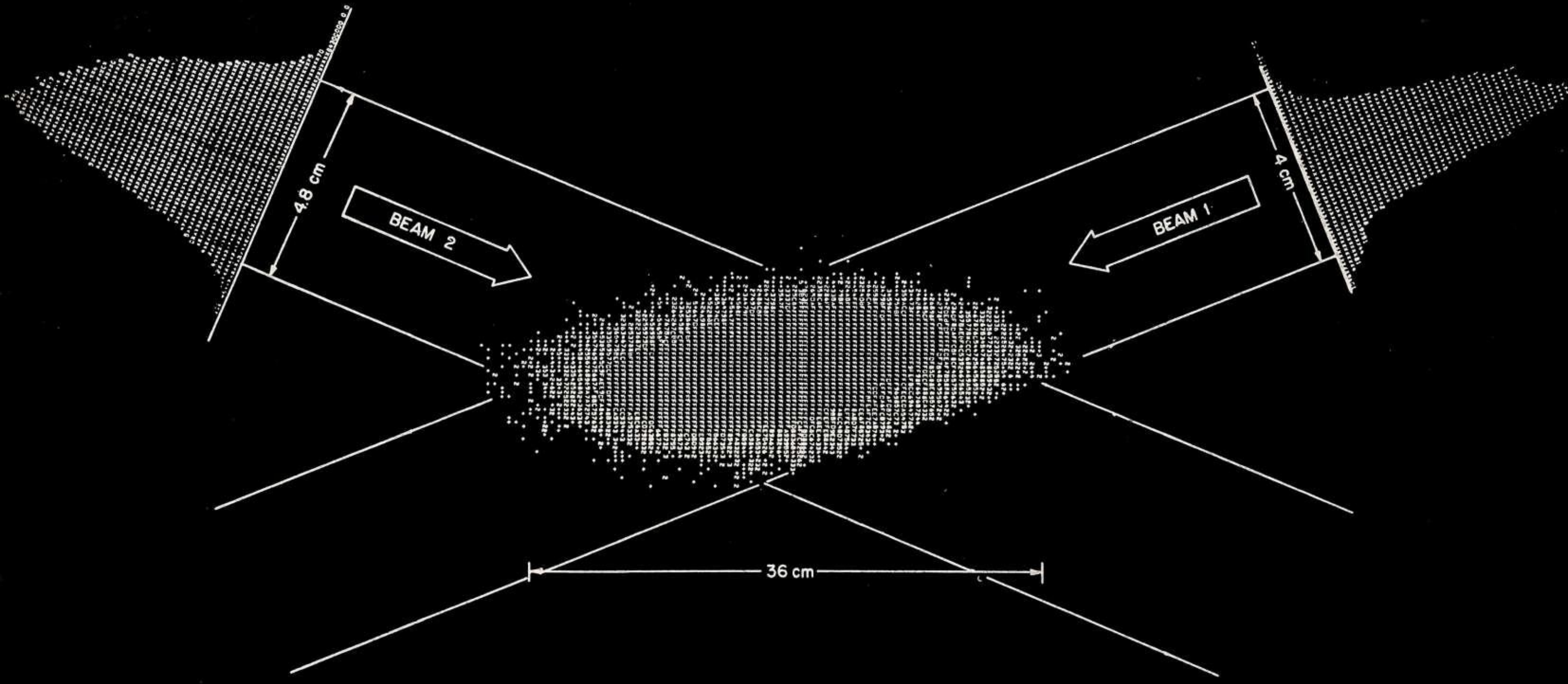
CERN COURIER

No. 5 Vol. 11 May 1971

European Organization for Nuclear Research



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 I and CERN II.

CERN I has been in existence 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 1200 physicists draw research material from CERN.

The CERN I site covers approximately 80 hectares almost equally divided on either side of the frontier between France and Switzerland. The staff totals about 3000 people and, in addition, there are about 650 Fellows and Visiting Scientists. Twelve European countries contribute, in proportion to their net national income, to the CERN I budget, which totals 353.4 million Swiss francs in 1971.

The CERN II Laboratory was authorized by ten European countries in February 1971; it will house a proton synchrotron capable of a peak energy of hundreds of GeV (usually referred to as the 300 GeV machine). CERN II also spans the Franco-Swiss frontier with 412 hectares in France and 68 hectares in Switzerland. Its budget for 1971 is 29.3 million Swiss francs.

CERN COURIER is published monthly in English and French editions. It is distributed free to CERN employees and others interested in sub-nuclear physics.

The text of any article may be reprinted if credit is given to CERN COURIER. Copies of most illustrations are available to editors without charge.

Editor: Brian Southworth
Assistant Editor: Philippe d'Agraives
Advertisements: Micheline Falciola
Photographs: PIO photographic section

Public Information Office
CERN, 1211 Geneva 23, Switzerland
Tel. (022) 41 98 11 Telex 2 36 98

Printed by: Ed. Cherix et Filancsa S.A.
1260 Nyon, Switzerland

Contents

Superconducting synchrotrons 123
Report on a recent seminar concerning the progress being made towards the application of pulsed superconducting magnets in a high energy synchrotron

CERN News

Gargamelle inauguration 127
Inauguration ceremony for the world's biggest heavy liquid bubble chamber

Omega progress 127
Some of the developments in preparation for the use of the large electronic detector system known as Omega

81 cm chamber pensioned off 130
Highlights from the career of the 81 cm hydrogen bubble chamber which has been closed down

ERASME computer ordered 132
Contract placed for the computer to be used with a new film scanning and measurement system

Radiation Protection Congress 133
Topics from a meeting on protection against accelerator and space radiation held at CERN at the end of April

Around the Laboratories

VANDERBILT: Sorting things out 135
Studies on the use of asymmetric high magnetic fields to sort non-ferrous metals from waste

RUTHERFORD: Superconducting lead cavities 136
Successful operation of full scale lead superconducting cavities in preparation for the construction of an r.f. separator

ILLINOIS: Superconducting linac first tests 136
Experience in operation of a section of a superconducting linac with an electron beam

STANFORD: Ideas on upgrading 20 GeV linac 137
Possible methods of opening up new energy ranges for research with accelerated electron beams at SLAC

CORNELL: Spectrometers uses MPCs 138
Use of a large scale multiwire proportional chamber system in a physics experiment at the 10 GeV electron synchrotron

PRINCETON: Accelerating nitrogen ions 138
Several months reprieve for the PPA to test acceleration of nitrogen ions and their use in cancer therapy

Cover photograph: Information on the ISR beams pulled out of a computer program used in association with an experiment being carried out by an Aachen, CERN, Harvard, Genoa, Turin collaboration in intersection region I-6. The points in the centre indicate the horizontal distribution of the positions where interactions between particles in the crossing beams took place (located using spark chambers on the downstream arm of each beam). The expected 'diamond' shape of the actual interaction region emerges quite clearly. Also plotted on the upstream path of each beam is the horizontal distribution of protons within the beam. The lines indicate approximately the beam profiles as they cross. The beam widths (between 4 and 5 cm) lie comfortably inside the vacuum chamber (16.6 cm). There will be more on the ISR experimental programme in a few months' time.

Superconducting Synchrotrons

Some topics from a Seminar, held on 26-29 April, organized by the Rutherford Laboratory.

This 'Seminar on Superconducting Synchrotrons' brought together about forty specialists working on the problems of developing pulsed superconducting magnets for use in synchrotrons. All the Laboratories with a major effort in the field (Berkeley, Brookhaven, Karlsruhe, Rutherford, Saclay) were represented with the exception of the Radiotechnical Institute Moscow, whose people were unfortunately unable to attend, and there were a few people also from CERN and Frascati.

With such a small knowledgeable gathering, it was possible to get deep into the subject from the word go. Each session concentrated on a few topics and was opened by one of the participants spending a few minutes listing the important problems. Each group could then present their approach to the solutions. The flow of information was fast and furious with some stimulating conflicts. This way of conducting the Seminar was very successful and was helped along by the able Chairmanship of D.A. Gray during all the sessions.

The Seminar was held in Cozener's House on the banks of the river Thames in Abingdon which serves as a hostel for the Rutherford Laboratory. This charming, characteristically English, setting was particularly appreciated by the visitors from the continent and the USA. Another characteristically English feature was the presence of a large dog which padded occasionally into the lecture room and barked at the more optimistic statements. It was particularly excited by speakers from Brookhaven. No-one could discern whether the barks denoted approval or rejection.

However, the human beings present were confident of the future of superconducting synchrotrons. As usual, this confidence is stated differently on either side of the Atlantic. The Americans tend first to state what can be done and then list the problems which remain to be swept out of the way in order to do it. The Europeans tend first to list the problems and then come to what could be done when they are solved. This subtle difference means a lot when it comes to the 'public relations' exercise of presenting this exciting work to others.

Nevertheless both sides, when pushed to it, would say that superconducting synchrotrons can be built. There remain many problems to come to grips with (quite apart from the detailed work to arrive at an optimum magnet design, there are major items such as the refrigeration and helium transport systems which have had little attention so far) but none of them look insoluble. However, because there is much work still to do, there is one parameter which no-one could yet confidently feed into the design of a superconducting synchrotron. To be realistic, it happens to be the most important one... the cost. To generalize a reaction to the Seminar, the question is no longer whether a superconducting synchrotron can be built but whether the studies of the next few years will refine all aspects of the design so that it can be built at an acceptable cost.

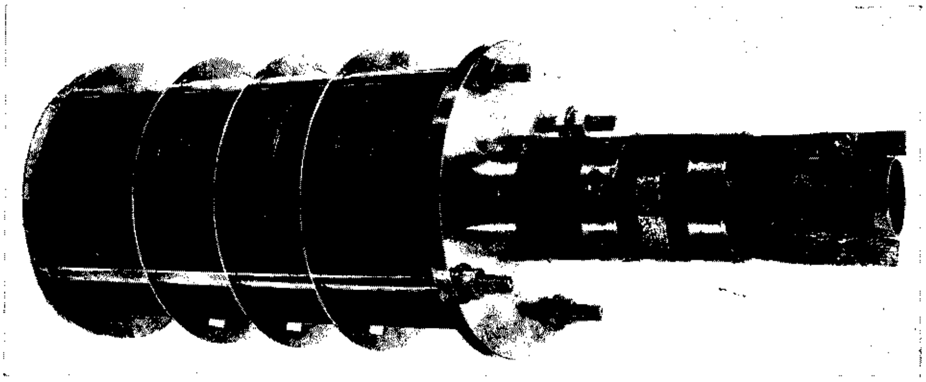
Magnet design

All Laboratories are concentrating on the use of niobium-titanium as the superconductor in the form of thin filaments in a twisted composite conductor where the filaments are embedded in copper and copper-nickel matrices (see, for example, vol. 10, page 48). For example, Rutherford have built cables of 7 or 19 twisted strands, each strand being about 0.35 mm diameter and having up to 1045 NbTi filaments of 8 µm diameter embedded (thus consisting of around 50 % superconductor). Other Laboratories, particularly Brookhaven, prefer the conductor formed into flat braid. The aim is to have a maximum current density — with the Rutherford conductor of over 20 kA/cm^2 for fields of over 4.5 T. (Others have rather similar aims — 30 kA/cm^2 for 5 T at Saclay, over 20 kA/cm^2 for 5 T at Berkeley.)

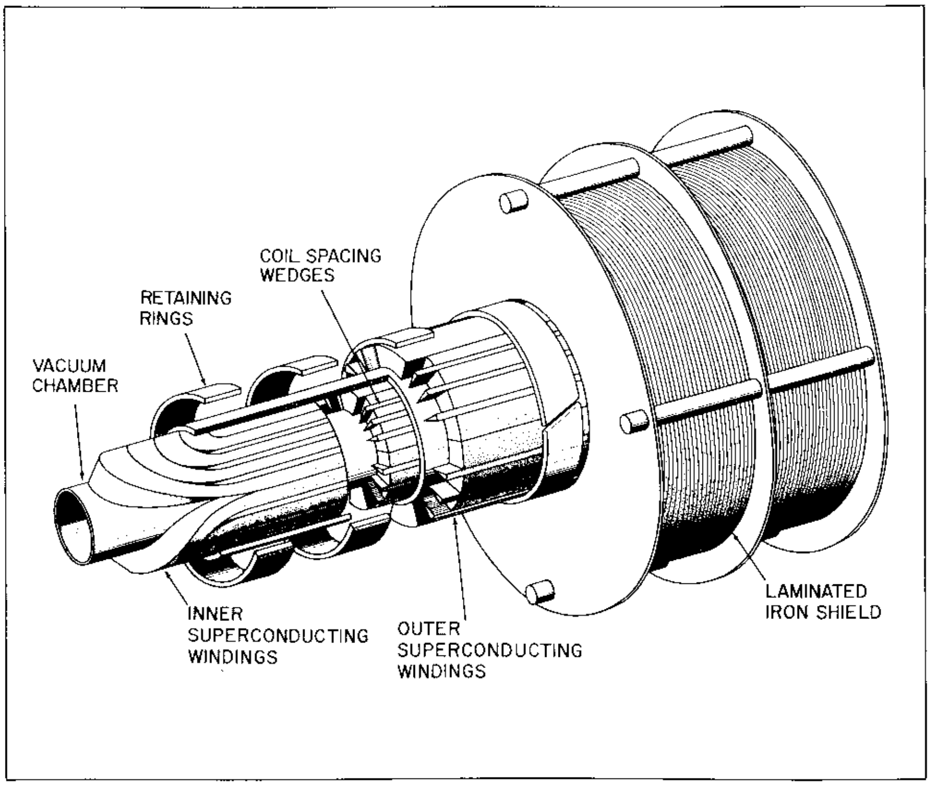
With cable, 'self-field' effects have to be watched (Rutherford once found current running in the wrong direction down the centre strand of a seven strand cable) but generally the indications are that losses due to self-field effects will be negligeable compared with other losses. (A calculation from Karlsruhe in one particular conductor configuration gave 0.1 W/m as the self-field loss compared with 4 W/m from hysterisis and 3 W/m from eddy currents.)

Before leaving the conductor, it is worth reporting some promising work at Brookhaven on another type of superconductor — vanadium-gallium, V_3Ga, which can also be produced in thin filamentary form. It can climb to considerably higher fields (over 20 T) than NbTi before going normal (losing its superconducting property) and its critical temperature (the temperature at which it goes normal) is 14.5 K. This could give great savings in refrigeration costs running V_3Ga at, say, 8 K rather than NbTi at 4 to 5 K. Brookhaven are having enough V_3Ga made to build a small magnet and Karlsruhe are also planning to study it. However, despite its enticing properties, it is unlikely that V_3Ga superconductor will be available on a commercial scale, as is NbTi, for many years.

There are a variety of approaches to potting the conductor in coils. Berkeley are averse to potting, maintaining that it leads to poor coil performance since it inhibits good cooling which they maintain is the



Photograph of a model superconducting dipole magnet built at Brookhaven. It uses niobium-titanium superconductor composite in braid form with the conductor around a circular aperture in a cos Θ distribution. Laminated iron closely surrounds the superconductor. Such magnets, to give 4 T in the aperture, are now being built 50 cm long.
A rather more complex design is shown in the drawing. It involves two layers of superconducting windings so as to achieve a field of 6 T. Note the coil spacing wedges which spread the conductor around the aperture and the 'clean' configuration of the conductor at the ends of the magnets.



more important factor. This is not borne out by others who are trying different materials. Rutherford, where the approach is typically broadly-based and thorough, have had many coils through many cool-downs both without impregnation and with impregnation (using unfilled epoxy resin, filled epoxy resin, wax, ice, oil or nitrogen). 'Training' (progressive approach to the performance achieved with short samples of the conductor) appeared to be correlated with internal mechanical energy stored in the coil during fabrication and cooling. As the coils settled down mechanically their performance improved and all the potted coils reached over 90 % of the short sample performance.

Rutherford are going for filled epoxy and will probably look at some inorganic potting materials also. Brookhaven have recently had some good results from a thermosetting plastic insulation (known as Polybondex 180) which has excellent low temperature properties.

Coil shapes to give the required field configuration in the magnet aperture come in two styles — constant current density, requiring appropriate distribution of the current carrying conductor (arranged in 'V' shape each side of a circular aperture in the Saclay design and like an elaborate 'U' each side of an elliptical aperture in the Karlsruhe design) and cos Θ distribution, where the conductor is spaced cylindrically around the aperture with the conductor on the median plane carrying higher current than those above and below. This latter is the favoured alternative at Brookhaven illustrated in both the photograph and sketch. It has by no means been proved to be the optimum design, and needs more work before required precisions are assured, but it appears to have a simplicity of construction (a 35 cm long, 5 cm aperture model was completely wound in less than four hours) which the design must ultimately have before magnets are produced commercially by the hundred for a high energy synchrotron.

The question of where to place the iron seems to be coming down in favour of iron as close as possible around the conductor. At Brookhaven, it is treated as a laminated iron core and an integrated part of the design, its thickness being selected to minimize the sextupole component of the field and its variations. It helps to keep stored energy down and can add over 1 T to the field in the aperture. It also serves as a mechanical clamp around the windings. The heat losses in the iron, which is within the cryostat, are not regarded as adding seriously to the refrigeration problems. Dipole magnets are however being built (e.g. at Saclay and Karlsruhe) with the iron used as a shield outside the cryostat to cut down external fields. Thus both options will be studied in the next few years.

Cryogenics, radiation problems, power supplies

Comparatively little attention has yet been given to the cryogenics problems on the large scale of a high energy synchrotron — there is little practical work to back up the calculations on the required refrigeration and on the costs likely to be involved. Estimates for the helium cooling system of a 1000 GeV superconducting machine put the total losses (the static load from the dewars, etc. and from the helium distribution system plus the pulsed load from the heat produced in the magnets) at between 25 and 100 kW (cold watts) requiring up to 15 MW (hot watts) of refrigeration, which is frightening but not prohibitive.

Associated problems — such as

that of keeping down the total volume of helium (not the world's cheapest commodity), of transporting helium around kilometres of machine (perhaps inside a nitrogen cooled pipe, perhaps using the magnets themselves as the transfer line), of using one or several refrigeration stations, of magnet cryostat design (Karlsruhe are working on a plastic cryostat), of possibly enclosing superconducting power leads to the magnets inside the helium lines — all need more thought and some practical experience.

The effects of high doses of radiation on the materials likely to be used in the magnets also need attention. The worry about degradation of the superconductor itself which followed some measurements at Los Alamos (vol. 10, page 184) have been cleared but it would be comforting to have behind us some systematic high energy irradiations of proposed magnet materials. Some beam time at the present high energy machines could usefully be made available for this.

The required power supply to feed a high energy superconducting synchrotron is another frightening but not prohibitive feature. The amount of energy which will need to flow from the power supply to the magnet and back in a 1000 GeV synchrotron is estimated at 150 MJ on the basis of the Brookhaven magnet design and a factor of four higher on the basis of present European designs (Brookhaven plan for 20 % lower field, iron close, lower operating temperature, more compact magnet — smaller aperture, less insulation). In either case, it is a lot of joules to pass around.

Several conventional motor-generator sets or static compensator systems (given a very healthy local electricity grid) could handle the problem. More appropriate, and potentially better if it can be proved in practice, is a novel superconducting power supply and energy store which is being studied at the Rutherford Laboratory. An analogue model of such a system is now in operation and it was one of the highlights of a tour of the superconducting work at the Laboratory to see the model in operation, with a pen recorder tracing out magnet cycles complete with injection platforms and flat-tops. An explanatory article on this power supply will appear in CERN COURIER in the next few months.

Machine design studies

A vital decision, when first sitting down to integrate individual components as discussed above into a machine, is to specify the required aperture. K. Green from Brookhaven puts it that you first work out your proton orbits and then put the hardware around them. Obviously, the smaller the good field aperture in the magnets the cheaper will be the magnets to build and to operate (probably reducing the refrigeration problems and certainly reducing the power supply problems since the stored energy goes up rapidly as the aperture is increased).

These considerations give added weight to the idea of building a superconducting synchrotron in association with an existing high energy machine which would serve as injector. Then the beam could be fed to the superconducting synchrotron already shrunk in size. (An interesting sideline debate on this topic concerned the shrinking in size of an accelerated beam above transition. Very recent results from the Brookhaven AGS indicate that it continues to shrink — they finish with a virtually circular beam in configuration space of 1 cm diameter at 30 GeV with 2×10^{12} protons. At the CERN PS the effect is not clear and detection equipment is being refined to give more precise measurements.)

With high energy injection giving a smaller beam, the aperture in the superconducting ring can go down while still catering comfortably for injection and acceleration. However, this will be to no avail if more aperture is then needed for ejection. Work on slow ejection so far indicates that it might be this which dominates the aperture decision. In designing the machine it may be necessary to begin at the end and define the ejection requirements first. But if ejection does seem to dominate the aperture decision, maybe it is time to rethink ejection schemes.

The attitudes of the different Laboratories at present range from Brookhaven maintaining that 5 cm diameter aperture is sufficient, to Saclay now building a magnet with 10 cm diameter aperture, with Karlsruhe now building a magnet with elliptical aperture 4×7 cm^2.

Another major decision is that of pulse repetition rate. On one side there is the philosophy promoted by R.L. Martin of Argonne to take the strain off the pulsing problems by running the machine as near d.c. as possible (10 s rise time, 100 s flat-top) keeping the physicists happy by accelerating 10^{14} or more protons per pulse. On the other side, most Laboratories are aiming for cycle times nearer to those to which we have become accustomed, i.e. in the 5 s range. This could need a superconducting power supply when the details of stored energy have been clarified.

Turning now to actual design studies : Berkeley are studying a 70 GeV machine, 160 m in diameter with a peak field of 5 T pulsing at between once every 2.5 and once every 10 s. The machine would be built in association with some existing facilities at LRL including initially 50 MeV injection. A slow-cycling 2 GeV superconducting booster could be added later. They are now designing and building superconducting magnets 30 cm to 1 m long.

Brookhaven have quite a detailed study of a 'Cold Magnet Synchrotron (CMS)', already in print (BNL 15430). They considered also the use of 'cryogenic' magnets (see CERN COURIER vol. 8, page 186) but these are now taking second place to superconducting magnets. They have designed a superconducting conversion of the 30 GeV AGS having another ring near the floor in the same tunnel. Parameters are — peak energy 112 GeV, diameter 260 m, magnetic field rising from 1 to 4 T injecting at 30 GeV from the AGS. (If the 6 T magnets, mentioned above, are mastered the peak energy could be nearer 150 GeV.) The beam intensity is set at 10^{13} protons per pulse with a repetition rate of one pulse per 4 s (1.2 s acceleration, 1.6 s flat-top). They have also considered a 2000 GeV superconducting synchrotron. The immediate effort is concentrated on building a set of magnets 30 to 50 cm long by the end of 1971 and, on the basis of experience with these magnets, to come to the detailed design and construction of magnets about 2 m long such as would be used in the machine.

Karlsruhe are thinking of a 1 GeV 'table-top' model which could eventually serve as 'meson factory'). They are constructing 40 cm dipole magnets and hoping to have, sometime in 1972, a 1 m magnet to give 5 T with a 2 s rise-time. They also have quite a broad programme of work on the associated problems — cryogenics, radiation, etc.

Rutherford have studied the possibility of a conversion, known as the SCS (superconducting synchrotron), of the 7 GeV Nimrod. Using the existing accelerator building, a machine with the following main parameters could be possible — 22 GeV energy, 55 m diameter, peak field of 6 T, injecting at 400 MeV from a booster fed in turn by the existing 15 MeV linac, accelerated intensity over 2×10^{12} protons per pulse at a repetition rate of 6.75 s. They have also considered a 50 GeV machine removing the restriction of using existing buildings. Model magnets 50 to 100 cm long to give around 4.5 T are being designed and built.

Saclay have also proposed a superconducting conversion of their existing machine, the 3 GeV Saturne. They maintain that before a very high energy machine could be undertaken, a 'pilot' machine of this kind should be built (other Laboratories might not insist on a full pilot machine but would certainly want to see a machine sector in operation). By about the end of 1971 Saclay hope to have a magnet 50 cm long, 10 cm aperture to give about 6 T with a 1.5 s rise-time.

A great deal of the effort at the three European Laboratories is going into the study of a superconducting synchrotron which might come about at the CERN Laboratory II. Options with regard to the use of pulsed superconducting magnets have been left open in the preliminary design of the CERN II machine (see, for example, vol. 10, page 110).

One option is that having started construction with conventional magnets (to give say 200 GeV) there could be sufficient space around the ring to slot in superconducting magnets to give at least double the energy. This idea of a single ring having both conventional and superconducting magnets looks rather less promising as the requirements of superconducting magnets become clearer. The need to go for the smallest possible aperture, for example, may prevent integration in a conventional ring. However, a ring in the same tunnel, possibly fed at high energy from a 200 GeV conventional ring, is another alternative. A possible operating scheme which could take the pressure off the rise time of the superconducting magnets, if need be, would be to interleave the output pulses from the superconducting ring (fed by the conventional ring) and the conventional ring, thus feeding physics programmes at two energy ranges. But it is too early to pin things down.

The three European Laboratories have formed a collaboration known as GESSS (Group for European Superconducting Synchrotron Studies) which is effectively carrying out development work on behalf of CERN II and advising CERN II on the possibilities. GESSS meets at regular intervals to discuss problems and to pool information on progress. They have as their ultimate goal the design and construction of a 1000 GeV superconducting machine at CERN II.

As the CERN II people, who will initially design a machine for several hundred GeV using conventional magnets, come together from the middle of this year there will no doubt also be close contact between them and GESSS. Several design decisions on the conventional machine could go a long way towards making life easier in any superconducting addition.

By the beginning of 1974, GESSS predicts that several superconducting pulsed magnets on a scale appropriate for a 1000 GeV machine will have been built and put through their paces over several million cycles. By then the associated technologies will also be better understood and it should be possible to have a realistic stab at the cost. This information will then be fed into the balance pans at CERN II in discussing the future development of the Laboratory.

CERN News

Gargamelle inauguration

On 7 May, the heavy liquid bubble chamber, Gargamelle, was inaugurated at a ceremony held in the Gargamelle hall. The chamber passed formally from the charge of its designers and builders at Saclay, to the charge of CERN. There was a large gathering in the hall, both of those who had worked on the construction and of those who are now to use the chamber in experiments. They gave the largest heavy liquid bubble chamber in the world at appropriate send off.

After everyone had had an opportunity to admire the huge chamber and to see photographs of the first neutrino tracks which it had produced, speech-time began and R. Levy-Mandel (Director of the Saturne department at Saclay), A. Lagarrigue (Director of the Linear Accelerator Laboratory at Orsay) and Ch. Peyrou (Director of the Track Chambers Division at CERN) traced the development since 1964, when A. Lagarrigue, A. Rousset and R. Florent first sketched the outline of the project. Saclay (with help from Orsay, Ecole Polytechnique and CERN) solved, one by one, the difficult problems involved in constructing an instrument of this size. The most worrying times were in 1968, when difficulties in the manufacture of the body of the chamber (one of the largest, most complex pieces of metalwork in steel ever attempted) made it clear that the original schedule for Gargamelle could not be met. The decision was then taken to assemble component parts directly at CERN and to omit the testing stage intended to take place at Saclay. Great efforts were made by the Gargamelle construction team (there was a gap of only four months between July 1970, when the chamber body arrived at CERN, and the first photographs of cosmic rays) to make up a considerable part of the delay. It is sad that one of the main architects of this success, J. Lutz, who for five years led the construction work, is no longer here to see the fruits of his labour.

View in the Gargamelle hall (the pressure tanks of the large heavy liquid bubble chamber can be seen in the foreground) during the inauguration ceremony on 7 May.

CERN 78.5.71

The Director General of CERN, W. Jentschke, concluded wishing Gargamelle well in its coming years of physics research. Before the inauguration ceremony, the chamber had already taken 14 500 photographs of antineutrinos and neutrinos which can be used (together with many photographs of neutrons, muons and protons) and the quality of its performance makes for an excellent start.

Gargamelle began its first scheduled physics experiment on 13 May. The first was very brief (two days) and consisted of an attempt to see new types of leptons (stimulated by some intriguing observations at Stanford). For this, the shielding of the neutrino line was directly bombarded with protons.

The next experiments will be those scheduled long ago (see vol. 10, page 254). The first is being done by the Aachen - Brussels - CERN - Ecole Polytechnique - Milan - Orsay - University College collaboration and will involve a total of 400 000 photographs to study neutrino interactions. The second, carried out by the Bergen - CERN - Strasbourg collaboration, will also involve 400 000 photographs to study neutral mesons.

Omega progress

One of the major items of the CERN I improvement programme is the construction of Omega — a large 'universal' detector using electronic techniques (described in vol. 9, p. 31). It is intended to be used in much the same way as a bubble chamber. This means that it will be fixed permanently in position in the West Hall and will accommodate a wide variety of experiments with little modification. The variety will come from the internal arrangement of detectors and the peripheral triggering systems which will vary from one experiment to another.

Possible use of Plumbicon

The main component of Omega is a large superconducting magnet which will provide a field of 18 kG over a useful volume of 14 m^3. It was decided that, for initial operation at least, optical spark chambers would fill the magnet aperture and events would then be photographed by cameras similar to those of bubble chambers. The advantage over bubble chambers is that the system would be triggered to photograph only the interesting events. Given the 'dead time' of at least 50 ms for normal optical spark chamber systems, a potential data-taking rate of ten photographs per PS cycle (500 ms slow ejection) would exist, though a figure half this would be more typical.

However, we would still be left with the messy and time consuming business of scanning and measuring photographs. It was suggested early on, that, to eliminate this drawback, television cameras could be used to give direct readings by converting the information in the spark chambers into electronic form, leading to direct processing by a computer. Vidicon television cameras, however, are less reliable than 'still' cameras and their resolution time is 100 ms, twice as long as an ordinary camera. Thus the early studies were halted.

In January 1971, a team from the University of Birmingham, Rutherford Laboratory and Westfield College London proposed the use of colour television cameras of the Plumbicon type which have recently become commercially available and which have a much shorter dead time (between 5 and 10 ms). There would be eight such cameras covering the Omega volume. Their data taking potential is over fifty events per PS cycle (though, again, figures half of this would be more realistic) implying that figures approaching a million events per day become possible. The accuracy with which sparks can be located with such a system should be better than 0.5 mm and neighbouring sparks should be resolved over 10 mm. One problem is the range of spark intensities with which the system will have to deal. It was known that the Plumbicon cameras could cope with a range of 50 to 1 but it has since been found that for detection efficiencies of over 90 % the range could be over 300 to 1 requiring uncomfortably large camera apertures.

People from the original proposing group, from CERN and from Ecole Polytechnique (where the digital electronics right through to the computer interface is being tackled) are working on the Plumbicon system. Two prototype cameras are being built and the eight required by Omega could be ready for operation in the first half of 1972. However, there has been delay in the construction of one of the support steel plates for the magnet and commissioning in the second half of 1972 is likely to proceed initially with only one coil in action.

Use of proportional chambers

Since the initiation of Omega, an additional factor has had to be taken into consideration — the possible use of multiwire proportional chambers (MPCs) in detection systems (see CERN COURIER vol. 10, page 150). Recent improvements have made them particularly suitable for use in a magnetic field where we want to use the volume to the full — as in the case of the ISR split-field magnet (see vol. 10, page 145) and Omega. For Omega, however, a change from optical chambers to MPC's has not yet been fixed. It will probably be when high energy beams from the 300 GeV accelerator become available.

The advantages of MPC's are, firstly, that they can operate in high magnetic fields, and secondly, and more importantly, that they have a very short resolution time (less than 100 ns), which means that the data taking rate can be very high. Initially, MPC's will be used for triggering, where they can be more selective than scintillators.

The associated computers

In addition to the advantage of fast data collection, it will be possible to trigger several experiments at the same time in Omega. This will allow groups to perfect their equipment without prejudicing the main experiment on hand and save valuable time. It requires close cooperation between the groups and the drawing up of a programme beforehand, mainly because they must plan the use of the two computers associated with Omega, an EMR 6130 and a C II 10 070, both of which have successfully passed acceptance tests at CERN.

The way in which the computers will be used will evolve in the course of operation. An experiment using the electronic technique must be continuously monitored (usually by a small on-line computer such as a PDP 11). In the case of Omega such computers can be connected to the C II 10 070 for more complex monitoring programs. During the data taking phase of the experiment, the EMR 6130 will also come into action serving mainly to record the data on tape. It may also be used to process results and display them on a screen, calling on the CII

10 070 for help with any complex programs.

Direct data processing would make it possible, primarily via display on a screen, to know results immediately. There are two schools of thought on this subject. The first is the traditional one, which considers that direct processing provides insufficient time for reflection and that time is needed to digest data thoroughly. The second is the 'instant discovery' school. Certain experiments could justify such processing but would require long and careful preparation in advance. In general, the lack of very large computers for on-line processing, will dictate the processing of some of the results immediately and the bulk at leisure.

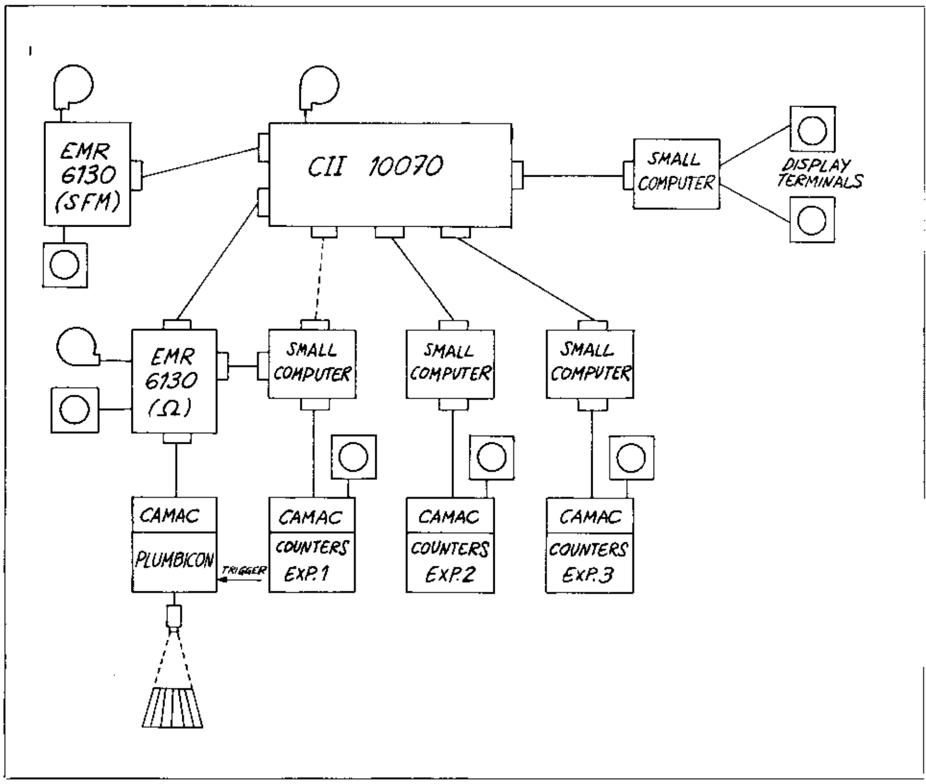
Another inter-relation of the EMR and C II computers would be when two experiments are carried out at the same time (using the same incoming beam, obviously). In such a case, the EMR would record data from one experiment and the CII from the other. The C II is likely to be very occupied also with postponed processing, particularly since it will also serve for experiments carried out with the ISR split-field magnet, which may take half its time.

First scheduled experiments

The diagram shows the arrangement of detectors for the first six experiments scheduled with Omega. The experiments will be carried out at momenta between 5 and 15 GeV/c with beams of about 400 000 particles per pulse using a hydrogen target 30 cm long and with a set of four proportional wire chambers available for triggering.

The normal data collection period will be about two weeks per experiment, and all these experiments are likely to be completed in the first year of full operation (1973).

A possible arrangement of the computer system for the first experiments with Omega. The main experiment (1) will use the EMR 6130 on-line to the Plumbicon cameras, a triggering system and a small computer (PDP-11). The equipment for experiments (2) and (3) can be tested at the same time using a small computer to monitor operation backed up, if necessary, by the C II 10 070. The C II computer will also be used for final processing.

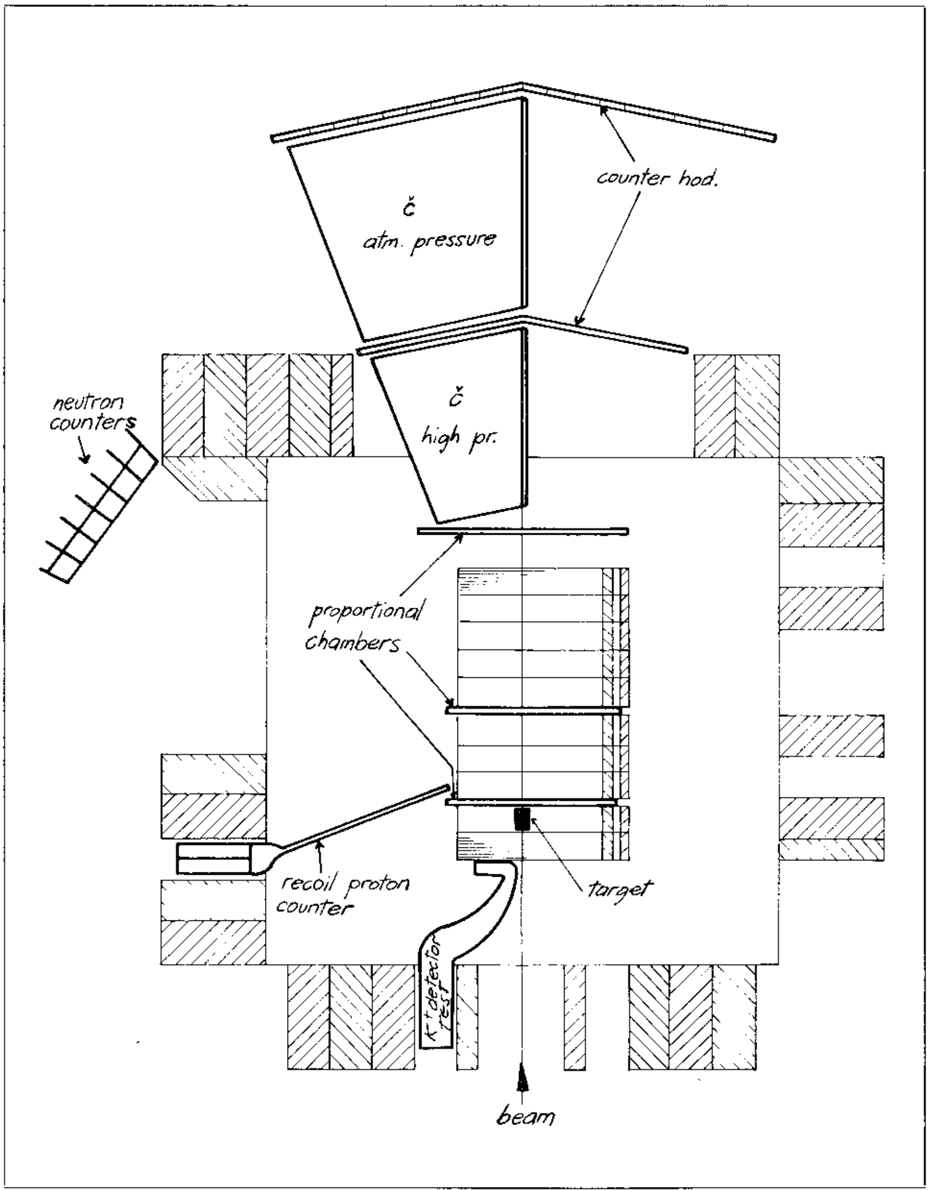


CERN 9.4.71

1. An EMR 6130 computer (made in the USA by a subsidiary of Schlumberger, France) which has just successfully completed acceptance tests. Two of these computers were ordered by CERN in 1969 — one for use with Omega and one with the ISR split field magnet.

CERN 120.1.71

2. View of the C II 10 070 computer, supplied by the Compagnie Internationale pour l'Informatique which completed its acceptance tests in March. The machine can now be used for compiling programmes for-Omega and for the ISR split field magnet, which will be its two main users.



An arrangement of the detectors to be used in the first experiments with Omega. The positive kaon detection system would be added if the experiment is approved.

It should be possible in every case to obtain greater accuracy in the experiments carried out with Omega because of the high statistics which will be possible by comparison with bubble chamber experiments. In this connection, a distinction must be made between two classes of experiment — those where the increase in statistics is of the order of 100 (the first three experiments below) and those where it is around 10 000 (the second three). In the first type it is a statistical increase relating to frequently occurring events that is sought ; in the second, the emphasis is on events which are very rare and therefore of special interest. Some of them have never yet been observed !

The first six experiments scheduled are :

1) Bari, Bonn, CERN, Milan, Liverpool and Daresbury studying negative mesons produced in the reaction $\pi^- + p \rightarrow p +$ negative meson. The recoil protons, curving in the magnetic field, are selected by a $2\,m^2$ scintillator which responds to a missing mass between 1 and 2 GeV. As in the next two experiments, the expected statistics (500 events per microbarn) could resolve some of the many problems raised by mesons encountered in this mass region (e.g. the A2).

2) Rutherford, Birmingham and Westfield College studying neutral mesons. This complements the experiment above and uses a neutron detector.

3) CERN, ETH studying strange neutral mesons $K^- + p \rightarrow K^{0*} + n$. The K^{0*} is detected via its decay products by means of two multiwire proportional chambers. Since the K^{0*} decay is of the type $K^{0*} \rightarrow K^0 + \pi^+ + \pi^-$, and the K^0 decays into a pion pair, the first chamber detects a pion pair and the second chamber two pion pairs. As the K^* is emitted in the forward direction, detection efficiency is excellent.

4) CERN, Collège de France, Ecole Polytechnique and Orsay studying the baryon exchange mechanism leading to a fast proton emitted in the forward direction. This is an extension to inelastic interactions of an experiment on elastic backward scattering, now being carried out at the PS.

5) CERN, ETH, Karlsruhe and Saclay studying the forward production of high energy lambdas by the exchange of strange baryons. This is a special case of the previous experiment, differing from it by a considerable simplification of the triggering system, because the lambda leaves the target before decaying into charged particles.

6) Glasgow and Saclay studying the production of strange or non-strange antibaryons. It is hoped, with this experiment, to be able to see very rare decay modes of heavy mesons.

Finally, a test on a positive kaon detector is scheduled, with the aim of subsequently carrying out an experiment on the production of excited baryons of double strangeness.

81 cm chamber pensioned off

Last month, the 81 cm hydrogen bubble chamber was 'retired' after ten years of operation at the 28 GeV proton synchrotron. Though still hale and hearty, it has been put out to grass in some corner at Saclay where, twelve years ago, it first saw the light of day. The chamber has been most productive, taking sixteen million photographs and deserves to pass into retirement with a suitable eulogy.

The decision to build the chamber was taken at Saclay in 1958. For economy and speed the plans of a chamber already being constructed were used (those of R. Shutt of Brookhaven, with the measurements extrapolated in a 5/4 ratio and with several changes of detail). At that time, small chambers (30 cm) were already in use, and larger ones (for example, 1.5 m at Rutherford and 2 m at CERN) were planned. There appeared to be advantages in the construction of a chamber of intermediate size which could be commissioned before the larger ones. The construction, led by B. Gregory and R. Florent, was completed in a little over two years. The first tests began at Saclay in January 1959 and six months later the chamber was commissioned at CERN.

Almost all of the physics laboratories and universities in the Member States of CERN have been involved in experiments with this chamber, as well as users from USA, India, Israel, Spain, Czechoslovakia and Poland. Its contribution to particle physics has been considerable — for example, the number of particles identified and studied for the first time in this chamber has been assessed at ten, while many more may well have been 'first-timers'.

The experiments which have led to important results may be divided into six categories :

1. The measurement of the relative parity of sigma and lambda, which was found to be 'even' in a study of the invariant mass spectrum of Dalitz pairs in the decay of unpolarized neutral sigma hyperons produced by negative kaons at rest in hydrogen.
2. The discovery of the antiparticle of the negative psi hyperon in antiproton-proton interactions at 3 GeV/c (simultaneously with Brookhaven).
3. Boson resonances. This is a specialized field of the chamber, using antiproton-proton annihilations either stopped or at very low energy. For this purpose, a very pure antiproton beam was used from 1961 onwards, the achievement of such a beam being itself regarded at the time as an outstanding success. Two electrostatic separators supplied by the University of Padua made it possible to select antiprotons from a secondary beam of the proton synchrotron. It has been possible, because of the systematic nature of the experiments, to study a large range of these annihilations and, in particular, to study boson resonances. The short-lived resonances can be recognized only by a study of their decay products. The following were identified :

— C meson : found in proton-antiproton annihilations which give $K\bar{K}$ plus two pions and appears as a $K\pi\pi$ resonance with a mass of 1280 MeV ;

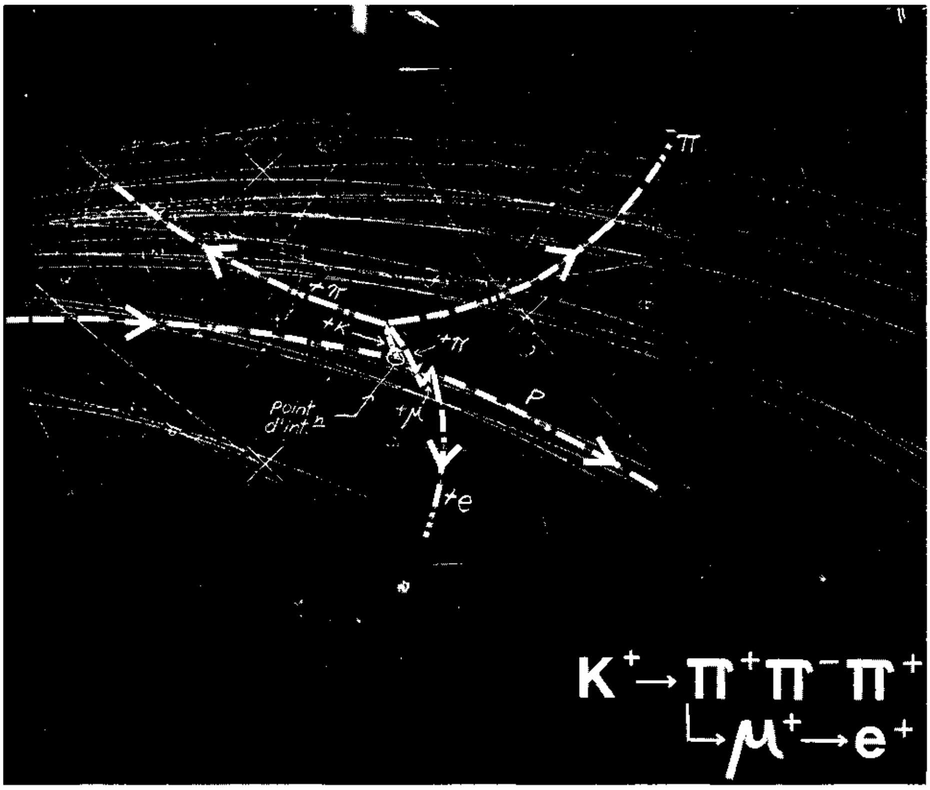
— E meson : observed in stopped proton-antiproton annihilations which give $K\bar{K}$ plus three pions and appears as a $K\bar{K}\pi$ resonance with a mass of 1420 MeV ;

— D meson : observed in low-energy proton-antiproton annihilations (1.2 GeV/c) according to the reaction where D^0 is produced together with an omega meson ;

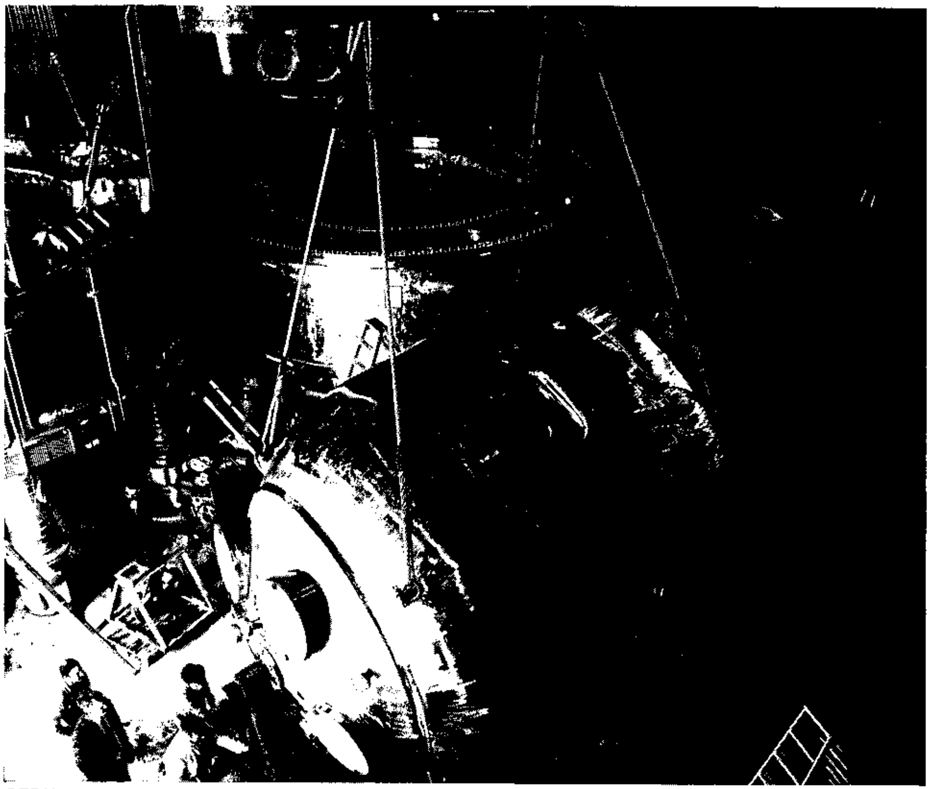
— F meson : observed in low-energy antiproton-proton annihilations appearing as a $\bar{K}K^*$ resonance with a mass of 890 MeV ;

— K^{**} meson : observed in kaon-proton interactions at 3.5 GeV/c incident momentum appearing as a $K^0\pi$ resonance with a mass of 1420 MeV.

4. Strange hyperon resonances : A series of experiments has been made in hydrogen and deuterium to study systematically the formation of strange hyperons in the collision of a negative kaon with a nucleon. This method has been used very successfully in pion nucleon interactions for many years and has provided almost all our knowledge of the excited states of the nucleon. The study consisted in progressively varying the incident kaon momentum (between 430 and



One of the last photographs taken in the 81 cm hydrogen bubble chamber during an experiment searching for 'exotic' resonances. The event recorded is of the elastic scattering of a positive kaon on a proton. The kaon subsequently decays into three charged pions and one of the pions goes to a muon which in turn goes to an electron.



CERN 173.4.71

The body of the large European Bubble Chamber (BEBC), constructed by Mannesmann (Thyssen), pictured shortly after its arrival at CERN on 23 April. The body has 6 windows through which the beam particles will pass, 4 apertures for laser beams and 5 apertures for lenses. It weighs 26 tons, measures 3.85 m high by 3.84 m in diameter, and in parts is 80 mm thick. The body will be installed at the end of August in its final position inside the vacuum enclosure after completion of pressure tests, installation of external heat exchangers and fitting of an inner lining of Scotchlite.

1400 MeV/c) in 20 MeV/c steps and observing the consequent variations in the cross-section and angular distribution of the different reactions produced.

Peaks in the cross-section appear at certain energies, denoting the existence of resonances, the masses of which are determined from the momentum of the incident Ks. A series of resonances with masses from 1540 to 1970 MeV were thus demonstrated. It has been shown, in particular, that the considerable peak repeatedly found around 1800 MeV is in fact due to the combination of two resonances, one of 1765 MeV and the other of 1815 MeV, the spin and parity of which $(5/2)^-$ and $(5/2)^+$ have been determined. In addition, three new resonances were identified (1670, 1690 and 1830 MeV).

5. Exotic resonances : An important programme of research has recently been undertaken to find out whether there exist baryons of positive strangeness, known as 'exotic states'. A set of experiments similar to the K^-N set mentioned above was organized to study their possible existence and the results are being analysed.

6. Weak interactions : The properties of the main decay modes of hyperons into particles sensitive to the strong interactions are well known. However, certain decay modes of the hyperons involve the production of particles sensitive to the weak interaction and had not previously been studied because of their rarity. These modes were studied during an extended series of experiments with stopped negative kaons. Precise values were obtained for the frequency of the rare lepton decay modes, while the study of the angular correlations between the particles from the decay and their momentum distribution made it possible to determine the hadron and lepton couplings which were found to be in accordance with Cabibbo's theoretical model.

The career of a chamber which has contributed much to our knowledge of the behaviour of particles is thus over. It could continue to render solid service for years to come but, in a period of tightening budgets, it gives way to the superior quality offered by the CERN 2 m chamber and the coming 3.7 m chamber, BEBC.

ERASME
Computer ordered

To cope with part of the output of the experiments to be done in the 3.7 m European hydrogen bubble chamber, a new data handling system is to be established at CERN. It has come to be known as ERASME, an abbreviation of Electron RAy Scanning and Measuring Equipment, and will be described in more detail in a later issue. Here we report an important step in the project which has been taken in the signing of a contract with Digital Equipment Corporation for a PDP-10 computer.

The design of ERASME has been based on the experience gained by the Data Handling and Track Chamber Divisions in the construction and operation of systems for handling bubble chamber film. It will consist of a number (there is potential for five) of scanning and measuring units (S/M units) linked to a central computer (the PDP-10). Each S/M unit will have its own precision cathode ray tube scanner (see vol. 10, page 9) to make the measurements, and the film image will be projected optically so that the operator will be able to find the events to be measured and to guide the system during the measuring procedure. Immediately after the measurement of an event the computer can reconstruct it in three dimensions. If problems arise during the measurement or in the reconstruction, the operator can provide extra guidance by means of a digital display and the projected images of the events.

The role of the PDP-10 (which will have 96 000 words of core memory, two large disk packs, two magnetic tape units and a line printer) is to provide to each of the S/M units, in a time-sharing manner, the necessary computing capability to control the measuring process, filter the measurements, reconstruct events, output the data on measured events, and communicate with the operators.

Radiation Protection Congress

Report on the International Congress on Protection against Accelerator and Space Radiation held at CERN on 26-30 April

In comparison with the problems posed by the installation of nuclear power stations or the testing of nuclear weapons, the protection of people in and around high energy physics laboratories appears relatively straight forward, and there are few of us who are worried about the radiation risks associated with cosmic rays. This is no doubt due, on the one hand, to the adequacy of radiation protection measures in and around accelerator laboratories and, on the other, to the fact that we live under a protective screen equivalent to about 10 m of water which has ensured the survival of the human race even under the worst solar flare conditions.

The trend in high energy physics is towards higher energies and intensities ; the trend in travel is towards higher altitudes with the risk of exposure to greater fluxes of natural high energy radiation. It was logical therefore that the groups thinking about safety and protection in the two fields should come together. Organized by CERN, the Société Française de Radioprotection and the Fachverband für Strahlenschutz of the Federal Republic of Germany and Switzerland (represented by J. Baarli, M. Avargues and G. Poretti), an International Congress was held from 26 to 30 April at CERN on 'Protection against Accelerator and Space Radiation'. More than 200 people participated from some 20 countries, including all those with a significant space or high energy physics programme.

The presence of biologists ensured that one was always aware of the fact that the subject under discussion concerned primarily human beings, although several aspects could be discerned — the academic (concerned with the fundamental characteristics of energy transfer and biological damage) ; the instrumental (concerned with measuring the desired quantities) ; the organizational (concerned with translating the known information into practical design data and providing the necessary protection service in an economic way).

Atomic energy developments have stimulated an enormous amount of work at low energies on the somatic and genetic effects of radiation and the recommendations of the International Committee for Radiological Protection are virtually universally accepted. Moreover they are explicit and relatively straightforward in interpretation. Extrapolation to high energies, however, is open to various interpretations and there is, as yet, almost no direct biological evidence.

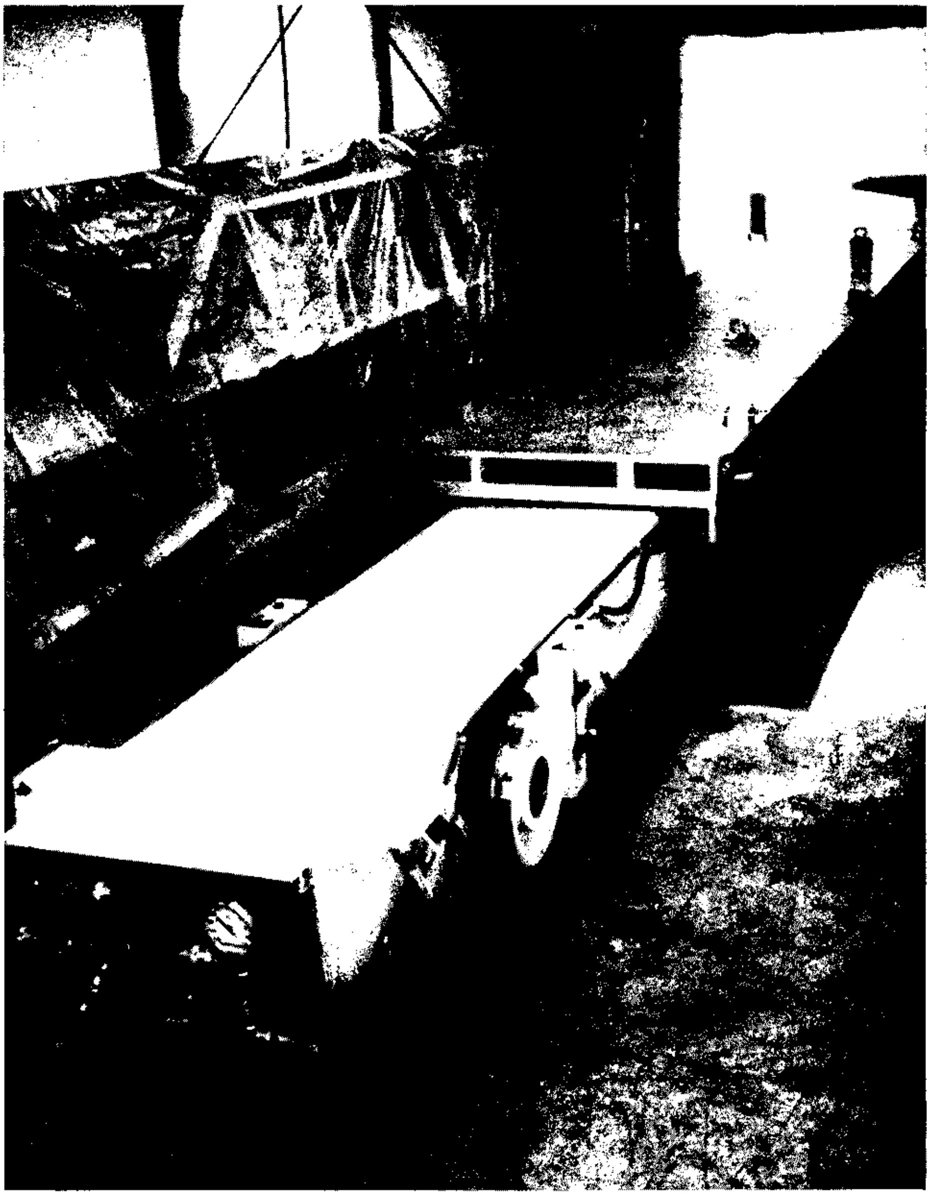
One of the problems in establishing new norms is to get agreement on the quantities that should be measured. The rad is still a perfectly respectable unit which describes the energy deposited macroscopically in a volume of one gram of matter. The LET (linear energy transfer) may mean something different to the physicist and the biologist. The physicist tends to think in terms of the microscopic energy loss from the incident particle, the biologist of the local energy deposition in the tissue.

Confusion also arises in the difference between RBE (relative biological effectiveness) and QF (quality factor), the former is a quantity determined from radiobiological experiments and depends on exposure and biological conditions, while the latter is used exclusively for estimating dose-equivalent for radiation protection purposes. Dose-equivalent, which is rad × QF, has units of rem (Röntgen equivalent man) and is the unit in which radiation effect on you and me is measured. Ambiguities in the interpretation of the units stimulated a special meeting prior to the Congress sponsored by the International Atomic Energy Agency and the World Health Organization both of whom have an interest in putting a little more order into the situation.

From the point of view of practical politics however, even if there are still no perfect mathematical models linking dose and damage, there is good evidence for basing protection systems on the assumption that the flux and the LET are the important quantities which take adequately into account the number of the incident particles and the density of energy deposition. At the dose rates likely to be encountered, damage is proportional to total dose.

To put a few numbers down : the ICRP recommends that exposures to the population should not exceed 5 rem in 30 years equal to a constant rate of 170 mrem per year (19 mrem per hour). The design of the new large accelerator at CERN specifies that, on the basis of present evidence, with a 1000 GeV beam and a loss in the ring of less than 5 % with 6×10^6 pulses per year, the surface dose should be only 1/5 of this figure. (The ring is actually 3 m deeper than is necessary giving an additional factor of 80.) The protection at the Batavia accelerator, NAL, is designed so that even with a catastrophic beam loss the maximum possible dose on a public road would not exceed 85 mrem. Papers from the USSR (quoting also data from other sources) gave the equivalent dose in rems from incident protons or neutrons in the range 0.4 to 2 GeV as 6 to 20 rem for an incident radiation of 10^8 particles per cm^2. Zond-5 on its moon trip recorded a total proton incidence of 3.2×10^6 per cm^2 giving a calculated dose of less than 1 rem.

In a violent solar flare Concorde could encounter doses of up to 1 rem per hour so that on-board warning is needed and the aircraft will need to dive to maintain the dose-rate below 100 mrem/h. (It is expected that the frequency of the need for evasive



The mobile target positioning trolley at NAL. The target, surrounded by steel shielding, can be placed in the beam line with high precision. The steel limits the activation of the soil in the surrounding area.

(Photo NAL)

action about equals that of an engine failure — if that's any comfort.)

With the growth of the subject of radiation protection, considerable effort has been put into the development of instrumentation which can distinguish the LET as well as the rad, particularly for higher energy radiation. There is an everyday need for field instruments and personal dosimeters which give results which are unequivocal and 'good enough'. Set against these last criteria, the speaker from NAL hailed the lithium fluoride in polythene detector, M3, as the greatest breakthrough in health physics instrumentation in ten years.

During the Congress, a number of approaches to the detailed calculation of shielding values were presented. The problem at high energies is complicated by the production of secondaries of high penetration, spallation effects and the production of stars and showers, as well as by the sheer scale (a muon shield may involve a thickness of several hundred metres of earth). In spite of these difficulties, there is reasonable confidence that the sums will not be far wrong. The evidence for this is the satisfactory agreement at Serpukhov and the ISR between the radiation levels experienced and those which had been predicted. But there are still some surprises — such as the fact that the production of N13 does not seem to be a principal source of activity around points on the accelerator where beam losses are significant, as was once assumed.

Radiation protection is however a rather bigger job than simply doing the sums and putting in concrete to fit. Of crucial importance is the organization of protection and the education of staff. It was clear that in many instances the experts felt it was not just the manual workers in radiation areas who needed the education but also laboratory managements and experimenters. There was also a universal wish that the radiation protection service be called in when new facilities are designed rather than after they have been built and proved to be inadequately shielded.

There was still, however, room for different philosophies of approach. At NAL, the tight budget and schedule has meant that capital installations have been reduced to a minimum. Shielding has been calculated on the basis of 0.1 % beam loss but more could be added if it proved inadequate. Target installations are designed to be removable for easy disposal. Remote handling techniques within the ring and service areas are reduced to a minimum and no hot labs are installed. The beam dumps are of aluminium surrounded by steel in a water tank and during operation rely on the heat capacity of the system. The water is only sent through the heat exchangers when the accelerator shuts down, to avoid the problems associated with short-lived activity in water circuits.

The main ring at NAL, like the ISR at CERN, is provided with a multiplex coupled system of monitors since automation has to be used when the areas involved become so large. Such systems have an additional value in giving information to the machine operators on beam loss. But they do not dispense with detailed surveys.

A warning of things to come was the heart-rending story of the fight to save the local children from self destruction (aided and abetted by the local cathedral authorities) in the precints of the Liverpool cyclotron and then the problem posed by the need to dispose of this gallant machine now condemned to oblivion. Is there no one with a requirement for a 300 ton steel muon shield who is not allergic to an odd residual gamma or two ?

Around the Laboratories

VANDERBILT
Sorting things out

Ideas on sorting non-ferrous metals by means of asymmetric magnetic fields have been successfully tested in pilot models at Vanderbilt University, USA. If these ideas can be carried through to machines operating on a commercial scale, the benefits, in terms of recycling resources and of the recuperated cost of materials normally thrown away, could be enormous.

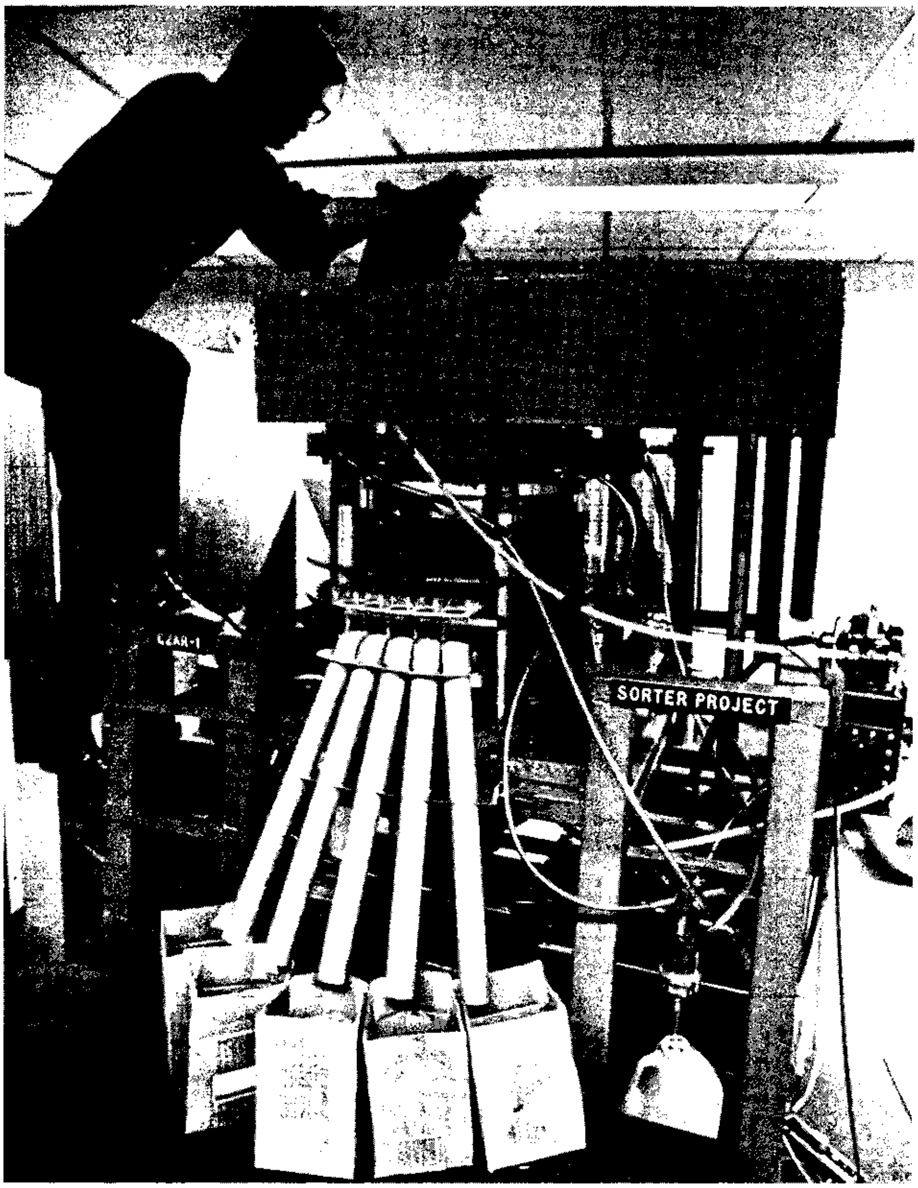
It was at Vanderbilt that the superconducting magnet for HYBUC, the hyperon bubble chamber, was designed (see the March issue, page 64) and it was while working on a National Science Foundation grant for research on hyperon magnetic moments that Ch. Roos side-tracked to look at the metal sorting problem.

A major application would almost certainly be in the disposal of used cars. At present about 6.5 million tons per year is handled by about a hundred car 'shredder' plants in the USA. There they are chewed into lumps of metal about the size of a fist. It is easy to pick out the ferrous materials with a magnet but the remainder, including other metals (copper, stainless steel, aluminium, brass, etc.), can only be sorted by hand or expensive chemical processes. It is thus usually dumped since to separate these metals from the fibre, rubber, glass etc. and to sort them one from another is not a commercial proposition.

The solution which is being developed is to feed the mixture including the shredded metals (normally with a simple gravity feed) through a strong asymmetric magnetic field. The different conductivities of the metals give different flux penetrations and with appropriate field configurations the different metals can be deflected by different amounts and thus separated. The HYBUC magnet was also used to demonstrate that large magnetic effects can be obtained in high magnetic fields with materials normally listed as non-magnetic, such as stainless steel.

Several pilot models have been built at Vanderbilt each with different features — for example, a travelling wave device for the sorting of large pieces of non-ferrous metal, a device called 'Popper' to get at smaller pieces, 'DICUS' which uses d.c. field gradients, 'CZAR' which uses a rotating field. The results of the tests have been very encouraging and devices on a scale compatible with commercial operations are being built.

The development is now supported by the US Environmental Protection Agency and is led by Ch. Roos, J.P. Barach and D.S. Loebbaka. About



One of the pilot models at Vanderbilt University where ideas on sorting non-ferrous metals are being tested. This type is known as CZAR (Cylindrical Z-Axis Rotator) and has a circular arrangement of magnets which is rotated. Numerous materials can be sorted. They are dropped into the device from the top and emerge sorted down the tubes near the bottom.

(Photo J. Corn, Nashville Tennesseon)

1. The 3 λ/2 niobium injector section of the Illinois superconducting linac being prepared for the tests with an electron beam which were carried out early this year.

2. Photograph taken looking from the output end of the cryostat in which the niobium section was installed during operation with the electron beam. As the beam emerges from the cryostat it passes by an ion pump to beam observation stations (a removable screen viewed from the side by a television camera and then a beam analyzing magnet which deflected the beam across a wire).

(Photos University of Illinois)

sixty commercial firms have already expressed interest in the work.

Quite apart from its contribution to the environment pollution problem, the widespread application of metal separation in this way could save the USA economy enough money to comfortably cover the high energy physics budget !

RUTHERFORD Superconducting lead cavities

Several Laboratories are trying to reap the benefits of superconductivity in r.f. cavities. The main potential advantages are high savings in power (which also make it possible to have much longer duty cycles) and much higher accelerating, or deflecting, field gradients. These properties are of interest for linear accelerators (under investigation, for example, at Stanford HEPL, Illinois University, Karlsruhe and Stanford SLAC) and for r.f. separators (under investigation, for example, at Brookhaven, Karlsruhe and Rutherford).

The investigations have almost everywhere swung to the use of niobium as the superconducting material for the accelerator or separator structure. This is because the potential properties of superconducting niobium could yield very high performance figures, and tests on small niobium cavities a few years ago gave very encouraging results. However it is proving difficult to reach these figures or to repeat the simple cavity results in large structures and niobium cavities are not out of the wood yet.

At the Rutherford Laboratory the work was directed towards achieving a superconducting r.f. separator to operate with an average deflecting field gradient of 3.6 MV/m. In the structure the peak electric and magnetic fields at the surface of the superconductor would be 13.8 MV/m and 0.054 T. These figures are within the performance characteristics which can be expected from superconducting lead. At the design operating temperature of 1.85 K the critical magnetic field for lead (the field above which the lead would lose its superconducting property) is 0.075 T. It was therefore decided not to follow the trend to niobium but to concentrate the research on to a lead-lined superconducting separator. An additional reason for the decision was that a 25 % duty cycle could be required from the separator and there is some doubt as to whether the poorer heat conduction in niobium would make this possible.

A full scale structure with two cells was operated by the team at the Rutherford Laboratory — A. Carne, R.G. Bendall, B.G. Brady, R. Sidlow and R.L. Kustom (Argonne) — in April. The structure was a single electroformed copper unit (to avoid problems with joints) lead-plated. Great care was taken during the plating process to avoid 'staining' of the lead and the cool down was done slowly to avoid mechanical stresses. It was powered at the design operating frequency of 1.3 GHz and the following performance figures were achieved: — At a temperature of 4.2 K a Q-value of 1.6×10^8 was recorded (84 % of the theoretical maximum) ; at 2.08 K a Q of 5.5×10^8 was recorded at low power falling to 3.4×10^8 at high power. The peak field was 0.051 T corresponding to a peak field gradient of 12.35 MV/m. Some readings 10 % in excess of these values were obtained and the performance seemed to be limited mainly by heating of the coupling loops which will be cured. Mean radiation from the model during the tests was less than 6 mR.

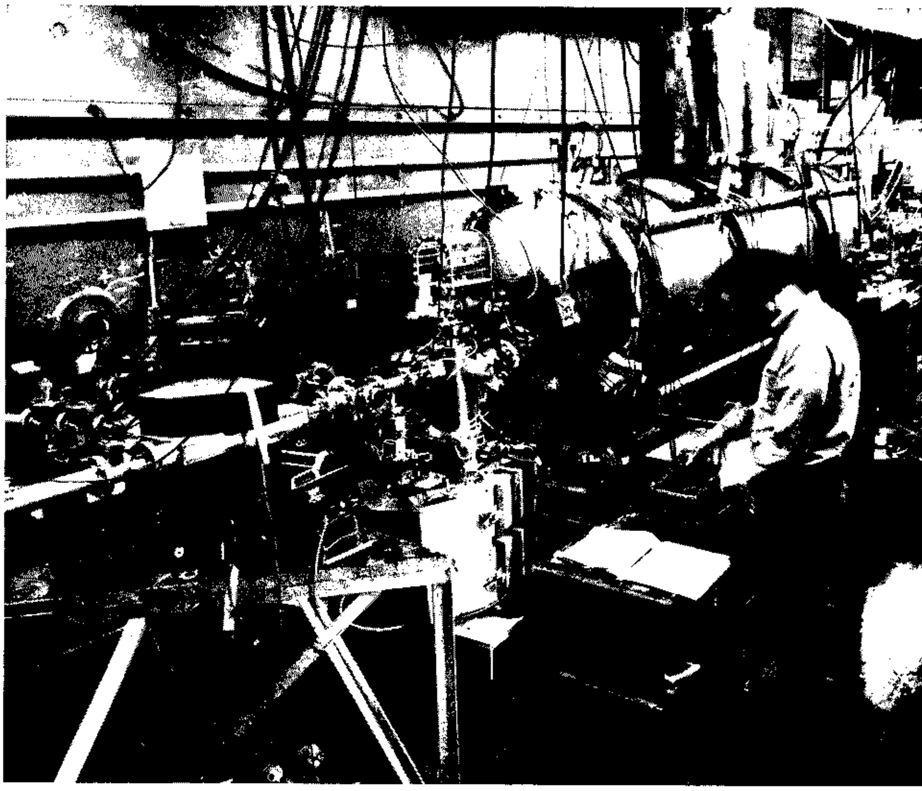
These results are comparable to or better than the best results obtained so far from large niobium structures (though figures at least a factor of two better are ultimately expected from niobium structures). The next step is to build a full size lead-plated structure which will be ready in about a year.

ILLINOIS Superconducting linac first tests

Following on from the Rutherford operation of superconducting lead cavities we can report the first tests with a large scale niobium structure at the University of Illinois. The ultimate aim is to build a 30 MeV superconducting linac which will be the accelerating unit in a 600 MeV microtron (see CERN COURIER vol. 9, page 78). A linac section was operated with an electron beam early in the year. On the one hand, it successfully accelerated an electron beam of good, controllable, quality and cleared several problems concerning vacuum seals, microwave control and cryogenics ; on the other, it has not yet approached the full potential of superconducting niobium cavities.

A 3 λ/2 section of the linac structure was installed in a liquid helium cryostat, operated at a temperature of 4.2 K and powered at 1.3 GHz. All other components of the linac, with the exception of a 13 λ/2 section of the structure, were ready for action. The electron gun is designed to supply 5 mA at 300 kV with energy spread with 0.1 %. For the tests it was operated at 270 kV and the current was limited to 60 μA since some beam-line components were not then capable of handling higher currents.

The superconducting section was assembled from irises and end pieces machined from solid niobium disks which had been forged and annealed



to achieve a fine grain composition so that abrasive polishing would not be needed after machining. Some abrasive polishing did however prove necessary and an initial chemical polishing was done. The Q-value was expected to be high with the niobium surfaces in this state and the structure was assembled without further treatment. A Q of 1.4×10^8 was measured with the temperature in the cryostat at 4.2 K. Following the tests, the section is receiving its final chemical cleaning and high vacuum baking at 2070 K. After this it will be reinstalled and is expected to give higher performance.

The 270 keV beam was accelerated to 1.05 MeV with 30 W of r.f. power into the structure. This corresponds to an accelerating field gradient of about 2.7 MV/m. The beam was 2 mm in diameter 3 m beyond the accelerating section and had an energy spread of less than 1 %. There was no difficulty in controlling the beam characteristics and all the special aspects of the supporting technologies in use in conjunction with superconductivity (vacuum, r.f. system, cryogenics) gave no problems.

The limitation on performance is almost certainly due to field emission from the superconducting surfaces. Effort is therefore moving particularly onto the improvement of surface quality in large structures. After the beam test a second light chemical polish of the $3\lambda/2$ section improved the Q up to 2.7×10^8 at 4.2 K when the section was tested in a vertical dewar.

Electron beams from the linac are scheduled to be used for research towards the end of this year. The 100 % duty cycle will be particularly useful in the production of tagged photons in the Illinois photon monochromator facility.

STANFORD
Ideas on upgrading 20 GeV linac

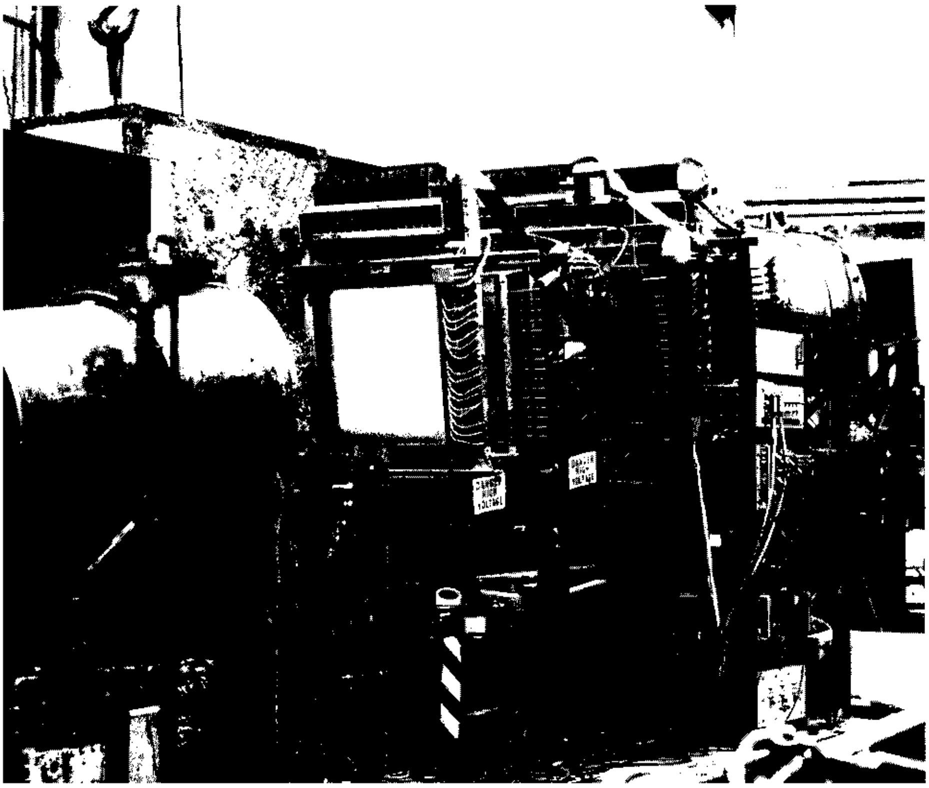
The 20 GeV electron linac at the Stanford Linear Accelerator Centre completes its first five years of operation next month. Its performance has been steadily improved (touching peak figures of 22.1 GeV energy, 82 mA current with a 1.6 μs pulse length and 880 kV average beam power) and it is supporting a vigorous research programme, supplying as many as six interlaced beams of different characteristics.

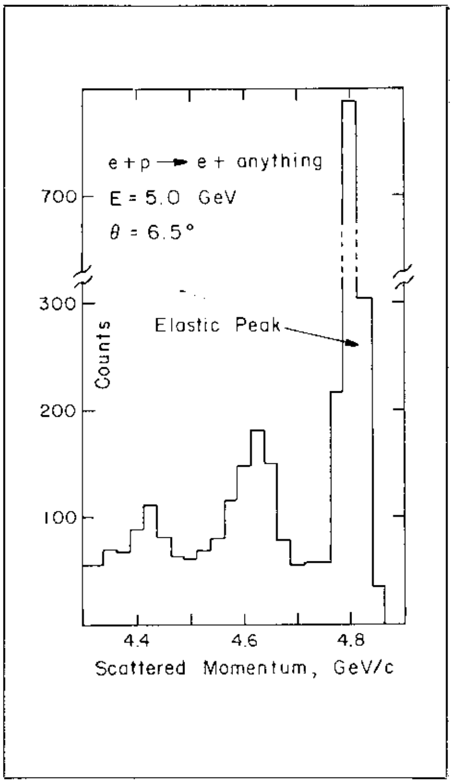
Thoughts on further developing the research possibilities at the linac were summarized in a paper by R.H. Miller, R.H. Helm, W.B. Herrmannsfeldt, J.V. Lebacqz, G.A. Loew, R.B. Neal, C.W. Olson and J.R. Rees at the USA Particle Accelerator Conference in March.

The first possibility is to up the energy to 35 GeV by installing more and higher power klystrons. The present 20 MW klystrons will be progressively replaced as they fail by 30 MW klystrons. After about 2 ½ years the peak energy should then climb to 25 GeV. Adding more klystrons (as was always envisaged in the machine design) so that two 30 MW tubes operate in parallel, and reducing the repetition rate to 180 Hz rather than 360 Hz, would give 35 GeV without significantly higher running costs. Alternatively 60 MW klystrons, if they are developed to a reliable state, might replace the 30 MW tubes. Schemes to improve the duty cycle, which would be an advantage in many experiments, are also being studied. Reducing the beam energy during such operation would keep the running costs the same.

Another possible refinement is a 'monochromatizer' — a travelling wave r.f. separator which would improve the energy spectrum of the available beams by a factor of thirty compared with the present energy defining slits in the beam switchyard.

Major energy increases could be obtained by storing the accelerated electron beam during the time (2.8 ms) between machine pulses and sending it back for acceleration through the linac. This could be achieved by having a loop of magnet at each end of the accelerator to turn the beam back into a long straight drift line parallel to the linac. Between linac





pulses, the beam would be stored in the loops and drift line. Such a stored beam could also be used for long duty cycle experiments.

The alternative path to very high energies for experiments is, of course, the colliding beam technique. There is already the storage ring SPEAR under construction at Stanford (see vol. 10, page 357) and a new possibility would be to collide a 20 GeV beam from the linac with the stored beam (the energy of the beam in the ring being in the 2 GeV region) in one of the long straight sections of SPEAR. There are also possibilities of colliding 20 GeV beams into one another by sending them opposite ways around one of the magnet loops in the recirculating scheme described above.

Finally there is the hope that superconducting linacs will be mastered in the near future leading to the option of converting the Stanford machine into a 100 GeV accelerator with a 6 % duty cycle (as described in vol. 10, page 284). 'Project Leapfrog', which is to study some of the problems in the application of superconductivity, is due for first operation this Summer.

CORNELL
Spectrometer Uses MPCs

The first year of operation of a high resolution spectrometer at the Cornell 10 GeV electron synchrotron has ended with the publication of some of the data obtained on rho electroproduction in deep inelastic electron scattering (Phys. Rev. Letters 26, 864 (1971)). The spectrometer is a rather conventional looking combination of two half-quadrupoles and a vertical bend ; however, what is novel is that the particle trajectories are determined by eight planes of multiwire proportional chambers (MPCs) instead of the more usual scintillator hodoscope system.

A momentum resolution of 0.3 % is achieved not by having a large bending angle (the angle is in fact only 7°) but by taking advantage of the very small vertical spread (about 1 mm) in the Cornell ejected electron beam and of the accuracy given by a wire spacing of 2 mm in the proportional chambers. The smaller bending angle also makes it possible to accept a 30 % range in momenta.

Each chamber plane has 256 wires, making 2048 in all. The wires are made of 20 μm gold-plated tungsten ; the gas is 70 % argon, 30 % n-pentane. Four of the planes have vertical wires and four horizontal. The voltage pulse on each wire is separately amplified by a three-stage linear amplifier and pulse shaper circuit with 1 mV input sensitivity and 4 k Ω input impedance.

When a 'clock' pulse is received from the fast logic trigger, each pulse shaper output is stored in a TTL D-flip-flop until read into the computer (initially an IBM 1800, now PDP-11 on-line to a PDP-10). The circuitry is relatively simple and cheap (about $ 10 per wire). Since there is no provision for delaying the voltage pulses from the wires, the clock pulse must arrive within 120 ns of the passage of the particle ; it is provided by a coincidence of two scintillation counters immediately downstream. The data are read into the computer only if all the trigger logic requirements of the particular experiment are met. The sensitive time under the usual operating conditions is 70 ns.

The chambers have operated very reliably for a year including about 2000 hours of running time. Approximately three million events have been analyzed. Typical plane efficiencies are at least 98 %, and since the analysis requires only three out of four planes in each projection, the track finding efficiency is always greater than 99.5 %. This is probably the first multiwire proportional chamber system of its size to be used in a physics experiment.

PRINCETON
Accelerating nitrogen ions

The Princeton Pennsylvania Accelerator which, as reported in the January

A view of the back end of the Cornell high resolution spectrometer showing the multiwire proportional chambers.

(Photo Cornell)

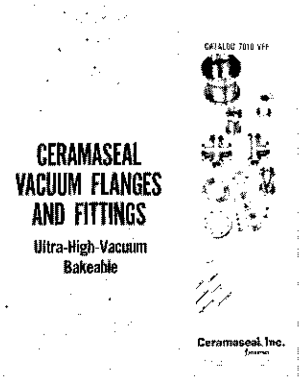
A momentum spectrum of scattered electrons obtained from a single setting of the spectrometer. The peaks, reading right to left, correspond to elastic scattering and the excitation of the first two nucleon resonances.

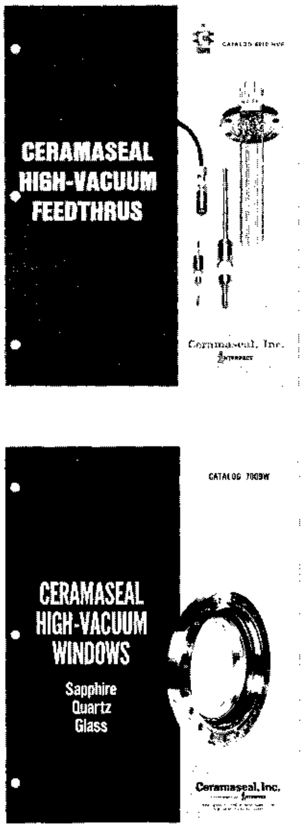
issue page 16, was scheduled to close down on 1 July, has won at least a temporary respite. A grant of $ 230 000 has been made to Princeton University by the Rippel Foundation to enable the PPA to continue in operation until 31 August. The weeks which have been snatched from the jaws of death will be used to achieve acceleration of nitrogen ions to GeV energies and to study the use of high energy heavy ions in cancer therapy.

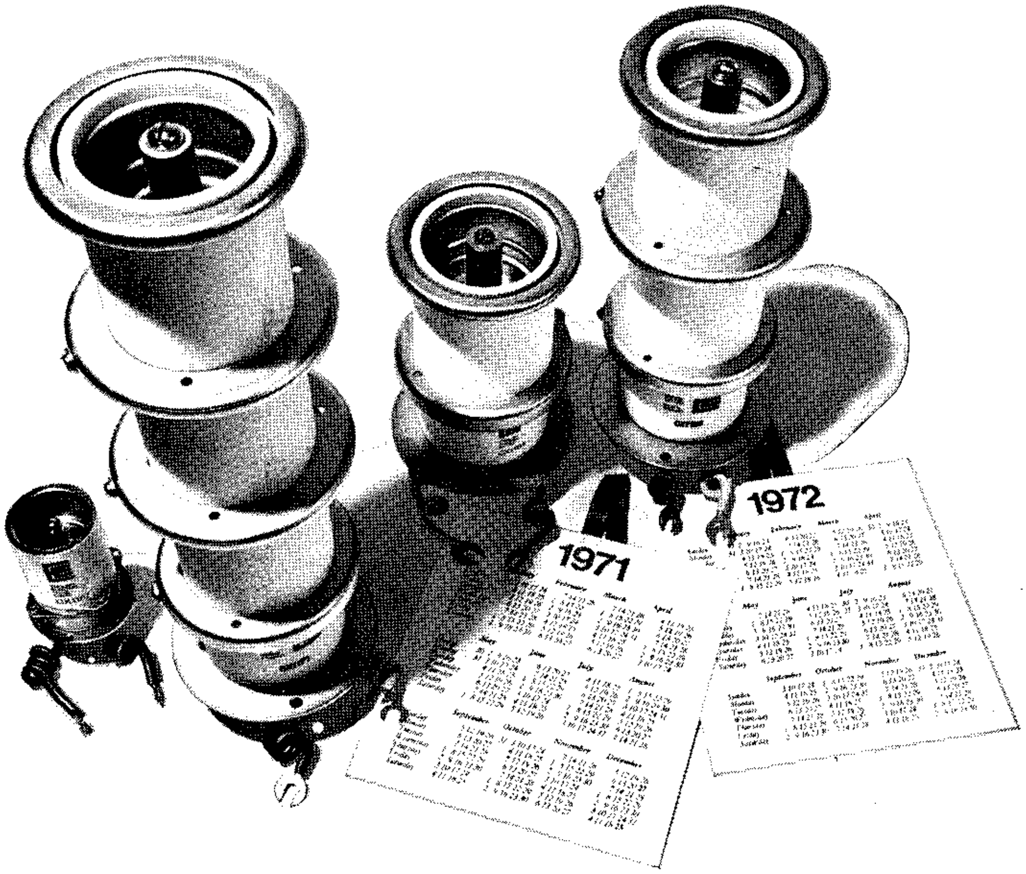
A nitrogen ion source has been installed and ions carrying three or four positive charges will be accelerated to 4 MV in the Van de Graaff injector. The emerging ions will then be further stripped to N^{6+} or N^{7+} in a carbon foil and, hopefully, pulsed currents of around 100 μA of such ions will be fed to the main ring for acceleration to a peak energy of about 16 GeV. (A pressure of 10^{-7} torr can be achieved with the existing vacuum chamber.) Research with the accelerated ions is likely to concentrate in the 3 to 6 GeV region which is best suited to cancer treatment.

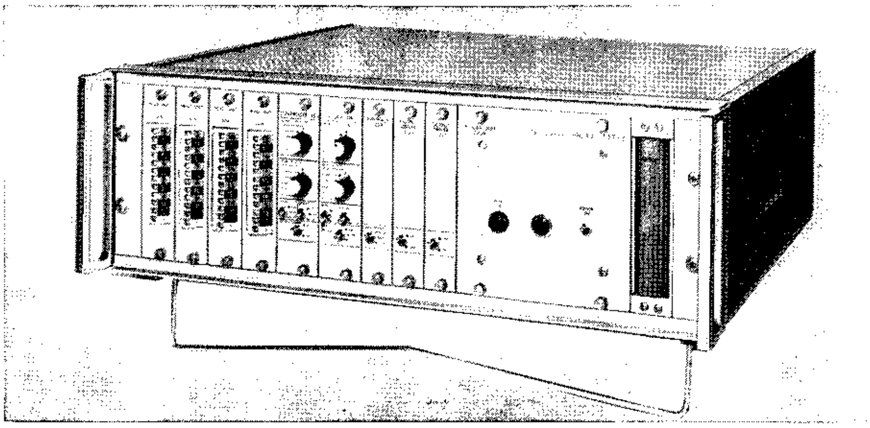
Theoretical comparisons of X ray, neutron, negative pion and nitrogen ion therapy, carried out by P. Todd, indicate that nitrogen ions and pions will both deliver about a fortieth of the skin dose delivered by X rays while destroying a given tumour. To kill a tumour with a volume of 100 cm^3 would require about 10^9 nitrogen ions or 10^{11} pions. The ion method could prove easier, cheaper and more controllable — hence the interest of the work at Princeton.

While these tests are being carried out, the indefatigable director of PPA, M.G. White, is continuing his efforts to secure the longer term future of the accelerator. The National Cancer Institute is being approached for funds to operate the accelerator for cancer studies. The staff is being reduced to 26 people and it is estimated that they could keep the machine ticking over for about 250 hours per month with an annual budget of around a million dollars.






1971
1972



seconds make 10,000 hours.

In nuclear physics you need absolute accuracy and long-term reliability from your electronic tubes. Especially thyratrons. EEV thyratrons can be fired with nano-second precision, with repetition rates of up to 50 kHz due to very rapid deionisation characteristics. Long life – 10,000 hours can be achieved – enables EEV ceramic thyratrons to be bolted into the circuit as with passive components.

EEV thyratrons meet the demands of major nuclear physics applications:

In linear accelerators they can withstand peak inverse voltages up to 20 kV following a pulse, and they give trouble-free operation in oil-filled equipment.

In particle accelerator work missed pulses are rare. Annular current-flow means rapid peak-current switching, too, without risk of arc extinction.

In spark chambers EEV thyratrons will eliminate spurious firing, and jitter can be kept as low as 1 ns. The CX1154 for example operates over a wide range of H.T. voltages at currents up to 10 kA without significant change in characteristics, so drive units can be used with different chambers – and the low trigger voltage means that simple firing circuits are possible.

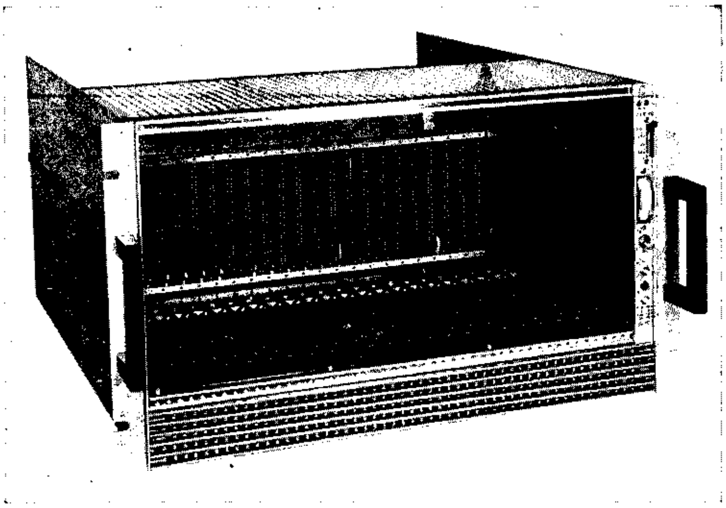
So, whether you're concerned about nano-seconds or thousands of hours, specify EEV thyratrons. And remember that EEV also make ignitrons, photo tubes, storage tubes, image intensifiers, vacuum capacitors, spark gaps, RF tubes (like tetrodes for driving RF separators) and magnetrons especially for linear accelerators. Send for details.

EEV know how.

ENGLISH ELECTRIC VALVE CO. LTD., Chelmsford, Essex, England, CM1 2QU. Tel: 0245 61777. Telex: 99103. Grams: Enelectico Chelmsford.

CRC 33

SAPHYMO-SRAT



Le pionnier
dans les alimentations
Standard « CAMAC »

RPI 95.3 B

C7 ALJ 13 D

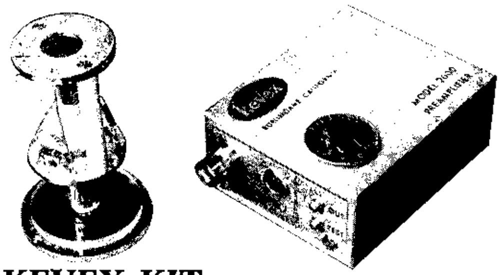
200 Watts disponibles

+ 6 v	25 A
— 6 v	10 A
+ 12 v	3 A
— 12 v	3 A
+ 24 v	3 A
— 24 v	3 A

DEPARTEMENT ALIMENTATIONS
SAPHYMO-SRAT
SERVICES COMMERCIAUX
51, rue de l'Amiral Mouchez - Paris 13e - FRANCE
Tél. 588.16.39, 588.45.39

AUTRES FABRICATIONS

Blocs BSI
Blocs type CEA
Alimentations variables de laboratoire
Alimentations haute tension
Alimentation multi-sorties
Alimentations sur mesure

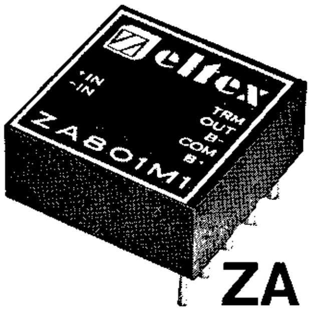


Tips + Topics

ZELTEX

FET-input differential

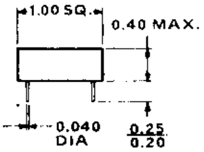
Amplifier

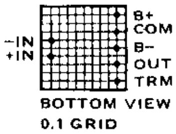


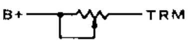
ZA 801 M1

Fr. 47.80 (100-unit level)

CASE STYLE M — Model ZA801M1







Zeltex INC.

PERFORMANCE SPECIFICATIONS

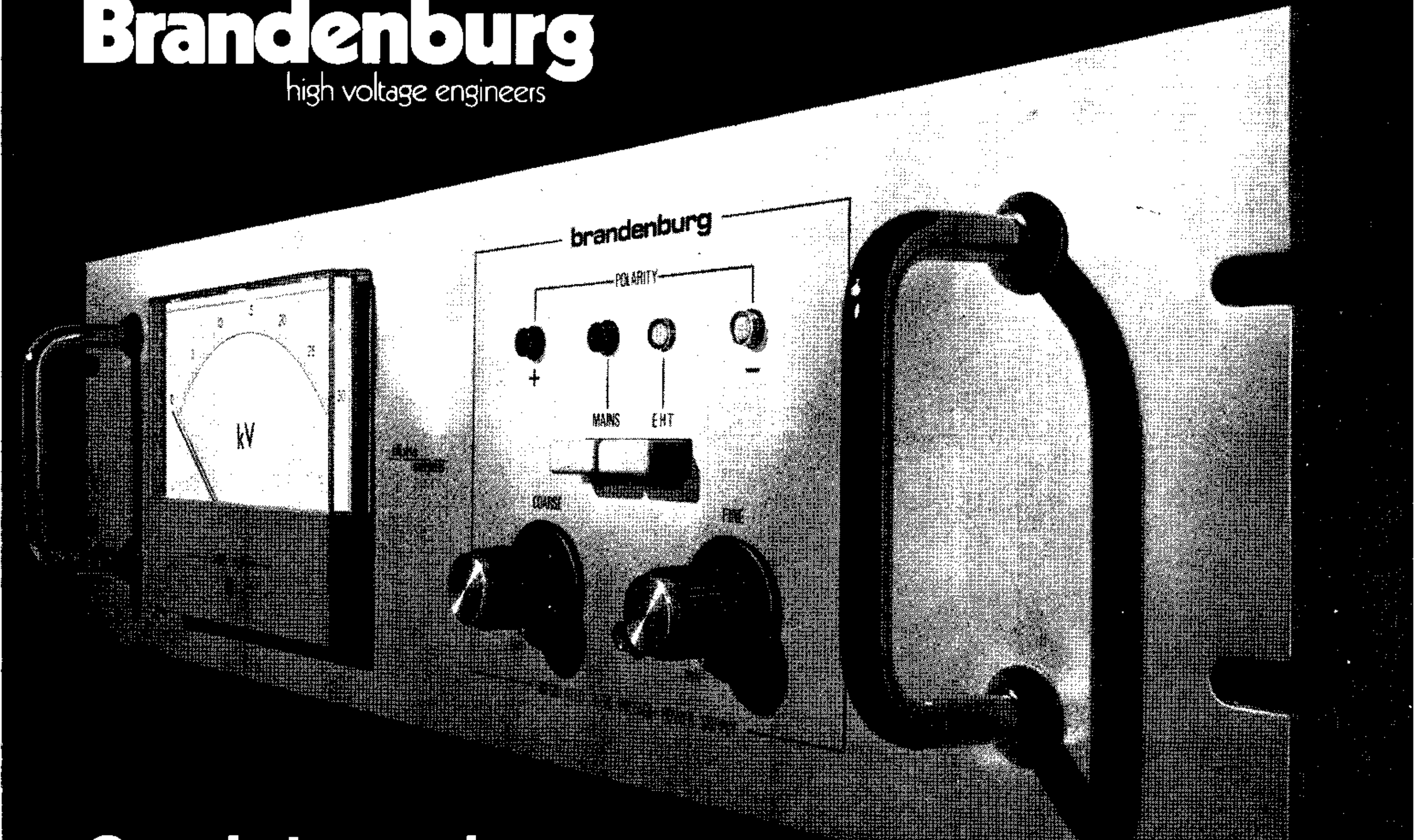
(Typical @ 25°C and ±15 V supply unless otherwise noted)

RATED OUTPUT	±10 V @ 7 mA, min. ±10 V @ 10 mA, typ.
OPEN LOOP GAIN	
@ dc, 1.4k load	10^5, min. 500K, typ.
FREQUENCY RESPONSE	
@ unity gain	4 MHz
@ full power output	100 kHz, min., 200 typ.
slew rate	6 V/μs, min., 12 V/μs, typ.
INPUT VOLTAGE OFFSET	
adjust to zero (5 kΩ)	
with fixed 1.5 kΩ trim	±10 mV, max.
average vs. temp. (—25 to 85°C)	50 μV/°C, max.
average vs. time	75 μV/day
average vs. supply	10 μV/%
INPUT CURRENT	
initial	25 pA, max.
average vs. temp.	doubles every 10°C
INPUT IMPEDANCE	
differential	10^{11}//5 pF
common mode	10^{11}//5 pF
INPUT VOLTAGE	
overvoltage, differential	±15 V, max.
common mode voltage	±10 V, min.
common mode rejection ratio (dc to 400 Hz)	10,000:1 @ ± 10 V
INPUT NOISE, VOLTAGE	
.01 to 1 Hz	4 μV, pp
10 Hz to 10 kHz	3 μV, rms
INPUT NOISE, CURRENT	
.01 to 1 Hz	0.1 pA, pp
OUTPUT IMPEDANCE	
open loop @ dc	1 kΩ
TEMPERATURE RANGE	
operating	—25°C to +85°C
storage	—55°C to +125°C
POWER SUPPLY	
voltage, nominal	±15 V
voltage range	±6 V to ±18 V
current (quiescent)	3 mA

baerlocher

POSTFACH 485, 8021 ZÜRICH ✆ 429900

Brandenburg
high voltage engineers



Spotlight on the new Alpha range of all solid state stabilised high voltage supplies –500V to 60kV.

(40 parts per million for 15 minutes - guaranteed)

Now-the famous Brandenburg Beta range goes into its second generation. We have called it Alpha. Alpha stabilised d.c. high voltage supplies are all solid state. Outputs, ranging from 500V to 60kV, from 0.4mA to 5mA, are continuously variable and polarity reversal is achieved within seconds. Solid state inverters, operating at high frequency into a ferrite cored transformer, provide the required voltage, which is rectified by a Cockcroft Walton multiplier. The Alpha range is light and compact, designed for rack mounting or bench use, and its performance meets the requirements of booth industrial and laboratory duties.

Output Voltage Control	Continuously variable by coarse and fine potentiometers on front panel
Output Voltage Indication	4.5 in scale length meter
Output Current Control	Current metering jack located on rear panel
Output Polarity	Reversible *(Except on Model 907)*
Output Plug and Socket	Brandenburg design moulded in polythene
Output Ripple	0.01 %
Source Impedance	2000 ohms worst case
Stability	0.01 % (against ± 7 ½ % mains change)
Drift	40 parts per million per 15 minutes

Note the prices !

MODEL	507R (Reversible) 500V to 5kV, 5mA, d.c.	Price £ 195
MODEL	707R (Reversible) 1.5kV to 15kV, 2mA, d.c.	Price £ 195
MODEL	807R (Reversible) 3kV to 30kV, 1mA, d.c.	Price £ 195
MODEL	907P (Positive*) 6kV to 60kV, 0.4mA, d.c.	Price £ 295
MODEL	907N (Negative*) 6kV to 60kV, 0.4mA, d.c.	Price £ 295

** with respect to ground*

For full details of the complete Alpha range ask for Publication No : 100/A

Brandenburg Limited

939 London Road, Thornton Health, Surrey,
CR4 6JE. England.
Tel. : 01-689 0441 Telex : 9461 49.

Sole Agents :
Switzerland : Fritz Weber, In der Rehweid 8,
8122 Pfaffhausen, Zurich. Telefon : (01) 85 44 44.
Germany : Mauler-Nukleonik GmbH, 565 Solingen 1,
Postfach 10 12 88. Telefon : (02122) 25682.

P 3630

Procedings of the BANFF Summer School

PROCEEDINGS OF THE BANFF SUMMER SCHOOL ON INTERMEDIATE ENERGY NUCLEAR PHYSICS, August 1970.

Main contributors :

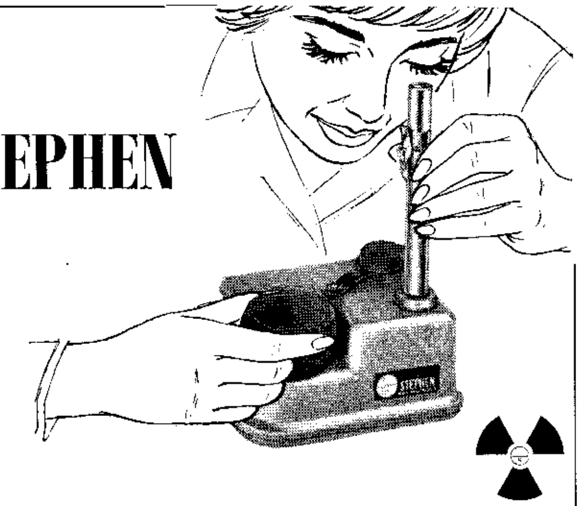
C. WILKIN	(Intermediate Energy Scattering Theory)
J.E. ROTHBERG	(Muon Physics)
T.E.O. ERICSON	(Pions-Nucleus Interactions)
H. PALEVSKY	(Experiments with 1 GeV Protons)
R.J. SUTTER	(Wire Spark Chamber Techniques)

Price (postage included) : $ 7.00 ; soft cover, 440 pp. Available from : The Nuclear Research Centre, University of Alberta, Edmonton, Alberta, Canada. Attention : Miss G. Tratt.

Size of advertisement :

For a 3" wide column, allow approximately 3/4" length.

STEPHEN



QUARTZ FIBRE POCKET DOSIMETER
the unfailingly reliable radiation measuring instrument. Recharging is effected easily and quickly with the

STEPHEN BENCH TYPE CHARGING UNIT
Robust and practical, it is energised by a U2 (1.5 V) flashlamp battery. Will charge all standard quartz fibre pocket dosimeters.

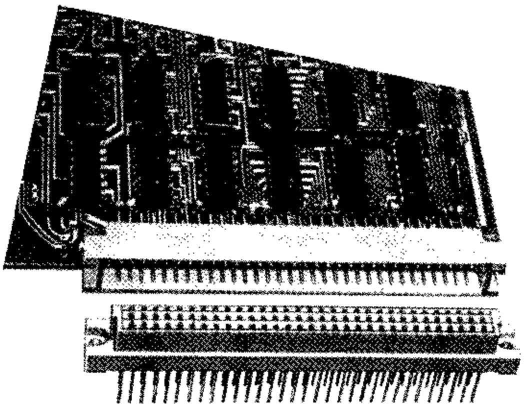
Ask for literature

R.A. STEPHEN & CO. LTD.,
MILES ROAD, MITCHAM CR4 3YP ENGLAND

PLUG - IN CONNECTION FOR PRINTED CIRCUIT BOARDS

« HIGH QUALITY »

Type STV 32, 64, 96 pins



Temperature range: —55°...+125° C
Resistance against shock and vibration:
no contact failure > 1 ms at 50 g between 10 and 2000 c/s

Designed according to: VG 0095324
Tested according to:
CEI and DIN standards

Application:
Space research, aviation, military equipment, general electronic equipment of high quality

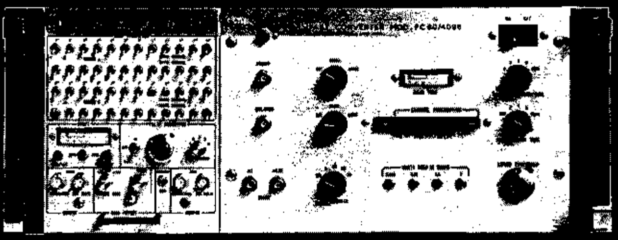
Suitable for single - double - or multilayer - prints.

ERNI + Co. Elektro-Industrie
CH-8306 Brüttisellen-Zürich
Telephon 051 / 93 12 12
Telex 53 699

ERNI

convert with LABEN to convert best

the ADC that opened a new era in data conversion techniques LABEN FC 60/4096



Patents: Laben 745348
Cise 699271

utilizes the sliding scale method to achieve a unique combination of high speed conversion and excellent differential linearity for any type of input signal

- 12 µsec fixed conversion time
- 0.1 % differential linearity
- 0.04 % integral linearity
- 3 input modes: AC or DC coupled, DC restorer
- used everywhere with any computer or pulse height analyzer
- equipped with all solid state Spectrum Stabilizer Mod. SS 60

the newest

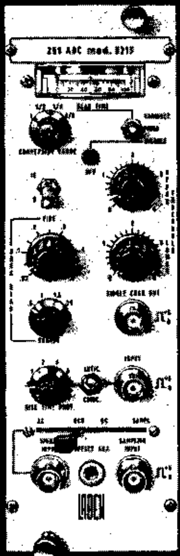
Mod.	Mod.	Mod.
8210	8211	8212
8192	4096	1024

channels

LABEN SERIES 8000
WILKINSON TYPE ADC's
now available
in a **DOUBLE-WIDTH NIM MODULE**
with good differential linearity at a
100 MHz CLOCK RATE

- 0.7 % differential linearity
- 0.04 % integral linearity
- 4 input modes: AC or DC coupled, DC restorer, sampling
- easily used with any computer or pulse height analyzer

the cheapest

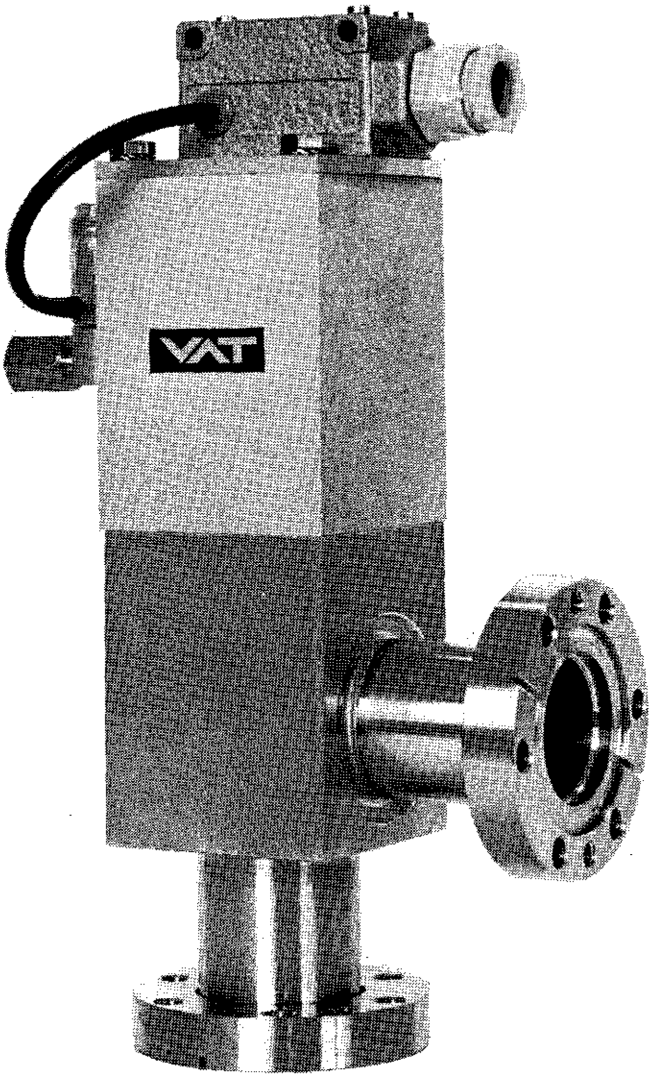


If you need several
and cost is a problem
Mod. 8213
256-channel ADC
is ideal for your multiparameter experiments

- highly versatile
- low-priced

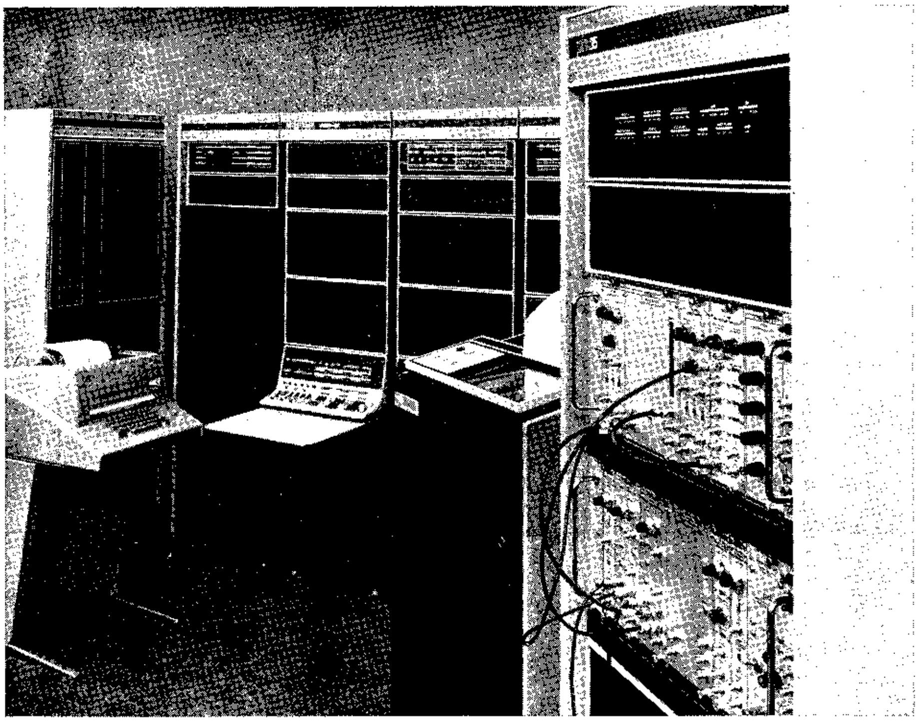
LABEN
Laboratori Elettronici e Nucleari

divisione della MONTEDEL Montecatini Edison Elettronica S.p.A.
Milano - via Edoardo Bassini, 15 - telefono, 2365551 - telex, 33451


VAT

THE PHYSICS COMPUTER

The PDP-15 from DIGITAL handles physics research problems like no other computer around. Take a tough pulse-height analysis. Or a rugged time-of-flight. A difficult accelerator control and monitoring problem. A gamma spectral analysis. Demanding NMR. Sticky problems in spark chamber data retrieval. Spiral reader control. And more.



PDP-15

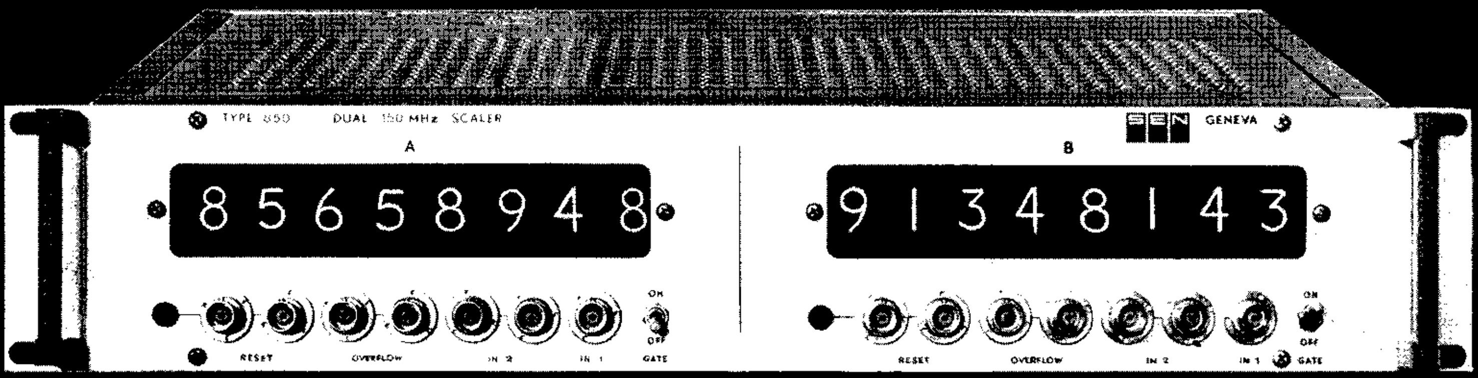
The PDP-15 is a hardware and software giant in high and low energy physics. Five PHA systems. A new CAMAC interface. A special on-line spark chamber software package. Gamma spectral analysis programs. A big 18-bit word. 800 nanosecond cycle time. New lab automation system. Special I/O facilities so operations occur concurrently in overlapping cycles. Many physics oriented peripherals. A super advanced monitor for program preparation. A new floating point processor. Background/foreground systems. A Real-Time System Executive for concurrent real-time tasks. Multi-processor systems. An unmatched price/performance ratio. More than 1200 DIGITAL computers already working in physics. And that's not all.

Write or call

digital

DIGITAL EQUIPMENT CORPORATION INTERNATIONAL EUROPE

81, route de l'Aire, 1227 Carouge/Geneva, Tel. (022) 42 79 50, Reading (0734) 85131, London (01) 579 2334, Manchester (061) 790 8411, Munich (0811) 35031, Frankfurt (06102) 5526, Cologne (0221) 522181, Hannover (0511) 697095, Stockholm (08) 98 13 90, Brussels (02) 13 92 54, The Hague (070) 99 51 60, Geneva (022) 42 79 50, Zurich(051)36 76 23, Milan (02) 87 27 48, Paris (01) 344 76 07, and Maynard, Mass. USA. (617) 897-5111.

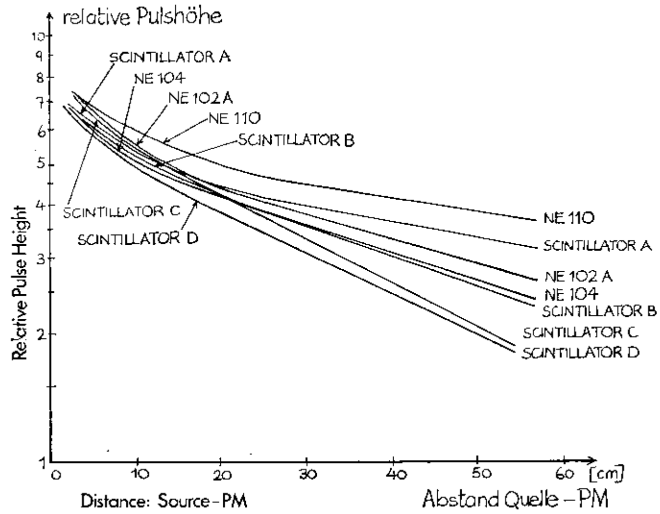

TYPE 850
DUAL 150 MHz SCALER
GENEVA
A
B
85658948
91348143
RESET
OVERFLOW
IN 2
IN 1
ON
OFF
GATE


TTY 33
CONTROLLER
RECORDING
Start
Stop
RECORDING
RESET
BUSY
Type 851

OUTSTANDING LIGHT TRANSMISSION WITH

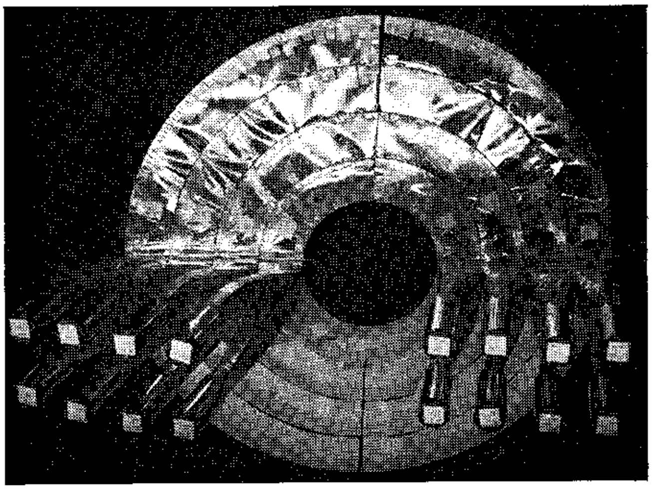
NE 110

Plastic Scintillator



NE 110 has outstanding light transmission with effective light attenuation of approximately 0.003/cm in large blocks corresponding to an attenuation length of over 3 metres. Its superiority over other plastic scintillators from 3 manufacturers is once again clearly demonstrated in a new report by DESY, Hamburg, from which the graph (above) is taken.

NE 110 plastic scintillator is especially recommended for use in large area sheets, and large volume scintillators. It is now in wide use in research establishments such as CERN, Rutherford and Daresbury for applications in nuclear physics, cosmic ray investigations etc.



Counter fabricated at CERN to measure total cross section.

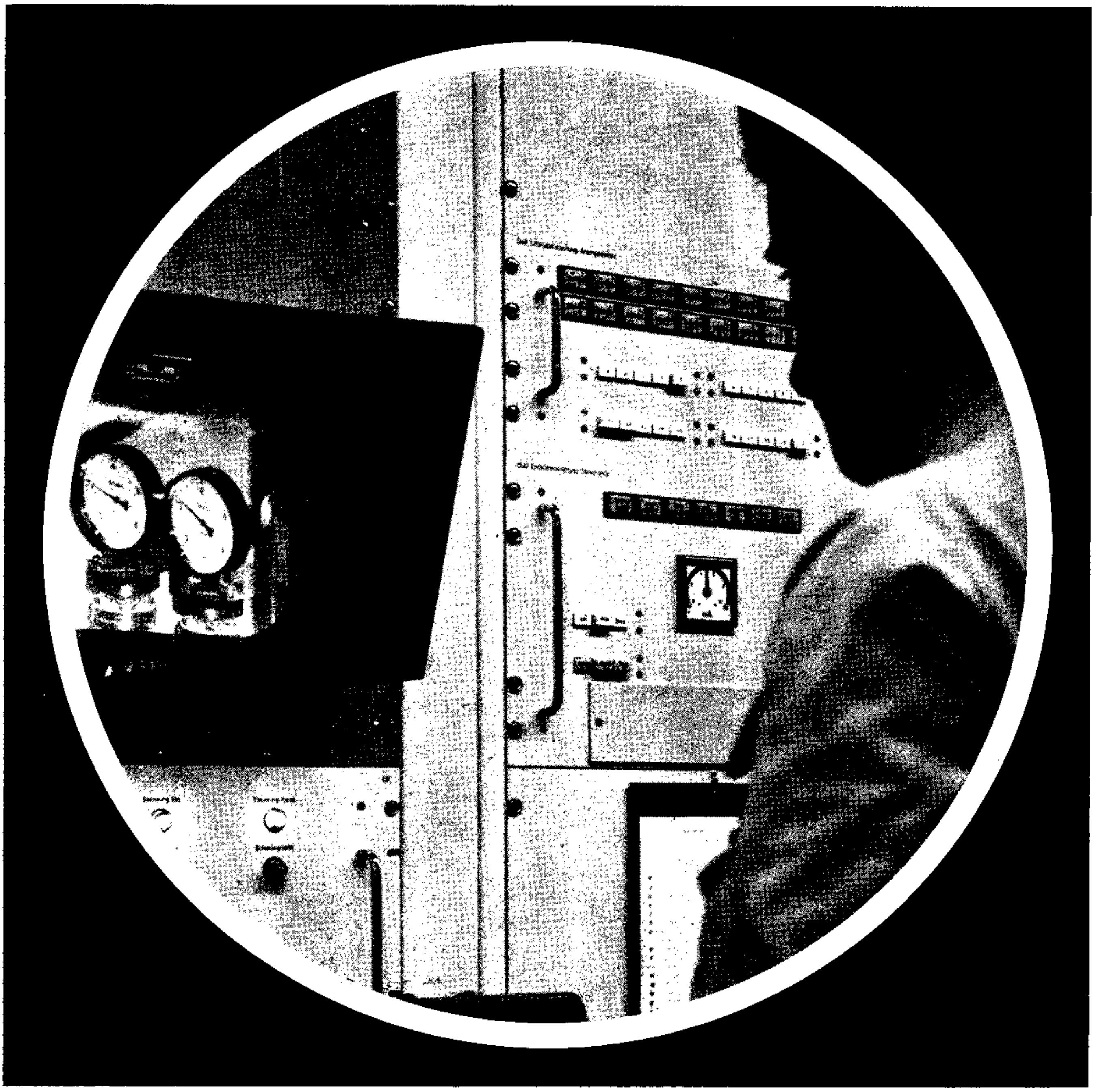
For example, the above photograph shows a counter of NE 110 plastic scintillator with its light guides. This counter has a diameter of approximately 1 metre, and has been assembled at CERN in preparation for total cross-section measurements to be carried out by a group from Pisa, using the new ISR facilities. Several much larger assemblies up to **2.6 metres in diameter** have now been manufactured at Edinburgh for Pisa University for the same project. **Over 70 square metres of NE 110 sheet were used for the 328 pieces required.**

For full technical data and references request Bulletin 58.

NUCLEAR
ENTERPRISES
LIMITED

Sighthill, Edinburgh EH11 4EY, Scotland. Telephone: 031-443 4060 Cables: Nuclear, Edinburgh Telex: 72333
Associate Companies: Nuclear Enterprises GmbH, 8 Munich 2, Karlstrasse 45, West Germany. Telephone: 55 30 03. Telex 529938
Nuclear Enterprises Inc., 935 Terminal Way, San Carlos, California 94070. Telephone: 415-593-1455. Telex: 348371

Swiss Agents : **High Energy and Nuclear Equipment S.A.,**
— 2, chemin de Tavernay, Grand-Saconnex, 1218 Geneva, tel. (022) 98 25 82 - 98 25 83



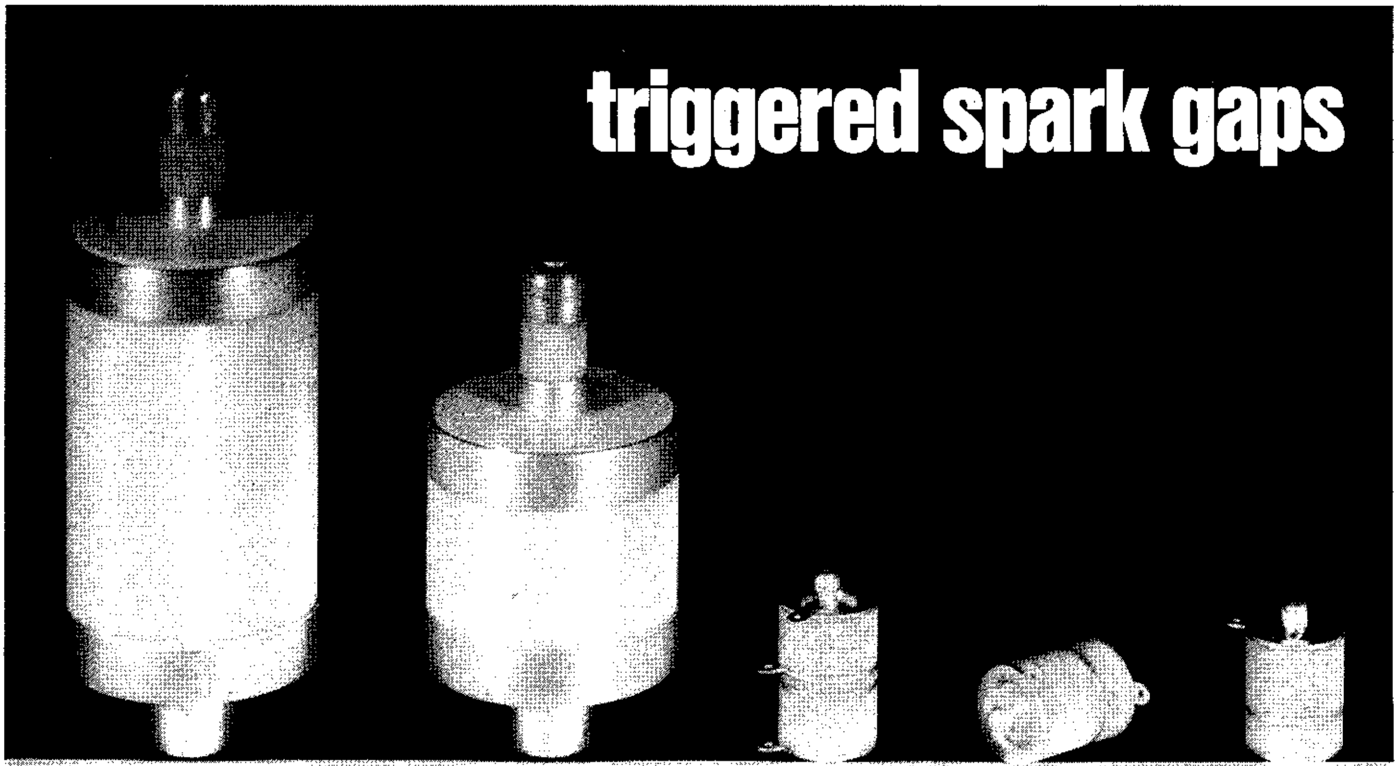
Quand un câble de télévision est-il parfait? Lorsque vous oubliez qu'il existe!

Les câbles de télévision Dätwyler garantissent une transmission parfaitement fidèle des signaux de télévision, de la caméra à l'émetteur, et de l'antenne au récepteur. Dans le domaine de la télévision industrielle, le nombre des possibilités et applications des câbles à haute fréquence Dätwyler est impressionnant. Le problème de la surveillance des endroits éloignés ou inaccessibles est ainsi facilement résolu. Selon l'utilisation, les câbles peuvent être combinés avec un nombre quelconque de fils de commande et de signalisation, de telle sorte qu'un seul câble d'un encombrement réduit, vient à bout de nombreuses missions. Sur demande, tous les câbles coaxiaux et de télévision industrielle Dätwyler sont livrables en exécution «Isoport» ; la corde d'acier insérée dans la gaine donne à ce câble la qualité d'autoporteur. Nos techniciens sont prêts à tout moment pour résoudre avec vous vos problèmes de câbles, s'il s'agit d'exécution spéciale de câbles à hautes fréquences ou à fréquences audibles, radar, radio, télévision, électronique, recherche et application médicales, industrielles ou nucléaires !

Câbles pour hautes fréquences et fréquences audibles

Dätwyler

Dätwyler SA, Manufacture Suisse de Câbles, Caoutchouc et Plastique Industriels, Altdorf-Uri



triggered spark gaps

They can switch to a load, in a fraction of a microsecond, the energy stored in a circuit (up to several thousands joules). They require a very low trigger signal.

FEATURES

- Instantaneous Operation (cold cathode) ☐
- Fast switching ☐
- High peak currents ☐
- Low inductance ☐
- Any mounting position ☐
- Reliable under severe environmental conditions ☐

APPLICATIONS

- ☐ Circuit protection (crow-bar)
- ☐ Very short pulses (microsecond) generators
- ☐ High speed cameras
- ☐ Rocket firing, stage separation...
- ☐ Kerr cells, spark chambers
- ☐ Plasma confinement

THOMSON-CSF

GROUPEMENT TUBES ELECTRONIQUES
8, RUE CHASSELOUP-LAUBAT / 75-PARIS 15e / FRANCE / TEL. 566.70.04

SPI 1251 E