

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 ± 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.

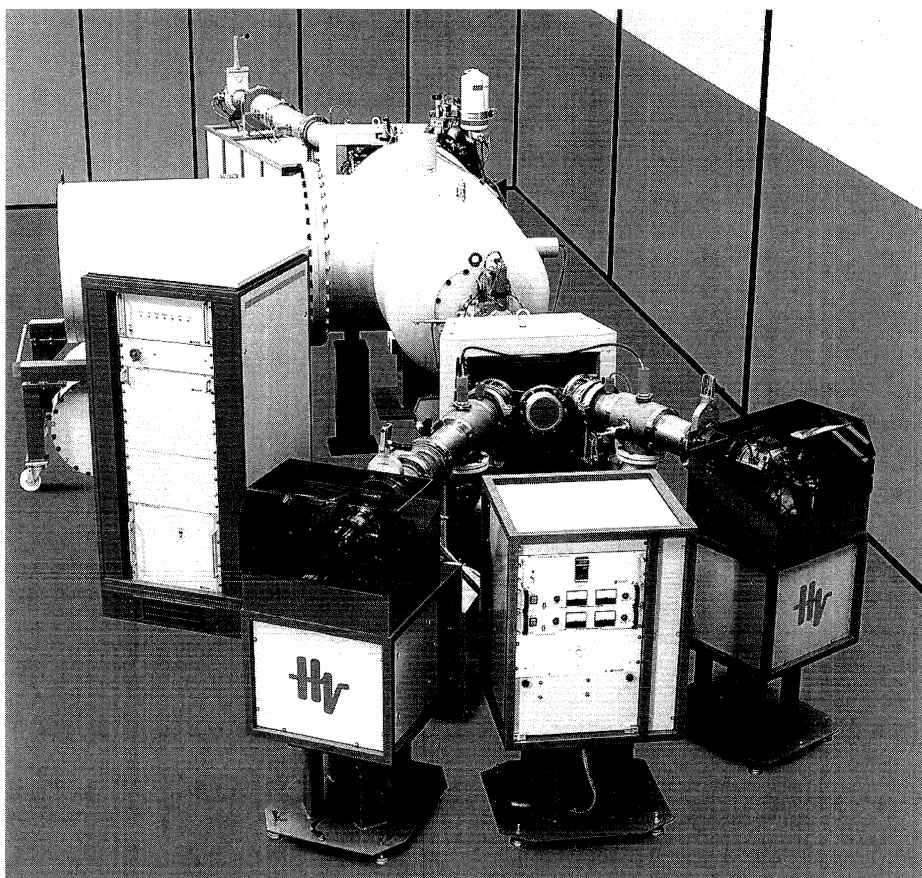
From H E Gove, Department of Physics, University of Rochester, NY.

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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As DESY has laboratories at two sites, in Hamburg and in Zeuthen near Berlin, applicants may indicate at which location they would prefer to work.

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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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References:

*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*

The future

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

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 $10^{14-15} \text{ cm}^{-2}\text{s}^{-1}$ (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