

# CURRENT SCIENCE

Volume 123 Number 3

10 August 2022

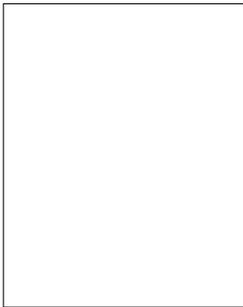
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- ◀ COVER. Dhruva (L) and CIRUS (R) reactors at the BARC, Mumbai have played a key role in harnessing the power of the atom for both power and non-power applications of atomic energy in India.

The Chief Editor thanks Dr R. B. Grover (Homi Bhabha National Institute, Mumbai) and Dr A. K. Mohanty (Bhabha Atomic Research Centre, Mumbai) for agreeing to be Guest Editors for special section.

### Foreword

Homi Bhabha recognized the importance of energy for the growth of our nation and the role nuclear energy has to play in India, a country not rich in energy resources. The Tata Institute of Fundamental Research (TIFR), Mumbai, has compiled a selection of Bhabha's speeches and writings in a volume published in 2009, which can be considered a resource book to study his thought process<sup>1</sup>. We have extensively used the contents of this book to understand the same.

In his welcome address at Geneva in 1955 to delegates at the International Conference on the Peaceful Uses of Atomic Power, Bhabha said:

'In a practical sense, energy is the great prime mover, which makes possible the multitude of actions on which our daily life depends. Indeed, it makes possible Life itself.'

Bhabha was cognizant of the overarching role of technology in harnessing atomic energy. Speaking in Geneva in 1955, he said:

'Generally, the basic ideas of atomic energy are simple but its technology is sophisticated and difficult. Hundreds of tons of special materials have had to be produced in states of extreme purity surpassing anything hitherto known even in the pharmaceutical industry. Highly radioactive substances have had to be treated chemically in bulk by remote control. All this required the development of new techniques at great expense and by enormous effort. .... As in all industrial operations, there is always room for technical improvement and alternative processes,....'

He realized the importance of nurturing practical experience and detailed know-how. Speaking at the inauguration of the Atomic Energy Establishment and Swimming Pool Reactor on 20 January 1957, Bhabha noted:

'Any country which does not wish to depend wholly upon outside aid, must have its own research and development organization, not only for investigating the many possibilities which remain unexplored, but also because, even in fields where general knowledge is available, practical experience and detailed know-how have to be obtained.'

It is interesting to note Bhabha's remarks regarding technology shaping the course of history. In a paper prepared for the 1961 MIT Centennial Conference on Science and Technology Education, he wrote:

'The successes of modern technology have been so great and its impact on life and society so powerful,

that one is apt to forget that technology in a broad sense, meaning by that "knowledge of techniques", has existed for thousands of years and determined the course of history.'

Bhabha was critical of continuing dependence on imports for transfusion of technology. Citing the example of the steel industry, he mentioned that the construction and operation of many steel plants have not equipped us with designing and building new steel plants. He did not want this to continue. He believed that 'If Indian industry is to take-off and be capable of independent flight, it must be powered by science and technology based in the country.' (Speech delivered at the International Council of Scientific Unions on 7 January 1966.)

Bhabha recognized the powerful role of technology in life and the growth of society, the importance of practical experience and the necessity of detailed know-how in nurturing the industry. This is in contrast to the oversimplification embedded in the linear model that implies causation from basic research to production and operation. The linear model emerged from the report of Vannevar Bush, and about which Bush himself was annoyed as the panels drafting the report excluded pioneering efforts of the kind exemplified by Wright Brothers in developing the flying machine<sup>2</sup>. Over the years, science and technology historians have rejected hierarchical models like the linear model (science drives technology) as well as the reverse linear model (technology creates scientific possibilities) in favour of non-hierarchical models, emphasizing a continuum or intertwining between science and technology in research leading to meaningful knowledge and deployable technologies<sup>2</sup>. Expressing a similar opinion differently, Narayanmurti<sup>3</sup> writes that 'path breaking scientific discoveries and engineering inventions go hand-in-hand, in a dance in which sometimes one leads, sometime the other, and sometime both occur simultaneously'.

In addition to nuclear power, Bhabha also paid attention to non-power applications of nuclear energy. In 1964, he wrote in *Nuclear India*, 'Isotopes and radioactive substances can be used for improving the strains of crops, for studying the best applications of fertilizers, for pest control, for the preservation of food, for the refined control of processes in industry, and lastly for diagnosis and therapy in medicine.'

Bhabha was keen to ensure that the work done for the development of nuclear power should benefit the industry in India. In his address to ICSU in 1966, he spoke at length about setting up a plant in Hyderabad for manufacturing a variety of electronic components and equipment. He also spoke about spin-offs from the work done by the Technical Physics Division in areas like vacuum technology.

At the beginning of the atomic energy programme, Bhabha established a Health Physics Division to safeguard

the health of workers and the general public. Speaking at Trombay on 16 January 1961 while inaugurating new facilities, he said, 'The amendments to the Atomic Energy Act, which will be put through shortly, will give Government powers to ensure that those who use radiation and radioactive materials do so in accordance with internationally accepted procedures to ensure that neither the worker nor any member of the public comes to harm.' This is a reference to the Atomic Energy Act, 1962, which was then under drafting and has enabled the Government to constitute the Atomic Energy Regulatory Board (AERB).

At the 12th Pugwash Conference held in Udaipur in 1964, Bhabha spoke about the inherently discriminatory character of the safeguards system through the International Atomic Energy Agency. The discrimination observed by him has been further accentuated with the coming into force of the Treaty of Non-Proliferation of Nuclear Weapons, commonly referred to as NPT. Bhabha's apprehensions were proved correct as following Peaceful Nuclear Explosion by India in 1974, any participation in international civil nuclear trade was denied to the country and the situation changed only in 2008 after intense negotiations<sup>4</sup>.

Bhabha nurtured nuclear technology and laid the foundation for ushering in the computer revolution. The institutions established by Bhabha during his lifetime and subsequently have advanced nuclear science and technology keeping in mind the concepts and organizational blueprint established by him. The most important concepts include the pursuit of a closed fuel cycle, paying utmost attention to nuclear safety and developing detailed know-how to spur indigenous manufacture of complex equipment for nuclear reactors and associated fuel-cycle facilities. The Department of Atomic Energy (DAE) established by Bhabha now has several institutions under its fold and the overall structure of the Department bears the stamp of his blueprint. It is important to note the intertwining of science and technology in the organizational structure as well as the working culture of most of the units of the DAE.

Through his actions, speeches and writings, Bhabha touched upon a wide range of topics, almost all aspects of nuclear science and technology, including the administration of research and development institutions. He was clear that the administration of research and development should be done by scientists and technologists themselves. The purpose of this Special Section is to convey to the country how far the institutions nurtured by DAE have lived up to Bhabha's dream of designing and building atomic power plants and associated fuel-cycle facilities; developing and deploying applications of nuclear science and technology to agriculture, industry, health care and research; and nurturing advanced-technology in India based on knowledge generated within the country. DAE today manages 29 units dealing with R&D, power and non-power applications of nuclear energy, related industries as well as academic institutions (Figure 1).

Articles included in this Special Section cover the subjects of nuclear power and fuel-cycle technologies, technical physics, accelerators, electronics, materials, nuclear fuel, health physics, heavy water and nuclear physics. None of the authors of these articles had the privilege of working with Bhabha, but all were inspired by his broad and deep vision.

Bhabha and his colleagues studied the linkage of electricity to the developmental needs, required growth of electricity generation in India, the energy resource profile, economics of electricity generation, technologies that can be nurtured in the country, and so on. It is noteworthy that his presentations at conferences and his lectures make detailed references to the economic aspects of nuclear power and stress on indigenous development.

Pathak *et al.* (page 281) have given an authoritative account of the present status of nuclear power development, including spent-fuel reprocessing and waste management. The indigenously developed 700 MW PHWR is set to become the workhorse of the Indian nuclear power programme and several such units are planned to be constructed.

Kain *et al.* (page 293) examine the efforts made towards exploiting sources of atomic minerals, while Kapoor *et al.* (page 310) describe how India has achieved self-sufficiency in manufacturing nuclear fuel. Heavy water is a crucial input for the PHWR programme, and India not only produces enough heavy water for its use but also exports it. Srivastava *et al.* (page 322) discuss heavy-water production in India and how the knowledge of chemical engineering acquired in the production of heavy water has been harnessed to produce speciality materials.

Mayya *et al.* (page 330) examine how indigenous capability in nuclear electronics, instrumentation and control

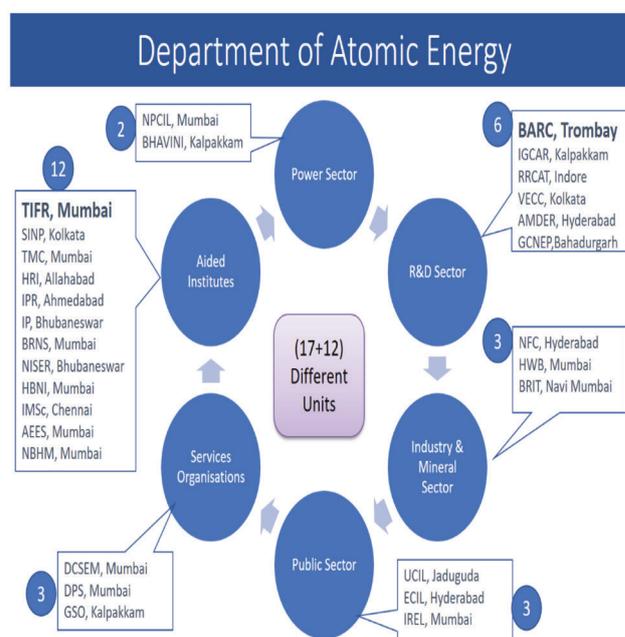


Figure 1.

systems for nuclear power plants was developed. They have also reviewed the role played by the Electronics Corporation of India Limited in the growth of the indigenous electronics industry in the country.

Bhabha desired that in the area of nuclear safety, DAE should set an example, and this is covered by Kulkarni and Nageswara Rao (**page 343**). They trace the evolution of health physics programmes in India and link it to the setting up of AERB.

Aswal *et al.* (**page 353**) trace the history of developments in technical physics leading to the setting up of accelerators and synchrotron sources, and their contributions to CERN.

Tyagi *et al.* (**page 361**) discuss about the omnipresence of chemistry in atomic energy programmes: in uranium mining, fuel fabrication, spent-fuel management, heavy-water production and in the development of non-fuel materials.

From surveys done in other countries, it is well established that non-power applications contribute a lot to the GDP, public welfare and employment generation. Venugopalan and Suprasanna (**page 370**) describe how by the use of radiation many new crop varieties having desirable traits have been developed and deployed. Pant *et al.* (**page 377**) deal with the application of radioisotopes and radiation technology in the industry, and Banerjee *et al.* (**page 388**) describe the use of radiation and radioisotopes for healthcare.

The advanced-technology base nurtured by DAE has been of use to several other sectors of the economy in the country. This is captured in three case studies. Lahiri *et al.* (**page 396**) discuss development of the instrumented pipe inspection gauge, Mayya *et al.* (**page 406**) on controlling telescopes, antennas and airborne radars, and Dasgupta *et al.* (**page 417**) on the development of carbon fibres and shape-memory alloys.

Nuclear and high-energy physics have been nurtured by DAE all along and Srivastava *et al.* (**page 429**) cover the journey of the community starting from detectors fabricated from components purchased from the scrap markets in Mumbai, to designing and constructing large facilities at

home and participation in the construction and use of international facilities.

For any achievement, a good education is a crucial factor, and education in nuclear science and technology has been well nurtured by DAE. A Training School was set up in 1957 to provide education in nuclear science and engineering to equip scientists to work on the development of nuclear programmes. It now functions as a graduate school. Grover *et al.* (**page 441**) write about the evolution of the Training School into the Homi Bhabha National Institute.

Ramakrishnan (**page 451**) touches upon TIFR incubating the atomic energy programme, establishing a graduate school, and converting it into a degree-granting institution in 2002. He describes in detail about the commitment of TIFR and its scientists to pursue new challenges with excellence, and pursuing research in applied fields to bring the benefits of science to common people.

The scope of the work done by institutions run by DAE is vast. While it has not been possible to cover everything, we hope that this Special Section will provide good coverage of most of the activities. The DAE institutions have come a long way in realizing Bhabha's dream of nurturing advanced-technology based on knowledge generated within the country. Progress is an open-ended endeavour, and we still have miles to go.

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  3. Narayanmurti, V., *NEA Perspectives*, National Academy of Engineering, USA, 18 January 2022.
  4. Grover, R. B., Resumption of international nuclear cooperation. *Science Diplomacy Case Studies, No. 2, Forum for Science Diplomacy*, RIS, 2019.
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– Guest Editors