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DEVELOPMENT OF PHYSICAL SCIENCES PROGRAM AT PINSTECH

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Pakistan Institute of Nuclear Science and Technology, established in 1965 is the premier research institute of PAEC in Physical Sciences. PINSTECH has undergone various phases of development during the last four decades the first decade was devoted to the development of infrastructure and establishment of R&D facilities, whereas the second decade saw both expansion and consolidation of R&D activities. In the second decade high priority was given to the R&D work directed towards technologically oriented goals without discouraging basic and applied research. Therefore, pilot plants were set up for the production of reactor-grade UO_2 for fuel fabrication and for the extraction of zirconium from beach sand. A comprehensive program for physical and chemical characterization of materials was started. The expansion of R&D activities and upgradation of facilities continued in the third and fourth decades. Studies on a numbers of projects such as establishment of a miniature neutron source reactor, power upgradation and conversion of the research reactor fuel to low enriched uranium, fabrication of lasers and electro-optical devices, charged particle accelerator etc. have been completed and various new projects have been started. Studies on the corrosion of metals and alloy development, synthesis of special ion-exchange resins, production of radiopharmaceutical cold kits, development of laser land leveller and environmental monitoring constituted important parts of R&D activities. Over the years PINSTECH has made significant contributions in various programs of PAEC and in the international pool of knowledge, which have received both national and international recognition. The Islamic Development Bank, in recognition of its valuable scientific contributions awarded the first prize to PINSTECH in 2002. PINSTECH has played an important role in the development of science and technology in the country. The technical contributions have been made primarily through quality manpower, development of processes and products, specialized services and provision of research environment that encourages innovation.

Keywords: PINSTECH, Research reactor, R&D activities, Training, Awards

1. Introduction

Soon after the discovery of nuclear fission in 1939 by two German Scientists, Hahn and Strassmann, efforts were made to maximize the neutron-induced interactions and to exploit the large amounts of energy released in this process. The first nuclear reactor based on self-sustaining nuclear fission chain reaction was built in the United State of America (USA) in 1942 by Enrico Fermi and his associates, working at the University of Chicago, which was utilized for various applications. At the same time other scientists were engaged in the development of military uses of nuclear energy. The first nuclear device "Trinity" was detonated in a test explosion in the Nevada desert in July 1945. On August 6 and 9, 1945, USA exploded two atom bombs on Japan. These devastating events created great fear in the minds of people all over the world regarding the destructive nature of nuclear energy. To dispel this destructive image, efforts were made to develop peaceful applications of atomic energy. In 1953 U.S. President D. Eisenhower made the "Atoms for Peace" proposal to the U.N. General Assembly, and a program for the promotion of peaceful applications of nuclear energy was started. In 1957, with the co-operation of 22 countries, the International Atomic Energy Agency (IAEA) was established to promote and regulate the use of atomic energy. Many countries were encouraged and assisted to start research and development programs on the utilization of atomic energy for the socio-economic advancement of humanity.

2. PAEC Founded

In order to harness nuclear energy for various applications, the government of Pakistan initially constituted an Atomic Energy Committee and then in 1955 established the Pakistan Atomic Energy Commission (PAEC) under the chairmanship of

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Dr. Nazir Ahmad. The main task of the Commission was to plan and organize various activities in the field of nuclear science and technology and to develop appropriate human resource. In the late 1950s the Commission chalked out a plan of action for the training of manpower and the establishment of various research and development centres. A number of bright young scientists and engineers were recruited and sent to Europe, America, Australia, etc., for academic and specialized training in various fields of nuclear science and engineering. This trained manpower, after return to Pakistan, started R&D activities at the Atomic Energy Centre, Lahore, which was established in 1962.

In the beginning of the 1960s the PAEC embarked upon a program of utilization of nuclear energy for the generation of electricity and for the applications of radiation and radioisotopes in industry, agriculture, medicine, etc. Successful implementation of this program required the development of necessary infrastructure, trained manpower and a broad knowledge base. Therefore, the PAEC planned a multidisciplinary research and development centre, which was named Pakistan Institute of Nuclear Science and Technology (PINSTECH). Initially, a site near the present National Institute of Health in Islamabad was considered to locate this centre but it was ruled out owing to the fear of possible radiation hazards to the city and to the nearby water reservoir, in case of an accidental release of radioactivity. Finally, a site on the south-eastern periphery of Islamabad for the location of PINSTECH was selected by Dr I. H. Usmani, the-then Chairman of the PAEC, and Prof. Abdus Salam, the-then Chief Scientific Advisor to the President of Pakistan. In 1961 AMF Atomics of USA was asked to prepare a master plan for establishing a nuclear research and development institute. The plan prepared by AMF Atomics was not approved by the PAEC, as it was inadequate on technical and aesthetic grounds. The PAEC then hired the world- renowned architect, Edward Durrel Stone, to prepare the design of the institute. This design is a beautiful blend of Moghul and modern architecture, and the institute is generally considered to be the most beautiful Reactor Building in the world.

The foundation stone of PINSTECH was laid on April 20, 1963 by the late Mr. Z. A. Bhutto, the-then Minister of Industries and Mineral Resources (including Atomic Energy), and the construction work started which was completed in two phases. The first phase comprising the reactor and a T-shaped building was completed in 1965, whereas the construction of buildings in the second phase was delayed due to financial constrains, and was completed in 1971.

Three types of research reactors, namely CP-5, DIDO and swimming pool type were considered by the PAEC for installation at PINSTECH. After technical and financial considerations a 5 MW swimming pool type reactor was selected, which uses highly enriched uranium fuel. The neutron flux of this reactor is relatively higher than that of CP-5. Pakistan's first Atomic Research Reactor supplied by the USA through the IAEA was installed in a dome-shaped building in 1965 by AMF (Atomics) of USA. The highly specialized task of the commissioning of this reactor was accomplished by a small but dedicated team of our engineers and scientists without any outside help. The initial criticality was achieved on December 21, 1965, at 1905 hours (PST) when our team successfully initiated a self-sustained fission chain reaction in the Reactor. This was a landmark in the history of Pakistan. The next day all the newspapers of the country reported this event as their headline with captions such as "Pakistan enters the Atomic Age". About six months later, the late Field Marshal Ayub Khan, the-then President of Pakistan, visited PINSTECH on June 14, 1966, and congratulated the scientists and engineers of the PAEC on this achievement. After the attainment of the initial criticality, further experimentations were carried out and the behaviour of various systems was studied. Finally, the reactor attained the full power of 5 MW on June 22, 1966.

3. R & D Activities

This reactor is a major experimental facility at PINSTECH. It has been used for research in nuclear science and technology, for the production of radioisotopes, and for training of manpower. Initially a few experimental facilities were set up around the reactor for the study of nuclear structure, nuclear fission and crystal structure, using neutron beams. Work on the production of radioisotopes was also started, and the first batch of radioisotopes was produced in 1967. The R&D program gained momentum after the completion of the second phase in 1972, when most of the scientists from AEC Lahore were transferred to PINSTECH. Various laboratories were established and the Institute became fully operational in 1974.

The first decade thereafter was devoted to the development of infrastructure and establishment of research and development (R&D) facilities, whereas the second decade saw both expansion and consolidation of PINSTECH activities. The laboratories established earlier reached a stage of maturity and produced useful R&D results. During this period high priority was given to the R&D work directed towards technologically oriented goals. Thus R&D work on the development and characterization of materials received significant importance. To achieve self-reliance in the production of nuclear fuel, a pilot plant for the production of reactor-grade UO_2 fuel was set up and the operating parameters were optimized. At the same time, problems involved in the pelletization of UO_2 powder and fabrication of fuel elements were tackled and viable solutions found. Later, work was started on the extraction of zirconium from physically upgraded zircon-containing sand of the Karachi beach area. Various parameters were studied and optimized, and a pilot plant for the production of nuclear-grade ZrO_2 was established.

A comprehensive quality -assurance program was established. Procedures were developed for the thorough analysis and testing of materials for chemical and physical characterization. A variety of highly sensitive nuclear and chemical analytical techniques such as neutron activation analysis, atomic absorption spectrometry, emission spectrometry etc. were developed, which can measure the impurities at parts per million or at parts per billion levels. For the study of the microstructure of materials, X-ray diffraction, X-ray fluorescence and electron microscopy techniques were employed. Facilities were established for the study of mechanical properties of materials and for the analysis of stresses developed under different conditions. Non-destructive techniques such as gamma-ray radiography, ultrasound, eddy currents, etc., were employed for the detection of faults in the components and inspection of various plants. Several persons from various organizations were trained in these techniques and these services were commercialized.

In the late 1970s, production of radioisotopes for use in agriculture and nuclear medicine was expanded, and new facilities including the large-scale production plants for Iodine-131, Gold-198 and Chromium-51 were commissioned. Production of radiopharmaceuticals and labelled compounds was started and facilities for the quality control and quality assurance of these products were established. Studies on the radiation sterilization of medical products led to the establishment of a commercial plant at Lahore in late 1980 named Pakistan Radiation Sterilizers (PARAS). The use of radioactive and stable isotopes for the investigation of ground water movement, water logging, salinity and other applications was intestified and a mass spectrometer for the measurement of low mass isotopes was developed. Studies on health-related environmental pollution were expanded and new techniques were developed for the analysis of food, water and other materials.

The second decade also saw the expansion of electronic repair, maintenance and calibration services, which helped to reduce the ‘downtime’ of various instruments. Limited-scale fabrication of specialized instruments, radiation detectors and printed circuit boards was started. For computational work both dedicated and general purpose computers were installed and later on a network of terminals was provided to the scientists. A comprehensive information resource base was also established, and a considerable part of PINSTECH’s library holdings was computerized. Different types of workshops for the design and fabrication of equipment were also established. Immediately after the Indian nuclear explosion in May 1974, studies on the monitoring of radio-nuclides in air particulates were intensified and new facilities were added. At the same time a micro-seismic study project was started for the measurement of underground seismic events and for the seismic evaluation of the sites of power plants.

The scope of radiation protection services was expanded and a secondary standard dosimetry laboratory was established to provide calibration services to radiotherapy institutes in the country. This laboratory offers technical expertise in the calibration of radiation measuring devices such as therapy level dosimeters, protection level survey meters and neutron survey meters. This facility is contributing significantly in improving the quality of clinical dosimetry measurements and the overall radiation protection regime.

Technological development in any sector can never be self-sustaining without a sound scientific base, especially in nuclear technology. Therefore, to be well balanced and to be tuned to the needs of the future, basic research was also encouraged at PINSTECH. Several groups in the Institute have

been contributing towards the better understanding of basic physical phenomena such as nuclear reaction characteristics of fast and thermal neutrons, nuclear structure, crystal structure, radiation damage and defects in metals and alloys. Numerical and computer simulation techniques have been employed for the study of polymers, condensed matter physics, plasma and nuclear physics. Work on solid state nuclear track detection furnished useful information on damage produced by charged particles and opened up new directions of applications. This technique was also utilized for uranium exploration in the country and for the measurement of radon levels in outdoor and indoor environment. With the dedicated efforts of its scientists, PINSTECH soon established a reputation for excellence in scientific research.

The expansion and consolidation of PINSTECH activities continued in the third and fourth decades since its inception. Research and development studies on neutron diffraction, Msösbauer spectroscopy, charge particle accelerator, high temperature superconductivity, laser spectroscopy, theoretical solid state and plasma physics, corrosion and alloy development constituted important parts of PINSTECH activities. Many of these studies were successfully completed and published in international journals. Addition of new facilities and development of products and processes continued apace.

The development and fabrication of various types of lasers and electro-optical devices, too, made significant progress. A number of new facilities were established and commercial-scale production of laser range finders (LRF) night sight devices, head-up displays for aircrafts, fire control systems, etc., was undertaken. These products were later on marketed through Al Technique Corporation of Pakistan (ATCOP). The operation of indigenously developed LRF was demonstrated to the late Gen. Zia ul Haq, the-then President of Pakistan, during his visit to PINSTECH on November 2, 1986.

4. Reactor Up-gradation

In the mid-1980s a major project was undertaken to modernize the reactor control and instrumentation systems, and a new control panel with enhanced capabilities was fabricated. Studies were also started for the conversion of the reactor core from highly enriched uranium to low-enriched uranium, and the upgradation of its power from 5 MW to 10 MW. The new control panel was installed and formally inaugurated by the late Mr. Mohammad Khan Junejo, the-then Prime Minister of Pakistan, on February 10, 1986, on the occasion of the 20th anniversary commemoration of PINSTECH. In 1989 a major new facility, namely a miniature neutron source type reactor (MNSR), procured from China, was established which attained criticality on November 2, 1989. A new facility for the storage of spent nuclear fuel and other radioactive materials was also built in the vicinity of the reactor. This reactor was to be inaugurated by Ms Benazir Bhutto, the-then Prime Minister of Pakistan, but owing to unavoidable circumstances she was unable to make it. However, she did visit this facility on January 15, 1994. The experience gained in the construction of the facility, especially the stainless steel lining of the pool of MNSR, was utilized for the renovation of Pakistan Research Reactor-I (PARR-I). The renovation and upgradation of PARR-I was completed in 1991 and criticality of the upgraded reactor was achieved on October 31, 1991, at 1139 hours. It was formally inaugurated by Mr. Ghulam Ishaq Khan, the-then President of Pakistan on May 25, 1992, on the occasion of the silver jubilee of PINSTECH. The experience and know-how gained from these projects promoted indigenous expertise and led to a degree of self-reliance in nuclear technology in Pakistan.

Various parameters for the small-scale fabrication of low-enriched uranium fuel for PARR-I were studied and optimized. Uranium silicide (U_3Si_2) alloy was produced and a few full size plates were prepared by cold rolling. The clad-meat-clad thickness, fuel homogeneity and bonding of cladding and fuel were examined by non-destructive testing (NDT). Similar studies on the preparation of pressurized water reactor (PWR) fuel pellets were initiated, and the necessary facilities installed. Green pellets with the required density and dimensions were prepared and the sintered pellets showed good structural integrity and the requisite density.

5. Expansion of R & D Activities

Studies on polymers were started, and expertise in the synthesis of various kinds of ion-exchange resins was developed. Pilot plants were set up for the production of special resins and for the selective separation of some metal ions with similar chemical behavior. Work on the development of flame retardant and radiation resistant wire insulation for use in defence equipment, automotive, aeronautical and

construction industries was started. Various formulations for flame retardant and anti-rodent materials were developed by radiation cross-linking, and the radiation-treated coatings were found to conform with international standards. Chemically cross-linked flame retardant formulations were also developed for industrial utilization, and the process was passed on to the cable industry. Facilities for the testing of electrical cables and wires were set up, and the expertise was utilized for evaluating the integrity and physical conditions of instrumentation and control (I&C) cables of KANUPP.

Work was also started on the construction of a 250 keV charged-particle accelerator, which was successfully completed, and another facility for basic and applied research work was established in 1995. Based on this experience a 100 keV accelerator was designed, fabricated and installed at the Government College University, Lahore, in 2001. Studies on the production of a stable and reliable laser land-leveller system were initiated, and a prototype unit named AGRO-LASER was fabricated. This system is a useful tool for leveling of agricultural land. A properly levelled land will save water up to 30%, increase yields up to 20% and improve uniformity of seed germination. After successful field trials, large-scale production was started and about 200 units have been supplied to various organizations.

A small-angle neutron diffractometer designed and fabricated indigenously has been installed at the beam tube of the reactor, and is being utilized to study nano-crystalline materials. It will help to resolve inhomogeneities in the materials from nanometer to micrometer range. A carbon-based nanotechnology laboratory has been set up and a new generation of carbon cluster sources has been tested. A special type of clustering source, which has dual hollow cylinders, has been designed. The cylinders have been encapsulated in a quartz tube to allow visual observation of different phenomena occurring in the regenerative sooting discharge.

Production of radioisotopes for medical applications was expanded and a new facility for the production of ^{99m}Tc generator was installed. A number of radiopharmaceutical cold kits were developed and supplied to different medical centres. Labelling of biomolecules for targeted radiotherapy, and production of therapeutic radionuclides by neutron activation of natural and enriched targets of some elements, were studied. Production feasibility of some neutron-deficient radioisotopes by the nuclear reactor was studied, and fission-neutron spectrum averaged cross-sections of some elements were measured.

Analytical facilities were further expanded by the addition of an X-ray fluorescence spectrometer, inductively coupled plasma emission spectrometer, atomic absorption spectrometer, gas chromatography coupled mass spectrometer, and gamma-ray spectrometers. Analytical chemistry facilities at PINSTECH are comparable with those existing in advanced countries and are unique in Pakistan. These facilities have been extensively utilized by various establishments of the PAEC and other organizations in the country for the elemental analysis of geological, biological, environmental, nuclear and high-purity materials. In view of the high-quality R&D studies and excellent performance in the intercomparison exercises for the certification of reference materials, our Neutron Activation Analysis Laboratory has been designated as regional resource unit for South Asia and Pacific region by the IAEA. National and international auditors have assessed the overall performance of this laboratory and it has been accorded formal accredition to ISO-17025 in April 2005 by the Pakistan National Accredition Council. The isotope hydrology laboratory due to its excellent performance has also been designated as regional resource unit by the IAEA.

6. Environmental Pollution

Environmental pollution studies have also received considerable attention at PINSTECH because of increasing concerns regarding the quality of air, water and food. The concentrations of various pollutants in air, water, food and other materials were measured, using sensitive and accurate nuclear and allied analytical techniques. Air samplers were set up in the industrial area and rural areas of Islamabad to collect coarse and fine air particulates. About 25 elements were measured in these samples. Soil of these areas was also analysed, and enrichment factors calculated. The elemental profile for the air quality has been compiled and different data analysis tools of chemometrics have been applied for finger printing and source apportionment of the pollutants. Similar studies of air pollution of some major cities have been undertaken in collaboration with Pakistan Environmental Protection Agency and Japan International Collaboration Agency. To assess the adequacy and safety of human diet the amounts of essential and toxic elements were measured in

various food items and mixed human diet. The pollution of water with toxic chemicals and microorganisms due to indiscriminate release of municipal and industrial waste has been studied. Quality of water of domestic supply, water reservoirs and industrial effluents of some areas of Islamabad has been assessed.

Studies on the measurement of environmental radiation levels were expanded and various materials including soil, rocks, house building materials, coal, fertilizers, etc., have been analysed to determine the concentration of radionuclides and the radiation dose rates. Some areas of relatively high radiation levels were identified. Country-wide radiological monitoring of air has been carried out to assess the environmental radiation levels through a network of air particulate sampling units. These collect particulates on routine basis, with a sampling frequency of two weeks. These units have been useful in identifying the radionuclides, which entered Pakistan's atmosphere from the Chernobyl reactor accident of 1986.

7. Human Research Development

The success of any nuclear program depends upon the availability of trained manpower in the highly specialized disciplines of nuclear technology. Therefore, in the late 1960s a Reactor School was started for the training of scientists and engineers, from which the first batch graduated in 1971. This school was upgraded in the middle 1970s, and renamed Centre for Nuclear Studies (CNS). In order to expand the scope of these studies, new buildings were constructed to relocate the CNS, and various new facilities were established in the late 1970s. The expansion program continued, and in mid-1980s a big boost was given to the CNS when substantial funds were made available for the construction of more blocks and the purchase of new equipment. In 1991, CNS became an independent establishment of the PAEC, and by now it has evolved into an excellent technical institute known as the Pakistan Institute of Engineering and Applied Sciences (PIEAS). Over the years, CNS has made valuable contributions to the programs of the PAEC by imparting academic and specialized training to hundreds of scientists, engineers and technicians. Many of these now head various establishments of the PAEC.

PINSTECH also maintains active collaboration with national and international research centres and universities in various areas of research. International collaboration flourished in the 1970s. However, this was considerably diminished in the 1980s owing to restrictions imposed by some technically advanced countries.

8. Honours and Awards

Research and development activities of the various divisions of PINSTECH have been reported in international and national journals, and in technical reports. The first technical publication from PINSTECH appeared in 1966. Since then, some 1250 research papers in international Journals, 300 in national Journals, and 950 technical reports have been published. Many of the R&D projects were supported by international organizations, which have awarded more than 400 research contracts to PINSTECH. In recognition of the high standard of research publications, Pakistan Council of Science and Technology (PCST) granted more than Rs. 10 million as research productivity allowances to 56 scientists and engineers of PINSTECH over the last three fiscal years. PINSTECH ranks first among the research organizations whose scientists and engineers received the research productivity allowances from PCST.

Many of our former and present scientists and engineers have won national and international recognition and received a number of awards. Twenty- three scientists and engineers have received civil awards from the Government of Pakistan, which include Nishan-i-Imtiaz, Hilal-i-Imtiaz, Sitara-i-Imtiaz, Tamgha-i-Imtiaz and Pride of Performance. Three scientists have received UNDP-Khwarazmi International award from the Iranian Organization of Science and Technology, and nineteen scientists have received Gold Medals from various national and international organizations. Seventeen scientists have been elected Fellows of learned bodies such as the Pakistan Academy of Sciences, Islamic Academy of Sciences, and the Third World Academy of Sciences. In recognition of its valuable scientific contributions to the pool of knowledge, the Islamic Development Bank awarded the first prize of US$ 100,000 to PINSTECH in 2002. This achievement was acknowledged by the unveiling of the commemorative plaque by the President of Pakistan, General Pervez Musharraf, during his visit to PINSTECH on March 29th, 2003.

9. Conclusion

PINSTECH is the premier research and development institute of the PAEC, and it has been playing a key role in capacity building in nuclear science and technology. Over the years it has made significant contributions to the development of science and technology and high-level human resource building in the country. In fact, PINSTECH has developed into one of the finest R&D Institutes in the Third World.

The expertise and experience of PINSTECH scientists and engineers have been utilized by various national and international organizations, where they have served as advisors and experts. Some of the scientists have carried out technical cooperation missions in various countries on behalf of the International Atomic Energy Agency. Our stress has been on excellence and our technical contributions have been made primarily through quality manpower, development of processes and products, specialized services and provision of research environment that encourages innovation. There is no short-cut to technological development. It takes time and cannot be achieved overnight. Therefore, research centres like PINSTECH, which provide high-level research environment, play an important role in the scientific and technological development of the country. In the coming years, PINSTECH will continue to develop as an institute of excellence, and , we believe, stand as a role model for other developing countries.

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