# Statement of Work

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Document Title: Hall D Cryogenic Liquid Hydrogen Target
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# Hall D Cryogenic Target Statement of Work

## 1 Scope

This document is a statement of work (SOW) for the Hall D cryogenic hydrogen target. This target system is closely modeled after the Hall B target with the major exception of a dedicated commercial refrigerator rather than the use of the ESR. The target system has several major subsystems which are listed in Section 3. The entire system shall be designed, fabricated, examined, tested, installed, and operated in compliance with JLAB EHSQ 6151.

## 2 Applicable codes and standards

The following codes and standards and those referenced therein are applicable to the design and or fabrication of the system.

1. JLAB EHSQ 6151 Pressure Systems Program
2. 10 CFR 851
3. ASME B31.12 Hydrogen piping and pipelines
4. ASME Boiler and Pressure Vessel Code Sections II, V, VIII, and IX
5. CGA G5.5-2004 (2007) Hydrogen Vent Systems
6. NFPA 2 Hydrogen Technologies Code

### 2.1 Code of Record

The following table outlines each subsystem and the Code of Record

| | |
|---|---|
| Hydrogen piping | B31.12 2011 |
| Hydrogen tank | ASME BPVC VIII D1 2010 |
| Hydrogen Vent | B31.12 2012 |
| Vacuum | N/A |

## 3 General Design

### 3.1 Overview

The following is a list of subsystems which make up the Hall D target system.

1. Hydrogen gas storage and handling
2. Hydrogen vent
3. Insulating vacuum (OVC) and scattering chamber
4. Internal hydrogen piping, heat exchanger, and cell
5. Refrigerator hoses, valves and cold head
6. Refrigerator cooling water
7. Electronics and controls

| Parameter | Value |
|---|---|
| MDMT | 15K |
| Cell design pressure | 50 psi |
| Piping design pressure | 100 psi |
| Max Temp | 120F |
| Fluid Service | Hydrogen |
| Operating pressure (cold) | 18 psia |
| Operating pressure (300K) | 25 psia |

Table 1: Hydrogen piping and pressure component design parameters.

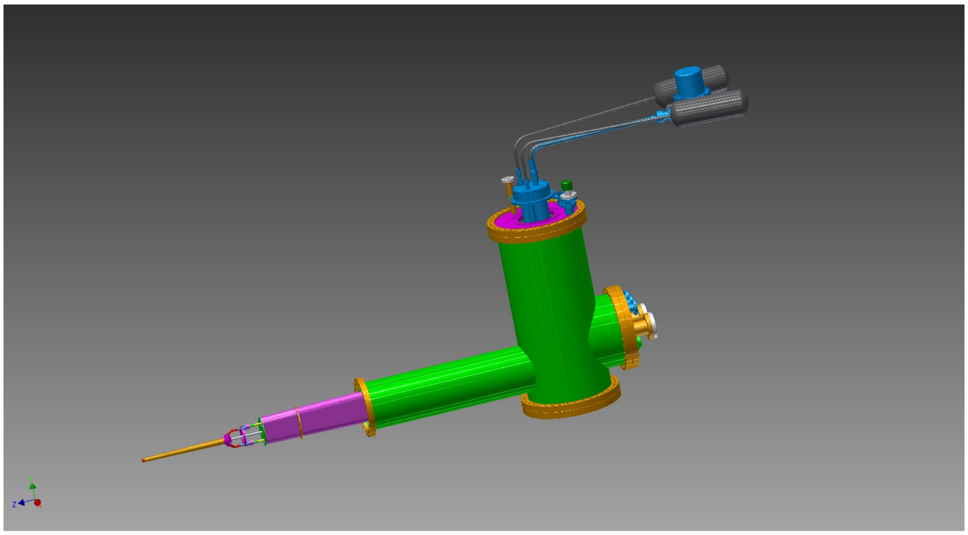

Figure 1: Preliminary model of Hall D Cryogenic Target

Each subsystem is discussed in some detail in later sections. The code of record for the hydrogen wetted components shall be B31.12 2012. The hydrogen piping and pressure components shall have the design parameters shown in Table 1. The total system volume and total liquid volume (when the system is cold) will not be known until testing is completed. Procedures for the safe operation and configuration of the entire target system shall be developed and maintained in DocuShare. Only trained operators shall be allowed to interface with the system.

## 3.2 Preliminary design

The preliminary design of the target internal piping and scattering chamber is shown in Figure 1. The key element in the system is the target cell where the photon beam interacts with the target fluid. For experimental physics reasons, the target cell is made primarily of Kapton with adhesive bonded seams. Due to its thin walls and fabrication from an unlisted material, there is no applicable national consensus code. This component will require a JLAB peer review. All other internal hydrogen piping components shall be designed and fabricated to B31.12 2011.

## 3.3 Cryogenic Components

The largest cryogenic component is the condenser. This component shall be designed and fabricated in compliance with JLAB policy "Policy for Fracture Toughness Testing Requirements for Pressure Systems and Components at Low Cryogenic Temperatures". Using this policy and UHA 51(g) it is expected that all components will be exempt from any impact testing. The cell is constructed from kapton and torlon which, based on extensive experience at JLAB, are both compatible with cryogenic service. With the exception of the cell, stainless steel, aluminum alloys and copper will be used for all other wetted parts. These metals are all compatible with hydrogen service at the system design pressure and temperature [1].

# 4 Design summary

This section gives some detail on each major subsystem.

## 4.1 Scattering chamber and vacuum system

The scattering chamber and vacuum system shall be compatible with hydrogen service. Interlocks shall be employed to ensure that power to gauges is interrupted during off normal vacuum conditions. Isolation for pumps not rated for hydrogen service shall also be engaged by these interlocks.

The scattering chamber is considered a secondary containment for the hydrogen cell in case of a rupture. Therefore, the chamber shall be relieved through a check valve to the hydrogen vent. A pressure rating for the scattering chamber shall be required and the check valve chosen such that this pressure is not exceeded. The scattering chamber vacuum system is shown in P&ID TGT-401-0001-1000.

## 4.2 Cold head and compressor

The cold head, connection lines, and compressor have already been purchased. The system is an unmodified commercial system with a UL listing. All paperwork shall be placed in the appropriate DocuShare folder. No further design calculations or inspections shall be performed. As an equipment protection, the compressor power shall be interlocked to cooling water flow.

## 4.3 Cooling water system

A dedicated cooling water system will be needed to operate the compressor for the cold head. This system must be specified. Many commercial systems would meet the requirements for this compressor.

## 4.4 Hydrogen storage

An ASME U-stamped vessel, with a capacity sized to give a warm pressure less than 26 psia and a cold pressure of 18 psia, shall be used for hydrogen storage. This tank will be permanently affixed to the insertion cart and connected to the gas handling system. The fittings on this tank must be modified slightly for use. A vacuum leak check shall be required as well as a final pressure test to ensure a leak tight system. The tank shall be connected to the main supply line to the gas panel as shown in the system P&ID TGT-401-0001-1000. Material for this tank shall be compatible with hydrogen service as listed in ASME B31.12. An operating pressure of 100 psi will ensure an acceptable margin of safety for overpressure protection.

## 4.5 Internal hydrogen piping

All internal hydrogen piping including the cell and relief line shall be designed for cryogenic service (see Section 3.3). This piping shall be designed and fabricated to B31.12 2011. All components with the exception of the cell shall be reverse pressure tested with a He mass spectrometer as an assembly to 55 psia using a pneumatic test with He as a test fluid. The cell shall be pneumatically tested at 55 psia using snoop or other similar leak testing method. The gas panel reliefs must be plugged for this test. The piping connections with the exception of the cell shall be made using welds or standard Swagelok fittings (VCRs). The design pressure for components other than the cell shall be 100 psi; the cell design pressure shall be 50 psi. All components will be exposed to the insulating vacuum (IV) which has been accounted for in the design pressure rating. The internal hydrogen piping system is shown in P&ID TGT-401-0001-1000.

The hydrogen cell is the most critical component of the system. For physics reasons, the cell must be fabricated from a low Z material having minimal thickness. The hydrogen stored in the cell is expected to boil slowly under normal conditions. The escaping gas bubbles must exit the cell and not cross the path of the beam. The thin walls of the cell also affect the pressure rating of the component. Two tests indicate that the current cell design withstands pressures up to 180 psi. There is however some variation in fabrication of cells. A strict code proof test requires a minimum factor of safety of 4 with a well known joint efficiency. The cell main body is fabricated from kapton sheet with a longitudinal lap joint using 3M DP-190 epoxy. The joint requires some hand work to taper the kapton sheet such that the lap joint will have the same thickness as the rest of the cell. Initial testing indicates that the epoxy is not the weak point in the joint and that the thinner sections of kapton are most likely to fail during a pressure test. Further testing is planned to better quantify the joint strength.

### 4.6 Gas handling

All hydrogen gas handling piping shall be designed and fabricated to B31.12 2011. The piping design pressure shall be 100 psi. All piping external to the OVC shall be stainless steel 304/304L or 316/316L. No piping larger than 1 1/4 in IPS shall be needed for this subsystem. The gas panel shall be installed on the insertion cart with hose connections to the main supply line from the storage tank. Flex hoses shall also be used to connect the gas panel to the top of the target on the OVC. If required a formal flex analysis of the piping system shall be performed using CaePipe. Loadings will be determined using ASCE-7 2005. The gas panel and connecting hoses will not require a formal flex analysis. Gauges will be located on the gas panel as will a vacuum pump for purification operations. The gas handling system is shown in P&ID TGT-401-0001-1000. A pneumatic pressure test shall be required with a test pressure of 110 psi. Gauges and reliefs shall be protected during this test.

### 4.7 Hydrogen vent

All hydrogen or potentially hodrogenic gas shall be vented to the atmosphere through the hydrogen vent system. This includes hydrogen from a relief event and pump exhaust from both the scattering chamber vacuum system and the gas panel vacuum pump. The piping consists of a 2 in IPS Sch 5 SST pipe which shall be capped with a parallel plate relief in a stack at least 40 ft from the hall exterior wall or air intake or 5 ft above the roof line of the hall. This line must have a design pressure of 150 psi as required in NFPA 2 which references CGA 5.5-2. The pipe shall be connected using 150# B16.5 fittings, Conflat flanges, or welds. Flexibility shall be added to the system as required using either expansion joints or flex hose assemblies. A formal flex analysis of the vent system shall be performed using CaePipe. Loadings will be determined using ASCE-7 2005.

The system shall be kept under a constant positive pressure of $< 2$ psig using an inert gas. This gas is assumed to be N2 from the house supply system. A low pressure alarm on the vent pressure shall indicate in the counting house and automatic paging system. The vent system is shown in P&ID TGT-401-0001-1000. A penetration in the exterior wall of the hall will be required for the 2 in pipe.

## 5 Overpressure protection

There are two credible sources of overpressure: 1) loss of insulating vacuum and 2) fire. It is assumed that all piping with a diameter less than 6 inch NPS need not be protected from overpressure due to fire in concurrence with future JLAB policy. A conservative estimate for the cell pressure during a loss of vacuum event is 45 psia (see TGT-CALC-401-001). The two parallel relief valves on the gas panel are connected to the internal target piping and cannot be isolated without breaking the system. Icing of the relief line is not considered possible due to the low refrigeration power. The parallel relief paths give a code allowed accumulation of 16%. Both valves exhaust into the hydrogen vent. However, during a loss of insulating vacuum event all hydrogen from the internal components of the target is expected to relieve through the main one inch check valve on the gas panel and return to the storage vessel without loss of hydrogen to the environment. The path to the target has three ball valves which shall be locked open during operation. The only credible source of overpressure for the hydrogen storage vessel is from fire. API and NFPA give guidance for determining heat loads from fire. A liquid hydrocarbon fuel fire with proper drainage shall be considered worst case failure mode for the vessel. Relief shall be through a single relief valve located on the tank with locking isolation valve for maintenance. The required relief capacity for deuterium as a target fluid is less than that of hydrogen therefore no additional capacity need be considered.

# 6 Hydrogen Safety

General hydrogen safety shall be provided by compliance with the listed codes and standards. Consultation with JLAB fire protection engineer has determined that any electronics near the gas panel, scattering chamber or main piping systems do not require a classification for hydrogen service. Vacuum pumps shall be driven by non-sparking induction motors. The supply bottle will require isolation from all electrical devices not meeting NEC Class 1 Division 2 Group B. It is assumed that the gas bottle must be 5 ft from potential ignition sources in plane and below and 12 ft from ignition sources located above. This shall be confirmed and approved by JLAB the fire protection engineer. It is assumed that a proper place for this bottle may be found near an exterior wall.

All gauges located on the scattering chamber vacuum shall be suitable for hydrogen service or power interlocked by high pressure alarm on scattering chamber vacuum. In the event of a cell rupture, the heater power, cold cathode gauge, and turbo pump shall be isolated or deenergized.

# 7 Required reviews

A review of the entire system shall be required by an internal JLAB team as determined by physics division management. The cell shall be peer reviewed by at least one JLAB design authority (DA) not associated with the Hall D target. The remaining components shall be reviewed any JLAB DA. The entire system shall be reviewed by JLAB EHSQ Q-A representative and the JLAB fire protection engineer.

# References

[1] ASME B31.12 Hydrogen Piping and Pipeline Code, American Society of Mechanical Engineers, NY 2012.

[2] API 521 Relief Device