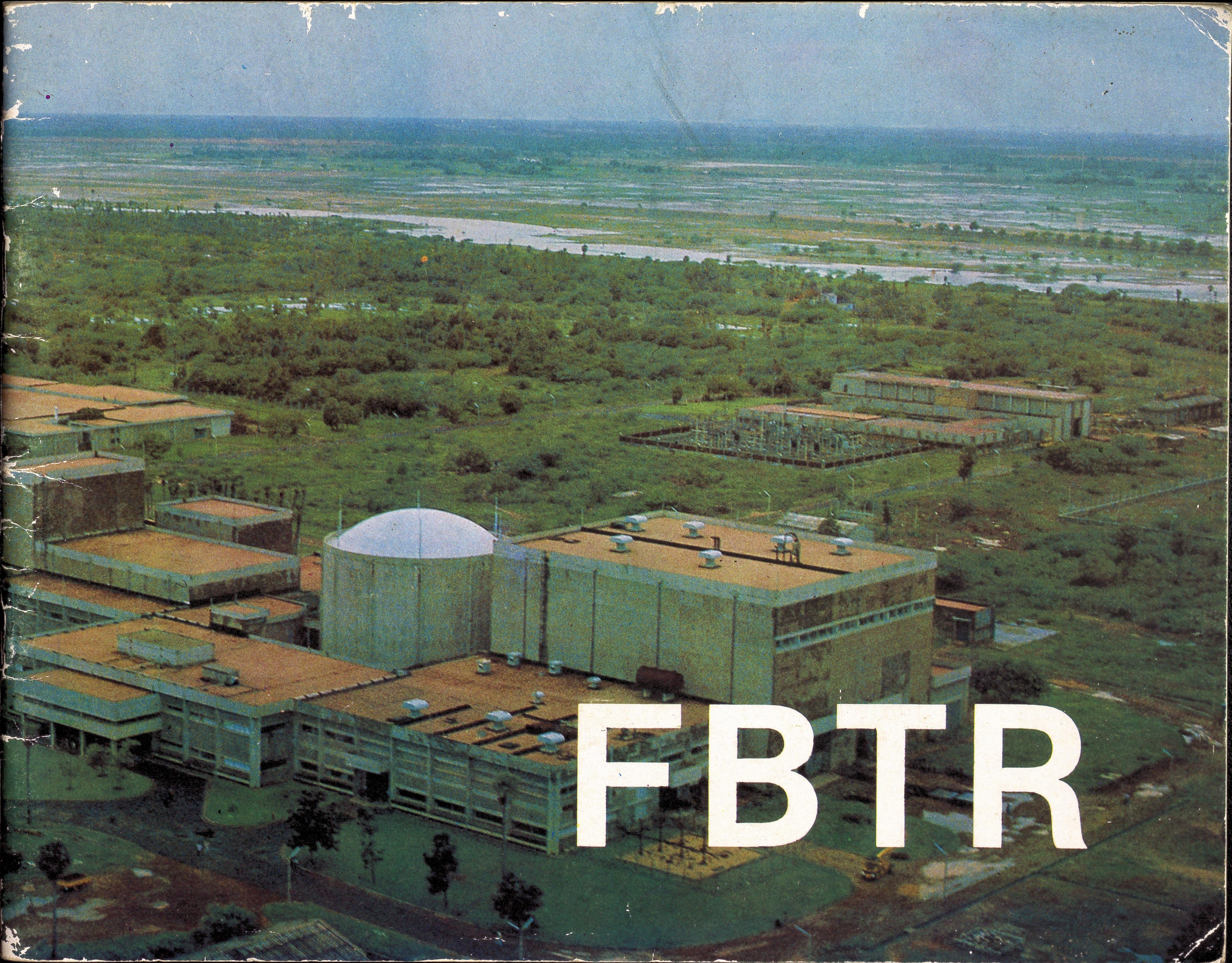


FBTR

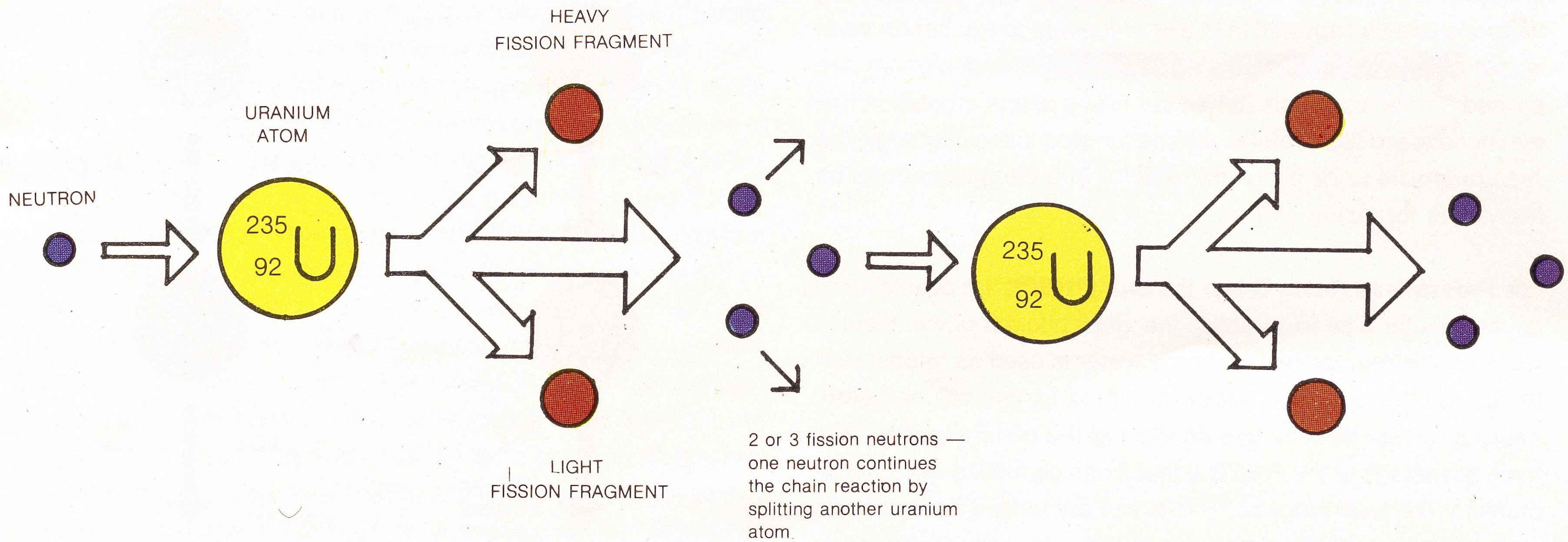
FAST BREEDER TEST REACTOR

सत्यमेव जयते GOVERNMENT OF INDIA
DEPARTMENT OF ATOMIC ENERGY
INDIRA GANDHI CENTRE FOR ATOMIC RESEARCH
KALPAKKAM

FBTR COMPLEX — VIEW FROM SOUTH

ON FAST BREEDER REACTORS

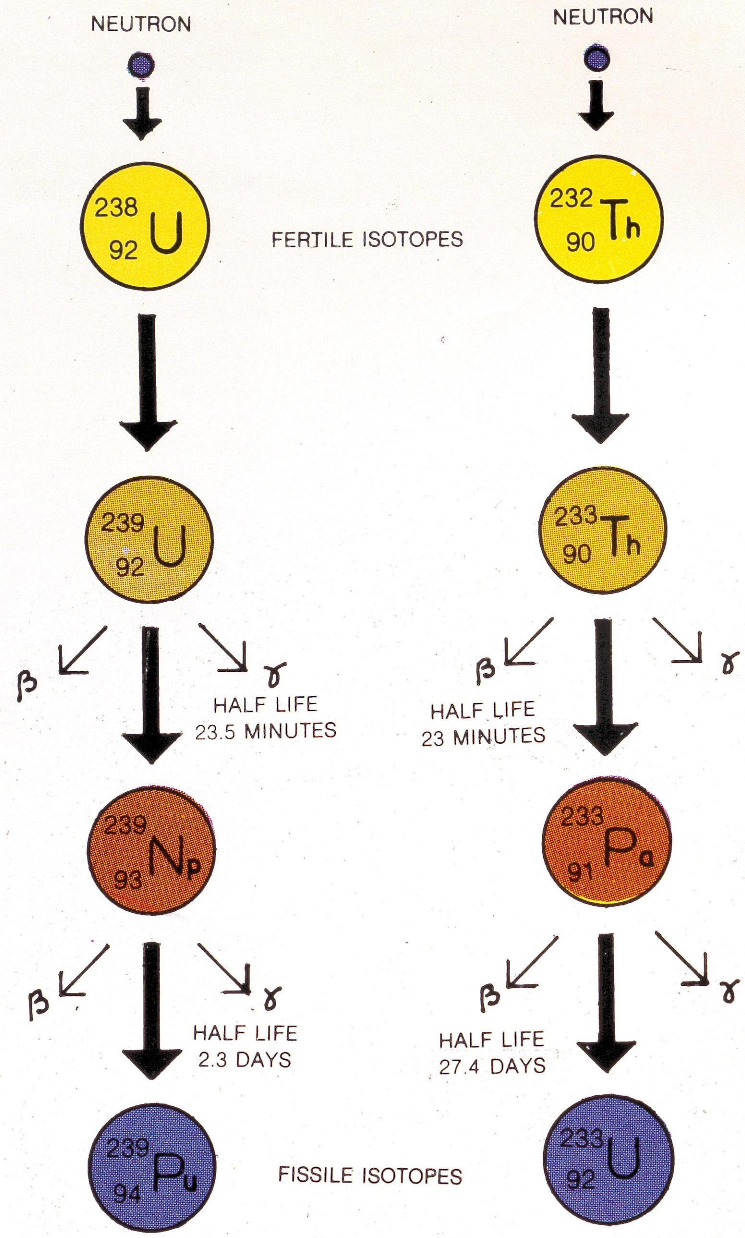
The discovery in 1939 of the fission of uranium atoms by neutrons was the beginning of far reaching developments, leading to the harnessing of nuclear energy for electricity generation.



FISSION CHAIN REACTION

U-235 is the only naturally occurring material which can sustain a fission chain reaction in a nuclear reactor, and is said to be 'fissile'. This isotope has an abundance of just 0.71% in natural uranium, the rest being U-238. Other fissile materials like plutonium or U-233 are man-made. The number of neutrons emitted during fission depends on the fissile atom as well as the energy of the neutron inducing the fission. Of the emitted neutrons, one is required to maintain the fission chain reaction, some are lost by leakage from the reactor, and some are captured by the fission products, core structural material and the coolant. The remaining neutrons can be captured in U-238 or thorium to transmute them respectively into plutonium or U-233. U-238 and thorium are termed 'fertile' materials. When the fissile atoms created in this manner exceed fissile atoms utilised for production of energy, the reactor is said to be a breeder reactor and the process can be termed as 'breeding of fuel'.

The **Pressurised Heavy Water Reactor (PHWR)** has been chosen as the reactor type to establish the initial nuclear power base in India. In this reactor system heavy water is used as 'moderator' to reduce the speed of fission neutrons to low values before causing further fissions and continuing the chain reaction. The main advantage of the PHWR is that it can be fuelled with natural uranium. The technology of PHWRs and associated fuel cycle has now attained a state of maturity in India. In addition to power generation, the operation of PHWRs progressively makes available plutonium as a by-product by the transmutation of U-238. The technologies for the reprocessing of plutonium from spent PHWR fuel and for the fabrication of a variety of plutonium bearing fuels,

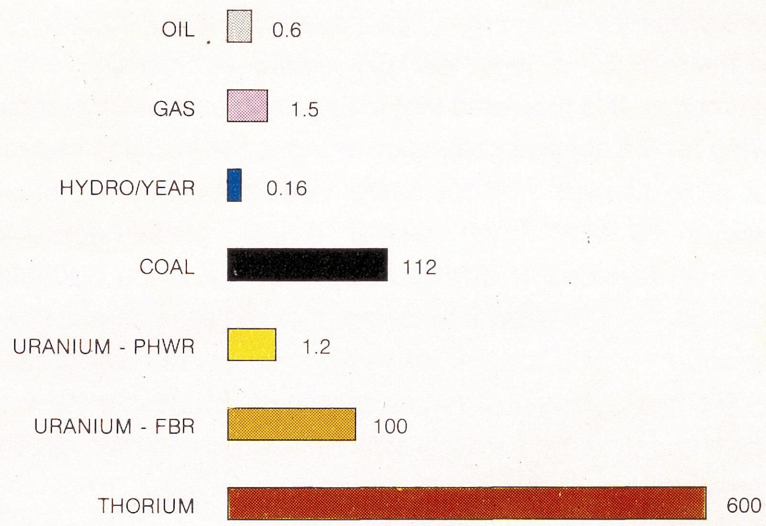


PRODUCTION OF FISSILE ISOTOPES

have been systematically established in this country through R & D and plant operations over the past two decades.

The stage has now been set for the effective utilisation of plutonium in **Fast Breeder Reactors (FBRs)** which will form the second stage of the Indian Nuclear Power Programme. FBRs provide the key to the full utilisation of the country's uranium resources and prepare the way for the long term utilisation of the more abundant thorium resources.

In FBRs, the fast neutrons released in fission are directly used to sustain the fission chain reaction without being slowed down. The higher neutron yield from the fast neutron fission of fissile atoms and the less loss of neutrons through parasitic capture in fission products, structural material and coolant result in a better neutron balance in FBRs, enabling the generation of more fresh fissile material than is consumed for power production. While a PHWR produces only about 0.6 kg of fissile plutonium (Pu-239 + Pu-241) for every kilogram of U-235 consumed, a large FBR could typically produce over 1.2 kg of fissile plutonium for every kilogram of such plutonium consumed. The surplus plutonium can be used to set up additional FBRs, which is the crucial advantage of these reactors. Analysis indicates that if the Indian nuclear power programme is limited to PHWRs, the known uranium reserves would permit the installation of a nuclear power generation capacity of only around 10,000 MWe. On the other hand, the deployment in FBRs of plutonium and U-238 discharged from PHWRs technically permits the establishment of a power generation capacity of as much as 3,50,000 MWe.



ENERGY RESOURCES IN INDIA
(in Billion tonnes Coal Equivalent)

India's present installed electrical capacity is about 40,000 MWe only making for a very low per capita commercial energy consumption. It is projected that to assure a reasonable standard of living for the general population of India, the installed capacity must grow to over 3,00,000 MWe. Growth of India's installed capacity to this level would cause gross depletion of the coal reserves. It is to be noted that coal is too valuable a natural chemical resource to be squandered away in mere heat generation. As indicated in the figure other energy resources in India like hydro-power, oil or gas cannot contribute significantly. It is in this context that the early establishment of commercial FBRs is considered to be essential.

The best developed type of FBR is the **Liquid Metal cooled Fast Breeder Reactor (LMFBR)** using liquid sodium as coolant to extract the heat from the reactor. The design of the LMFBR is in many ways different from that of the PHWR.

An LMFBR requires a substantial concentration of fissile material and cannot utilise natural uranium directly. Depending on the size of the reactor, the required fissile material concentration in the fuel varies from about 15% for large fast reactors to over 90% for small fast reactors. On account of the high concentration of fissile material in the fuel it becomes necessary from economic considerations to increase the average fuel power rating to over 100 MW/t and to have high fuel burnups of the order of 100,000 MWD/t. The high power densities coupled with the need to avoid neutron moderation lead to the choice of liquid sodium as heat transfer medium and stainless steel as compatible material of construction. With this choice of coolant and structural material, it is possible to operate LMFBRs at higher temperatures leading to a thermal to electrical energy conversion efficiency of 40% as compared to 30% in PHWRs. On the other hand, it should be mentioned that sodium is chemically very reactive — it burns on contact with air and reacts violently with water. Moreover, the high fuel ratings, the higher and more energetic neutron fluxes, and the high burnups can produce severe radiation induced damage in the fuel and structural materials. LMFBRs therefore require an advanced technology quite different from the technology of PHWRs.

FAST BREEDER TEST REACTOR AT KALPAKKAM

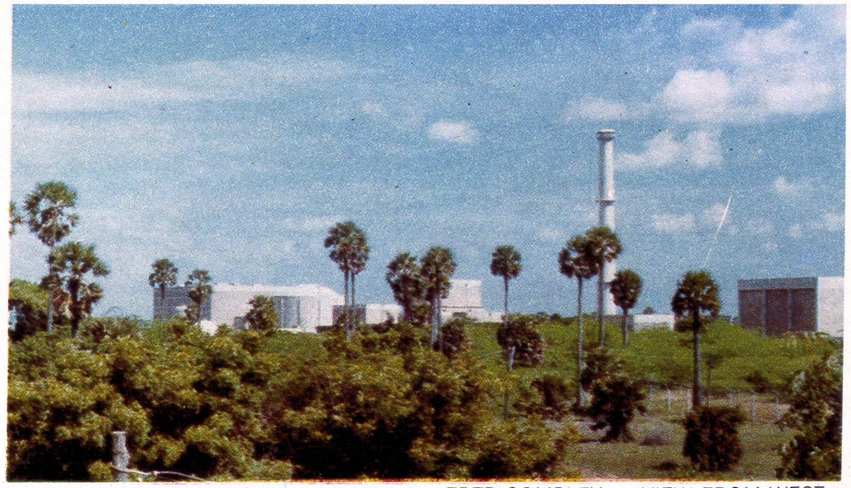
Considering the crucial role that FBRs are expected to play in India's future energy mosaic, the Department of Atomic Energy has established the **Indira Gandhi Centre for Atomic Research** at Kalpakkam, 60 km south of Madras, for the indigenous development of LMFBR technology. The main facility at this Centre is the **Fast Breeder Test Reactor (FBTR)** with a capacity of 40 MWt and 13 MWe. The purpose of constructing FBTR is to use it as an irradiation facility for the development of the FBR fuel cycle, and to gain experience in the design, construction and operation of LMFBRs.

FBTR has been designed and constructed with French collaboration and is similar to the RAPSODIE reactor in France. However, a number of design modifications have been incorporated in FBTR including the addition of sodium heated steam generators and a turbo-generator to produce electricity.

The emphasis during the construction of FBTR has been on maximum indigenisation. Almost all the major components have been manufactured within the country with the assistance of Indian industries. Names of the industries associated with the manufacture of key components in India are given at the end. Fuel pins have been fabricated by Radiometallurgy Division of BARC, and the core subassemblies by Nuclear Fuel Complex, Hyderabad.

The cost of FBTR is Rs. 687.2 million excluding the cost of the fuel and other core subassemblies. The import content of about 22% consists of payments for design and manufacturing know-how, raw materials, proprietary items and a few manufactured components.

The successful commissioning and operation of FBTR is an important stage in the efforts to establish the LMFBR as a viable solution to meet the future energy requirement in this country.



FBTR COMPLEX — VIEW FROM WEST

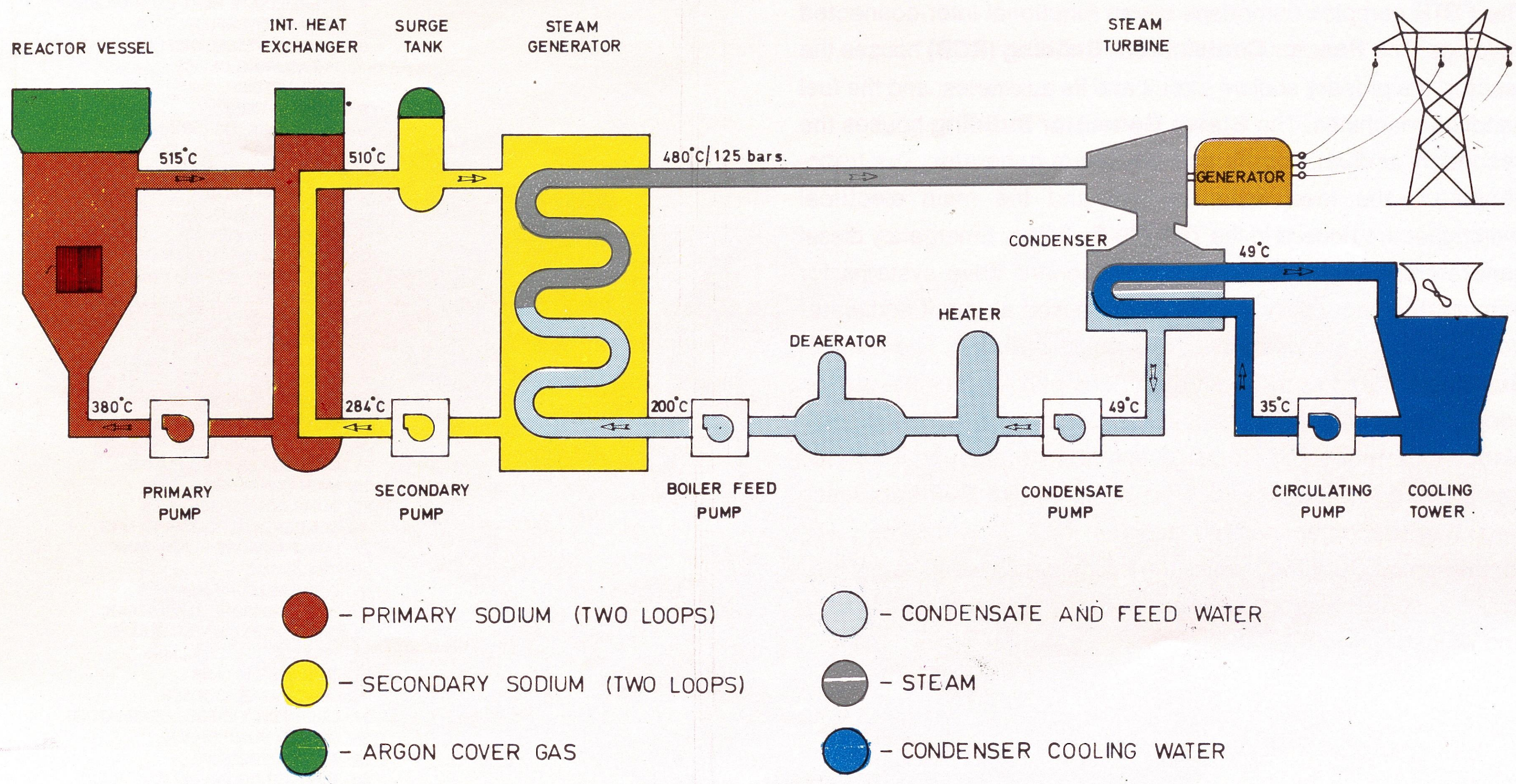
MAIN HEAT TRANSPORT SYSTEMS

FBTR is a 'loop' type reactor with two primary sodium loops, two secondary sodium loops and a steam-water circuit. Fission heat from the core is extracted by primary sodium and then transferred to non-radioactive secondary sodium through **Intermediate Heat Exchangers (IHX).** Secondary sodium flows through steam generators to produce steam which drives a turbo-generator and generates electricity.

Each primary loop consists of a main pump, an IHX and inter connecting piping. The sodium streams from both primary loops join a common inlet pipe and enter the reactor vessel from the bottom. The maximum pressure in the primary circuit is 4.5 kg/cm². An overflow tank accommodates the expansion of sodium due to temperature changes and maintains a constant level in the reactor vessel. All vessels containing sodium have been provided with free sodium levels covered by pure argon gas for ease of sealing. Purity of sodium is maintained by 'cold traps', specially designed to remove impurities and corrosion products. The primary piping is of double walled construction to prevent any leakage of radioactive sodium.

Non-radioactive sodium is circulated in the two secondary loops by two secondary sodium pumps. The maximum sodium pressure in the secondary circuit is 3 kg/cm². A leak in the steam generator could cause accidental inflow of water into the secondary sodium and generate pressure surges. To limit these surges to only a small part of the secondary sodium circuit and to protect the IHX two 'surge' tanks are provided on the upstream and downstream of the steam generators in each secondary loop. The downstream surge tank also houses the secondary sodium pump and the two tanks together accommodate sodium volume changes resulting from variations in sodium temperature. Electrical line heaters as well as special electrically heated vessels are incorporated in the secondary loops to prevent freezing of sodium when the reactor is shut down. The steam generator is of a modular type with two modules of 12.5 MWth capacity in each secondary loop. While the steam generators are made of stabilised ferritic steel, the principal material of construction of other sodium components and piping is special grade AISI-316 stainless steel.

A conventional feed water and steam circuit extracts the heat from the steam generators and supplies high temperature, high pressure super heated steam to the turbine. A major fraction of the steam expands from the initial pressure to the final pressure in supplying motive power to the turbine, while a small quantity of the steam is bled from three different stages of the turbine for preheating the condensate to a temperature of 200°C which corresponds to the water temperature at the inlet of the steam generator. This not only improves the thermodynamic efficiency of the plant but also leads to a lower level of stresses in the steam generator. The final heat rejection to the atmosphere is accomplished through a forced draft cooling tower. The circuit is provided with a full capacity by-pass dump condenser to enable operation of the reactor irrespective of the availability of the turbo-generator. Two full capacity boiler feed pumps (one as a standby for the other) circulate water during normal operation of the plant, while two 10% capacity auxiliary feed water pumps provide reliable water supply to the steam generators during reactor shut down for decay heat removal. A full flow on line condensate polishing system maintains the high purity of the feed water. A package boiler of 3 tonnes per hour capacity is incorporated in the circuit to supply saturated steam at 15 kg/cm² for preheating the steam water circuit and the auxiliary circuits during the start up period.

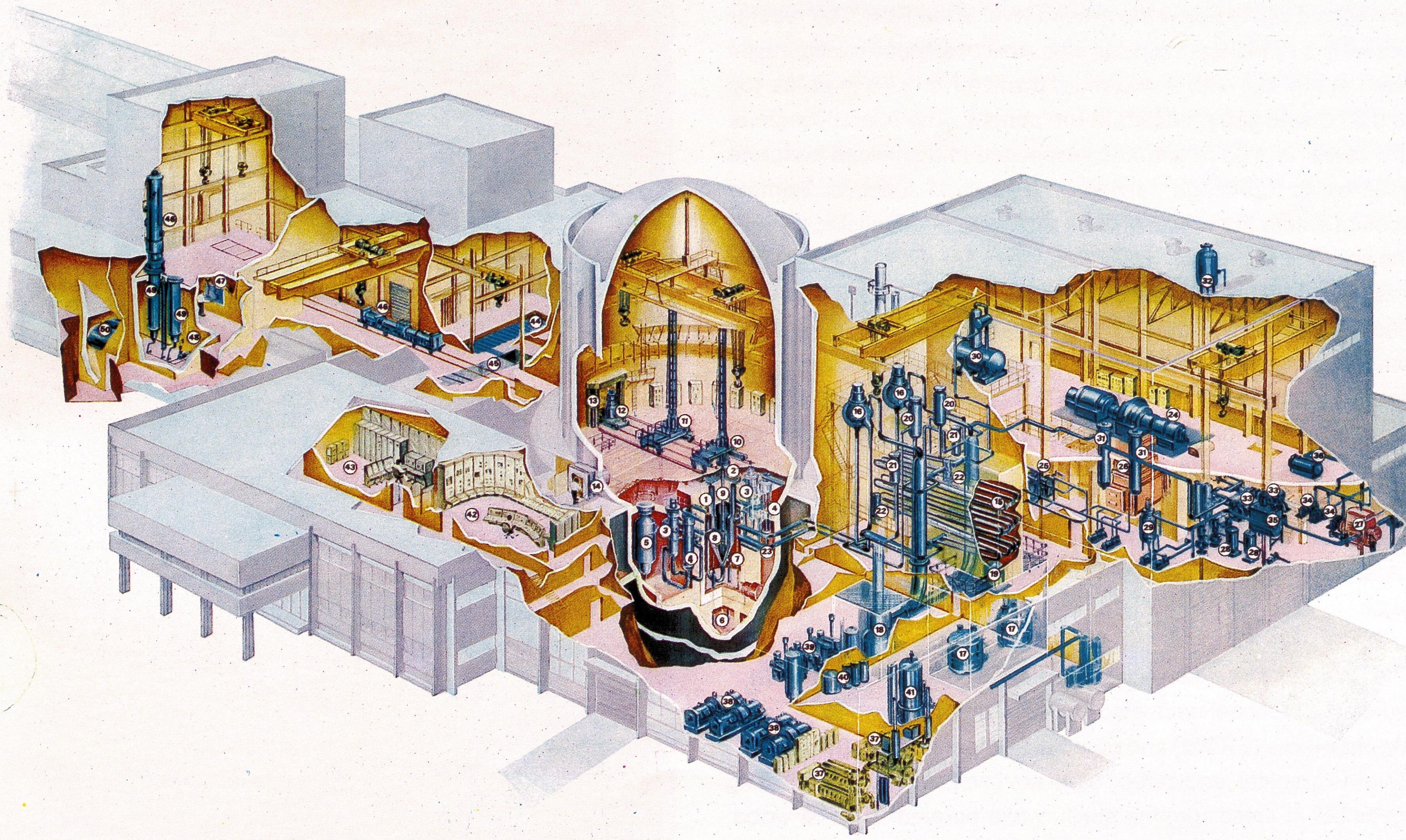


SCHEMATIC FLOW DIAGRAM

PLANT LAYOUT

The FBTR complex comprises seven functional inter-connected buildings. The **Reactor Containment Building (RCB)** houses the reactor, the primary sodium circuit and its auxiliaries, and the fuel handling machines. The **Steam Generator Building** houses the secondary sodium circuits and the steam generator. The turbo-generator, the feed water system and the main electrical switchgear are housed in the **Turbine Building.** Emergency diesel generators, station batteries, Ward-Leonard drive systems for primary and secondary pumps, compressed air plant and water treatment plant are located in the **Service Building.** The **Control Building** located at the front of the complex houses the station control room, personnel change and wash rooms, airconditioning plant, laboratories and offices. Fresh fuel storage and irradiated fuel storage facilities are located in the **Active Building** which also has decontamination facilities and a workshop. The **Maintenance Building** houses the maintenance workshop, mock-up area, spares storage, sodium flooding tanks, nitrogen plant, and offices.

1. REACTOR VESSEL
2. ROTATING PLUGS
3. PRIMARY SODIUM PUMPS
4. INTERMEDIATE HEAT EXCHANGERS
5. PRIMARY OVERFLOW TANK
6. REACTOR VESSEL DISPLACEMENT MEASURING DEVICE
7. STEEL VESSEL
8. REACTOR CORE
9. FUEL HANDLING CANAL
10. FUEL CHARGING FLASK
11. FUEL DISCHARGING FLASK
12. SECONDARY FLASK
13. MATERIAL AIRLOCK
14. PERSONNEL AIRLOCK
15. STEAM GENERATOR MODULES
16. SECONDARY SODIUM PUMPS
17. SECONDARY SODIUM STORAGE TANKS
18. CYCLONE SEPARATOR
19. DEPRESSURISER TANK
20. SECONDARY SODIUM SURGE TANKS
21. REHEATERS
22. SECONDARY COLD TRAPS
23. SECONDARY SODIUM MAIN PIPING
24. TURBINE-GENERATOR
25. MAIN BOILER FEED PUMPS
26. MAIN CONDENSER
27. DUMP CONDENSER
28. CONDENSATE POLISHING UNIT
29. LOW PRESSURE FLASH TANK
30. DEAERATOR
31. LOW PRESSURE HEATERS
32. HIGH PRESSURE FLASH TANK
33. CIRCULATING WATER PUMPS
34. PROCESS WATER PUMPS
35. TURBINE OIL TANK
36. CONDENSATE COOLER
37. EMERGENCY DIESEL GENERATORS
38. SODIUM PUMP DRIVES
39. AIR COMPRESSORS
40. MAKE-UP DEMINERALISER PLANT
41. AUXILIARY BOILER
42. CONTROL ROOM
43. CENTRAL DATA PROCESSING SYSTEM
44. SPENT FUEL STORAGE BAY
45. TRANSFER CARRIAGE
46. SPECIAL FLASKS
47. DISMANTLING CELL
48. DECONTAMINATION PIT
49. DECONTAMINATION VESSELS
50. LIQUID EFFLUENT STORAGE TANKS

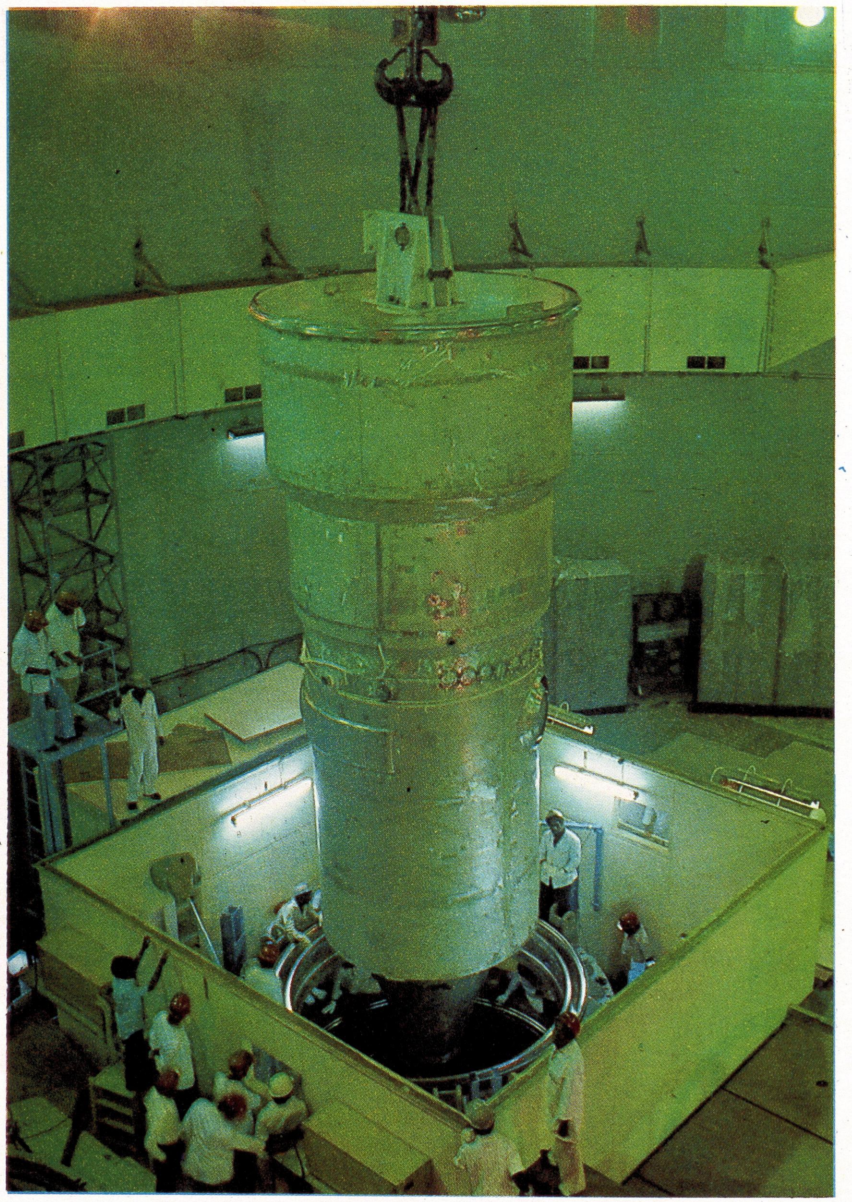


FBTR COMPLEX

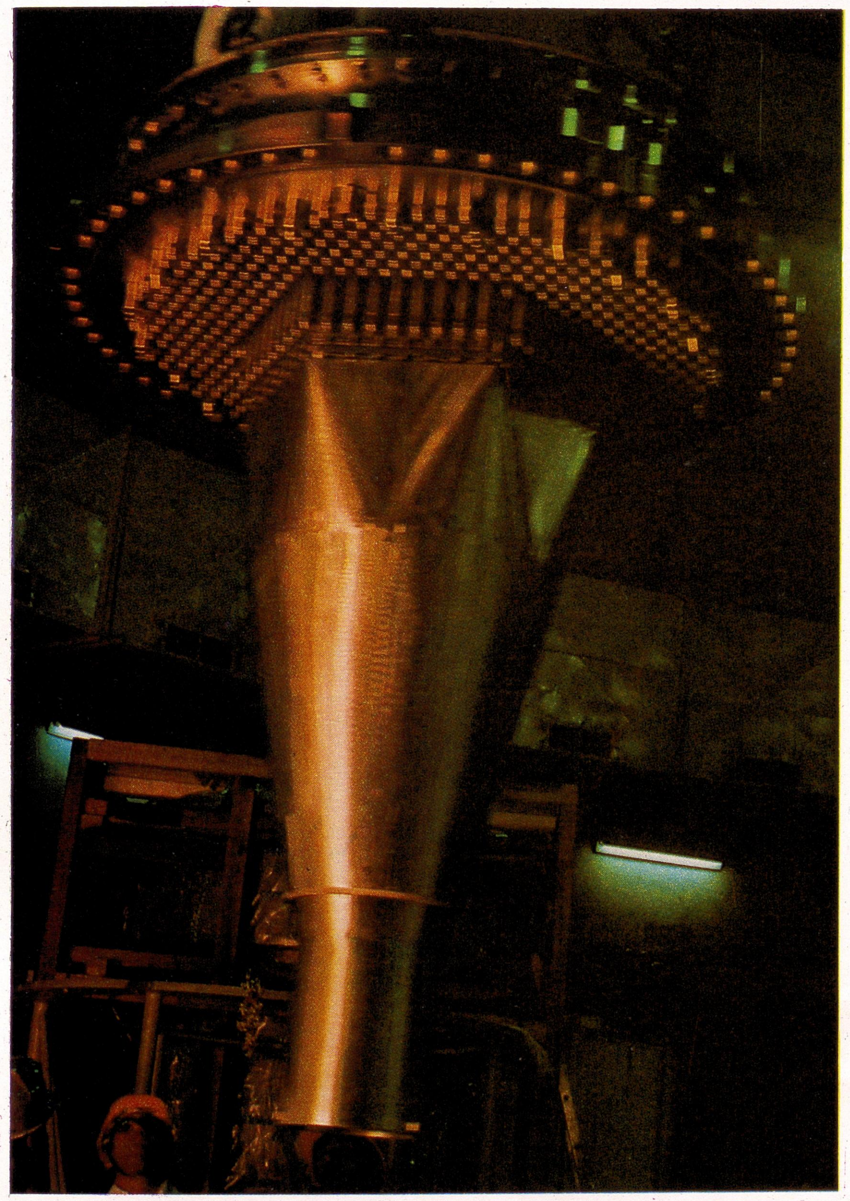
REACTOR ASSEMBLY

The reactor assembly along with the primary loops are located in shielded vaults below the ground level in the RCB. The reactor vessel is a cylindrical stainless steel tank of stepped configuration open at the top, with a maximum diameter of 3.18 m at the top and a conical entry diffuser at the bottom. The overall length of the vessel is 8.65 m and it is suspended in a shielded concrete vault by its top flange, resting on adjustable supports. Primary sodium enters the vessel at the bottom and after passing through the core exits through two outlet pipes near the mid height. The vessel is protected by neutron shields to prevent radiation damage and by thermal shields to protect against thermal transients. A precision machined **Grid Plate** bolted to the reactor vessel main flange, supports the various core subassemblies and distributes the sodium coolant. The top opening of the reactor vessel is closed by two heavy shielded assemblies called the **Rotating Plugs,** the smaller being located eccentrically in the larger plug such that combined rotations of the two plugs positions a 'fuel handling canal' located in the small plug onto any subassembly on the grid plate.

The rotating plugs serve as radiation and thermal shields for working personnel and also support the **Control Rod Drive Mechanisms (CRDM)** and other instrumentation for the reactor. Borated graphite, and carbon steel are used as principal shielding materials in these rotating plugs, while borated 'permali wood' is used to prevent neutron streaming. Leak tightness between the argon cover gas in the vessel and RCB atmosphere is achieved

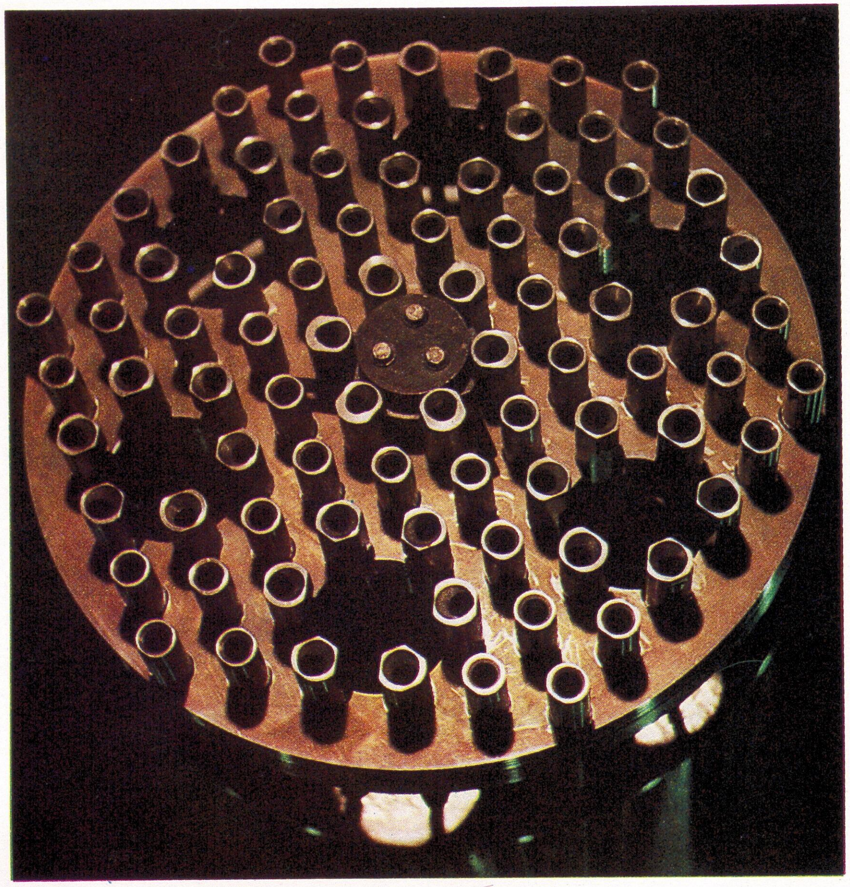


REACTOR VESSEL



GRID PLATE

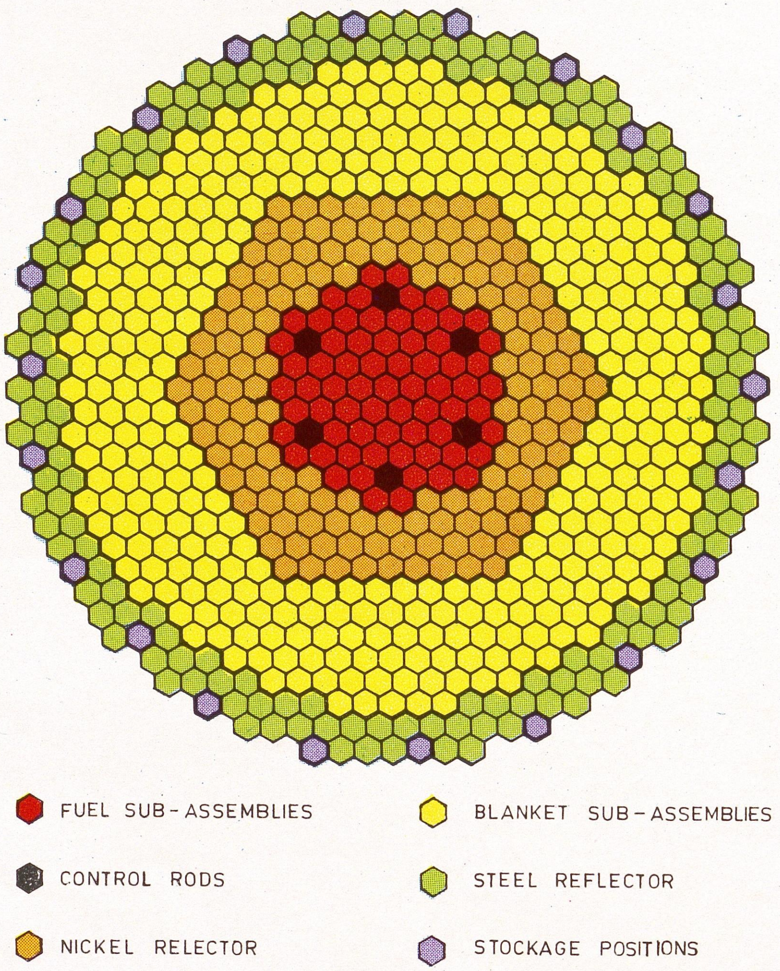
by special fusible metal seals, backed up by elastomer inflatable seals. The plugs rotate on precision ball bearings and are provided with drive mechanisms. The rotating plugs are cooled by circulating nitrogen gas through passages provided in them. A fixed plug called the **Control Plug,** is housed in the small rotating plug, to support the CRDM and core thermocouples through a 'core cover plate'. Each of the six control rods located in the core is held by a gripper of the CRDM which can move it up and down by a geared motor drive and a screw-nut arrangement. The control rods can be dropped rapidly into the core by breaking the electric supply to an electromagnet which couples the gripper rod to the motor drive. This action is called a **scram** and is used to shut down the reactor safely in abnormal conditions.



CONTROL PLUG

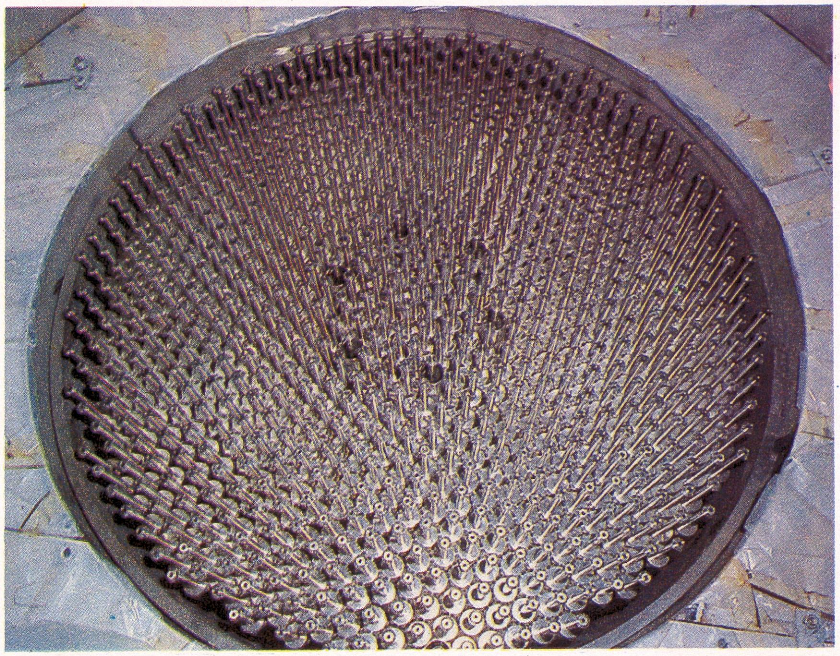
REACTOR CORE

The fuel used in FBTR is a mixture of plutonium carbide and natural uranium carbide (PuC:UC = 70:30). Sintered pellets of the mixed carbide are stacked inside a stainless steel tube of 5.1 mm diameter and 531 mm length. The pellets are kept in position in the tube by a spacer tube and a spring. The fission gas plena are at the top and bottom. The tube is sealed at both the ends by welded plugs. A spacer wire helically wound on the pin provides continuous support along the length of the slender pin, maintains

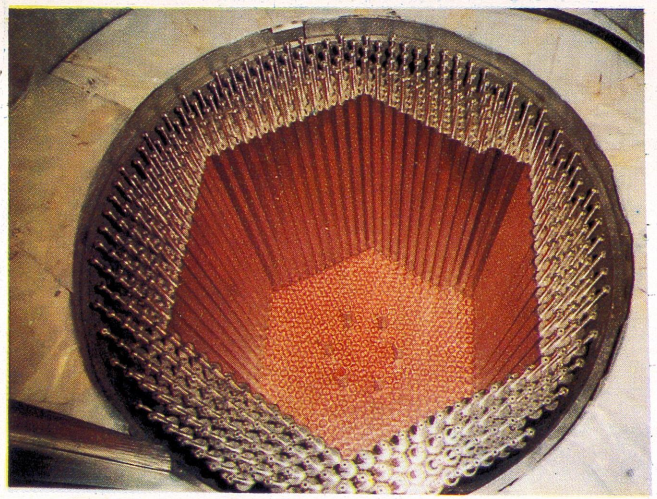


CORE CONFIGURATION

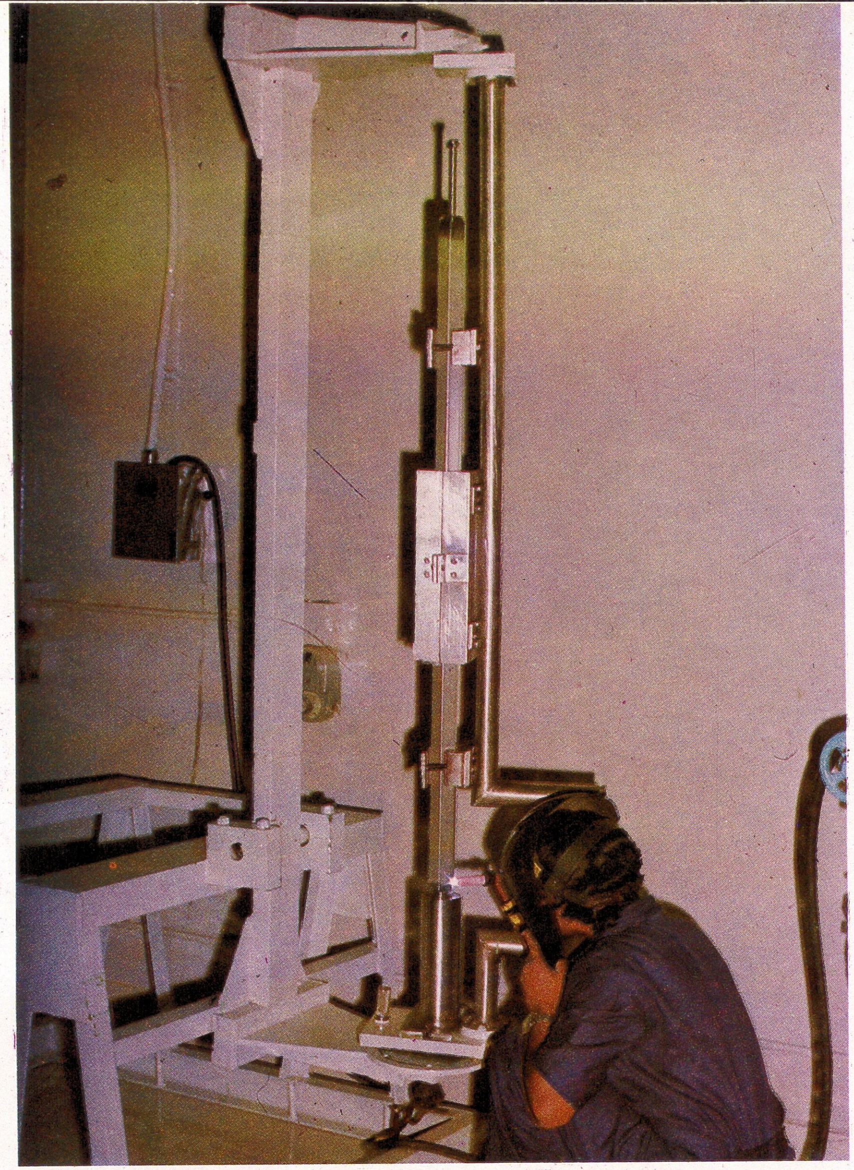
the distance between the pins, defines the passage for the sodium to flow and provides some mixing for homogenising the sodium temperature within a fuel **subassembly.** A fuel subassembly consists of 61 fuel pins supported inside a hexagonal sheath of stainless steel to which are welded a foot and a head piece. The foot enables locating the subassembly on the grid plate and the head is used for handling of the subassembly. Sodium enters through the foot of the subassembly, flows around the pins and removes the heat generated by nuclear fission. The overall length of the subassembly is 1.66 m. The first core of FBTR will consist of about 27 fuel subassemblies surrounded by nickel and steel reflectors. Six control rods containing enriched boron carbide placed symmetrically in the core are used to control the reactor power during normal operation and for shutting down the reactor. Besides the fuel subassemblies, there are about 700 other core subassemblies of various types positioned on the grid plate. The external dimensions of all the core subassemblies are identical. Initially, the reactor will be operated at 10 MWt power and the power will be raised to 40 MWt in stages, after studying the fuel behaviour by post irradiation examination. In subsequent core configurations the core will consist of 65 fuel subassemblies surrounded by nickel and thorium oxide blanket subassemblies.



CORE LOADING COMPLETED
(with dummy subassemblies)



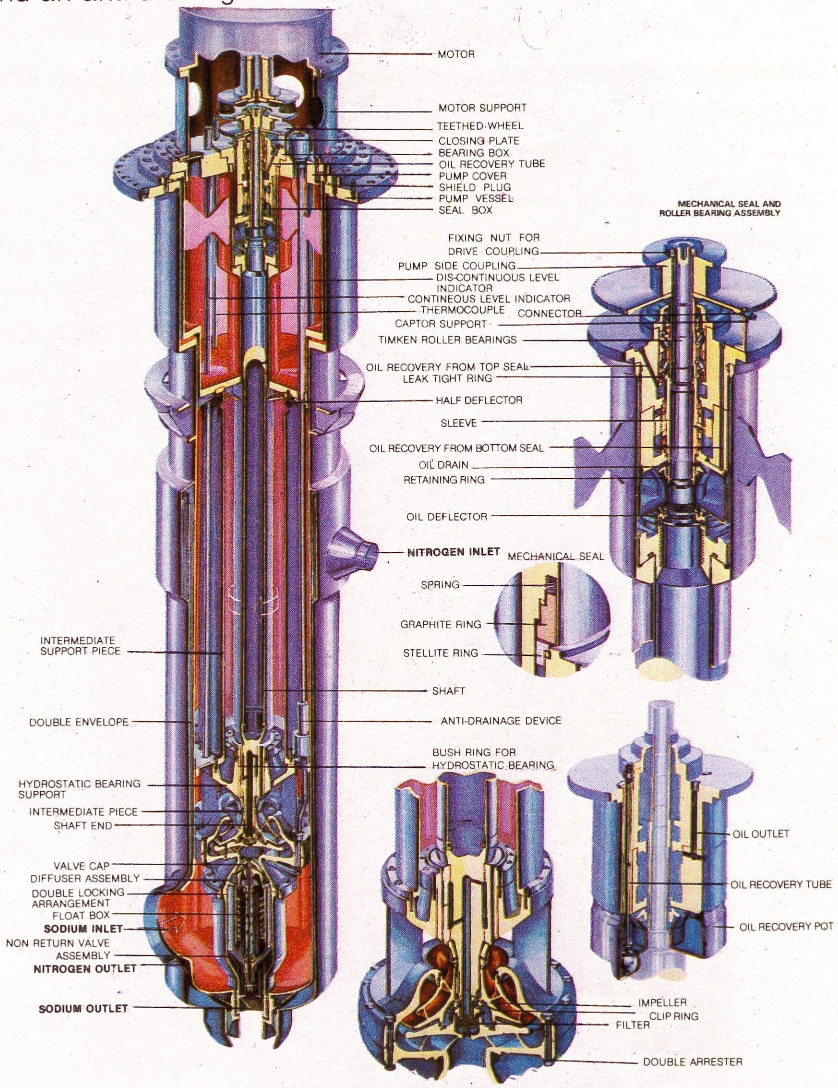
CORE SUBASSEMBLIES LOADING IN PROGRESS



FUEL SUBASSEMBLY

MAIN SODIUM PUMPS

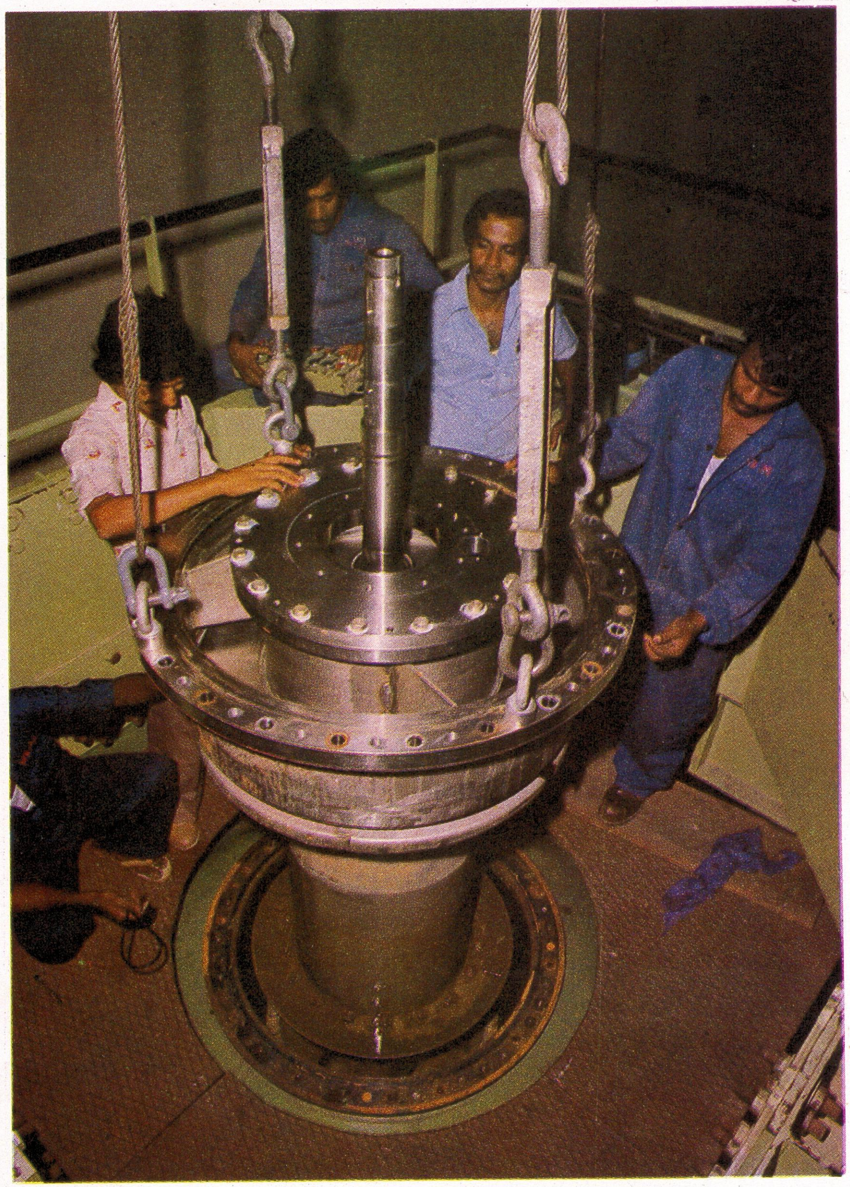
Two primary sodium pumps working in parallel circulate sodium through the reactor. Each pump is a vertical, single stage, centrifugal pump with an axial suction and radial discharge impeller. The removable portions of the pump assembly consist of a shield plug, a shaft, an impeller, a diffuser, a non-return valve and an anti-drainage device which are located in a fixed vessel



PRIMARY SODIUM PUMP

having inlet and outlet nozzles. This vessel forms a part of the primary loop. The pump shaft is guided at the bottom by a 'hydrostatic bearing' working in sodium and is supported at the top by tapered roller bearings and thrust bearings. The sealing between the rotating and the fixed parts is achieved by a double mechanical seal, cooled and lubricated by a separate oil circuit. A failure of one pump can result in a reverse flow through the failed pump and consequent by-passing of the reactor core. A non-return valve at the pump discharge prevents such an eventuality. The pump is driven by a 150 kw DC motor through a flexible coupling. The speed of the motor can be varied from 200 to 1300 rpm and regulated within ±1 rpm by a specially designed 'Ward-Leonard' drive system.

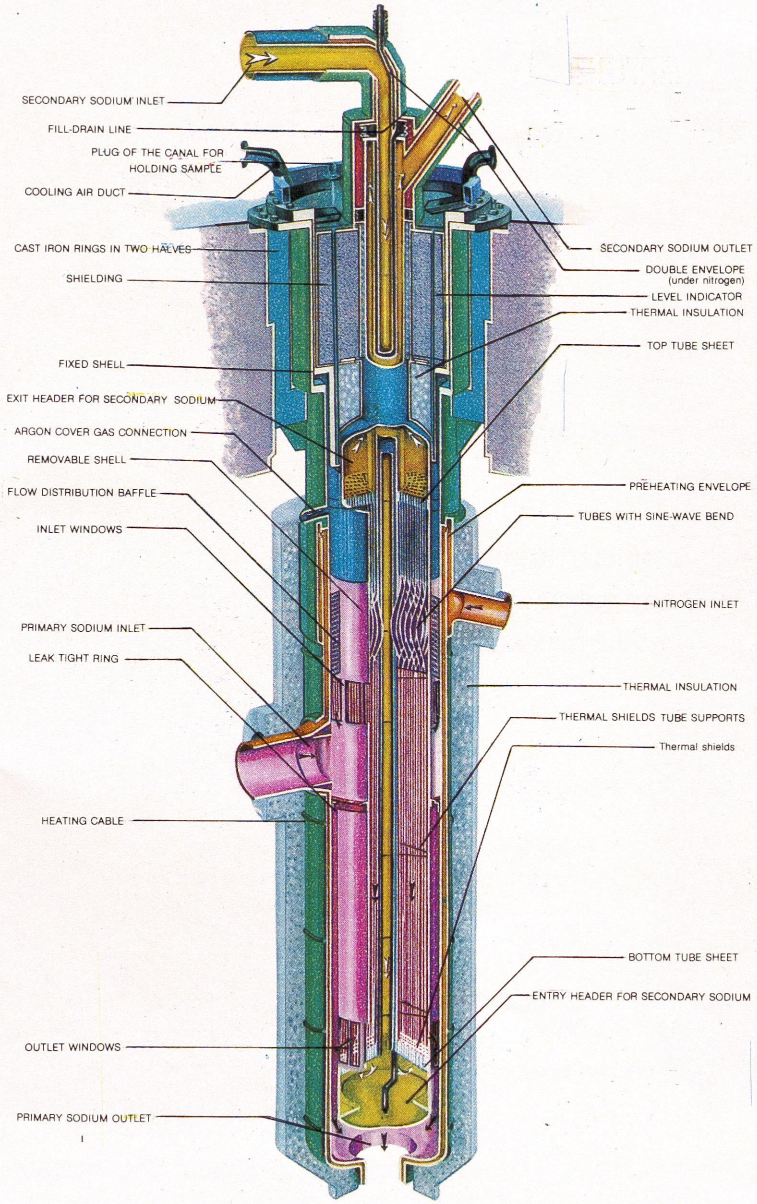
The secondary main pumps and their drives are similar to the primary ones except that they do not have non-return valves and shield plugs and are housed in spherical surge tanks which makes them shorter in length.

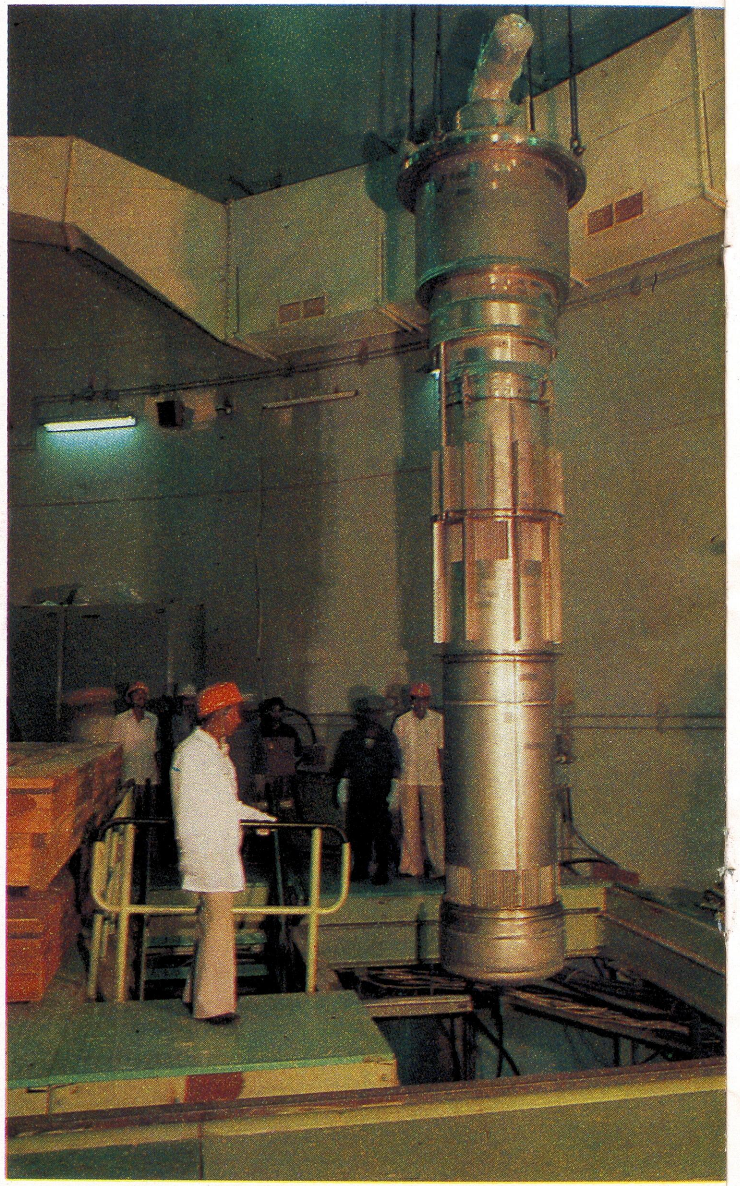


PRIMARY SODIUM PUMP TESTING

INTERMEDIATE HEAT EXCHANGERS (IHX)

The IHX is a vertical, sheet-and-tube, counter current, sodium-to-sodium heat exchanger with primary sodium flowing on the shell side from top to bottom and secondary sodium flowing through 888 tubes of 12/14 mm diameter. All the tubes are provided with expansion bends to take care of differential thermal expansions. While the tube bundle is a removable assembly, the shell is a fixed vessel with inlet and outlet nozzles forming part of the primary loop. Vertical baffles and windows are provided to distribute the primary sodium uniformly around the tubes. Anti-vibration belts are provided for each ring of the tubes.

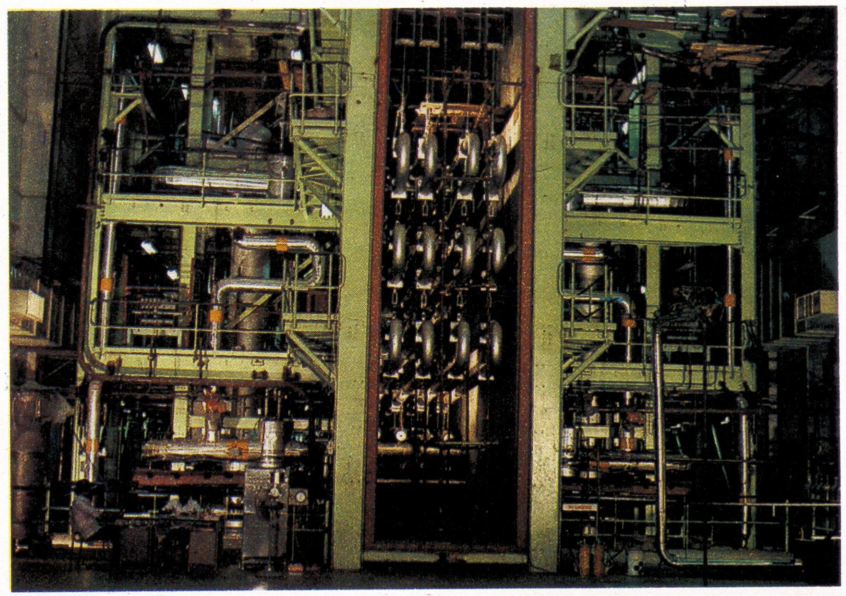




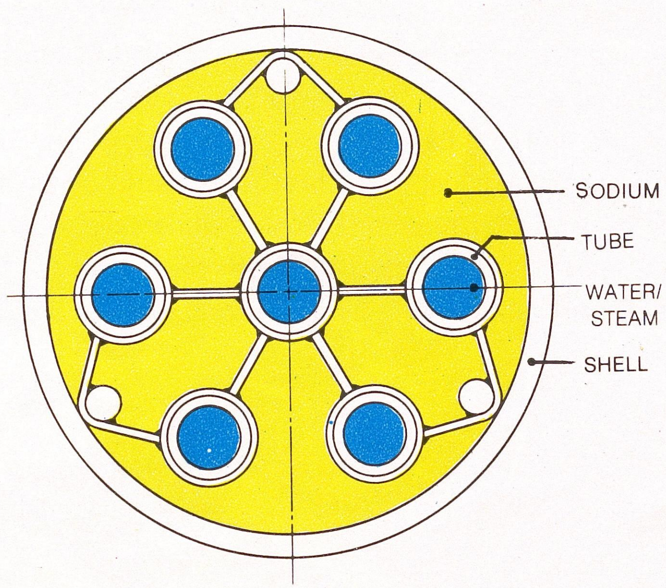
INTERMEDIATE HEAT EXCHANGER

STEAM GENERATOR

The steam generator is modular in construction and its design is based on a once through, integrated, tubes-in shell concept. Water/steam flows in a seven tube cluster and sodium flows on the shell side. Stabilised 2 ¼ Cr — Mo steel has been used as the material of construction. The tubes of 25.7/33.7 mm diameter are arranged in a 60 mm triangular pitch inside a 177.7/193.7 mm diameter shell. The total developed length of each module is 90 m and the module is fabricated in the shape of a 'triple-S' for compactness. Differential thermal expansion between the tubes and the shell is taken care of by the return bends in the modules. The tubes are led out of the shell laterally through thermal baffles, thus avoiding tube to tube sheet welds. Spider-web type tube supports have been provided in the straight portions of the modules. An orifice has been provided at the water inlet of each tube to avoid static and dynamic flow instability in the steam generator. Flow breakers on the down stream of the orifice break the jet which might cause corrosion/erosion damage to the nozzles. All the four steam generator modules are suspended by hangers in a metallic casing provided with heat insulation. In case of a total power failure, a door to the casing is opened to provide natural circulation air cooling for decay heat removal. In case of a leak on the shell side, the casing is filled with nitrogen gas to prevent sodium fires.



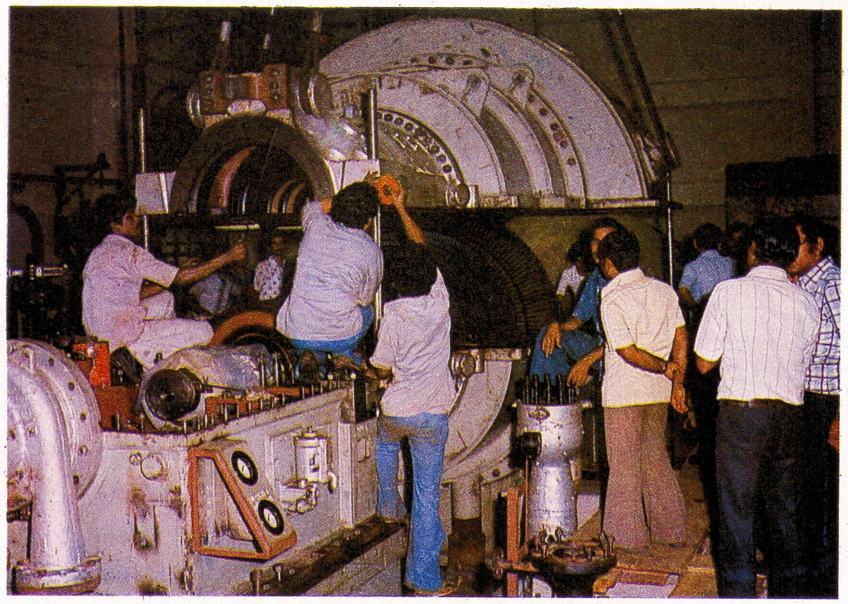
STEAM GENERATOR



STEAM GENERATOR SCHEMATIC

TURBO-GENERATOR

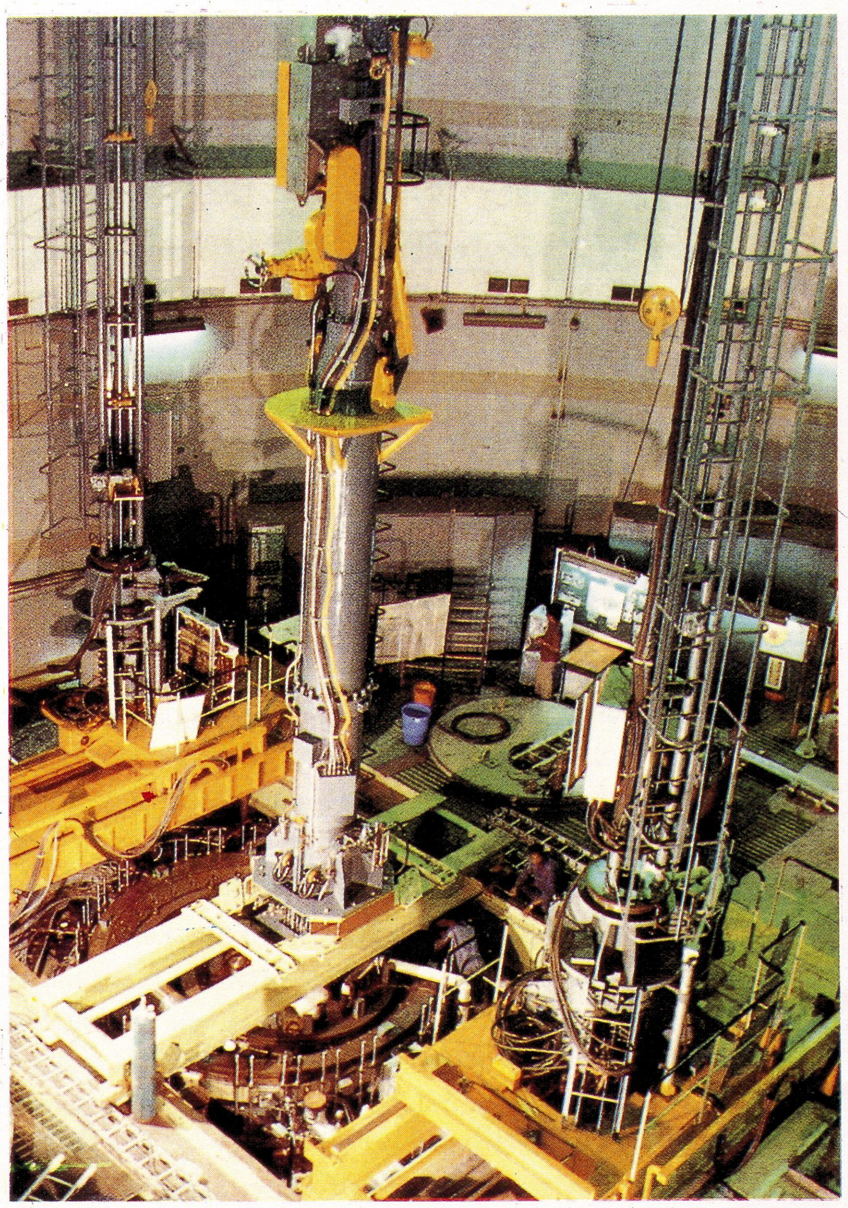
The turbine is a single cylinder, non-reheat condensing type specially designed for FBTR. It has a capacity to produce 16.4 MWe at 3000 rpm with steam stop valve flow conditions of 72.5 t/h at 125 kg/cm² and 480°C. There are 16 stages of steam expansion and steam is extracted from the third, tenth and fifteenth stages for feed water heating. The rotor is made from a single Ni-Cr-Mo steel forging and is supported on two journal bearings. A semi-flexible coupling is fitted between the turbine and the generator. The generator is an air cooled type with a rating of 19.3 MVA at 6.6 KV, 0.85 p.f. provided with a shaft driven d.c. exciter.



TURBO GENERATOR ERECTION

FUEL AND COMPONENT HANDLING SYSTEMS

The fuel reloading in this reactor is done under shutdown condition at intervals of about 50 days. Two special machines — **Charging** and **Discharging Flasks** — are used for loading and unloading of the core sub-assemblies on the pile. Access to the individual sub-assemblies inside the reactor vessel is through the 'fuel handling canal' located in the small rotating plug. The flasks have gripper fingers which engage with the heads of the subassemblies which are immersed in sodium, 6 m below the operating floor. The irradiated sub-assemblies taken out from the reactor are stored for a short period in the discharging pits inside RCB, and then taken out by a secondary flask. The irradiated fuel is cooled by air in a specially designed and shielded dry storage area. As sodium is chemically reactive and may be contaminated by fission products, components coming in contact with sodium need special handling devices for their removal/installation from the coolant circuits. Various flasks have been therefore provided for safe handling of fresh fuel, irradiated fuel, primary pumps, IHXs, control rod drive mechanisms and other experimental devices to and from the reactor. Separate facilities have been provided for decontamination of the parts taken out of sodium.



REACTOR BUILDING-INTERNAL

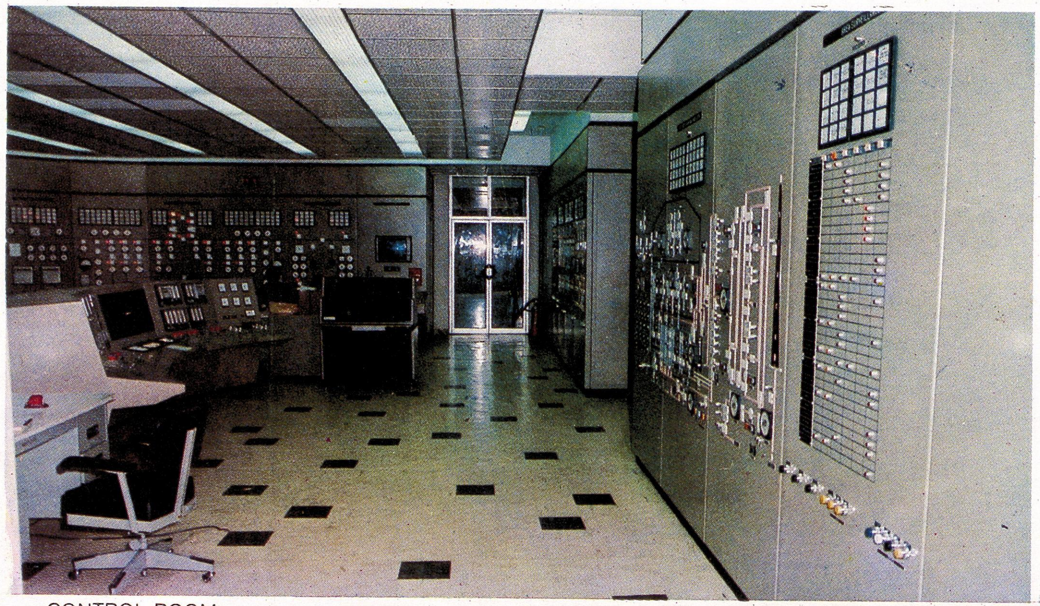
ELECTRIC POWER SYSTEM

The maximum power demand for FBTR during operation is about 4 MVA. The power supply from two independent sources is drawn through two 10 MVA transformers operating in parallel which step down the voltage to 6.6 KV from 33 KV. When electric power is generated by FBTR, the station loads are met from the inhouse power and excess power is supplied to the State electricity grid. In case of mains power failure, two emergency diesel generators of 1 MVA capacity each, start automatically within about 10 seconds and provide power for emergency loads of the reactor. Station batteries have been provided to supply uninterrupted power for the sodium pumps and control and instrumentation for a period of half an hour.

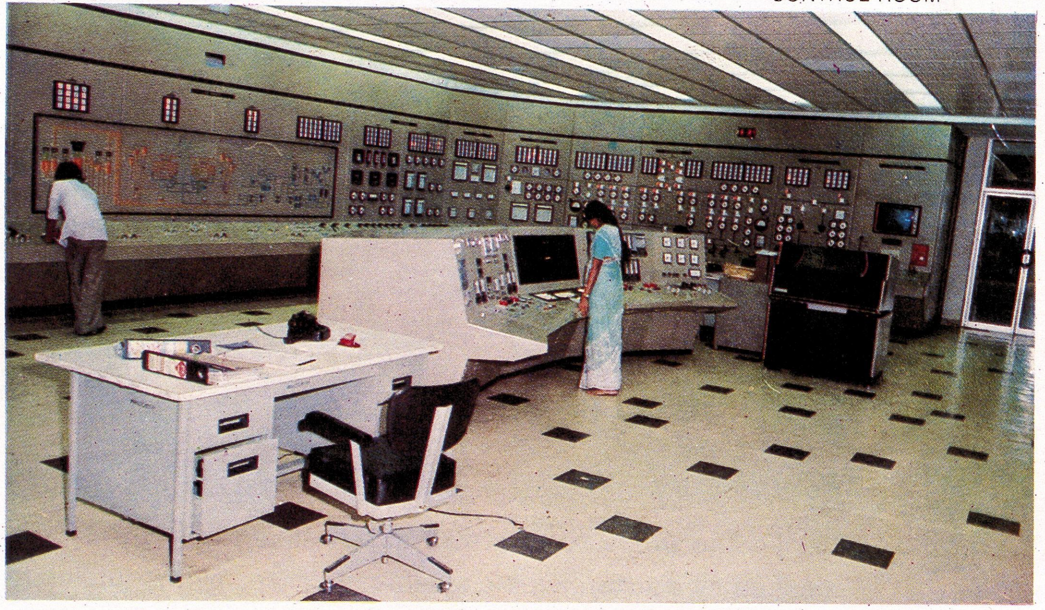
CONTROL AND INSTRUMENTATION

All the information necessary for the safety of the plant and its operation, start up, power control and shut down have been centralised in a Control Room.

The power of the reactor is controlled manually while the flow of primary sodium and secondary sodium is regulated automatically at the preset value. The reactor operates with constant flow of primary and secondary sodium over the entire range from start-up to full power. The flow of water through the steam generator is kept initially constant upto a specified power level and then varied to produce steam at constant superheat temperature of 480°C. The pressure of steam in the steam headers is held constant by discharging the steam not utilised by the turbine to



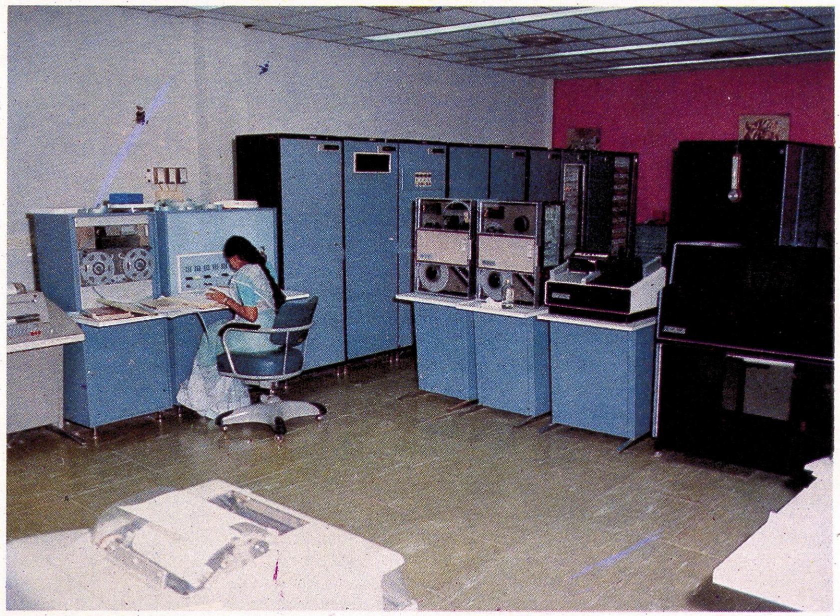
CONTROL ROOM



the dump condenser. Due to the negative reactivity coefficients, the reactor power remains stable within a narrow band as long as flow regulations in the primary, secondary and steam-water circuits remain operative. Operator intervention is only required for raising or lowering the control rods to adjust the power to the preset level. Important parameters like absolute power, reactor period, mean temperature rise of sodium across core, temperature of sodium exiting from individual sub-assemblies, signals indicating the failure of a fuel pin etc., constitute inputs to the reactor protection logic system which automatically shuts down the reactor by lowering of control rods or by 'scram' action when any unsafe condition is detected. When safety action is ordered, additional sympathetic measures are also implemented to minimise the magnitude of thermal shocks.

The neutron flux is monitored by 'fission counters', boron coated 'proportional counters' and 'compensated ion chambers', located in the concrete structure surrounding the reactor assembly. These adequately cover the wide range of variation of neutron flux from shut down to full power, and measure reactor power, period and reactivity. Detection of failed fuel is done by monitoring the **delayed neutrons,** emitted by the fission products in the sodium stream and by measuring radioactivity of the gaseous fission products in the argon cover gas. The temperatures of sodium coolant and stainless steel surfaces of various components are measured by strategically located thermocouples. Sodium flow and levels are measured by electromagnetic flowmeters and induction probes respectively.

An on-line **Central Data Processing System (CDPS)** consisting of two computers checks the various conditions of the plant and gives 'authorization' for the reactor start-up. During operation the CDPS monitors about 1000 plant parameters and also the health of the solid state relay circuits of the reactor protection logic system. If one of the two computers fails, the other automatically takes over the functions without having to shut down the reactor.



CDPS

SODIUM PURIFICATION FACILITY

SODIUM AND ITS PURIFICATION

Commercial grade sodium contains high amounts of oxygen, calcium, magnesium, carbon and chlorides and therefore cannot be used for nuclear service. A major purification facility was therefore set up to purify commercial sodium to nuclear grade. About 160 tonnes of sodium procured indigenously in the form of dry bricks were purified by a process developed at the Centre consisting of: (i) brick melting (ii) two-stage coarse filtration for removing bulk impurities (iii) vacuum decomposition of sodium hydride (iv) ageing to remove calcium and magnesium (v) microfiltration and (vi) cold-trapping with circulation. The above sequence of operations was carried out in a **Sodium Purification Facility** in two identical process chains. The operations were alternated between the two chains and thus pre-conditioned sodium was charged into 2 purification storage tanks of 30 t capacity each through a common microfilter. In the main purification loop, the pre-conditioned sodium was recirculated using an electromagnetic pump through an air-cooled cold-trap having knitted wire mesh packing. With the cold-trap retaining the impurities, the sodium purity was regularly monitored with the help of a 'plugging indicator'. The purified sodium was transported in batches of 6 tonnes in a specially insulated transportation tank to FBTR site and transferred into the storage tanks of the primary and secondary sodium circuits.

SAFETY ASPECTS

Ensuring safety in operation has been one of the principal considerations in the nuclear industry right from its inception.

Safety criteria and codes have been evolved and laid down based on extensive R & D efforts and operating experience of many reactors in the world. The first step is to design an inherently safe and stable core with negative temperature feedback coefficients so that uncontrolled power increase does not take place due to any disturbances. This is backed-up by incorporating diverse and redundant protection systems to take safety actions when an off-normal event is detected by monitoring neutron flux, sodium flow, temperature, failed fuel, sodium leak, high radiation level etc. Further, diverse and redundant heat removal systems are provided to avoid overheating of the core. Escape of radioactivity from the core is prevented by three barriers viz. fuel clad, reactor vessel and the containment building. The important specific safety provisions built into FBTR design are as follows:

— The sodium outlet temperature of all the fuel sub-assemblies is continuously scanned by the computer every second and safety actions are automatically initiated when the thresholds are exceeded.

— All temperature feedback coefficients are negative leading to extreme stability of operation.

— Diverse and redundant neutron monitors are provided to monitor reactor power and initiate safety actions to automatically shut down the plant when thresholds are exceeded.

— The entire primary sodium circuit is provided with a double envelope filled with nitrogen so as to avoid sodium fire in case of a leak. Leak detectors have been placed throughout the circuit. A siphon-break pipe prevents draining of sodium from the reactor vessel in case both the pipe and the double envelope develop leaks. When such leaks take place in the reactor vault, an additional quantity of 65 m^3 of sodium at 150°C, stored in 'flooding tanks' is injected into the reactor vessel to keep the core immersed and cooled.

— In the steam generators, continuous monitoring of water/steam leak into sodium is done by a very sensitive hydrogen detector. In case of a large leak the steam generator is isolated by automatically operated quick closing valves on steam-water and sodium pipes. The secondary sodium from the circuit is dumped into the storage tank and reaction products are dumped into a cyclone separator by the breaking of 'rupture discs'.

— Normally the decay heat is removed by main heat transport loops. The reactor is operated only when both the coolant loops are available. This ensures that at least one loop is available for decay heat removal. The pumps are provided power from two grid sources, backed up by emergency diesel generators as well as batteries. In case of complete power failure about 300 kw of heat can be removed by natural circulation. When circulation of sodium in the primary circuit is not possible, 350 kw of decay heat can be removed by circulation of nitrogen around the reactor vessel.

UTILISATION OF FBTR

While FBTR provides invaluable experience in the design, construction and operation of LMFBRs, its major role in the future will be as an irradiation test bed for the development of fuel and structural materials for future commercial fast power reactors. This assumes special significance in the context of the need to develop an advanced LMFBR fuel for effective breeding and rapid exploitation of our nuclear resources. On account of the economics of the fast reactor fuel cycle it is necessary to extract ten to fifteen times more energy per unit mass of LMFBR fuel than that extracted from PHWR fuel. The high fuel burnup combined with a hostile environment of intense fast neutron flux, elevated temperatures and liquid sodium cause interesting and challenging materials problems for in core LMFBR components. Important data that have to be generated through irradiation testing in FBTR pertain to swelling rates, creep rates, and evaluation of thermo-mechanical properties of candidate fuel and structural materials under fast neutron irradiation at high temperatures and high flux levels. In addition, studies are needed for the physical and chemical behaviour of the fuel and clad at high burnups involving phenomena such as fuel cracking, fission gas release, plutonium and fission products redistribution, clad corrosion, fuel-clad mechanical interaction, and including the effects of porosity and stoichiometry.

The fast neutron exposure obtained over the life of a commercial fast reactor fuel element is relatively high, and simulation of such an exposure can be obtained only by irradiation of test samples for a period of over 3 years in FBTR. The development of special sub-assemblies for inpile irradiation testing and measurements, the efficient execution of well planned irradiation experiments and the analysis of the obtained results will be the objectives of a purposeful and active research programme with FBTR in the coming years.

FIRST CRITICALITY

The first criticality of FBTR was attained on 18th October 1985 when a self-sustaining fission chain reaction was achieved with an initial core loading of 22 fuel sub-assemblies. FBTR is one of twelve LMFBRs presently operating in the world (in seven countries) and the only one with carbide fuel. The successful commissioning of FBTR is the culmination of over a decade of dedicated work to master a complex and precise technology.

WHAT NEXT?

In this process a deep insight has been gained by Indian scientists and engineers in LMFBR design and construction. The task of detailed engineering and construction of commercial FBRs can now be taken up with the tremendous confidence from actual operating experience of FBTR.

MAIN CHARACTERISTICS

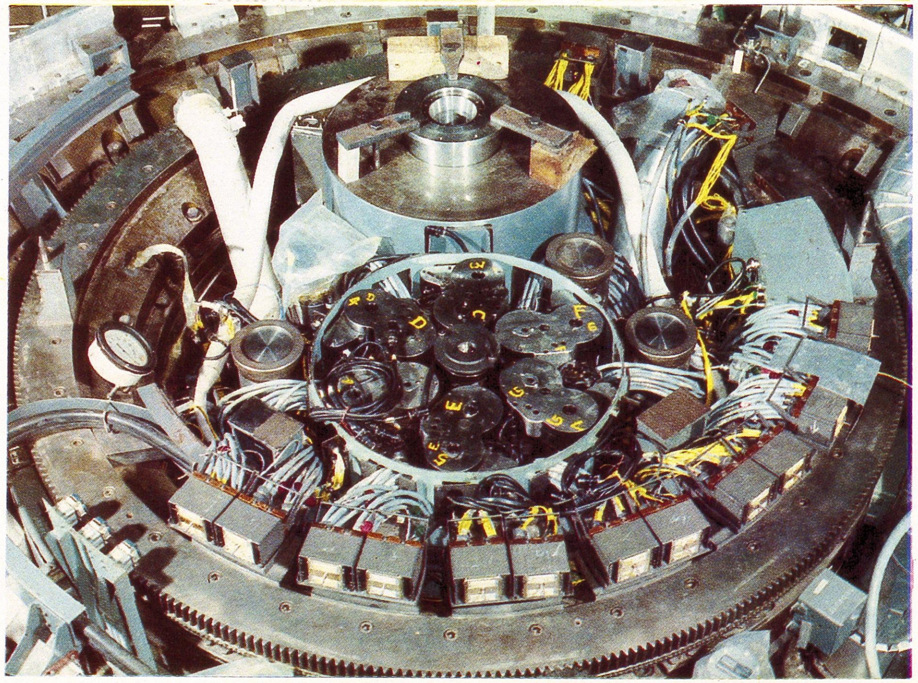
Reactor Power	40 MWt, 13.2 MWe
Reactor Coolant	Sodium
Concept of Primary Circuit	Loop
Number of primary and secondary loops	2
Fuel	70% PuC-30% UC (initially)
Fuel Pin Diameter	5.1 mm
Number of pins in a sub-assembly	61
Control Rod Material	B_4C (90% enriched in B-10)
Neutron Flux	3×10^{15} n/cm^2-sec
Core Height	320 mm
Sodium temperature at the reactor inlet	380°C
Sodium temperature at the reactor outlet	515°C
Primary sodium flow	1100m^3/h
Steam temperature	480°C
Steam pressure	125 Kg/cm^2
Sodium inventory	150 t
Steam Generators	Once through type, 7 tubes in a shell, in triple S shape.

MAIN PARTICIPATING INDIAN INDUSTRIES

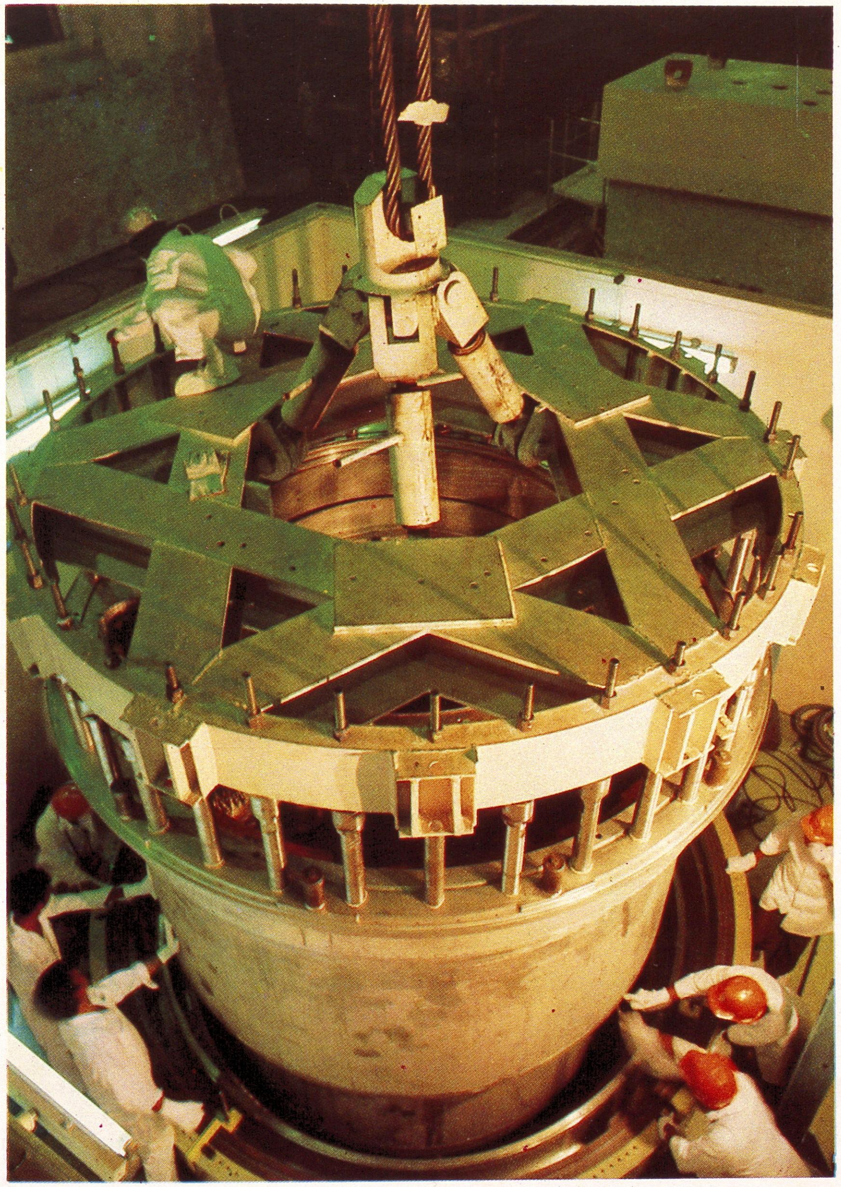
INDUSTRY	SUPPLY
Alkali Metals Limited, Hyderabad	Sodium
Bharat Heavy Electricals Limited, Bhopal	Turbo-generator and feed water plant
Bharat Heavy Electricals Limited, Hyderabad	Reactor Vessel
	Thermal Shields
	Large Rotating Plug
	Small Rotating Plug
	Liquid Metal Seals
	Vessel and Plug Support
Bharat Heavy Electricals Limited, Tiruchirapalli	Steam Generators
	Intermediate Heat Exchangers
	Stainless Steel Piping (primary)
	Carbon and Alloy Steel Valves
Development Consultants Pvt. Ltd.	Structural, Electrical and Ventilation Design
Electronics Corporation of India Limited, Hyderabad	Consultancy service for control & instrumentation
	Control & instrumentation packages
	Central Data Processing System
	Site installation of Control & instrumentation
Engineering Construction Corporation, Madras	Civil Works Main Plant Buildings
Everest Engineering Works, Coimbatore	Mixers and pull-outs
	Decontamination vessels
	Material airlock bellows
Heavy Engineering Corporation, Ranchi	Special Steel Forgings for Block Pile
Keltron, Trivandrum	220 Volt Uninterrupted Power Supply
Kirloskar Brothers Limited, Kirloskarwadi	Charging and Discharging Flasks
	Flask for control rod drive mechanisms and level detectors
Machine Tool Aids and Reconditioning, Hyderabad	Machined parts of core sub-assemblies
	Canal valve assemblies, couplings & sealing rings

INDUSTRY	SUPPLY
Machine Tool Aids and Reconditioning, Hyderabad	Machined parts of core sub-assemblies Canal valve assemblies, couplings & sealing rings
Mukund Iron & Steel Works, Bombay	Piping
New Standard Engineering Co. Ltd., Bombay	60 T Polar crane for Reactor Building
NGEF Limited, Bombay	High voltage and Medium Voltage switch-gear High Voltage and Medium Voltage Motors, Medium Voltage MCCs
Transformers & Switch Gears Limited, Madras	10 MVA Main Transformers
Triveni Structural Limited, Naini	Overflow Tank Secondary Sodium Storage Tanks Cyclone Separator. Cold Traps Secondary Flask Carriage for Special Flask Decay Pits CI Blocks for discharge pots
Variety Engineers, Baroda	Shielding Blocks Transfer Carriage No.2 Capsule Transfer Gripper Steel Shielding Doors
Walchandnagar Industries Limited, Machine Tool Division, Pune	Control Rod Drive Mechanisms Core Cover Plate Mechanism Plug Drive Mechanisms
Walchandnagar Industries Limited, Walchandnagar	Control Plug Anti-explosion floor Fuel Handling Canal Sodium Pumps

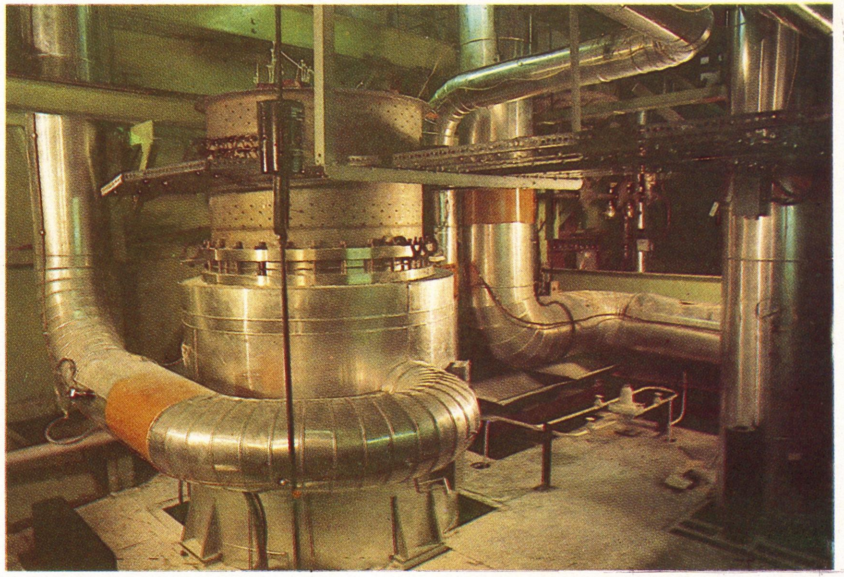
REACTOR DOME UNDER CONSTRUCTION



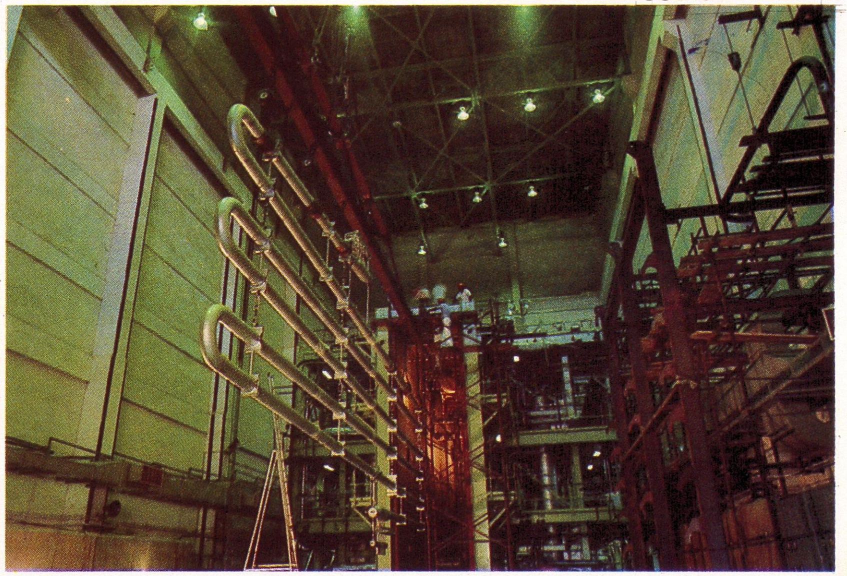
TOP OF PILE BLOCK SHOWING ROTATING PLUGS
AND CONTROL ROD DRIVE MECHANISMS



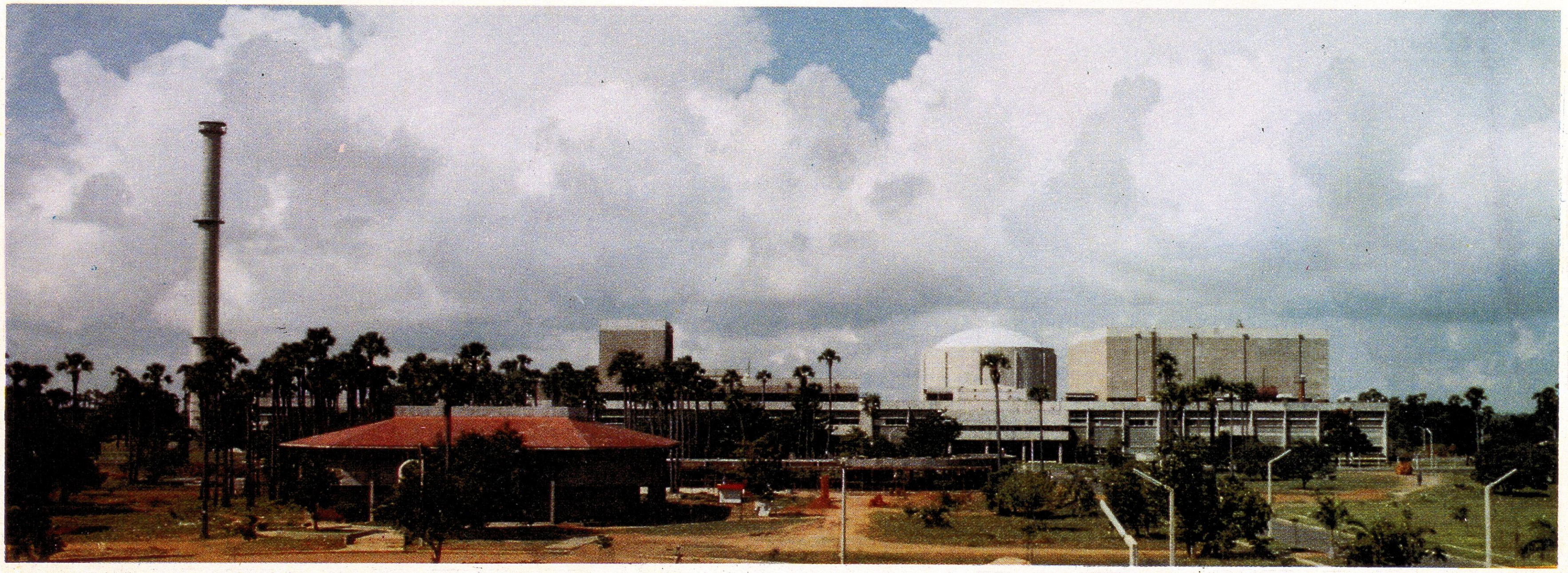
LARGE ROTATING PLUG ERECTION



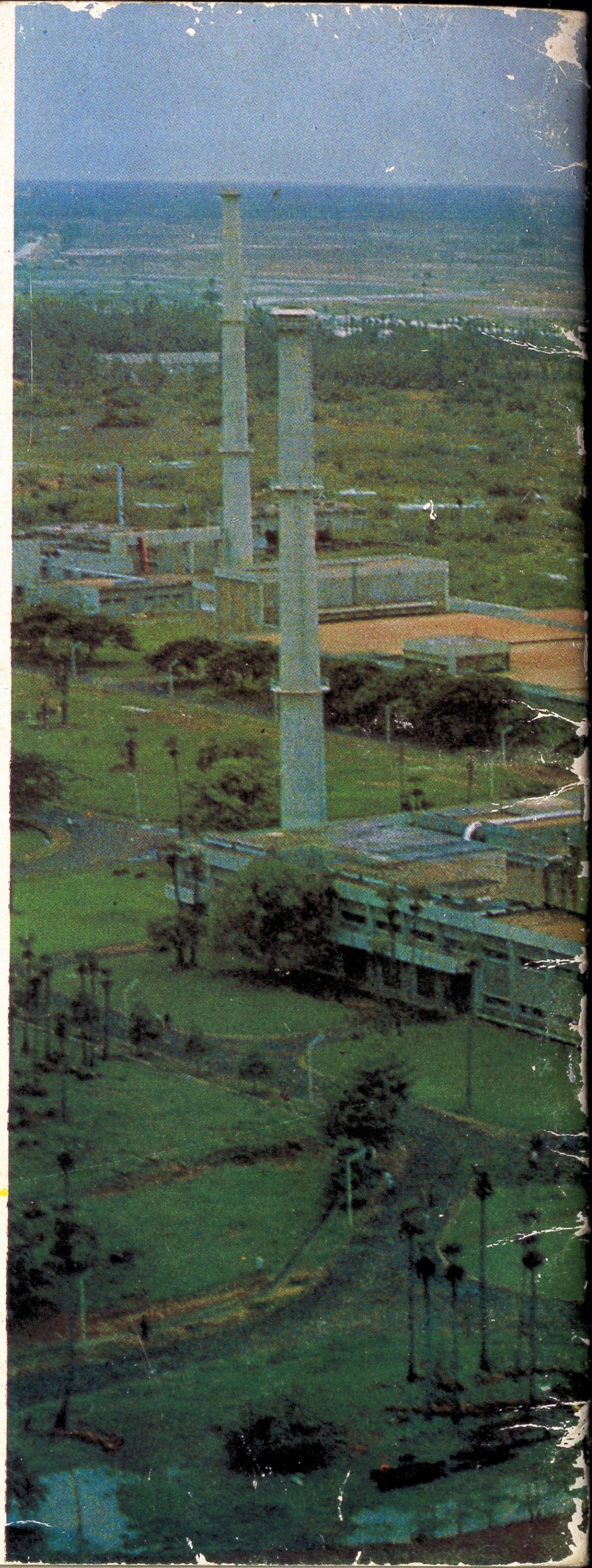
SODIUM PIPING



STEAM GENERATOR ERECTION



FBTR COMPLEX—GENERAL VIEW FROM EAST



Printed for the Department of Atomic Energy by Tamilnad Printers and Traders (P) Ltd., Madras 600 044.

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GOVERNMENT OF INDIA
DEPARTMENT OF ATOMIC ENERGY

INDIRA GANDHI CENTRE FOR ATOMIC RESEARCH

KALPAKKAM