CERN COURIER

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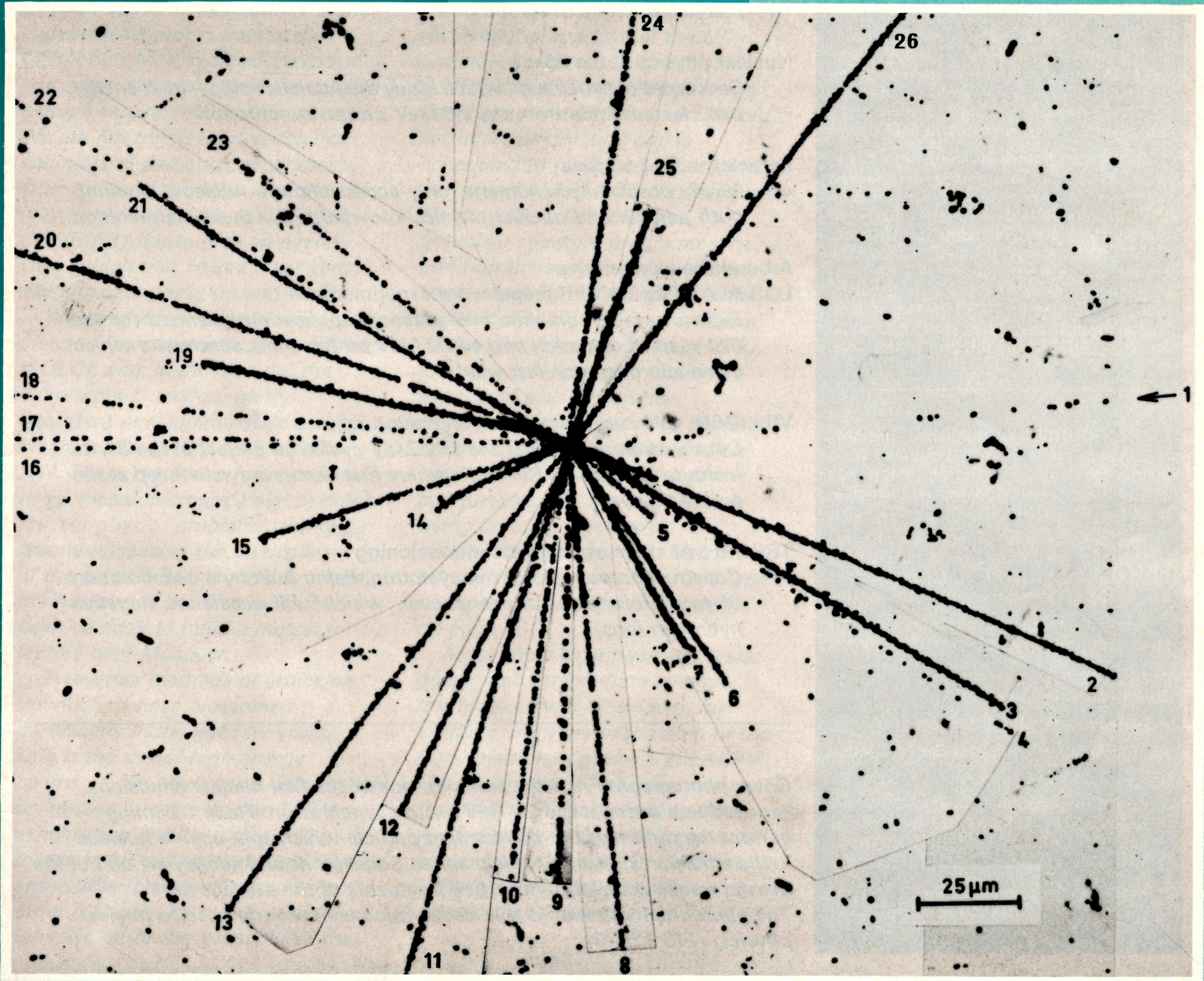

CERN, the European Organization for Nuclear Research, was established in 1954 to '... provide for collaboration among European States in nuclear research of a pure scientific and fundamental character, and in research essentially related thereto'. It acts as a European centre and co-ordinator of research, theoretical and experimental, in the field of sub-nuclear physics. This branch of science is concerned with the fundamental questions of the basic laws governing the structure of matter. The Organization has its seat at Meyrin near Geneva in Switzerland. There are two adjoining Laboratories known as CERN Laboratory I and CERN Laboratory II.

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

The CERN Laboratory I site covers about 80 hectares almost equally divided on either side of the frontier between France and Switzerland. The staff totals about 3000 people and, in addition, there are about 850 Fellows and Visiting Scientists. Twelve European countries contribute, in proportion to their net national income, to the CERN Laboratory I budget, which totals 382.9 million Swiss francs in 1973.

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

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Cover photograph: From the archives, one of the first nuclear emulsions exposed to a beam at the 28 GeV proton synchrotron. Track 1 coming in from the right was the bombarding particle which split open a nucleus in the emulsion in this dramatic manner. Some pions and kaons flew off but the heavier tracks were left by charged fragments of the nucleus itself.
The photograph introduces this issue which is mainly devoted to nuclear physics. (SIS 11073)

Comment

This month we are leaving aside high energies and taking a look at what is going on at intermediate energies, legally defined in the USA as covering the range from 100 to 1000 MeV. In particular we are leaning on nuclear physics (sometimes also typed as 'unclear physics'). The opening article covers some topics on what we think we know about the nucleus and some topics on what we are sure we do not know about the nucleus.

The nuclear physics theme carries through in a brief description of the experimental programme at the CERN 600 MeV synchro-cyclotron and some experiments at the on-line isotope separator ISOLDE.
We are not trying to give detailed accounts of particular experiments (this tends to come up in a one-off way in normal issues of CERN COURIER) but to give an overall view which tries to say what sorts of things are going on and why.

We have information on the planned improvements at the SC and ISOLDE and, in the 'Around the Laboratories' section, on the important new intermediate energy facilities at LAMPF, TRIUMF and SIN. These machines (often referred to as 'meson factories') aim to crack nuclear physics problems mainly by greatly increasing the intensities of the particle beams used to probe the nucleus. It has also recently been decided to build a meson factory near Moscow.

Two other methods of attacking the nucleus have blossomed particularly in the last few years. One is the use of high energy beams — we have some information on nuclear physics at the CERN synchrotron and there is similar research, for example, at the Saclay and Rutherford synchrotrons. The other is the use of accelerated heavy ions. Some of the possibilities that this opens up are mentioned in the first article and we covered heavy ion work at the Berkeley Bevatron last November (page 380). The proposed combination of the Bevatron with Super-Hilac is the most exciting project for nuclear physics with heavy ions.

Less energetic, but carrying with it the refined properties of the tandem Van de Graaff, is the 20 to 30 MV nuclear structure facility under detailed study at Daresbury which would be capable of accelerating a range of ions. This project recently received the approval of the UK Science Research Council.
At Darmstadt a versatile heavy ion linear accelerator known as UNILAC is under construction and is scheduled to produce its first beams at the end of 1974. The high intensity electron linac at Saclay has a nuclear structure programme. In addition there are many cyclotrons, some of which we reviewed in the context of the Vancouver cyclotron conference (see vol. 12 page 282), carrying out research in various aspects of nuclear physics.

Another growing area of research links nuclear physics with particle physics. Knowledge collected independently in the two fields is being brought together to investigate phenomena which would otherwise be inaccessible. One type of experiment is described briefly on page 40.

Much more than nuclear physics goes on at intermediate energy machines as will be evident, for example, from the description of the experimental programme at LAMPF. The energy range has been under study for sufficiently long to have yielded knowledge which can now be used. Applications in medicine, industry and agriculture are extensive and growing fast.

Looking at the nucleus

The study of the nucleus began sixty years ago when we found out it was there. Rutherford fired alpha particles at thin gold foils and, from the way they bounced off, it could be deduced that nestling at the heart of the atom is a solid lump carrying almost all the mass of the atom.

During the subsequent twenty years or so, there were glorious achievements in interpreting the atom, partly because existing experimental techniques made it possible to get in amongst the external cloud of electrons which predominantly dictate the atom's behaviour. In that context not so much was learned about the 'solid lump', except in the global way of determining some properties (those influencing the electron cloud) of the nucleus as a single entity. Nevertheless, in understanding the atom, theories of particle behaviour which have carried over into nuclear and particle physics were evolved.

It was quickly shown that the nucleus has constituents itself. In 1919 Rutherford bombarded nitrogen gas with alpha particles and observed the break up of the nitrogen nucleus. It was known that the nucleus contains protons and other constituents, which were initially interpreted as electron-proton combinations. The surfeit of protons (those not neutralized by electrons) gives the number of positive charges equivalent to the number of surrounding electrons and is different for each chemical element. In 1932 the neutron was identified and replaced the electron-proton concept.

The number of neutrons in nuclei of the same element was known to vary for many elements and these various manifestations of the same nucleus were called isotopes.

In 1935 Yukawa's theory postulating a new force in Nature (now called the strong nuclear force) was perhaps the first real insight into the workings of the nucleus. The new force, acting over very short distances (of the order of nuclear sizes) explains how the protons and neutrons can hold together so powerfully despite the disruptive presence of positive charges in close proximity pushing away from one another. The theory also introduced the mesons into the list of the particles as the carriers of this strong force (though they had to wait another ten years before being separately identified).

Experimental techniques then began prising open the nucleus much further when new accelerators, starting with Lawrence's cyclotron, made available the MeV energies which are necessary to penetrate the nucleus. The 'solid lump' was shown to have a structure every bit as intricate as that of its surrounding electron cloud.

The study of rather different aspects of nuclear behaviour then became dominant. For a long time the emission of particles from nuclei had been known — alpha, beta, and gamma decay were well documented and partly understood. Then, at the end of the thirties, the phenomenon of fission — the break up of a heavy nucleus into smaller fragments — was discovered with shattering results for mankind. Bohr and Wheeler put forward their 'liquid drop' model to explain what happens. The addition of another neutron to the heavy nucleus (regarded as initially spherical) was interpreted as initiating oscillations which disturb the energy balance in the nucleus and (like a drop to which too much liquid has been added) it can change into a dumb-bell shape and finally divide when the surface energy can no longer hold it.

The process liberates energy; the mass of the products is less than the mass of the original heavy nucleus and this mass difference is converted to energy. The way to initiate fission by sending in a neutron to tip over the stability of the nucleus was quickly learned and controlled fission in nuclear reactors and uncontrolled fission in atomic bombs were with us.

It was also realized that the inverse phenomenon to fission, where nuclei from light elements are welded together to form a heavier nucleus, is also a source of energy — a mass difference again occurs. This was used in an uncontrolled way in the hydrogen bombs and is still the subject of a lot of applied research in the attempt to achieve controlled thermonuclear fusion.

Use of accelerators opened up the understanding of the nucleus in several different ways. For example, by throwing particles at the nucleus it became possible to break into an existing nucleus and either to transform it into the nucleus of another element or to produce an isotope of the same element. In this way new elements were artificially produced heavier than uranium, which, with ninety two protons in its nucleus, is the heaviest found in Nature. (Not quite true — last year a Los Alamos search found minute traces of plutonium, which has ninety four protons, in a rare earth ore called bastnasite.) Creating isotopes has been fruitful both for studying the behaviour of nuclei and for a wide variety of practical applications.

But, in terms of attempting to understand the nucleus, most effort at the accelerators went into nuclear spectroscopy. A stage earlier, atomic spectroscopy had given vital insights into understanding the electron cloud. Observing the way the cloud emitted and absorbed discrete packets of energy (in the optical and X-ray wavelengths) as electrons moved between their allowed energy states, made it possible to calculate those energy states and to work out how the electromagnetic forces operating between the positive nucleus and the negative electrons cloud gave these energy levels.

The nucleus exhibits remarkably similar characteristics. This time the packets of energy emitted are greater (gamma rays) but again they have discrete values for a particular nucleus and the allowed energy states can be calculated. This has given us a 'shell model' of the nucleus with the idea of orbiting particles swirling around in the nucleus similar to the shell model of the orbiting electrons around the nucleus. But the strong force acting between nucleons is not known as well as the electromagnetic force and the interpretation of what we observe cannot be carried through with the same thoroughness.

We know that we can build up nuclei using from one to about 250 nucleons; we observe that, in general the heavier the nucleus the more the number of neutrons exceeds the number of protons. We can understand, in outline, why the nucleons hold together via the strong force but we do not know exactly how the pi meson plays its role in the nucleus. Though a lot of information has been gathered on the role of the meson in particle to particle interactions (learned from high energy physics experiments), we do not know how this is modified in the multi-particle complexity of the nucleus. Given a bunch of protons and a bunch of neutrons, we still cannot say with certainty which are the possible ways in which they can live together and, more importantly, why they can live together.

Another source of information is to measure the shape of the resulting nuclei and, in general, we see it grow as the number of nucleons increases in the way we would anticipate for a spherical nucleus (the mass being proportional to the cube of the radius). It is known however that some nuclei are slightly deformed into ellipsoidal shapes.

High energy electron scattering experiments have shown that particles over the bulk of the volume of heavier nuclei are rather uniformly packed but that there is a fuzzy surface region (the 'nuclear atmosphere') where the average density of particles falls off. The lighter nuclei have not enough volume to talk of an interior region and can be considered all 'surface region'. From there on, interpretations begin to get more difficult. Some maintain that neutrons dominate at the surface (thinking of minimum energy configurations, the neutrons would have a larger radius distribution), but it can be maintained that protons and neutrons are there in equal numbers ('exotic atom' information is probably the best route towards answering this question and is near to achieving the necessary precision), and others maintain that they have a tendency to cluster there as alpha particles (based on scattering experiments).

If we are so unsure about what goes on at the surface of the nucleus, we are even less sure about what goes on deep inside in the sense of knowing about the tightly bound states. Most experimental indications are that the protons and neutrons remain discernible as such and do not transform for example into complex resonances. This is supported by data from scattering experiments and by the emission of individual nucleons. However, as D.H. Wilkinson remarked, 'It has been noted before that the extraction of a bark from a dog does not prove that dogs are made of barks'.

Deep in the nucleus, the protons, neutrons and mesons may be meshed together in intricate ways. To find whether such intricacies are there or not and, if they are, to unravel them has been impossible up to now. The nuclear states we can get at are those of the outer energy levels. It is as if we had only been able to study in detail the outermost valence electrons in the atom and were not certain that the picture which emerged carried through to the more tightly bound electrons.

The nucleus has been under study for a long time and most of the present research is taking our knowledge of its behaviour a little further — gathering more details on energy levels and nuclear shapes, checking whether the known behaviour continues to prevail for nuclei pushed into extreme conditions, and so on. But the research is still capable of throwing up considerable surprises.

Last year, for example, a CERN, ETH, Imperial College, Milan team reported results of a particle physics/ nuclear physics experiment (coherent production of multi-pion systems and study of how the multi-pion system scattered on nucleons). Essentially what they found is that a three-pion or five-pion system can wriggle its way through nuclear matter more easily than one pion — as if five pions were smaller than one. What this type of experiment can tell us about the way in which protons and neutrons are distributed in the nucleus could be something completely new.

There are other potential sources of completely new information. One is the study of the hypernucleus where a neutron is replaced by a lambda particle. The lambda can filter down into the deeper energy states of the nucleus and we might be able to find out about those states in a way which is not possible with protons or neutrons.

Another area of study is that opened up by the acceleration of heavy ions. Here it will be possible to throw nuclei together in a new way. With the acceleration of individual particles we have probed the nucleus rather like firing a bullet at a custard pie, the high energy disturbance being concentrated in a small part of the nuclear volume. Now we can fire custard pies at custard pies. The results could be equally interesting (and could be equally difficult to tidy up).

Knowledge of the gross features of nuclear behaviour has been enough to yield applications which have had a tremendous impact on man's environment. Work on the detailed features is continuing. A great deal of new knowledge, and even occasionally some new understanding, is being added by nuclear physics experiments and the theoretical treatment of their results.

At the synchro-cyclotron

The physics programme at the 600 MeV synchro-cyclotron has included eighteen experiments in the course of the past year (not counting those at the isotope separator, ISOLDE, which we mention separately) involving scientists from about thirty research centres. The experiments have been mainly concerned with nuclear physics but there are several studying aspects of particle physics, where intermediate energies are appropriate (providing different information to that coming from synchrotron or storage ring energies). There is also a modest programme of radiobiology.

At ISOLDE, fed by the SC, short-lived 'exotic' nuclei are under study and the themes of several experiments are covered in the next article. Within the SC experimental areas there are related experiments such as an Orsay investigation of fragmentation which provides astrophysics with data on stellar and interstellar interactions and a Cologne study of the effect of SC beams on targets of lunar rock composition so as to estimate the effect of cosmic rays on the surface of the moon.

The energy of the synchro-cyclotron was selected so that the machine would be capable of copious production of pions. This ability has been used in a long sequence of experiments where pions have been fired at nuclei. One important experiment by an IISN Brussels, Orsay team compiled an unusually complete catalogue of data on the scattering of pions on the carbon 12 nucleus. The measurements cover the scattering in detail as a function of energy and angle. The welter of data makes it possible for the theoreticians to test pion-nucleon dispersion relations in a detailed way for the first time.

Other pion-nucleus experiments are continuing. To take a single example: a CERN, Goteborg, London, Oxford, SIN team are measuring total cross-sections with both positive and negative pion beams on a variety of nuclei. They recently finished data taking on positive pion-deuterium elastic scattering in the backward direction (when the pion would bounce off towards the direction from whence it came if we converted the interaction into centre of mass terms, i.e. as if the pion and nucleus were flying at one another rather than the pion hitting a stationary nucleus). The results are in good agreement with a model involving multiple scattering within the nucleus but at lower energies the angular distribution of the scattered pions shows the agreement with the predictions of the model becoming steadily worse. These agreement/disagreement results have not yet been explained.

Another disagreement with theory came in a series of measurements on nuclei such as helium and carbon which have isospin zero. Sending pions into these nuclei should give the same total cross-section for positive and for negative pions when account is taken of Coulomb effects due to the positive charge of the nucleus. However when the Coulomb correction is made there still remains an unexplained difference of close to 10 %.

Similar measurements with positive and negative pions on nuclei, such as beryllium 9, which have isospin of one half, give information on the real part of the scattering amplitude connected with the important pion-nucleon coupling constant. There is a link, via several manœuvres in the theory, with the nuclear coupling constants in beta decay.

Another particle available at the SC, in addition to the accelerated proton and the secondary pion, is the muon. A long series of experiments have used muon beams and four of them are in the current programme. One concerns the production of muonic atoms where the muon becomes a satellite of the atom in the same way as an electron. In a later article we survey the types of information that 'exotic atoms' from muonic to sigmic have brought or might bring us. Both muonic and pionic types have been staple diet at the SC for many years.

To avoid too much repetition we will just point out here a few of the measurements which are possible. When the muon is in the higher atomic energy levels, it is sensitive to the quadrupole moment of the nucleus — the muon orbits will be partly dictated by any asymmetry in the way the protons move around in the nuclear volume. In this way it has been possible to measure the quadrupole moment which is associated with the rotation of ellipsoidal, or cigar-shaped, nuclei.

The measurement of the X-rays emitted as the muon falls through its allowed orbits is an extremely sensitive measure of the energy levels. It is possible, for example, to detect a difference between the shape of an excited nucleus and a ground state nucleus. Very recent developments in experimental technique have taken the accuracy to the 1 % level.

With the pionic atom, the strong interaction adds itself to the electromagnetic. The pion in its orbit is sensitive not only to the way the charge is distributed in the nucleus but also to the way all the strongly interacting nucleons are distributed. Hyperfine structure effects due to the strong interaction have been observed in a qualitative way but the intensities of the SIN cyclotron (see page 43) are awaited to feed some numbers into the observation.

A new use of muonic atoms is an attempt to do a Lamb shift measurement on the difference between muon energy levels rather than electron energy levels. The original experiment

When the SC is rebuilt the internal target system will be changed. The targets shown in the photograph can be moved into the desired position (radially, azimuthally and axially) by remote control using a system of linear motors. With the increased repetition rate, the targets will receive much more beam; they have been designed to dissipate 1 kW of heat by radiation.

The new 'hooded arc' ion source will be introduced into the centre of the synchro-cyclotron from below on this long positioning device. It has four eccentric shafts which make it possible to position the source and the central electrodes.

by W.E. Lamb and R.C. Retherford in 1947 used atomic beam and microwave techniques to measure the energy difference between levels (2S and 2P) in the first excited state of the hydrogen atom. They found that the energy levels did not precisely line up with theoretical predictions. Quantum electrodynamics had to take into account the effect of the electron interacting with its own field. When this reformulation was incorporated in the energy level calculations, the Lamb shift was explained.

The Lamb shift measurement remains one of the most refined tests of the validity of the brillantly successful QED theory. Lamb, this time with M. Skinner in 1950, observed an even greater shift in singly ionized helium and it is this ion with a muon passing between the 2S and 2P levels that is studied at the SC. The experiment calls for highly refined techniques since the muonic helium ion does not exactly hang around to be measured. A method of stacking in the SC (as in the ISR) has been developed so as to feed short high intensity pulses of muons into a helium target at about 40 atmospheres pressure. A 50 ns pulse of light is fed in from a tunable laser and its frequency can be varied around 8150 angstroms, to flip the muon ion into the higher energy state. The frequency at which the X-rays from the muons falling from the 2P to 1S state peak to a maximum will give the energy level difference and hence the muonic Lamb shift. Up to now the laser frequency has been swung over a range from 8220 to 8160 angstroms and the data on the emerging X rays is being analysed.

These are just a few of the experiments at the 600 MeV synchro-cyclotron but they serve to indicate the sort of work that is under way. We will pass now to a little information on the machine itself.

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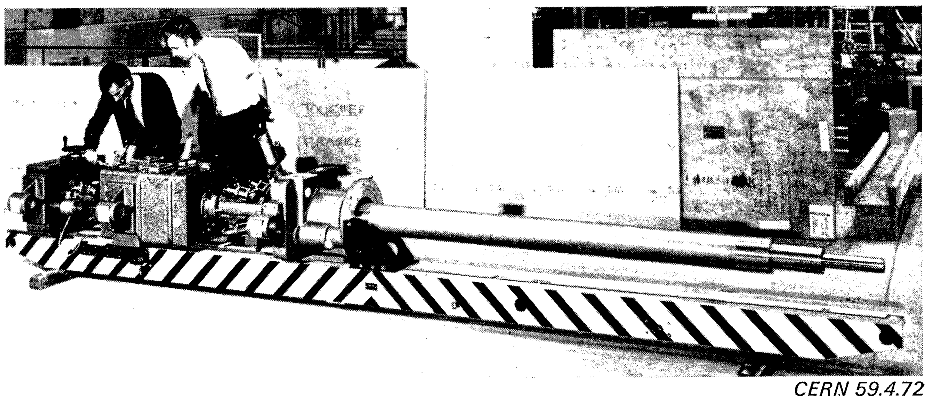

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Machine performance and improvement programme

During the past year the synchro-cyclotron provided protons for physics for just over 7000 hours. With multiple use of the beams this meant many more actual hours for experiments. The peak internal beam current is about 1.5 μA and to increase this by a factor of ten, and, at the same time, to raise the extraction efficiency well above its present value of around 6 % are the main aims of an improvement programme.

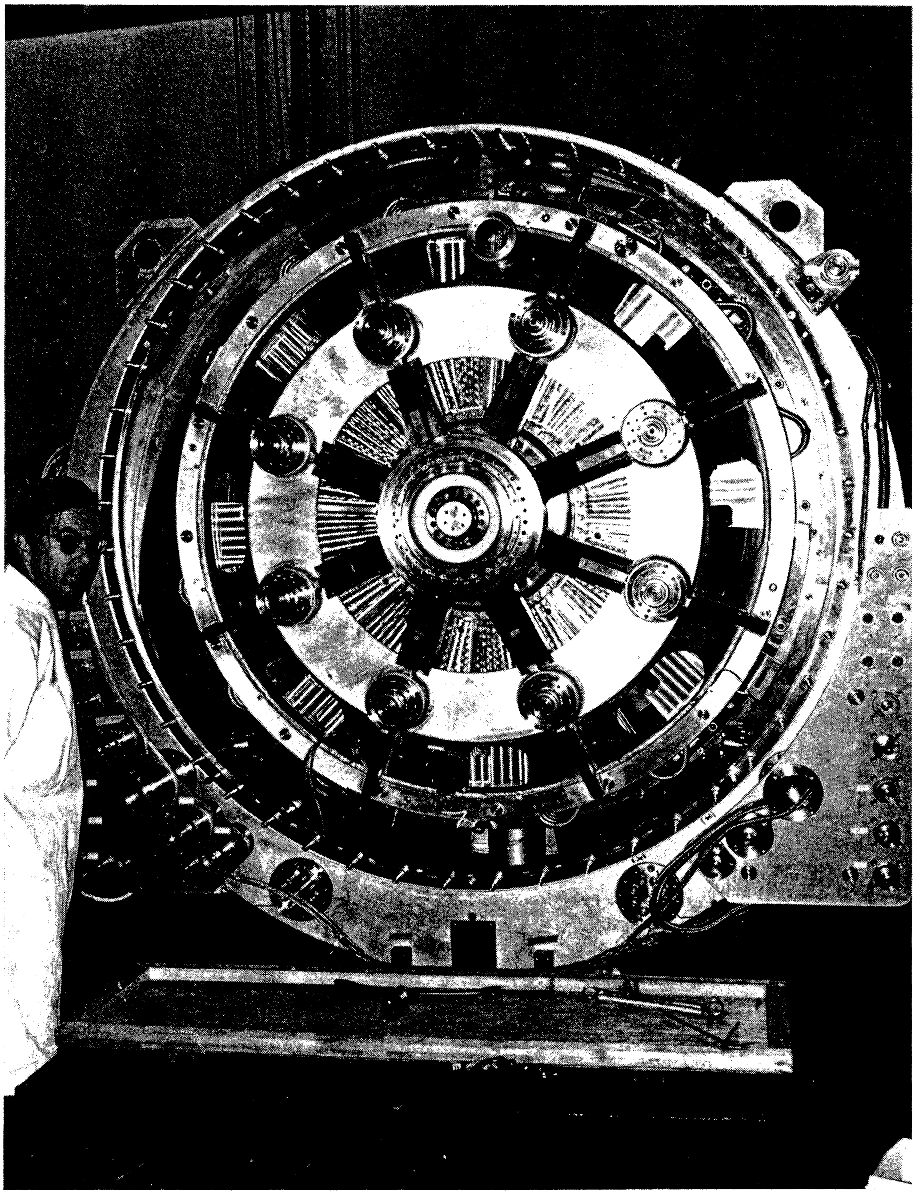
The new operation figures will be achieved by replacing several important machine components. The first is the ion source. At present, an 'open' type is used which prevents high accelerating voltages being applied in the source region to obtain a large change of radius per turn. A 'hooded arc' source and new central electrodes will be introduced to make fast acceleration possible which helps achieve good beam quality. Tests with a 15 MeV central region model cyclotron show that the desired current and beam characteristics (essential to achieve high extraction efficiency) can be achieved. The source and electrodes require a special mounting system which protrudes into the machine from below. It has been built and tested.

To take advantage of the hooded arc source however it is necessary to have higher acceleration voltages than the present radio-frequency system can provide. A new r.f. system has been designed to be capable of providing voltages as high as 30 kV, a frequency modulation from 30 to 16.7 MHz and a repetition rate of about 500 Hz. The mechanical tuning element is a rotary condenser (described in vol. 11 page 10). It has presented the major technical difficulties in the improvement programme and has in fact delayed implementation of the programme for over a year.

By now, the first of two rotary condensers, which are being built, has undergone mechanical tests and it was shown that the stringent dimensional requirements have been met. Vacuum tests were also successful — full speed operation for 24 hours saw no deterioration in the high vacuum. Electrical tests began in October and correct behaviour as regards the frequency range was achieved. It is now being prepared at the manufacturers for the vital high voltage tests. The design figure as stated above is 30 kV, but a lower voltage could still give a considerable improvement on present performance.

Other elements of the programme — a regenerative beam extraction system using a current bearing septum to give high extraction efficiency, radiation cooled internal targets to cope with higher currents, a Cee electrode for long bursts with small energy spread, a pulsed field coil to increase the duty cycle to over 50 %, a new vacuum chamber and new radiation resistant magnet coils — are ready, or can be completed as soon as they are needed.

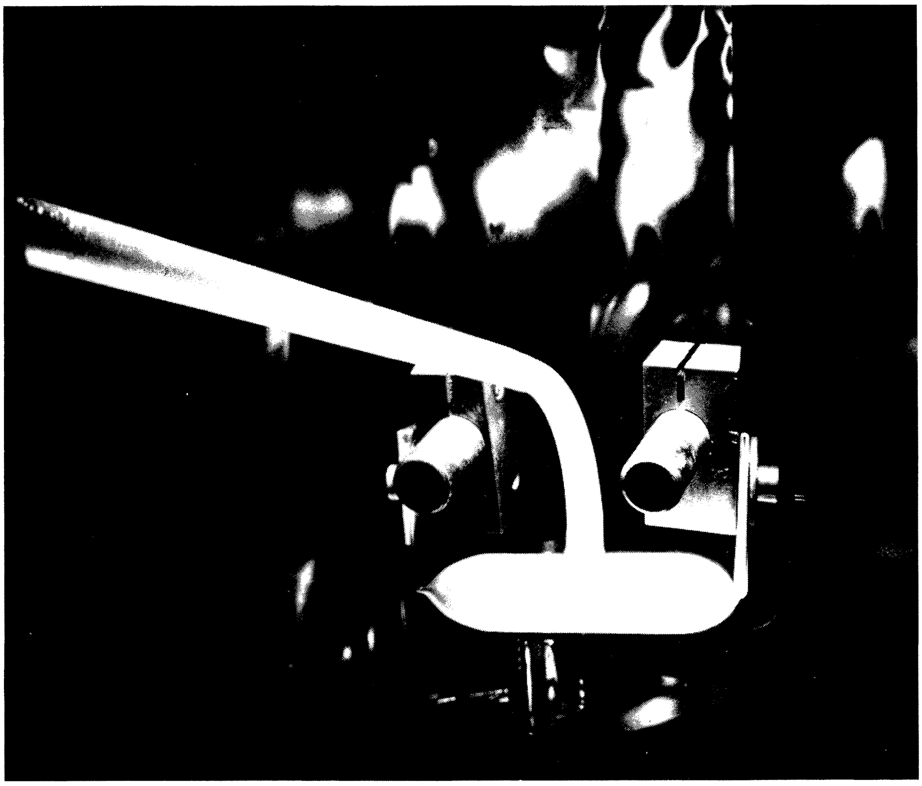
The shutdown to carry out all these improvements to the synchro-cyclotron is scheduled to last just under a year. What is not definitely fixed is its starting date, since the crucial rotary condenser has still not been fully tested. There is a strong recommendation from the improvement programme Advisory Panel (consisting of representatives of physics users) to bring the condenser to CERN and to complete it here after a preliminary test at the manufacturers. If this test does not reveal any major technical difficulties it is hoped that the shutdown could start before the middle of the year.



The rotary condenser of the r.f. acceleration system for the improvement programme at the SC photographed in its vacuum housing with the end shield removed. The eight symmetrically placed electrodes couple the condenser to the oscillator valve via the coaxial feed in the centre. The new r.f. system is designed to provide higher accelerating voltages and increase the pulse repetition rate of the synchro-cyclotron from 55 to over 500 Hz.

At ISOLDE
Isotope separator on-line

A new type of liquid metal target for the isotope separator, ISOLDE. An alternating current (the high current leads can be seen behind the target) keeps the metal at this glowing temperature in a tantalum container which is placed axially in the path of the SC beam. Ions of barium, cesium, xenon, iodine and tellurium, for example, can be obtained from a lanthanum target.



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There are now about sixty scientists coming to CERN as visitors to take part in the experimental programme of the isotope separator on-line, ISOLDE. The facility was described in vol. 7, page 23. Its essential ability is to make possible the study of short lived nuclei (far from the stability line) produced by bombarding targets with protons accelerated in the 600 MeV synchro-cyclotron.

A great many of the experiments are in the traditional field of nuclear spectroscopy — the painstaking work of pinning down the excitation energies, quantum numbers, etc., observed in the decays of the rare nuclei. Ultimately, the mapping of nuclear properties is the touchstone against which our attempts to interprete the nucleus stand or fall. We will mention three other experiments.

The first (by a Mainz team led by E.W. Otten) involves 'optical pumping', which has become familiar in connection with the laser, and a whole range of other atomic and nuclear techniques in order to unearth properties of nuclei far from stability. The panoply of techniques is necessary because the nuclei are in most cases available in very small numbers.

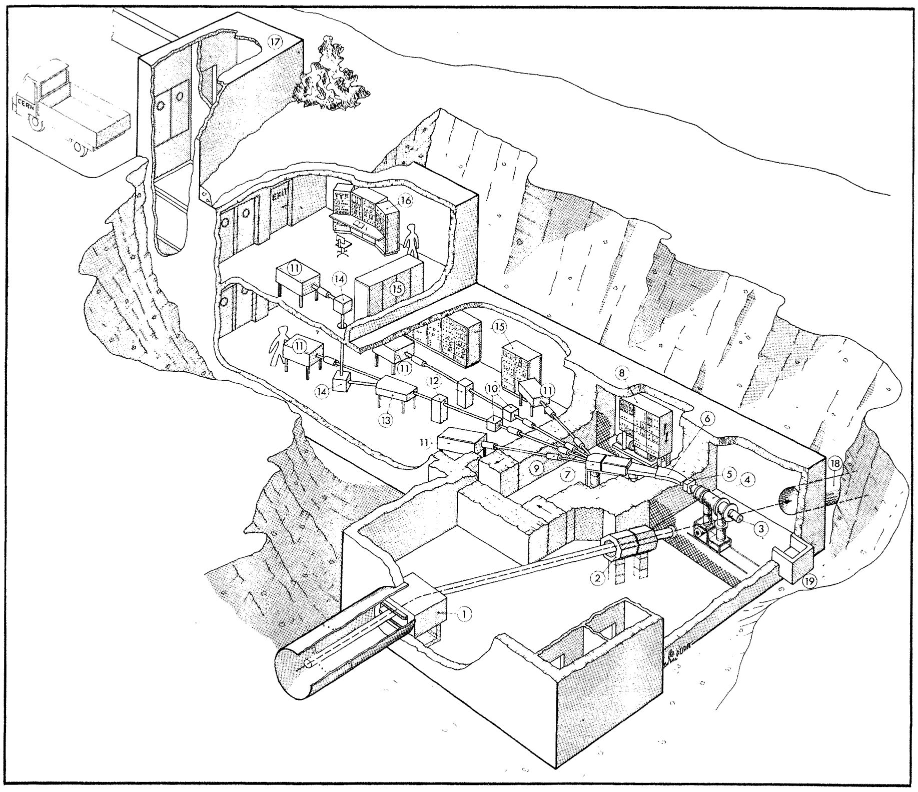
Without going through the experimental method again (see vol. 11, page 321) we will simply report their most intriguing result. They measured the atomic energy levels along a long chain of mercury isotopes and compared them with a stable isotope. This energy level difference (the 'isotope shift') is related to the nuclear shape (more specifically — the mean squared radius of the nucleus). For measured mercury isotopes from mass 205 down to mass 107 a neat straight line could be drawn through the measured energy differences corresponding to the expected decrease in nuclear radius with decreasing neutron number. Then, abruptly, for isotope 185 the energy difference veered a long way from the straight line — the change from 107 neutrons to 105 neutrons in the nucleus abruptly increased its effective radius. This change is sustained in measurements on mercury 183 and (a very recent result) 181.

The popular explanation is that for these three isotopes the nucleus is deformed into an ellipsoidal shape (such as is familiar for the rare earth elements). However another consequence of this type of deformation would be the possibility of rotation of the nucleus (again as with the rare earths) which should lead to observable fine structure in alpha decay. A newly developed target system has made it possible to look at mercury 184 produced from the alpha decay of lead 188. The experiment which was carried out by a team from Aarhus, CERN and Copenhagen, showed no sign of rotation.

An alternative idea, promoted by C.Y. Wong in October 1972, is that the nucleus transforms into something like a bubble with particles clustering around the outside of the sphere. This gives calculated energy differences in line with the Heidelberg results but needs other experimental investigation before it becomes more than an intriguing surmise.

A second series of measurements at ISOLDE has concerned the energy spectra of nuclei emitting 'delayed' particles. In the early studies of uranium fission it was observed that nuclei which are unusually rich in neutrons can sometimes survive for several seconds after their formation (an enormously long time on the nuclear timescale) before they emit neutrons. The same phenomenon for protons has been observed in a number of heavier nuclei at ISOLDE (see vol. 10, page 5) and at Dubna.

Cut-away view of the planned ISOLDE experimental area. The 600 MeV proton beam from the SC enters through a switching magnet (1) and focusing quadrupoles to the ISOLDE target and ion source (3). A beam of radioactive ions is set up by means of the acceleration electrodes (4) and mass-analyzed in a magnet (6). Individual masses are selected electrostatically in the switchyard (7) and taken to the various experiments (11) via secondary beam lines. Up to four experiments will be able to operate on-line simultaneously. A novel feature will be a second magnetic analysis stage (13) which is expected to provide a very clean beam for special low-intensity experiments. It is possible that at a later stage this beam will be taken by electrostatic deflectors up to the low background area (16) which also houses the controls of the isotope separator.



In recent work the fluctuations in the delayed particle spectra have been studied. This has revealed fine structure which is very reproducible for a particular nucleus but which varies in a seemingly random way from nucleus to nucleus. This is a way of looking at the nuclear 'noise' and the treatment of the results has followed the theory of noise in electrical circuits. From the measured spectra the average densities of the nuclear energy levels were deduced. Also information about how the levels are populated emerges.

The last series of measurements we will single out concerns the 'strength function' behaviour in beta decay. In the decay of nuclei far from stability, a very large number of states can be populated because the energy available is large. Instead of studying individual transition probabilities to isolated levels, their strength function behaviour can be studied — that is the total transition probability per unit energy interval with any trivial energy dependence removed. Studies as a function of mass number and atomic number has shown some surprising effects.

Beta decay of a particle inside a nucleus is very different from the beta decay of the same particle in the free state because the other nucleons affect the properties of the particle. One phenomenon is collective beta decay in which the beta decay process is produced jointly by a group of nucleons. Similar processes are known to occur in electromagnetic transitions in nuclei and in muon capture. The collective effects in beta decay manifest themselves by a different energy dependence for electron and positron emission. This can be seen by comparing the CERN data with that taken at the Studsvik reactor and also from analyses of delayed neutron emission results by A.C. Pappas and Y. Takahashi.

These studies indicate new 'simple' excitations of the nucleus. They may also be relevant to theories of stellar synthesis — the attempts to explain how the heavier elements (beyond lead) were built up when stars were formed.

Plans have been prepared for a major revamping of ISOLDE to go on at the same time as the SC shutdown so as to be able to make full use of the higher intensities. In fact a 10 μA SC beam is probably as much as the ISOLDE target could reasonably hold down and the SC improvement programme lines up well with the wishes of the ISOLDE collaboration.

Because of the high radiation levels a new layout will put the separator behind a shield wall with the target behind a second shield wall. Another change will be that the analysing magnet will be in the shield wall structure. Mobile electrostatic lenses will give much greater flexibility in beam selection to each experiment and should provide up to four simultaneous secondary beams in the experimental area.

Recent work on targets looks very promising. A new type of molten target and surface ionization source has been developed. The source has been fitted with a rhenium tip (which has a high work function) and it is then possible to have nuclei of earth alkalies and of certain rare earths accelerated into the separator. A high temperature oxide target (developed by the Copenhagen group) will be used to obtain the elements from thallium up to radon. Another development is a target where it is possible to vibrate the molten metal in order to get at the very short lived nuclei.

These modifications will open up further possibilities in the ISOLDE programme with the improved SC.

Nuclear physics at the PS

The use of the 28 GeV proton synchrotron for nuclear physics experiments has increased remarkably in the past two years. An indication of its growing role in the PS physics programme is that on 25 January the setting up of a PS Nuclear Structure Working Group was announced. We will describe four types of experiment here.

Probably the most fruitful series of experiments has been the study of exotic atoms. This began at the SC and extended to the PS when kaons and antiprotons were required which are beyond the energy capability of the SC. A detailed description of particular experiments can be found in vol. 10 page 251. Here we will run through the different types of atom and indicate what sorts of information they can tell us.

A non-exotic atom has its electron cloud and we recalled in the opening article how much was learned by watching the X-rays emitted as electrons excited to higher energy states tumbled back through the allowed energy levels to the original unexcited state. In exotic atoms an electron is replaced by another negatively charged particle and different information can be drawn by watching the X-rays as this particle tumbles down through its energy levels and, in some cases, by watching its subsequent interaction with a nucleon.

The most obvious candidate is the muon which for most purposes can be regarded as a heavy electron. Being heavier, their lower orbits go closer to the nucleus (and even pass through the nucleus) and are more influenced by the distribution of protons in the nucleus. Another advantage is that they are leptons, unaffected by the strong force. Thus their behaviour is dictated only by the electromagnetic interaction and is thus easier to interpret. There is still a discrepancy between QED theory and observation in muonic atoms which has not been explained away.

Next comes the negative pion. Here the strong force comes in and the pion-nucleon interaction, so important for understanding the nucleus, can be got at. Precise measurement of the energy levels in pionic atoms has also given the most accurate value yet of the pion mass.

Higher energy beams have made possible the formation of kaonic, antiprotonic and sigmic atoms. The negative kaon also feels the strong force and is not so happy to be in the nucleus as the pion. It interacts readily when it encounters neutrons or protons and thus provides a way of investigating the nuclear surface by detecting when the kaon X-rays stop — the kaon orbit having run into a nucleon. The absorption of the kaon by the nucleus has proved much stronger than anticipated.

Antiprotonic atoms are providing a way of checking that the magnetic moment of the antiproton is equal and opposite to that of the proton. This can be checked by observing the splitting of each antiproton energy level into two levels very close together, according to the two possible orientations of the magnetic moment. The effect has been observed but more precision is needed to give a clear result.

Sigmic atoms are interesting for the same reason. The negative sigma hyperon has a magnetic moment that is difficult to get at because, unlike its positive equivalent, the orientation of its moment in a magnetic field cannot be watched via the orientation of its decay products. Energy level splitting in sigmic atoms looks to be the most promising way to unearth a measurement and the measurement is important since there are detailed predictions of the value of the magnetic moment from particle theories such as, for example, the quark theory.

Another way into nuclear properties at the PS is via hypernuclear spectroscopy. A hypernucleus is one in which a lambda hyperon has taken the place of a neutron. They are produced at the PS by bombarding a target, such as beryllium, usually with negative kaons. The kaon has the right properties to interact with a nucleon to give a lambda. In general the bombarded nucleus will break up and the lambda will be lodged in a daughter nucleus (often referred to as a hyperfragment) such as helium if the target was beryllium.

The first observations of hyperfragments in 1953 were made by groups from Poland and from Imperial College London. The Polish group has been prominent in this research at the PS since then and celebrated the 10th anniversary of their first observation by detecting a double hyperfragment, with two lambdas in a nucleus, in 1963. The early work was done using nuclear emulsions but recently counter techniques have taken over.

Up to now, twenty species of hypernucleus have been seen ranging from hydrogen to carbon. The lambda is an unstable particle and the hypernucleus thus rapidly decays, the energy involved often breaking up the hyperfragment. Studying these phenomena has established lowest energy states for the hypernuclei. Measurements on the four lightest hypernuclei (variants of hydrogen and helium nuclei) have given information on the lambda-nucleon interaction which seems more solid than hyperon-nucleon scattering data obtained from bubble chambers.

There is still not enough known about this interaction to be able to interpret most of the data from hypernuclei. However, several of the unknowns should be cleared thanks to new information now being collected. Up to now hypernuclei have been

Particle/ nuclear physics

studied mainly using nuclear emulsions where all the tracks were measured and information was gathered on the ground states of the hypernuclei. Now gamma spectroscopy and pion spectroscopy using electronic techniques are coming into play. In 1971 there was the first confident observation, using electronic techniques, of gammas from a hypernucleus formed from a lithium target at the PS. This observation of excited states falling, with the emission of a gamma, into lower energy states is an approach to nuclear energy levels which could bring a lot of new information.

Another batch of nuclear physics experiments concerns the search for superheavy nuclei. This was stimulated two years ago by examination of a target from the PS by a Rutherford, Manchester team. They conjectured that hitting the target nuclei with multi-GeV protons could knock forward very heavy recoil nuclei with high energy thus setting up, on a tiny scale within the target, the sorts of conditions achieved at high energy heavy ion accelerators.

Such conditions could glue heavy nuclei together and there are theoretical reasons for believing that we have not yet produced the heaviest nucleus that would be stable. Using accelerators we have produced a dozen nuclei heavier than those of elements found in Nature reaching element 105. Theory predicts that around element 114 there should be several nuclei of reasonable stability if only we could throw enough protons and neutrons together hard enough to produce them.

The work early in 1971 suggested that traces of element 112 existed in the PS target. The evidence now seems to be believed less but the novel idea of looking in targets submitted to high energy bombardment for signs of superheavy element has been taken up by several teams. At the PS some are looking for the superheavies directly, others are looking for signs that the high energy heavy ion process, crucial to the whole idea, does in fact take place.

Finally, there has been an important programme of mass spectrometry by Orsay teams (the research being initiated by the late R. Bernas) which has been running intermittently at the PS for many years. One team is currently doing studies of exotic nuclei which has much in common with the work at ISOLDE described earlier. They concentrate on unstable light nuclei such as sodium and lithium.

Measurement of the production rates for the exotic nuclei is part and parcel of the experiments and is particularly important in the work of a second team. They are concerned with fragmentation cross-sections to feed more data into astrophysics calculations. We are aware that space has a fair share of high energy particles and we are aware that high energy environments in the various stages of star evolution are far more common in Nature than the mild environment we encounter on earth.

To understand many cosmological and astrophysical phenomena we need to learn, at our accelerators, what happens in high energy conditions. The Orsay team is currently contributing information on what happens to nuclei when bombarded with high energy cosmic rays.

It will have been obvious from the descriptions of several types of experiment in the earlier articles that knowledge of collective nuclear phenomena and knowledge of individual particle interactions are often meshed together. Watching how particles behave in the special environments of nuclei rather than in interaction with other individual particles can tell us new things about the particles and new things about the nucleus.

To give a particular example: It is difficult to study how very short-lived particles (resonances) scatter on other particles just because they are short-lived and disintegrate before they can even cross the distance between two nuclei. If however we produce the resonance in a multi-particle nucleus, it is closely surrounded by nucleons and can scatter from a nucleon before disintegrating. Thus the nucleus provides an environment to study the scattering of short-lived particles and this is the only way their scattering can be studied.

The interest in gathering information on resonance scattering emerges from the realization in symmetry theory that these particles are on an equal footing with their more stable brethren. The possibility of observing, in nuclei, the way in which they scatter is just as fundamental a piece of data as any of the more conventional scattering data concerning the stable particles and simply adds to the information which may help to unearth hadron structure.

The particular experiment mentioned in the introductory article concerned the production of multi-pion resonances and the measurement of their scattering cross-section. A CERN, ETH, Imperial College, Milan collaboration did this measurement in nuclei for the 3π and the 5π state. For the 3π state they emerged with a cross-section of 25 to 30 mb and for the 5π state with a cross-section of 20 mb, which is smaller than the cross-

Around the Laboratories

section for a single pion. Thus a five pion resonance can find its way through nuclear matter more easily than one pion!

This has been one of the most provocative pieces of information to emerge from nuclear/particle physics in recent years and has led to a great deal of scratching of theoretical heads. One possible explanation from L. Van Hove and C. Wilkin is that the formation time of the resonance is longer than the time taken to cross the internuclear distance and that we are thus considering the scattering of an evolving state rather than the finished resonance. Though we do our sums on the finally observed multi-pion state, the intermediate stage may concern what happens when the components of the resonance are swirling through the nucleus (components here being not pions but partons or quarks or whatever other objects are constituents of a hadron).

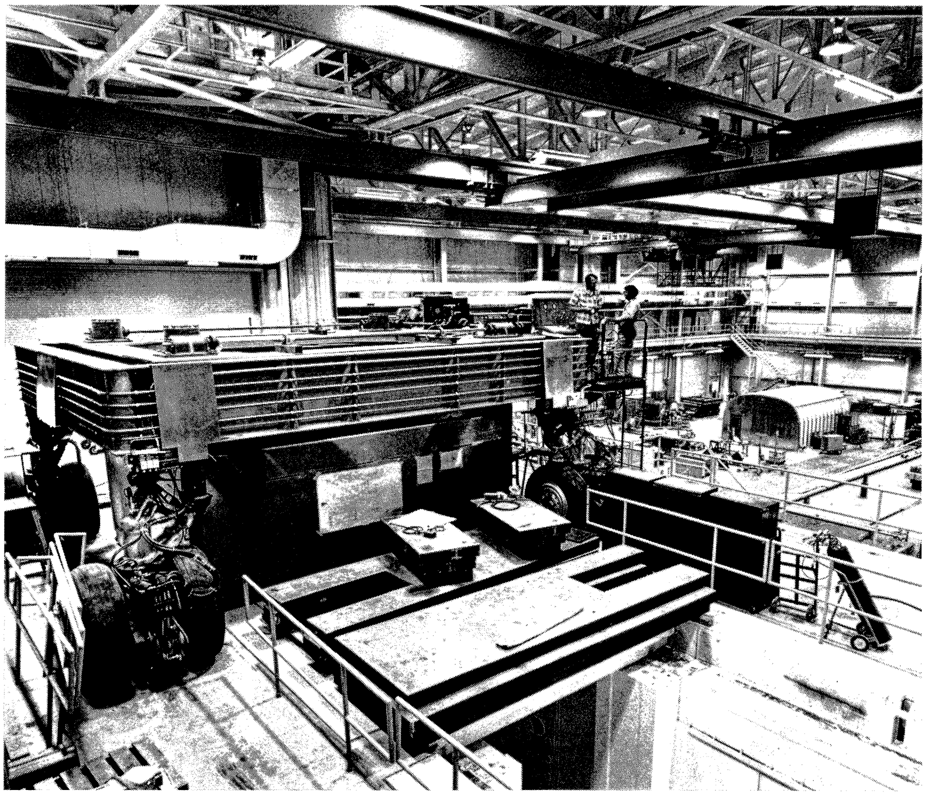
This is something completely new and is certain to be followed up by other related experiments. If the ideas which have emerged in attempting to understand the multi-pion results are correct, there should be important effects observable in the scattering of very high energy protons on different nuclei. It looks as if a new range of phenomena involving the evolution of hadrons towards their resonance states is opening up.

LOS ALAMOS
LAMPF prepares for experiments

The Los Alamos Meson Physics Facility, LAMPF, produced its first design energy beam ahead of schedule on 9 June last year. It accelerates protons to 800 MeV, comfortably above the pion production threshold, and aims eventually to give high quality beams of very high intensity (1 mA, composed of 0.9 mA protons and 0.1 mA negative hydrogen ions). Initially the current will be held way below this figure until the accelerator is thoroughly mastered so that radiation and induced radioactivity problems will be kept to managable levels.

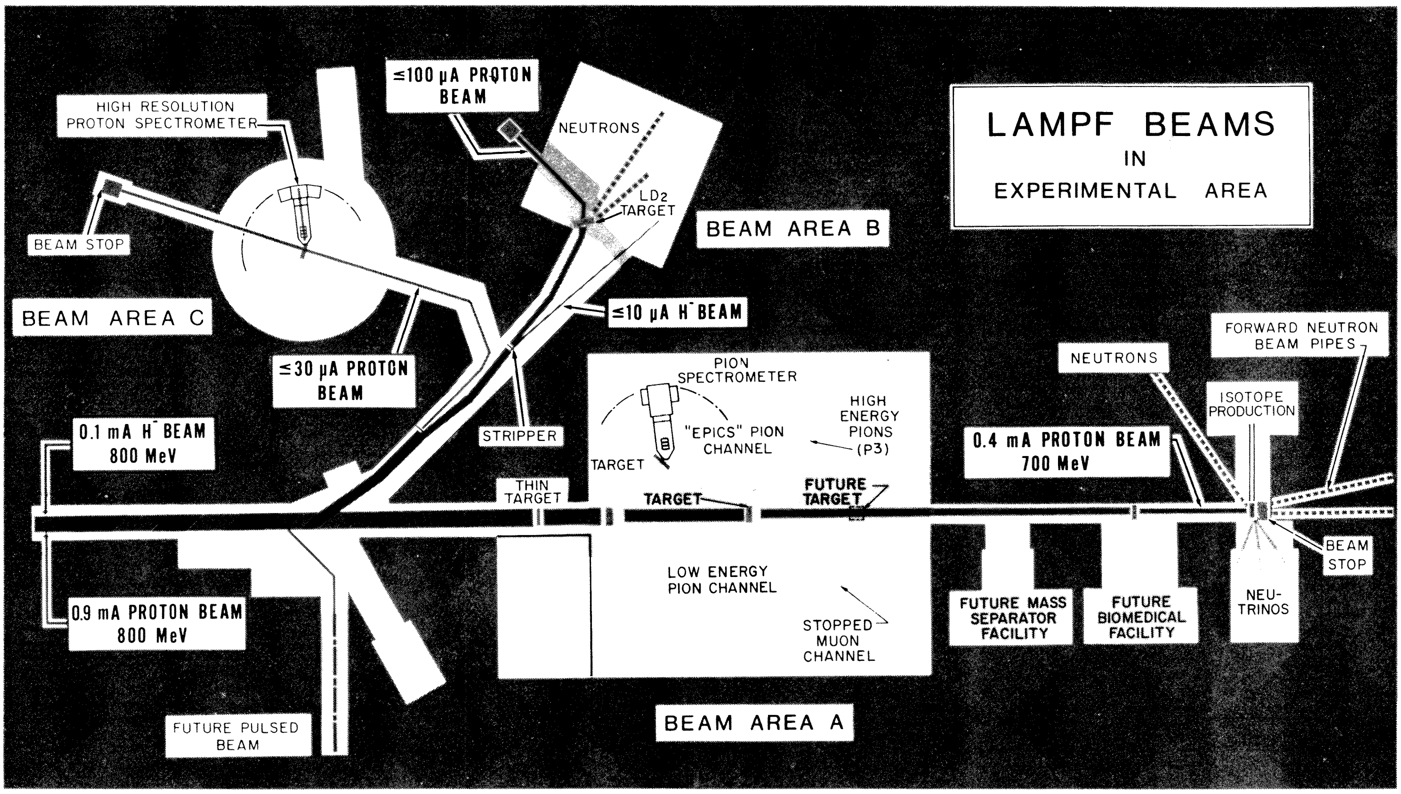
The machine design incorporated several features which were then new in accelerator technology — post-coupled Alvarez cavities, side-coupled waveguide cavities, extensive computer control, simultaneous acceleration of positive and negative particles. Information on the machine itself can be found in vol. 8 page 132. We will concentrate here on the preparations which are in full swing for the imminent start of the experimental programme.

The layout of the experimental area and the beams foreseen for the first years of operation are shown in the diagram page 42, the caption indicates anticipated beam intensities. The accelerated protons and negative hydrogen ions are separated in the beam switchyard where the negative ions are bent off. Stripper foils convert the ions to protons giving three beams — one will be directed to a high resolution (50 keV in 800 MeV) spectrometer in Beam Area C for proton-nucleus experiments, another will be fired at a liquid deuterium target to produce a high energy flux of neutrons in Beam



The problems associated with radiation and induced radioactivity are among the most difficult that meson factories have to solve. One of the LAMPF solutions is to have a mobile iron shield box known as Merrimac (after one of the first iron-clad steam frigates of civil war renown). It has a 200 ton box mounted from a self-propelled gantry which can drive along the top of a shield wall. Beam-line components are serviced by lowering the box through openings normally closed by large steel doors. It has manipulators to work on or remove targets or faulty equipment. It can bring them into the box and wheel them to hot cells.

(Photo Los Alamos)



Area B for neutron-nucleus experiments and the third (with very small angular divergence) will be used in small angle scattering experiments.

The accelerated proton beam will continue straight on through the switchyard (though there is provision for diverting a few percent of the beam to a target as a source of pulsed neutrons for time-of-flight experiments). It can pass through a thin target, various types being available for use in radiochemistry experiments. These experiments will collect data particularly on the properties of the short-lived nuclei produced in the collisions. The target will be accessible via a pneumatic 'rabbit' and products can be pulled back into a nuclear chemistry building for spectroscopic analysis.

Two targets then confront the proton beam (and there is provision for installing a third) to give pion and muon beams into Beam Area A extending on both sides of the proton beam — their properties are given in the caption to the diagram. Further on, two more targets are positioned to receive the remaining proton beam which is likely at this stage to be down to half its initial intensity and to have lost 100 to 200 MeV in energy. One target will serve the future biomedical facility and the second the isotope production facility. An on-line mass separator of the ISOLDE type is planned in this region also for some later date. The remaining protons will plough into a beam stop and even this will be used as a source of neutrinos and of low energy neutrons which will be used for studies of radiation damage.

Simultaneous operation of many beams will be possible and in the first year of the experimental programme it is hoped to feed sixty experiments which have been approved for beam-time. Proposals for about twice that number of experiments have been received by the Programme Advisory Committee. Over half of them are in the broadly-defined field of nuclear physics and about a third in particle physics.

The nuclear physics experiments will benefit from the very intense beams of protons, pions and muons to study such things as the nuclear charge and mass distributions and nuclear energy levels, via elastic and inelastic scattering, mesic X-rays, gamma spectroscopy, single and double charge exchange . . . The particle physics experiments will study such things as the conservation laws (conserved vector current, T violation, Fermi interaction), the mass of the muon neutrino, pion production by pions and, later, neutrino-electron scattering (a crucial topic in present weak interaction theory).

Nuclear chemists will be invading LAMPF in force because they will have the thin recoil target, high intensity pion and muon beams, both high and low intensity proton beams (making possible the study of rare proton-rich isotopes) and the isotope production facility. Experiments are planned to study such things as pion induced fission and spallation, fragment emission, pion-nucleon knock-out reactions . . . It will be possible to produce a wide range of isotopes many of which will have practical applications in medicine, agriculture and industry. Several large radio-pharmaceutical companies are in contact with LAMPF.

The biomedical facility will also be the scene of practical applications in the field of medicine. Radiation therapy is planned there using the exceptional properties of negative pions for cancer treatment. Negative pion beams of carefully controlled energy spread and carefully directed could be much more effective than X-rays or gammas in destroying diseased cells. LAMPF will be capable of delivering an average dose rate of about 1 rad per second to small tumours. Doctors from the Cancer Research and Treatment Centre at Albuquerque will participate in this work aimed at realizing the full promise of negative pion beams in cancer therapy. The biomedical facility is now being designed.

A practical application of LAMPF which is less demonstrably positive for the benefit of mankind is a weapons

Schematic diagram of the beam layout in the experimental area at the 800 MeV proton linear accelerator, LAMPF. The possible ways in which the accelerated particles and secondary beams can be distributed to experiments are indicated. Predicted intensities and energies not indicated in the diagram are as follows: Low energy pion beam — 3×10^9 positive or 8×10^8 negative pions per second at energies up to 300 MeV; High energy pion beam p3 — 10^{10} positive or 10^9 negative pions per second at energies between 100 and 600 MeV; EPICS pion beam — 4×10^8 positive or 10^8 negative pions per second at energies between 50 and 300 MeV; stopped muon beam — 5×10^7 positive or 10^7 negative pions per second at energies up to 165 MeV; Neutron flux in Area B — 2×10^7 per cm^2 per second at an energy of 755 MeV; Neutron flux from the beam stop — 10^9 per cm^2 per second at energies from 1 to 20 MeV; Biomedical beam — 2×10^8 negative pions per second at energies between 80 and 100 MeV; Neutrino flux — 5×10^7 per cm^2 per second at energies between 20 and 50 MeV.

1. The ring cyclotron photographed in September 1972 when the last of the eight magnet sectors was being assembled. One r.f. cavity can be seen in place on the left. The beam from the injector cyclotron will come into the centre of the ring from the direction at the top of the photograph and full energy (590 MeV) protons will be extracted towards the bottom of the photograph.

research facility where neutron beams will be used in studies of neutron absorption in materials used in weapons, for neutron cross-section measurements, etc.

Preparations for the experimental programme have been hindered by a cut of $3 million in the budget for fiscal year 1973. It is planned to have a low intensity beam (about 1 μA) available to feed Beam Area A in April. About six months later it is hoped to have enough shielding in place and to have mastered the accelerator sufficiently to be able to increase intensities to between 10 and 100 μA. Growing experience with the accelerator and with running the experimental programme will then dictate how quickly the climb to design intensity goes.

VILLIGEN SIN cyclotron nears completion

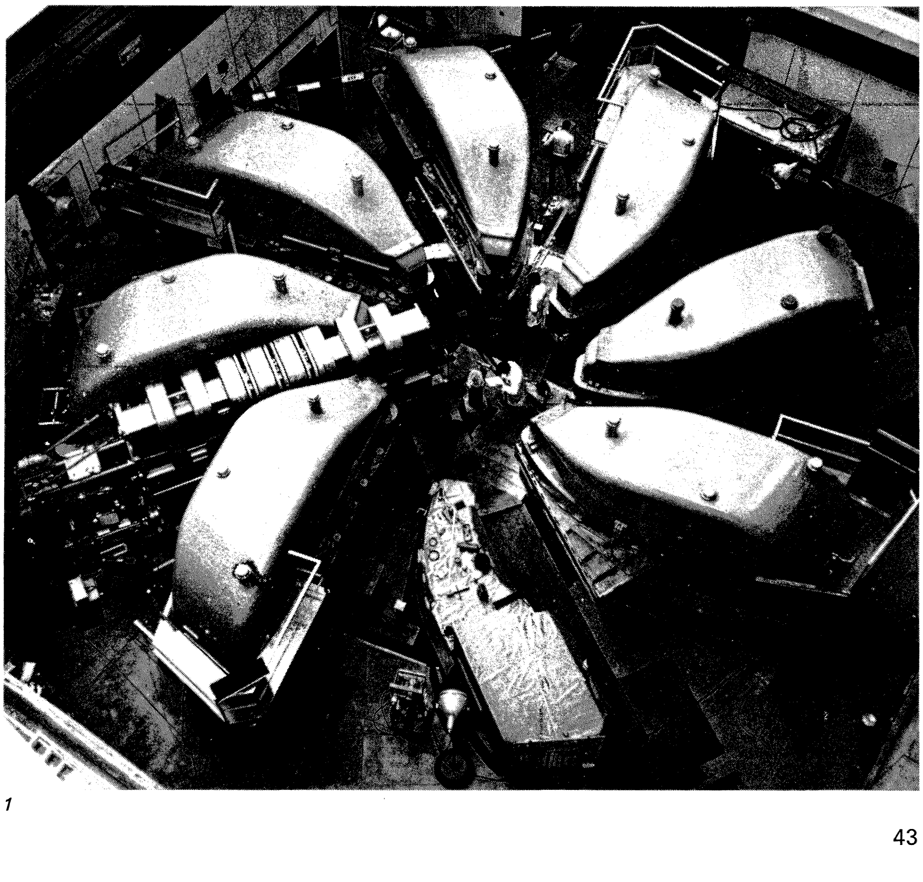
Assembly of the isochronous cyclotron at the Swiss Institute for Nuclear Research (SIN), Villigen, is nearing completion. All eight sector magnets of the ring accelerator are in place together with two of the four r.f. cavities. Complete assembly is scheduled for October of this year and the first protons will be extracted in December. The project was last described in CERN COURIER vol. 11, page 164. We will concentrate here on progress since then and a brief summary of the initial experimental programme.

The accelerator consists of two cyclotrons. An injector cyclotron, built by Philips, is designed to provide 100 μA of protons at 72 MeV to a ring cyclotron and also to provide a variety of ions and polarized beams at variable energy for an experimental programme at low energies. The ring cyclotron will continue the acceleration up to a peak energy of 590 MeV. It receives particles on an internal radius of 2.05 m and accelerates them via four r.f. cavities to a radius of 4.5 m. Since the central region has effectively been lifted out by having an injector cyclotron, high accelerating voltages can be applied in the cavities leading to considerable separation between the turns at extraction energy. This greatly simplifies the extraction problem and should result in very high extraction efficiency (95 % is aimed for).

The magnet of the injector cyclotron arrived on site about eighteen months ago and by the end of 1972 detailed field measurements had been taken. The calculated particle orbits show that good isochronism has been achieved and the field configuration seems suitable for a precessional extraction scheme. The r.f. system was successfully tested at Eindhoven and will soon be transported to Villigen. A polarized ion source, developed at the University of Basel, is being installed.

During 1972 the eight sector magnets of the main ring cyclotron, each weighing 250 tons, were progressively installed. Field measurements were carried out on the individual sectors and side shims were added to ensure a field configuration which does not deviate from the condition for isochronism by more than $\pm 1.5 \times 10^{-4}$.

In October a quarter of the ring was completely assembled including an r.f. cavity, vacuum chambers and electrostatic components of injection and extraction channels. It was then submitted to normal operating conditions (but without a beam, of course) to test component interaction, etc., as thoroughly as possible. A good vacuum was achieved within three days



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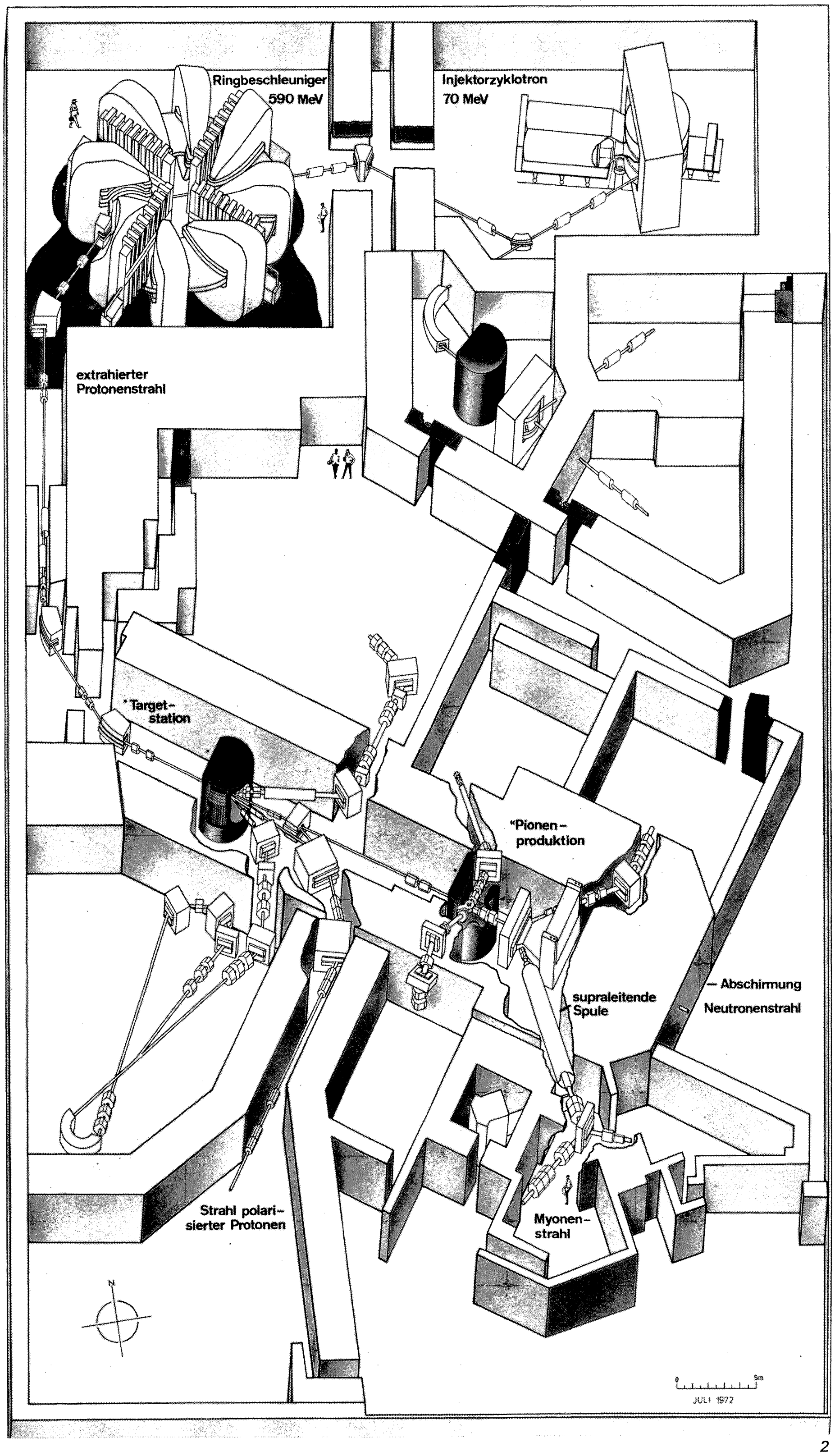
2. Isometric drawing of the cyclotrons and the experimental hall. Upper right are the low energy experimental areas. On the left, the full energy beam travels initially along the wall before being bent onto two target stations from which pion, muon and nucleon beams will be drawn.

(Photos SIN)



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of pumping and all components behaved satisfactorily. Particularly gratifying was the performance of the r.f. cavity. After it had been opened up for minor modifications, a voltage of up to 650 kV could be sustained which is comfortably in excess of the design value. This increases confidence that the desired extraction efficiency will be achieved. At present, work is going on to complete half of the ring so that there can be further tests, this time with injection and extraction magnets powered so that any effects on the isochronous field can be measured.

The general layout of the beams for experiments has remained unchanged. The experimental hall is divided into two regions. One will be fed by the injector cyclotron with low energy beams (protons up to 72 MeV, deuterons, alphas and ions up to oxygen at 100 MeV). The larger region will be fed by the 590 MeV proton beam and secondary beams will be drawn from two targets in series — a thin carbon target presenting 1 g per cm^2 to the beam for the production of pions and polarized protons and a thick target of about 20 g per cm^2, which may be of carbon, beryllium or molybdenum, for the production of pions and neutrons.

The design of the targets has been changed completely from the original helium gas cooled type. They now consist of radiation cooled rotating wheels. Tests of the new type, involving thermal simulation of the effect of the beam, were successful and showed that the problem of lubrication in vacuum had been overcome. Construction of prototypes is well advanced.

Among the special features of the beams and experimental equipment will be two muon beams using superconducting elements. A high intensity muon channel will have an 8 m long superconducting solenoid of 120 mm internal diameter. A 1 m section has

1. A photograph taken at TRIUMF about a year ago when the lower half of the magnet was in place. The spiral shape of the six magnet pole pieces is clear. At that time, the lower coil was welded in position but not insulated (the right-angular connections near the outer rim of the pole pieces can be seen). Around the magnet are the twelve support columns with lifting jacks in place. This type of photograph could no longer be taken because the 'vault' where the machine is installed has received the first layer of its concrete shielding lid.

1

been tested at Karlsruhe and has given a field of 4.5 T with 900 A (200 A/mm^2) through the intrinsically stable superconductor. It is cooled by supercritical helium. Thermal cycling and more than fifty quenches had no effect on performance.

A superconducting magnet is also being used in a polarized target. Tests with butanol, at a temperature of 0.5 K and a field of 2.5 T, have achieved 70 % polarization in the first target. A second is being constructed using a split coil configuration.

It is intended to bring a polarized proton channel into action in 1974 using scattered protons from the thin target or an accelerated polarized proton beam. There will also be an unpolarized neutron beam and facilities will exist for bringing in a highly polarized neutron beam at short notice. A high intensity stopped pion beam will be used for medical research and cancer therapy.

Twenty eight proposals for experiments have been submitted so far. They are grouped in three categories: (1) intermediate energy nuclear and particle physics (12 proposals); (2) applications of intermediate energies (9 proposals); (3) low energy physics using beams from the injector cyclotron (7 proposals).

In the first category there are searches for processes that are now commonly believed to be forbidden: the decay $\mu^+ \rightarrow e^+ \gamma$ (ETH group) and $\mu^- \rightarrow e^\pm$ conversions in nuclei (Bern-SIN). Other groups want to measure certain particle properties with greater precision: the charged pion and neutretto masses (Bern and ETH-SIN); the magnetic moment of the muon (ETH-SIN). Mesic X-rays will be studied by ETH-Fribourg and ETH-SIN groups. The Lausanne-Munich-Zurich group plans to use a large solid angle gamma detector (magnetic pair spectrometer) for a series of nuclear and particle physics experiments. An ETH-SIN group proposes a pion-proton asymmetry experiment, with the polarized proton target. Pion-nucleus interactions are going to be studied with a high resolution magnetic pion spectrometer (ETH-Grenoble-Karlsruhe-Neuchâtel). A Geneva group will continue their pp-scattering programme with the polarized proton beam, and a group from Freiburg will work with the unpolarized neutron beam.

In the second category of proposals, the possible use of pions in cancer therapy plays a dominant role (proposals from Bern-Zurich, Karlsruhe, Triemli and Waid Hospitals Zurich). Other proposals in the field of applications come from Munich, ETH-Zurich-Karlsruhe, Zurich, ETH-Fribourg and EIR (Eidgenössisches Institut für Reaktorforschung) groups.

In the third category, beams from the injector cyclotron will be used by EIR, Fribourg, Basel, ETH-Basel, Zurich-Basel, Neuchâtel-Zurich, and Vienna groups. There will be a programme of isotope production for which the injector cyclotron parameters are well suited. Also EIR, which is located next door to SIN has all the necessary facilities for handling isotopes. There is particular interest in proton-rich isotopes from the medical world.

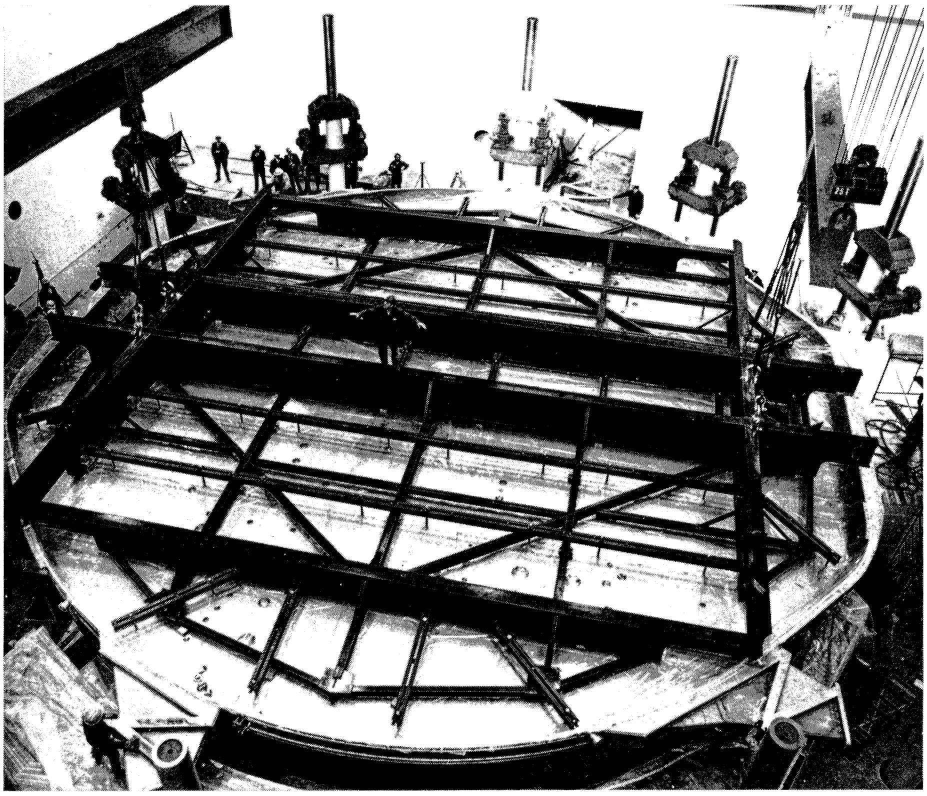
It is expected that the experimental programme will start in Spring 1974.

TRIUMF
At stage of magnet commissioning

The TRIUMF cyclotron, being built in Vancouver, has cleared several important milestones during the past year despite a serious labour dispute eating into construction progress during the summer months. The candle is now being burned at both ends to recover as much as possible of the lost time.

The cyclotron (see vol. 8 page 136 for design details) will accelerate negative hydrogen ions aiming to achieve near 100 % extraction efficiency when they are stripped to protons (the cyclotron magnet itself bending the particles of opposite charge out into the experimental areas). The cyclotron is of the sector focused type designed to provide beams of continuously variable energy from 150 to 500 MeV (and maybe a little higher) with intensities about 100 µA at peak energy. Two experimental areas on opposite sides of the machine will receive proton beams. Secondary beams of pions, muons and neutrons will feed several experiments simultaneously.

The buildings are essentially complete and assembly of the machine itself is well advanced. About a year ago the last of the six sectors of the



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2. Another 'aerial' view as the huge vacuum tank is manoeuvred into position over the lower half of the magnet.

(Photos TRIUMF)

Commissioning of the TRIUMF magnet began in December and the field plot shows part of the measurement of field against angle and radius.

lower half of the magnet (total magnet weight 4200 tons) was put in place. The bottom of the huge vacuum tank (about 18 m in diameter) was carried to the machine vault from one of the experimental areas where it had been welded, and laid on the magnet. The lid of the vacuum tank followed ten days later. Prior to assembly in the machine the tank was tested and no leaks were found in the stainless steel welds. With only part of the pumping system in action and without any baking, a pressure of 2×10^{-7} torr was achieved.

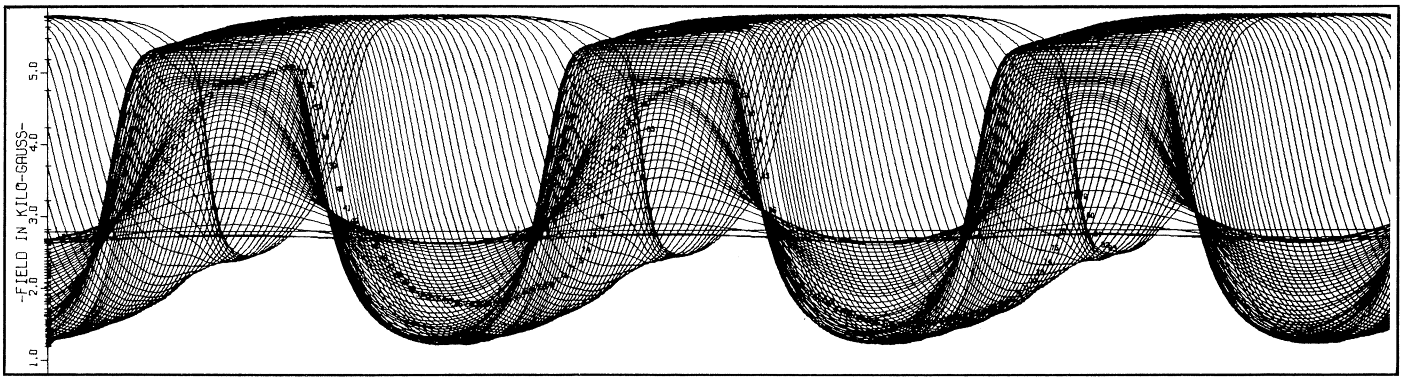
By the end of March the top half of the magnet was in place and work began on installing the overhead support structure. In mid-April this was complete and the upper tie rods, which run from the structure to the vacuum tank, were attached. These rods hold the tank against atmospheric pressure when it is pumped out (it then experiences a force of about 2700 tons). The support structure is also fitted with jacks so that it can raise the top half of the cyclotron (a load of 2200 tons) by just over 1 m so as to allow access to the vacuum tank. The lifting mechanism has been successfully tested.

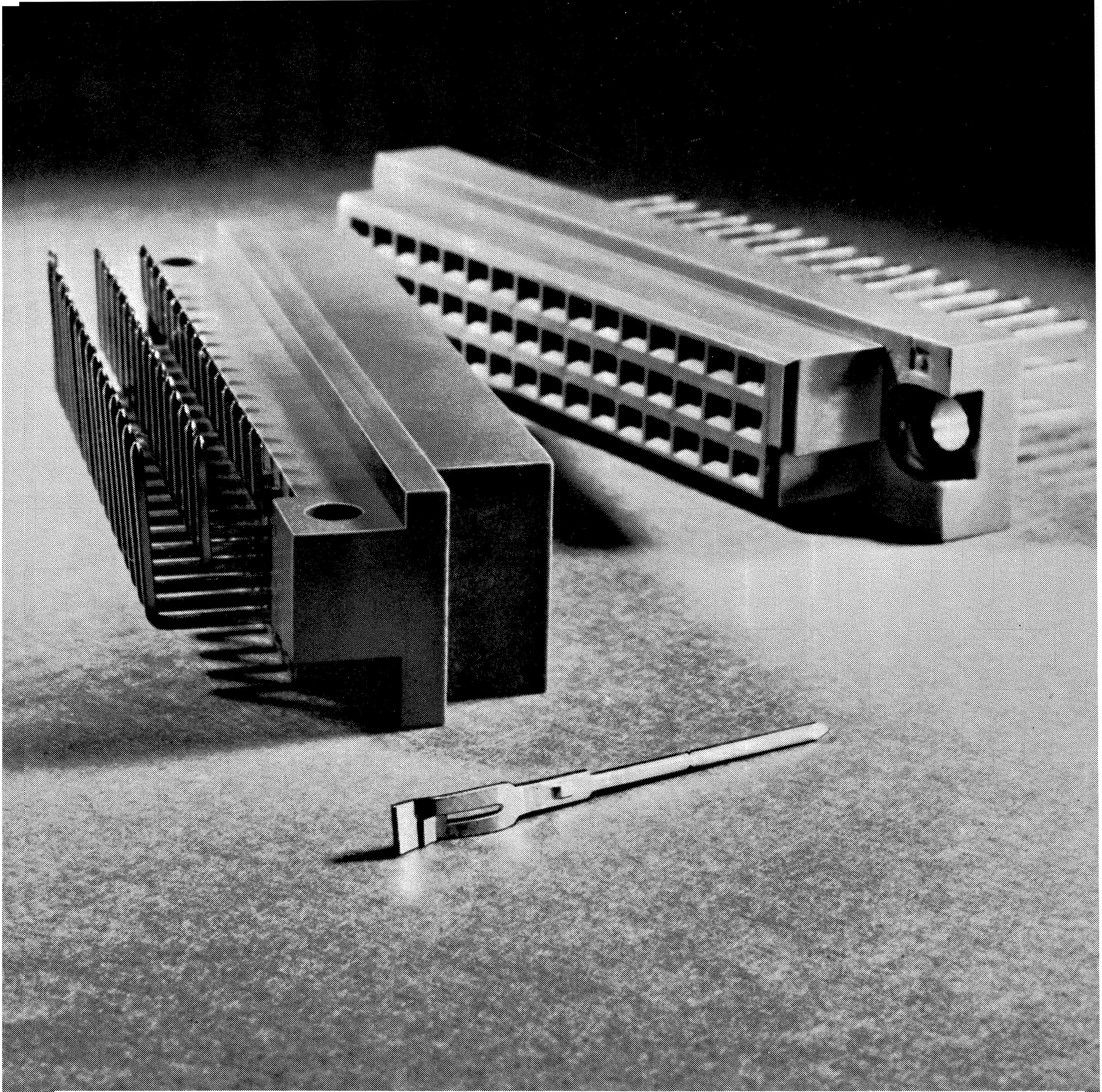
Construction work came to a halt in the summer months and it was November before the welding of the magnet coil was completed. The r.f. resonators were then assembled in an experimental area for tests 'in air' and low power tests began at the end of December. The frequency was 23.22 MHz, just the desired edge above the design figure of 23.1 MHz.

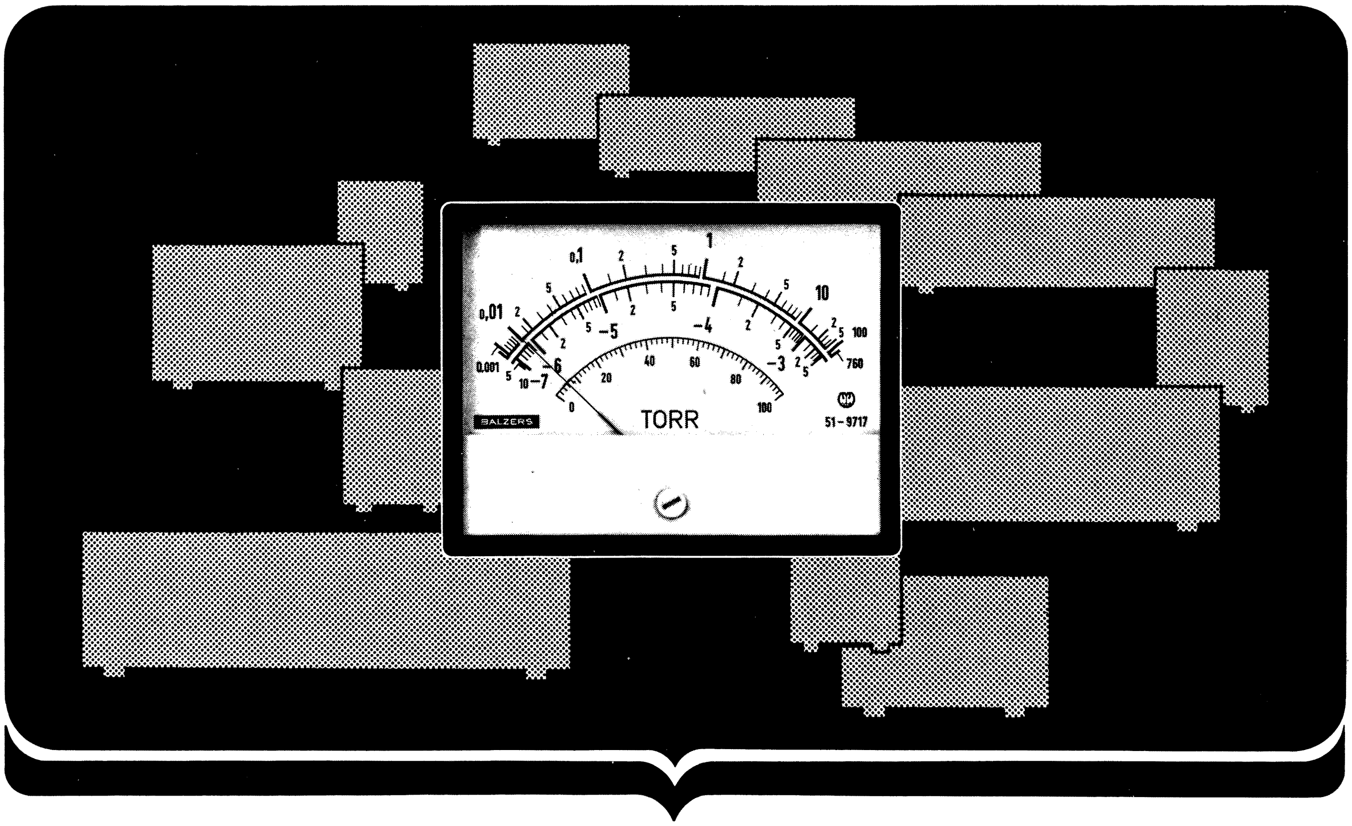
The ion source and associated supplies are now being assembled together with the beam transport line which will convey the negative hydrogen ions to the centre of the cyclotron. One of the major successes of the past year has been the excellent operation of the injection system used with the small test cyclotron (central region model). A beam from the prototype ion source was bunched, chopped and injected and a 10 μA beam was achieved at maximum radius in the test cyclotron, thus confirming that an intense ion beam can be retained during injection and first turns. This was regarded as one of the technically most difficult features of TRIUMF.

Current was fed to the magnet for the first time on 1 December and commissioning began two weeks later. A plot of the magnet field against radius and angle is shown below. The magnet current will be automatically controlled via a CAMAC system and this will be one of the first tests of the control system.

Preparations for the experimental programme have started. Initially, as with LAMPF, the accelerated current will be held down until the machine is mastered and the first experiments are therefore designed for low intensity beams. There has been an effort to broaden the programme to interest scientists working in other disciplines in addition to the obvious one of nuclear physics. Thus chemists, applied biologists, metallurgists and solid state physicists are involved in preparing experiments. In addition to the proton, pion and muon beams there will be a neutron source (for example, for radio-chemistry) and a beam for radio-biology and therapy.







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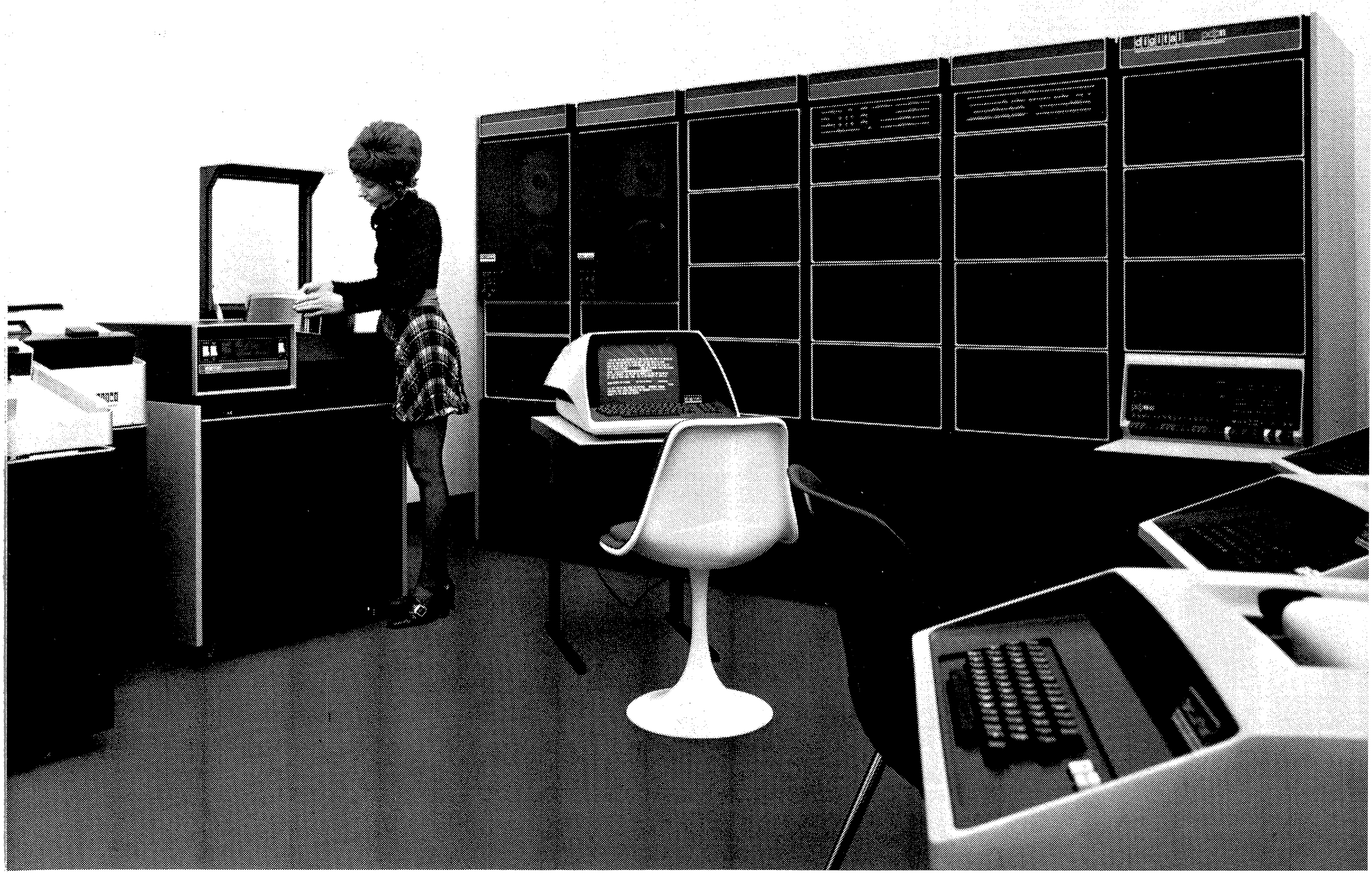

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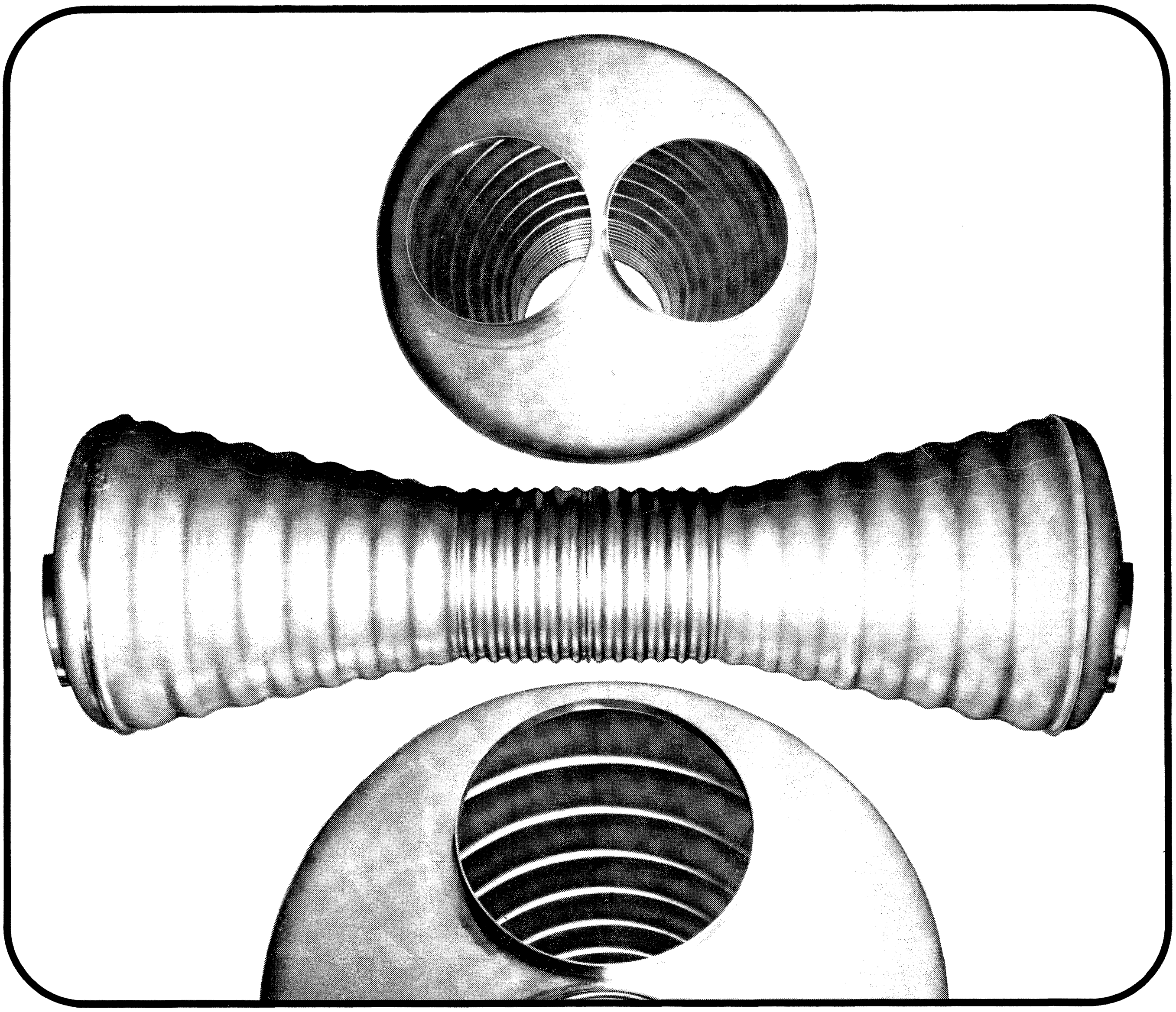

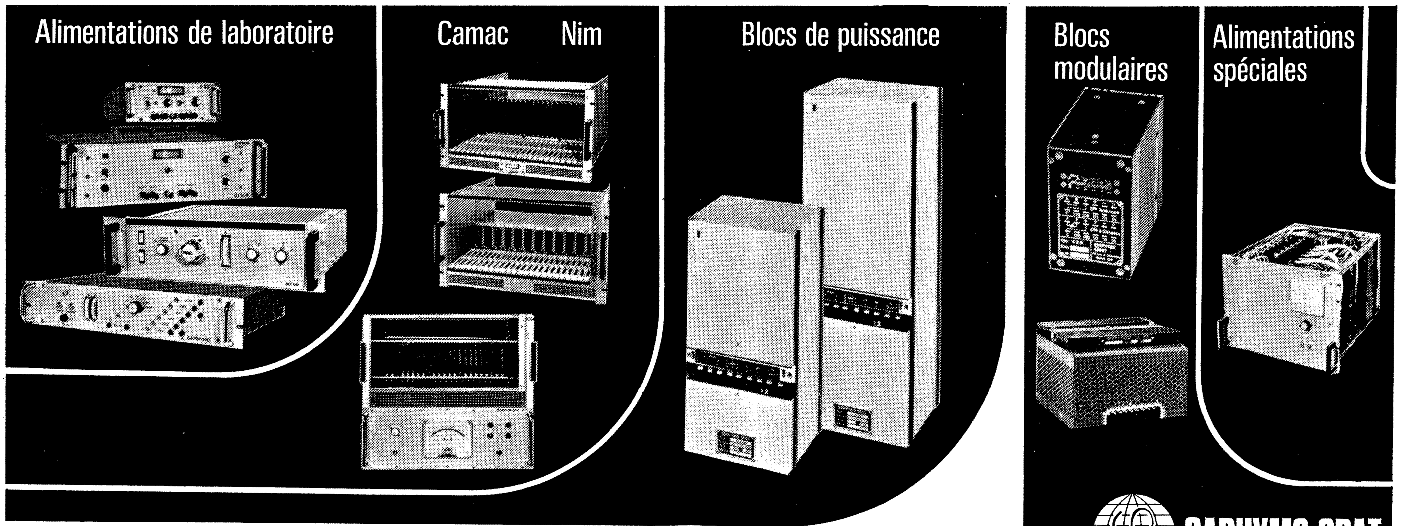

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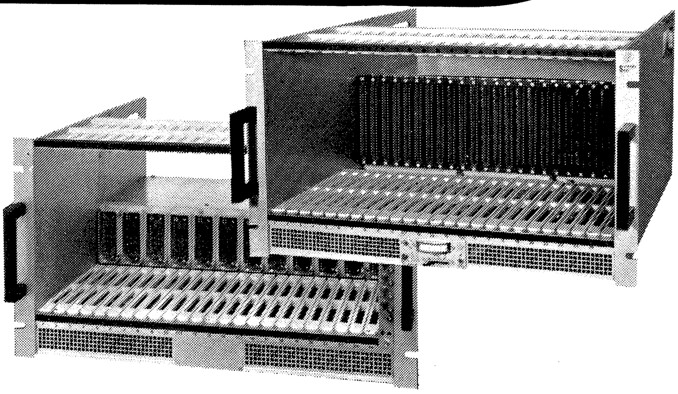

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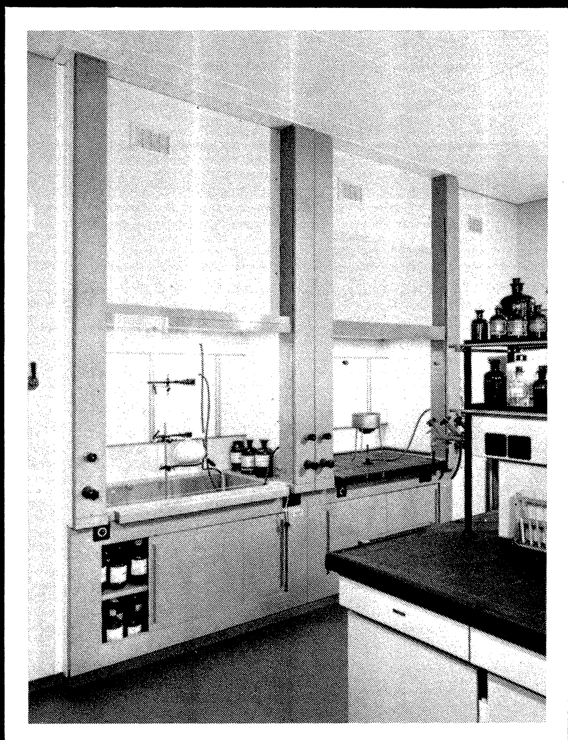

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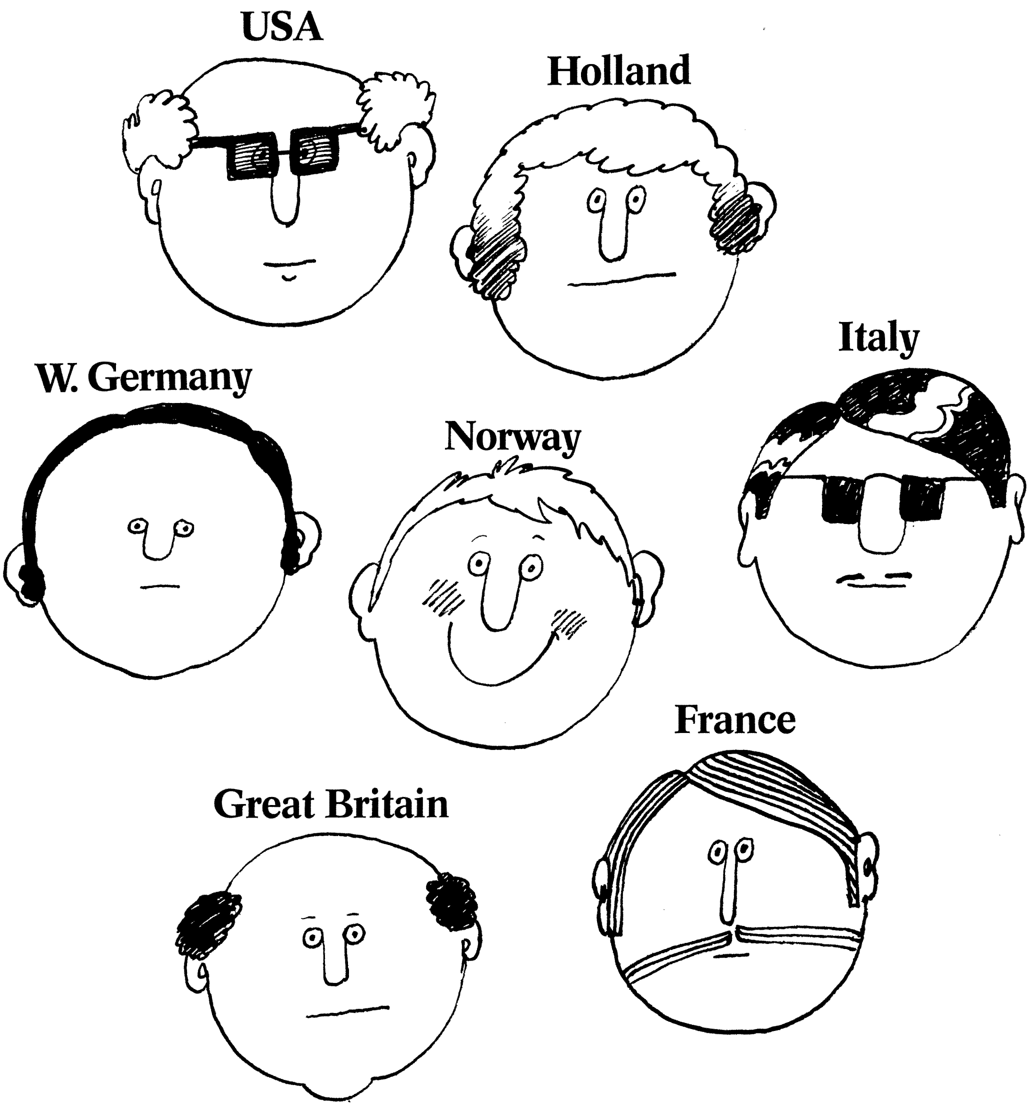

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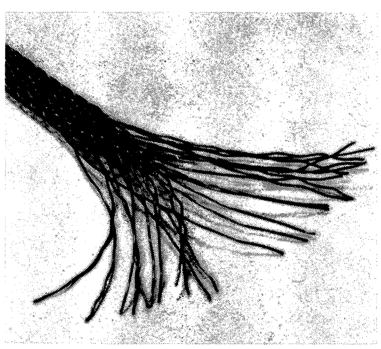

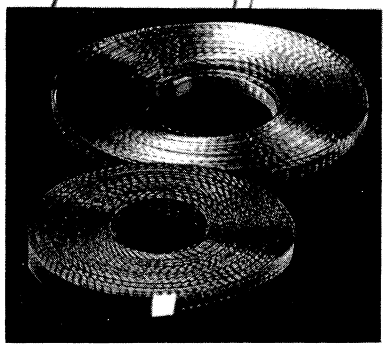

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