CERN
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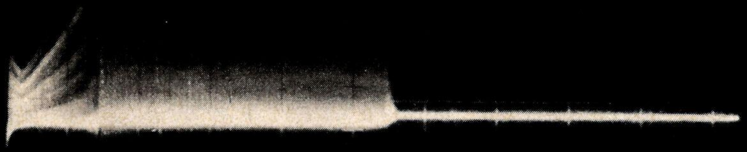
European Organization for Nuclear Research

10th anniversary of the first operation of the Brookhaven AGS



29 July 1960

30 GeV

CERN, the European Organization for Nuclear Research, was established in 1954 to '... provide for collaboration among European States in nuclear research of a pure scientific and fundamental character, and in research essentially related thereto'. It acts as a European centre and co-ordinator of research, theoretical and experimental, in the field of sub-nuclear physics. This branch of science is concerned with the fundamental questions of the basic laws governing the structure of matter. CERN is one of the world's leading Laboratories in this field.

The experimental programme is based on the use of two proton accelerators — a 600 MeV synchro-cyclotron (SC) and a 28 GeV synchrotron (PS). At the latter machine, large intersecting storage rings (ISR), for experiments with colliding proton beams, are under construction. Scientists from many European Universities, as well as from CERN itself, take part in the experiments and it is estimated that some 1200 physicists draw their research material from CERN.

The Laboratory is situated at Meyrin near Geneva in Switzerland. The site covers approximately 80 hectares equally divided on either side of the frontier between France and Switzerland. The staff totals about 2850 people and, in addition, there are over 450 Fellows and Visiting Scientists.

Twelve European countries participate in the work of CERN, contributing to the cost of the basic programme, 244.1 million Swiss francs in 1970, in proportion to their net national income. Supplementary programmes cover the construction of the ISR and studies for a proposed 300 GeV proton synchrotron.

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Comment

On 29 July 1960 proton beams were accelerated to peak energy in the Brookhaven Alternating Gradient Synchrotron for the first time. Operation of the AGS was just pipped by the CERN PS (whose tenth anniversary was celebrated in CERN COURIER in November of last year) but, with the experience of the 3 GeV Cosmotron and 6 GeV Bevatron behind them, our American colleagues were the first to get going with an excellent research programme.

Many of the plums in the newly available energy range — including such sensational discoveries as the existence of two types of neutrino, the crucial identification of the omega minus and the first observation of CP violation — fell to the AGS. This research programme was underpinned by excellent operation of the accelerator; to pick out just one feature — the intensity of the accelerated beam has been steadily above 10^{12} protons per pulse for many years.

We devote the major part of this issue to the AGS in honour of the people who built this great machine, and who have operated, developed and used it so successfully during the past ten years.

The articles have been contributed by the staff of the Brookhaven Accelerator Department and assembled by M.Q. Barton, D. Berley, H.N. Brown, E.D. Courant, H.W.J. Foelsche, G.K. Green, J. Hudis (Chemistry Department), M. Plotkin, J. Spiro, A. vanSteenbergen and G.W. Wheeler.

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Around the Laboratories

Cover photograph: 29 July 1960 the first 'mouse' appeared on an oscilloscope screen in the Main Control Room of the Brookhaven AGS. The mouse was generated by a wide band pick-up electrode system installed in the synchrotron ring which detected the passage of the proton beam as acceleration was attempted. The length of the mouse's body indicated that beam was accelerated throughout the acceleration cycle through to an energy of around 30 GeV. (6.849.70)

Brookhaven AGS

1. Commissioning Days

G. K. Green

Ken Green, photographed here speaking at the dedication ceremony of the AGS in 1961, has been Chairman of the Accelerator Department throughout the ten years of operation of the AGS and has been very closely associated with the success of the machine. Dr. Green will be succeeded in the near future by Dr. F. Mills from the University of Wisconsin and this is an appropriate occasion to pay tribute to his work in presenting, in this first article, his personal reminiscences of the commissioning days.

A particle accelerator comes alive with its first beam. When it accelerates beam it seems animate — at least to its builders and nourishers. When it is turned off it seems only a collection of parts. When it is turned off for the last time it expires, and a little something in its builders expires, too. It is for such reasons that 'beam day' is so important to accelerator builders. The builders have no doubts that it will 'work' (if they had such doubts they would never have begun their long and exacting tasks) but 'beam day' is the day on which their creation comes alive. It has no relation to proving that their ideas are good — that comes later when the machine is put to use — it has to do with the subtle difference between a loose collection of components and a functioning, complex, unified device.

Ten years ago the AGS was brought into operation. We were pleased to see our friends at CERN bring in the PS, but we were also a little disappointed to be several months behind. There were simply not enough AGS people, in those booming times in the USA, to put things together fast enough. It had been a decade of close and friendly ties with colleagues at Berkeley, at MURA, and at CERN and that relationship still brings a glow of pleasure at its remembrance. We shared all our ideas and data, indulged in lively and sometimes noisy debates, but never allowed our rivalry to descend to the level of vicious competition. We were too busy to publish much. Information was transferred by internal reports, by telephone, and best of all by visits.

The AGS really started in 1952. The Cosmotron had accelerated protons beyond 2 BeV (they were not yet called GeV) and, although the machine was still too rickety to do real high energy research, it was clear that the proton synchrotron could be extended to any size desired. CERN was being established to build on the next larger scale (we did not yet know that the Russians were embarking on the Synchrophasotron) and it seemed quite straightforward to extrapolate the technique. That is, it seemed straightforward until one looked critically at the technical and financial problems. Then Courant, Livingston and Snyder hit on alternating gradient focusing and realized that they had really struck something. Soon vast rings were being built in the air, and John Blewett's strong focusing linac would be a practical injector. I was away on a month's vacation and missed the beginning of the fun and excitement, but returned in time to join in the design of quadrupole lenses and the beginnings of beam transport. (Subsequent development of beam transport by the groups at the Cosmotron and Bevatron was an important factor in the successful exploitation of the PS and AGS.)

The nascent CERN group was making rapid progress. Ideas and people were flying back and forth across the Atlantic. The next large step in scale was obviously possible, and both groups were ready and anxious to begin. Leland Haworth wrote to the US Atomic Energy Commission to the effect that it would be good to build a large alternating gradient proton synchrotron. The AEC replied that it would indeed be good — why didn't we do so ? (In this time of telephone book size proposals, Haworth's five page letter is a prized classic.) During the first enthusiasm, a quick survey of an ideal AG synchrotron made everything seem easy. A closer examination of the properties of a real, imperfect synchrotron began to uncover hazards which must be avoided. First came the problems of the resonances, then the ghastly precision needed to obtain a tractable central orbit, the question whether impossibly small non-linearities in the magnetic fields would destroy the stability, the realization that the r.f. generation methods of the 'older' synchrotrons could not possibly accelerate protons in an AG synchrotron, the fearful complexity of strong focusing linac design.

We built the 'Electron Analog' to test the orbit theory, and to gain experience in alternating gradient design. This little *electrostatic* synchrotron was something accelerator people talk about, but seldom build — a device designed only to accelerate particles. It passed easily through phase transition with its 'phase lock', and demonstrated that non-linearities could readily be controlled. Slowly the problems came into perspective and solutions were found. Buildings were completed and apparatus began to arrive in a torrent. A

Date : 26 May 1960
Scene : Linac Control Room
Task : Achieve the first spiralling beam in the AGS.

1. Huddled in concentration around an oscilloscope are (left to right) G. K. Green, L. J. Haworth, J. Spiro, M. Plotkin (wearing head phones), V. Raciniello, with E. C. Raka at the scope controls.

2. Looking up to heaven for guidance (in fact with eyes glued on a monitor screen) are (left to right) R. R. Kassner, J. P. Blewett, M. H. Blewett and I. J. Polk.

3. Success is written on smiling faces. Clearly visible are G. K. Green, W. Link, L. J. Haworth, M. Plotkin (with head phones) and J. Spiro.

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machine began to emerge out of the confused stacks of parts, and finally it was ready to try.

The Cockcroft-Walton preaccelerator was fittingly the first of three accelerators in cascade. In place of gas-pump glass cylinders there were commercial rectifiers (solid state !) and ceramic-metal assemblies but it was a direct descendant of its sturdy ancestor. It first had beam in May 1959. There are immutable laws of physics that permit one to worsen the output of a synchrotron's preaccelerator, but never to better it. Many months of careful work were needed to bring the preaccelerator to the required level of performance.

On 13 April 1960 the linac accelerated protons to 50 MeV. Its output immediately climbed to a few milliamperes. One major worry was out of the way ! The workability and usefulness of the PS and AGS had been predicated on an injected linac current of at last a milliampere at 50 MeV, at a time when the record was 160 microamperes at 10 MeV. The linac group was in great good humour. When would the ring be ready for beam ?

The ring still lacked some sectors of vacuum, the magnet power supply was being recalcitrant, no r.f. accelerating stations were connected, and essential controls were lacking. Finally, on 17 May, the ring vacuum was continuous, the magnet could be pulsed, and basic controls were available in the linac control room.

The first turn in a large synchrotron is an important matter. Inaccuracies and small imperfections can scarcely be seen in just one turn, but mistakes will appear. No matter how much care is taken, and no matter how many cross-checks are applied, a mistake can creep in. And it can take a great deal of time to correct.

We gathered in the linac control room after dinner on 17 May. The linac was running rather well. Bill Link and Hugh Brown began their mumbo-jumbo of measuring emittance by observing the injection line flags and then setting the injection optics from their families of graphs. The current measurements were being made on a Type K potentiometer and so were rather slow. After a while, people began to be impatient and cries of *'That's* *close enough'* began to be heard. Nevertheless, they continued until they were satisfied.

Beam was injected into the ring and observed by television monitor on the detector flags at A7 and A13 in order to adjust the inflector voltage and the field markers. (Positions around the AGS are indicated in alphabetic/arithmetic fashion : there are twelve 'superperiods' labelled A to L each containing twenty magnets. Thus beam is injected into magnet A1 and travels round the ring to L20. Straight sections are designated by the magnet immediately upstream.) That some of these adjustments had to be made in the temporary control room, by instructions over the telephone, was not very helpful but finally injection was right and the spots were centred on A7 and A13. These flags were retracted and the television monitor was switched to C17, one-quarter way around the ring. There was the spot. Everyone had his eyes glued to the monitor. In quick succession the beam was found on F17, on I17 and then on L17, all the way around. It seemed a little too easy, but there was a sense of relief. We had not made mistakes in the ring.

The following week, on the evening of 26 May, we assembled to spiral the beam. The notes in the book show a series of settings of inflector voltage and timing to centre the spot on A7 — *'Could not see spot on A13 because of TV trouble'*. Since systematic injection setting was done with A7 and A13, the lack of A13 was a handicap, but *'Now saw spot on L7 at centre'*. Finally *'Inflector pulsed — saw about seven turns or nine. Picture 1 — see next page'*. Picture 1, stuck on the next page with now yellowed scotch tape, shows the scope trace that flickered before our horrified eyes. As the beam circulated it lost about half its intensity on each turn and disappeared completely in seven, or, if one used one's imagination, nine turns.

Something was badly wrong with the machine. Everything at hand was varied without observing any change in the loss of beam. Ernest Courant observed, rather mildly, that the loss was too regular, there must be something in the way. Suddenly Ralph Kassner grabbed a flashlight, said *'Turn the beam off'* and disappeared. Presently we were informed over the phone that the screenwire flag had been left in at L17. It had not been retracted before its power supply was removed for use at some other place. After a certain amount of confusion a storage battery was found and the motor ran the flag out. The various people were checked out of the tunnel against the gatekeeper's list (security was simple then — chains and padlocks and a gatekeeper at one gate in possession of the only key). We were tense while the beam was turned back on and settings were restored to what were thought to be the previous values. When the inflector was pulsed the beam calmly spiralled a hundred turns !

There are several pictures in the book. The spiralling was not very good and a few adjustments were tried but the machine was obviously in order, needing only careful setting. It had been a long day, we were tired and relieved, we turned it off and went home.

Nearly two months went by without injection while the r.f. system and control system were being connected. On 15 July a part of the accelerating system was in operation. Spiralling beam was set up and (written in Hildred Blewett's hand), *'The starting oscillator was turned on tentatively — perhaps some capture observed. Shut down 4 : 45.'* Crews were working day and night. By 17 July, five of the twelve power amplifiers were able to produce 6 kV of accelerating voltage each. Again spiralling beam was set up and beam was accelerated for about 2 milliseconds, the duration of the starting oscillator signal.

Three more r.f. stations were operating on 20 July, so a part of the day was used to refine adjustments of injection and capture. *'Capture was quite consistent on each pulse.'* On the following day the adjustments were repeated and, for the first time, the electronic switches were triggered to transfer the beam from the starting oscillator to the phase lock system. There were the usual troubles with the timing of the switches and with cutting cables to match the phases in the complicated system. The beam *'Went out to 6 to 7 milliseconds'* and after some adjustment of switch timing and phase *'Beam went to about 16 to 17 milliseconds — but not consistently. Shut down 4 : 45.'*

In order to control 'beam fever' the electronic switches had been timed to turn off soon after injection. Then overnight the r.f. group managed to make eleven of the twelve accelerating stations operate, and the excitement was almost uncontrollable. During the morning of 22 July, the system was adjusted to inject, capture, and change to phase lock but the power room was ordered to pulse the magnet for only ¼ second. The notes read *'After radial control turned on most beam lost after 40 milliseconds. Occasional pulse went 230-250 msec (transition ?) approx. 6-7 BeV !! Reason for beam going or not going is not known.'* A few of us were concentrating on the beam capture and phase lock with scopes set to sweep for only a few tens of milliseconds, but someone had connected another scope and set a longer sweep so that the occasional beam survival to the end of the magnet cycle could be seen.

There was serious trouble with the accelerating system and it made no sense to try for energy until the system was under some control. In spite of that, the control room became more and more crowded, cheers went up when the beam occasionally flashed to the end of the magnet cycle. The crowd became so dense that people began standing between us and the scopes (little correlation had then been achieved between the location of controls and the position of indicators). Tension and frustration built up and I recall with shame screaming in black rage. Finally some sanity returned and it became evident that a machine does not respond to screaming. We arranged for groups to visit the control room in more orderly fashion. At 6 : 15 the r.f. was stopped. The r.f. system had only been connected and there had been no time to make proper electrical measurements on it. The coaxial signal cables were not connected so there was no monitoring of the accelerating cavity voltages. Nevertheless, we decided, after much argument, to try to accelerate beam on Monday, just for luck.

It was no use. After struggling all day on 25 July, Blewett, Haworth and I had the accelerating stations turned off one

Date : 29 July 1960
Scene : AGS Main Control Room
Task : Achieve first full energy operation of the machine.

4. Just prior to first operation Ken Green is in the hot seat in a packed Control Room at the controls of the r.f. system.

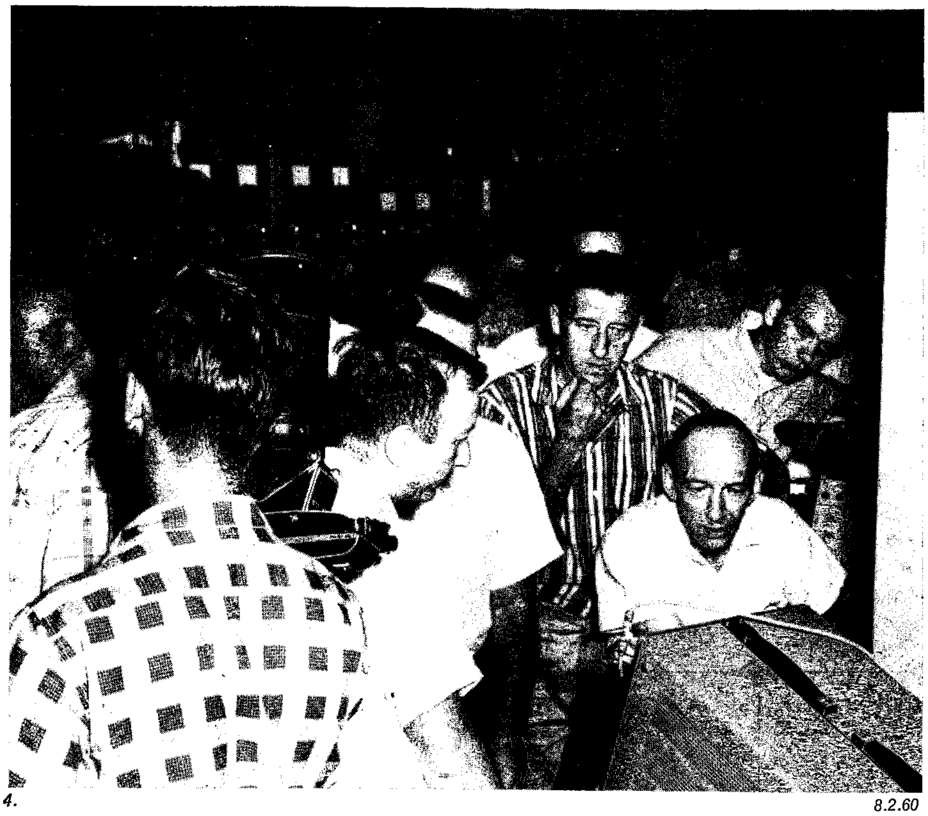
5. Success. Most eyes are focused on the 'mouse' appearing steadily on the oscilloscope screen showing that the AGS was accelerating beam to around 30 GeV. Left to right are — R. R. Kassner, J. P. Blewett (partially hidden), J. Spiro, G. K. Green (with L. J. Haworth hidden behind him), H. Halama, E. Boerner and R. H. Rheaume.

6. Smiling in triumph (left to right) H. S. Snyder, M. Barton (back to camera), E. D. Courant, L. J. Haworth, M. Plotkin and M. H. Blewett.

at a time. The control time delays, designed to protect expensive tubes, made the job last more than an hour. Only one station made any difference when it was turned off. We stopped the machine at 8 p.m. and told the r.f. group *'Back to the scope and signal generator'*. Next morning the ring was turned over to the r.f. effort and the troubles were quickly found. Most of the stations had 'holes' at some frequency and the phase tracking was at (or probably beyond) the limit of the control phase shifter. For three days the r.f. group plodded around a half mile of concrete ring with their instruments. Thursday evening the system was operating properly and the critical electrical measurements indicated that the system was within its control range. We agreed, *'Tomorrow it will work'*.

And on Friday, 29 July, it did work. There was steady progress with adjustments until a beam was being accelerated to phase transition, but there it stopped. After careful observation and erudite discussion we concluded that the transition switches were correct, but Marty Plotkin had some doubts. He said, *'Humour me, reverse the transition switch'*. It was reversed and the beam went out to 24 BeV. The book reads *'About 4 p.m. when beam was going through transition to end of magnet cycle to 850 msec fairly well magnet cycle was changed to 65 cycles. Corresponds to 5800 amp. This corresponds to 31 BeV. Beam went out to about 1.1 sec without loss of intensity !'* Under the photo of the 'mouse' it reads — *'Note added 8/2/60 — Estimate from picture 11 (according to H. Halama) about* 8×10^9 *protons.'* We had promised 10^9 protons at 30 BeV for 31 millions of dollars, and we had spent at that point a little less than 29 millions. We were elated.

Tattered Ring Data Book I describes the slow and painful process of gaining understanding of the AGS. Target studies began to appear in October 1960. On 1 November, an unknown hand proudly states 'Beam spiralling in ring and accelerated to the end of magnet cycle after 5 pulses.' The first High Energy Physics run is noted on 10 November, and on 21 December, Ernest Courant and Julius Spiro were setting up the target for experiments.



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2. Machine performance and development

When the alternating gradient principle was discovered it was recognized as an economical means for constructing a high energy proton synchrotron. But the beam current and 'brightness' obtainable from a linear injector were quite uncertain and only preliminary estimates had been made of the intensity limits imposed by space charge.

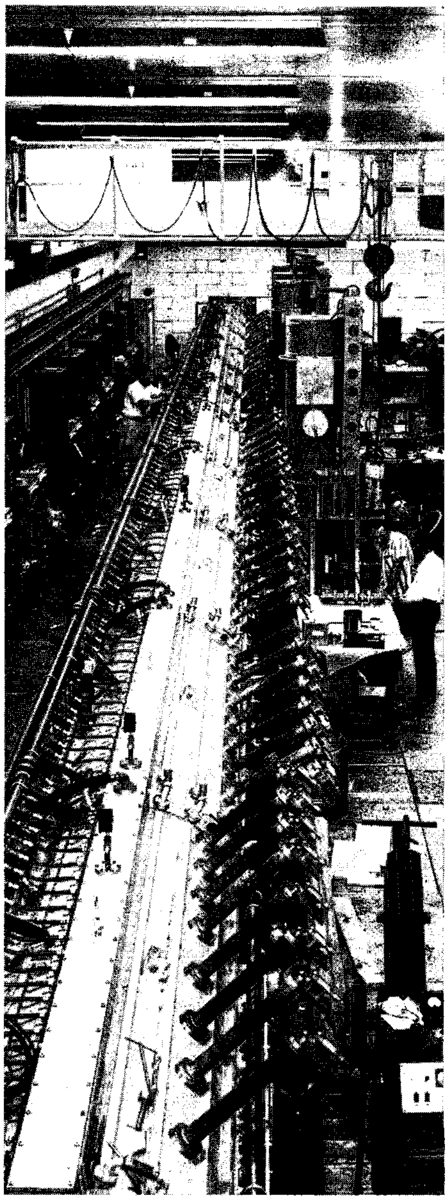
When the AG machines began to operate it soon became apparent that high intensity operation was possible. Immediately after start-up, the AGS exceed the proposed intensity of 10^9 protons per pulse by an order of magnitude and in about two years reached a level of 10^{11} protons per pulse. The prolific experimental programme which resulted from these early achievements provided strong motivation for the AGS Conversion project described in a later article.

But the operations group has not been idle while waiting for the conversion — a continuing programme of studies and improvements has steadily increased the intensity. At the time of writing, a peak intensity of 3×10^{12} protons per pulse has been achieved and 2×10^{12} protons per pulse average is routine. The peak intensity is higher than the quoted fundamental space charge limit of the machine with 50 MeV injection and is only about a factor of three lower than the average estimated after conversion. We will bring out here some of the developments which have given the increase in intensity.

Major improvements have been made to the 50 MeV linac injector. In the early days of AGS operation, the current available from the linac was limited to about 3 mA. In 1961, a debuncher was added which, with some improvements in the PIG (Philips Ion Gauge) ion source boosted the 50 MeV current to 8 to 10 mA. In 1963 improvements were made in the r.f. drive system and in 1964 an additional power tube was added and further modifications were made in the PIG ion source bringing the current up to 25 mA. In 1965 the apertures in the transport system from the preinjector to the linac and in the first eight drift tubes of the linac were enlarged. A pulse momentum analyzer, permitting performance analysis between AGS pulses, was put into operation., In 1966 the power tubes were replaced with new types capable of higher power ratings and a hard tube modulator to control the r.f. was installed. A duoplasmatron ion source came into operation at about the same time (satisfactory operational characteristics had been obtained much earlier with duoplasmatron sources but filament life was too short to justify operational use). In 1967 and 1968 the linac was modified to couple r.f. power in at three points in order to improve the compensation of the tank for beam loading. Finally, during the 1968 shutdown, a short (high gradient) accelerating column was installed. It is now possible to operate the linac with currents in excess of 50 mA for a pulse length of 120 μs. The short column improved the brightness of the beam and eliminated the phase space dilution present in the previous lower gradient column.

Incorporation of multiturn injection in 1964 gave a significant improvement in available intensity. At that time the linac pulse was stretched to a length of 40 μs. The scheme uses two ferrite 'bump coils' to move the local closed orbit from the inflector to the centre of the machine during a time corresponding to a few turns. This system was immediately successful and has since been in continuous use. Besides giving higher intensity, the scheme reduces the sensitivity to injection parameters, and allows the linac to operate at lower current and higher brightness. It does, however, require a much longer pulse from the injector. Currently 10 to 20 turn injection is common practice.

A continuing programme of studies and improvements for the main ring has been necessary to match these injection improvements. Understanding and correction of the perturbations of the magnetic field at injection have been most important to the operational success of the AGS. Very soon after first operation, it proved necessary to correct coupling between vertical and horizontal motion caused by stray fields. This puzzling problem had been solved by the CERN group in starting up the PS. By reconnecting the AGS 'pancake' vertical orbit correction coils, it was possible to generate the correct skew



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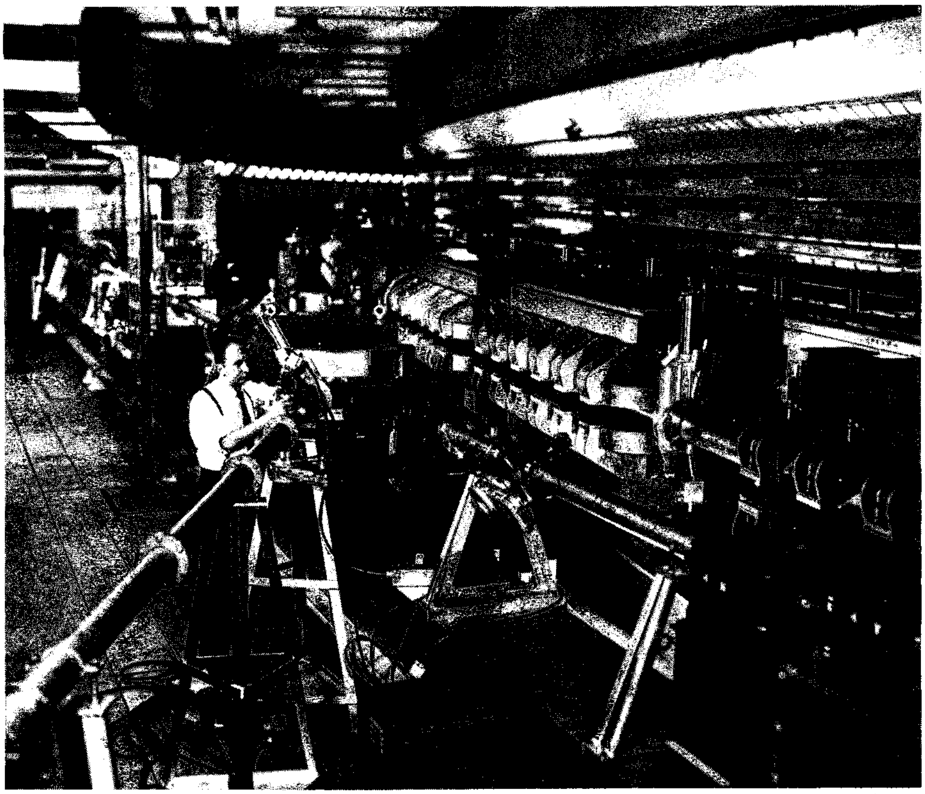
7. The 50 MeV linac looking from the pre-injector end towards the AGS magnet ring which is behind the shield wall. The three FTH470 r.f. amplifiers are visible on the right of the linac near the shield wall. Standing on the right are F. Toth and J.P. Blewett.

8. A photograph taken at the end of 1960 inside the AGS magnet ring tunnel at the position where the 50 MeV beam is injected. The beam from the linac enters through the shield wall top left. A pulsed magnet (centre of picture) was used to select some beam pulses from the injector, bending them off towards bottom left where the quality of the beam from the injector could be analysed.

9. The slow extracted beam console photographed in the Main Control Room of the AGS in January 1969. At the controls is L. Blumberg watched by A.V. Soukas.



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quadrupole field to compensate the perturbation. Soon it was found that these same correction coils could be powered in various combinations to reduce the 8th, 9th and 12th harmonic errors in the field strength. A small current in the 24 large quadrupoles in the ring adjusts the focusing strength and makes it possible to tune the machine to its optimum settings. Further orbit correction has come from the use of backleg magnet windings to reduce the effective aperture differences between 'open' and 'closed' magnets, and from the addition of thin magnetic shields to the open side of all the magnets to reduce their sensitivity to stray fields. Local field perturbations are corrected either by winding special coils or by providing special power supplies for local pancake coils. The sum total of all these manoeuvres is a significant increase in the effective aperture of the machine with concomitant improvements in intensity and stability.

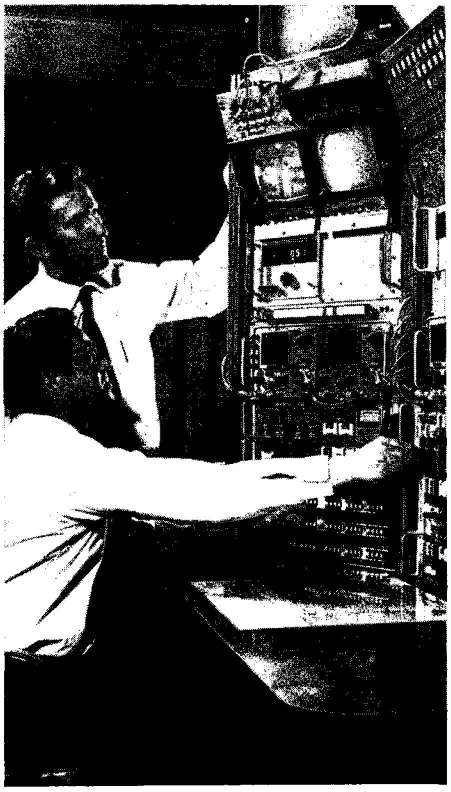
If the charge which is injected into the AGS is to be delivered to the target, the capture and acceleration processes must be efficient. The first oscillograms (the 'mouse') showed that the captured beam was being accelerated to full energy by the phase lock system. However, during the first year of operation it was found that the efficiency of capture was low and that some critical response characteristics of the phase lock system were deficient. Careful refinement of the electronic circuits doubled or tripled the accelerated beam. As the intensity increased, the system was further refined. Finally, the entire low level r.f. system was replaced with a physically small solid-state phase lock circuit which includes elaborate subcircuits for programming important variables. Additional feedback circuits have been added to damp instabilities which appear at the higher intensities. The radius control, at first single valued and somewhat unpredictable, has been developed until it can be programmed to steer the beam through the maze of targets and external beams. For satisfactory target operation the circuits must control the radial position of the beam within a fraction of a millimetre.

Improvements in intensity have been accompanied by developments in target and extraction techniques making it possible to feed more experiments and experiments of greater complexity. Initially, fast beam bursts were obtained by mechanically flipping the target through the beam. Relatively long beam pulses could be obtained by slowly reducing the r.f. amplitude so that the beam slowly spilled out of its stable regime and spiralled into the target.

In 1962 the fast target spill was improved by the installation of a rapid beam deflector (RBD). This consisted of a two-metre coil energized by a fast pulse from a capacitor discharge. The beam could be deflected as much as 25 mm to strike a target and to produce a short burst of secondary particles suitable for feeding a bubble chamber. The same year also saw the first use of 'flat top' for the improvement of counter beams. By lowering the voltage on the magnet at the end of the acceleration cycle, the magnet current is held nearly constant and a constant energy beam can be delivered for several hundred milliseconds. The low voltage is obtained by controlling the phase of the firing of the rectifiers in the main power supply and is, unfortunately, accompanied by large ripple voltage. In 1965 a ripple filter was installed and ultimately spills in excess of 400 ms with little time structure were obtained.

Work on beam extraction began in 1962 and the first fast ejected beam was used for the second Brookhaven neutrino experiment. It used a fast kicker magnet, a thin septum magnet and an ejector magnet — the fast kicker was a simple ferrite box with an aperture equal to that of the AGS vacuum chamber and powered by a pulse-forming network and hydrogen thyratron switches; the septum was a magnet with a coil or septum only 1.6 mm thick powered by a large bank of transistors. The septum and ejector magnets were rammed into position with hydraulic systems. A modification of this beam is still in use for the r.f. separated beam to the 80 inch bubble chamber.

In 1967 a slow extracted beam (SEB) was put into operation. This beam uses the $8\,{}^{2}/_{3}$ resonance excited by four of the



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AGS sextupoles. During the flat top, precise control of the magnet voltage causes a gradual movement of the beam into the region of the vacuum chamber where the resonance instability prevails. The protons with unstable oscillations spiral behind the 0.8 thick septum coil of a magnet which deflects them about 1 milliradian. This deflection causes the protons to pass behind the 6 mm coil of the ejector magnet which bends the beam into the external channel. Efficiencies as high as 80% have been obtained with spill times in excess of 400 ms. Last year the flexibility of the AGS was considerably enhanced by the development of a scheme to operate this slow extraction and an internal target simultaneously.

The targets themselves have required extensive development. For the first experiments, actuators made from the magnetic structures of small contactors erected the targets. Now small target motors operate millions of cycles in vacuum with precision and can be changed quickly by means of automatic air locks. An automatic target changer will select a new target from a magazine and attach it to the target motor while the operators watch on their TV monitor, far from the intense radiation field. The primary internal target is now a tiny slip of beryllium-oxide ceramic which glows white hot as the beam strikes it. Internal targets with multiple traversal have made an important contribution to the use of the AGS. The near ideal target efficiency produces intense secondary beams and the small target size is an ideal source for the optics of the beam transport systems.

The continual increase in AGS intensity has brought its problems. Radiation damage destroyed the transistors of the r.f. bias system and all these supplies had subsequently to be shielded. Organic materials such as the O-rings used for vacuum gaskets fail at a high rate. Metal and ceramics have replaced other materials in high radiation areas, and elsewhere plastics or organics are chosen with care. Improved insulation developed for the main magnet coils has more than ten times the radiation resistance of the original insulation. Although the new coils are used in critical areas and magnet units are interchanged to help equalize radiation dose, it is necessary to feed one to two units of coils into the ring system annually. Even the lowly rubber water hoses crack from radiation damage and spray surrounding equipment, sometimes with catastrophic results.

The solid-state revolution has made a major impact on the AGS. The diode, transistor, the silicon controlled rectifier and integrated circuit have crept in everywhere. Excepting the scopes, there are no vacuum tubes left in the Main Control Room. (Had it not been for solid-state devices the Control Room would have required expansion to at least twice its size.) Small computers assist in regular operation, and are necessary companions to accelerator physicists investigating the AGS.

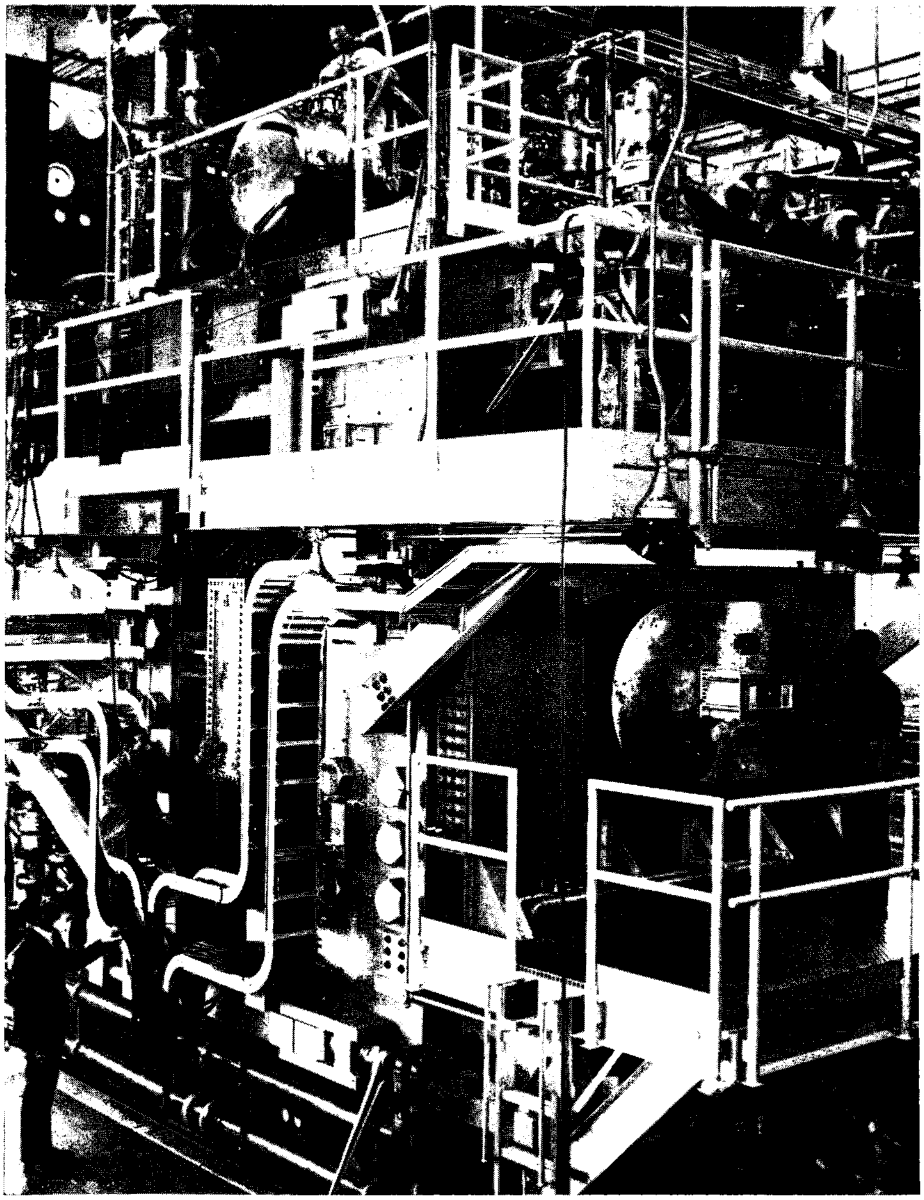
At high intensities a variety of beam instabilities has complicated operation. Coherent betatron oscillations are frequently present and must be suppressed by introducing non-linear focusing fields. Self-bunching instabilities are observed during flat top and destroy the smooth spill characteristics of internal target or slow ejected beams. These are suppressed by phase shifting the r.f. to an unstable phase for about two milliseconds prior to r.f. turn off. Recently a beam loading instability during acceleration caused a considerable amount of operational difficulty. This was traced to the effect of high frequency parasitic resonances in the r.f. cavities. Removal of these resonant modes stopped the instability. So far, all such instabilities have been operational nuisances but none has proved to be an insurmountable barrier to further development of the AGS.

3. Experimental facilities

Advances in experimental areas have kept pace with the development of accelerators. When the 3 GeV Cosmotron first operated, beam transport consisted of nothing more than holes in the shield walls and the area which was provided for experimentation proved to be only a fraction of what was eventually required. Deflecting magnets were ordered for analysis of momentum and bending of beams, but no practical lenses were available to focus the particles. The discovery of strong focusing, which was so important to the development of accelerators, was equally important to the development of the experimental areas and their apparatus. It led to quadrupole lenses which could take the particles diverging from a target and refocus them on the appropriate detectors.

Intensive development of beam transport techniques and equipment continued at the Cosmotron and Bevatron during the first decade of high energy physics. The scintillation counter appeared just in time to stimulate the research programme on the Cosmotron. The expansion cloud chamber gave way to the diffusion chamber and this in turn was replaced by the bubble chamber. The bubble chamber appeared too late to be taken into account in the original design of the experimental areas at the AGS and was initially accommodated by improvisation.

The initial AGS Target Building was 100 ft wide and 250 ft long. Although it seemed large when it was first constructed, its comparative size shrank rapidly as the beam transport and detectors were extrapolated to the new higher energy range. The first experiments were accommodated in the Target Building and even the narrow corridor on the inside of the ring within this building provided valuable space for setting up secondary beams. A debate raged concerning the merits of extending the beams and apparatus outdoors with temporary shelter as needed, or of extending the Target Building. This resulted, even before the AGS operated, in plans for the 'East Area Extension' which was completed in 1961. In 1962, the tunnel wall was breached at the I10 position to supply beam for the new 80 inch bubble chamber. In this area, *10. The 80 inch hydrogen bubble chamber photographed in 1963. Towards the centre left is the beam aperture window. On the right can be seen the four camera ports and the aperture through which the chamber is illuminated. On the top platform is the high vacuum pumping system. Refrigeration equipment and the hydraulic controls are located on the far side.*



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the beam apparatus was housed in temporary buildings and the control equipment was placed in adjacent trailers. A year later the Southwest Area was constructed by the expedient of digging a large basin in the sand. The tunnel was pierced with a 1 ft diameter pipe and the fast external beam was pitched upwards so that the basin would not need to be dug too deeply. No shelter was provided in the Southwest Area, mostly because the elements installed were mainly massive assemblies of shielding.

The next major changes of the Experimental Areas were done in connection with the Conversion project. A further large hall has been added to the East Area and has been nicknamed EEBA for 'East Experimental Building Addition'. This hall is offset with respect to the original one so that slow external beam paths can be run across diagonally with fans of secondary beams spreading from the targets. In addition, the tunnel wall has been breached again at the H10 position where the North Experimental Area is planned to extend outward far into the woods. Use of the Southwest Area is planned to discontinue at the end of 1970 and, as soon as possible, the 80 inch bubble chamber will be moved to the North Area and use of the I10 Area will be reduced.

Design of magnets and power supplies for beam transport had started before operation of the AGS, using the experience at the Cosmotron and Bevatron. It was decided to use only solid-state power supplies and to purchase no rotating d.c. machines. This proved to be a risky decision because serious difficulties were discovered in the use of silicon rectifiers. The difficulties were surmounted only just in time to permit the first power supplies to arrive before the experimental programme began.

The programme started with internal targets located at G10 and F10. Position G10 in the centre of the Target Building has been the mainstay of electronic experiments during the last ten years. Beams of secondary particles are conveyed both outside and inside the ring to the detectors. Although it was hoped that ejected proton beams with external targets would supplant the use of the G10 internal target, it now appears that this target will be employed into the indefinite future even though the beam intensity onto the target must be limited.

Pure counter experiments were eventually supplemented wtih spark chambers and at present all the experiments using G10 place primary reliance on spark chambers with counter systems used as auxiliaries. A major improvement was the installation of an electrostatic separated beam for counter-spark chamber experimentation; this beam has been in high demand. The original neutrino experiment blocked most of the G10 area for a time with the massive shield it required but when the Southwest Area was opened the neutrino experiment was placed there.

When the slow external beam came into operation in 1968 it was transported to what is now known as Target Station A, located in the original Target Building, where it produced secondary beams which are carried into the East Experimental Area. Further extension of the beams from Station A is being made into the EEBA, and at the same time, Station C is being developed to supply additional experiments in EEBA. Soon, work will begin on a beam splitter to divide the slow external beam between Station C and Station B, now being set up to provide still more experimental places in the total East Area complex.

The first experiment with an on-line computer began in 1962 using 'Merlin', a digital computer constructed at Brookhaven. In time, on-line experiments became standard and the OLDF (On-Line Data Facility) is now in general use. This facility is made up of a PDP-6, a PDP-10 and the required peripheral equipment mounted in trailers parked just outside the Target Building. The development of various types of wire spark chambers which can be coupled directly to computers, without the intermediate step of photography, has greatly facilitated experimental procedures. These methods are used for a large two arm spectrometer located in a corner of the East Experimental Area. Nevertheless, the Target Building still contains large tents housing optical systems and cameras for photographic recording of particle events.

The first use of F10 for a small angle diffracted proton beam was soon superseded by an electrostatic cross-field separated beam supplying particles to the 20 inch hydrogen bubble chamber. The 20 inch chamber was operated in the midst of the Target Building, a location ill-suited for such use. During 1962 a low momentum separated beam was installed from the F20 internal target to the 30 inch hydrogen bubble chamber inside the ring. This chamber was placed just outside the Target Building wall in a concrete hut. The separated beam was rebuilt making it suitable for very low momenta particles and for stopping particles. In 1964 the 20 inch bubble chamber was dismantled and rebuilt as the 31 inch chamber. It, also, was located in a hut inside the ring and supplied with beam by electrostatic separators from another internal target at location F20. This bubble chamber which began its work at the Cosmotron before moving to the AGS, is scheduled for honourable retirement in 1971.

The 80 inch bubble chamber began operation in 1963 using particles from an electrostatic separated beam from I10. After intensive development, a parallel r.f. separated beam containing two microwave cavities was brought into operation in 1966 providing separated particles to the chamber at momenta more than twice that available from the electrostatic separators. The r.f. beam is used only with short duration fast extracted protons because the copper separators can be pulsed for only a few microseconds.

A '7 foot test facility' originally intended to develop the design principles for very large bubble chambers, is being converted into a 7 ft bubble chamber with a superconducting magnet.

The '7 ft' is presently installed in the Southwest Area where it is expected to provide pictures for a neutrino experiment in deuterium. After the first run it will be moved to the new North Area where it can be supplied with neutrinos and other particles by the fast extracted beam from H10. It is hoped that during the moving process the chamber can be expanded to an 11 ft version. When funds and opportunity become available, it is expected that the 80 inch bubble chamber will join it in the North Area which is then planned to be fed by a three cavity r.f. separated beam.

Numerous types of transport magnets are available, some with special characteristics. More than 200 magnets of all types and some 200 power supplies are presently available for experimental use. Quantities of specialized equipment such as vacuum pipes, collimators and control equipment must also be supplied to set up the experiments. There is much design and construction of special cryogenic targets and, since most of these use hydrogen and deuterium which are explosive gases, the Experimental Areas include extensive facilities for monitoring and venting these devices to ensure equipment and personnel safety. Shielding also is prolific and at the present time the AGS inventory of movable steel and concrete shielding exceeds 100 000 tons.

The experimental areas use about three times as much power as the machine itself. The Conversion project has brought the 69 kV primary feeders to the edge of the AGS complex where a new sub-station increases the installed capacity of the system to approximately 70 MVA.

Under the policies developed over the years, the experimenter is expected to provide his detection equipment. The bubble chambers are an exception because they are massive, complex and require large specialized operating crews. But electronic experiments have also grown, becoming very complex and requiring large quantities of electronic equipment, which it would be difficult for each experimenter to obtain. Consequently, a group which was set up at the Cosmotron, procures and loans items such as counters, logic, and oscilloscopes. The HEEP group (High Energy Equipment Pool) expanded its inventory and continued its operation for the AGS. The first nanologic was designed by the BNL Instrumentation Division for HEEP and formed the basis for the first commercial nanologic. Every year extensive purchases are made to keep the HEEP inventory in step with modern technology.

4. Conversion project

The experimental programme for high energy physics used the AGS during all of 1961 and expanded rapidly during 1962. Experimental demands kept pace with the increasing intensity and interacted with improvements in the delivery of beam to targets. The physical size and complexity of beam transport systems and of detectors had been increasing while the AGS was being built and scarcely had the machine operated when work was started on a large addition to the Target Building. Requests for running time, and for space in the experimental areas, exceeded the supply by a large margin and applied serious strains to the organizational structures and administrative procedures.

As described in the previous articles, steady progress was made in all areas to develop the machine and this included, from time to time, major improvements and additions. But such improvements were obviously doomed to be overtaken by the relentlessly increasing demand and it was clear that, long term, the facility would require drastic modification to sustain the experimental programme.

Active planning for the conversion of the AGS began in 1963. The original proposal, submitted to the Government in 1964, was subsequently reduced in scope and accepted in 1965. The AGS Conversion project is designed to support an expanded and improved research programme, and to provide the increased intensity and facilities required. It involves replacing or modifying nearly every part of the accelerator.

In order to increase the accelerated charge to at least 10^{13} protons, the 50 MeV linac is being replaced by a high intensity 200 MeV linac expected to deliver a peak current of 100 mA in pulses up to 200 μs long at a repetition rate of 10 pulses per second. The preinjector is a 750 kV Cockcroft-Walton generator with a duoplasmatron source and high gradient accelerating column. The beam from the column is transported about 9 m to the linac by a system designed to minimize space charge effects, and which includes provision for detailed beam measurements. The preinjector has been operating since January 1970 and has delivered

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beam in excess of 200 mA to the entrance of the first linac cavity.

The linac consists of nine independent resonant cavities about 1 m in diameter and is 145 m in over-all length. The cavities are loaded with drift tubes, each of which contains a pulsed quadrupole for alternating-gradient focusing. In all cavities, except the first, the drift tubes are fitted with three or four stems since this configuration greatly improves the flatness and stability of the electric field distribution inside the cavity.

Each cavity requires about 3 MW of 200 MHz r.f. power to excite the accelerating field and make up the power losses, and an additional 2.5 MW to accelerate the beam. Nine complete r.f. systems terminating in superpower triodes will supply this power. Numerous servo systems control the nine independent cavities ; the control system employs solid-state elements and transmits its information to the Control Room by digital data acquisition display. Beam from the linac will be delivered to the AGS by beam transport elements in a small tunnel 80 m long. If it is ever desired, this system is laid out so that a booster ring can be installed. About 10 m beyond the linac a fast switching magnet is included to divert the pulses not used for injection into a side tunnel where a beam analysis station will provide continuous monitoring. At the end of this same tunnel the 200 MeV protons can be used for experiments in radiochemistry and for isotope production. It is expected that 9 out of 10 linac pulses will eventually be available to produce isotopes. As a sort of dividend, Curies of neutron-deficient isotopes can be made.

Protons were accelerated to 10 MeV for the first time in the first cavity of the linac in March 1970. Beams in excess of 120 mA at 10 MeV have since been achieved.

More accelerated protons per second can be obtained by reducing the rise and fall time of the powering cycle of the ring magnet. Better exploitation can also come from increasing the duty cycle — the percentage of time during which the accelerated beam can be spilled from targets to the experiments many of which are sensitive to the rate at which they receive particles. A new magnet power supply has been acquired which will halve the rise and fall times so that fast beam spills could be delivered once per second. The supply will also give a 50 % duty cycle with a one second flat top. Separate banks of rectifiers for the flat top will reduce the voltage ripple to reduce time structure in the spill. The rotating machine, now installed, has enough stored energy in its rotors to eliminate the need for a separate flywheel. The shaft speed will be controlled by solid-state units which will assure the timing precision necessary for the complex target procedures presently available.

Increased magnet power brings in its wake the need for increased water cooling not only for the ring magnet but also for numerous auxiliary components. Massive new water systems have been installed.

As the ring magnet rise time is reduced by half, the rate of rise of the magnetic field will be doubled. The r.f. accelerating system will then have to develop twice the voltage per turn. The possibility of radiation damage and the need for access for maintenance have made it imperative to remove the r.f. system electronics from the ring tunnel and, in 1969, twelve new wide band 120 kW amplifiers, together with the tuning supplies and detectors, were installed in a new building inside the ring (the building also houses the new magnet power supply). Cables in trays on posts run from this building through what is left of the forest inside the ring to convey the power to the cavities in the tunnel. The old cavities have been hardened against radiation and their input circuits have been modified to be compatible with the cables from the new power amplifiers. Increased cooling will permit them to operate at a higher voltage compatible with the new magnet power supply.

Ten new accelerating cavities are being built to operate at still higher voltage and to be capable of accelerating more than 10^{13} protons. A reduction in the number of cavities would free two ten foot straight sections to install units for beam manipulation. (It appears that no matter how many straight sections are built into a machine, it is always too few.) The new cavities have a tuning range with one of its limits equivalent to 200 MeV injection and they therefore cannot be used until the new linac is in operation.

Many components of the AGS are unavoidably subjected to bombardment by a small fraction of the proton beam. The resulting radiation damage and activation of these components has become increasingly troublesome with increasing

11. An aerial view of the AGS taken at the time of first operation in July 1960. The comparatively unencumbered ring is easily discernible straddled on the right by the initial 'Target Building'. To the right again are the service buildings.

12. An aerial view of the AGS (from a different angle) taken in September 1969. The impact of the years of development and particularly of the Conversion project is clearly seen. Top centre is the new 200 MeV linac building. To the lower right is the East Experimental Area — the rectangle of the initial Target Building can just be picked out, added to it are the 'East Area Extension' and the 'East Experimental Building Addition, EEBA' (the building with the whiter roof which is offset to take the slow extracted beam diagonally).

intensity. In order to improve the reliability of the accelerator and the ease with which it can be maintained, many of the components are being redesigned and replaced by units which are more resistant to radiation damage and which can be more rapidly replaced or repaired. Components which need not necessarily be in the ring tunnel are being removed and installed outside.

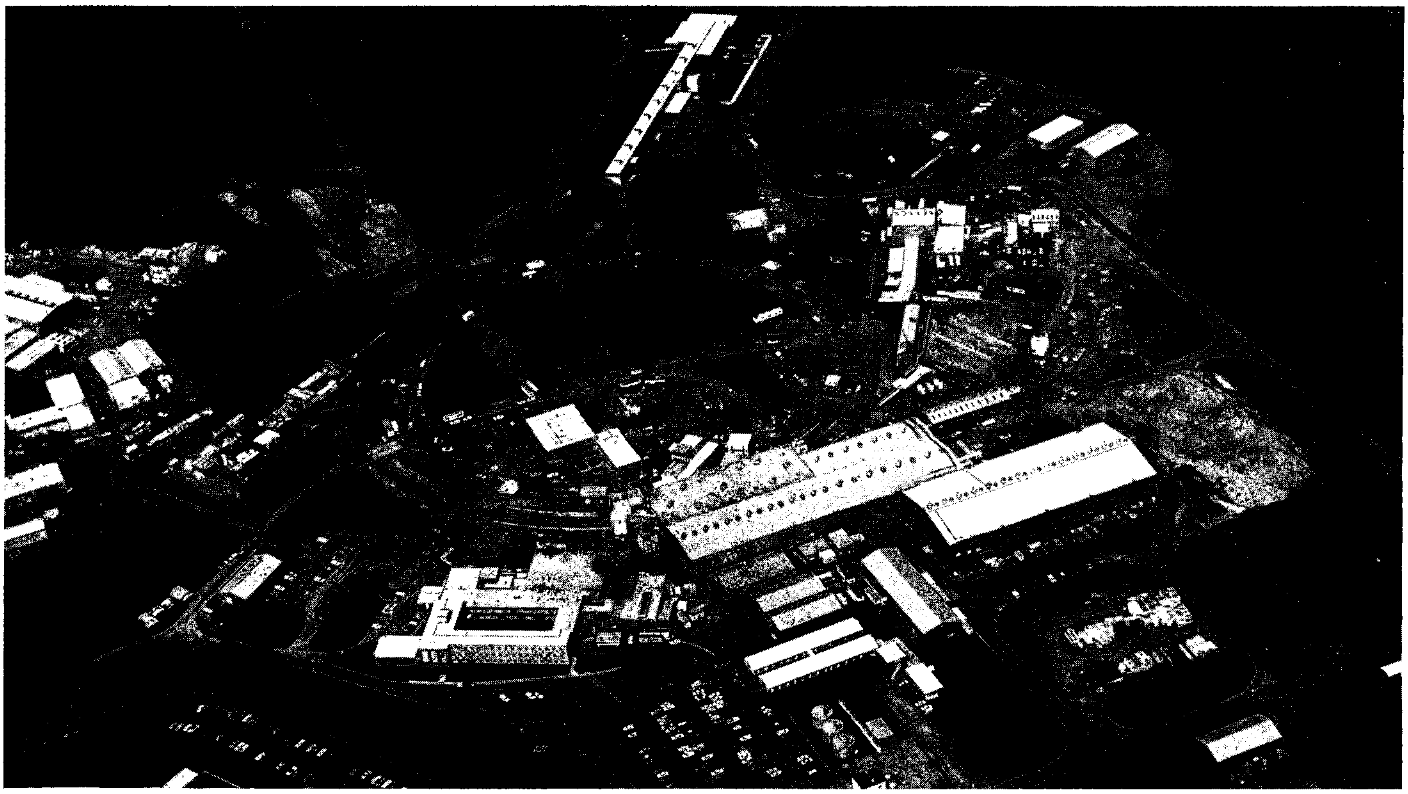
A complete new ring vacuum chamber has been designed, using metal vacuum gaskets and ceramic insulation. It has quick-disconnect end clamps, rather than bolted flanges. So far, it has been installed in about a quarter of the ring. New sputter-ion pumps are being installed (one on each magnet) to reduce the operating pressure to 10^{-7} torr. The reason for pushing the pressure lower is no longer the problem of gas scattering but is to avoid plasma instabilities, induced by residual gas, which can be a worry at high intensity.

The main magnet bus system and support have been redesigned to allow for rapid removal and replacement of a complete magnet module, including its vacuum chamber and pump. Methods of rapid, accurate repositioning of replacement magnet modules, as well as replacement straight section components, have been developed. Auxiliary equipment in the magnet tunnel is also being redesigned for unit replacement.

Improved delivery of beams to the experiments is an essential part of the conversion. The new magnet power supply and r.f. system have important design features related to better beam spills and so also do improvements in the control systems and in auxiliary devices. A new fast external beam system, coming out from H1O, will be set up to supply bubble chambers. Gigawatt switches will energize a new fast kicker and programmed bump coils will eliminate the need for hydraulic rams. Particle trajectories are being designed so that operation in various modes will be possible in order to accommodate a variety of experimental requirements. The slow external beam is being extended, step by step, as part of the operating programme. It will benefit greatly from the improved power supply operation, and will be split to serve several targets taking advantage of the increased intensity.

The AGS Conversion is an unusual construction project. The sequence and scheduling of the project, and often even the design of components, have been greatly influenced by the desire to ensure that the programme of particle physics experiments on the machine could continue to the maximum possible extent. Operation has often proceeded in the midst of construction.

Although the Conversion project will be formally completed before the end of 1971, improvements to the synchrotron will inevitably continue. Development of an accelerator is never completed.



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5. Major features of the experimental programme

13. One of the most famous photographs in the history of high energy physics. It was in this photograph, taken in the 80 inch bubble chamber at Brookhaven in 1964, that a track of an omega minus particle, whose existence was a crucial prediction of unitary symmetry theory, was first found. Negative kaons entered the chamber from below in the photograph and the sequence of interactions from which the omega minus was identified can be seen on the right.

High energy physics research began at the AGS in December 1960 with an extensive survey of secondary particles produced by 10 to 30 GeV protons incident on aluminium or beryllium targets.

The first experiments designed on the basis of this survey programme were total cross-section measurements investigating the behaviour of p-p, $\bar{p}$-p K^+-p and K^--p at momenta up to 20 GeV/c. A search (unfortunately negative) was made for magnetic monopoles produced by the 30 GeV protons. Simultaneously, the effects on particle yields of possible secondary interactions in the target nucleus were investigated. The diffracted proton beam at 30 GeV was used to make a number of emulsion stack exposures for several institutions. The same beam was used to establish the absolute cross-section for the production by protons of C^{11} from carbon and of Na^{24} from aluminium giving very useful information for calibrations and for monitoring beam intensities.

The first six months period was the beginning of an ever expanding experimental programme. A comprehensive review would be much too lengthy here and instead, a few examples of different lines of research to which the AGS has made significant contributions will be described.

Neutrino experiments

Pauli postulated the existence of the neutrino in 1930. This elusive and seemingly unobservable entity enabled Fermi to construct a theory of beta decay of the nucleus which reconciled the observed facts with the conservation of energy and angular momentum.

Muons are also coupled to neutrinos in weak interactions; muons can be absorbed by nuclei with the resultant emission of a neutrino in an analogous way to the electron capture form of beta decay. Muons also decay into an electron and *two* neutrinos. But here, a puzzling contradiction became apparent, since if these two neutrinos from the muon decay are of the same type, the muon should also be able to decay into an electron and a gamma ray.

The gamma-decay mode has never been seen in millions of experimentally observed decays. Feinberg, Lee and Yang pointed out that this could be explained by postulating two types of neutrinos — one coupled to the muon (ν_μ) and the other coupled to the electron (ν_e). A test of this hypothesis can be made using the neutrinos produced when pions decay into muons plus neutrinos. These neutrinos, which must be coupled to the muon (the ν_μ type) can be captured in nuclei with emission of a fast muon. Capture of the neutrino with emission of a fast electron would not be seen unless the neutrinos ν_μ and ν_e are the same type.

The experiment only became feasible with the advent of high energy accelerators because the interaction probability increases rapidly with neutrino energy. At the AGS, a Columbia University-Brookhaven group set up a large spark chamber, containing a total of 10 tons of matter, shielded from all particles, except the very penetrating neutrinos, by 5000 tons of iron. The AGS proton beam on an internal target produced copious pions which decayed in flight. The resultant neutrinos penetrated the shielding and passed through the spark chamber. In 800 hours of running time in 1961 and 1962, about 4×10^{17} protons were delivered onto the target, yielding an integrated flux through the spark chamber of about 10^{14} neutrinos. Fifty interactions were observed, 24 of them showing a single energetic muon and 26 showing muons produced with other particles. Electrons, which would have been identified by the characteristic electron-gamma ray showers, were not seen. It is concluded, therefore, that the neutrinos ν_μ which are coupled to muons do not couple to electrons, and that the neutrino ν_e is therefore of a different type.

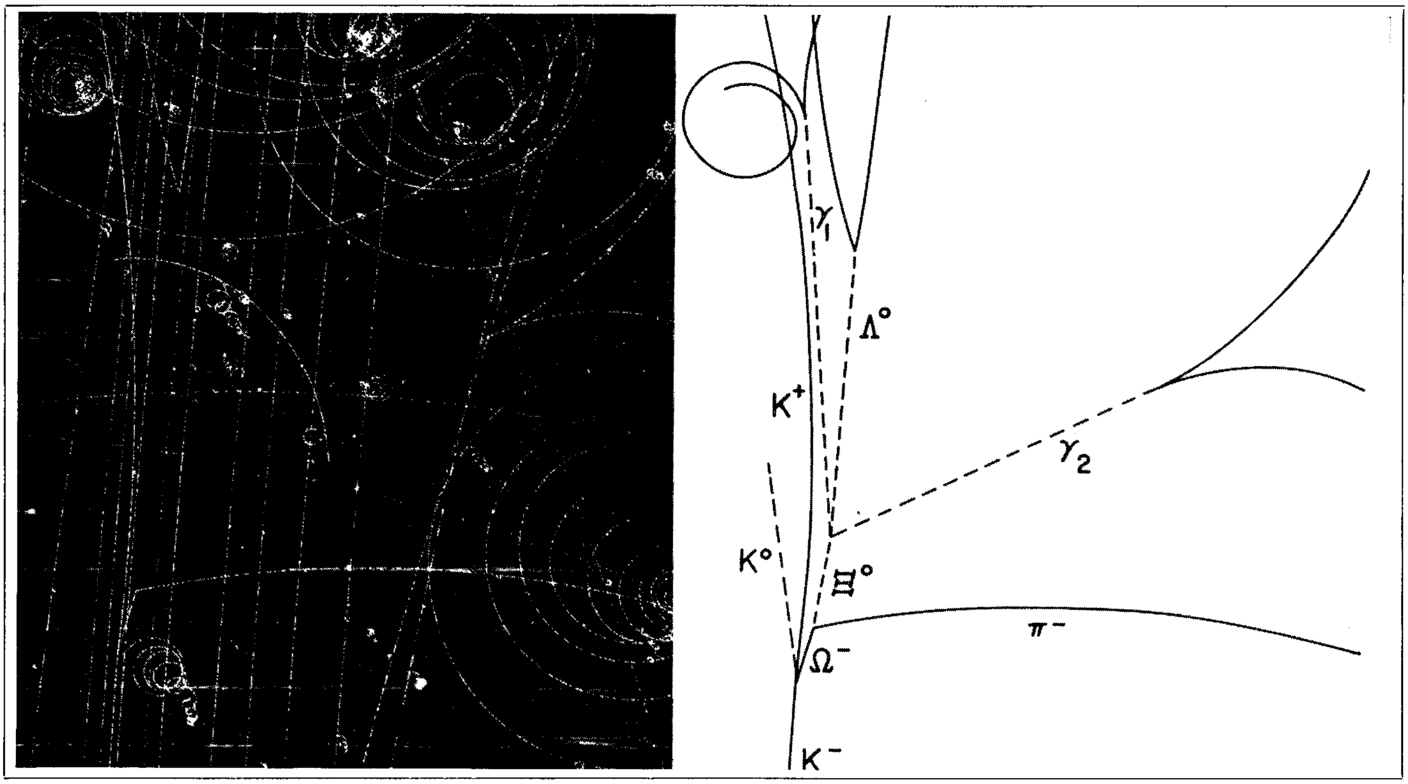
Research on neutrino interactions was continued by the Columbia-Brookhaven team in a new experimental area where a fast external proton beam on an external target was used to give higher pion yields and a pion focusing lens could be used to improve the flux density of the pions and of the neutrinos at the detector. An enlarged spark chamber array, totalling 60 tons of aluminium and iron, was constructed. The object of this experiment was a search for the existence of the intermediate boson, W, a short-lived particle hypothesized to be connected with the weak interactions.

In a fiducial volume of 24 tons in the production chamber, about 800 neutrino induced events were observed, and from these events, candidates were selected for decays of the W to electrons or muons. Detailed analysis of the data showed that none of these events could be ascribed to production of an intermediate boson. A careful neutrino flux survey was made, from which production cross-section calculations indicate that, at the 90 % confidence level, the intermediate boson must have a mass greater than two proton masses if it exists at all. This conclusion reinforced that of a CERN group using data taken at the CERN PS.

Particle resonances

The structure of the resonant mass spectrum and the quantum numbers (spin, parity, isotopic spin, strangeness) of elementary particle states have been studied since pions were first produced at cyclotrons. This study has intensified since the PS and the AGS were brought into operation. These machines give high quality beams of particles with energies great enough to reach the formation thresholds of resonant states. At even higher energies, the states are produced as fragments emerging from the collision process. Particle resonances have been studied at the AGS by two different techniques. One method measures the parameters of resonant states resulting from collisions detected in a bubble chamber. With a reasonably large sample of events, this technique is capable of making a precision determination of most of the resonance parameters.

A resonance had been discovered in the nucleon-pion system two decades previously at the University of Chicago. Now termed the Δ, it has a mass of 1236 MeV, and decays to its final states in about 10^{-20} seconds. The Σ_1 at a mass of 1385 MeV was found at the Lawrence Radiation Laboratory, Berkeley. As the evidence accumulated, it was pieced together to support the SU_3 unitary symmetry model. This model, based on relatively simple assumptions about the symmetry properties of physical laws, makes it possible to predict the properties of resonant states



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of particles. In 1962, a Syracuse University-Brookhaven collaboration exposed the 20 inch chamber to negative kaons and identified the Ξ ½ (1530) resonance which had been predicted by the SU_3 model.

Evidence supporting the SU_3 model continued to grow. Resonances of the strong interactions could be treated as 'particles' and grouped into remarkably orderly arrays. One array, called the baryon decuplet, neatly assembled nine known resonant states but its tenth member was missing. This tenth member, called the omega minus, Ω^-, was predicted by the mass formula to have a mass of 1680 MeV, and a lifetime of 10^{-10} seconds. Its existence was cited as a crucial test of the unitary symmetry theory of strong interactions and several laboratories were engaged in an effort to find it.

In February of 1964 a Brookhaven team announced the observation of the production and decay of the omega minus. More than 30 scientists (including three from Syracuse University and one from the University of Rochester) were directly involved in the experiment. The 80 inch hydrogen bubble chamber was exposed to 5 GeV/c negative kaons and about 100 000 pictures were taken. These pictures were analyzed for the more characteristic decay modes of the omega minus, and an event which could be interpreted as the elusive Ω^- was found.

Very careful fitting and cross checking of the momentum and bubble density measurements verified that the particle assignments were correct to a high degree of probability.The unusual and fortunate fact that two invisible gamma rays associated with the event both produced electron pairs within the liquid hydrogen, allowed a further cross-check. In view of the properties determined for the particle (charge —1, strangeness —3, and mass 1677 ± 9 MeV) it was clear that it could be identified as the predicted particle.

Another technique used in the search for resonances is the measurement of high energy collisions between various types of projectile and target particles. When the energy of the projectile is such that the resonant mass can just be formed, a peak is often observed in the total cross-section. This technique, using the high data taking rates of electronic detectors, can sensitively distinguish weak resonances masked by a background of other reaction channels. These cross-section measurements at the AGS yielded many results. Some of the 'peaks' in the cross-sections appear very small, but the statistical accuracy is so good that, on an expanded scale, they are meaningful.

Both bubble chamber and counter techniques have found a multitude of resonances. The measured masses, widths and spins have a direct bearing on the SU_3 model of the hadrons, or strongly interacting particles. The searches have by no means ended.

Studies of CP violation

An elegant experiment with a surprising and important result was carried out at the AGS by a group from Princeton University. Apparatus had been set up to study the decay of the neutral kaon. As observed in the laboratory, this meson exists in two forms, called K_S° and K_L°, which differ from one another in life-time, in decay modes, and very slightly in mass. The K_S° decays so quickly that it travels only centimetres before disintegrating into two pions. The K_L° has a longer life and travels tens of meters before decaying, usually into three particles. This particle complex has the remarkable feature that a K_L° may be converted into a K_S° in passing through matter, a process called regeneration.

The K° mesons were observed with a spectrometer which was aimed at a helium bag far enough from the target to permit essentially all the K_S° particles to decay. Only a very few produced by regeneration of K_L° in the helium would be observed. Since the K° is neutral, it can be detected only by making measurements on its decay products. Prior to this experiment, the K_L° was thought to decay only by a 3-body mode whereas the K_S° nearly always decays into two pions. In contrast, decay of the K_L° into two pions was forbidden by a fundamental principle of physics, CP (charge conjugation, parity) invariance. By inserting a piece of dense metal in the helium bag in the region of K° decay, it was possible to regenerate K_S° mesons which then quickly decayed into two pions. The apparatus was calibrated with sufficient exactness to establish this decay mode for the K_L°, should it occur. The regeneration material was then removed, and decays were still observed that were identical with those from the regenerated K_S° mesons.

It was very important to eliminate the possibility that these events were in some way simulated by the normal 3-body decay modes of the K_L°. Careful analysis eliminated this explanation and the experimenters concluded, as the most reasonable explanation of the observed events, that the K_L° meson decays into two pions at the rate of about 2 in every 1000 decays. This process violates CP invariance and strongly implies that time (T) reversal invariance does not hold, since CP and T are interdependent through the invariance of CPT, which appears to be firmly established for all interactions. Previously, it had been believed that the direction of time had no influence upon the laws of physics.

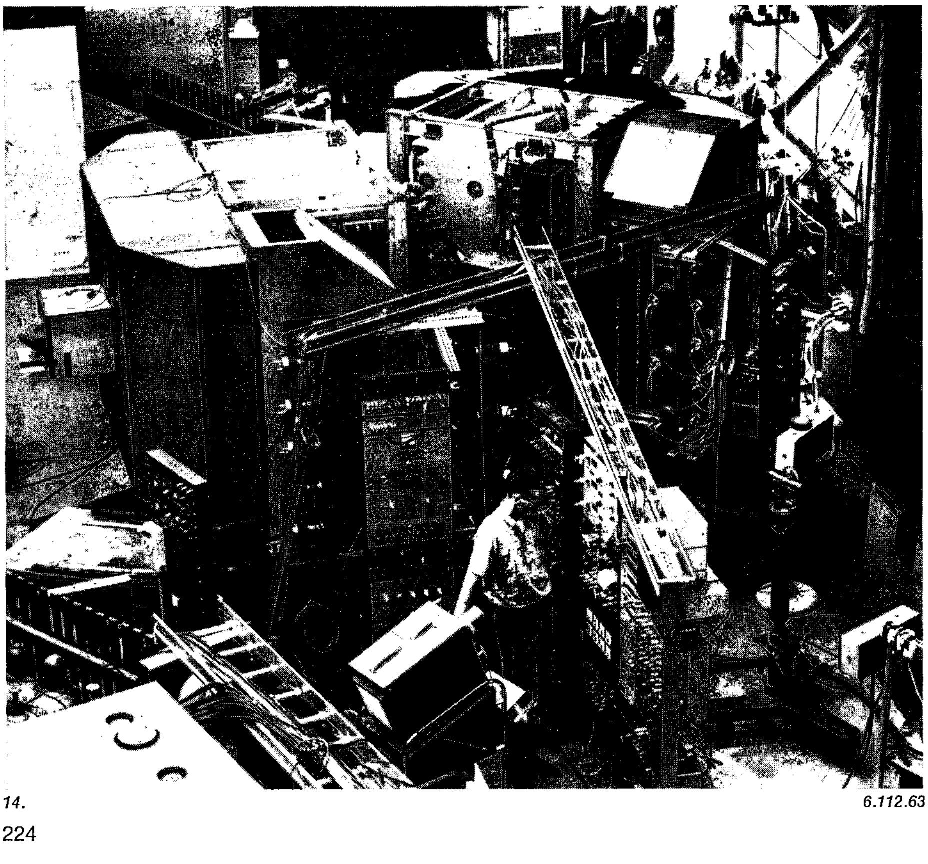
Almost immediately thereafter many experiments produced further understanding of the newly discovered violation.

Nuclear Chemistry

Nuclear chemists have made extensive use of the internal proton beam of the AGS to measure the distribution of products formed by the interaction of high energy protons with complex nuclei. By mapping yield distributions from a wide variety of targets at a number of energies an over-all picture of the mechanisms which are important in these reactions has been obtained. Spallation (the emission of many nucleons or small nuclei leaving a single, large residual product) and fission (break-up into two comparably sized products) are chiefly responsible for the observed yields.

Details of these mechanisms have been studied by a variety of techniques both with internal and external beams. Measurements of the angular and energy distributions of recoiling products, measurements using emulsion and mica track detectors, and counter experiments have been employed in these studies.

Major interest at the present time is centered on the nature of the processes which lead to the observed high yields of energetic fragments with masses between 15 and 30 from heavy target nuclei such as gold or uranium. The yield distributions for such fragments do not yet fit in with our present ideas of spallation and fishion. At the same time it is difficult to consider such large fragments being evaporated directly from highly excited nuclei in much the same way as are neutrons, protons, He and Li nuclei. Recoil measurements and counter experiments now in progress are specifically aimed at a better understanding of this problem.



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14. The spectrometer installed at the AGS for an experiment on neutral kaons by a team from Princeton University. This experiment discovered 'CP violation' for the first time by showing that the long-lived kaon can decay into two pions. The reverberations of this discovery in 1964 have still not died down.

6. The future

Studies have been under way at Brookhaven for several years searching for means to increase the energy of particle accelerators into the TeV (thousands of GeV) range. The pulsed proton synchrotron still appears to be the leading contender when built with conductors operating at very low temperature and producing high magnetic fields.

The pilot production materials already at hand would reduce the synchrotron ring diameter by half compared with the size given by simply extrapolating an AGS type of construction. Superconductors which are likely to be available in the foreseeable future will make possible rings one third the diameter of those built with copper for the same energy. Techniques for operating at a few degrees Kelvin are becoming commonplace, and refrigerators of adequate size can be obtained.

One can already visualize a multi-thousand GeV synchrotron built of magnets smaller in cross-section than a dinner plate, housed in a few kilometers of Dewar within a small and inexpensive tunnel encircling the Brookhaven site. The vacuum chamber would be only a few centimeters in diameter — requiring injection energy above 20 GeV for good intensity. There are practical problems remaining to be solved, but they are scarcely more formidable than those confronting the constructors of the PS and AGS in the early nineteen fifties.

A study group at Brookhaven is exploring these possibilities in detail, making use of recent cryogenic magnet developments. The Brookhaven site has room for a ring with a radius of 1.5 to 2 kilometers. With pulsed magnets that give peak fields of 40 to 60 kG the site could accommodate an alternating gradient synchrotron with an energy of about 2000 GeV.

The present studies towards this end include the following:
A group is developing designs of pulsed dipole and quadrupole magnets using finely stranded superconducting cable ; such magnets appear feasible for up to 60 kG.
Another approach under study is the development of 'window-frame' magnets

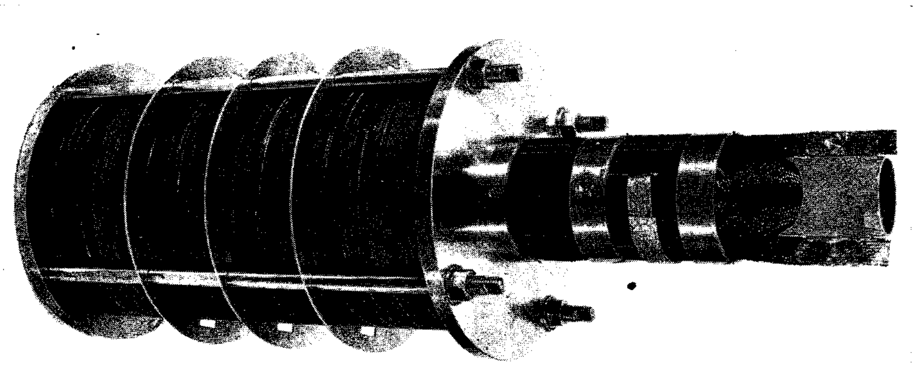
using rectangular iron yokes with conductors of very pure aluminium (impurities about 1 part per million) operating at 10-15° K. With careful design, such magnets can deliver fields of the necessary uniformity up to about 40 kG even considering the saturation of the iron yoke.

The problems involved in incorporating cold magnets of either type in a synchrotron are being investigated. Currently effort is being concentrated on a 'cold magnet synchrotron' (CMS) for energies of 100 to 150 GeV considering such questions as tolerances on the magnets, refrigeration systems; 'conventional' accelerator problems such as beam ejection and transfer, accelerating systems, shielding; and cost estimates.

Such a 100 to 150 GeV machine would serve three purposes: it would provide facilities for high energy physics beyond anything in the USA with the exception of the 500 GeV Batavia accelerator; it would serve as a pilot project for future very large cold accelerators; it could be used as the injector for a 2000 GeV synchrotron which could eventually be built at Brookhaven.

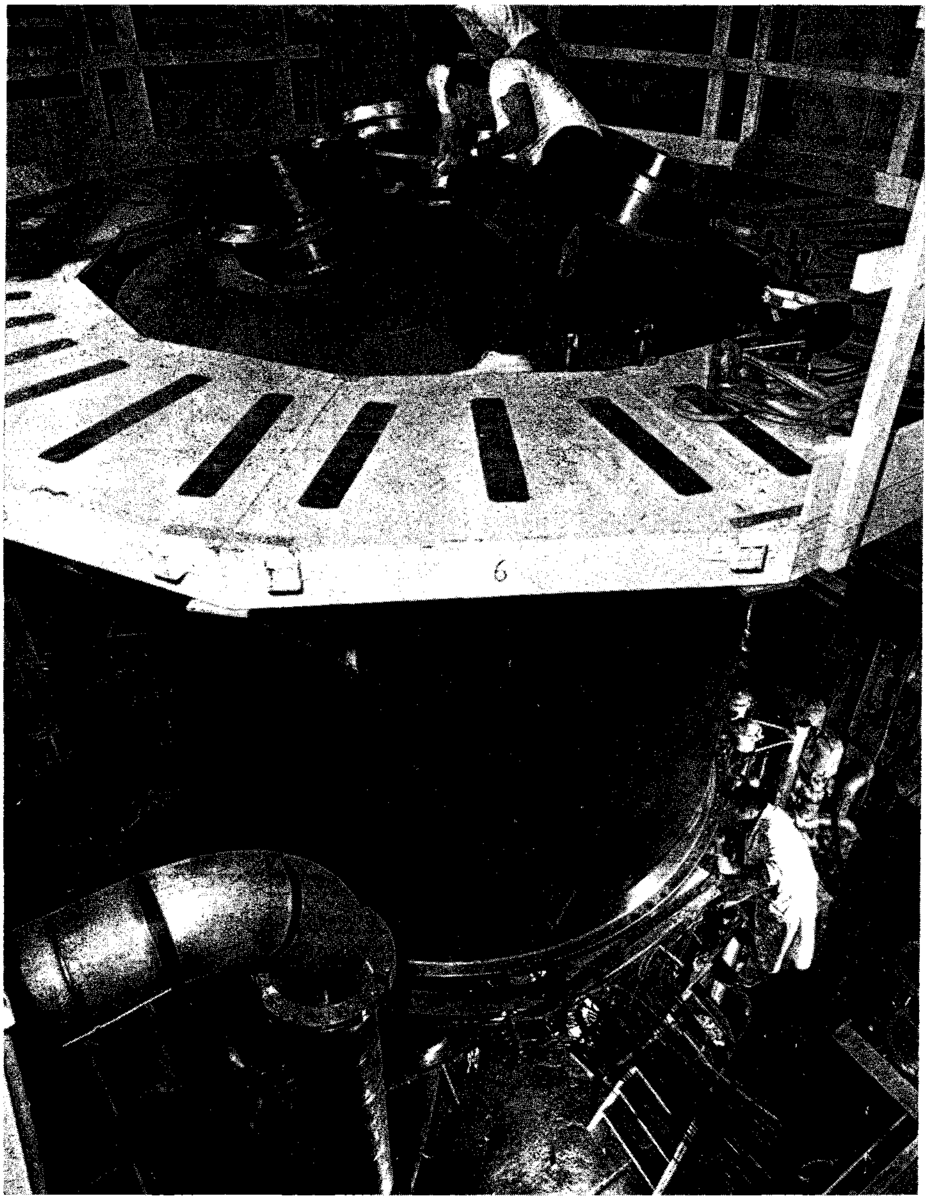
If one examines the problems associated with the experimental areas of such machines, it is evident that physical size and demand for electrical power must be controlled. Large bubble chambers have already employed superconducting coils and superconductivity is already finding its way into beam transport systems and into other detectors. The superconducting r.f. beam separator has promise for counter and spark chamber beams at high momenta. Experimental areas may still appear to be the same concrete jungles of shielding, but refrigerator transfer lines will have replaced the water hoses and electrical cables. Inside the shielding will be beams and apparatus designed to take advantage of intense magnetic fields.

The art has not yet stagnated !



15. 2.142.70

15. A test model of a superconducting iron-cored magnet such as could eventually be used in a synchrotron ring. The cylindrical vacuum vessel aperture, which is visible on the right is 5 cm diameter. A model 75 cm long is now under construction.



16. 10.764.69

16. The 7 foot hydrogen bubble chamber which has a large superconducting magnet designed for operation at 30 kG. The chamber took its first pictures in October 1969 and will be used for a neutrino experiment. It may eventually be converted to an 11 foot chamber and installed in the new North Experimental Area.

CERN News

Polarized deuterons

The CERN Polarized Target Group has obtained within the last few months very high polarization rates for protons bound in alcohols and has built operating targets of sizeable volume. The group has more recently tackled the polarization of deuterium nuclei bound in the same type of alcohols.

A first test at a temperature of 1° K, using 'heavy' ethanol (C_2D_5OD) mixed with 8 % heavy water (D_2O) and 2 % of porphyrexide (the free radical which is responsible for high polarization of spins in alcohols) gave a 6.5 % polarization.

However, it was possible to predict from these results and previous experience on polarized protons and according to a new theory, that a 20 % polarization could be obtained at 0.5° K in heavy butanol (M. Borghini and K. Schaeffer, Physics Letters A, 31, 535, 1970). Such a result was achieved at CERN on 10 July in a mixture of heavy butanol (98 % deuterated) mixed with 5 % heavy water and doped with 1 % porphyrexide, using a newly developed helium 3 cryostat (see CERN COURIER vol. 10, page 112).

The difference between the figure achieved with protons (65 % in the same conditions) is due to the smaller magnetic moment of the deuteron (deuterium nucleus) which is only $1/6$ that of a proton.

This is not the first attempt to polarize deuterium. In 1965 a Dubna group, using heavy LMN, achieved a polarization of the order of 10 %. But this could be used for useful experiments only with slow neutrons which have a low interaction rate with the other nuclei in the complex target molecule. In 1969, a Yale group obtained a 3.75 % polarization in solid deuterium.

The new targets developed at CERN could be useful for studying spin effects in elastic scattering on deuterium, such as in $\pi d \rightarrow \pi d$, or as polarized neutron targets, or for polarization measurements on pion photoproduction. In order to study the effects of the deuteron nuclear structure on polarization measurements which would use a deuteron as a target, the CERN-Orsay-Pisa group has performed a short test run with a beam, of 10 GeV/c negative pions on a 4 cm^3 target of heavy butanol, cooled to 0.55° K, with 20 % polarization.

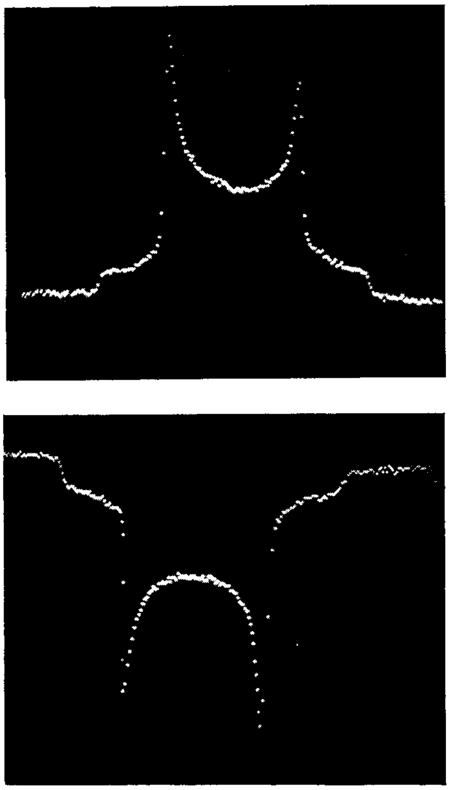
PS magnet replaced

It became necessary in 1966 to replace magnet No. 1 of the PS ring because of damage caused by radiation, which is intense at that point downstream of an internal target. The only spare magnet available at the time, No. 102, was installed.

A fault occurred in this replacement magnet at the end of February of this year. The 2500 metal foils forming the yoke of a PS magnet are stuck together with araldite and, under the effect of radiation (assessed at 10^9 rad from 1966 to 1970 in this region), the adhesive weakened and about thirty foils at the end of the yoke became detached at the edges. The movement of these foils, as the magnet pulsed, broke the welds securing the pole face windings to their

Figure 1 shows the nuclear magnetic resonance signals from deuterons in butanol, under positive and negative polarizations. In a magnetic field (25 kG in this case) each deuterium atom has three possible energy levels, corresponding to its magnetic quantum number (m) being 1,0 or -1. These levels (as illustrated in Figure 2) are evenly split by the interaction of the magnetic moment with the magnetic field by an amount proportional to m, (giving a splitting of the order of 16 MHz) and, to a smaller extent (about 50 kHz) by the coupling of the deuteron quadrupole moment with electrical gradients within the solid, by a quantity proportional to m^2. Magnetic resonance measures the frequency of transitions between the levels.

The splitting between the levels depends on the orientation of the electrical field with the magnetic field; as these orientations are random in frozen alcohols, the pattern observed is the sum of the pairs of lines corresponding to all possible orientations. One of the two peaks is mainly due to transitions between $m = 1$ and $m = 0$ levels, and the other between $m = 0$ and $m = -1$ levels. When deuterons reach a sizeable positive polarization, they spend more time in the $m = 1$ state, than in $m = 0$, and more time in the $m = 0$ state than in $m = -1$. Consequently, the peak corresponding to 1/0 transitions is higher than that corresponding to 0/-1 transitions. When the polarization is negative, the reverse situation occurs. This makes it possible to compute the degree of polarization (20 % in this case) from relative intensities of the peaks.



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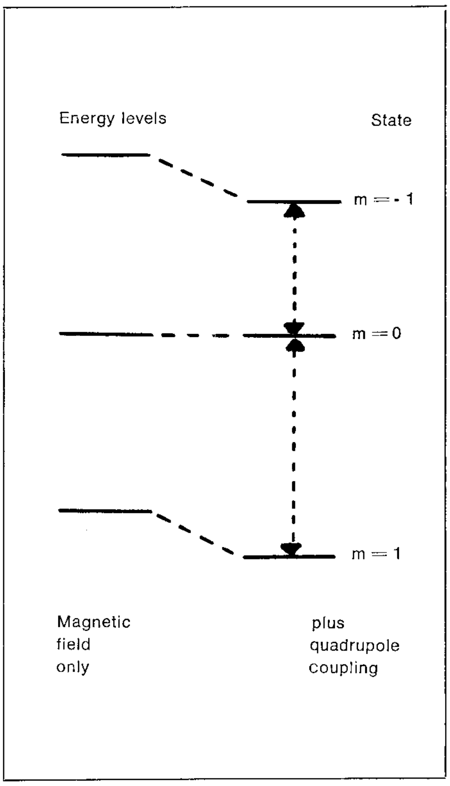

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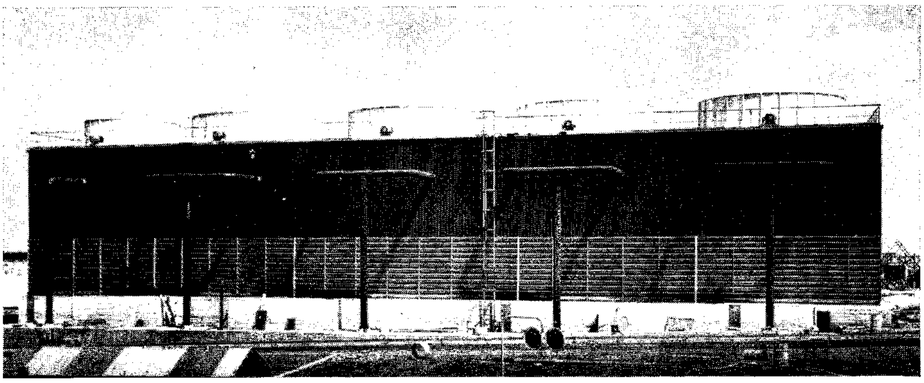
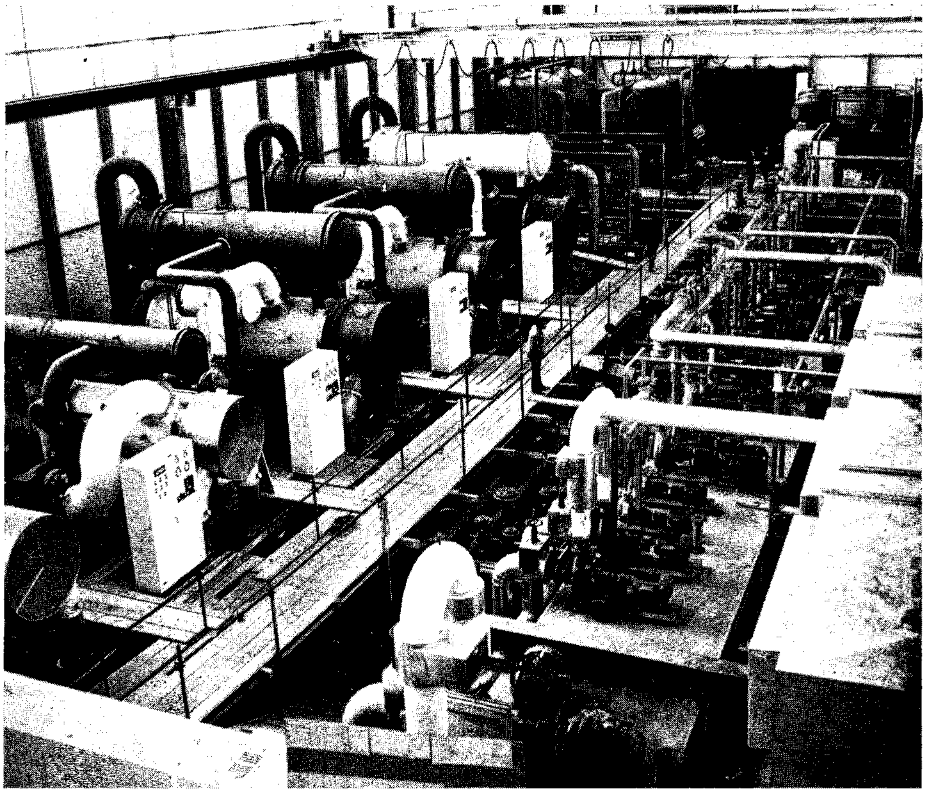


1. CERN/PI 35.7.70



2. CERN/PI 54.7.70

1. The five cooling towers for the cooling system of the Intersecting Storage Rings. The tower on the left is used in connection with the cooling for the air-conditioning plant; the four others are used in connection with the cooling for the magnets of the rings and the beam transfer lines.

2. The ISR cooling system plant room. On the left in the foreground are two small groups of refrigerators for the air-conditioning system, then three large groups of refrigerators for the magnet cooling. Partly hidden are the water-water heat exchangers. In the background are the water treatment units. On the right are the pumps which distribute the cooled water.

supply cables. An electric arc ensued, in turn burning the winding insulation, allowing white-hot materials to fall on to an aluminium vacuum chamber window, breaking the vacuum, etc...

The magnet could not be changed immediately because, although materials were available to build spare magnets, there was no assembly unit of the required type available. The defective magnet was kept in use temporarily as the irregularities in the field were relatively insignificant. Work began as soon as possible on building new magnets and, after two months of testing, magnet 103 was installed during a machine shutdown. Some of the foils from the yoke of magnet No. 1, removed from the machine in 1966, were used again for the new magnet.

The number of spare magnets built was restricted to four because of the limited number of foils remaining from the original production batch of steel. However, inspections which have recently been made of the edges of yokes have shown that there are now about ten ring magnets showing signs of coming apart at the end foils. These will have to be replaced within a few year's time. It will be possible to repair a hundred or more yokes by using new foils only for the ends. Adhesives which are much more radiation resistant than the previous types will be used.

In view of the increasing intensity of the PS with the improvement programme, it is likely that magnets will deteriorate more quickly than before, although the deterioration will not be proportional to the intensity because the size of the beam will hardly change as a result of the higher injection energy.

Various methods are being examined to prolong the useful life of the magnets, with the aim either of improving the adhesion between the end foils (using screws and welds, etc.) or of replacing the end foils by thicker, one-piece blocks. The eddy currents and the remanent field would thus be locally increased, but would probably still remain within acceptable limits. These studies have become particularly important in view of the proposal to use the PS as an injector for the 300 GeV accelerator.

ISR Cooling System

At full power, the cooling system for the Intersecting Storage Rings (not including the experimental areas) needs to have a capacity of about 27 Gcal/h, which is almost ten times that necessary for the PS. The difference is mainly due to the large beam transfer system and to the fact that the magnets in the two rings have a d.c. power supply.

An exchanger of the type used in the PS, with a total-loss water circulation system, would require an increase in the water supply to CERN of some 1200 m^3/h which, by itself, could cost about 20 millions Swiss francs. Preference was therefore given to a less costly system using cooling towers associated with water-water heat exchangers and refrigerating machines, probably representing the first application of such a system to the cooling of a large machine. There are two separate systems, one (23.4 Gcal/h) for the ring magnets and the transfer lines with their power supplies, and the other (3 Gcal/h) for the air-conditioning plant.

There is a closed circuit (referred to as the secondary circuit) of demineralised water for the magnets and power supplies, cooling the various components directly. At full power, water enters the magnets at 13°C and leaves at 33°C. It then passes through the water-water heat exchanger, on the primary side of which cooled water flows through the towers. The water will thus be cooled by at least 7°C at the height of summer. The secondary circuit water then flows in succession through the evaporators of three large refrigerating machines, leaving at 12°C. The condensers of these machines are themselves cooled by water taken from the primary circuit.

The water consumption is thus limited to 70 m^3/h lost by evaporation and percolation in the towers. To be precise, the word 'lost' is incorrect, for the water used for this circuit is itself taken from the surface water of CERN, which would otherwise run to waste, and which it is merely necessary to filter and decarbonise.

The water from the evaporators is sent to a manifold from which it is either recirculated or injected into the eight different networks (two for the main magnets of each ring, two for the auxiliary magnets for each ring, one for the equipment in tunnel TT1, one for the equipment in tunnels TT2 and TT2a, one for the equipment in the ejection tunnel to the West Hall, and one for the power supplies to the main magnets).

The compressors, working on freon 12, are of the centrifugal type, and their unit power is 1000 hp. The secondary circuit flow rate is 1200 m^3/h, and that of the primary circuit 4200 m^3/h.

The system providing iced water for the air-conditioning installation comprises a cooling tower and two refrigerating machines, with a combined power of 3 Gcal/h. The water is supplied at 5°C, and returned (at full power) at 12°C. The condensers of the two machines are connected together in parallel, whereas their evaporators are in series. The compressors, which are also of the centrifugal type, operate on freon 11. Their unit power is 500 hp.

The heat exchangers, refrigerating machines, iced-water pumps and water treatment systems are arranged in the same room. The total installation includes 25 km of water piping, of which 20 km are made of stainless steel.

The whole of the plant, without the distribution system, was supplied and installed by Brissonneau-York (France) on the basis of a specification drawn up by the Mechanical Construction Group of the ISR. The cost was about 6.5 million Swiss francs. The plant is now being prepared for operation.

Alongside this plant, a cooling installation with a power of about 18 Gcal/h will be set up for the experiments in the intersection regions. The requirements relating to temperatures are less onerous here, the permissible input and output temperatures being respectively 35 and 53°C. The installation, of the type which has now become conventional from its uses in the PS and elsewhere, will consist solely of cooling towers linked to water-water heat exchangers.

It is interesting to note that it has been possible to solve a cooling problem of this size with such a low water consumption.

3 MeV linac gives 100 mA beams

On 8 June the 3 MeV experimental linac topped 100 mA for the first time reaching a peak beam intensity of 120 mA. It is now operating regularly at 100 mA with stable beams.

The linac was described in vol. 9 page 384. It came into operation in November 1969 and is being used for studies of the behaviour of intense beams at the input end of a linear accelerator.

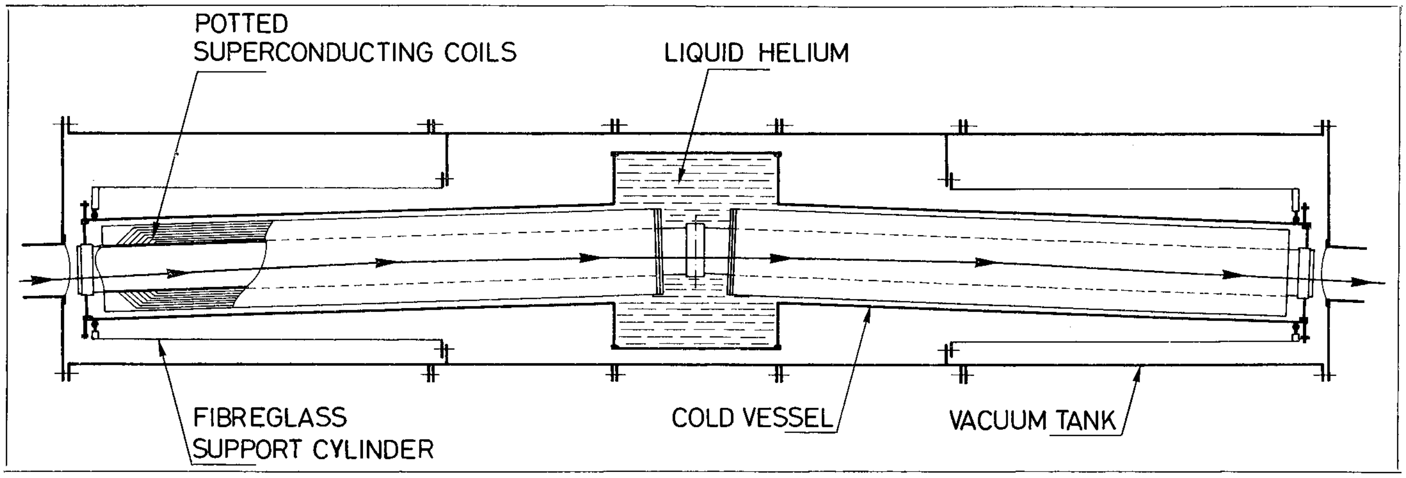
The high intensities have been reached following the installation of a buncher before the linac and the sorting out of the usual teething troubles on equipment of this type. The experimental programme is concentrating at the moment on the pre-bunching process. Extensive computation is going on in parallel using newly available computer programs which are able to predict beam behaviour correlating input and output conditions including the influence of space charge forces. Now that beams of 100 mA are available the observations on the 3 MeV linac can be directly related to the linac of the 28 GeV proton synchrotron which is also operating regularly with high intensity beams.

Superconducting bending magnet system

The layout of the beams to feed the 3.7 m European hydrogen bubble chamber has been provisionally fixed. It includes a mass-separated beam to provide particles of momentum up to 26 GeV/c and there is a problem to manoeuvre this beam around the edge of the 3000 ton iron neutrino filter which will sit almost immediately in front of the chamber.

In principle this could be done by using four of the standard CERN 2 m bending magnets to provide the bending power of 126 kG.m (to bend the beam through the fairly large angle of over 8°). However, this would have resulted in a magnet chain nearly 15 m long which is unacceptable in an already congested region. It was decided therefore to insert two identical superconducting magnets each having the following parameters — overall length 1.9 m, effective length 1.4 m, magnetic field 45 kG, beam aperture 130 mm.

The superconducting coils will be made of 'intrinsically stable' conductor with a



The superconducting magnet system being studied at CERN for use in beam transport to the European bubble chamber.

cross-section (including insulation) of $1.5 \times 3\,\text{mm}^2$ carrying an average current density of $220\,\text{A/mm}^2$. The maximum field inside the entirely impregnated coil will be 49 kG. (A model coil has been wound using copper conductor and some preliminary field measurements have been carried out). The bending field and current density parameters have been chosen conservatively — priority is being given to having a magnet system which will be reliable and durable since its efficient functioning will be an essential part of the physics programme with the 3.7 m chamber.

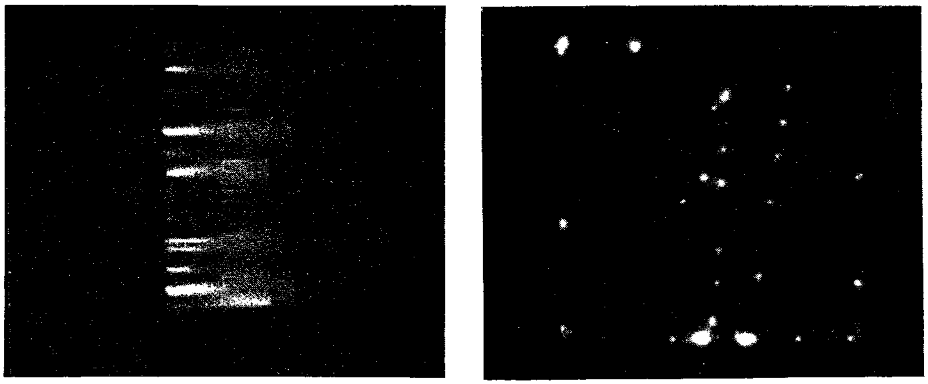
Conductor samples from various potential suppliers have been tested in the form of small solenoids, producing a maximum field strength and an approximate field gradient corresponding to the required values for the dipoles. The test solenoids were completely impregnated and surrounded by a glass-epoxy layer at least 10 mm thick, so that the cooling of the conductor was very poor. Nevertheless, in some cases critical currents well above the required values and in accordance with the short sample characteristics were achieved.

Cost estimates were made for a conventional magnet system and a superconducting magnet system (including power supplies and controls). Both came out close to 1 million Swiss francs. This does not include refrigeration for the superconducting magnets (which would add about 0.3 MSF) since, fortunately, the 1800 watt cooling plant for the chamber itself can easily absorb the extra 30 to 40 watts for the magnets. Another advantage comes with the operating costs where power consumption will save over 100 000 SF per year compared with a conventional system.

(A paper on the superconducting bending magnets was presented by G. Kesseler, P. Lazeyras and F. Schmeissner at the DESY Magnet Conference at the end of May.)

Streamers in hydrogen

The EMSA (Electromagnetism Studies and Applications) Group of the Track Chambers Division has started a programme to study the formation of streamers in hydrogen with the aim of developing an isotopic chamber which can be triggered like the present helium-neon streamer chambers, but in which the detecting medium also acts as a target as in the hydrogen bubble chamber.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Photographs of tracks taken in a hydrogen filled streamer chamber. The plane of photograph 1 is parallel to the electric field, and the photograph shows the discharges travelling from one electrode to the other and also, virtually equidistant from the electrodes, the 'arrested' streamers which are much shorter and which have formed on the track of an ionizing particle.

In photograph 2, the plane is perpendicular to the field lines, and it shows streamers along two ionizing particle tracks. The larger spots are the discharges which form preferentially along the rounded edge of the cathode, where the field is higher.

The first part of this programme consisted in building a small chamber (reported in TC-L 70-7) to test the feasibility of taking photographs of streamers in hydrogen. The 'useful' field volume is $15 \times 15 \times 4\,\text{cm}^3$. A chamber specially built was preferred to the use of one of the streamer chambers already in existence at CERN because of some special requirements when using hydrogen. The chamber was designed :

1) to be capable of operation at 10^{-5} torr, working at such low pressure is impossible with conventional streamer chambers, which operate under pressure, in which slight leaks are not a nuisance ;

2) to attain the high fields needed to obtain streamers in hydrogen (50 kV/cm at 760 torr).

The first photographs in which the visible streamers have been achieved were reported in June (TC-L 70-10). They were taken, using beta particles to produce the ionized tracks, under the following conditions : pressure — 250 torr ; composition — hydrogen 99.6 %, hydrocarbons 0.19 %, $H_2O + CO + N_2$ 0.5 %, He + Ne 0.16 % (residual traces of previous fillings with helium-neon mixture); electrodes — black, oxidized aluminium; pulse — triangular in shape provided by a Marx generator, 10 ns at the base; field — 25 kV/cm.

Although the results are encouraging, they are preliminary ones. Stray discharges are generated on the edges of the electrodes but, as the physical condition of the electrodes was most probably the cause of such discharges, it is hoped that they can be eliminated, even at higher fields, by shaping the electrodes in the same way as now done on the HT separators (see CERN COURIER, vol. 9, page 208). Experiments will be carried out using stainless steel and titanium electrodes.

Finally, in order to increase the luminosity of the streamers :

1) the effects of minutes traces of different gases added to the hydrogen is being studied ;

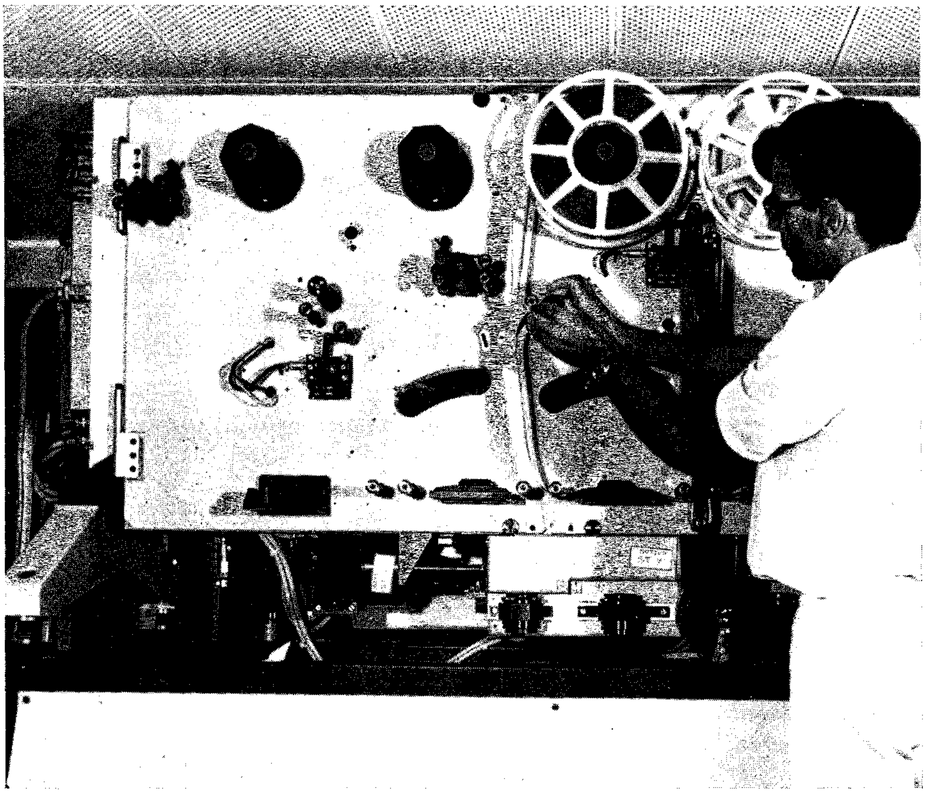
2) generators producing shorter and more rectangular pulses (Blümlein tri-coaxial line) are being built.

In another part of the programme, the design of a pulse generator to give 2 MV pulses of 5 to 10 ns duration suitable for supplying a chamber with two gaps of 25 cm is being examined. This equipment will consist of a 2 MV Marx generator, a spark gap and a 50 ns Blümlein line.

ADAM and EVA

Different problems are encountered in scanning photographs taken in large bubble chambers compared with those taken in conventional chambers and specially designed scanning and measuring equipment has to be developed.

Under the provisions of the CERN/Serpukhov agreement, CERN will have access to some of the film taken in Mirabelle (the large hydrogen bubble chamber built at Saclay for Serpukhov — described in CERN COURIER vol. 9, page 308). To cope with this film CERN has built a new scanning and measuring device intended primarily for Mirabelle



View of the upper part (projector and lens carrier) of the 'ADAM and EVA' scanning and measuring equipment. The images are projected on to a table four metres below.

CERN/PI 43.7.70

but which could also be easily adapted for film from Gargamelle or the 3.7 m European bubble chamber. It has tortuously acquired the name 'ADAM and EVA' from the French '*A*ppareil de *D*épouillement et d'*A*nalyse pour *M*irabelle et *EV*entuellement d'*A*utres Chambres' (scanning and analysing equipment for Mirabelle and possibly for other chambers). A group from the Data Handling Division led by C. Verkerk is responsible for its development.

'ADAM and EVA' is a highly automated, manually operated device combining the operations of scanning and measuring, to which is connected an on-line computer (CDC 3200) which immediately processes the data. (Several 'ADAM and EVA's could use the same computer). The operator has access to the results from the computer during the scanning and measuring process to give him a useful guide as to what is happening and he also has controls available which actuate certain semi-automatic operations. A keyboard is provided for communication with the computer.

'ADAM and EVA' has several other important features :

1) all movements are controlled via a PDP 8/L control computer ;

2) measurement is made in the film plane, giving greater accuracy ;

3) projection (at least in the version installed at CERN) is direct without the use of mirrors.

Optics: The ten lenses, giving a magnification of 17, are fitted in the same stage. The image is moved by movement of the stage and by coordinated movements of the lamps, while the film remains stationary. An overlap is arranged between the projection of the different parts of the film so that the images follow one another exactly in the plane of the beam in the chamber. The image projected onto the table, can be further magnified up to three times by a television camera.

Movements : The lens stage can be moved accurately along x and y directions to within ± 2 μ by means of Heidenhain linear encoders. Correspondingly, the lamps can be moved linearly along the y direction and with a tipping action along the x direction. The amplitude of the movements is such that each view can be brought directly in front of the operator.

Control computer : A PDP 8/L computer is used to centralize the control commands, whatever their origin (e.g. operator, on-line computer or the PDP 8/L itself) and to retransmit them uniformly. It also carries out the following operations :

a) storing and counting the pulses from the encoders ;

b) controlling the movement and correcting any errors in positioning compared with instructions received ;

c) transmission of measurement data to the CDC 3200 on-line computer ;

d) checking operation and providing warning signals.

Eventually, it is intended to use it to control the major part of the automatic track following.

Operation : After bringing the required exposure into position, the operator causes a fixed reticle with rotatable axes to coincide with the track to be measured by moving the film image. To do this, he uses a track ball for fine control together with a push button for coarser control and a reticle orientation control.

In an initial stage, it is intended to provide an aid to the operator in the form of a system for automatically causing the reticle to coincide with any point of which the coordinates have already been determined and are stored in the computer program — the vertex, for instance. Eventually, an automatic track following device will be added.

The prototype 'ADAM and EVA' will be operational at the end of 1970 with its CDC 3200 on-line computer, but with an incomplete software system. It will then be possible to make initial measurements on film taken with Mirabelle at Saclay ; the first photographs taken at Serpukhov will not be available until later.

Various study programmes on the PDP 8/CDC 3200 interface and on the detailed method of guiding the operator during scanning and measuring (operator — CDC 3200 communication) are very close to completion.

Soviet scientists have already expressed interest in having several 'ADAM and EVA's', and Saclay has undertaken the construction of a 'Gallicised' version using certain pieces of French equipment which are cheaper than imported components. Initial contacts have been made with industry with a view to a small production run.

Teaching aid

Under the general title 'Travaux pratiques sur la physique des particules' a first brochure entitled 'Interactions de la particule K^-' has been edited by J. Flechon and G. Baumann (Faculté des Sciences, Nancy University) and H. Annoni (Faculté des Sciences, Strasbourg University) in collaboration with CERN.

The brochure is available (at present in French only) together with a set of twelve slides, 5×5 cm^2. It is designed to help science students become acquainted with the study of particle interactions. Teachers who would like to make use of this material should contact CERN, Ref. PIO/EM, 1211 Geneva 23, Switzerland.

Around the Laboratories

DESY

Superconducting magnet for storage ring detection system

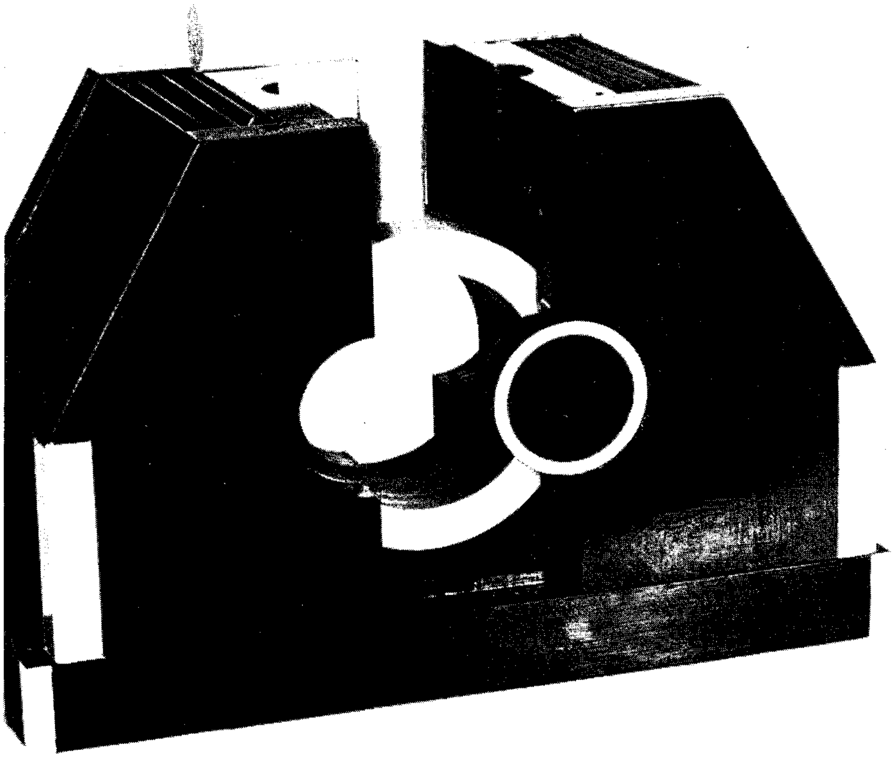
It is intended to install a superconducting magnet in one of the two interaction regions at the 3 GeV electron-positron storage rings which are now in their second year of construction at the DESY Laboratory. The magnet would have a large aperture to accommodate detection systems built up for example of wire proportional chambers.

A prototype, 1.4 m internal diameter and 1.15 m long, is now being built and is scheduled for completion by the end of 1970. Its performance will influence the design of a larger version which it is hoped to have installed in the storage rings in 1974.

The prototype will use a superconductor consisting of 220 niobium-titanium filaments twisted in a rectangular copper matrix of 3.6 × 7.6 mm^2 carrying a current of 1300 A. The field in the aperture will be 20 kG with a peak field of 25 kG at the coil itself.

To ensure that the circulating beams are not affected by the field in the interaction region two possibilities are under consideration. One involves having a superconducting solenoid 25 cm internal diameter shielding the beam region along the length of the large magnet. It has the disadvantage that particles emerging from the beam interactions could be scattered or could interact in the solenoid. The second possibility is to have two compensating superconducting magnets on either side of the large magnet to subject the circulating beams to equivalent fields in the opposite direction so that overall their trajectories are unaffected.

Wire spark chamber arrays can fill the aperture around the beam pipe (or around the solenoid if this is used). A special feature of the magnet design is that there will be gaps in the magnet yoke into which wire chambers or scintillators could be inserted for further muon detection.



A model of the superconducting magnet for the interaction region of the DESY storage rings. One half-yoke is shown slid back revealing the main superconducting coil (larger white cylinder). The smaller white ring would be the position of the superconducting solenoid which could possibly be used to shield the circulating beams. Note the slots in the magnet yoke where further detectors could be positioned.

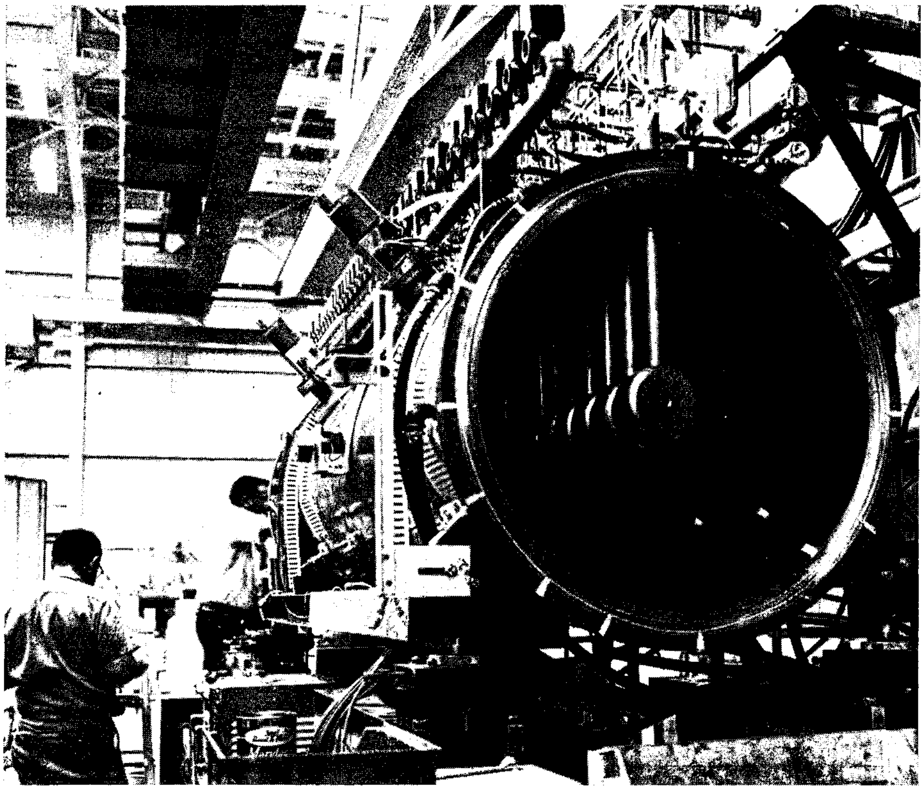
(Photo DESY)

On 10 June a proton beam was accelerated for the first time through a linac tank of LAMPF at Los Alamos reaching an energy of 5 MeV. In successful operation were the 750 keV Cockcroft-Walton injector, the low energy beam transport system and the first of the three tanks of the Alvarez type.

The coming important dates in terms of energy achieved are scheduled as — 100 MeV in a year's time when all three Alvarez tanks are installed ; the design peak energy of 800 MeV in two year's time when the side-coupled cavities are added.

The photographs show —
1. Completion of the assembly of the first Alvarez tank ;
2. The units in operation to reach 5 MeV. On the left can be seen the dome of the Cockcroft-Walton injector. From there comes the low energy beam transport system. (Note that the bending magnet in the centre of the photograph has three input pipes, two of them temporarily blocked off. Beams of negative ions and of polarized protons are also to be fed to the linac. On the right is the linac tank.)

(Photos Los Alamos)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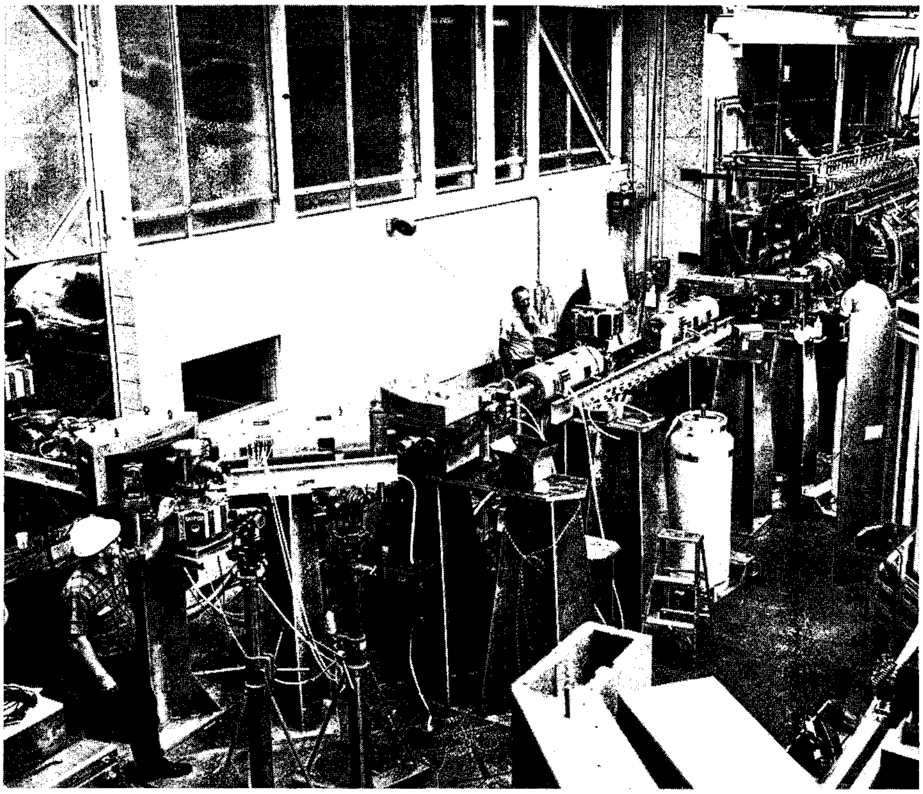
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Health Physics Training Course

The Fifth Annual Accelerator Health Physics Training Course will be held at the Lawrence Radiation Laboratory, Berkeley, from 24 February to 25 March 1971.

Lectures and studies will cover the general topics of the physics of particles, radiation fields and accelerators ; radiation environments at accelerators ; biological effects of radiation and safety standards ; measurement of radiation fields ; shielding ; health physics administration.

The course has proved very successful in the past and has trained about fifty people. This year health physicists from Europe are, for the first time, invited to attend. No tuition fee is charged but students are responsible for finding travel and living expenses. Application should be made to :

E. J. Vallario
Division of Operational Safety
US Atomic Energy Commission
Washington, D.C. 20545

BATAVIA

Project progress

Construction of the 200-500 GeV accelerator at the National Accelerator Laboratory continues to the schedule which aims to have the machine ready for the first acceleration of beams in July 1971.

Tank 1 of the 200 MeV linac gave a 110 mA proton beam at 10 MeV using the final preinjector but without the buncher. Tank 2, which has a resonant, post-coupled structure for extra field stability, was moved into the Linac Building in May. Some drift-tubes were disturbed during the move and realignment delayed operation at 37 MeV. Tank 3 (66 MeV) was scheduled for installation on 6 July and tanks 4 and 5 are assembled. A beam at 66 MeV is planned for the end of July and will be transported through the 200 MeV beam-transport line to the 8 GeV Booster to be fed into the first quarter of the Booster ring.

The Booster building was completed on 17 June and installation of components has been proceeding. The first of the four Booster power supplies has arrived and has been successfully tested. (The supply was manufactured by Brentford Electric, UK, in less than a year from receiving the contract — further proof that European industry can produce accelerator components at very high speed if required to do so.)

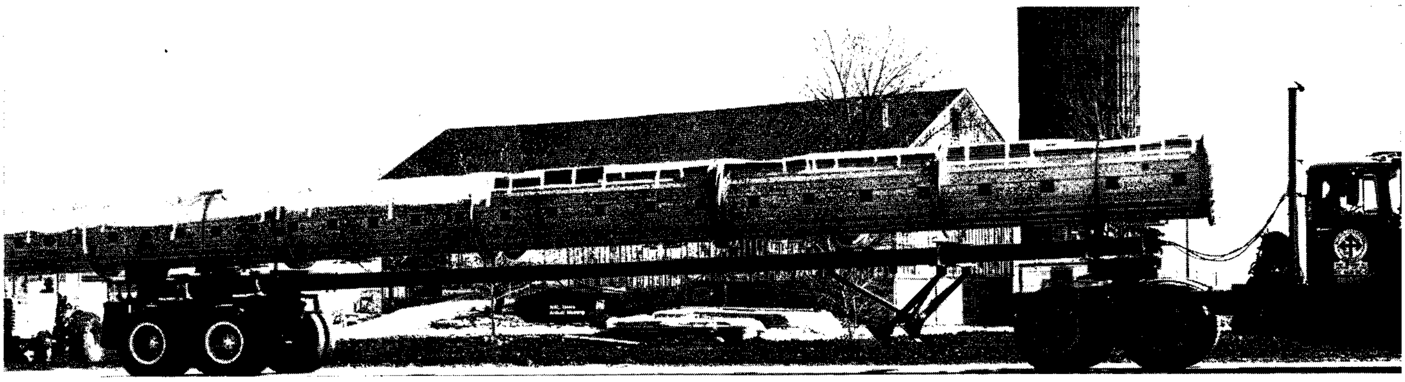
Phase 1 of the Main Ring construction was 80 % complete at the end of June. All the tunnel sections are in place and 'back-filling' is in progress. By the same date 70 magnets had been assembled; 19 of them had been taken to the tunnel and 8 installed in position. The high precision inner coils for the magnets are being manufactured by the Laboratory at the rate of 22 per week (2 more than required by the schedule). Magnet measurements indicate a long-term reproducibility of effective length of $\pm 3 \times 10^{-4}$ and a spread of effective length between different magnets of less than 10^{-3}.

76 proposals for experiments at the accelerator have been received and are being analysed in preparation for a meeting of the Programme Advisory Committee in August. Many of the proposals concentrate on the obvious questions to which access to much higher energies may give answers. They include — particle yield experiments, cross-section measurements, higher energy neutrino studies, high mass resonance production, higher energy neutral kaon studies, and searches for magnetic monopoles, for intermediate bosons, for heavy leptons and for quarks. Negotiations between Batavia and Serpukhov appear to have reached the stage where an exchange of experimental time on the USA machine and the 76 GeV Serpukhov machine is near final agreement.

Plans for the Experimental Areas have been further developed. Experimental Area 2 will be the first to be ready for experiments. It is now positioned West of Area 1 being fed by the ejected proton beam bent off before it reaches the Target 1 position. Secondary beams for the Area will emerge from the primary beam incident on Target 2. This target and the first collimators and beam transport magnets will be installed in an underground gallery 220 ft long. At the end of this gallery the beams will be sufficiently well separated physically to enter individual tunnels in an earth shield (designed to reduce the muon background to an acceptable level).

From there, the beams emerge into the experimental hall. Six beams are being designed — a proton beam, two high energy secondary beams, a medium energy secondary beam, and two neutral beams. Experimental Area 2 is scheduled to be ready for experiments by 1972 and, in order not to introduce any delays, it is being designed for a maximum proton beam energy at the target of 200 GeV.

Experimental Area 1 will have more specialized beams. It will be in direct line with the ejected proton beam and secondary beams will be drawn from Target 1. In particular, a high energy neutrino beam will be built for experiments with a 14 ft hydrogen/deuterium bubble chamber. (The proposed NAL/Brookhaven 25 ft chamber has been dropped.) A high energy r.f. separated beam will run parallel to the neutrino beam. Experimental Area 1 is being designed for incident proton energies at the target of 500 GeV. It is scheduled to be ready for experiments by 1973.



1.

1. Batavia linac tank number 2 trundling on its way past the 'Village Barn' to the linac building where it is now installed and was scheduled to produce beams at 37 MeV early in July. Prior to the installation of tank 2, tank 1 operation had given beams of 110 mA at 10 MeV.

(Photo NAL)

2.

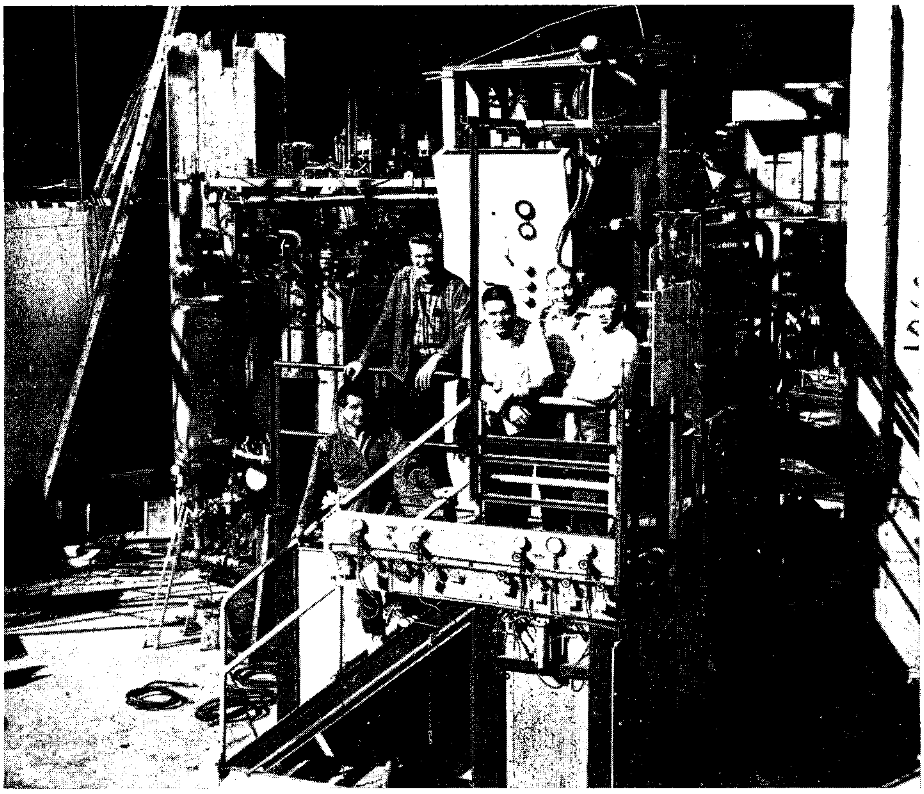
2. Excavation for the main accelerator building of the TRIUMF cyclotron project in Canada was completed in June. In the photograph, the TRIUMF staff pose in the hole. The project continues on schedule. The TRIUMF Annual General Meeting (usually held in May) will be held in August this year to coincide with the Banff summer school on medium energy physics.

(Photo TRIUMF)

Professor M. S. Livingston (right) is presented with a linac drift tube at a dinner party in his honour when he retired from the Laboratory at the end of last month. Making the presentation is the Laboratory Director, R. R. Wilson, watched by Mrs. N. Ramsey whose husband is President of Universities Research Association, Inc.

Professor Livingston also received last month the US Atomic Energy Commission Citation — 'For his outstanding contributions to the nation's atomic energy program as a pioneer in accelerator technology ; for his inventive imagination in collaboration with Ernest O. Lawrence in designing and building the world's first experimental cyclotrons ; for his leadership in the design and construction of cyclotrons at Cornell University and the Massachusetts Institute of Technology, 1934-1946 ; for his creative contributions to the design and development of the Cosmotron at the Brookhaven National Laboratory, 1946-1948, and for his major role in the discovery of the alternating-gradient focusing principle ; for his continuing contributions in the field of education and scientific research as professor of physics at MIT since 1954, Director of the Cambridge Electron Accelerator, 1956-1967, and Associate Director of the National Accelerator Laboratory at Batavia, Illinois.'

(Photo NAL)



The 25 inch hydrogen chamber at Berkeley took its last pictures on 25 May. It began operation in November 1963 and has taken some 9.3 million pictures. In 1964, it became the first chamber ever to 'double pulse' — operating twice during one cycle of the 6 GeV Bevatron — and was later converted to 'triple pulse'.

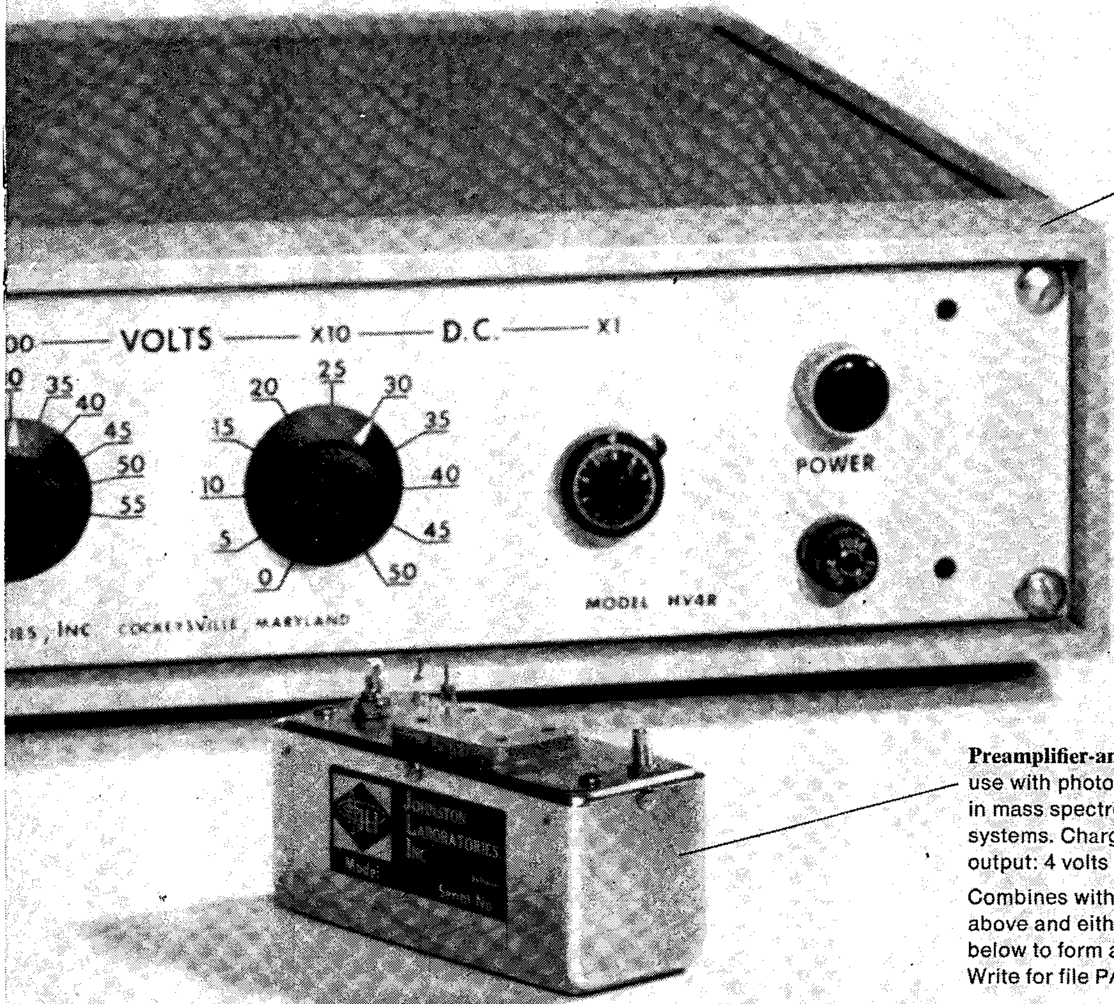
Two other innovations were — the movement of the entire ceiling of the chamber in applying the pressure changes which greatly reduced the turbulence giving exceptionally 'clean' pictures compared with earlier chambers where hydrogen flowed in and out during the expansion cycle ; the introduction of a movable platinum target in the chamber itself to produce short-lived particles (lambda hyperons) for study.

In the photograph taken after the final shutdown are some members of the operating crew, left to right — J. Chapman, G. Eckman, W. Hickman, B. Cahill and B. Dorris. Other names connected with the chamber are those of L. Alvarez and the late D. Gow who led the design and construction; B. Watt who with G. Eckman was in charge of operation ; P. Hernandez who led the mechanical design team ; W. Powell and J. Kadyk who have looked after the physics supervision.

(Photo LRL)

Six special things, not four.

(Four components. Or two systems. You choose.)



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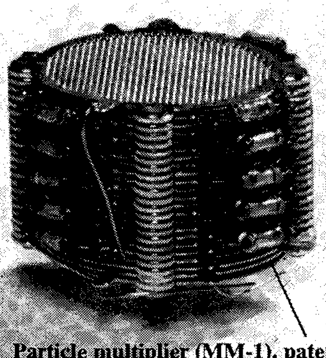

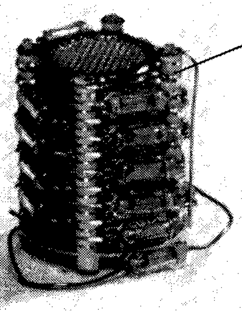

Particle multiplier (MM-2), patented—has the same general characteristics as the particle multiplier shown above, but is only half the diameter (1″).

Forms a complete matched system when combined with the high voltage power supply and preamplifier-amplifier-discriminator above. Write for file MM.

Particle multiplier (MM-1), patented—for pulse counting or current measurement of electrons, ions, UV or x-ray photons, and energetic neutral atoms or molecules. Adjustable high gain (up to 10^{10}), stable, guaranteed reactivateable, non-magnetic, no ion feedback or instability, integral resistor chain, small, light, rugged, bakeable, repairable.

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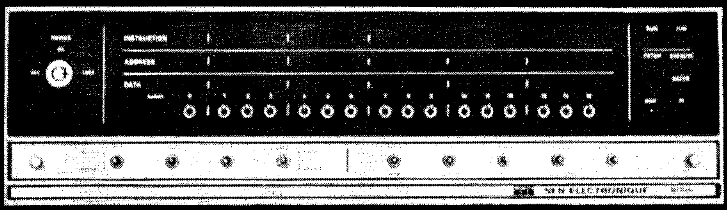

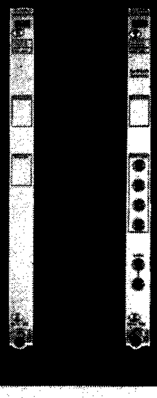

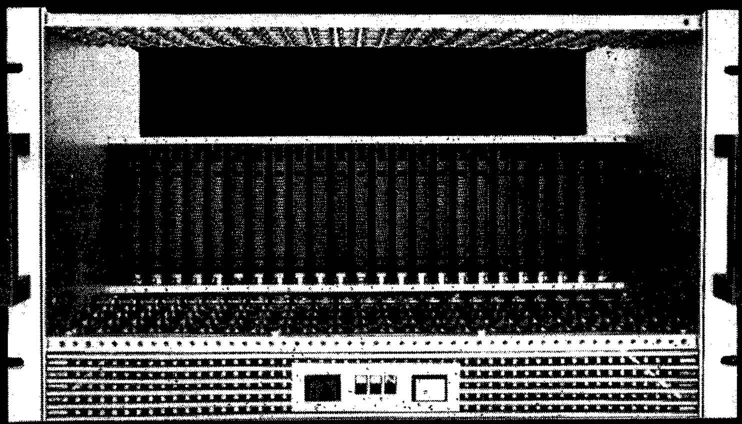

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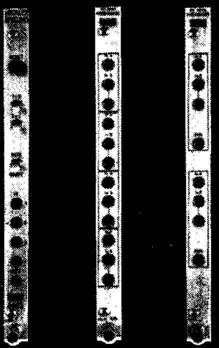

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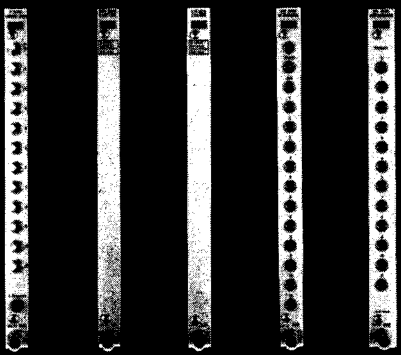

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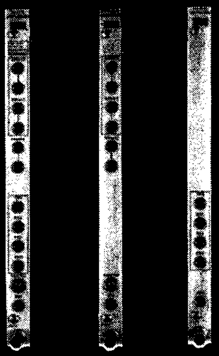

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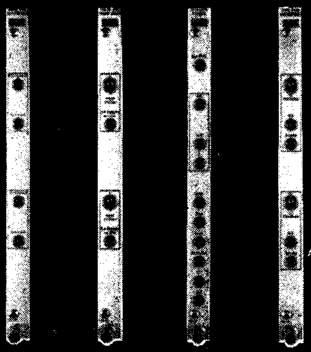

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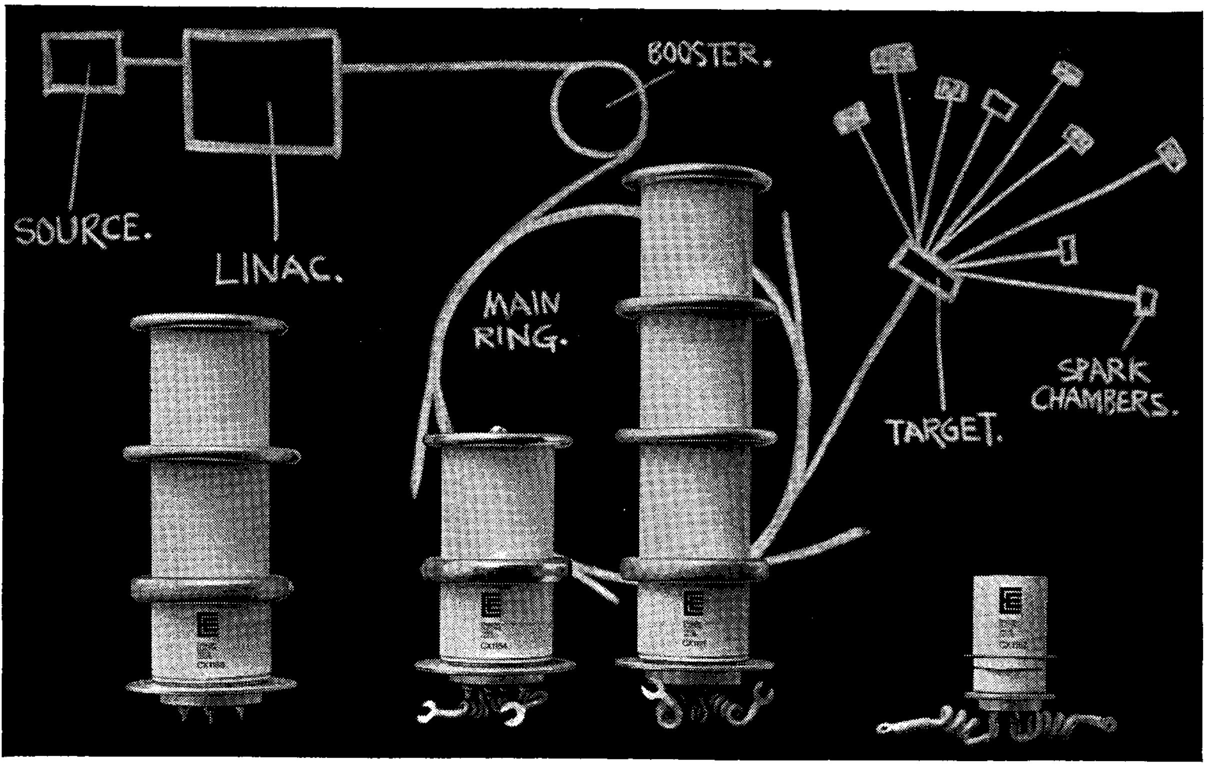

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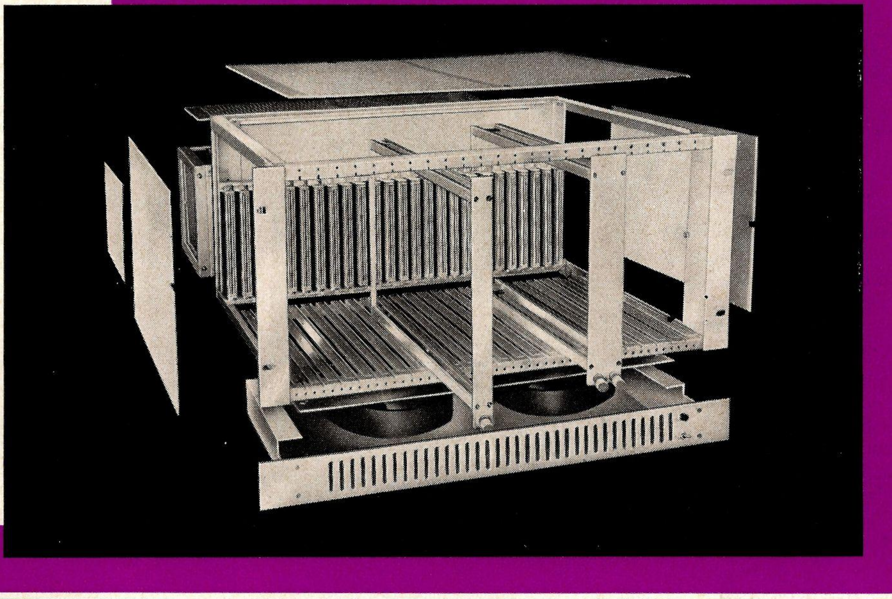

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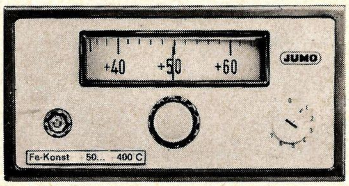

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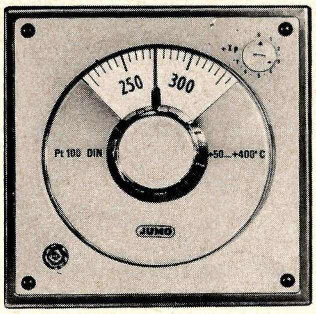

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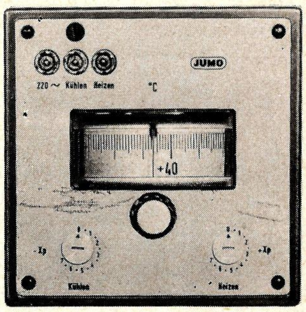

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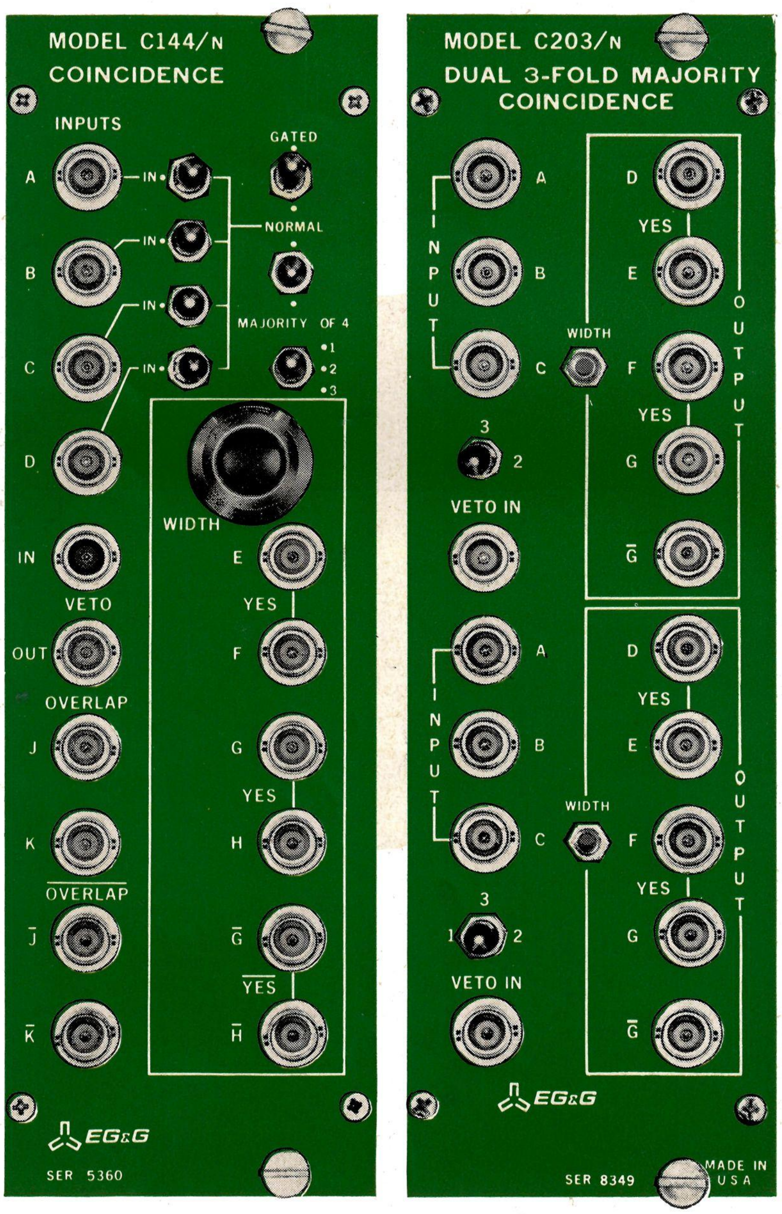

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