USE OF AN INTERNAL HYDROGEN TARGET.

In general, for the study of p-p (and p-n from a deuterium target) interactions at GeV energies at least two techniques are possible. One is to use an extracted proton beam and an external hydrogen target. The other employs the circulating beam and an internal hydrogen target. For the first case, a liquid hydrogen target six metres long would be required for one interaction length. On the other hand, however, if one takes advantage of the compaction characteristic of the strong focusing accelerator, many traversals of an internal target are possible. For example, a liquid hydrogen target of surface density 70 mg/cm^2 could be used for complete interaction with the primary beam. This latter scheme has obvious advantages when both refined beam optics with a concentrated target and maximum proton intensities are required. The ejection scheme is complementary to the internal target concept and has merits of its own. It would be necessary, for instance, to place detectors near the hydrogen target for short-lived secondaries or for coincidence counting. In which case the low efficiency of the external target could be tolerated for the advantage of getting the counters close to it. This could not be easily done with the internal target.

In particular, the following investigations might be included among those experiments which could be most accurately done with the aid of an internal hydrogen target. An extension of p-p elastic and inelastic scattering begun with the internal beam and a CH_2 - C subtraction method (NP Internal Report 67-17) could be made to wide angle scattering (at 90 c.m.s. scattering cross-sections are likely to be $\sim 10^{-31}$ cm^2/ster.). The elastic charge exchange p-n scattering cross section is expected to be small in the 10 to 28 GeV energy region so that again this experiment could be done best with the internal target. This is also true of rare processes such as deuteron production in association with a single pion from protons, involving high momentum transfer. Another interesting use is production of slow antiprotons. The two competing processes are the actual production ($\sim$ 10μb) and the absorption of $\bar{p}$ ($\sim$ 100mb) in the same nucleus. With a pure proton target this effect could be minimized.

The subject of this exploratory note is the internal hydrogen target, a topic which has been discussed before (PS/Int. MG/VA 60-3).

There are three principal possibilities; the hydrogen maybe gaseous, liquid or solid. These will be dealt with in inverse order of usefulness (for experiments) and of practicability.

1. The gaseous target, either in the form of a jet or contained in a tube, is the least promising from the point of view of low target density (high target density can only be obtained at the expense of thick containment walls). Also the gas jet gives a diffused type of target. This has been dealt with by Dr. Hine (private communication).

2. The solid hydrogen target, without walls, is the one most favoured by the experimental groups. A rod of solid hydrogen would be an ideal source of protons for p - p interactions for example, there being no subtraction technique necessary. For instance, the ratio of the number of proton interactions with a solid rod to those with the surrounding hydrogen vapour would be about 10^3, assuming the rod of density .09 g/cm^2 and a vapour pressure of 1 mm Hg. This idea, however, is technically difficult to put into practice and no effort has been spent on it to date. At Brookhaven N.L. a tentative proposal was to drop cubes of solid hydrogen into the beam (Pesvner, Accelerator Development Dept. Internal Report. B.N.L.). The internal hydrogen target project at Brookhaven has not advanced since that Report (August 1959).

3. With the hydrogen in the form of liquid, two possibilities are open to speculation; firstly a conventional liquid target contained with walls (target W), and secondly a liquid jet (target J). As far as experiments are concerned, the second one is to be preferred but again it is more difficult to construct. One example of target W has been proposed by Dr. Hine (PS/Int. MG/VA 60-3) in the form of a quartz sphere.

a) Target W.

The requirements of such a target include a high percentage of proton interactions with the hydrogen, as distinct from the container, and that the beam should be made to move fairly quickly on to the hydrogen.

The target W could be of standard design with the added complication of some device to move the target appendix near to the proton beam after the initial period of acceleration. This might be achieved by a rotation of the hydrogen cryostat with the appendix off-centre (see sketch, figure 1) requiring a movement of 90° in 1/4 second. One difficulty is to maintain a rotary vacuum seal during the duty cycle of rotation every three seconds, although this should be possible with careful design. An alternative method is to lower the target appendix from above, making use of bellows, and then steer the beam on to it. This has the limitation of fatigue of the bellows.

The heat introduced into the hydrogen from the beam (95 $^{o}/_{o}$) and by transfer from the surroundings (5 $^{o}/_{o}$) could be removed in a heat exchanger in the cryostat, possible using a cold helium gas refrigerator. For the case of 3×10^{11} protons/pulse, about 20 mg of hydrogen are evaporated per pulse. If thus boiling takes place in 20 msec, the resulting increase of pressure in the target chamber is a few cm Hg, assuming a reasonable length of 6 mm bore exhaust line and that the vapour remains near 20^{0} K. This localised boiling will result in a lowering of the mean density of hydrogen in the target volume.

Another problem is the estimation of the contribution of the proton interaction with the target walls. This problem is two-fold; the one technical and the other physical. If the mass ratio of hydrogen to wall material is high, then one finds for Mylar 12.5 μ thick, for example, that the container would melt if the empty target was exposed to the proton beam. An interlock with the beam would be required to prevent irradiation of an accidently empty target. If an interaction ratio R of hydrogen to Mylar $\leq$10 can be experimentally tolerated, then this problem can be overcome (R = 10 is a minimum experimental requirement). Secondly, the measurement of the background subtraction is complicated by the fact that the surface density of materials in the proton beam is reduced by a factor of $\sim$10 when the hydrogen is removed from the target (assuming 25 μ Mylar walls).

There is in addition the possibility of radiation damage to the Mylar. U.K.A.E.A. Reports (A.E.R.E. : R 3208, GP/R 1402 and T/M 173) quote a critical dose of about 5×10^8 rad after which Mylar repidly loses its mechanical strength. On this basis, a Mylar cylinder could be exposed for over 100 hours (the minimum useful time for machine operation) in a beam of 3×10^{11} protons/pulse, with a safety factor of about 10.

Regarding the position of this target in the PS ring, it should be possible to design it and the ancillary equipment so that the target could be introduced into a short straight section (e.g. ss 100, 3, 5 or 6).

Finally, due to the small quantity of liquid hydrogen involved in the target, hydrogen safety is not a significant problem.

b) Target J.

For the jet target, the proposed solution of the problem of introducing liquid hydrogen into the PS vacuum chamber is differential pumping. A vertical jet of 1 cm diameter flowing for about 1/4 second at a rate of about 100 cm^3/second (introducing about 3 gm H_2 per pulse) requires five pumping stations up- and downstream from the "injection cell" in order to keep the hydrogen gas pressure below 10^{-5} mm Hg at both ends of a long straight section, this being the minimum length for the target unit. This latter requirement might be a serious restriction. Injection and removal of liquid hydrogen would be done by remotely controlled valves on the transfer tube and sink funnel (see figure 2). The high consumption rate of liquid hydrogen required for the jet could be supplied by the CERN liquefier. Because of the need to handle and pump large volumes of hydrogen in the area of the PS ring, security arrangements would be complex.

Mechanical and diffusion pumps have only been considered for this problem. Cryopumping seems to be not very promising for a gas whose boiling point is as low as that of hydrogen.

When the pressure of cells 1 and 2 had reached the base pressure of the Roots pumps, these would be closed off and pumping done by the diffusion pumps of cells 3, 4 and 5. After each beam burst it is suggested that the hydrogen vapour in the jet cell 0 could be dumped into a large pre-evacuated vessel. A cylinder of 300 litres volume could cause a pressure reduction from one atmosphere to a few cm Hg in about 1/4 second. A second and third etc. vessel could be used between successive pulses, and the n vessels in turn could be exhausted in a time n f where the machine cycle is f.

The partitions forming the pumping cells would have apertures of 2 cm diameter and would be moved into position late in the acceleration cycle when the beam diameter had contracted to one cm. The partitions would have horizontal slits covered with Mylar to allow secondary particles to be emitted with small energy loss. Proton interaction with the jet would cause beam blow up but the scattered protons could be dumped on the vacuum chamber wall before being allowed to strike the partitions of the cells (see MPS/Int. VA 61-8).

Proton Interaction Ratio.

Calculations have been made to find out the mean value of the ratio R of the number of interactions of the proton beam with the hydrogen of the target and with the immediate surroundings, this being Mylar and hydrogen vapour the target W and target J respectively. For target W this has been done for a vertical right cylinder of one cm diameter, and for a vertical target of elliptical section with axes 1 cm and 3 cm. The results of interaction by a fairly fast kicker action (25μsec) and by a slow kicker (1msec) have also been compared. In the case of the jet target J, R has been calculated for different conditions of the liquid hydrogen. It is apparent that a good compromise between a solid rod and a liquid jet is a jet of cooled hydrogen e.g. at 15^{o} K where the vapour pressure is 10 cm Hg and liquid density .076 g/cm^3 (the corresponding value at the normal boiling point, 20^{o} K, is 071).

The targets J and W are briefly compared in the table where various values of R are included.

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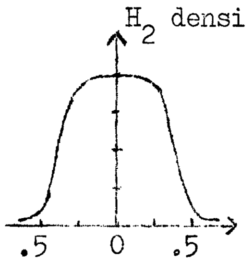
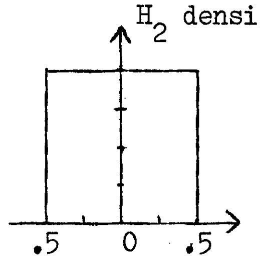
T A B L E

	TARGET J	TARGET W
Dimensions	Vertical jet 1 cm diameter	a) vertical right cylinder 1 cm Ø b) vertical elliptical cylinder 3 cm x 1 cm
Containment	H_2 vapour	i) 25μ Mylar ii) 12.5μ Mylar
Target shape presented to beam, radially	Slightly diffused  	Well defined. 
R	Liquid H_2 vapour press. cm Hg: 76, 36, 10 Temperature ^oK: 20, 18, 15 No. of p interactions in jet / in H_2 vapour: 8, 20, 100	No. of p interactions in liquid H_2 / with Mylar walls (25μs Kicker / 1ms Kicker) ai: 6.2 / 5.8 aii: 12 / 11 bi: 11 / 10
Liquid H_2 consumption (assuming liquid N_2 rad. shield)	max. 250 litres/day	~ 6 litres/day
Deuterium target	Expensive in D_2 consumption	O.K.
Target density	Depends on jet formation	Heat from beam may cause localized boiling and hence lower density.
Target Positioning in space	Fixed	? H_2 target to be moved into beam
Target Positioning in time	? Depends on jet formation	Fixed
Background subtraction	None	Difficult to make, empty target gives longer beam burst for 1m.f.p. Mylar wall thickness ≫ 25μ or empty target walls melt.
H_2 Safety	Normally, H_2 liquid flow controllable	Less than 100 cm^3 of liquid H_2 in target
	Fast acting vacuum valves up and downstream from H_2 target required to isolate target from rest of PS vac chamber in case of accident.	
Main danger	Liquid flow valve remains open	Burst of target walls