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APPLYING THE ACCELERATOR
SPECIAL ISSUE

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Covering current developments in high energy physics and related fields worldwide

Special issue - Applying the accelerator

Cover photograph: The accelerator applied. Proton beams from compact cyclotrons are used to bombard isotope targets for the manufacture of radio-pharmaceuticals. Of the 200 cyclotrons worldwide, around 35 are operated by commercial companies solely for the production of radio-pharmaceuticals. Another 25 accelerators produce medically useful isotopes. (Photo Amersham International plc UK)

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Special issue - applying the accelerator

Introduction

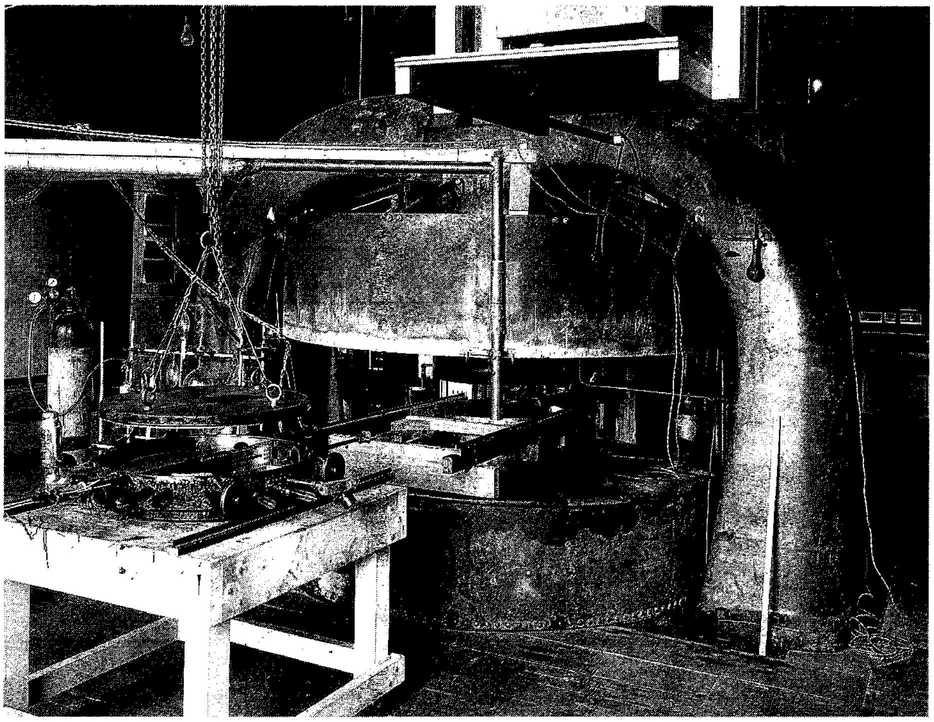
The CERN Courier is the international journal of high energy physics, covering current developments in and around this branch of basic science. A recurrent theme is applying the technology developed for particle accelerators, the machines which produce beams of high energy particles for physics experiments.

Twentieth-century science is full of similar examples of applications derived from pure research. This special issue of the CERN Courier is given over to one theme - the applications of accelerators.

Accelerator systems and facilities are normally associated with high-energy particle physics research, the search for fundamental particles and the quest to understand the physics of the Big Bang. To the layman, accelerator technology has become synonymous with large and expensive machines, exploiting the most modern technology for basic research. In reality, the range of accelerators and their applications is much broader. A vast number of accelerators, usually much smaller and operating for specific applications, create wealth and directly benefit the population, particularly in the important areas of healthcare, energy and the environment.

There are well established applications in diagnostic and therapeutic medicine for research and routine clinical treatments. Accelerators and associated technologies are widely employed by industry for manufacturing and process control. In fundamental and applied research, accelerator systems are frequently used as tools. The biennial conference on the Applications of Accelerators in Industry and Research at Denton, Texas, attracts a thousand participants.

This special issue of the CERN Courier includes articles on major applications, reflecting the diversity and value of accelerator technology. Under Guest Editor Dewi Lewis of Amersham International, contributions from leading international specialists with experience of the application end of the accelerator chain describe their fields of direct interest. The contributions are not meant to be exhaustive, but more as illustrations of the wide variety of uses to which accelerators have been harnessed.



The 27-inch cyclotron built by Ernest Lawrence at the Berkeley Radiation Laboratory in the early 1930s was the first accelerator used to produce radioactive isotopes for medical research.
(Photo LBL)

A hundred years of applications

It is appropriate to review the applications of accelerators in 1995 - the centenary year of the discovery of X-rays by Wilhelm Röntgen in Germany. While experimenting with electrical discharges from cathode-ray tubes shrouded with black cardboard, he inadvertently observed a "new kind of rays" which made solid objects transparent.

The implications of this discovery were immediately realized and the X-ray tube became the first particle accelerator to have applications beyond basic physics research. The radiographic applications of Röntgen's X-rays have become an essential part of everyday life and have profoundly improved the quality of our lives.

The subsequent 35 years brought many notable scientific discoveries, but particle accelerator technology remained limited to electrostatic

Medical applications

devices and voltages of less than 1MV.

The next major step forward was when Ernest Lawrence constructed the first cyclotron at Berkeley in 1932. Neutron beams became available and new artificially created radioisotopes were discovered. By 1936, Lawrence's 37-inch cyclotron was accelerating deuteron beams up to 8 MeV and providing most of the world's supply of neutrons and artificial radioactive isotopes.

Ernest Lawrence and his brother John were quick to recognize important medical applications for the cyclotrons - producing isotopes for biological and medical research, as well as isotopes and neutron beams for the treatment of cancer.

In 1938 Lawrence's mother became the first cancer patient to be treated successfully with neutrons from cyclotrons. Lawrence's drive and determination to improve accelerator performance and the quality of the engineering created the technology base for today's wide application of accelerators.

Since those early days, major advances in accelerator technologies have brought the Alvarez-type linac, Van de Graaff machines, klystron power sources, superconducting materials, synchrotron acceleration, and negative ion extraction. All these features have been incorporated into different types of accelerators - electrostatic accelerators, cyclotrons, microtrons, linacs and synchrotrons - used today for an increasingly broad range of applications.

In medicine, accelerators can be used in two ways - imaging and therapy.

For imaging, the accelerator generates radiation which is transmitted through the patient, or produces a radioactive material for subsequent injection. Analysis of the resulting radiation pattern from the patient's body is used for a diagnosis and to determine the appropriate treatment.

For therapy, the accelerator's radiation is itself the treatment, with a well defined radiation dose applied directly to the patient.

Imaging

In nuclear medicine, radioactive drug material (radio-pharmaceutical) is administered to patients and the resulting gamma ray distributions are detected by specialized gamma-cameras. Tomographic images of parts of the body are then prepared by computer techniques. This imaging provides diagnostic information on body function and metabolism which complements the anatomical or 'structural' images produced by other methods such as X-ray, computerized tomography (CT) or magnetic resonance imaging (MRI). Approximately 20 million patient procedures worldwide are carried out annually using radio-pharmaceuticals.

Isotope production

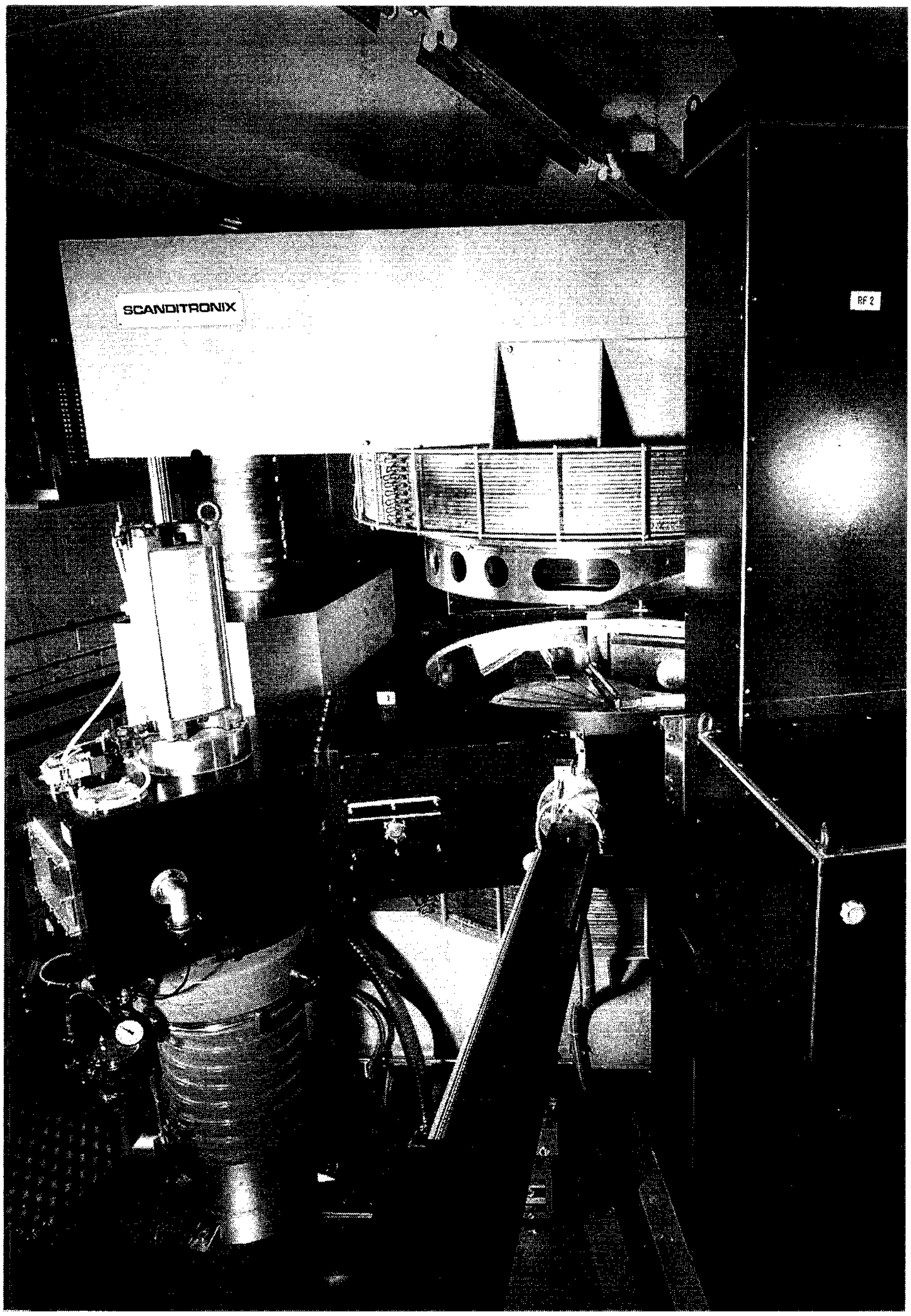
Some 20% of patients using radio-pharmaceuticals receive injections of materials produced by cyclotrons. There are over 200 cyclotrons worldwide; around 35 are operated by commercial companies solely for the production of radio-pharmaceuticals with another 25 accelerators producing medically useful isotopes.

These neutron-deficient isotopes are usually produced by proton bombardment. All commonly used medical isotopes can be generated by 'compact' cyclotrons with energies up to 40 MeV and beam intensities in the range 50 to 400 microamps. Specially designed target systems contain gram-quantities of highly enriched stable isotopes as starting materials. The targets can accommodate the high power densities of the proton beams and are designed for automated remote handling.

The complete manufacturing cycle includes large-scale target production, isotope generation by cyclotron beam bombardment, radio-chemical extraction, pharmaceutical dispensing, raw material recovery, and labelling/packaging prior to the rapid delivery of these short-lived products. All these manufacturing steps adhere to the pharmaceutical industry standards of Good Manufacturing Practice (GMP).

Unlike research accelerators, commercial cyclotrons are customized 'compact' machines usually supplied by specialist companies such as IBA (Belgium), EBCO (Canada) or Scanditronix (Sweden). The design criteria for these commercial cyclotrons are - small magnet dimensions, power-efficient operation of magnet and radiofrequency systems, high intensity extracted proton beams, well defined beam size and automated computer control. Performance requirements include rapid startup and shutdown, high reliability to support the daily production of short-lived isotopes and low maintenance to minimize the radiation dose to personnel.

In 1987 a major step forward in meeting these exacting industrial requirements came when IBA,



Proton beams from compact cyclotrons are used to bombard isotope targets for the manufacture of radiopharmaceuticals. Of the 200 cyclotrons worldwide, around 35 are operated by commercial companies solely for the production of radio-pharmaceuticals. Another 25 accelerators produce medically useful isotopes.
(Photo Amersham International plc UK)

together with the University of Louvain-La-Neuve in Belgium, developed the Cyclone-30 cyclotron. This was the first model to produce reliable, high intensity, extracted beam above 300 microamps; the first unit was installed at Amersham Medical Physics in the USA. Extracted beam is preferred so as to optimize target efficiencies and to maximize radiological shielding for target handling. In general, target station and remote handling systems are specific to individual companies and often incorporate proprietary commercial designs.

Cyclotron isotopes are delivered to nuclear medicine centres as sterile injectable pharmaceuticals containing a small radioisotope component with an activity up to 200 Mbequerels (or 5 mCuries). These isotope products are required to have just enough radioactivity to generate adequate diagnostic information from a 15-30 minute imaging period. But the activity of the injectable isotope should still be low enough to produce an effective dose to the patient of less than 5mSv (or 0.5 Rad). The gamma ray energy itself should be high enough to exit the patient tissue and avoid imaging complications from Compton scattering, but still low enough to allow efficient collimation at the gamma camera detector; gamma-ray energies in the range 50 to 300 keV are normally used.

The isotope half-life should allow for the extended manufacturing process and permit rapid delivery to hospitals, but should still be short enough to avoid a bio-dose problem to the patient.

Isotopes with half-lives of 3 days are most commonly used and there are over 30 medically useful cyclotron isotopes. Thallium-201 has become the most common cyclotron radio-pharmaceutical and is used routinely for heart imaging as a myocardial perfusion agent. It is produced by proton bombardment of thallium-203 at 25 to 28 MeV .

The world requirement for nuclear medicine imaging continues to grow at 7-8% per year. The demand for cyclotron isotopes continues, with specialist cyclotron companies manufacturing more efficient machines with proton beam intensities between 500 and 1000 microamps. Gamma camera manufacturers are improving their technology while the

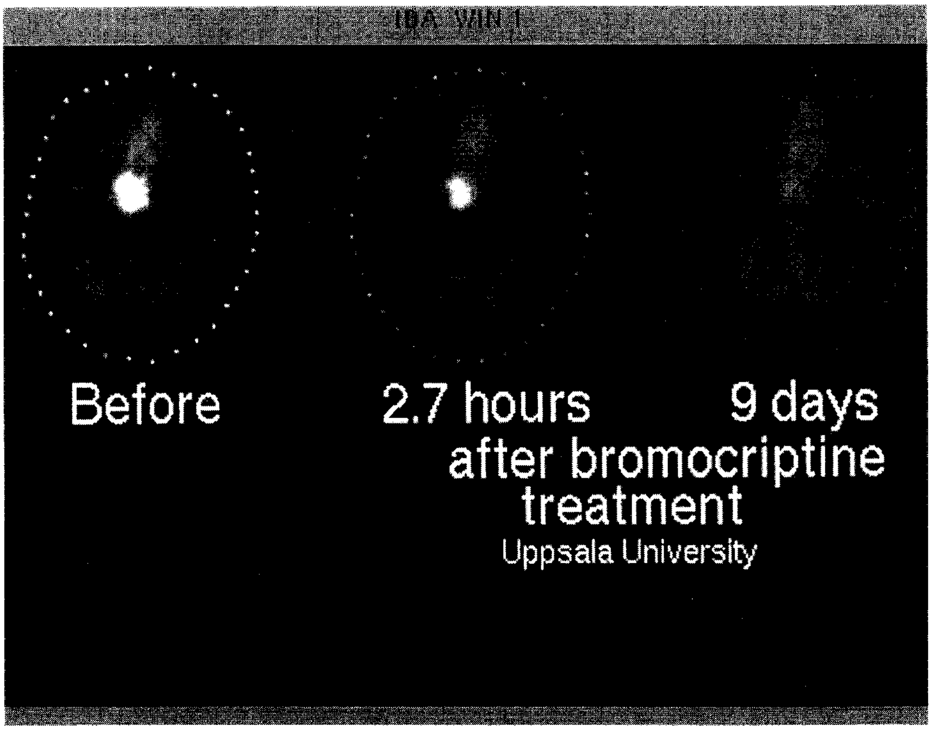
Common cyclotron radio-pharmaceuticals

Isotope	Half Life (hours)	Gamma-ray energy (keV)	Imaged organ
^{201}Tl	73.0	80	Heart
^{111}In	67.2	240	Infection
^{67}Ga	78.3	100 to 300	Abdomen
^{123}I	13.2	160	Thyroid

pharmaceutical companies are registering new products and procedures for cyclotron-produced isotopes.

From Dewi M. Lewis, Amersham International plc, Amersham, UK.

Positron Emission Tomography (PET) provides diagnostic information from tomographic measurements of the biochemistry and physiology of tissues and organs. If diseases are related to biochemical changes, these can be observed with PET long before any anatomical changes are detectable. This shows the results of carbon-11 methionine used in an investigation to estimate the effect of therapeutic drug treatment on a brain tumour. (Photo Uppsala University PET Centre, Sweden)



Positron emission tomography

Positron Emission Tomography (PET) is an advanced nuclear medicine technique used for research at major centres. Unique diagnostic information is obtained from tomographic measurements of the biochemistry and physiology of tissues and organs. In theory, diseases are related to biochemical changes and these can be observed with PET long before any anatomical changes are detectable.

In PET the radioactive component is a positron-emitting isotope or 'tracer'. The positrons annihilate with electrons in the body to produce two gamma rays 180° apart; coincidence detection of these gammas provides a very efficient method of determining the spatial distribution of the radioisotope tracer. Because physiological measurements are usually required in a single imaging session, very short-lived isotopes are used to label the tracer molecules; isotope production and labelling is usually carried out in situ. The most commonly used radionuclides are carbon-11 (half-life 20 minutes), nitrogen-13 (10 minutes), oxygen-15 (2 minutes), and fluorine-18 (110 minutes).

A PET system has three major components:

- a particle accelerator with targets for production of the positron-emitting isotopes;
- chemistry modules for synthesis and labelling of the desired tracers;
- and a PET camera for in-vivo measurements of the distribution of the tracer in the body.

Cyclotrons have become the standard accelerator for producing PET isotopes with typical protons energies of 10-18 MeV, and 5-9 MeV for deuterons with beam currents up to 75 microamps. Present-day PET cyclotrons are extremely compact, highly automated machines suitable for hospital environments and have little in common with the older laboratory-designed research machines.

All new PET cyclotrons are based on negative ion technology to facilitate beam extraction and minimize induced radioactivity build-up. Closed-loop computer control manages startup, tuning and irradiation, leaving only the choice of labelling compound and a few initial irradiation parameters to be determined by the user. With the exception of oxygen-15, the radioactivity level needed for a typical scan is 200 MBecquerel. A single production batch will be sufficient for two or more patient scans.

PET has expanded since the mid 1970s and there are now about 140 PET centres worldwide, half of them in North America. The PET procedure is similar to conventional isotope imaging but with improved sensitivity and spatial resolution. PET can image and measure quantitatively new biochemical parameters such as blood flow, fatty acid and glucose utilization, oxygen metabolism, amino acid transport, receptor densities and occupancy in the brain and other organs. The most com-

PET production

Radionuclide	Nuclear Reaction
C-11	$^{14}N(p,\alpha)^{11}C$
N-13	$^{16}O(p,\alpha)^{13}N$
O-15	$^{14}N(d,n)^{15}O$
F-18	$^{18}O(p,n)^{18}F$

monly used tracer is fluorine-18 deoxyglucose (FDG), a sugar analogue used in studying glucose metabolism in the brain and other organs. Researchers have been able to label more than 500 different PET compounds but kinetic biochemical models only exist for about 15 of these.

Promising applications exist in fields of oncology, neurology and cardiology. In oncology, PET is used to detect type and grade of primary tumours and metastases, the extent of tumours prior to surgery, to differentiate radiation necrosis from tumour, and to assess the degree of malignancy of lesions and their response to surgical or drug therapy.

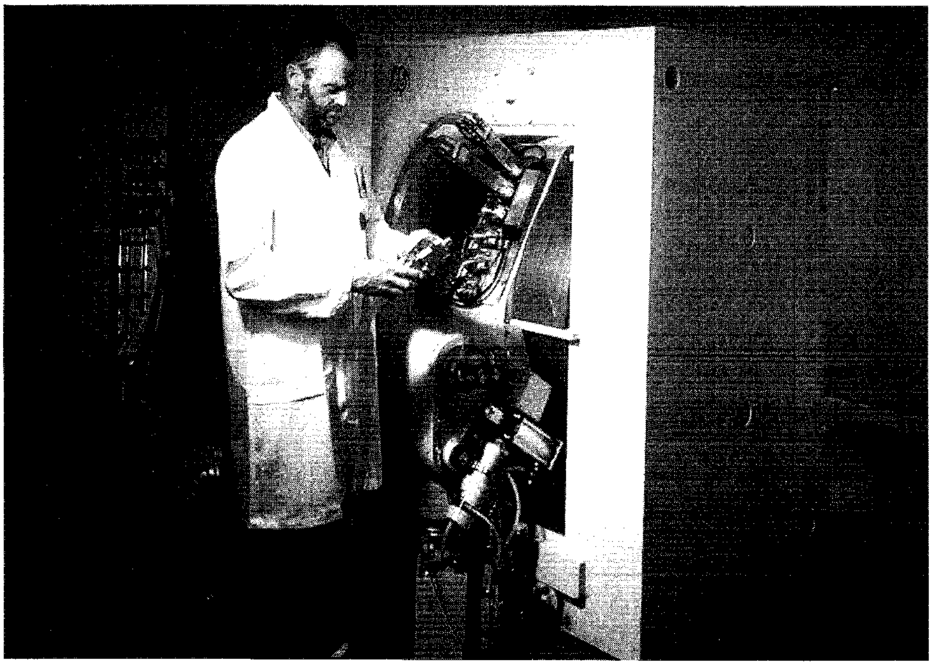
Applications in neurology include localization of seizure foci in epileptic patients, early detection of Alzheimer's disease, and differential diagnosis of movement disorders such as Parkinson's disease. In cardiology, PET is used for assessment of myocardial tissue viability, which is often a prerequisite for a bypass operation. Diagnosis by other methods often fails to identify tissue viability, possibly leading to unnecessary surgery. Assessment of coronary artery disease is another important PET application area in cardiology.

The world demand for new PET systems is estimated to be 15-20 units per year. Although it is not yet a routine clinical procedure, it is expected that once insurance companies start reimbursement for PET studies, then clinical use will grow rapidly. Recently the US Federal Drug Administration (FDA) approved the use of FDG as a diagnostic drug for the study of epilepsy.

General Electric and Siemens both supply complete PET systems, comprising cyclotron and camera, and enjoy around 90% of the market. Several smaller companies either manufacture cyclotrons (IBA and Oxford Instruments) or PET cameras (Positron Corporation and Shimadzu). Recently low energy linacs have been proposed for PET, but at the low linac energy of 4 MeV, high beam currents are needed to reach the required isotope yields.

Commercial manufacturers clearly face a challenge to expand the market for PET by reducing equipment capital costs and by designing systems that increase patient throughput.

From Stig Lindback, GEMS PET Systems AB, *Uppsala, Sweden*



A 11 MeV compact cyclotron with negative hydrogen ion extraction for generating very short-lived PET isotopes. Present-day PET cyclotrons are extremely compact, highly automated machines for hospital environments and have little in common with the older laboratory-designed research machines. (Photo GE Medical Systems, Uppsala, Sweden)

Therapy

As life expectancy steadily improves, the incidence of cancer also increases as the population ages. Up to 50% of cancer patients undergo radiotherapy - a form of protracted biological surgery by selective sterilization of malignant cells.

X-ray radiotherapy

The most common form of radio therapy is X-ray therapy, where a beam of photons or their parent electrons break down hydrogen bonds within the body's cells and remove certain DNA information necessary for cell multiplication. This process can eradicate malignant cells leading to complete recovery, to the remission of some cancers, or at least to a degree of pain relief.

The radiotherapy instrument is usually an electron linac, and the electrons are used either directly in 'electrotherapy' for some 10% of patients, or the electrons bombard a conversion target creating a broad beam of high energy photons or 'penetration X-rays'.

The simplest machine consists of several accelerating sections at around 3 GHz, accelerating electrons to 6 MeV; a cooled tungsten target is used to produce a 4 Gray/min X-ray field which can be collimated into a rectangular shape at the patient position. This tiny linac is mounted inside a rotating isocentric gantry above the patient who must remain perfectly still. Several convergent beams can also be used to increase the delivered dose.

More sophisticated accelerators operate at up to 18 MeV to increase penetration depths and decrease skin exposure. Alternatively, electrotherapy can be used with different energies for lower and variable penetration depths - approximately 0.5 cm per MeV. In this way surface tissue may be treated without affecting deeper and more critical anatomical regions.

This type of linac, 1 to 2 metres long, is mounted parallel to the patient with a bending magnet to direct the beam to the radiotherapy system, which includes the target, thick movable collimator jaws, a beam field equalizer, dose rate and optical field simulation and energy controls.

There are over 2000 accelerator-based X-ray treatment units worldwide. Western countries have up to two units per million population, whereas in developing countries such as Bangladesh, the density is only one per 100 million.

Several major medical equipment companies manufacture X-ray therapy systems - General Electric, Mitsubishi, Philips, Siemens and Varian. In this crowded marketplace where the useful lifespan of machines exceeds 10 years, purchase prices are less than $1 million per unit.

X-ray therapy remains the most common and cheapest form of accelerator therapy. Ongoing technical developments aim to achieve better matching of dose delivery to tumour volume; multileaf collimators shape the X-ray field to the biomedical target, and portal imaging from behind the patient can control positioning and dose delivery.

Combined compact X-ray sources are being developed with both treatment and realtime dosimetry control, incorporating CT scanning into one single device. Integrated diagnosis and therapy is the direction for R&D investment, and this should lead to smaller hospital space requirements, lower operating costs, and elimination of external data handling, resulting in simpler and more cost effective clinical procedures.

From D Tronc, General Electric Medical Systems, Paris

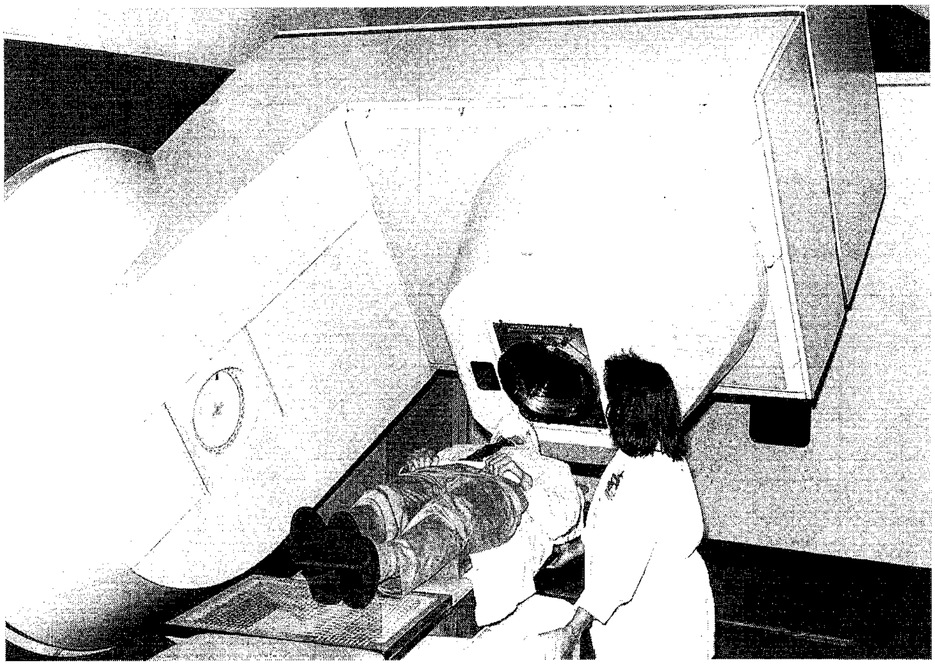
Neutron therapy

Standard radiotherapy uses X-rays or electrons which have low LET (linear energy transfer); in contrast, particles such as neutrons with high LET have different radiobiological responses. In the late 1960s, clinical trials by Mary Catterall at the Hammersmith Hospital in London indicated that fast neutron radiation had clinical advantages for certain malignant tumours.

Following these early clinical trials, several cyclotron facilities were built in the 1980s for fast neutron therapy, for example at the University of Washington, Seattle, and at UCLA. Most of these newer machines use extracted cyclotron proton beams in the range 42 to 66 MeV with beam intensities of 15 to 60 microamps. The proton beams are transported to dedicated therapy rooms, where neutrons are produced from beryllium targets.

Second-generation clinical trials showed that accurate neutron beam delivery to the tumour site is more critical than for photon therapy.
In order to achieve precise beam geometries, the extracted proton beams have to be transported through a gantry which can rotate around the patient and deliver beams from any angle; also the neutron beam outline ("field shape") must be

In the late 1960s, clinical trials showed that fast neutron radiation had clinical advantages for the treatment of certain cancers. In modern neutron therapy centres, protons from a cyclotron bombard a beryllium target to generate a collimated beam of neutrons. (Photo University of Washington, Seattle)



adjusted to extremely irregular shapes using a flexible collimation system.

A therapy procedure has to be appropriately organized, with physicians, radiotherapists, nurses, medical physicists and other staff in attendance; other specialized equipment, such as CT or MRI scanners and radiation simulators must be made available. Neutron therapy is usually performed only in radiation oncology departments of major medical centres.

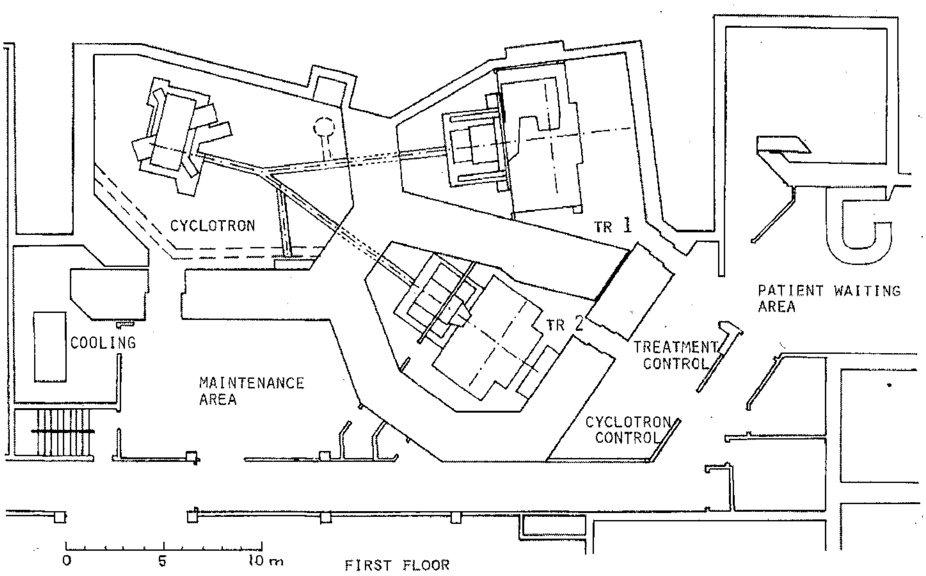
However neutron therapy is much more expensive than conventional photon or electron therapy. Often the cyclotron operation has to be shared with other users, particularly since beam-time for an actual therapy run is only a few minutes but involves considerable set-up periods between runs; radioisotope or PET production may be performed concurrently with neutron therapy. At present there are about a dozen neutron therapy facilities worldwide, but due to limitations of fixed beams, low energies or low intensities, only a few of these can deliver the precision beams required .

Clinical results with neutron therapy are very encouraging for certain specific tumour sites; for salivary gland tumours neutron therapy is considered the treatment of choice. Other promising areas of clinical research are advanced adenocarcinoma of the prostrate, some head and neck tumours, some lung cancers and sarcomas of bone and soft tissue.

For future neutron therapy systems there is a choice between two basic designs:

- a small cyclotron with internal target, mounted directly on the therapy gantry in a very compact machine dedicated to neutron therapy (such as that developed for Harper Hospital in Detroit using a superconducting deuteron cyclotron at 48.5 MeV); or
- a cyclotron in a separate vault with a beamline feeding one or more therapy rooms with rotating isocentric gantries. This type of facility has been built commercially, e.g. a 60 MeV system by Scanditronix.

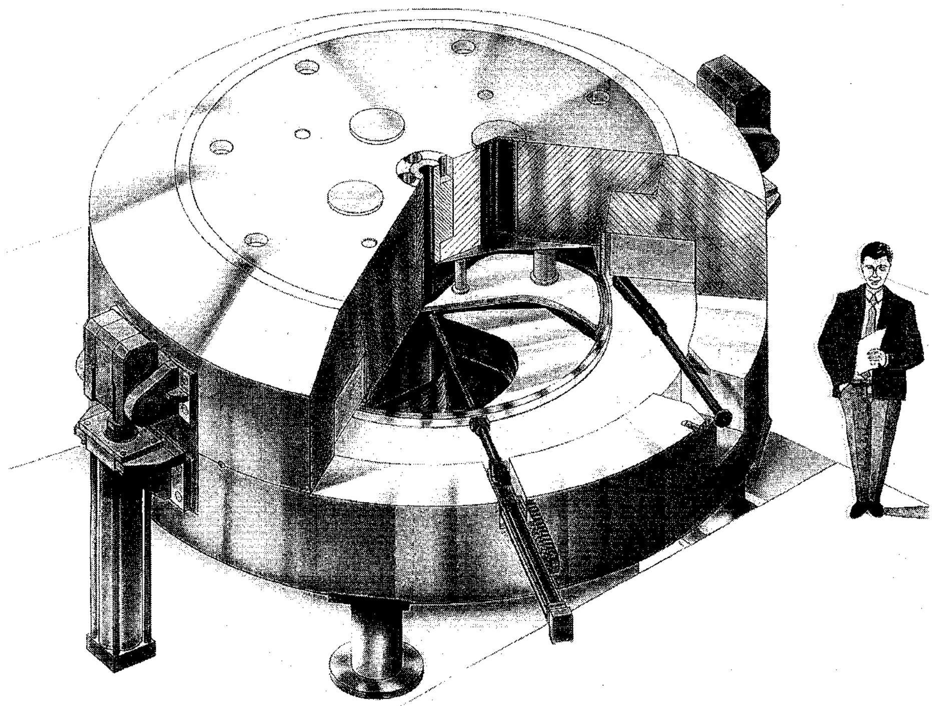
Like X-ray therapy, future developments in this field depend on reducing the cost of therapy systems and providing total systems suitable for hospital environments with limited technical and engineering resources.



Layout of a neutron therapy centre

To be clinically effective, energies of several hundred MeV are required for proton therapy. Pioneering projects had to work with complex, inadequate equipment originally intended for nuclear physics research, but recently a number of specialist organizations and commercial companies have been working on dedicated systems for proton therapy. This is an artist's view of a 235 MeV negative ion cyclotron for cancer therapy. This fixed energy isochronous cyclotron's magnet system is optimized for high magnetic field but is still small enough to be installed in a hospital; it can deliver beams of up to 1.5 microamps for treating certain categories of tumours.

(From IBA, Louvain-la-Neuve, Belgium)



As with other therapy methods, the accelerator is only one component, and it is important that manufacturers are able to offer integrated medical service systems

From Rudi Riesler, University of Washington, Seattle, USA

Proton therapy

Ideal radiotherapy deposits a large amount of energy in the tumour volume, and none in the surrounding healthy tissues. Proton therapy comes closer to this goal because of a greater concentration of dose, well defined proton ranges and points of energy release which are precisely known - the 'Bragg peak'.

In the past, the development of clinical proton therapy has been hampered by complexity, size, and cost. To be clinically effective, energies of several hundred MeV are required; these were previously unavailable for hospital installations, and pioneering institutions had to work with complex, inadequate equipment originally intended for nuclear physics research.

Recently a number of specialist organizations and commercial companies have been working on dedicated systems for proton therapy. One, IBA of Belgium, has equipment for in-house hospital operation which encompasses a complete therapy centre, delivered as a turnkey package and incorporating a compact, automated, higher energy cyclotron with isocentric gantries. Their system will be installed at Massachusetts General Hospital, Boston.

The proton therapy system comprises:

- a 235 MeV isochronous cyclotron to deliver beams of up to 1.5 microamps, but with a hardware limitation to restrict the maximum possible dose;
- variable energy beam (235 to 70 MeV) with energy spread and emittance verification;
- a beam transport and switching system to connect the exit of the energy selection system to the entrances of a number of gantries and fixed beamlines. Along the beam transport system, the beam characteristics are monitored with non-interceptive multiwire ionization chambers for automatic tuning;
- gantries fitted with nozzles and beamline elements for beam control; both beam scattering and beam wobbling techniques are available for shaping the beam;
- a control system including an "accelerator control unit" with independent and networked "therapy control stations". Through this network, each of the therapy control systems can also take over the computer-based unit controlling the cyclotron, the beamline and the gantry optics;
- a safety management system, independent of the control system, using hardwired interlocks and independent programmable logic controllers;
- a robotic patient positioning system, with monitoring equipment completely surrounding the patient.

A few companies have proposed other systems, which may differ in concept designs for the gantries, nozzles, patient positioners or safety and control systems. The proton therapy system at the Loma Linda University Medical Centre, California, is based on a proton synchrotron and was built by the Fermi National Accelerator Laboratory, the Loma Linda University, the Lawrence Berkeley Laboratory and Science Applications International Corporation (SAIC) of San Diego.

From Y. Jongen, IBA S.A., Louvain, Belgium

Industrial applications

As well as providing proton beams for cancer treatment, accelerators have also been used with particles with higher linear energy transfer (LET). Pioneer work with pions has been carried out at the accelerators at TRIUMF (Vancouver), the Swiss Paul Scherrer Institute and at Los Alamos. Therapy using ion beams is considered promising. The first clinical trials were at Berkeley, and an active programme has started at the GSI heavy ion Laboratory, Darmstadt, using ions up to 300 MeV per nucleon.

Confidence in ion therapy is so high that a $326 million dedicated synchrotron facility - HIMAC, the Heavy Ion Medical Accelerator in Chiba - has recently been completed near Tokyo. Ions from helium to argon can be accelerated up to 800 MeV per nucleon for difficult cancers, such as those in the head or neck, and preliminary work with carbon ions has shrunk tumours.

High capital and operating costs will inevitably restrict the availability of this therapy.

Interest in proton therapy is particularly high in the treatment of ocular melanoma where there is no alternative treatment, and success rates of up to 90% have been reported.

In manufacturing industry, beams from particle accelerators can be used for a variety of purposes:
- to improve the quality or finish of a product, as in the sterilization of medical equipment;
- to alter the material composition, as in ion implantation;
- to manufacture components, as in silicon wafer production;
- to provide information about manufacturing processes, such as wear studies of materials.

These industrial applications frequently require small but well engineered accelerator systems giving reliable performance.

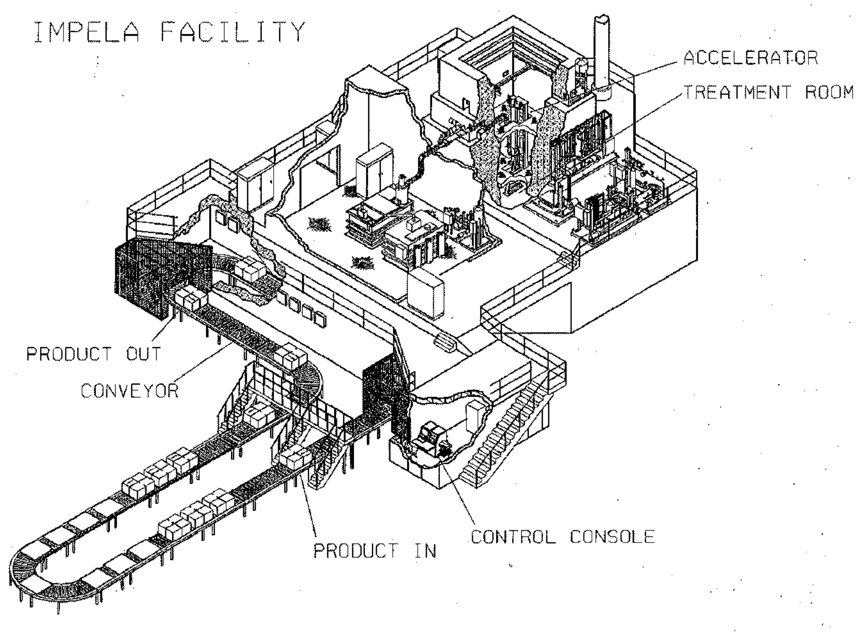
Industrial irradiation

Production lines for rubber gloves would not appear to have much in common with particle physics laboratories, but they both use accelerators. Electron beam irradiation is often used in industry to improve the quality of manufactured goods or to reduce production cost. Products range from computer disks, shrink packaging, tyres, cables, and plastics to hot water pipes. Some products, such as medical goods, cosmetics and certain foodstuffs, are sterilized in this way.

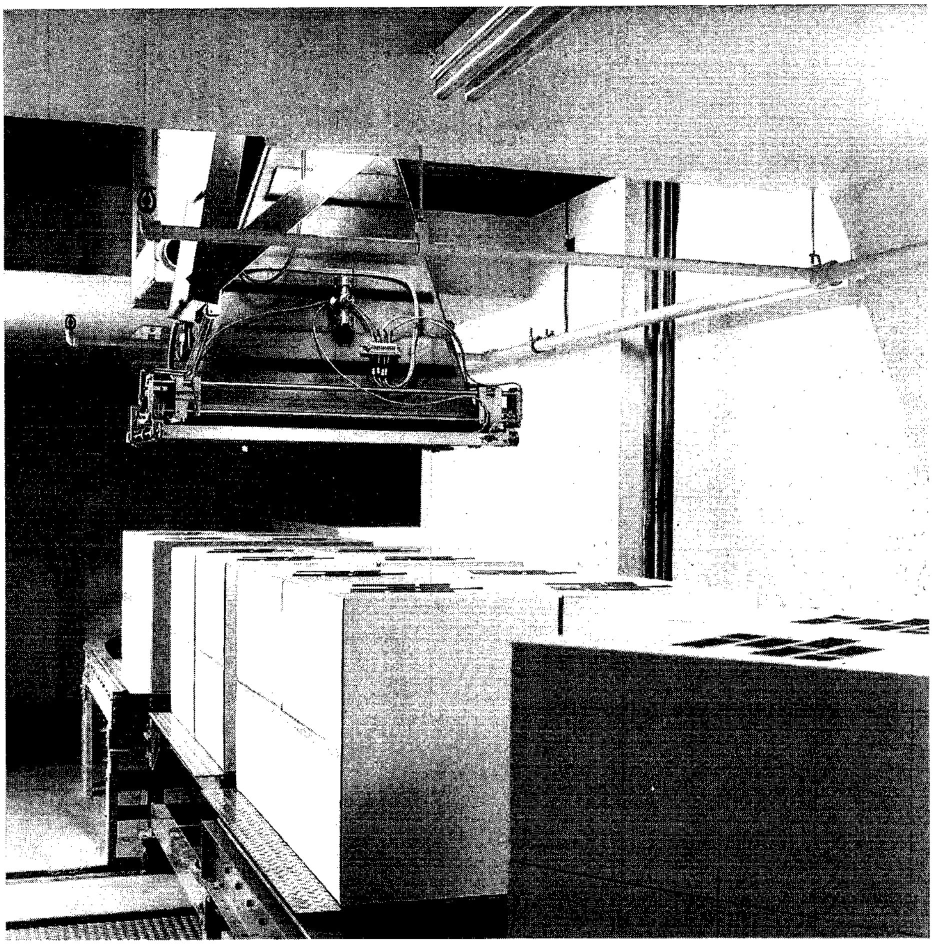
In electron beam irradiation, electrons penetrate materials creating showers of low energy electrons. After many collisions these electrons have the correct energy to create chemically active sites. They may either break molecular bonds or activate a site which promotes a new chemical linkage.

This industrial irradiation can be exploited in three ways: breaking down a biological molecule usually renders it useless and kills the organism; breaking an organic molecule can change its toxicity or function; and crosslinking a polymer can strengthen it.

In addition to traditional gamma



In this schematic of an industrial irradiation plant, a conveyor mechanism moves large containers through the radiation from an electron beam accelerator, The container contents are processed or sterilized. (Photos AEC Accelerators, Kanata, Canada)



Electron beam irradiation is often used in industry to improve the quality of manufactured goods or to reduce production cost.

irradiation using isotopes, industrial irradiation uses three accelerator configurations, each type defining an energy range, and consequently the electron penetration depth. For energies up to 750 kV, the accelerator consists of a DC potential applied to a simple wire anode and the electrons extracted through a slot in a coaxially mounted cylindrical cathode. In the 1-5 MeV range, the Cockcroft-Walton or Dynamitron(R) accelerators are normally used. To achieve the high potentials in these DC accelerators, insulating SF_6 gas and large dimension vessels separate the anode and cathode; proprietary techniques distinguish the various commercial models available. Above 5 MeV, the size of DC accelerators render them impractical, and more compact radiofrequency-driven linear accelerators are used.

Irradiation electron beams are actually 'sprayed' over the product using a magnetic deflection system. Lower energy beams of up to 750 keV are able to penetrate thin films, and processes have been developed for curing coatings such as inks and paints on metals and papers. Examples include beer cans, gift wrap, and glossy packaging where multicolour labels must be printed at high speed and there is no time for the ink to dry; electron beams are able to 'cure' instantly.

Another widespread electron-treated product is shrink film for packaging, where a polyethylene film, crosslinked during stretching, will, when heated, revert to its original shape. This 'memory' effect has widespread use in shrinkable connectors, such as tubes for electrical solder joints. Shrink tubes are also used to join gas pipelines and have also been made delicate enough for use by surgeons to reconnect human blood vessels.

Electron beams between 1 and 5 MeV are widely used to toughen and increase the fire and scuff resistance of wire cables. A similar process is used to increase the service temperatures of polyethylene pipes and tanks for hot water.

At energies up to 10 MeV, electrons sterilize syringes, gloves, cosmetics and pharmaceuticals, and recently, electron-curable epoxies have been developed for the production of aerospace parts. Electron treatments cure parts more rapidly than heat and induce less stress.

In France, the first plant for food irradiation using an accelerator will ensure that mechanically-deboned chicken is salmonella-free. Despite considerable research, the use of electron accelerators for food treatment is still largely undeveloped, the financial arguments remaining unconvincing.

Environmental applications are also largely undeveloped. Accelerators have been shown to disinfect sewage sludge so that it can be spread directly onto farmland, gardens or parks, with acceptably low pathogen levels. Pilot trials are also in progress to use electron beams to eliminate nitrous and sulphurous oxides from power station flue gas.

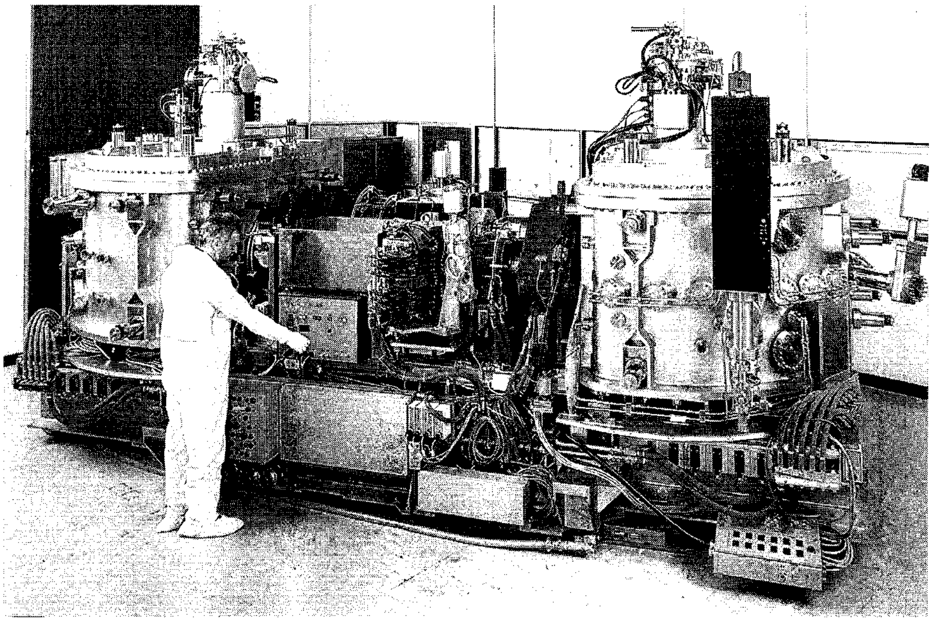
The economic and political environment of radiation processing is constantly changing. Although accelerator development opens up new technology, costs and regulations are also increasing. The technological exploitation of accelerators with energies to up to 5 MeV is seen as mature; 10 MeV electron accelerators have been upgraded to industrially significant power levels, and system improvements have reached the levels of reliability and efficiency demanded for operation by industry.

From Andrew J Stirling, AECL Accelerators, Kanata, Ontario, Canada

Thin layer activation

The reliability of industrial equipment is substantially influenced by wear and corrosion; monitoring can prevent accidents and avoid down-time. One powerful tool is thin layer activation analysis (TLA) using accelerator systems. The information is used to improve mechanical design and material usage; the

X-ray lithography is a technique for replicating patterns by shadow printing. HELIOS 1, a compact racetrack synchrotron for X- ray lithography, was assembled and tested prior to installation at IBM's semiconductor manufacturing facility at East Fiskill, NY, USA. (Photo Oxford Instruments plc, UK)



technology is used by many large companies, particularly in the automotive industry, e.g. Daimler Benz.

A critical area of a machine component receives a thin layer of radioactivity by irradiation with charged particles from an accelerator - usually a cyclotron. The radioactivity can be made homogeneous by suitable selection of particle, beam energy and angle of incidence. Layer thickness can be varied from 20 microns to around 1 mm with different depth distributions; the position and size of the wear zone can be set to within 0.1 mm. The machine is then reassembled and operated so that wear can be measured.

An example is a combustion engine comprising piston ring, cylinder wall, cooling water jacket and housing wall, where wear measurements on the cylinder wall are required in a critical zone around the dead-point of the piston ring. Proton beam bombardment creates a radioactive layer whose thickness is known accurately, and characteristic gamma radiation from this radioactive zone penetrates through the engine and is detected externally. Measurements can be made either of the activity removed from the surface, or of the (reduced) residual activity; wear measurement of the order of 10^{-9} metres is possible.

The particles employed are usually protons, deuterons or alpha particles with energies from 6 to 10 MeV giving sub-millimetre penetration depths in solids. One useful reaction uses cobalt-56, produced by 11 to 14 MeV proton bombardment of iron-56, where the reaction rate changes rapidly with energy, resulting in a variation of induced activity with penetration. Beam current will be adjusted in the range up to 10 microamps so that the radiation dose is below 0.1% of the critical dose at which radiation damage can occur.

For large machine parts, a proton beam extracted from a cyclotron via a thin window is directed onto the device some 150 mm away.
A precision 3-dimensional alignment system rotates the machine part around any axis to produce the required depth profile.

The gamma radiation is measured by conventional sodium iodide detectors with fast electronics; several radionuclides may be produced but energy discrimination and analysis of the radioactive decay can unravel the different nuclides.

Thin layer activation procedures have been developed in numerous irons, steels and alloys as well as sintered and other hard materials. Procedures have recently been developed in collaboration with industry for ceramics and several other hard materials.

From H. Schweickert and P. Fehsenfeld, Kernforschungszentrum Karlsruhe Gmbh (KFK), Germany

X-ray lithography

X-ray lithography is a technique for replicating patterns by shadow printing. The required pattern is created on a mask which is then positioned accurately in front of a wafer coated with a sensitive material known as a photoresist. X-rays shone through the mask cast a shadow on the wafer, thereby transferring the pattern from mask to wafer, and short X-ray wavelengths make high spatial resolution possible. The process is now being developed as a technique for producing the next generation of microchips and components.

Synchrotron radiation is broad spectrum, high intensity electromagnetic radiation generated when high energy electrons are deflected in a magnetic field (see page 20). Produced in multi-GeV electron synchrotrons and storage rings, synchrotron radiation provides the best X-ray sources for lithography, where high intensities (beam currents) are

ACCEL

ACCEL Instruments GmbH
Friedrich-Ebert-Strasse 1
D-51429 Bergisch-Gladbach
Phone: +49/2204/842500
Fax: +49/2204/842501

Contact person(s) at the stand/ in the enterprise:
Mr Dr. Hans-Udo Klein

Production line:
- Normal and Superconducting Rf Cavities
- Normal and Superconducting Magnet Systems
- Cryogenic, Vacuum and RF Systems
- Beamline and Experimental Equipment
- Monochromators
- Accelerator Modules and Systems
- Beryllium Components
- Specialised job shop services

Exhibited products:
- Superconducting Cavities
- UHV Vacuum Chambers
- Specific coil samples from Superconducting Magnets
- Various representative components

AFT
ADVANCED FERRITE TECHNOLOGY

AFT
Advanced Ferrite
Technology GmbH
Spinnerei 44
D-71522 Backnang
Phone: +49/7191/96590
Fax: +49/7191/965920

Contact person(s) at the stand:
Mr Dr. Arnold

in the enterprise:
Mr Dr. Arnold, Mr Weiser

Production line:
- High Power Circulators
- Fast Ferrite Tuner
- Phaseshifter
- Matching Network

Exhibited products:
High Power Circulator

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apra-norm Elektromechanik GmbH
Holunderweg 5
D-54550 Daun-Boverath
Phone: +49/6592/2040
Fax: +49/6592/7668

Contact person(s) at the stand/ in the enterprise:
Mr Appenzeller, Mr Schneider

Local Representative:

FS Elektrohandel + Consulting GmbH
Gartenstrasse 8a
CH-8552 Felben
Phone: +41/54/652225
Fax: +41/54/652225

Contact person(s) in the enterprise:

Mr Schneider

Production line / exhibited products:
19"- racks
- cabinets
- subunits
- blowers

DEUTSCHE BABCOCK

BABCOCK ROHRLEITUNGSBAU

BABCOCK ROHRLEITUNGS-
BAU GMBH
Duisburger Strasse 375
D-46049 Oberhausen
Phone: +49/208/8332286
Fax: +49/208/8334670

Contact person(s) at the stand/ in the enterprise
Mr Dipl.-Ing. H. Esgen

Production line / exhibited products:
Helium Transfer Line:
Babcock Rohrleitungsbau GbmH, Oberhausen, devision „Nuclear Plants" planned, delivered, installed and took into operation the helium transfer line for DESY HERA together with LINDE AG, Kryotechnik in the time from 1987 to 1989.
The 6.3 km long helium transfer line serves for cooling the Hera magnets with liquid helium (4.5 K) and has been operated until now without any objections

Balzers-Pfeiffer

Balzers-Pfeiffer GmbH
Emmeliusstrasse 33
D-35614 Asslar
Phone: +49/6441/8020
Fax: +49/6441/802202

Contact person(s) at the stand:
Mr Karl Abbel

in the enterprise:
Mr Karl Abbel, Mr Heinz Barfuß,
Mr Kuno Herrmann

Local Representative:

Balzers Hochvakuum AG
P.O. Box 437
CH-8037 Zürich
Phone: +41/1/2730055
Fax: +41/1/2730085

Contact person(s) at the stand:
Mr André Leder, Mr Daniel Pilet

in the enterprise:
Mr André Leder

Production line:
Turbomolecular pumps and pumping stations,
Rotary vane and Roots vacuum pumps and pumping stations, High vacuum laboratory systems, Dry backing pump Uni Dry[R]
Vacuum technological systems

Exhibited products:
urbomolecular- and Turbo-drag-pumps
Rotary vane pumps
Dry backing pump Uni Dry[R]

BESTEC

BESTEC GmbH
Rudower Chaussee 6
D-12484 Berlin
Phone: +49/30/6774376
Fax: +49/30/6775718

Contact person(s) at the stand/ in the enterprise:
Mr Dr. Christian Rempel

Production line:
Adaptive Engineering:
- Design and construction of special UHV-systems for surface coating and analysis (solutions for special requirements of the customers)
- Ultrashort time LASER systems and amplifier
- products for surface analysis and thin film growth techniques

Production line: LASER diagnostic devices for ultrashort time physics

Exhibited products:
RHEED-System (Reflected High Energy Electron Diffraction):usable for insitu -diagnostic of thin film growth techniques, especially for MBE (Molecular Beam Epitaxy) (patented deflection system)

CRYSTAL

Crystal GmbH
Ostendstrasse 2-14
D-12459 Berlin
Phone: +49/30/6953870
Fax: +49/30/6350436

Contact person(s) at the stand:
Mr Schwenkenbecher

in the enterprise:
Mr Sandner, Mr Schwenkenbecher

Production line / exhibited products:
- optical components, lenses, windows, prisms, ATR
- X-, n-, γ- and particle detectors
- solid state blue laser
  $\lambda = 452$ nm, p = 100 mW, $\tau_p \leq 10$ ns

ELEK LUFT

ELEKLUFT
Justus-von-Liebig-Strasse 18
D-53121 Bonn
Phone: +49/228/66810
Fax: +49/228/6681777

Contact person(s) at the stand:
Mr Hans-Peter Merker, Mr Hans-Ulf Paganetti

in the enterprise:
Mr Hans-Peter Merker

Production line:
- Technical Support
- Logistics
- Facility Management
- Documentation
- Training

Exhibited products:
Graphic panels showing ELEKLUFT's scope of activities

EUROSPACE
Technische Entwicklungen GmbH

EUROSPACE Technische
Entwicklungen GmbH
Heinrich Heine Strasse 5
D-09557 Flöha
Phone: +49/3726/783300
Fax: +49/3726/712378

Contact person(s) at the stand:
Mrs Dr. Beate Elstner

in the enterprise:
Mr Prof. Dr. Dr. Jürgen Waldmann

Production line
Enlargement of systems in scientific device technologies, in technologies of microsystems and optoelectronics with special application in space, in medicine and environmental protection

Exhibited products:
Diagnostic system with optoelectronic sensors in the range of Near-Infrared-Radiation (NIR)

F. u. G. Elektronik GmbH

F. u. G. Elektronik GmbH
Florianstrasse 2
D-83024 Rosenheim
Phone: +49/8031/28510
Fax: +49/8031/81099

Production line / exhibited products:
High and low voltage power supplies
(6,5 V to 150 KV; 7 W to 100 KW)

Contact person(s) at the stand/ in the enterprise:
Mr G. Giebichenstein, Mr A. Elsasser, Mr H. Führling

GESELLSCHAFT FÜR ELEKTRISCHE ANLAGEN
ELEKTROBAU GMBH

Gesellschaft für elektrische Anlagen
Elektrobau GmbH
Schmidener Weg 3
D-70736 Fellbach
Phone: +49/711/9573602
Fax: +49/711/9573688

Contact person(s) at the stand/ in the enterprise:
Mr Dieter Kern

Local representative:

Perrin, Spaeth & Associés
43, rue Louis-Favre
CH-1201 Genève
Phone: +41/22/7346878
Fax: +41/22/7348173

Contact person(s) at the stand/ in the enterprise:
Mr Christian Spaeth

Production line :
- Installation of electric facilities of all kinds in high and low-voltage area and in the field of pipe systems
- Production of high-quality control cabinet for (LV-) switch gears, control systems electronics

Exhibited products:
Demonstration-control cabinet for energy distribution and electronics
- Visual and text statements concerning installation and service

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Gerland ®

GERLAND Mikroelektronik
Kolberger Strasse 2
D-23879 Mölln
Phone: +49/4542/80050
Fax: +49/4542/86012

Contact person(s) at the stand/ in the enterprise:
Mr Torsten Mohrholz, Mr Jens Pernitt

Production line:
- Development, CAD-Layout
- Electronic Manufacturing
  Structured production lines Technical and equipment standards meet MIL standard and DIN ISO 9000 * Isolation techniques varnishing * casting
- SMT Manufacturing
  Automatic insertion system SIEMENS HS-180, Component recognition dynamic, optical and electronic with CCD camera control, Reflow soldering line with 8 temperature controlled zones
- PCB-manufacturing
  CIM-controlled production, Multilayer, Starrflex Dry-Film-Masks, Photosensitive-Liquid-Film-Masks, SMT-templates, market standards, Prototypes, Quick-service
- Function- and In-circuit-testsystems, Burn-In
- Testsystems

Exhibited products:
- Inserted PCS (Standard + SMT)
- Uninserted PSC (Double-sided, Multilayer)
- Compete Units

GMS

GMS - Gesellschaft für
Mess- und Systemtechnik mbH
Rudower Chaussee 5
D-12489 Berlin
Phone: +49/30/63926230
Fax: +49/30/63926245

Contact person(s) at the stand/ in the enterprise:
Mr Dr. Klose

Production line/exhibited products:
- High-resolving detectors including read-out electronics
- CAN/ADC modules
- Bipolar current supplies for precise controlling of magnetic fields at accelerators

GSI

GSI - Gesellschaft für
Schwerionenforschung mbH
P.O. Box 11 05 52
D-64220 Darmstadt
Phone: +49/6159/712598
Fax: +49/6159/712991

Contact person(s) at the stand/ in the enterprise:
Mr Dr Günter Siegert

Production line:
Research with accelerated heavy ions (0,05 to 2000 MeV/u): nuclear physics, nuclear chemistry, atomic physics, material research, biophysics and plasma physics, accelerator development

Exhibited products:
Tumortherapy with ion beams is demonstrated with 2 modules:
1. Therapy cave at GSI (operational in 1996)
2. Dedicated accelerator for tumortherapy

MANNESMANN
Hartmann & Braun

Hartmann & Braun AG
D-60484 Frankfurt am Main
Phone: +49/69/7990
Fax: +49/69/7992406

Local Representative:

Hartmann & Braun SA/AG
CH-4123 Allschwil

Technical Department:
Av. de l'Industrie 25B
CH-1870 Monthey
Phone: +41/25/724242
Fax: +41/25/724245

Contact person(s) at the stand:
Mr Pascal Bétrisey

in the enterprise:
Mr Raymond Bischoff

Production line:
Industrial automation, DC-Systems, Field Instrumentation and Gas monitoring systems, incl. engineering, installation, start-up, training and service.

Exhibited products:
Field instrumentation (temperature, pressure, indicators, recorders etc.)

EG&G HEIMANN
Optoelectronics

EG & G
Heimann Optoelectronics GmbH
Weher Köppel 6
D-65199 Wiesbaden
Phone: +49/611/9412528
Fax: +49/611/9412578

Contact person(s) at the stand:
Mr Dr. Wolfgang Hennerici

in the enterprise:
Mrs Jung

Local Representative:

Hutmacher & Co.
P.O. Box
CH-5023 Biberstein
Phone: +41/64/244413
Fax: +41/64/249140

Contact person(s) in the enterprise
Mr Hutmacher, Mr Mürset

Production line:
Flashtubes, Silicon Micromechanics, Image Tubes, Photoresistors, Thermopile sensors, Pyroelectric, Infrared Sensors, Large Area Electronics

Exhibited products:
Digital Position Sensing Detectors, Radiation Image Detectors

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HEW® KABEL

H E W - KABEL
H. Eilentropp GmbH & Co. KG
Gewerbegebiet Klingsiepen 12
D-51688 Wipperfürth
Phone: +49/2267/6830
Fax: +49/2267/683161

Contact person(s) at the stand:
Mr Klaus Schwamborn, Mr Herbert Winkel

in the enterprise:
Mr Klaus Schwamborn

Production line/exhibited products:
Special cables for extreme conditions:
Power Cables, High Temperature, Cryogenics, EMV-opti Data Cables, Temperature Sensing, Sensory Analysis, RF-Technics, Chemistry, Robotronics, Leakage Control, Traffic Engineering, Vehicle Engineering
Teflon®, Kapton®, PEEK, Silicone Rubber, Elastomere Compounds, TPE, High Performance Thermoplastics, Glas Fibres, Mica, Ceramic Fibres, X L Compounds -200°C up to +1.200°C

ILK Dresden

Institut für Luft- und Kältetechnik Dresden
Bertolt-Brecht-Allee 20
D-01309 Dresden
Phone: +49/351/4081510
Fax: +49/351/4081515

Development of technologies and design/planning of components and systems for heating, ventilating and air conditioning, arrangement of supply of components and systems included. Especially there are complex, energy optimized and ecologically friendly technologies like DEC (Desiccative and Evaporative Cooling), water as refrigerant, cfc-changeover concepts (metamorphoses of refrigerants R11 or R12) a.s.o.

Contact person(s) at the stand:
Mr Prof. Dr.-Ing. Günter Heinrich

in the enterprise:
Mr Dipl.-Ing. Siegfried Richter

INTEGRAL

INTEGRAL Energietechnik GmbH
P.O. Box 19 10
D-24909 Flensburg
Phone: +49/461/999333
Fax: +49/461/999399

Contact person(s) at the stand/ in the enterprise:
Mr Joachim Paul

Local representative:

UNELCO AG
Badener Strasse 701
CH-8048 Zürich
Phone: +41/1/4327733
Fax: +41/1/4329327

Contact person(s) at the stand:
N.N.
Contact person(s) in the enterprise:
Mr Jörg Keller

Production line:
Cooling (Plants) Installations
Ice-Making Plants
Binary Ice Systems for production of pumpable ice-slurry (Vacuum, FLO-ICE)

Exhibited products:
Binary Ice Maker (FLO-ICE)

ALCATEL KABELMETAL

kabelmetal electro GmbH
P.O. Box 260
D-30002 Hannover
Phone: +49/511/6761
Fax: +49/511/6762541

Contact person(s) at the stand/ in the enterprise:
Mr Dr.-Ing. D. Gerth, Mr Dipl.-Ing. K. Schippl

Production line:
Products for transmission and distribution of electrical energy

Exhibited products:
CRYOFLEX[R] Transferlines for liquid Gases

KCH

KERAMCHEMIE GMBH
Berggarten 1
D-56427 Siershahn
Phone: +49/2623/6000
Fax: +49/2623/600788

Contact person(s) at the stand:
Mr Ostrowski

in the enterprise:
Mrs Frenz-Steudter

Production line:
KCH-Surface Protection Engineering:
Corrosion protection with on-site and workshop rubber linings, tank rubber linings of ships, rail and road vehicles, synthetic resin coatings, synthetic resin coverings. Acidproof ceramic coverings and linings, sealings with elastomer and thermoplastic sealing sheets. Corrosion protection materials.
KCH-Process Engineering: Pickling and recovery technology
Installations for the chemical surface treatment of metals
Acid recovery
Environmental engineering Effluent treatment, waste air purification, decontamination of old refuse, reclamation
Aerating and venting installations. Fans.

KCH-Plastics Engineering: Appliances, vessels and pipework in thermoplastic and fibrereinforced duroplastic resins.
Gratings.
KCH-Ceramics: Domestic and industrial ceramics for external and internal use. Swimming pool ceramics. Ceramics for laboratories and kitchens. Laboratory gas purifier.

Exhibited products:
Samples, Synthetic resins coatings, photos, information tabloids

LEYBOLD

LEYBOLD VAKUUM
Bonner Strasse 498
D-50968 Köln
Phone: +49/221/3470
Fax: +49/221/3471250

Contact person(s) in the enterprise:

Mr Mörsch

Local representative:

LEYBOLD S.A. Zweigbüro Lausanne
Route de Bassenges 13
CH-1024 Ecublens
Phone: +41/21/6918414
Fax: +41/21/6916273
Contact person(s) at the stand/ in the enterprise:
Mr Fischer

Production line:
Vacuum-Technology, Measuring and Analytical Technology

Exhibited products:
Measuring and Analytical Instruments
Vacuum Components

LINDE AG
Werksgruppe VA München
Dr.-Carl-von-Linde-Straße 6-14
D-82049 Höllriegelskreuth
Phone: +49/89/74450
Fax: +49/89/74454929

Contact person(s) at the stand/ in the enterprise:
Mr J. Lesser

Local representative:

Linde Kryotechnik AG
Dättlikonerstrasse 5
CH-8422 Pfungen
Phone: +41/52/310555
Fax: +41/52/310550

Contact person(s) at the stand/ in the enterprise:
Mr A. Senn

Production line:
Helium liquefaction and refrigeration plants, Hydrogen liquefaction plants, Helium recovery and storage systems, Helium gas purification plants, Cryocomponents (Heat exchangers, turboexpanders, compressors, pumps, cryostats, dewars, tanks, containers, vacuum insulated transfer lines, impurity detectors)

Exhibited products:
- He-Turbine, dynamic gas beared
- He-Transferline
- Multi-component detector

Logotron AG
Leutschenstrasse 1
CH-8807 Freienbach
Phone: +41/55/473321
Fax: +41/55/481275

Contact person(s) at the stand:
Guy Antal, Ognjen Paucic

in the enterprise:
Marta Reichlin

represents the following German companies:

SIEMENS

hera

imk

Exhibited products:
Hybrid recorder, high-speed memory recorder, power supply networks distortion analyser, power supply, function generators, frequenzy meters, analog-digital oscilloscopes, spectrum analyzer, graphic printer, system instruments IEE (GPIB),
workbenches for production, assembly, repair and workshop
Transient recorders PSO systems (1 to 96 channels); MCS systems (1 to 800 channels)

MG
MESSER GRIESHEIM

Messer Griesheim GmbH
Fütingsweg 34
D-47805 Krefeld
Phone: +49/2151/3790
Fax: +49/2151/379554

Contact person(s) at the stand/ in the enterprise:
Mr Dr. Ewald

Local representative:

Sauerstoffwerk Lenzburg AG
Seonerstrasse 75
CH-5600 Lenzburg
Phone: +41/64/512335
Fax: +41/64/514782

Contact person(s) at the stand/ in the enterprise:
Mr H. Kahrom

Production line:
Industrial and Speciality Gases
Cryogenic Equipment
PSA and VSA Plants

Exhibited products:
Liquid Helium Tanks, Superinsulated Transfer-lines, High-Purity GasSupply Components

NOELL

Ein Unternehmen der Preussag

Noell GmbH
Alfred-Nobel-Strasse 20
D-97080 Würzburg
Phone: +49/931/9031318
Fax: +49/931/9031016

Contact person(s) at the stand/ in the enterprise:
Mr Gerd Edler

Production line:
Treatment of radioactive waste, reactor equipment, dismantling, remote handling systems, superconducting magnets for high energy physics and controlled fusion, dipoles, quadrupoles, cryostats.
Environmental Engineering, Hydropower, Materials Handling, Nuclear Engineering, Advanced Technologies

Exhibited products:
Cross-sections and models of superconducting and normal-conducting magnets

Optikzentrum NRW
Universitätsstrasse 142
D-44799 Bochum
Phone: +49/234/970700
Fax: +49/234/9707070

Contact person(s) at the stand:
Mrs Stefanie Kostelnik, Mrs Andrea Zaum

in the enterprise:
Mrs Stefanie Kostelnik

Optical Science and Technology Center Bochum/Germany

Our aim is application of modern optical technologies in industry and science. This includes the transfer of known technologies into new applications as well as the development of new optical processes, technologies and devices
Our field of work:
- Integration of optical measuring technology into industrial processes
- Development of measuring systems and processes
- Measuring, testing and characterisation
- Coating and surface technology
- Manufacture and development of optics
- Construction/Precision Mechanics
- Transfer of Technology/Training

SASKIA
HOCHVAKUUM

SASKIA Hochvakuum-
und Labortechnik GmbH
Am Vogelherd 3
D-98693 Ilmenau
Phone: +49/3677/6040
Fax: +49/3677/604110

Contact person(s) at the stand:
in the enterprise:
Mr Bürger
in the enterprise:
Mr Bürger, Mrs Hergenhan

Local Representative:

VACOTEC S.A.
36, Av. Charles Naine
CH-2300 La Chaux de Fonds
Phone: +41/39/264477
Fax: +41/39/267577

Contact person(s) at the stand/

Mr Paroz, Mr d'Angelo

Production line/exhibited products:
Rotary Vane Vacuum Pumps, Diaphragm- and Piston Pumps, High Vacuum Systems, Measuring and Testing Devices, Small Flange Components

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SCHOTT

SCHOTT GLASWERKE
OPTICS DIVISION
P. O. Box 2480
D-55014 Mainz
Phone: +49/6131/663509
Fax: +49/6131/662003

Contact person(s) at the stand/
in the enterprise:
Mr Schumann OGM

Local Representative:

Schott-Schleiffer AG
Feldbachstrasse 81
CH-8714 Feldbach
Phone: +41/55/417141
Fax: +41/55/424101

Contact person(s) at the stand/
in the enterprise:
M. Dr. Klaus

Production line:
Optical glass, Optical Filters, ZERODUR[R] glass ceramic, Interference Filters, Cerenkov glass, Laser glass, Scintillating glass

Exhibited products:
Optical glass, Cerenkov glass, Scintillating glass, ZERODUR[R] glass ceramic

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SKODOCK
Die Spezialisten

Hans Skodock GmbH
Entenfangweg 12
D-30419 Hannover
Phone: +49/511/793093
Fax: +49/511/793098

Contact person(s) at the stand/
in the enterprise:
Mr Klaus Peters

Local representative:

M. Hoffmann
Kaiserstrasse 22/24
CH-4310 Rheinfelden
Phone: +41/61/8369070
Fax: +41/61/8369071

Contact person(s) in the enterprise:

Mr Achstaller

Production line:
Expansion Joints
Metal bellows
Metal hoses
Thin wall pipe from stainless steel

- The application of flexible products are compensation elements of thermal expansion for pipelines
- Maintenance - free hermetic sealing of valve
- Hermetical, movable sealing of penetrations to rooms
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GmbH & Co.
D-37070 Göttingen
Phone: +49/551/6935971
Fax: +49/551/6935166

Contact person(s) at the stand:
Mr Dr. Schuhmann

in the enterprise:
Mrs Hoch

Local Representative:

Leica AG
Kanalstrasse 21
CH-8152 Glattbrugg
Phone: +41/1/8093311
Fax: +41/1/8107937

Contact person at the stand:
Mr Bonzoms, Mr Pidoux

in the enterprise:
Mr Hedinger

Production line:
Precision optics, Mechanics, Laser technology

Exhibited products:
Precision optics, OEM optics, optical tables, optical benches, optomechanical components, positioning systems, optoelectronics, laser technology

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STAHLKONTOR
GmbH + Co. KG

Stahlkontor GmbH + Co. KG
Preusserstrasse 28
D-58135 Hagen
Phone: +49/2331/90300
Fax: +49/2331/903030

Contact person(s) at the stand:
Mr König, Mr Willmes, Mr Putsch

in the enterprise:
Mr Putsch

Exhibited products:
Examples for application of Co^2-laser-cutting and abrasive high-pressure water-jet-cutting in extremely different materials

---

STATRON-elektronik GmbH
Ehrenfried-Jopp-Strasse 59
D-15517 Fürstenwalde
Phone: +49/3361/6970
Fax: +49/3361/697220

Production line:
Power Supply Technology
Measuring Technology
System Technology

Exhibited products:
Power Supplies

STRUCK

Dr. Bernd Struck
Bäckerbarg 6
D-22889 Tangstedt
Phone: +49/4109/550
Fax: +49/4109/55133

Contact person(s) at the stand:
Mr Dr. Bernd Struck

in the enterprise:
Mr Ronald Ölschläger

Production line:
Electronic Instrumentation for Particle Physics Research Crates, DSP-Readout and Frontend-Modules and High-Voltage Products in Standard systems VME, VXI, Fastbus, CAMAC and NIM

Exhibited products:
- DSP based fast Readout Engines in VME, VXI and Fastbus
- DSP Front end Modules in VME, VXI and Fastbus for Fast Triggering and Data Compression; DSP Add-ons for data stream processing of LeCroy ECLine, PCOS and FERA systems
- FLASH ADC Modules and Systems, VME based, Multi Channel, 40Mhz, 100Mhz and 250 Mhz, 8Bit for Particle Detector Readout and Accelerator Control
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Fax: +49/6181/382645

in the enterprise:
Mr Reinhard Dietrich

Local Representative:

Matthées AG
Peter-Merian-Strasse 22a
CH-4002 Basel
Phone: +41/61/2712077
Fax: +41/61/2718458

Contact person at the stand/

Production line:
Semi-finished Products, Parts, Lemination Packages, Superconductors, Magnetic Cores, Inductive Components, Magnetic Sensors, Rare-Earth Permanent Magnets, Magnet Systems

Exhibited products:
Samples and photos of superconducting wires and exampels of applications

---

VERO Electronics GmbH
Carsten-Dressler-Strasse 10
D-28279 Bremen
Phone: +49/421/8490-0
Fax: +49/421/8490151

Contact person(s) in the enterprise:

Mr J.-P. Gülstorf

Local Representative:

VERO Electronics GmbH Büro Schweiz
Langrütstrasse 112
CH-8047 Zürich
Phone: +41/1/4921950
Fax: +41/1/4921987

Contact person(s) at the stand/in the enterprise:
Mr W. Schneider

Production line:
Racks, Subracks, Power Supplies, Backplanes, Microracks, Enclosures

Exhibited products:
19" cases, Racks, Subracks, Small enclosures, Backplanes
(VXI, Futurebust, Multibus II,
VME, STEbus, G64, G96, Custommade), Microracks (Modular Microrack System), Power Supplies

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D-01324 Dresden
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Contact person(s) at the stand/
in the enterprise:
Mr Dr. Peter Lenk

Local Representative:

Balzers Hochvakuum Zürich
Förrlibuckstrasse 30
CH-8037 Zürich
Phone: +41/1/2730055
Fax: +41/1/2730085

Contact person(s) at the stand:
in the enterprise:
Mr Andre B. Leder

Exhibited products:
- double-ring-sputter-source
- pem 04
- etcher

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Phone: +49/461/774177
Fax: +49/461/774141

Contact person(s) at the stand:
Mr Jörgen L. Kristensen, Mr Wolfgang Kühn
Mr Franz von Niederhäusern, HiTech Systems, Geneve

in the enterprise:
Mr Jörgen L. Kristensen, Mr Wolfgang Kühn

Production line:
Powered Crates:

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- CAMAC-Crates:	CERN Spec. 099a, linear regulated CERN Spec. 336, switch mode
- FASTBUS-Crates:	CERN Spec. F6852, output up to 3.300 W, low noise, 3-phase input
- VMEbus-Crates:	CERN Spec. V-422 CERN Spec. V-430 Customer design
- Crates and Power Supplies:	Customer design, VES-Crates quality

Exhibited products:
Standard CERN-Spec. Crates
Customer designed Crates 6U - 9U
VMEbus-Crate 9U HEP-F prototype

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Anwendungszentrum
Hamburg GmbH

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Anwendungszentrum Hamburg GmbH
Harburger Schloss-Strasse 6-12
D-21079 Hamburg
Phone: +49/40/766291891
Fax: +49/40/76629199
Contact person(s) at the stand:
Mrs Dr. K. Uhde

in the enterprise:
Fr. B. Gutzki

Production line:
The Mikroelektronik Anwendungszentrum (MAZ) Hamburg GmbH is a development and systems house with focus on microelectronic solutions. MAZ Hamburg GmbH offers products and services in the application sectors of Communication Electronics, Electronic systems (including consultancy and test of electromagnetic compliance) and Industrial Electronics. The sector Communication Electronics focus on broadband applications: ATM chip design, ATM modules and development tools. With the Distributed ATM Switch (DAS) a product line of innovative ATM technology is available offering the integration of voice, data and video. The main feature of this product line is its high degree of flexibility together with its distributed control and network management concepts.

Exhibited products:
The ATM ICs developed by MAZ Hamburg GmbH provide the core components for the ATM product line: The ATM Interworking Unit (IWU) IC maps arbitrary sets of PCM channels from 2 Mbit/s ISDN primary rate interface onto virtual connections in a 155 Mbit/s ATM stream and vice versa. The ATM Switching Element (SE) IC is a 4 x 4 coupling field with 155 Mbit/s capacity at each port. During the exhibition, MAZ's ATM chips and modules will be shown which can be configured as ATM switch.

X-ray lithography can be used to make tiny mechanical parts. Using the LIGA (Lithographic Galvanoformung und Abformung) technique, very small components, such as this fibre optic connector, can be manufactured using radiation from synchrotron light sources. (Photo Institut für Mikrotechnik, Mainz, Germany)

needed to achieve high production throughputs. The small source size and strong collimation of synchrotron radiation provide good resolution for the relatively crude optical configurations that result from the lack of mirrors or lenses at these wavelengths.

The spectrum of synchrotron radiation is not unlike black body radiation - a peak close to the so-called critical wavelength, a fairly sharp cutoff at some shorter wavelength and a longer wavelength tail. By choosing an accelerator ring with the right critical wavelength, the spectrum may be matched to a particular application. For a given choice of critical wavelength the overall size of the ring scales as $B^{-3/2}$, where B is the bending field. Thus there is interest in using superconducting magnets to produce higher fields, and hence smaller rings.

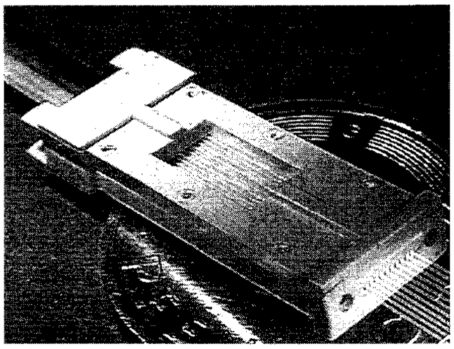
Compactness is important in a semiconductor fabrication facility, where space is extremely expensive and a small accelerator ring has to be delivered as a fully commissioned and tested unit.

The past 30 years have seen a steady increase in the power and complexity of circuits which can be put on a single chip, mainly due to the progressive reduction in the size of the circuit elements from some 50 microns in the 1960s to less than 0.5 microns at present. Continuing progress depends on the ability to replicate even finer circuit patterns. In mass production, electron beam 'writing' can already produce very fine patterns, but takes a long time and is therefore better suited to making the mask. Lithography is the mass production process which produces many copies from a single original.

Traditional optical lithography process uses visible or near UV light of wavelength 0.44 to 0.25 microns. As the feature size approaches these wavelengths, diffraction becomes increasingly troublesome. Many ingenious ideas are being developed to extend the useful range of optical lithography, but the ultimate limit will always be higher than the absolute minimum needed, perhaps around 0.25 micron. In X-ray lithography, the wavelength is around a nanometre and, even with simple shadow printing, the resolution can be better than 0.1 micron. In the longer term, projection X-ray lithography using reflection optics promises even better resolution.

Because of the potential benefits of X-ray lithography, many companies are now actively pursuing development programmes. IBM have the Advanced Lithography Facility at East Fishkill, New York, where the Oxford Instruments ring, Helios, provides several beamlines for lithography. Motorola have beamlines at Wisconsin's Aladdin ring and are planning a collaborative programme at East Fishkill. In Japan, NTT have two rings for lithography - NAR, a normal magnet ring and Super ALIS, a superconducting machine. SORTEC, a consortium of government and semiconductor companies, operates a normal ring driving several lithography beamlines. Mitsubishi, Sumitomo Electric and Sumitomo Heavy Industries have built compact superconducting rings for lithography. It seems likely that many of the logic and memory semiconductors of the future will be made using X-rays produced by accelerators.

Contribution from Martin Wilson, Oxford Instruments, UK



Micromachining

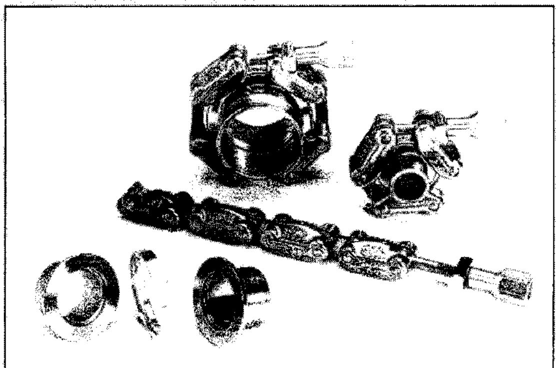
As well as making microcircuit components, X-ray lithography can also be used to make very small mechanical parts, either by using directly the exposed and developed photoresist, or as a mould to produce the component in another material such as ceramic or metal.

In this revolutionary technology, metal components are made via the LIGA (Lithographic Galvanoformung und Abformung) technique in which the exposed and developed photoresist is coated with a conducting material and then electroplated, after which the resist is stripped away.

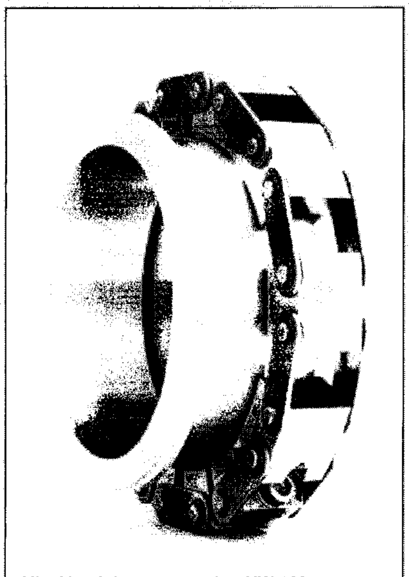
In addition to fine size and precision resolution, X-rays offer the advantage of deep penetration and small scattering through the resist, so that patterns may be up to a millimetre deep, with very accurate straightness in directions parallel to the beam.

Micromachining via LIGA was developed at KfK Karlsruhe; commercialization and further development is being vigorously pursued by the Institut für Mikrotechnik in Mainz and by Microparts GmbH in Karlsruhe. Significant developments have been made at the Synchrotron Radiation Centre in Madison, Wisconsin, with new programmes start-

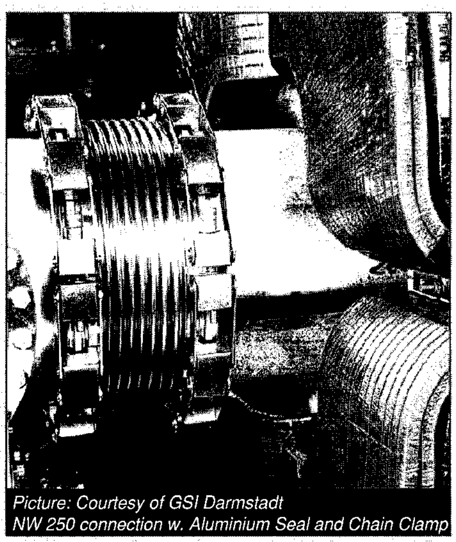
All - Aluminium Seals and Fittings for Accelerators



KF Chain clamps , flanges and seals



All - Aluminium connection NW 160



Picture: Courtesy of GSI Darmstadt
NW 250 connection w. Aluminium Seal and Chain Clamp

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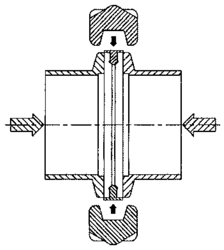

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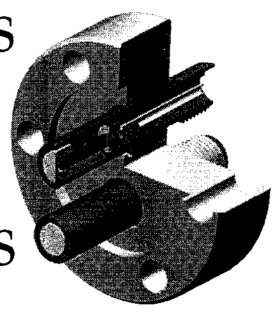

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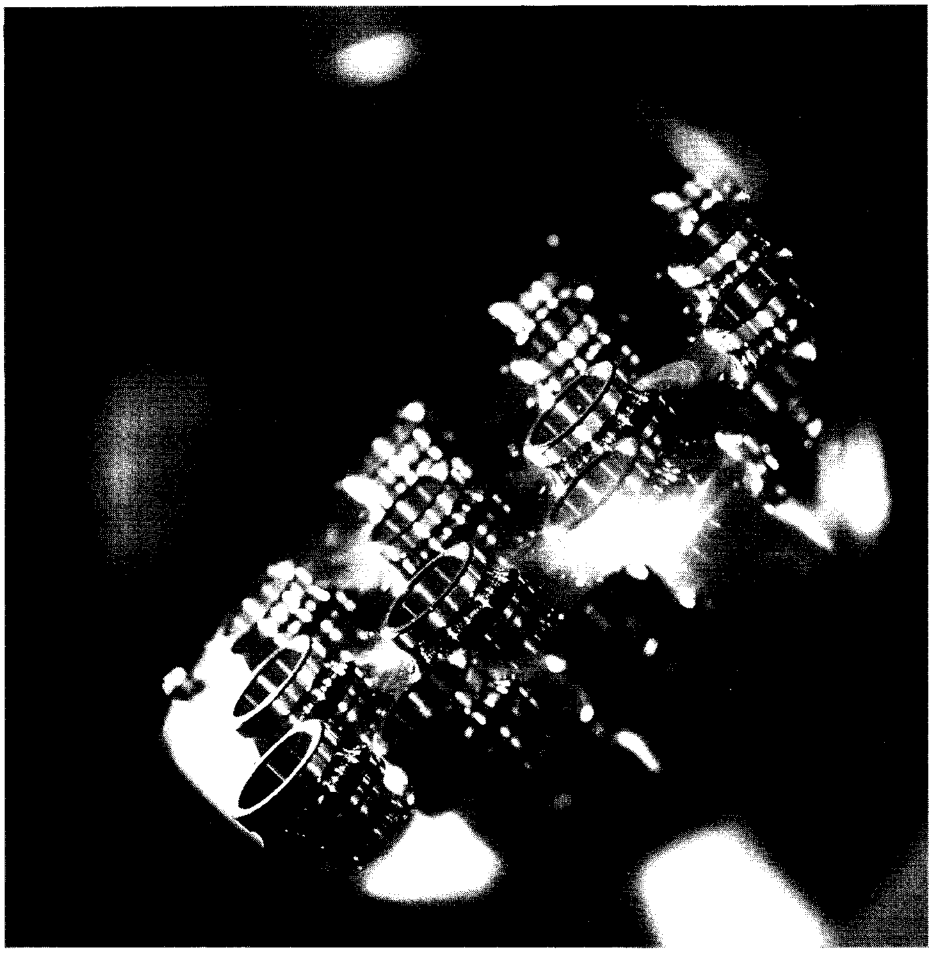
In ion implantation, accelerator beams are used to alloy a thin surface layer with foreign atoms, making for dramatic improvements in hardness and in resistance to wear and corrosion. This high current industrial system implants chromium ions into jet engine ball bearings, providing corrosion protection. (Photo Danfysik, Jyllinge, Denmark)



ing at SRRC (Taiwan), CAMD (Baton Rouge, Louisiana), and LURE (Paris). There is now an active European Special Interest Group for LIGA.

Commercially manufactured micromachines are starting to be used in sensors and connectors. The ability to integrate microdevices with microelectronics raises many interesting possibilities for the future, notably in medicine and for intelligent sensors. In all cases, however, widespread adoption will be governed by the ability to mass-produce cheaply, requiring high volume production. The high intensities of synchrotron radiation will assist in achieving these large throughputs.

From Martin Wilson, Oxford Instruments, UK

Surface engineering by ion implantation

A widespread commercial applica tion iof particle accelerators is for ion implantation. Accelerator beams are used for ion implantation into metals, alloying a thin surface layer with foreign atoms to concentrations impossible to achieve by thermal processes, making for dramatic improvements in hardness and in resistance to wear and corrosion.

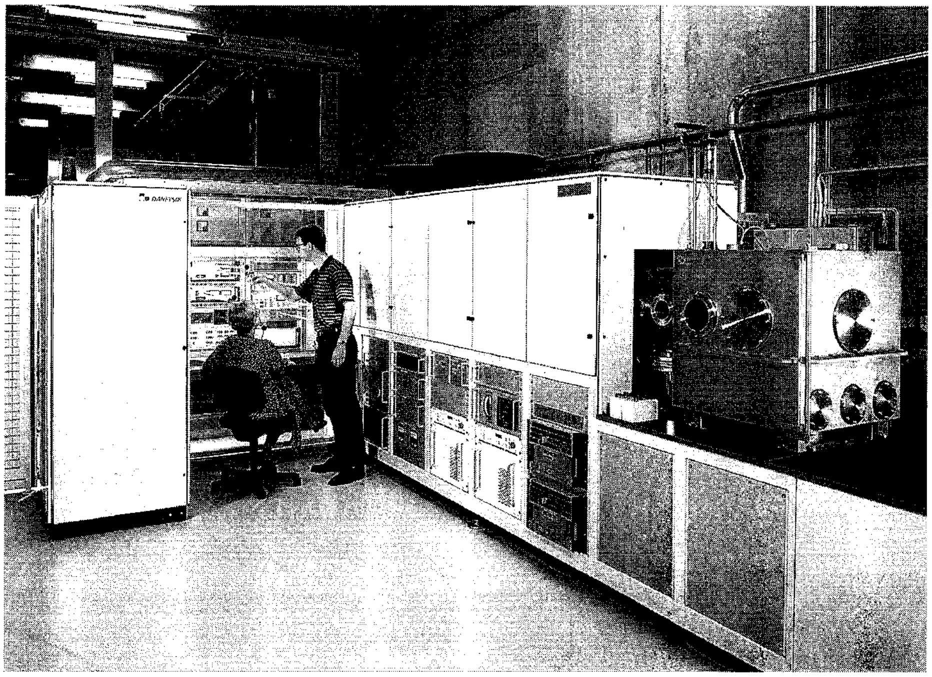
Traditional hardening processes require high temperatures causing deformation; ion implantation on the other hand is a "cold process", treating the finished product. The ion-implanted layer is integrated in the substrate, avoiding the risk of cracking and delamination from normal coating processes. Surface properties may be "engineered" independently of those of the bulk material; the process does not use environmentally hazardous materials such as chromium in the surface coating.

The typical implantation dose required for the optimum surface properties of metals is around 2 x 10^{17} ion/cm^2, a hundred times the typical doses for semiconductor processing. When surface areas of more than a few square centimetres have to be treated, the implanter must therefore be able to produce high beam currents (5 to 10 mA) to obtain an acceptable treatment time. Ion species used include nitrogen, boron, carbon, titanium, chromium and tantalum, and beam energies range from 50 to 200 keV. Since most components are three dimensional, it must be possible to rotate and tilt them in the beam, and control beam position over a large area.

Examples of industrial applications are:

- surface treatment of prostheses (hip and knee joints) to reduce wear of the moving parts, using biocompatible materials;
- ion implantation into high speed ball bearings to protect against the aqueous corrosion in jet engines (important for service helicopters on oil rigs);
- hardening of metal forming and cutting tools;
- reduction of corrosive wear of plastic moulding tools, which are expensive to produce.

A high-current industrial ion implantation system used for treating metal surfaces. (Photo Danfysik, Jyllinge, Denmark)



Most industrial ion implantation processing is handled by specialist companies and the demand is increasing. It is a challenge for the implanter manufacturers to satisfy higher demands for efficiency, reliability and reduced cost.

From Bjarne Roger Nielsen, Danfysik, Jyllinge, Denmark.

Ion implantation for semiconductors

Over the past two decades, thousands of particle accelerators have been used to implant foreign atoms like boron, phosphorus and arsenic into silicon crystal wafers to produce special embedded layers for manufacturing semiconductor devices.

Depending on the device required, the atomic species, the depth of implant and doping levels are the main parameters for the implantation process; the selection and parameter control is totally automated.

The depth of the implant, usually less than 1 micron, is determined by the ion energy, which can be varied between 2 and 600 keV. The ion beam is extracted from a Freeman or Bernas type ion source and accelerated to 60 keV before mass analysis. For higher beam energies post-acceleration is applied up to 200 keV and even higher energies can be achieved by mass selecting multiply-charged ions, but with a corresponding reduction in beam output.

Depending on the device to be manufactured, doping levels can range from 10^{10} to 10^{15} atoms/cm^2 and are controlled by implanter beam currents in the range up to 30mA; continuous process monitoring ensures uniformity across the wafer of better than 1%.

As semiconductor devices get smaller, additional sophistication is required in the design of the implanter. The silicon wafers charge electrically during implantation and this charge must be dissipated continuously to reduce the electrical stress in the device and avoid destructive electrical breakdown. Electron flood guns produce low energy electrons (below 10 electron-volts) to neutralize positive charge buildup and implanter design must ensure minimum contamination by other isotopic species and ensure low internal sputter rates.

The pace of technology in the semiconductor industry is such that implanters are being built now for 256 Megabit circuits but which are only likely to be widely available five years from now. Several specialist companies manufacture implanter systems, each costing around US$5 million, depending on the configuration and remote handling options. Current implanter capacities are around 60 wafers/hr, each wafer being 150mm in diameter with a typical doping level of 3 x 10^{15}cm^{-2}.

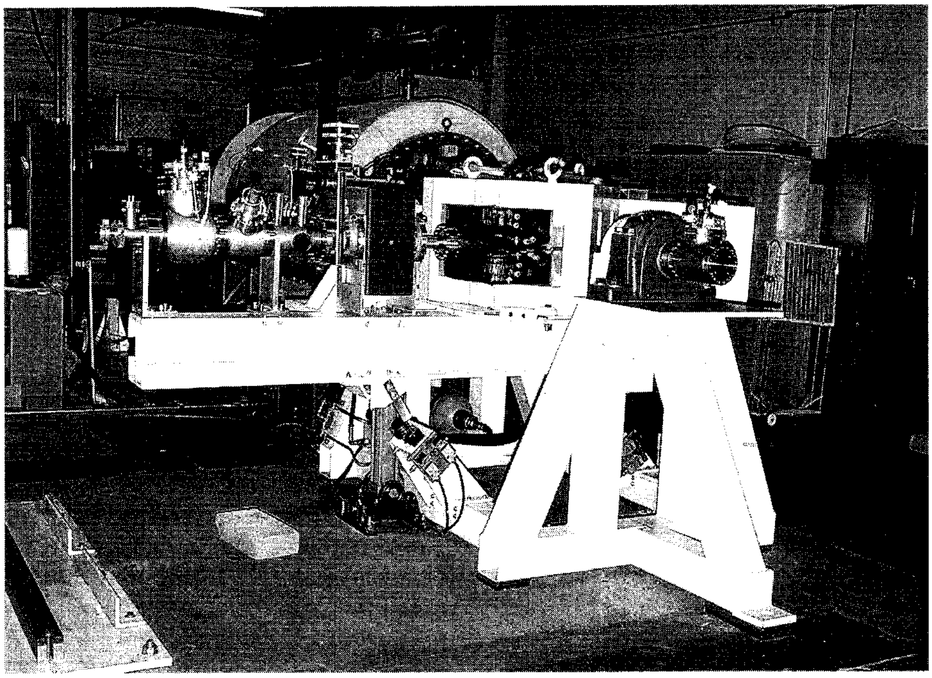
From T. Grey-Morgan, Amersham International, UK

Contraband detection

Inspecting incoming cargo for drugs, explosives and other contraband would quickly overwhelm inspection agencies even if a small percentage of the cargoes were manually searched. Now a new accelerator-based inspection system using pulsed fast neutron analysis (PFNA) allows automated inspection of loaded cargo containers and trucks.

A collimated pulsed beam of fast neutrons, scanned over the side of a cargo container as it passes, excites the nuclei of common elements in

A new accelerator-based inspection system allows automated inspection of loaded cargo containers and trucks. A neutron beam scans the cargo and the detected gamma ray emissions can give a reconstruction with the appropriate signature for drug materials.



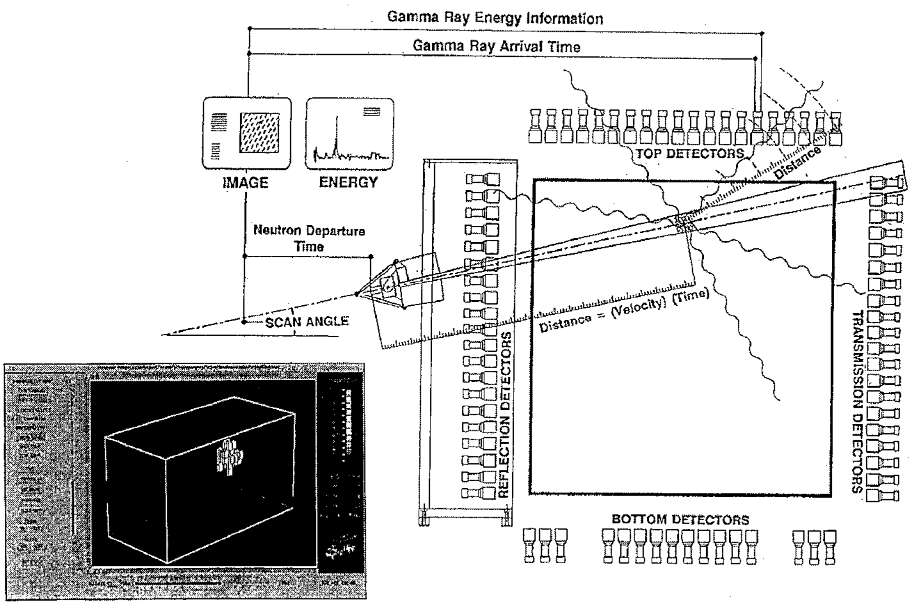
bulk materials. The primary signals of interest for contraband are gamma-ray emissions following inelastic scattering of the fast neutrons from carbon and oxygen.

Direct imaging of the contents of the material by time-of-flight analysis identifies the position of the interactions, while gamma-ray spectroscopy identifies the elemental gamma rays. The ratio of elements or other combinations of the elemental signatures are used to identify contraband - a high carbon-to-oxygen ratio, for example, is characteristic of drugs.

The system incorporates gamma ray detectors, and analogue and digital processors sort the pulses for position and elemental information. Detection algorithms produce three-dimensional images of possible concealed contraband. From these images the inspector can identify suspicious objects within the cargo container.

One PFNA device uses a beam of 8 MeV neutrons raster scanned across the face of a truck or container. The beam is produced by an 80 microamp beam of 6.0 MeV deuterons from a National Electrostatics Corporation (NEC) Pelletron tandem Van de Graaff. The ion source is a newly developed Toroidal Volume Ion Source (TORVIS) based on a Brookhaven design with an output of 300 microamps DC of negative ions. The deuteron beam is accelerated to 80 keV and then analysed in a dipole magnet before entering the bunching system. A 5 MHz double drift buncher achieves a bunching efficiency of 40% with a pulse width of 1 ns at full energy. The deuteron beam then enters a self-cooled deuteron gas target, where neutrons are produced.

The neutron beam is achieved by mechanically rastering the accelerated deuteron beam through 90° using a dipole magnet, and the scanning motion is accomplished by mounting the dipole, the 90° beamline and deuterium gas cell on a platform which rotates concentric with the beam axis. Driven by a hydraulic



In the PFNA technique for contraband detection, a deuteron beam is injected into a beamline and neutron production target mounted on a rotatable scan arm. The fast neutrons excite nucleii within the bulk material and analysis of the resulting gamma emission identifies possible illegal materials. (Photos SAIC, Santa Clara, California)

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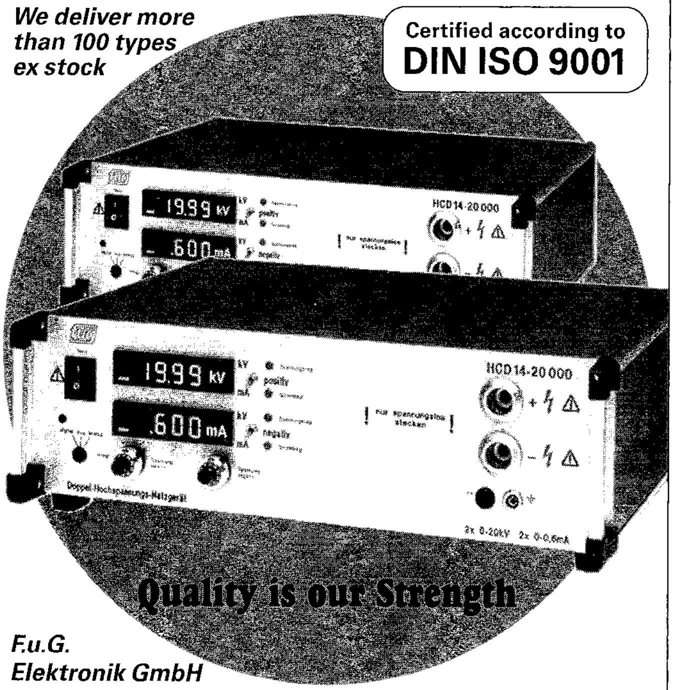

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Further details about the group can be found on World Wide Web (http://www.ph.rhbnc.ac.uk/research/hep/hep_home.html). Questions related to the post should be addressed to Dr M G Green, Physics Department, Royal Holloway University of London, Egham, Surrey TW20 0EX (phone +44 1784 443454, fax +44 1784 472794, email GREEN@V1.PH.RHBNC.AC.UK).

A letter of application and CV should be sent to Mike Green at the above address to arrive by Friday 4 August 1995. Applicants should also arrange for two references to be provided by the same date.

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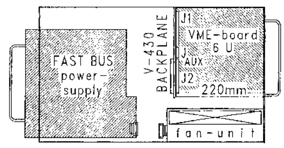

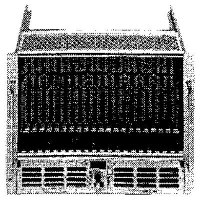

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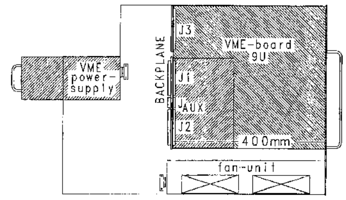

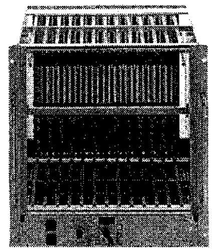

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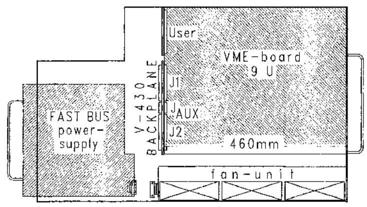

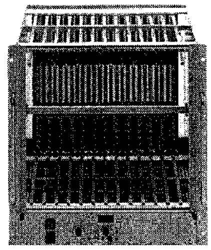

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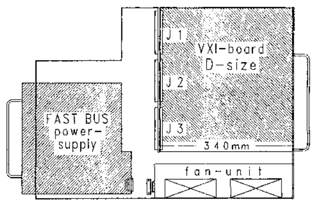

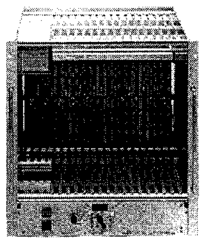

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Research applications

actuator, the scanning speed of the platform is adjustable up to approximately 0.25 Hz. Since the rotating and fixed beamlines are one continuous high vacuum system, a high vacuum rotary union is needed. A non-mechanical, low vapour pressure liquid (ferrofluid) vacuum seal is used. A collimator on the scan arm limits the vertical extent of the neutron beam and there is a fixed collimator in the horizontal plane.

The PFNA concept has undergone numerous tests to demonstrate its efficacy for detecting drugs and explosives. A full-sized system has been built by SAIC in Santa Clara and is undergoing integration testing with a variety of cargoes.

Increase in world trade favours the use of a tool like PFNA cargo inspection for monitoring incoming shipments. PFNA's ability to image elements can be expanded through advanced databases to verify cargo manifests and to monitor shipments. In a modified form, PFNA could also be used to examine the contents of sealed barrels of hazardous waste to avoid manual sampling.

From T.Gozzani, Science Applications International Corporation, Santa Clara, USA

Most types of accelerator were originally designed by accelerator engineers for particle or nuclear physics research. Today, there are some large and very sophisticated accelerators dedicated to a wide range of other research and development work. Particle accelerators provide a very valuable tool for studying the properties of matter.

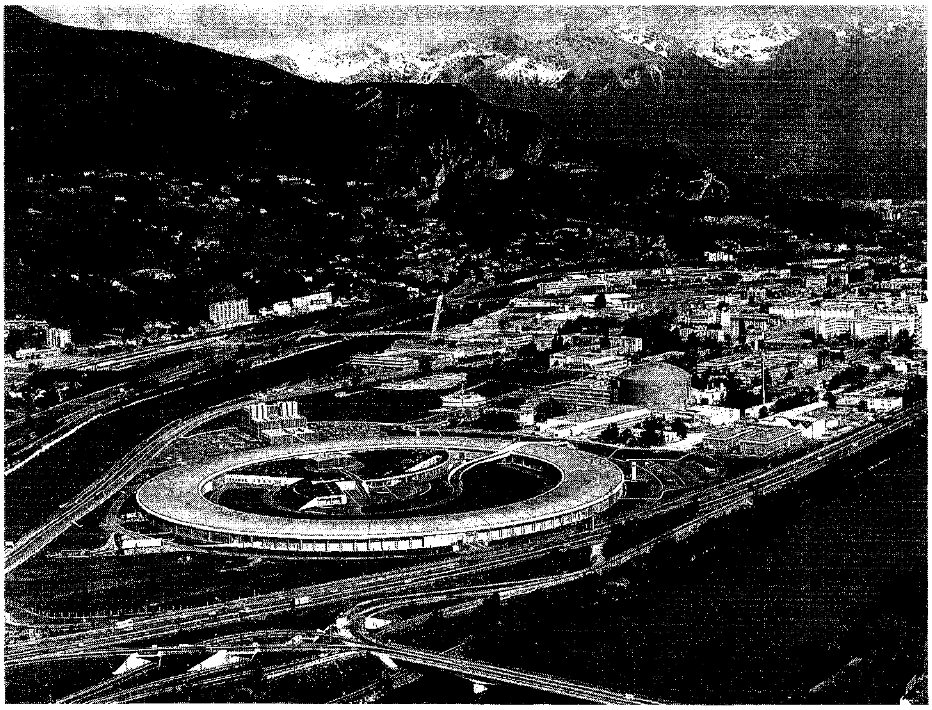
Synchrotron radiation research

In the many varied application fields of accelerators, synchrotron radiation ranks as one of the most valuable and widely useful tools. Synchrotron radiation is produced in multi-GeV electron synchrotrons and storage rings, and emerges tangentially in a narrow vertical fan.

Synchrotron radiation has been used extensively for basic studies and, more recently, for applied research in the chemical, materials, biotechnology and pharmaceutical industries.

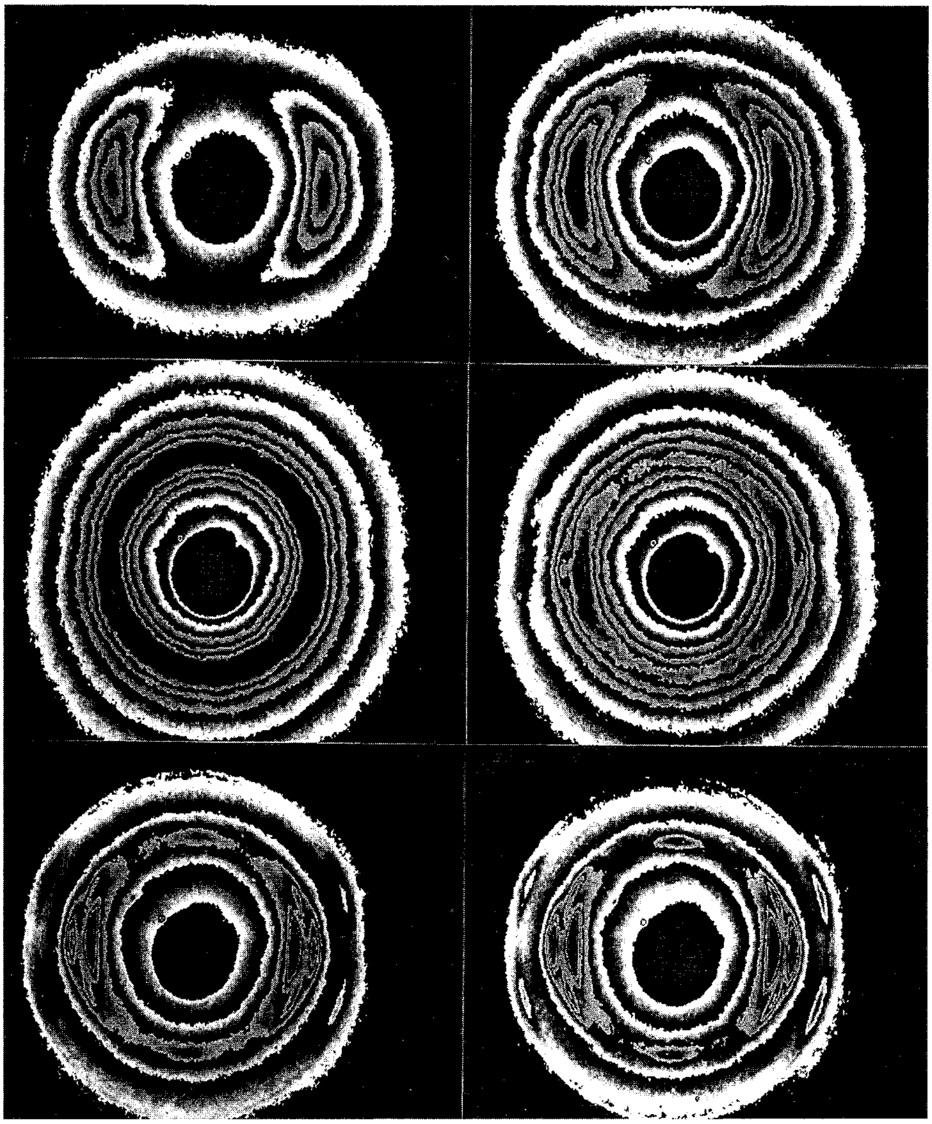
Initially, the radiation was a by-product of high energy physics laboratories but the high demand soon resulted in the construction of dedicated electron storage rings. The accelerator technology is now well developed and a large number of sources have been constructed, with energies ranging from about 1.5 to 8 GeV including the 6 GeV European Synchrotron Radiation Facility (ESRF) source at Grenoble, France.

A modern third-generation synchrotron radiation source has an electron storage ring with a complex magnet lattice to produce ultra-low emittance beams, long straights for 'insertion devices', and 'undulator' or 'wiggler' magnets to generate radiation with particular properties. Large beam currents are necessary to give high radiation fluxes and long beam



Synchrotron radiation is one of the most valuable and widely useful of all accelerator applications. The European Synchrotron Radiation Facility - ESRF - in Grenoble, France is a 6 GeV, third generation synchrotron radiation source which will provide up to 30 beamlines for fundamental and applied research.
(Photo ESRF)

Synchrotron radiation is often used for material research in industry - raw data from a time-resolved X-ray diffraction study of the annealing of a sample of a high performance polymer.
(Photo Keele University , UK)



lifetimes require ultra high vacuum systems.

Industrial synchrotron radiation research programmes use either X-ray diffraction or spectroscopy to determine the structures of a wide range of materials. Biological and pharmaceutical applications study the functions of various proteins. With this knowledge, it is possible to design molecules to change protein behaviour for pharmaceuticals, or to configure more active proteins, such as enzymes, for industrial processes.

Recent advances in molecular biology have resulted in a large increase in protein crystallography studies, with researchers using crystals which, although small and weakly diffracting, benefit from the high intensity. Examples with commercial significance include the study of HIV proteins and inhibitors, the SV40 virus (which can induce tumours), proteins involved in the metabolism of sleeping sickness parasites, and the investigation of xylose isomerase, used industrially to convert sugar to syrup.

Diffraction techniques are widely used in industry for the identification of phases and the analysis of stresses in materials such as thin films. Synchrotron radiation techniques increase the range and complexity of materials that can be studied, such as polymers and thermoplastics, and improve performance. For example Boeing were able to save 30% in weight in their 757 aircraft, and a larger reduction in cost, by replacing aluminium with glass-filled poly-ether-ether ketone (PEEK) resins.

Using synchrotron radiation, powder diffraction can be used to determine structure and assist in understanding material behaviour, following very rapid transformations. One example is the energy-dispersive rapid diffraction study of the synthesis of zirconia; composite ceramics based on this mineral are used for high temperature mechanical applications, and partially stabilized tetragonal zirconia powder dispersed in a compatible matrix such as alumina or magnesia can impart toughness by arresting micro-crack development. Dynamic "in-situ" studies with synchrotron radiation have shown that crystallization and transformation temperatures depend on the material's thermal history and on the chemical state of the initial zirconium hydroxide. Crystallization and transformation temperatures vary widely, so this information helps chemical engineers obtain the required degree of metastability in zirconia powders for each application.

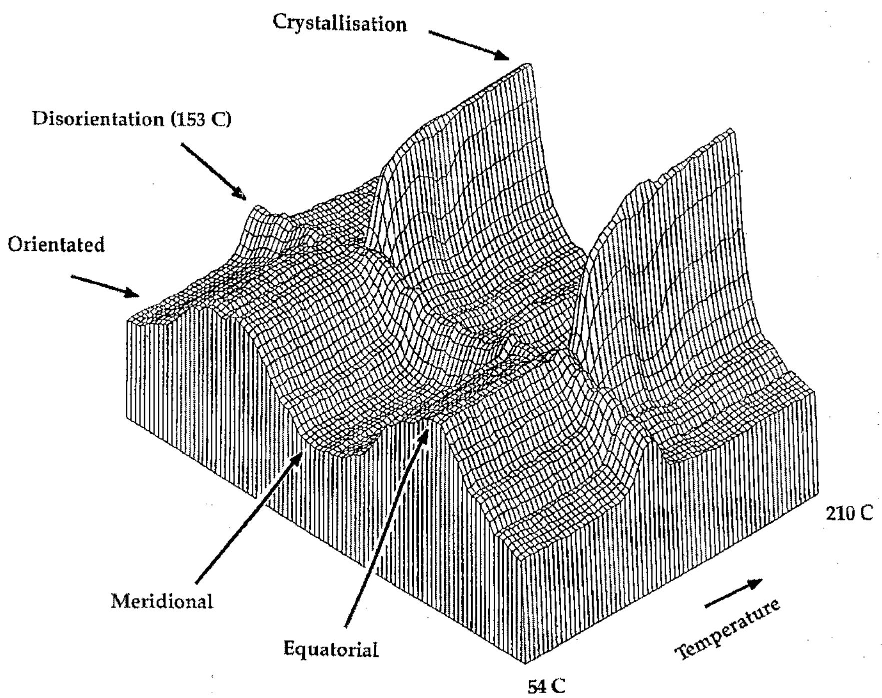
While X-ray crystallography can be used for well-ordered crystalline substances, other materials often do not have the long range structural order for this technique to be successful. In such cases, X-ray spectroscopy can be effective and X-ray absorption in matter and absorption spectra reveal sharp step increases at certain energies corresponding to the ejection of a bound electron from an atom. In condensed matter there are usually small oscillations superimposed on the top of these edges. These Extended X-ray Absorption Fine Structures (EXAFS), arising from interactions of the outgoing electron with the surrounding atoms, can be analysed to give information on the immediate surroundings. Industrial users of EXAFS facilities at the Daresbury Synchrotron Radiation Source are usually from the chemicals industry, and the work focuses on the behaviour of catalysts.

In the glass industry, the atomic structure of intrinsically disordered systems cannot be prescribed by diffuse diffraction techniques and again EXAFS is a powerful tool, leading to new insights into structure and properties. Combining EXAFS with reflectivity measurements has been important at looking at the surface layers for manufacturers such as Pilkingtons and Schott.

The number of synchrotron sources around the world is increasing rapidly, with two large facilities shortly to become operational in the USA and Japan; elsewhere, smaller sources are planned. The requirement for synchrotron is certain to grow for both academic research and materials development in industry.

From N. Marks, Daresbury and Rutherford Appleton Laboratories

Synchrotron radiation X-ray diffraction patterns such as these lead to the improvement of industrial material such as polymers. (Photo ICI plc, UK)



Positron sources

Normally positron sources are precursors for accelerator systems in high-energy particle physics; however very low energy positrons are commonly used to study the physics of atomic and condensed matter.

In these experiments low energy, monoenergetic positron beams are produced from high energy positrons by thermalization in special solid moderators. Due to intensity limitations on higher-energy positrons available from radioactive sources, electron linacs have been adapted for this purpose. High energy electron beams bombard thick, high-Z targets, where bremsstrahlung and subsequent pair production create electron-positron pairs. These high energy positrons are injected into a moderator (usually tungsten foils) and emerge at a few eV. The low energy positrons are electrostatically extracted and guided magnetically using low field solenoids. Although the efficiency of the moderation process is around 1 per 10^6, up to 10^9 slow positrons per second have been achieved using linacs with energies up to 100MeV and currents of 200 microamps.

These high intensity slow positron beams are used for condensed matter studies and atomic physics research, particularly when time correlation is needed between the positron beam and the measured signals or other pulsed devices such as lasers.

In condensed matter research, important results have been obtained from the measurements of the two-dimensional angular correlation of annihilation gamma rays of positrons at surfaces from velocity spectroscopy, and using positronium time-of-flight measurements. This has led to a better understanding of the population of electron states at surfaces.

For atomic physics research, fundamental experiments include collision rate measurements for positrons with gas atoms, measurements on the excited states of positronium etc.; all these demand high positron intensities because of the low reaction rates. Comparisons with similar electron measurements provide crucial tests of quantum electrodynamics.

A few linac-based beams are available in Ghent, Belgium; Lawrence Livermore, California; Tsukuba, Japan and elsewhere. In Japan, there are projects for even higher intensities - above 10^{10} slow positrons per second. For these higher intensities, remoderation and brightness enhanced stages can be incorporated to reduce the beam diameter to millimetre sizes or lower. Pulsing systems (in the MHz region) for the slow positrons can be installed for positron lifetime measurements and depth profiling analysis of solids. Positron Annihilation induced for Auger Electron Spectroscopy (PAES) can also benefit from high intensities for positron microscopy.

From D Segers, University of Ghent, Belgium

Accelerator mass spectrometry

Accelerator mass spectrometry (AMS) was invented in 1977 as a means of directly detecting long-lived radioisotopes at very low concentrations in the presence of much larger quantities of their stable isotopes. Its sensitivity depends on the fact that the radioisotope is measured, not by its radioactive decay, but by determining its atomic number and mass (Z and A). The original impetus was to detect radiocarbon (carbon-14 with a half-life of 5730 years) in organic material to establish its age. AMS required a thousand times less material than the Libby decay counting method.

Very soon it was realized that many other long-lived radioisotopes of cosmogenic, anthropogenic or natural origin could also be readily measured for a wide variety of purposes. These included beryllium-10, aluminium-26, calcium-36 and iodine-129 with half-lives of up to 15.9 million years. AMS could also be used to measure traces of stable isotopes.

Accelerator mass spectrometry detects tiny concentrations of long-lived radioisotopes in the presence of much larger quantities of their stable isotopes. The original impetus was to detect radiocarbon (carbon-14, with a half-life of 5730 years) to accurately establish the age of ancient artifacts, such as this bust of a daughter of the Egyptian king Akhenaton (1350 BC).

AMS measurements are often carried out with tandem electrostatic accelerators, many designed for nuclear physics research. The sample is inserted as a solid in the sample wheel of the cesium sputter ion source. Singly-charged negative ions are produced by bombarding the material with 20 keV cesium ions. (The neutral atom of most elements will bind an extra electron to form a negative ion.) These 20 keV negative ions are momentum analysed in a magnet, further accelerated through 150 keV and injected into a tandem electrostatic accelerator. They are then accelerated to the terminal in the centre of the accelerator through a voltage that varies from 2 to 10 MV. A foil or differentially pumped gas cell in the terminal strips the ions of several electrons and dissociates molecules.

The latter is one of the most important functions of the tandem - if three or more electrons are stripped from a neutral molecule, it is dissociated and its fragments lost in the second half of the accelerator. In this way molecules of the same mass as the element to be detected (molecular interference) are eliminated.

The required multiply-positively charged ions are accelerated through the second half of the tandem where a combination of magnetic and electrostatic deflectors select ions with a specific mass/charge ratio.

A limitation of AMS is its relatively low mass resolution - only one part in a few hundred. Hence if a radioisotope has a stable isobar, the two cannot be mass separated. In some cases the stable isobar does not form a negative ion (nitrogen-14 in the case of carbon-14 studies), but for beryllium-10 and chlorine-36 the stable isobars boron-10 and sulphur-36 form negative ions, so for beryllium-10 an absorber can stop the boron. For chlorine-36 careful chemical procedures can minimize the sulphur and measurements of the rate of energy loss in the final ionization detector can separate chlorine from sulphur if the final energy of ions is sufficiently high (100 MeV or so).

A measure of the sensitivity of AMS can be judged from the detection limits on the ratio of the radioisotope to stable isotope that can be measured. For carbon-14 and chlorine-36 it is better than one part in 10^{15}. The improvement factor over decay counting in these two cases is about 10^5 and 10^6 respectively.

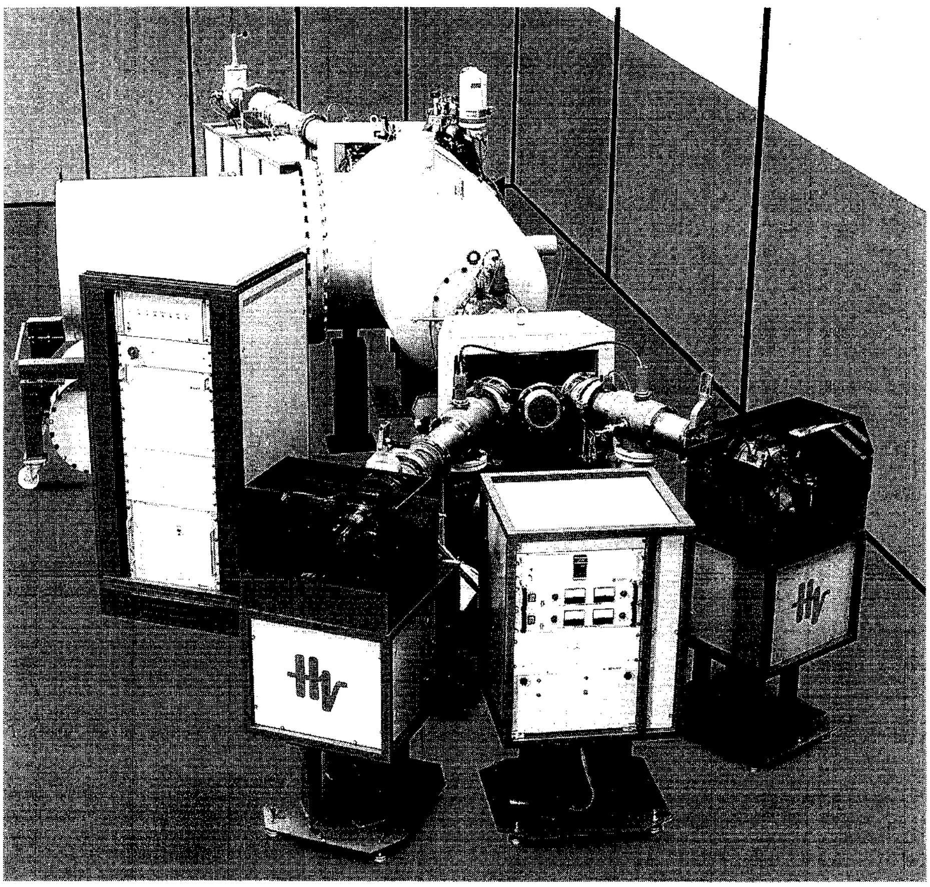
Applications of AMS are diverse - determining the ages of ancient artifacts (the Turin shroud was dated by AMS to 1325$\pm$ 33 AD) and the epoch of the Meteor Crater in Arizona (55 million years ago), identifying the leakage of radioactive waste from former nuclear fuel reprocessing sites, and measuring the diffusion of chlorine in silicon wafers used for solid state devices, and the neutron fluence produced by the nuclear weapon detonated over Hiroshima, and many more. In the case of Hiroshima, the measurements proved that up to 70% of radiation damage to humans was from neutrons rather than gamma rays as previously believed.

An application of AMS likely to become more important in the future is in the field of biomedical research. One example is a study of how carcinogens labelled with carbon-14 are metabolized. With AMS the doses are below permissible limits and the tissue samples themselves are very small.

At present there are some 40 laboratories with tandem electrostatic accelerators throughout the world engaged full- or part-time in AMS measurements. International symposia on AMS are held every three years; the seventh in the series will take place at the University of Arizona in 1996.

From H E Gove, Department of Physics ,University of Rochester, NY.

Ion beam analysis is used in the study of materials and the structure of matter. The accelerators, not generally installed at specialist accelerator laboratories, have to be easy to maintain and simple to operate. This shows an ion beam analysis experiment using an electrostatic accelerator producing milliamp beams with energies of a few MeV. (Photo Institut für Kernphysik, Frankfurt am Main, Germany)



Ion beam analysis

Ion beam analysis is an accelerator application area for the study of materials and the structure of matter; electrostatic accelerators of the Van de Graaff or Dynamitron type are often used for energies up to a few MeV. Two types of machines are available - the single-ended accelerator type with higher beam currents and greater flexibility of beam management, or the tandem accelerator, limited to atomic species with negative ions.

The accelerators are not generally installed at specialist accelerator laboratories and have to be easy to maintain and simple to operate. The most common technique for industrial

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Closing date for receipt of applications is September 15, 1995. The University of Florida is an equal employment opportunity/affirmative action employer. Anyone requiring special accommodations to complete applications should contact the Search Committee Chair.

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Apsimon, R.J. and G.J. Tappern: ***Binary Ice as Coolant for the ATLAS Silicon Tracker.*** *Proceedings WELDEC Int. Workshop, Univ. Lausanne & CERN (October 1994), p. 197-204* research is Rutherford Back Scattering Spectrometry (RBS). Helium ions are the preferred projectiles, since at elevated energies (above 3 MeV) nuclear resonance scattering can be used to detect photons associated with target molecules containing elements such as carbon, nitrogen or oxygen.

Due to the large amount of available data on nuclear reactions in this energy range, activation analysis (detecting trace elements by irradiating the sample) can be performed with charged particles from accelerators over a wider range of atoms than with the conventional use of neutrons, which is more suited to light elements. Resonance reactions have been used to detect trace metals such as aluminium, titanium and vanadium.

Hydrogen atoms are vital to the material performance of several classes of materials, such as semiconductors, insulators and ceramics. Prudent selection of the projectile ion aids the analysis of hydrogen composition; the technique is then a simple measurement of the emitted gamma radiation. Solar cell material and glass can be analysed in this way.

On a world-wide basis, numerous laboratories perform ion beam analysis for research purposes; considerable work is carried out in cooperation between scientific laboratories and industry, but only a few laboratories provide a completely commercial service.

From K. Bethge, Frankfurt am Main, Germany

The future

Particle accelerator development must rank as one of the major scientific achievements of the twentieth century. Progress in computing methods, engineering design techniques and advances in material science have all contributed to today's highly-developed, precision technology where small versatile machines are used for a wide range of applications.

The accelerator community has opportunities to expand the range of applications in industry and medicine, particularly by increasing beam intensities. In some cases, the required 'technology-step' improvements can be achieved by employing existing materials and present day techniques.

Medicine

In the competitive commercial world of radiopharmaceuticals, the trend is to employ higher intensity accelerators for lower-cost production of isotopes and to operate these machines under increasingly more stringent radiological controls.

Several accelerator manufacturers are developing higher current machines in the range 500 to 1000 microamps, demanding production targets better suited to handling heat production. One company, IBA in Belgium, has already supplied 2 mA, 18 MeV positive-ion cyclotrons with internal targetry for the commercial production of a new therapeutic isotope, palladium-103, for cancer brachytherapy. In Canada, EBCO Industries together with TRIUMF have announced the development of 1000 microamp extraction from their existing 30 MeV cyclotron.

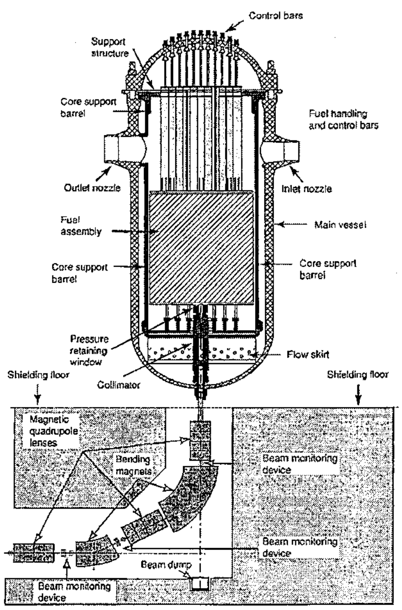
The isotope production industry is a major opportunity for accelerator technology. Historically, material-testing reactors have always provided low-cost isotopes to the industry and to medical companies; however many of these reactors are reaching the end of their lives and are not being replaced.

Diminishing research in nuclear power generation and fuel testing, combined with the dilemma on waste disposal, has made fission-based reactors less attractive. High intensity accelerators with appropriate targetry could be constructed to produce the necessary neutron fluxes in the range 10^{14-15} $cm^{-2}s^{-1}$ (e.g. spallation sources at 500 to 1000 MeV with intensities of a few mA). With no criticality issues and no fuel management problems, this type of accelerator could replace nuclear reactors for this purpose; so far no laboratory has produced such plans.

Of the present day reactor-generated isotopes, molybdenum-99 remains the most common medical isotope and is produced by fission of enriched uranium-235 in thermal neutron reactors. A proton-driven intense subcritical neutron source has been proposed recently by Yves Jongen of IBA where a 150 MeV, 1.5 mA proton beam from a cyclotron would strike a molten lead target, surrounded by a water and graphite reflector, to produce neutrons by spallation. These primary spallation neutrons would strike secondary targets containing subcritical amounts of uranium-235, producing a thermal neutron flux up to 2×10^{14} and a fission power of over 500 kW. Manufacturers could then position their own molybdenum-99 production targets in this machine and continue to produce a radiopharmaceutical grade product without the need to access a nuclear reactor. This small device would cost much less than a new research reactor.

The accelerator-based free electron

To avoid proliferation of uranium and long-term transuranic radioactive waste, new power generation ideas propose using accelerator-driven systems for fission using fuels such as naturally occurring thorium. This is a schematic of an idea suggested by Carlo Rubbia and his collaborators at CERN, using an accelerator beam to bombard a target assembly containing nuclear fuel and moderating material.



laser (FEL) at Vanderbilt University, Tennessee, has been built for research applications in medicine and biology. Early results are promising for the targeting of FEL radiation to the amide II band of proteins leading to tissue ablation without substantial damage. The free electron laser could provide a wavelength scalpel for precision surgery.

Power generation

New concepts of power generation using accelerator-driven systems for fission have been proposed using fuels such as naturally occurring thorium. Successful implementation of this technology would lead to less proliferation of uranium and less long-term transuranic radioactive waste.

At CERN, Carlo Rubbia and his collaborators have suggested employing an accelerator to produce a 1 GeV, 7 mA beam to bombard a target assembly containing nuclear fuel and moderating material. Thorium would be used to breed fissile uranium-233 and to sustain stable energy production. Careful design of the fuel would ensure subcritical operation with a thermal neutron flux of 10^{14} cm^{-2} s^{-1}, and a prototype 'energy amplifier' could generate electrical power in excess of 100 MW. Interestingly, the thermal neutron flux level of this device is close to that required for isotope production.

The original Los Alamos proposal for accelerator-driven transmutation technology (ADTT) included a programme for energy production where the fuel would be thorium and the assembly would remain subcritical.

The fuel would be embedded in a lithium-beryllium fluoride molten salt to facilitate efficient high temperature operation. The advanced study at Los Alamos has highlighted not only the demanding requirement for a high intensity accelerator but also the extreme performance levels required for the materials employed. Similar study programmes are progressing in laboratories in Japan, Russia and elsewhere.

Power generation by inertially-confined fusion is another possibility and several accelerator groups are investigating the standard deuterium-tritium reaction; the reaction of protons on boron-11 also invites attention.

Pellet design can benefit from early laser investigation but to raise the temperature above the Lawson criterion - 10 MJ energy within 15 nanoseconds - the demand on the accelerator system will be extreme. Preliminary studies on a linac-storage ring complex have already been carried out at the GSI Laboratory, Darmstadt.

The environment

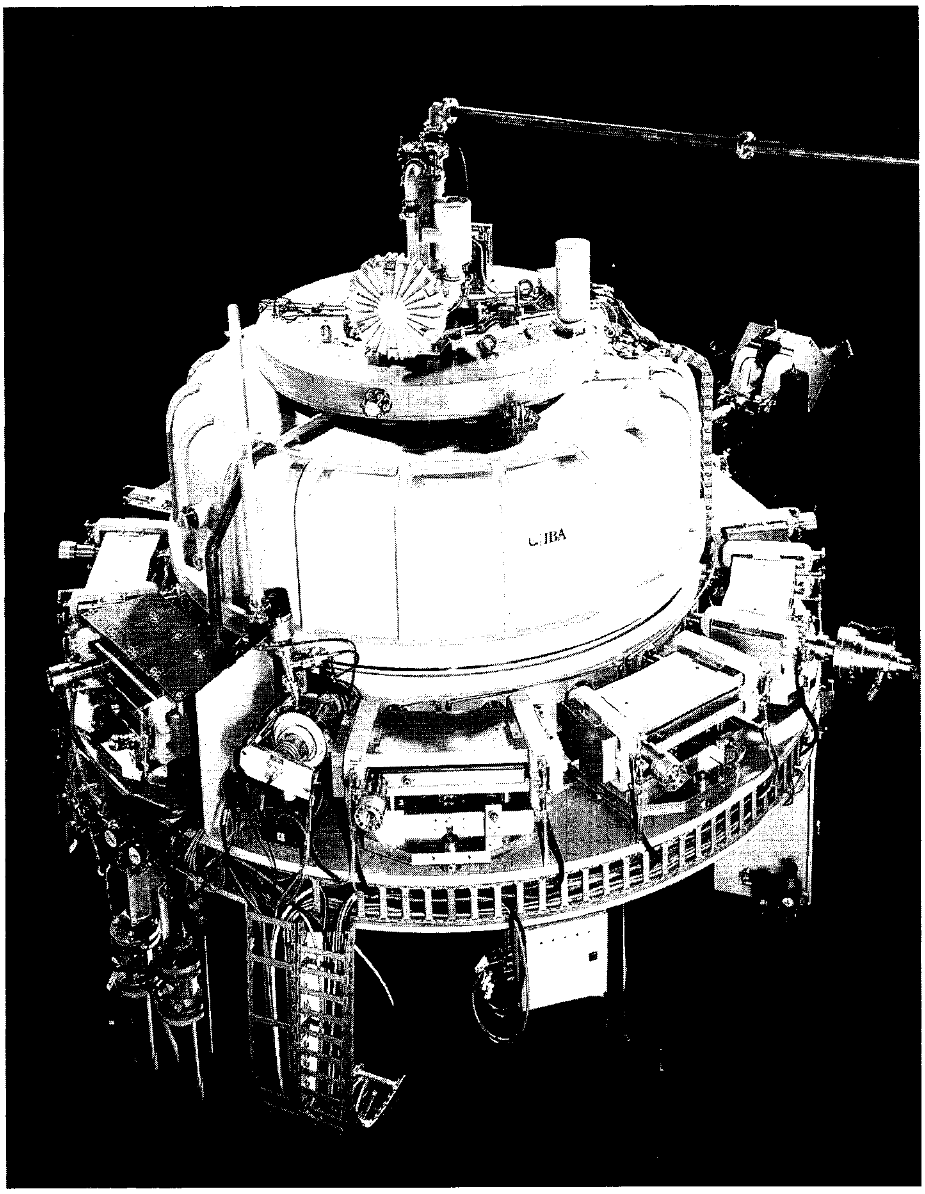
Accelerator technology could benefit the environmental management of the planet in the transmutation of nuclear waste. Used nuclear fuel contains highly radioactive waste products including long-lived actinide isotopes and long-lived fission products such as iodine-129 (half-life 1.6×10^7 years). Storage of this material remains a serious public and political concern. Accelerator-driven transmutation of waste (ATW) offers a solution.

The ATW concept proposed by Los Alamos requires a 100 - 200 mA beam of protons or deuterons at up to 1.6 GeV. By interaction with a spallation target, up to 50 fast neutrons per incident particle are generated and contained inside a moderating blanket. The high neutron flux of 10^{16} cm^{-2} s^{-1} is thermalized to produce a thermal neutron flux sufficient to convert actinide products such as neptunium-237 (half-life 2.1×10^6 years) to the fissile neptunium-239 and fission product technetium-99 (half-life 2.1×10^5 years) to stable ruthenium-100.

While accelerator-driven neutron sources do allow transmutation of most of the very long-lived radionuclides, the accelerator facilities and handling operations will inevitably be expensive.

Smaller accelerators can also assist in environmental control and although their application has been limited so far, the use of environmentally-invasive chemical methods is becoming less attractive and cost effective. Accelerator technology can be applied to water and waste treatment, sludge sterilization and combustion flue gas treatment in large industrial plants. The elimination of pathogens and toxins are attractive openings for environment research using smaller accelerator devices.

This 10 MeV, 10 milliamp electron beam accelerator (the Rhodotron) is an example of a new generation of machines, purpose-designed for future industrial users, in this case for applications such as industrial irradiation and sterilization. (Photo IBA, Louvain-la-Neuve, Belgium)



Guest editor

Guest Editor for this special issue of the CERN Courier on the applications of accelerators was Dewi M. Lewis of Amersham International plc, UK.

Dr. Lewis was educated at the Physics Department, University of Wales, Swansea, and learnt his accelerator physics as Engineer-in-Charge at the CERN Intersecting Storage Rings before joining industry in 1979 at the beginning of the boom for commercial cyclotrons. Having managed the installation of Amersham's second and third isotope production cyclotrons in the UK, his industrial experience encompassed isotope manufacturing and business management in radiopharmaceuticals and organization of joint ventures. Following closure of several research reactors in 1990, his responsibilities extended to reactor isotope production as well as technology transfer with international laboratories. He was responsible for creation of the first Russian 'weapons to ploughshares' joint venture with the Radioisotope Association, Mayak and the Russian Atomic Energy Ministry. Dr. Lewis currently chairs the European Radiopharmaceutical Industry's committee on future reactor isotopes and is currently involved in the technical development for accelerator technology.

Amersham International is one of the world's leading isotope companies, engaged in development, manufacturing, international sales and distribution of radioisotope products in markets for healthcare, research compounds and industrial products. Formerly part of the United Kingdom Atomic Energy Agency, Amersham was one of the first companies to be privatized in 1982

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Das PSI ist ein nationales, multidisziplinäres Forschungszentrum. Für das Projekt 'Pion-Beta Experiment' suchen wir auf vertraglicher Basis eine/n

Postdoktorandin/Postdoktoranden (Experimentalphysik)

Ziel dieses Projektes ist die Präzisionsmessung der Zerfallsrate $\pi^+ \rightarrow \pi^0 e^+ \nu_e$ des Pions. Für dieses Experiment wird ein neuer Detektor am PSI aufgebaut.

Aufgaben:

- Leitung des Aufbaus und der Inbetriebnahme des Pion-Beta Detektors (Triggerelektronik, CsI-Kalorimeter, Vieldrahtkammern)
- Datenaufnahme und -auswertung nach Fertigstellung des Detektors

Wir setzen Erfahrungen beim Aufbau von kernphysikalischen Detektoren sowie experimentelles Geschick voraus.

Für weitere Auskünfte steht Ihnen Herr Dr. S. Ritt, Tel. 0041 56 99 37 28, gerne zur Verfügung.

Ihre schriftliche Bewerbung mit den üblichen Unterlagen senden Sie bitte an das

PAUL SCHERRER INSTITUT, Würenlingen und Villigen, Personaldienst, Kennziffer 1111A, 5232 Villigen PSI, Schweiz.

University of Copenhagen

Niels Bohr Institute
for
Astronomy, Physics and Geophysics

Assistant Research Professorship in Experimental Particle Physics

A position as assistant research professor (forskningsadjunkt) in experimental particle physics at the Niels Bohr Institute for Astronomy, Physics and Geophysics (NBIfAFG) will be open from January 1, 1996. The duration is for two years with a possibility for an extention.
The NBI group is involved at CERN in the ALEPH and DELPHI experiments at LEP and the future experiment ATLAS at LHC and in HERA-B at DESY. In addition to physics analysis the group contributes to the hardware and software.
While based in Copenhagen, the chosen candidate is expected to work in one of the LEP experiments and one of the future experiments.
The chosen candidate is expected to participate in the University teaching program at all levels. The language of undergraduate instruction is Danish, but English will be accepted.
The application must include a *curriculum vitae* and a complete list of publications indicating which publications are considered most relevant for this position. The publications should not be sent.
The applicants' qualifications will be evaluated by an Evaluation committee, and the enitre report of the Committee will be sent to all applicants. The Evaluation Committee may ask for supplementary material.
The position will be under the agreement between the Confederation of Professional Associations and the Ministry of Finance.
Salaries are determined by seniority. For example the annual salary for a candidate four years after Masters' Degree is appr. 245,000 DKK after contributions to the pension scheme, but before tax.
The application, written in English, must be mailed to Professor Jørn Dines Hansen, Niels Bohr Institute for Astronomy, Physics and Geophysics, Blegdamsvej 17, DK-2100 Copenhagen Ø, Denmark; tel: +45 35325293, fax: +45 31421016, E-mail: dines@nbi.dk, from whom more information can be obtained. In order to be considered, applications must have been received no later than August 25, 1995.

MIT

LABORATORY FOR NUCLEAR SCIENCE

Postdoctoral Associate/ Research Scientist
Experimental Accelerator Physics

The MIT Bates Linear Accelerator Center operates a 1 GeV electron linear accelerator-recirculator system for nuclear physics research and has recently completed a pulse stretcher/storage ring for delivering high duty factor beams to internal and external target experiments. We are seeking applicants for a Postdoctoral Associate or Research Scientist position working in the accelerator physics group. Responsibilities include taking part in planned upgrades and improvements to the linac and recirculator, which will enhance operational efficiency. This will include working with accelerator operations during experimental runs. and taking an active part in the commissioning of the new ring.

Requirements: a Ph.D. and experience in experimental accelerator physics.

Please send a letter of application, resume, and the names of three references to: **Prof. Stanley Kowalski, MIT Bates Linac, | P.O. Box 846, Middleton, MA 01949.** MIT is an Equal Opportunity/Affirmative Action Employer and encourages applications from women and minorities. This position is located in Middleton, MA. MIT is a non-smoking environment.

MASSACHUSETTS INSTITUTE OF TECHNOLOGY

UNIVERSITY OF OXFORD

University Lecturership in Experimental Particle Physics in association with Corpus Christi College

Applications are invited for the above post which becomes available from 1 January 1996. Stipend according to age on the scale £15,154 - £28,215 per annum. The successful candidate may be offered a tutorial fellowship by Corpus Christi 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 college posts) may be obtained from the Deputy Administrator, Department of Physics, Nuclear & Astrophysics Laboratory, Keble Road, Oxford OX1 3RH, UK.

The present experimental Particle Physics research programme includes the DELPHI experiment at LEP (CERN) and ZEUS experiment at HERA (DESY); the SOUDAN2 and MINOS experiments (USA); the Sudbury Neutrino Observatory project (Canada); the development of cryogenic detectors and the CRESST experiment (Gran Sasso) plus the development of the ATLAS/LHC experiment in high energy pp physics. The appointee would be expected to participate in some of the above programmes, or possibly develop new initiatives associated with other projects.

Applications (eight copies except in the case of overseas candidates when only one is required) should be sent to arrive no later than 31 August 1995. The applications should include a curriculum vitae, list of publications, a statement of research interests and teaching experience plus the names of three referees. Referees should be asked to send references to Dr G Myatt, Acting Head of Particle and Nuclear Physics at the above address by the closing date.

It is expected that shortlisted candidates will be interviewed in Oxford in October 1995. All applicants are asked to indicate an email address or fax or telephone number where they could be contacted during September 1995.

The University exists to promote excellence in teaching and research, and is an equal opportunities employer.

Guest Editor for this special issue was Dewi M. Lewis of Amersham International plc, UK.

by the Thatcher Government and went on to enjoy considerable commercial success.

In the 1960s, Amersham was also the first company to purchase a cyclotron solely for commercial purposes, and is now the largest operator with seven production cyclotrons at sites in the UK and at its subsidiary, Medi+Physics in the USA.

Products have been developed with appropriate pharmaceutical licences for isotope products for myocardial perfusion imaging (heart), cerebrovascular disease (stroke), pain palliation for prostatic cancer and for infection imaging.

The Editor of the CERN Courier would like to thank

- CERN Courier Advisory Committee Chairman Ted Wilson for suggesting the idea of a special issue on accelerator applications with a Guest Editor;

- Dewi Lewis for such an agreeable and educational collaboration; and

- all contributors.

A whole new generation of PMTs

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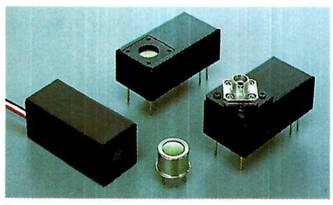

Left: H5783 (cable output type) Center: H5773 (on-board type which allows to mount directly on a printed circuit board) Right: H5773 with fiber connector

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