MASTER

ARGONNE NATIONAL LABORATORY
Argonne, Illinois 60439

Parameters and Performance Characteristics of the

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High Energy Physics Division

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HISTORY

June, 1964	- - - - -	Proposal Submitted
May, 1965	- - - - -	Design Started
June, 1966	- - - - -	Construction Started
December, 1968	- - - - -	Superconducting Magnet Tested
August, 1969	- - - - -	First Chamber Cooldown with Liquid Nitrogen
October, 1969	- - - - -	First Chamber Cooldown with Liquid Hydrogen
October, 1969	- - - - -	First Particle Tracks
September, 1970	- - - - -	First Experimental Pictures Taken
November, 1970	- - - - -	First Neutrino Event in Liquid Hydrogen
October, 1971	- - - - -	First Chamber Cooldown with Liquid Deuterium
October, 1971	- - - - -	First Neutrino Event in Liquid Deuterium
March, 1972	- - - - -	1,000,000 Physics Pictures Taken
March, 1972	- - - - -	Expansion System Reached 1,500,000 Pulses
March, 1972	- - - - -	30,000 Track Sensitive Expansions in the Double and Triple Pulse Mode at Intervals as close as 150 ms.

A. Liquid Volume (See Figure 1)

The overall enclosed volume of the chamber measures $\sim 26.5 \text{ m}^3$ of which 15.5 m^3 serve as a useful fiducial volume. Scotchlite panels are hung from the ceiling around the inside perimeter such that the visible inside diameter measures $\sim 376 \text{ cm}$. Additional panels cover the inside surface of the piston. A total of 16 usable fiducials are located around the vertical panels.

The Scotchlite panels serve two functions. First, it allows bright field illumination and second, it allows for parasitic bubbles generated near the wall or bottom to rise to the chamber top behind or under the panels. This helps in reducing the background and turbulence in the pictures.

B. Optics

The optics consists of 4 cameras located symmetrically on a 7 ft. diameter circle, (Figure 2). Each one is oriented in such a way that the optical axis points toward the chamber center. This arrangement maximizes the visible volume but at the same time results in different orientations of the beam tracks when projected onto the films. The camera lenses are protected by concentrically located glass fish-eye windows. The glass and the two vacuum spaces between the windows serve as transparent thermal barriers so that the space in which the cameras reside can be kept at room temperature.

Camera and Film Parameters:

Angular Lens Coverage	-	140°
Paraxial Focal Length	-	21 mm
Range of f-numbers	-	Fixed stops from f/8 to f/22
Illumination	-	Bright Field
Flash	-	Circular xenon discharge tube
Flashtube energy	-	$\sim 50 \text{ J}$ at 2.5kV
Flashtube lifetime	-	Designed for 10^6 Pulses at 500 J
Film type	-	Eastman Kodak Microfile AHU Mylar base (Panchromatic)
Film size	-	70 mm, <i>Perforated</i>

Liquid Volume (See Figure 1)

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Optics

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Camera and Film Parameters:

Angular Lens Coverage	-	140°
Axial Focal Length	-	21 mm
Range of f-numbers	-	Fixed stops from f/8 to f/22
Illumination	-	Bright Field
Light Source	-	Circular xenon discharge tube
Light tube energy	-	$\sim 50 \text{ J}$ at 2.5kV
Light tube lifetime	-	Designed for 10^6 Pulses at 500 J
Film type	-	Eastman Kodak Microfile AHU Mylar base (Panchromatic)
Film size	-	70 mm, Perforated

Maximum wavelength accepted by film	-	6300 Å
Minimum wavelength transmitted through lens system (lower end cut by orange filter)	-	5500 Å
Camera based fiducials	-	4, projected via fiber optics from the xenon flash tube onto the film symmetrically around chamber image
Data box	-	one binary, one decimal. Both projected from the back side onto the film
Film capacity	-	1200 ft. = > 6000 frames per magazine
Length of film path	-	~12 ft. on either side of lens

The xenon flash tubes, employed for illumination, are concentrically located around the lenses. The combination of highly retrodirective Scotchlite and the closeness of the flash tubes to the lenses allow for effective bright field illumination. Reduction in chromatic lens aberration and maximum retrodirectivity of the Scotchlite is achieved by limiting the accepted band width to $\sim 800 \text{ Å}$ in the wavelength region quoted above.

Film changes are performed by splicing a new roll to the feed side. This avoids rethreading the film through the 24 foot path. Rethreading often times is only accomplished by pulling the camera stem which requires emptying the chamber for safety reasons.

At present the data box information is flashed onto the film with incandescent light bulbs. This arrangement is not too reliable since the bulb filaments burn out quite easily in the chamber magnetic field. Improvements in this area will include the replacement of the bulbs with light emitting diodes (LED). One camera has already been equipped with these. The reason for not utilizing LED's before is that they have only recently become available for wavelengths below 6500 Å . Figure 3 is a display of a typical photograph.

Down-time due to vacuum problems in the optics system has been reduced considerably by setting up a technique for switching cartridges with the chamber at nitrogen temperature. This process takes about 4-5 days compared to 10-12 days needed for a complete warm-up and cool-down.

C. Expansion System

The main descriptive items of the expansion system are as follows:

1. The expansion stroke is adjustable up to 1.125 inches
2. Nominal expansion pulse duration is adjustable between 0.033 and 0.050 seconds.
3. Expansion repetition capability is 3 pulses every 2 seconds with individual pulses initiated as close together as 0.15 seconds.
4. System is capable of at least 10^6 cycles without major overhaul.

Presently, fire resistant Pydraul 60 oil is used as the hydraulic fluid.

D. Magnet

Some of the bubble chamber magnet parameters are displayed below:

Type of Magnet	-	Superconducting
Field Strength	-	Up to 18 kG
Charge Rate	-	~10 kG/hr
Conductor Material	-	Niobium, titanium, copper stabilizer (coextruded)
Number of NbTi strands per conductor	-	6
Number of turns per pancake	-	84
Number of pancakes	-	30
Total conductor length	-	40,000m
Return frame	-	Carbon Steel
Weight of return frame	-	1600 tons
Total weight of magnet	-	1750 tons
Discharge	-	slow rate (days) or fast rate through 0.1 ohm resistor (minutes)

One of the reasons for choosing a superconducting instead of a conventional magnet was the power-operating cost savings which was estimated at \$400,000/year. It should also be emphasized that the magnet was built with an iron return frame. The advantages of such a frame are as follows:

- 1.) With the iron the required current in the windings for a particular field strength is less than that without the iron. Hence, the stresses in the windings are considerably reduced.
- 2.) Nearly perfect field uniformity can be achieved over the entire chamber volume by use of the iron. (The absence of any appreciable radial field component allows the use of a metallic chamber piston).
- 3.) Large stray fields are eliminated. This results in reasonable working environments at the film drives, at the expander, etc. even under full field strength. (The stray field at the film drives was measured as 500G for the magnet at 18 kG).

The magnet has been mapped at three currents, 1000, 1538, and 1800 amperes corresponding to 10, ~15, 18 kG respectively. Polynomial fits for all three fields exist with a functional accuracy of $\pm 0.1\%$. Figure 4 shows the field map in the beam plane at 1800 amperes. Each line corresponds to an angular sweep through 360° at a particular radius. (The radii are incremented in steps of 15.217cm with a radius of 0.5 cm. near the chamber center).

E. Cryogenics

At present there is a 10,000 gallon nitrogen dewar. This tank is quite sufficient to maintain the "open loop" supply of nitrogen to the various systems.

The existing deuterium is stored in a 10,000 gallon dewar. About 80% of this tank is full of D_2 . The tritium/deuterium ratio is small ($<10^{-14}$) and does not hinder any D_2 bubble chamber experiment.

Hydrogen is stored in a 12,000 gallon dewar. An auxiliary H_2 storage facility exists with another 10,000 gallon dewar. It is planned to eventually employ this auxiliary dewar for neon storage. (Neon-hydrogen mixtures are contemplated for improved γ detection efficiencies). However, at present the auxiliary dewar cannot support more than 34,000 lbs. in liquid weight. A 61% mole neon mixture corresponds to such a weight.

The helium needed for the superconducting chamber magnet is stored in a 2600 gallon dewar inside the chamber building. During operation the magnet requires

~1850 gallons to fill.

Compressors and expansion engines are needed to refrigerate helium and hydrogen. (Note that at present it is cheaper to run nitrogen on "open loop" than through a refrigeration system).

The hydrogen compressor is driven by a 900 HP motor and delivers up to 19 kWatts refrigeration power. During actual chamber running, without any major cooling efforts, only 8 kW are utilized of which 1.3 kW are used by the magnet cryostat and 0.3 kW by the deuterium dewar condensing loop. The full refrigeration capacity is utilized during cooldown of the magnet or chamber system.

The helium compressor is driven by a 250 HP motor and delivers 500 Watts at 70°K (the temperature of the magnet nitrogen shield). At 4.5°K the refrigeration output is 400 Watts. This capacity is more than adequate for present needs.

F. Control Room

Monitoring systems for the bubble chamber are located in the control room. The chamber expander can either be run manually or put into the automatic mode which is maintained by a PDP-9 computer. A central console allows for display and interruption switches for all major components. The computer also monitors all temperature, pressure and volume sensing devices by printing any discrepancy on a line printer and signalling audio alarms.

During operation, the chamber, as well as the support facilities, are constantly maintained, inspected and controlled by the crew members.

Operating conditions for this big chamber have now been set as follows:

For H_2 : Vapor Pressure Between 50 and 60 psia (between 25.2° and 26.2°K)

Static Pressure Between 65 and 75 psia

Expanded Pressure . . Between 12 and 16 psia

(Track Sensitivity has been achieved for temperatures as high as 28.5°K)

For D_2 : Vapor Pressure Between 58 and 74 psia (between 29.3 and 30.6°K)

Static Pressure Between 80 and 95 psia

Expanded Pressure . . Between 12 and 20 psia

Some detailed studies on bubble growth and density have already been done for hydrogen. In all cases it was found useful to inject the beam into the chamber at 2 ms before the pressure minimum. Pictures were then taken at different flash delays. It was concluded that bubble growth continues up to 4 ms after the beam entrance. Any later growth effects are hidden in the bubble coalescence and re-compression. Ionization information will be obtainable for temperatures of 25.2 to 25.7°K. At present a distinction between heavy (solid) and minimum ionized tracks can be obtained only. It is believed that better discrimination will be possible in the near future.

In general the bubble image has a diameter of ~1.5 mm in real space. Using very deep expansions (4, 6 psia) bubbles of ≥ 3 mm in space have been observed. These bubbles exhibit the pattern of a doughnut which is due to the extended circular light source.

The contrast (transmission of center of bubble image divided by the background transmission) is approximately 4.0 for presently available film.

SCANNING and MEASURING

Scanning of the 12 ft. bubble chamber film can efficiently be done on any table which projects 70mm film with a magnification of 10 or more. (Demagnification from the beam plane onto the film is approximately 60). Good focus and high intensity projection lamps certainly enhance the overall scanning performance for this bright field film. The rates at ANL are about 110 frames/hour when scanning neutrino film using one view. For the 12 GeV/c proton film the rate is 20 frames/hour using all four views with an average of 8 beam tracks per picture. In the latter scan every interaction is recorded. For hadron experiments it is important to spread the beam as much as possible (beam window is 8 feet wide) in order to facilitate scanning and measuring. From experience with the 12 GeV/c proton film it seems that film with 8 to 10 tracks can be efficiently scanned.

Measuring of the 12 foot film is presently being done on conventional high precision machines and on POLLY III. The measuring rate is 4 events/hour with 4 tracks per event for the conventional machines. For POLLY the rate at present is 45 tracks/hour of which 50% pass subsequent programs. It is expected that with improved software, reduced background (i.e. cleaner chamber), and better uniform picture image this measuring and pass rate can be improved considerably.

The ultimate reconstruction accuracy of 12 foot bubble chamber tracks is difficult to assess at present. Figure 5 displays RMS deviations for several track samples taken from the 12 GeV/c proton experiment. Clearly the average RMS error for straight through (non-interacting) beam tracks is larger than for all event tracks. It seems that distortions caused by poorly determined optical constants result in higher RMS deviations for very long tracks.

The standard technique for checking reconstruction is to generate stretch plots of a large sample of tracks. The parameters employed are usually ϕ = azimuthal angle, $s = \tan(\text{dip angle} = \lambda)$, $k = 1.0/[p \cdot \cos \lambda]$ with the stretch defined as

$$T = \frac{a_{\text{meas.}} - a_{\text{fitted}}}{\sqrt{|\epsilon_{\text{meas.}}^2 - \epsilon_{\text{fitted}}^2|}}$$

where a is either ϕ , s or k and $\epsilon_{\text{meas.}}$ = measured error, ϵ_{fitted} = fitted error.

Distributions of this kind should be "normal", i. e. should have a width of 2 at FWHM and centered around 0.

The events employed for such histograms consisted of all tracks from four constraint 4 and 6 prongs. It was necessary to set the angle floors (see below) to 2 and 1mr for ϕ and λ respectively in order to obtain normal stretch plots. Such large floors on the angles will have to be improved in the future by better optical constants. To achieve this, we plan to place wire grids in different planes inside the chamber and photograph them with a liquid H_2 fill. These would give a large number of fiducials in the center of the chamber and hence should improve the determination of the optical constants.

The RMS is lower for actual event tracks than for long beam tracks. In fact, the average RMS error distribution peaks at 5μ on film for tracks that have a length between 1 and 2m on the average. Such an error corresponds to $\sim 300\mu$ in real space.

Figure 6 exhibits several momentum and angle errors for $|\vec{B}| = 18$ kGauss and a setting error of $\epsilon = 300\mu$. The standard formulae were employed for these graphs (see for instance C. M. Fisher, HEP/MISC/8, Rutherford High Energy Laboratory). In a somewhat sketchy notation these error formulae can be broken into several parts:

$$\left(\frac{\Delta P}{P}\right)^2 = \left(\frac{\Delta P}{P}\right)_{\text{Coul.}}^2 + \left(\frac{\Delta P}{P}\right)_{\text{Meas.}}^2 + \left(\frac{\Delta P}{P}\right)_{\text{Angle}}^2 + \left(\frac{\Delta H}{H}\right)^2$$

where Coulomb stands for error due to Coulomb scattering, Meas. stands for measuring error for automatic machines and Angle stands for error due to a dipping track. $\Delta H/H$ can be ignored since the field is known to within 0.1% throughout a reasonable fiducial volume. Figure 6 (c) shows that for an average track length of 1.5m, the momentum uncertainty remains near 1% which is comparable to the momentum uncertainty obtained in smaller existing chambers.

Figure 6 (b) separates the momentum error into the contributing parts. Clearly the Coulomb scattering dominates for low energies and for 1.5m long tracks. One should note, however, that for 1.0m track length the error due to measuring dominates for momenta above 3.5 GeV/c. An improvement in ϵ would certainly help in the reduction of momentum errors for short tracks.

The dependence of the total momentum error on ϵ is best illustrated in Figure 6 (a) which shows that for 1.5m track length and small momenta, $\Delta P/P$ changes little as ϵ is

varied from 500 to 150 μ .

Angle errors play a minor role in terms of overall momentum errors. As mentioned earlier they help in reducing the RMS deviations and they certainly help in reducing the error in effective mass calculations which depend on $\Delta P/P$, $\Delta\phi$ and $\Delta\lambda$. The angle errors are determined by

$$(\Delta\phi)^2 = (\Delta\phi)^2_{\text{Coul.}} + (\Delta\phi)^2_{\text{meas.}} + (\Delta\phi)^2_{\text{Floor}}$$

$$(\Delta\lambda)^2 = (\Delta\lambda)^2_{\text{Coul.}} + (\Delta\lambda)^2_{\text{meas.}} + (\Delta\lambda)^2_{\text{Floor}}$$

Note that arbitrary constant values for the angle floors are added to the angle errors. As mentioned above, these are needed to change the ϕ , k and s stretch distributions to the correct shape and value. Figure 6 (d) shows the angle errors for $\epsilon = 300\mu$ and 1.5m track length. With the ϕ floor at 2m radians, only tracks with momentum less than 1.0 GeV/c are dominated by $(\Delta\phi)_{\text{Coul.}}$. For the λ floor at 1m radians the $(\Delta\lambda)_{\text{Coul.}}$ becomes important below a momentum of 2 GeV/c. The $(\Delta\phi)_{\text{meas.}}$ and $(\Delta\lambda)_{\text{meas.}}$ are in both cases quite small.

It should be kept in mind, however, that for shorter tracks the measuring error contribution becomes increasingly significant at lower momenta. The following table illustrates this:

Track Length (m)	$(\Delta\phi)_{\text{meas.}} > (\Delta\phi)_{\text{Coul.}}$ P (GeV/c)	$(\Delta\lambda)_{\text{meas.}} > (\Delta\lambda)_{\text{Coul.}}$ P (GeV/c)
0.5	1.0	2.25
1.0	3.25	8.75
1.5	7.25	>12.0
2.0	>12.0	>12.0

In conclusion it is clear that effort should be put into reducing the angle errors. Once these are below the level where the Coulomb term dominates, the errors due to measuring will become insignificant.

PARTICLE BEAMS

An overall view of the existing, planned and contemplated beams for the bubble chamber is shown in Figure 7.

1.) The main beam (ν beam line):

Resonance extracted protons from the ZGS at energies up to 12 GeV/c. This beam line will be available for a long time to come.

2.) The K_L^0 beam:

This beam transports pions created by proton interaction with a target in the ν tunnel. The pions interact with a liquid hydrogen target near the bubble change. The resulting K_L^0 decays and interactions are then observed within the bubble chamber.

3.) The radio frequency separated beam:

This beam line is presently being built and should be operational by October, 1972. Kaon beams can be obtained at 4.6, 6.5, and 8.0 GeV/c. Protons and pions are available from 2 to 11 GeV/c. Antiprotons may be realized below 5.8 GeV/c.

4.) The stopping (k^- , $\bar{p}$ beam):

This beam is still in the design stage. It will require two electrostatic separator and will enter the chamber in the direction indicated in Figure 7. Construction of this beam will not begin until early 1973.

5.) The travelling wave beam:

No proposals exist for this beam. The line at the downstream end would overlap with the RF beam. This beam could provide K 's and $\bar{p}$'s either between 1.5 and 3.0 GeV/c or between 2.5 and 4.0 GeV/c. It would in fact be a complimentary beam to the RF beam. No definite installation date has been set.

Appendix I

Experiments

Up to March, 1972, the following experiments have been run with the 12 foot bubble chamber:

1. $p + p$ Interactions in Hydrogen at 12 GeV/c
No. E267, 110K Pictures Taken, ANL, Illinois Institute of Technology, Notre Dame University
Preliminary Results: ANL/HEP 7124
2. $p + p$ Interactions in Hydrogen at 8 GeV/c
No. E308, 30K Pictures Taken, Tohoku University in Sendai, Japan
3. $\nu + p$ Interactions in Hydrogen
No. E234, 350K Pictures Taken, ANL
4. $\nu + d$ Interactions in Deuterium
No. E234, 330K Pictures Taken, ANL (not completed)
5. K_L^0 Decays and Interactions in Hydrogen
No. E244, 45K Pictures Taken, ANL, Carnegie-Mellon University (not completed)

Additional Approved Experiments

6. $K^- + p$ Interactions in Hydrogen at 6.5 GeV/c
Using the RF Separated Beam (100 events/ μb); 1,000K Pictures
No. E289, E292, Michigan State University, ANL
7. $\bar{p} + p$ Interactions in Hydrogen for Study of $\bar{n}n$ Final State
Using Stopping (K^- , p) Beam;
No. E303, University of Wisconsin; 300K Pictures

Proposals Pending

8. $K^+ + p$ Interactions in Hydrogen at 6.5 GeV/c
Using RF Separated Beam (30 events/ μb)
No. P309, University of Massachusetts; 250K Pictures
9. $K^+ + d$ Interactions in Deuterium at 6.5 GeV/c
Using RF Separated Beam (20 events (n)/ μb)
No. P309, University of Massachusetts; 160K Pictures
10. K_L^0 Interactions in Hydrogen (<600 MeV/c)
No. P328, University of Wisconsin, 300K Pictures
11. K_L^0 Interactions in Deuterium (<600 MeV/c)
No. P329, University of Wisconsin, 300K Pictures
12. K_L^0 Interactions in Hydrogen (0.5 - 1.5 GeV/c)
No. P330, University of Wisconsin, 200 to 300K Pictures

Appendix II

Future Plans

In addition to a steady improvement of the reliability of the chamber, the following developments are under way:

- 1.) Prepare and test the expansion system for double and triple pulsing in intervals of 150 ms.
- 2.) Test all optics systems for double and triple pulsing
- 3.) Design, build and implement new camera stems which are capable of triple pulsing. Using this new system, the lenses will be left at the bottom of the camera well covering the inside of the fisheyes. This allows for removal of the stems with the chamber filled. In addition, this arrangement is needed for step 4.) .
- 4.) Design, build and implement fisheye centering jig. This device is needed to measure the alignment of the fisheyes with respect to the pupil position while the chamber is full at cryogenic temperatures. Such parameters are needed to greatly improve the existing optical constants.
- 5.) Replace all data box lights with light emitting diodes to improve reliability.

A competent staff of physicists, engineers and technicians is available to offer their talents, imagination and experience for designing, building, implementing and testing any modifications, additions or other changes required for new experimental techniques.

Figure Captions

- Figure 1** **Cross sectional view of the 12 foot bubble chamber**
- Figure 2** **Top view of the 12 foot bubble chamber**
- Figure 3 a, b, c** **8.0 GeV/c protons in hydrogen**
- Figure 4** **Map of the B_z field component in the beam plane at 1800 amperes**
- Figure 5** **RMS deviations for several 12 foot bubble chamber track samples**
- Figure 6** **Momentum and angle errors for tracks in the 12 foot bubble chamber assuming 18 kG magnetic field and setting error of 300 μ**
- Figure 7** **Present and future beam lines to the 12 foot bubble chamber**

Fig. 1

SHEET 1 OF 2

REVISIONS			
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75	12-1-68	J. W. B.	J. W. B.
76	12-1-68	J. W. B.	J. W. B.
77	12-1-68	J. W. B.	J. W. B.
78	12-1-68	J. W. B.	J. W. B.
79	12-1-68	J. W. B.	J. W. B.
80	12-1-68	J. W. B.	J. W. B.
81	12-1-68	J. W. B.	J. W. B.
82	12-1-68	J. W. B.	J. W. B.
83	12-1-68	J. W. B.	J. W. B.
84	12-1-68	J. W. B.	J. W. B.
85	12-1-68	J. W. B.	J. W. B.
86	12-1-68	J. W. B.	J. W. B.
87	12-1-68	J. W. B.	J. W. B.
88	12-1-68	J. W. B.	J. W. B.
89	12-1-68	J. W. B.	J. W. B.
90	12-1-68	J. W. B.	J. W. B.
91	12-1-68	J. W. B.	J. W. B.
92	12-1-68	J. W. B.	J. W. B.
93	12-1-68	J. W. B.	J. W. B.
94	12-1-68	J. W. B.	J. W. B.
95	12-1-68	J. W. B.	J. W. B.
96	12-1-68	J. W. B.	J. W. B.
97	12-1-68	J. W. B.	J. W. B.
98	12-1-68	J. W. B.	J. W. B.
99	12-1-68	J. W. B.	J. W. B.
100	12-1-68	J. W. B.	J. W. B.

12-H₂ BUBBLE CHAMBER ASSEMBLY

BSK-27

Fig. 2

MAIN CHAMBER VALVES

CAMERA

HEAD DRUM

SUPERCONDUCTING COIL HANGERS

MAIN VACUUM LINE

PRIMARY BEAM

MULTI-LAYER INSULATION

CHAMBER VESSEL

VACUUM VESSEL

SUPERCONDUCTING COILS IN HELIUM VESSEL

MAGNET IRON

RADIAL MAGNET SUPPORT

SEE SHEET 1

HYDRAULICS PIT

BATHYSCOPE

SERVICE PIT

0 1 2 3 4 5
SCALE: FEET

SHEET 2 OF 2

REVISIONS			
NO.	DESCRIPTION	DATE	BY
1	DESIGNED	12/1/54	W. J. ...
2	APPROVED	12/1/54	W. J. ...
3	CONSTRUCTED	12/1/54	W. J. ...
4	TESTED	12/1/54	W. J. ...
5	RELEASED	12/1/54	W. J. ...
6	REDESIGNED	12/1/54	W. J. ...
7	RETESTED	12/1/54	W. J. ...
8	REDESIGNED	12/1/54	W. J. ...
9	RETESTED	12/1/54	W. J. ...
10	REDESIGNED	12/1/54	W. J. ...
11	RETESTED	12/1/54	W. J. ...
12	REDESIGNED	12/1/54	W. J. ...
13	RETESTED	12/1/54	W. J. ...
14	REDESIGNED	12/1/54	W. J. ...
15	RETESTED	12/1/54	W. J. ...
16	REDESIGNED	12/1/54	W. J. ...
17	RETESTED	12/1/54	W. J. ...
18	REDESIGNED	12/1/54	W. J. ...
19	RETESTED	12/1/54	W. J. ...
20	REDESIGNED	12/1/54	W. J. ...
21	RETESTED	12/1/54	W. J. ...
22	REDESIGNED	12/1/54	W. J. ...
23	RETESTED	12/1/54	W. J. ...
24	REDESIGNED	12/1/54	W. J. ...
25	RETESTED	12/1/54	W. J. ...
26	REDESIGNED	12/1/54	W. J. ...
27	RETESTED	12/1/54	W. J. ...
28	REDESIGNED	12/1/54	W. J. ...
29	RETESTED	12/1/54	W. J. ...
30	REDESIGNED	12/1/54	W. J. ...
31	RETESTED	12/1/54	W. J. ...
32	REDESIGNED	12/1/54	W. J. ...
33	RETESTED	12/1/54	W. J. ...
34	REDESIGNED	12/1/54	W. J. ...
35	RETESTED	12/1/54	W. J. ...
36	REDESIGNED	12/1/54	W. J. ...
37	RETESTED	12/1/54	W. J. ...
38	REDESIGNED	12/1/54	W. J. ...
39	RETESTED	12/1/54	W. J. ...
40	REDESIGNED	12/1/54	W. J. ...
41	RETESTED	12/1/54	W. J. ...
42	REDESIGNED	12/1/54	W. J. ...
43	RETESTED	12/1/54	W. J. ...
44	REDESIGNED	12/1/54	W. J. ...
45	RETESTED	12/1/54	W. J. ...
46	REDESIGNED	12/1/54	W. J. ...
47	RETESTED	12/1/54	W. J. ...
48	REDESIGNED	12/1/54	W. J. ...
49	RETESTED	12/1/54	W. J. ...
50	REDESIGNED	12/1/54	W. J. ...
51	RETESTED	12/1/54	W. J. ...
52	REDESIGNED	12/1/54	W. J. ...
53	RETESTED	12/1/54	W. J. ...
54	REDESIGNED	12/1/54	W. J. ...
55	RETESTED	12/1/54	W. J. ...
56	REDESIGNED	12/1/54	W. J. ...
57	RETESTED	12/1/54	W. J. ...
58	REDESIGNED	12/1/54	W. J. ...
59	RETESTED	12/1/54	W. J. ...
60	REDESIGNED	12/1/54	W. J. ...
61	RETESTED	12/1/54	W. J. ...
62	REDESIGNED	12/1/54	W. J. ...
63	RETESTED	12/1/54	W. J. ...
64	REDESIGNED	12/1/54	W. J. ...
65	RETESTED	12/1/54	W. J. ...
66	REDESIGNED	12/1/54	W. J. ...
67	RETESTED	12/1/54	W. J. ...
68	REDESIGNED	12/1/54	W. J. ...
69	RETESTED	12/1/54	W. J. ...
70	REDESIGNED	12/1/54	W. J. ...
71	RETESTED	12/1/54	W. J. ...
72	REDESIGNED	12/1/54	W. J. ...
73	RETESTED	12/1/54	W. J. ...
74	REDESIGNED	12/1/54	W. J. ...
75	RETESTED	12/1/54	W. J. ...
76	REDESIGNED	12/1/54	W. J. ...
77	RETESTED	12/1/54	W. J. ...
78	REDESIGNED	12/1/54	W. J. ...
79	RETESTED	12/1/54	W. J. ...
80	REDESIGNED	12/1/54	W. J. ...
81	RETESTED	12/1/54	W. J. ...
82	REDESIGNED	12/1/54	W. J. ...
83	RETESTED	12/1/54	W. J. ...
84	REDESIGNED	12/1/54	W. J. ...
85	RETESTED	12/1/54	W. J. ...
86	REDESIGNED	12/1/54	W. J. ...
87	RETESTED	12/1/54	W. J. ...
88	REDESIGNED	12/1/54	W. J. ...
89	RETESTED	12/1/54	W. J. ...
90	REDESIGNED	12/1/54	W. J. ...
91	RETESTED	12/1/54	W. J. ...
92	REDESIGNED	12/1/54	W. J. ...
93	RETESTED	12/1/54	W. J. ...
94	REDESIGNED	12/1/54	W. J. ...
95	RETESTED	12/1/54	W. J. ...
96	REDESIGNED	12/1/54	W. J. ...
97	RETESTED	12/1/54	W. J. ...
98	REDESIGNED	12/1/54	W. J. ...
99	RETESTED	12/1/54	W. J. ...
100	REDESIGNED	12/1/54	W. J. ...

12'-11/2" BUBBLE CHAMBER ASSEMBLY
BSK-27

1538
3695
-0379

1538
3696
2-0379

Fig. 3a

8.0 GeV/c Protons

1538
3808
-0379

1538
3809
2-0379

Fig. 3b

8.0 GeV/c Protons

Fig. 3c

8.0 GeV/c Protons

Map of the B_z Field Component in the Beam Plane at 1800 Amperes

(Each line corresponds to an azimuthal sweep at a particular radius. R1 is near the chamber center and R13 near the wall. The radii are equally spaced at 15.217 cm.)

Fig. 4

Fig. 5

Figure 6

12 FT. BUBBLE CHAMBER MOMENTUM AND ANGLE ERRORS ($\bar{B}=18 \text{ kG}$, $\text{DIP}=20^\circ$)

Fig. 7