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The Brookhaven National Laboratory
80-Inch Liquid Hydrogen Bubble Chamber*

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MASTER

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ABSTRACT

A description is presented of the newest and largest liquid hydrogen bubble chamber facility to be placed in operation recently. The description covers all of the basic design parameters of the chamber including special material requirements and buildings. A review of the first year of operation is given, with emphasis on equipment performance. Data such as cool-down rate, refrigeration requirements, both static and dynamic, and temperature stability and equilibrium are presented and discussed.

1. Introduction

One year ago, Sunday, June 2, 1963, marked the successful conclusion of a design, development and construction project of over four years duration. On this date the first pictures of tracks produced in the BNL 80-inch hydrogen bubble chamber by high energy nuclear particles were taken. Preliminary studies and basic designs were made by the engineers and physicists of the Bubble Chamber Group. The fabrication of components was done by various companies in this country and in Europe. All of the designs were completed and the orders placed by January of 1962, and the remainder of the time (until May, 1963) was spent in assembling and testing individual systems as they arrived. The effort required approximately 244 man-years of work at BNL and untold man-years of fabricators' time. The total cost of the project, including the building, was approximately six million dollars. Since June, 1963, the chamber has been operated for both engineering and physics data.

2. Facility and Chamber Description¹

An aerial view (Figure 1) shows a layout of the complex. The construction in the upper left is the beam path from the accelerator. The tall portion of the central building is the chamber room, the right wing is the equipment room containing compressors, vacuum pumps, etc.; and the central portion and left wing are the control room,

motor control center and magnet power room. The concrete pad is the gas storage area for high and low pressure hydrogen and nitrogen process gases. The large sphere on the right is the emergency dump sphere.

Figure 2 is a picture of the magnet open showing the chamber in place and the safety chamber being inserted. The total weight is 480 tons. The magnet produces a field of 20,400 gauss with a power consumption of 4 megawatts. The complete structure can be translated 60 feet, elevated 24 inches, and rotated 360° . The upper left end contains the refrigerator platform, the upper right end the vacuum pumping equipment, and the camera and optics platform is on the lower right.

The chamber body, shown in Figure 3, is a combination of castings and wrought material fabricated by welding.² At the top is the cylinder where the expansion piston fits. This piston is 36 inches in diameter and 32 inches long with a maximum stroke of 1-1/2 inches. The piston is fabricated of inconel "X" "Hexcel", with rings top and bottom, weighing 250 pounds. The chamber has a total volume of 1,500 liters and a visible volume of 900 liters of liquid hydrogen. The large glass window fits in the step on the front of the chamber. On the rear of the chamber the back section of the multiple layer insulation³ may be seen. Figure 4 shows the front portion of the

insulation being installed. This insulation consists of 3 inches, 100 layers per inch, of aluminized mylar wrapped on a stainless steel liner.

5. Refrigeration System

The refrigeration system⁴ is usually looked upon as the major cryogenic contribution to a bubble chamber, but a close look at the preceding paragraphs will show this to be untrue. It is true, however, that the refrigeration system occupies the largest space. There are two five-stage nitrogen compressors, of 227 SCFM at 3,000 psig discharge pressure, provided for the nitrogen refrigeration system, two five-stage hydrogen compressors, of 227 SCFM at 2,000 psig discharge pressure, for the hydrogen refrigerator, and one three-stage hydrogen compressor, of 500 SCFM capacity at 250 psig, which is used to drive the expansion system. Also in this room are the gas distribution panel, the nitrogen pre-cooling unit, process vacuum pumps, and the ambient temperature hydrocarbon and moisture removal towers for all gases.

The platform on the bubble chamber contains all of the cryogenic temperature equipment. This includes the cryogenic purifiers for the process hydrogen, the nitrogen and hydrogen refrigerators, and the control systems for the bubble chamber refrigeration loops. The system may be viewed as a closed cycle cascade system. The nitrogen and hydrogen cycles are of the Simple Linde type with precooling.

Precooling for the nitrogen cycle is provided by an R-22 unit which cools approximately 40% of the 3,000 psig nitrogen flow to a temperature of 205°K . The nitrogen refrigerator operates in part as a true refrigerator and in part as a liquefier. The hydrogen refrigerator is precooled with liquid nitrogen at 80°K . The present capacity is 2,600 watts with the possibility of being increased to 4,000 watts.

The loops for refrigeration of the chamber proper begin with an expansion valve that reduces the pressure of the gas at the lower end of the Joule-Thompson heat-exchanger from 2,000 psig to approximately 210 psig. This gas is then piped to a manifold where it is distributed to the four cooling loops and two filling valves. The inlet to each cooling loop⁵ is a valve which controls the flow in the loop using the superheat across the loop as the control variable. The absolute temperature of the fluid flowing in the loop is controlled by a second valve, using the temperature of the liquid hydrogen in the chamber, at a point close to the loop, and the absolute pressure of the fluid in the loop as primary and secondary control variables working in a cascade system. The effluent from each loop is then returned to the cold end of the hydrogen refrigerator. The chamber may be filled by any of three methods. One is by direct liquefaction into the chamber at two points, one just below the piston, and the other slightly above the lower piston rings. A second

is by condensation and a third is by direct filling from a storage vessel. The unliquefied portion is returned cold to the cold end of the refrigerator.

6. Equipment Performance

The first year the chamber was in operation for 3,604 hours. During this operating time the chamber was expanded 1,300,000 times and 557,000 pictures were taken. Two notable events marked this period, one in engineering, and the other in physics. The most important event in an engineering sense was the first cool-down itself. The chamber was assembled and cool-down was begun on May 11, 1963. During the following three weeks the chamber was cooled, filled with liquid, successfully expanded, and the first pictures were taken with and without magnetic field. This was the first time that all the component systems had been in operation together. Figure 5 is a picture of the chamber, taken during the first filling operation, showing the chamber half full and raining hydrogen. The most important event from a physics point of view has already received considerable attention from the scientific community. Figure 6 is an enlarged picture of a portion of the chamber on the left side with the particular event drawn on the right, this is the first picture taken of the production and decay of an Ω^- particle.⁶

Approximately 50% of the operating hours have been devoted to engineering studies of various types. Chamber operating conditions have been catalogued from 25°K to 26.9°K , with varying piston strokes and pressure drops, and expansion rates to 1 per second.

Cooling and filling of the chamber normally takes 5-6 days. The cooling rate is not determined by refrigeration capacity available, but by the rate at which the large main window may be cooled. The cooling rate of the window is determined by the allowable stresses (1,000 psi) produced by temperature gradients in the glass. If a large temperature gradient is observed, then the cooling rate must be reduced. Despite the size and poor heat transfer characteristics of the glass, it is possible to keep the gradients small, approximately $5\text{--}10^{\circ}\text{K}$, which allows an average cooling rate of about 2.5°K per hour. The filling rate is controlled by the refrigerator, 160 liters per hour when operating as a liquefier, and 100 ± 10 liters per hour after transfer and static losses are subtracted. The warm-up of the chamber takes 4-5 days and is governed by the glass in the same manner as the cool-down.

Refrigeration requirements may be broken into two parts, the static losses and the dynamic load due to the expansion process. In this chamber there are two different static losses given. The

first is a true static loss, as determined by standard boil-off tests, of 90 ± 5 watts. The second is a static loss so far as the chamber is concerned but includes refrigeration losses due to transfer lines, valves, heat exchangers, etc. This loss is 500 ± 25 watts. The expansion load is the most difficult to analyze because of the many variables involved. These are expansion rate, expansion ratio or piston stroke, absolute chamber temperature, chamber pressure, temperature distribution in chamber, and even the cleanliness of the chamber. To be a useful tool the chamber must be expanded into the super-heated liquid region where it is sensitive to ionization of high energy charged particles. This ionization produces bubbles in the liquid along the path taken by the particle, and the number of bubbles per unit length of track is a direct function of the properties of the liquid at the time of the particle's passage. Therefore, the density of the tracks can be varied at any given temperature by selecting the pressure at which the particle beam is injected. Since the expansion load does vary with the expansion ratio and may vary with temperature as well, data on the whole sensitive region are not yet complete. The data presented here represent only a few of the many points already run. Figure 7 is a plot showing the total refrigeration load as a function of the number of expansions per hour. These particular data were taken at the following conditions:

Chamber pressure	80.0 psia
Chamber temperature	25.7°K
Piston displacement	0.6% total chamber volume or 9 liters

The calculated load value is 0.45 watt per liter of chamber volume per expansion or $1,185 \pm 50$ watts at a 1 second pulse rate. The portion of the load attributable to the expansion process was found by calculating heat balance on the refrigerator using known temperatures, pressures, and flows, and subtracting the known static losses. One interesting conclusion to be drawn from these data is that less than 50% of the available refrigeration is required for the chamber at a 1 second repetition rate. The adiabatic efficiency of the expansion process is the most important calculation to be made from these data. A completely irreversible process would be one in which all of the volume displaced by the piston would turn to gas and have to be condensed by the refrigerator; also a completely reversible process would be one where no change of phase occurs at all. A piston-expanded bubble chamber approaches the latter. In the case of these data 9 liters are displaced and if all of it changes phase the calculated heat load would be 13.0 watts per liter per expansion. Using the previously calculated actual load of 0.45 watt per liter per expansion it is found that the process is 96.5% reversible. This is shown more clearly in Figure 8 which is an oscilloscope picture of the chamber pressure - displacement diagram. Measurement

of this diagram gives a reversibility of 94.1%.

The temperature control system for the refrigeration loops has performed exceedingly well. The main problem has been the size of the control valve. During cool-down, when the fluid is warm, the valves must be large to pass the flow; however, when the chamber is cold and full the high density of the fluid requires a small valve for fine control. The present inlet or flow control valves have an orifice size of 0.093 inch with needle stems that taper from that dimension to nothing in 3/4 inch length. During cool-down and warm-up there are times when these are wide open and will still not carry the full compressor flow. When the chamber is full they operate at 30% or less of capacity. Adding more valves with consequent greater losses is not a good solution to the problem, nor does one appear to exist. During cool-down the loops are under manual control so that the amount of refrigeration applied to each of the different areas can be balanced for even cooling. Also, the normal control variables do not exist until the chamber is close to liquid temperature. This manual control will soon be replaced by the process control computer, since sensing temperatures, calculating rate of change and resetting valve openings to compensate is a relatively simple operation for the computer. During normal operation, when the chamber is full, the loop controls (previously described) have maintained the chamber temperature

to $\pm 1/50^{\circ}\text{K}$ for periods of several days with varying loads. It has been possible to reverse the normal temperature distribution of cold at the bottom and warm at the top. This means that the area under the piston is colder and much less sensitive to boiling, which obviously contributes to the efficiency of the expansion process.

The performance of the multiple-layer insulation has been extremely good and very trouble free. The main problems anticipated were pump-down time and residual contaminants on the many acres of surface that might eventually pump to the cold chamber surfaces and particularly to the viewing windows. The former has proved to be of no consequence and the pumping period before cool-down is normally 2-3 days with the vacuum space pumped to 2×10^{-5} to 10^{-6} Torr in that time, with the chamber warm and using N_2 temperature baffles. The latter also appears to be of small consequence. Although the windows have fogged on occasion, the trouble has always been traced to a leak or to some source other than the insulation. Perhaps the greatest virtue of this type of radiation shielding is its relative insensitivity to what on bubble chambers are normal pressure changes in the vacuum space. On at least one occasion the chamber was operated for several hours with a pressure in the vacuum space of up to 100 microns. The refrigeration requirements

did increase, but at no time was control of the chamber lost. An N_2 temperature radiation shield is an expensive item on bubble chambers and the substitution of the multiple-layer insulation has been highly successful and has simplified the chamber construction and operation.

7. Conclusions and Proposed Plans

Large hydrogen bubble chambers are extremely stable devices and are not subject to the fast changes experienced in smaller models. The BNL 80-inch bubble chamber has already proven itself to be a valuable tool for high energy physics research. Also, this very highly instrumented chamber is of extreme value in engineering studies of bubble chambers. The results obtained thus far have encouraged the design of even larger chambers, 20 to 30 times the volume, without the doubts of a few years ago.

There is a continuing plan to obtain engineering data from this chamber. This program, which includes exploring the complete sensitive region of liquid hydrogen, will continue; and later, data will be taken on deuterium. As new data are gathered, modifications and improvements in the chamber will be made.

8. Acknowledgements

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* F. Anderson, J.G. Androulakis, J.A. Bamberger, D.P. Brown, H.W. Courant, H.O. Courtney, B.B. Culwick, J.J. Diener, W.B. Fowler, C.L. Goodzeit, J. Hanush, E.L. Hart, C.R. Hedberg, B.H. Hertzendorf, H. Houtsager, D.A. Kassner, H.L. Kraybill, D.T. Liverios, R.I. Louttit, S.C. Mo, T.W. Morris, G.T. Mulholland, R.B. Palmer, P.A. Pion, R.R. Rau, E. Rutan, N.P. Samios, R.P. Shutt, J.H. Sondericker, A.M. Thorndike, W.A. Tuttle, I.J. Winters, H. Woelfel, D.H. Wright, and S.S. Yamamoto

References:

1. There are available engineering notes on various systems and components by contacting the author.
2. C.L. Goodzeit, Weldability and Stability Studies of Some Stainless Steel Castings Alloys for Cryogenic Service in the 80-Inch Liquid Hydrogen Bubble Chamber, submitted to the 1964 Cryogenic Conference.
3. NRC-2 multiple-layer insulation patented by National Research Corporation under an exclusive licensing agreement to Standard Steel Corporation.
4. J.A. Bamberger, D.P. Brown, and J.E. Jensen, Bubble Chamber Group, Engineering Note B.C.-03-0D, May 1962.
5. J.G. Androulakis, Bubble Chamber Group, Engineering Note, B.C.-03-0E.
6. V.E. Barnes et al., Observation of a Hyperon with Strangeness Minus Three, Phys. Rev. Letters 12, 204 (1964).

Figure Captions:

- Figure 1 Aerial view of the 80-inch bubble chamber facility.
- Figure 2 View from left side with magnet open and chamber in position.
- Figure 3 Chamber body with instrumentation and back half of superinsulation.
- Figure 4 Installation of front superinsulation.
- Figure 5 80-inch bubble chamber first fill, chamber one-half full.
- Figure 6 Photograph and line diagram of event showing decay of Ω^- .
- Figure 7 Plot of refrigeration consumption vs. repetition rate.
- Figure 8 Oscilloscope picture of pressure-displacement diagram.

FIGURE 1

FIGURE 2

FIGURE 3

FIGURE 4

FIGURE 5

FIGURE 6

FIGURE 7

OSCILLOSCOPE TRACE PRESSURE-DISPLACEMENT

FIGURE 8