CERN COURIER

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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. The Organization has its seat at Meyrin near Geneva in Switzerland. There are two adjoining Laboratories known as CERN Laboratory I and CERN Laboratory II.

CERN Laboratory I has existed since 1954. Its experimental programme is based on the use of two proton accelerators — a 600 MeV synchro-cyclotron (SC) and a 28 GeV synchrotron (PS). Large intersecting storage rings (ISR), are fed with protons from the PS for experiments with colliding beams. Scientists from many European Universities as well as from CERN itself take part in the experiments and it is estimated that some 1500 physicists draw research material from CERN.

The CERN Laboratory I site covers about 80 hectares almost equally divided on either side of the frontier between France and Switzerland. The staff totals about 3100 people and, in addition, there are about 1100 Fellows and Scientific Associates. Twelve European countries contribute, in proportion to their net national income, to the CERN Laboratory I budget, which totals 382.9 million Swiss francs in 1973.

CERN Laboratory II came into being in 1971. It is supported by eleven countries. A 'super proton synchrotron' (SPS), capable of a peak energy of 400 GeV, is being constructed. CERN Laboratory II also spans the Franco-Swiss frontier with 412 hectares in France and 68 hectares in Switzerland. Its budget for 1973 is 188 million Swiss francs and the staff will total about 370 people by the end of the year.

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Cover photograph: Recent aerial view over the region of France and Switzerland where the CERN Laboratories are situated. The camera looks along the North Area beam-line (indicated by a dashed white line) towards the SPS ring. The ring will always appear on aerial views as a dashed line rather than a circular mound or building since it is being built underground. CERN Laboratory I, with the Proton Synchrotron and Intersecting Storage Rings, lies beyond the SPS ring. The Franco-Swiss border is picked out by small crosses and in the background can be seen the ribbon of the river Rhone and the Jura mountains. (Photo Swissair)

Progress in construction of the SPS

Part II: Controls, R.f., Civil engineering and Experimental areas

The continuing saga of the building of the Super Proton Synchrotron... Last month we described how far things had advanced with the injection-ejection systems and with the ring magnets and their power supplies. This month we turn to other major features of the machine — the control system, the radio-frequency accelerating system, the civil engineering work on the site of the new machine and the two experimental areas which will receive the accelerated protons.

Keeping control

Work on the control system of the SPS has now moved to the hardware phase as the detailed requirements have been fixed. This follows a thinking phase when the general philosophy was worked out; the think has resulted in a control system with novel features which will extend the techniques of accelerator control in several directions.

It is hard to imagine that only four years ago the use of computers in machine control was still a subject for debate (see, for example, vol. 9, page 166). Now accelerator controls are built around computers and the debate is only on how best to use them. The SPS team were able to learn from the work of other Laboratories (particularly on the 400 GeV synchrotron at NAL and LAMPF at Los Alamos) and to make decisions in the light of the experience that had been gathered.

One novelty is to move away from the concept of a large central control computer overseeing small computers. Instead of this monolithic approach, the control tasks will be divided between many small or medium sized computers which are effectively interchangeable. Even at the control consoles themselves there will be three virtually identical computers whose function will be dictated only by the software which is brought into them at a particular time. This approach loses the number crunching ability of a big computer but this is rarely called upon in machine control and for the few occasions when it is needed (such as quadrupole positioning during commissioning) a bicycle ride with a magnetic tape to a link to the CERN central computers will not be too arduous.

The small computer solution is also cheaper. Norsk Data-Elektronikk (Norway) is to provide 24 computers of their NORD-10 type. By early December, six had arrived at CERN and, apart from some minor teething troubles with faulty memories (now completely cured), they are performing excellently. A NORD-I was lent within two months of the contract being signed and was operating satisfactorily within a few hours of being plugged in. In addition to seven at the control centre, they will be sprinkled in the six service buildings around the circumference of the SPS ring and in the experimental areas.

Novelty number two is in the mysterious realm of software. A major problem in the past has been the interdependence of programs that have to be 'compiled' as a separate process before they can be run in the computer. A system has been adopted in which the programs are kept as statements of a specially developed control language called NODAL. These statements are interpreted directly when the program is run and the 'interpreter', resident in each computer, has access to all the information necessary to enable it to make the required cross-references and links. Avoiding separate compilation means that changes can be made without disturbing the whole software system. The statements in NODAL are very similar to those used in everyday speech in accelerator control. This results in great simplicity, flexibility and a large measure of 'instant programming' — which is so essential for commissioning, maintenance and machine studies.

The programs can be called on and adapted individually without disturbing anything else. Also the mini-programs can be run on any of the computers. One thing which is lost is speed of execution. However, for almost all control applications, a millisecond is not forever and the speed is entirely adequate.

All the computers are linked through a Message Transfer System and one computer can ask another to perform some measurement, control function or calculation by using a few simple typed statements.

A lot of thought has been given to the layout of the central control room. It will have three identical consoles. Only one will be needed for routine machine operation but for commissioning and machine development it will be necessary to have extensive and separate control over such systems as the r.f., magnet power supplies, etc. In this case it will simply be necessary to call for the appropriate software to be switched to a particular console.

The stage at which the human being comes into the picture (the 'operator interface') will also have its novelties. In addition to some conventional control aids, such as black and white television display screens and computer input keyboards, there will be colour display screens (enabling more information to be transmitted and absorbed on one display), a new type of touch button screen (to select the desired control function) and a knob with feed-back from the computer (stiffening the turning mechanism so that, for example, megawatts cannot be twirled with a little finger).

The whole gamut of lights and switches and knobs etc., which clutter the control rooms of yesteryear have to be represented on a single console. It is via the touch panel that the

A control console being used to optimize the various control facilities which will be available to operate the accelerator. It is linked to one of the NORD-10 computers which can be seen on the right.

Below: Not the result of a life test on a machine operator but simply a bit of ergonomics while working out the best layout of the consoles for the SPS control room.

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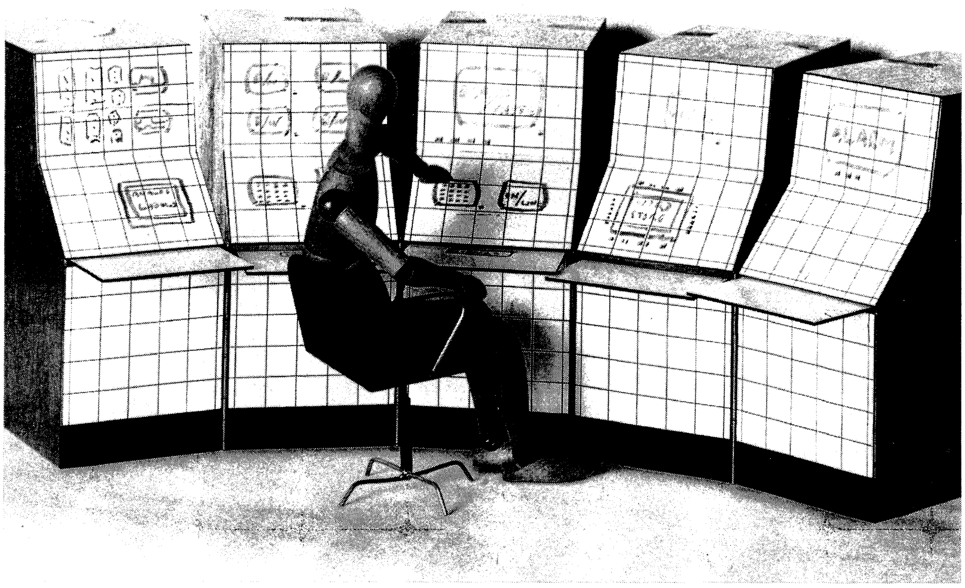

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required abilities are brought to the operator. Each button has a label written on it by the computer. Pressing a button changes the electrical capacity at that point behind the panel and selects a particular function. The computer can re-write the labels on the buttons at will — the operator can thus choose the system he wishes to adjust, the particular component, the property he wishes to change and then implement the change itself.

The computers are linked to the equipment via CAMAC units and a multiplex system involving nearly 3000 electronic units which will be manufactured by Borer (Switzerland). The message transfer system will be produced by TITN (France) and the many kilometers of cable will come mainly from Thompson-Brandt (France). Oddly enough, cable which is more resistant to radiation (using polyethylene) and is enclosed is a flame retardant sleeve, came out cheaper than the normal cable (using PVC).

Instrumentation for monitoring the beam includes much standard equipment (beam current transformers, screens and television, etc.) such as is found on lower energy accelerators. One problem arose in the development of the pick-up stations. If they were to cope with the injected beam, which they could detect because of the modulations it had hanging around from its time in the PS, and in addition cope with the 200 MHz that the SPS r.f. system subsequently introduced, the associated electronics would be uncomfortably complicated. To overcome this a 200 MHz modulation will be induced in the beam before it leaves the PS so that 200 MHz is the only frequency the pick-up stations need worry about.

The r.f. system

Work on the radio-frequency accelerating system is building up to the

The power amplifier unit which operated for the first time at the manufacturers on 4 December. Five of these 125 kV units are built into each power amplifier feeding a radio-frequency accelerating cavity.

(Photo SIEMENS)

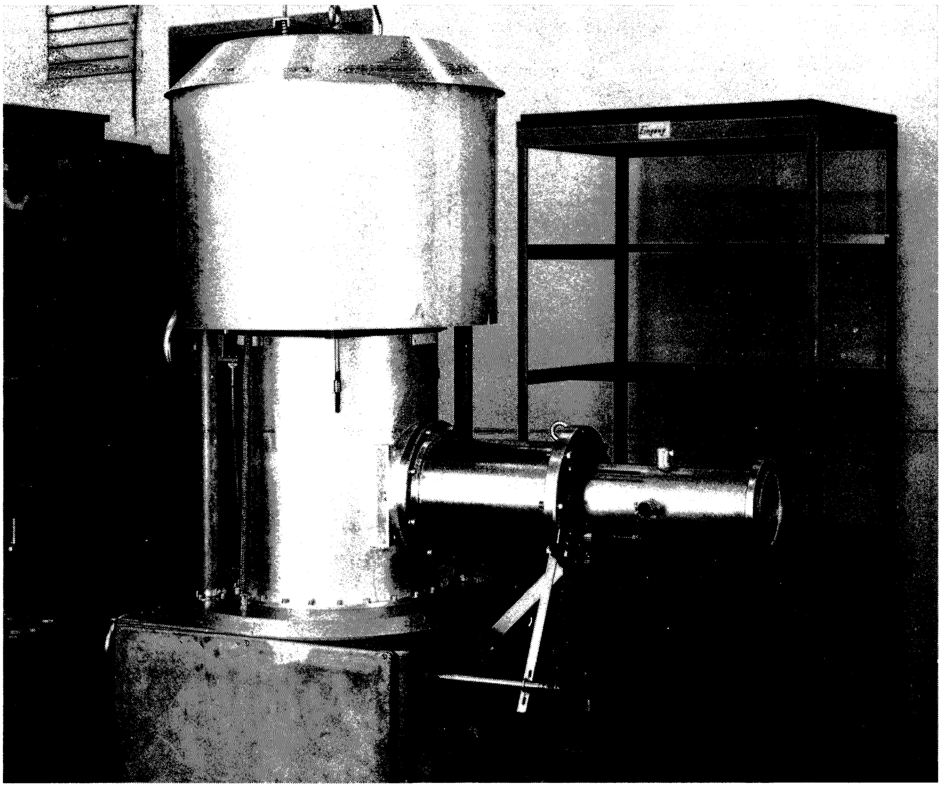
A full-scale two-cell model of the r.f. cavity to be used in the SPS shown installed for a series of tests in the proton synchrotron ring. It was used to study multipactoring, rebunching and the performance of the SPS phase lock system.

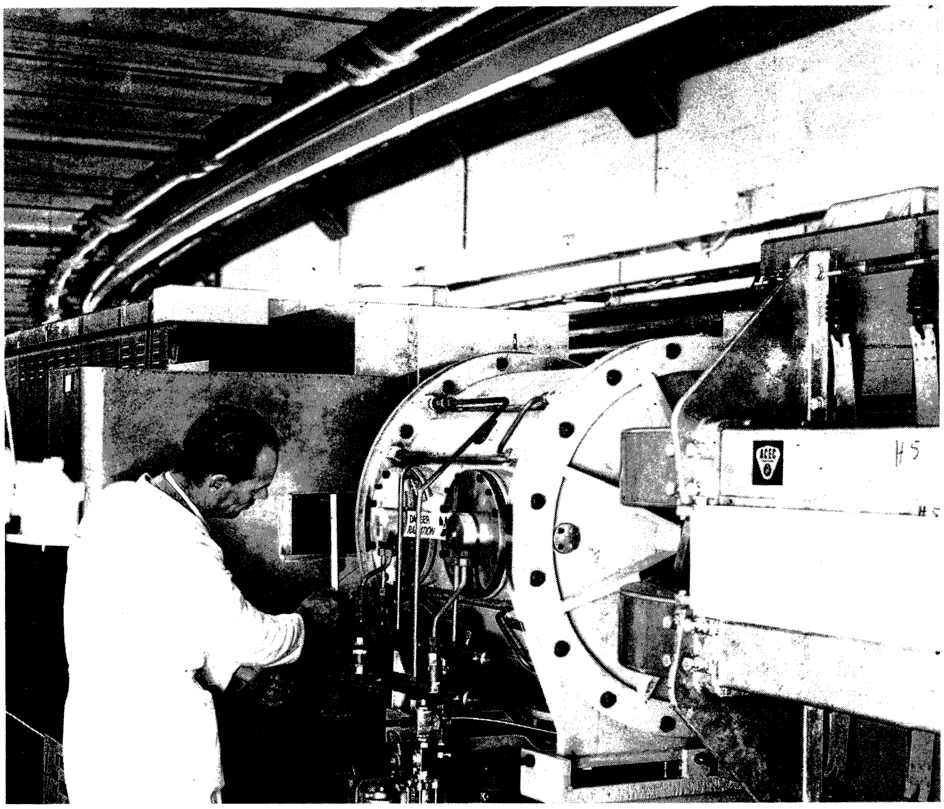
time next year when tests can be carried out on a complete full-scale assembly of a cavity and power amplifier. This will be the moment of truth for the R.f. Group because the tests which can be carried out up to that stage can only simulate some of the operating conditions but not all at the same time.

Manufacture of all the necessary components is now under way. The two large travelling-wave cavities which will sit in the SPS ring are being manufactured by Leybold Heraeus (Federal Republic of Germany). The copper-clad steel sheets were ready in the middle of the year and the first cavity sections have been rolled, welded and machined. Because of the manufacturing technique, the copper surfaces do not emerge gleaming as r.f. accelerating structures often do. However, when the sections were tested, they revealed Q values of 95 % of the theoretical value, at the design frequency. This is much better than could be expected and the somewhat unaesthetic appearance can therefore be most happily accepted.

A half-scale, two-cell model has been used to check the effects of errors in the important dimensions. This was necessary because it is intended to do the tuning of the cavities by carefully controlling the mechanical dimensions during manufacture so that no tuners will be needed on the finished cavities.

Other important tests have concerned the phenomenon of multipactoring. This can be a problem in the operation of r.f. equipment — it involves electrons bouncing around between the walls of the structure under particular conditions, sucking up a large part of the power fed into the cavity as they do so. A full-size two-cell section has been operated with currents and voltages in excess of those which will be experienced in the SPS. It was installed in the 28 GeV





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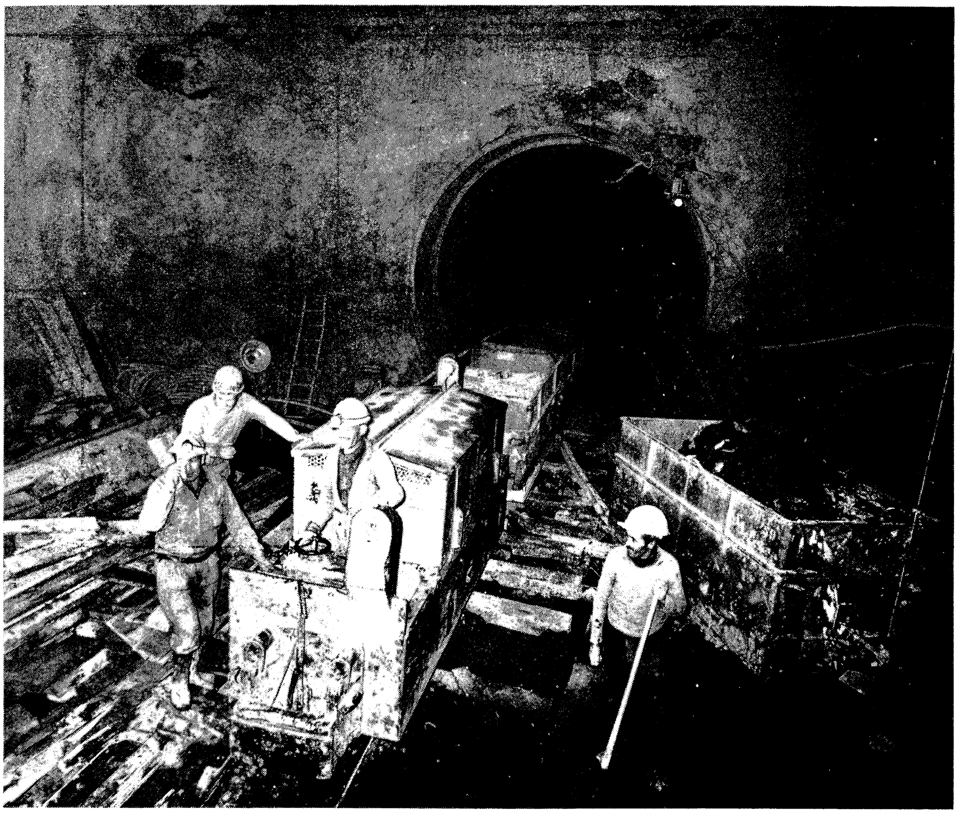

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In the depths of the earth at the location of straight-section No. 2. The mole has disappeared, continuing its burrowing around the ring, down the tunnel on the right. Emerging from the tunnel is part of the train which carries concrete lining sections towards the mole and brings back the molasse which has been cut out.

synchrotron to observe its behaviour with a proton beam and no multipactoring was detected after the section had been conditioned for a short while.

Each cavity will be fed with 500 kW of r.f. power at 200 MHz which will be provided by an amplifier using five 125 kW power tubes. Three of these amplifiers are being built at Siemens (Federal Republic of Germany). The first batch of tubes was successfully tested at full power in October and, on 4 December, the final version of the amplifier cavity was operated for the first time. Anyone who has played with high frequencies will be aware how parasitic modes can creep in everywhere in these systems. There are so many possibilities that it is virtually impossible to calculate them all in advance and to take steps to avoid them. They need to be eliminated while commissioning. A 500 kW unit is scheduled to be assembled at CERN by November of next year and it will then be possible to test the full chain of the r.f. system.

Components for transmitting this r.f. power from the amplifier to the cavity will also be on hand by then. Among the trickiest of them are the ceramic vacuum windows which link the feeder lines to the cavities. A novel design has been developed which, by avoiding an r.f. structure giving temperature gradients which such windows normally experience, has eliminated the source of mechanical stress which often causes such windows to fracture. In addition, the design makes it possible to change a window rapidly and this could be an important asset in the high radiation environment of the accelerator tunnel.

Another important task is the control of the high power r.f. system to provide efficient acceleration and handling of the beam (capture, transition and debunching). The low power r.f. comprises several closed loops controlling r.f. parameters. One example is the phase lock which, by picking up signals directly from the bunches of protons orbiting the ring, ensures that the r.f. cavities give the kicks of further energy at exactly the right time. It is the first time that a phase lock has been required for a proton synchrotron operating at a frequency of 200 MHz and the timing precision involved is unusually high. All the manoeuvres will be done at an intermediate frequency around 20 MHz using coherent mixers. A prototype has been made and successfully tested with the PS beam.

Radial steering of the beam during acceleration will require accurate control of the frequency which will be done with the help of a dedicated computer. The longitudinal behaviour of the beam, and hence the performance of the r.f. system, will be monitored by a wide band pick-up station (operating at up to several GHz). Here the major difficulties are to steer clear of waveguide modes which can arise from the electrodes and from the vacuum chamber itself.

Very civil engineering

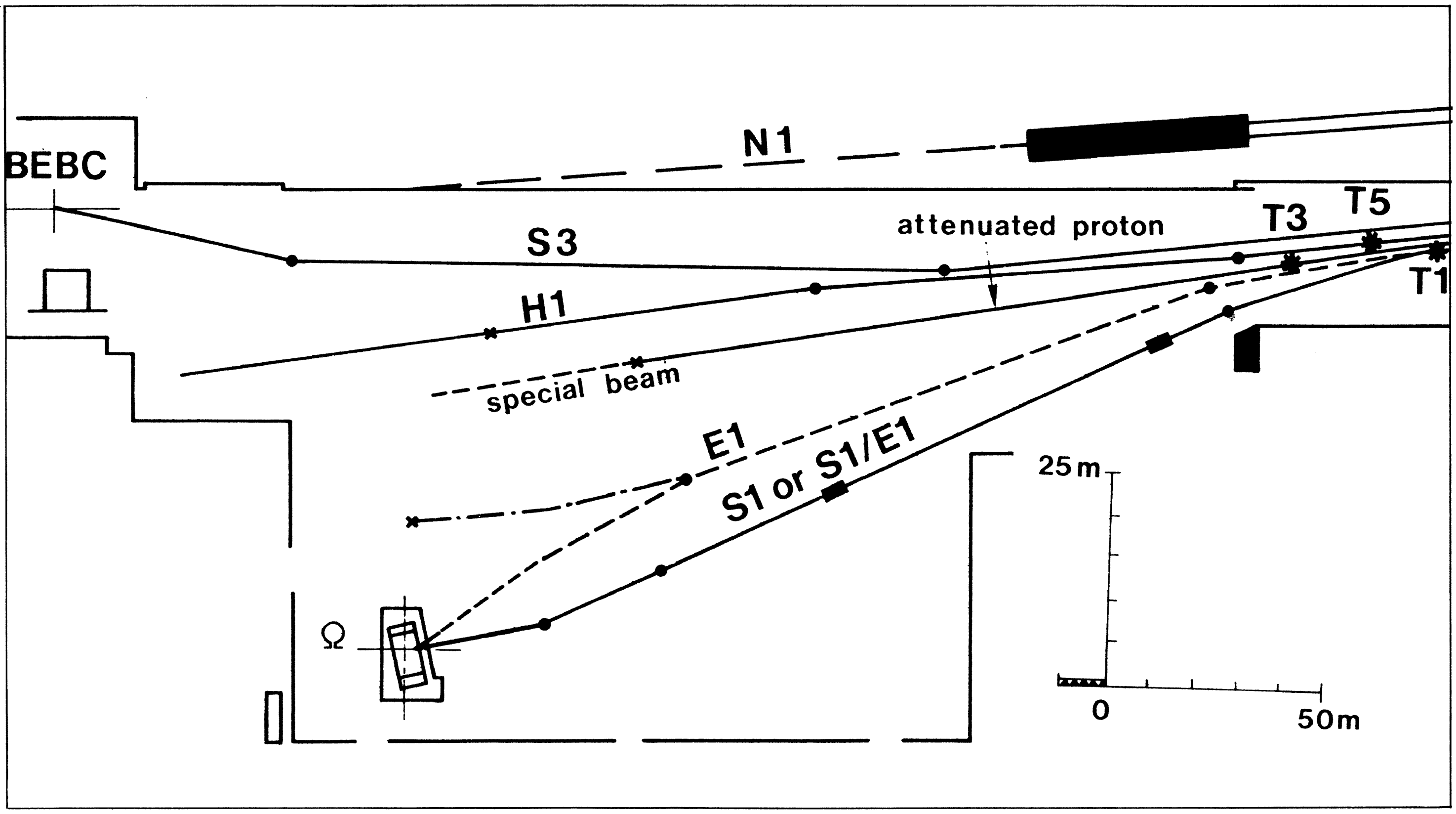
We have tended to keep in touch with the civil engineering work in the pages of CERN COURIER because, up to this stage of the game, it has been the most spectacular manifestation of the activity on the SPS project. We restrict ourselves here, therefore, to a quick run through of the progress which has been achieved so far.

Some tens of metres below ground, the mole has continued its boring way round the 7 km circumference of the SPS. On 12 December, the Robbins machine emerged at the location of straight section 4 having thus carved out the tunnel halfway around the ring.

On average, it has advanced at the rate of 20 m per day and has reached a peak of 35 m per day. In general the work has gone smoothly apart from running into pockets of methane which required special measures for ventilation. The explosive methane was sometimes accompanied by liquid hydrocarbons but, alas, not in quantities which would have the slightest impact on the present fuel crisis.

Soon the access shaft, PP4, near straight section 4 will take over as the point where spoil is removed from the tunnel and where the concrete lining sections are introduced. This will liberate the half of the ring which has already been bored out so that it can be tidied up ready for the installation of machine components.

The tunnels which will house the injection beam-line, bringing the protons from the PS, and the two ejected beam-lines, taking the protons to the West and North experimental areas, have been excavated. The access shafts around the circumference of the



The general scheme of beams which are foreseen for the West experimental area of the SPS. A neutrino beam reaches BEBC and other detectors via beam-line N1. BEBC is also fed by an r.f. separated beam (S3), which climbs to the surface in the same tunnel as an ejected proton beam-line bringing protons to three targets (T1, T3, T5). These generate hadron and electron beams for experiments in the West Hall.

ring are dug out and most of them have their concrete lining.

Meanwhile, on the surface, all the office and laboratory buildings have been completed, the last of them (Block III) opening its doors to the Laboratory II staff in November. Such signs of civilization as a post office and a bank are in action and they will be joined early next year by a restaurant.

The power line, to bring electricity at 380 kV from the nearest point on the European grid at Génissiat to the site, is under construction and should be completed in April of next year. Provision for bringing the other important commodity, water, is also well in hand. Two large reservoirs (5000 m^3 each) are being built on the Swiss part of the site and the pipe-lines, which will carry the water from the pumping station at Le Vengeron on Lac Léman, are being laid.

The experimental areas

The last major decisions concerning the SPS project were taken towards the end of the year. They determine the general scheme of the particle beams which will be available for experiments during the first years after the accelerator has come into operation. These decisions are extremely important (because, after all, an experimental programme with very high energy beams is the purpose of the exercise) and the whole of the particle physics community in Europe has been involved in working out the best possible solutions within the available boundaries of money, manpower and time.

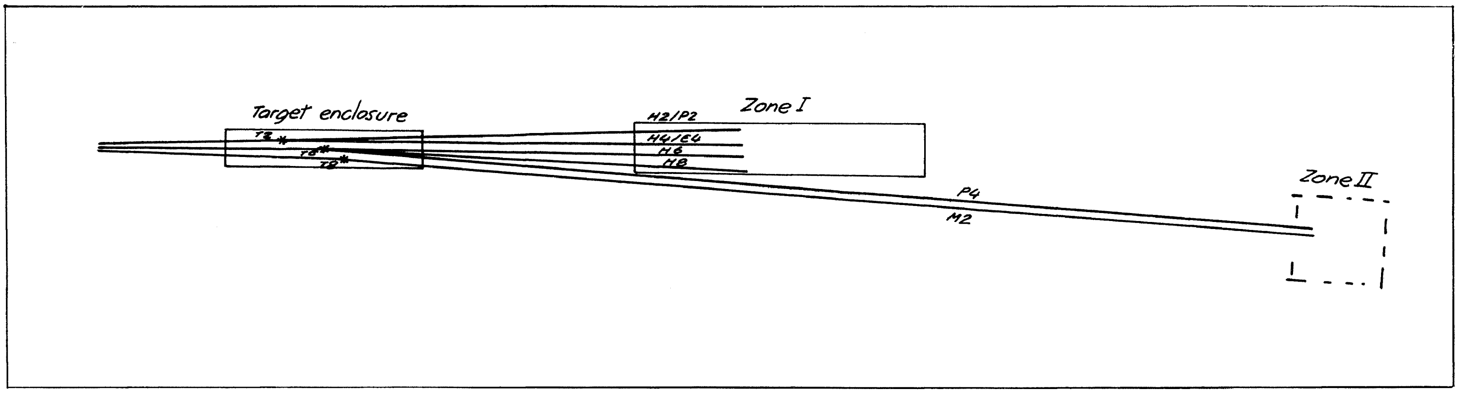
The process started, under the auspices of ECFA (European Committee for Future Accelerators), many years ago before the project was authorized. Ideas were up-dated and refined by Working Parties which presented their conclusions during a study week at Tirrenia in 1972 (see vol. 12, page 318). Finally, the SPSC (the 300 GeV Experiments Committee) has received the first 'letters of intent' concerning the experimental programme. This vast accumulation of information has led to the following scheme:

The accelerated beam ejected towards the West experimental area can be directed, in an underground switchyard, either onto a target (T7) to provide secondary particles for an r.f. separated beam, or onto a target (T9) to provide neutrino parents, or it can travel on as a proton beam. The proton beam and the r.f. separated beam climb to the surface in the same tunnel emerging near the West Hall. The r.f. beam goes to the 3.7 m European bubble chamber, BEBC; the proton beam can be split to bombard three targets (T1, T3, T5) giving a series of secondary beams.

Both the r.f. separated beam and the West Hall beams will be generated from a primary proton beam of 200 GeV maximum energy. The r.f. beam (S3) can then select pions, kaons, protons or antiprotons up to a maximum energy of 150 GeV. Another r.f. separated beam (S1) can be drawn from target T1. It will serve the Omega spectrometer (using superconducting r.f. cavities being built at Karlsruhe) with pions, kaons, protons and antiprotons up to a maximum energy of 40 GeV.

This second r.f. beam might also be used as an electron/photon beam-line to Omega (when it is referred to as S1/E1). Alternatively electrons and photons could reach Omega via a different beam-line (E1) which could be used for other experiments not involving Omega. Target T3 provides high energy hadron beams (up to 150 GeV along beam-line H1) and target T5 will be the source of special beams, a hyperon beam being a probable example.

It is the West Area Neutrino Facility (WANF) which has seen the major changes since we last discussed the



The general scheme of beams which are foreseen for the North experimental area of the SPS. The ejected proton beam is split onto three targets (T2, T4, T6) which generate secondary particle beams for experiments in the two zones. Note that the scale has been greatly reduced along the ***beam direction and exaggerated at right angles to it, so as to present the division of the beams.***

SPS experimental programme in our pages. Previously it had been intended to use BEBC with neutrinos generated from a target bombarded with protons up to a maximum energy of 200 GeV and to have higher energy neutrino experiments in the North experimental area. It has now been decided to make WANF an all-singing, all-dancing neutrino facility and to have no neutrino work in the North, at least in the early years of the experimental programme.

First of all the beam-line is being built so that it can cope with primary protons of energy up to 400 GeV. Secondly, it will provide either wide-band or narrow-band neutrino beams. Thirdly, more detection systems will be set up in addition to BEBC.

Pions and kaons produced from bombarding target T9 with high energy protons, will be focused and pointed towards the detectors. They travel down a tunnel where they decay producing the neutrinos and also muons. These muons need to be filtered out of the beam and iron disks will be installed along 170 m of tunnel (followed by a further 170 m of earth) to achieve this.

The wide-band beam gives maximum neutrino intensity and is produced by pointing the primary protons towards the detectors before they hit the target and attempting to catch the maximum number of pions and kaons using a focusing horn and reflector. Neutrinos will then have energies ranging up to about 300 GeV but with the peak flux being in the region of some tens of GeV. The narrow-band beam gives lower neutrino intensity but more precisely known energies cutting out the lower energy peak. This is done by selecting, with a magnet system, the energies of the pions and kaons which are allowed to travel on to decay into neutrinos and the primary proton beam is not pointed towards the detectors so as to avoid neutrinos of different energies, coming from other interactions initiated by the protons, reaching the detectors.

It is proposed to move Gargamelle near BEBC to participate in the neutrino experiments, to add an external muon identifier and to install detectors for neutrino counter experiments.

The North area plans have also been considerably modified. The slow ejected proton beam rises towards the surface from the accelerator over a distance of 590 m. It can then be split between three targets (T2, T4, T6) housed in a separate target enclosure which is also crowded with the first components of six emerging beam-lines. From T2 and T4, four beams are drawn to serve experiments in Zone I. This Zone is now to the West rather than East of the continuing beam-lines.

Target T2 gives particles down the beam-line H2/P2 (which is a high resolution hadron beam with maximum energy up to 350 GeV or an attenuated proton beam up to the full machine energy which could be used as the source of special beams within Zone I) and down the beam-line H4/E4 (which is a medium energy hadron beam of up to 270 GeV or an electron/photon beam). Target T4 gives particles down two further beam-lines, H6 (which is another medium energy hadron beam of up to 200 GeV) and H8 (which is a high resolution hadron beam for energies up to 350 GeV).

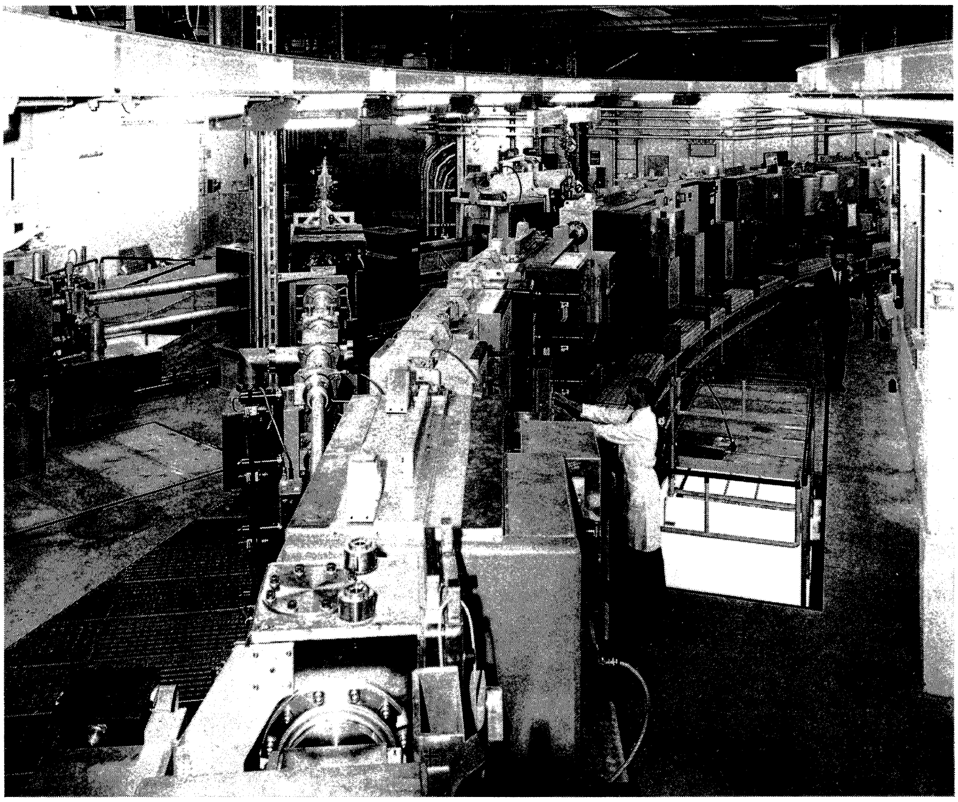
Now that neutrinos will go West, it is intended to limit Zone 2, at least initially, to proton and muon experiments. Beam-line P4 will carry protons up to full machine energy and beam-line M2 will carry muons of energy up to 250 GeV.

Experimental Zone 1 will be covered by a huge hall (50×290 m²). The arrangements for Zone 2 are not yet frozen. Though this will be more expensive initially than covering experiments with individual 'igloos', it will give greater flexibility in the use of the beams and over the years of exploitation of the accelerator will be much more convenient and cheaper.

The precise form that the experimental facilities are to take has, understandably, been the last major aspect of the SPS project to be decided. They offer a wide range of possibilities to Europe's high energy physicists.

CERN News

The 800 MeV Booster at the CERN proton synchrotron whose excellent performance in November enabled the average intensity of the synchrotron to be increased by a factor of three. The photograph is taken at the location where the 50 MeV beam arrives from the linac (at the top). The four superposed rings of the Booster curve round on the right and the beam-lines which bring protons from the four levels in the Booster go off to the synchrotron on the left. (Two beam-lines are visible and these are merged into one before the synchrotron ring.)



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PS intensity record broken

We squeezed a 'late news' paragraph into the last issue giving brief information of an increase in the accelerated beam intensity of the 28 GeV proton synchrotron during a neutrino experiment with the heavy bubble chamber Gargamelle. During this experiment, which began on 14 November at 19.00 h and lasted for seventy-six hours, the average intensity was 5.2×10^{12} protons per pulse at **26 GeV/c an intensity increase of a factor of three over the usual PS average.**

This achievement is one of the most spectacular results of the improvement programme of the machine which has been on hand for several years now. The two main aims were:

– to increase the machine repetition rate (this was done in 1968 when a new magnet power supply was commissioned shortening the cycle time to 2 s at 26 GeV/c);

– to increase the number of protons accelerated per pulse.

In 1969, the intensity climbed to about 2×10^{12} ppp, a limit dictated mainly by the injection energy of 50 MeV from the linac. The space charge effects, which all increase with the density of the protons in the beam, can be overcome only by increasing the injection energy. The solution adopted was the construction of a synchrotron injector, or Booster, inserted between the linac and the PS ring, thus raising the proton injection energy into the ring from 50 to 800 MeV.

To use the capabilities of the Booster, it was necessary to modify the linac considerably so as to attain currents of 50 mA with a pulse duration of 100 μs. Going further puts the linac under severe strain; a new linac will be built (see November issue, p. 332) to cope with these requirements with comparative ease.

Each pulse from the linac is injected over a maximum of fifteen turns into the four, 50 m diameter, superimposed rings of the Booster. Each ring accelerates five bunches of protons up to 800 MeV and the bunches from the four rings are then transfered, one ring after another, into the PS ring to provide the twenty bunches which are further accelerated to GeV energies.

When the November run began, the Booster immediately looked in good health. The doctoring it had received seemed to have cured the problems which were encountered earlier in the year (see July issue, page 219). The beam instabilities were studied during the summer and, at least as far as the intermediate intensities at which the Booster is now operating are concerned, they seem well mastered.

It has been possible to suppress the longitudinal instabilities partly by increasing the energy spread of the linac beam, and partly by improving the beam control with the aid of the r.f. system. A longitudinally stable beam is now being obtained. The transverse instabilities are more of a problem. It is now possible, thanks to work on optimising the operating points in the Q_H Q_V plot, to prevent slow beam blow-up during the acceleration cycle, but the beam can still blow up rapidly at injection.

The horizontal transverse instabilities (betatron oscillations) are the hardest to eliminate. To transfer oscillation amplitudes to the vertical plane 'skew' quadrupoles (a quadrupole with its axes inclined at 45° in relation to those of a focusing or defocusing quadrupole) can be powered. This operation increases the efficiency of multiturn injection and reduces the likelihood of vertical blow-up during the acceleration cycle. The beam emittances thus obtained are still acceptable to the PS main ring.

Many transfer tests into the PS were made during August. The beam recombination system, which brings the bunches from the four Booster rings to the PS, works well. Fine adjustments still have to be made to reduce differences existing from one ring to another, but, although such adjustments take a painfully long time, they are not fundamentally difficult. Matching Booster emittance to the acceptance of the PS is improving at every test.

A stable beam was obtained from the Booster in the middle of September and was progressively improved during October. On 10 October transfer tests began using Booster ring 3. The 1.7×10^{12} ppp beam circulating in this ring was trimmed vertically to the nominal emittance before being passed to the PS. The remaining 1.2×10^{12} protons were all captured and accelerated without any longitudinal beam blow-up. Transfer of the untrimmed beam was also tried, and 85 % was captured, 1.5×10^{12} protons being accelerated without difficulty.

The tests then moved to the use of the four rings of the Booster. The intensity in the transfer line reached 6×10^{12} ppp but there was a 30 % loss on injection. Nevertheless, the average intensity in the PS reached 4.3×10^{12} ppp with acceleration to 26 GeV/c taking place in good conditions. On this occasion, the gamma transition jump proved particularly effective and the beam remained stable.

On 19 October, the PS beam intensity climbed, on average, to 5×10^{12} ppp. The fast ejection system was tried and ejection took place with about 97 % efficiency. During the first few days of November, the trimmed beam from the Booster was fully captured by the PS. It was then possible to carry out the experiment with Gargamelle and, from 14 to 17 November, to send the PS beam by fast ejection towards the large heavy liquid bubble chamber for the neutrino experiment. The beam was very stable and the average intensity for the experiment was 5.2×10^{12} ppp. The percentage of time loss through breakdowns was only 3.3 %.

The important factors are, firstly the efficiency in the PS of nearly 100 % (injection, acceleration, ejection). Secondly, the behaviour of the beam was similar to that at 2×10^{12} ppp without any longitudinal blow-up and with vertical blow-up by a factor of two occurring at high energies due to coupling resonances.

From the point of view of the neutrino experiments with Gargamelle, this increase in intensity is reflected by a factor three increase in the interaction rate in the bubble chamber, which is an important help in the investigation of weak interactions and, especially, of neutral currents (see October issue, page 291), a subject of great topical interest in the world of high energy physics.

Experiments with BEBC

The 3.7 m European bubble chamber, BEBC, took photographs in November for an experiment being carried out by the Birmingham/CERN/Glasgow/Heidelberg/LPHE Paris collaboration. This first experiment with the chamber started in June with a 9 GeV/c negative kaon beam but was interrupted in July, as scheduled.

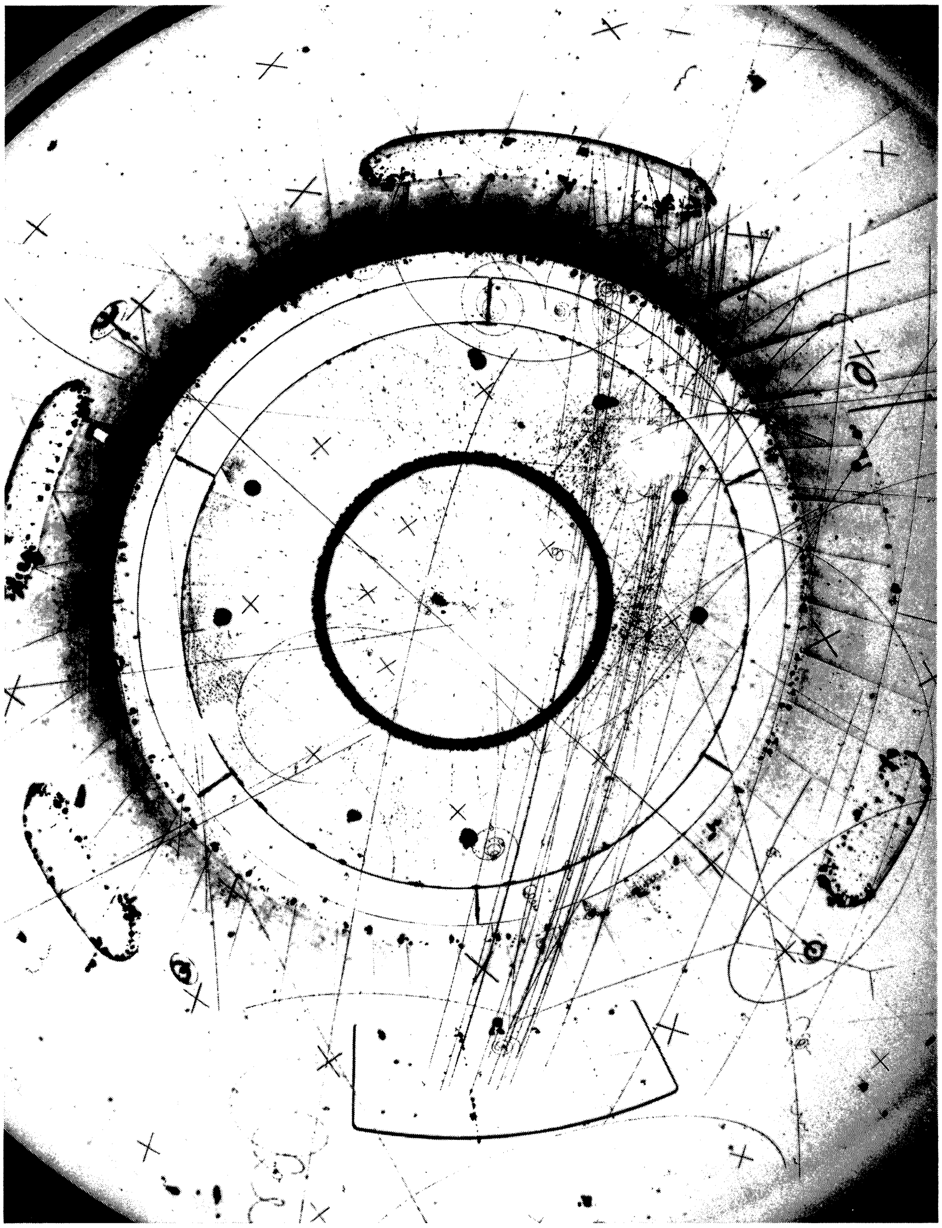
The June-July run had a triple aim: to check the improvements made following the engineering run in March, to determine the optical parameters required for the geometrical reconstitution of the tracks, and to take the first batch of photos for a physics experiment.

The results were promising: good quality photos, successful tests of the masks placed between the objective and the film, removal of spurious bubbles at the fish-eyes and their partial elimination on the Scotchlite. On the other hand, some difficulties appeared. It was not possible to use all four cameras, since one of the fish-eyes had cracked during tests. Also the piston was surrounded by spurious bubbles because the lip seal was not tight enough and a guide had become badly worn, apparently due to a 2 mm misalignment of the piston when cold. Moreover, the incoming beam was not in good shape.

Beginning in August, a number of modifications and repairs were carried out, and the chamber was brought back into operation in mid-October. There was an unpleasant surprise because, despite the meticulous resetting of the piston, its position when cold was 4 mm out of true. This indicated that the cause of the phenomenon had nothing to do with the initial alignment. Several days' tests suggested that it was a thermal effect — convection in the hydrogen gas between the cold piston head and the warm end of the rod setting up an asymmetrical temperature gradient and causing the rod to bend. This diagnosis proved correct: eliminating convection by injecting warm hydrogen gas along the rod, immediately cured the 4 mm fault. It is only a temporary remedy, however, since it has the disadvantage of introducing heat below the piston head, which disturbs the temperature in the visible volume of the chamber. It can give rise to spurious boiling on the bottom of the chamber.

The second problem which emerged during the summer run was resolved by using a lip seal. This considerably reduces the spurious boiling around the piston; a ring of small bubbles remains but it is mainly an aesthetic drawback since it does not interfere with track measurement and could be

Tracks recorded, at the end of November, in the 3.7 m European bubble chamber, BEBC. The picture covers the whole of the chamber and shows three areas. In the centre is the piston surrounded by a ring of bubbles. The bottom of the chamber has valves and pressure and temperature sensors which appear as eight black dots (soon to be screened by Scotchlite). The wide circular area is the cylindrical wall of the chamber covered with Scotchlite strips. Six windows can be seen, two of which are already covered by Scotchlite. The lowest window is the beam access port, the others allow the secondary particles to leave. The parallel tracks are of negative kaons of 9 GeV/c; the other tracks are of cosmic rays or particles produced by interactions outside the chamber.



further reduced if necessary. Other improvements have been made since mid-October. All the fish-eyes (one for each of the four cameras and one for the periscope) are now in place, the beam has the required quality (the chamber receives about twenty kaons per pulse) and the quality of the photos is very good.

Between 14 and 17 November, the 28 GeV proton synchrotron operated with the Booster and the heavy liquid bubble chamber (Gargamelle) and did not provide beam for other experiments. Immediately afterwards, the PS had its usual four-day maintenance shutdown. During these eight days, when there was no beam for BEBC, various magnet and chamber tests were carried out. On 18 November, the nominal magnet current of 5700 A was obtained, corresponding to a field of 3.5 T in the chamber volume. The cameras and the expansion system continued to function normally in spite of the strong fringe field. However, after the third test at full field, an intermittent fault appeared in a superconducting coil — probably a momentary short-circuit. After systematically powering the coil with increasingly higher currents (up to 3900 A), the fault disappeared.

BEBC is now operating with a metal piston and photos are being taken with a magnetic field of 2.2 T in the chamber. Everything seems to indicate that it is now in a good enough state to take up its experimental programme in which scientists from all over Europe are involved.

Computing School

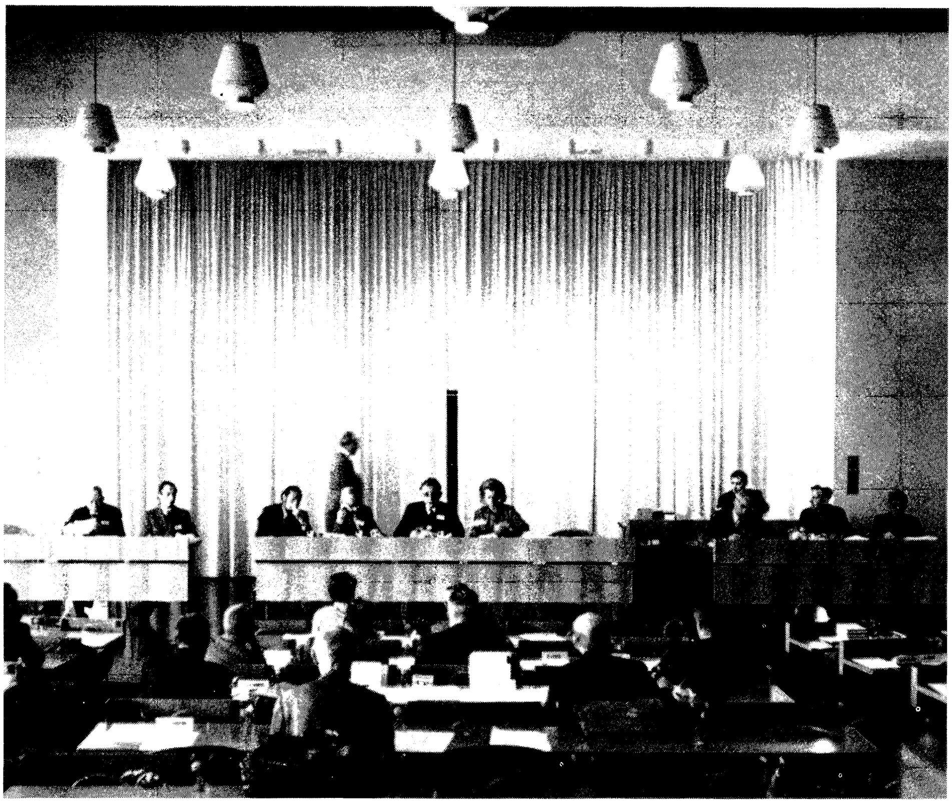
The 1974 CERN School of Computing will be held in Godøysund near Bergen, Norway, from 11-24 August 1974. It is the third School in this series and is open to high energy physicists and computer scientists working in the CERN Member States or in Laboratories closely associated with CERN. The number of participants will be limited to about 70 and the programme will include courses on the following topics:

Programming methods — Programming discipline by O.J. Dahl (University of Oslo), The Hydra system R. Böck (CERN), Software engineering J.N. Buxton (University of Warwick).

Computer systems architecture — Introduction to computer systems architecture C. Otrage (CII Grenoble), Virtual memory F. Sumner (University of Manchester), Multiprocessor systems L. Bolliet (University of Grenoble), Special purpose processors C. Verkerk (CERN).

Interactive computing — Survey of interactive computing A.J. Perlis (Yale University), Erasme W. Jank (CERN), *The Council of the European Physical Society met at CERN on 27 November. They are photographed here in session in the CERN Council Chamber under the chairmanship of Professor H.B.G. Casimir, President of the Society.*

Members of the Assembly of the Department de l'Ain (the French Department where CERN Laboratory II is located) visited CERN on 3 December. Dr. J.B. Adams (Director General of CERN Laboratory II), who is on the left in the photograph, welcomes M. Anthonioz (Vice-President of the National Assembly), J. Saint-Cyr (President of the Conseil général de l'Ain) and H. Boucoiran (Préfet de l'Ain).



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Data presentation J.H. Friedman (SLAC).

All correspondence concerning the School, including requests for application forms and further information, should be addressed to the Scientific Conference Secretariat, Mrs. I. Barnett or Miss D.A. Caton, CERN, 1211 Geneva 23, Switzerland.

Honour for CERN theoretician

On 29 November, André Martin of the CERN Theory Division was awarded the degree of Doctor Honoris Causa of the University of Lausanne.

Dr. Martin has worked at CERN since 1959, apart from intermittent visits elsewhere including a two year stay at Princeton and Stony Brook in the USA. His main research has been working out the logical consequences of general principles concerning particle behaviour when they collide. Working from principles such as the conservation laws and causality he has demonstrated how to establish limits on such things as particle interaction cross-sections at high energy. He has thus made the link between the abstract general principles of field theory and the particle properties which can be observed in experiments. Martin has earned a world-wide reputation for his work in the theory of particle physics.

At the same ceremony, two other well known physicists received the same honour — Piotr Kapitza for his contributions in many areas of physics, from nuclear physics to the study of the superfluidity of helium, and David Schoenberg for his research in solid state physics, particularly related to superconductivity and to the electronic structure of metals.

Around the Laboratories

UK Laboratories EPIC Project

During the past year, the high energy physics community in the UK has been studying an ambitious project which is intended to re-equip their physics programme for the 1980s. By then the two existing accelerators (the 5 GeV electron synchrotron NINA at Daresbury and the 8 GeV proton synchrotron NIMROD at Rutherford) would have had about fifteen years of operation and are likely to have exhausted much of the interesting physics in their energy ranges.

At the present time, throughout the world, most interest in terms of new facilities is concentrated on the possibilities of electron-positron-proton colliding beam systems. In the last issue, for example, we reported on three separate meetings related to this topic. The project in the UK has therefore concentrated on such a system, setting its sights on reaching an energy of 14 GeV for electrons and positrons and 200 GeV for protons. It is known as EPIC — Electron Proton Intersecting Complex.

During the year, eight Working Groups have been studying the various areas of high energy physics which can be attacked by such a system and accelerator teams from the two Laboratories have produced a machine design and preliminary cost estimates. The implications of the project for the total European programme (and in particular the relationship with the work of CERN) are also being considered and the first moves to get the project off the ground have been taken.

The machine design has absorbed as many of the existing facilities as possible. This involves building the storage rings linked to the present location of NIMROD at the Rutherford Laboratory and bringing NINA to act as an energy booster in the injection system for the rings.

Electrons are accelerated in the NINA linac (probably with its energy raised) located in the hall of the existing NIMROD injector. They are then transported to NINA or are converted into positrons which also pass into NINA. NINA sits partially in Experimental Hall 1 and accelerates each type of particle to just over 2 GeV before transferring them to the storage ring.

In the storage ring 10^{12} electrons and 10^{12} positrons, distributed in four bunches (two of each type), are accelerated to a peak energy of 14 GeV. The ring has a total circumference of 2120 m, average radius of 340 m, with four 185 m straight sections (insertions) where the bunches collide. The magnets for the electron-positron ring are of conventional type (peak bending magnet field about 0.28 T, peak quadrupole focusing field about 4.7 T/m).

Protons are accelerated in the 70 MeV NIMROD linac now under construction and transported to NINA where, with a new additional r.f. system, their energy is increased to 4 GeV before transferring them to their storage ring. Several times 10^{12} protons distributed in four bunches, are accelerated further in the storage ring located above the electron-positron ring in the same tunnel.

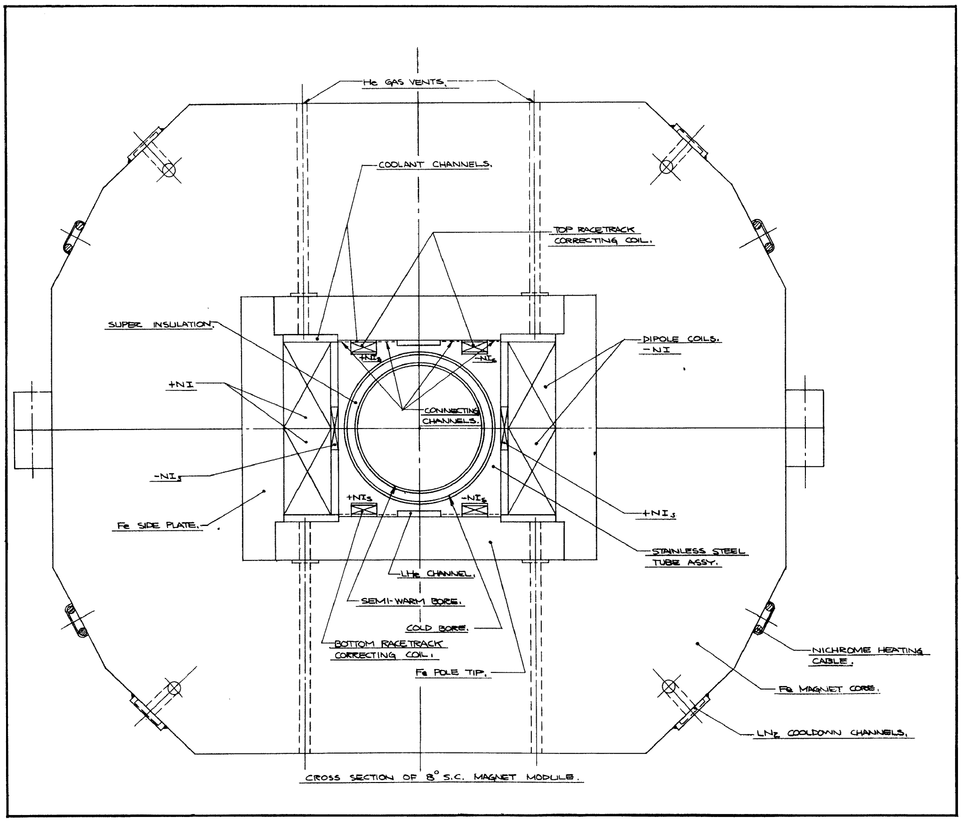
Several possibilities for the proton ring have been studied. The first involves the use of conventional magnets (peak bending magnet field 1.6 T) resulting in a maximum proton energy of 80 GeV. The second involves the use of superconducting magnets (peak field 4.5 T) around the ring but taking up only half the available circumference in a missing magnet lattice and resulting in a maximum proton energy of 100 GeV. The third involves a full ring of superconducting magnets resulting in a maximum proton energy of 200 GeV. Decisions on this topic will obviously await the outcome of the latest stages of superconducting magnet development which should give answers on reproducibility, reliability and cost.

With this complex, high energy interactions of electron-positron, electron-proton and proton-proton (filling the electron ring with protons) could be observed. Much work has gone into the study of machine lattices and the interaction regions. It is believed that luminosities of several times 10^{31} could be obtained.

The project is of a nature that can be tackled in several phases. Phase 1, which is now under serious discussion, is to build the 14 GeV electron-positron ring. The cost is estimated at £ 20 million and this money could be found from the foreseeable budgets for the national UK high energy physics programme provided that the existing machines, NINA and NIMROD, are phased out. If this approach to the re-equipping of the facilities in the UK is accepted quickly by the various parties involved, construction of Phase 1 of EPIC could begin in 1975.

Construction would not affect the participation of UK scientists in the experimental programmes at CERN, except in the sense that more use of the CERN accelerators would be desirable in the absence of domestic machines while EPIC is being built. More money would be available for the CERN programme to accommodate this.

Electron-positron colliding beams of 14 GeV energy will support many interesting experiments and, after the completion of Phase 1 of EPIC, several years around 1980 are likely to be assigned to these experiments. It is hoped to have developed the mechanisms for broad European use of the facility and European collaboration



Cross-section of the superconducting dipole magnet operating at Brookhaven. Note that it is a warm bore magnet and has a separate sextupole correcting coil. The total length of the two magnet sections is about 4 m. Other major parameters are given below.

Aperture diameter	7.3 cm
Magnetic field	4 T
Dipole	
Ampere-turns	408 000
Current	1200 A
Current Density	30.5 kA/cm²
Sextupole	
Ampere-turns	18 000
Current	300 A
Stored Energy	150 kJ per unit
Inductance	0.2 h per unit

will be even more welcome in confronting Phase II — the construction of the proton ring. By then it is hoped that superconductivity will be thoroughly mastered so that a 200 GeV ring (or a 100 GeV ring followed by a further Phase, doubling the energy) could be built.

BROOKHAVEN Superconducting magnet operates at AGS

At the beginning of November a large superconducting bending magnet was brought into operation at the Alternating Gradient Synchrotron. It is installed to give an 8° bend to the primary proton beam in a new beamline leading to the 7 foot bubble chamber in the North Area.

The performance of the magnet seems to have answered several outstanding questions concerning superconducting magnets. One concerns the reproducibility of magnets. Two magnet sections have been built and show identical magnetic characteristics to one part in 10^{-5} which are also in agreement with the design computations. Since the magnets are made of standard materials using construction techniques which present no outstanding difficulties, it should be possible to manufacture such magnets reliably in industry. They are of a type that could be used in future accelerators. A second question concerns the ability of superconducting magnets to withstand heavy doses of radiation. The magnet withstood large beam losses without problem. In view of these results, we give quite a few of the construction details.

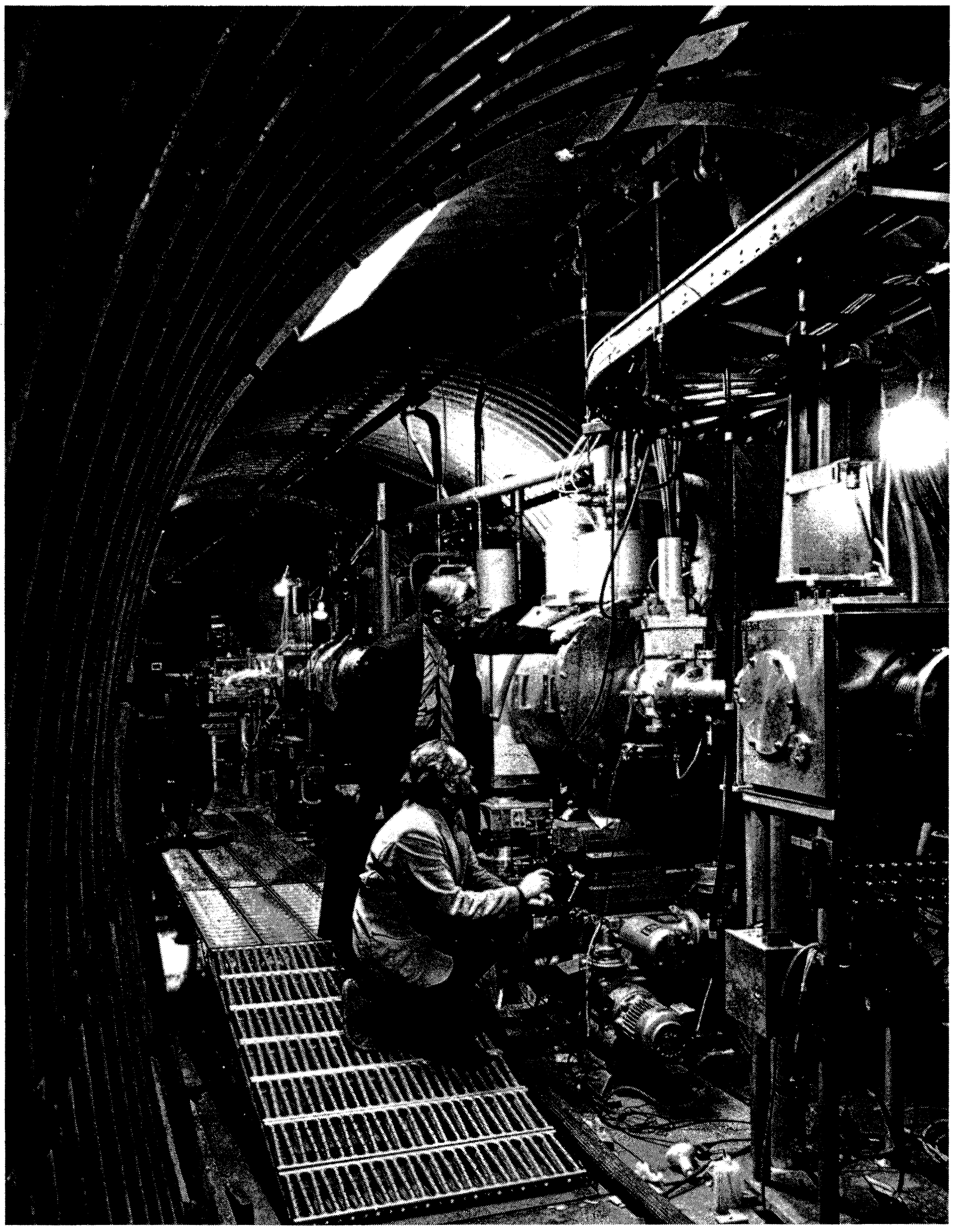
The magnet is constructed in two sections with a total length of about 4 m. It has a rectangular aperture ('window frame' type) with the iron core surrounding coils also of rectangular cross-section. The overall dimensions are 37.8 cm high and 43.5 cm wide. Other parameters can be seen in the table.

The iron core, wrapped close around the coil, reduces the ampere turns required for magnetic fields below saturation by a factor greater than two. The magnetic images of the coil in the iron simulate extended dipole sheets, producing very uniform fields below 2 T. Above this field, saturation requires an auxiliary correcting coil which is approximately an air-core sextupole. The correcting coil needs to be powered at field levels of about 2 T increasing linearly to several per-cent of the dipole coil ampere turns by 4 T. The combination of the two coils permits precise fields to be obtained at all levels, as well as providing available sextupole tuning where desired.

The dipole coil is wound with 340 turns of superconductor composite with a rectangular cross-section of about 1.4 by 2.9 mm². In this conductor, 361 filaments of niobium-titanium, 75 μm diameter, are embedded in copper and the whole matrix is twisted one turn per inch. Sheets of anodized high purity aluminium are placed between each of the vertical layers of conductor and are grooved to provide vertical liquid helium coolant channels over 50 % of the surface area. The aluminium gives good thermal and dynamic stability.

The magnet is immersed in liquid helium at 4.5 K. It is designed to operate at twice the magnetic field of conventional magnets and has been successfully tested at 4.4 T. This was reached after a few training quenches — where the superconductor returns to the normal state due to a release of heat in the material. Training refers to the relief of built-in stresses (under the pressure due to the magnetic field) which often gives a small release of heat sufficient to cause a quench. After initial training the magnets reached maximum field without quench even after repeated cool-downs from room temperature.

The magnetic characteristics of the two sections agreed to about 0.01% which indicates that it is practical to produce many of them with the expectation that they will be magnetically and mechanically inter-



View of the superconducting magnet installed in the new beam-line leading to the 7 foot bubble chamber in the North Area at the AGS.

(Photo BNL)

changeable. The mechanical precision compares favourably with the best conventional magnets. Designs already exist on paper for magnets of even greater precision to give fields of over 6 T.

Detailed design began a little over two years ago. Since it is envisaged as a forerunner of more extensive superconducting magnet beam transport lines, considerable attention was given to making it a complete system which would require little direct supervision. The helium refrigerator, located 10 m from the magnet, is connected to the magnet dewars by liquid nitrogen shielded transfer lines. The dewars and refrigerator comprise a closed loop to which have been added auxiliary equipment for recovering and storing the helium gas. The magnets, refrigeration and recovery systems have instrumentation for automatic operation and provision has been made for computer monitoring.

In the early hours of 25 October, the external beam was set up. There remained the uncertainty as to whether a beam pulse would be sufficiently free of stray particles to keep the heating of the coil due to radiation within acceptable limits. The pulse carries an energy of 10 kJ at an intensity of 2×10^{12} protons and a few mJ of heat per gram of superconductor are sufficient to cause a quench. The magnet passed its maiden pulse without difficulty but, a few minutes later, a component failure elsewhere gave rise to a heavy radiation overdose which quenched the magnets.

In all subsequent studies, the magnet performed without incident at high intensity (5×10^{12} protons per pulse) even under abnormal beam heating conditions. During faulty operation, the magnets received several hundred joules of radiative energy in a time of 3 μs without quenching while small pressure pulses were observed in the helium bath due to momentary heating. This ability to absorb large beam losses is very significant since future superconducting accelerators depend on a reasonable ability to operate under conditions of heating due to sudden beam loss. This is the first experimental evidence on this fundamental question.

The happy outcome followed some times of stress en route to meet the schedule for operating the North Area beam-line — including the accidental destruction of a coil due to overheating. The coil had to be spliced and partially rewound but now performs as satisfactorily as an undamaged one. Magnet design and construction has been led by G.T. Danby and J. Allinger and the North Area Extraction work by R. Blumberg.

It is an important achievement in the field of superconductivity for Brookhaven. Superconducting technology is relevant to the future of high energy physics and is also central to many promising developments in the production and distribution of energy, in transport systems, etc.

KEK Synchrotron construction in Japan

Construction of the 12 GeV proton synchrotron at KEK (Ko-Energi-butsurigaku-Kenkyusho which means High Energy Physics Laboratory) is now well advanced. The Laboratory is located at the Tsukuba Science City about 60 km from Tokyo and is a national centre for particle physics research in Japan.

Main features of the accelerator are — 20 MeV linac (single tank 15.5 m long) to provide a maximum current of 100 mA at a repetition rate of 20 Hz;

Aerial view of the synchrotron site at Tsukuba. The ring shape of the accelerator can be distinguished upper left. Top left is the building to house the 75 cm bubble chamber. Adjoining the ring on the right is the large hall for counter experiments. Further round in the clockwise direction is the location of the linac and booster. It is impressive that fifteen months ago a similar view would have shown just the preinjector building and a series of holes.

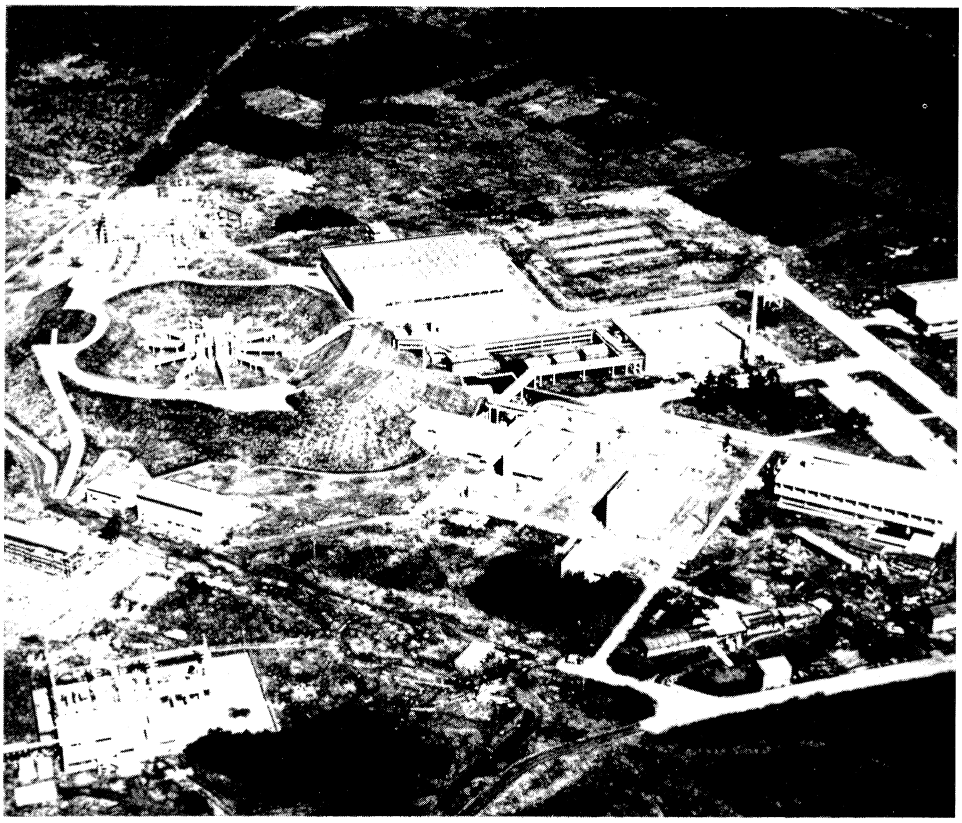
(Photo KEK)

500 MeV booster (radius 6 m, combined function magnets with peak field of 1.1 T) to provide a maximum intensity up to 2×10^{12} protons per pulse at 20 Hz; 12 GeV main ring (radius 54 m separated function magnets with peak field of 1.75 T) to provide over 2×10^{12} protons per pulse at a maximum repetition rate of 0.5 Hz.

The accelerating column of the preinjector is in place and has been tested up to a voltage of 850 kV. An ion source, with a new type of nozzle type expansion cup, has yielded about 200 mA with high brightness. Linac construction began in April 1971 and the tank, drift tubes, r.f. power system and controls are now in place. In fabrication of the tank and drift tubes, a method of electro-plating copper onto steel was used and gave excellent results — the surface is smooth to within 0.3 μm. The first 20 MeV beam from the linac is scheduled for April of next year.

The 500 MeV booster synchrotron has eight C-shaped magnets and their installation, together with their power supplies is almost complete. The r.f. system is still under construction. The booster is a fast cycling machine and will provide nine pulses to fill the circumference of the main ring during one machine cycle. It is scheduled to accelerate beam to 500 MeV in September 1974 and to transfer protons to the main ring six months later.

The main ring has 48 C-shaped bending magnets plus 56 quadrupoles. Some of these magnets are already in place and all are due to be delivered by March 1974. There are four long straight sections to be used for injection, fast ejection to a bubble chamber (see photograph caption), slow ejection to counter experiments, and for r.f. cavities. The r.f. system operates with a harmonic number of 9 and has a frequency swing from 0.67 to 0.88 MHz. The r.f. units, vacuum system and injection system will be built by the end of 1974 so that first high energy beams will be available in Autumn 1975.



Preparations for the experimental programme are about to begin and early next year groups will be invited to propose experiments. It is expected that the machine will serve about 50 bubble chamber physicists and 50 counter physicists. A large number are likely to move from the 1.3 GeV electron synchrotron at Tokyo.

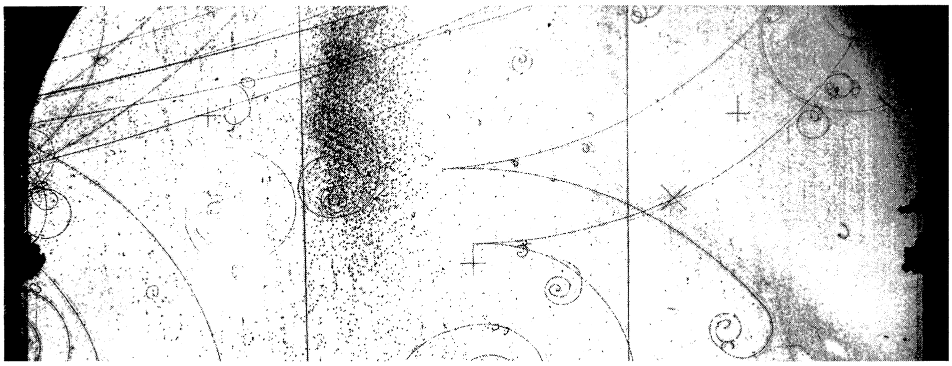
Obviously the energy range available from the first high energy proton machine in Japan is no longer in the front line of particle physics research and the accelerator builders are hoping to develop further the capabilities of their facility. A colliding beam scheme known as TRISTAN (Three Ring Intersecting STorage Accelerator in Nippon!) is under study. The first stage is for a ring 648 m in diameter which would take protons to 40 GeV and also electrons to 15 GeV. This could also be used for electron-proton experiments.

This ring would use conventional magnets but work on pulsed superconducting magnets is to start soon and the second stage of TRISTAN is seen as two superconducting rings for proton-proton experiments up to 180 GeV per beam. However, these additional rings are well in the future. It is unlikely that the first stage could start before 1978 and the second stage is ten years away. The accelerator physicists in Japan will thus have plenty of time to master their present machine.

ARGONNE TST tests

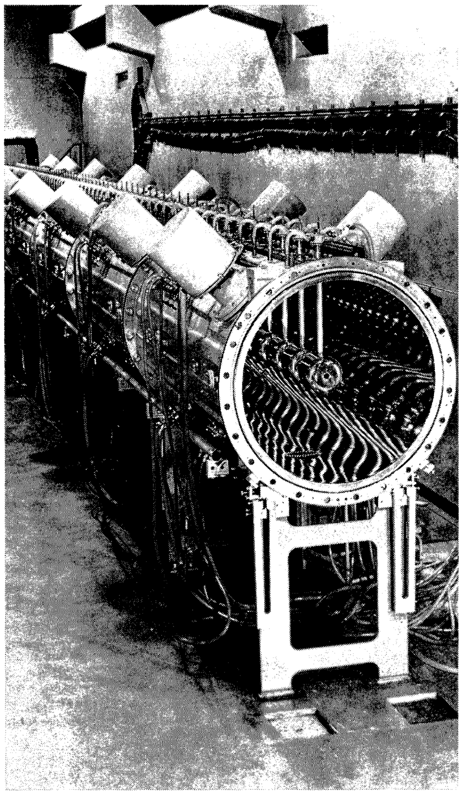
A first engineering run using a track sensitive target took place with the Argonne 12 foot bubble chamber at

Photograph taken in the 75 cm hydrogen bubble chamber for the KEK synchrotron at the end of October. The chamber is being tested at the electron synchrotron at the Institute for Nuclear Study, University of Tokyo. 50 000 pictures were taken with 600 MeV electrons and positrons. The chamber will move to the proton synchrotron site at Tsukuba mid-1974.



The tank of the 20 MeV linac for the KEK synchrotron. An electro-plating technique resulted in the highly polished finish which can be seen on the copper surfaces of the drift tubes and the r.f. cavity.

(Photo KEK)



the end of October. Some teething troubles developed but, nevertheless, it was possible to check performance over 23 500 expansions and to confirm that quality pictures, recording particle tracks both inside and outside the target simultaneously, could be taken.

These tests are important since they are the first time that this new technique has been used in a large chamber. They show that the technique can be extended to the new generation of chambers without great difficulty.

'Track sensitive target' is the name given to a volume of pure hydrogen held in a perspex container within the larger volume of a bubble chamber which is filled with a hydrogen/neon mixture. Incoming high energy particles interact in the hydrogen volume, thus preserving the advantage of having interactions occurring on free protons. Particles emerging from the interactions may pass into the surrounding hydrogen/neon mixture, thus gaining the advantage of heavier liquids — a shorter radiation length with better gamma detection.

The idea came from CERN and was developed at DESY and, particularly, at the Rutherford Laboratory. In collaboration with CERN, Rutherford has carried out a series of experiments with a TST in the 1.5 m bubble chamber. They have gathered about 2.6 million pictures and film analysis is going well. It looks possible to hand the film to automatic film measuring machines such as the HPDs and this will be tried early in 1974 using 60 000 pictures taken with 4 GeV positive pions as the incoming particles. This will be a significant exercise because it will greatly influence the future of TSTs if it can be shown that the film can be treated as for any conventional bubble chamber experiment.

(The Rutherford 1.5 m chamber, incidentally, is now closing down. The magnet will be used in a multiparticle spectrometer with its aperture filled with detectors, à la Omega. The bubble chamber has had a busy life, including two years of operation at CERN in 1964 and 65 and, with the TST work, it goes out with flying colours.)

Following the success at Rutherford, TSTs have been spreading. They have been built for the 80 inch chamber at Brookhaven, for the 12 foot chamber at Argonne and are under study for the 3.7 m European bubble chamber at CERN and for the 15 foot chamber at Batavia. The 15 foot has been lucky in that its design came after the TST idea and has therefore already incorporated the necessary plumbing. These two last mentioned big chambers will especially benefit from the use of TSTs since they will cope with beams from the new high energy accelerators where the shorter radiation length of hydrogen/neon will help extend their abilities.

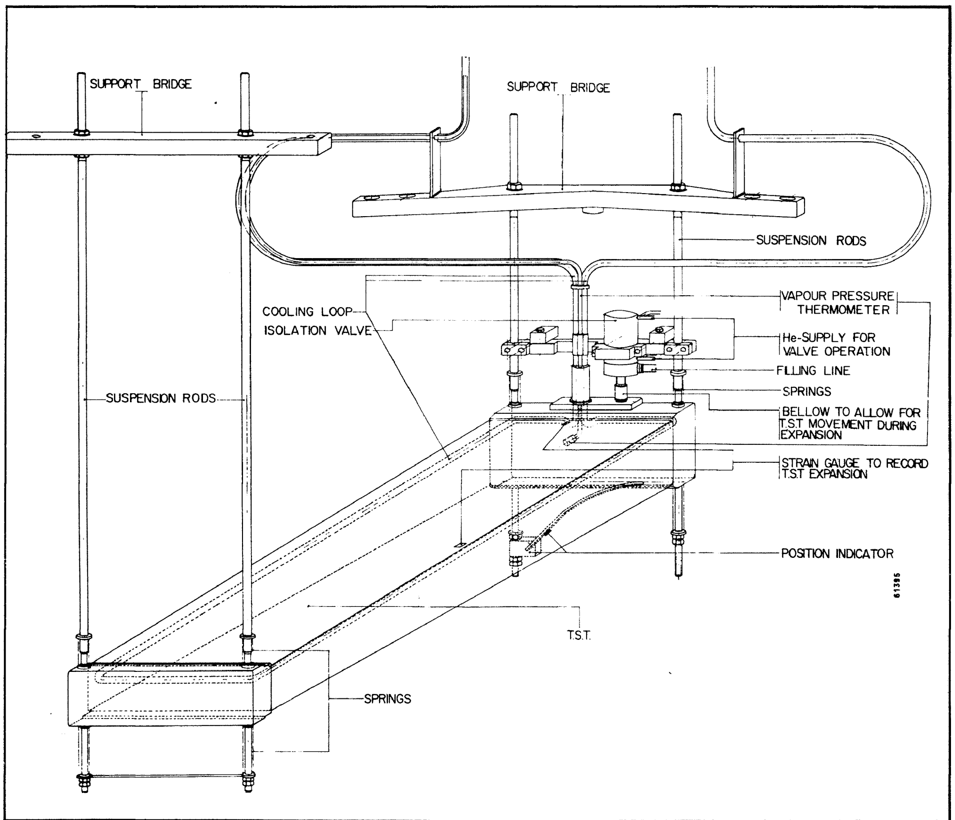
The development at Argonne also involved CERN and Rutherford people. The target itself — a box of 8 mm plexiglas, 200 cm × 36 cm × 8 to 10 cm — was built at CERN by H. Leutz and J. Tischhauser and arrived at Argonne in September. The following month was absorbed by installation in the 12 foot chamber with help from Rutherford and CERN visitors (P. Williams, J. Ayres, E. Fitzharris, H. Leutz).

Cooldown was completed on 28 October and operation was tested under several different operating conditions. To reduce the complications, both the target and surrounding volume were filled with hydrogen. It was demonstrated that the TST could be kept at a temperature 1 to 2 K below that of the surrounding liquid and this will be necessary to give acceptable track quality when operating with hydrogen/neon.

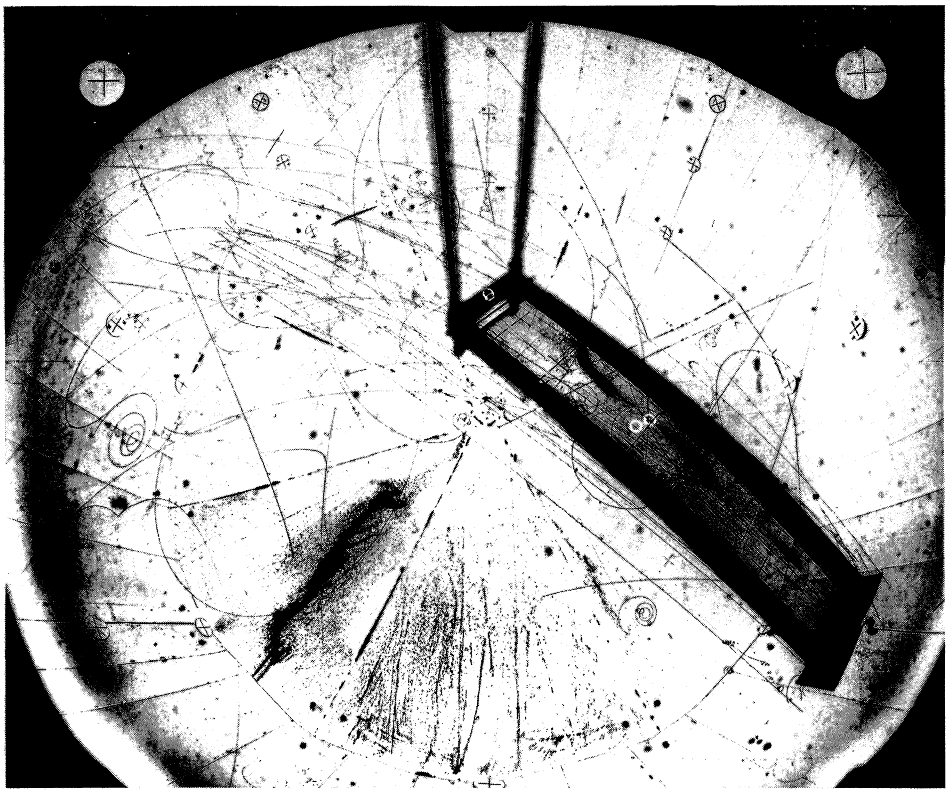
The Zero Gradient Synchrotron was accelerating polarized protons to 6 GeV and sent a small fraction of the beam to the chamber during the tests so that about 6000 photographs were taken (from about 23 500 expansions).

Difficulties developed with the hydrogen flow adjustment to the cooling loop which made it impossible to keep refined control of the temperature of the target in the region of 28 to 29 K. Some work on valves and instrumen-

Diagram of the track sensitive target which has been tested in the 12 foot bubble chamber at Argonne. The TST is designed to contain a volume of hydrogen enclosed in perspex within a larger volume of hydrogen/neon mixture in such a way that particle tracks can be photographed in both liquids.



A photograph taken during the tests which confirmed that the TST technique can be extended to large chambers without great difficulty. Tracks are visible inside and outside the target. The black shadows in the target location are there simply because, for the tests, the perspex enclosure was not constructed so as to be transparent to the cameras. This will easily be rectified in the final version.



tation should clear this. When the chamber was reopened, a small crack was discovered near the cooling loop entrance. The target has been returned to CERN for detailed examination. A second target is scheduled to be built in a few months' time.

Enough neon is available for a second engineering run, hopefully in the late Spring of 1974. By the end of the year it is hoped that the TST will be in action for an Argonne/CERN/Rutherford experiment studying 6 GeV positive pion-proton interactions.

CERN COURIER Correspondents

We close CERN COURIER for 1973, recording our thanks to the correspondents from other Laboratories whose help in gathering up-to-date information for our pages has, as always, been very valuable.

ARGONNE	T.H. Groves
BATAVIA	R.A. Carrigan
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BROOKHAVEN	J. Spiro
CORNELL	K. Berkelman
DARESBURY	H. Sherman
DARMSTADT	H. Prange
DESY	E. Dammann
DUBNA	V.A. Biryukov
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MODEL 5175

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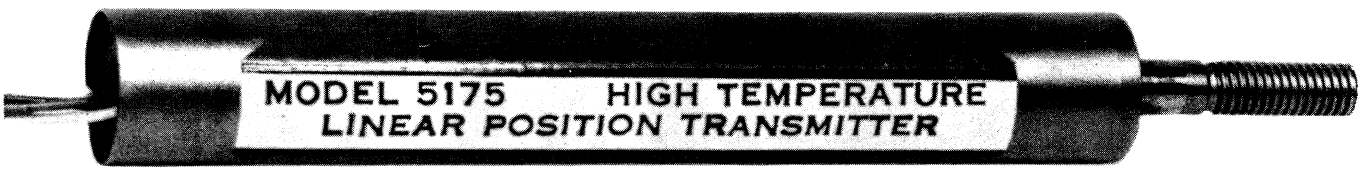

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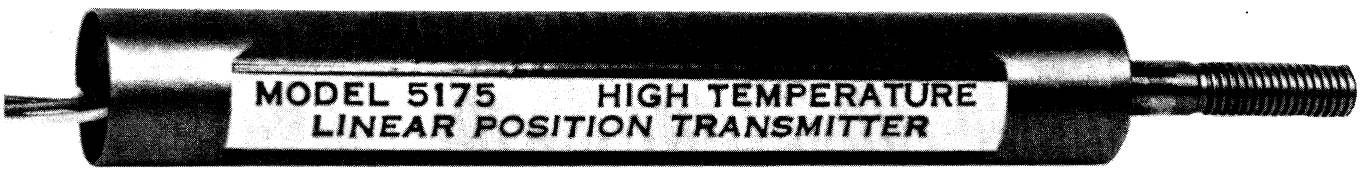

PRINCIPLE OF OPERATION

The transducer contacts are positioned along a precision electrical element which varies the resistance. Excited by either an AC or DC input voltage, mechanical backlash is eliminated by a positive connection between the shaft and contact assembly.

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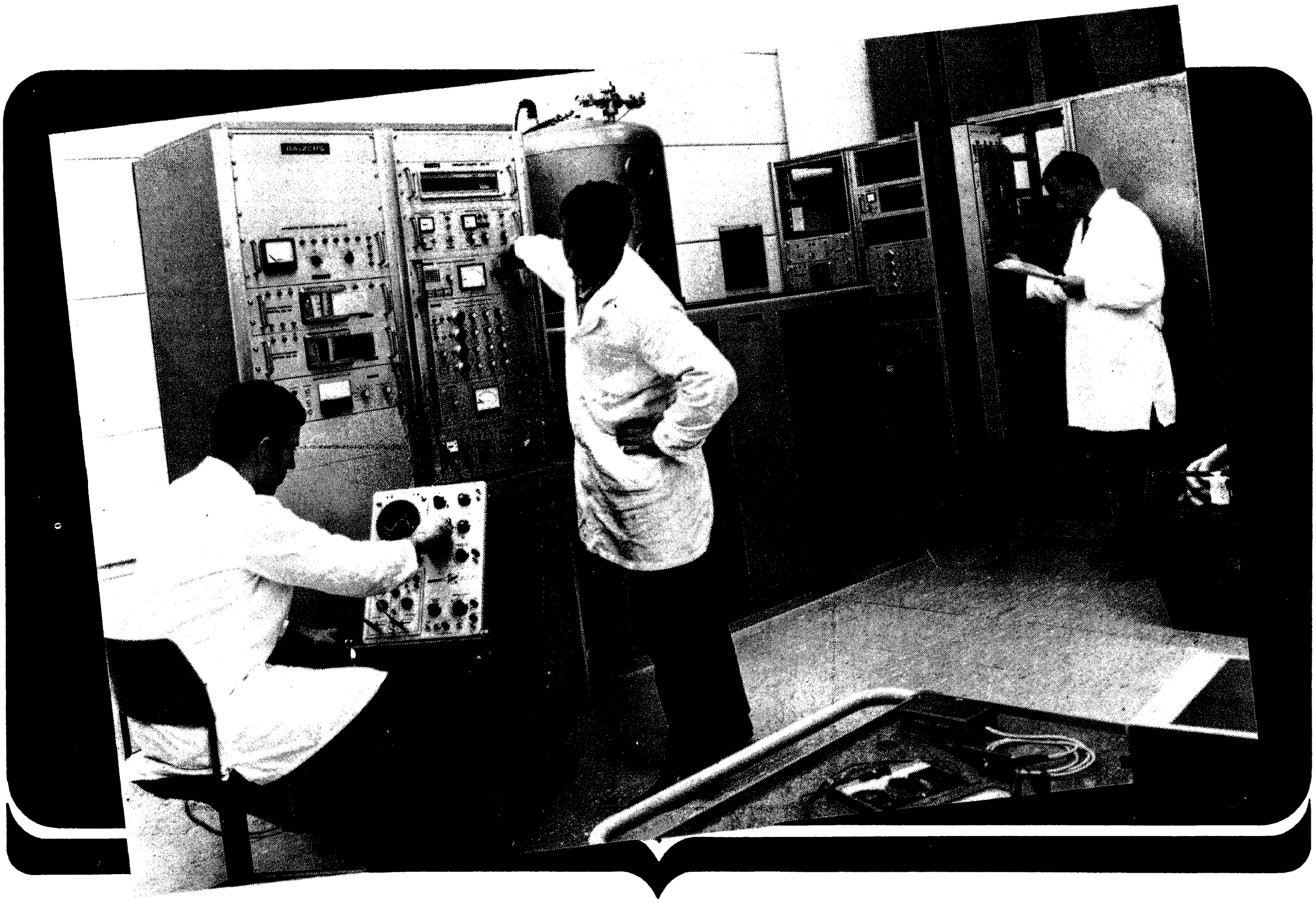

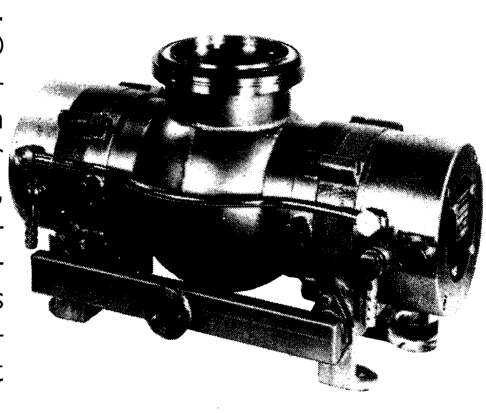

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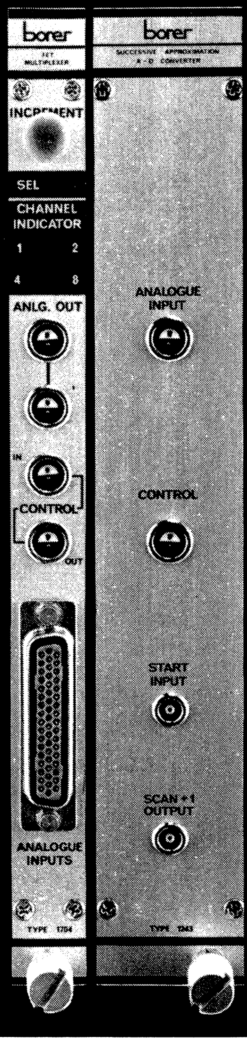

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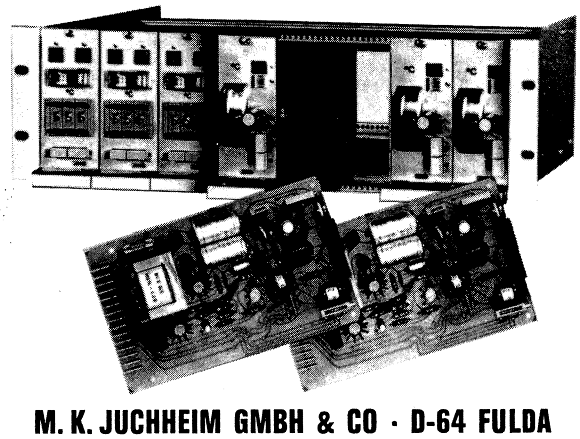

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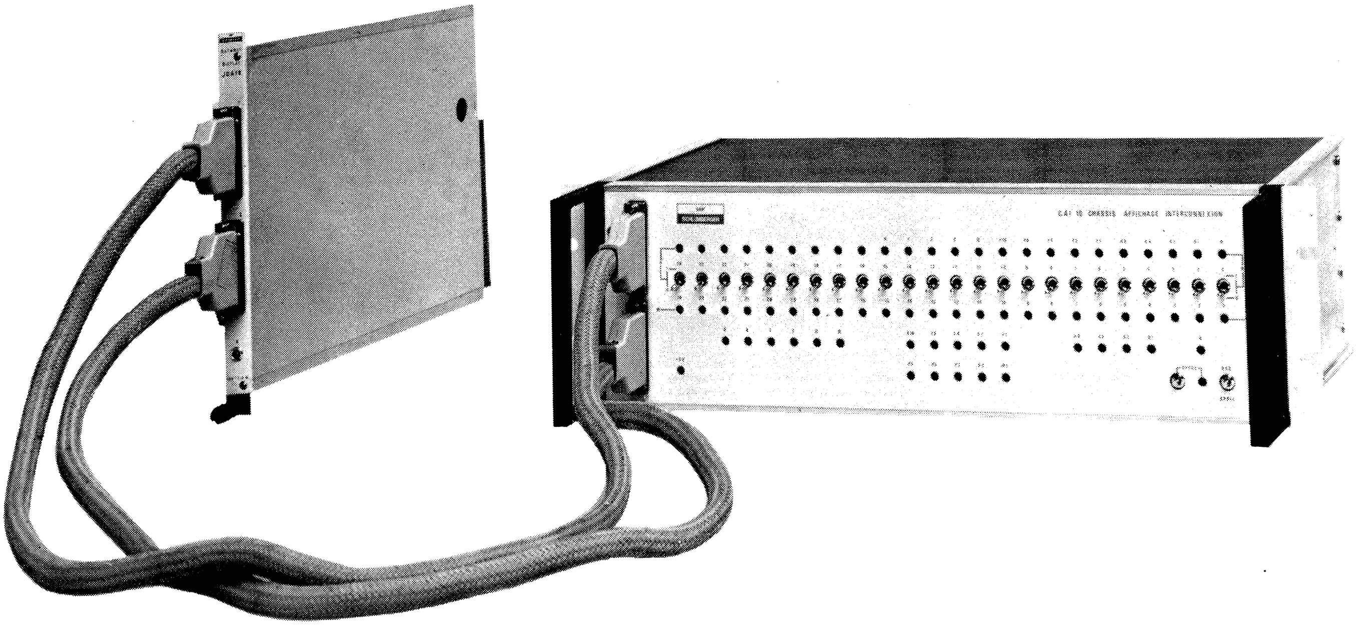

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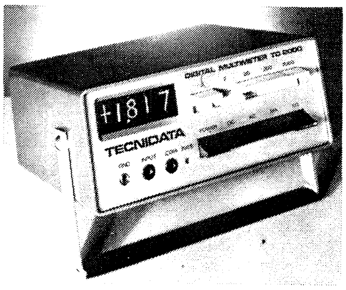

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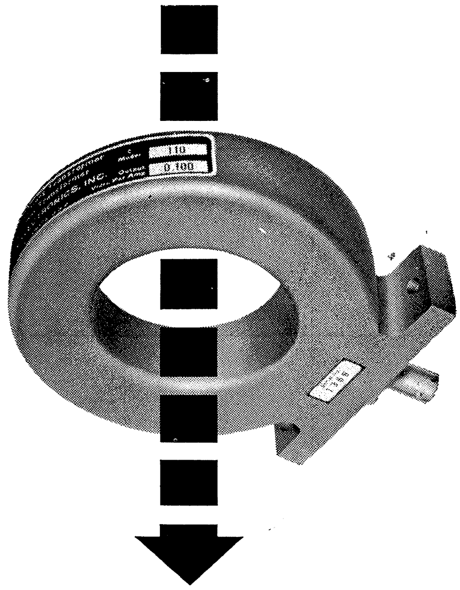

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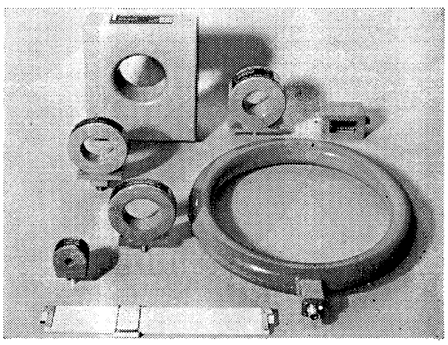

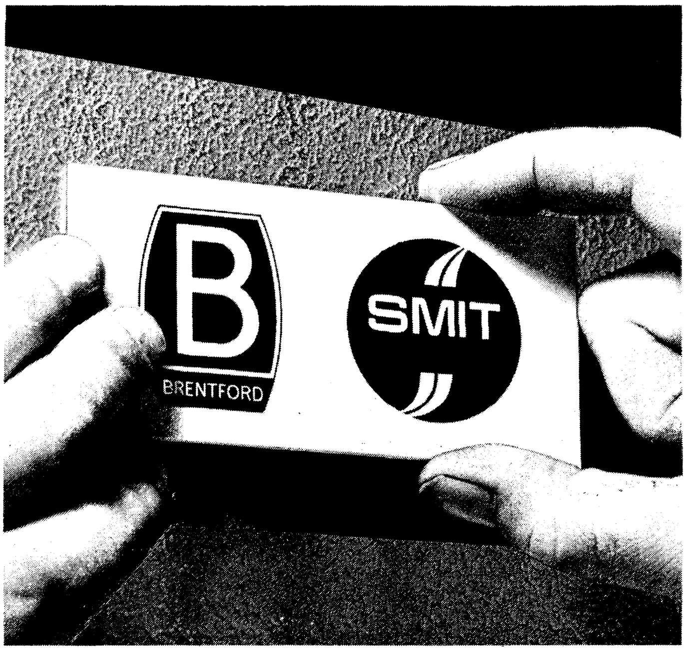

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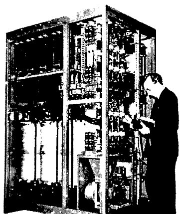

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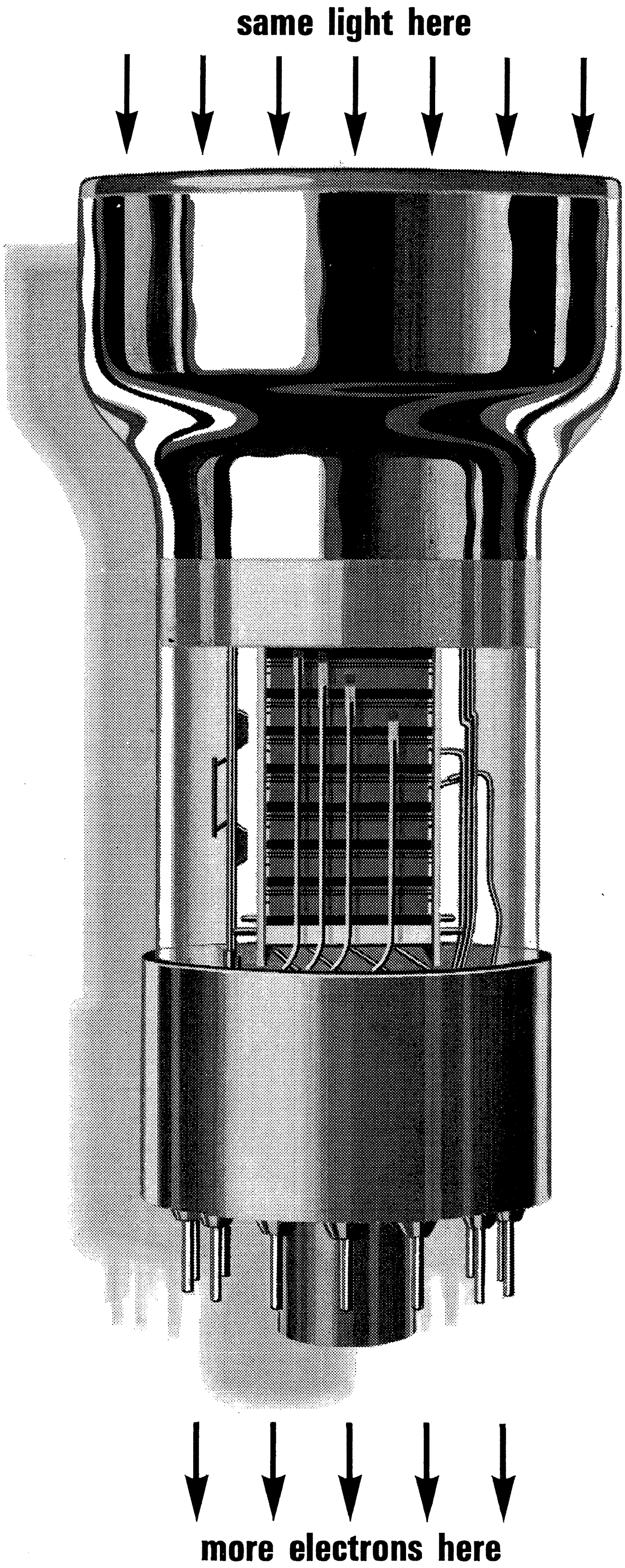

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* type XP 2000 is a direct replacement for types 8053, 4523 and 9655; type XP 2030 for types 8054 and 4524.

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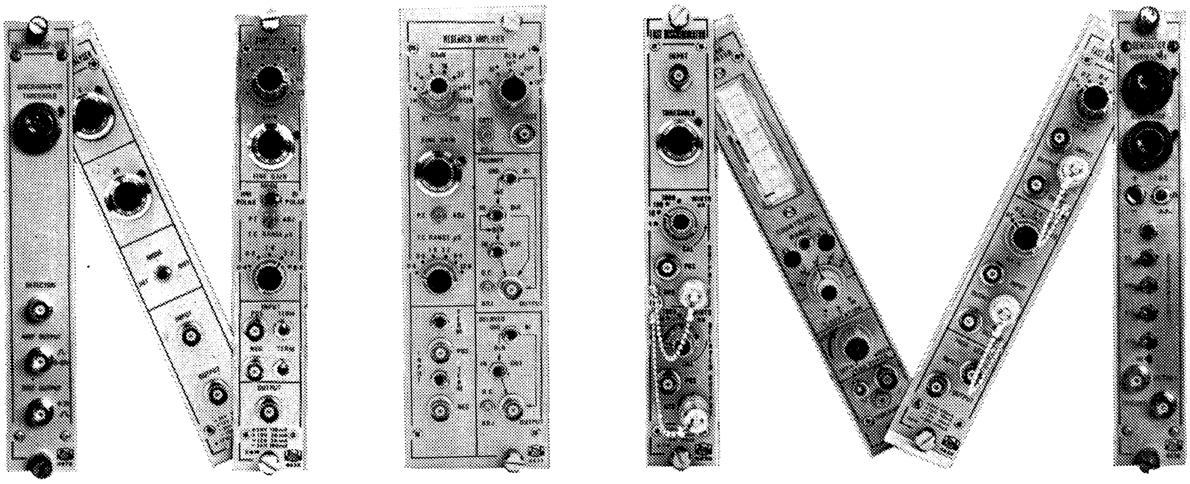
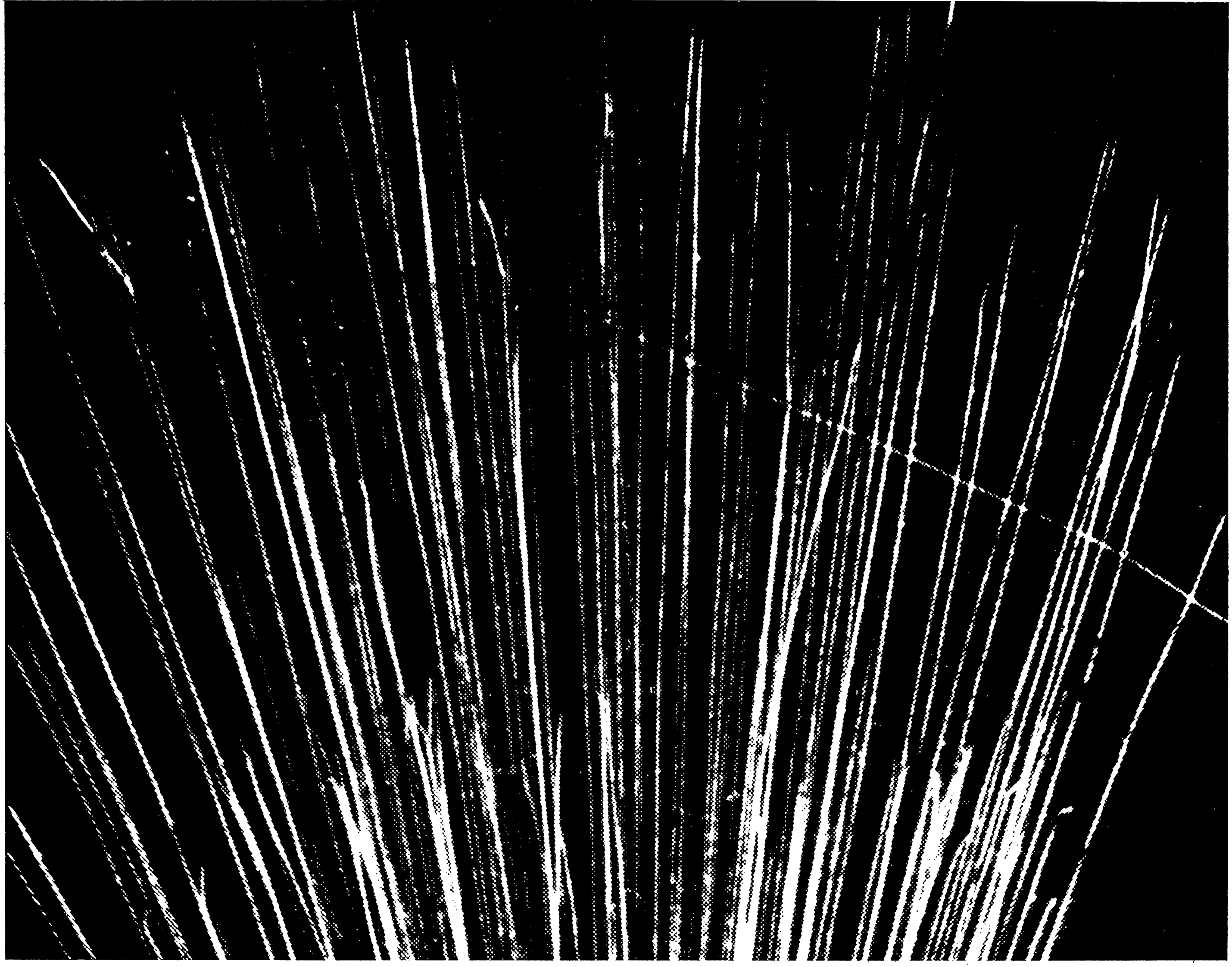
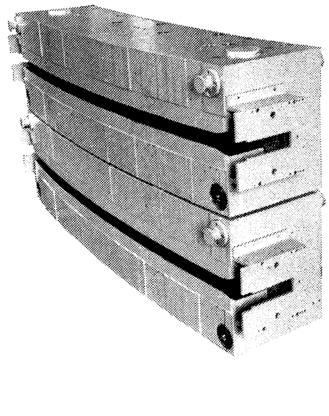




Nuclear transmutation



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FEATURES

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