



Document Title	ISIS Cryogenic Supply Systems – Hydrogen Specific Requirements		
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1 Introduction

1.1 Purpose

This Technical Specification defines the specific requirements for the design and manufacture of the Hydrogen Cryogenic Supply System (HCSS).

The requirements of this Technical Specification are in addition to those described in the companion document ISIS-TS1-UPG-SRV-Sp-0010 ISIS Cryogenic Supply Systems – General Requirements.

Requirements for the Methane Cryogenic Supply System (MCSS) are given in the companion document ISIS-TS1-UPG-SRV-Sp-0011.

1.2 System Overview

The system is required to provide cryogenic liquid hydrogen at stable temperature, pressure and flow rate at its outlet to the moderator vessel. The system is connected to the moderator vessel by a vacuum insulated transfer line (with concentric flow and return) routed through several meters of radiation shielding material.

All equipment is contained within a vacuum vessel in order to minimise heat loss, and refrigeration power is supplied from a helium refrigerator unit originally manufactured by Sulzer.

The existing equipment has been operating successfully for over 30 years and it is therefore critical that no change is made which is detrimental to current operation. As a minimum, the new HCSS must retain all functionality of the existing system including:

- Provision of stable hydrogen flow to the moderator within operating parameters.
- Connection with existing interfaces (hydrogen pipework, vent system, vacuum system).
- Compatibility with existing control system and software.
- Compatibility with available space on the Target Services Trolley.

Additionally, we are looking to implement improvements in the new system in terms of improved ortho/para hydrogen ratio provided by an enlarged catalyst volume.

1.3 Ortho and Para Hydrogen

Molecular hydrogen exists in two different forms, known as Spin Isomers: orthohydrogen, in which the protons spin in the same direction, and parahydrogen, in which they spin in opposite directions

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The Spin Isomers have different properties that affect their neutronic performance, and parahydrogen provides the optimum performance for our purposes.

The ortho/para fraction varies with temperature - at ambient temperature the ratio is approximately 75% orthohydrogen to 25% parahydrogen while at system operating temperature, the ratio is 99.9% parahydrogen. However, the conversion from orthohydrogen to parahydrogen is very slow, taking many hours to achieve desired levels. A catalyst is therefore required to speed up the process.

The new system shall therefore include vessel containing a suitable catalyst volume to allow a parahydrogen fraction of 99% to be maintained, while not adversely affecting system pressure, temperature and flow stability.

2 Overall System Design Requirements

2.1 Design Conditions

Design Pressure	:	Full Vacuum (0 BarA) – 20 barG
Design Temperature	:	4 K – 310 K*
Process Fluid	:	Hydrogen
Operating Pressure	:	7 – 8 barA
Operating Temperature	:	21 K ± 0.5K
Minimum Flow Rate	:	36.5 g/s
Refrigeration Power available	:	600 W Approx.
Pressure Drop across Moderator and Transfer Lines	:	0.45 bar Approx.
at Steady State Operating Conditions		
*except Catalyst Vessel and associated valves – see Section 4.7		

Additional loads resulting from equipment testing, for example the additional weight of liquid nitrogen, shall be considered.

2.2 Heat Loads

Estimated values in current equipment at steady state operation

Moderator	:	0 - 400 W
Heat Inleak	:	30 W
Transfer Line	:	60 W
Circulator Heat Input	:	60 W
TOTAL	:	150-550 W

2.3 Insulation Requirements

Total heat in leak for all equipment within scope of supply shall not exceed 30 Watts.

Insulation shall be sufficient to ensure that temperature and temperature stability requirements are met for all functionality described in Section 2.1

External surfaces shall be ice and condensation free during operation.

Heat loads shall be minimised wherever possible / practicable and supplier shall provide evidence of how this is achieved.

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Supplier shall provide specification of suitable insulation. It is anticipated that MLI shall be used on all appropriate surfaces.

3 System Functional Requirements

3.1 Modes of Operation

System operation is split into two main processes:

- System Cool Down
- Normal Operation

Additionally, shutdown/warm-up and routine maintenance operations will need to be considered.

3.1.1 System Cool Down

During initial start up the equipment shall follow the below procedure in order to achieve operating temperature.

- All system pipework (including transfer lines) is filled with gaseous hydrogen to operating pressure.
- Circulation pump starts up to start circulating gas around system.
- Refrigeration unit is switched on to begin cooling and circulating helium through the heat exchanger with the hydrogen.
- Hydrogen cools as it circulates around the system. When pressure drops below the lower set point, hydrogen supply valve PV222H opens to add more gas to the system. When pressure reaches operating pressure, PV222H is closed.
- Process continues until operational temperature is achieved.

Note that during this process, a significant period is encountered where 2-phase flow is present within the system.

In current operations, the duration of the System Cool Down process, from ambient temperature to operating temperature, is approximately 6 hours.

STFC recognises that cool down rate is largely dependent on the refrigeration capacity provided by the Helium Refrigerator. However, Supplier shall ensure that the equipment selection and system design allows a fluid flow to be maintained during the entire process, in order to provide constant and even cooling.

3.1.2 Normal Operation

System shall supply cryogenic liquid hydrogen at stable pressure, temperature and flow rate controlled within the design values and tolerances given in Section 2.1 to the outlet to the Transfer Line to Moderator Vessel.

Cold liquid hydrogen flows in a continuous closed loop between the heat exchanger and the moderator, driven by one circulator (while the other is on standby).

- Pressure is controlled in the main circuit within limits (upper / lower set point). If pressure drops below lower set point, hydrogen supply valve PV222H opens and additional gas is



added to the system until operating pressure is restored. If pressure reaches upper set point, hydrogen vent valve SV182H opens until operating pressure is restored.

- Temperature is measured by temperature sensor TS50 downstream of the heat exchanger. This feeds back into the Sulzer Helium Refrigerator, which then controls the cooling power provided to the hydrogen.

3.1.3 Shutdown for Routine Maintenance

During shutdown, refrigeration power is turned off and the hydrogen allowed to warm up gradually to ambient temperature – no additional process heating is required. During this period, normal pressure control is maintained.

Once ambient temperature and pressure have been achieved, the system is subject to a purge/vacuum cycle (repeated 3 times) with helium in order to remove all flammable fluid.

After maintenance has been carried out, the system is subject to a purge/vac cycle (repeated 3 times) with helium in order to remove any air. The system is then subject to a purge/vac cycle (repeated 3 times) with hydrogen in order to remove all inert gas. The HCSS is then ready for the system cool down process (see Section 3.1.1)

4 Mechanical Design of HCSS Components

4.1 Coldbox Vacuum Vessel

All equipment, except where stated, shall be enclosed within a single vacuum vessel.

The vacuum vessel shall be fitted with suitable provision to allow lifting into position.

Vessel material shall be austenitic stainless steel, Grades 304, 304LN or 316.

Pressure rating*: Full vacuum (0 barA) – 0.5 barG

*In combination with the Coldbox Vacuum Vessel Top Plate.

4.1.1 Coldbox Vacuum Vessel Connections:

- Vessel top plate
- Port on underside of vessel for vacuum connection
- Port on underside of vessel for vacuum gauges connection

4.2 Coldbox Vessel Top Plate

The Coldbox Vessel Top Plate shall be designed, in combination with the Coldbox Vacuum Vessel, to support all equipment contained within and all associated equipment above (for example circulator motors, valve actuators, etc.), including any additional loads resulting from equipment testing, for example the additional weight of liquid nitrogen.

The Coldbox Vacuum Vessel Top Plate shall be fitted with suitable provision to allow lifting into position. This provision shall have sufficient capacity to allow the Top Plate, Vacuum Vessel and all connected equipment and pipework (as supplied) to be lifted as one item.

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4.2.1 Coldbox Vacuum Vessel Top Plate Connections

With the exception of those connections listed in Section 4.1.1, all process, equipment and instrumentation connections shall be routed through the Coldbox Vessel Top plate.

Required connections include (but not limited to):

- Hydrogen Supply/Vent
- Transfer Line to moderator vessel
- 2 x Circulators
- Valves
- Temperature sensors
- Pressure sensors
- Vacuum overpressure relief device connection
- Flow Meter
- Catalyst Vessel
- Helium Refrigerator Transfer Lines (Flow and Return)

4.3 Transfer Lines to Helium Refrigerator

Vacuum insulated transfer lines are used to supply and return helium from/to the Sulzer Helium Refrigerator.

Existing transfer lines will be used, supplier to provide a suitable connection – see Section 5.2

4.4 Internal Pipework

Supplier to design pipework in order to meet system operational requirements.

Pipework shall be fully welded except where identified, or where an alternative jointing method is unavoidable.

Any non-welded joints used must be agreed by STFC.

Pipework layout should be designed to limit low points where oil/contaminants can accumulate.

Pipework layout should be designed to limit high points where gas bubbles can accumulate.

4.5 Circulators

4.5.1 Scope of Supply

Supplier shall provide 2 off installed circulator pumps

Supplier must also provide 1 off complete spare pump and 1 off maintenance kit for each pump.

Supplier shall provide control equipment (for example Variable Frequency Drive) to allow the pumps to be controlled by ISIS PLC Control System.

4.5.2 Design Requirements

The HCSS shall incorporate 2 circulators pumps. In operation, one circulator will be active while the other is on cold standby.

Each circulator shall be sized for full system operation.



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Standby circulator must be kept ready for operation – i.e. at operational temperature

Circulator shall be certified for use in ATEX Zone 2 area as described in Section 5.7 of the General Requirements document (ISIS-TS1-UPG-SVS-Sp-0010).

NOTE that the circulator and drive must be certified together as a system.

Units shall incorporate the facility to be lifted individually.

Circulators must be capable of providing stable flow at the design flow rate at the system operating conditions for all operational modes as described in Section 3.12.1 (except where noted below).

In particular, the following design requirement should be noted:

Gas / Liquid / 2-Phase Flow Capability

The circulators shall be designed for Liquid operation but shall also operate as vapour blowers and be able to operate in conditions of 2-phase flow created during System Cool Down procedure.

Hydrogen gas is introduced to the system and cooled to liquid while it is circulated. There is therefore an unavoidable period (typically 5 hours in the existing system) where the fluid is a mixture of liquid and gas phase, and the circulator must be able to operate in these conditions without damage to the circulator or loss of circulation of the fluid.

NOTE: it is acceptable for the flowrate achieved during cool down phase to differ from that at full system operation, i.e. the circulator can run at a reduced rate in order to cope with 2-phase flow.

However, the fluid flow must be maintained during the entire process at a flow rate sufficient to achieve constant and even cooling.

4.5.3 Maintenance

Routine maintenance should have a minimum period of 12 months.

Circulators shall be removable for maintenance without breaking vacuum in the coldbox vessel.

4.5.4 Control

The circulators shall be controlled from PLC located outside of the TSA. Supplier shall provide suitable pump control equipment, for example VFD, to interface with PLC. Speed control method to be agreed by STFC; this can be achieved using standard industrial network protocol, voltage or current loop.

Any electronics used for pump control must have the capability to be cabled, using an Atex compliant method, through the shield wall to the outside of the TSA - minimum 60m cable (suitable for routing along drag chains) required.

4.6 Heat Exchanger

4.6.1 Function

Cooling power to the hydrogen shall be provided from the Sulzer Helium Refrigerator Unit by means of a heat exchanger within the hydrogen vacuum vessel.



Supplier shall design and incorporate a heat exchanger unit capable of providing sufficient cooling power in order to control the hydrogen temperature

4.6.2 Summary of Parameters

An extract from the Sulzer Technical manual is provided as an appendix to this document.

Note that the design values given below are taken from the Sulzer Technical Documentation Provided at initial installation. At this point, the Hydrogen was operated at 15 bar and 22K.

The system operation was changed after installation to the values given in Section 2.1. No modification was made to the Helium Refrigerator at this time and the unit has operated successfully in this configuration for 30+ years.

Cooling Capacity	:	600 W
Helium Supply Temperature	:	17 K
Helium Supply Pressure	:	2.1 Bar
Helium Return Temperature	:	21 K
Helium Flow Rate	:	32 g/s

4.7 Catalyst Vessel

Supplier shall provide a suitable vessel, filled with catalyst material, to enable the system to maintain a stable parahydrogen fraction of 99%.

4.7.1 Design Requirements

Catalyst Type:	:	Hydrous Ferric Oxide (Ionex type O-P catalyst)
Minimum Catalyst Volume:	:	5 L
Vessel Design Pressure:	:	Full vacuum (0 barA) – 20 barG
Design Temperature:	:	4 K – 350 K

NOTE that Design Temperature is higher than that of the rest of the system.

Catalyst vessel shall allow full flow across the catalyst.

60µm filters shall be incorporated at the inlet and outlet of the Catalyst vessel in order to contain the catalyst material and to protect against the possibility of catalyst being released into the system in the event that the material breaks up over time.

Vessel shall be designed to prevent fluidisation of catalyst material during operation.

4.7.2 Catalyst Loading

Supplier shall be responsible for loading catalyst during equipment manufacture.

Equipment shall be delivered to STFC with the catalyst ready for use. The Supplier shall, in advance of shipping, carry out any preconditioning of the catalyst that is required or recommended by the catalyst manufacturer.

Catalyst material can be degraded by contact with moisture. It is therefore critical that catalyst does not come into contact with air or any other source of moisture at any time.



Supplier shall design the system in such a way as to prevent air/moisture ingress during catalyst loading.

4.7.3 Valve Arrangement

Valve arrangement shall be such that it is possible to isolate the catalyst vessel from the hydrogen circuit and seal in the contents.

4.7.4 Catalyst Regeneration

There is a possibility that the catalyst will require regeneration during its service lifetime. This can be achieved by heating the catalyst while passing dry gas across it.

The valve and piping arrangement shall therefore be suitable to allow hot, dry gas (nitrogen at 350 K) to be pumped through the catalyst material and vented, while the vessel is isolated to the rest of the system.

The vessel shall be made accessible to allow the fitting of a heater for the regeneration operation. It is anticipated that this will be achieved by positioning the vessel within a removable 'top hat' extension of the vacuum vessel – see Drawing Ref: *SI-5600-100 Sheet 3 – Detail B*.

4.7.5 Instrumentation

The conversion from orthohydrogen to parahydrogen is exothermic and so a small temperature rise is expected across the catalyst vessel. The magnitude of the temperature rise can be utilised to find the amount of conversion taking place within the vessel.

The catalyst vessel shall be equipped with suitable temperature sensors located at its inlet and outlet.

Sensing elements should be positioned such that they are in direct contact with the hydrogen fluid.

Due to the small temperature changes involved, these sensors require much greater accuracy than other system temperature sensors – see Section 4.11.2

4.8 Filter

An additional 60µm filter is required in order to protect the circulator pumps from any debris accumulated in the system during manufacture.

Filter should be located immediately upstream of the circulator pumps.

The filter must have the facility to be removed for filter element replacement.

Supplier to provide one spare filter element.

4.9 Cryogenic Valves

Supplier should provide suitable valve arrangement to allow the system to be operated as described in Section 3.

Supplier to provide one complete spare and one maintenance kit for each valve type used.

All valves, except where specifically identified, shall be remotely operated by PLC control system.

Valves must have the provision to allow routine maintenance without breaking into coldbox vacuum.

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Where 3-way valves are used, they must be designed such that it is not possible to close off both outlets simultaneously.

Valves shall be fitted with suitable means to communicate position to PLC (Position switches).

Valves and ancillary equipment including actuators and position switches shall be certified for use in ATEX Zone 2 area as described in Section 5.7 of the General Requirements document (ISIS-TS1-UPG-SVS-Sp-0010).

Valves shall fail to safety (TBD on valve-by-valve basis during the Design Phase).

Valves should have the capability to be locked in position to allow maintenance

4.10 Relief Devices

4.10.1 Process Safety Relief Devices Valves

Supplier to supply appropriate safety relief devices to protect the system

Pressure Relief Valve Set Point: 165 PSIG (11.4 BarG)

Bursting Disc Set Point: 13 BarG

Safety Case shall be the total loss of vacuum in the entire moderator system

Relief devices will vent to ISIS Relief System pipework. STFC shall provide details of the Relief System pipework during Design Phase

4.10.2 Vacuum Relief Devices

Supplier shall provide appropriate overpressure relief devices for the protection of vacuum equipment

Pressure Rating: 0.5 barG

Safety Case: Full bore pipe leak into vacuum space

Vacuum relief devices will vent to ISIS Relief System Pipework. STFC shall provide details of the vent System pipework during Design Phase.

4.11 Instrumentation:

Supplier to provide suitable instrumentation to allow the system to be operated as described in Section 3.

All instrumentation shall be ATEX compliant, and supplier shall provide evidence of how this is to be achieved as part of the tender package.

Supplier to provide suggested Instrument List at Tender Stage.

Supplier to provide Finalised Instrument List for STFC agreement at completion of design stage.

4.11.1 Temperature Sensors – Control

Temperature Sensor at location TS50 is used for control of the Helium Refrigeration Unit.

Suppliers to install 2 x Temperature Sensors at this location for redundancy.



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Sensing elements should be installed such that they are in direct contact with the hydrogen fluid.

Supplier shall be responsible for sensor selection. Sensors shall be of a type suitable for use with neutron radiation. Existing equipment utilizes silicon diode type and so STFC have good experience of the reliability of this equipment in radiation conditions. Additionally, Carbon Ceramic Cryogenic sensors and Cernox are used successfully at similar facilities.

Required accuracy : ± 0.1 K at Operational Temperature
 Reproducibility : ± 20 mK at Operational Temperature

Supplier to terminate with Atex suitable connection

Wherever possible, it should be possible to extract and reinstall temperature sensors from the system without the need to break the coldbox vessel insulating vacuum, to allow for the replacement of failed sensors.

4.11.2 Temperature Sensors – Catalyst Vessel

Temperature sensors located at its inlet and outlet to catalyst vessel are for use in monitoring Catalyst performance – see Section 4.7.5.

Sensing elements should be installed such that they are in direct contact with the hydrogen fluid.

Due to the small temperature changes involved, these sensors require much greater accuracy than other system temperature sensors:

Supplier shall be responsible for sensor selection. Sensors shall be of a type suitable for use with neutron radiation. Existing equipment utilizes silicon diode type and so STFC have good experience of the reliability of this equipment in radiation conditions. Additionally, Carbon Ceramic Cryogenic sensors and Cernox are used successfully at similar facilities.

Required accuracy : ± 0.10 K at Operational Temperature
 Reproducibility : ± 5 mK at Operational Temperature

Supplier to terminate with Atex suitable connection

4.11.3 Temperature Sensors – Diagnostic

Temperature Sensors at other locations are for use in system diagnostics only.

Suppliers to install 1 x Temperature Sensor at each location.

Sensing elements should be installed such that they are in direct contact with the hydrogen fluid.

Supplier shall be responsible for sensor selection. Sensors shall be of a type suitable for use with neutron radiation. Existing equipment utilizes silicon diode type and so STFC have good experience of the reliability of this equipment in radiation conditions. Additionally, Carbon Ceramic Cryogenic sensors and Cernox are used successfully at similar facilities.

Required accuracy : ± 0.25 K at Operational Temperature
 Reproducibility : ± 20 mK at Operational Temperature

Supplier to terminate with Atex suitable connection



Wherever possible, it should be possible to extract and reinstall temperature sensors from the system without the need to break the coldbox vessel insulating vacuum, to allow for the replacement of failed sensors.

4.11.4 Pressure Sensors

Supplier to provide pressure tapplings for sensor attachment at Coldbox Vessel Top Plate.

Pressure sensors shall be supplied by STFC.

Supplier to terminate pressure tapping with suitable tube fitting, to be determined during Design Phase.

4.11.5 Flow Meter

Flow meter required for system diagnostics only – not used as part of system control.

Flow meter shall give a measurement of liquid hydrogen flow rate during Normal System Operation.

Flow Meter type	:	Differential Pressure/Orifice Plate
Fluid Conditions	:	See Section 2.
Flow Range	:	0 – 1.0 L/s*
Accuracy	:	± 5%
Output	:	0 – 10 V

Electronics cannot be located within the TSA. Equipment must have the capability to be cabled through the shield wall to the outside of the TSA - minimum 60m cable (suitable for routing along drag chains) required.

*To be confirmed during design phase, dependent on maximum flow capacity of system.

5 Interfaces

5.1 Transfer Line and Moderator

The HCSS is connected to the moderator vessel via a vacuum insulated transfer line by means of concentric flow and return lines.

The transfer line is routed through existing concrete and steel shielding blocks and its location, as shown on Layout Drawing: *Ref SI-5600-100 Sheet 2*, is therefore fixed.

An adaptor piece, provided by STFC, will be used to connect between the coldbox top plate and the point at which the transfer line enters the shielding.

A suitable connection shall be provided for this adaptor piece – to be determined during Design Phase.

Moderator Vessel Volume	:	0.9 Litres Approx.
Transfer Line Total Volume	:	14.5 Litres Approx.
Pressure Drop across Moderator and Transfer Lines at Steady State Operating Conditions	:	0.45 Bar Approx.

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5.2 Helium Refrigerator

The Helium Refrigerator location, as shown on Layout Drawing *Ref SI-5600-100 Sheet 4* should be considered fixed for quotation purpose.

Additional information about the Helium Refrigerator Unit is provided in the attached document *ISIS-TS1-UPG-SVS-Eq-0001*.

Connection between the Hydrogen Coldbox and the Helium Refrigerator Unit is via two transfer lines.

Connection Type is Weka Coupling TLK-G DN25/PN25.

5.3 Hydrogen Supply / Vent

Hydrogen Supply pressure is 8.5 BarA

Pressure in the vent system is controlled between 1.2 BarA and 1.5 BarA.

Hydrogen supply and vent pipework will be installed by STFC

Supplier to terminate with pipe stub or other suitable connection type (to be agreed during Design Phase), so allow connection into STFC pipework systems.

5.4 Relief System

Equipment shall be connected into existing relief system by STFC.

Total number of connections shall be minimised. Wherever possible, connections to the relief system shall be combined with supply/vent connections.

5.5 Vacuum System

Supplier shall provide vacuum connections, located on under-side of the coldbox vacuum vessel to allow STFC to connect into existing vacuum system.

Supplier shall provide suitable vacuum connections if additional separate vacuum vessels are used.

Connection size to be agreed with STFC during Design Phase

Connection type shall be ISO-K or ISO KF Flange.