OPERATION AND UTILIZATION OF INDIAN RESEARCH REACTOR DHRUVA

SAMIR KUMAR MONDAL
Bhabha Atomic Research Centre,
Mumbai,
India
samirkm@barc.gov.in

1. INTRODUCTION

The role of research reactors for the development of the nuclear programme of any country is well established. Research reactors are utilized to produce radioisotopes and offer irradiation facilities for testing various nuclear fuel and structural materials. Apart from providing a large volume neutron source for carrying out a variety of experiments, the research reactor forms the basic training facility for grooming scientists and engineers for various aspects of a nuclear programme.

India's fifth research reactor Dhruva, which became critical on 8 August 1985, is a natural uranium fuelled, heavy water moderated and cooled thermal research reactor with a rated power level of 100 MW and a maximum thermal neutron flux of 1.8×10^{14} $cm^{-2}s^{-1}$. The indigenously designed and built reactor is located at the Bhabha Atomic Research Centre (BARC) in Trombay. Dhruva is a product of technological initiatives taken in India during the 1970s with a totally indigenous effort when a need was felt for a research reactor having a high neutron flux to meet the growing demands of research and development. In addition, large scale production of radioisotopes with high specific activity was possible with the commissioning of Dhruva. This high flux reactor was designed and built with many innovative features which were being considered for our power reactors at that time. The reactor has a vertical core and employs natural metallic uranium in seven-pin cluster fuel assemblies installed in Zircaloy guide tubes in a stainless steel reactor vessel. Heavy water is used as the moderator, primary coolant and reflector. Helium is used as a cover gas. Reactor power regulation is achieved by moderator level control. Fast shutdown of the reactor is effected by actuation of nine cadmium shut off rods with simultaneous dumping of the heavy water moderator. Heat from primary coolant is transferred to a secondary closed loop system recirculating demineralized light water in a set of heat exchangers. The secondary coolant is cooled by tertiary sea water coolant in another set of heat exchangers. The sea water coolant is drawn from the Mumbai harbor bay and flows through the heat exchangers on once-through basis. A simplified schematic of the heat transport system is shown in Figure 1. The reactor provides facilities for basic and applied research, material testing and production of radioisotopes and training of manpower. The reactor has been well utilized for two-and-a-half decades on continuous operation basis with high availability and an excellent safety record.

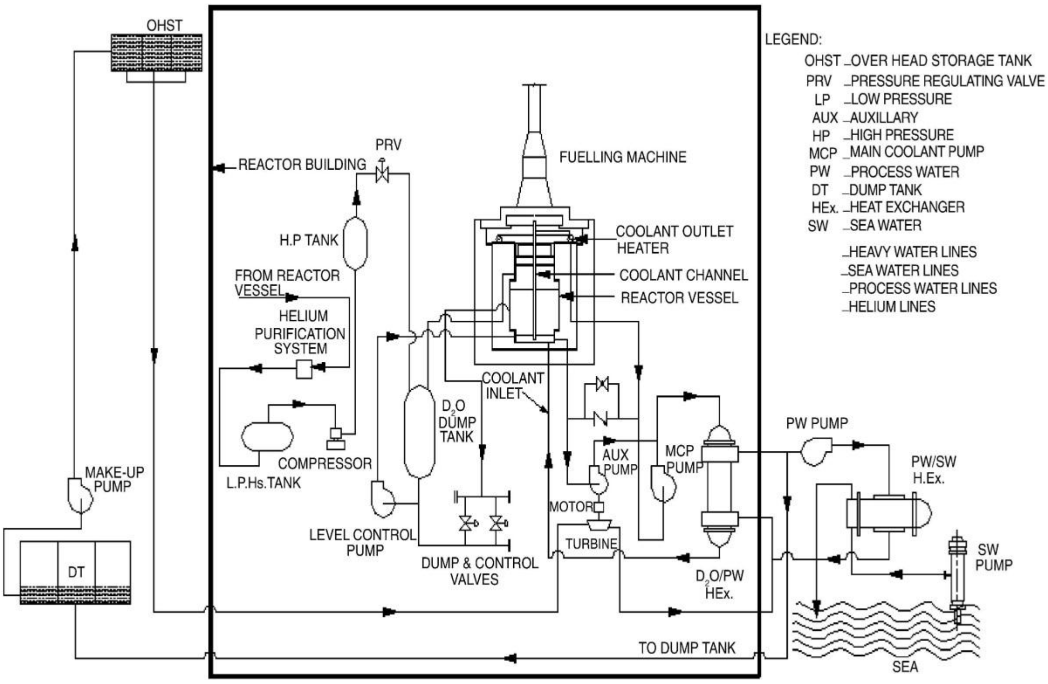


Fig. 1. Simplified schematic of the heat transport system.

2. BASIC DESIGN FEATURES

2.1. The core

The reactor core is contained in a cylindrical stainless steel reactor vessel which is placed vertically in a light water filled vault. There are 146 lattice positions in the reactor vessel arranged in a square lattice with a pitch of 18 cm to accommodate fuel assemblies, shut off rods, isotope production and other experimental facilities.

2.2. Major shielding

The reactor vault which houses the reactor vessel is made of high density concrete and is lined with stainless steel. The vault is filled with demineralized water to provide lateral shielding against neutrons. The high density concrete surrounding the vault provides the biological shielding around the reactor. The end and annular shields provide shielding above the reactor vessel as shown in Figure 2.

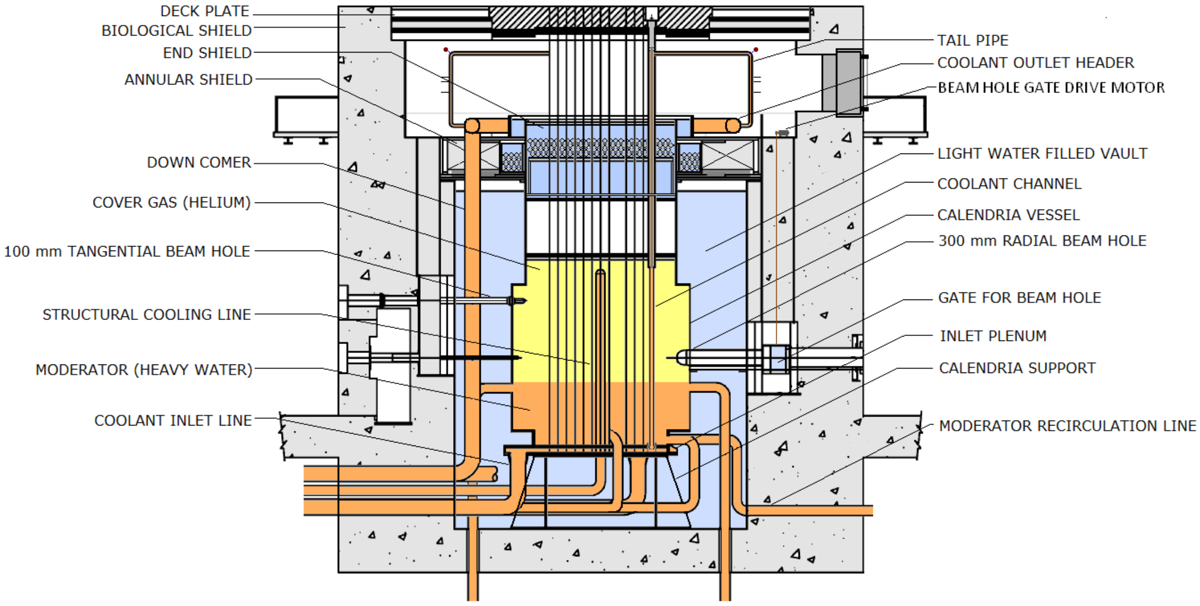


Fig. 2. Dhruva reactor vertical section.

2.3. Fuel

The reactor is fueled with seven-pin clusters of metallic natural uranium clad in aluminium. The fuel configuration and the fuel pin size are mainly based on physics parameters and thermal hydraulic considerations. A complete fuel assembly consists of three subassemblies, namely, a cluster subassembly, aluminium shield subassembly and a seal and shield plug subassembly. Installation and removal of fuel rods into and from the reactor core is done with the help of a fuelling machine.

2.4. Primary coolant

Heavy water is used as coolant, moderator and reflector in the reactor. Heat generated from nuclear fission in the fuel assemblies is removed by heavy water coolant. The heavy water is recirculated in three separate loops. Each loop has a main coolant pump and a heat exchanger. Coolant from the outlet of the heat exchangers enters at the bottom of the calandria, flows upward through individual coolant channels and comes out through individual tail pipes. All the tail pipes join a common outlet header from where downcomers lead the coolant to the suction of each of the three pumps. Auxiliary coolant pumps are also provided in each loop in parallel with the main pumps. These pumps start automatically in case of a main coolant pump trip and thus provide shut down cooling to the core. The auxiliary coolant pumps are provided with two prime movers (electrically driven motor provided with an uninterrupted ac supply and gravity driven water turbine) connected to the same shaft. Heavy water coolant also cools other reactor internals. As part of a special design feature, heavy water in the main coolant and the moderator system gets intermixed in the reactor vessel, thereby the reactor vessel acts in the system as an expansion tank as well. This feature also makes the system inherently safe since any breach in the primary coolant boundary automatically lowers the moderator level in the reactor vessel, shutting down the reactor. Moreover, heavy water in the reactor vessel automatically makes up for leaked water from the main coolant circuit. Moderator level is controlled by control valves and level control pumps.

2.5. Cover gas

Helium is used as a cover gas to heavy water for creating an inert blanket for the heavy water system to avoid its isotopic and chemical degradation. It also provides venting for the moderator and coolant systems. Helium flow is maintained to carry away the products of radiolytic decomposition of heavy water. The gas coming out of the reactor is passed through a purification system consisting of moisture separators, coolers, recombination units, a freezer dryer and activated charcoal adsorbers.

2.6. Secondary coolant (Process water)

A process water system is designed to act as an intermediate system boundary between the heavy water and sea water systems. The intermediate coolant is recirculated in a closed loop consisting of pumps and heat exchangers. System chemistry is maintained through an online polishing stream. Process water pressure is always kept less than main coolant system pressure. This is to avoid ingress of light water into heavy water, in case of a possible tube leakage in heavy water heat exchangers. Necessary online instrumentation is provided to detect if heavy water leaks into the process water.

2.7. Tertiary coolant (Heat sink)

Sea water is used as the once-through tertiary coolant to remove heat from the process and other auxiliary systems. Sea water being corrosive, carbon steel piping lined with concrete or rubber has been chosen. Sea water is chlorinated to inhibit algae and marines growth in pipe lines and heat exchangers.

2.8. Reactor regulation and protection

Reactor power regulation is achieved by controlling the moderator level with constant in-flow and variable out-flow. Reactor start up and power maneuvering can be done by varying moderator level with the help of level control pumps, control valves and electronically driven logic cards. Three independent channels of instrumentation are provided for every important parameter. A reactor trip signal is generated whenever any reactor or process parameter exceeds its limiting safety system setting. The protection system brings the reactor to a safe state within a very short duration whenever any process or nuclear parameter exceeds its preset limit. This system operates on two-out-of-three coincidence logic. This failsafe system calls for primary and secondary shutdown devices for actuation within a minimum delay. Nine shut off rods constitute the primary shutdown system of the reactor. The absorber consists of cadmium sandwiched between two concentric aluminium tubes. Shut off rods are cooled by process air. The secondary shutdown system consists of pneumatic control valves and dump valves, three of each in parallel. Normally dump valves are closed and control valve opening is governed by the reactor regulating system. On reactor trip, all control and dump valves open fully within two seconds to bring down moderator level.

2.9. Power supply

Electrical power to various equipment is supplied from the 22 kV substation located in service building, which receives power from the grid via a 100 kV substation of BARC. Three diesel generator sets of 500 kVA each are also provided and kept in a poised state to feed essential equipment in case of off-site power failure. A no-break ac supply is provided with the help of two motor alternator sets to cater to emergency core cooling system and other essential loads.

A no-break ac supply for control and protection system is provided by a set of two static inverters. A no-break dc supply for instrumentation and control is provided by automatic constant voltage rectifiers backed up by battery banks.

2.10. Emergency core cooling system (ECCS)

Even though the primary coolant system of Dhruva operates at low temperatures and moderate pressures, provisions have been made for catering to a situation arising out of a significant loss of primary coolant due to a double ended rupture of the largest 300 mm diameter pipe in the system. An engineered safety feature in the form of an ECCS has been incorporated to compensate for a loss of primary coolant from the system. This system consists of detection for a loss of coolant, collection of leaked heavy water and automatic injection of leaked inventory back to the main coolant system in a recirculation mode. The system is subjected to quarterly surveillance testing.

2.11. Containment

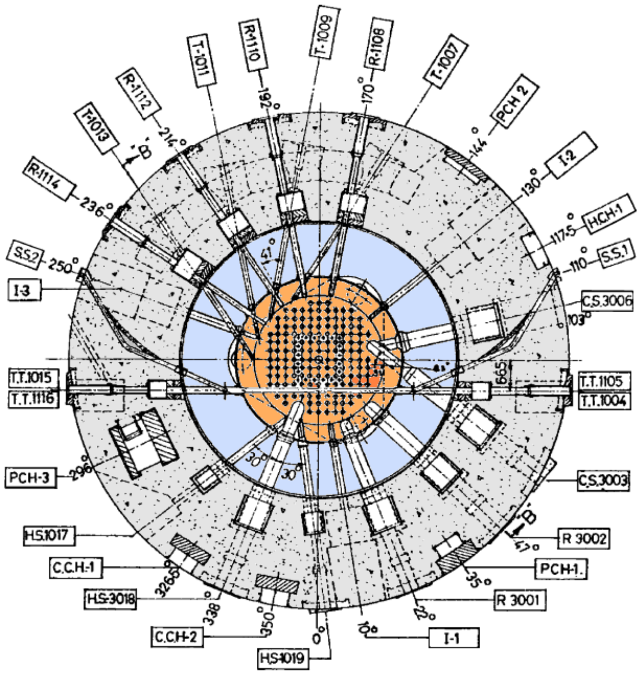
The reactor and the associated heavy water primary coolant system piping and equipment are located inside the reactor building containment. The high density concrete containment structure of the reactor building helps in containing the radiation and radioactivity within the reactor building in case of an unlikely event of an accident. Personnel and vehicle airlock doors provide access to the reactor hall. The reactor containment building is designed for a positive pressure of 300 mm of water column and negative pressure of a 100 mm water column.

The Dhruva core provides a maximum thermal neutron flux of 1.8×10^{14} $cm^{-2}s^{-1}$ and an excess core reactivity of about 2.49 δk (20 mk) exclusively to cater to various in-core experiments and irradiations at the rated power level of 100 MW. The optimized core design has been achieved by using heavy water as coolant, which provides better neutron economy than light water.

3. IRRADIATION AND EXPERIMENTAL FACILITIES

3.1. Neutron beam research facilities

A number of horizontal beam tubes, as shown in Figure 3, distributed around the reactor core provide access to high neutron fluxes for beam research and irradiation experiments. The tangential beam tubes provide thermal neutron beams with a low background of gamma rays and fast neutrons.



LEGEND

I	**Ion chamber basket**
R300	**300 mm diameter Radial Beam Hole**
PCH	**Pile Chase**
CS300	**300 mm diameter Cold Neutron source**
TT	**Through Tube**
SS	**Self Serve facility for short duration irradiation**
HCH	**Helium Chase**
T100	**100 mm diameter Tangential Beam Hole**
R100	**100 mm diameter Radial Beam Hole**
HS	**Hot Neutron source**
CCH	**Cable Chase**

Fig. 3. Cross section of reactor core showing beam tubes.

The 30 cm diameter beam tube placed at a slightly off-radial position is used for inserting a liquid methane moderator maintained at about -160 C to provide very low energy (“cold”) neutrons. A provision exists in one of the 30 cm diameter radial beam tubes facing the cold methane moderator for extracting the cold neutrons, which have an average energy of about 0.01 eV compared to the average neutron energy of about 0.03 eV in the reactor core. Two evacuated tubes made of rectangular glass elements coated with nickel and facing the cold source guide the low energy neutrons to a guide tube laboratory adjoining the reactor building.

Another 30 cm diameter radial beam tube is used to place a block of thermally insulated graphite exposed to the neutrons and gamma rays in the peripheral region of the core. Nuclear heating due to gamma rays and neutrons hitting the graphite block maintains its temperature at about 1325 C. The neutron emerging from graphite has an average energy of about 0.1 eV. Two 10 cm diameter beam tubes facing the hot graphite on either side at an angle of 30° provide hot neutron beams. The cold and hot sources are under development.

There are two “through tubes” at two different heights passing from one side of the reactor to the other along a chord of the cross section of the calandria. At the centre of the lower tube there is a compartment of heavy water, which acts as a secondary source of scattered neutrons. The lower through tube is used for neutron research. At both ends of upper through tube self-serve facilities are provided to irradiate samples.

The provision of tangential beam holes, through tubes and facilities for re-thermalisation of neutron beams are the additional features built into the experimental facilities in Dhruva. Neutron beams are transported using mirror guides to an adjacent laboratory for conducting experiments in low radiation background conditions. A neutron beam line shielding tunnel of 100 t was installed at the neutron beam tube (100 mm through tube), providing multi-port neutron scattering experiments.

For conducting experiments with the neutron beams, a number of microprocessor controlled neutron spectrometers based on new experimental techniques are set up around the reactor inside the reactor building and in the guide tube laboratory. The present day facilities include single crystal and powder diffractometers, a polarization analysis spectrometer, a high Q diffractrometer, triple axis and filter-detector spectrometers and a quasi-elastic scattering spectrometer all installed in the reactor hall, and two small angle neutron scattering (SANS) instruments, a spin-echo spectrometer and a reflectrometer in the guide tube laboratory. These facilities are used by university students in addition to from the researchers of the institution.

A prompt gamma neutron activation analysis (PGNAA) system using the guided neutron beam facility has been setup at Dhruva and well utilized. A Controlled Temperature Irradiation Facility (CTIF) for carrying out irradiation studies on structural materials at elevated temperatures is being installed in one of the 300 mm diameter radial beamhole positions of the reactor.

3.2. Isotope production facility

Fairly large quantities of isotopes are being produced in tray rods after appropriate periods of irradiation at considerably high flux levels. The isotope tray rods made of aluminium have a total length of around 9.5 m. The tray section of the assembly, which is around 3 m long, has multiple cups to accommodate the capsules containing the target material to be irradiated for radioisotope production. Each tray rod consists of 30 trays and can accommodate at most 90 aluminium capsules of dimensions 22 mm in diameter and 46 mm in length. The on-power tray rods are handled every week with the reactor in operation. There are two tray rods for regular isotope production. Radioisotopes produced in tray rods are unloaded with master-slave manipulators into hot cells and then transferred to the Radio Pharmaceutical Division in suitable lead casks. A facility for irradiation of xenon gas for production of iodine-125 isotopes has also been provided in one of the on-power tray rods after suitably modifying the tray section. Apart from this, isotope production and other special irradiation requiring substantial cooling can be engineered in any of fuel positions.

3.3. Pneumatic carrier facility (PCF)

This facility is especially meant for irradiation of short-lived samples at a reasonably higher flux and which require minimum transit time between the completion of irradiation and counting. This facility provides for injection of the sample into the core for irradiation and receipt from a laboratory outside the reactor building. Small quantities of the target material packed inside a polypropylene capsule is transferred into the reactor position with the help of compressed air. The sample is received back after the irradiation for a preset period. The transit time in either direction is a couple of seconds. The received material is analyzed immediately. PCF is useful for carrying out research in areas like nuclear fission, nuclear reactions, nuclear spectroscopy and many applied areas using neutron activation analysis such as forensic studies.

3.4. In-pile engineering loop facility

For irradiation and testing of experimental fuel bundles for Indian power reactors under simulated conditions of temperature and pressure, an in-pile loop with a heat removal capacity of 2 MW is being commissioned in a 150 mm diameter experimental lattice position (G-13) of the reactor pile. The loop being an independent system in the reactor, the experiments can be carried out over a wide range of operating conditions. The loop pressure, temperature, coolant flow, water chemistry, etc., can be varied to suit the requirement of specific experiment. This facility can accommodate the larger fuel bundles of 500 MWe pressurized heavy water reactors and advanced heavy water reactors for testing.

3.5. Self-serve facility

The self-serve facility is meant for producing small quantities of isotopes at relatively lower neutron flux levels. Dhruva has a set of two self-serve units located in the upper through-tubes. Each unit has five irradiation locations. An aluminium capsule containing target material is located in a spherical ball. This ball is rolled into the irradiation location under gravity, and at the end of the irradiation, the ball is rolled out into a lead shielded flask. Further extraction of the sample is carried out in the shielded cell. This irradiation can be carried out without affecting reactor operation.

4. UTILIZATION OF DHRUVA

4.1. Neutron beam research

Neutron beam research at BARC received a great boost with the availability of Dhruva. In Dhruva two main new features are introduced, namely, through-tubes and neutron guides. Through-tubes provide a clean thermal neutron beam selected from near the centre of the core. A Neutron Guide Tube Laboratory (GTL) with additional instruments having specific features has been built adjacent to the reactor hall. Two nickel coated neutron guides, emanating from a beam port inside the reactor hall are taken into this laboratory.

A neutron beam shielded tunnel (100 t in weight) has been installed at one of the 100 mm diameter neutron beamhole which provides multi-ports for neutron scattering experiments, thus expanding the scope of our research facilities. A National Facility for Neutron Beam Research has been created to cater to the needs of the Indian scientific community in the field of neutron beam research.

In the reactor hall, two profile analysis powder diffractometers and the high Q diffractometer have been provided specifically for structure studies of liquid and powder samples. These instruments utilize linear ^{3}He position sensitive detectors. Usage of the multi-detector system has improved the throughput substantially. It is possible to record a diffraction pattern in a few minutes. The profile analysis unpolarised neutron diffractometers have been the workhorses for studies of chemical and magnetic structures and for investigating phase transformations in different classes of magnetic and non-magnetic compounds.

In the guide tube laboratory, in the G2 neutron guide, there are two SANS instruments, a double crystal based and a conventional type, and a neutron reflectometer. The SANS (low Q) diffractometers in the Guide Tube Laboratory have been extensively used for investigating spatial structures, inhomogeneities and agglomerates, with sizes of a few tens to thousands of nanometers. The double crystal based SANS diffractometer has been used to study pore size, pore morphology and pore surface roughness in different natural rocks, coal and porous silicon, fluid permeability and fractal dimensions in membranes, heat treatment effect on nanoparticle agglomerates, precipitates in nuclear materials and metallurgical alloy specimens. A neutron spin echo spectrometer is used in polarised small angle scattering. The neutron reflectometer is suitable for vertical sample geometry. Chemical and magnetic profiles of thin film samples, multilayer, etc., have been studied using polarised neutron reflectometry.

A neutron triple axis spectrometer, filter detector spectrometer and a quasi-elastic neutron spectrometer have been used to study several dynamical processes like phonon dispersions, magnetic excitations, rotational and translational diffusion in molecular systems, etc. The lattice dynamics of several geologically important minerals, available as natural single crystals, have been investigated by triple axis measurements.

4.2. Radioisotope production

The use of metallic uranium fuel enables the reactor to provide an excess reactivity of around 20 mk for various irradiation programmes. The high thermal neutron flux, adequate excess reactivity and the large irradiation volumes enable large scale production of radioisotopes with high specific activity. This results in handling and processing of a comparatively reduced volume of radioactive material. The design provision has been made for loading and unloading of radioisotope samples at power. Nearly 70 different radionuclides produced in reactor have been processed and supplied in various radiochemical forms. The bulk of the radionuclides prepared are used in nuclear medicine, agricultural research and industrial applications. Major radioisotopes, e.g., ^{99}Mo, ^{131}I, ^{153}Sm, ^{32}P and ^{51}Cr, for medical use are produced and supplied weekly or fortnightly (refer Table I).

TABLE 1. (LIST OF MAJOR REACTOR PRODUCED RADIO NUCLIDES AND THEIR APPLICATIONS)

Radionuclide	Period of irradiation	Application
^{99}Mo ^{99m}Tc	1 week	Preparation of ^{99m}Tc radiopharmaceuticals for diagnosis
^{131}I	3 weeks	Diagnosis and therapy of thyroid disorders and thyroid cancer
^{32}P	6–8 weeks	Radionuclide therapy & P^{32}-labeled nucleotides
^{51}Cr	1 week	RBC labelling-for studies in biology etc.
^{153}Sm	1 week	Radionuclide therapy- treatment of bone pain in metastatic cancer
^{166}Ho	1week	Radionuclidic therapy-treatment of rheumatoid arthritis
^{125}I	2 weeks	RIA, brachytherapy of cancers, X-ray source etc.
^{46}Sc	1 week	Sediment transport, underground water seepages studies
^{203}Hg	2–3 months	Mercury inventory studies
^{82}Br	4–7 d	Leak detection, residential time distribution measurements
^{198}Au	1 week	Seepage, sediment transport studies in hydrology
^{192}Ir	3 months	Industrial radiography & brachytherapy

About 100 TBq (~2700 Ci) of these radiochemicals are supplied to about 200 nuclear medicine centres in the country per annum. This caters to about 250 000 patient investigations involving diagnostic and therapeutic applications in a year. ^{125}I, which has a much better gamma merit ratio as compared to ^{131}I, is the recent addition to the variety of radioisotopes for medical uses. ^{125}I is used worldwide for radioimmunoassay and as a brachytherapy source for treatment of eye and prostate cancer. To meet the growing demand of radioisotopes and to facilitate production of ^{125}I, a second isotope production tray rod assembly was suitably modified. This assembly has facility for irradiation of xenon gas for production of iodine-125 isotopes and can be handled at power. Radioisotopes produced are used in industries in echo benign technologies (e.g., Radiation vulcanization of rubber latex, radiation sterilization of medical products, radiation cross linking, etc.) and also in the treatment of domestic and

industrial waste (e.g., radiation hygienisation of sewage sludge, treatment of flue gases, etc.). Radionuclides like ^{82}Br, ^{203}Hg, ^{198}Au, ^{47}Sc, ^{140}La ^{24}Na, etc., used for leakage and blockage detection in buried pipe lines, residence time distribution studies in chemical reactors, sediment transport, effluent dispersion, seepage studies in canals and dams, etc., are produced according to specific requirements of the users. ^{192}Ir is produced regularly for use in industrial radiography and brachytherapy. Though there is no design provision for regular production of ^{60}Co radioisotopes in Dhruva, two fuel positions were used for producing cobalt-60 of high specific activity in large quantities. ^{60}Co is used for radiation sterilization of medical products. Reactor produced radionuclides for miscellaneous applications that support basic research in the country have been an important area of focus. Earlier, for loading and unloading of samples to and from the tray rod, the reactor had to be shut down. To reduce the frequency of reactor shutdowns on this account, on-power tray rod handling was envisaged after incorporating necessary modifications and safety features. A facility for irradiation of xenon gas for production of iodine-125 isotopes has also been provided in one of the on-power tray rods after suitably modifying the tray section. Iodine-125 is extensively used as a diagnostic and therapeutic agent for the fast and precise study of various malignant disorders.

4.3. Neutron activation analysis

Neutron activation analysis (NAA) is essentially a non-destructive nuclear analytical method capable of simultaneous multi-element analysis. It is one of the major applications of a research reactor. Neutrons, being non-charged particles, interact with nuclei of isotopes of all elements resulting in nuclear reactions. The product formed in such a nuclear reaction might be a radioisotope. By measuring the radioactivity formed, the concentration of the isotope that underwent nuclear reaction is measured. Using the isotopic abundance, the elemental concentration is calculated. NAA has been used in a large number of areas of research like biology, geology, agriculture, anthropology, chemistry, engineering and industry, fisheries, forestry, medicine, oceanography, pharmacy and forensics. The Pneumatic Carrier Facility (PCF) at Dhruva is utilized for irradiation of short-lived isotope samples that require minimum transit time between the completion of irradiation and counting for NAA. With higher neutron flux levels in the Dhruva PCF, elemental detection limits have improved and the scope for studying short-lived isotopes hass also been enhanced. Prompt gamma neutron activation analysis (PGNAA) using the thermal neutron beam at Dhruva reactor has provided an avenue for the on-line analysis of various materials.

4.4. Material and fuel testing:

Dhruva has been extensively used for basic and applied research in the frontier areas of science and technology and radioisotope production. Besides utilization of regular irradiation facilities for these purposes, some of the fuel and other in-core positions have also been used for carrying out certain specific engineering experiments. In order to develop various fuel and structural materials for Indian pressurized water reactors, a facility has been installed in one of the 300 mm diameter radial beamholes, which would enable neutron irradiation of samples of fuel cladding, pressure tubes, end fittings, end shields, etc., at a controlled temperature to assess the effect on their fracture toughness, impact and other mechanical properties at various neutron fluences. Since all the in-core irradiation assemblies are cooled by the primary coolant, it is possible to engineer an irradiation or experimental assembly in any of the fuel positions. The Dhruva core has a provision for installing a facility for the testing of advanced reactor fuels. An in-pile loop facility with high heat removal capacity is being provided in Dhruva. This facility can accommodate the fuel bundles of 500 MW$_e$ pressurized heavy water reactors and advanced heavy water reactors for testing.

4.5. Manpower training

During the last 25 years a large number of engineers, scientists, operators and technicians have been trained at Dhruva reactor. This trained manpower is contributing to our nuclear programmes in various capacities.

5. SPECIAL EXPERIMENTS CARRIED OUT AT DHRUVA

- **Validation of thermohydraulic codes:** An instrumented Dhruva fuel assembly was irradiated in the reactor for validating thermal hydraulic code used for estimating fuel cladding temperatures.
- **Study of irradiation growth in Zircaloy:** The manufacturing route of the Zircaloy calandria tubes for the Indian pressurized heavy water reactor was to be changed from sheet rolling, bending and seam welding to hot extrusion and cold pilgering to obtain seamless calandria tubes, for reasons of economy and a faster production rate. Samples of welded and seamless Zircaloy calandria tubes were test irradiated in the Dhruva reactor to study their comparative in-pile growth behaviour. These studies resulted in finalization of manufacturing route for the pressurized heavy water reactor calandria tubes.
- **Study of applicability of neutron noise measurement technique for condition monitoring of in-core components for heavy water reactors:** The neutron flux signal is composed of a steady or mean component of neutron flux produced by the power operation of the reactor and a very small fluctuating component called noise. Analysis of the neutron noise from suitably located sensors is a proven technique to monitor the condition of the in-core components of a light water reactor. However, it is generally felt that its applicability to a heavy water reactor will be limited due to the unfavourable transfer characteristics of these reactors. An attempt was made to check the applicability of this technique for pressurized heavy water reactors. An experiment was carried out at Dhruva using in-core neutron detectors housed in a specially fabricated assembly. The result of this experiment showed the suitability of this technique to identify the change in condition of reactor internals that are otherwise inaccessible.
- **Accelerated life testing of ion chambers:** Neutron detectors of various types and sensitivities are developed in India. Before these detectors can be used for various reactor regulation or protection systems they have to be tested for their performance under simulated conditions. Accelerated life testing of uncompensated neutron ion chambers was successfully done in one of the 300 mm diameter radial beamhole facilities in Dhruva.

6. FUTURE UTILIZATION PROJECTS AND PLANNING

- A dedicated beam line for PGNAA is being developed. PGNAA and PCF would enlarge the scope for activation analysis as well as basic studies like nuclear spectroscopy.
- A preliminary analysis for production of fission molybdenum-99 in Dhruva reactor has been done from a reactor physics point of view. ^{99}Mo is currently produced by neutron capture, but 20% LEU-Al alloy has been considered as a target material for this purpose, and design of an irradiation rig is in progress.
- It has been proposed to produce NTD Silicon in one of the 300 mm diameter radial beamholes of Dhruva. For this, mapping of thermal and fast neutron fluxes along the beam path and across the beam cross section using a self-powered neutron detector was

carried out towards optimizing the silicon ingot dimensions and its irradiation location in the beam hole. Finalizing of the scheme is in progress.

- It has been planned to commission a 2 MW in-pile loop facility for testing future power reactor fuels by the end of 2010.
- Irradiation of thorium rods in one of the fuel positions for generating data on irradiation behaviour of the fuel is planned.
- Irradiation of cobalt slugs in tray rods installed in one of the fuel positions to meet the growing requirement of cobalt-60 is also planned.

7. CONCLUDING REMARKS

Dhruva has completed 25 years of operation with an excellent safety record. It has contributed immensely to nuclear science and technology in general and neutron beam research and radioisotope production in particular. Utilisation of Dhruva, both in terms of quantity and quality, has been of a very high standard. The safety and availability records for 25 years operation proves the soundness of the basic design and dedication of O&M personnel. The gains accrued with the construction, commissioning and operation of Dhruva certainly outweigh the efforts invested in its making and subsequent operation.