CERN COURIER

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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 Laboratory I and CERN Laboratory II.

CERN Laboratory I has existed since 1954. Its experimental programme is based on the use of two proton accelerators — a 600 MeV synchro-cyclotron (SC) and a 28 GeV synchrotron (PS). Large intersecting storage rings (ISR), are fed with protons from the PS for experiments with colliding beams. Scientists from many European Universities as well as from CERN itself take part in the experiments and it is estimated that some 1200 physicists draw research material from CERN.

The CERN Laboratory I site covers about 80 hectares almost equally divided on either side of the frontier between France and Switzerland. The staff totals about 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 Laboratory I budget, which totals 353.4 million Swiss francs in 1971.

The CERN Laboratory II was authorized by ten European countries in February 1971 ; it will house a proton synchrotron capable of a peak energy of hundreds of GeV. CERN Laboratory 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.

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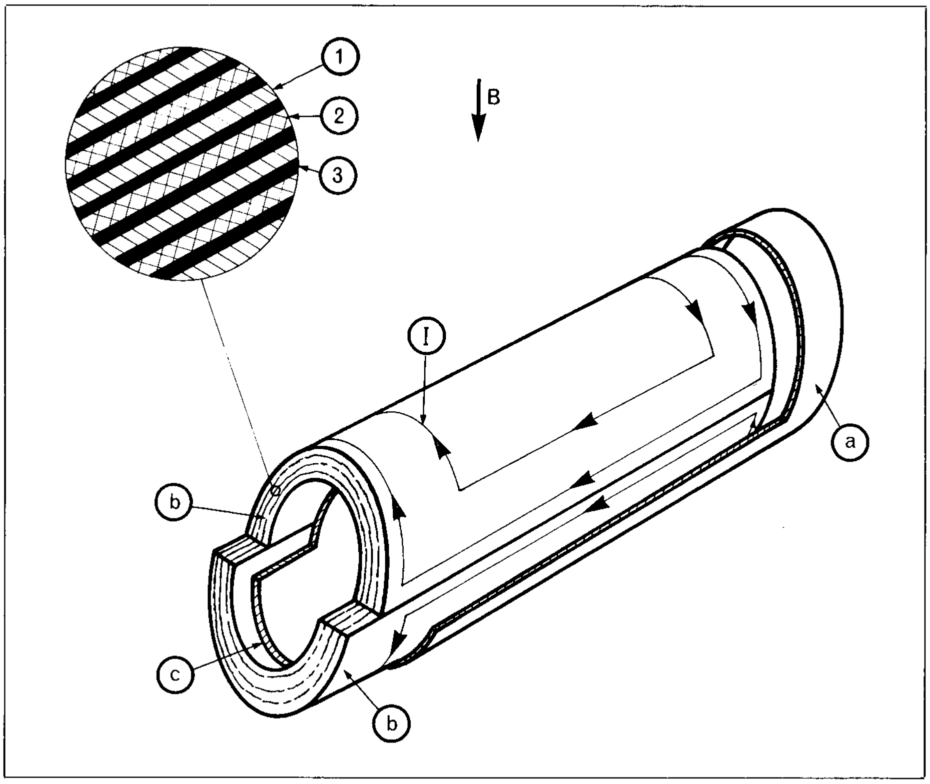
Annual Report

The CERN Annual Report for 1970 has now been published. Copies are available on application to the Public Information Office (CERN, 1211 Geneva 23, Switzerland) stating clearly — name, address, number of copies, language version (English or French).

Cover photograph: Familiar works of sculpture at high energy physics Laboratories — light guides to convey the light signals produced when charged particles traverse sheets of plastic scintillator to photomultipliers which convert the information into electronic form. These particular specimens were made in the West workshop at CERN for a CERN, Karlsruhe experiment at the 28 GeV proton synchrotron. (CERN 58.6.71)

CERN News



Schematic diagram of a field shield. Currents (I) are established in the superconducting cylinder, constructed in two half-shells (b), so as to oppose the applied field (B) and shield the volume inside the cylinder. Construction of the field shield is completed by an outer retaining cylinder (a) and an inner support tube (c).

The composition of the superconducting half-shells is picked out top left : (1) aluminium strip, (2) niobium-titanium superconductor, (3) mesh which allows the passage of the helium for cooling.

Field shields and persistent magnets

We have not lived long enough with our knowledge of the phenomenon of superconductivity to have learned more than a few of the ways in which we can use it. In high energy physics Laboratories we are becoming familiar with its use in d.c. magnets where the properties of zero resistivity, combined with high critical field and potential high current density, give higher fields in smaller magnets for equivalent performance and give much lower power consumption than conventional electromagnets. We are also well on the way to having superconducting r.f. linacs and separators, with low power consumption and high electrical field gradients, and to having pulsed superconducting magnets (as discussed in the May issue) such as might be used in a synchrotron.

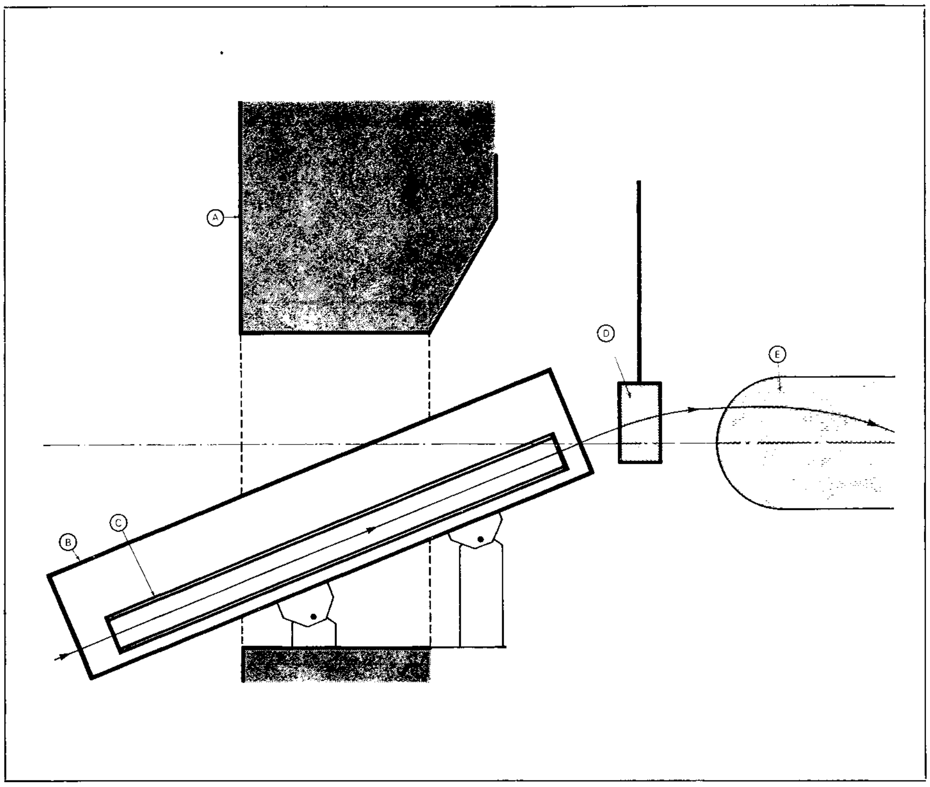
The magnet applications that we have mentioned are however 'classical' in the sense that having wound a magnet with a particular configuration of conductor we have set our field distribution and can only vary the field strength by changing the amount of current passed through the conductor. An entirely different use of the properties of Type II superconductor makes it possible to build 'field shields' (to shield a volume from external fields) or 'persistent magnets' (to retain within a volume an already established field).

Nature tends to resist change. We can observe this mechanically when a car shows its inclination to carry on in a straight line rather than turn a corner and we can observe this electromagnetically when we try to change a magnetic flux. A flux change will induce currents in a conductor whose effect will be to set up magnetic fields to retain the status quo. With normal conductor this is not a long-lived phenomenon because the resistance of the conductor will cause the induced currents to die away very quickly. But with superconductor which has zero resistance the induced currents can persist for as long as the superconducting property is retained.

Often this can be a problem (for example, in the coils for the large European Bubble Chamber, BEBC, where the build up of magnetization currents could reach high levels and lead to field distortion). Modern superconducting magnets are specially designed to keep magnetization currents low (multifilament conductors, twisted and transposed). But, as usual, what is a source of trouble in some cases can be used to advantage in others.

If the superconductor encloses a volume (for example, the inside of a cylinder of superconductor) and is arranged so as to encourage the build up of high persistent magnetization currents, then the volume can be protected from a rising external field. Alternatively, the removal of an applied field which has already established a field inside the volume (prior to the conductor being cooled to the superconducting state) will be opposed by the superconductor by setting up magnetization currents which retain the field inside the volume. Such 'persistent magnets' will retain their field indefinitely so long as they are kept sufficiently cold to retain the superconducting property. Fields of almost any configuration can be shielded or trapped in a volume provided that superconducting paths in the surrounding walls are available for the currents in all directions.

The level of field which can be shielded or trapped is a function of the total persistent magnetization current which can be built up in the



Schematic diagram of how the field shield to be built for the 2 m hydrogen bubble chamber will be used. The superconducting cylinder (C) is located in its cryostat (B) in the beam entry gap of the magnet yoke (A). Low energy charged particles can pass through the bore of the cylindrical shield uninfluenced by the stray magnetic field, through an attenuator (D), so that they curve within the visible volume of hydrogen (E).

Two magnets (one of the focusing and one of the defocusing type) which are powered in series with the magnets in one ring of the ISR. Two others are in series with the other ring. The magnets sit in the Reference Unit Room and are used in monitoring and controlling the ISR magnetic fields. The computer (a Hewlett Packard 2114) used in the system is on the left of the photograph.

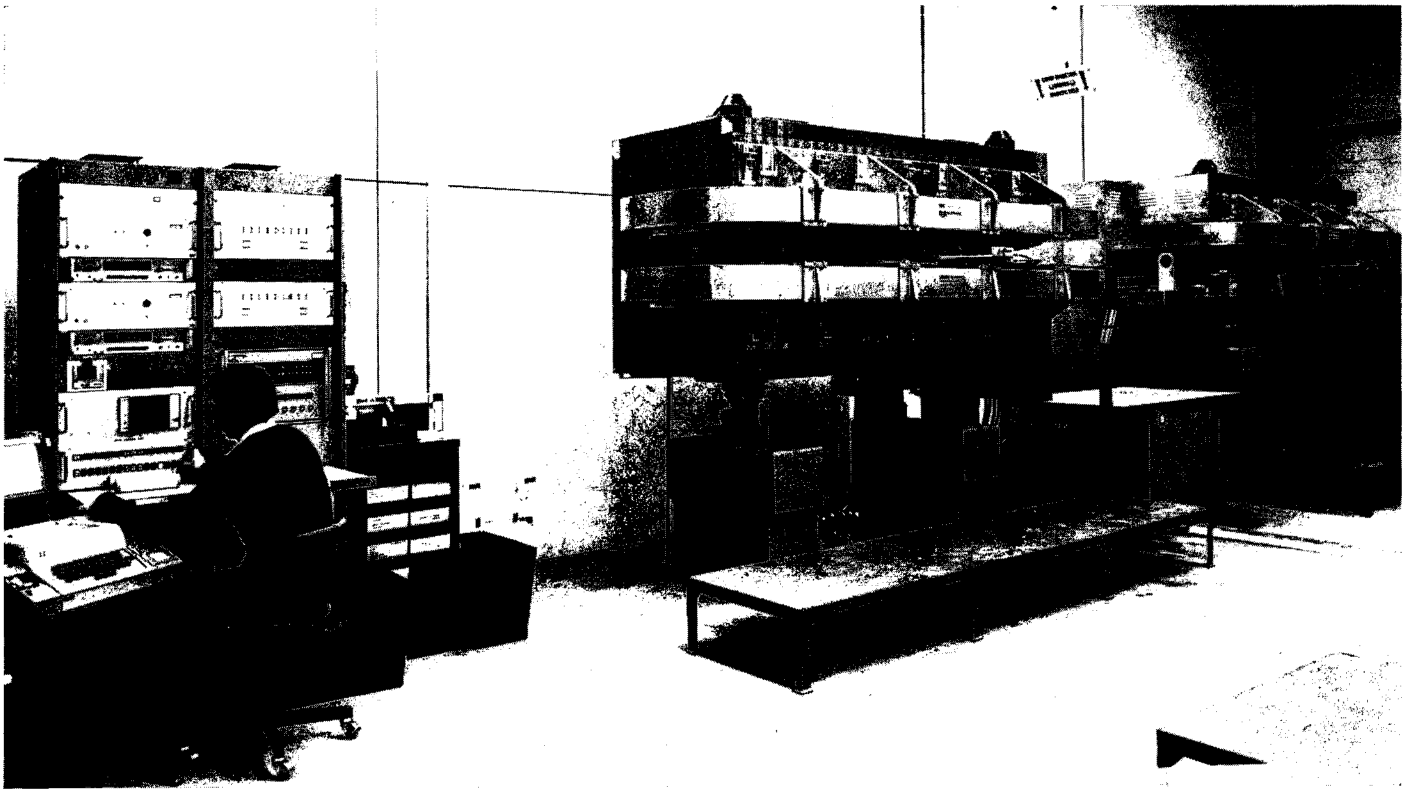
superconductor. This tends to be limited by the fact that, as field penetrates further and further from the cooled surface of the superconductor, more and more heat is produced (by the moving field) and it becomes progressively more difficult to get it out, resulting finally in a run-away temperature increase which temporarily destroys the superconducting state. To avoid such 'flux jumps' it is usually necessary to divide up the superconductor in some way so that no part of it is very far from the liquid helium. Past work has generally relied on the porous nature of sintered niobium-tin to get the helium around, but manufacturing difficulties make this technique unsuitable for large structures.

Fortunately, it is not always necessary to provide superconducting paths in all directions. Currents are never required to flow parallel to the field direction and, in most geometries, the required superconducting paths in directions perpendicular to the field can be provided by suitably arranged stacks of thin sheets of superconductor. This allows space between the sheets for the helium and some high conductivity normal metal to stop a flux jump in one layer from propagating to the rest. Using this technique very large total persistent magnetization currents can be built up and it seems that the size of structure is only limited by the dimensions of superconducting sheet which can be produced.

The particular problem which has promoted interest in this topic at CERN is that of channelling low momentum particles through the stray field of a large detector magnet. Getting 500 to 800 MeV/c charged particles into the 2 m hydrogen bubble chamber at full nominal field of 1.75 T requires a field-free beam path of about 15 cm diameter and several metres long, inclined at about 25° to the normal particle beam axis so that the particles stay within the visible volume when curved by the field in the chamber. Such a field-free beam path can be provided in the bore of a tube made of concentric layers of superconducting sheets, suitably cooled and stabilized. The stray field of the bubble chamber magnet is perpendicular to the tube axis and the currents induced in the wall when the field is first applied have the same configuration as in a 'saddle wound' dipole. These currents are not required to cross the plane bisecting the cylinder perpendicular to the field direction, so the cylinder can be made from two half-shells. This means that the required width of superconducting sheet is half the maximum circumference (about 30 cm in this case).

An experimental programme to investigate the behaviour of this type of shielding tube is under way in the Low Temperature Laboratory of the Track Chambers Division. A number of tests have been done on 18 cm long cylinders with internal diameter of 25 mm and with walls 15 mm thick, made up of concentric layers of 0.1 mm niobium-titanium alloy sheet, interleaved with normal metal and provided with access for liquid helium. The maximum applied transverse field which has been shielded by these cylinders to date is 2.6 T — an encouraging result since few existing large detector magnets have fields much higher than this. Theoretically, such cylinders, with 0.1 mm thick NbTi, should be able to shield about 3.4 T, so there is still some room for improvement.

A test cylinder of the same bore, but only 3.6 mm thick, made from Nb_3Sn ribbon shielded about 3.7 T and a small one, 10 mm bore and 50 mm long, shielded over 4.1 T. These results correspond fairly well with the theoretical predictions, but Nb_3Sn



CERN 204.3.71

ribbon is expensive and not yet commercially available in required sizes.

The NbTi cylinders have trapped fields of up to 2.3 T and on one occasion the field was kept for seven days before being deliberately destroyed by heating the cylinder. Variation of field during this time, if any, was less than a few parts in 10^5 — the detection limit of the instrumentation. The small Nb_3Sn cylinder has been made to trap 4.2 T.

At this stage any conclusion drawn from these experimental results must be tentative, but it seems likely that transverse fields produced by classical electromagnets can be shielded by cylinders made from niobium-titanium strip and it may be possible to improve the shielding ability to field levels available from large superconducting electromagnets. The cylinders of niobium-tin tape have already shielded such fields and it remains to be seen whether they can be made and used in larger geometries.

It appears possible to make persistent dipole magnets of similar size and field levels to existing classical bending magnets and there is good hope of achieving twice these field levels. Such magnets should be considerably cheaper than comparable superconducting electromagnets, have a much smaller consumption of liquid helium (since there are no current leads — usually the major source of heat into the magnet cryostat), require no power supply and be relatively resistant to radiation (since they are all metallic). In addition, the field distribution of these magnets is not fixed once and for all during manufacture.

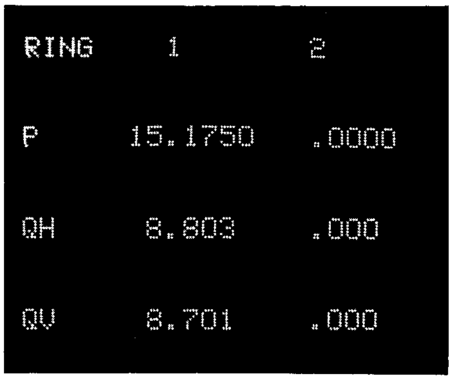
Of course, a charging magnet is necessary to provide the desired field configuration and intensity which is to be trapped within the superconductor. This magnet must be large enough to take the cryostat of the persistent magnet and it will very likely need to be an air cored superconducting electromagnet. Such a device is rather expensive and, therefore, persistent magnets as a whole may only turn out to be ecomonic if they are used in fairly large numbers.

ISR
Magnetic Field Display

The characteristics of the two main magnetic fields of the Intersecting Storage Rings are continuously monitored and displayed in the Control Room (SRC). This is done by measuring the field on the central orbit and the gradient at three radial positions, in four reference magnets (one of the focusing and one of the defocusing type for each ring) installed in a 'Reference Unit Room' close to the ISR. The windings of these reference magnets (main, compensation and pole face windings) are connected in series with the corresponding windings in the rings. Since these magnets have been carefully measured with reference to a master unit, in the same way as all the other magnets in the rings, the complete characteristics of each ring may be calculated at any time from measurements made in the reference magnets.

The actual measuring equipment is derived from that developed and used for measuring all the units : a coil rotating through 180° for field measurement and one moving over a radial distance of 18 mm to measure the gradient. A hydraulic mechanism is used and great care was taken in the mechanical construction to ensure the necessary reliability and accuracy (1 to 2×10^{-5} for field measurements at 15 GeV/c). For example, the stroke of the 'gradient' coils must be stable and accurate to within a micron, while the 'field' coils must be positioned in the aperture to an accuracy of 0.01 mm.

The instrument for integrating the signals from the coils had to be specially designed, since there was nothing of sufficient accuracy and speed available commercially. The method finally adopted consists of integrating the coil signal and then switching the input of the integrator to an extremely stable and carefully calibrated reference voltage V_r and in measuring the time t taken for the zeroing of the integrator. The effect of the integration constant is thus



RING	1	2
P	15.1750	.0000
QH	8.803	.000
QV	8.701	.000

CERN 25.1.71

+.05 T

RING 1

P 11.6244

0

-.05 T

CERN 207.3.71

Photographs of ISR magnetic field parameters as displayed on a TV screen.

1. With just Ring 1 in action the magnetic field is set to that corresponding to a proton momentum 'p' of 15.175 GeV/c and horizontal and vertical betatron oscillation frequencies of $Q_H = 8.803$ *and* $Q_V = 8.701$.

2. Rapid field variation is displayed in the form of an index moving along a graduated scale. The initial field, which corresponded to a proton momentum of 11.6244 GeV/c, has been changed by approximately + 0.02 T.

eliminated and the flux variation in the coil deduced directly as $V_r \times t$.

Automation of the operation and processing of the information has been made possible by the use of a computer (Hewlett Packard model 2114). It is programmed :

- to control the various measurement sequences ;
- to read the counters and calculate the final values ;
- to display the results on a cathode ray tube in the Control Room (and in the Reference Unit Room) ;
- to transmit the results to the ISR central computer.

As well as the various parameters (surfaces and resistances of the coils, carriage strokes, reference voltages) needed in the measurement procedure, the memory of the 2114 computer also contains the average results of the magnetic measurements made on all the ISR units. On the basis of measurements in the reference units, it is capable of calculating the behaviour of the entire rings. The display in the ISR control room shows either the magnetic characteristics of each ring (bending and focusing parameters) or the related beam parameters :

- the momentum corresponding to the central orbit ;
- the vertical and horizontal betatron oscillation frequencies ; (Q_V and Q_H are calculated with variation formulae drawn from experimentation with the ISR).

The rate of measurement is essentially limited by the time required for the movement of the coils (60 s for a complete measurement).

Further facilities have recently been added to the system to allow a rapidly varying field to be measured. The voltage induced in the measuring coils (which in this case remain stationary) is converted into a frequency and the field variation is displayed in the form of an index moving along a graduated scale. The first stage of the computer-controlled sequence includes the automatic compensation of the integrator drift.

This monitoring system, built by the Magnet Group, has been extensively used since the beginning of tests on the ISR. It gives a direct, fast and extremely accurate indication of the magnetic characteristics of each ring.

200 mA from 3 MeV

The 3 MeV experimental linac accelerated a proton beam (analysed) of over 200 mA for the first time on 12 May — the peak current which has been achieved is 215 mA.

The big beams, whose energy spread and emittance have not yet been studied, came after changing the 18 focusing quadrupole settings in the linac tank (to operate in the +—+— mode rather than ++—— as in the 50 MeV linac of the proton synchrotron). The last 20 µs of 100 µs pulses of protons from the 500 keV preinjector were selected for acceleration; these corresponded to the most stable part of the preinjector pulse. The modifications which brought about the high currents could not be translated directly to the PS linac where the quadrupole cooling is not as efficient as on the small experimental linac. The pressure at the PS linac is, in any case, to deliver 100 mA in 100 µs pulses ready for the coming into operation of the 800 MeV Booster and the 3 MeV linac has been helping by studying long pulse effects in the preinjector region. (The preinjector on the experimental linac is the same as on the PS linac.)

In fact the recent push to high currents came as something of an interlude in the midst of a difficult study of space charge effects in low energy beams. Here computations predict that the space charge forces (where the positive charges on the protons are pushing away from one another giving a 'blow up' of the beam) have a considerable effect on the beam behaviour.

Initially one aim, working with the 500 keV preinjector beam, was to remove the space charge effect by controlled neutralization, injecting electrons into the beam to cancel out the positive charges on the protons. But this has proved very difficult to master mainly because the proton beams have been shown to be neutralizing themselves without any help ! This was evident from the fact that theory and experiment did not line up and beams of much higher current than calculated could be transported.

The self-neutralization appears to be coming from two sources — from ionization of residual gas which yields electrons, and from particle loss (protons and other ions) to the metallic walls which liberates electrons. At first sight it seems nice to be getting required neutralization for free but the trouble is that self-neutralization is not easily controllable. The degree of neutralization is difficult to predict and the electrons are of low energy (a few eV, for example) and hence easily disturbed, by imposed focusing fields or biases, abruptly changing the space charge property of the beam.

The implications of these findings for the PS linac are being considered and will probably result in reorganization of some of the focusing at the low energy end in such a way that space charge or beam neutralization is not a dominant influence on the beam behaviour and reproducibility.

The availability of the 3 MeV linac is making it possible to carry out more detailed studies on high intensity, low energy proton beam behaviour than has ever been done before. Generally, a linac is swept into action to feed a synchrotron, leaving little time to get to know the beam well.

Applications of Accelerators

L. Rosen

It is important to step back, from time to time, and look at our work in the context of the preoccupations of society as a whole. This article takes a look at what role accelerators are playing in modern life.

We could say that science should not need technology as a raison d'être but there is no doubt that, when science is costing a lot of money, to be able to point to subsequent technological applications is an important influence in encouraging continued investment in science. When, in the process of increasing our knowledge of man's environment, we develop the technology which eases man's lot in his environment, it is a bonus we should be very ready to talk about. Thinking of accelerators, the financial benefits already drown the financial investments as this article brings out.

The author (Louis Rosen — Director of the Los Alamos Meson Physics Facility) always presents our work, and LAMPF in particular, is a broad context. In this article he concentrates on what has come, and is coming, from our mastery of acceleration techniques. It is taken from a talk 'Relevance of Particle Accelerators to National Goals' given at the 1971 Particle Accelerator Conference held in Chicago in March. This is a version of the talk, abridged and generalized, to be accessible to a wider audience, by kind permission of the author.

There was a time, not long ago, when science and motherhood were beyond reproach. Today, both are under attack.

Much of the basis for the attack on science is emotional, even irrational. But not all of our troubles can be blamed on unreasoning critics ; a substantial part of our misery is self-inflicted. We have not taken seriously that part of our responsibility to society which dictates that we explain, interpret and justify our activities in language understandable to the non-specialist. We and we alone can do that. We and we alone can provide the best advice on meaningful priorities based on the intellectual and practical worth of our pursuits. We and we alone can provide the best assessment that a given development will have a utilitarian purpose at an acceptable cost. We and we alone can develop the sophisticated phenomenological models which have some chance of predicting the interactions between technology, industry, education, society and our environment.

We are admonished from many quarters to start asking not what our society can do for science, but what science can do for our society. And it is precisely this question, to the extent it concerns particle accelerators, that I wish to discuss.

If we look at the world-wide inventory of particle accelerators, we could claim that they all have value for intellectual and educational pursuits. However, most of us feel that basic knowledge about the constituents of matter and about the forces that govern the most fundamental properties of sub-nuclear matter are most likely to arise from experiments at the highest energies, assuming that sufficient intensity is available to make statistically significant observations. It is the highest energy accelerators, particularly, that contribute to education and the acquisition of new basic knowledge.

To understand the importance of these contributions, we must recognize that one of the main distinguishing characteristics between man and the lower forms of animal life is his curiosity — curiosity about himself, his immediate surroundings and the universe. Curiosity is one of the elements of life which gives it substance and meaning, and one of the major ways to satisfy human curiosity is through the pursuit of science — the interrogation of nature. In order to pursue science, one must continually press on the frontiers which are usually at extremes : very high temperatures and very low temperatures ; very high pressures and very good vacuums ; the very large (cosmology) and the very small (nuclear and sub-nuclear entities). High energy particle accelerators permit us to explore the smallest quantities of matter and energy in nature.

In addition to these intellectual merits, we can point to other benefits from the construction and utilization of accelerators. For example, one that we will pass over briefly, is the promotion of international collaboration. The research is world-wide and, perhaps, in no other field is there such open, friendly and practical collaboration across frontiers.

Let us push on further and get to some directly demonstrable applications of accelerators. The history of science tells us that, up to now, the practical results alone have more than paid for all the scientific effort. Even the highest energy accelerators already have economic ramifications for they are producing technological spin-offs (for example in computer technology, cryogenics, vacuum technology, the art of constructing large magnetic fields, and of fabricating

A list of some of the applications of accelerators with numbers assigned to each category and the capital investment involved (taken from a report of the Subpanel on Accelerators to the Nuclear Science Panel of the Physics Survey of the National Academy of Sciences, USA).

Application	Number of Accelerators		Investment ($ M)	
	1964	1968	1964	1968
Nuclear science and engineering	282	297	101.4	129.7
X rays and neutrons	234	376	24.2	46.9
Radiation effects	225	315	26.3	36.4
Atomic and solid state physics	5	35	0.5	2.8
Radiation processing	36	60	3.7	6.5
Totals	782	1083	156.1	222.3

materials which have no electrical resistance) all of which will have a decisive influence on the technologies required to sustain comfortable life on this planet in the future.

But let us examine not what might be but what already is, remembering that what today are considered low energy accelerators were yesterday characterized as high energy accelerators.

Accelerators in industry

If we look at the situation in the United States there are about 1000 accelerators of all kinds, representing about 50 % of the world's inventory of accelerators. Less than 150 are devoted mainly to basic research. Of the remainder, about one-third are devoted to industry and medicine, and the rest to the applied sciences. Those devoted to industry and medicine represent a capital investment of 77 million dollars. The annual production of goods and services associated with these machines is about 2000 million dollars.

Non destructive testing

A growing use of accelerators is in the area of nondestructive testing. There are three main categories :

1) Radiographic inspection using x rays and gamma rays (e.g., inspection of pipeline welds)
2) Thickness gauges (alphas and betas have long been used for this purpose and now protons are beginning to show promise — using 147 MeV protons, the Harwell Group have shown that the thickness of graphite can be determined to an accuracy of 0.0015 %, compared to 2 % by conventional methods)
3) Activation analysis (mainly with neutrons).

Radioisotope production

Two-thirds of all radioactive nuclei were discovered via accelerator-induced reactions. However, 80 % of the curies are now produced by reactors. This situation appears to be changing, especially in the medical area to which we shall return.

Market statistics and predictions (in $ M) for the sale of radioisotopes are as follows :

	1969	1970	1971
Basic radionuclides	10	11	13
Radiochemicals	12	14	16
Radiopharmaceuticals	32	40	50
Sealed sources	5	6	7
	59	71	86

The point is that the sales are substantial and the rate of increase is large. The present market for cyclotron-produced isotopes is three million dollars per year, and increasing rapidly. It is estimated that a market for about twenty cyclotron facilities may develop for radioisotopes by 1975. Here the economies are far less important than the pain and suffering these isotopes can prevent.

Power production

Accelerators have played and continue to play a critical role in development of power sources based on nuclear fuels. This goes to the heart of problems of the conservation of fossil fuels, environmental pollution and the quality of life. Here are a few examples of how nuclear cross-section measurements have contributed :

1) Careful measurements of the ratio of neutron capture to fission for ^{239}Pu showed that an entire family of water-cooled plutonium-fueled reactors would not be feasible as breeder reactors, thus preventing the waste of hundreds of millions of dollars.
2) Some years ago, I published results on the interaction of fast neutrons with ^{7}Li, which showed that a controlled thermonuclear reactor could operate on the D-T cycle (which is much easier than the D-D cycle because the required temperature is lower) and produce more tritium than is consumed. It now appears likely that the first thermonuclear reactors will operate on the D-T cycle.

   However, Rand McNally Jr. of ORNL has recently proposed the use of energetic protons, (or deuterons, tritons and ^{3}He) to ignite ^{6}Li or ^{6}LiD fuel, thus avoiding the problem of heating incoming fuel material to fusion energies. One barrier to the pursuit of this idea is grossly incomplete knowledge of nuclear reaction cross-sections for light nuclei at low energies, which accelerators can provide.

It is a fact that particle accelerators provide the basic information for calculating nuclear properties of reactors. Much basic nuclear data are still needed, especially for fast reactors which make best use of our uranium resources. Annual fuel cost uncertainties, resulting from nuclear data uncertainties, are about $ 100 million in 1980, $ 300 million in 1990, and $ 700 million by the end of the century. Accelerators can clear these uncertainties.

Neutron and gamma-ray cross-sections are destined to play a crucial role in reactors for space applications, for desalination in the agro-industrial complexes and for process heat. The problems are mainly those of neutron economy and materials damage — another field for accelerators.

Radiation processing

Radiation processing may be used to increase the melting point, tensile strength, durability, and adhesive property of materials. Of the 270 accelerators in private industry, 46 are devoted to radiation processing on a production scale (exclusive of food processing). The current value of irradiated products, not including food, is about $ 200 million per year, and much of this is due to electron accelerators. Radiation curing of coatings and finishes, especially for building materials, textiles and metals, is the area of greatest potential in the near future. Irradiation of plastics accounts for the largest share of capacity, with applications to packaging materials and electrical insulation showing great economic advantages and rapid commercial utilization.

As an example, pigmented monomers (without solvents) are processed by electron curing. The monomer is polymerized to produce a superior paint finish. The elimination of solvents from the paint industry should reduce the pollution problem.

Accelerators in defence

The role of accelerators in defence is not as great as it used to be, but it remains extremely important. Perhaps the most serious problem in this category is a book-keeping one. It has to do with detection, control and monitoring of fissionable materials, mainly those produced in power reactors. We must have the capability of nondestructive interrogation of materials. Accelerators need to be developed which produce neutrons and gamma rays of appropriate energy and intensity and which can be used to interrogate sealed packages to deduce their contents.

By 1980, power reactors around the world will be producing plutonium at the rate of 200 pounds per day, sufficient for tens of nuclear weapons per day. Plutonium is now a commercial commodity, subject to private ownership. To monitor this situation simple, reliable methods must soon be developed for interrogating materials and accurately determining their makeup. Neutrons and gamma rays, produced by accelerators, offer one possibility and much has already been accomplished in this direction. Here, accelerators appear destined to play a central role for a long time to come.

Sooner or later there must evolve an all-inclusive international treaty for control of fissionable materials. Effective verification procedures are essential to the implementation of any agreement which involves production and distribution of fissionable materials and the limitation of development, production, and deployment of nuclear armaments. Highly specialized accelerators will certainly be part of the policing mechanism.

The nondestructive analysis techniques, particularly the accelerator-based active interrogation techniques which give promise of high accuracy and sensitivity, may be immediately applicable to the identification and control of pollution in air and water. Neutron activation techniques, in particular, offer an extremely sensitive method of tracing low-level contaminants in air, water and soil.

Accelerators for medical purposes

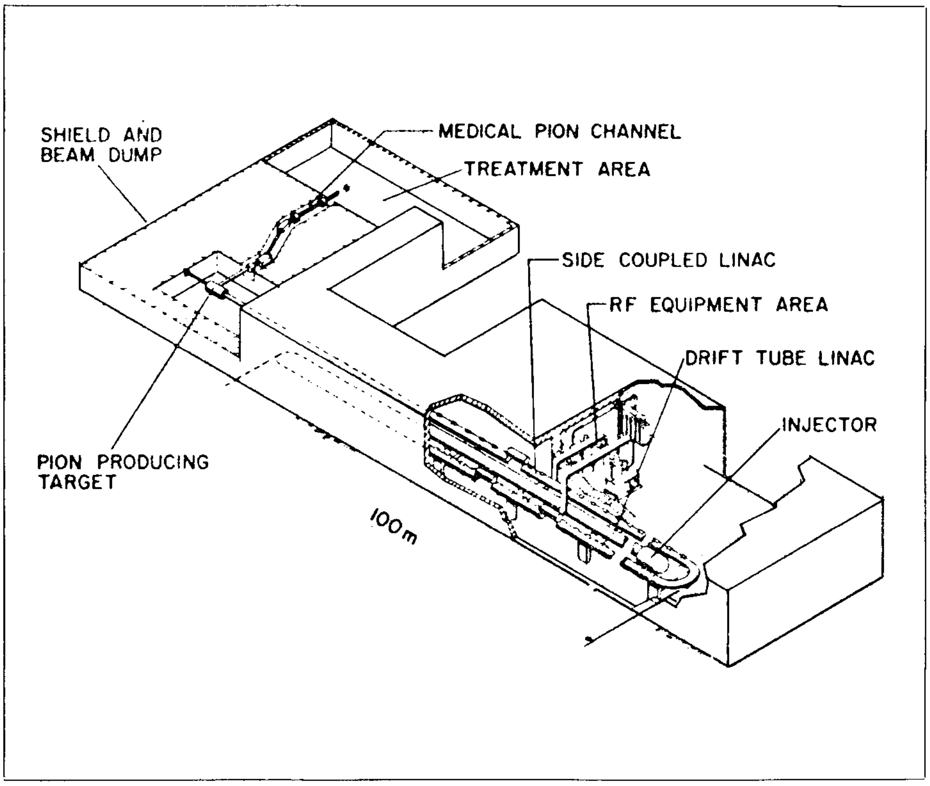
Perhaps in no area has accelerator development had such a marked impact on mankind as in medicine — in nuclear medicine and in radiation therapy. Radioisotopes are used in diagnostic medicine in connection with : thyroid uptake, blood volume determination, renal function, vitamin B_{12} absorption, fat malabsorption, RBC survival, iron turnover, cardiac output, hepatic function. At the moment most of the isotopes are discovered with accelerators and manufactured with reactors. However, accelerator-produced isotopes are increasing in volume.

Of all isotope administrations, about one-third employ ^{131}I. The use of ^{123}I for *in vivo* thyroid uptake studies, brain scans, blood volume measurements, and liver and lung scans, reduces the radiation exposure to patients by about a factor of 100 over ^{131}I because ^{123}I has no particulate radiation and has a much shorter half-life. This reduced dose is especially important in pediatric and obstetric cases.

The second most widely used radioisotope in organic function studies is accelerator-produced ^{57}Co for vitamin B_{12} absorption tests. The reason is shorter half-life and greater counting efficiency for the lighter isotope.

The new Brookhaven linac and LAMPF can produce substantial amounts of ^{72}Zn. Preliminary studies indicate this nuclide may become a routine scanning agent to be used in all males, over middle age, for early detection of prostatic cancer. No such agent exists at the present time although prostatic cancer is currently the third most frequent cause of death in male cancer patients.

In 1968, 300 000 people were treated by radiotherapy, involving 3.5 million treatments, representing a 300 000 dollar effort towards the arrest of cancer.



An inexpensive meson factory, such as might be used exclusively for diagnostic and therapeutic medicine, as conceived by a Los Alamos group. A machine of this type could yield a 500 MeV, 0.5 mA proton beam for the production of intense beams of pions and muons.

Concluding remarks

I have described what has been and what is now. But what about the future ?

Some trends in accelerator applications are discernible. I have already mentioned that new accelerators need to be developed in order to achieve nuclear energy sources on the one hand and help with the world-wide management of fissionable materials on the other. New types of accelerators are needed for uses in every sphere from the preservation of food to the sterilization of sewage.

The field of medicine appears to have an insatiable appetite for accelerators which are tailored to their purposes. Just now, six cyclotrons for isotope production of the short-lived isotopes ^{15}O, ^{13}N and ^{11}C (2, 10 and 20 minute half-lives) have been, or are in the process of being, installed in the USA.

With increased emphasis on nuclear medicine, the medical profession will be in a position to make use of new radionuclides which have properties more amenable to diagnostic procedures. Many of these can be provided by accelerators. Perhaps the most dramatic utilization of accelerators is in the treatment of malignancies where there are great advantages to be realized by using high-energy charged particles in radiation therapy. High-energy protons are much superior to x rays and we have been remiss in not using our high energy accelerators for this purpose. Our colleagues in the USSR are far ahead of us and I commend them for that.

In order to build LAMPF, a new accelerator structure had to be invented and developed. Very soon after, the feasibility, stability, and efficiency of this accelerator was demonstrated by building an electron prototype ; the basic design features were adopted by industry, which is now producing them for x ray machines of 4 MeV (and higher) energy. At least five companies are building these machines ; several dozen are already installed in hospitals, several dozen more are under construction.

Lest you worry that higher energy machines be left out of medical applications, let me assure you that this is not the case. The meson factories — LAMPF in USA, TRIUMF in Canada, and SIN in Switzerland — are scheduled to provide negative pions for radiation therapy.

The problem of determining the beam energy necessary to achieve stopped pions uniformly and at a prescribed depth in the tumor volume seems near solution and a suitable pion channel has been designed.

It now appears that muons too may be useful in medicine — in diagnostic medicine. It occurred to me, several years ago, that muons might be used to determine elemental composition in tissue just as neutron activation analysis is now used, but with less damage to the host organism. Recently some results have been obtained which are most encouraging.

The promise of pions and muons in medicine naturally raises the question of whether one might devise a very inexpensive, single-purpose meson factory. D. Nagle, E. Knapp, and D. Hagerman have given some thought to this question and have arrived at the concept shown in the drawing. A 3 MeV pressurized Cockcroft-Walton feeds protons into a 400 MHz drift-tube linac which in turn ejects into a 1200 MHz side-coupled linac. The initial estimate is that a 500 MeV 0.5 mA average current, low-duty factor machine can be built for about $ 5 million. It is beginning to appear that two of the physicists most cherished particles are destined for a central role in diagnostic and therapeutic medicine.

I see particle accelerators assuming an ever more prominent role in our everyday life. It is not completely unreasonable to expect, within our life-time, the emergence of a mail order catalogue which would list :

1) Electron linacs (1-100 MeV) for the inspection and surveillance of nuclear materials and polymerization of plastics ;
2) Isochronous cyclotrons (100-400 MeV) for isotope production and radiation therapy with protons and alpha particles ;
3) Meson factories for isotope production, radiation therapy with negative pions, and mu-activation analysis for medical diagnosis ;
4) Electrostatic machine (0-100 MeV) for radiation damage with neutrons and charged particles, isotope production, neutron cross-section measurements, and neutron activation analysis ;
5), 6), 7), etc. And more to come which we have not yet thought out.

Around the Laboratories

Farewell ceremony at the 50 MeV linac injector at Brookhaven which is now being replaced by the 200 MeV linac as part of the AGS Conversion Project. The 50 MeV linac is being moved to the Bevatron at Berkeley replacing a 20 MeV injector.

Machine transplants are becoming almost as common as among human beings (hopefully with a lower rejection rate). The CERN PS linac is currently receiving parts of the closed down 50 MeV PLA from Rutherford to be incorporated in the complex r.f. 'plumbing' of a new debuncher which will help the linac cater for the needs of both the Booster and the PS.

(Photo Ray Abbott)

ARGONNE
ZGS operating again
First booster tests

Pulsing of the magnet of the 12 GeV Zero Gradient Synchrotron at the Argonne National Laboratory began again at the end of April bringing to an end an enforced shutdown which followed the failure of a coil in octant 3 of the machine on 9 January. The beam intensity was rapidly brought to near normal levels and from 10 May the physics programme has been under way again. Seven experiments were receiving particles with the ZGS providing 2.4×10^{12} protons per pulse.

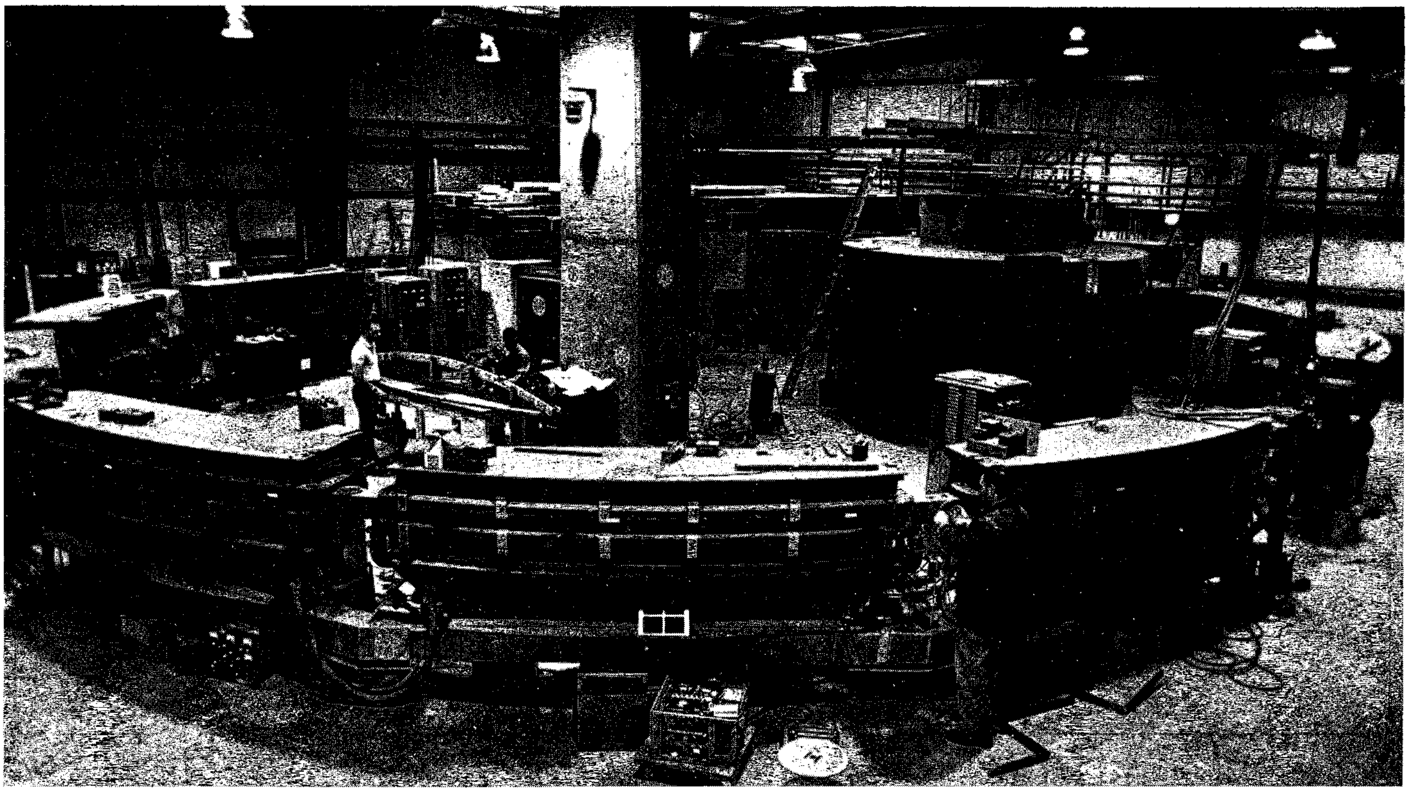
Initially the magnet was pulsed at a voltage lower than that normally applied, though with the usual peak operating current. The ZGS repetition rate, with a 700 ms flat-top, was then one pulse every 4.5 s. Operation in this mode continued until a one week shutdown at the end of May when additional protective circuitry was installed to reduce the likelihood of further coil failures. The machine is now in action with its normal cycle characteristics.

Repair of the two damaged turns (out of 30) of the main coil of octant 3 presented some challenging problems. The damaged area was about 3.5 m from one end of the 18 m coil and it was desirable not to disturb the delicate hand-fitted insulation at the coil ends. It was therefore necessary to insert a copper splice into each of the damaged turns (the copper cross-section is about $2.3 \times 3.5\ \mathrm{cm}^2$) without affecting good insulation in either direction from the splice.

The solution was to free the two turns from the main body of the coil for about 2 m in either direction from the final and most critical joint of a 1 m splice. A specially designed fixture was used to bend each part of a turn outward in an 'S' curve by a precise amount (5 cm) such that thermal expansion, due to local heating at about 1000 K to make a silver braze, joined the two coil sections with about $2 \times 10^6\ \mathrm{Nm}^{-2}$ of compression (monitored by strain gauges). After the braze joint was completed the turn was held in this outward position without putting large forces on the epoxy joints 2 m away by heating a large portion of the free section of the turn to 340 K while the brazed joint was cleaned. On cooling to the temperature of the main body of the coil the turn moved back into its proper position after which it was reinsulated. The repair techniques appear to have been successful and the coil is in use again in octant 3.

Just before the ZGS came back on the air, a series of very encouraging tests were carried out in connection with the project to increase the accelerated intensity in the ZGS by injecting at a higher energy from a fast cycling booster synchrotron. The outline of this project was described in vol. 9, page 239. Its novel feature is that it aims to achieve high currents in the booster by negative hydrogen ion injection. Initially, the aim was for 500 MeV from the booster but sights have had to be lowered to 200 MeV using what was previously the Cornell 2 GeV electron synchrotron. This was shipped to Argonne at the end of 1969 following its close down at Cornell in November of that year (see vol. 9, page 392).

In three evenings of tests with negative hydrogen ion injection, the circulating proton current was built up to 30 mA (from 0.25 mA injected) and, since easily implemented sources of improvement are known, it should be possible to flood the booster with protons up to its space charge limit when serious operation is attempted.



The installation of the H^- ion source was completed early in April. A negative ion beam was accelerated through the 750 kV pre-injector and emittance measurements, with the buncher removed, were carried out prior to sending the beam through the linac. One surprising finding was that 60 to 70 % of the 7 mA beam consisted of other negative ions (possibly O^-, OH^- or H_2O^-). When these heavier ions are substantially removed, the H^- beams achieved through the 750 kV column should be considerably higher since half the beam from the source is being lost due to space charge blow up. A negative hydrogen ion beam of 14 mA has been obtained at 30 kV from a source in bench tests.

A beam of about 0.75 mA was accelerated to 50 MeV through the linac with good pulse to pulse reproducibility. This can be doubled by simply reinstalling the buncher (the linac transmission is 50 % with and 25 % without the buncher). The maximum current injected into the booster was 0.25 mA (the beam transport line from linac to booster can be tuned up to greatly improve the beam transmission here also).

To avoid problems with timing during these short tests the booster was run d.c. (It has however been run a.c. at 30 Hz, which is the maximum possible cycling repetition rate, and up to field levels equivalent to 200 MeV proton beams.) Injection took place for 200 μs through a fixed stripper foil. The negative hydrogen ion beam observed just prior to injection was stripped to protons and guided to another measuring point half way round the ring apparently without loss.

The beam was then circulated all the way round. Large increases in circulating current came following improvements of the vacuum in the booster and applying correction fields. Further increases should be possible here.

The ratio of the circulating current which was built up (30 mA) to the current being injected (0.25 mA) implied an average of 120 turns through the stripping foil which was in agreement with a measured decay time of 60 μs for a short injected beam. This lifetime is not as high as anticipated but the potential improvements, which have been mentioned above, give considerable confidence that, despite this, it will be possible to fill the booster up to its predicted space charge limit with a 2 to 3 mA beam of negative hydrogen ions which is eventually expected to be accelerated through the linac.

The booster r.f. system was powered at fixed frequency during the tests and there was evidence of beam bunching. For accelerating the beam to 200 MeV further components are needed in the r.f. system and are expected to be completed by September of this year when further booster tests will take place. It is intended that, by about mid-1972, 200 MeV beams, initially with 8 pulses of 6×10^{11} protons per pulse will be injected into the ZGS during 1 s to establish a circulating beam of 5×10^{12} protons. Subsequently, the injection of 10^{12} protons per pulse will be the aim with all the injection components operating at 30 Hz.

One problem in the commissioning of the booster is not to interfere (by H^- acceleration) with the ZGS physics programme. A way out of this might be to have H^- injection direct from the linac at 50 MeV into the main synchrotron ring if acceptable accelerated proton beam intensities can be obtained. Then the commissioning could proceed concurrently with the physics programme.

VILLIGEN
Progress of SIN cyclotron project

The beginning of June saw the start of assembly of the accelerator at Villigen near Zurich which is being built by the Swiss Institute for Nuclear Research (SIN). The first of the eight large sector magnets for the main ring cyclotron is being installed and assembly of the injector cyclotron has also begun.

The 200 MeV ZGS booster at Argonne (formally the 2 GeV Cornell electron synchrotron). Some very encouraging tests have recently taken place with negative hydrogen ion injection into the booster.

(Photo ANL)

1. An isometric drawing indicating the layout of the major components of the SIN cyclotron project. On the right is the injector cyclotron which will feed the main accelerator and also provide a range of particles for low energy experiments. On the left is the ring cyclotron, with eight magnet sectors, which will accelerate protons to 585 MeV.

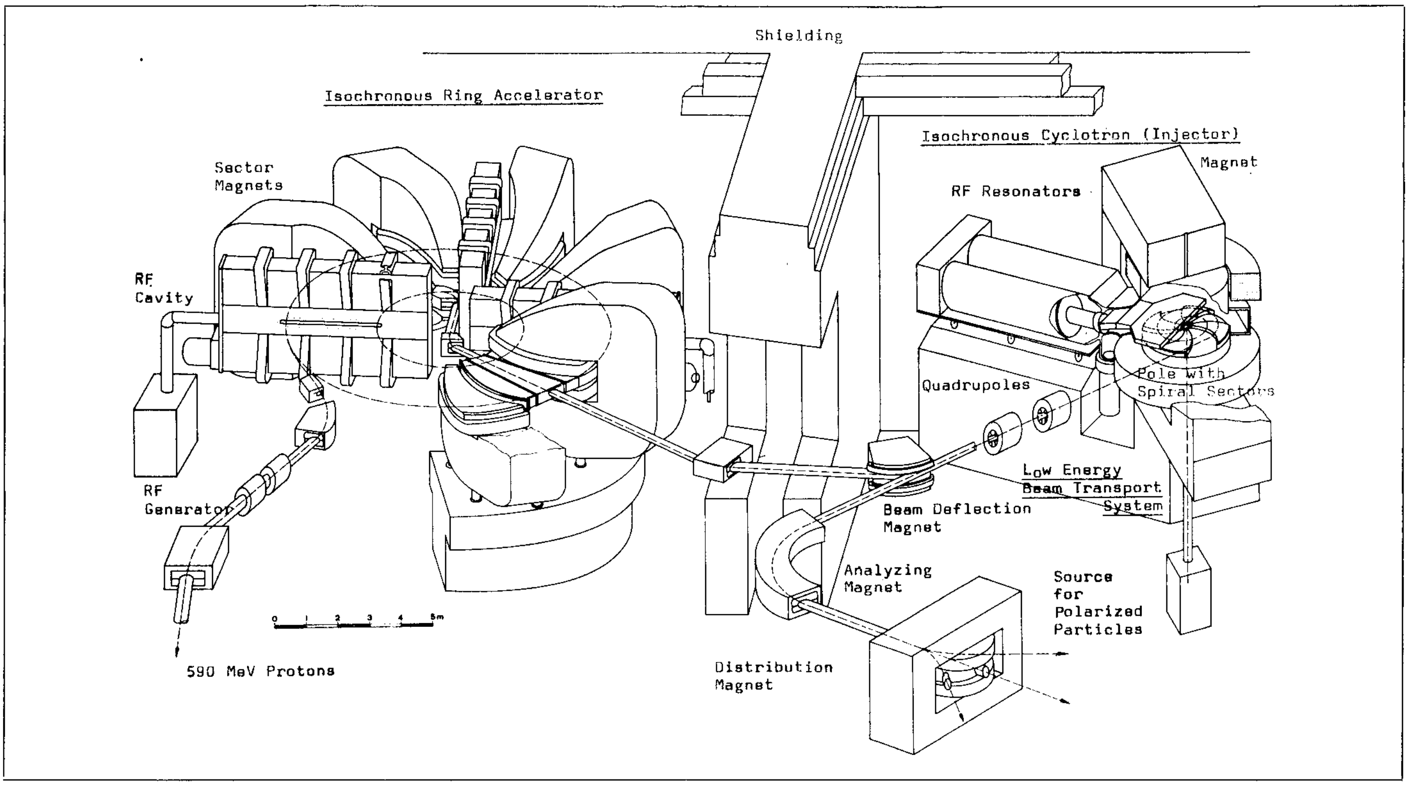
The SIN accelerator was described in some detail in vol. 9, page 139; we restrict ourselves here, therefore, to recalling the outline of the project. We will concentrate on features which have changed over the past two years, on the tests with component prototypes and on preparations for the experimental programme.

The aim is the construction of an accelerator to serve as a 'meson factory' producing intense proton beams with an energy in excess of 500 MeV, well over the production threshold for pions. The intense beams are to be obtained using two stage acceleration — an injector cyclotron providing over 100 μA of 72 MeV protons (this cyclotron will also be used for low energy physics accelerating protons and other light ions) feeding a ring cyclotron which will complete acceleration to peak energy. This two stage approach effectively lifts out the centre portion of an isochronous cyclotron and makes it possible in the remaining ring cyclotron to install high voltage cavities which will give high energy gain per turn. This results in considerable separation between the turns at ejection energy and ensures good ejection efficiency, which is essential in a high intensity machine.

The injector cyclotron is being supplied by Philips. The ring cyclotron has been developed by SIN. It receives particles at 72 MeV on a radius of 2.05 m and accelerates them out to a radius of about 4.5 m. Eight sector magnets produce the field in which the protons are guided on spiral orbits and provide the focusing forces.

A major change has been to increase the peak energy to 585 MeV which was possible with little modification to the initial design. This will result in production of more intense fluxes of pions and it moves the energy spectrum of the pions higher (giving a good flux in the region of the N* resonance at about 200 MeV). It means, however, crossing a resonance where there is coupling between the radial and vertical motions of the particles but calculations indicate that this can be done with very small beam loss.

The design accelerated beam intensity stays at 100 μA. A move to considerably higher currents would need improved ejection efficiency (above 90 to 95 % which is the present design figure) since the rate of particle loss would otherwise render the accelerator so radioactive that servicing would become extremely difficult. There are ideas on adding an r.f. cavity operating on the third harmonic of the accelerating cycle frequency so as to 'flat-top' the r.f. volts at ejection to improve the efficiency.



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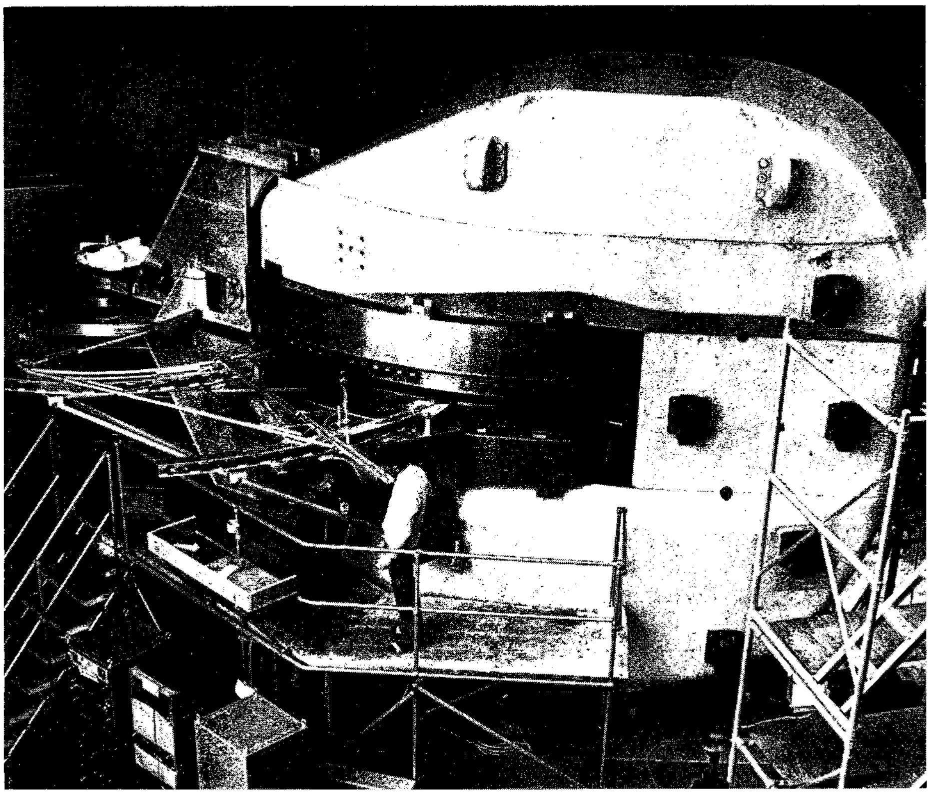

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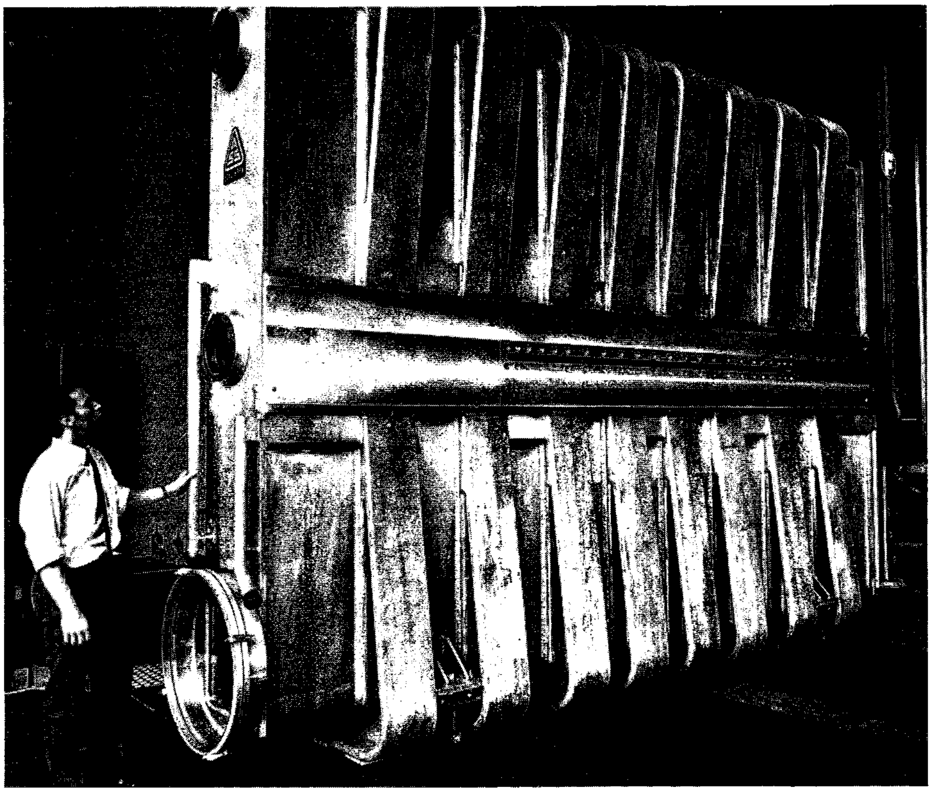
2. The prototype sector magnet for the SIN cyclotron in which it was confirmed that the magnet design would provide the high precision fields needed in an isochronous cyclotron. Field mapping equipment protrudes from the aperture on the left.



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3. The prototype r.f. cavity for the SIN cyclotron which achieved accelerating field gradients comfortably in excess of the design figures.

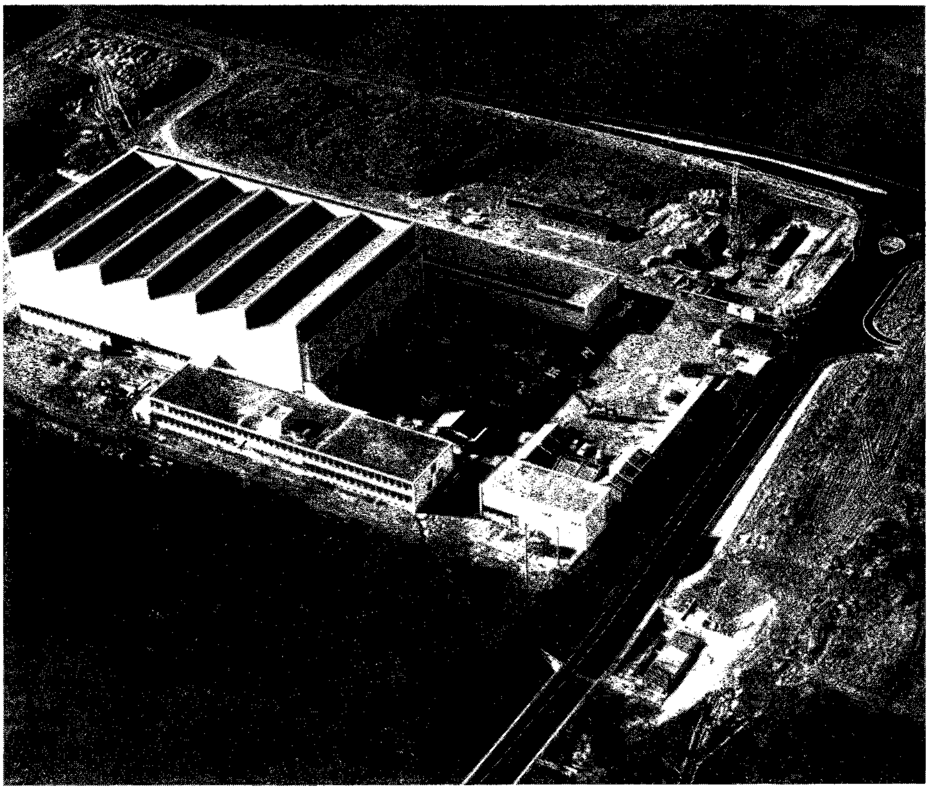
Tests on the prototype r.f. cavity for the ring cyclotron went very well. The aim was to show that 500 kV could be obtained reliably across the cavity gap. Four such cavities will be installed around the ring, one between every second magnet, to provide an energy gain of 2 MeV per turn giving an orbit separation of about 8 mm at peak energy. With the prototype, 200 kW of r.f. power at 50 MHz were fed into the cavity and voltages of about 600 kV across the gap were reliably achieved (and up to 700 kV for short periods). The energy gain per turn could therefore climb to 2.4 MeV further improving the orbit separation and easing the ejection problem.

Tests on a prototype sector magnet were also very satisfactory showing that the stringent field tolerances necessary in an isochronous cyclotron could be met. By now, three of the eight magnets have arrived at SIN and have been assembled and measured. The required performance has been achieved.

Other points to note concerning the machine itself are that a polarized ion source has been designed for the injector cyclotron and its components have been ordered. Axial injection is still under study. It has been decided to computer control both accelerators using an IBM 1800 (where some advantage can be gained from experience with the same computer in the control of the CERN PS and other accelerators).

Study of the beams to be provided in the experimental hall is well advanced. At the injector cyclotron there will be a programme of low energy research with variable energy and a range of accelerated particles (protons, deuterons, alphas, heavier ions...). From the ring cyclotron the proton beam will be taken along one wall of the hall to feed two main target stations in series. The first will have a thin target and will be the source of three pion beams and a nucleon beam. The second will have a thick target and will be the source of four pion beams, one of them for medical research and cancer therapy, and of a muon beam (using a 10 m long superconducting solenoid channel). The targets will be cooled by helium gas to avoid the problems of water activation. The proton beam can also be directed to a third target station (travelling adjacent to the wall of the experimental hall) where it will be used initially to provide neutron beams. A polarized target with a superconducting magnet is being developed along with many other facilities for experiments.

It has always been the intention that a sizable fraction of the experimental programme will be contributed by European groups and discussions have already started concerning col-



4.

4. Aerial photograph, taken early this year, of the site at Villigen. The cyclotron and its experimental hall is located in the central building (with the saw-tooth roof) flanked by a services building on the right and the control room and workshop on the left. Towards the top right and corner of the photograph, the start of construction of the laboratory building can be seen and in the foreground is the Aare River.

(Photos SIN)

laboration. Research groups, from Switzerland and elsewhere, will go to Villigen to carry out experiments and then return to their home base, as they do with CERN.

It has always been recognized as a possibility that the Villigen cyclotron could eventually take over the research programme now sustained by the CERN 600 MeV synchro-cyclotron. A decision on this is, however, still some time off. If the SC is closed down, the SIN facilities would need considerable extension to cater for a much bigger programme of intermediate energy physics. There is scope for extension — for example, the experimental hall design is such that the building could be extended easily and new areas fed with beams without much disruption to the layout already being implemented. Close collaboration between SIN and CERN is already under way.

It is hoped that the research programme will be able to start in the spring of 1974 following first acceleration of proton beams to full energy in the autumn of the previous year.

CORNELL Improvement programme

An improvement programme is under way to extend the facilities of the Cornell electron synchrotron Laboratory in three ways. The maximum beam energy from the accelerator, the available experimental area and the Laboratory's computing capacity are each being increased.

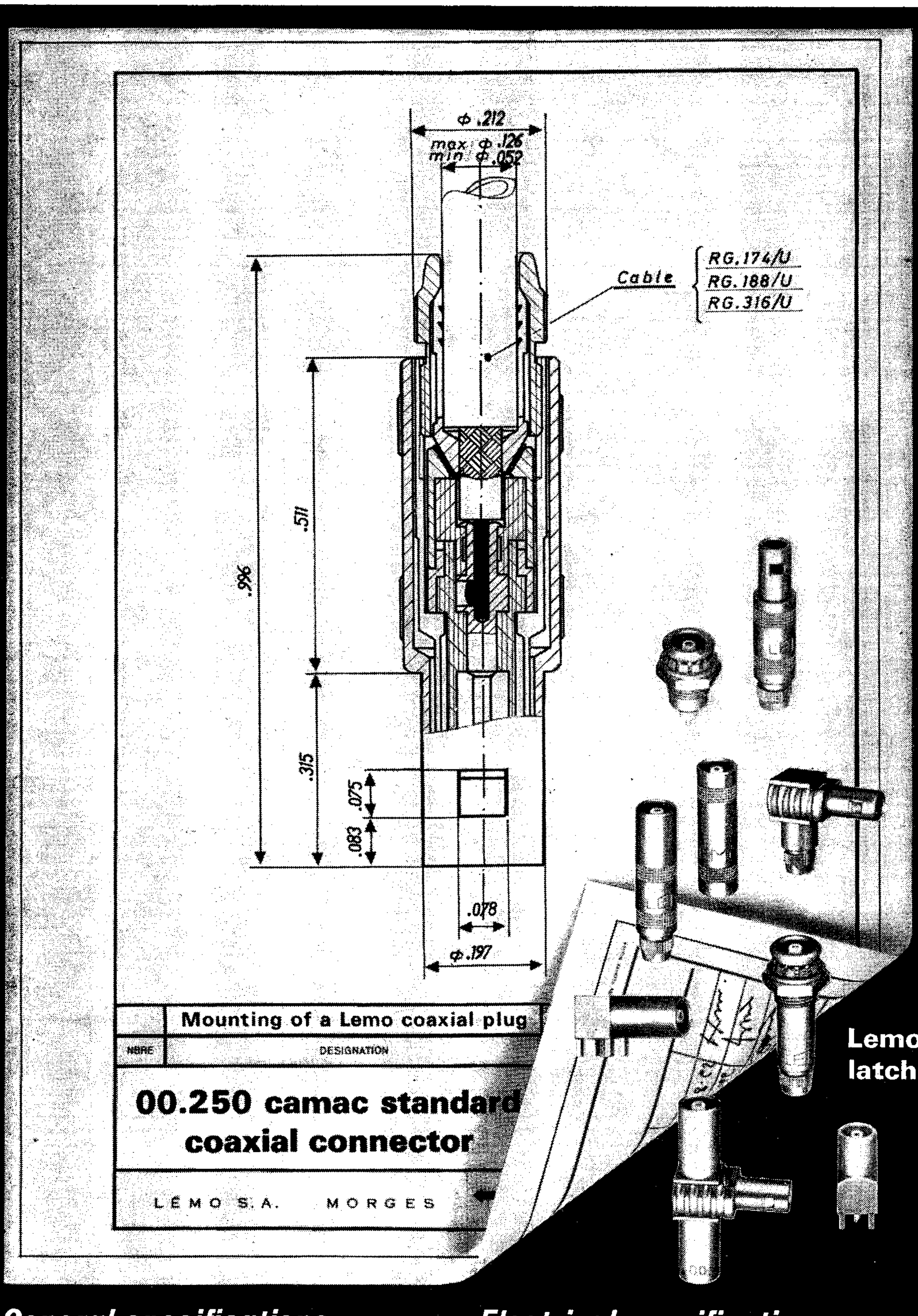
A step-by-step programme to increase the energy of the synchrotron from its present value of 10 GeV to an ultimate energy of 15 GeV has begun. The ring magnet and its power supply have already been run at 12 GeV levels and minor modifications are in progress which will allow magnet operation to produce fields equivalent to a beam energy of 15 GeV. Any energy increase, however, also requires major changes to the r.f. system because the loss of energy by synchrotron radiation goes up steeply with increasing beam energy and this has to be made up by the r.f. system in addition to providing the power for further acceleration.

Since even a modest increase in energy will be of immediate and significant benefit to the physics programme, the plan is to proceed in at least two steps. The first phase will be to take the peak energy to 12.3 GeV using conventional r.f. cavities ; this will be done by the addition of one high power amplifier (1.25 MW peak, 170 kW average) and one accelerating section to the present system. Tests of the additional accelerator structure (which will be a bar-loaded waveguide rather than disk-loaded for economy and simplicity of construction) have been made, and a new amplifier and modulator are now under construction. This phase should be completed by autumn of this year.

The second phase will depend heavily upon experience with the first phase. If the promise of superconducting r.f. cavities is realized by that time, such a system would be used in the Cornell machine. If not, it appears feasible to increase the energy to 15 GeV by adding two more high power amplifiers and six accelerating sections (five of which would replace sections now in the synchrotron).

The National Science Foundation has recently approved a proposal (at a cost of $ 1 M) to build an extension to the experimental hall almost doubling its area. This will make it possible for the Laboratory to accommodate more users, thus increasing the efficiency of utilization of the accelerator. The level of use by external groups has significantly increased in the past year.

Until recently the Laboratory used an IBM 1800 computer in a time sharing mode for synchrotron control, for on-line experiment data logging and preliminary analysis, and for some off-line computing. Although the 1800 worked rather well for these functions, it was limited in capability, and a larger computer was very much needed. In December 1970, a PDP-10 was installed to provide a much larger capacity for on-line data recording and analysis in a real time sharing mode. The main computer is interfaced to individual experiments through PDP-11 mini-computers which can log the data directly onto magnetic tape without involving the PDP-10, or buffer it into the PDP-10 for on-line analysis.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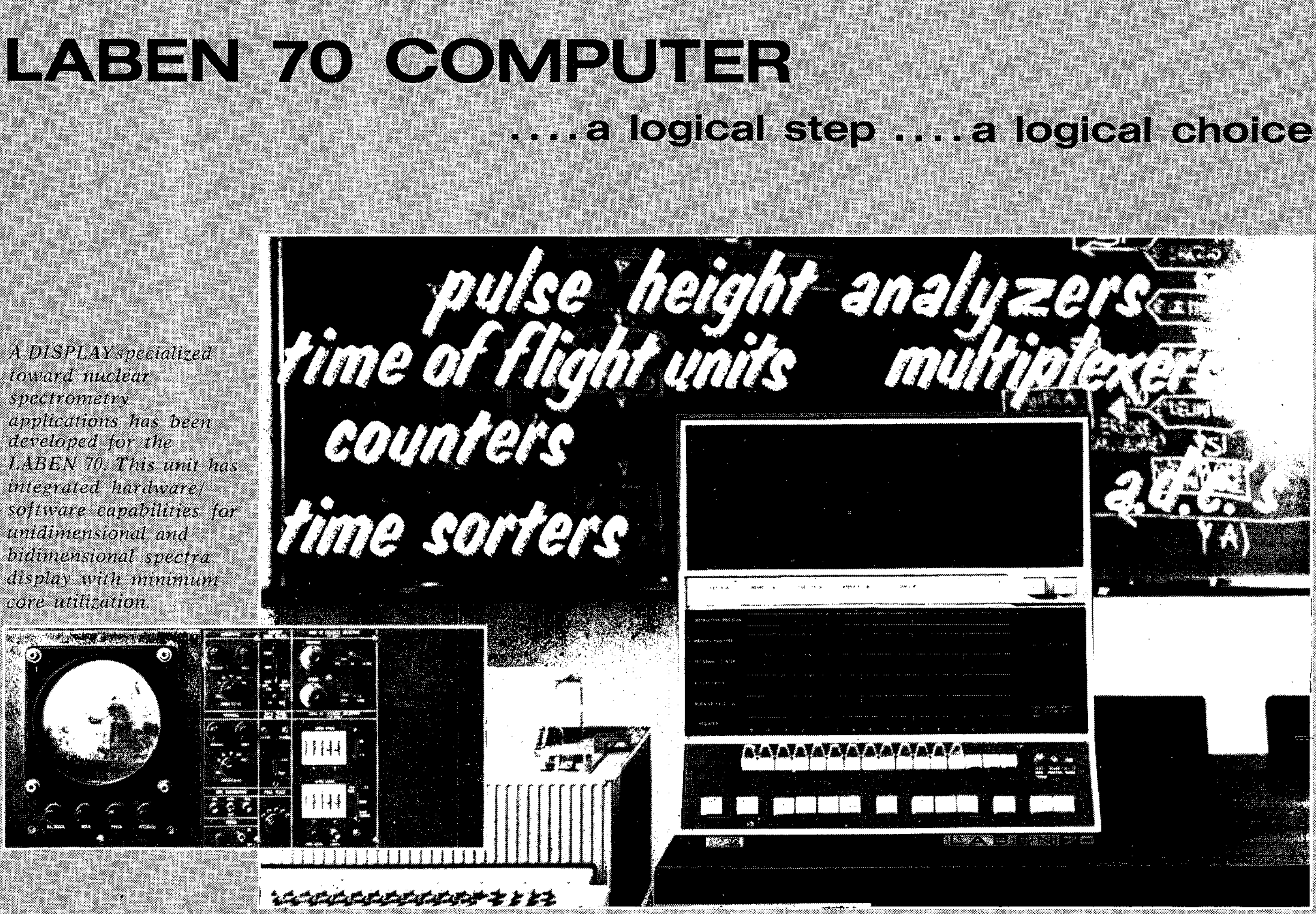

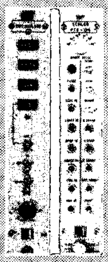

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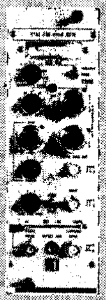

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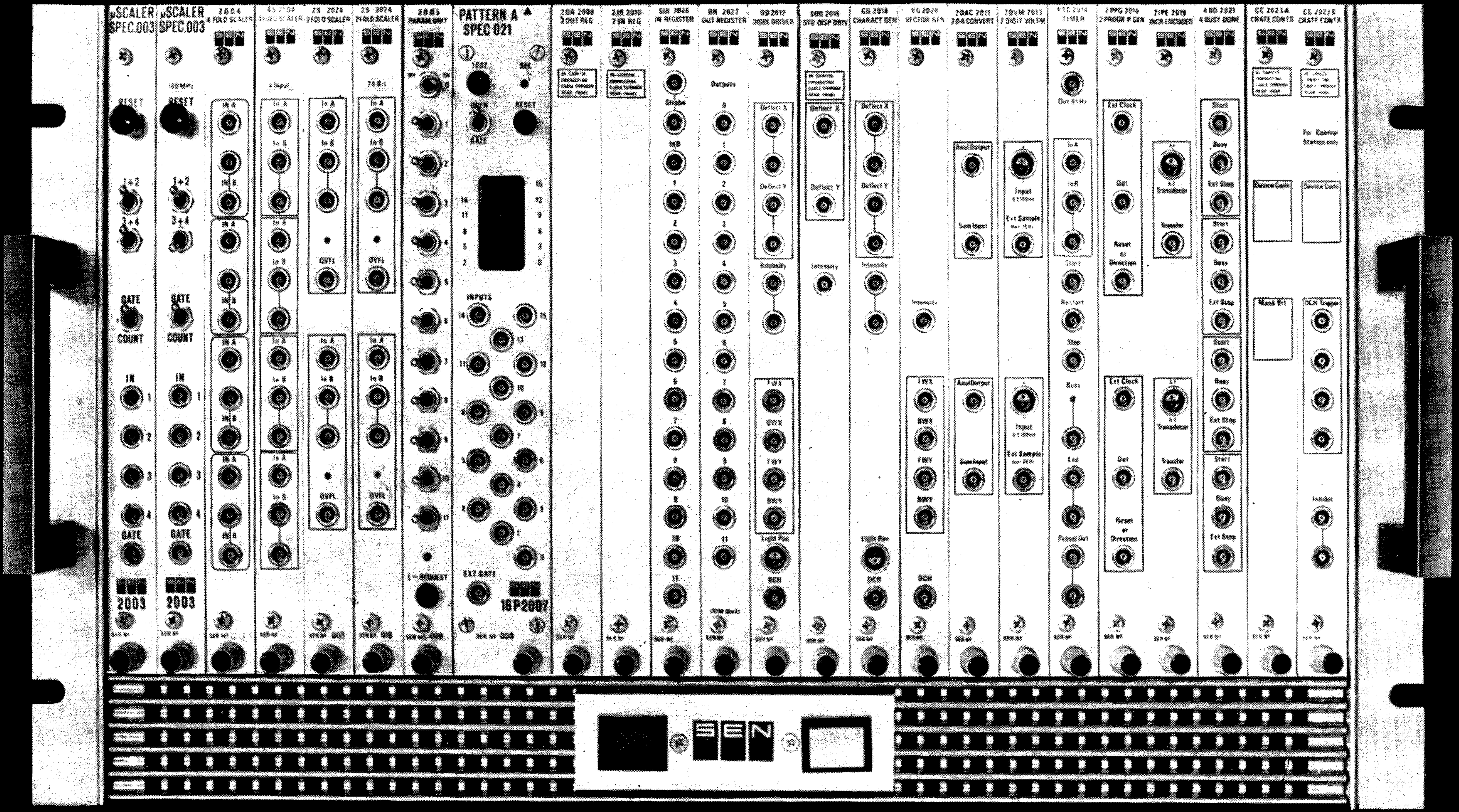

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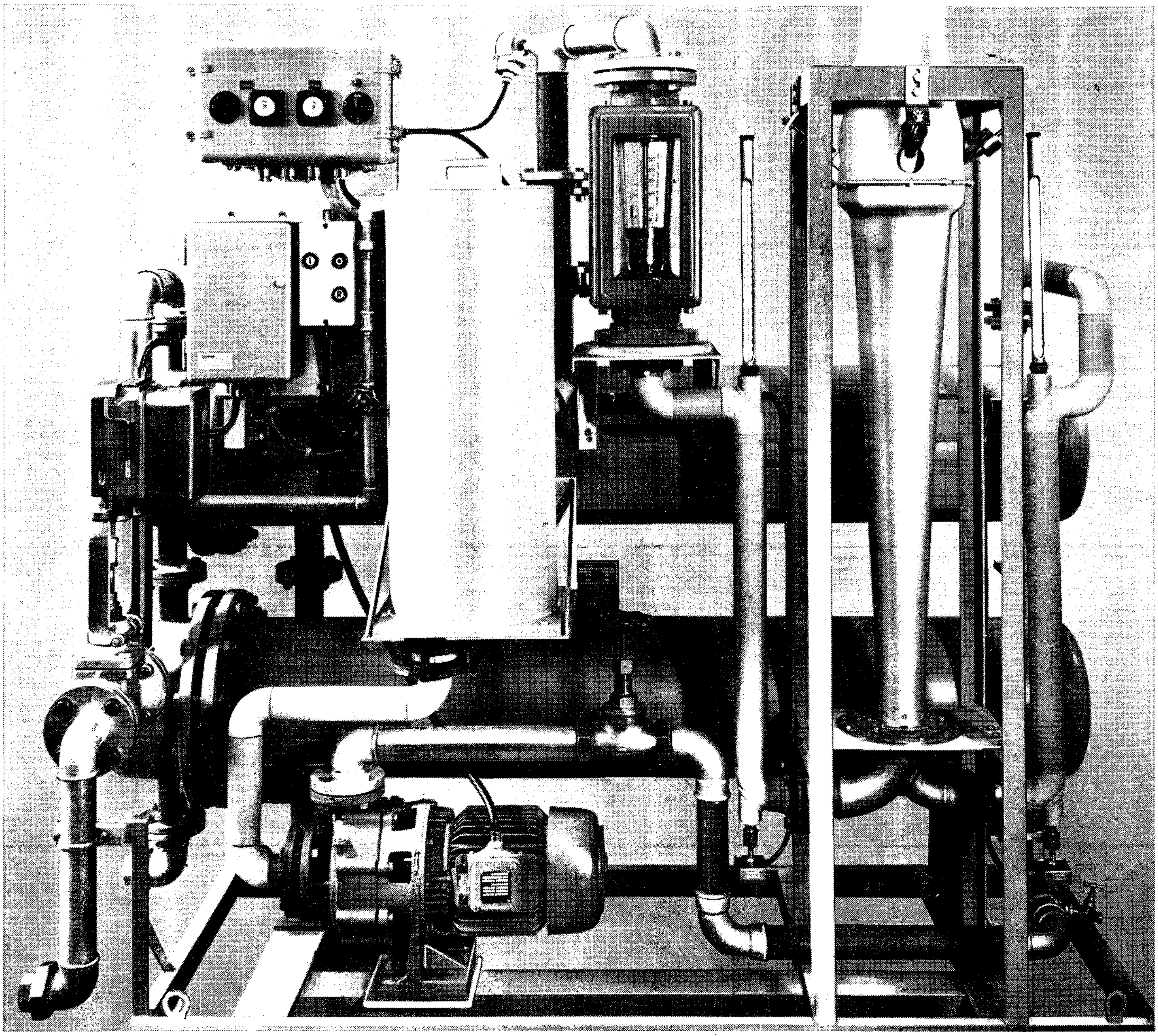

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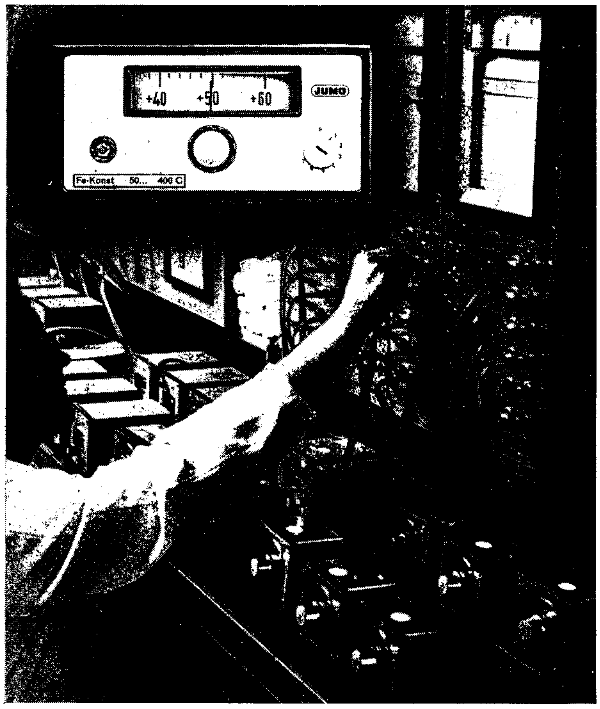

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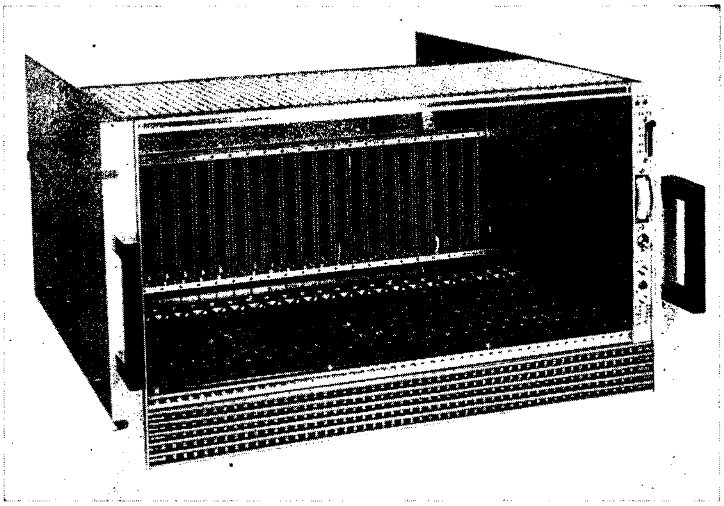

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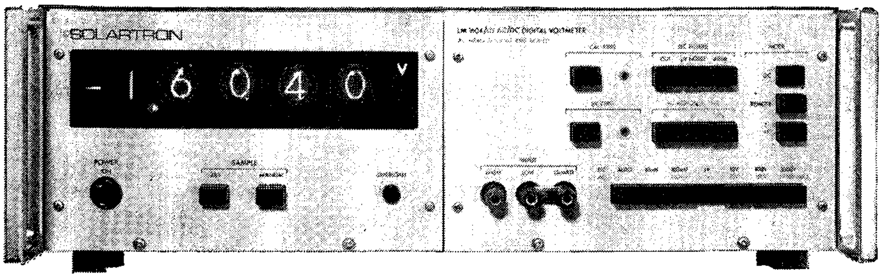
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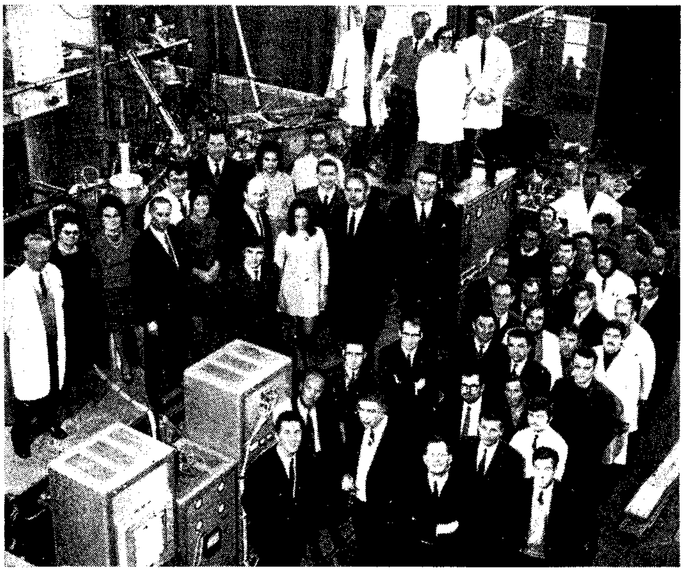
POWER
SAMPLE



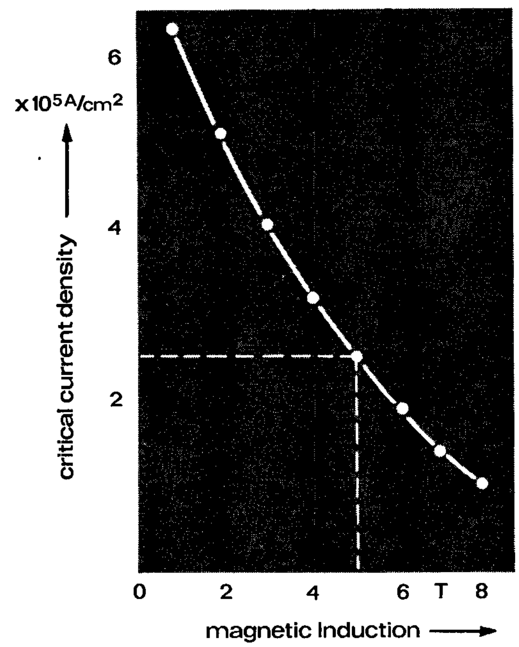
VAC
VACUUMSCHMELZE

Multicore Conductor 3,5 x 7,6 mm² twisted, with cryostatic stabilization

NbTi based alloy High Field Superconductor

VACRYFLUX 5001®

Application: Magnets both of big volume and on laboratory scale



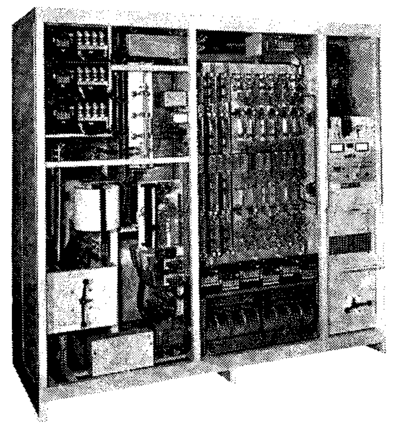
Single core conductors for magnets of high homogeneity (critical current density about 2-2,5 x 10⁵ A/cm² at 5 T)

Multicore conductors containing 30 to 250 twisted superconducting strands, various degrees of stabilization, cross section circular or rectangular (diameter of superconducting cores: 0,1-0,2 mm)

Filament conductors containing 60 to about 1000 twisted superconducting strands, intrinsically stable (critical currents varying from 100 to 2000 A at 5 T)

VACUUMSCHMELZE GMBH · 645 HANAU

Stabilised DC power… Brentford performance keeps ahead



A 220 KW 110 volt 2000 ampere, highly stabilised power supply supplied to Rutherford Laboratory of S.R.C. Equipment has overall stability including ripple, of one part in ten thousand of set point over a 10/1 range, and incorporates a Brentford/Hingorani D.C.C.T. and a Brentford D/A converter for computer control.

Back in the early 60's, we supplied DC power stabilised to 1 part in 1000 long term, including ripple, for the beam line magnets of the 'Nimrod' proton synchrotron at the Rutherford High Energy Laboratory in the U.K. On our latest installations we are doing better than 1 part in 100,000.

The reason could be summed up in one word. Experience. Since the 50's, we have developed stabilised DC power supplies from 10 to 10,000 KW, 50,000 amperes. Our reputation as specialists has taken our equipment into many advanced projects – into CERN Switzerland, the Culham and Harwell laboratories of the U.K.A.E.A., the Rutherford and Daresbury laboratories of the Science Research Council, the Argonne and National Accelerator laboratories U.S.A., and Heidelberg and D.E.S.Y. in West Germany.

As our experience grows, our designs achieve ever tighter tolerances. We can hold that beam steady, even with coincidence of load resistance changes, ambient temperature changes, frequency variations, step functions and slow rate changes in the AC supply.

While you search deeper and deeper into the nature of matter – leave the DC power problems to Brentford.

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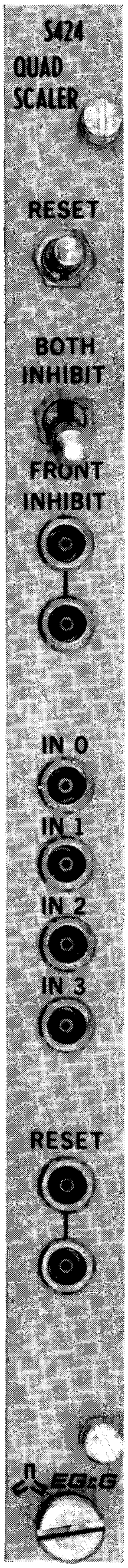
1 part in 1000

1 part in 10,000

1 part in 100,000



New CAMAC modules from EG&G

Quad 24-bit CAMAC Scaler . . . 125 to 150 MHz continuous operation
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- Front-panel NIM fast RESET on "Bridging" input
- Overflow or Carry at rear output

Quad 16-bit CAMAC Scaler . . . 50 MHz typical, 40 MHz guaranteed
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- CAMAC INHIBIT gate common to all sections
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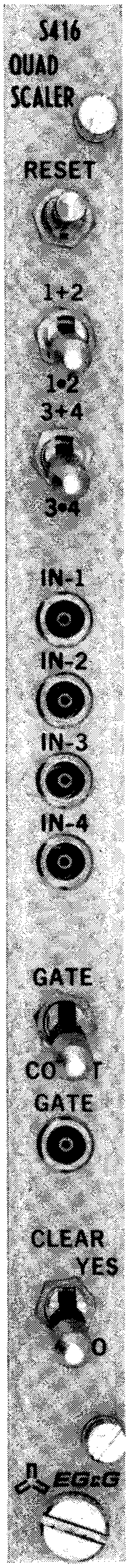

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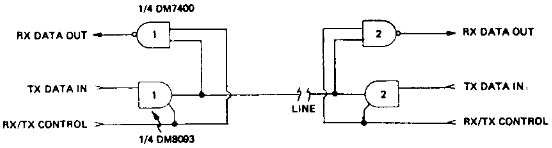
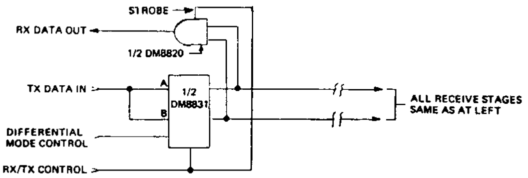
TTL NATIONAL'S TRI-STATE LOGIC

TYPICAL APPLICATIONS

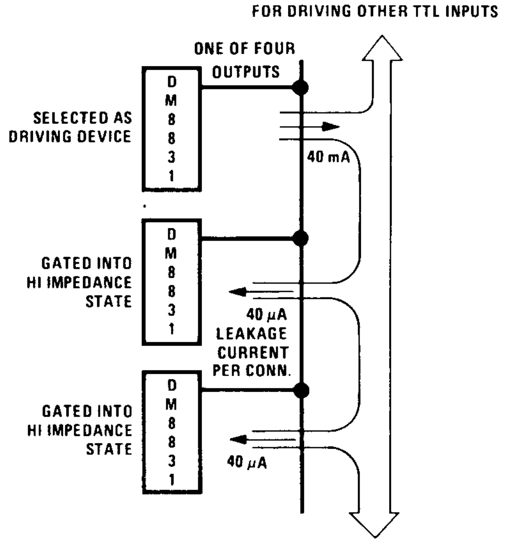


SINGLE-ENDED TRANSMISSION



DIFFERENTIAL TRANSMISSION

BI-DIRECTIONAL DATA LINES



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THE TRI-STATE FAMILY TODAY — AND THE FUTURE

The listing below indicates the part numbers and descriptions of all tri-state elements defined to date. The date in parantheses next to a device indicates its scheduled release date if not currently available. In the National numbering system the DM7xxx is the — 55° to + 125°C full military version while the DM8xxx is the 0°C to 70°C commercial version.

1. DM7551/DM8551 — Quad-D Flip-Flop
2. DM7230/DM8230 — Bus Line Demultiplexer
3. DM7831/DM8831 — Party Line Driver
4. DM7093/DM8093 — Tri-state Buffer Gate
5. DM7094/DM8094 — Tri-state Buffer Gate
6. DM7214/DM8214 — Dual 4-Line-to-Line Multiplexer
7. DM7552/DM8552 — Decade Counter & Latch (2nd Qtr '71)
8. DM7553/DM8553 — Eight-Bit Storage Latch (3rd Qtr '71)
9. DM7554/DM8554 — Hexadecimal Counter & Latch (2nd Qtr '71)
10. DM7598/DM8598 — 256-Bit Expandable ROM

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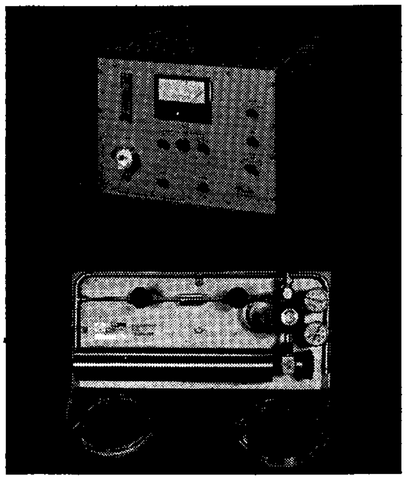
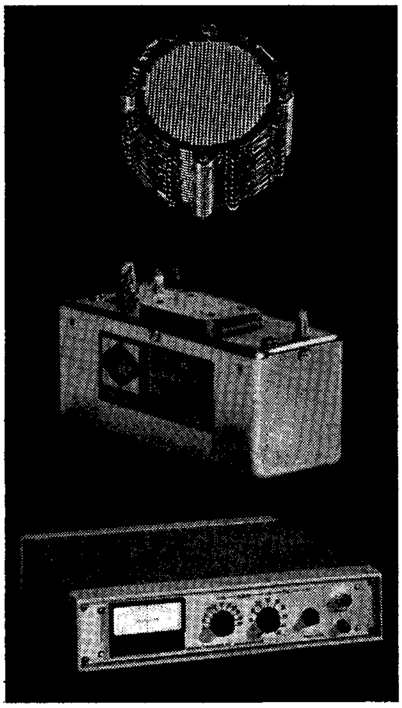


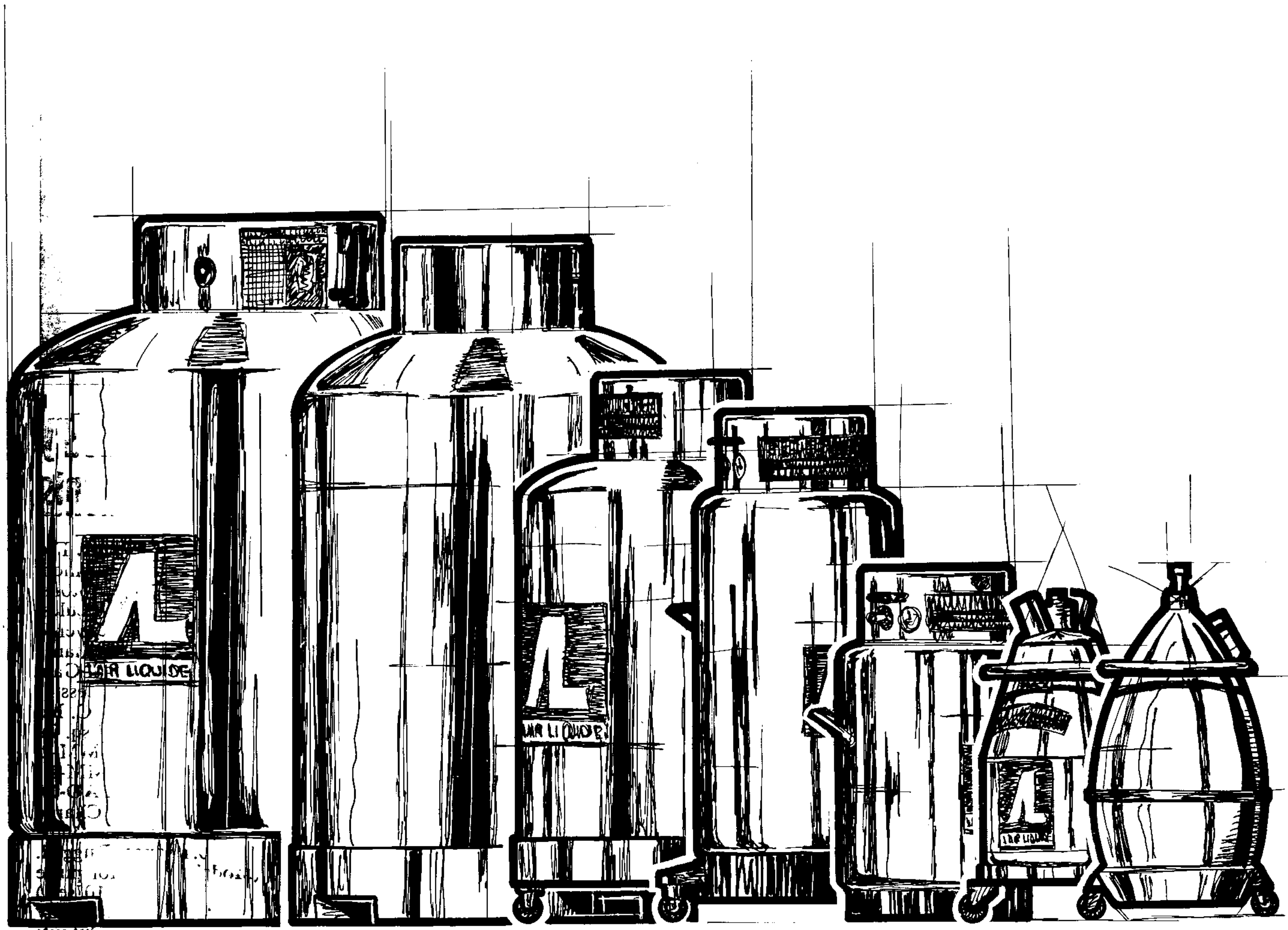
Radioactive Gas Monitors

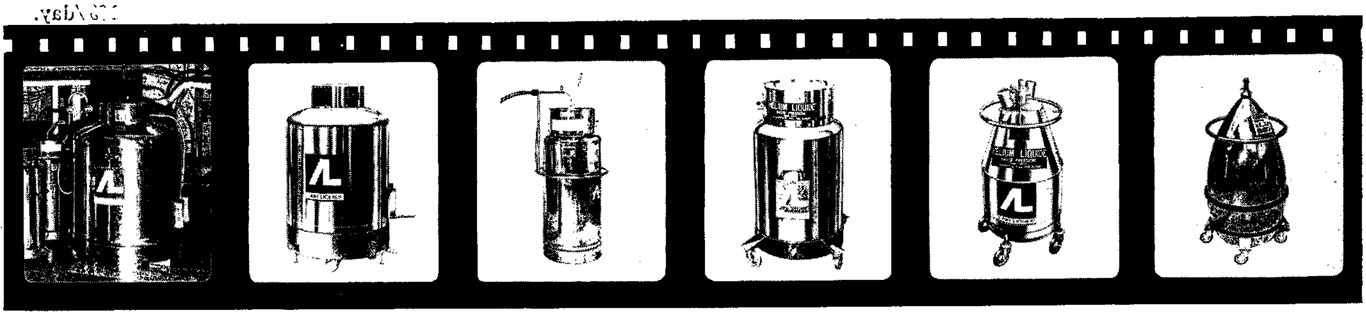
TRITON systems monitor gamma radiation, tritium, argon-41, carbon-14, chlorine-36, fluorine-18, krypton-85, radon-222, sulfur-35, xenon-133, and xenon-135. Features: 0.5 micron absolute filters, electrostatic precipitators, positive displacement pumps, gamma compensation to 5 mR/hour. **Triton 955.** Exceptional sensitivity: $10\mu Ci/M^3$ full scale for H^3. **Triton 1055.** Portable. Operates on rechargeable batteries. Sensitivity: $50\mu Ci/M^3$ full scale for H^3. **Triton 755C.** Suitable for rack mounting. Sensitivity: $100\mu Ci/M^3$ full scale for H^3. **Triton 1125.** Mil-Spec quality. Portable, rugged, rainproof. $100\mu Ci/M^3$ full scale for H^3. **Tritium Calibrator (CL-1).** For field calibration of Triton monitors. Accurate, rapid calibration in 3 to 5 minutes. **Remote Alarm (RA-1).** Audible and visual. Powered from main instrument. Operates up to 500 ft. from main instrument.



Spectrometry Components

Focused Mesh Multiplier (MM-1). For pulse counting or current measurement of electrons, ions, UV or x-ray photons, and energetic neutral atoms or molecules. Guaranteed reactivateable. Delivered gain: 10^6 to 10^8. Noise less than 1 count/minute at 10^7 gain. Gain stability at count rates in excess of 10^6/second. Bakeable at 350° C. No ion feedback. Non-magnetic. 1.5 sq. in. active surface area. (Model MM-2, miniature version of MM-1.) **Pulse Amplifier Discriminator (PAD-1).** Low power consumption. Charge sensitive input. Rise time: 3 nanoseconds. Adj. discriminator: 20:1 range. Rugged. Miniature. (Model PAD-2 for pulse counting rates to 10^7sec.) **Regulated High Voltage Power Supply (HV-4R).** No vacuum tubes. Output: 500 v. to 6.1 kv. Reversible polarity. Noise less than 300 microvolts RMS. Drift less than .01%/hour, .02%/day.


L'AIR LIQUIDE
1000 l.
500 l.
250 l.
100 l.
50 l.
25 l.
25 l.


RS1000
RS500
RS100
RS50
RS25
VS25