Talk given at the International
Conference on Instrumentation
for High Energy Physics
September 9-10, 1966

MASTER

A-159 (BC)

BNL 10751

CONF-660918-15

CFTT PRICES

DEC 12 1966

BROOKHAVEN NATIONAL LABORATORY

Department of Physics
Upton, L.I., N.Y.

HC 3.00, MN 65

RELEASED FOR ANNOUNCEMENT
IN NUCLEAR SCIENCE ABSTRACTS

BNL's Large Bubble Chamber Program*

W.B. Fowler

As presented in the report of the last instrumentation conference (1964 Dubna), the Bubble Chamber Group at Brookhaven National Laboratory has been doing design and development work toward very large cryogenic bubble chambers. The paper at the last conference contained information relevant to the need for chambers of visible volume greater than 10,000 liters, as well as some of the design solutions that were available at that time. Since 1964, efforts have continued towards finding the most economical way of producing satisfactory photographs of these chambers. A summary of progress toward achieving the next generation of large volume chambers, with minimum cost and maximum probability of success, is given below.

One of the most dominant elements of the BNL work is the belief that it is possible and desirable to construct a multipurpose chamber, i.e. a chamber that leaves open the possibility of operation with pure hydrogen, deuterium, or neon-hydrogen mixtures. The neon-hydrogen mixture capability opens up the use of a cryogenic chamber as a fully efficient heavy liquid chamber. By this I mean that an equivalent-size heavy liquid chamber would have no physics advantage over an

*Work performed under the auspices of the U.S. Atomic Energy Commission

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency Thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

DISCLAIMER

Portions of this document may be illegible in electronic image products. Images are produced from the best available original document.

equivalent-size cryogenic chamber filled with the appropriate neon-hydrogen mixture.

For high-detection efficiency for gamma-rays in the cryogenic chamber, we do not mean to exclude the possibility of multiple plate arrays as an alternate method. However, most experiments that have been investigated seem to be able to be accomplished with equal or better efficiency in a cryogenic chamber filled with neon-hydrogen mixtures. Therefore, a single device, capable of utilization either as a heavy liquid chamber or as a hydrogen chamber is thought to give maximum flexibility for accomplishing the future experimental requirements in high energy physics. Following this approach we have, therefore, done design work on chambers with magnetic fields of approximately 30 kilogauss in order to have good momentum measurement in the neon-hydrogen mixture fillings.

Over the last year, several developmental programs have been carried out at Brookhaven to verify certain features of the current design. Fig. 1 shows the results of tests conducted, using the 20-inch bubble chamber. Tracks are seen in this photograph taken with a mixture of 74 atomic percent neon mixed with hydrogen. Operating conditions were: chamber temperature, 30°K ; expansion ratio, 0.75%; equilibrium pressure, 120 psia. Further tests have shown an ability to operate with essentially any desired percentage of neon in hydrogen or deuterium. Results of a high demagnification optical test are shown in Fig. 2. Here the top photograph shows tracks in the BNL 80-inch bubble chamber, taken on microfile film at $f/11$, with a demagnification of 100. The bottom photograph is presented for comparison and is a normal BNL 80-inch bubble chamber photograph with a demagnification of 14. The current BNL 14-foot cryogenic bubble chamber design will have a demagnification of about 100 at beam height when 30mm lenses are used.

To verify the feasibility of multiple pulse operation in large chambers, tests were conducted using the BNL 80-inch bubble chamber, using a double pulse mode. The top photograph in Fig. 3 shows tracks in the chamber taken during the first pulse. The bottom photograph in Fig. 3 shows tracks taken during the second pulse 0.075 sec later. The chamber was operating at 30 psi overpressure. The insert at the top of this figure shows piston stroke, chamber pressure drop, and expansion valve control pressure for the two pulses on a 0.010 sec per division time scale. Beam spill during this test was continuous; faint tracks are, therefore, presumed to be early in the expansion pulse.

The present design consists of a 14-foot diameter cryogenic bubble chamber for use with hydrogen, deuterium, or neon-hydrogen mixtures. Before every passage of a beam of particles from the AGS, the chamber is sensitized by lowering the pressure of the liquid by means of an expansion piston. The expansion system is designed for two expansions separated by a minimum time of 0.060 sec for each accelerator cycle. The time between pulses can be lengthened to accept beam intervals convenient for best accelerator operation. Fig. 4 shows a cross sectional view of the expansion system. Here we see a seven-foot diameter piston, made of fiber glass epoxy laminate, which will be hydraulically coupled by means of liquid hydrogen to a large flexibly mounted baffle at the bottom of the chamber. This gives the advantage of a large expander with the resulting uniform liquid motion with only a relatively small force required to operate it. This is possible because a high-response hydraulic system can be built to move the smaller piston a total of 8.4 inches in order to provide a one percent expansion ratio. The level is maintained in the volume beneath the piston by imposing a temperature gradient along the wall of the

conical section. The piston is coupled to the hydraulic drive cylinder by means of a filament-wound glass epoxy rod. The main hydraulic control valves are shown in cross section in Fig. 4. These are high-response Venturi valves, mounted to the hydraulic cylinder.

The optical system proposed for the 14-foot chamber involves illumination and photography through five ports located on top of the chamber. The ports are furnished with spherical windows for sealing the chamber, with separate thermal radiation shield windows and separate vacuum tank sealing windows. The proposed system uses a bright field illumination system in which the light from a ring-shaped flash tube mounted concentrically with the photographic lens is returned to the lens by retrodirecting Scotchlite mounted on the walls and bottom of the chamber. Photography will be done by 90° 30mm and/or 60mm focal length lenses, and recorded on 70mm film. The five camera ports are spaced at the corner of an equilateral pentagon. Most experiments will require three or four views, but the positions of these can be chosen for maximum efficiency with a given beam configuration. Fig. 5 shows a plan view of the chamber and indicates the different camera positions that might be used, depending on the energy of the beam bombarding the chamber. Possible beam orbits are shown for 2.3 BeV/c and 4.5 BeV/c at a magnetic field of 30 kilogauss. Also shown are possible beam entry ports in the chamber walls, the magnet dewar and the vacuum tank. The pentagonal placement has been chosen to eliminate pairs of cameras in a plane containing the axis of the chamber. For such pairs, there exists strong reflection of light source of one member, from the front surface of the retrodirecting Scotchlite mounted at the bottom of the chamber, seen by the second member in the center of its

field of view. A summary of the lens specification is given in Table I. Numbering the camera positions clock-wise, beginning with 1 over the beam entry port, Table II shows the visible volume of the present design. Specifications for the proposed spherical windows are as follows:

<u>Window Location</u>	<u>Inside Radius r</u>	<u>Outside Radius (r + t)</u>	<u>Thickness t</u>	<u>Material</u>
Chamber Body	15 cm	20 cm	5 cm	BK 7
Shield	9 cm	14 cm	5 cm	BK 7
Vacuum Chamber	6 cm	7.25 cm	1.25 cm	Quartz

All surfaces must match a precision test spherical surface to within two fringes per centimeter. Outer and inner surface concentricity on each window must be maintained such that an axial ray shall not be deviated more than 2×10^{-5} radians.

Inquiries to manufacturers have revealed that there should be no difficulty in obtaining such windows.

The approximate 30 kilogauss magnetic field of the present design is to be generated by current flowing in superconducting coils cooled to 4.2°K by a helium refrigerator. We have eliminated an approximately 2900-ton iron yoke from our previous conventional magnet design. By the elimination of this yoke, many simplifications in the chamber design have been possible, and the yoke funds have been applied to the somewhat more expensive superconducting coils and associated equipment. The superconducting magnet design has, in addition to the elimination of the yoke, the advantage that, based on the current estimates, it is possible to achieve at least 50% more magnetic field for the same cost. Other advantages of the absence of the magnetic yoke are: (1) larger magnetized

LEGAL NOTICE

This report was prepared as an account of Government sponsored work. Neither the United States, nor the Commission, nor any person acting on behalf of the Commission:

A. Makes any warranty or representation, expressed or implied, with respect to the accuracy, completeness, or usefulness of the information contained in this report, or that the use of any information, apparatus, method, or process disclosed in this report may not infringe privately owned rights; or

B. Assumes any liabilities with respect to the use of, or for damages resulting from the use of any information, apparatus, method, or process disclosed in this report.

As used in the above, "person acting on behalf of the Commission" includes any employee or contractor of the Commission, or employee of such contractor, to the extent that such employee or contractor of the Commission, or employee of such contractor prepares, disseminates, or provides access to, any information pursuant to his employment or contract with the Commission, or his employment with such contractor.

A summary of lens specifications.

	<u>A Lenses</u>	<u>B Lenses</u>
Full field angle	90°	90°
Image Diameter	61mm	122mm
Front Barrel Diameter	Less than 2-1/4"	Less than 3-1/4"
Object Distance	3 meters	3 meters
Aperture	f/11	f/11
Modulation of 50 l/mm sinegrating	50%	50%
Distortion	Approximately 30μ	Approximately 60μ
Chromatic correction	500-650 mμ	500-650 mμ

TABLE I

14-foot Cryogenic Bubble Chamber

Volume visible in several lens combinations assuming a useful inner volume of 14-foot diameter (total volume 62,000 liters) and nearest points of good focus for each lens of 4.5 feet.

<u>Cameras</u>	<u>Visible Volume (thousands of liters)</u>
1 (or 3, or 4)	48
1 and 3 (or 1 and 4, or 3 and 4)	47
1, 3, and 4	46
2 (or 5)	39
2 (or 5), 3 and 4	38
2 and 5	34
2, 3, 4, and 5	33
All cameras	33

TABLE II

volume makes a chamber of greater height economically feasible resulting in further improvement in measurements, and a greater number of neutrino events per accelerator beam exposure; (2) greater flexibility is allowed in choosing the best location for expansion system and optics as well as greater freedom in the detail design of these systems; (3) mobility of the chamber becomes feasible which simplifies and improves beam entry conditions. In addition, because of the ac power of eleven megawatts for the iron magnet is no longer required, reduction in required electrical utility equipment has been possible. Also significant savings in operations costs should occur. Table III lists magnet parameters for the current design.

Two refrigerators are provided for the cooling and filling of the hydrogen chamber and for the cooling and filling of the helium dewar for the superconducting magnet. The size of the hydrogen refrigerator is based on a 7000 watt static load and a 0.3 watts per liter pulsing load at a repetition rate of one expansion pulse per second. Operating as a liquefier, the hydrogen refrigerator could fill the chamber in approximately 44 hours. The 1000 watt helium refrigerator capacity is based on an estimate of the heat losses associated with the superconducting magnet. Operating as a liquefier, the helium refrigerator should be capable of filling the magnet system in approximately 50 hours. Both of these refrigerators are based on a liquid nitrogen precooling. Table IV lists the specifications for the hydrogen and helium refrigerators.

Fig. 6 is a cross sectional view of the entire chamber complex. Visible are the cameras at the top, the chamber body, the helium dewar, and the vacuum tank. The helium dewar and chamber body are in a common vacuum vessel. Also shown

14-foot Cryogenic Bubble Chamber Project

Magnet Parameters

Magnetic field intensity	30 kilogauss
Ampere-turns	18×10^6
Coil current	10,000 amperes
Total turns	1,800
Number of "pancakes"	28
Turns per "pancake"	64
Turns per "pancake" layer	32
Total conductor length	1.02×10^5 feet
Inductance	14 henries
Stored energy	725 megajoules
Weight of magnet coils	120 tons

TABLE III

14-FOOT CRYOGENIC BUBBLE CHAMBER

Calculated Refrigerator Parameters

HYDROGEN:

Q_{H_2} , refrigeration	=	30 kW at 25° K
Total hydrogen flow	=	4.77×10^5 gm/hr
Flow through engine	=	1.50×10^5 gm/hr
Flow through expansion valve	=	3.27×10^5 gm/hr
E, fraction of flow through expansion valve liquefied	=	80.7%
W_c , work of compression	=	1200 Hp = 895 kW
W_e , work of engine	=	22.9 Hp = 17.1 kW
Liquid nitrogen precooling required	=	276 liters/hr
Amount of liquid hydrogen produced operating as a liquefier	=	2240 liters/hr

HELIUM:

Q_{He} , refrigeration	=	1 kW at 4.3° K
Total helium flow	=	2.8×10^5 gm/hr
Flow through engine	=	3.8×10^4 gm/hr
Flow through expansion valve	=	2.4×10^5 gm/hr
E, fraction of flow through expansion valve liquefied	=	62.2%
W_c , work of compression	=	400 Hp = 298 kW
W_e , work of engine	=	0.8 Hp = 0.6 kW
Liquid nitrogen precooling required	=	21.3 liters/hr
Liquid hydrogen precooling required	=	147.3 liters/hr
Amount of liquid helium produced operating as a liquefier	=	240 liters/hr

TABLE IV

is the flexibly mounted baffle which isolates the expansion piston from the main chamber volume. The cryogenic components are shielded from radiant heat gains by multiple layer reflective insulation. The bottom of the vacuum chamber is attached to an undercarriage and slide rails, along which the machine can be translated in order to place it in optimum position for experiments or beams. The chamber is to be located in a new experimental area at the AGS, approximately 1000 feet from the accelerator.

Including an estimate of about \$3-million for buildings and experimental facilities and \$3-million for contingency, the estimated cost for this project is about \$16-million including manpower. A three and one-half year construction schedule is estimated.

FIGURE CAPTIONS

Fig. 1 Particle tracks photographed in the BNL 20-inch bubble chamber during an experiment using mixtures of neon and hydrogen.

Fig. 2 Shown in the top photograph are tracks in the BNL 80-inch bubble chamber, taken on microfile film, at $f/11$, with a demagnification of 100. The bottom photograph is presented for comparison and is a normal BNL 80-inch bubble chamber photograph.

Fig. 3 Prints from bubble chamber film showing particle tracks produced in double-pulsed operation in BNL's 80-inch bubble chamber. The top is the first pulse and the bottom is the second pulse 0.075 sec later. The chamber was operating at 30 psi overpressure. Insert at top shows piston stroke, chamber pressure drop and expansion valve control pressure for the two pulses on a 0.010 sec per division time scale. This indicates the feasibility of multiple pulsing of chambers of large volume.

Fig. 4 14-foot bubble chamber proposed Expansion System, side elevation.

Fig. 5 Cross section of chamber and magnet dewar showing location of beam port for most effective utilization of chamber volume for low and medium energy beams.

Fig. 6 14-foot bubble chamber main assembly drawing, side elevation-half section.

Fig. 1

Fig. 2

Fig. 3

FIBERGLASS - EPOXY LAMINATE PISTON
REINFORCED WITH RADIAL RIBS

FILAMENT WOUND GLASS - EPOXY
PISTON SKIRT AND SEAL CARRIER

TEMPERATURE CONTROL
AND SPLASH BAFFLE

PROPOSED LIQUID LEVEL

VACUUM TANK COVER

ROTARY PISTON
POSITION ENCODER

FROM EXPANSION
ACCUMULATOR

EXPANSION VENTURI VALVE

HYDRAULIC CYLINDER

H₂ GAS AT ~ 32°K
BUFFER VOLUME

28°K

H₂ LIQUID

24°K

SPLIT STAINLESS STEEL
GUIDE SLEEVE

FILAMENT WOUND GLASS - EPOXY ROD
INTEGRAL WITH PISTON

STAINLESS STEEL
COUPLING INSERT

OMEGA BELLOWS
EXPANSION JOINT

TO RECOMPRESSION
ACCUMULATOR

RECOMPRESSION VENTURI VALVE
WITH INTEGRAL CHECK

TO BUFFER ACCUMULATOR BANK

SCALE - FEET

Fig. 4

1	2	3	4	5	6	7	8	9	10
11	12	13	14	15	16	17	18	19	20
21	22	23	24	25	26	27	28	29	30
31	32	33	34	35	36	37	38	39	40
41	42	43	44	45	46	47	48	49	50
51	52	53	54	55	56	57	58	59	60
61	62	63	64	65	66	67	68	69	70
71	72	73	74	75	76	77	78	79	80
81	82	83	84	85	86	87	88	89	90
91	92	93	94	95	96	97	98	99	100

◉ CAMERA LENS POSITIONS

○ ALTERNATE CAMERA LENS POSITIONS

14' BUBBLE CHAMBER

2.3 BEV/C BEAM ORBITS

4.5 BEV/C BEAM ORBITS

30 KG MAGNETIC FIELD

Fig. 5