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.

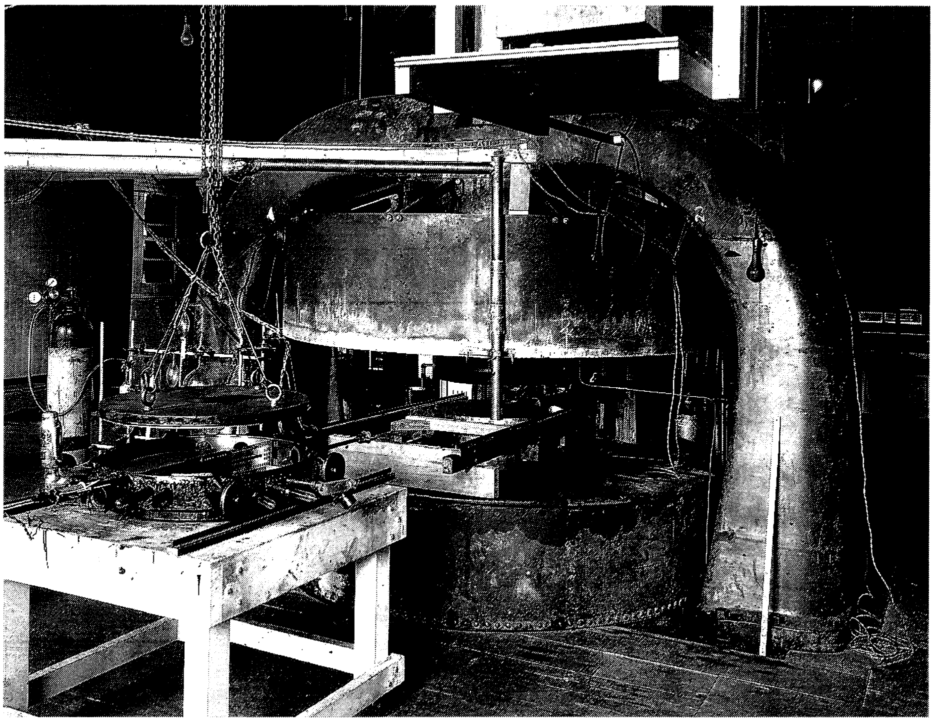
Twentieth-century science is full of similar examples of applications derived from pure research.

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,