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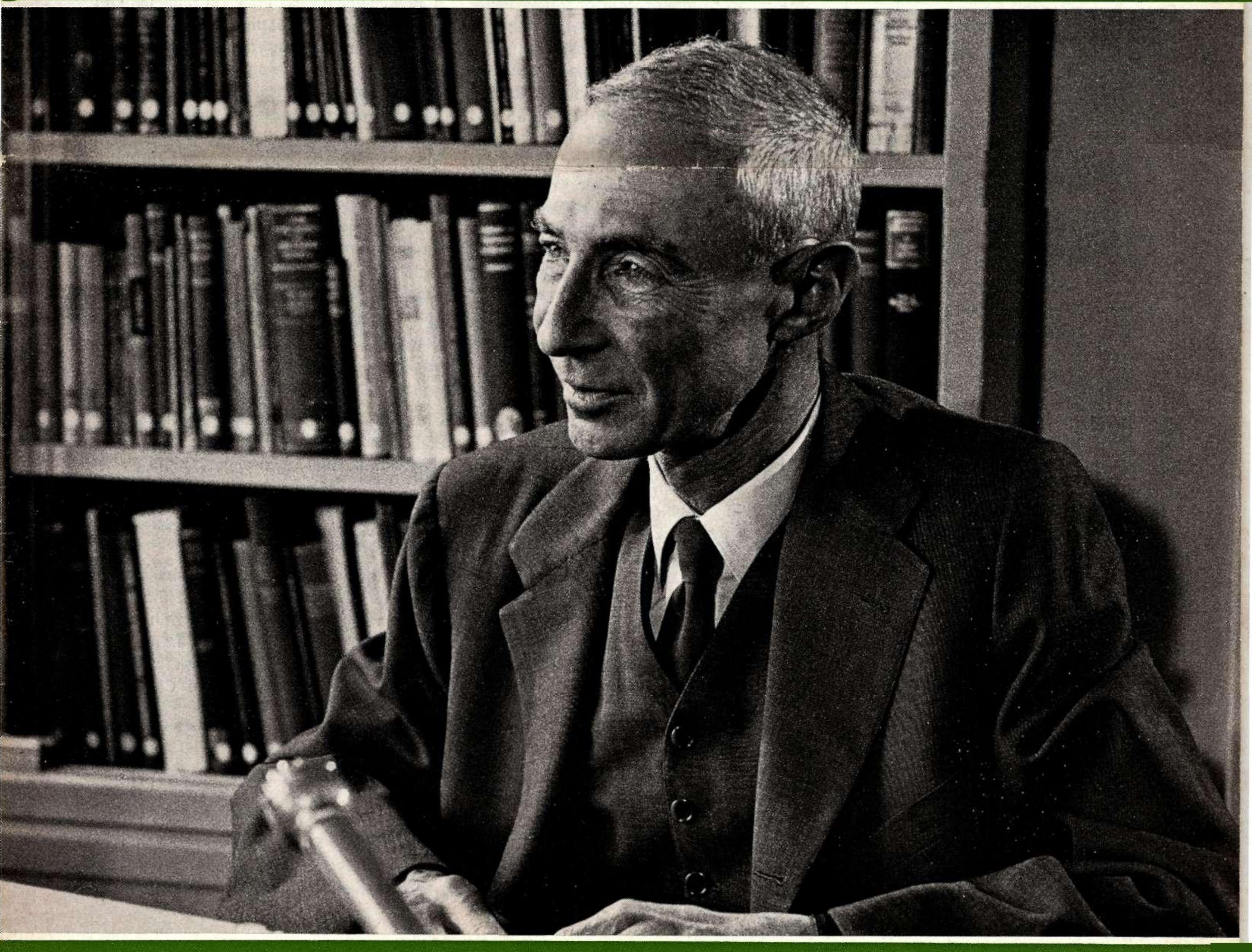

Cover photograph: As this issue was going to press, news came of the death on 18 February of Professor Robert Oppenheimer. Professor Oppenheimer was one of the world's outstanding theoretical physicists. A tribute to his work will appear in the March issue. This photograph was taken when he attended the high energy physics conference at CERN in 1962. (CERN/PI 5847)

Comment

Contents

The isotope separator-on-line is an important development of the research facilities at CERN, involving many European research centres. It is the most significant reflection of the growing use of the smaller of CERN's proton accelerators — the 600 MeV synchro-cyclotron — for nuclear physics.

Our knowledge of the structure of matter, which has emerged from the research of this century, can be considered is three distinct phases — the analysis of the atom; the investigation of its nucleus; the investigation of the particles which make up the nucleus. The ISOLDE project fits into the second stage of this increasingly refined penetration of matter, that of the investigation of the nucleus.

In the November 1966 issue of 'The Physics Teacher', Lester Paldy described the present situation as follows: 'Nuclear physics today reminds one of a deep and cloudy sea whose surface features are distinct, but whose currents and depths are hidden and unknown; a sea whose landfalls are provided by isolated islands between which one must sail with caution. The islands are the various theoretical models of contemporary nuclear physics. The shell, rotational, optical, and other models attempt to provide explanations and predictions of various nuclear phenomena. None of them is complete in the sense that they are adequate to describe all of the phenomena, but all of them are valid and useful within certain limits.'

To see how the ISOLDE project helps us to peer into this cloudy sea, let us first explain a few terms. A nucleus can be classified according to which chemical element it belongs... whether it is a nucleus of hydrogen, or sodium etc... The chemical behaviour which gives this classification is dictated by the number of electrons in the atom, which is identical with the number of protons in the nucleus. Thus a nucleus of helium will always have the same number of protons (two) but may have one, two, three or more neutrons. These nuclei with different numbers of neutrons we call the isotopes of helium. Each can exist in various energy states (similar to the resonant states of the particles in sub-nuclear physics) and a broader term for isotopes and their energy states is the word nuclides.

The nuclides readily found in Nature are those with numbers of protons and neutrons which lead to stable nuclei. For some time now, by using accelerators or nuclear reactors, it has been possible to examine

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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. CERN is one of the world's leading Laboratories in this field.

The experimental programme is based mainly on the use of two proton accelerators — a 600 MeV synchro-cyclotron (SC) and a 28 GeV synchrotron (PS). At the latter machine, large intersecting storage rings (ISR), which will allow experiments with colliding proton beams to be carried out, are under construction. Scientists from many European Universities and national Laboratories as well as from CERN itself take part in the experiments and it is estimated that some 700 physicists outside CERN are provided with their research material in this way.

The Laboratory is situated at Meyrin, Canton of Geneva, Switzerland. The site covers approximately 200 acres about equally divided on either side of the frontier between France and Switzerland. The staff totals about 2300 people and, in addition, there are over 360 Fellows and Visiting Scientists.

There are thirteen member States participating in the work of CERN. The contributions to the cost of the basic programme, 172.4 million Swiss francs in 1967, are in proportion to their net national income. Supplementary programmes cover the construction of the intersecting storage rings and preliminary studies on a proposed 300 GeV proton synchrotron for Europe.

ISOLDE
isotope separator on-line project
by A. Kjelberg and G. Rudstam

a large number of radioactive nuclides not readily found in Nature. These decay into the more stable ones and, generally speaking, the greater the difference between a nuclide and the stable nuclide of a particular mass (also described as the distance 'off the stability line'), the more rapidly it decays.

A great deal can be learned about nuclear properties by examining the behaviour of these radioactive nuclides produced under extreme conditions. But unfortunately, the rapid decay can mean that they disappear before we can get at them with our analysis equipment. Until recently, the investigations have usually involved production at an accelerator for example, and then rapid transportation to the laboratory where the analysis was carried out. (This has been called the SRAFAP system — Students Running As Fast As Possible.) Obviously, only nuclides with average lifetimes of at least the order of minutes can be examined in this way, no matter how athletic the students. Yet many nuclides can be produced with lifetimes of the order of seconds. How do we get at these ? ISOLDE is an answer.

The radioactive nuclides will be produced in targets bombarded by protons from the synchro-cyclotron. Those of a particular element can be separated out by chemical means (since chemistry does not care about the nucleus, only about the characteristics of the electron cloud around it). This initial separation sorts out nuclides of a particular element when nuclides of the same mass but of a different element can be produced in the target. Then the isotopes of the element can be separated by electromagnetic fields which sift a beam of particles into its components of different mass. And finally, measurements can be carried out on the separated isotopes. In ISOLDE, these operations are all strung together 'on-line'.

In the course of the experiments, which are scheduled to start in Summer, new areas of the map of nuclides, which present the same sort of challenge as unexplored areas of the geographical map, will be explored. The ISOLDE project will provide more information to help us understand the nucleus.

In the Summer of 1966, a conference was held at Lysekil, Sweden, on the topic 'Why and how should we investigate nuclides far off the stability line ?'. When the organizing committee counted the application forms, they found the number to be much above what had been anticipated. Interest in short-lived nuclides far off the stability line has been growing over the last few years, mainly because new experimental techniques have reduced the previous serious limitations in precision of the measurements.

The 'ISOLDE' project — the Isotope Separator On-Line with the CERN 600 MeV synchro-cyclotron — is one answer to the question 'How ?' in the title of the Lysekil conference. Before going into details of the project itself, however, some remarks on 'Why ?' will help to set the background.

Why ?

The most obvious answer is to present Fig. 1, which shows the chart of the nuclides with the stable nuclei represented by filled squares and the radioactive nuclei, known at present, as open squares. The curves $B_p = 0$ and $B_n = 0$ represent the approximate limits for nuclei stable with respect to nucleon emission. Between these limits, there are still literally thousands of nuclei which, with suitable experimental techniques, should be accessible for study.

The first property measured for a new nuclide is usually its half-life. This quantity is of value both as an identification tag and because of its relation to the kind of transition taking place in the decay. A still more interesting quantity, however, is the total decay energy, in other words, the mass difference between the nuclide and its daughter. A systematic study of this quantity will extend the useful region of the semi-empirical mass formula, sometimes known as the 'bible of nuclear matter'. This formula gives the masses of the nuclides expressed by their proton and neutron numbers and by empirical parameters, which have so far been based on nuclides close to the stability line (a 'line' through the black squares of Fig. 1). Nevertheless, it has been extensively used far outside this region, especially in theoretical studies of nuclear reactions and for estimating various nuclear properties.

The decay energy will, in general, increase with increasing distance from the stability line. Sooner or later one will reach nuclides which are either themselves particle unstable, or give decay products in such a high energy state as to allow the emission of nucleons or alpha-particles. In the latter case, these particles are 'delayed' by the decay time of the parent.

In the early studies of fission of uranium it was observed that some of the neutron-rich fission products emitted neutrons, with periods of the order of seconds. Recently, studies of the delayed emission of protons (which generally have half-lives of seconds or less) have been undertaken in several laboratories. Because of more powerful experimental techniques, these studies can give more detailed information about nuclear decay than the study of delayed neutron emission.

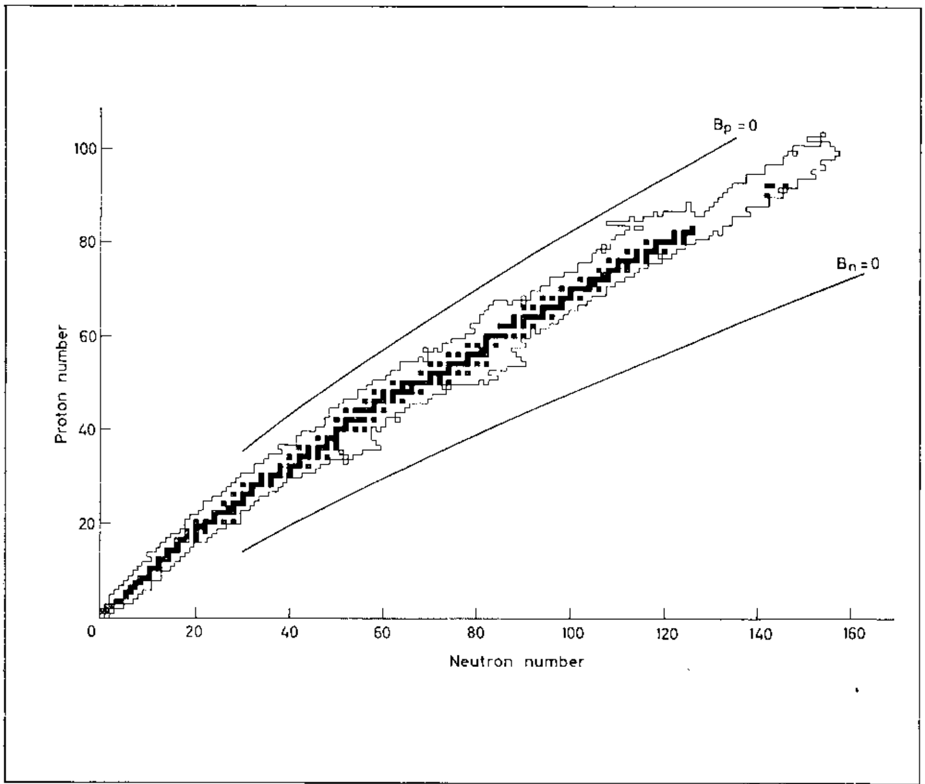
These are a few selected features of radioactive decay, but the general problem is, of course, to make detailed studies of the nuclear decay properties. Such studies far away from stability, have previously been almost completely missing.

New information of great theoretical interest could emerge from studies of nuclides around the N = Z line (where N is the number of neutrons and Z the number of protons in the nucleus) and in the doubly 'magic' regions, such as the Z = 28, N = 28 region around ^{56}Ni, the Z = 50, N = 50 region around ^{100}Sn, and the Z = 50, N = 82 region around ^{132}Sn. (These numbers 28, 50, etc. are called 'magic numbers' as they represent nucleon configurations of particular stability.) Another important problem is to explore the regions of deformed nuclei, both the presently known ones and those theoretically predicted.

Finally, we should be able to measure reaction cross-sections very much further off the stability line than before. Thus, the knowledge of high energy nuclear reactions, such as fission and spallation, could be considerably extended. This information is of particular interest to the astro-physicists, as is evident from the number of publications from these 'latter day alchemists' on the topic of the formation of the elements.

Fig. 1 The chart of the nuclides which have been identified up to now. Stable nuclides are represented by black squares and radioactive or unstable nuclides by open squares.

Fig. 2 The mass spectrum of rubidium isotopes produced by bombarding uranium with 150 MeV protons in an 'on-line' experiment by the Bernas group at Orsay. The isotopes of mass 96, 97 and 98 had not previously been observed.



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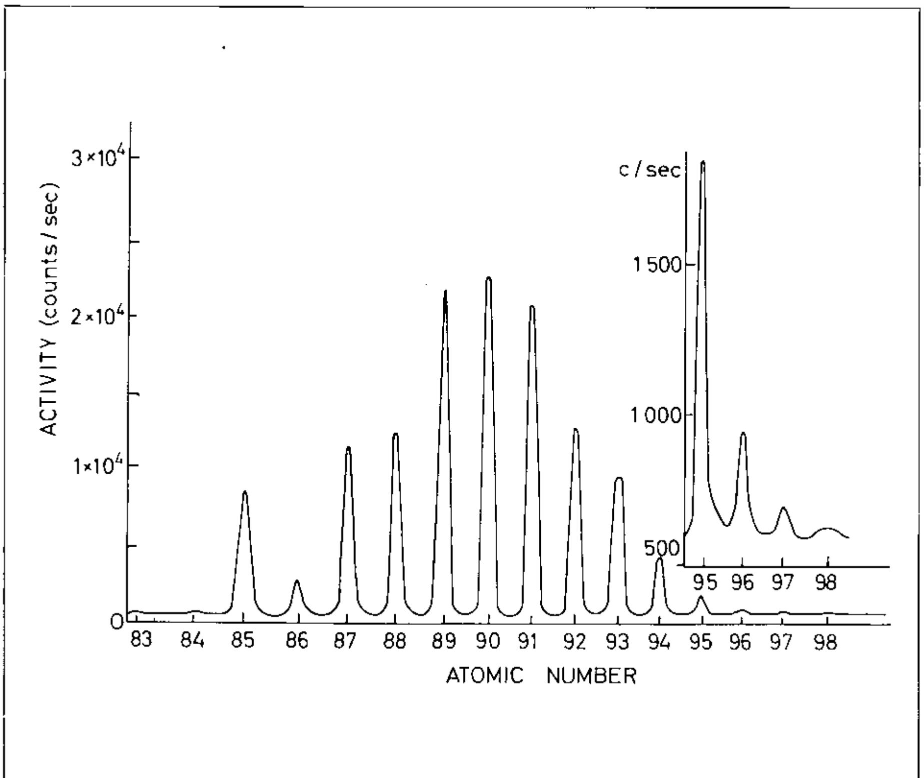

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How to produce

Next we have to tackle the question: 'How should we study nuclides far off the stability line ?'. This we will discuss in some detail because it is closely related to the provocative question sometimes put forward: 'Why at CERN ?'.

The first point to consider is obviously the methods used to produce very unstable nuclides. The production mode can be best described by going back to Fig. 1. The shorter lived neutron-rich nuclides so far studied have, to a large extent, been produced in fission reactions. This is evident from the 'bumps' around Z = 35 and Z = 55, where the highest yields in thermal neutron induced fission of U^{235} occur. Other methods for the production of neutron-rich nuclides are neutron-capture reactions and charged-particle induced reactions.

Neutron-deficient nuclides can be produced by bombarding a target with charged particles such as protons or alpha-particles of medium to high energy. Spallation belongs to this group of production methods. Another method is to let accelerated heavy ions (ions of mass up to around 20 have been used so far) merge into suitable target nuclei. These heavy-ion reactions are particularly suitable for producing nuclides of high spin.

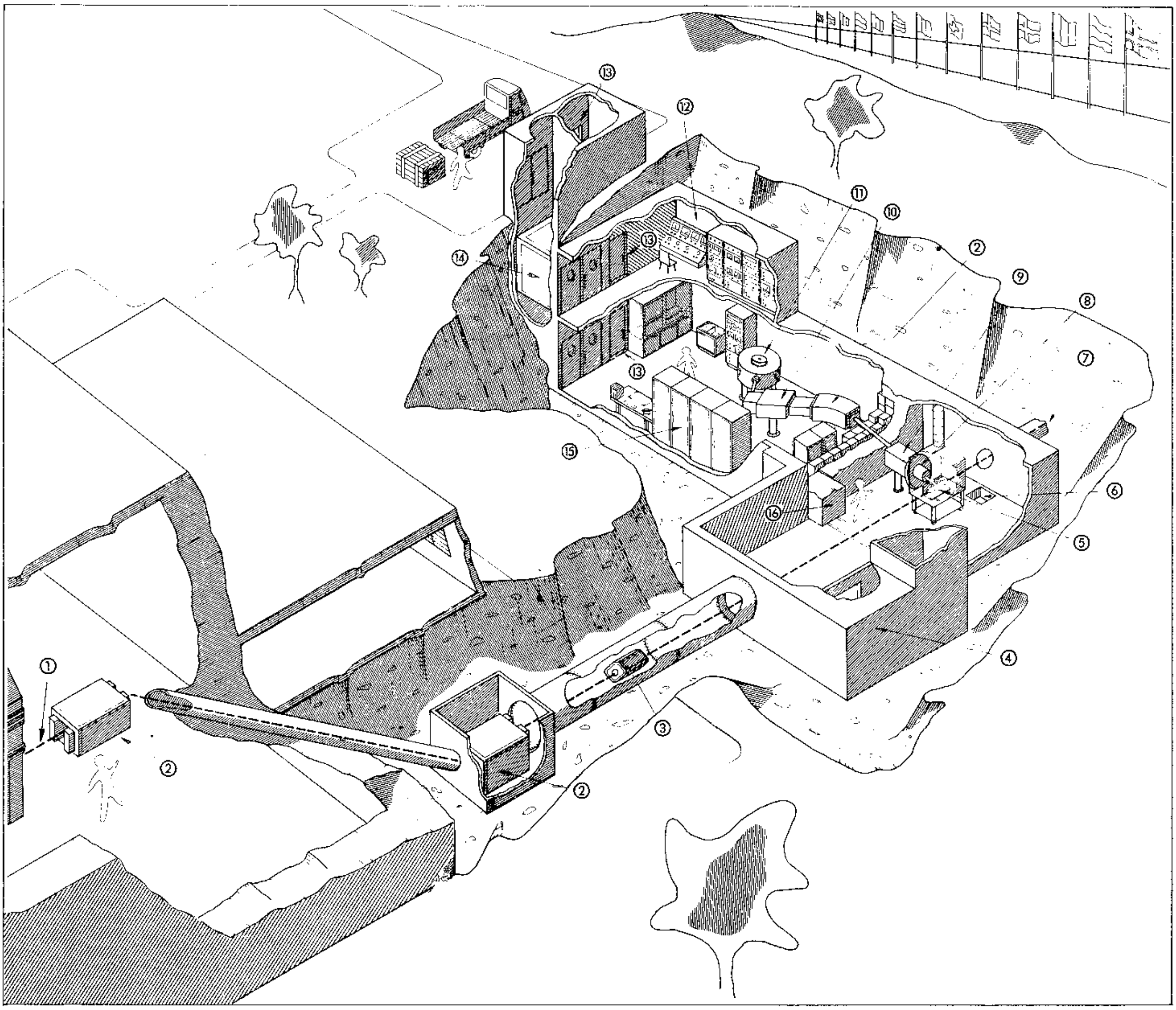
Thus, spallation and heavy-ion reactions are both possible methods for the production of neutron-deficient nuclides. A comparison of available facilities in Western Europe shows, however, that for the time being, the most efficient way to produce these nuclides would be to use the CERN synchro-cyclotron. This is the answer to the question 'Why at CERN ?'.

How to separate

Unfortunately, both fission and spallation give very complex mixtures of reaction products. Direct measurements on the target is almost out of the question. Even isolation of an element by chemical separation may not be sufficient because the sample may still contain a large number of radioactive isotopes. This calls for an additional separation step, namely isotope separation, so that one gets, at least initially, a well defined nuclide to measure

Fig. 3 A general view of the ISOLDE facilities.

1	beam from the synchro-cyclotron	9	lens chamber
2	bending magnet	10	collector chamber
3	quadrupole	11	beta spectrometer
4	ventilation	12	counting room
5	target	13	exit
6	cave	14	lift
7	beam dump	15	electronic equipment
8	ion source	16	door



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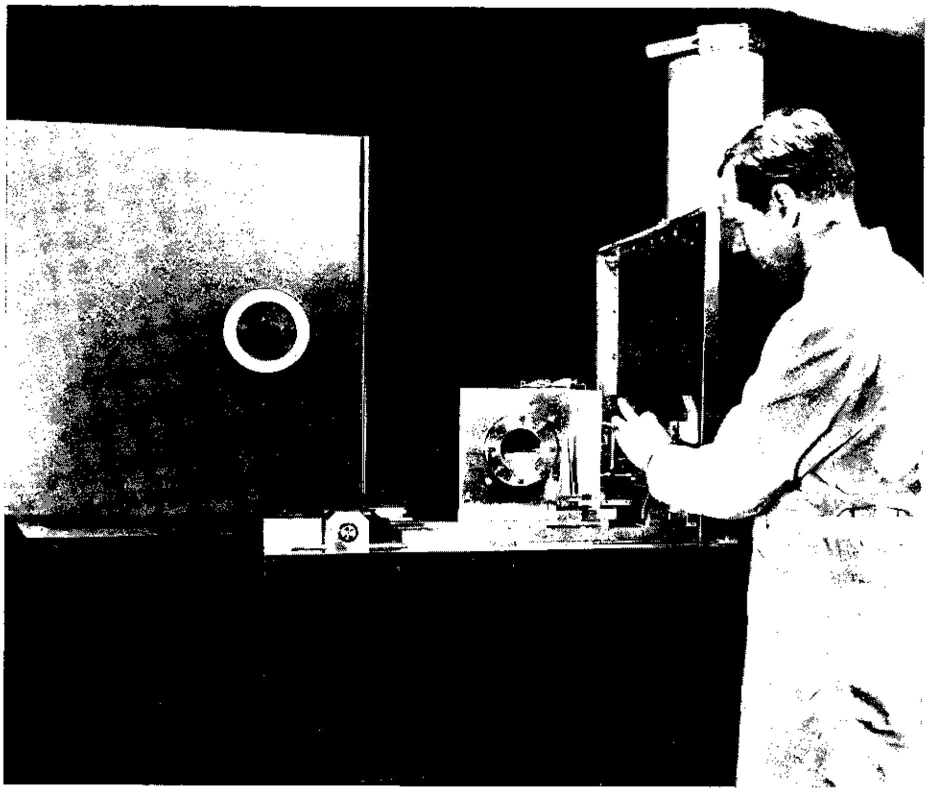
(daughter products will gradually grow into the sample). Actually, the Nuclear Chemistry Group at CERN has used an isotope separator off-line for many years for decay and nuclear reaction studies.

An isotope separator has a furnace, where the sample is evaporated. The vapour is then brought into an ion source, and the ions accelerated and analysed according to mass in an electromagnetic field. Each individual isotope for the particular element is collected, for example, on small strips of aluminium foil and is then ready for measurement.

These 'off-line' methods meet with difficulties if the half-lives of the nuclides to be studied are short. The 'record' for spectroscopic investigations at CERN is ^{199m}Po with a half-life of 4.1 minutes which was produced at the SC. It involved people running through corridors from the SC to the nuclear chemistry laboratory with heavy lead-shielded target containers, rapid chemical separation of polonium from the rest of the reaction products, transfer of the target to the isotope separator, electromagnetic separation and finally, measurement of the alpha-activity of the separated sample. That this study was at all possible under the far from ideal circumstances, was thanks to an athletic team of people 'tuned in' for the experiment.

Obviously, the only way to avoid time-consuming transports between the various pieces of equipment used in the experiments is to move up to the nuclide-producing machine and to attach all components 'on-line' to this machine. Pioneer work of this kind was carried out by the



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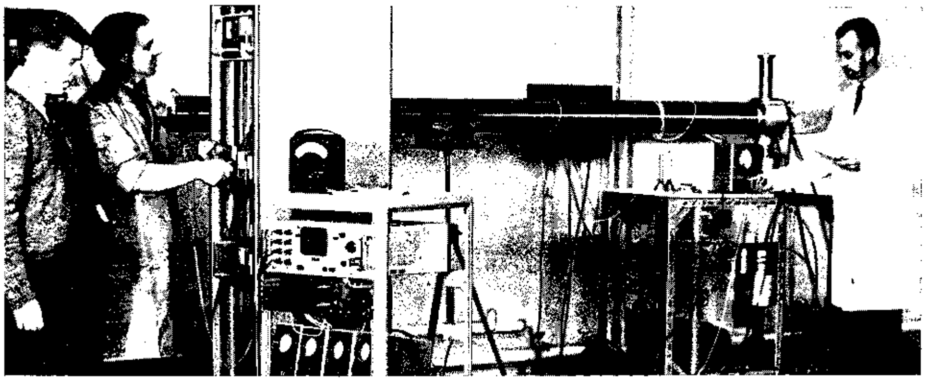

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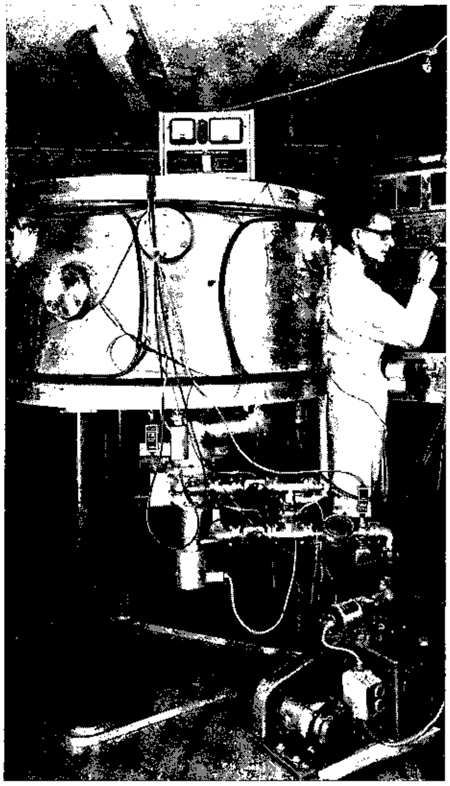
Fig. 4 Target arrangements being developed at CERN. A built-in oven evaporates elements from the targets. The hood on the left swings over during operation and various remotely-controlled safety devices are incorporated.

Fig. 5 A test set-up for ion-optical studies photographed at the University of Aarhus.

Fig. 6 The electromagnetic beta spectrometer, built by the Danish participants in the ISOLDE project, photographed in January soon after its arrival at CERN.



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Copenhagen Group (O. Koford-Hansen and K. O. Nielsen) who managed, in the late 1940's, to study separated, fission-produced, krypton isotopes.

This technique has also been taken up in France, Germany, Israel, Netherlands, Sweden, USA and USSR. Very impressive results have been obtained at Orsay by the Bernas group which bombarded uranium with 150 MeV protons and separated fission-produced rubidium and cesium isotopes on-line. Fig. 2 shows the observed rubidium isotopes in the mass range 83-98.

The ISOLDE technique

We can now answer fully the question: 'How to identify the short-lived nuclei ?'. Use chemical separation followed by electromagnetic isotope separation on-line. In favourable cases, this will give isotopically pure samples from complex reaction mixtures with a delay of seconds, or even fractions of a second, after production.

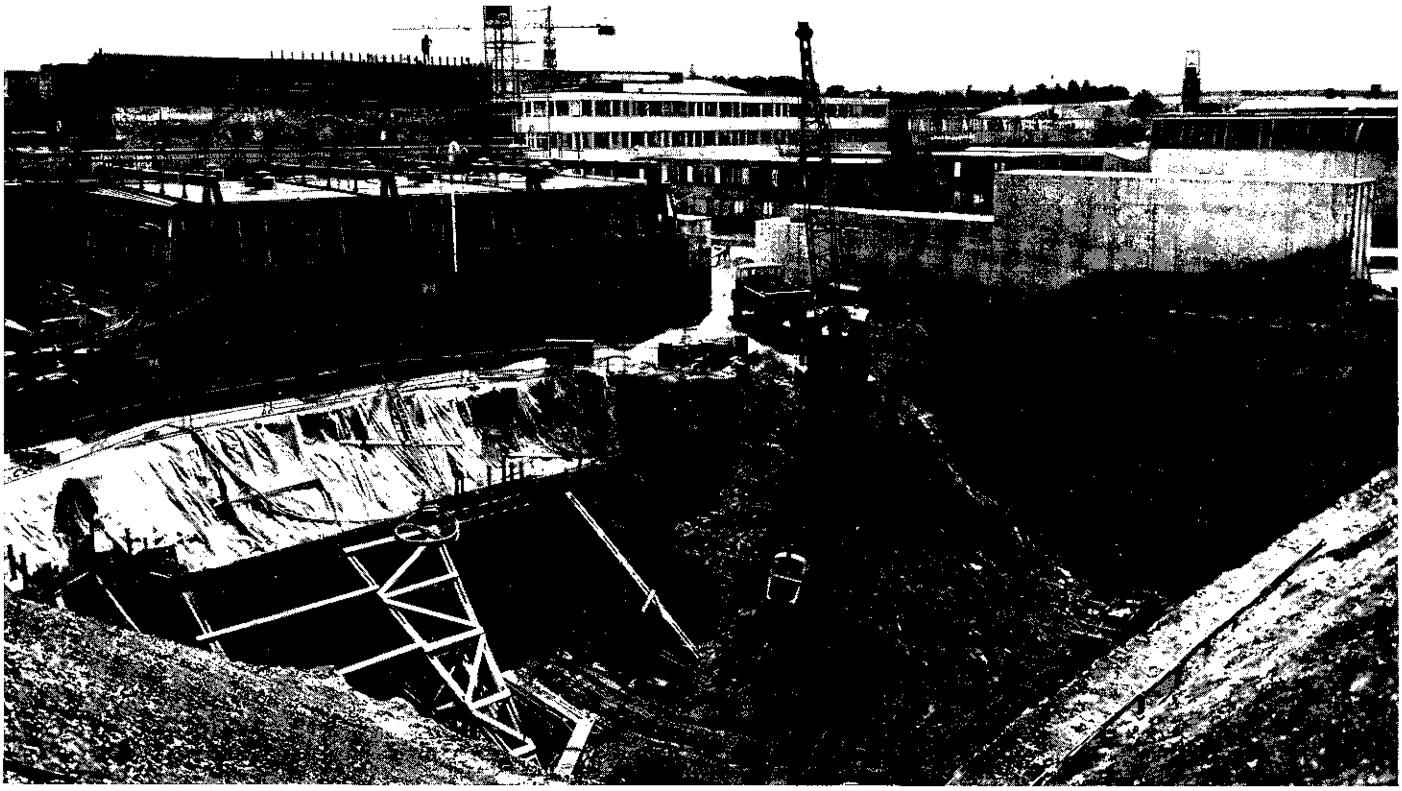
The rest of the recipe is: Produce a steady supply of the short-lived nuclei, transport the isotopically-separated ion beams of these products into adapted nuclear spectroscopic equipment... and make sure there is an abundance of experienced people to handle all the techniques involved.

The ISOLDE project includes all these factors. When the first ideas of attaching an isotope separator on-line to the SC took shape, a team of experimentalists was formed with participants from various laboratories in Denmark (Aarhus and Copenhagen), France (Orsay), Germany (Heidelberg), Norway (Oslo), and Sweden (Gothenburg and Stockholm) and from the CERN Nuclear Chemistry Group. These laboratories brought tradition and experience in all the relevant fields.

Following approval of the ISOLDE project by CERN in the fall of 1964, preparations have proceeded smoothly. A new laboratory (built underground for shielding purposes — see Fig. 7) is almost completed next to the SC (see Fig. 3). A proton beam-line, to give an intensity of about 5×10^{11} protons/s, will be constructed by the Synchro-cyclotron Division and be brought down through the foundations of the SC building to the target room. There it will be directed onto a target to induce nuclear reactions, and selected products, after diffusing through the target material and passing a chemical separation apparatus, will enter the ion source of the isotope separator. A beam of ions, accelerated to about 100 keV, will be formed and led through a tube in a shielding wall (2.5 m thick) into the magnet of an electromagnetic isotope separator placed in the experimental hall. The isotopically pure beams will then be either transported by ion-optical methods or by mechanical tape transport systems into the various pieces of measuring equipment, such as magnetic beta-spectrometers, scintillation counters or solid state detectors. The latter may even be placed at the focal plane inside the collector chamber of the isotope separator.

The coming-of-age of an assortment of solid-state detectors for spectroscopic measurements is a particularly fortunate development. They completely revolutionize the concepts of resolution one can obtain particularly in gamma spectroscopy.

Fig. 7 An early view of the excavations for the underground laboratory to house the ISOLDE project. The proton beam from the synchro-cyclotron will be brought down through the foundations of the synchro-cyclotron building (left of centre). With the laboratory underground, external radiation will be kept to acceptable levels.



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At present the isotope separator is being built at the University of Aarhus, Denmark (see Fig. 5) and the target arrangements for the first experiments are being developed at CERN (see Fig. 4). Some of the nuclear spectroscopic equipment has already arrived (see Fig. 6) and some is under development at the participating laboratories. Long term work on target systems is also being pursued by team members.

The initial programme

Installation of the experimental equipment is expected to take place in Spring, and the tests should start by early Summer. The first elements to be studied on-line will be xenon and mercury, which have very favourable chemical properties and thus will probably reduce the target problems. Short-lived daughter products of the xenon isotopes (isotopes of iodine, tellurium and antimony), may be obtained using xenon as a convenient 'transport medium'. Other elements to be studied in the initial period are krypton and alkali metals.

This programme will also allow us to gain experience with various target techniques. Whilst xenon and krypton can be released efficiently and selectively from certain chemical compounds even at room temperature, mercury will diffuse out only at a temperature close to the melting point of the target material (lead). For extremely short-lived species (less than 1 s), it may be necessary to make the target part of the ion source and use specific methods to single out elements of interest. Thus, surface ionization, will be used for the alkali metals.

We foresee a long period of further development. In particular, the problems connected with the various targets are formidable. Also, the 'on-line' chemistry techniques, required to remove unwanted contaminants, are quite unexplored and will present challenging problems.

To sum up: The ISOLDE project is a cooperative effort by chemists and physicists to penetrate the unknown areas on the nuclear chart, and to study the properties of the discovered nuclei and their reaction cross-sections in various targets. Not least, the project is an effort to engage new experimental groups from the CERN member States in experiments where it can be safely said that CERN offers unique facilities in Europe and even in the world.

Lining up the spins

A report covering the recent conference on polarized targets and ion sources, held at Saclay, appears on page 30. At the December Council Meeting, the Director General in his Progress Report especially mentioned the success of the CERN experiments using polarized targets. The following article is a general introduction to the physics of these targets and the problems they involve.

Elementary particles can have intrinsic angular momentum, a property which we call their spin. They behave as if they are spinning about an axis and the forces between particles when they interact depend to a considerable extent on the value and direction of their spins. (To return to the usual billiard ball analogy, it is obvious that what happens when two balls collide is influenced by the speed with which they are spinning and the directions in which they are spinning.) But the influence of these properties is difficult to investigate because, unless special measures are taken, the particles in a beam or a target will be spinning in all directions making it impossible to sort out their effect. What we need to do is to line up the spins in a known direction, a process known as polarization.

This lining up can be done for the beam particles by using a polarized source to produce the beam, or by multiple scattering techniques which polarize an initially unpolarized beam; or for the target particles by using a polarized target; or for both together. We will not describe the production of polarized beams since they are not used at synchrotrons, though beams from polarized sources have been used with success on linear accelerators and cyclotrons. We will further limit our description to polarized proton targets, though polarized heavy nuclei targets are used extensively in nuclear research. (For people interested in a fuller description of polarized targets than we can give space to here, there is an excellent article in Scientific American, July 1966, p. 69 — Polarized Accelerator Targets, by Gilbert Shapiro.)

The problem is to line up the spins of the protons in the target material in a known direction. The principle is simple. A spinning proton behaves as if it had a tiny bar magnet along its axis and we can therefore use magnetic fields to line them up. The complication is that the spinning protons are such weak magnets that it needs very, very little energy to knock them out of alignment again. For example, we might expect the protons at the nuclei of the hydrogen atoms in water to line up in the direction of the earth's magnetic field (which has a strength of about half a gauss) but, at normal temperatures, the thermal motions of their neighbouring particles is easily sufficient to knock them out of line. On the average, from every twenty thousand million protons 10 000 000 001 will point along the earth's field, while 9 999 999 999 point in the opposite direction. The polarization produced (defined is the number pointing along the field minus the number pointing in the opposite direction divided by the total number) is very small and is quite useless for those particle experiments which require some knowledge of spin directions.

The obvious next move is to use very high magnetic fields to take a firmer hold of the proton magnet and to cool the target material containing the protons to as low a temperature as possible, so as to reduce the probability of thermal motion knocking the protons out of line. This combination of high field and low temperature used alone to produce polarization is called the 'brute force' method. It has not been extensively used up to now because, to produce useful polarizations (of say 50 %) requires magnetic fields of about 100 000 gauss and temperatures only $1/50^{\circ}$ from absolute zero. Even with the rapid development of superconductivity to give high fields and cryogenics to produce extremely low temperatures, this is pushing present technology too far. (The conference report however indicates that the successful use of 'brute force' may be just round the corner.)

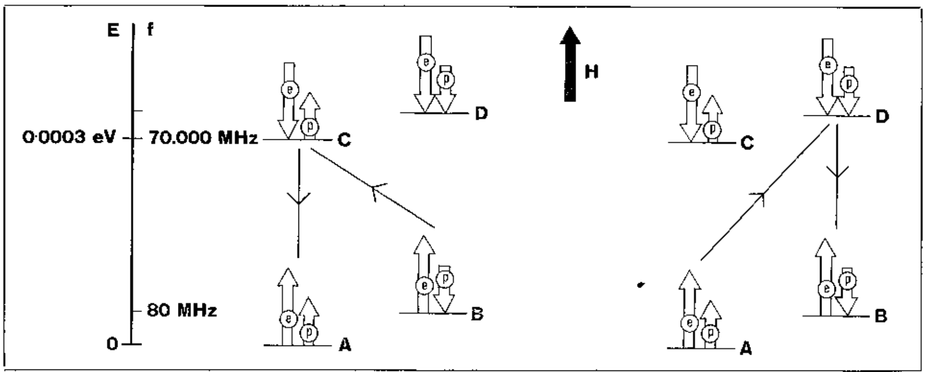
The method almost universally adopted at present, was discovered by A. Abragam at Saclay and developed there and at Berkeley (by C. D. Jeffries). It is called 'dynamic polarization by the solid effect' and makes use of the fact that electrons in a target material can serve as magnets a thousand times stronger than the protons. High fields and low temperatures can be used to line up the electrons and, if the protons can be tied to the electrons in a suitable way, proton polarization can be achieved via the electrons. The target material used is lanthanum magnesium nitrate (LMN) with the addition of about 1 % neodymium; some outer electrons of the neodymium atoms have a large magnetic moment and are easily polarized. LMN has 24 molecules of water of crystallization (LMN = $La_2Mg_3(NO_3)_{12}.24H_2O$) and it is the protons at the nuclei of the hydrogen atoms in the water which the electrons pull into line.

If we think of a simple system of a free electron and proton in a magnetic field there are four possible states that the system can take up (illustrated in the figure). State A, where both the electron and proton have their magnets in line with the field, is the lowest energy state which the system would naturally tend to take up, but since the energy difference between A and B (where the proton is pointing in the opposite direction to the field) is very small, almost equal numbers of electron-proton systems in a target will be in each state. Again we will not have achieved significant proton polarization.

The way round this is to irradiate the target with microwaves of the frequency (about 70 000 MHz) which will give state B pairs the correct amount of energy to lift them into state C. This is a fast process (a fraction of a second). They will then emit their excess energy and fall to state A, again a fast process. Any change from A to B takes place much more slowly (many minutes) and thus by this technique we can greatly increase the number of electron-proton pairs in state A and achieve proton polarization. A slight alteration of the microwave frequency makes it possible to raise the spin pair from state A into state D which then decays into state B. This results in the same degree of polarization but in the opposite direction.

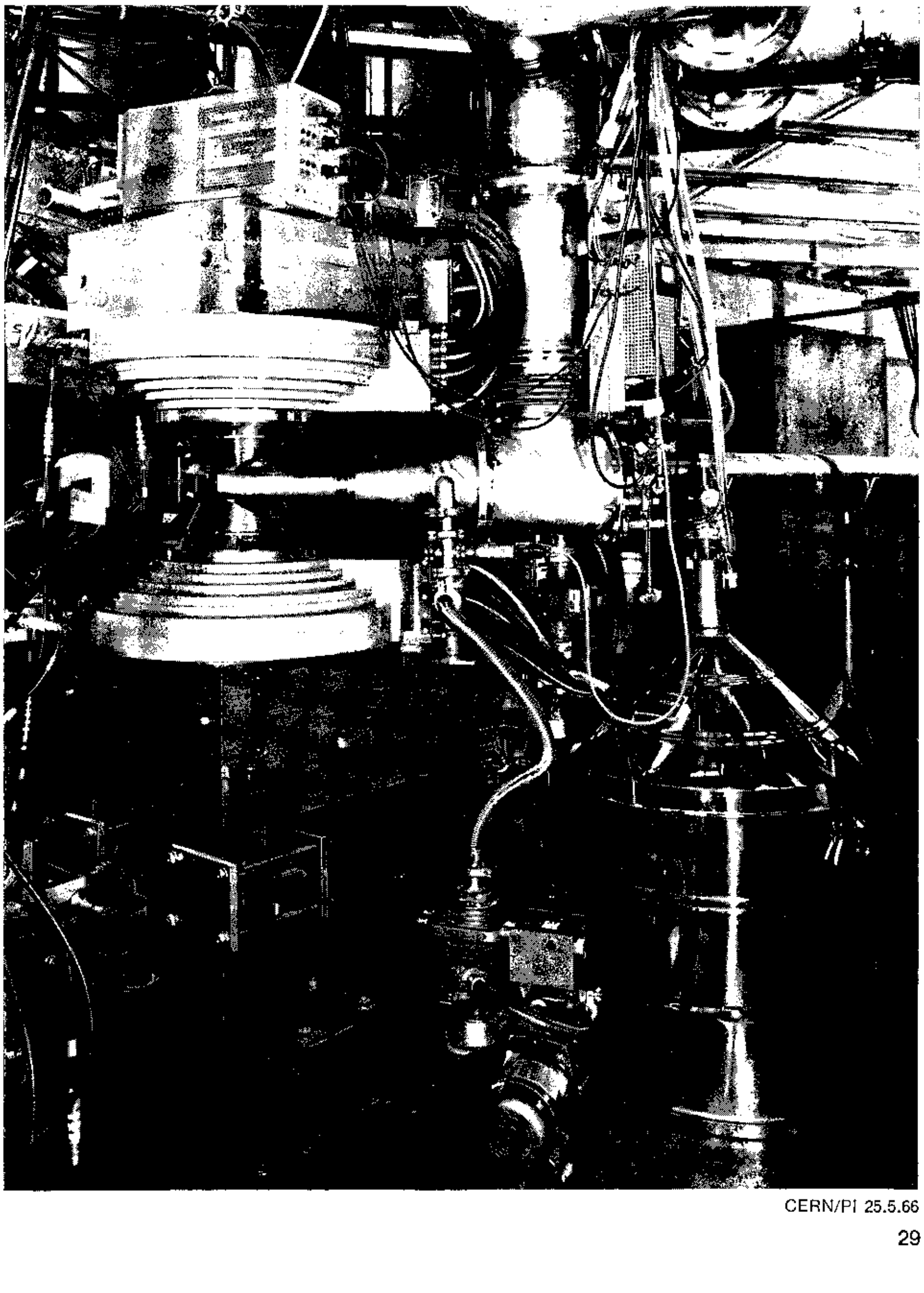
This method has proved very successful but, using LMN crystals, it has a serious limitation in that only about 3 % of the nucleons in the target are 'free' protons at the nuclei of the hydrogen atoms. Although it is sometimes possible to differentiate in the experiment between interactions involving free protons and interactions involving 'bound' nucleons, any development which increases the proportion of hydrogen in the targets will be an advance.

The energy states that spinning electron and proton pairs can take up in an applied magnetic field. On the left, the steps taken to achieve proton polarization in the direction of the field, are represented; on the right, to achieve polarization in the opposite direction to the field. (H is the direction of the applied magnetic field; f the microwave frequency; E the energy.)



One of the two polarized proton targets in use at CERN. The targets have been used in experiments for the determination of hyperon parity and for proton-proton and pion-proton scattering.

The magnet, which can be identified by its conical pole-pieces, provides a uniform magnetic field, in the vertical direction, of 18.5 kg over the target volume (up to 1.5 cm square cross-section by 5 cm long). The target is an LMN crystal cooled by vaporization of liquid helium to near 1° K. The horizontal cryostat, fed from the large liquid helium container on the floor on the right, protrudes into the magnet aperture. Polarizations of around 70 % have been achieved.



CERN/PI 25.5.66

Polarization conference

by M. Borghini

A report on the first international conference on polarized targets and ion sources which was held at Saclay, from 5 to 9 December 1966.

The emphasis at the Conference was mainly on polarized proton targets, although some papers dealt with deuteron, helium 3 and heavy-nuclei targets and one review paper with recent progress in polarized proton and deuteron beams.

Theoretical questions involved in the use of polarized targets were discussed by J. D. Jackson (generalities), M. Jacob (invariance tests, spin-parity measurements), R. J. N. Phillips (high-energy scattering), R. H. Dalitz (resonances, Ω^-) and H. P. Noyes (two and three nucleon systems). The theory of various polarization schemes was treated by A. Abragam (generalities), M. Borghini (brute force and dynamic polarization by the solid effect), C. D. Jeffries (nuclear spin refrigerator), T. R. Carver (problems in polarizing dense helium 3), and G. K. Walters (polarization of gaseous helium 3 by optical pumping). Experiments with polarized targets were reviewed by O. Chamberlain (high-energy physics), G. C. Phillips (polarized helium 3), P. Catillon (low-energy physics), V. I. Lutchikov (neutron physics at Dubna), and R. I. Shermer (neutron physics at Brookhaven), and the technological aspects were covered by H. H. Atkinson ('high-energy' targets), D. Garreta ('low-energy' targets), R. Beurtey (ion sources) and P. Varoquaux (helium 3 — helium 4 mixture cryogenic systems).

Almost all the high energy physics Laboratories with large proton accelerators (Brookhaven is one of the exceptions) have one and sometimes two polarized proton targets. The polarized material is always lanthanum magnesium nitrate, LMN. The hydrogen atoms are polarized by the solid effect with polarizations ranging between 40 and 70 %, known with a relative uncertainty varying between ± 5 and ± 15 %. The operation at Dubna of a LMN target containing 99.5 % of heavy water with its deuterons polarized by solid effect up to 10 % was reported. Helium 3 targets are polarized up to 40 % by optical pumping at room temperature and are made of pure gaseous helium 3 at a pressure of a few millimetres of mercury.

Amongst the research using polarized proton targets which was described, were experiments to determine the spin and/or parity of the Σ^+ at Berkeley, of the Ξ^- at CERN, of the N*(2190) (7/2, —) at the Rutherford Laboratory and of the N*(1688) (5/2, +) and the N*(1920) (7/2, +) at Argonne;

measurements of the polarization parameter in elastic scattering and charge exchange reaction for proton-proton from 330 to 740 MeV and from 1.7 to 6 GeV, and pion-proton from 470 MeV to 3.6 GeV at Berkeley, for proton-proton and pion-proton from 6 to 12 GeV/c and pion-proton charge exchange at 6 and 11 GeV/c at CERN and for proton-proton from 0.5 to 1.2 GeV at Saclay;

spin-spin correlation measurements in proton-proton scattering at 10 and 26 MeV at Saclay, at 140 MeV at Harwell, at 575 MeV at CERN, at 680 MeV at Berkeley and from 0.5 to 1.2 GeV at Saclay, and for neutron-proton at 23 MeV at Los Alamos.

At Dubna, an original use is made of a polarized proton target to polarize, by transmission beams of neutrons with energies ranging from 1 eV to 100 keV.

Some proposed experiments were discussed, including the electroproduction of resonances using polarized proton targets, as suggested by T. D. Lee and N. Christ, to test the T invariance of the electromagnetic interactions; the measurement of the spin parameters in high-energy hadron elastic scattering, and charge exchange reactions in the forward and backward directions, and the study of resonant state production. However, most of these experiments require polarized targets containing more hydrogen than the LMN ones which are in operation at present.

This problem of improving the hydrogen content of the polarized targets was discussed at some length. In view of the recent advances in the production of high magnetic fields using superconductors and in achieving very low temperatures by helium 3 — helium 4 mixture devices able to dispose of sizeable amounts of heat, the 'brute force' method of polarization is being reconsidered.

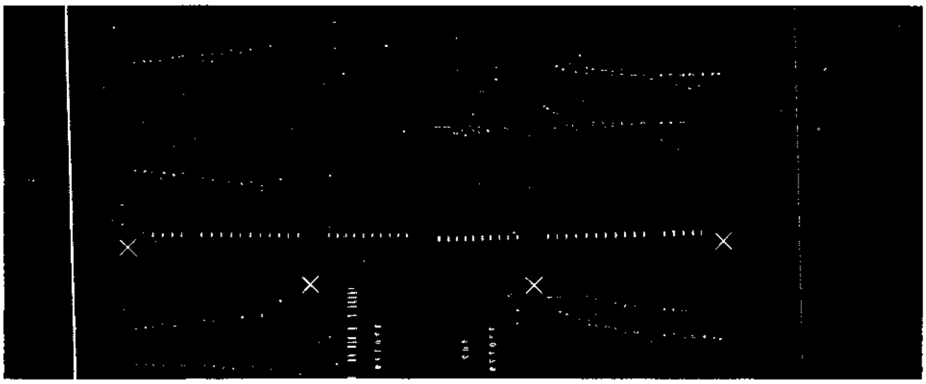
No way of getting round the ortho-para complication and of polarizing pure hydrogen has been proposed, but it has been pointed out that, because of the spin statistics of its molecules, the protons in solid methane (CH_4) would have nearly twice the polarization of those in substances like polyethylene $(CH_2)_n$, deuterated hydrogen (HD) or lithium hydride (LiH). With methane, polarizations of almost 50 % could be obtained at a temperature of 0.04° K in a magnetic field of 100 000 gauss which is almost within the reach of technology.

A new dynamic method of polarization, called the 'nuclear spin refrigerator', was described. It has been developed at Berkeley and could produce useful polarizations by simply rotating a suitable substance in a magnetic field of 50 000 gauss at a temperature of 1° K for example. So far, polarizations of 35 % have been produced by this method in the still rather complicated yttrium ethyl sulphate (YES = $Y(C_2H_5SO_4)_3.9H_2O$). Studies of dynamic polarization by the solid effect are under way at a number of Laboratories and the best results were reported by the CERN polarized target group, who have achieved polarizations of 35 % in various mixtures of water and methyl, ethyl and propyl alcohols (H_2O, CH_3OH, C_2H_5OH and C_3H_7OH) containing a free radical.

One of the main conclusions that can be drawn from the conference (apart from the evidence of the fast development of the field since 1962), is that a new generation of polarized proton targets is likely to appear soon, making a new range of useful experiments possible.

CERN News

A spark chamber photograph taken in the experiment to observe the decay of the long-lived K meson into two neutral pions. It detects the four gamma rays, produced as the pions decay, when they convert in aluminium in the spark chambers into an electron and positron. Dividing the picture into quarters: on the right, are two views of the sparks initiated by the electron and positron in the right half of the symmetrical array of detectors; on the left, two views of the sparks in the left half of the array of detectors. A system of mirrors brings the information onto one photograph.



CERN/SIS 25.825

New CP violating decay of K^0_L meson

An experiment on the CERN proton synchrotron, which measured the rate at which the long-lived neutral K meson, K^0_L, decays into two neutral pions, was reported in Physical Review Letters on 2 January. The experiment involved a collaboration between Rutherford Laboratory, AERE Harwell, Aachen and CERN, and was one of the experiments incorporated into the research programme at CERN following the power supply failure on the Nimrod accelerator at the Rutherford Laboratory.

The decay of the K^0_L into two charged pions, first observed at Brookhaven in 1964, has stimulated a variety of subsequent experiments. This decay involves the violation of charge-parity (CP) symmetry which was previously presumed to hold good in weak interactions (see, for example, CERN COURIER, vol. 6, page 171) and there have been many ideas put forward about the origin of the violation. One crucial way to distinguish between the various possibilities is the study of the K^0_L decay into two neutral pions. The CERN experiment has shown that this decay, which also violates CP symmetry, does occur.

One of the theoretical schemes proposed to explain the CP violation, is called the 'super-weak' theory. It predicts that the ratio between the rate at which the K^0_L decays into two neutral pions and the rate at which it decays into two charged pions should equal $1/2$. This figure was tested in the experiment.

A beam of secondary particles was produced in the synchrotron and filtered by a magnet (to remove charged particles) and a lead shield (to remove gamma rays), leaving a beam of neutral particles. Some of the K^0_L particles in this neutral beam decayed into two neutral pions. These decays could be detected when the pions decayed further into gamma rays. A symmetrical array of scintillation counters and spark chambers measured the direction and energy of the gammas and data was collected on the number of times these measurements agreed with those required for a decay of K^0_L into two neutral pions. The experimental arrangement was in large part given over to ensuring that the more frequent decay into three neutral pions did not trigger the data-recording apparatus too often.

87 $\pm$ 22 events were recorded implying a ratio between decay into two neutral pions and decay into two charged pions of about 2. Despite an appreciable margin of error, the result is remarkably large compared with the value $1/2$ predicted by the superweak theory.

A few weeks after the measurement at CERN emerged, it was confirmed by a very elegant experiment on the Princeton accelerator in the USA. The team at Princeton arrived at an identical result with greater accuracy using a different experimental technique. They reported their experiment in the same issue of Physical Review Letters.

'Measurement of the decay of long-lived neutral K meson into two neutral pions'
J. M. Gaillard, F. Krienen, W. Galbraith, A. Hussri, M. R. Jane, N. H. Lipman, G. Manning, T. Ratcliffe, P. Day, A. G. Parham, B. T. Payne, A. C. Sherwood, H. Faissner, H. Reithler. Physical Review Letters, 2 January 1967.

Seven new mesons

The 'missing-mass spectrometer' experiment was concluded at the proton synchrotron in January. Over a period of about a year, it identified seven heavy mesons for the first time and more may emerge from the analysis of the latest results. The research involved the development of a very interesting experimental technique which has attracted a great deal of attention. About 25 scientists and engineers from ten European countries, USA and USSR participated at various stages of the experiment in a team led by B. Maglic.

The basic interaction investigated was $\pi^- + p \rightarrow p + X^-$. Negative pions produced in the synchrotron were directed onto protons in a hydrogen target and could result in recoil protons and the production of negative mesons of different masses (represented by X in the equation). The momentum and direction of the incoming pion were determined and measurements on the recoil proton indicated the mass of the meson. In other words (remembering that energy can be represented as mass), the information gathered about the particles on the left-hand side of the equation and on the recoil proton on the right-hand side, gave the 'missing-mass' which was that of the meson.

An intricate system of acoustic spark chambers, wire spark chambers, a counter matrix, hodoscopes and a time-of-flight counter system (amounting to about 100 scintillation counters) was used in the experiment, all feeding information into a small on-line computer (a SDS 920) which was then connected on-line to the large CDC 6600 computer. In each recorded event between 100 and 200 pieces of information were collected and this at a rate of 3 to 10 events per second. Preliminary calculations could be carried out as the experiment proceeded and information displayed on a television screen in the experimental hall. (This system was developed by the experimental team in collaboration with the Data Handling Division.)

Apart from its intricacy, the novelty of the missing-mass spectrometer technique lay in the way it carried out its measurements on the recoil proton, avoiding the conventional use of a large magnet to determine momentum. The array of detectors for the proton could be moved on a turn-table through angles known with respect to the direction of the incoming pion beam. It can be calculated that associated with each meson which can be produced in the interaction, there is an angle at which a high percentage of the recoil protons will emerge. (The method is known as 'using Jacobian peaks in the angular distribution'.) Thus, as the proton detector was moved through different angles, the number of protons rose sharply at those angles corresponding to the production of a meson. The widths of the peaks found in the experiment were surprisingly narrow, implying longer lifetimes for such heavy particles than is generally expected.

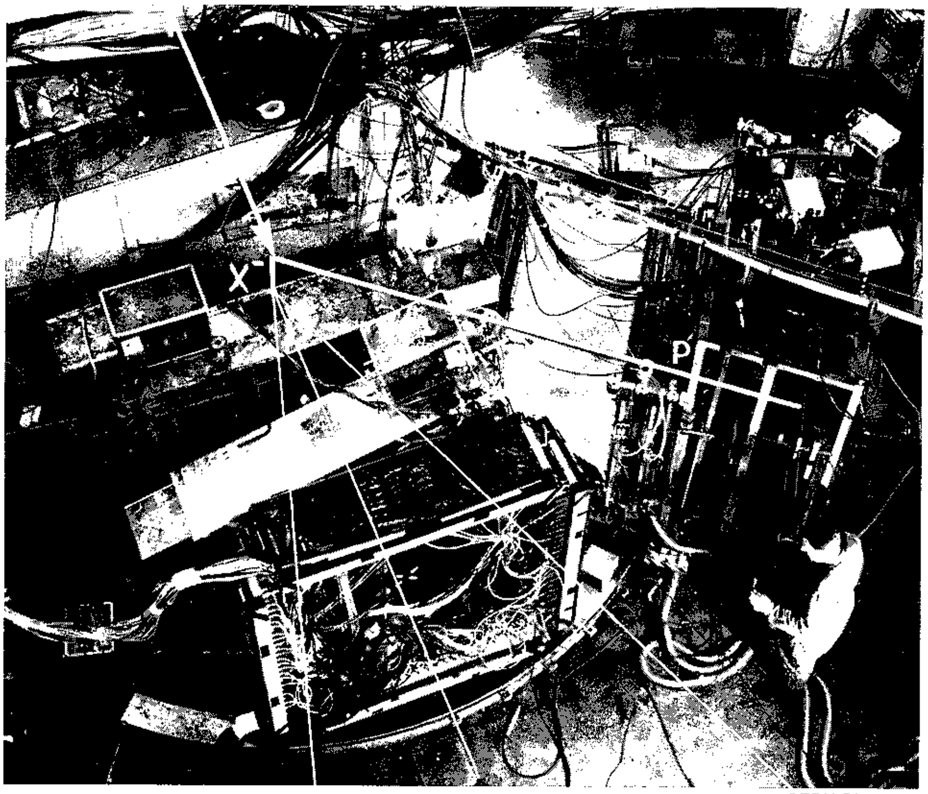
The technique has been described as fishing with a net instead of a hook. Seven new 'fish' have been caught to date. They have been named the δ (963), R_1 (1634), R_2 (1700), R_3 (1748), S (1929), T (2195) and U (2382), where the figures in brackets give their masses in units of MeV. There is a remarkable regularity in the mass spectrum of these particles — the squares of their masses lie neatly on a straight line. It has been pointed out (for example, by Professor Dalitz at the Berkeley Conference last year) that this fits well with the model of an underlying quark - anti-quark system.

It is expected that results from the latest run will be available in about two months time.

'Evidence for a singly charged boson of mass 1675 MeV and width $\Gamma = 66$ MeV'. J. Séguinot, M. Martin, B. C. Maglic, B. Levrat, F. Lefèbvres, W. Kienzle, Maria N. Focacci, L. Dubal, G. Chicovani, C. Bricman, H. R. Blieden and P. Bareyre. Physics Letters, 1 January 1966.

'Evidence for three new charged bosons of masses 1929, 2195 and 2382 MeV and narrow widths'. G. Chikovani, L. Dubal, M. N. Focacci, W. Kienzle, B. Levrat, B. C. Maglic, M. Martin, C. Nef, P. Schübelin and J. Séguinot. Physics Letters, 1 August 1966.

'Mass spectrum of bosons from 500 to 2500 MeV in the reaction $\pi^- + p \rightarrow p + X^-$ observed by a missing-mass spectrometer'. M. N. Focacci, W. Kienzle, B. Levrat, B. C. Maglic and M. Martin. Physical Review Letters, 17 October 1966.



CERN/PI 38.1.67

A view of the missing mass spectrometer taken just before the experiment was concluded in January. Superimposed is a typical event — the incoming pion producing a heavy meson (X^-) in a hydrogen target. The intricate experimental array to detect the recoil proton (p) and the decay products of the meson can be seen mounted on the turn-table.

2 m shutdown

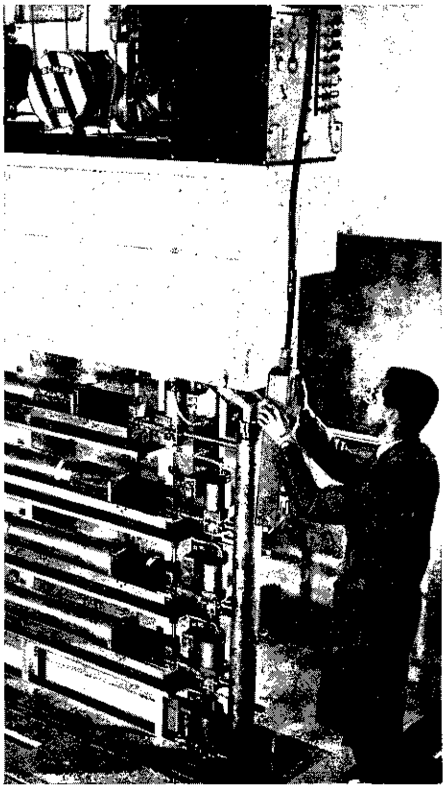
The 2 metre hydrogen bubble chamber began a three months shutdown on 15 February. During this time general maintenance work will be carried out and several modifications will be made to the chamber to meet the requirements of the future physics programme. The main item in the maintenance work is the complete overhaul of the optical system. All the lenses and the main windows of the chamber will be cleaned and recoated.

The emergency evacuation system, which transfers the hydrogen in the chamber to a large sphere outside the bubble chamber building in case of accident, will be reinstalled on the beam-exit side of the chamber. Its move from the beam-entrance side is necessary to make room for a new beam-line, called k8, which will be brought into operation at the end of 1967. k8 will provide low energy (1-2 GeV/c) K meson beams. Also on the beam-exit side, a thin window is being incorporated so that high energy K mesons passing through the 2 metre chamber can be used for a 'JET experiment'. This experiment will involve the CERN heavy liquid chamber when it has completed its run in the neutrino beam.

A number of comparatively minor changes to the 'plumbing' of the chamber will be carried out to prepare it for filling with deuterium instead of hydrogen. Deuterium, where the target nucleus consists of a proton and neutron as opposed to a proton alone in hydrogen, is the nearest approach to a free neutron target that can be devised and several experiments are planned for the 2 m chamber filled with deuterium.

On 15 May, the chamber is scheduled to be brought into operation again using hydrogen to complete a programme of experiments on the m6 beam-line and the u4 beam-line (the existing u3, which will be modified by the addition of another radio-frequency separator during the shut-down to provide pions up to 14.5 GeV/c and anti-protons up to 17 GeV/c). In August, the change-over to deuterium will take place and it is hoped to take 400 000 pictures within eight weeks, before changing back to hydrogen.

The storage arrangements in the 'hot-lab.' for the target units used in the proton synchrotron. One of seven racks, each of which can store 8 units, is being lowered into position. When in position, they are kept under a vacuum of about 10^{-3} torr (pumps and controls are visible on top of the concrete block). The target units are in the cylinders, lying horizontally on the shelves, which serve as small vacuum covers which can be sealed off to keep the units under vacuum while they are transported to the synchrotron. The concrete block (80 cm thick) provides adequate shielding for the radiation from units which have been used in the PS.



CERN/PI 10.1.1.67

Flying Spots

From 18-20 January, the '1967 Conference on Programming for Flying Spot Devices' was held in Munich. The conference was organized jointly by the Max Planck Institut für Physik und Astrophysik and CERN, and brought together 144 scientists from Universities and high-energy physics Laboratories in Europe, USA and USSR, including 22 from CERN. It was the fourth formally organized conference on this subject (after those of Paris, Bologna and New York and their informal predecessors reaching back to 1960). We select here a few topics of interest which were reported at the conference with emphasis on the developments involving CERN.

Considerable progress has been made over the past year on the problems of measuring bubble chamber and spark chamber tracks using flying spot devices. In his concluding address to the conference Professor Kowarski remarked that these devices have entered 'the third era' of their history. The first era was that of the development of the hardware — the instrumentation aspects of the operation of the devices; the second era was that when progress was 'bogged down in software' — the problems of programming the computers to run the devices and process their output. Now at last, in their third era, they are being used in productive physics. Many Laboratories were able to report experiments analysed by various types of flying spot, or flying slit, device. At Berkeley, the 'Spiral Reader' is measuring many hundreds of pictures a day. At CERN, one 'Luciole' machine and one HPD have been measuring pictures throughout the year connected directly to the CDC 6600 computer. A second HPD is now being brought into production work. (For a description of these devices see CERN COURIER, vol. 6, page 7.)

The problems of computer programming have been tackled in various ways. In bubble chamber work, the more ambitious pattern recognition schemes with 'zero guidance' (which leave the computer to find the tracks which are to be measured using the information supplied by the device without any human intervention to pinpoint the interesting areas of the photograph) have still not emerged into current use. About a year ago, all HPDs were operating with 'road guidance', a process in which several points on the interesting tracks were picked out in advance to help the computer find its way. This is now being carried to a further stage of simplicity mainly by a CERN/Rutherford Laboratory effort, so that the computer needs to be informed only of the vertex of the interesting tracks. Other systems retain human intervention 'on-line' as the measurement proceeds.

Other reports at the conference, showed how the problems can be greatly simplified, when it is possible to clearly define the job which the measuring device is required to do and then design the device for that job alone. This is at the opposite end of the scale to the HPD type of project where the development is concentrated on producing a machine which is universally applicable to the measurement of all types of bubble chamber and spark chamber pictures. A very successful computer controlled flying spot digitizer for the spark chamber photographs of one particular experiment (on the interference between long-lived and short-lived K mesons) was reported by P. Scharff-Hansen from CERN).

Professor Kowarski speculated in his concluding remarks that the development of these machines may turn out to be useful not only in relation to problems in high energy physics but also in terms of a wider ambition to provide a computer with an eye.

Conferences

A conference on 'High Energy Physics and Nuclear Structure' is being held at Rehovoth, Israel, from 27 February to 3 March. The CERN Scientific Conference Secretariat is participating in the organization in conjunction with the Weizmann Institute. Post-conference summaries are available to journalists from N. Meyers, Public Affairs Office, the Weizmann Institute of Science, Rehovoth.

From 1-3 March the 1967 US National Particle Accelerator Conference (accelerator engineering and technology) will be held in Washington. Dr. P. M. Lapostolle and Dr. K. Johnsen, both of the CERN ISR Division, are to give papers on the design of a high intensity proton linear accelerator and the CERN storage ring project respectively. Abstracts of the conference papers are to be published in the Bulletin of the American Physical Society.

Colloquia

The following colloquia have been arranged for the coming weeks —

2 March: Professor P. Dustin from the University of Brussels will talk about cancer research

8 March: Professor W. Fucks from the University of Aachen will talk on the subject of 'Prognostics and development of the potential of the big powers'

16 March: Professor A. Jaumotte from the University of Brussels will talk about 'Air cushion vehicles and their possibilities'

6 April: Dr. B. J. Mason, Director General of the Meteorological Office at Bracknell, UK, will talk about 'Recent developments in cloud physics'.

Book reviews

Science Year

The World Book Science Annual, volumes 1965 and 1966. (Field Enterprises Educational Corporation, Chicago, $ 6.95 each).

Who, among those interested in the progress of science, has not deamed of finding in one book a comprehensive survey of present knowledge ? Who also, if that dream could be realized — whether fully or not — would not wish that the book be kept up to date by regular additions of new knowledge. Several attempts have been made to fulfill the first dream and here, in the volumes of Science Year for 1965 and 1966, is an attempt to fulfill the second.

Most of Science Year 1965, consists of 15 surveys which, though they are each concerned with one of the small areas into which contemporary science is divided, nevertheless cover the most important topics, both in terms of their present progress and their fundamental features.

Attention to detail has not been lost in the attractive presentation; for example, the account of the experiment by the team from Princeton University on the violation of the law of CP symmetry does not make for easy reading, and the explanation of the genetic code, could discourage more than one reader.

But what kind of reader ? To whom are these very attractive annuals directed ? According to the publisher: school children, students of science, teachers, even scientists, will find in these books information to satisfy their curiosity. This is a justifiable claim, with the reservation that for the well-qualified scientist it will provide only a pleasant diversion.

There are 394 pages in the volume covering the year 1964-65, with three reports on space research — including that in the Soviet Union (more a historical review than a survey of recent developments) — one on botany and one on ecology. Other articles are concerned with research in the Antarctic, biology, medicine, and surgery. The laser, anthropology, and the use of underground nuclear explosions are presented on 44 pages preceeding the last article in this part of the book which concerns a prizewinning teaching machine developed by a young student to study the physics of colour.

A good hundred pages are then allocated to reports of the main developments in the leading sciences and several pages contain obituaries of prominent scientists who died during the year. At the end of the book is a biography of a Nobel Prize winner, and a list of the winners of the major scientific prizes during the period 1964-65.

It is rather difficult to work out exactly what period the annuals do in fact set out to cover. For example, in the volume '1965' many of the topics covered concern developments in 1964 — including the experiment by Fitch et al. on the violation of CP, the symmetry of charge and parity, in sub-nuclear physics. The theory of the quark is also described in this volume. The survey of sub-nuclear physics is concentrated on the situation in the USA: the possibility of constructing a 200 GeV machine in America is described but no mention is made of the European project for a 300 GeV machine.

Science year 1965 cannot therefore be regarded as perfect. In general, however, there is much to admire: excellent typography, very attractive presentation, and the merit of being — as far as we know — the first annual to be devoted completely to science. Perhaps one could complain of the American magazine approach to layout, but that is a subjective opinion, which one could not hold against 'Science Year' for long if its forthcoming editions overcome the bias introduced by choosing authors from the USA only.

The last comment above applies to the second volume which appeared in November 1966. 'Science Year 1966' has a European genetician among its seven editorial advisors, the others coming from the USA with one from Canada.

The volume is bigger than for 1965: 442 pages instead of 394. This increase is in part due to the decision to introduce each chapter by a survey of existing knowledge. The book begins with splendid colour reproductions of the photographs of the earth taken on a Gemini flight and this is the first indication of the remarkable quality of the illustrations throughout the book. The finest of these is a representation of a heart attack in 'trans-vision' — a tour de force in graphic art making excellent use of consecutive layers of transparent coloured plastic.

Sixteen sections cover, in detail, the major sciences: two are concerned with space research, two with astronomy and astrophysics, six with knowledge of the earth, four with the life sciences, one with plasma physics and one with science in China. The volume contains also a review of other recent developments, three chapters on people — including Eugene Wigner — and a list of science prizes awarded since 1965.

It would be presumptuous to attempt to analyse the book completely but two comments are worth making to those who are concerned with sub-nuclear physics.

No detailed study of this field appears in the 1966 edition. One can perhaps predict this omission from the words of an introductory essay 'Science and the future of society' where the author stresses the benefit man can draw from science and technology to control his natural environment, without mentioning the benefit of fundamental research for the development of applied research.

The second comment concerns the section 'Elementary particles'. The author is rather optimistic in saying that the classification of particles is already accomplished. He reports the violation of charge symmetry in the decay of the eta meson; it would be useful to know the last date for the review of contents, because this violation was disproved at the end of August by the result obtained at CERN. Also, the Soviet 70 GeV accelerator at Serpukhov is ascribed to Dubna and, once again, the 200 GeV project is described without reference to the European 300 GeV project.

In the book's favour, the chapter on 'new words' gives definitions of hadron, mesic atom, meson factory, proton knife, etc. This chapter, the index, and the references to other books are happy features. If the book cannot be considered as a reference work for everyone, we must acknowledge that the publishers successfully hold the attention with a very fine presentation. They can still make improvements by drawing their authors and editorial advisors from a broader geographical spectrum and by a less subjective choice of the disciplines covered.

R. A.

Irradiation damage to solids

by B. T. Kelly, (Oxford Pergamon Press Ltd., 1966, 25s).

This book comprises a comprehensive assessment of the theoretical basis of the interaction of high-energy radiation with crystalline solids. It is divided as follows:
Chapter I deals with calculations of the number of atoms displaced from their normal lattice sites by all types of radiation (electron, proton, neutron, etc.)
Chapter II contains a description of how the atoms are displaced, and includes some modern experimental techniques for studying the defects introduced by radiation
Chapter III discusses, in detail, the effect of nuclear radiation on electrical, mechanical and physical properties
Chapter IV deals with the annealing of defects created in solids by nuclear radiation
Chapter V compares the results of irradiation carried out under various conditions.

Although the discussion of radiation effects in solid inorganic materials is stated very generally, the aspects are applicable to all crystalline materials; further information concerning specific solids can be found in the up-to-date and extensive list of references at the end of each chapter. The mathematics throughout the book are very clearly presented and are always interpreted from the physicist's point of view. Most of the tables and figures are related to studies undertaken with reactors and, in the text, the author manages to express useful values in an extremely handy form.

For the physicist already working in this field, this small book will be of practical interest; for the scientist who would like to become familiar with the field, it provides a very complete introduction.

M. H. Van de Voorde

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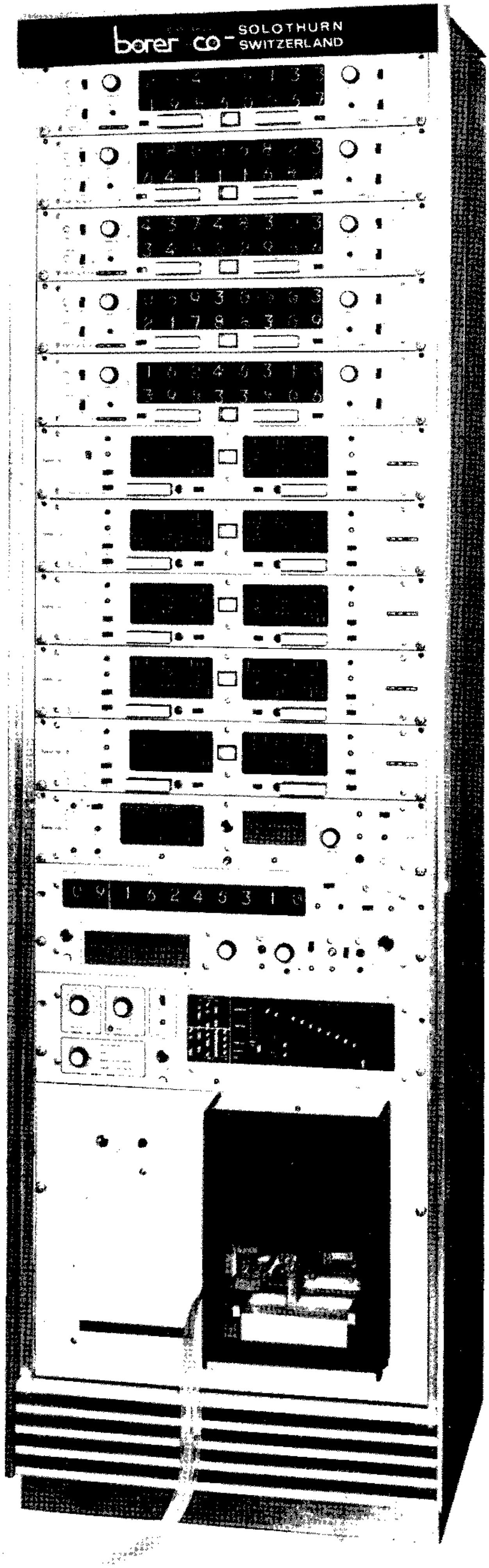

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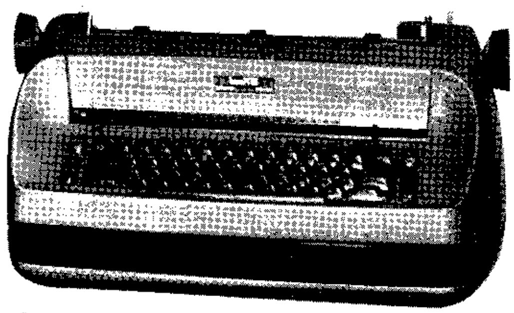

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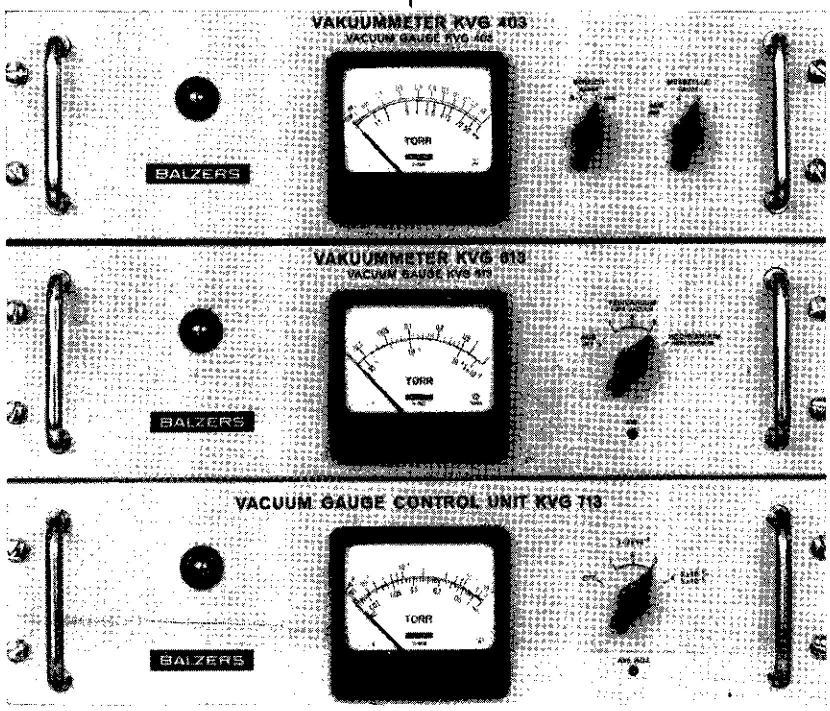

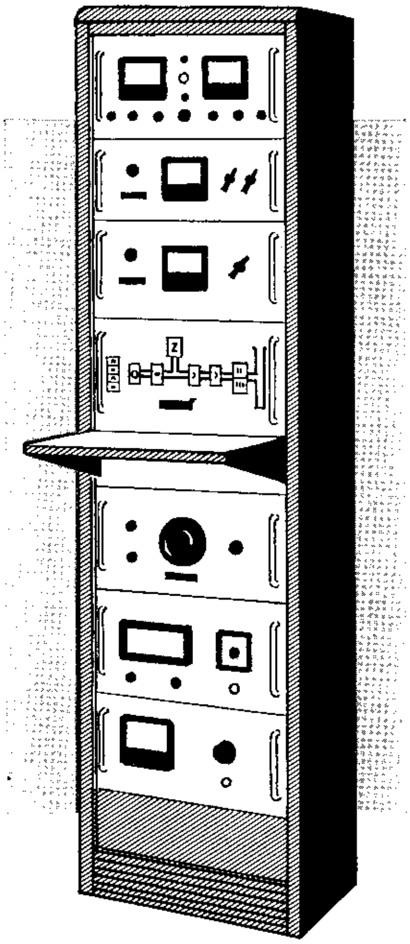

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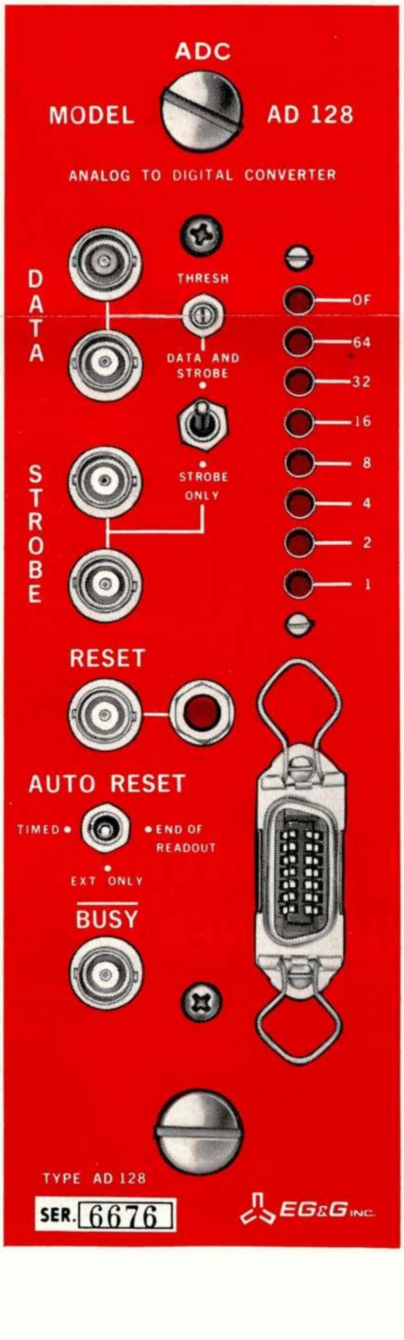

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Seven-bit digital output; 8th bit for digital data or overflow reset signal.

All M100 modules are available in both the EG&G package and in a NIM-compatible package (NBS-AEC TID-20893 rev.).

Contact: EG&G, Incorporated, Salem Laboratory, 36 Congress Street, Salem, Massachusetts 01970 Tel.: (617) 745-3200.

Field offices: Chicago, Illinois, (312) 237-8565; Palo Alto, California, (415) 327-8328.

Representatives in foreign countries.