ACTIVITIES ON THE DEVELOPMENT AND APPLICATION OF PARTICLE ACCELERATORS IN INDONESIA

A. Djaloeis
National Atomic Energy Agency of Indonesia
Jl. KH. Abdul Rohim PO Box 4390, Jakarta 12043, Indonesia
and
Sudjatmoko
Yogyakarta Nuclear Research Centre
Jl. Babarsari PO Box 1008, Yogyakarta 55010, Indonesia

Abstract

Activities on the development and application of particle accelerators in Indonesia have been carried out by the National Atomic Energy Agency (BATAN) on a modest scale since 1979. At the Yogyakarta Nuclear Research Centre (YNRC) of BATAN, the scientists and engineers primarily through the method of learning by doing and in spite of very limited funds have succeeded step by step to upgrade their scientific and engineering capability to design and construct most of the components of a Cockcroft-Walton type 200 keV ion accelerator for ion implantation. Similar activities were successfully performed on a 150 keV deuteron accelerator as part of a neutron generator. Presently in progress are the activities to develop low energy electron accelerators to be used for various practical applications. Activities to plan the development of a modern accelerator based laboratory at the YNRC are also currently being carried out. BATAN has also acquired, installed and operated two electron accelerators (300 keV and 2 MeV) which are primarily used as electron irradiators at the BATAN Centre for the Application of Isotopes and Radiation (CAIR) in Jakarta, and a fixed low energy cyclotron mainly for radioisotope production at BATAN Radioisotope Production Centre in Serpong. Several hospitals in Indonesia have acquired and operated electron linear accelerators for nuclear medicine. This paper presents a brief overview of the status and future prospects of the activities on particle accelerators in Indonesia.

1 INTRODUCTION

A particle accelerator is one of the most versatile instruments designed by physicists. From the technology point of view, the development of particle accelerators has given a wide range of spin-off benefits, such as magnet technology, vacuum technology, high voltage and RF techniques, particle detection techniques, electronic control technology and many others. Indeed, the accelerator technology has stimulated the growth of many branches of industries.

Today the application of particle accelerators has given significant contributions in the growth of fundamental and applied sciences in single-disciplinary subjects, such as physics and chemistry, as well as in multi-disciplinary subjects such as biology.

Industrial applications cover a broad range, for instance ion implantation in the semi-conductor industry, modification of surface properties of materials, etc. A particularly promising application is microlithography with synchrotron radiation for high density integrated electronic circuits. Radiation by particle beam is also used in a variety of processes, such as to preserve food, neutralize dangerous waste, sterilization and polymerization. It is probably in medicine that accelerators have found their wider field of applications, either for isotope production in view of diagnosis or treatment, or for therapy with gamma rays and, more recently, with neutrons and heavy charged particles [1,2].

In the field of medicine and health, accelerators are used for diagnostics and for therapy. In medical diagnostics the radioisotopes produced by accelerators have proved to be able to give unique biochemical and physiological information when injected into living organisms. The possibility of external detection offers a non-invasive way to follow changes in the distribution of tagged atoms, to observe anomalies of metabolism or to detect tumours. In radiotherapy, particle beams with defined energy and profile are used to destroy malignant cells without damaging the healthy tissues.

In view of the above, the National Atomic Energy Agency *(BATAN)* of Indonesia is presently considering to build an accelerator based laboratory at its research centre located in Yogyakarta. The development of such a laboratory is expected to serve three purposes, namely to acquire the accelerator technology itself, to use the accelerator to solve problems in many branches of activities such as in industry, health/medicine, biotechnology and environment, and to serve as a versatile tool in the development of human resources.

This paper presents a brief overview of the past and present activities in accelerator technology and applications in Indonesia, and a glimpse into the future describing the essential ideas involved in the development of the envisaged accelerator based laboratory in Yogyakarta.

2 THE PAST AND THE PRESENT

In Indonesia, activities connected with the technology and applications of particle accelerators were started by BATAN on a modest scale in 1979. So far only very few accelerators have been acquired or developed, name those listed below :

- 200 keV ion accelerator for ion implantation
- 150 keV ion accelerator for neutron generator
- 300 keV dan 2 MeV electron accelerators for electron beam processing
- 20 MeV cyclotron for radioisotopes production
- 10 MeV electron linear accelerators for radiotherapy.

The first two are of Cockcroft-Walton type, designed, constructed and installed by BATAN scientists and engineers, as part of their excercise to acquire knowledge and skill in accelerator technology. The 300 keV and 2 MeV electron machines as well as the cyclotron were purchased commercially, while the electron linear accelerators *(linacs)* were acquired by the hospitals for medical therapy.

2.1 Cockcroft-Walton Type Ion Accelerators

At the Yogyakarta Nuclear Research Centre *(YNRC)* of BATAN, the scientists and engineers primarily through the method of learning by doing and spite of very limited funds have succeeded step by step to upgrade their scientific and engineering capability to design and construct most of the components of a Cockcroft-Walton type 200 keV ion accelerator for ion implantation. Similar activities were successfully performed on a 150 keV deuteron accelerator as part of a neutron generator.

Research and development activities of accelerator technology have been conducted by YNRC on a modest scale since 1979. The research and development activities can be classified into two subjects :

- Design and construction of an ion implantation machine, and its application for research activities
- Design and construction of an deuteron ion accelerator for neutron generator, and its application for research activities.

❑ Ion Implantation Machine

The ion implantation accelerator constructed at YNRC consists of a Penning ion source, a Cockcroft-Walton high voltage generator with a maximum of 200 kV, an acceleration tube system, a mass separator system, a beam sweeping system, a vacuum system, and a target chamber. A maximum beam current of 100 μA is obtained for Ar ions, 200 μA for P, B and C ions, and 600 μA for N ions.

At present the research and development activities on the techniques of implantation into semiconductor materials are concentrated on :

- the study of dopant behaviour in implanted semiconductors
- the determination of the range distribution of dopant species, lattice disorder, location of dopant species on substitutional and interstitial sites in the lattice
- the study of ion implantation into II-VI and IV-VI semiconductors for solar cells or infrared detectors.

Activities on ion implantation technique into non-semiconductor materials are carried out with emphasis on :

- **implantation into metals** : to modify the mechanical properties of metal surfaces; surface hardness, corrosion resistance, friction coefficient, fatigue behaviour and adhesive properties
- **implantation into optical materials** : research and development of light guides by alteration of the refractive index.

❑ Deuteron Ion Accelerator for Neutron Generator

In the beginning of 1979 the YNRC has developed the programme to design and construct the low energy deuteron ion accelerator for a neutron generator. The YNRC neutron generator which has been constructed consists of a RF ion source, a Cockcroft-Walton high voltage generator with a maximum voltage of 150 kV, an acceleration tube system, a beam focusing system, a vacuum system, a target and cooling system.

The ion optical system consists of a primary beam focusing unit, an accelerating system and an accelerated beam transport system. The target unit is constructed in form of a Ti-T fixed target using an intensive cooling. A maximum deuteron beam current of 2.5 mA is obtained.

At present the YNRC neutron generator has been utilized for research and development programmes, with emphasis on the following areas:

1. Biological and environmental research, namely
    - the determination of protein content of corn, soybean and peanut
    - the determination of nitrogen and phosphor content in the fertilizer
    - the quantitative analysis of element composition of aerosol pollutions.

2. Nuclear physics research:
    - the acquisition of neutron activation cross-section data around 14 MeV, especially for calculations on radiation damage, nuclear transmutation, and induced activity.

2.2 Electron Beam Machines

Two electron accelerators have been installed and operated at the Centre for the Application of Isotopes and Radiation *(CAIR)*, i.e. a 300 keV electron beam machine *(EPS 300)* installed in 1984, and a 2 MeV electron accelerator GJ-2 type installed in 1993.

The main characteristic of the EPS 300 are as follows:

- maximum electron energy : 300 keV
- maximum electron beam current : 50 mA
- scanning width : 120 cm
- speed of conveyor : 2.5 - 25 m/minute.

The GJ-2 electron accelerator is characterized by:

- maximum electron energy : 2 MeV
- maximum electron beam current : 10 mA
- scanning width : 120 cm.

Those machines are primarily used:

- as a pilot-scale demonstration plant for radiation curing of surface coating technology
- for training course, demonstration as well as for studying both technical and economic aspect of cross-linking of wire and cables
- to increase awareness of the industries on the potential applications of electron radiation technology including its benefits
- to promote radiation as a means of rubber vulcanization, curing of surface coatings and cross-linking of wires and cables [7].

2.3 Cyclotron Facility

BATAN has installed and operated a fixed low energy cyclotron model CS-30 at the Radioisotope Production Centre in Serpong. The cyclotron facility has six beam tubes of switching magnet, two beam tubes are used for Ga-67 and Tl-201 production, and other tubes for research activities.

The main characteristic of the Cs-30 cyclotron is as follows :

- diameter of magnetic poles : 96.52 cm
- gap between hills : 5.08 cm
- gap between valleys : 10.16 cm
- magnetic field *(hills)* : 22,500 gauss
- magnetic field *(valley)* : 14,400 gauss
- magnetic field *(average)* : 17,500 gauss
- radio frequency : 26.901 MHz *(for H^- ion)*
- resonator : moving short type
- ion source : Ionization Gauge *(PIG)* type
- extraction beam current : 78 µA of proton
- energy : 26.5 MeV *(proton)* on extraction radius of 41.5 cm.

The main application areas of this facility involve the production of Ga-67 and Tl-201 short-life radioisotopes used for medical diagnostics. Other activities performed using the Cs-30 cyclotron are to develop a solid-target station and a manipulation system, as well as an irradiation facility development outside the vacuum system.

2.4 Linear Electron Accelerators

So far in Indonesia, only three hospitals have installed and used electron beams for medical therapy. These are the Dr. Soetomo Hospital in Surabaya, the Dr. Karyadi Hospital in Semarang and the Harapan Kita Hospital in Jakarta. All of them have installed 10 MeV linear electron accelerators.

General technical description of the electron linear accelerator installed at these hospitals :

- Electron beams are accelerated by a standing wave field created in a coupled cavity structure. The low voltage 5 MW klystron serves as a RF power supply.
- The achromatic bending focusing system directs the accelerated electrons into the radiation head to form X-ray beams.
- The accelerating structure with the electron gun and vacuum pump, the achromatic bending magnet and the radiation head are mounted in the movable part of gantry, which can rotate through a total useful range of 360 °.

These linear accelerators are especially used for cancer therapy and they become a main choice compared to the Co-60 facilities; but there are problems in the linear accelerator systems namely the maintenance of the vacuum system and the RF power supply, especially about the klystron unit.

3 THE FUTURE

The National Atomic Energy Agency *(BATAN)* of Indonesia is the highest authority charged with the task to promote, develop and utilize the nuclear sciences and technology for the welfare of the Indonesian people. The agency, currently with a total workforce of over 4000 people, was set up in 1964 and has been actively pursuing scientific research, technological development and application oriented activities geared towards solving national development problems. Since its birth BATAN has gradually developed the national scientific-technological capability in the form of R&D facilities, supporting infrastructure and trained personnel. So far BATAN has made significant contributions in the fields of agriculture, livestock sciences, industry, human health and environmental care. Considerable efforts have been made to pave the way for the safe, effective and economic utilization of nuclear energy in Indonesia.

With its R&D centres located in Jakarta, Bandung, Yogyakarta and Serpong, BATAN is so far equipped with two types of major instruments, namely :

Three research reactors *(1 MW Triga Mark II reactor located at the Research Centre for Nuclear Techniques in Bandung, 150 kW self made reactor located at the Yogyakarta Nuclear Research Centre and 30 MW reactor located at the BATAN R&D complex in Serpong, West Java).*

Several photon *(gamma)* irradiation facilities and electron beam machines *(300 keV and 2 MeV)* located at the Centre for the Application of Isotopes and Radiation, Pasar Jum'at Jakarta.

In order to enhance its participation in the national development, BATAN is currently planning to establish an accelerator based laboratory at the Yogyakarta Nuclear Research Centre. The establishment and operation of the laboratory is expected to provide significant contributions in :

- Solving various scientific-technical problems, primarily those related to human health and medicine, industrial techniques, environmental care and biotechnology.
- Developing and acquiring a wide spectrum of modern technologies, such as those related to ion sources, particle acceleration techniques, beam handling and diagnostics, magnet technology, vacuum techniques, detector technologies, nuclear electronics, and data acquisition as well as processing techniques.
- Developing and upgrading of Human Resources in various branches of nuclear sciences and technology, in particular in collaboration with the local universities and foreign institutions.

The envisaged laboratory is planned to have an accelerator system, equipped with several experimental stations and supporting facilities. From the user point of view the laboratory may be divided into two areas, namely the Low Energy and the Medium Energy Areas.

3.1 The Low Energy Area

This area is foreseen to accommodate a low energy ion accelerator and an electron accelerator. The choice of the accelerator type could be made among the three available types, namely the electrostatic, RFQ *(radio-frequency quadrupole)* or cyclic *(e.g cyclotron)*. Optimization will be made with respect to the ion types *(light, medium and heavy)*, achievable beam current, beam phase space quality and time structure. It is envisaged that the low energy accelerator may be used not only as a stand-alone machine to serve several experimental and application facilities, but should also be able to serve as an injector into a higher *(medium)* energy machine for further beam acceleration and handling.

The ion accelerator facility shall have several experimental stations equipped with appropriate scientific instruments to perform R&D and application oriented activities. In addition, the low energy ion accelerator will also serve as an injector to the intermediate energy facility.

The various different beams shall be used among others in activities in the following fields :

1) **Industrial applications**, such as :
   - ion implantation technique for development of semiconductor devices
   - ion implantation technique is used to modify the mechanical properties of material surfaces to achieve special effects connected for instance with electrical conductivity, surface hardness, corrosion resistance, friction coefficient, fatigue behaviour, adhesive properties or catalytic behaviour
   - implantation into optical materials, such as for the fabrication of light guides by alteration of the refractive index.
2) **Biotechnology**, such as creation of new plant varieties through genetic mutation induced by particle beams.

3) **Health** and **Medicine**, primarily for diagnostic and therapeutic purposes.

4) **Environmental care**, primarily as an analytical tool in the identification of various types of pollutants in air, water or soil samples.

3.2 The Medium Energy Area

The injected beam from the low energy ion accelerator will be further accelerated by an intermediate energy accelerator *(e.g. synchrotron)* and manipulated in its phase space and /or time structure to meet different user requirements. Envisaged are primarily light ion beams with medium energy *(200-300 MeV/nucleon)* for medical and other scientific applications.

In this intermediate energy area, scientific facilities are foreseen among others for the following activities :

- Health/Medical research and therapy
- Application oriented as well as fundamental research
- Development of special techniques and analytical methods.

Planning and promotional activities are currently in progress. In an attempt to optimize the benefits-costs ratio, careful considerations based among others upon user requirements shall be given to the selection process to obtain the most suitable type of accelerator *(linear, cyclic or electrostatic)* among those commercially available. The basic overall conceptual design, including the specification of the laboratory, the arrangement of experimental stations, as well as detailed technical specifications and the project implementation strategy shall follow thereafter.

4 CONCLUSION

Particle accelerators have evolved into a wide variety of devices up to the giant colliders of particle physics. The accelerator technology has given a wide range of spin-offs, which have given significant contributions in the growth of many branches of industries. The particle beams have found a multitude of applications, ranging from basic and applied sciences, industrial processes, health and medicine, the development of analytical techniques used for instance in the environmental studies.

The role of particle accelerators is expected to give significant contributions in the national development in Indonesia, especially in the acquisition of technology, in the solution of various scientific-technical problems in many branches of development activities *(agriculture, industry, health/medicine, environmental care)*, and in the human resources development.

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