

HOMI BHABHA

MASTER BUILDER OF NUCLEAR INDIA

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The founder of two of India's preeminent nuclear-science research centers insisted that scientists be surrounded by culture and beauty.



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Homi Jehangir Bhabha (1909–66), one of the key architects of India's nuclear-science program, founded and directed two of the institutions that would bring India into the nuclear age: the Tata Institute of Fundamental Research (TIFR) and the Atomic Energy Establishment, Trombay, later renamed the Bhabha Atomic Research Centre (BARC) in his honor. TIFR remains a crown jewel of Indian science. Internationally renowned in theoretical physics, mathematics, computer science, radio astronomy, and molecular biology, it attracts distinguished visitors from across the globe. Because of its integral connection to India's nuclear weapons program, BARC has been more secretive and less visible, though no less important for Indian science.

The two research centers might be considered fraternal twins, sharing a common history and often research facilities and staff, but with very different missions. TIFR is open to scientists of every country and unfettered by secrecy. BARC is closed and its research is classified and focused on national security. TIFR faces west, literally and symbolically, out to the Arabian Sea. BARC faces southeast, across the harbor toward Navi Mumbai, the modern metropolis planned, though never fully realized, by famed Mumbai architect Charles Correa.

A school comparable with the best

Bhabha, shown in figure 1, strongly believed that exposure to the arts brought out the best in creativity from scientists, and the aesthetics of Western art and music would be a constant reference point for him. An accomplished amateur painter and music connoisseur, Bhabha spent hours at his phonograph, dressed in Western formal attire, listening to the works of Ludwig van Beethoven and other classics. "He knew who was singing at La Scala," wrote an American colleague who spent time at TIFR. "He knew what was showing at the Tate."¹ Bhabha tried to imbue the scientific institutions he led with that spirit of high culture. He hired world-class architects to design them, filled them with museum-worthy collections of fine art, surrounded them with carefully tended formal gardens, and arranged musical concerts for the staff.

Along with Jawaharlal Nehru, a personal friend, political mentor, patron, and India's first prime minister, Bhabha believed that catching up with the West would mean "establishing the centrality of science in the autobiography of the Indian nation."² He expected TIFR and BARC to be Western in their orientation and international in their aspiration. Writing



NIRUPEN MADHUVANI, COURTESY OF THE TATA INSTITUTE OF FUNDAMENTAL RESEARCH ARCHIVES

in 1944 to Sorab Saklatvala, chairman of the Sir Dorabji Tata Trust, he explained, “It is absolutely in the interest of India to have a vigorous school of research in fundamental physics, for such a school forms the spearhead of research not only in the less advanced branches of physics but also in problems of immediate practical application in industry. . . . I hope to build up in the course of time a school of physics comparable with the best anywhere.”³

At the core of nuclear India would be an essential tension between internationalism and nationalism, between openness and secrecy, between central planning and grassroots organization. TIFR and BARC enjoyed political connections and financial resources that would be the envy of India’s other nuclear research centers. Bhabha’s ambitions for Indian physics would be reflected and reinforced by the architecture he chose for the two institutions.

An atmosphere like Cambridge and Paris

Born into a wealthy and influential family, Bhabha was educated at the University of Cambridge, where he received a PhD in 1935 for his thesis, “On cosmic radiation and the creation and annihilation of positrons and electrons.” Four years later he was on vacation in India when World War II broke out. Since it was nearly impossible for him to return to the Cavendish Laboratory in Cambridge, Bhabha instead joined the faculty of the Indian Institute of Science in Bangalore (now Bengaluru). Even as the war raged, Bhabha’s work received recognition. He was elected a fellow of the Royal Society in 1941 and was awarded the Adams Prize by the University of Cambridge in 1942. Those recognitions, combined with a political situation that saw Indian independence as imminent, were critical factors that shaped Bhabha’s ambitions as an institution builder.

In line with Nehru’s sense that science was important for a modern state, the period that followed India’s achieving independence in 1947 saw 11 national laboratories being built under the auspices of the Council for Scientific and Industrial Research. Bhabha strongly supported Nehru’s technocratic, top-down vision of nation building, and in return he was among the few scientists who would enjoy Nehru’s unstinting support. His rivals, most notably Meghnad Saha, sought a bottom-up approach that often put them at odds with the Nehruvian vision and at a political and financial disadvantage (see the article by Soma Banerjee, *PHYSICS TODAY*, August 2016, page 38).

Bhabha had set up TIFR in 1945, with funds from the Tata Trust. The institute’s original home was the Indian Institute of Science. Later it moved to rented premises on Pedder Road in Bombay (now Mumbai), and with further expansion it relocated to Bombay’s Old Yacht Club. As early as April 1944, Bhabha remarked in a letter to astrophysicist Subrahmanyan Chandrasekhar that his vision included not just an institution that did science but also one that was similar in atmosphere, both culturally and intellectually, to the places he had known in Europe. He intended to “bring together as many outstanding scientists as possible . . . so as to build up in time an intellectual atmosphere approaching what we knew in places like Cambridge and Paris.”⁴

It was not until 1954, however, that Bhabha managed, after a lot of negotiation, to acquire a suitable site for the permanent TIFR building. Inaugurating the edifice in 1962, Nehru admit-

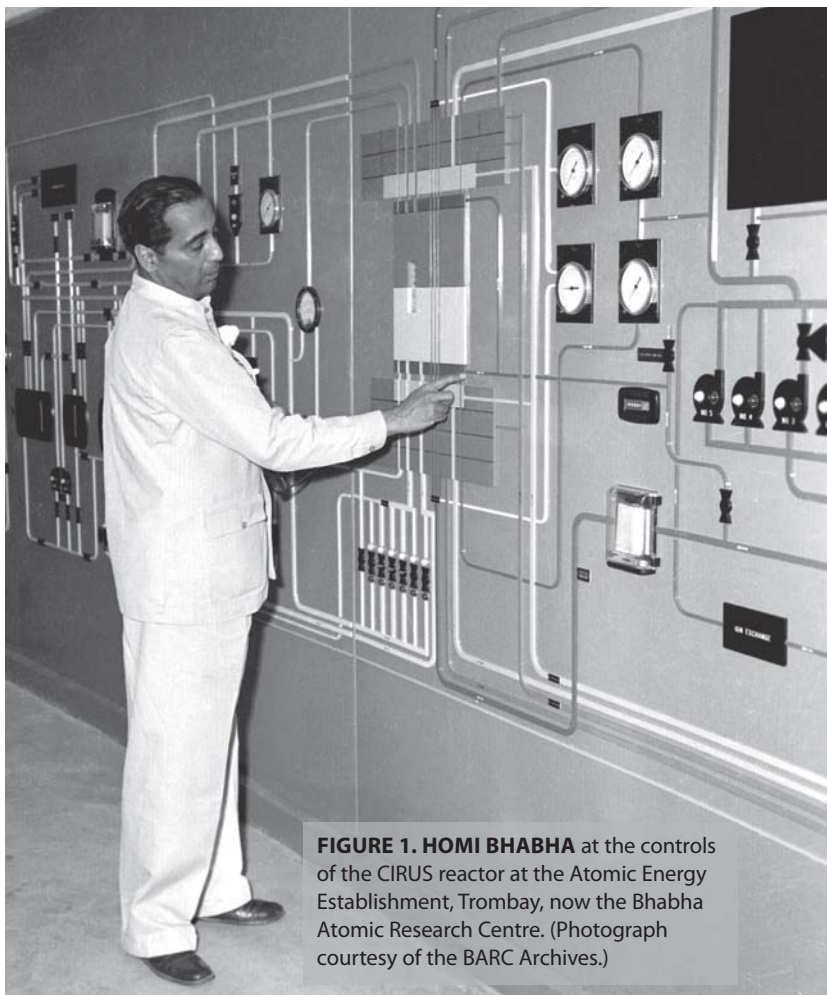


FIGURE 1. HOMI BHABHA at the controls of the CIRUS reactor at the Atomic Energy Establishment, Trombay, now the Bhabha Atomic Research Centre. (Photograph courtesy of the BARC Archives.)

ted that although the eight years spent in construction were “rather excessive,” he was suitably impressed by the building and what it contained.⁵ Bhabha, in his inauguration speech explained, “This building has taken so long to construct because we had to do a lot of pioneering in the course of it, pioneering that has resulted in permanent benefit to the country.”⁶ The aluminum frames in the windows and on the glass walls were manufactured in India—the first time such a product was fabricated there—and testified to the success of Bhabha’s efforts at capacity building in the new nation.

Thinking, arguing, and sauntering

Designed by Helmuth Bartsch, TIFR was constructed in the International Style from locally available material. Laid out in a simple rectilinear horizontal form, the building had repetitive bands of metal louvred windows that were set flush against the exterior wall (see figure 2). The louvred windows kept out the harsh sun but allowed a view of the Arabian Sea from the offices that faced westward. The location was ideal. Bhabha’s choice of architect and the design of the building were significant departures from the established norms in India, where the Central Public Works Department built all government institutions before and after independence.

The building featured floor-to-ceiling glass in the west canteen and in the foyer—a characteristic of the International Style. But its high-modern style of postwar American architecture was attuned to the local landscape. An exterior open gallery allowed Bartsch to incorporate an element of “playfulness” and to present “magnificent views of the nearby sea as it appears



FIGURE 2. THE TATA INSTITUTE of Fundamental Research, circa 1970, as viewed from the seaside promenade to the west. In the foreground is the Amoeba Garden, designed by Homi Bhabha. (Photograph courtesy of the TIFR Archives.)

through various architectural frames,” as the architect wrote in a note prepared for the inauguration.⁷ The colonnade area of the building, with its tall cylindrical pillars, created a space for sauntering scientists to enjoy a view of the sea and the feel of the sea breeze. A short walk down a crazy cobbled pathway led past Bhabha’s Amoeba Garden to the seaside promenade. In such areas, scientists could take a break from the routine of thinking, arguing at blackboards, and working at the lab bench to refresh mind, body, and spirit.

The image on pages 48–49 shows the foyer of TIFR. Note the statue of Bhabha to the right and the free-standing cantilever staircase that leads to the mezzanine library. The stairs draw the eye toward a mural by M. F. Husain, *Bharat Bhagya Vidhata* (*The Ruler of India’s Destiny*), whose title echoes lines from India’s national anthem. Excellence in the artistic sphere, Bhabha believed, could be achieved only by the “creation of new art forms, possibly through synthesis of the ancient Indian and European traditions in art.”⁸ For him and the committee that selected the mural, young Husain had achieved that synthesis.

The interior of TIFR echoed the building’s modern aesthetic, as can be seen in figure 3. The furniture in the ground-floor lobby and in the faculty lounge consisted of upholstered armchairs with wooden legs; carpenters built the pieces in-house, working from catalogs that Bhabha had brought back from his travels to the US. Bhabha was particularly proud that the dialog between the scientists and the architect resulted in a harmonious coordination between function and aesthetics.

Academic exclusiveness and expertise

Scientific work at TIFR began well before the new building was ready. By the time it was completed, research at the institute had expanded. Nuclear physicist Bernard Peters worked at the institute for 10 years beginning in 1950 and guided a group that observed strange particles. Balloon flights were an important part of work done at TIFR; in the basement of the new building, balloons were made on a 300-foot-long table with a hot-wire technique developed at the institute. TIFR also had a central workshop and other facilities that supported work in cosmic-

ray physics, high-energy physics, geophysics, nuclear physics, solid-state physics, and chemical physics, to name only a few fields. The new building housed the institute’s first computer, the TIFR Automatic Calculator, named by Nehru and commissioned in 1962.

The move to the new facility was organized according to need. The workshop that was so important for the institute’s experimental programs moved in 1961. The mathematics group, one of the institute’s most significant, was the last to relocate; it had to wait until the library was also ready to be moved.

Soon after the building’s inauguration in 1962, TIFR expanded to include two new fields: molecular biology and radio astronomy. Significantly, the presence of biologists in a physics institution enabled interdisciplinary engagements. Fume hoods and facilities for microbiology had to be added to what was essentially a space for physics, but Bhabha’s control over budgets made those additions possible. The radio astronomy group first built an interferometer at Kalyan, a town near Mumbai, and soon afterward built a radio telescope in Ooty, in the southern state of Tamil Nadu. As TIFR expanded, its groups went on to found the National Centre for Biological Sciences in Bangalore in the south of India and the National Centre for Radio Astrophysics in Pune in western India.

From the beginning, the monumental design of the building separated it from other laboratories in India and suggested academic exclusiveness and expertise. The authority that the building commands is invoked as much by the expertise it houses as by its inaccessibility to ordinary people and its isolation from the city.⁹ Apparently, Bhabha sought isolation for his elite institute, not engagement with other centers of Indian physics.

Bhabha’s multifaceted personality and his attention to the details of science and aesthetics drew the admiration of the younger scientists—admiration that survived his untimely death in an airplane crash in the French Alps in 1966. The journey that began with cosmic rays and particle physics now includes string theory, cosmology, astroparticle physics, condensed-matter physics, and other fields. In recent years TIFR has made significant contributions to understanding statistical

models that manifest self-organized criticality. Moreover, Bhabha had ensured support for his institute from India's Department of Atomic Energy. Therefore, TIFR not only remains an elite, well-supported institution; it can also afford to replicate its model through the specialist institutions it founded in other parts of the country, each echoing architectural elements of the parent institution.

Western visitors often say that TIFR reminds them of MIT and other familiar campuses. Amherst College physicist George Greenstein wondered why "Bhabha adopted so resolutely Western an architectural tone? Why didn't the building there *look* Indian?"¹⁰ Because for Bhabha, a successful Indian research institute would be one where the best scientists from Western countries would immediately feel at home.

Difficulties such as algae

Just after independence, Bhabha prepared a brief for Nehru, titled "Organisation of Atomic Research in India," that outlined a road map for a new nuclear nation. Nehru subsequently named Bhabha the first chairman of India's Atomic Energy Commission. The post, which put Bhabha in charge of the nation's nuclear effort, gave him an essentially unlimited budget and almost total political autonomy.¹¹ Bhabha recognized that a self-reliant Indian nuclear program would require long-range planning. So he conceived a three-stage plan for nuclear self-sufficiency. The first step was to design uranium-fueled reactors whose spent fuel rods would yield plutonium. Next was to construct second-generation, plutonium-fueled reactors that could convert thorium, which India had in abundance, into fissionable uranium-233. The finale¹² would be third-generation breeder reactors fueled by Th and ²³³U.

To realize that vision, Bhabha acquired 5 km² of land in Trombay, an industrial area along Mumbai's southeast harbor, where he would build a complex of laboratories, reactors, and processing plants that would dwarf TIFR in size. As the cornerstone for self-confident and self-reliant programs of nuclear science and technology, BARC embodied the paradox of postcolonial science: Of necessity, it borrowed from the West, but it would enable the self-sufficiency that had eluded an earlier generation of Indian physicists. The Trombay facility began with Apsara (named after a celestial nymph in Hindu culture), a tiny 1 MW, swimming-pool-type research reactor derived from a British design. Gradually, the facility came to have an entire family of reactors, a plutonium processing plant, and an enormous engineering laboratory; together they would make Indian nuclear aspirations a reality. When Trombay's first recruits arrived in 1954, they had virtually no experience in reactor design. Bhabha sought advice from former British colleagues but insisted that his team do as much of the design and fabrication as possible. Aside from some specialized electronic valves, the Indian team made all of Apsara's components in the workshops at TIFR.

After Apsara was completed, Trombay's burgeoning team of scientists collaborated with Canadian scientists and engineers on CIRUS (Canada-India Reactor US, a heavy-water reactor that used natural uranium fuel rather than the en-

riched variety. From their time together at Cambridge, Bhabha knew Wilfrid Lewis, director of the Canadian Nuclear Laboratories at Chalk River. Looking forward to an international market in reactors, Canadian officials offered to build India a 40 MW natural uranium-heavy water research reactor. Again, Bhabha intended that his scientists and engineers do the design and fabrication work themselves. "If Indian industry is to take off and be capable of independent flight," he declared in a 1966 speech before the International Council of Scientific Unions, "it *must* be powered by science and technology based in the country."¹³ For Bhabha, CIRUS offered experience in building and operating a powerful reactor, a source of medical isotopes, a neutron source for experimental physics, and a source of plutonium.

By design, CIRUS remade foreign technology—Canada's NRX research reactor—into something India could call its own. Indian scientists and engineers fabricated nearly all of the reactor's components themselves, including its uranium fuel rods. Indians also did most of the heavy lifting. For all its high-tech style, CIRUS was largely handmade. Construction photographs, such as figure 4, prominently showed head-basket-carrying workers silhouetted against the modernist icon. The Indian workers also had to adapt the reactor design to local conditions never anticipated by the Canadians. As Bhabha reported to Nehru in a letter of January 1962, "When the Canadians handed

FIGURE 3. THE LOUNGE on the ground floor of the Tata Institute of Fundamental Research offers a view of the Amoeba Garden and the Arabian Sea. The modern style of furniture was built at the institute's workshop. (Photograph courtesy of the TIFR Archives.)



over the reactor at the end of 1960 it could not be taken up to a power above 17 megawatts, and a number of difficulties, such as, growth of algae in the primary system, corrosion, pressure drop in the rods, rupturing of the rods, etc., impeded its operation even at a relatively low power level."¹⁴ Bhabha's team overcame each of those challenges on its own.

Modern temples

To someone else, 5 km² of scrubland adjoining an oil refinery might have seemed an unlikely site for a nuclear showcase. But Bhabha envisioned Trombay as a scientific Versailles, an enormous canvas on which to paint an image of India's future. He fought hard to keep construction out of the hands of the Central Public Works Department and established his own civil en-



FIGURE 4. THE CIRUS REACTOR ended up a modern icon, but some construction techniques were anything but modern. (Photograph, 1958, Dinodia Photos/Alamy stock photo.)

gineering division to give himself more control. Only Bhabha, who met Nehru every couple of weeks, had that kind of political clout.

For his chief architect, Bhabha hired Rustam Patell, who had formerly worked under Frank Lloyd Wright. Bhabha, though, would be the true master builder. He kept a site plan of Trombay in his home office and would compulsively fine-tune it. As he wrote to Nehru in 1959, “I think both Trombay and the Tata Institute of Fundamental Research will be architecturally, and botanically beautiful, when they are completed.”¹⁵ BARC’s current director, Kamlesh Nilkanth Vyas, told one of us (Chowdhury) that he had been “captivated by the beauty of the landscape and elegant architecture” when he visited Trombay for an interview in the late 1950s.

With its metal-sheathed dome surrounded by a handcrafted stone wall, CIRUS looked like a modern temple. Its Canadian prototype could have passed for a paper mill. Bhabha’s predecessors, notably Jagadish Chandra Bose, sometimes called their institutes temples of science. Bhabha had in mind something closer to Nehru’s modern temples—the dams, steel mills, power plants, research institutes, and other public investments

that would spark independent India’s economic development.¹⁶ Bhabha took classical European ideas and dressed them for the Indian climate, both political and meteorological. He modeled the reactor’s on-shore cooling pond and fountains on the pools of the Viceroy’s House in New Delhi and spent countless hours experimenting with spray-nozzle variations to get the perfect combination of efficient cooling and eye-catching fountain display. However proud he was to show off CIRUS as an Indian achievement, Bhabha kept secret such details as the exact temperature setting for cooking the fuel rods for weapons-grade plutonium.

For stage two of his nuclear program, Bhabha needed to extract the plutonium from spent CIRUS reactor rods. For him, even a plutonium reprocessing plant should be beautiful. He contracted with Vitro International, a US company with extensive experience building PUREX (plutonium uranium redox extraction) plants. Vitro drew up the engineering plans, and architect Edward Durell Stone brought them to life on the Trombay shoreline. Stone’s lavish US Embassy in New Delhi had redefined neo-Mughal (see also the article by Stuart Leslie, *PHYSICS TODAY*, February 2015, page 40). For Trombay, Stone decorated

the heavy concrete walls with precast concrete panels and at either end of the sprawling building put open courtyards, one with a large cooling pond and fountain. Meticulous as always, Bhabha noticed that the plant's prominent exhaust stack did not properly align with the CIRUS reactor. He insisted that the contractor break up and repour the foundation to preserve Trombay's strict geometry.

Bhabha gave BARC's modular laboratory building—called the longest building in Asia—the same scrutiny he gave TIFR. To take full advantage of the site, he insisted that the laboratory be placed on stilts, so that it would appear to an observer on Trombay Hill to float like a ship on the bay behind it. Whereas TIFR focused on thinking, BARC had to turn theory into practical devices and processes. To that end, Bhabha specified that each laboratory division—reactors, radiochemistry, nuclear fuels, spectroscopy, and electronics—should have its own workshops. Heavy machinery would be in the basement and laboratories on the upper floors along with adjoining high-ceilinged engineering halls for prototype and pilot-scale work. Bhabha wanted a flexible design, so that laboratories or entire groups could be reconfigured without significant structural changes.

Characteristically fastidious, Bhabha came up with three or four basic designs for the modular laboratory building and had scale models constructed before he finally approved one. He typically visited the BARC construction site every other day. Details mattered. "If a wall had to be painted, small patches of sample colours (suggested by the architects) would be painted on a wall for the big man to see and select," one associate recalled. "Sometimes it would be months before a selection was made because Dr. Bhabha was not available as he was on tour. But *he* had to approve before the full painting operations could commence."¹⁷

Sheer distance became an important architectural feature in the building. Simply walking the long corridor on the way to lunch in the glass-walled canteen ensured a certain serendipity. As former BARC director Anil Kakodkar recalled to Chowdhury, "If you have a problem that you want to solve at lunch, you just take a stroll in the corridor, walk from one end to the other, you'll meet people, and by the time you get back to your office the problem will be solved."

As with TIFR, Trombay got its own collection of modern Indian art. Ironically, though, Bhabha's version of postcolonial science could never completely give up its attachment to the West. Even though BARC was closed to most Western scientists, Bhabha insisted that the place feel Western. As long as he was alive, BARC had Western utensils in the canteen and its researchers, like their TIFR counterparts, generally wore Western-style clothing.

Bhabha took the Versailles model seriously. The chief landscape architect for TIFR actually trained at Versailles, but the institute had only limited space for gardens. At Trombay, Bhabha

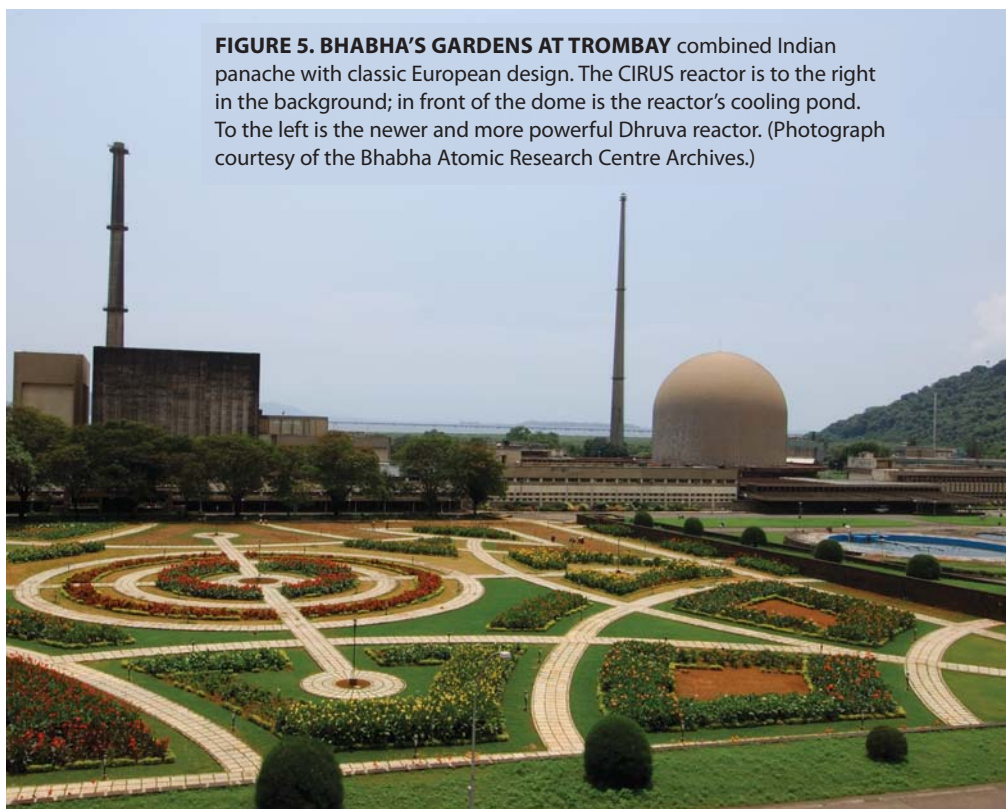


FIGURE 5. BHABHA'S GARDENS AT TROMBAY combined Indian panache with classic European design. The CIRUS reactor is to the right in the background; in front of the dome is the reactor's cooling pond. To the left is the newer and more powerful Dhruva reactor. (Photograph courtesy of the Bhabha Atomic Research Centre Archives.)

could set his reactors in an immense landscape of his own design (see figure 5). To improve the view, Bhabha reforested the hill between the oil refinery and the reactor with more than a million trees and shrubs. The all-Indian botanical garden he created—an intricate geometry patterned on the European classics but with subtropical flair—was maintained by a dedicated professional staff. Subsequent directors did their best to preserve Bhabha's original design and often moved new laboratory facilities to off-site locations rather than upset the delicate balance of Bhabha's plan. Although Bhabha designed Trombay to inspire the staff, he also had an eye on a wider audience. Only people with the right clearances could enter the grounds of the classified facility, but anyone could appreciate Trombay from a distance, nowhere better than from the city ferries to the ancient temples on Elephanta Island.

The nexus of truth and beauty

Bhabha has few peers as a master builder of nuclear science and technology. The two institutions he founded, TIFR and BARC, symbolized a new postcolonial engagement with the world, later emphatically underscored by India's first nuclear test of 1974. They became, as Bhabha knew they would, symbols of modernization and key resources for India's nuclear weapons program. Bhabha never received the Nobel Prize in Physics that his early promise suggested he might. Instead, his lasting legacy to India would be the laboratories and the trained scientists and engineers that would make it a nuclear nation. In his proposal to the Tata Trust to establish TIFR, Bhabha had pointed out, "When nuclear energy has been successfully applied for power production, in say a couple of decades from now, India will not have to look abroad for its experts but will find them ready at home." To ensure a pipeline of well-trained nuclear scientists and engineers, Trombay opened its own Atomic Energy Training School in 1957. The school's first corps of students—200 were selected each year—were chosen by

competitive examination. The thousands that followed them would go on to provide the nation's essential scientific talent.

For decades TIFR and BARC remained elite research institutes, with relatively few connections to India's chronically underfunded universities. Saha had introduced a nuclear-physics curriculum at Calcutta University in 1939, on the theory that India should train its own future nuclear scientists. Bhabha staffed his institutes with Indian physicists trained in Western institutions and supplemented them with homegrown talent. Although it remains a research institute, TIFR now offers its own PhD degrees. It has also opened a satellite campus in Hyderabad with a small graduate program devoted to interdisciplinary sciences. BARC, meanwhile, has expanded its training school into the Homi Bhabha National Institute, which offers doctoral degrees in nuclear science and engineering.

Bhabha's successors have ensured that TIFR and BARC continue to flourish. Those institutions stand today as living testaments to Bhabha's conviction that the scientific enterprise can and must be enhanced by architecture and art. Much like his US contemporary physicist Robert Wilson—the accelerator builder, sculptor, and amateur architect who designed and built Fermilab¹⁸—Bhabha believed that the sciences and the humanities exist in the same nexus of truth and beauty, forever enhancing and shaping one another.

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REFERENCES

1. G. Greenstein, *Portraits of Discovery: Profiles in Scientific Genius*, John Wiley & Sons (1998), p. 69.
2. D. Arnold, *Isis* **104**, 360 (2013), p. 361.
3. H. J. Bhabha to S. Saklatvala (12 March 1944), file D-2004-2026, Tata Institute of Fundamental Research (TIFR) Archives, Mumbai, India, available at Wilson Center Digital Archive, <http://digitalarchive.wilsoncenter.org/document/114188>.
4. H. J. Bhabha to S. Chandrasekhar (20 April 1944), file D-2004-00227, TIFR Archives, ref. 3.
5. TIFR, *The Tata Institute of Fundamental Research: Inauguration of New Buildings, Bombay, January 15 1962* (1962), p. 52.
6. Ref. 5, p. 37.
7. Ref. 5, p. 56.
8. H. J. Bhabha to M. A. K. Azad (24 July 1947), file D-2004-0004, TIFR Archives, ref. 3.
9. For additional detail, see I. Chowdhury, *Growing the Tree of Science: Homi Bhabha and the Tata Institute of Fundamental Research*, Oxford U. Press (2016), p. 58.
10. Ref. 1, p. 78.
11. R. Anderson, *Nucleus and Nation: Scientists, International Networks, and Power in India*, U. Chicago Press (2010).
12. G. Perkovich, *India's Nuclear Bomb: The Impact on Global Proliferation*, U. California Press (1999).
13. G. Venkataraman, *Bhabha and His Magnificent Obsessions*, Universities Press (1994), p. 159.
14. Ref. 13, p. 165.
15. Ref. 13, p. 183.
16. "Jawaharlal Nehru (1889–1964): Architect of India's modern temples," *Hindu*, 7 July 2003.
17. Ref. 13, p. 196.
18. H. Petroski, *Am. Sci.* **103**, 170 (2015).

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