Temporary Operational Safety Procedure (TOSP)

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Title: **G0 Target Hydrogen "No-Beam" Tests**	
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Risk classification (See EH&S Manual Chapter 3210.)	Without mitigation measures: 1
	With specified measures implemented: 0
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G0 Cryotarget Hydrogen "No Beam" Tests in Hall C at Jlab

Silviu Covrig, May 23, 2002

1. Purpose

To quantify the performance of the G0 cryogenic target with liquid Hydrogen in the intrinsic conditions of the G0 experiment in Hall C and to determine the coolant needs and consumption from the target only.

2. Introduction

The commissioning plan for the G0 cryogenic target has two parts. The first part is the commissioning of the target with "no beam" or the "pre-beam" commissioning, and the second part is the commissioning of the target in beam. The pre-beam commissioning plan for the G0 target has three steps, all of which have to be completed, according to the general G0 Installation Schedule, by mid June. The first step, the installation of the target system into the Hall, has been completed. For the second step the target has to pass a safety test consisting of a simulated sudden loss of vacuum when the target is full of liquid Neon and the subsequent boil off of Neon. The second step is supposed to start on May 28 and be finished by the end of May. The third step and the last one that the target has to go through before being declared "ready for beam" is the subject of this TOSP and consists of liquefying Hydrogen for the first time in this target, assessing the overall performance of the target with LH_2 in more or less the same way it was done in [1] and determining the coolant load on ESR from the G0 target only.

3. The G0 Target System

The G0 target system consists of a cryogenic loop, a gas handling system, a coolant circuit, and controls. For the target "in beam" position the cryogenic loop sits horizontally inside the G0 Superconducting Magnet Spectrometer (SMS) and is held in place by the target service module (SM). The target cell is an Al can 6 mils thick on the outer walls, 20 cm long for electrons and 5 cm in diameter. The can is soldered on an Al manifold that mates through transition Al-stainless CFs to the two horizontal legs of the loop. At the end opposite to the target cell the two legs of the loop are connected through a bellow. One of the legs contains the cryogenic vane-axial pump that operates with the motor immersed, and pushes the target fluid round the loop, the high power heater that can go to a maximum of 1000 W, and a tachometer for monitoring the pump rotational speed. The other leg contains the heat exchanger and the low power heater that can go to a maximum of 80 W. Along the loop there are six temperature sensors immersed into the fluid that will be in the loop for temperature monitoring. The service lines to the loop connect across the cryogenic pump, the coolant service lines connect across the heat exchanger. The coolant circuit intrinsic to the target system is instrumented with three temperature sensors, two of them are

connected right at the inlet and outlet of the heat exchanger, the third one is connected right before the JT valve for the target coolant. The gas handling system consists of a gas panel for gas distribution to the target, service lines and a ballast tank. The coolant circuit consists of service lines, two female bayonets that connect the target internal coolant lines to the U-tubes in Hall C and a JT valve for coolant control. All this coolant circuit is inside the SM. Controls consist of instrumentation for target system monitoring and control, a dedicated target control computer for operating and reading the instrumentation, a software package with various GUIs for target monitoring and control and an archiver for data logging. For a full description of the target system and the latest changes to the system please refer to [2, 3, 4].

During normal operation in beam, the heat load on ESR from the target system is expected to be less than 500 W. The volume of the liquid in the target is supposed to be less than 8 liters. The volume of the loop as estimated by C. Jones [2] is 6.6 liters, the volume for liquid as conservatively estimated by K. Gustafsson [3] is 8 liters and accounts for the latest changes in the internal Hydrogen service lines and assumes that the interface between liquid and vapor will be in the vertical line inside the cryocan. When this volume, the 8 liters, is filled with LH_2 we expect the target to contain no more than 560 grams of H_2. The normal operating point with liquid Hydrogen is 2 K subcooled liquid at 20 K/25 psia in the loop. The thickness of the target in these conditions is 1.402 g/cm^2. The nominal G0 electron beam for forward scattering, of 40 μA and 3 GeV, has 120 kW total power, of which about 350 W will be heat deposition into the target. Additional heat load to the target should be less than 150 W, making the total heat load on ESR to be less than 500 W. The additional heat load comes from the cryogenic motor that powers the pump and from the thermal and radiative loses of the loop to the outside world, which, for this target loop, will be a liquid Nitrogen shield that envelops the inner core of the SMS.

The G0 cryogenic target system underwent several tests in the Test Lab during the last year and a half. A complete description of the tests is given in [3, page 7]. The target system passed all the required controlled static pressure tests and went through several cool-downs with Helium on Helium in the Test Lab at JLab that tried to assess the performances of the cryogenic pump and heat exchanger and the overall functionality of the target controls. Based on these tests several improvements have been implemented and tested. We found from these tests that the initial proposal for a motor for the cryogenic pump is not adequate. The G0 target has very tight space constraints. The horizontal loop has to fit inside a tube of 2' diameter and the motor that drives the cryogenic pump is supposed to work immersed. Our initial proposal for a motor that would fit the space constraints in the loop and will have negligible magnetic interference with the SMS didn't prove to have enough torque to deliver the nominal flow for G0 in cryogenic conditions. We found stronger motors on the market that would fit the space constraints and as general common characteristics, that are also different from the original motor, they are three orders of magnitude higher in price than the original motor, contain strong permanent magnets and are rated for cryogenic conditions. We settled for solutions from two different vendors, a step motor from Phytron and a sensorless brushless DC motor from Barber & Nichols. Both these motors have been tested in a closed mini-loop in LN_2 in March 2002 and they proved to be cryogenic units. The cryogenic DC motor made by Barber & Nichols was also tested in cold He in the Test Lab with the G0 target loop and after we tuned the controller its performance was as expected. This is the motor that we will use for the rest of the commissioning plan. The Phytron motor will be a spare. Each motor has its own fully assembled pump.

The heat exchanger performance in the Test Lab with He on He was as expected from semiempirical heat exchange computations. Anyway, we cannot make a clear statement about the heat exchanger performance in the Hall until we test it there since the coolant conditions in the Hall are very different from those in the Test Lab (TL coolant, He at 4.5 K/ 3atm; Hall C coolant He at 15 K/ 20 atm), and in the Hall we'll have He on H_2. The heat exchanger has a flow diverter, an Al plug, in the middle of it that forces the liquid to go through the fin tubing. We found no significant change in the heat exchanger performance whether the plug is in or not [see 2, Appendix E, for a description of the heat exchanger], but based on a JLab recommendation we put the plug in and will stay in for all the tests for target commissioning.

Target controls were continuously improved and now there is a manual that describes them posted on the web [4]. This manual will be continuously updated to include the most recent changes to target controls. U.Md. subgroup of the G0 target group is responsible for target controls. Target monitoring relies on a combination of GUIs in MEDM and StripTool. Steve Wood from Hall C provided us, more than a year ago, with a Linux box to run the target controls. This computer is now the dedicated G0 target control computer, gzerol2.

Based on a recommendation made by the G0 Target Safety Review Committee that met at JLab on Feb 11, 2002, the internal service lines for H_2 have been redirected to come out of the service module on top of the cryo-can instead of the side of the service module, to add some vertical drop for a more stable interface between liquid and gas [5,6].

The target system has been installed in Hall C during the month of April 2002 and the target itself sits inside the SMS. This is the configuration in which the target will undergo the Hydrogen tests.

4. Run plan

Prior to the Hydrogen tests the target has to pass the JLab's Safety Neon test. After this test if the target system doesn't need any servicing we will start cooling down with Hydrogen and fill the loop with liquid following the target manual [7]. We will maintain all the time a Hydrogen bottle connected to the gas panel. There will be only one Hydrogen bottle at all times in Hall C.

The list of tests and measurements that will be performed with liquid Hydrogen are outlined in what follows:

1. Cryogenic pump performance – measuring the frequency response of the pump versus the set frequency on the motor controller, between 10 and 60 Hz set frequency;
2. Measure the power deposition of the motor versus pump speed;
3. Measure the differential pressure across the pump versus pump speed;
4. ΔT across the high power heater versus the high power heater setting for different pump speeds with the low power heater off and the high power heater in manual control;
5. Commission and tune feedback parameters for the pid loop for the high power heater in temperature control;
6. Commission and tune feedback parameters of Oxford controller for low power heater;
7. Determine the maximum allowable heat load from the high power heater;

8. If possible, try the above list of measurements for a different from the nominal of 17 g/s coolant flow rate;
9. Reliability test for the pump, have the pump working continuously for a week in LH_2.

To complete step 9 above we will have to run the target with LH_2 for at least a week. We estimate that completing the rest of the steps will take no more than two to three days. So, in principle we will run the target cold for a week. For a Hydrogen run we will arrange shifts to cover monitoring of the target system 24/7. Tests on the target will happen only during the day and the target will be manned from the Hall. There will be two persons on shift during the tests and one person on shift for target reliability run and night shifts. The reliability run and the night shifts will be manned from the Hall C counting house. The phone number in the Hall C counting house is x6666 and the closest wall phone to the target control computer in the Hall is x5290. For the whole duration of the Hydrogen run the target operator on shift will coordinate with the target operator on shift in Hall A. The phone number in Hall A counting house is x6349. After the tests are over we will boil off the target, recover the Hydrogen in the ballast tank, isolate the tank from the target lines and pump and purge the target lines and the gas panel with Helium and leave the lines and the target backfilled with Helium.

5. Authority and Responsibility

The members of the G0 Target Group participating in these tests will be responsible for following safe work procedures. ESR personnel are responsible for coolant delivery. U. of Maryland subgroup is responsible for the target controls. JLab Polarized Cryogenic Target Group is responsible for target gas handling system connections in the Hall. For a Hydrogen run we will arrange shifts to cover monitoring of the target system 24/7. The G0 target group is responsible for manpower, attached is the list of people. Silviu Covrig will be responsible for scheduling shifts, and informing the people participating in this test about any last minute changes in the run plan. Greg Smith agreed to be the point person for the duration of the test. G0 target experts are responsible for operating the gas panel. The underlined names in the list of personnel for manning the tests are target experts. There will be the responsibility of the target experts to set safe limits for the EPICS Alarm Handler, changing these limits will be done only by a target expert.

For the whole duration of the tests a target expert will carry a cellular phone, whose number is 757-810-7698. The target pager that will be carried by the target operator on shift is 757-584-5543. The single point of contact person pager number is 757-584-5405, this pager is carried by Greg Smith. Silviu Covrig's pager is 757-584-5501.

6. Analysis of Special Hazards and ODH

The target loop, when full contains less than 8 liters of liquid. The expansion factor between liquid Hydrogen at 25 psia and 20K and Hydrogen at room temperature and one atmosphere is 825. If the loop ruptures and the gas will make into Hall C the Hydrogen will expand to 6600l in Hall C. The Hall C volume stands at about 26,600,000l, the number was checked out by

G. Smith. The resulting Oxygen percentage will be **20.994**. Based on this, Hall C will be classified as an **ODH0** area for the duration of the tests. If the loop ruptures but the gas stays inside the G0 magnet vessel the pressure rise in the vessel is expected to be, for Hydrogen, 3.8 psia. A 3" lift relief valve (rated at ~ 1 psig, or 16psia) is mounted on the 4-way cross of the target service module [1, page 38]. There is also a 1.2 atm parallel plate relief on the magnet vessel. If this happens we don't expect any of the RVs to open to Hall C. There are two flammable gas detectors in the Hall, RGD90, calibrated for Hydrogen, one located on top of the gas panel that services the target and one on top of the SMS on the target SM side, above the SM. Instrumentation and operation of the Hydrogen detectors is the responsibility of the Hall C.

The G0 cryogenic target is described in [2]. An analysis of the safety issues for the G0 target can be found in [2, chapter 4].

According to [2, section 4.2.2] the hazardous gas risk classification in the actual conditions for the G0 target into the Hall would make the G0 target a Class 1 installation.

The only changes to [2, section 4.2.3] are: we are using a new cryopump motor, but this one is also brushless; and there are four AC servo-motors responsible for target motion and alignment located outside the SM that transmit the motion through mechanical actuators to the target holder. There is no electrical part of the target motion mechanism that goes inside the SM and in the vacuum.

The nomenclature of the valves on the gas panel has changed since the target design document [2] was written and approved more than three years ago. Old SV7 is the new SV13, old RV7A&B are new RV13A&B, old SV6 is new PV12. The RD on the ballast tank was found to be leaky and replaced with RVs set to 100 psi, by JLab staff. The most updated catastrophic boil off evaluation for Hydrogen is in [3, ch. 2.2], the peak pressure is expected to be about 29 psia, and this is the worst-case scenario, only 4 psi above the normal operating point. The target cell was tested to 85 psid twice and passed, once on its own and once soldered on the manifold. If the target system has passed the Neon Safety Test, and no Hydrogen testing will be performed unless this will be the case, it means that the target plumbing connections and design of the venting system for the target is adequate to safely relieve the target in an accident.

There is no need for exclusion of personnel in Hall C during the tests, but only people that signed this TOSP will have active involvement in operating the target system.

MV57 and MV29 will be locked open during the run and the target expert on-call will carry the keys.

Additions to this list will have to be approved by:
Dr. Greg Smith, JLab

I have read and understood the attached TOSP "G0 Target Hydrogen "No-Beam Tests"

List of Personnel

Institution/Name	Signature	Date
Caltech		
Robert McKeown		
Robert Carr		
Silviu Covrig		
Jeffery Martin		
Lars Hannelius		
U. of Maryland		
Elisabeth Beise		
Retief Neveling		
Jianglai Liu		
JLab		
Mikell Seely		
Greg Smith		
David Meekins		
Christopher Keith		
James Brock		
Rusty Salmons		
Mark Hoegerl		

Walter Kellner

Paul Hood

Aamer Rauf

Attachments:

[1] "A high power liquid Hydrogen target for parity violation experiments", E.J.Beise el al., NIMPR **A378** (1996) 383

[2] "G0 Liquid Hydrogen Target Preliminary Design Document", C. Jones and E. Beise, Nov 25, 1998

[3] "Report to the G0 Cryotarget Safety Review Committee", K. Gustafsson, Feb.1, 2002

[4] "The G0 Target Controls Manual", E. Beise, Mar.1, 2002

[5] "Report on the G-Zero Target Safety and Technical Review", Feb. 11, 2002

[6] Sketch of the H_2 service lines modifications

[7] "The G0 Target Manual", R. Carr, Jan. 30, 2002

[8] G0 target gas panel diagram

[9] Addendum to Appendix E of the Target Preliminary Design Document [2]

Addendum to Appendix E of the Target Preliminary Design Document [2]

FLUID	LIQUID HYDROGEN (LOOP)	HELIUM (COOLANT)
Temperature [K]	20	15
Pressure [psia/atm]	25/1.7	294/20
C_p [J/g.K]	9.447	6.64
Density[g/cm^3]	0.07122	0.067
Viscosity[g/cm.s]	$1.367 \cdot 10^{-4}$	$4.1 \cdot 10^{-5}$
Th. cond. [W/cm.K]	$10.32 \cdot 10^{-4}$	$3.22 \cdot 10^{-4}$
Prandtl no.	1.251	0.847
Flow area [cm^2]	30.4	0.3377
HX area [cm^2]	9500.73	1110
Eff. ϕ for HX [cm]	0.46	0.46

Frequency [Hz]	Mass flow LH_2 [g/s]	Mass flow He [g/s]	U [W/K]	ΔT_{LM}[K](@500W)
10	141.23	17	431.13	1.16
20	282.46	17	507.83	0.98
30	423.69	17	544	0.92
40	564.92	17	565.61	0.88
50	706.15	17	580.18	0.86
60	847.38	17	590.75	0.84