Accelerators in science and industry: Focus on the Middle East & Europe

Many countries are applying advanced technologies using low-energy accelerators, but not all are able to reap benefits

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Originally developed as tools for frontier physics, machines commonly known as particle accelerators today are routinely applied in science, industry, medicine, environmental protection, and other fields. While they come in a range of sizes and types, accelerators that produce relatively low energy beams have become some of the most powerful nuclear analytical tools. Among the practical applications of such low-energy accelerators are highly sensitive scientific analyses of trace elements in studies of air pollution, for example, or in health care and treatment.

Despite the range of practical applications, this high-level technology has not yet made significant inroads in most developing countries, in stark contrast to the situation in the industrialized world. In the interests of narrowing this technological gap, and in light of health and economic benefits derived from applications of low-energy accelerators, the IAEA initiated a regional project in 1993 through its technical assistance and co-operation programmes. The project on low-energy accelerators in science and industry is keyed to co-ordinating efforts among interested countries in the Middle East and European region, and it complements a number of separate national projects in this field.

This article presents a brief overview of common applications of low-energy accelerators and describes work being done within the framework of the IAEA's national and regional projects involving countries in the Middle East and Europe. More than 20 countries intend to take part in the regional project.

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The regional project addresses some fundamental problems regarding the interconnections between the effective transfer of technologies and scientific and industrial development. In industrialized countries, the link between scientific institutes and industries typically is a strong one, and developmental policies are firmly in place. In the developing world, on the other hand, this most often is not the case, a weakness that can prevent countries from reaping practical benefits of advanced technologies. The regional project seeks to help countries build such necessary links and establish effective policies. In this regard, it is important to keep in mind that today's emerging technologies are tomorrow's conventional ones, and countries must carefully and selectively build up their scientific and industrial capabilities in areas that can give them a competitive edge.

Applications of accelerators

Accelerators and their products are used in almost all branches of high technology and modern medicine. Some typical applications of low-energy accelerators — most of them being cyclotrons, electrostatic generators (Van de Graaff or similar), and linear accelerators ("LINACs") — are briefly described below.

Accelerators as analytical tools. In many areas, several powerful analytical techniques based on accelerator technology have made impressive impacts. *(See figure.)* The list includes particle induced X-ray emission (PIXE); Rutherford backscattering (RBS); nuclear reaction analysis (NRA); particle elastic scattering (PESA); particle induced gamma emission (PIGE); channeling microscopy (CM); scanning transmission ion microscopy (STIM); and secondary electron microscopy (SEM).

By the proper combination of the detected reaction products, one can obtain information on the total elemental composition related to the morphology of the sample. Scanning by spot-size ion beams has transformed these techniques from analytical tools into an imaging device. They thus map the distribution of elements and become a veritable nuclear "microscope".

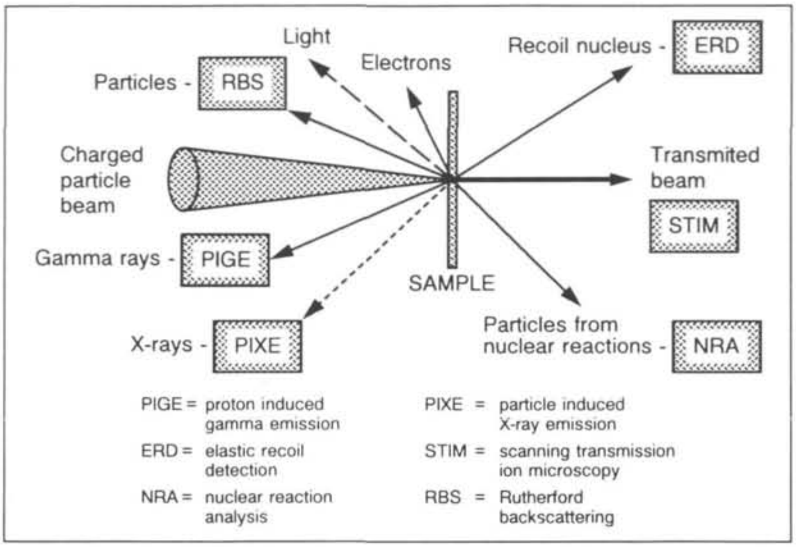
Another technique — accelerator mass spectrometry (AMS) — uses an accelerator and its beam transport system as an ultra-sensitive tool. It is capable of detecting isotopic abundances of long-lived radioisotopes (beryllium-10, carbon-14, aluminum-26, chlorine-36, calcium-41, iodine-129) in the range 10^{-15} to 10^{-16} in small (mg) samples. AMS has been accepted for use in more than 30 laboratories worldwide.

Applications are abundant — for example, in areas of archeology, art, paleo-anthropology, geology, paleo-climatology, extraterrestrial mineralogy, and biology. AMS is used in the majority of radiocarbon dating measurements, for instance, giving a much greater sensitivity than the more traditional method of counting the beta decays of carbon-14.

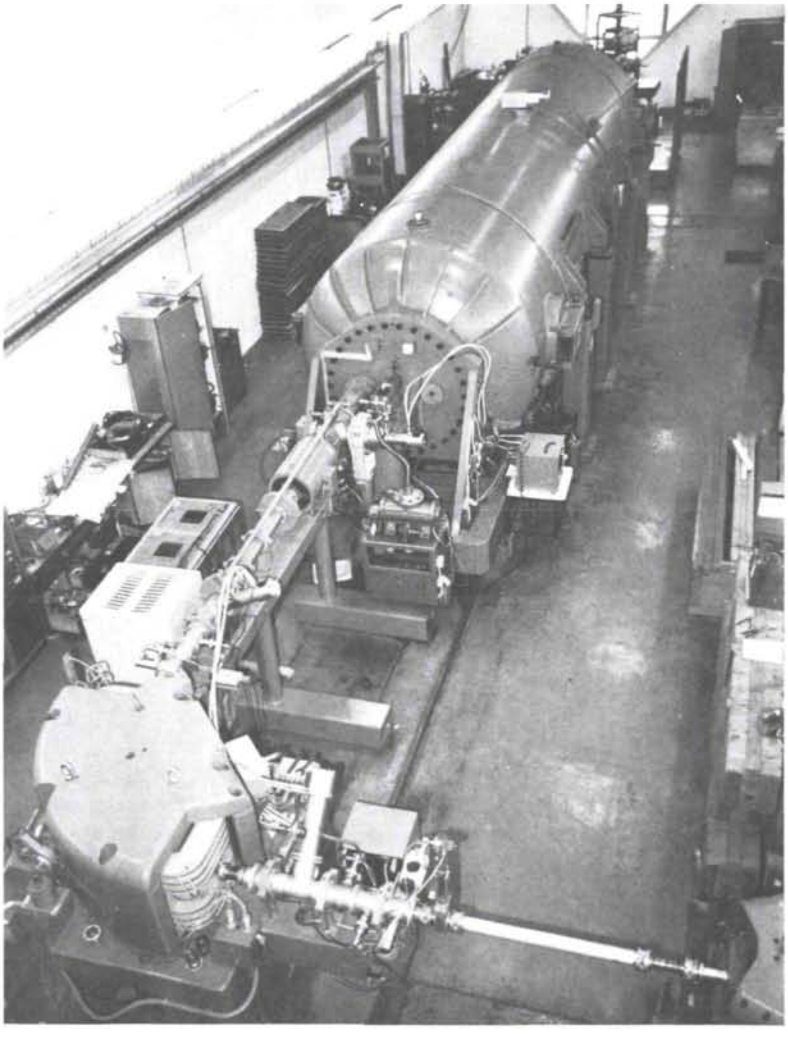
Accelerators in life science and medicine. Particle beams produced by accelerators can be used in medical institutions for both diagnostic and therapeutic applications. Diagnostic applications include the use of nuclear analytical techniques for element analysis, the use of different radioisotopes, and especially the use of positron emitters. Therapeutic applications are not limited to radiotherapy. They also include a broad spectrum of other activities ranging from the use of special materials to surgical applications.

Analyses of the concentration levels of trace elements in body fluids and tissues hold much promise as a clinical test. Techniques based on accelerators offer a very interesting approach to these problems because of their abilities to detect simultaneously several trace elements in very small samples (biopsy, hair, blood, etc.). Perhaps as in no other area, the development of accelerators has had a marked impact in medicine — specifically in the field of nuclear medicine and in radiation therapy. A range of radioisotopes for medical application which are not available from a nuclear reactor is produced by a cyclotron. These radioisotopes can provide a better understanding of the processes through which human diseases develop. Some radioisotopes have very short half-lives, measured in minutes and they must therefore be produced close to where they will be used. The most often needed radionuclides used in positron emission tomography (PET) are carbon-11, nitrogen-13, oxygen-15, and fluorine-18.

In addition to conventional radiation like gamma or X-rays produced by electron linear accelerators, several centres have been using



When a sample is bombarded with beams of charged particles, a number of processes take place. All of them can be used to obtain analytical information about a sample under investigation, and a number of them have been developed into accepted nuclear analytical techniques. *Photo:* The EN Tandem Van de Graaff accelerator that was donated by Rice University in Houston, Texas, to the Ruder Boskovic Institute in Zagreb, Croatia.



neutron and proton radiation therapies. Superior results are reported for the control of selected diseases by a dozen facilities which are currently investigating proton radiation therapy. In addition, facilities for heavy-ion treatment will soon be available at several locations. Heavy-ion beams exhibit a favourable depth/dose distribution and give the possibility of neurosurgical applications.

Accelerators in material science. The use of accelerators in material modification and subsequent analysis has been a fast-growing area of accelerator-based technologies. Numerous applications of ion implantation technology have been transferred from the research laboratory to industry. One outstanding example is the development of ion implantation for improving the wear resistance of artificial protheses.

It is an accepted view that a new industrial revolution will be brought about by the establishment of advanced material processing and machining technologies that can create new materials down to an atomic and molecular level. This could be accomplished by accelerator-based technologies through the development of high-energy ion beams that are focused, clustered, and wide-ranging.

Modifications and analyses of different materials employing ion beams in the range of mega-electron volts (MeV) are being done with an increasing number of charged particle accelerators. Some of the tasks performed include: ion implantation and processing; synthesis of thin films and surface modifications; fabrication of bio-materials; study of corrosion-erosion phenomena; concentration profile measurements; and diffusion phenomena studies.

Currently at least five companies worldwide have high-energy ion implantation systems available. All are designated to accelerate singly or doubly charged heavy ions such as boron, nitrogen, phosphorus, arsenic, and antimony. By controlling the beam's energy, the systems can be used to treat materials at desired surface depths. In this way, for example, extremely high quality multi-layers or modified surface layers having numerous functions can be formed on ordinary materials.

Accelerators in environmental protection. Accelerator-based analytical techniques are used in monitoring environmental pollution and for identifying the pollution sources. Because of their multi-elemental capabilities, and the possibility of measuring concentration profiles, they have been extensively used for air pollution studies. *(See graphs.)*

One of the major sources of air pollution is coal burning for electrical power generation and heating, despite improvements in combustion operations and the use of gas cleaning devices such as electrostatic precipitators (and electron accelerators). Moreover, electrical precipitators may show minimal collection efficiency for particles in the 0.1 - 1.0 micrometer size range. Such particles have longer atmospheric residence times and greater effects on health and air quality than would an equal mass of larger particles. They contain unusually large surface concentrations of potentially toxic trace elements which increase with decreasing particle size, owing to mechanisms of fly ash formation.

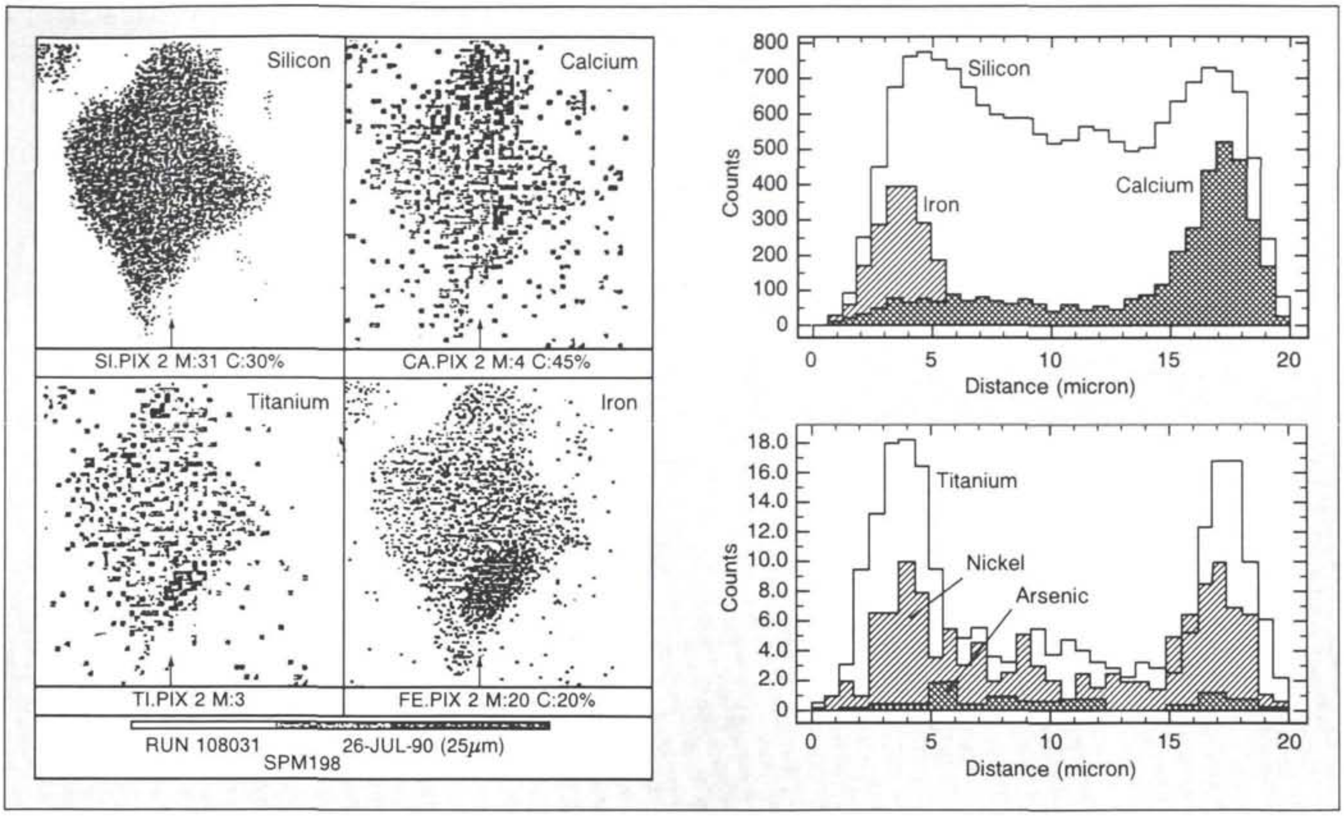
Accelerators in industry. Another noteworthy application is ion projection lithography. The microelectronics industry requires the development of lithography capabilities below 0.3 micrometers for advanced silicon devices and capabilities below 0.1 micrometers for hetero-structure and quantum coupled devices. Ion projection lithography may meet these strict requirements, surmounting the limits of optical and X-ray lithographic methods.

Industrially developed countries are aware of the potential of accelerator-based technologies. For example, Germany has 23 electrostatic accelerators, nine of them being tandems with experimental set-ups for hydrogen profile determination, RBS, ion implementation, channelling, microprobe, and AMS. Many of these facilities devote more than 50% of their operating time to applied research. In addition, there are 16 cyclotrons, some designed exclusively for isotope production, at least three with PET capabilities, and 11 synchrotron and linear accelerators mainly used for heavy ion acceleration. In Japan, medical applications of accelerators alone include 13 cyclotrons with PET capabilities, heavy-ion accelerators, and more than 500 linear accelerators used for therapeutic applications.

IAEA-supported national projects

For the past 15 years, the IAEA's technical assistance programme for the Middle East and Europe region has included a number of projects involving accelerator technologies. Several laboratories in Albania, Bulgaria, Croatia, Greece, Hungary, Iran, Jordan, Poland, Portugal, and Romania, among other countries, have been assisted under national projects having objectives to upgrade or establish accelerator laboratories. Using large amounts of non-convertible currency funds in the late 1970s and early 1980s, the IAEA provided accelerators of Soviet origin to Bulgaria, Hungary, Poland, and Portugal, for example.

In Hungary, a national laboratory in Debrecen received a cyclotron which was put



In air pollution studies, accelerator technologies (namely PIXE and RBS) can be used to characterize fly ash particles by measuring element concentrations, and providing element concentration profiles. Shown here are results of areal and line scans of the aluminosilicate fly ash particle.

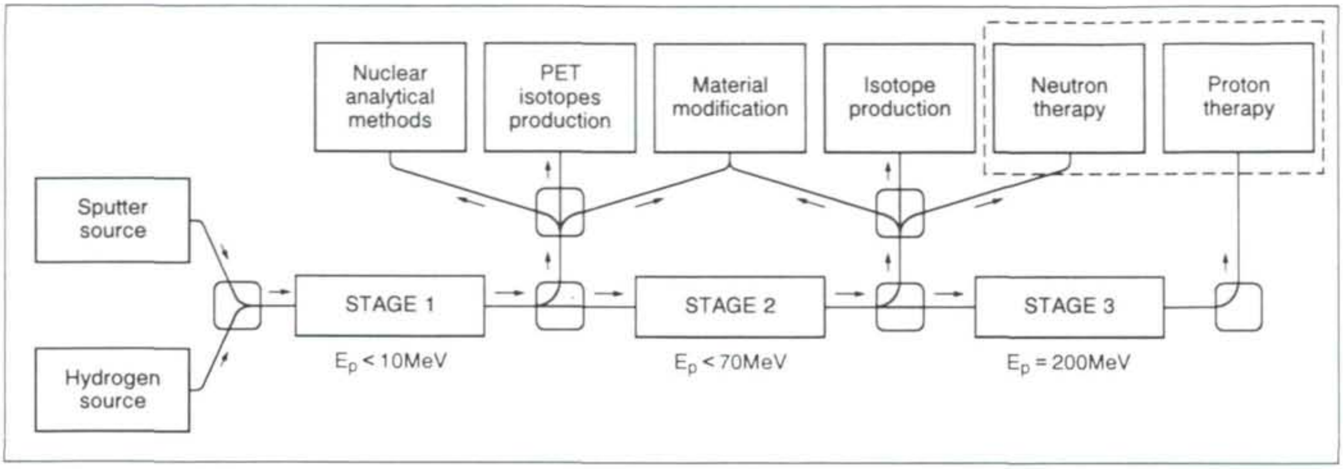
into operation in 1985. Extensive use is being made of it today for fundamental research in atomic and nuclear physics, and for applications in industry, agriculture, and medicine, including isotope production. The laboratory has become one of the leading ones in the region and is active in providing expertise, and in organizing meetings, seminars, and group and individual training sessions.

In Bulgaria, IAEA assistance has been provided since 1984 toward establishment of an accelerator laboratory at the Higher Institute of Chemical Technology in Burgas. The objective is to support applications in the petrochemical and cable industries. An electron accelerator was installed in 1991. It is expected that the project will lead to Bulgarian production of more heat-resistant wire insulation and new packaging materials, thereby reducing the need for imports of such products.

In Poland, the Institute of Nuclear Chemistry and Technology in Warsaw has been assisted by the IAEA for the last 10 years. Early on, a pilot electron accelerator and some auxiliary equipment from the former Soviet Union was provided. Today it is being used for the pilot production of heat shrinkable tubes and tapes, among other applications.

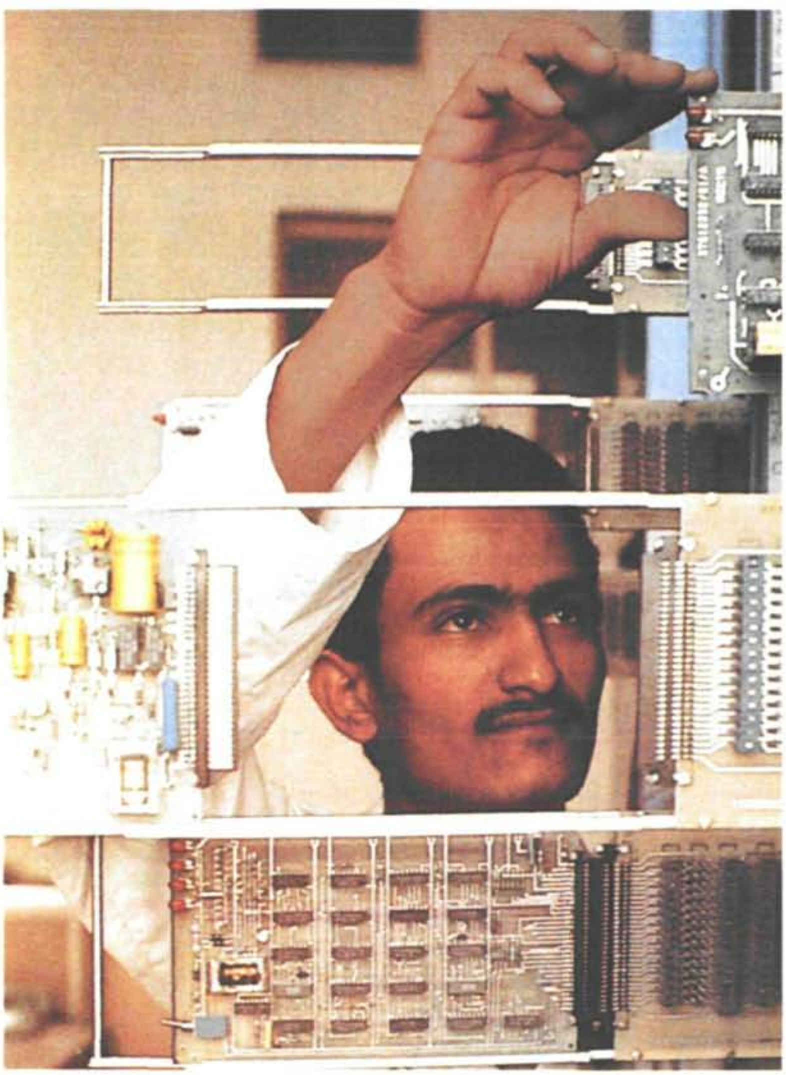
One highly visible project in Poland was initiated in 1987 with the same Institute in Warsaw. It involves the use of electron beam technology for the purification of flue gases in Polish coal-fired power stations. Based on two accelerators of Soviet origin, a demonstration facility was constructed in Warsaw and the concept is now being extended on a larger scale in the Szczecin area. Positive impacts on the environment are expected through the effective, simultaneous removal of pollutants, namely SO_2 and NO_x gases. The project is being generously supported by contributions from the United States and Japan, and in many respects has become a model one. A number of other countries in and outside the region have expressed their interest in the technology, and continued support will be required.

In Albania, Croatia, Greece, Iran, Portugal, and Romania, the IAEA's assistance has helped to upgrade the experimental capabilities of laboratories equipped with Van de Graaff accelerators. At the Ruder Boskovic Institute in Zagreb, current efforts under the project are directed at upgrading a previously installed accelerator to enable microanalytical work. Present applications of the accelerator include development of nuclear analytical techniques;



Above: **A schematic of a three stage accelerator facility in a typical hospital environment.**

Below: **Industrial applications of accelerators include research and development of materials for microelectronics.**



studies of trace elements in coal, bio-medical samples, and other materials; and research involving nuclear reactions and dosimetry.

In Greece, an accelerator laboratory at the Demokritos centre in Athens is being provided with a goniometer under a US-funded project. This will open new possibilities for applications in material science and other areas. Similarly, in Portugal, the existing Van de Graaff accelerator has been equipped with facilities to carry out research in the fields of atomic and solid state physics. Essential items included a computer, a multichannel analyzer, a semi-conductor detector, and vacuum equipment. Using the PIXE and RBS techniques, among other analytical methods, studies have been undertaken involving biological samples, aerosols, and silicon devices.

In a number of countries in the region, there is increasing interest in cyclotron applications for modern radiation therapy. In Iran, a cyclotron laboratory is under construction and the IAEA is providing guidance, expertise, training, and some equipment. The facility is designed for medical applications (including production of radioisotopes such as thallium-201, gallium-67, and iodine-123; and the future use of PET) and research in nuclear physics. A similar project is contemplated by Turkey and the IAEA is helping authorities there with a feasibility study.

Use of linear accelerators also has been supported. In Portugal, for instance, the Laboratorio de Engenharia e Tecnologia Industrial was equipped with an electron beam accelerator of Soviet origin to support research and development of promising radiation-induced processes. They include the curing of surface coatings and inducing cross-linking or polymerization in plastics such as those used in cable sheathing.

At the Ruder Boskovic Institute in Zagreb, the IAEA is supporting installation of a linear accelerator donated by Germany, while in

Poland, the IAEA has provided equipment to the Institute of Applied Radiation and Chemistry of the Technical University in Lodz, which houses a linear accelerator. The Institute's work embraces applied research in polymer chemistry, synthesis of labelled compounds, studies of biological and bio-active materials, and industrial sterilization of medical products.

Additionally, nearly all countries in the region have been interested in electron beam technology for food irradiation under a separate IAEA regional project. However, only Poland has decided to construct a facility, and the IAEA has supported the construction of an accelerator there.

Regional needs and initiatives

Despite the range of national technical assistance projects, not all countries have been able to realize practical applications of accelerator-based technologies. The most successful projects have been those for which the necessary infrastructure and local support already exist. Cases in point are projects in Hungary and Poland. At the other extreme are a number of other countries, including Turkey, Syria, and Cyprus, for example, who have had little or no experience with accelerator technologies. The situation illustrates the inherent difficulties in instituting effective multi-year projects and the importance of a solid preparatory phase, including decisions on the allocation of funding, as preconditions for effective broad-based projects.

One practical need with respect to both planning accelerator-based projects and promoting effective co-operation among participants is the development of a database. Unlike the case of nuclear power or research reactors, for example, full information about accelerators and their applications is lacking, on a regional as well as worldwide basis. The IAEA has started work on compiling a database for low-energy accelerators (100 keV to 100 MeV energy interval). Although planned as a worldwide survey, the first step is a pilot study for the Middle East and Europe , and a questionnaire has been mailed to IAEA Member States in the region.

In January 1993, the IAEA further initiated a regional project for the Middle East and Europe on low-energy accelerators and their applications in science and industry. It has two overriding objectives:

- to promote the use of low-energy ion accelerators for industrial applications by regional co-operation and transfer of newly developed methodologies and techniques from advanced countries to developing ones;
- to promote the use of accelerator-based analytical techniques in environmental and biomedical studies by regional co-operation and to familiarize more specialists with the techniques used by advanced countries in the region.

The project's work plan includes three basic tasks: The first one involves data collection and processing about the accelerators available in the region. This would cover information on the location, type, and parameters of the facility, among other data. This work further would identify the available expertise in the region, fields of common interest, and training needs.

The second task concerns improving scientific capabilities through a series of workshops that address specific subjects. These would cover, for example, sample preparation for accelerator-based analytical techniques; use of accelerator-based techniques in mineral prospecting and exploration; software required for X-ray, gamma ray, and charged particle spectra evaluation; and inter-calibration exercises among participating laboratories. Workshops on other subjects also are contemplated.

The third task relates to promotion among industries of accelerator-based techniques for specific applications. Workshops for scientists, accelerator specialists, industrial managers and policy makers are planned. Toward this end, the experience and know-how of advanced laboratories in the region — such as the Laboratori Nazionali di Legnaro in Padua, Italy — will be drawn upon, in the interests of promoting the transfer of technologies. As guidance for detailed feasibility studies that countries may desire to do, the IAEA also is considering the preparation of a manual on the subject.

In summary, the IAEA's new regional project should stimulate greater awareness of accelerator-based technologies and closer collaboration among countries interested in applying them. A number of IAEA-supported national projects in this field already have had a positive impact in the region, including those seeking to establish new centres equipped with an accelerator (cyclotron) for medicine and science. It is hoped that these initiatives will help strengthen the links between scientific institutes and industries and help developing countries formulate required policies that take into account the interconnections of basic science, research and development, and the transfer of technologies. In this way, more possibilities may open for countries in the Middle East and Europe to effectively apply advanced technologies for their social and economic development. ❒