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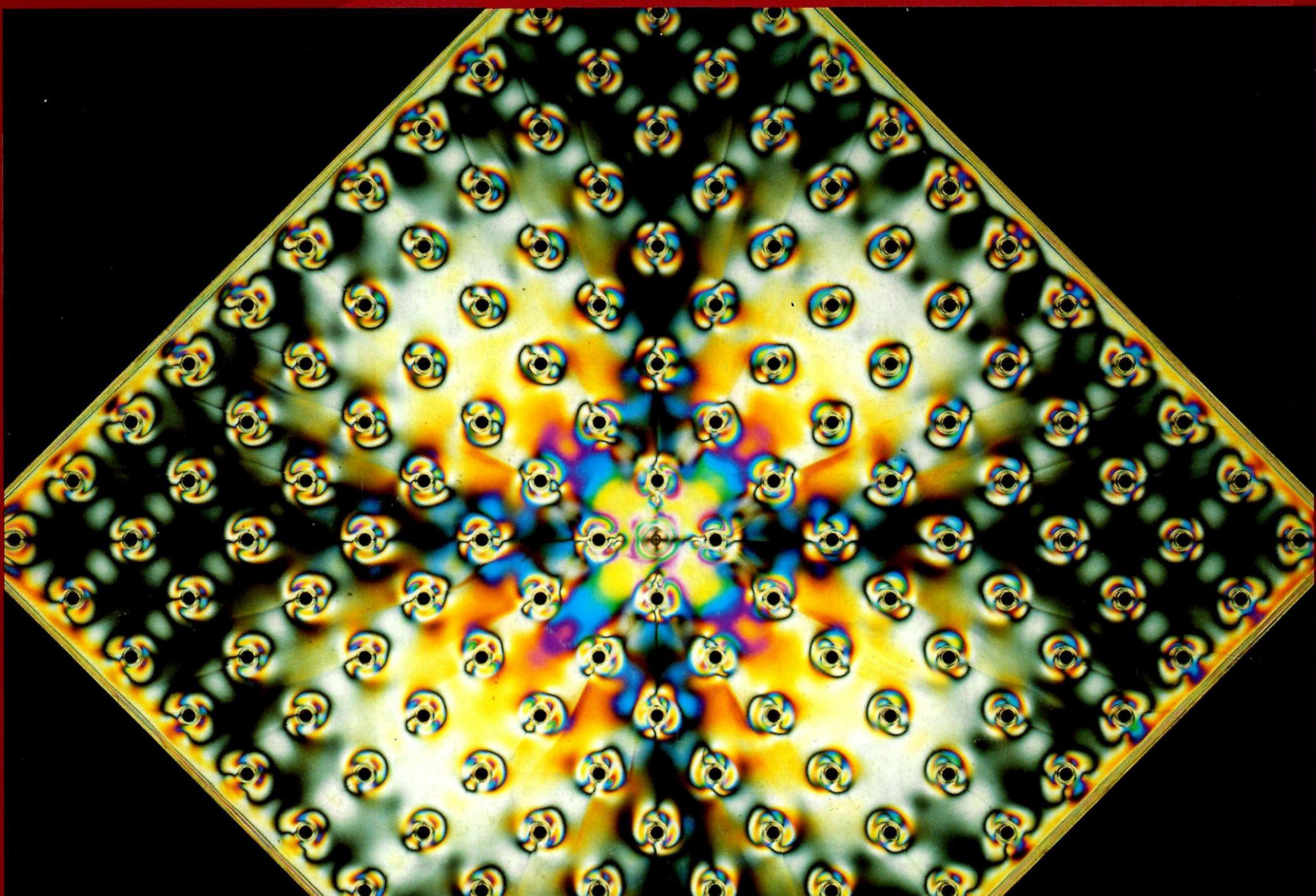

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Micheline Falciola
Advertising Manager
CERN
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Fax: +41 (22) 782 1906

Rest of the world

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Editor: Gordon Fraser (COURIER @ CERNVM)*
Production and Advertisements:
Micheline Falciola (FAL @ CERNVM)*
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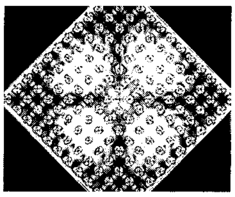
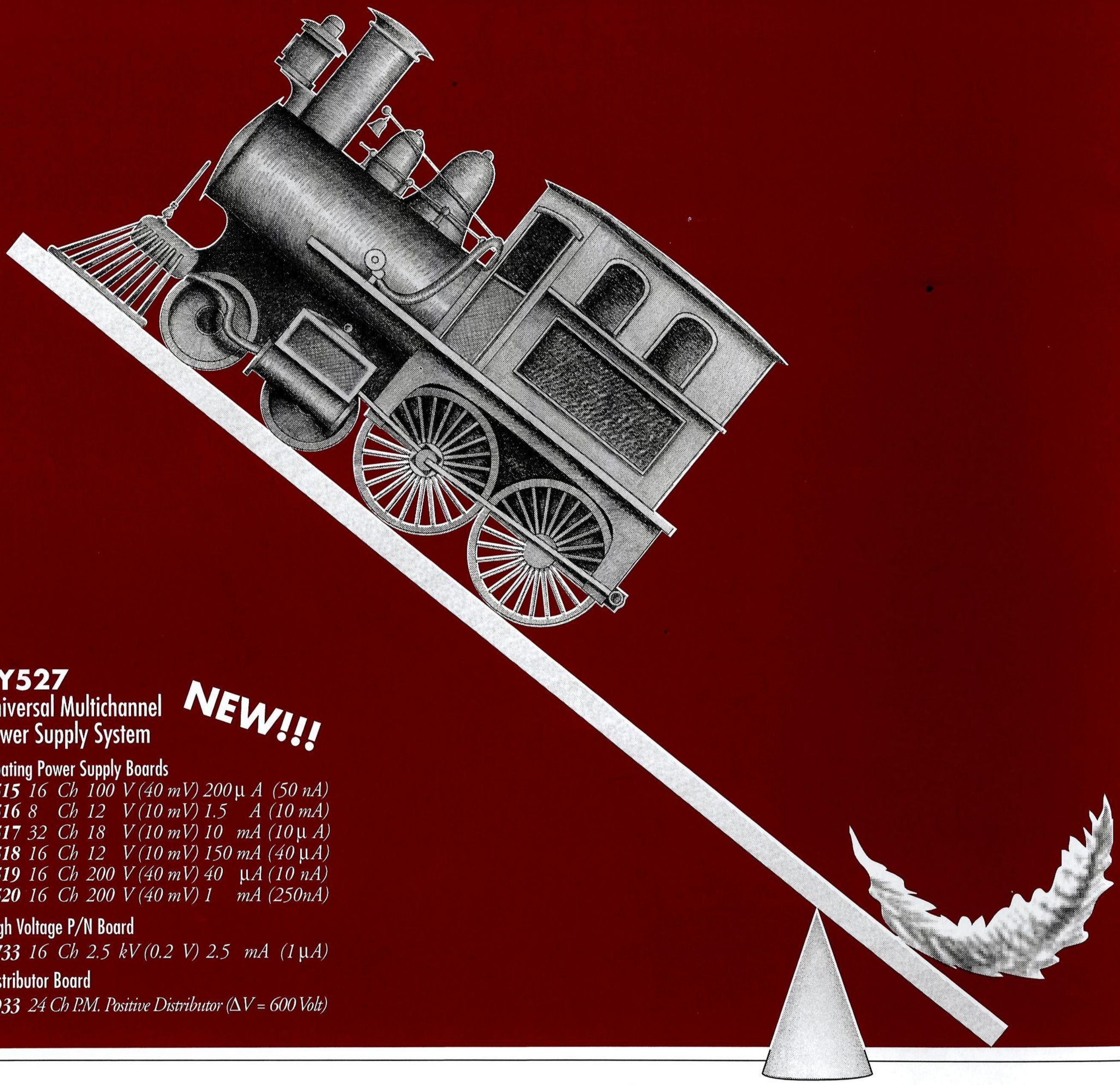


Cover photograph: Polarized light shows up the normally invisible stresses in a sample of scintillator pierced by an array of moulded holes (Photo CERN IT35.1.92)



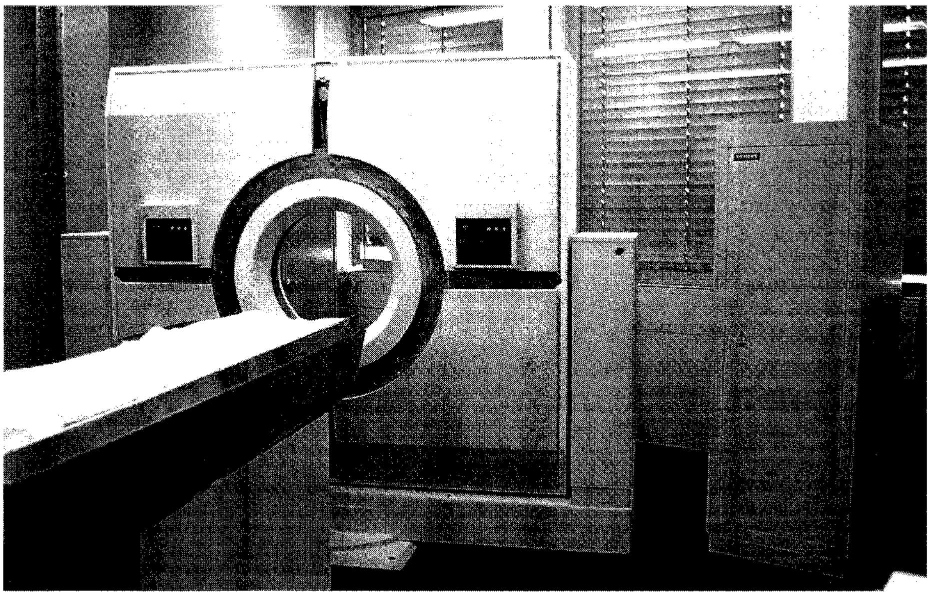
Physics instrumentation for medical imaging

by D.W. Townsend, Geneva University Hospital

From Röntgen to Charpak

The first Nobel Physics Prize, awarded in 1901, went to Wilhelm Röntgen for his discovery of X-rays in 1895. This, and the most recent physics Nobel, to Georges Charpak last year for his detector developments, span several generations of applied science.

As well as helping to launch the science of atomic physics, Röntgen's discovery also marked the dawn of a medical science - radiography - using beams of various kinds to image what otherwise cannot be seen. Ever since, physicists and radiologists have worked hand in hand to improve imaging techniques and widen their medical applications.



PET scanner assembled at CERN and operational at Geneva's University Hospital for the past two years. About 200 patients have been scanned.

Ever since Röntgen's discovery of X-rays in 1895, a great deal of effort, mostly using electromagnetic radiation and ultrasound, has been devoted to imaging the human body with the aim of identifying signs of disease as early as possible.

For the radiation to image internal organs, it must have sufficient energy to penetrate body tissues, but not too much so that it passes through unabsorbed. Internal structures are then visualized from the resulting absorption patterns.

X-rays (70-100 keV) readily distinguish bone from surrounding soft tissues, with the image captured on film. The medical speciality of radiology was established to interpret the often subtle radiograph effects. However even experts sometimes had difficulty with an image where all tissues between the source and the film were projected onto a single plane. In addition, such images were purely anatomical and revealed little, if anything, of the behaviour of internal organs.

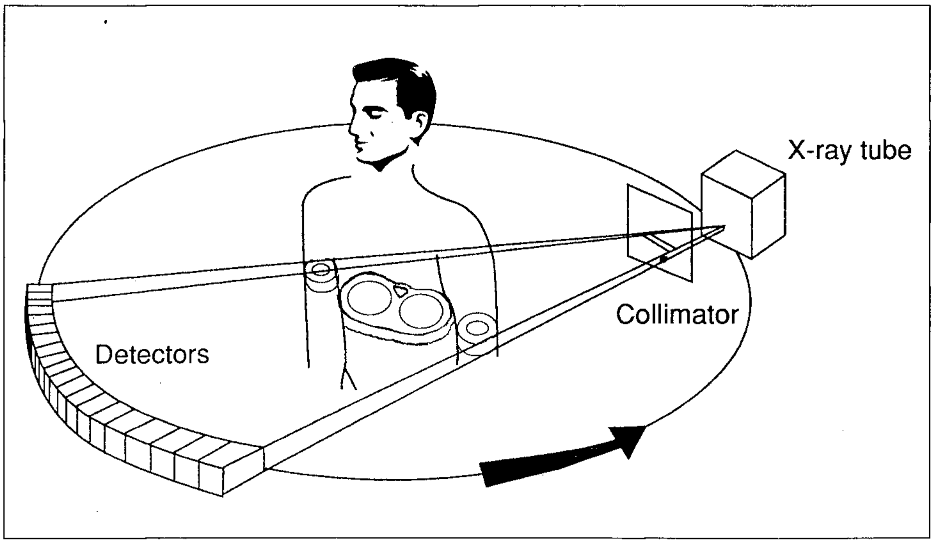
During the late forties, a new technique made its appearance in which a radioactive substance was administered (either orally or intravenously), and its distribution inside the patient's body monitored externally through the emitted radiation. The advantage over conventional radiography is the ability to target a particular organ and follow its behaviour. This procedure has now developed into the speciality of nuclear medicine, with its own experts to interpret the images.

The most widely-used radionuclide for nuclear medicine is an isomer of technetium, ^{99m}Tc, which decays with a half-life of 6 hours, emitting a 140 keV photon. Sodium iodide (NaI) crystals are highly efficient detectors of these photons, and the gamma camera, a large sodium iodide crystal with photomultiplier readout invented by Hal Anger at Berkeley, has been the standard imaging device for nuclear medicine since the mid fifties.

To form an image, a collimator, consisting of a thick lead sheet perforated with many thousands of small holes, must first be placed between the incident radiation and the crystal to eliminate obliquely-incident photons. In theory, the holes allow only perpendicularly-incident radiation through, although in practice it is impossible to prevent some penetration by obliquely-incident photons. The collimator greatly reduces the effective sensitivity of the sodium iodide crystal. In practice only about 0.02% of the radiation from the patient contributes to image formation.

Like conventional radiographs, nuclear medicine images are projections of a three-dimensional distribution onto a two-dimensional plane.

The Computer-assisted Tomography (CT) scanner images a section of the body transverse to the long axis, perpendicular to the plane of a conventional radiograph. The section is typically a few millimetres thick, and is obtained by measuring not just a single projection, but many, each from a different direction.



With depth information missing, interpretation of the images requires special skills, as the effect of the surrounding structures is often extremely misleading.

This problem was dramatically solved in 1972 with the appearance of the Computer-assisted Tomography (CT) scanner, the brainchild of Godfrey Hounsfield at EMI, who shared the Nobel Prize for Physiology and Medicine with Alan Cormack in 1979. The CT scanner images a section of the body transverse to the long axis, perpendicular to the plane of a conventional radiograph. The section is typically a few millimetres thick, and is obtained by measuring not just a single projection, but many, each from a different direction.

The X-ray source, collimated into a fan beam within the section, is rotated around the patient, and the transmitted beam captured by an opposing arc of high pressure xenon detectors. One-dimensional projection profiles are reconstructed into a two-dimensional image of a transverse body section.

Within a few years, tomographic methods were also applied in nuclear medicine. A gamma camera rotating around the patient takes a series of two-dimensional projections from different directions. Applying CT reconstruction techniques, the internal distribution of the radioactive tracer can be recovered simultaneously for parallel two-dimensional transverse sections. This technique, called Single Photon Emission Computed Tomography (SPECT), is particularly useful for three-dimensional imaging of certain tracer distributions in the brain and heart.

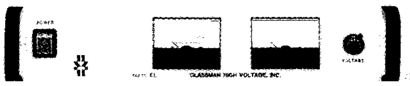
Although the most common radionuclide used in nuclear medicine is ^{99m}Tc with its 140 keV photons, this is by no means the only possibility. Isotopes with lower energy photons such as ^{201}Tl (80 keV) and ^{178}Ta (55-65 keV) are useful for imaging the heart, ^{201}Tl for tumour imaging, and ^{133}Xe (80 keV) for lung ventilation studies. With lower energy photons, alternative detectors, such as multiwire proportional chambers, can be used. Pressurized xenon wire chambers have been used with ^{178}Ta for imaging the heart by J. Lacy's group from Houston, Texas.

L.I. Shekhtman's group in Novosibirsk has looked at wire chambers to replace film in conventional radiography. The advantages include lower X-ray doses and high resolution digital images with a large dynamic range. Since the wire chamber is more efficient for detecting charged particles, Jean Saudinos and Georges Charpak in the late seventies tried using a proton beam instead of X-rays. While these low-dose proton radiography results were interesting, the need for a 500-1000 MeV proton beam limits application.

Some radionuclides used in nuclear medicine emit photons with an energy greater than 140 keV, for example ^{123}I (160 keV), ^{131}I (360 keV), ^{51}Cr (323 keV) and ^{111}In (250 keV). In principle radiation energies from a few tens of keV up to several hundred keV can be used to image the human body. However at higher energies the gamma camera collimator must be especially thick to minimize penetration, thereby reducing efficiency and degrading spatial resolution.

The highest energy radiation currently used for medical imaging is 511 keV, with photons from the annihilation of a positron with an electron. During the early fifties, medical researchers such as E.R. Wrenn and co-workers, and G. Brownell and W.M. Sweet in Boston realised that neutron-deficient isotopes emitting positrons instead of single photons offer some particularly interesting possibilities.

The annihilation of a positron with an electron produces two 511 keV photons emitted back-to-back, and detecting these coincident photons



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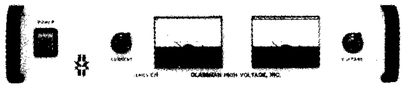

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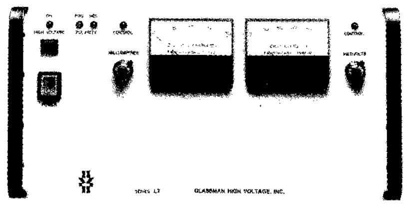

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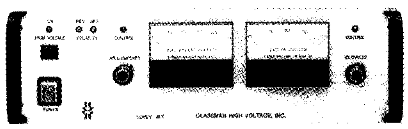

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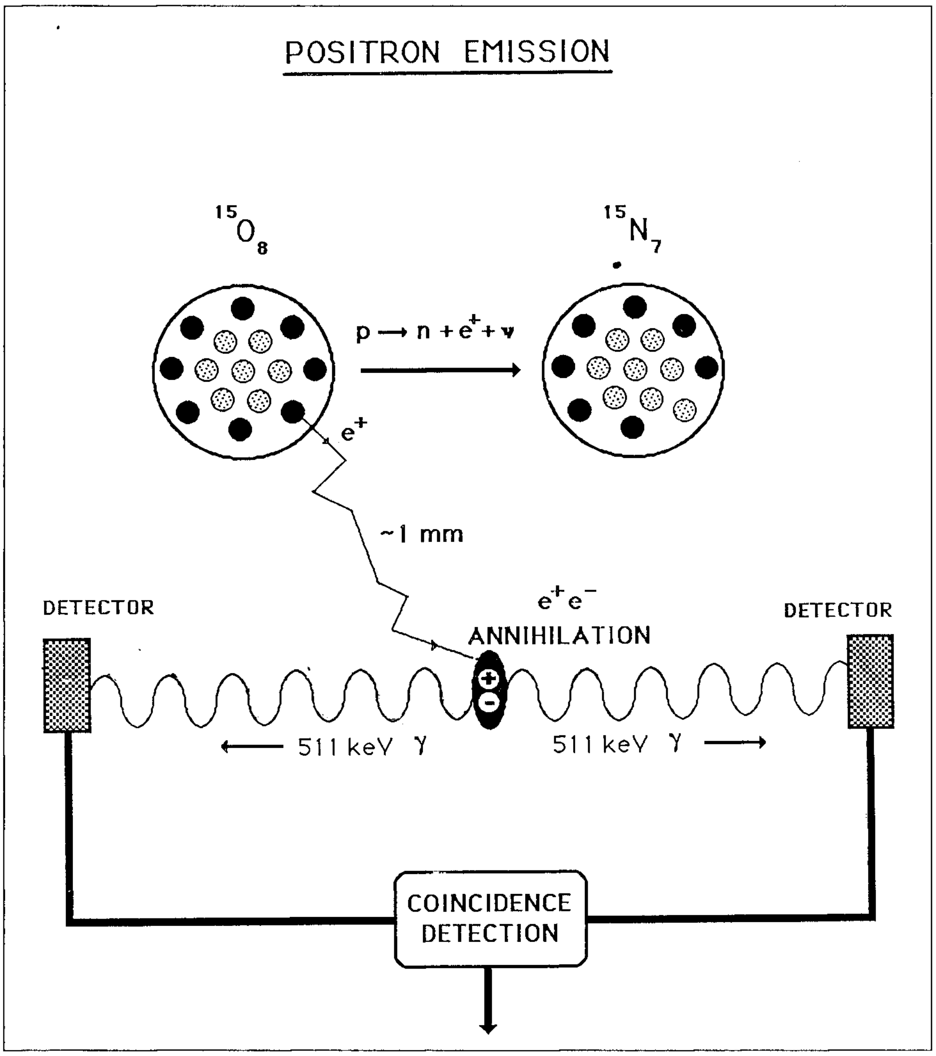
In Positron Emission Tomography (PET), the annihilation of a positron with an electron produces two 511 keV photons back-to-back, and detecting them measures the direction of the event immediately.



measures the direction of the event immediately, without the need for a collimator (which at 511 keV would have to be impracticably thick). With no collimator, photons at all angles can be accepted, increasing the sensitivity compared to SPECT by a factor of 20 or more.

Only hydrogen among the principal elements of life does not offer a convenient positron-emitting isotope. In fact, for medical imaging the only useful isotopes of oxygen, nitrogen and carbon provided by nature are positron emitters with short half-lives - 2, 10 and 20 minutes respectively.

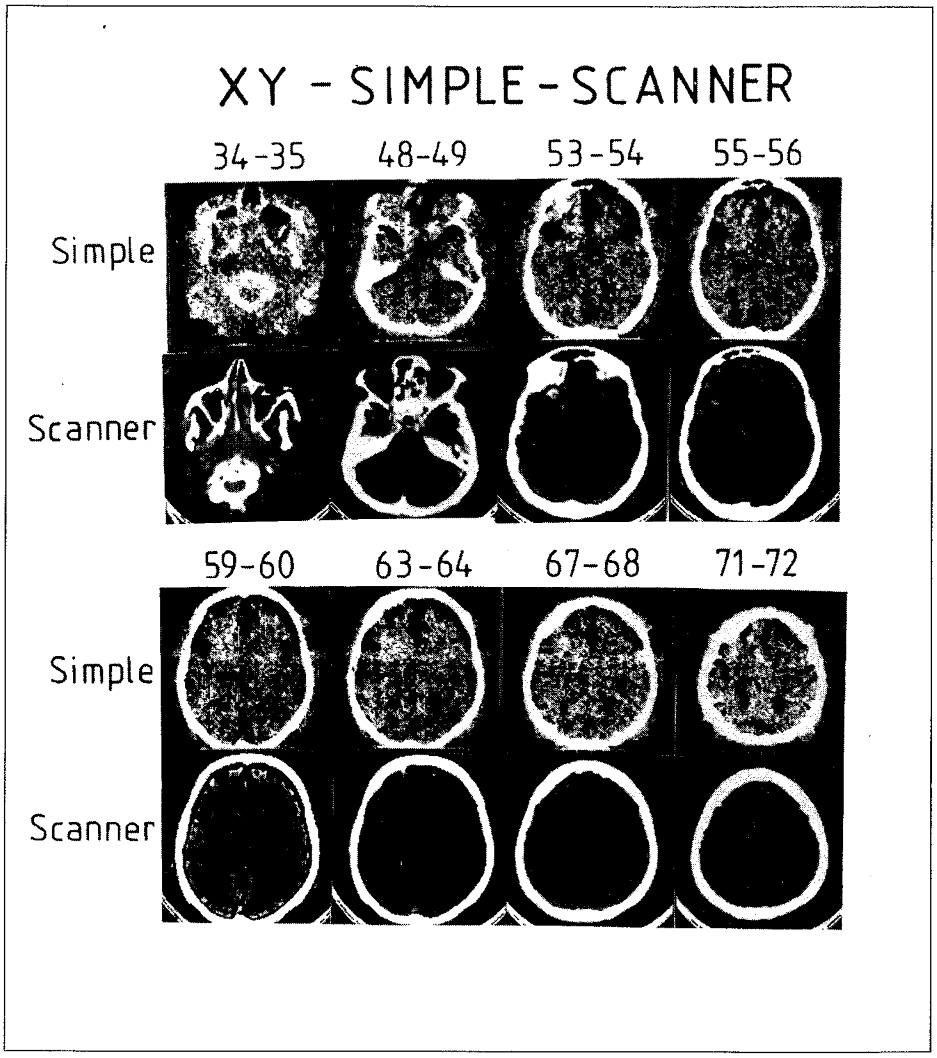
Despite these obvious advantages, it was almost thirty years before the first commercial scanner became available for positron emission tomography (PET), built by EG & G ORTEC in the USA and based on work by Mike Phelps and Ed Hoffman at UCLA and Michael Ter-Pogossian at St. Louis. The reasons were essentially technological - the problems with using NaI crystals to detect 511 keV photons, the difficulty of recovering the underlying tracer distribution from the annihilation data, and the need for a nearby cyclotron to produce the short-lived isotopes. In the forty years since the concept of PET was first proposed, the first two difficulties have been largely overcome, while cyclotron proximity remains a constraint.

During the seventies and early eighties, the advantages of positron-emitting isotopes stimulated research into detectors optimized for 511 keV photons. Once again, multiwire proportional chambers played a role by offering large area detectors with high spatial resolution at low cost, with pioneering work by Victor Perez-Mendez in Berkeley.

The problem is to make the detectors sensitive to 511 keV photons, and to localize incident photons to within one or two millimetres. Proposed solutions for the necessary high density proportional chambers included increased gas pressure in the chamber, and the insertion of convertors constructed from multiple lead sheets (E. Bateman at the UK Rutherford Laboratory), perforated thick lead stacks (A. Jeavons at CERN) or fused lead-glass tubes (A. Del Guerra in Pisa). While good spatial resolution was achieved, adequate sensitivity was not, and multiwire chambers were only a modest success for clinical PET imaging.

The widely-used sodium iodide crystal is far from being the ideal high energy radiation detector. Early attempts to develop a crystal-based PET scanner centred around two geometries: a circular hexagonal configuration of small sodium iodide crystals proposed by Lars Eriksson in Stockholm and Michael Ter-Pogossian and colleagues at St. Louis, and a pair of uncollimated gamma cameras operated in coincidence, by Gerd Muehllehner and co-

Since the wire chamber is more efficient for detecting charged particles, Jean Saudinos and Georges Charpak in the late seventies pioneered radiography using a proton beam instead of X-rays. Here the results ('Simple') are compared with a CT scan of the time.



workers at Searle Radiographics in Chicago. Then, in the late seventies, the first PET scanner using bismuth germanate (BGO) crystals was developed by Chris Thompson and colleagues at the Montreal Neurogical Institute in Canada, and since then almost all commercial PET scanners have been based on multi-ring BGO configurations, built by CTI Inc in Knoxville, Tennessee and the former Scanditronix Co. (now GE) in Uppsala, Sweden.

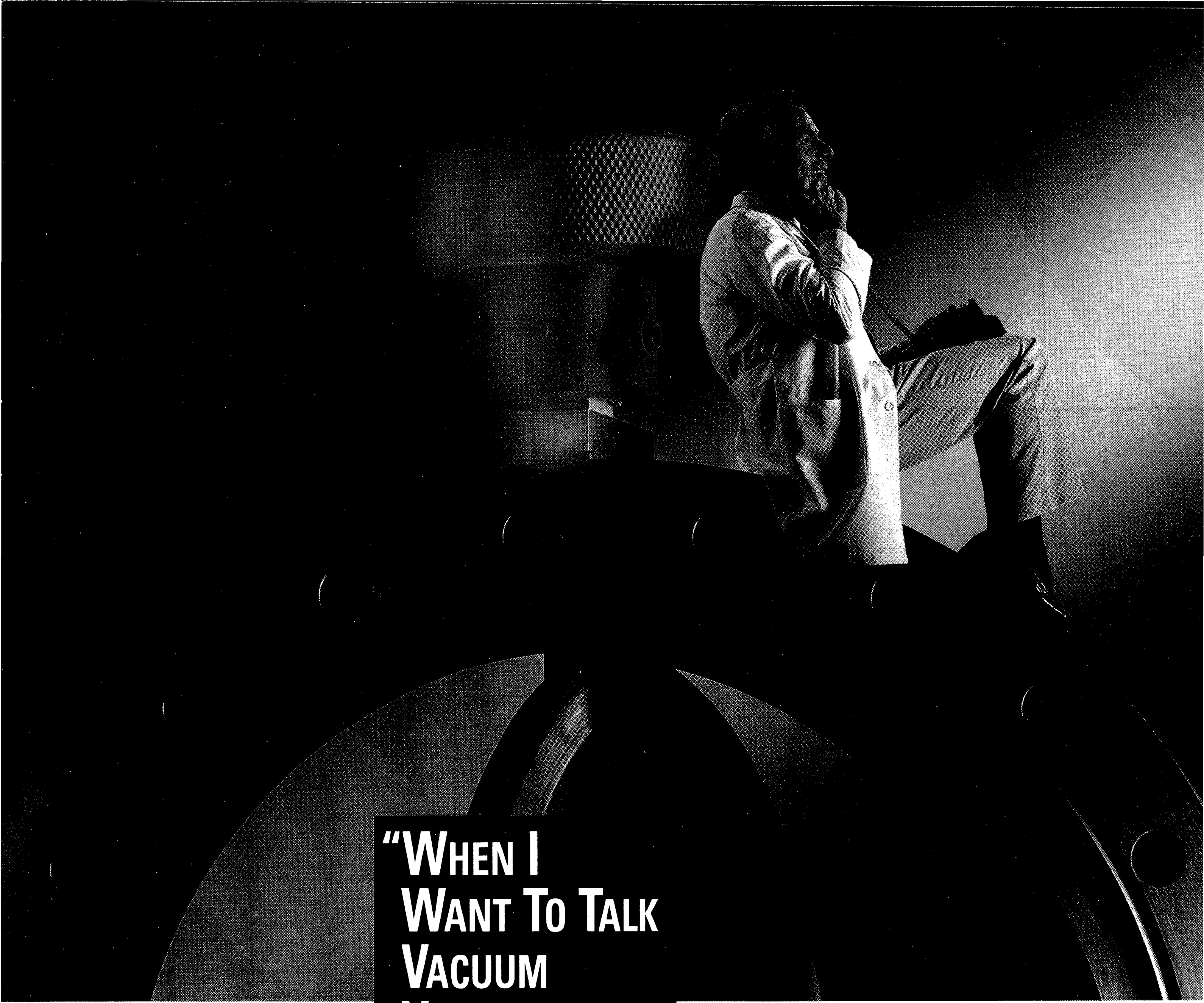
BGO has better stopping power, although poorer energy resolution, than NaI. Alternative crystals, such as the fast scintillators BaF_2 and CsF, suggested by R. Allemand and colleagues from LETI in Grenoble, and Michael Ter-Pogossian in St. Louis, are interesting because they can measure the time difference between the arrival of two photons, although they are intrinsically less efficient than BGO for stopping 511 keV radiation. The search for the ideal detector material - fast, large nuclei (high Z), good light output - has been led by Steve Derenzo from Berkeley for the past few years, and recent candidates include cerium fluoride, lead carbonate and lutetium orthosilicate.

Liquid scintillators have also been suggested. An idea which emerged in the late 80s gave new life to the possibility of using multiwire chambers for PET. Recognizing that fast, high Z crystals offer the best efficiency, Charpak at CERN and Bateman at the Rutherford Laboratory have investigated a hybrid configuration of BaF_2 crystals inside a wire chamber, aiming for both good efficiency and high spatial resolution, at reasonable cost and complexity.

In the past few years, positron tomography has become an important research and diagnostic tool. Despite the cost and complexity of the accompanying technology, PET's potential is considerable, not only in medical research, but also for more routine applications. The ability to measure both blood flow and metabolism of internal organs, to label the brain's chemical mediators, to follow cancer drugs, to localize tumours and to pinpoint epileptic foci in the brain, are just some of the applications that drive efforts to reduce the cost and simplify the technology.

A lower-cost, BGO-based PET scanner, designed in collaboration with Siemens/CTI and assembled at CERN by Martin Wensveen (with financial support from the Swiss Commission for the Encouragement of Scientific Research - CERS - in Berne), has been operational at the Cantonal Hospital in Geneva for the past two years. Hopefully this development will open up clinical PET studies to a wider medical community.

A few groups have been using PET to study normal brain behaviour.



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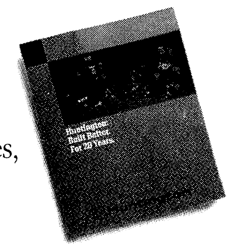

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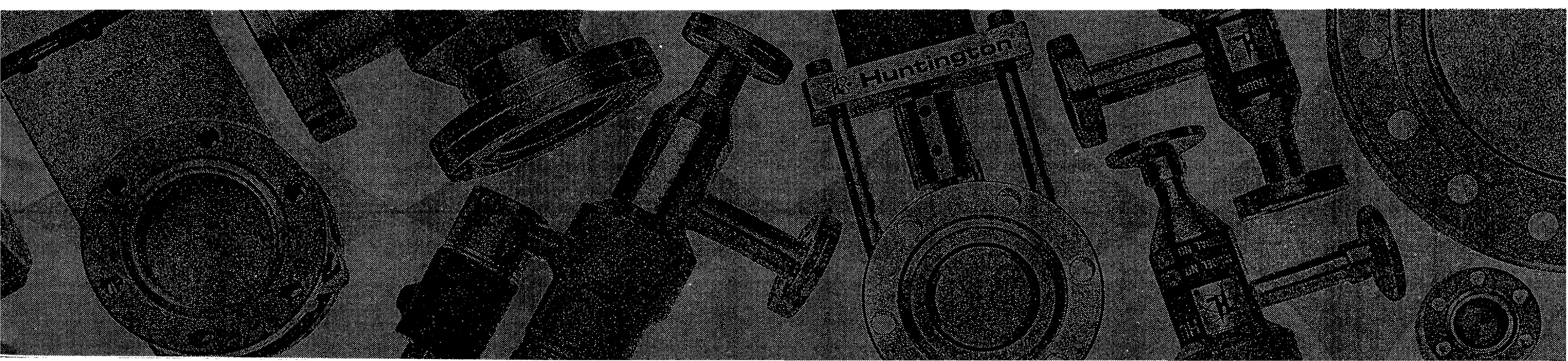
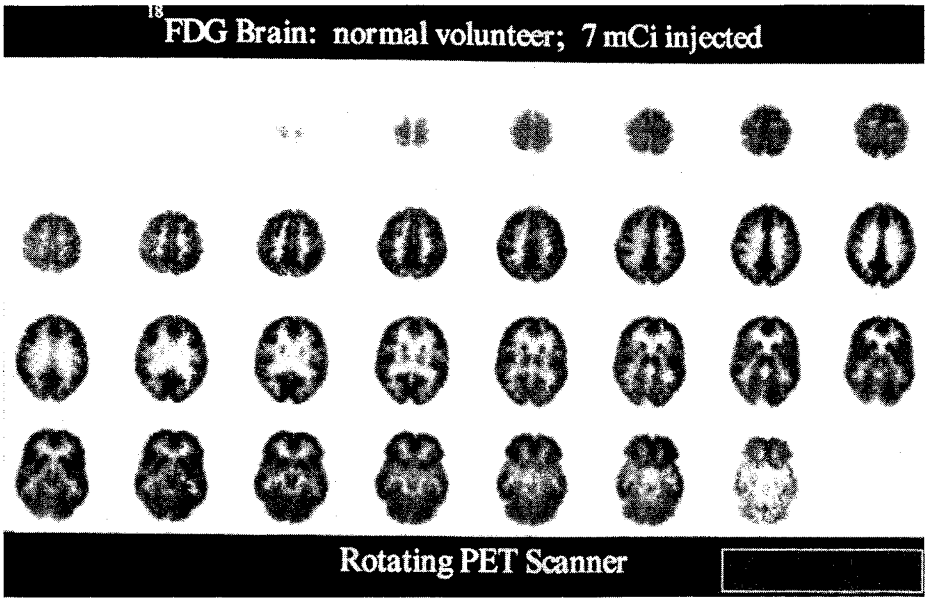




Imaging the utilization of glucose in the brain by the BGO-based PET scanner at Geneva University Hospital.

Understanding the functioning - and malfunctioning - of the human brain remains one of the greatest challenges facing mankind. Subtle changes in blood flow can be detected by PET and related to areas which respond to particular stimuli. Centres for language, vision, motion, colour, memory and even pain have been identified at a number of centres, including Richard Frackowiak and his group at the MRC Cyclotron Unit in London, and Marcus Raichle and colleagues at St Louis in the US. Such maps were previously possible only in animals, using invasive techniques.

Prior to using a new radioactive tracer in humans, it has often been necessary to validate its behaviour in animals and develop an appropriate biological model. The usual procedure is autoradiography, where the tracer is injected and then, at the appropriate moment, the animal is sacrificed, frozen and sectioned. Each section is then placed on photographic film and exposed, often for many days. This gives a high resolution image of the tracer biodistribution, but the process must be repeated (with a different animal) to follow the complete biological process.

Gaseous detectors have recently made a significant impact on the autoradiographic technique. Two devices, a wire-chamber-based system developed by Alan Jeavons, now at Oxford Positron Systems in Oxford, and an avalanche chamber with optical readout developed by Georges Charpak in Geneva are able to produce good quality, digitized images in hours rather than days or weeks. Such devices are also used successfully for imaging DNA sequences and electrophoresis plates.

Recent PET technological progress is also having an impact on conventional autoradiography. Two groups, one under Terry Jones at the Medical Research Council's Cyclotron Unit in London and a second at Brussels' Free University led by Stefan Tavernier are developing small-scale animal scanners, based respectively on a small ring of BGO crystals, and a pair of hybrid BaF_2-wire chamber detectors. Their success in achieving high spatial resolution will enable the biodistribution of new tracers to be followed in a small animal, which then lives to tell the tale. PET applied to humans has been termed *in vivo* autoradiography, and hopefully this can be 'extended' to animals with these new detector developments.

Photon energies around 80-100 keV are used for radiological (X-ray) imaging, whereas for radioisotope imaging somewhat higher energies are usual (140-200 keV), the annihilation radiation of PET setting an upper limit at 511 keV. Below a few tens of keV, approaching the region of visible light, the human body becomes increasingly opaque, (which is at the root of the whole problem!).

Infrared and microwaves can penetrate a small distance into human tissue, and infrared imaging of low density structures such as the breast are current research areas. Somewhat surprisingly, another window then opens, magnetic resonance (MR), using very low energy, non-ionizing radiation of 10^{-10} keV. Since the early eighties, this technique has made a tremendous impact, after early developments by Paul Lauterbur at Stony Brook, Peter Mansfield in Nottingham, England, and others.

An external magnetic field initially orients the spins of hydrogen nuclei within a body section. Then radiowaves are used to manipulate these spins, and the radiofrequencies emitted as the nuclei return to their original state can be captured by an antenna close to the patient. Additional magnetic field gradients are used to recover the spatial distribution of hydrogen (water) within the body section.

Around the Laboratories

Resonance ensures that sufficient nuclei emit together (in phase) for the signal to be detectable, even though the energy of each individual photon is only 10^{-7} eV. For hydrogen at least, the nuclear density is enough (about 10^{23} per cubic centimetre) for a detectable signal to be obtained from a small volume. Additional information on the chemical state of body tissues is given by the decay characteristics of the nuclear resonance signal.

These high quality images, obtained without ionizing radiation, ensure an important role for magnetic resonance in clinical medical imaging. In research, recent applications by Jack Belliveau and colleagues at Massachusetts General Hospital and Harvard University of sequences for rapid repetitive manipulation of nuclei within a brain section has extended MR to activation studies, once an exclusive PET domain. For activation work, as with other studies, MR offers both better temporal and spatial resolution than PET.

With these techniques, it is now possible, for example, to monitor directly the changes in a volunteer's brain when subjected to different visual stimuli. Applied science has come a long way since Röntgen first X-rayed his hand in 1895.

CERN
LEP in the Alps

In January, when CERN's LEP electron-positron collider is enjoying a well-earned break, it has now become traditional for the hard-pressed LEP team to have no respite. Instead they pack their bags and depart for Chamonix in the nearby French Alps to review the past year's experience and plan for the future.

In the cold January 1993 light of Chamonix, 1992 (January/February, page 4) was deemed to have been a good year for LEP operations, with the switch to 90° betatron phase operation having paid off. The 65% improvement in integrated luminosity over 1991 was attributed to longer beam lifetimes, faster filling and improved overall efficiency. The commissioning of the eight-bunch 'pretzel' scheme was facilitated with the new optics, and break-even quickly achieved, so that physics could benefit from more bunches in the machine.

During 1992, the injection chain was fully tested with eight bunches, and when this comes into routine operation this year, the pretzel scheme will benefit. Pretzel running also opens the possibility of still higher luminosity, up to 2×10^{31} per sq cm per s, doubling the present level.

However the finishing touches to high luminosity running are still more an art ('haute cuisine') than a science. Continuing studies of the intercorrelation of different LEP conditions will help make this more systematic.

The main factors affecting performance at 45 GeV are transverse mode coupling instabilities. The present working point gives good results, but there are still potentially interesting regions which need to be checked out.

Beam lifetime and background are both limited by beam size and aperture. Background was reduced by improved focusing, while beam size is dominated by beam-beam effects.

At their annual January strategy meeting in Chamonix in the French Alps, CERN's LEP electron-positron collider team review the previous year's running and plan for the coming year.

90° operation proved its worth in 1992, but the inability to produce polarized beams was a disappointment, and a combined 90°/60° horizontal/vertical combination looked like offering the best of both worlds.

Although some realignments, etc, could yet bring polarization with 90° operation, this is by no means certain. With polarization providing precision fixes on the beam energy for physics, the 90°/60° combination was voted clear favourite for 1993 running.

45 GeV running continues to be LEP's bread-and-butter, but behind the scenes (and sometimes even in front of them) preparations are pushing ahead for boosting LEP beam energy towards 100 GeV (LEP2). Chamonix sessions reviewed LEP2 progress (January/February, page 1) and looked at the expected performance. Producing an integrated physics luminosity of 500 inverse picobarns (over several years) will call for some ingenuity but is not ruled out.

A major LEP2 milestone this year will be the installation of a complete niobium-coated four-cavity superconducting radiofrequency module, supplied by industry.

FERMILAB

Collider detectors

At Fermilab's Tevatron proton-antiproton collider, the CDF detector, in action since 1985 and now significantly upgraded, has been joined by D0. Both are logging lots of data in the continuing search for the long-awaited sixth ('top') quark.

Last year's excitement of the first collisions in the D0 detector at Fermilab's Tevatron proton-antiproton collider was the culmination of more than eight years of hard work by a large and dedicated group. D0 is now really in business.

First D0 physics results

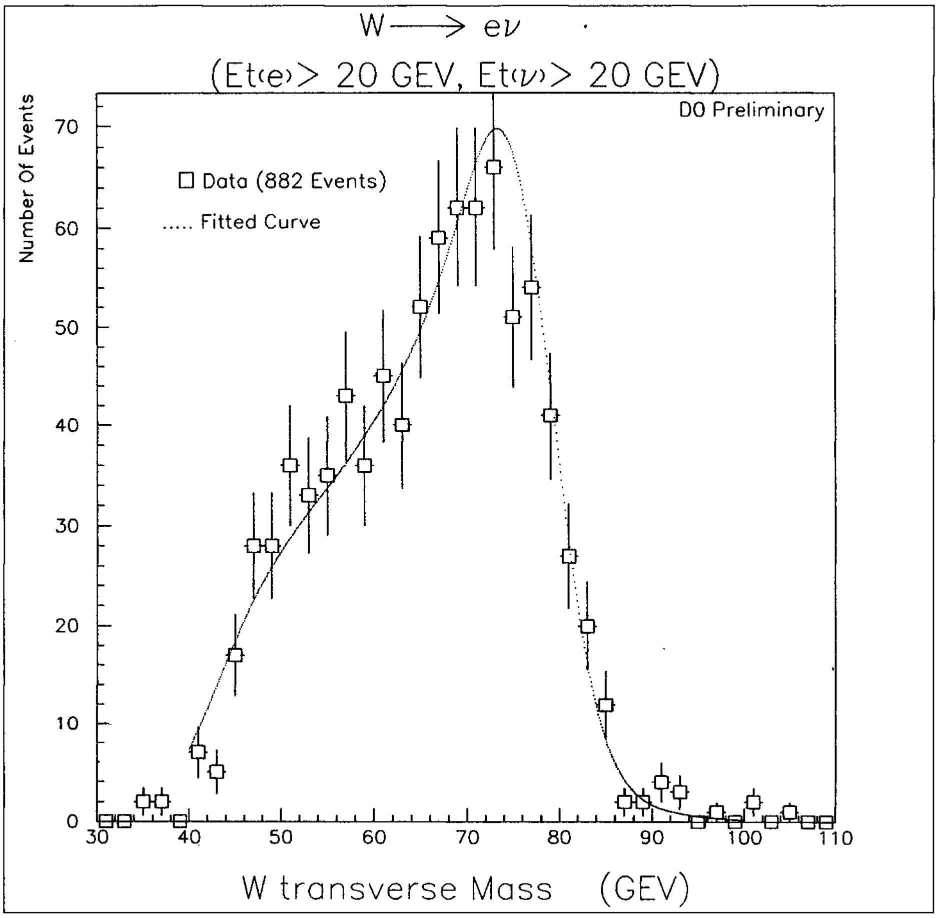
The excitement of observing the first collision in the D0 detector at Fermilab's Tevatron proton-antiproton collider on May 12 1992 was the payoff for more than eight years of hard work by a large and dedicated group of physicists, students, engineers, technicians and other support staff. The D0 detector - an international collaboration of about 370 physicists (including some 65 graduate students) from 36 institutions - had completed the journey from design (1983-1984) to final construction and subsequent rolling in to the collision hall in February 1992.

Commissioning the detector with beam lasted from May-July 1992 and went very well. The collaboration showed that the detector was well on the way to achieving design goals including precision measurements of electrons, muons and photons, together with quark and gluon jets, and to be sensitive to missing transverse energy indicative of non-interacting particles such as neutrinos.

With the start of the physics run in August 1992, the collaboration turned its attention to extracting the first results in time for the major (DPF) meeting at Fermilab last November (January, page 12). By the mid-January break in the run, D0 had accumulated about 7 inverse picobarns of physics data. Large samples of Ws and Zs have been logged in both electron and muon channels. This will allow sensitive studies of the W mass and of the triple WWZ gauge boson coupling.

The strengths of the detector will provide a powerful tool to search for the elusive top quark. With the top expected to decay solely to a W boson and a b quark, sensitivity is needed to leptons, jets and missing

Preliminary profile of the W particle from first D0 data.



transverse energy, or combinations of them. The search is underway.

The full coverage of the detector, and the ability to trigger on jets at small angles makes it well suited for studies of quark field (QCD) dynamics. In addition, fine segmentation and good energy resolution allow good measurement of direct photons, revealing the gluon content of hadrons, while jet multiplicity distributions will test QCD and ultimately measure its parameters.

The large muon coverage as well as D0's compactness and thickness offer good potential for B physics. First studies will include measurement of the B production rate, B-particle mixing and searches for new particles containing b-quarks. High quality measurements of leptons, photons, jets and missing transverse energy could point the way to new physics, including new particles.

D0's rapid turn-on has been very gratifying, and with the detector working well, the collaboration is preparing for an early harvest over a broad range of physics.

KEK 60GeV boson hunt

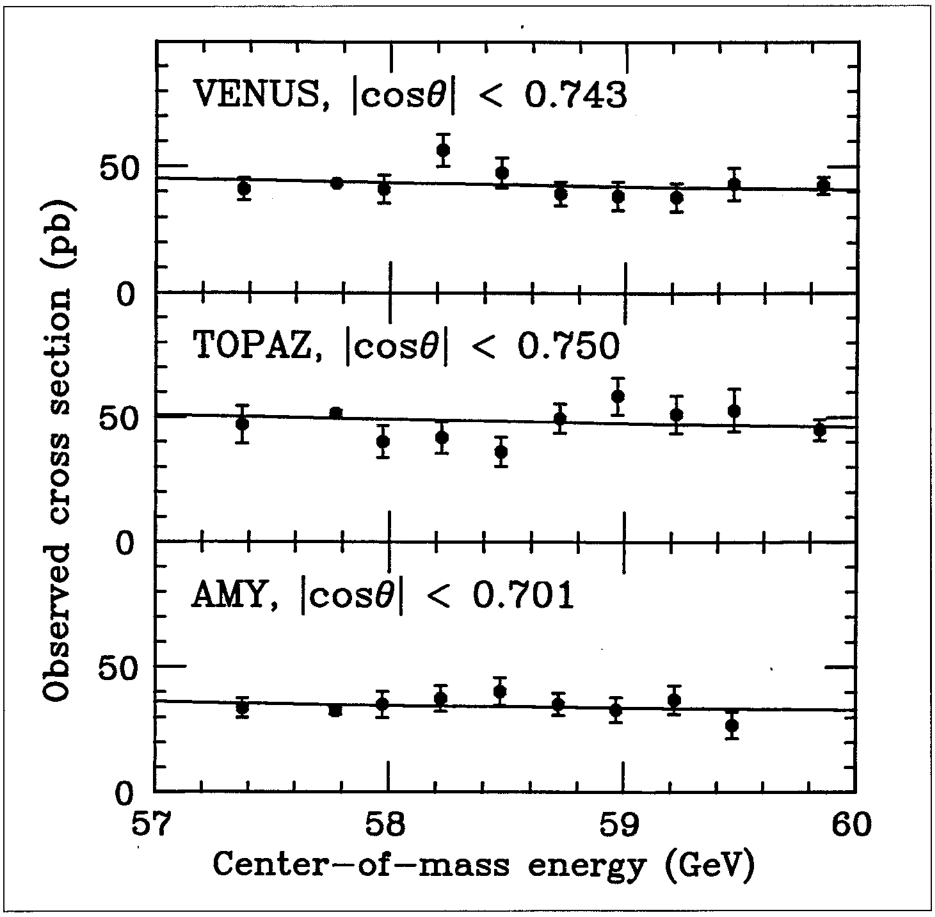
The Japanese KEK Laboratory had a busy December. The TRISTAN electron-positron collider, then running at 58GeV, quickly acted on the news from CERN that something unexpected might be hidden close to 60GeV (January, page 16). After a month's rapid scan over the energy region in question and careful analysis, with an enforced three-week computer shutdown for an upgrade in between, the three experimental groups (AMY, TOPAZ and VENUS) now have conclusive results.

The L3 collaboration at CERN's LEP electron-positron collider recently reported clean events with a muon or electron pair accompanied by a widely separated pair of high energy photons. There were too many such events to be easily explained by conventional processes and, in particular, the photon pairs suggested a particle near 60GeV.

This observation, together with some similar events from the Delphi group, attracted attention because it could signal the production of the long waited Higgs boson via Z boson decay. Although its interpretation as the Higgs seemed very unlikely because no similar clustering was seen with anything other than a photon pair, the phenomenon could nevertheless still have been related to a new heavy boson. Was it new physics?

The TRISTAN theory group, quickly calculated the rate expected from conventional processes, and the result agreed with the calculation reported by L3. Neither could explain the observed signal, and the L3 events stood as an excess. Not being Higgs-like, any new boson would have a sizeable coupling to electrons, and such an object should be observed at TRISTAN as a narrow peak in the electron-positron elastic scattering and in the reaction producing two photons. Furthermore, the observed rate being only a few out of a million Z events, it would take LEP experiments some time to settle the matter.

After some evidence at CERN's LEP electron-positron collider had hinted at the possibility of a new particle near 59GeV decaying into two photons, a hunt was rapidly launched at the Japanese KEK Laboratory's TRISTAN electron-positron collider. Shown here are the data from the three groups for the reaction producing two photons, with no narrow peak visible. All other channels are similarly unremarkable.



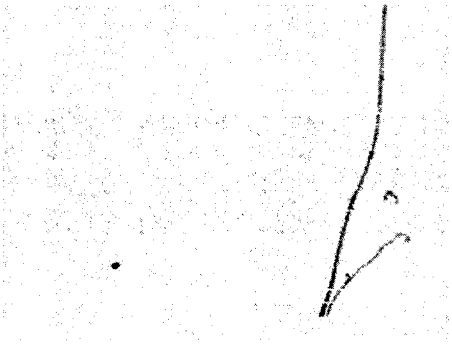
To search for a narrow boson, TRISTAN made an energy scan between 57.4 and 59.5GeV in about 0.25GeV steps. The measurement was done at the end of December, with about one inverse picobarn of data collected at each point. There is no indication of a narrow state - not only in the two photon channel, but also in all others. The result translates into very stringent upper limits and effectively excludes any new boson that predominantly couples to two photons, as well as leptons, in the suspected mass range. The L3 group's careful conclusion "a quantum electrodynamics fluctuation can not be ruled out " is strongly supported.

UNDERGROUND - 1
ICARUS prepares to fly

Operating at CERN since 1991 is a 3-tonne liquid argon time projection chamber, a detector breakthrough which combines the visual advantages of bubble chamber tracks with the flexibility of fully electronic data acquisition. The 3-tonne chamber is a prototype for a much larger configuration for the ICARUS* solar neutrino and proton decay detector to be installed in the Italian Gran Sasso underground laboratory.

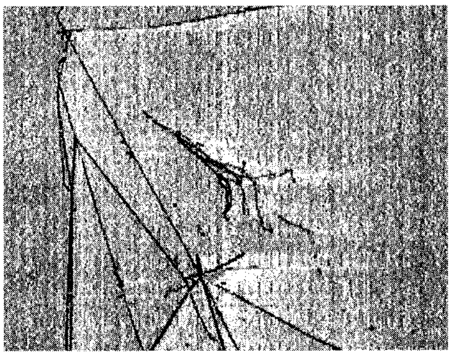
ICARUS (Imaging Cosmic And Rare Underground Signals) is built around the cryogenic imaging chamber idea initially proposed by Carlo Rubbia in 1977. With electrons drifting for a relatively long time (several milliseconds) and with sensitive amplifiers picking up the ionization from just a few millimetres of track, events can be imaged inside the cryogenic volume. A special arrangement of readout wires provides drift time measurements and ensures simultaneous imaging in several different views.

The 3-tonne prototype ICARUS liquid argon time projection chamber combines bubble chamber-like clarity with self triggering and electronic readout. Here a cosmic ray muon (top) slows down (denser signal), eventually coming to rest, emitting a delayed electron.

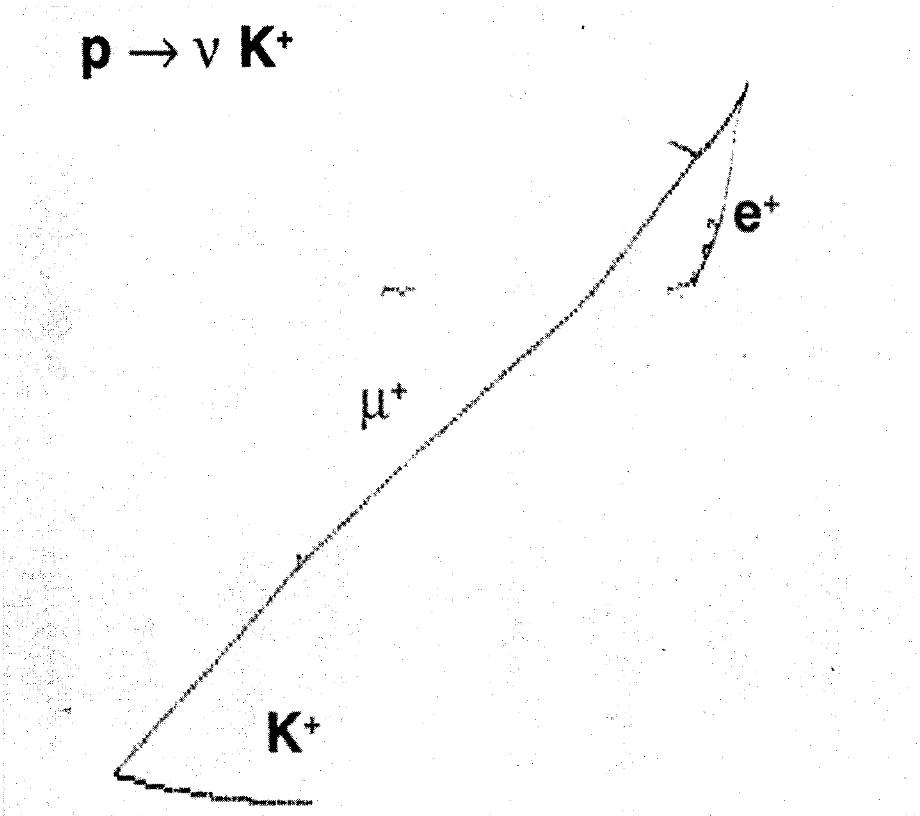


The prototype has shown that the challenges of obtaining ultra-pure argon and operating readout techniques for large sensitive volumes have been met. The full ICARUS detector (with three liquid argon modules each containing 5,000 tonnes) will be able to detect low energy electrons (down to a few MeV) emerging from solar neutrino interactions, proton decays, or other rare events over a large volume.

An ICARUS prototype cosmic ray hadron shower.



A simulation of a possible proton decay as it would be seen in ICARUS. A static proton produces a kaon, which is gradually brought to rest before decaying in turn.



ICARUS' proponents call their detector an 'electronic bubble chamber' and the recorded tracks have an eerie bubble-chamber-like quality. However unlike a conventional bubble chamber, the events are self-triggering, the device is continuously sensitive, and has all the advantages of electronic readout. Resolution is 150 microns. In addition the bubble size (less than a millimetre in any direction) also gives a measurement of energy deposition.

Readout uses three parallel wire planes - a screening/focusing grid, and an induction plane and a collection plane with mutually orthogonal 2mm-pitch wires. Maximum electron drift distance in the prototype is 42 cm. For the full detector, where electrons will drift up to 2 metres, additional logic based on modern TV technology would give real time pulse identification.

To attain the necessary level of purity, industrially clean argon (1 part per million of impurities) passes through a molecular sieve and an 'oxysorb' impurity absorber. The technique is now able to handle liquid, a boon for such a large installation, even a small plant coping with some 50 tonnes of liquid per hour.

With precision Standard Model measurements from LEP now suggesting how the electroweak and strong forces might unify at higher energies, proton instability again becomes a burning issue, and ICARUS will be well suited to lifetimes up to 10^{34} years, and a wide range of potential decay processes.

The other major ICARUS goal is neutrino physics. With the solar neutrino question still wide open, ICARUS' ability to make model-independent solar neutrino measurements should lead to new insights. Atmospheric neutrinos too need a closer look.

As well as natural neutrinos, ICARUS could also monitor what happens to a neutrino beam from CERN after 730 kilometres. To provide particles for CERN's future LHC proton collider, a new proton line would be built linking the SPS synchrotron with the LEP tunnel, and this points almost exactly in the right direction for Gran Sasso.

*(*In Greek mythology, Icarus tried to escape from Crete on wings made by his father, Daedalus. Venturing too close to the sun, the wax on the wings melted and he fell into the Ægean sea at the point now known as Icaria. Daedalus, an inventor employed by King Minos in Crete, had better luck, flying to Sicily. Hopefully the technology being developed for the ICARUS experiment will be more reliable than its mythological forebear.)*

UNDERGROUND - 2
New Soudan detector nears completion

Late last year a team at Argonne put the finishing touches to the 227th 4.3-ton calorimeter module for the Soudan 2 nucleon decay detector. This completed the fabrication of the steel and plastic drift chamber modules which began at Argonne and the Rutherford Appleton Laboratory in 1985 (June 1991, page 16).

Module components were constructed by collaborators at Minnesota and Oxford while Tufts built the active shield of proportional tubes which now surrounds the massive underground tracking calorimeter.

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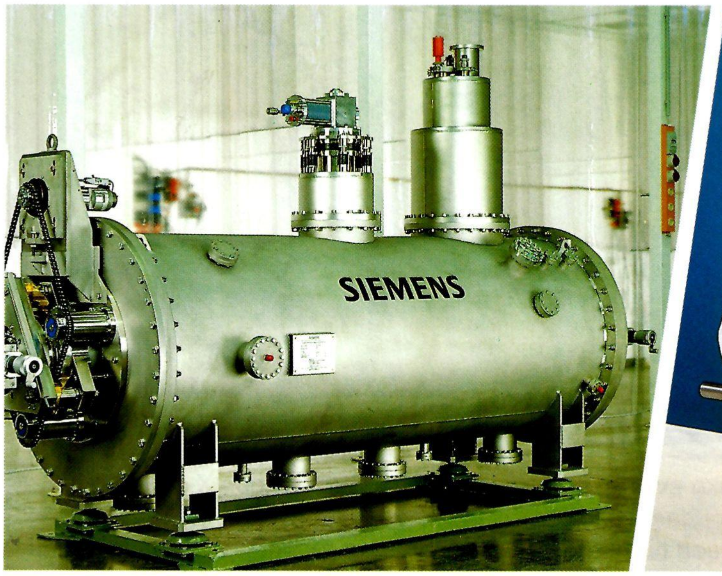

Superconducting accelerator module for the JAERI FEL experiment, Japan

Assembly of the first short model coils of CQM magnets for the superconducting super collider SSC, USA

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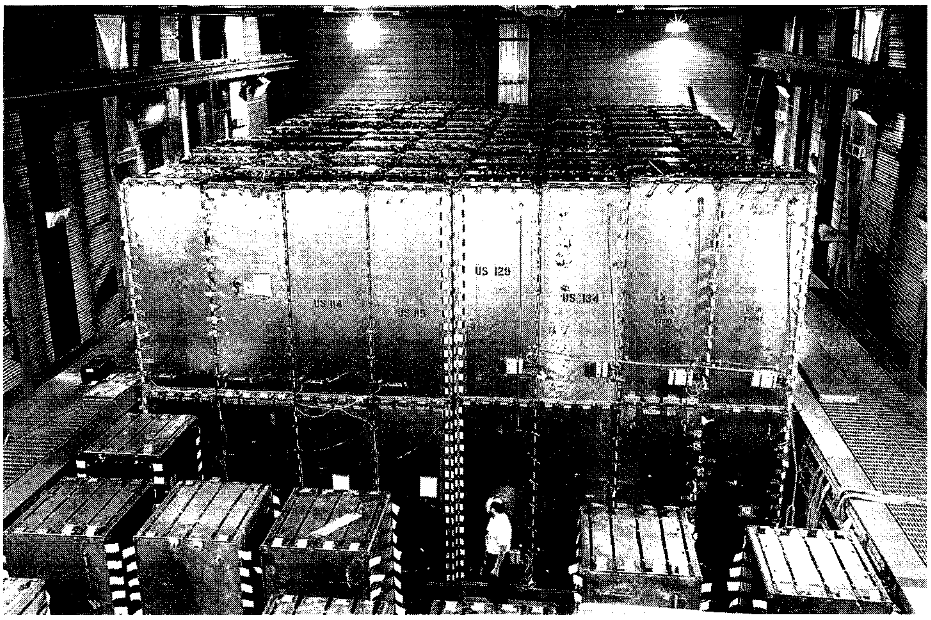
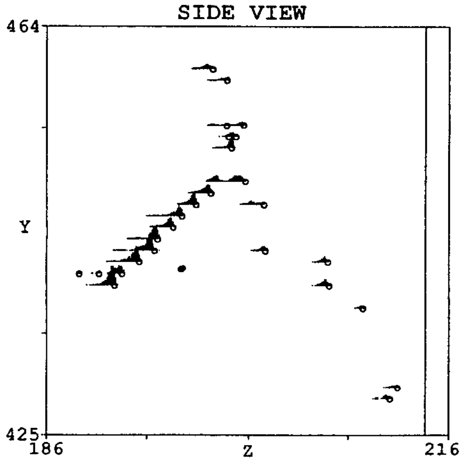
The Soudan 2 detector, 700 metres underground. The rectangular boxes are the 4.3-ton calorimeter modules. The aluminum-extrusion proportional tubes of the active shield can be seen on the ceiling and walls of the cavern. Individual 4.3-ton modules in the foreground are undergoing performance tests prior to installation.
(Photo T. Kafka)



Candidate neutral current event from an atmospheric neutrino inelastic interaction in Soudan 2. A slow neutral pion (reconstructed mass of 137 MeV) decays into two nearly back-to-back gamma showers (top and lower right) which emerge from the neutrino interaction vertex. The straight track is the recoil proton, whose increasing ionization makes larger pulses as it slows down. Scales are in centimetres.



The experiment is set up in the Soudan mine in a specially excavated cavern 700 metres beneath northern Minnesota's Iron Range. This historic century-old iron mine is maintained and operated as a tourist attraction by the Minnesota Department of Natural Resources, which also provides valuable assistance in operating the underground research laboratory. The overhead rock shields off cosmic rays which would confuse the search for rare events - only neutrinos and a few of the highest energy cosmic ray muons can penetrate to this depth.

Soudan 2 is designed to detect the spontaneous decay of protons or bound neutrons, predicted by Grand Unified Theories (GUTs) of the strong and electroweak forces. It is optimized for decays producing charged kaons, predicted by the supersymmetric GUTs favoured by extrapolations of LEP results (November 1992, page 15), and for complicated modes difficult to analyse in large water Cerenkov detectors.

Ionization measurements and bubble-chamber-like event reconstructions allow Soudan 2 to distinguish clearly between nucleon decay and the neutrino interactions which can mimic it. The ICARUS detector proposed for the Gran Sasso Laboratory (see previous story) will eventually be a strong competitor, but for the next few years Soudan 2 has a head start. The first 820 tons of Soudan 2 are now in routine operation, with the detector scheduled to reach its final mass of 960 tons by this autumn.

The experiment has been active since the first 250 tons came into full operation in 1989. So far more than 1 fiducial kiloton year of exposure has been recorded for nucleon decay and cosmic neutrino searches. A sample of 15 million cosmic ray muons is also being studied to learn about the nuclear composition of cosmic ray primaries. This is aided by a surface detector measuring the energies of the parent air showers for a subset of the underground muon events.

Soudan physicists have already published the results of a search for heavily ionizing magnetic monopole tracks, as well as tantalizing evidence for a burst of muons from the direction of Cygnus X-3 during its January 1991 radio flare.

Soudan recently presented preliminary measurements of atmospheric neutrino interactions from the first half kiloton year exposure. Although the statistics are still limited, the resulting ratio of muon- to electron-neutrino interactions appears to support the anomalously low value obtained by the Irvine/Michigan/Brookhaven (IMB) and Kamiokande water Cerenkov experiments. The Soudan neutrino sample will soon be doubled. A popular explanation of the unexpectedly low muon to electron neutrino ratio is that muon neutrinos oscillate into tau or electron neutrinos in the atmosphere.

Physicists from the Tufts Soudan group recently put forward an alternative idea: the electron neutrino rate may appear high because of contamination by positrons from proton decay (into a positron and a neutrino pair). Although physicists building big underground detectors have worked very hard to reduce the background to nucleon decay from atmospheric neutrinos, until now few have worried

With its ability to cleanly identify a fraction of neutrino events by observing recoil protons, the Soudan detector will be able to test this idea experimentally. As with other major underground facilities, Soudan has also been considered as a distant target for a beam of synthetic neutrinos, in this case from Fermilab, searching for neutrino oscillations after 730 kilometres. If the atmospheric neutrino result is due to oscillations, many of Fermilab's muon neutrinos would become tau or electron neutrinos on their way to Soudan. This would decrease the fraction of the 900 interactions per year containing final state muons, and provide an unambiguous signal of neutrino oscillations.

Attractive features of this proposal are both the operating Soudan 2 detector and the possibility of building a bigger detector at the same site. When the US Department of Energy approved the excavation in 1983, they allowed for future follow-on experiments by funding a space large enough for a second major detector after Soudan 2. Several ideas are now being developed. The neutrino beam from Fermilab is expected to be ready in 1998, after completion of the planned 5 kiloton year exposure for nucleon decay. With the construction of Soudan 2 modules completed, the experiment is now on the threshold of a long programme of exciting particle physics measurements in its underground laboratory.

ICFA

The 23rd meeting of ICFA (International Committee for Future Accelerators) was held on 13 January at the Japanese KEK Laboratory. This committee, set up in 1976, promotes international collaboration in the construction and exploitation of very high energy accelerators, and organizes topical workshops and meetings.

At the KEK meeting, there was major discussion on planning for a future TeV electron-positron linear collider, envisaged as the next very large accelerator following the SSC and LHC proton collider projects. Already there is considerable international R&D collaboration for such a machine, and ICFA is much involved in promoting this collaboration and providing forums to discuss the accelerator and physics issues which arise as the project advances.

The DESY, Hamburg, Laboratory in May will host an ICFA seminar on 'Future Perspectives in High Energy Physics'. These seminars, held every three years, are among the most significant in-depth international reviews of the state of high energy physics, covering both the science itself and the essential accelerator tools. A major topic at the DESY Seminar will be TeV electron-positron linear colliders.

Fermilab Director John Peoples is ICFA Chairman 1993-5.

ICFA people

In January, John Peoples of Fermilab became ICFA Chairman (until December 1995), succeeding Alexander Skrinsky of Novosibirsk. Long-serving (since 1978) Secretary Owen Lock (CERN) retired from ICFA in December, his place being taken by Roy Rubinstein (Fermilab). Continuity is provided by Helga Schmal (CERN), who remains as Assistant Secretary.

Unification, small and large

Fruitful exchanges between particle physics, astrophysics and cosmology have become a common feature in the last decade. In January, Coral Gables near Miami was the stage for a 'Unified Symmetry in the Small and the Large' meeting.

Coral Gables is a famous physics venue. In January 1964, the year that the quark model of hadrons emerged, Behram Kursunoglu initiated a series of particle physics meetings that continued for 20 years and formed a regular focus for this development. The final such meeting was in 1983, coinciding with both the 80th birthday of field theory pioneer Paul Dirac, who worked in Florida towards the end of his career, and the discovery of the W bosons at CERN.

The resurrected Coral Gables meeting began with historical accounts of the emergence of Big Bang cosmology, by Robert Ralph and Herman Alpher, while Andrei Linde proposed our expanding universe as a small part of a stationary system, infinite both in space and in time.

The observational status of Big Bang cosmology was reviewed by Bruce Partridge, John Mather and Martin Harwit, emphasizing the cosmic background radiation, where temperature is now measured by the COBE satellite detectors to 2.726 ± 0.010K. The tiny fluctuations observed by COBE pose problems for standard cold dark matter models.

Edward ('Rocky') Kolb reported on new studies on the electroweak phase transition, based on an analogy with the physics of liquid crystals. Richard Holman discussed the fate of global symmetries at energies near the Planck (grand unification) energy, and Paul Steinhardt talked about tensorial and scalar metric fluctuations in the light of the COBE results.

Anthony Tyson gave an impressive description of dark matter studies using gravitational lensing, now emerging as a unique tool for indirectly observing intervening dark matter. A neutrino mass of 10 electronvolts could account for observed dark matter distributions, but fails to provide the necessary seeds for galaxy formation. A conservative limit for the cosmic mass density (Ω) is 0.2.

Theoretical problems of gravity and cosmology were dealt with by Behram Kursunoglu, Robert Brandenberger and Katherine Freese. Leonard Susskind emphasized the clash between general relativity and quantum theory arising through black hole singularities and their evaporation. Louise Dolan, Pran Nath and A. Jevicki looked at supergravity and superstring theories.

In the neutrino physics session chaired by Frederick Reines, Paul Langacker and Stephen Mintz reviewed the status of the solar neutrino problem, while Frank Avignone reported on the ongoing search for neutrinoless double-beta decay, providing an upper limit of 1.4 eV on a Majorana neutrino mass. Pierre Sikivie covered the ongoing search for axions.

After a theoretical introduction by Boris Kayser, the programmes of CP-violation studies, including the B-particle sector, at electron-positron colliders and at hadron machines, were outlined by Jonathan Dorfan and Vera Lueth respectively. While Dallas Kennedy reported on sensitive radiative electroweak corrections, Edward York-Peng Yao and Martin Einhorn looked at the growing use of effective Lagrangians to describe heavy particles at low energy.

Alan Krisch emphasized the importance of polarized beams for strong interaction studies, especially nonperturbative quark field theory (QCD) effects, and Frederick Zachariasen described new analytic methods to derive the heavy quark potential. Chiral QCD liquids and their role in the physics of heavy nuclei and neutron stars were covered by Brian Lynn. E.C.G. Sudarshan described a new way to look at the decays of kaons. Stephen Pinsky, Charles Thorn and Mark Samuel looked at special particle topics, while Peter Carruthers described galaxy distributions in an unconventional way, linking them to the properties of multihadron spectra.

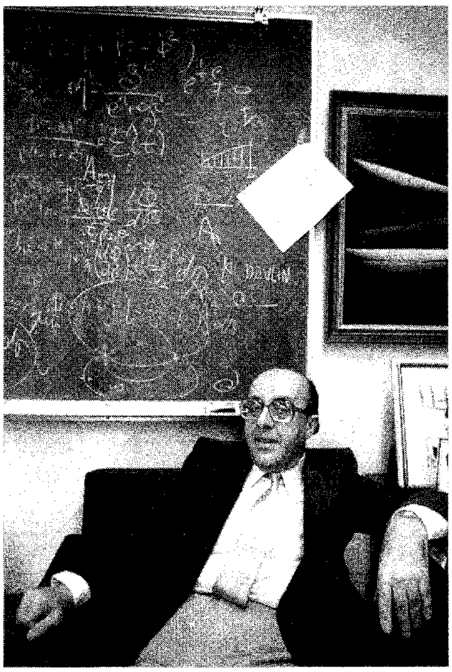
A substantial part of the time was given to speculations on the nature and origin of Standard Model constants, especially fermion masses. After an introduction by Yoichiro Nambu, Sydney Meshkov, Harald Fritzsch and Pierre Ramond outlined a new view of quark and lepton mass spectra as signals of new types of broken symmetries, opening a possible window to physics beyond the Standard Model.

Gordon Kane reviewed supersymmetric possibilities at high energies.

The revived Coral Gables meetings will now continue, hopefully seeing the emergence of physics beyond the Standard Model. This year's meeting was organized by Behram Kursunoglu of Coral Gables' Global Foundation, assisted by Sydney Meshkov (SSC), Stephen Mintz (Florida) and Arnold Perlmutter (Miami).

From Harald Fritzsch

Behram Kursunoglu - putting Coral Gables on the physics map.



Bookshelf

Perspectives of meson science, T. Yamazaki, K. Nakai and K. Nagamine, Eds., Elsevier, ISBN 0444895558

Unstable particles such as mesons and muons are now used in various domains of physics, chemistry, engineering, and life sciences. This book covers current applications and future perspectives from a very broad viewpoint, with 27 invited contributions from fields such as muon and muonium spin rotation, muon hyperfine interactions, muon catalyzed fusion, medical diagnostics, exotic atoms, mesons in nuclei, and exotic decays of mesons.

The examples are mainly drawn from work carried out at KEK in Japan and at TRIUMF in Vancouver under Japanese research grants, although major references are also made to results from Brookhaven, CERN, Los Alamos and PSI (Switzerland).

The book is, in a way, complementary with "The Meson Factories" (T. Ericsson, V. Hughes and D. Nagle, Eds.) published recently by the University of California Press, which summarizes research in the meson factories.

Magnetism, superconductivity, diffusion of hydogenlike impurities, and muonium chemistry, using positive muons stopped in solids, are the subjects of the first ten papers. Here spin rotation offers a unique tool, and the results have led to substantial theoretical work, deepening our understanding of condensed matter.

Two papers describe progress in muon catalyzed fusion. Although breakeven in energy production seems still remote, other applications are proposed in intense sources of 14 MeV neutrons for isotope production, and in sources of slow negative muons which could open new fields of meson science.

Advanced muon beam production is the topic of a fine paper by Nagamine and Ishida. They discuss many new ideas, including ultraslow muon beam production using re-emission from material surfaces (already used to produce bright positron beams), or beam cooling, familiar from electron and antiproton synchrotrons.

What happens when a negatively charged hadron or muon is stopped in condensed matter? This familiar question is debated in three papers dealing mainly with exotic atoms and other low-energy muon and hadron physics.

Hypernuclear spectroscopy and other hadron-induced nuclear phenomena are covered in the remaining ten papers. The physics covers many aspects of modern nuclear and particle physics, including meson production and other relativistic heavy ion topics .

In his review "Low-energy muon science" J.H. Brewer claims "Muon science is one of the most dramatic interdisciplinary scientific legacies of the 20th century...". The reader of this book will quickly agree.

By Tapio Niinikoski

Tapio Niinikoski addresses the recent 10th International Symposium on High Energy Spin Physics in Nagoya, Japan.

People and things

External correspondents

Argonne National Laboratory, (USA)
D. Ayres

Brookhaven, National Laboratory, (USA)
P. Yamin

CEBAF Laboratory, (USA)
S. Corneliussen

Cornell University, (USA)
D. G. Cassel

DESY Laboratory, (Germany)
P. Waloschek

Fermi National Accelerator Laboratory, (USA)
M. Bodnarczuk

GSI Darmstadt, (Germany)
G. Siegert

INFN, (Italy)
A. Pascolini

IHEP, Beijing, (China)
Qi Nading

JINR Dubna, (USSR)
B. Starchenko

KEK National Laboratory, (Japan)
S. Iwata

Lawrence Berkeley Laboratory, (USA)
B. Feinberg

Los Alamos National Laboratory, (USA)
O. B. van Dyck

Novosibirsk, Institute, (USSR)
V. Balakin

Orsay Laboratory, (France)
Anne-Marie Lutz

PSI Laboratory, (Switzerland)
J. F. Crawford

Rutherford Appleton Laboratory, (UK)
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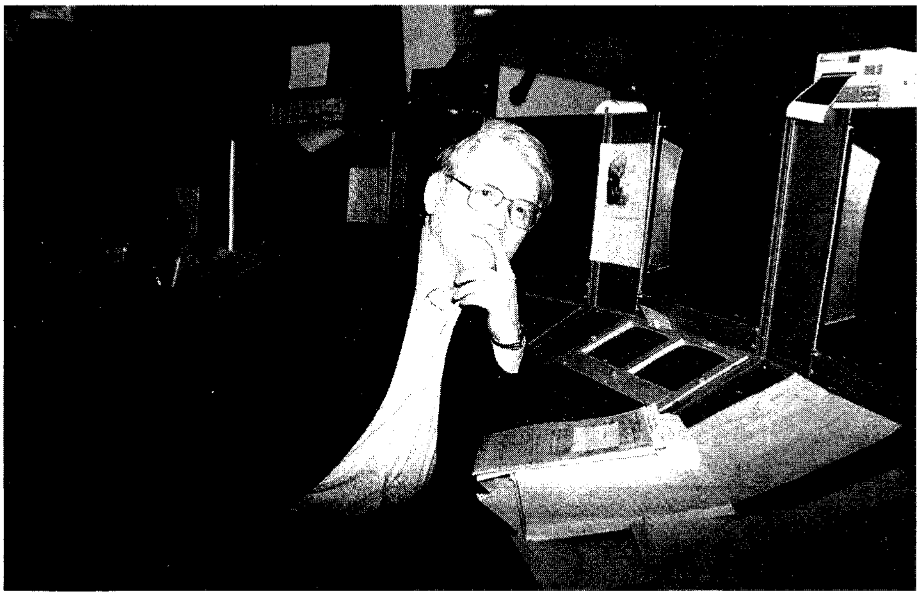

On 1 March, Bjorn H. Wiik (above) became Director (more accurately Chairman of the Directorate) of the DESY Laboratory in Hamburg.

(Photo Petra Harms)

Below: Retiring DESY Director Volker Soergel (right) receives Germany's Distinguished Service Cross (Verdienstkreuz 1. Klasse des Verdienstordens der Bundesrepublik Deutschland) from Gebhard Ziller of the Ministry of Research and Technology.

(Photo M. Müller)

Parke Rohrer (left), Brookhaven's Associate Director for Management and Physical Plant, receives his Outstanding Contractor Program Manager Award from William Happer, Director of the US Department of Energy's Office of Energy Research. As well as two spells at Brookhaven, Rohrer has contributed to a wide range of DoE projects, having been general manager of the joint venture of architects and engineers that built Fermilab from 1968-74.

Bjorn Wiik becomes DESY Director

On 1 March, Bjorn H. Wiik became Director (more accurately Chairman of the Directorate) of the DESY Laboratory in Hamburg, succeeding Volker Soergel, in office since January 1981.

Born in Norway in 1937, Bjorn Wiik moved to Germany in 1956 for seven years of physics studies. After several years research in the US, he came to DESY in 1972, where he became, with Gustav-Adolf Voss, one of the leaders of the HERA electron-proton collider project. Wiik had long been an advocate of the hitherto untried electron-proton approach, with the apparently structureless electrons probing the parts of protons other beams cannot reach. His was the special responsibility for the superconducting proton ring.

For the future, as well as developing the HERA programme, boosting synchrotron radiation possibilities and overseeing the integration of the Zeuthen institute in former East Berlin, he stresses DESY's continuing and challenging role in the international planning and development work for new accelerators, and sees the decreasing resources available in today's cost-conscious climate as stimulating creativity and new ideas.

Volker Soergel

Volker Soergel's 12-year spell as DESY Director ended on 28 February. For his contributions to the Laboratory in general, and in particular for his role in developing international research collaboration, especially with scientists from Eastern Europe, he was awarded Germany's Distinguished Service Cross (Verdienstkreuz 1. Klasse des Verdienstordens der Bundesrepublik Deutschland). Soergel now moves to Heidelberg, and becomes a member of Germany's delegation to CERN Council.

On people

After a two-year spell at the SSC Laboratory, Ray Stefanski returns to Fermilab to become Assistant Director, working with Associate Director for Technology Dennis Theriot.

Meetings

A Summer School on QCD Analysis and Phenomenology, organized by the CTEQ Collaboration (Coordinated Theoretical/Experimental Project on Quantitative QCD Phenomenology and Tests of the Standard Model), will be held from July 25-August 3 in Lake Monroe, Indiana. Jorge G. Morfin of Fermilab is Chairman. Further information from Cynthia M. Sazama, Fermilab MS 122, PO Box 500, Batavia, IL 60510; fax: 708-840-8589; e-Mail: CTEQSCHOOL@FNAL

The 6th European Conference on Integrated Optics, this time with an accompanying Technical Exhibit, claimed to be the first of its kind, takes place in Neuchâtel, Switzerland, from 18-22 April, at the Aula des Jeunes Rives, Espace Louis-Agassiz 1. Further information, fax +41 38 205 580.

An international meeting 'Neutral Currents Twenty Years Later', at the Ministère de la Recherche et de l'Espace, Paris, from 6-9 July will review the 1973 discovery of neutral currents and the current status of all fields of electroweak physics. Further

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University Lecturership in

EXPERIMENTAL PARTICLE PHYSICS

Applications are invited for the above post which commences 1 October 1993. Stipend according to age on the scale £ 13,400 to £ 26,407 per annum. The successful candidate may be offered a tutorial fellowship by Somerville College, for which additional emoluments would be available. Further particulars (containing details of the duties and full range of emoluments and allowances attaching to both the university and the college posts) may be obtained from Prof. R.J. Cashmore, Particle and Nuclear Physics, Keble Road, Oxford OX1 3RH.

The present experimental research programme of the Particle and Nuclear Physics Laboratory includes the DELPHI experiment at LEP (CERN) and ZEUS experiment at HERA (DESY); the SOUDAN 2 experiment; the Sudbury Neutrino Obeservatory project; the development of cryogenic detectors and preparations for high energy pp physics. The Department would expect the appointee to participate in some of the above programme, or possibly develop new initiatives associated with future accelerator or other project.

Applications (eight copies except in the case of overseas candidates when only one is required) should be sent to arrive no later than 7 May 1993. These should include a curriculum vitæ, list of publications, a statement of research interests and teaching experience and the names of three referees. Referees should be asked to send references direct to Prof. Cashmore to arrive by the above date.

Shortlisted candidates will be interviewed in Oxford on 10th and 11th June 1993. All applicants are asked to indicate a telex, fax email or telephone number where they can be contacted during the period 21st May to 2nd June.

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DESY

Das Deutsche Elektronen-Synchrotron DESY ist ein Zentrum der physikalischen Grundlagenforschung mit etwa 1.400 Mitarbeitern und ca.1.000 in- und ausländischen Gästen.

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für Betrieb und betriebsnahe Weiterentwicklung der umfangreichen Hochfrequenz-Anlagen in den Elektronen-und Protonenbeschleunigern bzw. Speicherringen von DESY; dazu Studien- und Projektierungsaufgaben für mögliche zukünftige Projekte. Es handelt sich um umfangreiche Anlagen mit Teilchenbeschleunigungsstrecken (Hohlraumresonatoren), Hohlleitersystemen zur Leistungsverteilung und Senderanlagen (gepulst wie auch Dauerstrich) im Megawattbereich bei Frequenzen zwischen 3 MHz und 3000 MHz; hierzu gehören ferner umfangreiche weitgehend prozessrechner-gestützte Mess-, Steuer- und Regeleinrichtungen.

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The EISCAT Scientific Association performs ionospheric research with incoherent scatter radar systems operated in northern Norway, Finland and Sweden. As an important step in the evolution of the EISCAT Scientific Association a new radar station, the EISCAT Svalbard Radar (ESR), will be built on the island of Spitsbergen in the Svalbard Archipelago north of Norway.

For the construction of the EISCAT Svalbard Radar instrumentation, a

System Integration Engineer

will be installed. This engineer will assist the Radar Project Engineer in technical matters and conduct and supervise digital engineering as well as the interfacing of digital and analogue instrumentation of the ESR system, work on the acquisition of auxiliary subsystems, specification and execution of test procedures, the implementation of monitoring and control systems and the integration, tests and quality control of the ESR system to be installed on Svalbard.

A highly qualified and well motivated individual, possessing a degree in electronic engineering, computer engineering or technical physics as well as practical knowledge of digital and analogue instrumentation is required. Familiarity with modern system software design is important and practical knowledge of RF engineering is desirable. The successful candidate should be prepared to be substantially involved in the practical construction of the radar system. An ability to communicate effectively in spoken and written English is essential. The system integration engineer will initially work at the EISCAT site in Tromsö, Norway, but must also be willing to spend considerable time at the Svalbard site during the system implementation and tests.

This position will be available for a period of four years through the entire construction, implementation, test and initial operation phase of the EISCAT Svalbard Radar. The salary will depend on qualifications and experience and will follow the corresponding Scandinavian scales.

More information on the EISCAT Scientific Association and a detailed description of the EISCAT Svalbard Radar can be obtained from The Director, EISCAT Headquarters, P.O. Box 812, S -981 28 Kiruna, Sweden (Tel. +46-980-79153. Fax +46-980-79161). Applications should be sent to the same address by 30 April 1993.

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On 18 January, a 'Festkolloquium' at the Hamburg DESY Laboratory marked the 60th birthday of theoretician Gustav Kramer, well known for his contributions to jet studies and heavy flavour transitions.

Magnetic field computation specialist C.W. ('Bill') Trowbridge, Chairman of Vector Fields and formerly of the Rutherford Appleton Laboratory, receives the UK's OBE award.

information - Ung Nguyen Khac, NC93, Ecole Polytechnique, 91128 Palaiseau cedex, France, email NC93@FRCPN11

CERN Accelerator School

The Fifth Advanced CERN Accelerator School will be held on the Island of Rhodes from 20th September until 1 October. The course, which complements the General School held in 1992, will mainly be of interest to staff in accelerator laboratories, university departments and companies specializing in the equipment for particle accelerators. It requires a knowledge, up to first degree level, of physics , mathematics or engineering. The course is being organised with the help of the University of Athens and N.C.S.R. Demokritos. Details and application forms are now available by e-mail (CASRHO@CERNVM.CERN.CH), by fax (+41 22 782 4836) or by writing to Mrs. S. von Wartburg, CERN Accelerator School, CH-1211 Geneva 23. (Please ignore a later date mentioned in an earlier issue).

Meanwhile the next CERN Accelerator School will be in Capri on the subject of Radio Frequency Engineering. This is organized with the help of INFN Frascati and Naples together with the Universita degli Studi di Napoli, Frederico II, Departimento di Scienze Fisiche, Naples. The dates are 29th April to 5th May.

12 April marks the 80th birthday of Venedikt Dzhelepov, now Honorary Director of the Joint Institute for Nuclear Research, Dubna.

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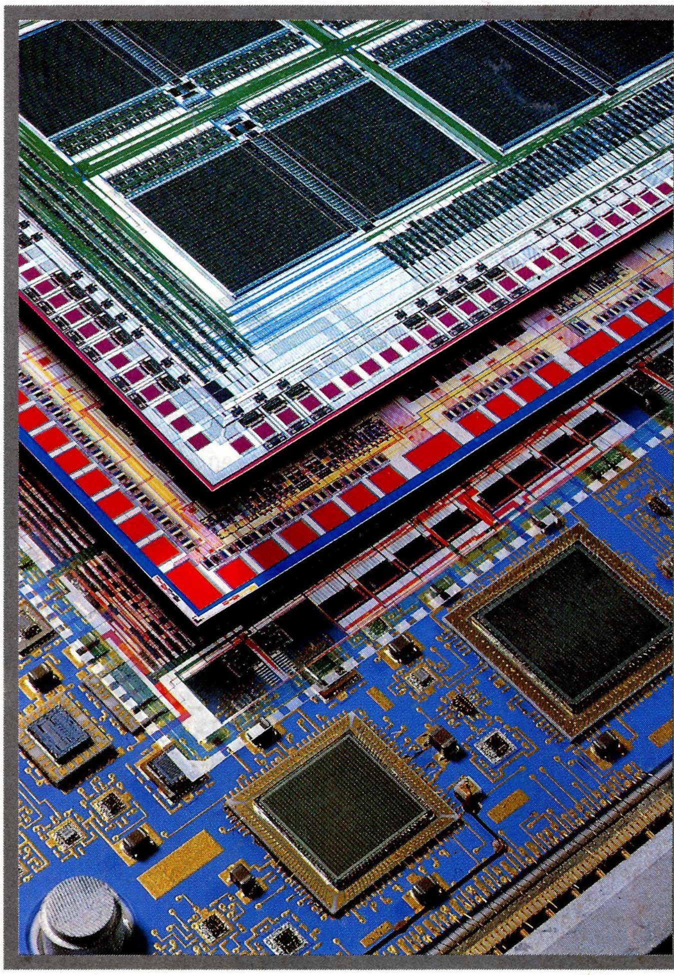

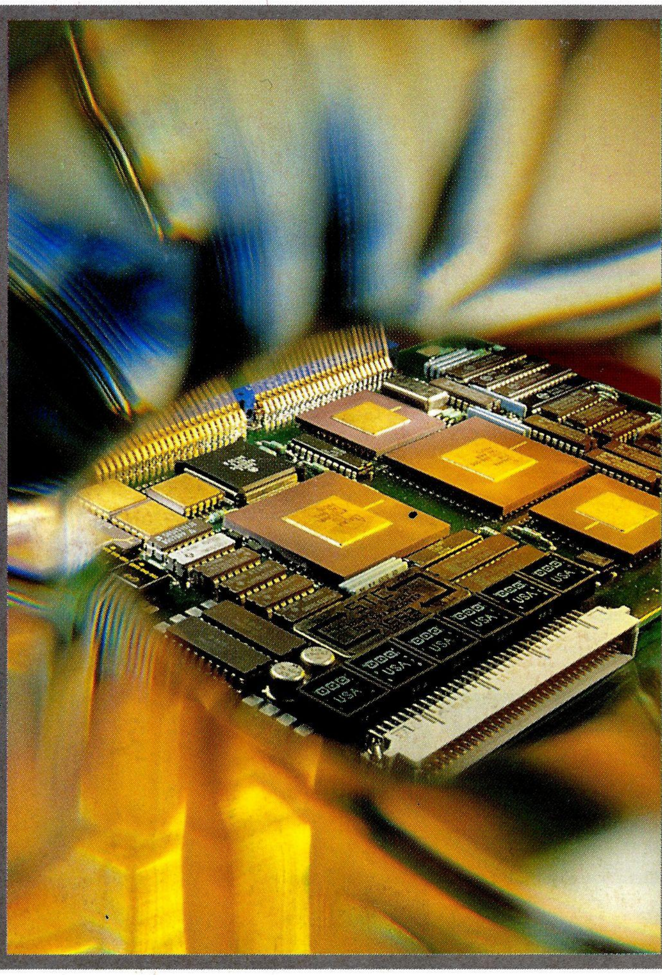

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