with MCS
4. MCS architecture: Where the system has an interface with MCS, the system shall comply to the MCS architecture, processes and interfaces. Ref. SCK CEN/38585071.
5. Control and Monitoring Interface: The interface between QPLANT (Contractor) and Control System (ICS) shall comply to the **Slow Fieldbus** Control and Monitoring Interfaces type C as listed in MCS Interface Catalogue Ref. SCK CEN/48276492.
   * 1. Interfaces with MIS
6. MIS architecture: Where the system has an interface with MIS, the system shall comply to the MIS architecture, processes and interfaces. Ref. SCK CEN/39550252.
7. Slow Interlock Interface: The interface between QPLANT (Contractor) and Interlock System (ICS) shall comply to the Slow control interface catalogue. Ref. SCK CEN/48443569 §AD 16.
8. Slow interlock interface specification: Where the system has a slow interlock interface, the slow interlock interface shall comply to the slow interlock interface document: Ref. SCK CEN/48282970.
9. Interlocks from or to QPLANT Control System to or from MIS ( See Figure 8 ) shall use hardwired interfaces. The list of interlocks will be defined during the project execution by SCK CEN.
10. * 1. Interfaces with MIT
11. MIT architecture: Where the system has an interface with MIT, the system shall comply to the MIT architecture, processes and interfaces. Ref SCK CEN/39553304.
12. MIT Interface catalogue: The interface between QPLANT (Contractor) and SCK CEN Information Technology (ICS) shall comply to the MIT interfaces as listed in catalogue Ref. SCK CEN/55564083
13. Network Integration Physical: The QPLANT shall be physically connected to the MIT network in a redundant, fault tolerant way. At minimum 2 physical links will be foreseen, each link routed via a separate pathway. The physical connections need to be distributed over at minimum 2 separate physical endpoints on the QPLANT side.
14. Network Integration Logical: The QPLANT shall be connected to the MIT IP network using a single logical routed connection ("layer 3"). At both sides, a single gateway IP will be configured as destination IP for packet forwarding.
15. System logging: Where the QPLANT:CS or one of its components supports system logging, the contractor shall provide system logs remotely through at least one of the protocols mentioned in the MIT interface catalogue chapter "System logging". Ref. SCK\55564083
16. Application logging: Where the QPLANT:CS support application logging, the System shall log remotely either by using a protocol defined in section "Application logging" of document "MIT interface catalogue" ( Ref. SCK\55564083 ) or alternatively adhere to the following:
    * + Logs are provided in a data and file format that is machine readable, text based and non-proprietary. Examples of this include, but are not limited to: CSV (Comma Separated Values), JSON (JavaScript Object Notation), GELF (Graylog Extended Log Format) or “Common Log Format”.
      + The details of the used log format(s) are provided. This includes, but is not limited to: the message structure and the possible key/value pairs with their type, possible value and description.
      + Logs can be encrypted during transport if and when the security classification of the data permits this, but in this case the decryption procedure and required secret(s) need to be provided.
17. Timing synchronization: The QPLANT:CS shall support timing synchronization by at least one of the protocols mentioned in the MIT interface catalogue chapter "Timing synchronization". Ref. SCK\55564083
18. Remote access: Where the QPLANT:CS requires remote access, Systems shall provide remote access through at least one of the protocols listed in the MIT interface catalogue chapter "Remote access". Ref. SCK\55564083
19. Patch panel: The connection of the QPLANT:CS with MIT, shall terminate on a patch panel.
    1. Factory Testing
       1. Welding, pressure and leak tests
20. Certified personnel shall carry out the weld inspections, pressure and leaks tests. The associated valid certificates of the qualified personnel shall be provided by the Contractor in the deliverable documentation (**Error! Reference source not found.**.).
21. As a minimum, the following tests shall be conducted during construction of the components.
    * + For welding tests, 100% visual inspection and radiography with degree of inspection required in design and construction codes.
      + Pressure tests shall be performed in accordance with the design and construction code.
      + Leak test shall be performed at ambient temperature after the pressure tests.
      + Leak tests of specific cold components (e.g. transfer lines) shall be carried out after spraying liquid nitrogen on welds.
      + The Contractor is, however, free to perform additional tests to ensure the specified performance or quality.
      1. Tests of components
22. All possible functional tests at the manufacturer sites shall be performed to detect any faults before delivery and confirm the performances indicated in the technical specification. These tests shall include at least:

* All helium compressors or pumps shall be tested individually at the manufacturer’s premises. The measured values shall include at least flow rate, pressures, temperatures, helium leak, noise level and vibrations.
* Compressor motors shall be tested individually at the manufacturer’s premises. The measured values shall include at least power consumption, temperatures, noise level, vibrations, efficiency etc.
* Turbines, cold compressors and cold circulators shall be tested at the manufacturer’s premise at design rotation speed at ambient temperature. Measurements shall include vibrations, rotor stability and noise.
* All cryogenic helium valves shall be delivered with leak test certificates of the body and the seat.
* All safety components shall be delivered with the necessary certificates.
  + 1. Electrical, wiring and control system tests

1. After mechanical assembly and cabling of any sub-assembly, the Contractor shall execute a complete electrical and wiring test. All components and cabling shall conform to the international electrical standards (IEC). The electrical and wiring tests shall include at least:
   * + Visual inspection of cabling.
     + Checking of conformity with the electrical wiring diagrams.
     + Checking of correct labelling.
     + Checking of the grounding of all components and measuring of insulation resistance for all electrical wiring and electrical components.
     + Performing functioning of valves with adjustment of the positioners.
     + Checking of the instrumentation cabling.
     + Checking of the electrical cabinets (instrumentation, power supply and control) with injection of inlet signals and detection of outlet signals.
2. For the WCS electrical tests, before the connection between the motor and the compressor, the Contractor shall:
   * + Verify the direction of motor rotation.
     + Check of phase rotation direction on the electrical cubicle busbar before switching on 3 phases electrical motors.
3. The QPLANT control system operation shall be tested in simulation mode before shipment.
   1. Transport and Storage
4. The Contractor is responsible for the transport and storage of all the QPLANT components from the manufacturing sites to the SCK CEN final positioning. It includes the storage, transport, loading, unloading and final positioning activities.
5. Prior to transportation, all process circuits of the QPLANT components shall be filled with inert gas at a fixed pressure and sealed during transport. Necessary caps, blind flanges and hand valves shall be considered at that stage. Pressure gauges shall be installed and checked at the departure from manufacturer premises and at the arrival on SCK CEN site. It is recommended to provide transportation boxes with appropriate accelerometers for the refrigeration cold box.
6. Appropriate packaging shall protect every item during transport from degrading environment, be suitable for the selected transport and consider temporary storage in the open air.
7. Each package shall be clearly marked with a label stating the Contractor’s name, the destination, the name of the component and its identification number, the weight, and a link to the documentation.
8. Prior to transportation, the package units shall be visually inspected at the manufacturer premises and a certificate about proper packaging and availability of the necessary documentation shall be issued. Representatives of the SCK CEN shall be invited by the Contractor to witness the inspection. The inspection shall consist in a visual verification of the packaging and a check of the formal and technical documentation.
   1. Installation and Assembly
9. The Contractor shall install and assemble all components (compressors, ORS, QRB, warm panels, interconnection lines, electrical cubicles, control system equipment’s, analysis cubicles, among others) and perform their connections on the SCK CEN site and to utility supplies.
10. The Contractor and its subcontractors shall follow the local regulations applicable on the SCK CEN site, including the safety and logistic rules and the necessary trainings.
11. For all activities on SCK CEN site, the Contractor shall comply with the SCK CEN Safety and Health Plan (AD 2).
12. Utilities (electricity, cooling water, compressed air) except fluids (helium and nitrogen) will be supplied free of charge from start of installation to end of acceptance tests at the SCK CEN site. The Contractor shall provide a list of needed utilities with date of availability at the end of the conceptual design and updated at the final design (**Error! Reference source not found.**).
13. The existing cranes in the buildings will be made available for the work on site, however, qualified operators shall be provided by the Contractor.
    * 1. Incoming inspection at SCK CEN site
14. Upon arrival on the SCK CEN site at Mol, at least the following inspections shall be performed and documented:
    * + Inventory control of components.
      + Visual inspections: checking for any damage of the packages, examination of the surfaces and welds of the components for cracks.
      + Checking of pressure settings of all volumes after transport by the reading of the pressure gauges, and comparison with pressure measured before shipment.
      + Checking of all installed shock detectors and accelerometers.
15. An incoming inspection report shall be provided by the Contractor and approved by SCK CEN (to be included in deliverable **Error! Reference source not found.Error! Reference source not found.**) before starting installation.
    * 1. Test after Mechanical assembly completion
16. After assembly of subsystems (WCS, QRB, storages), the following tests shall be performed and documented:
    * + Conformance of the assembly with the piping and instrumentation diagrams, verification of the labelling.
      + Inspection of assembly welds shall be performed according the ASME standard. Moreover, all cryogenic joint welds shall be 100 % X-rayed.
      + Pressure tests of subassemblies with dry nitrogen gas. The Contractor shall take in charge all measures concerning safety precautions during these pressure tests.
      + Leak tests on subsystems (including warm lines) with recording the vacuum level for at least 24 h shall confirm the maximum leak rates specified in section 3.3.8.
      + All electrical and wiring tests shall be performed on site after assembly.
      + Tests of the measuring chains and instrumentation shall be performed with the test of the QPLANT control system and the inlet/outlet signals.
      + Checking of safety components and particularly the safety valves.
17. An assembly test report shall be provided by the Contractor and approved by SCK CEN (**Error! Reference source not found.**) before starting commissioning.
    1. Commissioning

* They need to commission,
* They need to provide all the He needed for the commissioning and all testing.
  + 1. Tests to be done during Commissioning

Preliminary tests

1. The commissioning shall start with preliminary tests to control and check all components at ambient temperature. The preliminary tests shall include at least the following tasks:
   * + Controlling of the instrument circuits and settings on Human Machine Interface.
     + Checking of all connections.
     + Operation and checking of all utilities (cooling water, air and vacuum pumping circuits, electrical power supply, oil, nitrogen).
     + Conditioning of the circuits (evacuation, purging, flushing), with pure helium gas and calibration of the gas analysers.

Running tests

1. Each individual subsystem (vacuum systems, WCS, gas storages, Refrigeration Cold Box) shall be commissioned during running tests:
   * + Helium filling and gas management.
     + Oil removal system.
     + Rotating machines.
     + Individual leak test of rotating machines.
     + Checking of dust removal filters.
     + Checking of the QPLANT control system including instrumentation.
     + Validation the QPLANT control system operation including test of interfaces and test of safety functions and interlocks.
2. WCS and QPLANT commissioning test reports shall be provided by the Contractor (**Error! Reference source not found.**) and approved by SCK CEN before starting acceptance capacity tests.
   1. Site Acceptance testing

All tests described in 3.8 shall be conducted under Contractor responsibility following the local site rules.

The tests on site consist of an incoming inspection after arrival on site, inspection after positioning of the components, verification after mechanical assembly completion, a commissioning period for the Contractor to prepare the QPLANT for acceptance capacity tests. The acceptance capacity tests aims at verifying the functional operation and capacity of the WCS alone and then the functional operation and capacity of the complete QPLANT.

* + 1. Site acceptance tests

1. Test shall contain the validation of the position of the interfaces (especially the one to the QLM).

General definition

1. During acceptance capacity tests on site, the Contractor shall demonstrate proper operation and verify the performance requirements specified in §3.2 (except cool-down and warm-up of QCELL’s which could only be performed after QCELL’s are connected. Nevertheless, operation sequences for cool-down and warm-up shall be demonstrated by the Contractor).
2. During these tests, all aspects e.g. mechanical and capacity, safety requirements and process control system shall be tested and validated.
3. A draft of the test program shall be submitted prior to start manufacturing (**Error! Reference source not found.**). The final version of the acceptance capacity test program shall be submitted latest 10 working days before the envisaged start of the tests (**Error! Reference source not found.**) and be approved by SCK CEN.
4. The acceptance capacity tests shall be performed with the specified heat loads applied by heaters on the different cooling circuits to be representative of the operation with QPLANT connected to the accelerator. Dedicated test cryostat, if necessary (and to be provided by the Contractor), could be used. Control valves in relevant circuits shall also simulate appropriate pressure drops.
5. The acceptance capacity tests of the QPLANT (including Warm Compression Station and QPLANT) shall be reported in deliverable **Error! Reference source not found.**.

Leak test and leak rate

WCS functional tests

1. During these tests, the WCS is not connected to the Refrigeration Cold Box. The functional tests shall consist in:
   * + Checking of mechanical characteristics.
     + Measuring of vibrations, noise, oil pressures and temperatures.
     + Checking of the cooling water system.
     + Testing of control software and interlocks during operation and simulated failures.
     + Measuring of main characteristics such as helium flow rates, pressures, temperatures.

WCS capacity tests

The capacity tests of the WCS shall be undertaken after the successful completion of the functional tests.

1. The capacity tests of the WCS shall consist in warm tests of the WCS during 48 hours in steady state conditions corresponding to the maximum mass flow rate for each stage and maximum pressure ratio.
2. The following values shall be permanently monitored during the tests:
   * + Mass flow rates delivered by the compressors.
     + Pressures: VLP, LP, HP.
     + Helium temperatures.
     + Cooling water temperatures.
     + Measuring of the capability of the oil removal system (hydrocarbons level after ORS) and capability of the dryer.
     + Individual electrical motor currents and voltages.
3. The Contractor shall estimate uncertainties on the measurements. The estimated uncertainty will be added or subtracted (depending on the measurement) to the measured values before checking the acceptance capacity criteria.
4. The capacity test of the WCS will be deemed as successful when all compressors run at full charge during the full period of the test (48 hours), without any discontinuous operation and with acceptable temperatures of cooling water according to 3.4.4. The accepted stability criteria are: for the LP: ± 3 % and for the HP: ± 2 %.

QPLANT functional tests

1. After successful functional and capacity tests of the WCS, the functional tests of the QPLANT (Refrigeration Cold Box) could start. The functional tests shall include at least:
   * + Checking of mechanical characteristics.
     + Measuring of vibrations of the rotating machines.
     + Checking of cold absorbers operation in the QRB with a full regeneration cycle on each of the 80 K adsorbers and on the 20 K adsorber.
     + Checking of control software and interlocks according to the functional analysis.
     + Testing of the rotating machine (cold compressors) at the design points (Minimal and Nominal) and at full speed.
     + Checking of the safe shut down of the QPLANT after the following abnormal modes simulated on the QPLANT control system:
       - * Failure of the QPLANT control system.
         * Loss of utilities (electrical power, cooling water, instrument air, vacuum loss, impurities in helium gas).
     + Checking of the operation of all valves, instruments, heaters and rotating machines in the Refrigeration Cold Box and warm panels for all the defined operating modes.

QPLANT capacity tests

1. The QPLANT capacity tests shall start when all the functional tests described above have been successfully completed and all specified documents have been provided.
2. The QPLANT capacity tests shall be performed for the defined steady state modes (Cold stand-by; Thermal Shield stand-by; 2 K operation: Minimal and Nominal Design Points).
3. The capacity tests of the steady state modes will be performed under the environmental conditions and utilities described in 3.4. If conditions given are out of range during capacity tests, the Contractor in agreement with SCK CEN could propose a correction for the measurements.
4. During capacity tests, the test heaters shall operate at least the required values defined in the heat loads table (Table 3).
5. During each capacity test, the following values shall be continuously monitored:
   * + mass flow rates, pressures / pressure drops, temperatures at the supply and return lines of the QRB.
     + liquid levels of LHe thermal baths.
     + main mass flow rates, pressures and temperatures VLP, LP HP in the WCS.
     + pressure in storage helium tanks.
     + cooling water temperatures and mass flow rate.
     + individual electrical motor current and voltages.
     + heat power of electrical heaters.
6. The Contractor shall estimate uncertainties on the measurements. The estimated uncertainty will be added or subtracted (depending on the measurement) to the measured values before checking the acceptance capacity criteria.

#### Thermal Shield stand-by

1. The Thermal Shield stand-by capacity test shall consist of:
   * + Establish the mass flow rates corresponding to Thermal Shield stand-by mode using the test configuration with the necessary by-pass valves.
     + Start heaters as defined in requirement Req # 305.
     + One 24 hours Thermal Shield stand-by run without operation of the VLP compressors from the cold stand-by mode and followed by the cold stand-by mode.
2. The capacity tests of the QPLANT during Thermal Shield stand-by mode are deemed as passed if during the full period of the test, without any discontinuous operation, the achieved values verify the performance requirements described in Table 3 and Table 4.

#### Cold stand-by

1. The cold stand-by capacity test shall consist of:
   * + Filling all the liquid helium baths to their minimal operating levels.
     + Establish the mass flow rates corresponding to cold stand-by mode using the test configuration with the necessary by-pass valves.
     + Start heaters as defined in requirement Req # 305.
     + One 48 hours cold stand-by run without any sub-atmospheric compressor followed by a transition to 2 K operation minimal design point with start of the sub-atmospheric compressors.
2. The capacity tests of the QPLANT during cold stand-by mode are deemed as passed if during the full period of the test, without any discontinuous operation, the achieved values verify the performance requirements described in Table 3 and Table 4.

#### 2 K Operation

1. The 2K operation capacity tests in stable conditions shall be performed for the nominal and minimal design points. It shall consist:
   * + Establish the mass flow rates corresponding to 2K operation (one test at nominal design point and one test minimal design point) using the test configuration with the necessary by-pass valves and heaters.
     + Start heaters as defined in requirement Req # 305.
     + One 48 hours 2K operation run at nominal design point and one 48 hours 2K operation run at minimal design point, both with VLP compressors operating in the condition defined in Table 3.
     + During each test, the VLP bath pressure stability shall be better than +/- 0.3 mbar.
2. The 2K operation capacity tests is deemed as passed if during all 2 K operation tests, without any discontinuous operation, the achieved values verify the performance requirements described in Table 3 and Table 4.

#### QPLANT transition tests

The liquefaction rate plus the static heat load on the cavities is to be tested.

1. Test of the liquefaction rate at the end of cool-down: the liquefaction rate shall be at least 125 Liters per hours to cope with the filling requirements. With a static heat load of 560 watts applied on helium bath (at 4.5 K), the Contractor shall demonstrate the liquefaction rate which shall be kept for at least half an hour to validate the test.
2. Test of the pumping rate of the cryomodule volumes: the Contractor shall demonstrate using the 2 K helium bath that the pumping of the 2 K helium cryomodule volumes (2900 liters) from 1.3 bars to 26 mbars could be performed in maximum 24 hours, with static heat load of 560 watts applied.
3. Test of stability during transitions between the nominal and the minimal 2 K operation design points: The test of transition between the 2 K operation design points shall be performed with at least two cycles. It shall consist of:
   * + Two operation cycles from minimal design point to nominal design point and being back to minimal design point, with operation stabilized for 2 hours at each level of heat loads. The transition duration from minimal to maximal heat load is lower than five seconds.
     + Establish the mass flow rates and heating power corresponding to 2 K operation initially minimal design point then nominal design point using the test configuration with the necessary by-pass valves and heaters.
     + The VLP bath pressure shall be kept stable in a range of +/- 0.5 mbar.

The stability of the operation during the transition between the minimal and maximal 2 K operation is to be demonstrated.

* 1. Spare Parts (Option 2)

In their offer, the Applicant shall provide a detailed list of recommended maintenance and capital spare parts for two years of operation. A detailed cost breakdown of each recommended spare part is required, along with all necessary recommendations for preventive maintenance and repairs.

The Applicant shall consider all necessary operational and maintenance spare parts for two years of operation, including but not limited to gaskets, filters, instrumentation, valves, safety devices, fuses, transformers, oils, and adsorbents. Special attention shall be given to critical components (to be exhaustively listed) with expected long procurement lead times, such as turbines, cold compressors, and warm compressors.

1. In the offer, the Applicant shall provide a top level list all components with a MTBF < 10 years or replacement rate >3 in 40 years. The Contractor shall then detail this list during the Contract execution. shall have a defined spares inventory and shelf life, aligned with the RCM plan.
   1. After-sales services

The Contractor shall provide after-sales services for the full Lifetime of the QPLANT. The after-sales services shall include at least (but not be limited to) the services stated below:

* + - * + The helpdesk shall offer remote technical support on Business Days during normal working hours, from 07:00 am until 19:00 CE(S)T (via telephone, MS® Teams, or other commonly available communication tools), within 24 hours after SCK CEN notifies the Contractor of the defect.
        + Technical field service, available to provide technical support at the site, in case of unforeseen issues (corrective Maintenance).
        + Annual maintenance service, covering predictive and preventive maintenance, for the QPLANT lifecycle.

The technical support shall provide fault identification/analysis and troubleshooting, as well as general support, for all and any aspects of the QPLANT, including but not limited to electrical, mechanical, controls, software, firmware, etc.

For the after-sales services, the Contractor shall only deploy personnel which is suitably qualified and experienced in relation to (the relevant aspect of) the QPLANT.

Following a request for support from SCK CEN, the actions and respective response times shall be as follows:

* + - 1. Complete the fault identification and analysis and establish the strategy to realize the solution, including a preliminary cost and time estimate:

within maximum 3 Business Days after SCK CEN’s request for support, in case presence at the SCK CEN by the Contractor is not required for fault identification / analysis.

within maximum 5 Business Days after SCK CEN’s request for support, in case presence at the SCK CEN site by the Contractor is required for fault identification / analysis.

the Contractor shall propose a solution which implies as little downtime as reasonably possible for the operation of the LINAC.

* + - 1. Submit a formal quote for the solution:

within maximum 3 Business Days after completion of the previous step (fault identification / analysis completed, strategy for solution established);

This quote shall clearly state

1. technical description of the proposed solution.
2. price for the realization of the proposed solution.
3. the lead time for the realization of the proposed solution.
4. Notwithstanding the foregoing, the Contractor shall at all times provide the solution without undue delay.
5. In the offer, the Applicant shall provide the following information regarding the after-sales service:
   * + 1. Organization of the after-sales service – at least a concise description of the approach to handling customer requests and an overview of the available staff shall be given.
       2. Procedure to be followed for requesting after-sales service – at least a comprehensive description of how the helpdesk can be contacted (including all relevant information such as contact data (telephone, email or equivalent) and availability) shall be given.
       3. Pricing of the after-sales service – at least the labour costs (hourly rates) shall be clearly stated. Any spare parts or Components needed in view of the after-sales service shall be remunerated according to the price list for spare parts requested under § 3.10 “Spare Parts Supply”.
   1. Documentation
6. Throughout Contract performance the Contractor shall, at a minimum, deliver the documentation listed in Table 14.
7. As part of #DD04, the Contractor shall provide the necessary technical data and design datasheets of critical components such as heat exchangers, piping, rotating machines, and valve information with sufficient detail to allow SCK CEN to model the complete cryogenic system including the cryogenic plant in simulations.
8. The Contractor shall provide all relevant information regarding materials and components including, but not limited to:
   * + - * Material specifications.
         * Technical datasheets.

* Material certificates compliant with EN 10204 (especially type 3.1 and 3.2), where applicable
  + - * + Calibration reports, where applicable.
        + Installation/user/service manuals where applicable.

1. The Contractor shall deliver a maintenance manual and lifecycle strategy documentation, including but not limited to:

* Spare inventory and obsolescence plans
* PPE, alarms, and recovery training
* Simulation-driven scenario testing
* OPEX estimations.
* Operator commissioning and technician maintenance and replacement involvement
* Real-time MTBF vs prediction curve tracking

1. The process flow diagrams, process and instrumentation diagrams and temperature-entropy diagrams showing all the operation modes (including cool down) of the QPLANT shall be subject to approval by SCK CEN.

Table 14 Documentation Deliverables

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1. Lifecycle Cost Management and Reliability-Centred Maintenance
2. The Contractor shall implement a comprehensive Lifecycle Cost Management (LCM) strategy supporting a fixed-price contractual framework.   
     
   The LCM strategy shall integrate as per ISO 15288:2023: Capital Expenditure (CAPEX), Operational Expenditure (OPEX), Maintenance forecasting and spares replacement, Upgrade and obsolescence planning, End-of-life and disposal planning

It shall comply with principles and methodologies of: ISO 15686-5 (Lifecycle Costing), IEC 60300-3-3 (Reliability-Centered Maintenance), and ISO 55000 (Asset Management).

In the Offer, the Applicant shall provide the expected lifecycle cost including the main cost driving elements, including but not limited to:

* RCM strategy details.
* MTBF of main components and systems;
* PFD and SIL analysis;
* Spare part strategy (e.g. replace, run to fail, ….);
* OPEX items like electricity, maintenance staff need

1. In the offer, the Applicant shall explicitly describe, quantify, and justify their proposed Reliability-Centred Maintenance (RCM) strategy for QPLANT and QPLANT:CS. This shall include whether a validated digital model (e.g., process twin, thermodynamic model, control system simulation, or AI-based reliability estimator) is used to support diagnostics, predictive maintenance, and lifecycle cost reduction via virtual sensors and replacement deferrals.

*If a validated model is included, the Applicant shall provide:*

An explanation of how the model contributes to:

* Reduced MTBF-driven part replacement, based on predictive or condition-based intervention,
* Generation of virtual signals where instrumentation is infeasible or cost-limiting,
* Reduction in functional test cycles, unplanned outages, and inventory reserves.

A quantified cost disclosure, covering:

* Model development and integration into the QPLANT:CS design architecture and software stack,
* Hardware and system-level impacts (BoM additions or changes for real-time integration, computing load, or I/O expansion),
* Commissioning and acceptance testing activities supported or replaced by the model,
* Ongoing model validation, updates, and QA/QC effort over the operational lifecycle
* Integration of model upkeep as a line item in the RCM cost structure and lifecycle maintenance forecast.

*If no model is proposed, the Applicant shall:*

* Provide a rationale for its exclusion, with a supporting cost-benefit justification,
* Detail the alternative methods for achieving equivalent RCM outcomes (e.g., historical statistics, empirical MTBF planning, SCADA-based failure diagnostics),
* Describe the impact of the absence of a model on:
  + Diagnostic scope and operator support, and training
  + Testing coverage and lifecycle cost,
  + Required commissioning and redundancy in QPLANT:CS design.

In the offer, the applicant shall provide:

* Fixed-price offer section including the costed RCM strategy,
* Model architecture or simulation integration summary (if applicable),
* BoM elements attributable to the model (hardware/software),
* Maintenance and diagnostic strategy for 5-year lifecycle horizon,

1. Safety, Codes and Standards
   1. Safety

SCK CEN is responsible for the Oxygen Displacement Risk Management. SCK CEN install and commission the required sensoring, alarming system, evacuation protocols etc.

1. The Contractor shall provide all the required input to allow SCK CEN to correctly implement the ODH-system e.g accurate helium inventory.

In the offer, the Applicant shall indicate if the status of the ODH-system is a required input to the QPLANT.

* 1. Codes and Standards

1. The design of the QPLANT shall follow the applicable technical standards for such kind of components (typically EN 13458) in addition of the specific requirements applicable for the project listed in the Applicable Documents.
2. The Contractor shall provide to SCK CEN the applied codes, rules and standard for the design, manufacturing and testing of the QPLANT.
3. The Contractor shall provide a EU declaration of conformity for the QPLANT and CE mark all QPLANT components. Therefore the Contractor shall at least:
   * + - * Identify all EU directives applicable to the QPLANT and ensure compliance with said EU directives. The directive listed below is identified by SCK CEN as a minimum requirement, but doesn’t exclude other directives from being applicable.
         * Low Voltage Directive 2014/35/EU
         * Machinery directive 2006/42/EC
         * EMC Directive 2014/30/EU
         * Pressure Equipment Directive (2014/68/EU)
         * Identify the applicable standards (harmonized or non‑harmonized), and technical specifications that support compliance with the essential requirements outlined in the EU directive(s).
         * Submit the technical file, at the latest before shipment to SCK CEN of QPLANT parts, to demonstrate conformity with the directive(s) and shall be submitted by default in English, extra languages are indicated when needed. The technical file shall include:

* A general description of the product;
* An overall drawing of the product, as well as other drawings to cover specific aspects of the product, such as circuit diagrams. The drawings shall, where appropriate, be accompanied with descriptions and explanations to understand the product;
* The HAZOP reports for;
  + - * The QPLANT
      * The Interfaces with other SCK CEN systems
* The description of the protective measures implemented to eliminate identified hazards or to reduce risks and, when appropriate, the indication of the residual risks associated with the QPLANT;
* The list of standards and other technical specifications used to show compliance with the essential requirements outlined in the EU directive(s);
* Instructions and other information for the safe use of the product covering at least, but not limited to, handling, shipping, installation, integration, operation, maintenance, de-commissioning, disposal, etc. in English, and Dutch
* Where appropriate, copies of the EU declaration of conformity of components incorporated into the assembly;
* A copy of the QPLANT EU declaration of conformity in the original language, in English, and Dutch;
* A copy of the nameplate(s) with CE mark;
  + - * + Submit specific detailed parts of the technical file, when requested by SCK CEN, to demonstrate conformity with the directive(s) in English. The detailed parts of the technical file are:
* Full detailed drawings;
* Calculation notes,
* Test reports, certificates, etc.;

1. In case of any utility losses (electricity, compressed air, water, vacuum, etc.), the QPLANT shall ensure the safety of the QPLANT and people, minimizing as much as possible the loss of helium.
2. A complete safety lifecycle including specific failure mode analysis (FMECA, HAZOP or equivalent) shall be performed by the Contractor during the design phase with the participation of SCK CEN.
   * 1. Pressure Equipment & Safety

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| --- | --- | --- |
| **Ref** | **Standard** | **Scope** |
| PED | 2014/68/EU | EU Pressure Equipment Directive |
| ASME VIII‐1 | Unfired pressure vessels | Design / certification |
| EN 13445 | Unfired pressure vessels | EU compliance |
| API 520/521 | Pressure relief sizing & selection | PSVs / BD |
| EN ISO 4126 | Safety valves & RD devices | Proof‑test ≤ 5 y |
| ISO 21013‑1/2 | Cryogenic safety devices | LP & HP vessels |

* + 1. Functional Safety & Control

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| --- | --- | --- |
| **Ref** | Standard | Scope |
| **IEC 61508** | Functional safety (E/E/PE systems) | SIL assignment |
| **IEC 61511** | SIS for process industry | SIS lifecycle |
| **IEC 60204‑1 / 61439** | Electrical equipment & switchgear | Control cabinet |
| **IEC 60300‑3‑3** | RCM assessment | Links to DMAIC Control |

* + 1. Asset & Maintenance Management

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| --- | --- | --- |
| Ref | Standard | Scope |
| ISO 55000 | Asset management lifecycle | 40‑y RCM plan |
| ISO 14224 | Reliability & maintenance data | MTBF reporting |
| IEC 60300‑3‑12 | Life‑cycle costing | CAPEX/OPEX modelling |

* + 1. Cleanliness & Purity

|  |  |  |
| --- | --- | --- |
| Ref | Standard | Scope |
| ISO 8573‑1 Class 0 | Oil‑free compressor classification | Compressors |
| ASTM D5464 | Helium purity test | Getter skid validation |

* + 1. Proof‑Test & Control‑Phase Requirements
* Proof‑test intervals: PSVs/BDs ≤ 5 years; SIL sensors ≤ 3 years; logic proof ≤ 4 years.
* RCM linkage: Tests scheduled in RCM manual (OTC‑012) per ISO 55000 / ISO 14224.

1. Schedule

Contractual performance shall proceed in phases (6.1). These phases represent the highest level breakdown of work packages expected for the project. A phase will be considered as completed when all associated deliverables (Table 14) are approved by SCK CEN. In their offer, the Applicant shall develop the phases according to its own expertise and experience and propose a detailed work schedule. In doing so, the Applicant shall take into consideration the preliminary schedule in 6.2 by including the milestones and respecting the milestone dates provided in Table 15. The Applicant may add (to a reasonable extent) additional milestones as they think appropriate.

* 1. Contractual Phases

Phase I - Design and Development

Activities expected to be performed in this phase shall, at least, include:

* Establishing the project management baseline (Management Dashboard & underlying processes, Quality Assurance Program and Risk Management Plan) for review and approval by SCK CEN.
* Developing the conceptual design, verifying/ validating conformance with technical specifications, defining specific requirements for buildings and utilities and preparing/ submitting the Conceptual Design File (**Error! Reference source not found.**) for review and approval by SCK CEN.
* Developing the detailed design, verifying/ validating conformance with technical specifications, defining the list of components (incl. procurement specifications, manufacturing drawings), setting final requirements for buildings and utilities, developing plans and procedures for the next phases (e.g. MIP, packaging and transportation plan, installation plan) and preparing/ submitting the Detailed Design File (**Error! Reference source not found.**) for review and approval by SCK CEN.

Phase II – Procurement and Manufacturing

Activities expected to be performed in this phase shall, at least, include:

* Procurement/ manufacturing of components and services necessary for performing the Contract, execution/ reporting of tests and inspections (incl. FAT), Non-Conformity handling, preparing final plans and procedures for Phase III and IV and preparing/ submitting the Procurement and Manufacturing File (**Error! Reference source not found.**) for review and approval by SCK CEN.

Phase III – Installation

Activities expected to be performed in this phase shall, at least, include:

* Transportation to SCK CEN (only after manufacturing QC and FAT shall be approved by SCK  CEN), incoming inspections of supplies, installation of QPLANT, execution/ reporting of assembly tests, Non-Conformity handling and preparing/submitting the Installation File (**Error! Reference source not found.**) for review and approval by SCK CEN.

Phase IV – Commissioning and Acceptance

Commissioning and Acceptance testing may not necessarily follow a strict sequential order (as a part of the system may require successful acceptance to initiate commissioning and vice versa). The Contractor shall develop the phase according to its own expertise and shall at least include the following activities:

* Stand-alone commissioning of the QPLANT, integrated commissioning with controls, Non-Conformity handling and preparing/ submitting the Commissioning File (**Error! Reference source not found.**) for review and approval by SCK CEN.
* Execution/ reporting of SAT and preparing/ submitting the Acceptance Test File (**Error! Reference source not found.**) for review and approval by SCK CEN.
* Project closure and submission of the Final Report (**Error! Reference source not found.**) for review and approval by SCK CEN.
  1. Preliminary Schedule

Table 15 Preliminary Schedule and Main Milestones

*“ED” = Earliest possible Date, “LD” = Latest Possible Date, “M” = months, “wks” = weeks, “BD” = Business Days, “CD” = Calendar Days.*

|  |  |  |  |
| --- | --- | --- | --- |
| **ID** | **Description** | **Responsible** | **Dates** |
| TO | Contract Conclusion | SCK CEN | ED: Q4 2025 |
| **Phase I -Design and Development** | |  |  |
| M11 | Kick-Off meeting | SCK CEN | T0+15 BD |
| M12 | Management Dashboard & QAP submitted for review/approval | Contractor |  |
| M13 | Risk Assessment/ Management Plan submitted for review/approval | Contractor |  |
| M14 | Preliminary Information on Site Infrastructure delivered | SCK CEN | M11 + 1M |
| M15 | Deliverables associated with M12 and M13 approved | SCK CEN |  |
| M16 | Conceptual Design File submitted for review/approval | Contractor |  |
| M17 | Detailed Design File submitted for review/approval | Contractor |  |
| M18 | Detailed Design File approved | Contractor |  |
| **Phase II – Procurement and Manufacturing** | |  |  |
| M21 | Manufacturing started | Contractor |  |
| M22 | Installation Plan submitted for review/approval | Contractor |  |
| M23 | Manufacturing completed | Contractor |  |
| M24 | FAT approved | SCK CEN |  |
| **Phase III – Installation** | |  |  |
| **MXX Building ready for installation** | | **SCK CEN** | **XXXX** |
| **Infrastructure provided by SCK CEN ready** | | **SCK CEN** | **XXXX** |
| M31 | Incoming Inspection Report submitted for review/approval | Contractor |  |
| M32 | Installation started | Contractor |  |
| M33 | Installation completed | Contractor |  |
| M34 | Installation & Assembly Test Report submitted for review/approval | Contractor |  |
| **Phase IV – Commissioning and Acceptance** | |  |  |
| M41 | Commissioning Test Report submitted for review/approval | Contractor |  |
| M42 | Acceptance Capacity testing started | Contractor |  |
| M43 | SAT Report submitted for review/approval | Contractor |  |
| M44 | Provisional Acceptance and handover | SCK CEN | T0 + 34 M |

* 1. Hold and Witness Points

Throughout the performance of the Contract, at least the following review/inspection (by SCK CEN) steps shall be implemented:

* + - * + Hold Points

FAT approval in view of shipments

Approval Incoming Inspection Report in view of start installation

Approval Installation and Assembly Test Report in view of start commissioning

Approval Commissioning Test Report in view of start acceptance capacity testing

* + - * + Witness points

Approval of the Conceptual Design File

Approval of the Detailed design File

* Approval of the Procurement and Manufacturing File
* Approval of the Installation File
* Approval of the Commissioning File
* Approval of the Acceptance Test File
* Approval of the Final Report

Upon receiving the Contractor’s finalized project schedule and Manufacturing and Inspection Plan, SCK CEN reserves the right to add or remove HP(s)/WP(s) from those currently foreseen and will duly notify the Contractor of such decisions.

SCK CEN has at its disposal a maximum of 30 Calendar Days (60 Calendar Days when involving (an) external partner(s)) to complete all formalities) concerning approval of a certain HP. Nonetheless, SCK CEN shall always aim to give feedback to the Contractor concerning the HPs without undue delay. The envisaged lead time is 10 Business Days (to be determined taking into account SCK CEN’s and/or its collaboration partner’s days of closure)

1. Contract Performance
   1. General Organization
2. In accordance with article 20.1 of Addendum I, the Contractor shall assign a member of its staff to be responsible for the follow-up of the Contract (further referred to as “Project Manager”). The Project Manager shall be responsible for planning, organizing, monitoring and controlling, and directing the performance of the Contract, to ensure that the Contract is accomplished on time, within budget, and compliant to the requirements laid down in the Contract.
3. The Contractor shall notify SCK CEN in writing in case a different Project Manager is appointed. Replacement of the Project Manager is subject to prior written approval by SCK CEN. In case of replacement, the substitute shall always have a level of education, skills and experience equivalent to or better than the original resource proposed for this role.
4. At the conclusion of the Contract, SCK CEN shall designate the Leading Officer for the Contract and inform the Contractor. The Contractor shall be notified of any change in writing.
5. With regard to the practical follow-up of the Contract, SCK CEN reserves the right to have itself represented by a third party of its choice, acting on its behalf (further referred to as “Representative(s)”).
6. In this respect, SCK CEN grants to the Representative(s) the same rights as SCK CEN has accrued under the present Contract and the Contractor shall give effect thereto. The Contractor shall grant the Representatives the same access rights (physical access, document access, etc.) as have been contractually instated for SCK CEN.
7. Notwithstanding the foregoing, SCK CEN will remain the sole principal to the Contract and therefore:
   * + 1. any approval/acceptance/equivalent step which has been contractually set, shall only be approved, respectively accepted, if and to the extent that SCK CEN has confirmed its approval, respectively acceptance, of such step in writing.
       2. any decision to deviate from the terms and conditions as have been contractually agreed upon, may only be implemented after having obtained approval thereto from SCK CEN in writing.
   1. Communication

All communication, including - but not limited to - tender documents, offers, technical documentation, any correspondence and all meetings, related to the Contract, shall be in English.

Any information that a Party considers significant enough to bring to the attention of the other Party, shall be deemed correctly communicated if exchanged in writing (e-mail suffices) between the two persons in charge of the general organization of the Contract.

Any contract-related request – of technical or any other nature – directed by SCK CEN to the Contractor shall be adequately responded to within five Business Days. If such request cannot be answered within this lead time, e.g. due to a technical question requiring additional time to be answered, the Contractor shall at least communicate (within this lead time) when SCK CEN will receive the answer.

If the Contractor anticipates any delays or difficulties in meeting the schedule, planned deliveries or any other milestone within its offer, they must promptly notify SCK CEN.

* 1. Contract Management
     1. Progress Dashboard

1. The Contractor shall implement a digital dashboard giving SCK CEN at a glance up-to-date information on the current status and progress of the Contract. The information shall be continuously (at least monthly) updated with the latest information. The Contractor shall produce and submit monthly progress reports to SCK CEN at least three Business Days prior to the monthly progress meeting (7.3.2.1). If comments or revisions arise during the progress meeting, the Contractor shall issue an updated version five business days after the meeting. To this end, SCK CEN shall provide access for the Contractor to SCK CEN’s designated document management system.
2. After consultation with the Contractor, the key indicators to be included, the format, and the update frequency of the dashboard shall be communicated by SCK CEN to the Contractor. Said indicators shall, as a minimum, include the following:
   * + 1. A concise summary of the Contract progress
       2. Updated open-action-register.
       3. Work completed for the last period including encountered difficulties and improvement proposal.
       4. Work scheduled for the next period
       5. Monitoring of the schedule (delays, impact on milestones, etc.), containing:

* An updated schedule of the project.

A physical progress curve based on significant milestones to show the global physical progression on the project.

* + - 1. Updated issue register, and any other points-of-attention identified during the performance of the Contract
      2. Updated Change register
      3. Updated Non-Conformity register
      4. Updated Risk register

1. In the offer, the Applicant shall include a concise description of the dashboard as well as the underlying management processes. This description must include sufficient detail to demonstrate compliance with the aforementioned requirements.
   * 1. Meetings

Meetings will take place at either of below locations:

* The Contractor’s premises;
* SCK CEN: Boeretang 200, 2400 Mol, Belgium or Avenue Hermann-Debroux 40, 1160 Brussels, Belgium;
* Any other location mutually agreed upon by the Contractor and SCK CEN, such as the premises of the deliverables component suppliers;
* In audio or video conferencing.

The Contractor shall ensure that all relevant information for these meeting is made available to SCK CEN at least three Business Days in advance including, but not limited to, meeting agenda, reports and presentations. The Contractor shall draft the minutes of these meetings and submit them to SCK CEN for review and approval within 5 Business Days following the meeting.

Travel expenses are paid by the party who travels.

Progress Meetings

1. The Contractor shall organize Progress meetings between the Contractor and SCK CEN at least on a monthly basis.

Milestone Meetings

1. Milestone Meetings shall be held at least for the following milestones, organized at the initiative of the Contractor:
   * + 1. Kick-Off meeting (M11)

This meeting is a “face-to-face” meeting to be held SCK CEN.

* + - 1. Conceptual Design Review meeting
      2. Detailed Design Review meeting
      3. Installation review meeting in preparation for commissioning
      4. Provisional Acceptance Meeting/Contract Performance Closure meeting

This meeting is a “face-to-face” meeting to be held at SCK CEN.

Technical Review Meetings

1. Additionally, TRMs with the necessary stakeholders shall be held to define the technical baseline and identify any evolutions between reviews.
   1. Risk Assessment and Risk Management Plan

The Applicant shall submit a preliminary Risk Assessment as part of their offer. It shall contain all risks with a severity that are bound to compromise the successful completion of the Contract either in terms of schedule, budget or technical requirements, irrespective of probability.

Based on the preliminary Risk Assessment, the Applicant shall submit a preliminary Risk Management Plan as part of their offer. It shall present a top‑level view of the mitigation strategy that the Applicant shall implement during contract execution, for all the risks that have been identified as unacceptable.

During contract execution, the Contractor shall detail, complete and continuously maintain the Risk Assessment and update the Risk Management Plan accordingly. The Contractor shall continuously monitor, identify and document any new risks that might threaten the successful completion of the Contract in any way. The Contractor shall duly implement the mitigation strategy in accordance with the Risk Management Plan.

* 1. Factory Access

1. During the performance of the Contract, SCK CEN shall have access during normal working hours to (all) the location(s) where (part of) the Contract is being performed (including Contractor’s and Subcontractors' premises). The Contractor shall be notified of any site visit at least five Business Days in advance. Any changes to the specified location(s) shall require prior written approval from SCK CEN.
2. Quality Assurance and Control
   1. Quality Assurance
      1. General requirements

The Contractor shall ensure status identification of each deliverable and all of its components throughout all stages of manufacturing, assembly, packaging and transportation, installation, and commissioning to ensure that only items that have passed all required quality inspections and tests are used and/or supplied. The Contractor shall ensure traceability to the required level in accordance with Good Industry Practices.

A review and/or approval by SCK CEN shall never entail (provisional) acceptance or a release of responsibility vis-à-vis the Contractor in any way.

* + 1. Quality Management System

Contractors who subcontract work to a Subcontractor shall ensure that the Subcontractor’s quality management system is in accordance with ISO 9001, certified by a nationally accredited body and applicable to the scope of work defined in the Contract.

In absence of an ISO 9001 certified QMS, an equivalent system may be accepted after written approval from SCK CEN. If deemed necessary, SCK CEN may request an audit as foreseen in section §8.1.8.

The Contractor shall inform SCK CEN of any change in certification during performance of the Contact.

* + 1. Quality Assurance Program

Prior to beginning its work, the Contractor shall submit a detailed Quality Assurance Program, QAP, for review and approval by SCK CEN demonstrating compliance with the requirements set out in the Contract. In the offer, the Applicant shall include a preliminary version of this QAP.

The Contractor shall adhere to the QAP and shall apply the mandatory QA/QC measures to each deliverable. In case a deviation is required from one or another condition set out in this Contract, such request shall be clearly stated in the QAP.

Contractors who subcontract work to a Subcontractor must take appropriate measures to ensure that the Subcontractor complies with the QAP.

* + 1. Qualification of personnel

The Contractor shall ensure that all personnel involved in the performance of the Contract is qualified and well trained to deliver results complying with SCK CEN requirements and specifications. Special training and qualifications are specifically required for personnel responsible for:

* + - * + Welding
        + Pressure tests
        + Leak tests
        + Electrical tests

The Contractor shall maintain records of personnel qualification and make them available to SCK CEN free of charge upon simple request.

The Contractor shall ensure that all personnel who have direct contact with SCK CEN can understand as well as express themselves fluently in English, both orally and in writing.

* + 1. Document management

1. A minimum retention period of ten years (or the period required by the applicable law, whichever is longer) for all documents created under the Contract shall be observed.

Documents provided by the Contractor to SCK CEN:

* + - 1. Shall be uploaded to SCK CEN’s designated document management system.
      2. When applicable shall include the unique identifier of the parts.
      3. Shall be written in English.
      4. Shall be reviewed and approved by competent and authorized individuals, prior to submission to SCK CEN.
      5. Shall include author, reviewer, approver names and functions, their signatures and date of signature.
      6. Shall be identified through a unique document code, version and document title.
      7. Shall include reference to the Contract (not applicable for documents that were created outside the context of the Contract).
      8. Shall be version controlled and include a change log. For each new revision, the change log shall be updated with relevant listing of the applied changes. Each new revision shall be reviewed and approved by competent and authorized individuals, prior to submission to SCK CEN.
      9. Shall be provided in digital format, suitable for reading and editing using commonly available application software for Microsoft Windows OS and transmittable via internet. If such forms of exchange are considered inconvenient or impossible, the Contractor shall propose alternative methods to SCK CEN for review and approval.
      10. COTS: any documentation that the Contractor receives from the original manufacturer shall be stored and shared with SCK CEN (as is, and including translation to English if original is in different language).

Documents provided by SCK CEN to the Contractor:

* + - 1. The Contractor shall version-control the documents received from SCK CEN. When a new version of a document is received, the old version shall be removed from circulation as soon as reasonably possible.
      2. These documents shall be made accessible to the Contractor’s employees / Subcontractors only on a need-to-know basis, for the purpose of the Contract, for a limited time, for as long as the documents are needed.
    1. Change Management

Proposals for change to the project, its scope of work and/or previously approved deliverables, either initiated by the Contractor or by SCK CEN, shall be analysed and documented (in a “Change Request”) by the Contractor and submitted for approval to SCK CEN.

A Change Request shall at least contain following information: the initiator of the change, the justification for the change, the impact of the change (on product and/or (related) service(s), safety, risks, contract price and schedule), the description of the change and the plan of implementation.

The Contractor shall include the Change Request template in annex to the QAP.

Only Change Requests approved by SCK CEN may and shall be implemented.

A Change Request having a financial impact on the Contractor shall form the basis for a Variation Order. In such event, the Change Request shall be considered as approved when the Variation Order is issued by SCK CEN.

The Contractor shall create and maintain a Change Register, accessible to SCK CEN, in which all Change Requests shall be logged, including at least (*i*) a unique identifier, (*ii*) title, (*iii*) date of issuance, (*iv*) financial impact, (*v*) impact on the Contract schedule, and information about the status of (*vi*) the decision (potential, pending, approved, withdrawn or disputed) and (*vii*) the implementation .

Deviations from the specifications defined in the Contract, that were not explicitly authorized by SCK CEN in advance in writing, shall be treated as Non-Conformities.

* + 1. Non-Conformity Management

A Non-Conformity is defined as any non-compliance with, or deviation from, any of the requirements and/or conformity criteria set forth in the Contract or approved Change Requests.

The Contractor shall have a process in place for managing Non-Conformities that arise during the performance of the Contract, including receiving and processing notifications of Non-Conformities from SCK CEN and/or third parties (such as its suppliers or Subcontractors).

In case of a Non-Conformity, the Contractor may not ship, or shall recall at its own risk and expense, the impacted supply. Any steps of the Contract execution, which are (potentially) affected by the Non‑Conformity, shall be put on hold.

The Contractor shall notify SCK CEN in writing of any such Non-Conformities by means of a Non-Conformity Report (NCR). A NCR shall be submitted to SCK CEN as soon as reasonably possible after a Non-Conformity is identified.

The NCR shall cover at least the following aspects:

* + Detailed description of the Non-Conformity;
  + Identification of all potentially affected deliverables;
  + Identified (root) cause(s) including verification thereof;
  + Proposed corrective actions including their anticipated effectiveness;
  + Proposed reoccurrence prevention plan (if applicable).

The Contractor shall include the NCR template in annex to the QAP.

The NCR shall be submitted to SCK CEN for approval. SCK CEN shall be entitled to reject the solution(s) proposed by the Contractor in case SCK CEN deems the solution not useable given the circumstances.

The Contractor shall perform the necessary actions to correct the Non-Conformity (in accordance with the SCK CEN approved NCR) at its own risk and expense. Said necessary actions shall not only concern redoing (parts of) the manufacturing and/or its related processes (assembly, packaging, delivery, …), but shall also entail redoing all QA/QC activities associated therewith. Next to that, if so requested by SCK CEN, the Contractor shall moreover reimburse SCK CEN for the costs incurred by SCK CEN to have the FAT/SAT of the impacted items redone.

The Contractor shall keep SCK CEN duly informed about the progress of the implementation of the actions identified in the NCR and, if applicable, shall provide a revised schedule identifying the time impact of the implementation of said actions; the Contractor shall minimize the consequences on the schedule in any case.

At the specific request of SCK CEN, in order to avoid repetition of possible recurring Non-Conformities during the execution of the Contract, or when imposed by the Contractor's quality management system or the QAP, the Contractor shall carry out a root cause analysis of the Non-Conformity. Such an analysis shall:

be documented and submitted for approval to SCK CEN.

include the identified Non-Conformity cause(s).

propose an action plan to minimize the probability of a recurrence.

For actions taking more than 1 month, the Contractor shall provide a regular status report describing the result of implementation according to the due dates in the action plan.

Performing the root cause analysis and implementing any preventive/corrective actions arising therefrom, shall not give rise to any additional compensation for the Contractor.

Any Non-Conformities identified and reported by SCK CEN to the Contractor, as well as any other complaints received by the Contractor from SCK CEN, shall be treated as Non-Conformities and duly documented, investigated and resolved according to the stipulations under this clause*.*

Neither the implementation of the aforementioned procedure on Non-Conformity management, nor the approval by SCK CEN of a Non-Conformity Report, shall waive or reduce the Contractor’s responsibility, according to the relevant stipulations of the Contract, to indemnify and hold SCK CEN harmless against all losses, damages, and costs (e.g. due to delay on the schedule) arising from such Non-Conformity.

* + 1. Audits

SCK CEN shall be entitled to carry out, or to have carried out by a third party on its behalf (procured at SCK CEN’s own cost), an audit of Contractor/its Subcontractor’s premises, equipment, procedures to assess the ability of Contractor/Subcontractor to comply with the requirements of this document and the Contract.

1. SCK CEN may request such audit when at least one of the following conditions is met:
   * + 1. to qualify a Contractor/Subcontractor which is not ISO 9001 certified.
       2. to address performance issues.

SCK CEN shall inform the Contractor in advance of the audit and shall take all necessary steps not to unduly interfere with the performance of Contractor’s business operations. SCK CEN shall provide an audit report within two weeks of completing the audit. The Contractor shall respond within two weeks with an action plan to address the identified Non-Conformities.

* 1. Quality Control
     1. General requirements

The Contractor shall be fully responsible for the quality of the deliverables, including the quality of all components, materials, and services procured by the Contractor.

The Contractor shall ensure that the Contract is performed in accordance with all applicable regional, national and international laws, regulations and industrial codes and standards and Good Industry Practices.

Additionally, to ensure compliance with the requirements outlined in this document, the QAP shall include at least the qualification and validation requirements specified in this document.

The Contractor shall ensure that all components, materials, equipment and/or tools used at the performance of the Contract are appropriately designed, constructed, installed, calibrated, and operated. The Contractor shall develop, maintain, and comply with appropriate schedules for adjustment, cleaning, calibration, or any other required maintenance. The Contractor shall maintain records of these activities and make them available to SCK CEN upon simple request and without any right for further compensation or payment.

All measurement and testing instrumentation used at the performance of the Contract shall have the appropriate qualifications and shall be regularly calibrated to ensure appropriate accuracy and precision for the measurement at hand. SCK CEN reserves the right to request a measurement system analysis and/or proof of calibration in case of any doubt of appropriateness.

The Contractor shall provide all equipment necessary to perform and to evaluate the tests on site. Additional test cryostats, valves and instrumentation for acceptance tests shall be delivered by the Contractor.

Additionally, the Contractor shall describe special test facilities that will be used in the course of the contract.

The inspections, measurements, and testing activities described in the Contract are mandatory but comprise only the minimum required. These activities are not intended to supplant any control, measurement, examination, inspection or test usually performed by the Contractor to ensure the quality of the product. The Contractor shall perform the quality control according to best practices, as generally recognized, as well as, as assessed based on his internal know-how and prior experience.

In the offer, the Applicant shall outline the quality control process that shall be implemented during Contract execution.

* + 1. Manufacturing and Inspection Plan

The Contractor shall prepare a Manufacturing and Inspection Plan (MIP) covering all tests and inspections from start of manufacturing to provisional acceptance. It shall, as a minimum, include test and inspection plans & procedures and (if on-site at SCK CEN) utilities necessary for executing the tests. It shall indicate the Hold Points and Witness Points defined in the Contract as well as any other HP/WP defined by SCK CEN during execution of the Contract.

The MIP shall serve to verify that all tests and inspections are executed as planned and in compliance with the agreed HP/WP.

A preliminary version of the MIP shall be provided as part of deliverable **Error! Reference source not found.**. The final version shall be provided as part of deliverable **Error! Reference source not found.**.

In the offer, the Applicant shall explain the approach to implementing the above MIP requirements.

* + 1. Declaration of conformity with all requirements

1. Together with the delivery, the Contractor shall submit to SCK CEN a Declaration of Conformity certifying that all the requirements have been met. Such declaration shall include at least the following information:
   * + 1. Identification of the deliverable, including the purchase order reference no. and Contract reference.
       2. A list of approved changes, waivers, or deviations from the aforementioned specifications.

Such declaration shall be dated and signed by a duly authorized representative of the Contractor responsible for quality assurance as indicated in the approved QAP.

* 1. Acceptance Tests
     1. General Requirements

The acceptance tests shall be performed according to a duly reviewed and SCK CEN approved Acceptance Test Program (FAT/SAT). The test program shall be prepared and submitted by the Contractor to SCK CEN for review and approval at least 3 months prior to the date scheduled for the tests, unless otherwise specified.

The Acceptance Test(s) Program(s) shall describe:

* + - * + General overview: the purpose of the tests, a comprehensive list of the tests to be performed, the participants to be present on site during the test, and a description of the communication strategy and logistical organization for conducting the tests.
        + General requirements: tools, instrumentation, and computing devices to be used; environmental conditions that must be in place; required consumables and utilities (e.g.: process gas, electricity, cooling water); qualifications of the personnel to conduct the testing.
        + Safety requirements which have to be respected during the testing.
        + Parameters to be measured and their measurement accuracy, noting the target values, range of acceptability, on which test stage which parameters are measured, the measurement instruments used to perform the measurements, the measurement methodology, the calculation formulas (if no direct measurement is possible), etc.
        + Test setups and methods, including a description of each test setup and the method used to establish an accurate measurement.
        + Reporting, including a description of how the acceptance tests shall be documented, what the documents shall contain and to what organizations these documents shall be transmitted.

The Acceptance Test(s) shall be documented in FAT/SAT reports, clearly documenting the results of each individual test and whether the deliverable has passed or failed the acceptance test (incl. applicable Non-Conformity reports).

* + 1. Factory Acceptance Test (FAT)

The FAT program shall take into account, as a minimum, the requirements outlined in 3.7.1.

SCK CEN and its representatives may witness these tests at the Contractor and his Subcontractor's sites.

Before transportation to SCK CEN, results of the tests at the manufacturer workshops shall be approved by SCK CEN.

* + 1. Site Acceptance Tests

The SAT program shall take into account, as a minimum, the requirements outlined in 3.9.1.

SCK CEN and its representatives shall have access to participate to the tests on site.

The SAT report shall be included in **Error! Reference source not found.**.

1. Acceptance and Warranty
   1. Provisional Acceptance

A Provisional Acceptance Certificate shall be issued by SCK CEN for each deliverable (together with the required documentation), provided that no shortcomings are identified during the provisional acceptance.

The provisional acceptance shall be subject to (*i*) the successful completion of the SAT **and** (*ii*) all identified Non-Conformities (e.g. documentation lacking) having been duly corrected by the Contractor.

* 1. Warranty Period

SCK CEN imposes a warranty period of at least 2 years following the provisional acceptance.

The actual warranty period shall start on the day of the issuance by SCK CEN of the Provisional Acceptance Certificate for the duration indicated in the applicant's offer.

* 1. Warranty Conditions

1. During the warranty period, the Contractor shall at its own risk and expense remedy any outstanding issues, as well as any shortcomings and defects that were not visible during the acceptance tests.
2. The Contractor’s methods of solving a warranty issue shall always need to be approved in advance by SCK CEN. SCK CEN reserves the right, at its sole discretion, to not allow for repair and to demand replacement of a defective item.
3. In case the warranty work needs to be performed at SCK CEN, the Contractor shall take into account and comply with SCK CEN’s instructions relating to working hours, access, etc., without being entitled to any additional compensation.
4. The Contractor’s warranty obligation shall not apply:
   * + 1. to normal wear and tear of the QPLANT, as well as any associated consumables.
       2. to defects of which the Contractor is notified after the Warranty period, unless SCK CEN can demonstrate that such defect has arisen before the end of the Warranty period in which case such defect shall fall under the warranty obligation.
       3. to failures or defects which the Contractor can substantiate are due to alteration, misapplication, inappropriate use in view of the conditions of use as outlined by the Contractor (if any are provided), and/or maintenance not carried out according to the Contractor’s nominal conditions as set forth by the Contractor, lack of trained maintenance personnel (other than the Contractor’s personnel), operation above rated capacities either intentional or otherwise, or physical damage caused by persons other than the Contractor’s personnel.
5. During the warranty period, the Contractor shall execute repairs and/or replacements without undue delay at the Contractor’s risk and expense. SCK CEN may request warranty service during non-normal working hours or for services excluded from the warranty coverage as defined herein, provided that SCK CEN shall pay the reasonable overtime premium portion of the non-normal hours worked or the normal service charge respectively.
6. In-warranty repairs and/or replacement parts shall be warranted for at least one year after execution, or for the unexpired portion of the original warranty period of the deliverable, whichever is longest. Notwithstanding the foregoing, the warranty period is suspended for the duration between formal notice by SCK CEN to the Contractor on the defect and resolving of said defect by the Contractor.
7. If the Contractor fails to fulfil its obligations under the warranty, so that final acceptance cannot take place at the scheduled time, the warranty period shall be automatically extended, without any right to compensation and/or remuneration for the Contractor, until final acceptance takes place.
8. The Contractor shall keep a register of all interventions that the Contractor performs during the warranty period which can be consulted by SCK CEN at all times. In the event that SCK CEN can demonstrate a trend of failure occurring during the warranty period, which is not attributable to any inappropriate use of the equipment, this will be considered as a deficiency and the Contractor shall be liable to replace at his own risk and expense the affected item. I.c. “trend” is defined as a similar occurrence, which is found at least 3 times.
9. In addition to the above rights, SCK CEN shall be entitled to full compensation for all damages incurred in view of these outstanding issues, shortcomings and/or defects during the warranty period for which the Contractor is responsible.

The warranty as described in this section shall in no way constitute a restriction on the applicable Belgian statutory regulations on hidden defects.

* 1. Final Acceptance

1. At the end of the warranty period, if the QPLANT has not given rise to complaints during that period, SCK CEN will formally notify the Contractor of SCK CEN’s final acceptance by issuing an official certificate of final acceptance within fifteen days before the end of the warranty period.
2. Appendix
   1. Cooling Power for Cool-down

Heat loads (W) refers to the heat power to be removed from the user systems.

Heat capacity(W) corresponds to the power to be extracted from materials of mass M to allow its cool-down at the defined cool-down speed. **P ≈ MCdT/dt** (dT/dt being the cool-down speed and C the specific heat capacity).

Cool-down power (W) is the required cooling power for cool-down = sum of the two heat contributions.

Cooldown to 50 K

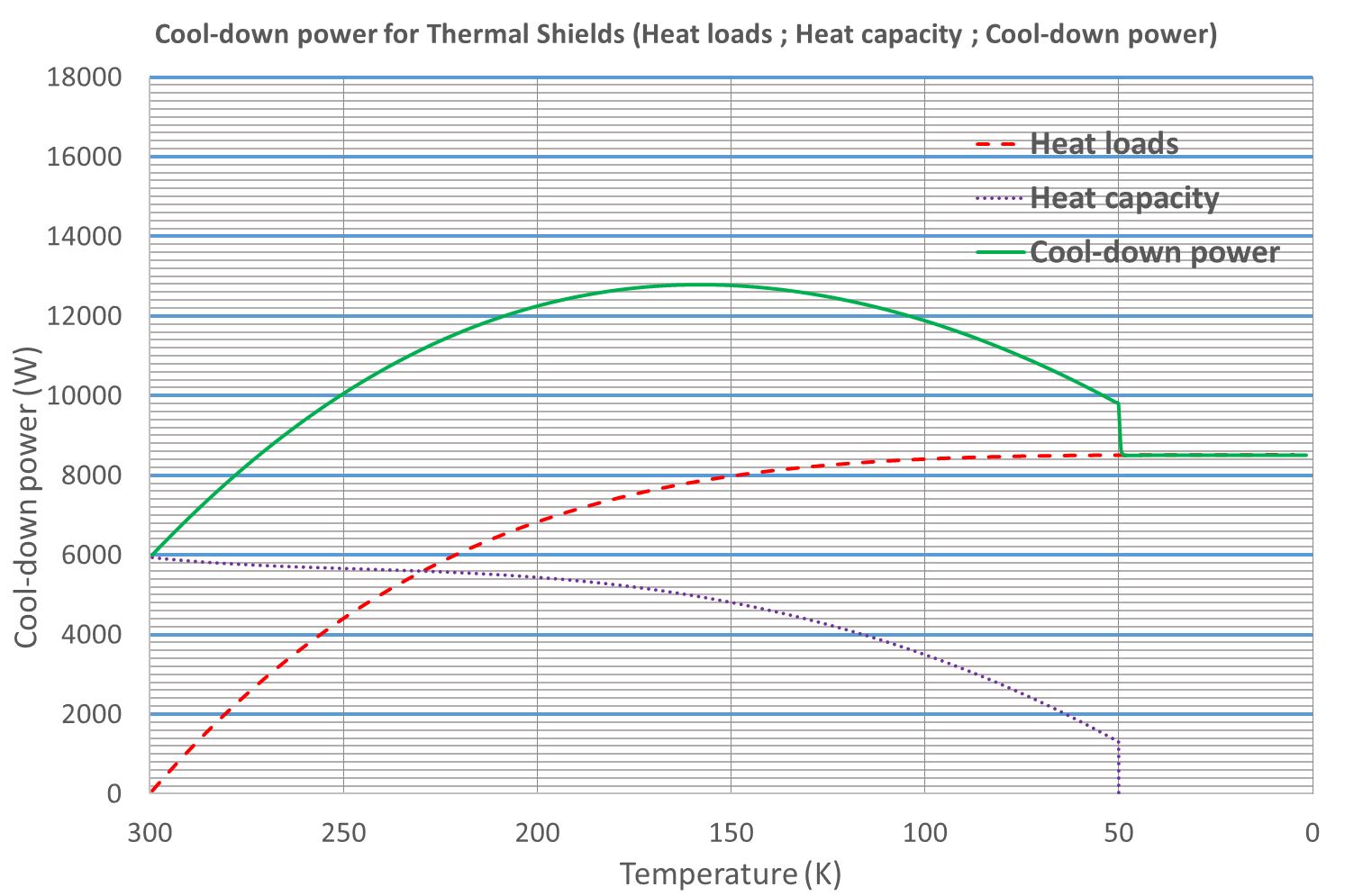


Figure 12 Cool-down power for Thermal Shields (based on cool-down speed of 4 K/h ~ 72 hours)

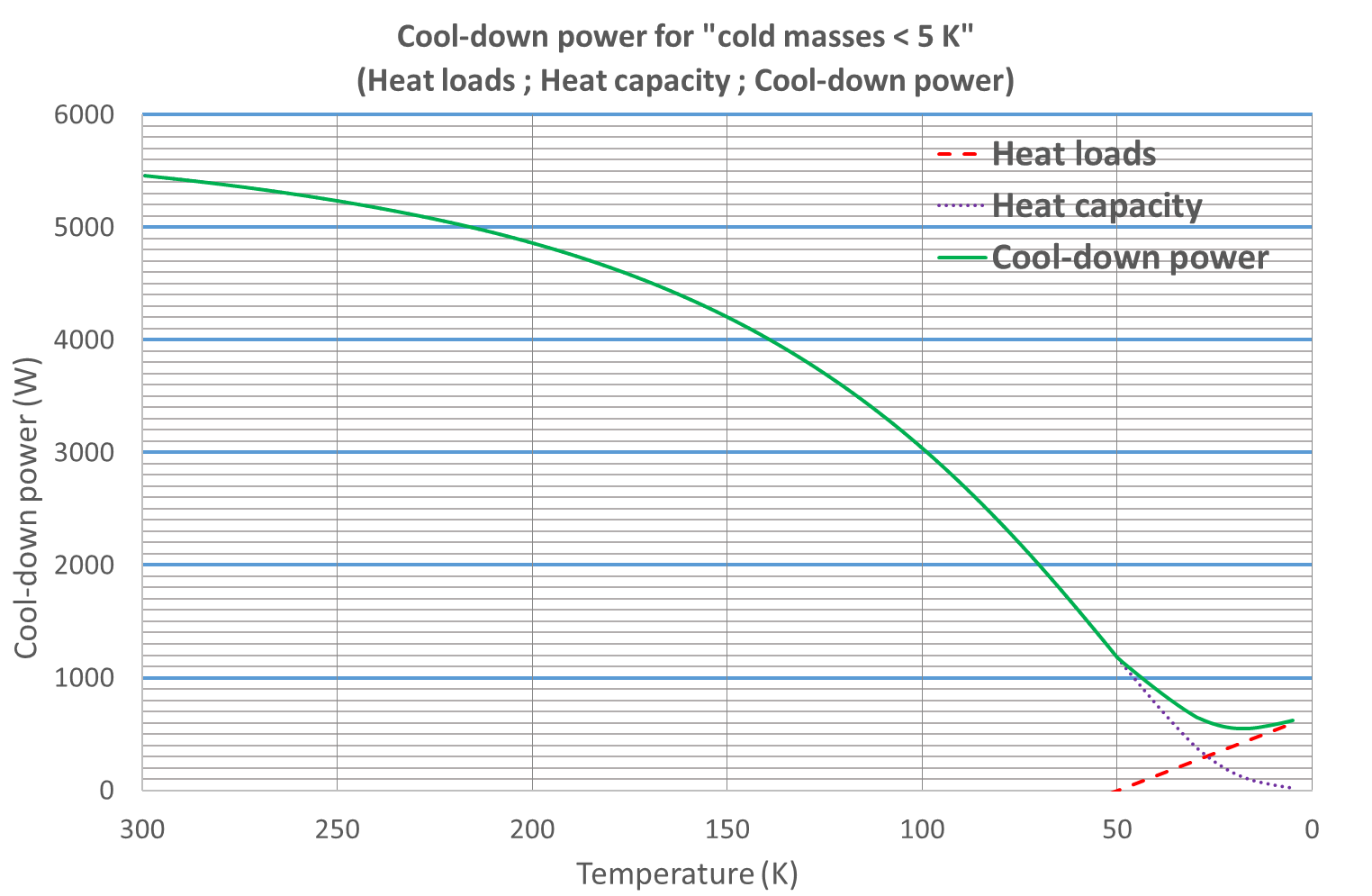


Figure 13 Cool-down power for cold masses < 5 K (based on constant cool-down speed of 4 K/h ~ 72 hours).

Table 16 Cool-down power down to 50 K (4 K/h)

|  |  |  |  |
| --- | --- | --- | --- |
| Temperature of Thermal Shields  (K) | Required Cool-down power for Thermal Shields  (W) | Average temperature for "masses < 5 K"  (K) | Cool-down power for "masses < 5 K"  (W) |
| 290 | 6 950 | 290 | 5 450 |
| 250 | 10 100 | 250 | 5 250 |
| 200 | 12 300 | 200 | 4 900 |
| 150 | 12 800 | 150 | 4 200 |
| 100 | 11 900 | 100 | 3 050 |
| 50 | 8 600 | 50 | 1 200 |

Cool-down to 4.5 K

When the magnetic shields temperatures are below 70 K, cool down of the cavities and couplers from the Thermal Shield temperature to 4.5 K can start. The QPLANT shall be able to remove at least the cool-down power during this cool-down phase is given in Table 17 and section 10.1.

Table 17 Cool-down power below 50 K (4 K/h)

|  |  |  |  |
| --- | --- | --- | --- |
| Average temperature for Thermal Shields  (K) | Cool-down power for Thermal Shields (W) | Average temperature for "masses < 5 K"  (K) | Cool-down power for "masses < 5 K"  (W) |
| 50 | 8 600 | 50 | 1 200 |
| 50 | 8 600 | 5 | 650 |

LHe filling

When the cavities reach the liquid helium temperature, the liquid filling of the helium baths can start.

Cooldown to 2 K

Cool-down of cavity circuits to 2 K. This 2 K cool-down includes also a complementary liquid helium filling. The pumping duration to reach 31 mbar in every QM bath (+QVE) from about 1.3 bar shall be achieved in less than 24 hours.

1. References
   1. Applicable Documents
2. SCK CEN will provide the required information necessary for the performance of the Contract as outlined bellow. The level of maturity provided at the current stage is the necessary for the Applicant to put forward an offer. Within Contract performance SCK CEN shall, in due time, provide the final documentation.

Table 18 Applicable Documents (AD)

|  |  |
| --- | --- |
| Designation | Reference |
| AD 1 SCK CEN Auxiliary Building  *Total of 16 files (reference link to navigation and subsequent links)* | [SCK CEN/89811518](https://ecm.sckcen.be/OTCS/llisapi.dll/Overview/89811518) |
| AD 2 SAFETY AND HEALTH PLAN | [SCK CEN/56057080](https://ecm.sckcen.be/OTCS/llisapi.dll/link/56057080) |
| AD 3 NF – List of Codes and Standards | [SCK CEN/81777062](https://ecm.sckcen.be/OTCS/llisapi.dll/link/81777062) |
| AD 4 General Specification for Steel Piping Materials | [SCK CEN/81912295](https://ecm.sckcen.be/OTCS/llisapi.dll/Overview/81912295) |
| AD 5 Piping Material Classes Specification | [SCK CEN/81912897](https://ecm.sckcen.be/OTCS/llisapi.dll/Overview/81912897) |
| AD 6 Requirements for Electrical Equipment Included in Package Plants | [SCK CEN/81913364](https://ecm.sckcen.be/OTCS/llisapi.dll/Overview/81913364) |
| AD 7 EMC Guidelines | [SCK CEN/81913579](https://ecm.sckcen.be/OTCS/llisapi.dll/overview/81913579) |
| AD 8 SCADA HMI Guideline | [SCK CEN/53012565](https://ecm.sckcen.be/OTCS/llisapi.dll/Overview/53012565) |
| AD 9 Technical Specification for Control Valves | [SCK CEN/81912936](https://ecm.sckcen.be/OTCS/llisapi.dll/Overview/81912936) |
| AD 10 Technical Specification for Instruments | [SCK CEN/89816164](https://ecm.sckcen.be/OTCS/llisapi.dll/link/89816164) |
| AD 11 Painting and coating specification | [SCK CEN/81913862](https://ecm.sckcen.be/OTCS/llisapi.dll/Overview/81913862) |
| AD 12 Technical Specification for Plate Heat Exchangers | [SCK CEN/81912893](https://ecm.sckcen.be/OTCS/llisapi.dll/Overview/81912893) |
| AD 13 Technical Specification for Safety and Relief Valves | [SCK CEN/81912045](https://ecm.sckcen.be/OTCS/llisapi.dll/Overview/81912045) |
| AD 14 Technical Specification for Shop Fabricated Tanks | [SCK CEN/81913369](https://ecm.sckcen.be/OTCS/llisapi.dll/Overview/81913369) |
| AD 15 TS Of Manual and Motor Operated Metallic Valves | [SCK CEN/81912050](https://ecm.sckcen.be/OTCS/llisapi.dll/Overview/81912050) |
| AD 16 MIS Slow Interlock interface  (*applies also to non-safety digital communication)* | SCK CEN/48282970 |
| AD 17 Analog Signals: 4-20mA (NAMUR NE43) |  |
| AD 18 MCS Secondary Interface Catalogue : Profibus DP | SCK CEN/48483448 |
| AD 19 MCS Slow Control OPC UA Interface | SCK CEN/56163474 |
| AD 20 MCS Slow Control PROFINET Interface | SCK CEN/55190851 |
| AD 21 General Software and Hardware Requirements for Contractors | SCK CEN/55310227 |
|  |  |

* 1. Cold masses of Cryogenic Users and Cryogenic Distribution

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Table 19 Cold masses at 4.5 K / 2 K | | | | |
| Estimated weight | Cryomodule (QM)  For 1 QM | Cold Valve Box (QVB)  For 1 QM | Cryogenic lines 4.5 K pipes | TOTAL cold mass for 30 cryomodules (4.5 K-2 K) |
| Stainless Steel (kg) | 80 | 60 | 2 800 | 7 000 |
| Niobium (kg) | 80 | NA | NA | 2 400 |
| Titanium (kg) | 40 | NA | NA | 1 200 |
| **Total (kg)** | **200** | **60** | **2 800** | **10 600** |

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Table 20 Cold masses at 40 K / 60 K | | | | |
| Estimated weight | Cryomodule (QM) Thermal Shields  For 1 QM | Cold Valve Box (QVB) Thermal Shields  For 1 QM | Thermal Shields  (in cryogenic lines) | TOTAL cold mass  for 30 cryomodules  (40-60 K) |
| Stainless Steel (kg) | 30 | 20 | 1 000 | 2 500 |
| Copper (kg) | 120 | 80 | To be refined | 6 000 |
| Aluminum (kg) |  |  | 2 000  (thickness 3 mm for the TS) | 2 000 |
| **Total (kg)** | **150** | **100** | **3 000** | **10 500** |

* 1. PFD of the QVE (not included in the QPLANT procurement)



Figure 14 General PFD of the QVE (end box) with interfaces

# Annexes



Operational and maintenance expected needs over a defined period of 5 years including:

* + Preventive and corrective maintenance activities, software updates, calibration, compliance re-certifications, and energy efficiency optimization. Specific assumptions apply for forecasted OPEX:

1. Nitrogen cost: 250€/ton
2. Electricity cost: 142 €/MWh
3. Helium inventory: 250 €/kg (annual losses to be defined the Applicant)

[DD # 9ets 118](#_Toc198427123)

DD # 1ets

DD # 1

QQQ\_01. The QPLANT shall operate in “2K operation” uninterrupted for at least 6 months. 20

QQQ\_02. The maintenance plan of the QPLANT shall adhere to the following constraints: 20

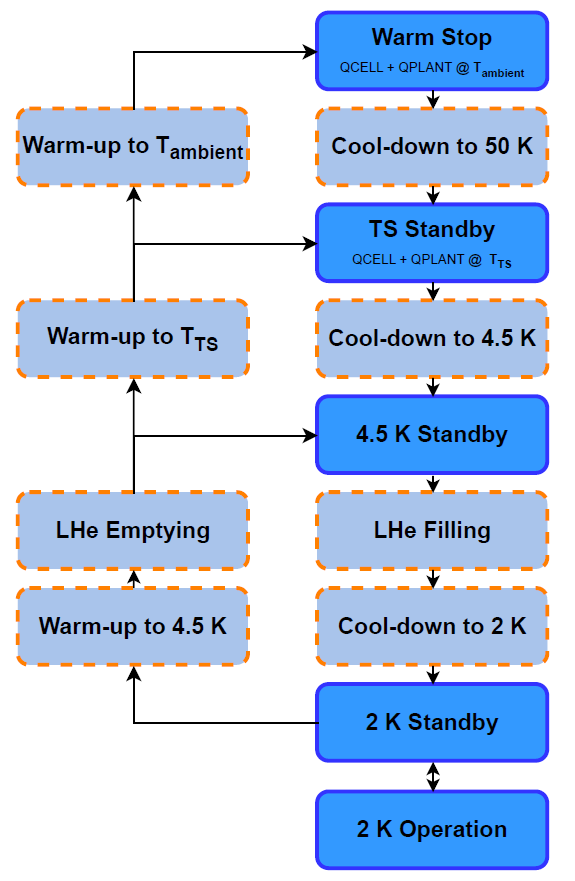
QQQ\_03. The QPLANT shall have a lifetime of at least 40 years. 20

QQQ\_04. The QPLANT shall withstand at least 50 warm-up/cool-down cycles (between 300 and 2K) during its lifetime. 20

QQQ\_05. The QPLANT shall operate in the operations scenarios given in Table 2 20

QQQ\_06. When in 4.5K standby, the QPLANT shall allow the (partial) stop of the (cold and/or warm) VLP compressors. 20

QQQ\_07. The QPLANT shall support the transitions given in Figure 6. 21

 22

QQQ\_08. The Contractor shall not drive the design and size of the QPLANT by the cool down requirements. 22

QQQ\_09. The QPLANT shall perform the cool-down of the QPLANT simultaneously with the cryogenic users. 22

QQQ\_010. The Contractor shall assume that the TS-circuits (headers “D” to “E”) and cold mass circuits (headers “A” to “B”) are cooled down simultaneously. 22

QQQ\_011. The QPLANT shall be able to cope with a warm-up of the cryogenic users from 2K to 300 K in less than 5 days. 22

QQQ\_012. The QPLANT shall support the following main phases for the warming-up of the cryogenic users: 23

QQQ\_013. The Contractor may implement a manual purging, manual conditioning and manual initial preparation of the QPLANT. 23

QQQ\_014. If a manual operation for this step is chosen, the Contractor shall provide a detailed procedure. 23

QQQ\_015. The Contractor shall assume that the LHe filling and emptying occurs when the cryogenic users are at 4.5K and XXXXX give them header A condition before JT expansion. 23

QQQ\_016. During LHe filling, the QPLANT shall provide 2900 liters of LHe to the users. 23

In their offer, the Applicant shall indicate the expected duration of the LHe filling as well as the maximum filling rate the QPLANT can produce. 23

QQQ\_017. The Contractor shall consider an enveloping range for the warm-up rate, encompassing the following boundary conditions: 23

In their offer, the Applicant shall indicate the expected duration of the emptying phase as well as the maximum flow rate that can be accepted while conserving the helium inventory. 23

QQQ\_018. The Contractor shall use the simplified heat load deposition sources as indicated in *Figure 4.* 23

QQQ\_019. The QPLANT shall be designed for the heat loads defined inTable 3 23

QQQ\_020. The QPLANT shall support the operating fluid conditions at the QRB as listed in Table 4. 24

QQQ\_021. For the Thermal Shield circuits (header “D” to “E” in Table 4), the Contractor shall optimize the mass flow, temperatures, and pressures (staying within the stated operating window of) to improve the overall efficiency or capital investment. 24

QQQ\_022. The QPLANT shall protect itself from any damage and allow subsequent recovery after these events. The Contractor shall identify all such events including but not limited to: 24

QQQ\_023. The abnormal event management shall be included in the failure and safety lifecycle analysis (e.g. HAZOP, FMECA, or equivalent methodology) and shall take into account all identified abnormal events. The Contractor shall develop the resulting risk mitigaion strategy covering the entire QPLANT system, its subsystems, and all physical and functional interfaces with external systems or facilities. The strategy shall define mitigation measures, responsible parties, implementation timelines, and the verification and validation methods for each identified risk. 24

The outcome shall be documented in a dedicated Abnormal Event Mitigation Plan, which shall be reviewed and approved by the Client during the design review phases.. 25

QQQ\_024. All pressure values shall be given in absolute pressures using the bar or mbar unit, the zero-value referring to vacuum. 25

QQQ\_025. All other measurement units (not covered by the previous requirement) shall be given in SI units. 25

QQQ\_026. The inverse COP shall be smaller than 380 under any operating scenario within the defined design envelope. 25

In the offer, the Applicant shall state the inverse COP for each of the steady-state scenarios they commit to deliver. 26

In the offer, the Applicant shall provide a substantiated justification via e.g. design configuration, operating assumptions, and calculations, measurements, … 26

Higher efficiency levels will be considered a technical advantage during bid evaluation. 26

QQQ\_027. The efficiency value shall be tracked throughout the Contract lifecycle: at design reviews, implementation stages, and final acceptance. 26

QQQ\_028. Final validation shall be conducted through mutually agreed test protocols, including calorimetric, flow-based, or standardised methods (e.g., ISO 5167, EN 13445, or equivalent). 26

The Applicant shall include in the Offer the electrical power measurement method they will apply on the QPLANT side, specifying the level of integration (e.g., total plant consumption including auxiliaries, compressors, control systems) and the measurement uncertainty. The Offer shall also specify the corresponding reciprocal measurement methodology expected to be applied by SCK CEN, including temperature, flow, and enthalpy balance, or equivalent performance indicators, to validate claimed energy figures. 26

QQQ\_029. Any deviation greater than ±5% from the claimed inverse COP at final acceptance shall trigger contractual review, including performance non-conformity, penalties, or corrective actions. 26

QQQ\_030. The QPLANT shall apply proven processes and be based on industrially proven technologies in order to reach very high reliability. 26

QQQ\_031. The QPLANT shall have an MTBF (Mean Time Between Failure) of at least 5 years. 26

In the offer, the Applicant shall present a preliminary FMEA showing compliance of the proposed design with this MTBF. The Contractor shall continuously update this FMEA during the design process ensuring that the MTBF is maintained. 26

QQQ\_032. The Contractor shall provide the Mean Time Between Failures (MTBF) values for all major QPLANT components, including but not limited to: 26

 Equipment and assemblies listed in the main Bill of Materials (BoM) 26

 Safety-significant or reliability-critical Structures, Systems, and Components (SSC), such as: 26

o Sensors and instrumentation 26

o Control and shut-off valves 26

o Pressure relief devices and bursting disks 26

o Actuators, regulators, and any components affecting operational safety or availability 26

QQQ\_033. MTBF values shall be substantiated by manufacturer data, field performance records, or predictive reliability models. The level of detail shall be proportionate to the component’s criticality in the overall system reliability and availability architectur. 27

QQQ\_034. The Contractor shall provide the detailed maintenance plan for all the QPLANT main components in order to meet the reliability requirements. 27

QQQ\_035. Operating scenario, minimum turndown or nominal operation shall not influence or impact reliability. 27

QQQ\_036. The Contractor shall deliver a preventive Functional Test Plan as part of the maintenance plan. 27

QQQ\_037. The Contractor shall deliver a Reliability-Centered Maintenance (RCM) Plan, defining failure modes, MTBF, inspection/replacement intervals, and spares recommendations for each system component. Specific strategies including but not limited to 27

QQQ\_038. The QPLANT:CS shall support real-time monitoring of instrument health (drift, dropout, deviation from expected range) with alarms and diagnostic flags for early fault detection. 27

QQQ\_039. A component-level replacement schedule for 40 years shall be provided by the Contractor, including MTBF data, estimated downtime impact, and cost per intervention. 27

QQQ\_040. Pressure design shall follow general specification (*AD 4*) for steel piping materials as a minimum requirement. 27

QQQ\_041. The opening pressure of the safety relief valves and other safety components shall be set at least 10% higher than the operating pressure in the components. 27

QQQ\_042. The design pressures of components shall be higher or equal to the opening pressure of their safety devices. 27

QQQ\_043. The Contractor shall take the Cryogenic system user input into account when deciding on the opening pressure of the safety components. e.g. the back pressure in the “S” or “B” header shall never exceed 1.9 bar to protect the users. 28

QQQ\_044. The general specification (*AD 4*) for steel piping materials shall be applied by the Contractor. 28

QQQ\_045. All components shall be new. 28

QQQ\_046. All materials shall be accompanied by their respective certificates and are part of the documentation deliverables. 28

QQQ\_047. Cold volumes containing helium shall be protected by safety devices according to EN 17527. 28

QQQ\_048. Any cold volume that can be isolated by valves and all insulation vacuum volumes shall be protected by safety devices. 28

QQQ\_049. The QPLANT safety valve exhausts shall either be collected or safely discharged to the outside to minimuize. 28

QQQ\_050. The recovery header shall be protected against over pressures by safety devices and non-return valves with an exhaust to atmosphere at a safe location. 28

QQQ\_051. The burst disks shall exhaust in a safe way regarding operators and equipment to avoid any risk of cold burn and/or anoxia. 28

QQQ\_052. The analyses and calculation of safety devices shall be subject to approval by SCK CEN. 28

QQQ\_053. All safety devices shall be accessible and removable during maintenance period for calibration or replacement. 28

QQQ\_054. The pipework surrounding the safety devices shall be designed to allow dismounting of safety valves and burst disk. 28

QQQ\_055. The Contractor shall recommend and guide SCK CEN to define the location of the oxygen deficiency detectors in the QPLANT buildings. 28

QQQ\_056. Technical Specification for Safety and Relief Valves (*AD 13*), shall be applicable to all warm valves unless superseded by more stringent requirement for helium operation based on the Contractor experience. The cryogenic valves inside QRB shall be of the extended-spindle type, sealing by metallic bellows. 29

QQQ\_057. Cryogenic valves shall be welded to the pipework and preferably to the top plates of the cold box. 29

QQQ\_058. The control valves at ambient temperature shall follow *AD 9* and shall be adapted to the process and to the fluid to be controlled. 29

QQQ\_059. The shut-off valves shall be ball or butterfly valves depending on size. 29

QQQ\_060. Dismountable joints in the QRB below room temperature are not recommended and shall be subject to approval by SCK CEN. At ambient temperature, metal and Viton O-rings are allowed. 29

QQQ\_061. The use of bellows to compensate thermal contraction shall be avoided by appropriate piping design. If the Contractor cannot avoid the use of bellows, location and type of bellows shall be subject to approval by SCK CEN. 29

QQQ\_062. All permanent junctions shall be welded; brazing must be exceptional, and its use is subject to approval by SCK CEN. 29

QQQ\_063. All junctions separating helium and water shall be welded with the weld on the water side. 29

QQQ\_064. All welding and brazing surfaces shall be cleaned before assembly, using proper solvents and water to remove any trace of acid flux, organic depositions and any other dirt and dust. 29

QQQ\_065. All metallic surfaces shall be cleaned, pickled and passivated. The completed components shall also undergo cleaning (degreasing, cleaning and drying) prior to helium leak testing. 29

QQQ\_066. Every component operating below atmospheric pressure shall be protected from air ingress by a helium guard filled with pure helium with a pressure higher than 1.05 Bar. 29

QQQ\_067. In order to detect leaks it shall be possible to isolate each helium guard circuit by means of a hand valve. 30

QQQ\_068. The helium guard pressure shall be monitored by a pressure transmitter which is accessible by the QPLANT control system. 30

QQQ\_069. All static seals not completely welded and operating between air and sub-atmospheric helium shall be doubled; the space between the seals shall have a connection to the helium guard system. 30

~~QQQ\_070.~~ ~~A mobile vacuum pumping system, integrated on a skid frame with wheels, shall be provided so it can be used for the pumping and conditioning of various components, including storage vessels.~~ 30

QQQ\_071. The Refrigeration Cold Box up to the vacuum barrier with cryogenic distribution system shall be equipped with a dedicated pumping system. 30

QQQ\_072. The pumping stations shall be able to pump at room temperature the vacuum vessels from atmospheric pressure to less than 10-5 mbar within one week or less. 30

QQQ\_073. The exhaust of the roughing pump shall be collected and sent outside the building via a dedicated pipe. 30

QQQ\_074. A fast insulation valve shall be provided on the vacuum port upstream of the secondary pump to protect the vacuum in the cryostat vessel. 30

QQQ\_075. A dedicated flange shall be provided between the secondary and primary pump for connection of a leak detector. 30

QQQ\_076. The necessary valve actuators and vacuum gauges shall be provided to allow safe remote automatic operation of the cold box pumping. 30

QQQ\_077. Necessary purge connections equipped with valves shall be installed for the pumping and filling of the overall helium pipework and volumes. These connections shall be subject to approval by SCK CEN. 30

QQQ\_078. Each purge valve shall be connected to a purge collector. 30

QQQ\_079. This purge collector shall allow venting, pumping and filling of all the volumes requiring purge. 30

QQQ\_080. The helium pumped or vented shall be sent to atmosphere outside the buildings. 30

QQQ\_081. The purge collector shall have a connection to pure helium supply equipped with a dedicated valve. 30

QQQ\_082. For the pumping, purging and conditioning of the cryogenic lines and of the cryogenic distribution, necessary purge connections shall exist on the Refrigeration Cold Box. 31

QQQ\_083. Downstream the vacuum barrier, the vacuum jacket interfacing with the QLM shall be equipped with a pumping port (DN 160). 31

QQQ\_084. The Contractor shall establish a helium leak detection and monitoring program in accordance with EN 13185:2001, Clause 6.2 (Leak Detection Methodology) or equivalent, including routine leak testing and automated isolation mechanisms. 31

QQQ\_085. The leak rate of the complete QPLANT (including all interconnecting piping, joints and components operating at maximum operating pressure and ambient temperature) shall not exceed the values defined in *Table 5*. The system shall be qualified for leak-tightness under operational and standby conditions. 31

In the offer, the applicant shall explicitly quantify and elaborate: 31

 Expected global and local leak rates, including thresholds for diffusive losses expressed as % loss per year. Estimated number and types of valves and fittings contributing to leak paths. 31

 Detailing the type of helium leak detection methods, pressure hold test procedures, vacuum decay or rise time methodologies, and long-term monitoring techniques. Acceptance criteria for each method and the calibration procedure for leak detection equipment. 31

 Post-installation and operational phase monitoring strategy, if applicable, including thresholds and frequency 31

QQQ\_086. The Contractor shall implement a comprehensive helium recovery strategy. This strategy shall cover all credible initiation events, including but not limited to Loss of Offsite Power (LOOP), Loss of Vacuum or Instrument Air (LOCA/LOIA), Cooling Circuit Trip, Turbine Trip, QRB Trip, HP Compressor Trip, and PVPS Trip. For each scenario, the Contractor shall identify at least: 32

QQQ\_087. The helium recovery strategy shall cope with the following He flow from the users: 32

QQQ\_088. The Contractor shall ensure that venting of helium to atmosphere is minimized under any defined failure or transition scenarios, unless explicitly triggered by the machine protection system (MPS). 32

QQQ\_089. The Contractor shall assume that, in the event of a Loss of Offsite Power (LOOP), the following utilities are available after a short interruption (few minutes): 32

QQQ\_090. System shall recover and compress helium at a nominal flow range of 3.5–35 g/s. Measurability via Flow measurement logs; control system feedback loop 32

QQQ\_091. System shall sustain 100 g/s helium recovery for 6 hours under LOOP conditions. Verification via Simulation + integrated testing; VFD power demand log 32

QQQ\_092. Control system and infrastructure shall support upgrade to 2×100 g/s N+1 redundancy. Verification via Design documentation, scalability matrix, PLC spare I/O validation 33

QQQ\_093. Pneumatic backup shall ensure actuation of all critical WCS and QRB valves during a 6-hour LOOP scenario. Verification via Endurance test; backup cylinder sizing calculation; pressure decay test 33

QQQ\_094. Pressure Safety Valves (PSVs) and Burst Disks (BDs) shall comply with PED and API 520 for 1 bar to 200 bar envelope. Verification via Inspection certificates; calibration records; system blowdown test 33

QQQ\_095. At least two buffer configurations (e.g., 50 bar balloon + 200 bar sphere) shall be available to decouple flow and ensure non-loss transfer. Verification via P&ID confirmation; vessel certification documents 33

QQQ\_096. Control architecture shall interface with QPALNT:CS, WCS, and HeR:CS with modular integration (future-proof). Verification via I/O mapping; communication protocol tests (Modbus/TCP or OPC-UA) 33

QQQ\_097. System shall be handed over with 40-year RCM plan, failure diagnostics, spare parts, and validated commissioning package. Verification: RCM deliverables; FMECA; maintenance plan; signed handover form 33

QQQ\_098. The Contractor shall integrate the recovery system with the QPLANT process systems. 33

QQQ\_099. The Contractor shall design the system with flexibility to enable implementation of either balloon (including purification and dedicated compression and/or dedicated storage) or compressor-based (existing QPLANT infrastructure) recovery, as per final AFA decision. 33

QQQ\_0100. If a Recovery Balloon is used as part of the strategy, its maximum capacity shall be limited to 200 m³ at ambient pressure, consistent with physical constraints of ~10 m × 10 m × 2 m, as referenced in AD1. 33

QQQ\_0101. In case of balloon use an oil-based air lock shall be installed, preventing ambient air ingress at sub-atmospheric pressures (max differential pressure: 1100 mbar). 33

QQQ\_0102. The passive venting mechanism shall comply with EN 13648 and ISO 21013 standards. 33

QQQ\_0103. The Contractor shall perform a reliability analysis including e.g. failure to start. 33

QQQ\_0104. The He recovery system shall support lifecycle monitoring per RCM principles, including Preventive Functional Diagnostics (PFD) bi-annually. 33

In the offer, the Applicant shall provide RCM details as per MTBF vs Replacement vs Spares. 33

QQQ\_0105. In the event of a Loss of Offsite Power (LOOP), the Contractor shall provide a dedicated pneumatic backup system to ensure full support of helium recovery operations requiring pneumatic actuation. The system shall satisfy the following minimum requiremens: 33

QQQ\_0106. The pneumatic backup system be commissioned and functionally tested under simulated LOOP conditions to verify switching, autonomy, and integration with the helium recovery sequence. 34

QQQ\_0107. The QPLANT shall be sufficiently instrumented to allow automatic control of its proper functions and to allow a safe operation. 34

QQQ\_0108. The number, type, accuracy, and positioning of the sensors shall be chosen in a way to Control the components performances and to verify the required performance values during acceptance tests. 34

QQQ\_0109. The Contactor shall prove that all measuring instruments are suitable for their purpose using appropriate references. 34

QQQ\_0110. Location and measurement ranges shall be defined by the Contractor and shall be assessed by SCK CEN during the design phase. 34

QQQ\_0111. Redundancy measurements and heaters shall be provided for inaccessible components and vital for operation and safety. 34

QQQ\_0112. A complete wiring diagram shall be included in Deliverable package ***Error! Reference source not found.***. 34

QQQ\_0113. Hard wire protection to prevent damage of main components, in particular compressors, turbines, pumps, and heaters shall be provided by the Contractor. 35

QQQ\_0114. The contacts of controlled equipment driven by hard wire (using sensors such as flow, pressure, temperature and level switches, valve end switches, etc.) shall be set as opened in abnormal situations (positive logic). 35

QQQ\_0115. Electrical heaters shall be protected against overheating by temperature sensors acting on the power or the control unit. 35

QQQ\_0116. All heating elements required for control and operation shall be replaceable without breaking the insulation vacuum or redundant elements shall be installed. 35

QQQ\_0117. The power measurement of heaters shall be transmitted to the QPLANT control system. The list of heaters shall be subject to approval by SCK CEN. 35

QQQ\_0118. Heating power of the power control units shall be controllable from the remote control room. 35

QQQ\_0119. Dielectric test shall be carried out and successfully passed during each main phase of the mounting and at the end of the assembly. 35

QQQ\_0120. Two twisted pairs of wires shall be used from the temperature element to the signal conditioner. 35

QQQ\_0121. The mounting of temperature elements shall be done in the way to minimize sensor self-heating and to limit the amount of heat brought by the wires using thermalization when necessary. The mounting principle shall be subject to approval by SCK CEN. 35

QQQ\_0122. Temperature elements outside cold boxes shall be mounted directly in the fluid stream, using a protection tube welded on the pipe. 35

QQQ\_0123. For each kind of temperature range to measure, the temperature measurements (including the whole thermometry chain) shall meet the requirement in *Table 6*. 35

QQQ\_0124. The choice between standard and high precision measurements shall be subject to approval by SCK CEN. 35

QQQ\_0125. A calibration curve shall be provided for each sensor when relevant. 36

QQQ\_0126. Each pressure transmitter shall be installed with at least one isolation valve and at least one connection for calibration, venting with isolation valve. 36

QQQ\_0127. The pressure measurement ranges of the instruments shall be agreed with SCK CEN, with a particular caution for the VLP line instrumentation. 36

QQQ\_0128. All pressure transmitters shall withstand, without de-calibration or damage, any pressure from vacuum to the maximum operating pressure (given by the setting of the relevant safety valve). 36

QQQ\_0129. The long-term drift for pressure measurement shall be less than ±0.5 % of the maximum span per year. 36

QQQ\_0130. The accuracy for absolute pressure measurement shall be better than ±0.5 % of the calibrated span. 36

QQQ\_0131. The accuracy for differential pressure measurement shall be better than ±0.25 % of the calibrated span. 36

QQQ\_0132. In addition to the isolation and calibration valves, the differential pressure shall be equipped with a by-pass valve. 36

QQQ\_0133. Vacuum pressure measurement shall cover the range from to mbar. 36

QQQ\_0134. Each vacuum gauge shall be equipped with at least an isolation valve. 36

QQQ\_0135. Each vacuum gauge shall be able to withstand gas inrush. 36

QQQ\_0136. Liquid helium level shall be measured by differential pressure or using a superconducting level sensor. Any other technology used for liquid level measurements shall be subject to approval by SCK CEN. A conversion curve to the volume shall be provided for each level measurements. 36

QQQ\_0137. The liquid level sensors shall not be disturbed neither by electrical heaters (bubbles) nor by flow turbulence. 36

QQQ\_0138. Liquid level measurements shall be displayed in percentage. Accuracy required for the measured value shall be better than 2% for helium and better than 5 % for other fluids. 36

QQQ\_0139. For helium flow rate measurements at cryogenic temperature, temperature and pressure shall be measured upstream flow measurements for the mass-flow rate calculation by the QPLANT control system. According to the Contractor experience standardized orifices as venturi associated differential pressure measurement shall be used. A calibration curve shall be provided. Accuracy required shall be better than 5% of the full range. 36

QQQ\_0140. For helium flow rate measurements at room temperature and water, other types of the flow meters are allowed. The accuracy required shall be better than 2% of the calibrated span. 37

QQQ\_0141. The display units for mass flow rates shall be g/s for helium flow and l/s or m3/h for water flow. 37

QQQ\_0142. The location of sampling points shall be agreed with SCK CEN. 37

QQQ\_0143. Two dedicated gas analyser cubicles shall be installed for the QPLANT (one in the compressor room and the second one in the cold box room). 37

QQQ\_0144. All capillaries used for permanent monitoring shall end at the gas analysis. These sampling lines shall be provided with at least a pressure regulator, a proper removable filter element and a manual process isolation valve. 37

QQQ\_0145. Temporary sampling points shall be at least equipped with a manual process isolation valve and proper plug. 37

QQQ\_0146. Each gas analyser shall be equipped with a dedicated calibration line. 37

QQQ\_0147. Gas sampling components and piping shall be in compliance with gas analysers accuracy requirements. 37

QQQ\_0148. The analysed gas samples shall be sent back to the Low Pressure of the WCS. 37

QQQ\_0149. Moisture, nitrogen in helium shall be measured continuously and anomalies shall trigger alarms on the QPLANT control system HMI. 37

QQQ\_0150. Gas analysers will be chosen according to the Contractor experience and shall have at least a measuring range of 0-100 ppm by volume for moisture and nitrogen. Accuracy required shall be better than or equal to ± 1 ppm by volume for the full range, with a long-term drift better than ± 1ppm by volume per year. 37

QQQ\_0151. In the compressor room, the residual hydrocarbons shall be measured with suitable instrumentation. 37

QQQ\_0152. The Contractor shall propose a solution to be approved by SCK CEN to minimize the Electro Magnetic Interferences effects (*AD 7*) required for standard measurements (e.g., using suitable shielded cables, twisted pairs, routing properly and separating voltage levels, etc.). 37

QQQ\_0153. In order to ease diagnostic and checking of measurement chains, knife-switch type terminal blocks or similar cabling interface shall be fitted for input and output signals connections with the QPLANT control system. 38

QQQ\_0154. All electrical components (cables, cubicles, cable trays, etc.) shall be in accordance with the applicable international electrical standards (IEC including IEC 61508 and IEC 61511 for lifecycle safety aspects) and *AD 6*. 38

QQQ\_0155. All cable sheathing shall be adapted to their environment (moisture, cable trenches, oil, heat and cold conditions, external environment, EMI effects, etc.). 38

QQQ\_0156. Each electrical and instrumentation cabinet shall have at least 25 % available space to allow later installation of equipment. 38

QQQ\_0157. The Contractor shall install harmonic filtering devices on the major variable frequency drives (for LP-HP compressors) and refer to *AD 6* for variable frequency drive requirements. 38

QQQ\_0158. The naming convention for cryogenic system shall be based on existing reference projects and shall be agreed with SCK CEN. 38

QQQ\_0159. For pressure equipment, vessels and safety devices, the Contractor shall comply with the requirements as detailed *AD 5*, *AD 13*, and *AD 14*. 38

QQQ\_0160. The valve actuators of the QPLANT control valves shall be equipped with an electro-pneumatic positioner and a numerical feedback signal of valve position. 39

QQQ\_0161. Valve position shall be displayed on the QPLANT control system. 39

QQQ\_0162. Based on reliability and safety analyses, some manual process on/off valves shall be at least equipped with two end switches confirming their positions during operation. The list of manual valves that shall be equipped is subject to approval by SCK CEN. 39

QQQ\_0163. The WCS shall provide helium flows at required pressures to allow the QRB to achieve its required performances. 39

QQQ\_0164. The WCS shall create at least 3 pressure levels (VLP, LP, HP). 39

QQQ\_0165. The design of the WCS shall allow easy accesses for maintenance, repair, and inspection. 39

QQQ\_0166. The WCS shall be connected to the warm gas helium storage. 39

QQQ\_0167. At least one by-pass valve shall be installed between VLP, LP and HP levels. 39

QQQ\_0168. By-pass valve size shall allow the maximal flowrate of the compressors to pass. 39

QQQ\_0169. Two controls valves shall link the helium gas storage to the LP suction for the loading and to the HP discharge for unloading. 39

QQQ\_0170. The HP unloading valve shall be installed downstream of the fine dust filter after the oil charcoal adsorber. 39

QQQ\_0171. Connections with the QRB shall be performed via control valves located in the WCS building in order to prevent fast pressure variation. 39

QQQ\_0172. Helium lines connected to the suction and discharge sides of the compressors (for every compressor stage) shall be equipped with non-return valves which close when the compressor stops. 39

QQQ\_0173. Each compressor noise shall not exceed 80 dB(A) at a 1 meter distance. 39

QQQ\_0174. The Contractor shall provide documents including values for the noise level of every compressor and every electrical motor drive according to the international standard for machine noise (Deliverable ***Error! Reference source not found.*** after manufacturing tests and ***Error! Reference source not found.*** after acceptance tests). 39

QQQ\_0175. The maximum allowable vibration levels for the compressors and rotating machines shall be in accordance with the ISO 2372 standard. 40

QQQ\_0176. During the design phase, the Contractor shall submit report and calculation basis justifying all the guaranteed vibration levels for SCK CEN’s approval. During commissioning, the vibration level shall be measured by the Contractor using dedicated instruments for measuring vibrations following the ISO 2954 standard. 40

QQQ\_0177. The total heat dissipated by the WCS to air shall remain below 120 kW. 40

QQQ\_0178. The WCS shall have a local heat dissipation duct which 40

QQQ\_0179. The heat produced by the LP/HP compressors shall be at least 65 % recovered using the appropriate heat recovery water flow given by SCK CEN. The heat recovery system can only operate when needed on SCK CEN site. 40

QQQ\_0180. The Contractor shall confirm the expected values concerning operating temperatures and percentage of possible heat recovery considering 27 °C as cooling water supply (*3.4.4*). 40

QQQ\_0181. The size and the number of machines (at least three per compressor stage) used for each compressor stage shall be defined by the Contractor in order to allow the best adaptation to the various flows necessary according to the operation modes. 41

QQQ\_0182. The LP/HP compressors shall be all identical to facilitate the maintenance and repair. 41

QQQ\_0183. The supply voltage for the motors shall be 400V, 3Φ, 50 Hz. 41

QQQ\_0184. The drive between motor and compressor shaft shall be direct, with a dismountable shaft coupling. 41

QQQ\_0185. Oil-retention reservoirs shall be incorporated in the base frames of each compressor skid to handle the full oil content of the skid in case of pipe rupture. 41

QQQ\_0186. The compressor flow shall be adjustable by use of integrated slide valves. 41

QQQ\_0187. The compressor flow shall be adjustable by use of variable-frequency drive, with a frequency of 50 Hz to be used at the 2 K nominal operation mode. 41

In the offer, the Applicant shall state the number of LP/HP compressors. 41

QQQ\_0188. The cooler shall be designed in accordance with the cooling water characteristics described in *3.4.4*. 41

QQQ\_0189. A manual or a thermostatic control valve shall be provided at the outlet of each cooler. 41

QQQ\_0190. On the gas side, the coolers shall be equipped with purge valves for rinsing. 41

QQQ\_0191. On the water side, valves to drain the water and to purge air shall be installed. 41

QQQ\_0192. A water manual shut off valve shall be set up at the inlet of each cooler. 41

QQQ\_0193. For the first filling, the Contractor shall provide a suitable oil type for the commissioning and acceptance tests. The oil shall have the following purity rate: 41

QQQ\_0194. The Contractor shall give recommendation on oil preparation prior to fill for operation and after major maintenances. 41

QQQ\_0195. An autonomous oil-pump shall be provided for each compressor. 41

QQQ\_0196. The upper part of the oil-retention vessel shall include a separator for oil droplets allowing to reduce the oil content of the helium at the outlet of each vessel to a level of impurity compatible with the Oil Removal System performance. 42

QQQ\_0197. The suction line of the oil pumps shall not be connected to the lowest point of the vessels. 42

QQQ\_0198. The suction line of the oil purge and filling circuits shall be connected to the lowest point of the vessels. 42

QQQ\_0199. Each retention vessel shall include heater for pre-heating the oil. 42

QQQ\_0200. The oil pumps providing oil bearing, shaft seals and slide valves shall possess at the suction side, double oil filters mounted in parallel. 42

QQQ\_0201. A fine oil filter shall set up at the injection of the compressor bearings and shaft seals. 42

QQQ\_0202. A wire mesh filter (100 µm) shall be integrated in the oil-supply line for each screw compressor. 42

QQQ\_0203. Manual shut-off valves shall be installed upstream and downstream of each oil filter. 42

QQQ\_0204. Each compressor shall be equipped with manual isolation valves in all connecting piping to allow isolation of all circuits for maintenance. 42

QQQ\_0205. The Contractor shall design the purge system and slope piping in order to avoid oil migration to oil-free region. 42

QQQ\_0206. Downstream HP primary oil removal system, minimum three coalescing filters shall be installed in series, with dimensions such that sufficiently low gas velocity is achieved through the filter elements for efficient coalescing. 42

QQQ\_0207. The gas velocity shall be determined for the highest possible volumetric flow during the different phases of compressor operation, plus a 20% margin. 42

QQQ\_0208. The coalescer arrangement and its seal construction shall be capable of withstanding compressor vibration. 42

QQQ\_0209. All coalescers shall be equipped with stand pipe on which magnetic level indicator is positioned. Level is monitored locally and from the control system with high level alarms and shutdowns. 43

QQQ\_0210. The oil collected from the first two coalescers is to be re-injected to the suction side of the LP/HP compressors. The automatic flush of oil from coalescer to compressor suction shall be carried out using a motorized valve controlled by the level indicator mentioned above. 43

QQQ\_0211. The coalescers shall reduce the oil content of the stream to less than 40 ppb. 43

QQQ\_0212. The last coalescer operates as guard unit. Any confirmed sign of oil collected therein shall lead to a shutdown of the compressor station. 43

QQQ\_0213. The charcoal oil adsorber shall be designed for a flow 20 % higher than the maximum compressor flow going to the cold box. 43

QQQ\_0214. Only charcoal in the form of smooth pellets shall be used as adsorbent filling. No filling consisting of irregularly broken particles shall be accepted. 43

QQQ\_0215. Charcoal shall be cleaned and dried by the Contractor to avoid dust and moisture. 43

QQQ\_0216. The filling shall permit an operation time in the 2 K operation mode of at least 3 years without exceeding the guaranteed maximum outlet impurity of 10 ppb. 43

QQQ\_0217. Contractor shall verify that the filling of the bed is regular and no preferred passages for the helium exist. 43

QQQ\_0218. Contractor shall demonstrate (based on design and previous experiences) that movement of the adsorbent and the carry-over of dust particles is avoided. 43

QQQ\_0219. The flow direction of the gas through the charcoal bed shall be from top to bottom. 43

QQQ\_0220. Any equipment necessary to fill the adsorber without degrading the adsorbent shall be supplied by Contractor. 43

QQQ\_0221. The heating unit necessary for the procedure of drying of the adsorbers shall be supplied by the Contractor. 43

QQQ\_0222. The adsorber vessel shall be equipped with adequate thermal insulation in order to prevent from personal risk of burn on hot surfaces throughout the drying of the adsorber by means of hot nitrogen. 43

QQQ\_0223. The helium dryer shall be designed for the full helium mass flow (HP total mass flow) contaminated up to 50 ppm by volume of water for a duration of 12 hours before regeneration. 43

QQQ\_0224. The capacity of the dryer shall remove water in the helium to a level of less than 1 ppm. 43

QQQ\_0225. The dryer shall operate at the High Pressure of the WCS without generating a total pressure drop of more than 0.5 bar. 44

QQQ\_0226. The total regeneration time shall not exceed 12 hours. 44

QQQ\_0227. The helium dryer unit shall include inlet and outlet valves and a by-pass circuit. The regeneration shall be performed by circulation of warm and dry nitrogen gas. 44

QQQ\_0228. At the dryer outlet, a wire mesh filter of 30 µm shall be installed in order to trap particles of dryer adsorbent. 44

QQQ\_0229. As adsorbent material, a molecular sieve of alkali alumino-silicate (Zeolite) or equivalent is required. The necessary replacement frequency and associated procedure shall be provided by the Contractor. 44

QQQ\_0230. The QPLANT shall include a recovery header for helium gas at room temperature and atmospheric pressure collecting safety valves and potentially for future external user. 44

Envisaged future external user amounts (future external helium users liquid supply by dewar and gaseous return) will be about 200 litres for initial cooldown and 50 litres/day while the relevant experimental setup is operational). 44

QQQ\_0231. This recovery header shall be connected to the LP of the warm compressors. 44

QQQ\_0232. The pressure and mass flow through the recovery header shall be permanently measured. 44

QQQ\_0233. The possibility to connect in the future to a recovery gas bag and external purification system shall exist. The Contractor shall make recommendation on required external purification system, or as a minimum specify the limits (in terms of impurities) to avoid negative impact on the main QPLANT function. 44

QQQ\_0234. The Contractor shall install at least the following gas filters: 44

QQQ\_0235. The Contractor shall submit to SCK CEN for approval all measuring points necessary for operation and protection of the equipment. 44

QQQ\_0236. At least the measuring points defined by Table 7 shall be exploitable by the QPLANT control system. 44

QQQ\_0237. The QRB shall be a horizontal cold box to fit with the building constraints (see *AD 1*). 45

QQQ\_0238. The QRB shall comprise the following internal components: 45

QQQ\_0239. The external components of the QRB shall be: 46

QQQ\_0240. The Refrigeration Cold Box shall be installed in the Cold Box room, as described in *3.4.2*. 46

QQQ\_0241. The final location of the QRB in the cold box room shall be agreed with SCK CEN. 46

QQQ\_0242. The QRB can use liquid nitrogen between 300K and 80K, if the Applicant is able demonstrate that this solution has a real benefit in term of capital and operation cost (including delivery logistics and impact on the reliability in terms of logistics) for the QPLANT and such a solution shall be agreed with SCK CEN. In case of liquid nitrogen pre-cooling, the Contractor shall be responsible for all the related components and integration. 46

QQQ\_0243. The Contractor shall demonstrate the possible access to QRB components and instrumentation located in the vacuum vessel. 46

QQQ\_0244. At least a manual shut-off valves shall be installed on each line connected to the WCS. 46

QQQ\_0245. The vacuum vessel shall be designed for internal vacuum and for overpressure. 46

QQQ\_0246. The vacuum vessel shall be protected by a suitable safety device sized according to regulations. 46

QQQ\_0247. The design of the passage of every line (cold or warm) connected to the QRB shall avoid any condensation or frost formation at the interfaces during any operation mode or any transition between operation modes of the QPLANT. 47

QQQ\_0248. The ports of the vacuum vessel carrying cold valves, turbines, transfer lines connections and instrumentation feedthrough shall be fabricated from stainless steel. The vacuum vessel may be fabricated from mild steel. 47

QQQ\_0249. The pumping port of vacuum vessels shall be designed to avoid the intake of any loose sheets of superinsulation into the vacuum pumps. 47

QQQ\_0250. The QRB shall be equipped with a vacuum barrier at the Cryogenic Distribution System interface. 47

QQQ\_0251. Aluminium plate fin heat exchangers shall be vacuum brazed. Stainless steel heat exchangers shall be of all-welded construction. 47

QQQ\_0252. For all heat exchangers, the type and origin of materials and transition pieces (Aluminium-Stainless Steel) shall be provided. 47

QQQ\_0253. All heat exchangers operating below 20 K shall be arranged vertically with the warm end at the top. 47

QQQ\_0254. A system on the first heat exchangers (between 300 K and 80 K) is required in order to warm up and regenerate it for frozen water removal in the HP sides. The differential pressure between inlet and outlet of the heat exchanger shall be measured in orderto follow the pressure drop evolutions during operation. 47

QQQ\_0255. In case of use of nitrogen for 80 K pre-cooling, a separated heat exchanger between nitrogen and HP helium flow shall be installed to avoid solidification of nitrogen in case of important return of cold helium flow in the LP stream. 47

QQQ\_0256. Only turbines with gas lubricated or magnetic bearings are accepted. 47

QQQ\_0257. The power extracted by the turbines shall be transferred to water cooled heat exchangers. These exchangers shall have high resistance to corrosion. Acceptable materials for the water channels are stainless steel and copper compatible with the water qualiy as described in *3.4.4*. The water side shall give easy access for cleaning. 47

QQQ\_0258. In order to allow the easy exchange of turbine cartridges, the system shall include all the elements needed to isolate, warm up, purge and cool down each turbine. This exchange shall be done in situ without warming up heat exchanger blocks. Heating by ciculation of gas is preferred to electrical heating for this application. 47

QQQ\_0259. Duration of the replacement of one turbine cartridge shall not exceed 3 hours. 47

QQQ\_0260. To cope with the high reliability requirements, the technology shall be centrifugal compressor with active magnetic bearings. 48

QQQ\_0261. The pressure fields (of the cold compressors) shall be provided by the Contactor. It represents the pressure ratio as a function of the reduced flow for different reduced iso-speeds. The stall and choke lines shall be provided. 48

QQQ\_0262. Mass flow rate of helium shall be easily adjustable via rotation speed regulation using Variable Frequency Drive. Rotational speed of the cold compressor shall include at least 10% speed margin with respect to the maximum value encountered in the differet operation modes. The bearing system should allow the rotational speed of each cold circulator be lowered down to 30 % of nominal speed while remaining in the operational window. 48

QQQ\_0263. The cool-down and start-up procedures of the cold compressor shall be detailed and subject to approval by SCK CEN. 48

QQQ\_0264. The supplied system shall allow inspection, maintenance and exchange of cold compressor. The intervention time including the warm-up and cold compressor exchange shall be less than 4 hours. 48

QQQ\_0265. Two helium phase separators shall be installed in the QRB: one at 2 K pumped by the cold circulators and one at 4.5 K. The phase separators will contribute to the operation for the control of the cold compressor and for restart after a short break. 48

QQQ\_0266. The phase separators shall be sized to cope with the different operating modes and to perform the acceptance tests with stabilized levels. The volume of the phase separators shall subject to approval by SCK CEN. 48

QQQ\_0267. The phase separators shall be equipped with electrical heaters in order to adjust the level of liquid helium, to empty from liquid helium and potentially to perform acceptance tests of the QPLANT. 48

QQQ\_0268. In order to reduce gas velocity, a diffuser shall be installed at the inlet of the fluid coming from the final expansion valve into the phase separators. 48

QQQ\_0269. Inlet and outlet of the phase separators shall be adequately spaced to avoid cross connection of the helium flows. The drawings of the helium baths shall be subject to approval by SCK CEN. 48

QQQ\_0270. Two 80 K parallel switchable adsorbers to remove air impurities shall be installed with an operating temperature below 85 K during cold operation modes. 48

QQQ\_0271. Each of these adsorbers shall be sized to purify the full HP compressors flow contaminated up to 50 ppm by volume of air during a time that shall be designed by the Contractor. 49

QQQ\_0272. The adsorption/regeneration time shall be designed by the Contractor in order to guarantee continuous operation. 49

QQQ\_0273. The necessary equipment for fully automatic switching, regeneration and cool-down of the 80 K adsorber beds shall be included. A by-pass between outlet of switchable 80K adsorbers and LP line of the QRB shall be installed which could be used for helium prification. 49

QQQ\_0274. One single 20 K adsorber operating below 25 K during cold operation modes shall be installed to remove from the process cycle the remaining impurities of neon and hydrogen. 49

QQQ\_0275. This 20 K adsorber shall be sized to retain impurities of the full helium flow contaminated up to 1 ppm by volume of hydrogen and neon each, for a duration of at least 200 hours. 49

QQQ\_0276. The necessary equipment for fully automatic regeneration of this 20 K adsorber bed shall be supplied. It shall be possible to regenerate and re-cool the contaminated adsorber with the QRB operating within 12 hours. 49

QQQ\_0277. All adsorbers shall be equipped with a by-pass allowing to pass the full helium mass flow rates relevant for all operating modes. 49

QQQ\_0278. The design of the adsorbers shall allow access for the periodic change of the adsorbent. 49

QQQ\_0279. The design of the adsorbers shall avoid any movement of the adsorbent and any emission of dust. The adsorbent material shall be chemically and mechanically stable under any operating conditions. 49

QQQ\_0280. All adsorbers shall be also equipped with gas analysis ports (cfr. *3.3.16.4*). 49

QQQ\_0281. Downstream of each adsorber bed, a 10 m wire mesh filter shall be installed. Filters of 10 m retention ability shall be installed at the inlet of turbines. The Contractor shall decide the number and positions of any additional filters required. 49

QQQ\_0282. All filters shall be accessible for cleaning and purging in a way to be proposed by the Contractor considering the operation scenario requirements (*3.2.1*). On the vacuum vessel, openings shall be installed to allow access to the filters to be changed. All filters are to be designed such that no dust collected can fall into the connected piping during replacement. 49

QQQ\_0283. The Contractor shall install heaters wherever necessary to permit a full warm-up of all the circuits, including cryogenic distribution and the cryomodules as described in *3.2.3.2*. Heaters shall also be used to demonstrate the QPLANT performance during the Acceptance Tests. 50

QQQ\_0284. The capacity and the location of the heaters shall be defined by the Contractor and subject to approval by SCK CEN. 50

QQQ\_0285. Heaters and associated electrical wiring shall be designed to minimize the heat loads to cold surfaces using necessary thermalization and optimized wiring diameters. 50

QQQ\_0286. For heaters located in helium phase separators, redundancy and easy replacement shall be considered in line with the requirement Req # 116. 50

QQQ\_0287. The Contractor shall submit to SCK CEN for approval all measuring points necessary for operation and protection of the equipment. 50

QQQ\_0288. At least the measuring points defined in *Table 8* shall be exploitable by the QPLANT control system. 50

QQQ\_0289. The Contractor shall define the total helium inventory required for the entire cryogenic system based on the helium inventory specified for the cryogenic users in *Table 9* as well as for the QPLANT, regardless of whether *Option 1* is granted. 51

QQQ\_0290. The helium gas storage on site shall be sized for the full helium inventory, as required by the operation modes and availability. 51

QQQ\_0291. The High Pressure of the WCS shall be used as the maximum storage pressure when calculating the storage volume required to accommodate the full helium inventory. 51

QQQ\_0292. A minimum of three vessels shall be considered to store the full helium inventory of the Cryogenic System. 51

QQQ\_0293. As a contingency to account for potential volume deficiencies and to include operational margins to offset helium loss, a margin of 20% shall be applied to the helium inventories and the corresponding helium storage facilities. 51

QQQ\_0294. To minimize the footprint impact in the storage area, the vertical positioning of the helium storage vessels is currently considered as baseline. However, the final volumes and arrangement shall be validated by SCK CEN. 51

QQQ\_0295. The Contractor shall address supply continuity for critical fluids (helium, nitrogen), including: 52

QQQ\_0296. If *Option 1* is granted, the foundation requirements shall be provided by the Contractor at the end of the design phase to SCK CEN. The interfaces will be finalized during the design phase with SCK CEN. 52

QQQ\_0297. The helium storages shall be located outside the building and installed vertically to reduce the footprint (*AD 1*). 52

QQQ\_0298. If *Option 1* is granted, the Contractor is responsible for the design of the storage vessel and all the necessary mechanical analysis to cope with the site environment. 52

QQQ\_0299. At least an inspection manhole shall be installed on each storage vessel. 52

QQQ\_0300. If *Option 1* is granted, the Contractor shall design, manufacture, inspect and test the storage vessels in conformity with the applicable codes and especially with the European Directive for Pressurized Equipment (PED 2014/68/EU). 52

QQQ\_0301. If *Option 1* is granted, the Contractor shall prepare the technical specification for the storage vessels (see internal SCK CEN reference requirements in *AD 14*). A particular caution shall be taken concerning the treatment including cleaning of inner surfaces to avoid corrosion, grease, oil, particle and moisture. For the inner surfaces treatment, the use of Rustol (Owatrol) or equivalent treatment is recommended. The outer surface shall receive a coating to withstand with outside condition. The color of the painting shall be decided in agreement with SCK CEN. The technical specification for the storage vessels shall be reviewed and validated by SCK CEN. 52

QQQ\_0302. If *Option 1* is not granted, the Contractor shall review and approve the technical specification for the storage vessel in charge of SCK CEN. 53

QQQ\_0303. The storage vessels shall be equipped with the necessary valves and ports to allow the different operation including purging, conditioning, and gas analysis. 53

QQQ\_0304. The vessels shall be interconnected with valves and also connected to the LP side and the HP side of WCS with automatic valves in order to regulate the process pressures. 53

QQQ\_0305. A gas management warm panel for the storage vessel valves shall be installed in the compressor room to manage the storage vessels. 53

QQQ\_0306. At least the measuring points defined in *Table 10* shall be exploitable by the QPLANT control system. 53

QQQ\_0307. The QPLANT:CS shall incorporate at least the components shown in green in the reference architecture defined in Figure 8. Furthermore, it shall include any additional systems or subsystems required to meet the overall performance, functionality, and safety objectives of the cryogenic plant. 59

QQQ\_0308. The QPLANT:CS shall use a commercially available control system that is industrial-grade and proven in comparable applications, meeting predefined performance, safety, and reliability standards; it shall be procurable off-the-shelf from an approved vendor with documented lifecycle support and compliance with relevant regulatory requirements to ensure long-term system sustainability and minimal vendor dependence. 59

QQQ\_0309. The QPLANT:CS shall enable autonomous operation (without operator intervention) of the QPLANT across all specified scenarios and transitions between them. 59

QQQ\_0310. The Contractor shall deliver of a fit-for-purpose Test System for System Under Test (SUT) which is used during functional testing, validation, and commissioning of QPLANT and QPLANT:CS. This Test System shall: 59

▪ Represent key operational states (start-up, shut-down, transients, faulted/degraded performance). 59

▪ Support alarm logic verification, interlock testing, and diagnostics without reliance on a live operational system. 59

QQQ\_0311. The Contractor shall not be required to implement a digital twin per se; however: 59

 If a validated digital twin or process-control simulation model (e.g., Simulink®, SimCryogenics, RNN, empirical/statistical thermodynamic or reliability models) is proposed, it must be: 59

o Based on certified, validated, or standards-compliant toolsets. 59

o Configured to support operator training, diagnostics, and maintenance planning. 59

o Allow future Integration with instrumentation and control system architecture to enable virtual sensors or diagnostic inference. 59

 If no model is proposed, the Applicant shall: 59

o Explicitly state and justify the exclusion, supported by a cost-benefit or reliability impact rationale. 59

o Describe in detail the alternate approach used for initiating event training, commissioning testing, and system diagnostics. 59

o Demonstrate how operational reliability, functional verification, and maintenance readiness are ensured in the absence of a digital model. 59

QQQ\_0312. Controlling mass flow rate and supply temperature: The QPLANT shall supply and regulate the mass flow rate and supply temperature at the QPLANT–QCELL interface (via QINFRA to QRB in the coldbox room), such that the temperature change rate—during both cool-down and warm-up—of each QCELL remains within predefined and controlled limits. The temperature change rate is defined as the maximum allowable rate of change of the internal QCELL temperature, expressed in K/h (e.g., 4 K/h). These limits shall be adjustable via process control, depending on the thermal inertia of each QCELL and the operational mode. 60

QQQ\_0313. The QPLANT:CS shall support bidirectional communication with the Broker, exchanging real-time operational and control signals at an update rate of 1 Hz. This will be used by the Broker system, implemented within MCS, to actively control and enforce this temperature change rate by issuing setpoints and operational constraints to the QPLANT Control System (QPLANT:CS). 60

QQQ\_0314. GSHRC: The Contractor shall follow the applicable sections from the General Software and Hardware Requirements for Contractors (GSHRC) containing quality and other requirements related to software, firmware and interoperability. The table below contains a specific instruction to the respective requirement *§AD 21*. 60

QQQ\_0315. Autonomous operation: When the MCS is unavailable or a communication loss occurs, the QPLANT:CS shall continue to operate as long as the systems safety as well as personnel safety are guaranteed. 61

QQQ\_0316. Remote parameters access: All the control parameters (like setpoints and thresholds), where manufacturing calibration data is optional, shall be available to the remote control interface with MCS. 62

QQQ\_0317. Interlock thresholds shall not be writable through the remote control interface. 62

QQQ\_0318. The QPLANT Control System should allow every actuator to be controlled manually in the event of a malfunction (for example a motor can have an auto, manual and maintenance mode to accommodate this behaviour). 62

QQQ\_0319. The QPLANT Control System should allow every sensor value to be set by the operator (mode maintenance) to be interpreted by the QPLANT:CS as it is the real value coming from the sensor. 62

QQQ\_0320. Records of all measured values, valve positions, operator actions, log book and alarms shall be accessible in QPLANT Control System. 62

QQQ\_0321. As part of **Error! Reference source not found.**, the following controls related information shall be provided: 62

- The detailed documentation of the software architecture, covering all modules, functional blocks, and components, along with their inputs and outputs. 62

- lists of alarms, protection functions, instruments, events, and parameters. 62

QQQ\_0322. PLCs shall be programmed in accordance with the IEC 61131-3 standard. 62

QQQ\_0323. The use of Instruction List(IL) is highly discouraged. Higher-level languages like Structured Text (ST) are highly recommended for better clarity, maintainability, and portability of PLC programs. Therefore, users and developers are strongly advised to avoid new implementations in IL and to migrate any existing IL-based code to ST or other recommended IEC 61131-3 languages whenever possible. 62

QQQ\_0324. When the Software Component includes human readable information (for example, but not limited to: HMI, logging, source code), it shall be in English. 62

QQQ\_0325. The Contractor shall develop a functional analysis (first version is part of the **Error! Reference source not found.**) and a detailed description of all control scenarios including interfaces. The detailed description shall also include program sequence plan (functions and procedures used in the program). 62

QQQ\_0326. For each software module, functional block, functional component or data block, the Contractor shall provide a description of the conditions to act on the output parameter. 62

QQQ\_0327. Versioning info through MCS interface: Each Software Component and Hardware Node shall include a unique version identifier that uniquely represents the build date and Git commit hash, automatically generated during the build process to ensure traceability; this identifier must be retrievable in a consistent and read-only manner through the MCS control and monitoring interface. 62

QQQ\_0328. Establishment of a Dedicated Test Environment: The supplier should use a dedicated test environment that replicates the production system's configuration, functionality, and critical interfaces for software changes. This environment may be virtual, physical or a combination. 63

QQQ\_0329. Environment Fidelity: The test environment shall mirror the production system to a level that allows reliable validation of all changes under simulated real-world conditions, including performance, response time and stress scenarios. 63

QQQ\_0330. Comprehensive Testing: All changes shall undergo rigorous functional, integration, and regression testing in the staging environment before deployment to the production system. 63

QQQ\_0331. Approval Before Deployment: No changes shall be implemented on the production system without prior approval based on documented test results and validation in the test environment. 63

QQQ\_0332. Rollback Plan: The supplier shall provide a pre-tested rollback plan to ensure the system can be restored promptly to its previous state in case of issues. 63

QQQ\_0333. Version Control and Audit Trail: All changes shall be tracked in a version control system with an audit trail, providing clear documentation of modifications and approvals. 63

QQQ\_0334. Minimizing Downtime: Changes shall be designed and tested to ensure minimal impact on system availability during deployment, including options for hot-swapping or scheduled maintenance windows. 64

QQQ\_0335. Disruption-Free Testing: The supplier shall guarantee that all testing activities in the staging environment remain completely isolated from production operations to prevent any unintended disruptions. 64

QQQ\_0336. Regulatory Adherence: All regulatory requirements applicable to the delivery of the plant shall also be adhered to for any changes made after delivery, ensuring compliance with safety, environmental, and industry standards. 64

QQQ\_0337. Audit and Monitoring: The contracting authority reserves the right to audit the testing process, staging environment, and changes at any time to ensure adherence to requirements. 64

QQQ\_0338. Continuous Improvement: The supplier shall collaborate with stakeholders to evaluate and improve the testing and change management process based on operational feedback and lessons learned. 64

QQQ\_0339. The Change management should be in place after Factory Acceptance Test and used for changes needed to integrate the consumers. 64

QQQ\_0340. Local Operator Station: The Contractor shall deliver local operator stations to provide local data collection and reporting for the QPLANT system to support maintenance activities. As a minimum one is expected in the Compressor Room and one in the Cold Box Room. 64

QQQ\_0341. No Full SCADA System: The Contractor shall not deliver or implement an enterprise level QPLANT SCADA system (multi-user or multi-server architecture) as part of the scope. 64

QQQ\_0342. Temporary SCADA System for Standalone Commissioning: The Contractor shall deliver and implement a temporary QPLANT SCADA system exclusively for use during the standalone commissioning phase. This solution is intended solely to support initial testing, commissioning, and operator training, and should be decommissioned and replaced by the MCS solution once integration is realized. This temporary system shall also be used as reference design for the development of the MCS Navigator therefor sufficient documentation is required. 64

QQQ\_0343. Integration Support: The Contractor shall provide support for integration of the QPLANT Control System with the MCS Navigator. This includes, but is not limited to: 64

QQQ\_0344. Industrial-Grade Platform: The Contractor shall ensure that the operator stations (whether HMI panels or dedicated Industrial touch PCs) are based on industrial-grade hardware specifically designed for continuous operation in a production environment. This includes robust construction, compatibility with the QPLANT’s environmental conditions (temperature, dust, vibrations, etc.), and adherence to relevant industrial standards. 65

QQQ\_0345. Long-Term Software Update Support: The platform shall be supported with software updates, firmware updates, and security patches for a minimum of 20 years from the date of commissioning. The Contractor shall provide documentation or official manufacturer statements guaranteeing availability of updates throughout this period. 65

QQQ\_0346. Migration to Newer Hardware: The visualization (HMI) project shall be designed in such a way that it can be migrated to newer hardware of the same manufacturer if the originally delivered hardware becomes obsolete or requires upgrade. This includes ensuring future compatibility of project files and software licenses, and providing guidelines for seamless transfer of project data and configurations. 65

QQQ\_0347. The touchscreen display shall have a minimum diagonal size of 24 inches to ensure sufficient screen space for detailed process graphics and user interaction. 65

QQQ\_0348. The display shall support a resolution suitable for clear viewing of process graphics, text, and trends. A minimum resolution of 1920×1080 (Full HD) is recommended for a 24-inch display. 65

QQQ\_0349. Where the system includes a local Human Machine Interface (HMI) that supports local control, it shall implement a control selection mechanism based on a 3-state principle: Local - Free - Remote. Local or remote control can only be granted when the system is in the "Free" state. If the system is not free, the requester will be denied the requested control, and any write commands from that side will be ignored. However, reading the system state shall always be permitted in any state, allowing either side to retrieve information about the system's status and confirming whether a request was successful. Writing (changing) is only allowed when the request is accepted. It is important to note that this control mechanism only pertains to local versus remote control states. Any other state machines within the system shall remain active, ensuring that, for example, regulation loops continue to function in either state. 65

QQQ\_0350. Release: Once a system is reserved in a specific control mode, it shall automatically transition to the "Free" state if a configurable timeout period (maximum of 5 minutes) of non-activity expires. "Releasing" means transitioning from a specific control state to the "Free" state. Non-activity refers to the absence of local or remote actions. 65

QQQ\_0351. Non-Critical System Role: The Operator Station shall be designed as a non-critical component of the control system. No real-time or safety-critical control functions shall reside in the Operator Station; it is purely for monitoring, visualization, and local interaction. 65

QQQ\_0352. Data Storage & Retention: The Operator Station shall store operational data (e.g., trends, alarms) only for a limited amount of time, sufficient for short-term analysis and troubleshooting. The data stored locally shall not be formally backed up; once data ages out of the configured retention period, it may be overwritten or discarded. 65

QQQ\_0353. The Operator Station shall provide capabilities for plotting curves and trends, enabling real-time and short-term historical visualization of key process variables. 66

QQQ\_0354. The Operator Station shall include graphical process views, providing an intuitive interface for monitoring equipment states and process flows. 66

QQQ\_0355. The Operator Station shall show and log alarms and events for immediate operator awareness without functionality to acknowledge alarm occurrences 66

QQQ\_0356. Graphical process views shall be agreed with SCK CEN. 66

QQQ\_0357. All the sensors and actuators shall be integrated in different graphical views. 66

QQQ\_0358. The Operator Station software shall support a default data acquisition period of maximum two seconds. For critical turbine data an acquisition rate of 100 ms is required. 66

QQQ\_0359. The HMI software shall allow at least two permission levels with different functions available. 66

QQQ\_0360. The HMI software package shall allow to automatically call or e-mail “on call” staff through MIT (see *Figure 8*). 66

QQQ\_0361. The graphical views shall be in accordance with the Process & Instrumentation Diagrams to easily understand and operate the system. 66

QQQ\_0362. The HMI software package shall be installed on two workstations with large screens (at least height 24 inches monitors) to visualize the useful information during QPLANT operation (see *Figure 8*). 66

QQQ\_0363. Internal Inventory for Plant: The Contractor shall maintain and provide an up-to-date internal inventory of all components, equipment, and services delivered as part of the plant. This inventory must include detailed information on internal applications, devices, network interfaces, and communication protocols used within the plant. The internal inventory should be updated and shared with the client whenever any changes or updates occur in the plant. 67

QQQ\_0364. Network Ports and Protocols Requirement: The Contractor shall supply a detailed list of the network ports and protocols necessary for the correct functionality of their system and application. (**Error! Reference source not found.**) 67

QQQ\_0365. Responsibility for Network Configuration: The Contractor shall be responsible for configuring the necessary network elements based on the inventory of network ports, protocols, internal and external applications. 67

QQQ\_0366. IP Address Allocation and Compliance: The Contractor shall use IP address ranges for the QPLANT:CS as provided by the customer. This includes equipment in Level 0 of the Perdue model. These ranges will be pre-assigned by MIT to ensure consistency with the overall network architecture and addressing schemes. The Contractor is responsible for implementing the provided IP ranges without deviation, and any additional IP requirements shall be communicated to and approved by MIT prior to implementation. Additionally, the Contractor shall document the use of the assigned IP ranges for each device and submit this documentation to MIT upon completing the configuration. (**Error! Reference source not found.**) MIT reserves the right to audit the Contractor's implementation to ensure adherence to the assigned IP ranges and network configuration standards. 67

QQQ\_0367. Remote upgrade: Where a Software Component can be upgraded, the QPLANT:CS shall support an upgrade procedure which can be automated as script(s), without the need for an Internet connection. A list of required tools has to be provided. **Error! Reference source not found.** 67

QQQ\_0368. Backup: Where backup of a system is required, for each system following shall be defined (**Error! Reference source not found.**): 67

QQQ\_0369. Monitoring systems with OS: Where the system has an operating system, the System shall support monitoring by at least one of the protocols mentioned in the MIT interface catalogue chapter "Monitoring". Ref. SCK\55564083 68

QQQ\_0370. Authorization and security: Where the system has no operating system and requires authorization, the System shall support authorization by at least one of the protocols mentioned in the MIT interface catalogue chapter "Authorization and security". Ref. SCK\55564083 68

QQQ\_0371. Authorization and security systems with OS: Where the System has an operating system, the System shall support authorization by at least one of the protocols mentioned in the MIT interface catalogue chapter "Authorization and security". Ref. SCK\55564083 68

QQQ\_0372. Authentication: Where the system has no operating system and requires authentication, the System shall support authentication by at least one of the protocols mentioned in the MIT interface catalogue chapter "Authentication". Ref. SCK\55564083 68

QQQ\_0373. Authentication systems with OS: Where the System has an operating system which requires authentication, the System shall support authentication by at least one of the protocols mentioned in the MIT interface catalogue chapter "Authentication". Ref. SCK\55564083 68

QQQ\_0374. Network addressing service: The System shall support network addressing service by at least one of the protocols mentioned in the MIT interface catalogue chapter "Network addressing service". Ref. SCK\55564083 68

QQQ\_0375. Network naming service: The System shall support network naming service by at least one of the protocols mentioned in the MIT interface catalogue chapter "Network naming service". Ref. SCK\55564083 68

QQQ\_0376. Automatic IP Address Assignment: The Contractor shall implement a mechanism for automatic IP address assignment based on MAC addresses whenever possible, utilizing DHCP services to ensure efficient and consistent configuration. In scenarios where DHCP is not feasible, the Contractor shall configure static IP addresses in accordance with MIT's assigned IP ranges. All configurations shall align with MIT's network architecture standards to ensure seamless integration and avoid IP conflicts. 68

QQQ\_0377. Device Identification and MAC Address Tracking: The Contractor shall provide a comprehensive list of all devices, including their respective MAC addresses, prior to configuring the network. This list is crucial for tracking and managing devices, especially when configuring static IP addresses or ensuring proper DHCP assignment. (**Error! Reference source not found.**) 68

QQQ\_0378. Procedure for Enabling DHCP on Devices: If a device is DHCP-capable but not configured for DHCP, the Contractor shall provide a detailed procedure for enabling and configuring DHCP on the device. The procedure shall include all necessary steps for ensuring proper DHCP functionality, such as network settings, IP lease time configuration, and alignment with MIT’s DHCP service and network standards. (**Error! Reference source not found.**) 68

QQQ\_0379. Aggregation Network Redundancy: The aggregation network shall use a redundant ring topology, with a dedicated redundancy manager and client switches. The network shall automatically reconfigure within 300 ms in case of interruptions. Redundant connections to the backbone shall be established using a master/slave configuration, ensuring failover times under 300 ms. All links within the aggregation network, including connections to the backbone and cell networks, shall support 1 Gbit/s bandwidth. The network design shall incorporate fault recovery mechanisms to reroute traffic in the event of failures, ensuring uninterrupted data flow. Rationale: The aggregation network ensures high reliability and performance by implementing redundancy to minimize downtime and enable fast recovery during faults. 69

QQQ\_0380. Standby Redundancy for Backbone Connections: The QPLANT:CS shall establish redundant connections to the backbone network using standby redundancy. Each connection shall include a master and backup device, with failover mechanisms ensuring that if one device or connection fails, the other takes over seamlessly. The failover time shall be deterministic, with a maximum duration of 300 ms to minimize downtime. Rationale: Redundant connections ensure continuous backbone network availability by enabling quick failover during link failures, minimizing disruptions and maintaining system stability. 69

QQQ\_0381. Contractor Compliance with Customer Security Policy: The Contractor shall comply with the SCK CEN cybersecurity policy, ensuring alignment with the IAEA NSS17 (Nuclear Security Series), ISO 27001 (Information Security Management), and IEC 62443 (Industrial Communication Networks – Network and System Security) standards. This includes implementing required security controls, risk management processes, and incident response protocols as outlined by these frameworks. 69

QQQ\_0382. Security Documentation and Client Approval: Documentation of the system's security features and their alignment with the client's standards must be provided for review and approval before deployment. **Error! Reference source not found.** 69

QQQ\_0383. Integration with Client's Security Infrastructure: The Contractor shall work with the client to verify that the system integrates seamlessly with the client’s existing security infrastructure, including firewalls, VPNs, and any other relevant security tools. 69

QQQ\_0384. Identification of Relevant Products and Digital Elements: The Contractor shall identify all products and digital elements used in the production plant, including Commercial Off-The-Shelf (COTS) materials and custom-built systems, that fall under the scope of the Cyber Resilience Act. These products must be evaluated for compliance with the CRA's cybersecurity requirements. 69

QQQ\_0385. Remote Access to Plant: If the Contractor requires remote access to the plant, he shall utilize the standard solution provided by the customer. Access will be granted with restricted permissions to ensure that only necessary functions are available, safeguarding the integrity and security of the plant's systems. The Contractor is responsible for adhering to the defined access protocols and ensuring compliance with the customer's security policies. 69

QQQ\_0386. Internal interlocks: The QPLANT shall not rely on the MIS, unless the interlock has to be propagated to or relies on other systems. 70

QQQ\_0387. Interlock status to MCS: The QPLANT shall ensure that the status of each interlock is monitorable through the MCS control interface. 70

QQQ\_0388. Personnel protection standards: When the system has personnel protection, the systems personnel protection shall be designed according to standards IEC 61508 (Functional Safety) or one of the sector-specific derived standards (IEC 62061, IEC 61511) or alternative (e.g. ISO 13849-1). 70

QQQ\_0389. The welding connection between QRB and QLM shall be done by SCK CEN. 71

QQQ\_0390. For the acceptance tests, the Contractor shall provide the necessary welded caps on pipes on the QRB side. 71

QQQ\_0391. The following warm lines are distributed in the tunnel. The interface with the QPLANT will be located in the cold box room, around the QRB. The final location and pipe requirement shall be defined during the design phase with SCK CEN. 71

QQQ\_0392. The QPLANT shall be designed to fulfil the site constraints (buildings, rooms) given in *AD 1*. 72

QQQ\_0393. For the cryogenic areas, the Contractor shall provide the general assembly drawings with QPLANT components and 3D models. (\*.step files may be used). 72

QQQ\_0394. The compressor room (16 m \* 14 m \* 6.5 m) shall house the WCS. The Contractor shall reserve space in this room for future upgrades (e.g. a dedicated purification system), for spare parts storage as well as for an unloading area. 72

QQQ\_0395. The Contractor shall define the positioning of all equipment in this room in agreement with SCK CEN. 72

QQQ\_0396. The compressor units may be installed and grouped on skids. 72

QQQ\_0397. During the conceptual design phase, the Contractor shall evaluate the need for a crane in the compressor room and shall provide the necessary inputs in the deliverable ***Error! Reference source not found.***. 72

QQQ\_0398. The access for the installation of the large components could take place from the road by removal of the wall dismountable panels. SCK will be in charge of the dismountable panels dismounting and mounting. 72

QQQ\_0399. The Cold Box Room (20 m\*10 m~200 m², see details in *AD 1)* shall host the Refrigerator Cold Box and associated warm panels, the electrical cabinets, the gas analysers and pumping system. The height of the ceiling is around 6.5 meters. 72

QQQ\_0400. During the conceptual design phase, the Contractor shall evaluate the need for crane in the cold box room and shall provide the necessary inputs in the deliverable ***Error! Reference source not found.******Error! Reference source not found.***. 73

The access for the installation of the large components could take place from the road by removal of the wall dismountable panels. SCK will be in charge of the dismountable panels dismounting and mounting. 73

The cold box room shall be connected to the compressor room by the different warm lines of the QPLANT. 73

QQQ\_0401. These warm lines of about 60 meters long shall be installed on the roof or below the roof close to the ceiling of the buildings between compressor room and cold box room. 73

QQQ\_0402. The gas helium storages and potentially liquid nitrogen storage shall be installed in the storage area (17 m\*10 m ~170 m²), next to the compressor room. The total helium inventory is detailed in *§3.3.17* . 73

QQQ\_0403. The positioning of the different storages shall consider the possibility of the fluid refilling by trailers. 73

QQQ\_0404. The following site operating conditions shall be considered for the design and operation of the QPLANT and auxiliary equipment (see *AD 1*): 73

QQQ\_0405. The Contractor shall provide the power supply consumption at the end of the Conceptual Design phase. 74

QQQ\_0406. The Contractor shall provide the Low Voltage distribution and associated LV cubicles associated to the QPLANT procurement. 74

QQQ\_0407. The Contractor shall provide routing, cabling, cable trays and connectors for all QPLANT components related to the compressor room, the cold box room and the storage area. 74

QQQ\_0408. The electrical diagrams, cable trays and electrical management shall be subject to approval by SCK CEN. SCK CEN will provide the grounding connections in the compressor room, cold box room and storage area (in compliance with the international standards). 74

QQQ\_0409. The Contractor shall connect all cryogenic equipment to the grounding of their buildings following the IEC standards. 74

QQQ\_0410. The piping (helium, water, air) and Low Voltage cables shall be grouped in a single building feed-through and connected to equipotential bounding in order to reduce the EMI effects. EMC standards and guidelines shall be followed by the Contractor (*§AD 7*). 74

QQQ\_0411. The Contractor shall provide to SCK CEN a proposal for UPS backup power in case of loss of electricity to supply HMI, PLCs, network, digital inputs. Centrally managed UPS backup power is provided by SCK CEN. 74

QQQ\_0412. A list of sensors and transmitters to be powered by UPS shall be proposed by the Contractor and subject to approval by SCK CEN, based on a risk analysis of the relevant signals by the Contractor. This allows SCK CEN to dimension the centrally managed UPS and to provide the required backup power. 74

QQQ\_0413. Where the QPLANT has high power or high voltage components, the Systems embedded controls electronics shall be powered with a segregated AC power interface. 74

QQQ\_0414. The Contractor shall provide the cooling water expected consumption at the end of the Conceptual Design phase. 74

QQQ\_0415. The Contractor shall distribute the cooling water inside the dedicated technical rooms to the different QPLANT users. The scheme of the cooling water distribution in the buildings shall be subject to approval by SCK CEN. 75

QQQ\_0416. The Contractor shall install the necessary instrumentation and additional control elements where required to measure/control temperature, pressure and mass flow rate of the cooling water loops. 75

QQQ\_0417. The Contractor shall provide local drains considering that the draining of cooling water is a glycol type waste, and therefore needs to be connected to the SCK CEN PS03 system. 75

QQQ\_0418. The Contractor shall provide the compressed air needs at the end of the Conceptual Design phase. 75

QQQ\_0419. The Contractor shall distribute the compressed air inside the dedicated technical rooms to the different QPLANT users. The scheme of the compressed air distribution shall be submitted to SCK CEN’s approval. 75

QQQ\_0420. The Contractor shall provide a quantitative analysis of heat dissipation to the HVAC system covering: 75

 Heat load to room and cooling air (in kW) for steady state (24 and 30 QCELL) operational and standby per room of WCS and QRB. 75

 Validation of SCK CEN provided exhaust routing to designated HVAC intake points during commissioning and acceptance testing. 75

QQQ\_0421. The Contractor shall ensure the integration of the HP compressor exhaust ducting with the Compressor Room (WCS in CCB). SCK CEN provides extraction from defined scope boundary. 75

In the offer, the Applicant shall furnish interface (HP compressor exhaust outlet/terminal points) quantitative data (heat dissipation, flow rates, pressure drop, …) 75

QQQ\_0422. HVAC system to allow for partial by-pass or heat injection during cold ambient conditions. The system shall be designed to minimize energy input while ensuring reliable operation. 76

QQQ\_0423. The exhaust of the vacuum system(s) from the QPLANT process rooms shall be collected and vented outside the building. The location of these exhausts shall be subject to approval by SCK CEN. 76

In the offer, The Applicant shall quantify the number, size and location of expected roof/wall penetrations. 76

QQQ\_0424. The Contractor shall provide the necessary helium to be used during the installation and pre- commissioning phases including leak tests and conditioning of the QPLANT circuits. 76

QQQ\_0425. If liquid nitrogen is used for the QPLANT precooling, the Contractor shall be responsible for the entire nitrogen equipment including liquid nitrogen tanks, heaters, etc. If the liquid nitrogen is not used for the QPLANT precooling, SCK CEN could provide gas helium for regeneration purpose. SCK CEN will provide the necessary support as required. 76

QQQ\_0426. During installation and commissioning, the Contractor shall be in charge to supply the necessary nitrogen linked to these activities. 76

QQQ\_0427. MCS architecture: Where the system has an interface with MCS, the system shall comply to the MCS architecture, processes and interfaces. Ref. SCK CEN/38585071. 76

QQQ\_0428. Control and Monitoring Interface: The interface between QPLANT (Contractor) and Control System (ICS) shall comply to the **Slow Fieldbus** Control and Monitoring Interfaces type C as listed in MCS Interface Catalogue Ref. SCK CEN/48276492. 76

QQQ\_0429. MIS architecture: Where the system has an interface with MIS, the system shall comply to the MIS architecture, processes and interfaces. Ref. SCK CEN/39550252. 77

QQQ\_0430. Slow Interlock Interface: The interface between QPLANT (Contractor) and Interlock System (ICS) shall comply to the Slow control interface catalogue. Ref. SCK CEN/48443569 *§AD 16.* 77

QQQ\_0431. Slow interlock interface specification: Where the system has a slow interlock interface, the slow interlock interface shall comply to the slow interlock interface document: Ref. SCK CEN/48282970. 77

QQQ\_0432. Interlocks from or to QPLANT Control System to or from MIS ( See *Figure 8* ) shall use hardwired interfaces. The list of interlocks will be defined during the project execution by SCK CEN. 77

QQQ\_0433. 77

QQQ\_0434. MIT architecture: Where the system has an interface with MIT, the system shall comply to the MIT architecture, processes and interfaces. Ref SCK CEN/39553304. 77

QQQ\_0435. MIT Interface catalogue: The interface between QPLANT (Contractor) and SCK CEN Information Technology (ICS) shall comply to the MIT interfaces as listed in catalogue Ref. SCK CEN/55564083 77

QQQ\_0436. Network Integration Physical: The QPLANT shall be physically connected to the MIT network in a redundant, fault tolerant way. At minimum 2 physical links will be foreseen, each link routed via a separate pathway. The physical connections need to be distributed over at minimum 2 separate physical endpoints on the QPLANT side. 77

QQQ\_0437. Network Integration Logical: The QPLANT shall be connected to the MIT IP network using a single logical routed connection ("layer 3"). At both sides, a single gateway IP will be configured as destination IP for packet forwarding. 77

QQQ\_0438. System logging: Where the QPLANT:CS or one of its components supports system logging, the contractor shall provide system logs remotely through at least one of the protocols mentioned in the MIT interface catalogue chapter "System logging". Ref. SCK\55564083 77

QQQ\_0439. Application logging: Where the QPLANT:CS support application logging, the System shall log remotely either by using a protocol defined in section "Application logging" of document "MIT interface catalogue" ( Ref. SCK\55564083 ) or alternatively adhere to the following: 77

QQQ\_0440. Timing synchronization: The QPLANT:CS shall support timing synchronization by at least one of the protocols mentioned in the MIT interface catalogue chapter "Timing synchronization". Ref. SCK\55564083 78

QQQ\_0441. Remote access: Where the QPLANT:CS requires remote access, Systems shall provide remote access through at least one of the protocols listed in the MIT interface catalogue chapter "Remote access". Ref. SCK\55564083 78

QQQ\_0442. Patch panel: The connection of the QPLANT:CS with MIT, shall terminate on a patch panel. 78

QQQ\_0443. Certified personnel shall carry out the weld inspections, pressure and leaks tests. The associated valid certificates of the qualified personnel shall be provided by the Contractor in the deliverable documentation (***Error! Reference source not found.***.). 78

QQQ\_0444. As a minimum, the following tests shall be conducted during construction of the components. 78

QQQ\_0445. All possible functional tests at the manufacturer sites shall be performed to detect any faults before delivery and confirm the performances indicated in the technical specification. These tests shall include at least: 78

QQQ\_0446. After mechanical assembly and cabling of any sub-assembly, the Contractor shall execute a complete electrical and wiring test. All components and cabling shall conform to the international electrical standards (IEC). The electrical and wiring tests shall include at least: 79

QQQ\_0447. For the WCS electrical tests, before the connection between the motor and the compressor, the Contractor shall: 79

QQQ\_0448. The QPLANT control system operation shall be tested in simulation mode before shipment. 79

QQQ\_0449. The Contractor is responsible for the transport and storage of all the QPLANT components from the manufacturing sites to the SCK CEN final positioning. It includes the storage, transport, loading, unloading and final positioning activities. 79

QQQ\_0450. Prior to transportation, all process circuits of the QPLANT components shall be filled with inert gas at a fixed pressure and sealed during transport. Necessary caps, blind flanges and hand valves shall be considered at that stage. Pressure gauges shall be installed and checked at the departure from manufacturer premises and at the arrival on SCK CEN site. It is recommended to provide transportation boxes with appropriate accelerometers for the refrigeration cold box. 79

QQQ\_0451. Appropriate packaging shall protect every item during transport from degrading environment, be suitable for the selected transport and consider temporary storage in the open air. 80

QQQ\_0452. Each package shall be clearly marked with a label stating the Contractor’s name, the destination, the name of the component and its identification number, the weight, and a link to the documentation. 80

QQQ\_0453. Prior to transportation, the package units shall be visually inspected at the manufacturer premises and a certificate about proper packaging and availability of the necessary documentation shall be issued. Representatives of the SCK CEN shall be invited y the Contractor to witness the inspection. The inspection shall consist in a visual verification of the packaging and a check of the formal and technical documentation. 80

QQQ\_0454. The Contractor shall install and assemble all components (compressors, ORS, QRB, warm panels, interconnection lines, electrical cubicles, control system equipment’s, analysis cubicles, among others) and perform their connections on the SCK CEN site and to utility supplies. 80

QQQ\_0455. The Contractor and its subcontractors shall follow the local regulations applicable on the SCK CEN site, including the safety and logistic rules and the necessary trainings. 80

QQQ\_0456. For all activities on SCK CEN site, the Contractor shall comply with the SCK CEN Safety and Health Plan (*AD 2).* 80

QQQ\_0457. Utilities (electricity, cooling water, compressed air) except fluids (helium and nitrogen) will be supplied free of charge from start of installation to end of acceptance tests at the SCK CEN site. The Contractor shall provide a list of needed utilities with date of availability at the end of the conceptual design and updated at the final design (***Error! Reference source not found.***). 80

QQQ\_0458. The existing cranes in the buildings will be made available for the work on site, however, qualified operators shall be provided by the Contractor. 80

QQQ\_0459. Upon arrival on the SCK CEN site at Mol, at least the following inspections shall be performed and documented: 80

QQQ\_0460. An incoming inspection report shall be provided by the Contractor and approved by SCK CEN (to be included in deliverable ***Error! Reference source not found.*Error! Reference source not found.**) before starting installation. 81

QQQ\_0461. After assembly of subsystems (WCS, QRB, storages), the following tests shall be performed and documented: 81

QQQ\_0462. An assembly test report shall be provided by the Contractor and approved by SCK CEN *(****Error! Reference source not found.***) before starting commissioning. 81

QQQ\_0463. The commissioning shall start with preliminary tests to control and check all components at ambient temperature. The preliminary tests shall include at least the following tasks: 81

QQQ\_0464. Each individual subsystem (vacuum systems, WCS, gas storages, Refrigeration Cold Box) shall be commissioned during running tests: 81

QQQ\_0465. WCS and QPLANT commissioning test reports shall be provided by the Contractor (***Error! Reference source not found.***) and approved by SCK CEN before starting acceptance capacity tests. 82

QQQ\_0466. Test shall contain the validation of the position of the interfaces (especially the one to the QLM). 82

QQQ\_0467. During acceptance capacity tests on site, the Contractor shall demonstrate proper operation and verify the performance requirements specified in *§3.2* (except cool-down and warm-up of QCELL’s which could only be performed after QCELL’s are connected. Nevertheless, operation sequences for cool-down and warm-up shall be demonstrated by the Contractor). 82

QQQ\_0468. During these tests, all aspects e.g. mechanical and capacity, safety requirements and process control system shall be tested and validated. 82

QQQ\_0469. A draft of the test program shall be submitted prior to start manufacturing (***Error! Reference source not found.***). The final version of the acceptance capacity test program shall be submitted latest 10 working days before the envisaged start of the tests (***Error! Reference source not found.***) and be approved by SCK CEN. 82

QQQ\_0470. The acceptance capacity tests shall be performed with the specified heat loads applied by heaters on the different cooling circuits to be representative of the operation with QPLANT connected to the accelerator. Dedicated test cryostat, if necessary (and to be provided by the Contractor), could be used. Control valves in relevant circuits shall also simulate appropriate pressure drops. 82

QQQ\_0471. The acceptance capacity tests of the QPLANT (including Warm Compression Station and QPLANT) shall be reported in deliverable ***Error! Reference source not found.***. 83

QQQ\_0472. During these tests, the WCS is not connected to the Refrigeration Cold Box. The functional tests shall consist in: 83

QQQ\_0473. The capacity tests of the WCS shall consist in warm tests of the WCS during 48 hours in steady state conditions corresponding to the maximum mass flow rate for each stage and maximum pressure ratio. 83

QQQ\_0474. The following values shall be permanently monitored during the tests: 83

QQQ\_0475. The Contractor shall estimate uncertainties on the measurements. The estimated uncertainty will be added or subtracted (depending on the measurement) to the measured values before checking the acceptance capacity criteria. 83

QQQ\_0476. The capacity test of the WCS will be deemed as successful when all compressors run at full charge during the full period of the test (48 hours), without any discontinuous operation and with acceptable temperatures of cooling water according to *3.4.4*. The accepted stability criteria are: for the LP: ± 3 % and for the HP: ± 2 %. 83

QQQ\_0477. After successful functional and capacity tests of the WCS, the functional tests of the QPLANT (Refrigeration Cold Box) could start. The functional tests shall include at least: 84

QQQ\_0478. The QPLANT capacity tests shall start when all the functional tests described above have been successfully completed and all specified documents have been provided. 84

QQQ\_0479. The QPLANT capacity tests shall be performed for the defined steady state modes (Cold stand-by; Thermal Shield stand-by; 2 K operation: Minimal and Nominal Design Points). 84

QQQ\_0480. The capacity tests of the steady state modes will be performed under the environmental conditions and utilities described in *3.4*. If conditions given are out of range during capacity tests, the Contractor in agreement with SCK CEN could propose a correction for the measurements. 84

QQQ\_0481. During capacity tests, the test heaters shall operate at least the required values defined in the heat loads table (Table 3). 84

QQQ\_0482. During each capacity test, the following values shall be continuously monitored: 84

QQQ\_0483. The Contractor shall estimate uncertainties on the measurements. The estimated uncertainty will be added or subtracted (depending on the measurement) to the measured values before checking the acceptance capacity criteria. 84

QQQ\_0484. The Thermal Shield stand-by capacity test shall consist of: 85

QQQ\_0485. The capacity tests of the QPLANT during Thermal Shield stand-by mode are deemed as passed if during the full period of the test, without any discontinuous operation, the achieved values verify the performance requirements described in Table 3and Table 4. 85

QQQ\_0486. The cold stand-by capacity test shall consist of: 85

QQQ\_0487. The capacity tests of the QPLANT during cold stand-by mode are deemed as passed if during the full period of the test, without any discontinuous operation, the achieved values verify the performance requirements described in Table 3and Table 4. 85

QQQ\_0488. The 2K operation capacity tests in stable conditions shall be performed for the nominal and minimal design points. It shall consist: 85

QQQ\_0489. The 2K operation capacity tests is deemed as passed if during all 2 K operation tests, without any discontinuous operation, the achieved values verify the performance requirements described in Table 3and Table 4. 85

QQQ\_0490. Test of the liquefaction rate at the end of cool-down: the liquefaction rate shall be at least 125 Liters per hours to cope with the filling requirements. With a static heat load of 560 watts applied on helium bath (at 4.5 K), the Contractor shall demonstrate the liquefaction rate which shall be kept for at least half an hour to validate the test. 86

QQQ\_0491. Test of the pumping rate of the cryomodule volumes: the Contractor shall demonstrate using the 2 K helium bath that the pumping of the 2 K helium cryomodule volumes (2900 liters) from 1.3 bars to 26 mbars could be performed in maximum 24 hours, with static heat load of 560 watts applied. 86

QQQ\_0492. Test of stability during transitions between the nominal and the minimal 2 K operation design points: The test of transition between the 2 K operation design points shall be performed with at least two cycles. It shall consist of: 86

The stability of the operation during the transition between the minimal and maximal 2 K operation is to be demonstrated. 86

QQQ\_0493. In the offer, the Applicant shall provide a top level list all components with a MTBF < 10 years or replacement rate >3 in 40 years. The Contractor shall then detail this list during the Contract execution. shall have a defined spares inventory and shelf life, aligned with the RCM plan. 86

QQQ\_0494. Throughout Contract performance the Contractor shall, at a minimum, deliver the documentation listed in Table 14. 88

QQQ\_0495. As part of *#DD04, t*he Contractor shall provide the necessary technical data and design datasheets of critical components such as heat exchangers, piping, rotating machines, and valve information with sufficient detail to allow SCK CEN to model the complete cryogenic system including the cryogenic plant in simulations. 88

QQQ\_0496. The Contractor shall provide all relevant information regarding materials and components including, but not limited to: 88

QQQ\_0497. The Contractor shall deliver a maintenance manual and lifecycle strategy documentation, including but not limited to: 88

QQQ\_0498. The process flow diagrams, process and instrumentation diagrams and temperature-entropy diagrams showing all the operation modes (including cool down) of the QPLANT shall be subject to approval by SCK CEN. 88

QQQ\_0499. The Contractor shall implement a comprehensive Lifecycle Cost Management (LCM) strategy supporting a fixed-price contractual framework. The LCM strategy shall integrate as per ISO 15288:2023: Capital Expenditure (CAPEX), Operational Expenditure (OPEX), Maintenance forecasting and spares replacement, Upgrade and obsolescence planning, End-of-life and disposal planning 90

It shall comply with principles and methodologies of: ISO 15686-5 (Lifecycle Costing), IEC 60300-3-3 (Reliability-Centered Maintenance), and ISO 55000 (Asset Management). 90

QQQ\_0500. In the offer, the Applicant shall explicitly describe, quantify, and justify their proposed Reliability-Centred Maintenance (RCM) strategy for QPLANT and QPLANT:CS. This shall include whether a validated digital model (e.g., process twin, thermodynamic model, control system simulation, or AI-based reliability estimator) is used to support diagnostics, predictive maintenance, and lifecycle cost reduction via virtual sensors and replacement deferrals. 90

*If a validated model is included, the Applicant shall provide:* 90

An explanation of how the model contributes to: 90

A quantified cost disclosure, covering: 90

*If no model is proposed, the Applicant shall:* 91

In the offer, the applicant shall provide: 91

SCK CEN is responsible for the Oxygen Displacement Risk Management. SCK CEN install and commission the required sensoring, alarming system, evacuation protocols etc. 92

QQQ\_0501. The Contractor shall provide all the required input to allow SCK CEN to correctly implement the ODH-system e.g accurate helium inventory. 92

QQQ\_0502. The design of the QPLANT shall follow the applicable technical standards for such kind of components (typically EN 13458) in addition of the specific requirements applicable for the project listed in the Applicable Documents. 92

QQQ\_0503. The Contractor shall provide to SCK CEN the applied codes, rules and standard for the design, manufacturing and testing of the QPLANT. 92

QQQ\_0504. The Contractor shall provide a EU declaration of conformity for the QPLANT and CE mark all QPLANT components. Therefore the Contractor shall at least: 92

QQQ\_0505. In case of any utility losses (electricity, compressed air, water, vacuum, etc.), the QPLANT shall ensure the safety of the QPLANT and people, minimizing as much as possible the loss of helium. 93

QQQ\_0506. A complete safety lifecycle including specific failure mode analysis (FMECA, HAZOP or equivalent) shall be performed by the Contractor during the design phase with the participation of SCK CEN. 93

Figure 13 Cool-down power for cold masses < 5 K (based on constant cool-down speed of 4 K/h ~ 72 hours). 111

When the magnetic shields temperatures are below 70 K, cool down of the cavities and couplers from the Thermal Shield temperature to 4.5 K can start. The QPLANT shall be able to remove at least the cool-down power during this cool-down phase is given in Table 17 and section *10.1*. 111

When the cavities reach the liquid helium temperature, the liquid filling of the helium baths can start. 111

Cool-down of cavity circuits to 2 K. This 2 K cool-down includes also a complementary liquid helium filling. The pumping duration to reach 31 mbar in every QM bath (+QVE) from about 1.3 bar shall be achieved in less than 24 hours. 112