BERKELEY 72" HYDROGEN BUBBLE CHAMBER

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(presented by A. H. Rosenfeld)

I want to start out with a disclaimer; I was invited to this conference to talk about data analysis, and Don Gow was invited to give this talk. At the last minute Gow found himself unable to come, so he spent a few hours trying to teach me about the big bubble chamber. Apart from that my main contribution to the 72″ chamber was not to worry the people who were building it !

I shall assume that most of you have heard at least one talk on the 72″ chamber, so I shall try to emphasize what they tell me is new, what works well, and what works badly.

The first experiment was to pass through the chamber a separated beam of $\bar{p}$'s of 1.65 GeV/c, which is just above threshold for $\bar{p}+p \rightarrow \bar{\Lambda}+\Lambda$. The cross-section for this reaction turns out to be small, so that only 7 such events were seen. Again I had no part in this work; it was done by L. Stevenson, P. Eberhardt, and others (Fig. 1-3).

The 72″ liquid hydrogen bubble chamber came into operation at the Lawrence Radiation Laboratory in March of this year, approximately five years after its conception. The active design and construction phases occupied a period of four years, and some 65 man-years of engineering effort went into the project. The cost of all engineering, materials, equipment and assembly amounted to $ 1 400 000. An additional amount of $ 500 000 was expended on a building to house the instrument.

During the design and fabrication period, two smaller chambers, 10 inches and 15 inches in diameter, were constructed and operated. These chambers served to provide a large amount of operating experience which proved valuable in the design of the 72″ instrument.

The fact that the 72″ chamber would be used for many experiments impossible to visualize or specify in the design stages was realized. Therefore, much emphasis was placed on flexibility and mobility of the instrument. The chamber was intended for use with a primary beam energy up to 6 GeV. The kinematics of the interactions expected at such energies indicated that the chamber should be quite long compared to its width, and the dimensions 72″×20″×15″ were chosen for the visible liquid volume.

After considerable study of the possible ways of bringing particle beams into the chamber, and of the mechanical assembly problems, a horizontal window design was adopted. Although this choice, as opposed to a design having one or more vertical viewing surfaces, does bring in some problems relating to thermal gradients in the liquid, it was felt that the research advantages far outweighed the difficulties involved, and experience appears to bear out this conclusion. I shall have more to say about this at the end.

A one-window viewing system is employed, which permits the use of a pole piece in the magnet, giving substantially more magnetic field than would otherwise have been available. The one-window system also contributes to operational safety, since the chamber, hydrogen shield and top plate form a closed region, isolated from the main insulating vacuum region, in the event of window failure (Fig. 4, 5).

A special building was constructed to house the chamber, control room, compressors and maintenance facilities. A location with respect to the Bevatron target area was chosen such that beams of particles with momenta ranging from 400 MeV/c to 5 GeV/c could be brought easily into the building.

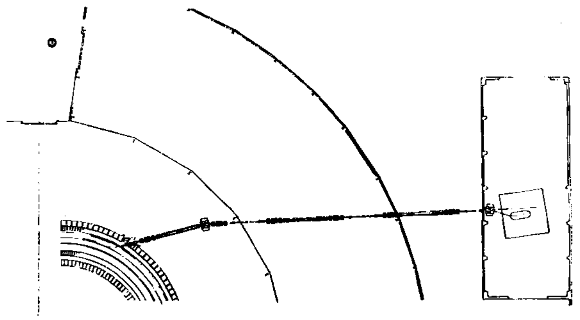

Fig. 4 Location of chamber and its building relative to the Bevatron. The beam shown is the 1.65 GeV/c anti-proton beam.

The chamber and compressor room areas are powered and lighted with equipment meeting explosion proof standards. The control room and shop can be sealed off from the rest of the building during hydrogen operation, and therefore normal industrial wiring is used in these areas.

A 15-ton capacity crane, equipped to explosion proof standards, is provided for the chamber area. The ability to use the crane with hydrogen in the equipment has proven very valuable.

The following sections are intended as a brief description of the major components of the large bubble chamber.

MAGNET

The magnet weight is approximately 200 t. It produces a field of 18,000 G at the centre of the chamber when energized with 4 600A d.c.. The dissipation at full field is 2.5 MW. The coil is wound with extruded hollow square copper bar, and directly cooled by circulating low conductivity water. Provision was made for bringing particle beams into the chamber along directions at an angle to the major axis by providing a removable section through the magnet steel (Fig. 6).

SUPPORT STRUCTURE

The mobile part of the apparatus, comprising the magnet, chamber and expansion system, refrigerator and recompression purification equipment, is supported on four hydraulically actuated feet. This system serves to move the chamber into position for various experiments and gives minimum floor loading, an important point since the chamber building stands on filled land.

VACUUM TANK

The vacuum tank, which is inserted into the magnet coils, is of mild steel construction. A beam entrance window of one-eighth inch stainless steel is provided in one end of the tank, at chamber height. A copper liner, normally operated at 77°K, is provided inside the vacuum vessel and serves as a thermal radiation shield for the chamber. Pumping is provided by two independent 700 l per second diffusion pumps (Fig. 7).

CHAMBER ASSEMBLY

The top plate of the vacuum tank forms the support for the hydrogen shield and bubble chamber. These components are of stainless steel for good low temperature strength. The hydrogen shield is a reinforced weldment, the chamber proper is a casting. The 5″ thick optical glass window separates the liquid volume of the chamber from the internal hydrogen shield volume. The weight of the low temperature assembly is approximately 7,000 pounds. A beam entrance window of $^1/_8$″ stainless steel is provided at one end of the chamber (Fig. 8).

WINDOW SEALS AND GASKETS

Metallic gasket seals, of either indium or lead, are used throughout the low temperature assembly. Due to the large difference in the coefficient of expansion between the glass window and the metal parts, it is impractical to make a vacuum-tight window seal at room temperature and maintain the seal during the cool-down phase. Therefore, an inflatable gasket, consisting of a stainless steel inner tube and indium sealing surfaces, is used between the glass and the chamber casting. Indium pads serve to restrain the top surface of the glass. The indium seals are all of double-gasket construction, with a pump-out space provided between seals. During the cool-down phase, the gasket pressure is relieved and the gasket surface is allowed to slide over the glass. When a temperature of about 75°K is reached, the gasket is inflated, with carefully purified helium, to a pressure of 500 p.s.i. Leak rates across the inner seal of 100 to 1,000 micron litres per second are commonly encountered. This rate is sufficiently low to prevent serious leakage across the outer seal when pump-out vacuum is provided. In addition, the glass edge area is separately gasketed and isolated from the main vacuum and hydrogen shield vacuum

Fig. 1 A 1.65 GeV/c anti-proton enters the 72"chamber and produces the reaction $\bar{p}+p\rightarrow\bar{\Lambda}+\Lambda$, $\Lambda\rightarrow\pi^-+p$, $\bar{\Lambda}\rightarrow\pi^++\bar{p}$, $\bar{p}$ annihilates with a proton.

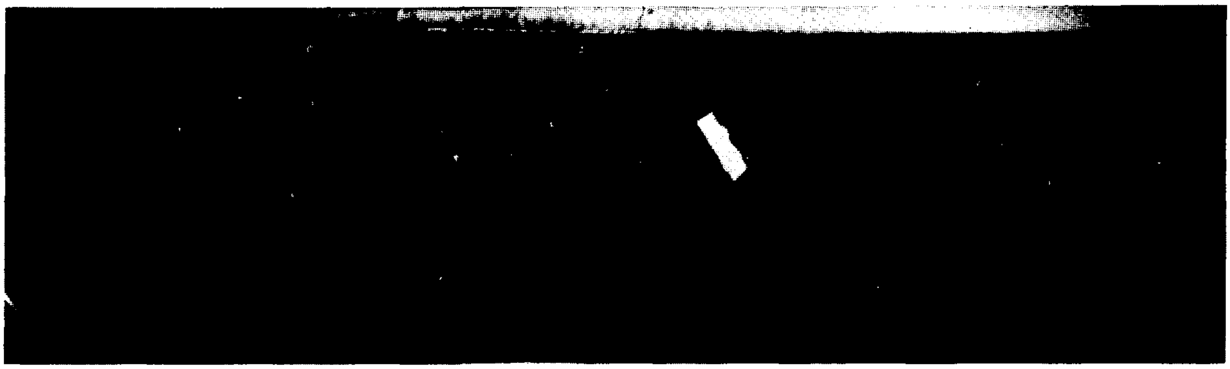

Fig. 2 Low energy physics in the big chamber. A 1.6 GeV/c K⁻ scatters and comes to rest. It is captured by a proton to give $K^-+p\rightarrow\Sigma^-+\pi^+$, $\Sigma^-\rightarrow\pi^-+n$; $p_{\pi_-}\sim$ 200 MeV/c.

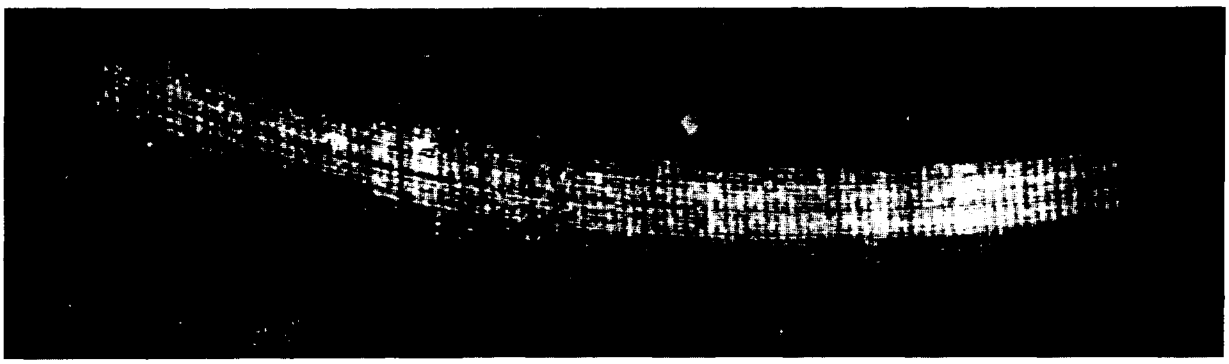

Fig. 3 The 1.65 GeV/c anti-proton beam with the separator off. We see about 30 000π^-, and presumably one anti-proton.

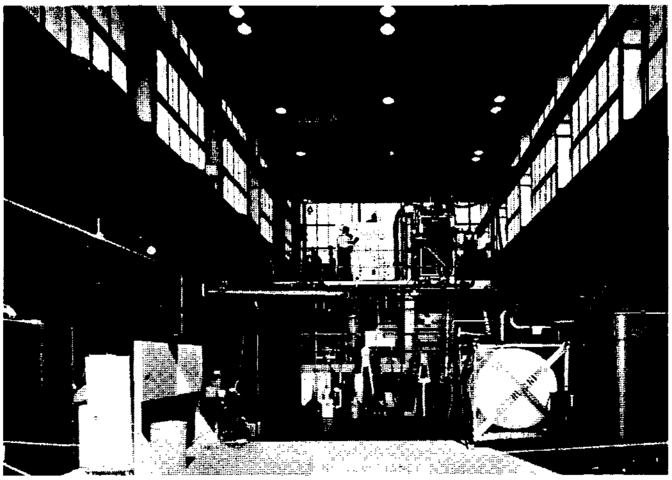

Fig. 5 Bubble chamber magnet and support structure.

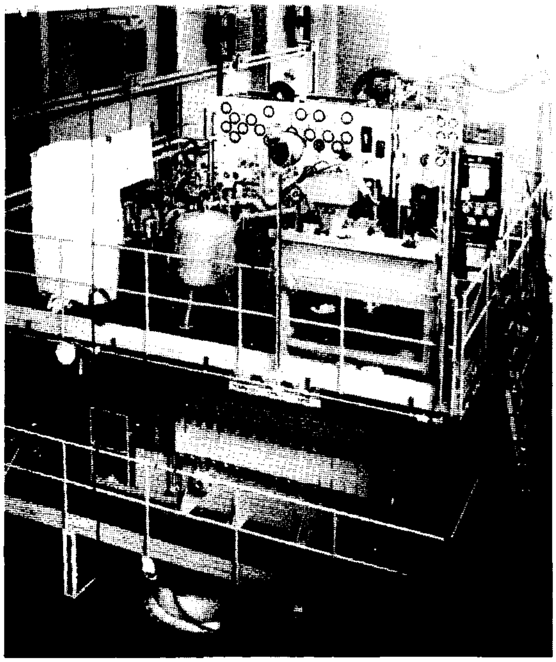

Fig. 6 Closer view of the magnet and support structure.

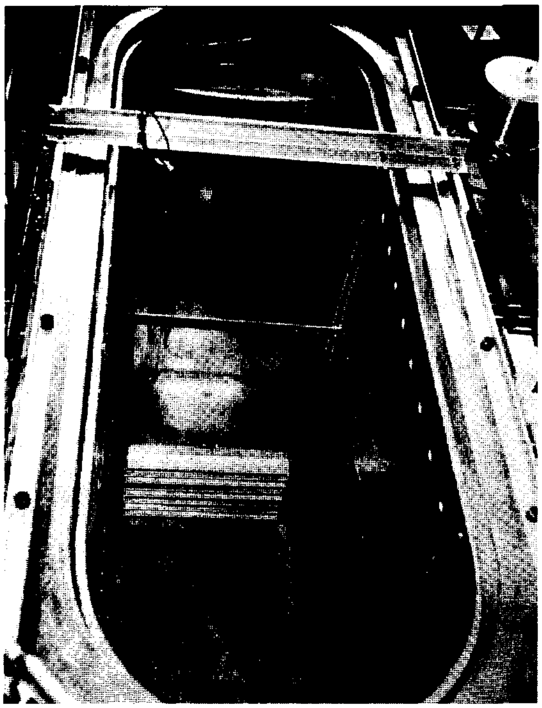

Fig. 7 Chamber vacuum tank and Cu liner, operated at 77°K.

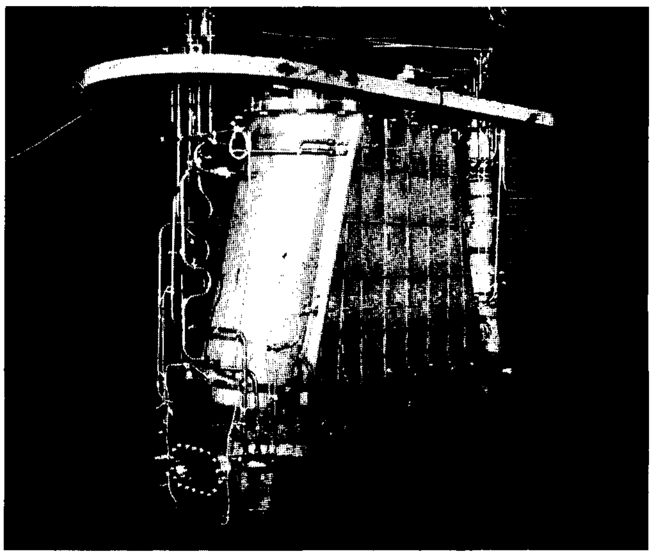

Fig. 8 Chamber casting and internal hydrogen shield.

volumes. This space is separately pumped to provide additional insurance against trouble from leaks across the inflatable window seal. During the test run this seal was cycled from room temperature to low temperature three times, with no loss in seal efficiency.

Even when unconstrained at the edges, the 5″ window must still be cooled slowly, otherwise severe thermal gradient will make it shatter.

Thermocouples are placed on the top and bottom of the glass and along the edge, and the thermal differences are recorded. The hydrogen shield above and the chamber below are cooled simultaneously and as fast as the observed thermal differences will permit. Cooling takes three days. The first day is definitely limited by the glass. On the second and third days the glass can be cooled almost as fast as the refrigerator, working at 1.5 kW capacity, can absorb the heat.

REFRIGERATION

Refrigeration is accomplished by means of a 1 500 W Joule-Thompson expansion refrigerator. This unit is supplied with 2 000 p.s.i. hydrogen, at a rate of 200 cubic feet per minute, which is circulated. The associated compressor and purifier train are located in the compressor room. All other refrigerator components are mounted on the upper deck of the bubble chamber structure. The expansion valve is pneumatically actuated, its opening being controlled in response to a pressure signal derived from a hydrogen vapour pressure thermometer located inside the bubble chamber. The temperature regulation system has a stability of better than 0.05°K at the normal operating temperature (Fig. 9).

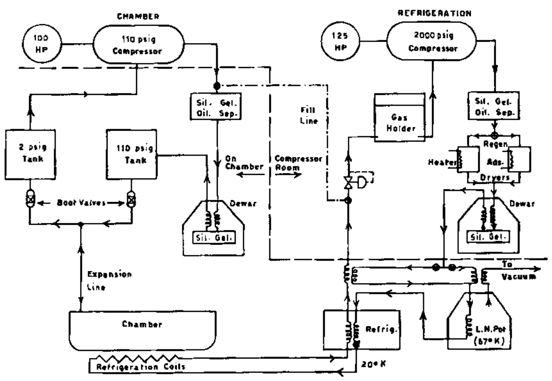

Fig. 9 Expansion and refrigeration circuits. The chamber must be filled with H_2 containing $< 10^{-6}$ impurities, or else " frost " will condense in visible amounts on the coat-hangers and top glass. This extreme purity is achieved by using the " fill connection " shown. The H_2 is liquefied once, and the refrigeration circuits are used as a hydrogen-temperature trap. The boil-off from the refrigeration circuit is then cross-connected to the purification system of the expansion-recompression system.

EXPANSION SYSTEM

A vapour phase, room temperature expansion-recompression system is used. False sides, referred to as expansion plates, are used inside the chamber to define the useful volume. Each of these plates are drilled with 500 $^3/_8$″ diameter holes to provide an expansion and recompression flow essentially normal to the beam direction. The volume back of the plates communicates with the expansion line which is located at the end of the chamber opposite the beam entrance window. The expansion line is 8″ in diameter and is equipped with a " spinner " which is intended to prevent liquid from being entrained in the emergent gas during expansion.

It was calculated that if the hydrogen rose smoothly up the line during expansion, then it would not transfer worrisome amounts of cold. It was not known whether or not the flow would, in fact, be turbulent. It was decided to keep the impedance of the expansion line as low as possible, inserting nothing but the spinner to stop splashing. This made it almost certain that we would see tracks on the first test, and we did. But we also learned that the line is too open, and there is far too much transfer of heat (and cold) by gas currents set up during expansion and recompression. On this first experiment the chamber can be pulsed only four times per minute (to the Bevatron's ten); at higher pulse rates i) the neoprene in the expansion " boot " valve cools and cracks, and ii) the refrigerator cannot handle the load.

On the next shut-down, smaller pipes, perhaps 2″ in diameter, will be used to divide up the present 8″ line, and a heat " regenerator " may be added. (This is a thermal reservoir sold by Phillips. It consists of thousands of turns of loosely-wound fine Cu wire. Cold hydrogen, rising through the regenerator, cools the copper and is itself warmed. On recompression the warm gas, above the now-cold regenerator, passes through it and is cooled, and the regenerator temperature rises to its value at the beginning of the cycle). With these modifications we anticipate no trouble operating at 10 pulses per minute.

Grove " flexflow " valves are used to control the expansion and recompression cycle; we call them " boot " valves. One such valve connects the upper part of the expansion line to the 30 cubic foot expansion tank, which is maintained at a 2 p.s.i.g. pressure. Momentary opening of this valve results in the sharp reduction of pressure desired for expansion. A similar valve connects the upper expansion line to a vessel, of 10 cubic foot volume, maintained at 110 p.s.i.g. Momentary opening of this valve, after expansion, results in the restoration of chamber pressure. A large compressor followed by a purifier train serves to restore the desired pressure difference between the expansion and recompression tanks.

The chamber has been operated over a range of hydrogen vapour pressures from 60 p.s.i.g. to 85 p.s.i.g. in test operation. The normal operating point is at a vapour pressure of 70 p.s.i.g., with a corresponding temperature of 28.3°K. The chamber is pressurized to about 85 p.s.i.g. prior to expansion, and the pressure is reduced to 40 p.s.i.g. during the sensitive period. The time required for the pressure to drop from its initial to minimum value is 10 to 15 ms depending upon exact operating conditions.

ILLUMINATION AND PHOTOGRAPHY

Light from three E.G. and G. xenon-filled flash tubes serves to illuminate the chamber. The tubes are normally operated with 50 Ws of electrical energy, with a flash duration of 0.5 ms. Light from the flash tubes is collected by a high efficiency condensing lens system and directed through the chamber window on to the retro-directive optical assembly. Light returning from this assembly is refocused onto the source (Fig. 10).

Returning light is scattered from bubbles to form track images on each of three photographic views of the chamber. All three views are photographed on a single strip of 46 mm film, with a 15 : 1 demagnification. The various views from a given picture are interlaced with those of preceding and succeeding pictures in such a way as to provide minimum film usage (Fig. 11).

A data board carries essential data on chamber operating conditions, beam counts, and roll and frame number. It is photographed simultaneously with each exposure.

A polaroid Land camera is used to monitor over-all operation of the chamber.

SAFETY SYSTEM

A 22-foot diameter evacuated " Horton Sphere " is provided for emergency removal of the chamber hydrogen. A 6-inch vent line connects this spherical tank to relief valves and bursting disks which communicate to the main vacuum vessel, the hydrogen shield volume and the chamber volume. Manual by-pass valves are also provided. In the event of an emergency, essentially all of the hydrogen in the system can be rapidly transferred to the sphere. The 6″ vent line is constructed of aluminium and the interior of the safety sphere is filled with empty tin cans, to minimize the danger of failure due to thermal shock during an emergency venting operation.

LIQUID NITROGEN CONSUMPTION

This runs about 3 000 l per day. One half of the consumption is in the hydrogen refrigerator; the remainder is used in the purifiers, nitrogen shield and miscellaneous traps.

Finally, here are some remarks on what we see on the film :

TURBULENCE AND DISTORTION

No thorough study has yet been made; however, during the first engineering run 3.5 GeV/c pions were passed through the chamber with the magnetic field off. The 72″ Franckenstein was not working at the time, but a crude attempt was made to measure the sagitta of these tracks. The result was a spurious curvature $1/\rho = 0 \pm (200\,\mathrm{m})^{-1}$. The radius of curvature expected from multiple Coulomb scattering is about 800 m, so that about all we can say right now is that turbulence is certainly not terrible, and it may be excellent.

TEMPERATURE GRADIENTS IN THE CHAMBER

On this first run, with the overly open expansion line, the top of the chamber is more sensitive than the bottom. These temperature gradients are most

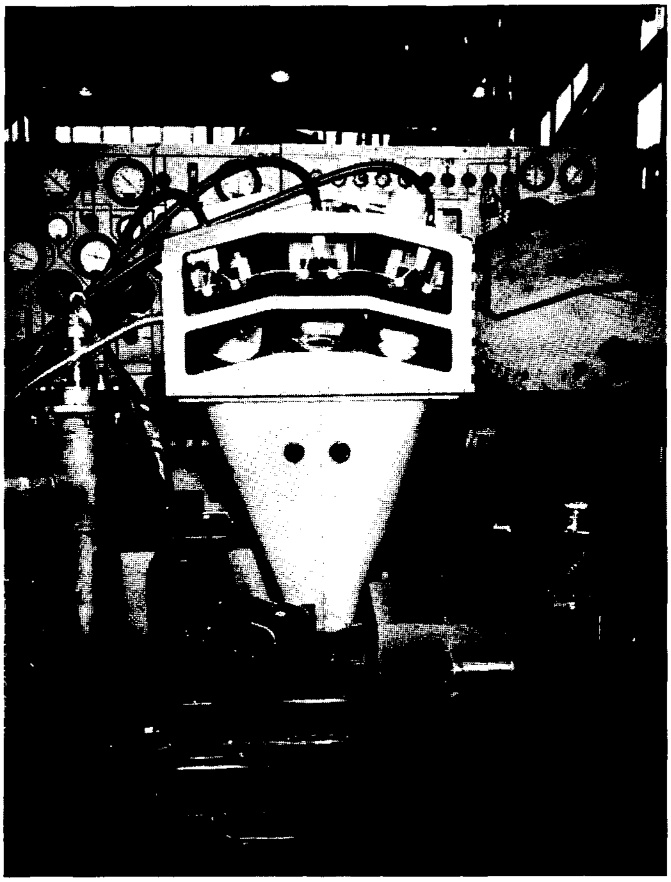

Fig. 10 Arc source.

Fig. 11 The camera. The camera has three lenses, which all image on the same 46 mm film.

noticeable in the top and bottom few inches, the middle seems to exhibit a rather uniform bubble density. We are not much worried about these gradients for three reasons :

1) A heater has already been built into the bottom of the chamber; it is not being used now because the experimenters are eager to get every pulse they can, and would prefer to have four pulses per minute, with some temperature gradient, than three without.

2) There are separate refrigeration circuits, so that it is possible to cool the top of the chamber more than the bottom. However, for this first run, in an attempt to simplify the plumbing and operating, these separate circuits were connected in series.

3) The chamber is also equipped with gulpers which suck off some warm hydrogen from underneath the higher side of the sloping top glass, thus contributing to a uniform temperature. But the present open expansion line introduces about twice as much heat per pulse as it should do eventually. Thus the gulpers should eventually function about twice as efficiently as they do now.

Finally, there is the comforting fact that the 15″ chamber operated with no measurable temperature gradient.

DISCUSSION

HILDEBRAND : You said that in view of your present experience you might prefer a different shape for the chamber. Would you say more explicitly what dimensions you would now prefer and whether you would change the ratio of size to magnetic field?

ROSENFELD : I wish I could be more helpful. I believe that the qualitative thought which I mentioned is correct, but as for details I am uncertain.

PEYROU : I wonder a little about how efficient a regenerator in your expansion line can be because we tried to figure out an efficient regenerator for the CERN chamber which would not throttle the expansion, and it turns out that it cannot be done. I mean it can be done if you make it one half square metre in cross-section and one metre high, but then at each expansion you have to expand such a volume that you have to have more megawatts in your compressor than in the magnet.

ROSENFELD : You are correct, of course, that we cannot use a regenerator purely as a regenerator. But it has useful anti-splash and anti-turbulence properties, so we might as well fill the available volume with it, if it does not increase the impedance of our expansion line too much and if it will hold together.

GARWIN : I have two comments. One is that lead is a very good material to make a low temperature regenerator, because it has a much higher specific heat than copper at low temperatures, and the other is a question : have you any idea what the temperature of the magnet is on the inside of the turns? Because that magnet, I believe, has its water connections all on the outside, and, if there is good heat exchange between layers, the temperature at the inside could be 80° or 90°C when the effluent water is 40°C.

ROSENFELD : No, I do not know this temperature.

BLOCK : Are the cameras focused at different depths?

ROSENFELD : No, they are not. They focus on the whole depth of the chamber. They are, as you know, stopped down to f : 22 so that we have a large depth of focus.