

IUCF LIQUID HYDROGEN TARGET SYSTEM\*

K. Komisarck, H.O. Meyer, T. Bertuccio, W. Manwaring and W. Smith†  
 Indiana University Cyclotron Facility, Bloomington, IN 47405, USA

Abstract

A liquid hydrogen or deuterium target system is described for use with intermediate energy light ion beams at IUCF. In its present use as a production target for polarized neutrons, the target cell is mounted within the beamline. Thus, certain safety features are required which prevent a possible hydrogen explosion inside the beamline or the cyclotron. These safety devices include an acoustical delay line which slows the hydrogen gas shock wave and a fast valve which closes before any large volume of escaping gas reaches it. Other safety interlocks to reduce the chances of target cell breakage and to quickly shut off ignition sources are discussed. We also describe a device involving a variable heat load which is coupled directly to the cryocondenser and is used to continually monitor and stabilize the pressure and temperature of the liquid hydrogen.

1. Introduction

While it is relatively straight-forward, using commercially available refrigeration techniques, to condense hydrogen into a thin-walled volume, serving as a target, there are other related aspects of such a device that warrant a report. One problem arises from the need to provide stable running conditions in an environment where the heat load on the cryogenic system may change abruptly due to variations in the bombarding beam intensity. Another area of concern is connected with the use of a highly combustible gas; we will therefore discuss possible measures to be taken to insure the safety of personnel and equipment.

Although deuterium is currently used with the described target system, the apparatus is equally suited for hydrogen, whose thermal properties are close enough to deuterium. In fact, tests of the system were mostly carried out with hydrogen.

2. Description of the System

The target is shown in Figure 1. The cooling power is derived from a hydrogen cryocondenser/recondenser (CTI<sup>+</sup>, model 1023) which is a closed cycle helium cooling system (1). It provides a 77K pre-cooling reference point (2) and a 20K cold surface (3) for the condensation of hydrogen. The cooling power at the condenser is about 10W at 20K and depends roughly linearly on temperature (~1W/K). The condensed hydrogen flows by gravity to the target cell (4). The target cell which mounts to the bottom of the cryocondenser is made entirely of stainless steel to avoid problems arising from materials with different coefficients of thermal expansion. Surrounding the condenser and target cell is an electro-polished aluminum radiation shield (5) which is thermally connected to the 77K flange (2). The whole assembly is enclosed by a vacuum tank, which is part of the proton beam line. The proton beam at this point is inclined downwards at an angle of 10°.

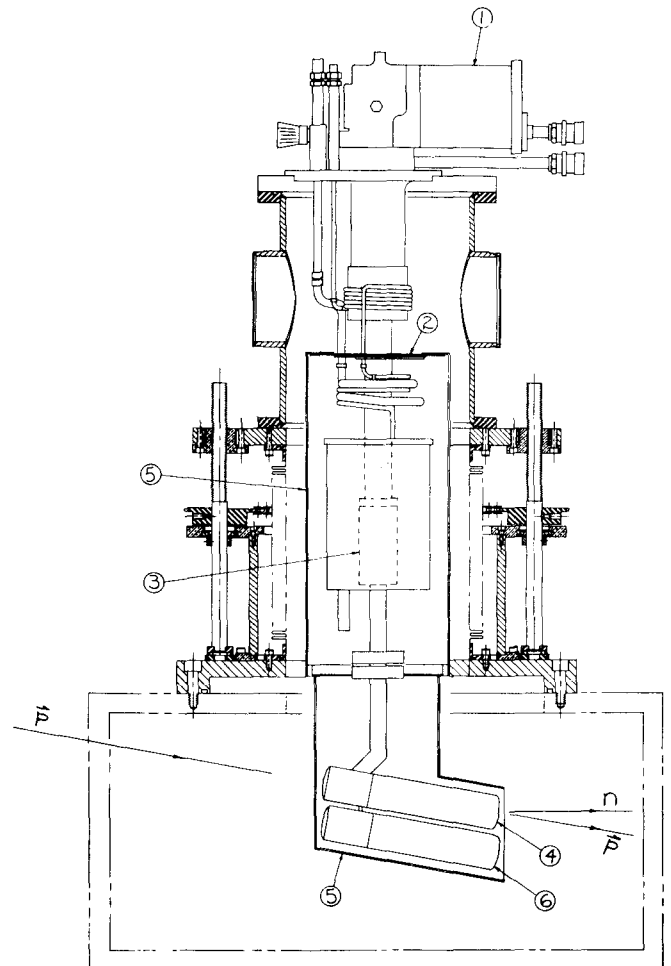


Fig. 1. View of target system. 1. Condenser/recondenser, 2. 77K reference flange, 3. 20K condensing well, 4. target cell, 5. radiation shield, 6. dummy target.

A gas handling system has the purpose of transporting the target gas (99.999% hydrogen or 99.5% deuterium) to and from the target. When the target is initially filled, the gas handling systems provides filtering of the target gas. An important part of the gas handling system is a large storage vessel. It has a volume of 370 l and is made from 0.95 cm thick aluminum. The storage vessel performs two functions. First, it is used to store the deuterium gas at low pressure when the target is not in use. In this way,

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†Presently with W.R. Smith, Engineering Consultants, Bloomington, Indiana 47401, USA

‡Cryogenic Technology, Inc., Waltham, MA

the same gas can be used again without the need for a compressor. Second, the storage vessel is part of the safety system which will be discussed later.

### 3. Operation and Thermal Stabilization

Initially, the fill lines and filters are evacuated to a pressure of ~0.1 mm Hg. The cryocondenser is then switched on and allowed to cool itself and the target cell to ~10°K. This takes approximately 2 hours. Once the condensing well is cold, gas from the storage vessel is introduced into the cryocondenser. Complete filling of the target cell takes about 100 minutes.

Once the target cell is full, the net cooling power delivered to the system must be regulated to achieve stable running conditions. The regulation mechanism consists of a variable, parasitic heat load thermally connected to the condensing surface. This heat load, is simply a 200 Ω, 5W carbon resistor clamped to the outside of the condensing well.

The thermodynamics of such a system are rather easy to understand, if one makes the following assumptions. The specific heat of the wall material is negligible, as is true at very low temperatures. The volume of saturated vapor in contact with the liquid is so small that a change in temperature (and thus in pressure) does not result in an appreciable change of the mass M of the liquid. Then a change in the internal energy  $Q_T$  of the target system is given by

$$dQ_T = M \cdot c_v \cdot dT \quad (1)$$

where T is the temperature and  $c_v$  is the specific heat of the saturated liquid. There are three external sources of energy that have to be considered, namely, radiation, refrigeration and the heat load resistor. The power,  $P_R$ , supplied by radiation is determined by the law of Stephan-Boltzmann and details of the design of the cryosystem. For small changes of T (around 20K) this can be assumed to be constant and was found experimentally to be about  $P_R \approx 4W$ . The cooling power,  $P_C$ , of the refrigerator depends roughly linearly on temperature,  $P_C = P_{CO} + C_C T$ , with measured values of  $P_{CO} = -4W$  and  $C_C \approx 1.1W/K$ . The power,  $P_L$ , delivered by the heat load resistor depends on the temperature dependent value of the resistor.

Energy conservation dictates

$P_L + P_R - P_C = M \cdot c_v (dT/dt)$  and integrating this expression one finds for the time dependence of the temperature

$$T(t) = T_\infty + (T_0 - T_\infty) \exp. (-t/\tau) \quad (2)$$

Here,  $T_\infty$  is the equilibrium temperature and  $T_0$  is the temperature at  $t=0$ . The value of  $T_\infty$  is independent of the thermal properties of the target gas and can be determined by choosing I, the heat load current. This means the cryosystem attains a stable state if the heat load resistor is driven with a current source. The characteristic time  $\tau$  for approaching this stable state in our case is calculated to be about 400 s. The above expressions were found to give an excellent description of the temporal behavior of the target parameters as obtained by experiment.

The time constant for stabilization can be substantially reduced if the heat load current is adjusted in a feedback loop. Since the target is operated as a saturated liquid-gas mixture, the saturation pressure is the most direct information on the temperature of the liquid. This pressure was measured with a pressure transducer. This information governs a controller for the heat-load current.

A constant current source is servoed via a feedback signal derived from a semiconductor type pressure transducer<sup>†</sup> (Fig. 2). Initially the system is operated in an open loop mode by setting a desired

target pressure and adjusting a command current  $I_{set}$ , until a pressure reading null is achieved. At null, the servo loop is closed and pressure deviations due to added or subtracted heat loading are automatically corrected for. Providing the correct command for a given heat load environment of the target at the beginning of operation has the effect of increasing the overall loop gain without adversely affecting the closed loop stability of the regulator.

With this variable heat load, the time constant for stabilization,  $\tau$ , becomes approximately 3 minutes.

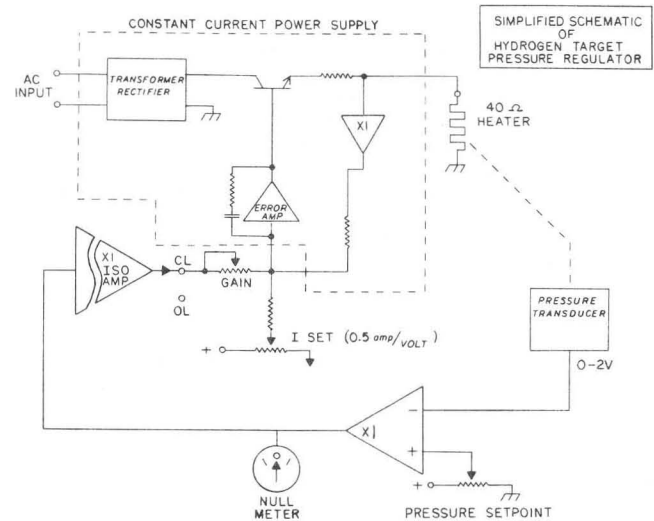


Fig. 2. Pressure regulation circuit. With loop open, set current through target heater, wait for equilibrium. Zero pressure transducer, then close loop.

### 4. Safety Related Considerations

Since hydrogen is a very flammable gas there is great concern over a possible explosion and therefore the safety and well being of nearby personnel and equipment must be insured. These concerns have led us to design a safety system along the following lines.

There are three levels of safety precautions; each successively addresses a more potentially dangerous situation. The first line of defense prevents the hydrogen gas pressure from breaking the target cell windows. A number of problems can cause a rise in the target pressure. A power outage, a breakdown of the refrigerator unit or a loss of vacuum in the target box will all lead to a rapid warming of the liquid deuterium. If this should happen, spring loaded Marpac\*\* ball valves automatically open and provide a path from the target cell to the storage vessel for the gas boiling off the warming deuterium. The size of the storage vessel is chosen such that at room temperature, the system pressure is still within safe operating conditions for the target cell.

The second line of defense is against an actual leak in the target cell. Should this occur the shock wave due to the escaping hydrogen gas is first slowed down in a delay line to allow enough time for fast

<sup>†</sup>Cryogenic Technology, Inc. Waltham, Mass.

closing valve to isolate the PNF beamline from the rest of the cyclotron. The shock wave delay line is immediately upstream of the target. It consists of a large cylinder 33.0 cm in diameter by 2.3 m long. Each expansion chamber is 25.4 cm in diameter by approximately 29 cm long (14.8 l). The orifice of each plate is about 2.5 cm in diameter.

Approximately 8 m upstream from the end of the shock wave delay line is a fast closing valve designed by Brookhaven National Laboratory.<sup>1</sup> Consisting of a spring loaded guillotine type blade which closes in less than 5 ms. This response speed is necessary since the shock wave travels approximately at  $10^3$  m/s. The fast valve is not completely vacuum tight. Therefore, a standard 10 cm VRC<sup>+++</sup> gate valve is placed immediately downstream of the fast valve and will close too whenever the fast valve fires. The actuating solenoid of the fast valve is energized via the discharge of 2200  $\mu$ f charged up to 150 volts (Fig. 3). The circuit to the valve is completed when the SCR is triggered by a window comparator. The input signal to the comparator is a compounded version of the load current of a small ion pump (Varian #921-0015 Vacion pump) which monitors the vacuum in the neighborhood of the target cell. Two decades of load current in this pump are compressed via a log circuit into a 60mV-900mV window; any current outside of this window causes the valve to 'fire'. If the pump is turned off the fast valve will also fire.

To avoid needless false responses, the comparator 'fire' command is gated through to the SCR only if dangerous initial conditions prevail, i.e. if the VRC gate valves to the cyclotron are open and liquid deuterium is present in the target. The slow gate valves cannot be opened until both the ion pump and cold cathode gauges are on and in a safe vacuum range, and the fast valve is open and cocked. Both the Vacion pump and the cold cathode gauge are possible ignition sources for the released deuterium<sup>2</sup>. Consequently both of their high voltage power supplies must be crowbarred. This is accomplished using high voltage reed relays with operation times less than 3 ms. The Vacion crowbar command is derived from the window comparator trip signal and the ion gauge is tripped whenever its analog output exceeds 10 mV. This 10 mV signal is filtered, amplified to 1 V, and then applied to a fast comparator, whose output fires the latching crowbar.

A vacuum excursion during a run, then, will: a) fire the fast valve, b) crowbar the high voltages in the vacuum sensors, and c) close the gate valves. A remote annunciator panel in the control room which monitors thirteen variables of the system will alert the operator.

If the pressure in the beamline becomes greater than 50 kPa the third line of defense is reached; the hydrogen gas is expelled into a tent which surrounds the target area and, from there, is vented outside the building.

The cryocondenser and target cell are mounted in an aluminum can which is attached to the beamline. Mounted on a port of this can is an aluminum foil window. On one side of this window is a razor blade, mounted so that any positive pressure inside the can will push the aluminum foil window against the razor blade and cut it. In this way deuterium from a broken target cell is vented to the outside before it can build up explosive pressures and rupture the aluminum can.

Surrounding the target area is a tent made of Herculite<sup>++++</sup> which is a flame retardant cloth. This tent prevents the gas from escaping into the room. At the top of the tent is a 30.5 cm diameter vent pipe

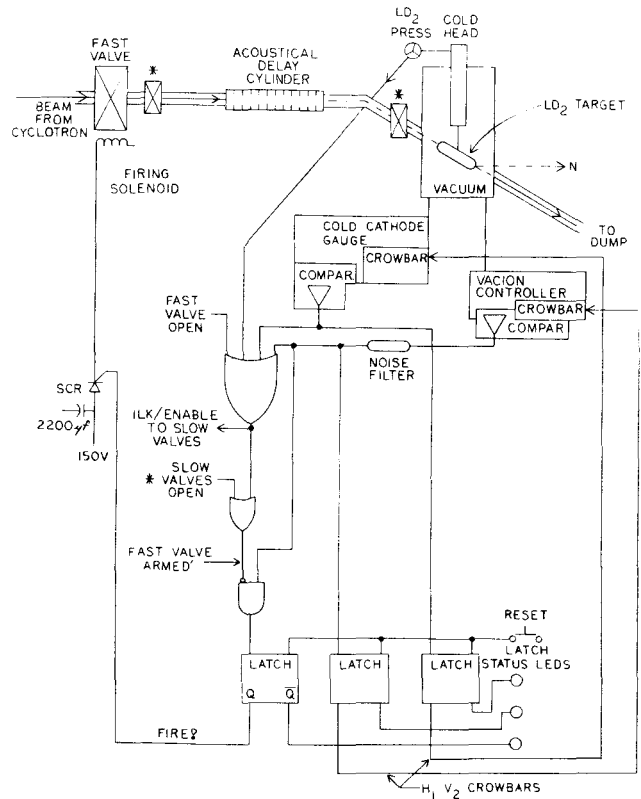


Fig. 3. Safety interlock circuit. To arm fast valve electronics: 1. LD<sub>2</sub> in target, 2. CCG & Vacion pump on and ok, 3. fast valve cocked, 4. slow valves (\*) open. Separate latches & LED's provide diagnostics in case of misfire.

which allows the gas to escape outside the building. An explosion proof fan with a DC motor is attached to the vent and draws air from the tent at a rate of 6 m/sec or 17 m<sup>3</sup>/min. The motor has a lead acid battery backup in case of a power failure.

Hydrogen gas sensors are placed in three locations; at the top of the tent, in the vent pipe, and near the ceiling of the PNF room. These sensors are manufactured by International Sensor Technology.\* They are solid state devices in which metal oxides dissociate the gas into charged ions which causes current to flow between two electrodes. These sensors give an alarm if any one of them measures a concentration of hydrogen gas at 30% of the lower explosive level, and at that point they close an automatic valve that stops any more deuterium flowing into the target cell.

#### References

1. Overslizen, T., National Conference on Synchrotron Radiation Instrumentation, 1981.
2. Williams, W., Walker, R., Argonne National Laboratory Internal Report, No. 81.

<sup>+++</sup>Herculite Protective Fabric, Corp. New York, NY  
<sup>\*</sup>International Sensor Technology, Irvine, CA

<sup>+++</sup>Vacuum Research Co., San Ramon, CA