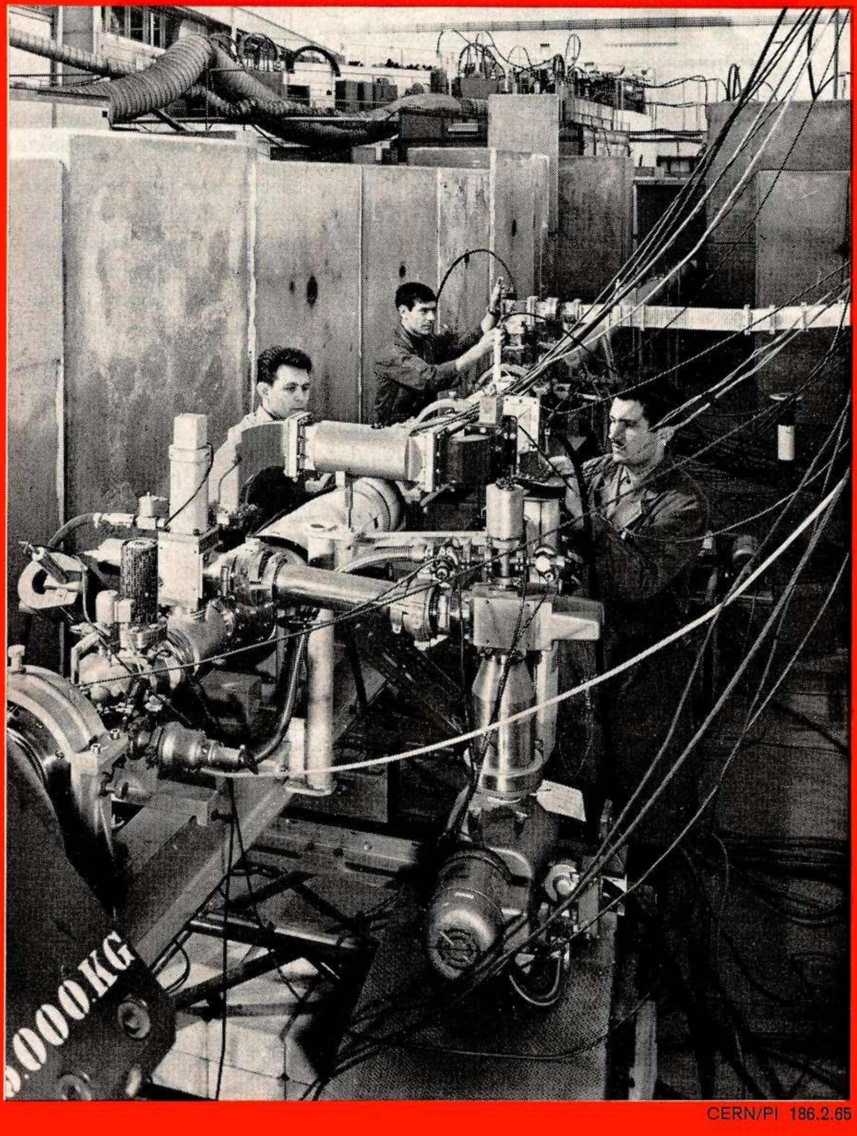
CERN COURIER



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Contents

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The cover photograph shows 'r.f. cavity no. 2' in the o_2 beam line at CERN's proton synchrotron. This equipment forms part of the radiofrequency particle separator that was recently put into operation and enables reasonably 'pure' beams, of particles of a given kind, to be obtained for bubble-chamber experiments at a much higher energy than was possible hitherto. The equipment is rather complex and difficult to describe from a photo such as this (taken from within the few-metres width allowed by the concrete shielding walls). However, at the back, A. Costal (left) and J. Bouad stand at either end of the 'cavity', which consists of three 1-metre sections of circular disc-loaded waveguide inside a lagged cylinder through which water flows to maintain a constant temperature. The radiofrequency power is fed in via a coupler from the horizontal rectangular waveguide at the back and out through a similar coupler at the near end, from where it goes into an absorbing load, next to G. Crochat. In front of the load is the roughing pump for the vacuum system; one of the titanium getter pumps, which maintain the cavity at a pressure of about 10^{-7} torr, is on the other side of the beam pipe on the extreme left of the picture.

CERN COURIER

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The European Organization for Nuclear Research, more commonly known as **CERN** (from the initials of the French title of the original body, 'Le Conseil européen pour la Recherche nucléaire', formed by an Agreement dated 15 February 1952), was created when the Convention establishing the permanent Organization came into force on 29 September 1954.

In this Convention, the aims of the Organization are defined as follows:

> **'The Organization shall provide for collaboration among European States in nuclear research of a pure scientific and fundamental character, and in research essentially related thereto. The Organization shall have no concern with work for military requirements and the results of its experimental and theoretical work shall be published or otherwise made generally available.'**

Conceived as a co-operative enterprise in order to regain for Europe a first-rank position in fundamental nuclear science, CERN is now one of the world's leading laboratories in this field. It acts as a European centre and co-ordinator of research, theoretical and experimental, in the field of **high-energy physics,** often known as **sub-nuclear physics** or the **physics of fundamental particles.**

High-energy physics is that front of science which aims directly at the most fundamental questions of the basic laws governing the structure of matter and the universe. It is not directed towards specific applications — in particular, it plays no part in the development of the practical uses of nuclear energy — though it plays an important role in the education of the new generation of scientists. Only the future can show what use may be made of the knowledge now being gained.

The laboratory occupies an area of 41 hA (100 acres) at Meyrin, Canton of Geneva, Switzerland, next to the frontier with France. A similar area on adjacent French territory is expected to be taken over shortly.

Its main experimental equipment consists of two large particle accelerators:

— a 600-MeV synchro-cyclotron,
— a 28 000-MeV (or 28-GeV) proton synchrotron,

the latter being one of the two most powerful in the world.

The CERN staff totals some 2000 people.

In addition to the scientists on the staff, there are nearly 300 Fellows and Visiting Scientists, who stay at CERN, either individually or as members of visiting teams, for periods ranging from two months to two years. Although these Fellows and Visitors come mainly from universities and research institutes in the CERN Member States, they also include scientists from other countries.

Thirteen Member States contribute to the cost of the Organization, in proportion to their net national income:

Austria (1.95%)
Belgium (3.83%)
Denmark (2.07%)
Federal Republic of Germany (22.74%)
France (18.57%)
Greece (0.60%)
Italy (10.78%)
Netherlands (3.92%)
Norway (1.47%)
Spain (2.18%)
Sweden (4.23%)
Switzerland (3.19%)
United Kingdom (24.47%)

Poland, Turkey and Yugoslavia have the status of Observers.

The budget for 1965 amounts to 128 760 000 Swiss francs (= $29 800 000), calling for contributions from Member States totalling 126 400 000 Swiss francs (= $29 300 000).

A supplementary programme, financed by eleven states, covers design work on two possible future European projects in high-energy physics — intersecting storage rings for the 28-GeV accelerator at Meyrin and a 300-GeV accelerator to be built elsewhere ●

Sifting high-energy particles

CERN's r. f. separator

As announced in a footnote to 'Last month at CERN' in the January issue of CERN COURIER, the first full tests of a high-energy 'separated beam' produced with the aid of a radio-frequency (microwave) separator system were successfully carried out recently at CERN. This article, based on information supplied by B. W. Montague, briefly describes the principles of the new apparatus and gives some details of its development.

At 5.30 a.m. on the morning of 25 January 1965 the first photograph was taken showing the tracks and interactions of 10 GeV/c negative kaons in the 152-cm British bubble chamber at CERN. The kaons came from a target in the 28-GeV proton synchrotron and were separated from a much greater number of other particles in passing along the o_2 beam line equipped with radio-frequency separators. The kaon momentum was nearly twice as high as that obtained when using electrostatic separators in this beam line. In fact, this is by far the greatest momentum yet achieved anywhere for a separated beam of kaons, and European physicists are now in a position to take advantage of facilities that are not yet available elsewhere.

Separated beams

One might well ask at this point: 'What is a separated beam?', or 'What is a particle separator?'. The answer follows from consideration of the fact that when the primary accelerated-proton beam of the synchrotron strikes a target a whole shower of secondary particles is produced — pions, kaons, antiprotons, neutrons, etc. Before these particles can be used to initiate further interactions in particular experiments, they have to be collected into a beam*. When, as is often the case, the interactions of only one kind of particle at a specific momentum are to be investigated, the equipment forming the beam line has, in principle, to separate the wanted particles from all the others. For experiments with abundant particles, such as negative pions, full separation may not even be necessary, but with rare kinds such as kaons considerable ingenuity is required to select the wanted particles whilst eliminating several hundred times as many unwanted ones. In either case, initial momentum selection of charged particles is usually provided by the bending magnets and focusing magnets of the beam line, which provide a beam at a given momentum in the same way that a collection of prisms and lenses can produce a beam of light of one colour from a source of white light. For experiments with rare particles, especially, this is not enough, because the small number of wanted particles can be swamped by a large number of unwanted ones having the same momentum. A selection of particle mass has also to be made. This leads to the concept of the separated beam, the apparatus that provides the mass selection being known as a particle separator. The production of separated beams has become an important branch of high-energy physics technique and the complexity is such that months or even years may be needed between the conception of a new one and the final operation of the beam line to provide it.

Electrostatic separators

The simplest form of particle separator is basically a strong electrostatic field, created by applying a high voltage between two parallel metal plates. As a charged particle travels between the plates it is deflected by an amount that depends on its velocity, so that particles with the same momentum but different velocities are deflected by different amounts. This separates particles with different mass, since heavier particles have a smaller velocity for a given momentum. In practice, very high voltages are required to produce a reasonable separation between particles of high energy; furthermore, as the desired energy is increased so the difference in velocities becomes smaller — because of the relativity effect — and finally it becomes no longer possible to achieve any worthwhile separation. At CERN, for instance, the o_2 beam line, 180-metres long and including some forty separate components, required three electrostatic separators in series to give a reasonably pure beam of kaons of 6 GeV/c momentum, each separator having plates 9 m long and operating with about 500 000 V across a gap of 10 cm.

Radiofrequency separators

To enable particles of higher momenta to be separated, a new technique was needed. As early as 1956, W. K. H. Panofsky, of Stanford University, U.S.A., suggested the use of radiofrequency electromagnetic fields to provide a means of distinguishing particles at high velocities, and similar suggestions were made by V. I. Veksler (U.S.S.R.) in 1958. Prof. Panofsky put forward more specific ideas at CERN in December 1959; these were taken up and developed in a modified form with the final result now seen.

The new separator is basically a sensitive timing device, in the sense that only those particles covering a particular distance at the correct velocity are allowed to go through, whilst the others are intercepted. Before they can be handled by the separator, all the particles must have the same momentum (within, say, ± 1%), and this initial selection is done in the first part of the beam line. Referring now to figure 1, the beam enters from the left and passes down the centre of the first radio-frequency cavity RF1. This cavity, a 3-metre length of iris-loaded waveguide* similar to that used in electron linear accelerators, guides a travelling electromagnetic wave of a particular kind, known as a hybrid E_{11}/H_{11} mode. The incoming particles travel through the cavity at the same speed as the wave and thus experience a steady electromagnetic field, which deflects them in a vertical plane through an angle that depends on the

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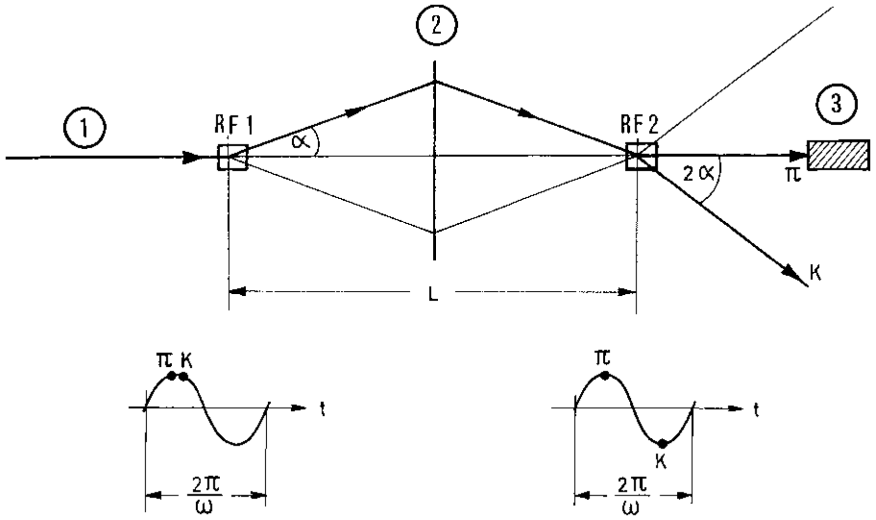
* See **CERN COURIER**, vol. 4, p. 110, August 1964.

* A precision-made tube containing many diaphragms equally spaced along its length.



1. Diagram illustrating the principles of operation of the radio-frequency separator.
RF1, RF2, – first and second deflecting cavities;
(1) – incoming beam of particles, all having the same momentum;
(2) – electromagnetic 'lens' system to focus particles from RF1 into RF2;
(3) – beam stopper to intercept unwanted particles.

time of arrival of the particle with respect to the wave amplitude; in the example shown, a pion (π) and a kaon (K) both arrive at the peak of the wave and receive the full deflection α.

At a distance of 50 metres further along the beam line there is a second cavity, RF2, guiding an identical wave. All the particles from the first cavity are focused into the second one by means of a magnetic lens system (2), but owing to the slight difference in velocity between pions and kaons of the same momentum the pion will arrive first. The system is so adjusted that the pion meets exactly the same part of the wave as before (the peak in our example) whereas the kaon arrives when the wave has reached its peak in the opposite sense. The pion is thus deflected again through an angle α, proceeding along the axis of the system, whilst the kaon is turned through an angle α in the opposite direction, emerging finally at an angle 2α to the axis.

No matter when the particle arrives at the first cavity, if it is a pion it will finally emerge along the axis of the system and if it is a kaon it will be deflected twice as much as if it had passed through only one cavity. The emerging pions therefore form a narrow beam which can be absorbed in a beam stopper (3) whilst the kaons form a fan of angle 4α, from which they can be collected again into a beam by a suitable lens system. Of course some of the kaons are also caught in the beam stopper, but this cannot be helped. At first sight, too, it may seem strange to arrange for the pion beam to follow the axis, since it is the kaons that are desired, but in fact the real problem is to eliminate the maximum number of unwanted particles (which outnumber the others by several hundred times) and these can be guided more surely into the stopper when they are kept near the axis of the system.

Each cavity is fed with up to 20 megawatts of pulsed radiofrequency power, from a klystron of the type used in radar equipment, continuous operation at this power not being feasible at the present time. The pulse length is 8 microseconds and this can be repeated at the rate of 1 pulse per second. The frequency used is 2855 Mc/s, corresponding to a wavelength of 10.5 cm, from which an idea can be gained of the precision of this device: when a pion, taking less than 0.000 000 2 second to cover the separation of 50 metres, reaches the second cavity, a kaon that started at the same time is 5.25 cm behind.

Because of the limitations imposed by the short pulse length of the r.f. system, this type of beam is mainly useful for bubble-chamber experiments*. Here the aim is to get a dozen or so particles of one particular kind into the chamber over a short period of time and this can be achieved by starting with a high-intensity short burst of secondary particles from the synchrotron target. At present this is a rather complicated process since an internal target has to be used; when a fast-ejected beam becomes available in the East experimental hall of the synchrotron, operation of the separator system will become much easier.

Development at CERN

The particular waveguide mode used in the CERN radiofrequency separator is an unusual one with some very curious properties. When the first cavity was tested, in June 1964, and produced a deflection in agreement with the theoretical calculations, the justified elation was therefore tempered with a certain amount of relief. At that time, so far as is known, the only other deflection tests that had been done were at much lower energies – at Stanford U.S.A. with 30-50-MeV electrons and at Orsay, France, with 0.4-MeV electrons. Neither system used exactly the same form of the mode as th CERN equipment, so that the latter had some features still untested up to then.

In October 1964 the second cavity was ready at CERN and the first proof could be obtained of actual separation between two different types of particles. However, the necessary short burst on the target was not available and measurements had to be carried out with 'gated' Cherenkov counters, that is counters giving signals only during the expected time of arrival of particles from the separator. An 'enhancement' of the kaon fraction in the beam by a factor of a few hundred was indicated by the measurements, leaving further work on the stability of the r.f. supply and optimum adjustment of the whole system to be carried out. A further test period using the synchrotron was allotted in December, but although the separator system gave every indication of working well, the targeting method could not be made to function properly in the limited time available.

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* Future developments in long-pulse high-power klystrons or in superconducting deflecting cavities could make possible r.f. separators for use in spark-chamber or counter experiments as well.

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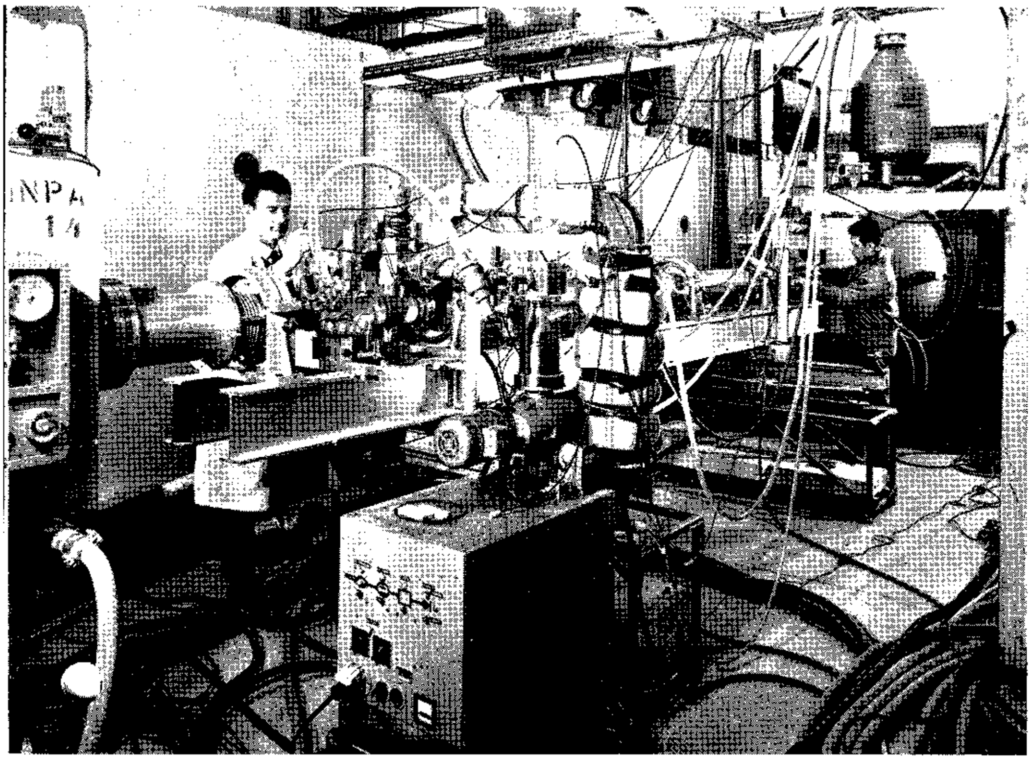

2. Photograph of cavity no. 1 in the o_2 beam line. The arrangement is almost identical to that of the cavity shown in the cover photograph; the circular waveguide – here without its logging – can be seen towards the back, near to where A. Costal is making some adjustments. The short cylindrical section visible in the exit (rectangular) waveguide contains a ceramic vacuum window; the main cavity is kept under high vacuum whilst the feed waveguides contain air at 3 atmospheres pressure, since either high pressure or low pressure is necessary for propagation of the microwaves at high power. At the near end of the cavity, near to where A. Bellanger is working, are the valves, gauges and other components of the vacuum system, and in the foreground is the roughing pump unit, which is completely mobile. The cavity is situated in the beam line between two of the 10-metre electrostatic separators (one of which can just be seen in the background), and is mounted on twin aluminium beams on cross rails so that, if desired, it can be moved sideways out of the line when not in use.

Finally, in January, came the first photographs. In the targeting procedure adopted, three targets were used to intercept part of the beam briefly during the accelerating part of the cycle, giving short bursts of particles for various other experiments; when the rest of the beam had reached full energy the kicker magnet (normally used for fast ejection) was pulsed, causing the protons to 'snake' round the ring and pass once through the target for the o_2 beam after a further $1^{2}/_{3}$ turns; three more targets then interrupted the beam before it could strike the rear of the kicker magnet – all in a few hundredths of a second, repeated every two seconds.

PEOPLE INVOLVED

Scientific staff of the R.F. Separator Group, AR Division:

Mrs. M. Bell (waveguide computations), **P. Bernhard*** (liaison with MPS Division), **P. Bramham** (microwaves and r.f. instrumentation), **R. D. Fortune** (beam instrumentation), **E. Keil** (design of beam optics, beam testing and liaison for targeting and operations), **H. Lengeler*** (responsible for separator when it is handed over to TC Division), **B. W. Montague** (Group leader), **L. Thorndahl** (timing).

Technical staff:

A. Bellanger, P. Cottet*, J. Delfosse, M. Disdier, R. Huguenin (electronics and vacuum); **J. Bouad, G. Crochat, F. Streun** (mechanical); **H. Klun, W. Sax** (mechanical design).

Past members:

H. G. Hereward (Group leader 1961-1962), **P. Lapostolle** (Group leader 1960-1961), **W. Schnell** (designed basic r.f. separator layout in 1960).

Valuable contributions from the following:

W. W. Neale** (with Keil, o_2 beam designing and testing: organization of beam teams for testing), **I. Lehraus*** (operation of Cherenkov counters), **E. Keppel*** (running of o_2 beam), **B. Kuiper, G. Plass and others***** (fast kicker), **W. Richter****** (targeting operations).

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* TC Division; ** Imperial College, London;
*** NPA Division; **** MPS Division.

Cherenkov-counter measurements of the intensity and purity of the beam showed some 12 negative kaons per burst, accompanied by about 6 muons. The intensity was deliberately reduced when particles were actually sent into the bubble chamber, and the photographs obtained show an average of 7 kaons per burst, with only 5 or 10 % contamination from other strongly interacting particles. During the test period the beam line was also set up for positive kaons, with equally satisfactory results.

Not in isolation

Although the CERN radiofrequency separator is the first in the world to give a beam of high-energy particles it has not been developed in isolation. The group in the Accelerator Research (AR) Division that has brought the project to fruition has had the assistance of many people including those in other Divisions at CERN and members of the beam group of the British National Hydrogen Bubble Chamber, the Rutherford High Energy Laboratory (Chilton, U.K.) and the Atomic Energy Research Establishment (Harwell, U.K.). The separator was built mainly in the AR laboratories, though the high-power microwave equipment was supplied by an industrial firm. Many of the component parts were fabricated in the CERN workshops.

A separator of the same type is under construction at Brookhaven (U.S.A.) and related types are being built at Dubna (U.S.S.R.), Stanford (U.S.A.) and Orsay (France) ●

Informal conference

CERN, 20-22 January 1965

On experimental neutrino physics

by **G. PLASS,** Nuclear Physics Apparatus Division

As noted in last month's CERN COURIER, an informal conference was held at CERN from 20-22 January 1965, on the subject of experimental neutrino physics. At this conference, which seems to have been a 'world première' and will probably turn out to be the first of a series, all aspects of neutrino physics were treated together for the first time. The accompanying article, based on the papers presented at that conference, summarizes the different kinds of neutrino experiment and gives information on various proposals for increasing the rates of observed neutrino events. This is followed by a discussion of the use of bubble chambers in neutrino experiments and of proposals for large new bubble chambers. The article ends with a brief summary of the present CERN plans for continuing experiments of this kind.

Neutrino physics is one of those fields of physics where, at present, we are at the limit of our possibilities in trying to extort from nature the answers to our many questions. This is primarily due to the very nature of neutrinos, which interact only 'weakly', with other matter and therefore extremely rarely. Nevertheless, the variety of the experiments that are done is surprising. Neutrino experiments* are carried out at accelerators (as at CERN), at reactors, and deep underground in coal mines or gold mines, where neutrinos of solar or cosmic origin can best be studied.

At the moment, these various approaches have two distinct aims: the accelerator and reactor experiments are designed to study the interaction mechanisms involved whilst those on neutrinos of extra-terrestrial origin are intended for the study of cosmological problems, such as the processes by which energy is produced in the sun and other stars or questions concerning the development of the universe.

Interactions induced by neutrinos were first observed in 1956, in an experiment carried out by Cowan, Reines *et al.* to detect neutrinos radiated by a nuclear reactor. This gave direct proof of the existence of these particles, superseding the previous indirect proof given by the momentum balance in radioactive beta decay (the particles radiated by a reactor arise from beta decay of the fission products and, to be exact, are now classed as antineutrinos), and thereby triggered off the whole field of experimental neutrino physics. Experiments similar to this pioneering one are still being carried on, as shown by two reports to the conference. One of these reports treated the interaction of neutrinos with protons and deuterons, whilst the other was concerned with what we may call a 'curiosity' — a detector of neutrino interactions with a volume of only two litres instead of the cubic metres that are normally used.

Neutrinos of natural origin

Nuclear processes involving neutrinos, of the kind we have recently been able to induce and detect on earth, are supposed to take place on a large scale in certain parts of the universe. Thus, an important field of neutrino physics, now in its initial stages of development, involves the search for neutrinos produced in these processes in the sun or in other celestial bodies. The measurement of the neutrino flux, of its variation with time, of its variation with direction, and so on, is of great interest for certain cosmological theories.

To obtain proper shielding against interactions induced by other cosmic particles, the detection equipment in such experiments is most often installed in abandoned mine galleries. All strongly interacting particles are then completely absorbed by the rocks above, and even muons can only reach such depths if they arrive vertically from the zenith. A muon registered as travelling in a near-horizontal direction must be due to the interaction of a neutrino that has traversed the 'side-shield' formed by the earth itself. The deepest installation of this kind has been set up in the Kolar gold mines, in Southern India.

A similar experiment has also been proposed for setting up in the tunnel soon to be opened through the Mont Blanc massif, between Chamonix and Courmayeur. The equipment here would be located in a gallery pierced at right angles to the main tunnel, and the necessary shielding would be conveniently provided by the mountain range above.

The detectors developed for this kind of neutrino physics are of various kinds, but they all have the same basic characteristics: they must indicate the direction of flight of the particle registered and they must be simple and reliable, suited for 'runs' of many months duration. The Kolar experiment, for example uses large arrays of neon-filled flash tubes; at the University of Utah, an array of several hundred sonic spark counters, manufactured from iron pipes 15 cm in diameter and 10 m long, is being prepared.

Cherenkov detectors, registering the Cherenkov light emitted by fast-moving electrons from neutrino interactions, have also been proposed. It was even suggested that solar and cosmic neutrinos could be studied comparatively easily, just by lowering photomultipliers (perhaps combined with suitable light collectors) into the ocean depths and recording the Cherenkov light emitted by electrons and muons passing through the water. Liquid scintillators are another possibility for underground experiments, since they can be arranged rather easily in tanks to form a direction-sensitive 'telescope'. Radiochemistry can also be used, and a group at Brookhaven proposes to measure the flux of solar neutrinos by means of the reaction $\mathrm{Cl} + \nu_e \rightarrow \mathrm{A} + e^-$. Their 'detector' will be a tank containing some 400 000

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* The term 'neutrino', in the context of this article, usually covers electron and muon neutrinos and electron and muon antineutrinos indiscriminately.

litres (100 000 gallons) of perchlorethylene, a dry-cleaning fluid. After several months a few of the chlorine atoms in the liquid are expected to be changed, as a result of neutrino interactions, into argon atoms and these could be extracted from the liquid and identified by their radioactivity.

Alternative search for lepton conservation law

It is interesting to note that at Brookhaven neutrino physics is being pursued by three different methods at the same time. Apart from this search for solar neutrinos with perchlorethylene and the continuation of the experiment at the AGS accelerator, confirmation of an important result of the high-energy neutrino experiments, namely the existence of a lepton conservation rule, is being sought for in a completely different way. In an experiment where extreme purity of materials and supreme patience are the essential ingredients (it takes two years to produce the necessary sample of the calcium isotope ^{48}Ca to begin the experiment) the possibility of so-called double beta decay is being examined. If this process, in which two electrons would be emitted from the nucleus without the emission of any corresponding neutrino, could be shown not to occur, the non-identity of neutrino and antineutrino would again be proved.

Neutrino experiments at accelerators

One may turn now to the field of neutrino physics at accelerators, where certainly most advances have been made in the past few years. The neutrinos here are produced in the decay of fast pions and kaons and have energies of around 1 GeV, that is between 100 and 1000 times greater than the energy of reactor-produced neutrinos. The interaction cross-section is perhaps 100 000 times higher and the event rates are of the order of 10 per day, per ton of detector, at present, probably reaching 100 per day in the not too distant future — much different to the few events per year that is all than can be anticipated in some of the experiments mentioned above. With these high rates and energies, the results of an interaction can actually be seen in spark chambers and bubble chambers and the processes can be analysed in detail; one does not have to be content just with the information that something has happened.

One of the main accents of the CERN neutrino experiments, in 1963 and 1964, particularly in the spark-chamber observations, was the question of the quantum of the field mediating the weak interactions, a boson usually known as the W. Though of very short life itself, it should produce decay products that would have been identified in both detectors — spark chambers and bubble chamber — of the CERN experiment, if the particle existed and had a mass small enough for it to be created by neutrinos of the energy available. An early paper in the conference was, in fact, concerned with the detailed proof that the mass of this particle must be greater than 1.9 GeV/c^2[*], that is, more than twice that of the proton. Unfortunately this leaves the question of the existence of such a particle completely open, since the theoretical upper limit of its mass is very much bigger.

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Physics underground. Photograph exhibited by Dr. Reines at the conference, showing part of a detection system for cosmic neutrinos installed at a depth of over 3000 metres in a mine in South Africa. The aim is to detect muons arising from neutrino interactions in the earth on either side. Tanks of liquid scintillator are arranged in two rows about 40 metres long and 2 metres high, each row having an upper, middle and lower section, so that some information can be obtained on the angle to the horizontal made by the muon path.

Various other refinements to the results from the CERN heavy-liquid bubble chamber were treated in a paper presented by the group concerned. For example, some of the so-called 'elastic' events had been reclassified, leading to a readjustment of the 'form factor' derived from their analysis. Concerning the fundamental question of the non-identity of the electron neutrino and the muon neutrino, the CERN results had of course amply confirmed the distinction, first established at Brookhaven in 1962[**].

The progress of the related accelerator experiments at Brookhaven and Argonne was treated in several contributions. In both laboratories, much emphasis has been placed on the measurement of the neutrino energy spectrum, whereas at CERN, until recently, computed spectra served as the whole basis for the analysis (though in the end these were confirmed by experiment, within the limits of error). The essential result from the latest runs at Brookhaven was another determination of the lowest possible mass for the W boson, agreeing very well with the CERN results. At Argonne, the actual neutrino run had not yet started.

Facilities for accelerator experiments

An important part of the conference was reserved for a discussion of neutrino beams at accelerators and of neutrino detectors, for both existing and planned experiments, and to the question of the determination

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[*] Slightly higher than the value deduced on the basis of the former incomplete analysis of the results.

[**] The reader may well ask what it means to establish sub-groups of a 'particle' that has none of the familiar qualities such as mass and electric charge and appears to be nothing but a package of directed energy. The neutrino was postulated because the mechanics of observed beta-decay processes could only be explained on the basis of a reaction involving three particles instead of the two that were seen. One 'neutrino' was then sufficient for all cases, but when the existence of antiparticles was confirmed for all other particles the question naturally arose whether there was an antineutrino distinguishable from a neutrino. On the basis of a conservation law for certain particles, a distinction between neutrino and antineutrino could be inferred and it was found that in fact certain reactions could only be caused by one, certain reactions only by the other, thus providing a good case for the distinction. In a similar way, since the electron and the muon appear to be identical apart from their mass, the question whether neutrinos (or antineutrinos) emitted with electrons (positive or negative) were the same as those emitted with muons was of obvious interest. We are thus faced with four entities, all of which have no electric charge and probably no rest mass but which are distinguishable by the interactions they induce. Unlike the photon (which also has no mass or charge), neutrinos cannot be identified as quanta of one of the familiar force fields. Because they obey Fermi-Dirac statistics, rather than Bose-Einstein statistics, they must be classed as 'particles' although their description can only be by sets of quantum-mechanical quantities.

of the neutrino spectrum. Methods included measurement of the muon flux in the shield, measurement of the flux of particles giving rise to the neutrinos — in auxiliary experiments using counter methods or a target immersed in a bubble chamber — and a proposal to measure this 'parent' flux directly, in the decay tunnel between target and shielding. The neutrino spectrum could also be determined from the energy measured in certain types of event; this could be the most reliable method, if the mechanism of weak interactions were already completely understood and if there were a greater number of events of the necessary kind.

Neutrino intensities in the accelerator experiments have already reached values a hundred or more times higher than expected when experiments without extracted beams were considered. However, the obtaining of a further increase in event rate is still one of the dominant problems in approaching a quantitative evaluation of the weak-interaction phenomena, and higher accelerator intensities would be of great value in this respect.

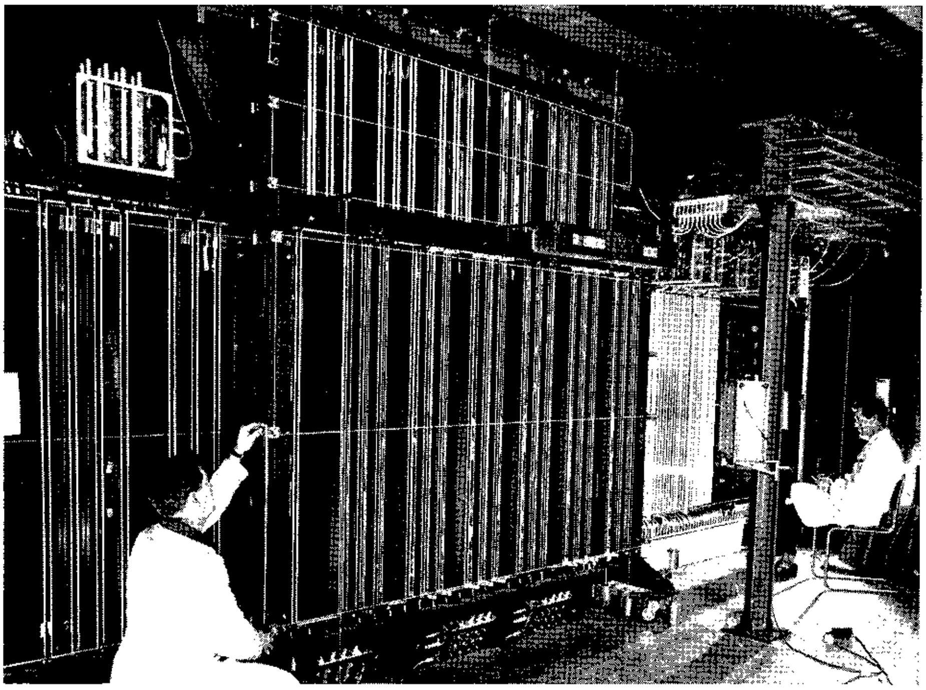
At Argonne, work is still directed mainly towards reaching the design goal of 10^{13} protons per pulse, but the possibility of replacing the present 15-MeV linac injector by one giving 200 MeV has already been considered as a further improvement. Both at Brookhaven and at CERN, substantial improvements are being planned in respect of the repetition rate, so that acceleration to top energy would become possible once every second (instead of once every 2.4 seconds or 3 seconds, respectively, as at present). Space-charge forces would still limit the intensity during each acceleration cycle to a value around 2×10^{12} protons per pulse, in both cases, and plans are therefore under consideration to install completely new linacs. At Brookhaven, this would provide injection into the synchrotron at 500 MeV, at CERN 200 MeV, instead of the present 50 MeV. Intensities of 10^{13} protons per pulse, or more, should then be possible, although serious problems of radiation damage and difficulties of servicing would in turn arise. These improvements would take several years of materialize, in any case, and the necessary funds are not yet authorized.

Particularly at the present accelerated-proton intensities, efficient use of the available beam, by means of focusing devices for the neutrino parents and optimum design of shielding, are of primary importance. Talks were given on the 'plasma lens' developed at Brookhaven and on the 'magnetic horn' designed and used at CERN. The CERN device, which has also been developed at Argonne for use under somewhat different conditions, appears to give a rather higher gain than the plasma lens, though a fault that destroyed the power cables on the latter soon after it was put into operation prevented a detailed comparison.

As one of the highlights of the conference there came a proposal by R. Palmer, from Brookhaven, for a new type of focusing apparatus, the 'magnetic finger' or 'inverted horn'. An improvement of the flux to close on the theoretical limit is claimed for this device, which would mean an increase over present levels by a factor of two in most of the energy band and even more for the particles of highest energy. Detailed computations have been started at CERN in order to evaluate as soon as possible whether there would be any real advantage in replacing the existing installation with equipment of the new design.

New detectors for accelerator experiments

There is in principle another, very simple (though costly) way of increasing the event rate — just by increasing the mass of the detector. A first step in this direction is now being accomplished at CERN by increasing the visible volume of the CERN heavy-liquid bubble chamber to almost 1100 litres, the total volume being rather more than doubled. However, much useful information will still be lost, even with this increased volume, because of particles that pass out of the chamber without leaving a sufficient length of track to give full data for their identification. A much larger chamber of this type, with a diameter of 1.9 metres, is therefore being designed by a French



A view of part of the spark-chamber installation for the second phase of the CERN neutrino experiment, now completed, taken during setting up of the equipment early in 1964. In the centre of the picture, the vertical spark-chamber modules can be identified by the white lines along the edges of the mirrors that enabled one camera to 'see' along all the gaps. Between the chambers are the magnetized iron plates that caused positive and negative particles to be deviated in opposite directions. On the right, the close-packed spark-chambers of the production region can be seen.

collaboration, with the hope that it can be built in the next few years for use at CERN. Since this chamber would contain 12 000 litres of liquid, with a visible volume of 8000-10 000 litres, the rate of analysable events would be increased at the same time; the actual improvement factor would depend on the properties of the beam and lie between the ratio of the chamber diameters and that of the chamber volumes.

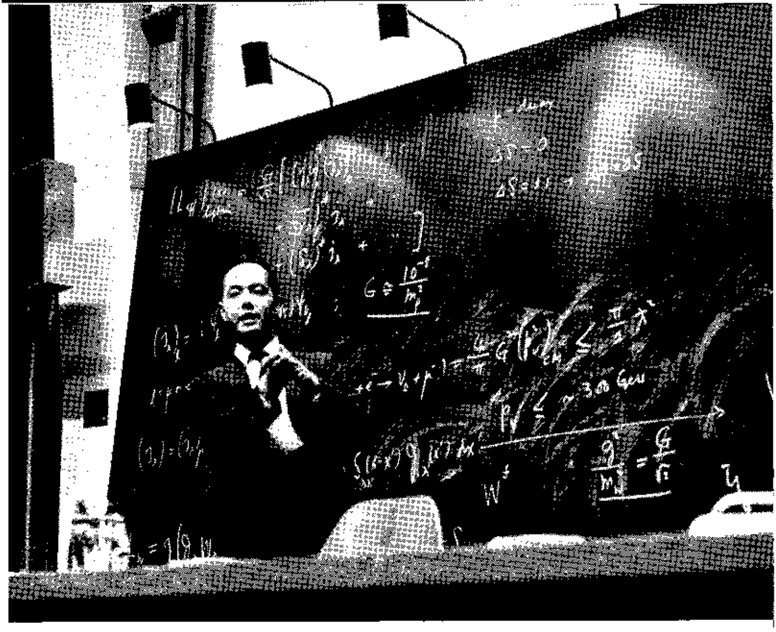
Even so, there is still another important aspect of the picture. Certain data concerning the interactions can be extracted only with considerable error from events that occur in 'heavy liquid' or in the metal plates of spark chambers, because the primary interactions are obscured by secondary effects inside the large atomic nuclei. The metal plates of the spark chambers, generally aluminium or brass, or the freon liquid in the bubble chamber, as used so far, form the most suitable detectors in many respects, but have this disadvantage of being composed solely of large nuclei. There is hence considerable interest in studying at least some interactions with hydrogen nuclei, which of course consist of just single nucleons. One way of doing this is to fill the heavy-liquid chamber with propane. The density, and hence the event rate, would be only about one third of that for freon, but there would in fact be more hydrogen in the chamber than in a similar volume of pure liquid hydrogen. The carbon atoms in the propane would, unfortunately, still disturb certain experiments, but on the other hand they would permit the carrying out of others (polarization experiments, for example) that would be difficult to perform otherwise. For the study of processes occurring in almost free neutrons, propane containing deuterium instead of ordinary hydrogen could be used, though this would be expensive to manufacture.

An approach from the opposite angle has been made at Brookhaven, where early tests have shown that a hydrogen bubble chamber can be operated successfully with a high proportion of neon mixed with the hydrogen. This would enable the overall density of the liquid to be increased somewhat whilst still retaining a useful number of hydrogen nuclei in the target volume.

For completely unambiguous results on the interaction between neutrinos and protons, it remains true to say that liquid hydrogen by itself (or liquid deuterium if one wants to look specifically at neutrino reactions on neutrons) remains the ideal substance. Experiments in the 2-m hydrogen bubble chambers at both Brookhaven and CERN have therefore been considered, but the low density will give an event rate that will be below that needed for the study of many rare kinds of interactions. Partly because of this, but also for more general reasons, huge hydrogen chambers, with volumes between 25 000 and 40 000 litres, have been proposed at Argonne, Brookhaven and CERN.

Theoretical ideas

One session of the conference was devoted to theoretical contributions. In an invited review paper, also, the problems in weak-interaction physics that underlie the accelerator experiments were formulated. In particular, a summary was given of some recent suggestions that certain basic hypotheses in weak-interaction theory (conserved vector currents and partially conserved axial-vector currents) could be tested in polarization experiments with neutrinos. Unfortunately, there was no similar, concise review of the motivation for the experiments on extraterrestrial neutrinos.



CERN/PI 298.1.65

Although the conference dealt primarily with the experimental aspects of neutrino physics, theory could not be forgotten. The final talk, in fact, was given by Nobel Prize winner Prof. T. D. Lee, seen here as he resumed the basic problems in the theory of neutrino interactions.

Looking ahead

The field of experimental neutrino physics at accelerators for the next decade was thus sketched in. With higher accelerator intensities, improved neutrino facilities and enlarged detectors, one may expect neutrino physics after 1970 to be done with overall event rates that are customary now in strong-interaction experiments. One paper, a contribution from the Berkeley study group for a 200-GeV synchrotron, looked even further; for neutrino experiments at this accelerator a magnetic-lens channel about 1 km long is projected, going so far as to provide the possibility of selecting neutrinos in a certain momentum band at the end of it. Before this time the Russian 70-GeV accelerator at Serpukhov will go into operation — in 1968 according to present plans. A brief status report was given on this machine, but detailed studies on the experimental arrangements do not appear to have been carried out yet.

'Think big', in the words of Prof. Goldhaber, Director of Brookhaven National Laboratory and one of the two closing speakers, appeared to be the motto of the conference. But it is not only the future projects that seem so huge; our present-day installations would have appeared like science fiction only 25 years ago. To end, then, we might look at the more immediate plans for the CERN neutrino facility. A run with the enlarged heavy-liquid chamber filled with freon, in an antineutrino beam, is scheduled for the spring of this year. The chamber will then be used for an experiment on another problem, but plans are being made to prepare it after this for a propane filling. The possibilities of obtaining deuterated propane are also being investigated, with a view to the later use of this material, as already described. At the same time, the possibility of using spark chambers in polarization experiments, of the type mentioned in the report on the theoretical contributions, is also being looked into at CERN ●

Last month at CERN

British bubble chamber reaches its first million pictures

At 2 p.m. on the afternoon of Saturday 13 February the 152-cm British national hydrogen bubble chamber registered its millionth photograph. This was during a run in which protons with momentum of 10 GeV/c were being directed into the chamber.

During February, also, statistics were published on all the bubble-chamber photographs taken at CERN during 1964. These, reproduced below, show that over $2^{1}/_{2}$ million pictures were obtained altogether, including nearly half a million for the CERN neutrino experiment. More than a million pictures were solely for groups outside CERN, and no less than 34 universities and research institutes, mostly in the CERN Member States, participated in the bubble-chamber experiments.

PS operation

As mentioned in last month's *CERN COURIER*, the second two weeks of operation in January were used mainly by bubble chambers. During this time the 81-cm Saclay/Ecole Polytechnique chamber, filled with liquid deuterium, took 220 000 photographs showing negative kaon interactions in the momentum range 800-1200 MeV/c. After being devoted to the radio-frequency separator tests during the first part of the run, the 152-cm British chamber was used to obtain some 65 000 pictures showing interactions in hydrogen of positive pions of momentum 11 GeV/c.

At the same time, the o_2 monitor beam (coming from the same target as the o_2 beam that passes through the 152-cm chamber) was converted to an electron beam of known energy and used to calibrate lead-glass Cherenkov counters and special scintillation counters (lead-Plexiglas sandwich counters) with electrons of energy between 400 MeV and 1 GeV. This formed part of the preparations for a new experiment at CERN on the anomalous magnetic moment of the muon. Similar calibrations, together with some on an experimental wide-gap spark chamber, in the same beam, were continued during the first part of February.

During February, the usual scheduling was used for the proton-synchrotron operation, with the first fortnight devoted primarily to counter experiments and the second to bubble-chamber runs. It is hoped to give further information concerning this period of operation in the next issue of *CERN COURIER.*

What can be reported, however, is that in the last week of February, the first experiment to be carried out anywhere with a beam of separated kaons of momentum as high as 10 GeV/c was begun with the 152-cm bubble chamber. The kaons, of negative charge, were obtained by means of the new radiofrequency separator in the o_2 beam (as described in the article beginning on p. 35 of this issue). Although this separator had only recently completed its tests, its operation proved so successful that it could be controlled by the beam group in the normal way, from the annexe to the bubble-chamber building rather than from the r.f. stations themselves in the East hall. Some 77 000 pictures were obtained in this first run, with an average of nine tracks per photograph, about half of them of kaons and half of muons. The number of tracks of negative pions (the only particles that could cause serious confusion) was very small. It is planned to devote a further two weeks running time to this experiment, the photographs for which are being divided between groups in Aachen, Berlin, CERN and Vienna.

SUMMARY OF BUBBLE-CHAMBER RUNS IN 1964

Beam		Chamber	No. of pictures	Laboratories sharing films	Date
K^-,	6 GeV/c	Saclay HBC 81	70 000	Birmingham, Cambridge, Glasgow, Imperial College, Munich, Oxford, NIRNS	February
π^+,	8 GeV/c	Saclay HBC 81	141 000	Aachen, Berlin, CERN, Krakow, Warsaw	February-March
p,	10 GeV/c	Saclay HBC 81	84 000	Cambridge, Hamburg, Stockholm, Vienna	February-March
K^+,	5 GeV/c	Saclay HBC 81	90 000	Brussels, Cambridge, CERN	February-March
π^-,	20 GeV/c	Saclay HBC 81	14 000	CERN/TC	March
ν,		CERN HLC 100	400 000	CERN/NPA	April-July
$\bar{p}$,	1.2 GeV/c	Saclay HBC 81	300 000	CERN, Collège de France, Institut du Radium, Liverpool	June-July
K^-,	0.8-1.2 GeV/c	Saclay HBC 81	250 000	CERN, Heidelberg, Saclay	June-July
K^-,	5 GeV/c	BNHBC 152	140 000	Birmingham, Cambridge, Glasgow, Imperial College, Munich, Oxford	June-July
K^-,	6 GeV/c	BNHBC 152	398 000	Birmingham, Cambridge, Glasgow, Imperial College, Munich, Oxford	June-July + September-October
K^+,	5 GeV/c	BNHBC 152	60 000	Brussels, Cambridge, CERN	June-July
π^+,	5 GeV/c	BNHBC 152	65 000	Bonn, Durham, Ecole Polytechnique, Nijmegen, Turin	October + December
p,	19 GeV/c	Ec. Poly. 1-m HLC	90 000	CERN/NPA	October
π^-,	16 GeV/c	Ec. Poly. 1-m HLC	100 000	Ecole Polytechnique	October
K^+,	at rest	Saclay DBC 81	120 000	Bari, Berne, Genoa, Turin	October
$\bar{p}$,	at rest	Saclay DBC 81	70 000	Padua, Pisa	October
$\bar{p}$,	in flight	Saclay DBC 81	80 000	Rome, Trieste	October
K^-,	0.8-1.2 GeV/c	Saclay HBC 81	80 000	Argonne, CERN, Heidelberg, Saclay	December
p,	10 GeV/c	BNHBC 152	50 000	Cambridge, Hamburg, Stockholm	December
		Total:	2 602 000		

Of these:
1 177 000 pictures were for groups outside CERN only
921 000 pictures were for groups outside CERN and for CERN
14 000 pictures were for CERN/TC (Track Chambers Division)
490 000 pictures were for CERN/NPA (Nuclear Physics Apparatus Division)

Another new resonance

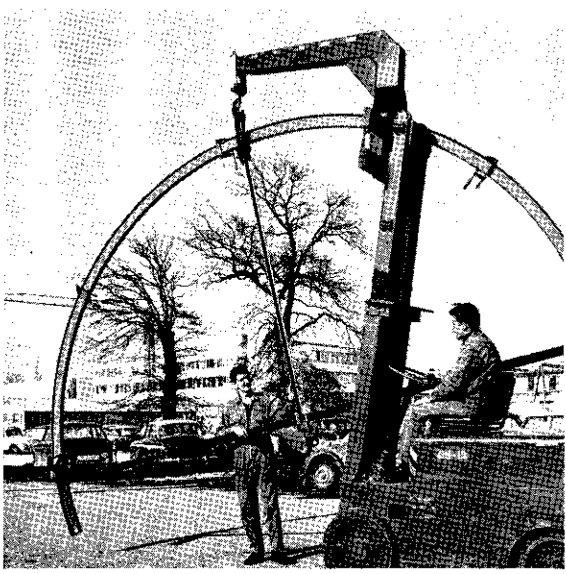
A paper published in *Physics Letters* on 15 February (vol. 14, p. 338) under the names of 30 physicists from the Universities of Birmingham, Glasgow, London (Imperial College) and Oxford, together with the Rutherford High Energy Laboratory, gives the results of an analysis of 300 000 photographs taken with the Saclay/Ecole Polytechnique 81-cm liquid hydrogen bubble chamber at CERN in 1963.

The photographs showed interactions in the hydrogen caused by negative kaons of momentum 3.5 GeV/c and, in the results reported, those interactions giving a neutral antikaon, a negative pion and a proton (reaction: $K^- + p \rightarrow \bar{K}^0 + \pi^- + p$) had been selected — a total of 339 events.

From measurements made on the selected photographs, the physicists concluded that the most common way in which the reaction took place was through the 'peripheral' production of a well-known kaon resonance (K^*) with a mass of 890 MeV, this resonance then decaying almost immediately into the $\bar{K}^0$ and the π^-. Other common resonances were not in evidence, but a hitherto unobserved state with a mass of 1400 MeV (± 10 MeV) was found to be present. This also decayed into a neutral antikaon and a negative pion. The new resonance has an observed 'width' of about 160 MeV, corresponding to a lifetime of about 10^{-20} second. A detailed analysis of the events leads to the result that the spin and parity are more likely to be 2^+ (that is, a spin quantum number of 2 with positive parity) than 1^-, with 0^+ ruled out. Although the resonance was not observed by other groups in a similar experiment (also at CERN) using incident kaons of 3 GeV/c momentum, this is thought to be due to the slightly lower energy available in that case.

Italian Diplomat visits CERN

On Wednesday 3 February, CERN was visited by H. E. J. Giusti del Giardino, Head of the Permanent Delegation of Italy in Geneva, together with two other members of the Delegation. The visitors, who were accompanied on their tour by one of the senior Italian physicists at CERN, were shown both the Organization's accelerators, together with experiments in progress in the East and South halls of the proton synchrotron. The 2-metre bubble chamber was also visited, and some time was spent discussing the future projects under study in the Accelerator Research Division. The tour ended with a view of the CERN facilities for measuring and analysing bubble-chamber photographs, including the large new computer now being brought into operation ●



CERN/PI 48.2.65

With a storage ring for electrons in operation, and those for protons under active discussion, CERN is also constructing a storage ring for muons.

Essentially, this will consist of a large circular magnet, about 5 metres in diameter, in which high-energy muons produced in a vacuum tube inside the magnet will make many revolutions during their lifetime. Appropriate measurements on the decay electrons will enable the anomalous magnetic moment (g-2) of the muon to be evaluated to a much higher order of accuracy than before.

In this photograph, one of the excitation coils for the new storage-ring magnet is seen leaving CERN's main workshop on its way to the South experimental hall of the proton synchrotron, where the magnet will be assembled. Driving the transporter is Maurice Cartier and Maurice Chatel steadies the coil. In the background is the new laboratory 13 of Track Chambers Division.

BOOKS

Tracking down particles, by R. D. Hill and E. Gerjuoy (New York, W. A. Benjamin Inc., 1963; cloth $5.45, paper $3.25).

The Benjamin series to which this book belongs is intended principally for elementary students of science and provides introductions to each of a number of important fields. Non-scientists may also use these books in order to gain familiarity with the various subjects treated, though it is clear that the series is not specifically aimed at them.

This book is about high-energy physics and its authors have attempted to make it easier to read by dividing it into two parts. Thus there is first a systematic account of the most important discoveries, techniques and developments in this field, written by R. D. Hill, and this is followed by an analysis of the theoretical background, including an explanation of the basic relevant differences between classical and modern physics, by E. Gerjuoy, who is also the general editor of the series.

It is, of course, possible to justify a treatment of this kind, though it has the serious disadvantage, for the reader with little time to spare, of requiring at least two readings before the book is fully understood. Since this is an introduction to the subject, rather than a detailed textbook, it would surely have been much simpler to raise the various theoretical issues while developing the main theme: particles and the means by which they are discovered.

Apart from this drawback, this is a lively and interesting summary of the present state of knowledge in high-energy physics. It is also a useful contribution to wider understanding of a field that, regrettably, remains inaccessible to all but a few initiates.

There are many diagrams and photographs, and the book is provided with an adequate index, a glossary and a world list of accelerators.

M.J.O.S.

Nuclear reactor theory, by Giovanni Lanza (London, McGraw-Hill Ltd., 1964; 39s.).

This book is the fifth in the series *Nuclear engineering fundamentals*, of which the other four deal with 'Atomic physics', 'Nuclear physics', 'Interaction of radiation with matter' and 'Nuclear materials'. Each book forms a separate entity, though there is some cross-referencing between them.

As stated in the preface to the current volume, the series is aimed at people who, while not themselves physicists or engineers, have an interest in nuclear physics and engineering. As a consequence the present volume contains little that is new for a qualified physicist.

Mathematical passages that are assumed difficult for the type of reader in mind are clearly marked and it is easy to follow the text leaving out these sections. A wide field is covered in relatively few pages and the coverage given to each topic is naturally limited, so that it is unfortunate that at least a general list of references was not given. The first three chapters do contain a few 'examples' at the end, but references to other publications would probably have been of more value.

Two interesting chapters in the book have been contributed by different authors. One of these, 'Sanitary engineering aspects of radioactivity', by Kenneth R. Read, deals with the problem of radioactive waste, its absorption in special materials, and its disposal. The second, by George P. Sutton, entitled 'Nuclear reactors in aviation', devotes about twenty pages to the ideas and the problems concerning the use of nuclear reactors in aviation and in space research.

As a guide to the prospective reader, the following list of the remaining chapter headings may be useful, although the detail covered in any particular topic is, as mentioned above, rather limited.

— Basic concepts of reactor theory;
— Neutron physics;
— Nuclear reactor theory I: collision theory;
— Nuclear reactor theory II: slowing-down theory;
— Nuclear reactor theory III: diffusion theory;
— Reactor design;
— Reactor control;
— Reactor safety and shielding;
— Purification of foods by atomic radiation.

Many books have been written at this level on various aspects of nuclear physics and nuclear engineering. This particular one is characterized by the fact that it does try to explain some of the theoretical concepts involved in reactor technology.

J. R. Sherwood

Also received:

Nuclear orientation, edited by M. E. Rose (New York, Gordon and Breach Science Publishers Inc., 1963 ; $ 4.95) — a volume in the publisher's *International Science Review Series*, providing a collection of reprints of representative papers dealing with the theory, observation and detection, and applications of nuclear orientation.

Point defects in metals, by A.C. Damask and G.J. Dienes (New York, Gordon and Breach Science Publishers Inc.,

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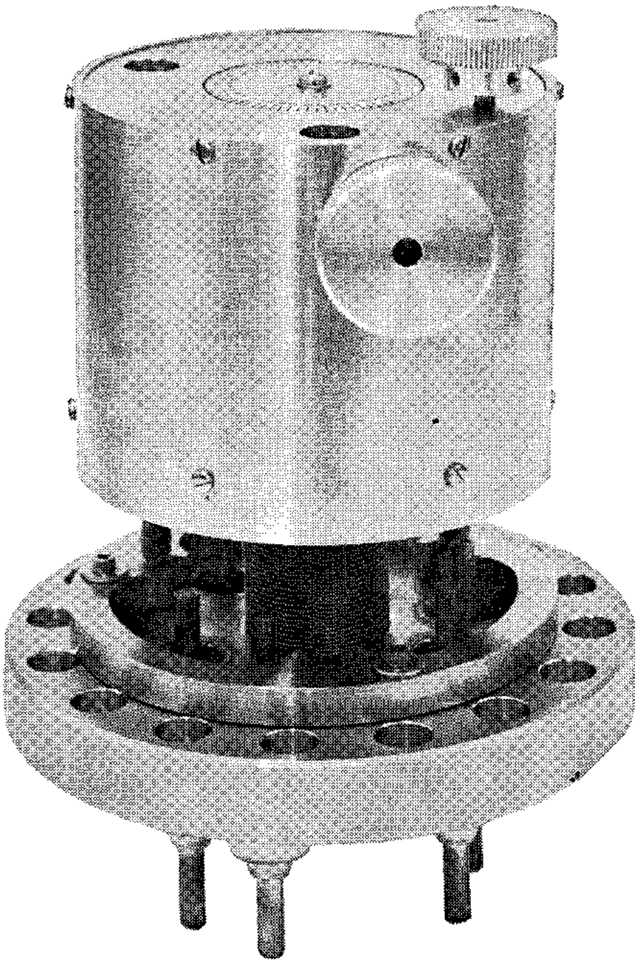
1963; $19.50, 'Professional edition' $9.50) — presents the theoretical and experimental methods employed in investigating these crystalline irregularities of atomic dimensions which play a central role in the interpretation of many physical properties and processes in solids.

Atlas and tables for emission spectrographic analysis of rare-earth elements, by Ch. Kerekes (Oxford, Pergamon Press Ltd., 1964; £5) — tabulates analysis lines in order of decreasing wavelength, with interfering lines of other rare earths, scandium and yttrium; atlas shows positions of lines with respect to iron spectrum.

Göttinger Atomrechtskatalog : Atomic-energy law — part L, Laws and regulations, treaties, vol. 8, Denmark-Gabon (Göttingen, Institut für Völkerrecht der Universität Göttingen, 1964) — latest in series intended to show all provision of atomic-energy law emanating from International Organizations and States and international agreements dealing with non-military uses of nuclear energy; titles in original language, or language considered to be most frequently used, and in German, English, French.

Nuclear structural engineering, editor T. Jaeger (Amsterdam North Holland Publishing Company, Vol. 1, No. 1, January 1965; $25.00 per volume) — new journal, to be published every two months, devoted to civil, mechanical and chemical structural engineering problems of nuclear power plants, radiation facilities, radioactive waste; although primarily concerned with nuclear engineering, some of the contents could be of interest to accelerator builders and users ●



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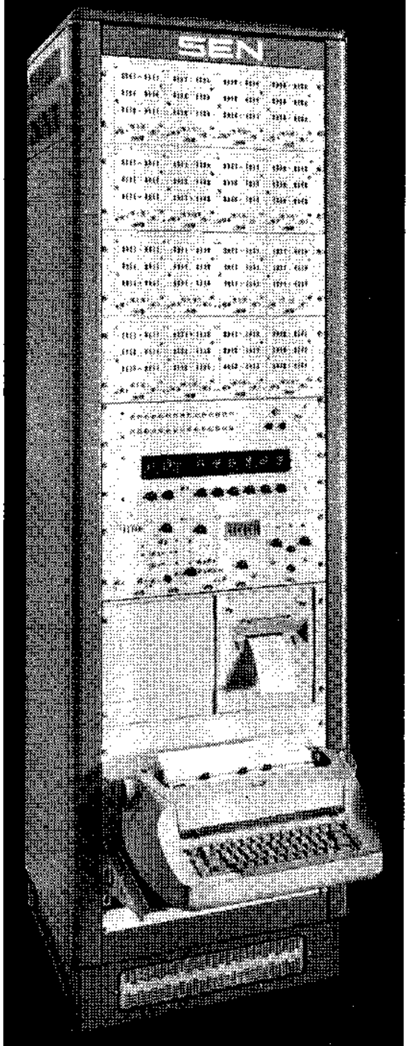

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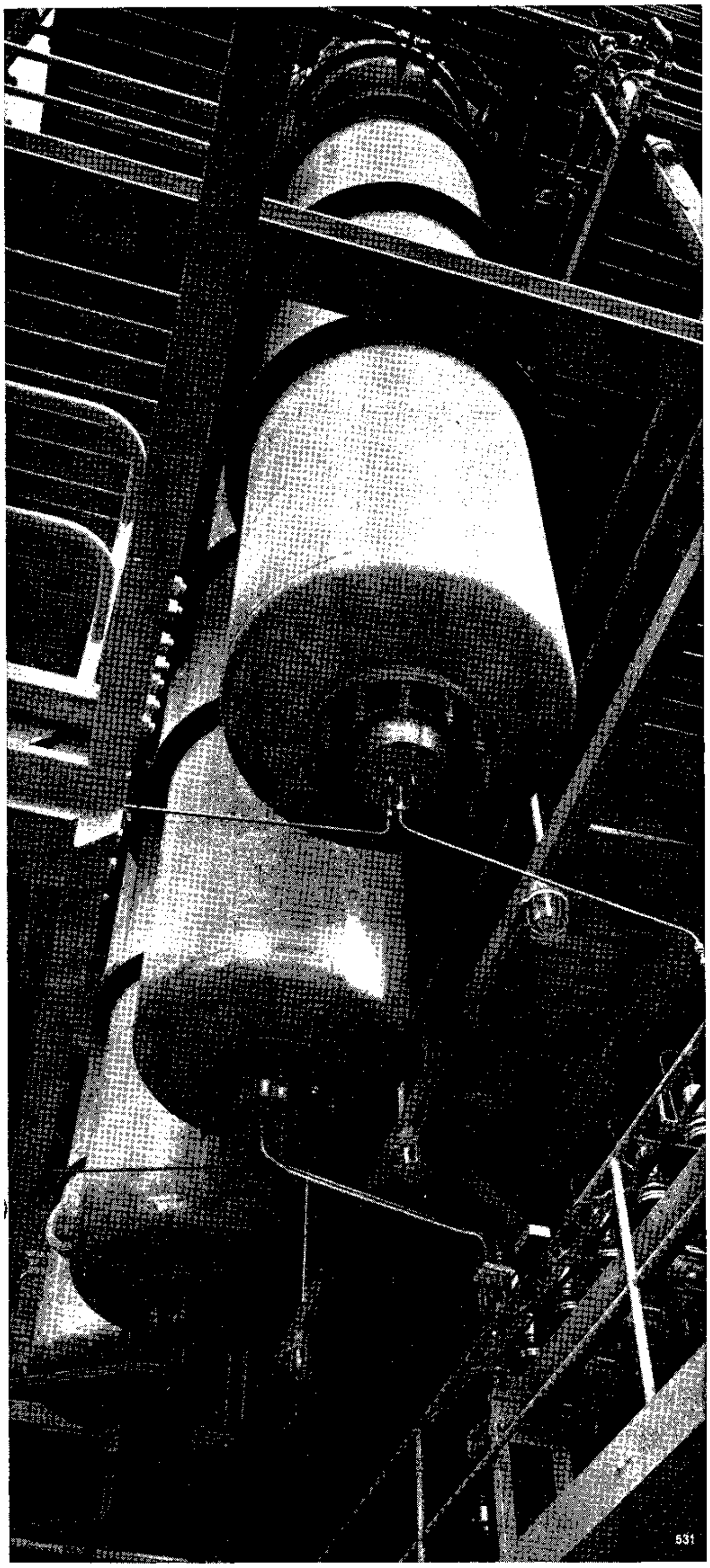
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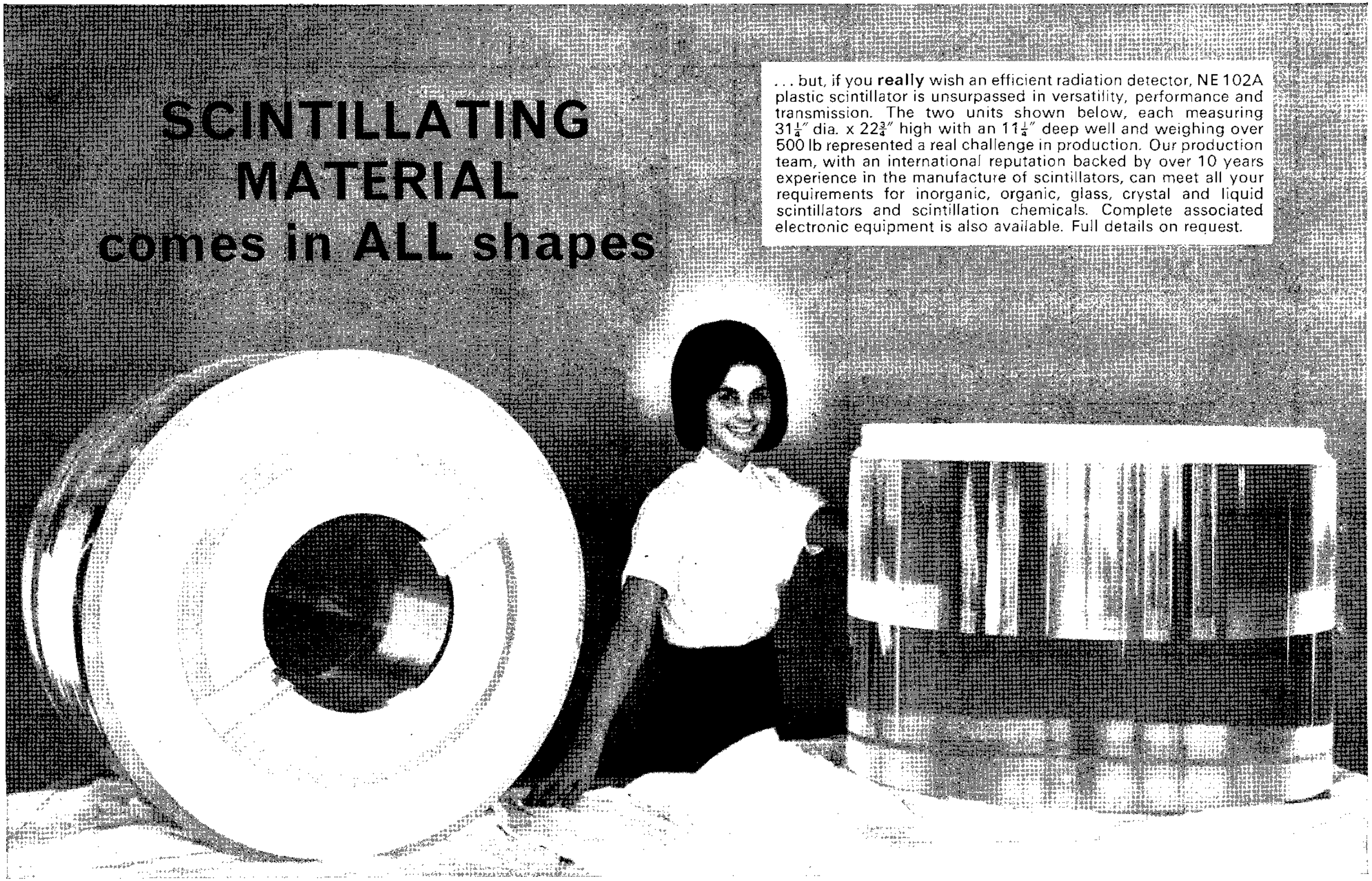

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