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Prototype Tests on a 200 Watt Forced Convection Liquid Hydrogen/Deuterium Target*

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ABSTRACT

A forced convection target system is being developed for use at the Clinton P. Anderson Meson Physics Facility (LAMPF) which will produce neutrons by bombarding liquid deuterium with a proton beam via the process $p + d \rightarrow n + 2p$. The work described herein discusses the design and operating characteristics of a prototype unit designed to operate with a heat input of 200 watts. Data are presented on the operating characteristics of the unit using liquid hydrogen with heat disposition from both electrical heaters and from an electron beam of 25 MeV which has a time structure and intensity similar to that of LAMPF. Electron beam energy depositions of 25 W/cm^3 were achieved. Using data obtained on these tests a final target system has been designed and will be briefly discussed.

*This work performed under the auspices of the United States Atomic Energy Commission.

ROUGH DRAFT

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I. Introduction

A forced convection target system is being developed for use at the Clinton P. Anderson Meson Physics Facility (LAMPF) which will produce neutrons by bombarding liquid deuterium with a proton beam via the process $p + d \rightarrow n + 2p$. Incident energies will vary in the range from 300 to 800 MeV. This neutron source is favorable from two points of view: 1) at zero degrees the emitted neutrons have a small energy spread and good separation from lower energy neutrons associated with meson production, and 2) at an angle near 26° the neutrons are emitted with a spin polarization averaging 30% and with a degraded but usable energy spectrum. To obtain an 800 MeV neutron flux of 10^7 /(cm^2-sec) at 8 meters from the source will require 84 μA proton beam passing through 15 cm of LD_2 which implies 500 W dissipation in the deuterium. This value of beam dissipation has been used as a design goal in our earlier planning. For various reasons we have lowered our sights and we are now aiming at a goal of 150 W beam dissipation capability at negligible density variation.

In the past relatively few accelerators operating at medium and high energy had sufficiently intense external beams to require special consideration for heat removal from LH_2 targets. An exception is the SLAC high energy electron linear accelerator, where external beams of 15 μA are

ROUGH DRAFT

accelerated. Since the area of the SLAC beam is small, approximately 0.25 cm^2, high power density is created in a target substance, and for cryogenic LH_2 targets reduction of liquid density occurs owing to vaporization in the path of the beam. Two approaches have been used at SLAC to circumvent this problem. Anderson[1] described a target in which enhancement of natural convection was used to remove heat from the interaction region. Subsequently, Bell et al.[2] described a forced convection target in which LH_2 is driven through a closed loop by a fan. Part of the loop comprised the target cell and part was in thermal contact with a LH_2 reservoir where the deposited heat was extracted. With this system density variations were reduced to less than 1%.

Kaiser[3] has made calculations of thermal conduction in LH_2 being driven by heat input from 60 MeV electron beams. He investigated the temperature rise in cylindrical geometry in which the outer radius is that of the target cell, maintained at a fixed reservoir temperature. Effects of convection were not considered. He found that relatively small average beams of approximately 1 μA could cause 10°C temperature increases in the interaction cylinder, for reasonable geometries. An implied conclusion of this work is that thermal conduction alone is not adequate to remove the heat deposited in LH_2 by relativistic electron beams greater than 1 μA intensity.

In this paper the characteristics of a prototype target designed to operate with a heat input in the neighborhood of 100 to 200 W are discussed. Data are presented on the operating characteristics of the unit using liquid hydrogen with heat deposition from both electrical heaters

ROUGH DRAFT

and from an electron beam of 25 MeV which has a time structure similar to the LAMPF beam. In the electron beam experiments energy depositions of approximately 25 W/cm^3 were achieved. Using data obtained on these tests the final target system was designed and will be briefly discussed.

The basic objectives of the prototype flow loop tests were the following:

(a) Confirm the design of the heat exchanger between the LH_2 and the GHe heat sink.

(b) Provide operational data on the pumps used for LH_2 circulation.

(c) Study effect of energy deposition by an electron beam with emphasis on the question of vaporization at high power densities.

II. Equipment and Instrumentation

A schematic flow diagram of the system is shown in Fig. 1. The major components of the system are the compressors, purifier, gas holder, Collins refrigerator, vacuum jacketed transfer lines between the flow loop and refrigerator, the prototype target loop and associated beam diagnostic equipment.

The 200 W helium refrigerator used was Collins unit model CHC-14. The incoming high pressure warm gas is first progressively cooled within the main heat exchanger by the cooler outgoing helium gas and by LN_2 used in a precooling coil. It is then expanded to its final temperature (14 K) in two reciprocating expansion engines. This cold gas is then piped to the load where it picks up heat and is then returned to the refrigerator. After going through several heat exchangers the warm low pressure gas is compressed and the cycle repeated.

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ROUGH DRAFT

A representation of the prototype flow loop is shown in Fig. 2. The major components of this system are the LH_2 - GHe heat exchangers, the LH_2 pumps, a venturi/target test section and a series of three heaters to provide a load for testing the refrigerator when not in use at the Electron Prototype Accelerator (EPA) and for balancing the beam load with the refrigeration capacity. Instrumentation consisted of a microphone to monitor pump operation, pressure gauges, carbon resistor temperature sensors and carbon resistor level sensors. The stainless steel flow loop held approximately 13 liters of LH_2 -- this volume being partly a result of the fact that the pumps were fans capable of only a 12 mm Hg pressure differential. The system was sized to keep within this ΔP limitation.

The pumps used were submersible 3-inch blowers.[4] They utilize three phase motors that operate from 10 to 40 volts depending on torque requirements. Speeds vary from 500 to 3500 rpm. The ball bearings are non-lubricated with a non-metallic retainer.

Two cell sections were used. The first was a venturi used to calibrate the pumps. The second was the thin aluminum window test section. The windows were hydro-formed[5] from flat 1100 aluminum sheets and each had a final thickness of 0.0076 cm. The window aperture was rectangular in shape, being 13 cm long and 2.5 cm wide. They were dish shaped to provide a relatively smooth flow passage for the LH_2 moving through the cell. The seal between the window and flow channel was made by compressing

ROUGH DRAFT

a 0.16 cm diameter Cerroseal (low temperature indium solder) O-ring. It was necessary to use a new O-ring each time the window w. replaced. Self-energized, teflon-coated O-rings were used to attach the cell sections to the flow loop. These rings leaked on several occasions and would not be recommended for use on the final target system.

In the countercurrent GHe-LH_2 heat exchanger the cold gaseous helium passes through the twenty-two 1 cm inside diameter copper tubes in parallel while the LH_2 flows in the annulus around the outside of the tubes. Also attached to the heat exchanger section were three, 300 W, heaters which were used to simulate beam heat input during the initial testing. The calculated heat transfer coefficients were 0.21 W/(cm^2-K) on the H_2 side for a flowrate of 38 kg/min and 0.014 W/(cm^2-K) on the helium side at a flow of 0.015 kg/min. The overall heat transfer coefficient, U, was 0.013 W/(cm^2-K). With a log mean ΔT of 3 K this should provide a heat removed capability of 260 W. It should be noted that the controlling coefficient is on the He side. With a larger refrigerator and compressor the heat removal capability of the heat exchanger should improve until the He coefficient becomes comparable to that on the LH_2 side. The heat exchanger was designed so that it could be removed easily from the loop without dissembly of the loop.

The gas handling system provided the capability of filling the loop directly with LH_2 or by gas condensation on the heat exchanger. Safety relief valves were installed both on the flow loop and vacuum jacket. Most of the gas handling valves were 110 V remotely operated solenoid units. The vent lines were sized to minimize the pressure

ROUGH DRAFT

rise in the system in case of a vacuum failure.

Since seven hours was required to condense the loop full of LH_2 this technique of filling was not used after the initial runs. In general the loop was purged and maintained under positive gaseous helium pressure, the refrigerator started and the cooldown allowed to proceed until LN_2 temperatures were obtained. At this point the gaseous helium was replaced with LH_2 from an external storage vessel. As the liquid H_2 began to subcool the electrical heaters were adjusted to maintain the desired degree of subcooling.

Throughout this experimental program difficulty was experienced with the operation of the refrigerator. Premature shutdowns resulted from repeated seizures of the pistons in the expansion engines. Installation of a LH_2 trap on the GHe line to remove neon and other possible contaminates did not solve the problem.

III. System Performance

The operating characteristics of the blowers are shown in Fig. 3 for both a single unit and two units in series. To achieve maximum flow in the series configuration a vane straightening section was placed between the blowers.

The fluid velocity required to move a particle of H_2 across the beam path between 8.3 msec beam pulses is 100 cm/sec. It is desirable to operate at velocities in excess of this to ensure that new fluid is in the path of the beam for each pulse. The gaseous-helium liquid-hydrogen heat

ROUGH DRAFT

exchanger performed as expected. At a maximum experimental total heat removal rate of 175 W no degradation of performance was noted. With 175 W being removed by the heat exchanger, the LH_2 temperature was 19 K. This value lowered to 18.5 K at a 135 W removal rate. Depending upon the helium overpressure applied to the top of the loop several degrees of subcooling could be achieved.

The 0.0076 cm aluminum windows were rupture tested to determine the pressure rise in the system following window failure. It was necessary to provide a puncture unit since the windows maintained their integrity at pressures in excess of 160 psi. Following rupture of the window the vaporization of LH_2 caused a peak of 30 psig in the containment vessel approximately one second after the break. The containment vessel had a volume of 530 liters and was equipped with a 1 psi relief valve.

IV. Tests in the 25 MeV Electron Beam

The Electron Prototype Accelerator (EPA) was built at Los Alamos to test the side coupled linear accelerator cavity design and to provide a target testing capability at high beam power. The time structure of the EPA electron beam was the same as the LAMPF proton beam, namely 500 μsec macro pulse length at 120 Hz repetition rate and a superimposed 200 MHz radio frequency. Beam intensity was likewise comparable, ranging up to 1 mA average.

Figure 1 shows a plan view of the installation of the EPA. The electron beam enters a collimator from the right-hand side of the figure, directly from the accelerator without focussing. The graphite collimator has a diameter of 0.9 cm, its purpose being to confine the beam to a fixed region of the target. Two beam measurement devices are placed after the

ROUGH DRAFT

collimator, namely an x-y wire scanner for profile measurement and a toroid beam transformer for measurement of the peak current in the macro-pulse.

The beam then enters the cryostat vacuum enclosure and passes through the target cell. A fraction of the beam will be scattered by the windows and hydrogen of the cell and will be collected on an annular graphite electrode called the beam scraper. The electrical signal from this electrode may readily be measured on an oscilloscope, and has the characteristic R-C rise and decay time characteristic of a rectangular current pulse charging a cable capacitance with resistive termination. That part of the beam not collected on the beam scraper is stopped in the final graphite beam stop. Both scraper and stop were water cooled.

The system was aligned by optical observation of burn spots made by the beam and by observations on beam tube centers. The center position of the x-y scanning wires was observed and calibrated. The shape of the beam was that of an elongated oval with long axis vertical. Figure 4 shows an example of the measured profile on one of the runs. The area of the beam was approximately 0.5 cm^2 at a section corresponding to 1/10 maximum intensity.

The electron beam deposits heat in the target cell by energy loss in two each 0.003-inch aluminum windows and in 5.72 cm LH_2. Using standard tables[6] for collision energy loss at 25 MeV incident energy, we have $\Delta E = 1.94$ MeV in LH_2 and $\Delta E = 0.073$ MeV in both foils, for a total energy loss 2.013 MeV. One micro ampere average beam then deposits 2.01 watts into the target cell.

ROUGH DRAFT

In passing through the target a fraction of the beam is scattered by multiple Coulomb interactions. A major part of the scattering is due to the mass of hydrogen, which represents a signal related to the average density of hydrogen in the beam path. By use of an approximation formula(7) the multiple scattering can be estimated as follows: $\theta_{RMS} = 2.38°$ from 5.72 cm LH_2, and $\theta_{RMS} = 1.20°$ from 0.020 cm aluminum, for 25 MeV electrons incident in both cases. We define the angle θ_1 to be the angle subtended by the inside radius of the annular beam scraper which for our geometry was $\theta_1 = 4.19°$. The probability of multiple scattering at or beyond the angle θ_1 is given by $\exp(-\theta_1^2/\theta_{RMS}^2)$. This probability gives the fraction, f_s, of indicent beam scattered to θ_1 or greater. A measurement of f_s gives θ_{RMS}^2 which may be related to the average LH_2 density by the multiple scattering formula.

Figure 5 shows the calculated values of fraction of beam scattered, f_s, as a function of the fraction of normal LH_2 density in the path of the beam. The curve includes the effects of the windows, as measured. Also shown on the figure are three measured values of f_s for the empty target cell. The curve indicates two things. First there is a reasonable sensitivity to f_s relative to variations in the average LH_2 density. Secondly, the scattering due to the LH_2 alone is an order of magnitude greater than that due to the target windows. It will be seen below that the calculation of f_s for full LH_2 density are in reasonable accord with low beam measurements.

ROUGH DRAFT

In any case the calculations of multiple scattering given above are not meant to be more than reasonable estimates of the true scattering.

The significant results of the EPA measurements are shown in Fig. 6. The results are sparse owing mainly to trouble with the refrigerator, as noted above. Figure 6 shows measured values of scattered fraction, f_s, vs average beam intensity, I_B, in μA. Data for four runs are shown numbered from 1 to 4 in chronological order. In each case the runs were aborted after short periods, but we learned to get more data in less time in the last two runs which we consider most reliable. The measured values of f_s for low beam intensity are in reasonable agreement with the calculated values shown in Fig. 6, namely f_s approximately 0.15. In runs 3 and 4 we have data at 24 and 36 μA and in run 3 we have one measurement at 48 μA. At 36 μA the average beam dissipation is approximately 72 W. The effective volume is 2.85 cm^3 which implies 25 W/cm^3 power density. By reference to Fig. 5 we conclude that the data of runs 3 and 4 were obtained for 88% or greater effective hydrogen density in the path of the beam. This is not a very strong conclusion, but it was sufficient to give us confidence that the prototype system was operating as we hoped it would. Looking at run 4 alone would have allowed a stronger conclusion.

Using the data obtained from these experiments a new target system has been designed for experiments at LAMPF. Briefly the new system consists

ROUGH DRAFT

of a forced convection flow loop very similar to that described herein. Instead of teflon O-rings Aeroquip Conoseal joints are used throughout and the target section is of welded construction to replace the indium seals. The loop can be moved vertically to present new aluminum window surfaces to the proton beam when radiation damage has occurred. A CVI turbine refrigerator[8] will provide 250 W total refrigeration power, which is limited by the compressors which are now in use with the system. With proper compressors the refrigerator itself is capable of absorbing 700 W at 20 K. It is anticipated that the system will be used on some of the first experiments at the LAMPF accelerator in July of this year.

Acknowledgement

We would like to acknowledge our thanks to the EPA accelerator crew under Mr. J. Busick for their support. Mr. J. C. Martin provided much help in setting up the equipment at the EPA.

References

1. R. L. Anderson, Nucl. Instr. Methods, 70, 87, (1969).
2. R. Bell, H. Clay, J. Mark and W. Pierce, IEEE Trans. Nucl. Sci., Vol. NS-16, No. 3, 631 (1969).
3. H. F. Kaiser, IEEE Trans. Nucl. Sci., Vol. NS-12, No. 3, 519 (1965).
4. Type VAX-3 blowers, Globe Industries, Dayton, Ohio.
5. Units made by the Metal Fabrication Section of CMB-6, Los Alamos Scientific Laboratory, Los Alamos, New Mexico.
6. Publication 1133, National Academy of Sciences, National Research Council, Washington, D. C. (1964).
7. Sternheimer, Methods of Expt. Physics, Vol. 5A.
8. Manufactured for the National Bureau of Standards and Argonne National Laboratory by CVI Corporation of Columbus, Ohio (1965). We are indebted to D. Chelton and O. Voth of NBS, Boulder, Colorado, for help with the sytem.

Figure Captions

Figure 1. Schematic diagram (plain view) of the prototype target system, as setup at the Electron Prototype Accelerator (EPA).

Figure 2. Drawing of the prototype flow loop (elevation) showing: (a) heat exchanger, (b) LH_2 pumps, (c) window venturi test section, (d) heaters.

Figure 3. Pumping capability of the Globe VAX-3 blowers, showing flow vs RMS voltage across each unit, for one pump only and for two pumps in series.

Figure 4. Measured 25 MeV electron beam profile at the EPA. Secondary electron current (arbitrary units) vs horizontal or vertical position of a probe wire.

Figure 5. Calculated valves of scattered fraction of electron beam vs relative hydrogen density. Also shown are three measurements of traget empty fractions.

Figure 6. Scattered fraction of electron beam vs average beam intensity for LH_2 target loop full. Symobls are indexed as follows: □ run 1; ● run 2; X run 3, Δ run 4.

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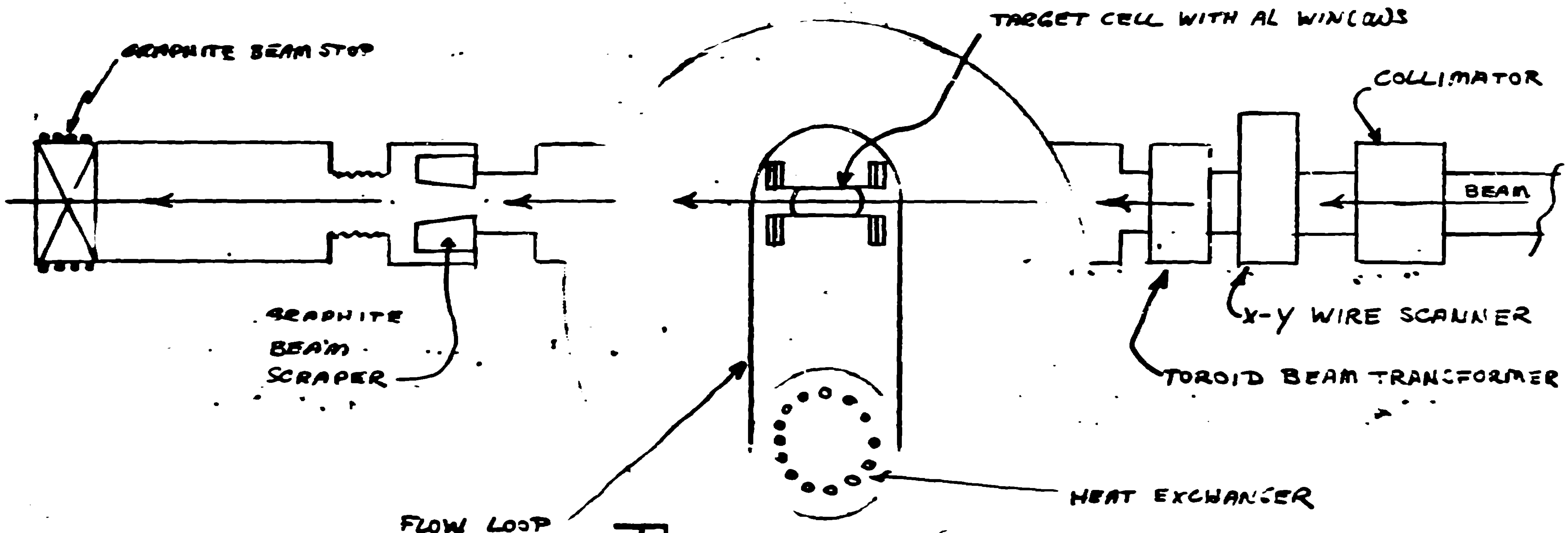

FIGURE 1

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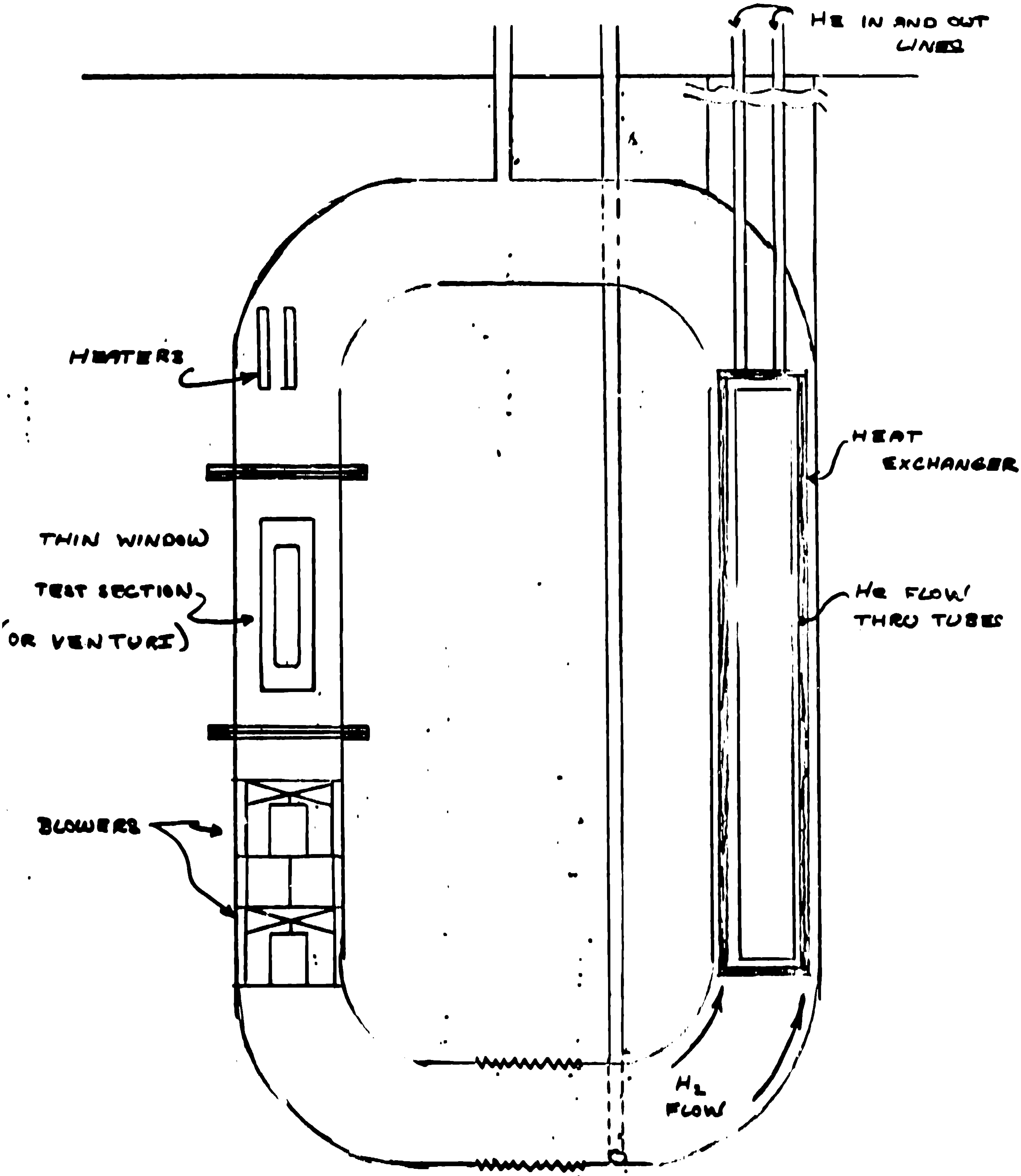

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FIGURE 2

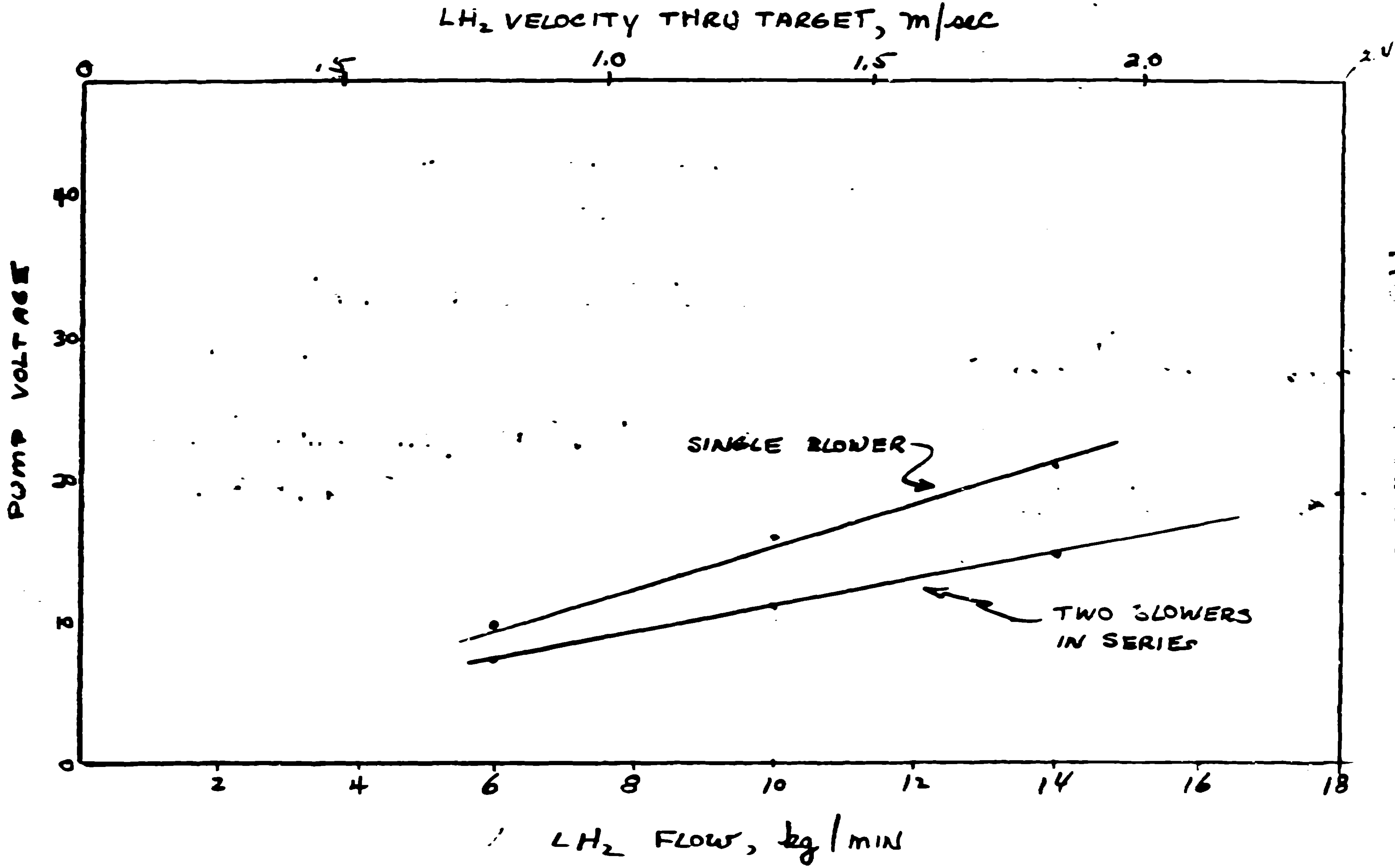

FIGURE 3

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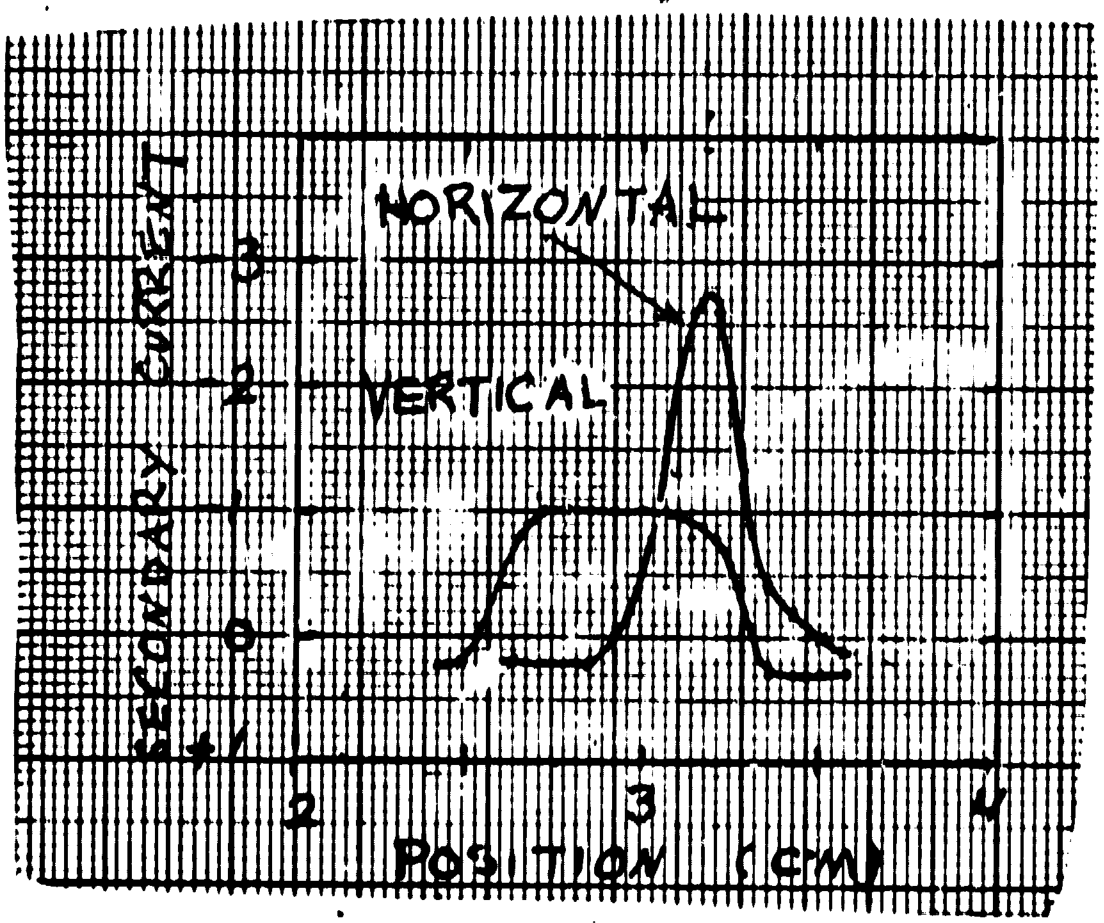
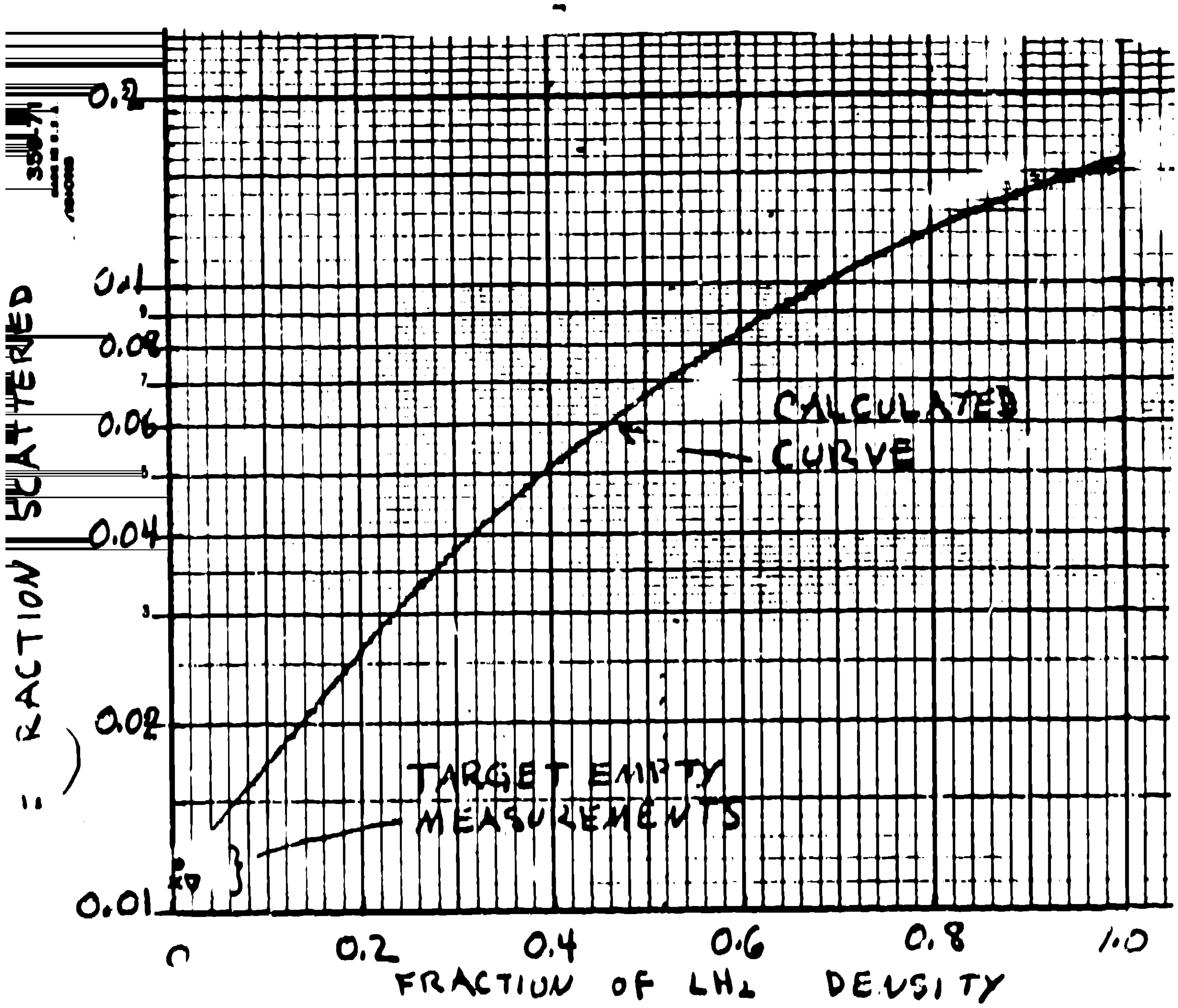


FIGURE 4



FRACTION SCATTERED
0.2
0.1
0.08
0.06
0.04
0.02
0.01
CALCULATED CURVE
TARGET EMPTY MEASUREMENTS
0
0.2
0.4
0.6
0.8
1.0
FRACTION OF LH2 DENSITY

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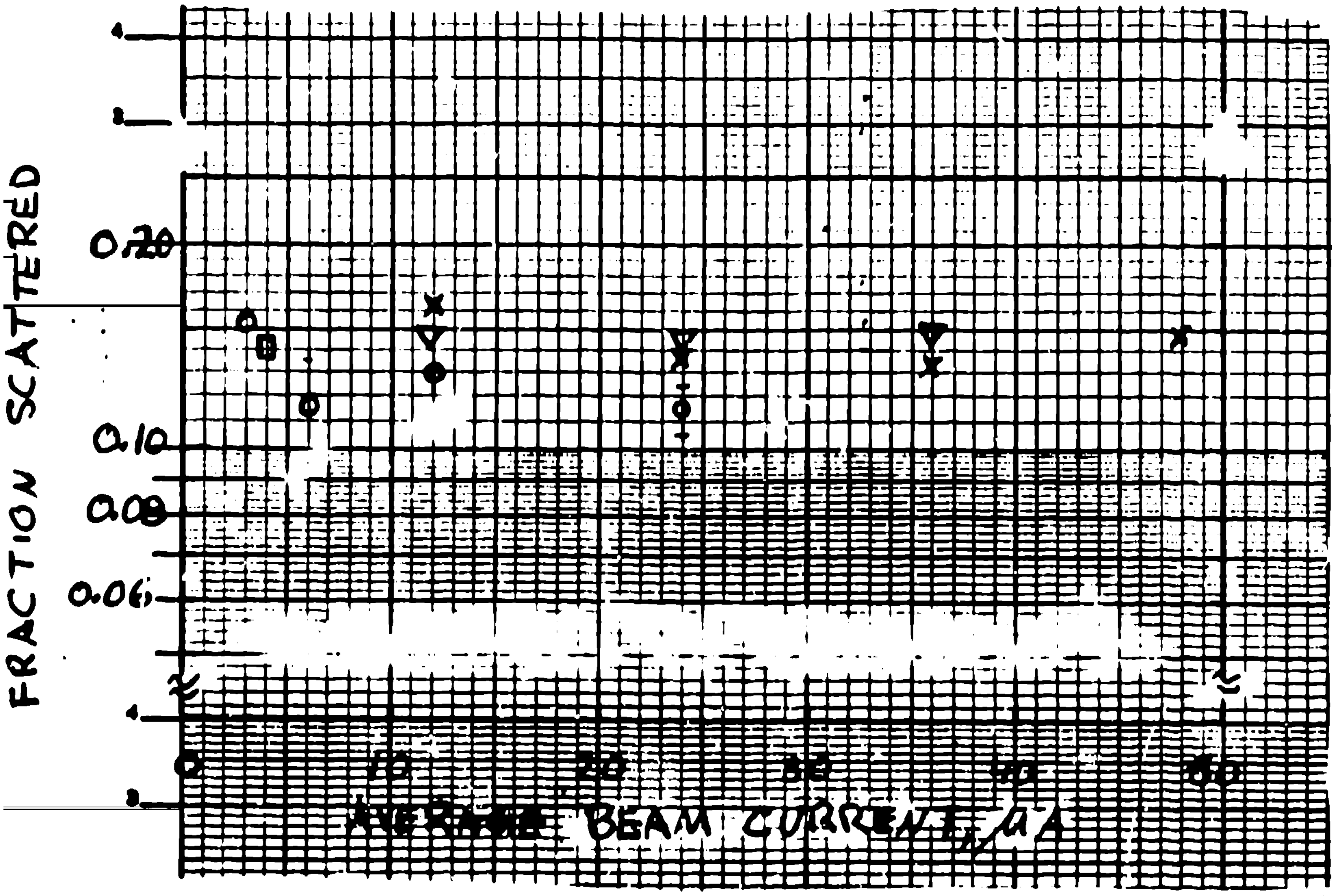

FIGURE 6