# Nuclear Power in India – Past, Present and Future

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## 1.0 Introduction

The huge potential of the atom had been envisioned in India in the ancient times and references to the same can be found in some of the ancient scriptures. Such references provide us a tantalizing glimpse into the ancient Indian history and, indeed, into the level of advanced thinking that these civilizations had reached in those times. In the modern times, it was Dr. Homi Bhabha, who foresaw, as early as in 1944, the potential of harnessing nuclear power in improving the quality of life of the millions of people stated:
"Any substantial rise in the standard of living in this region – that can be sustained in the long term – will only be possible on the basis of very large imports of fuel or on the basis of atomic energy."
The issues of energy sustainability and inevitability of nuclear power, which are only now receiving global attention, was foreseen by him over half a century ago. When the rest of the world was working on the military applications of atomic energy, he focused on harnessing atomic energy for the improving the quality of life. In the 1950s, nuclear power in the world was still in its infancy and India had just gained independence. The nascent nation was essential a rural economy, with practically no technology or industrial base. Therefore, realizing such a technology-intensive vision, which involved complex reactor and fuel cycle technologies must have seemed like a fantasy. However, with his clear vision, Dr Bhabha went ahead, building institutions – R&D facilities, research reactors, industrial units – to develop technologies and to deploy them.

Soon, a sequential three-stage nuclear power programme, aimed at optimum utilisation of India's nuclear resource profile of modest uranium and abundant thorium, with the objectives of improving the quality of life of the people and self-reliance in meeting the energy needs of the nation was conceived and adopted with a long-term vision. The three stages comprise Pressurised Heavy Water Reactors (PHWRs) in the first stage, Fast Breeder Reactors (FBRs) in the second stage and thorium-based systems in the third stage. Based on a closed fuel cycle, where the spent fuel of one stage is reprocessed to produce fuel for the next stage. This multiplies manifold the energy potential of the fuel and greatly reduces the quantity of waste.

It is thus a single-basket solution for meeting the country's energy needs in a sustainable manner, securing its energy future in the long term.

### 1.1 Building Institutions to Ensure Linkages

Just before India attained independence, Dr. Bhabha, in 1944, approached the Sir Dorabji Tata charitable trust for funding to set up an institute for atomic research in India. The Tata Institute of Fundamental Research (TIFR) was thus established in 1945. After India's independence in 1947, the framework for the programme was put in place. The Atomic Energy Act was enacted and the Atomic Energy Commission (AEC), the policy-making body, was set up in 1948. The Department of Atomic Energy, under the Prime Minister, was set up in 1954 to administer the programmes of atomic energy.

Even as the framework for the activities was being worked out, institutions for development of technologies and production of fuel, heavy water and other materials began taking shape.

#### 1.1 .1 R&D Facilities

Considering the need to develop an R&D base for the programme, the Atomic Energy Establishment was set up in the 1950s at Trombay, Mumbai (later renamed Bhabha Atomic Research Centre – BARC). The Centre housed laboratories and facilities for carrying out multi-disciplinary R&D in basic nuclear sciences and for various applications of nuclear energy, like energy/power and several other societal applications health & medicine, industry, agriculture, etc. Research reactors – examples of which are APSARA (1956), CIRUS (1960) – were set up for production of isotopes and experiments for perfecting the technologies. Facilities at the Centre were also set up for production of uranium ingots, fabrication of fuel and a reprocessing plant for production of plutonium. R&D carried out at the Centre helped develop key materials, technology, tools and equipment, for the nuclear power programme.

Later in 1970, a dedicated R&D centre for all aspects of Fast Breeder Reactors, including reactors, fuel cycle and associated materials and systems – Indira Gandhi Centre for Atomic Research (IGCAR) – was set up at Kalpakkam, Tamilnadu. A 40-$MW_{th}$ Fast Breeder Test Reactor (FBTR) was commissioned in 1985 at the centre. The centre has evolved the design for the commercial 500-MW Prototype Fast Breeder Reactor (PFBR), which is now at an advanced stage of construction.

R&D centre for lasers and accelerators – Raja Ramanna Centre for Advanced Technology – was set up at Indore. Several other centers were set up across India for carrying out R&D on certain specific aspects of nuclear science and its applications.

### 1.1.2 Facilities for Production of Nuclear Materials and Backend

Facilities for production of fuel, heavy water and other materials for the nuclear power programme were set up under the aegis of the Department of Atomic Energy (DAE). Indian Rare Earth Limited was incorporated for mining and processing of rare earths like zircon and thorium for the programme. Uranium Corporation of India Limited (UCIL) was set up to mine and process uranium ore. The company now has mines in Jharkhand and Andhra Pradesh and an entire PHWR reactor fleet till recently was fuelled by the fuel mined by UCIL in the country. Nuclear Fuel Complex (NFC) was set up for fabrication of fuel bundles/ assemblies. Given the special requirements of instrumentation for nuclear plants, Electronics Corporation of India Limited (ECIL) was set up to develop and manufacture the special instrumentation. Heavy Water Plants were set up for production of heavy water for the PHWRs at various locations in the country

Facilities for back end of the fuel cycle – reprocessing and waste management plants were – developed in the DAE and set up at various locations for reprocessing spent fuel of the first stage.

### 1.1.3 Human Resource Development

A training school was established in 1957 to train personnel in nuclear science and engineering for the planned programme. This established has produced a large number of trained resources for meeting the needs of the programme. Subsequently, the same was expanded, and several training schools for specific requirements, like nuclear power plants, R&D, fuel fabrication, etc., were set up at different locations in the country.

### 1.1.4 Industry

At the time of country's independence in 1947 and for several years thereafter, the industry's capability was limited, necessitating large efforts, which were put by DAE and Nuclear Power Corporation of India Limited (NPCIL) to develop the Indian industry to achieve high standards in manufacturing of equipment for nuclear power technology. In addition to transfer of technologies, measures like investments in development of workshops and facilities for testing were initiated to enable the industry develop its capabilities.

Over the years, Indian industry has developed and its capability in design, engineering and manufacturing of equipment that is comparable to the international standards. It has also grown to take up large-package contracts for engineering, procurement, and constructionin several conventional, auxiliary and balance of plant areas of nuclear power plants.

### 1.1.5 Regulatory Framework

An independent regulatory body, the Atomic Energy Regulatory Board (AERB) was established simultaneous to the development of the programme, which was later reorganized in 1984 to enforce safety regulations in nuclear power plants and other nuclear installations in the country. A robust regulatory mechanism has evolved in the country that, in addition to the prevailing safety culture, has helped achieve high standards of safety in all aspects of nuclear power reactors from siting to design, construction, commissioning operation and maintenance and renovation and modernization and regulate other activities of the Atomic energy programme in the country. Over the last few years, AERB has taken up an expansion plan in capacity and capability to gear up with the current and future requirements of expanding and diverse nuclear power programme.

## 2.0 Nuclear Power Programme Evolution

The first nuclear power plant in the country, comprising two nuclear reactor units, was set up at Tarapur, Maharashtra on turnkey basis by GE, USA. The construction of these units began in 1964 and they became operational in October, 1969. Indeed, India was the first country in Asia, and among a few countries in the world, that had operating nuclear power reactors in the year 1969, demonstrating the safe and reliable operation of nuclear power in Indian conditions. These reactors were set up to gain experience in operation of nuclear power in Indian conditions and to establish their suitability for the country. These nuclear power reactors, in their 41$^{st}$ year, are the one among ten reactors of their vintage in operation today world over.

Subsequently, work on the Presuurised Heavy Water Reactors (PHWRs) of the first stage began with construction of RAPS-1&2 at Rawatbhata, Rajasthan**.** The first stage programme went through stages of technology demonstration, indigenization, standardization, consolidation, and finally, commercialization. While the first stage began with 220-MW reactors supplied by AECL, Canada, the subsequent PHWRs have all been indigenous. In 1974, even as the second unit of Rajasthan was under construction, the Canadian assistance was withdrawn. It brought an international technology denial regime and isolation of the country from the rest of the world. Under such difficult and challenging circumstances, the

Indian scientists and engineers rose to the occasion, and with their untiring and innovative efforts, not only RAPS–1 was completed successfully but they could also design, construct and commission the other unit, too (RAPS-2).

Subsequently, MAPS units-1&2 were designed, constructed and commissioned with indigenous efforts. The design of 220-MW PHWRs was standardized, and NAPS-1&2 and KAPS-1&2 set up. Kaiga-1&2 and RAPS-3&4 were also set up with further improvements in design. The standard 220-MW design was scaled up to 540 MW, and TAPP 3&4 (2x540 MW) have been set up. The 700-MW PHWR design, using the same core of the 540-MW, has been developed and construction of four such reactors has commenced. These reactors are expected to be completed in the year 2016-17. More nuclear power reactors of this design are planned to be set up in the future.

In parallel to the indigenous three-stage programme, additionalities based on international technical cooperation have also been introduced, essentially for faster nuclear power capacity addition in the near term, considering the lead times involved in the indigenous nuclear power programme. Two Light Water Reactors (LWRs) of 1000 MW each are under construction at Kudankulam in technical cooperation with the Russian Federation. Sufficient experience in respect of implementing the large-size LWRs, based on international cooperation, has been gained especially in evolving and implementing an innovative execution model, understanding and adopting the technical requirements and integration of the same with Indian regulatory framework. With the fruition of international cooperation and developments in nuclear power globally, more LWRs, totaling to about 40 GW, are planned to be set up in the next two decades.

## 3.0 Nuclear Power Today

India today is recognized as a country with advanced nuclear technologies. Comprehensive indigenous capabilities have been developed in all aspects of nuclear power and associated fuel cycles. It has a large R&D base, qualified human resource and facilities for continual development of human resource, industrial capability and capacity as well as robust regulatory framework. The performance of Indian nuclear power stations and implementation of projects have been comparable to international benchmarks. The technologies for several complex in-core operations have been developed and deployed successfully.

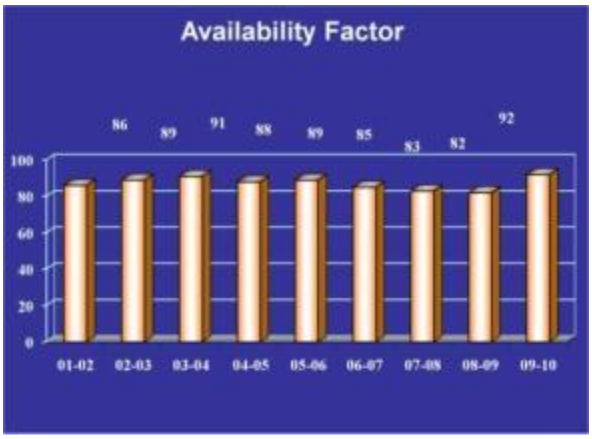
### 4.0 Present Status of NPPs

There are presently 19 nuclear power reactors in operation with a capacity of 4560 MW. The 20th reactor, Kaiga-4 (220-MW), currently under the process of fuel loading, is expected to go in operation by December 2010, thus raising the nuclear power installed capacity to 4780 MW. Kaiga-4 brings yet another distinction to the country, elevating it to 6th rank in the world after US, France, Japan, Russian federation and Republic of Korea to have 20 or more nuclear power reactors in operation currently. In addition, three nuclear power reactors with a capacity of 2500 MW are at an advanced stage of construction and four reactors each of 700 MW, two each at Kakrapar in Gujrat and Rawatbhata in Rajasthan, respectively, have also been launched for construction during this year. With the completion of the reactors under construction, the nuclear power capacity in the country will reach 7280 MW by 2012 and 10080 MW by 2017.

### 4.1 Performance Overview

#### 4.1.1 Operations

Nuclear power reactors in operation have achieved high availability factors of 85% and higher consistently over the last several years. The highest performance in terms of uninterrupted operation has been 529 days, with eight reactors achieving continuous runs of over a year without scrams, and other reactors, too, registering nearly the similar feat. This indeed evidences the sound technology, design and operation and maintenance competencies in safe and reliable operation of Indian nuclear power plants.




### 4.1.2 Safety Performance

The performance of Indian nuclear power reactors in respect of safety has been excellent, with about 340 reactor years of safe, reliable and accident-free operation. The releases of radioactivity to the environment have been a small fraction of the limits prescribed by the Atomic Energy Regulatory Board (AERB). The yearly radiation dose around the Indian NPPs, measured over the last many years, is an insignificantly small fraction of natural radiation dose and the stipulated regulatory limits.

### 4.1.3 Construction of Nuclear Power Projects – The Project Management

The construction of nuclear reactors in the country started with research reactors APSARA, followed by CIRUS in the early fifties. These reactors were of modest rating. However, they provided useful inputs in construction technology, setting the stage for taking up construction of commercial nuclear power reactors, at Tarapur, TAPS-1&2 (BWRs) and Rawatbhata, RAPS-1&2 (PHWRs) in the sixties. This was followed by the construction of a series of reactors – MAPS, NAPS, RAPS-3-to-6, TAPS-3&4. The simultaneous construction of eight reactors, of diverse technology, during the years 2002–2007, indeed, demonstrates the capacity and project management capability in construction of NPPs by NPCIL.

Over the last several years, NPCIL has developed and implemented innovative methodologies and strategies in effective project management, which have resulted in achieving reduction in gestation periods and costs.
The construction and commissioning of TAPS 3&4 and Kaiga-3 in 5 years with substantial cost savings evidences this.

A comparison of the country-wise typical gestation time achieved in construction of the nuclear power reactors world over and in India shows undeniably that country’s strength in project implementation is comparable to international standards.

### 4.2.4 Life Extension

Maximizing safety and reliability in nuclear power plants operation is the ultimate mission in the nuclear industry. The nuclear power plants are designed and operated with a philosophy of defence-in-depth principles. The periodic health assessment and ageing management is an integral part of the nuclear power technology to assure the safety and reliability in all phases of nuclear power, encompassing design, construction, commissioning, operation and waste management. Life extension of components, equipment and the systems in a nuclear power plant is a key aspect. Further, up-rating , upgrading, and thus, extending the life of operating capacity amounts to effectively adding capacity. The various programmes to achieve this objective are: appropriate ageing management, renovation & modernization, safety upgrades, etc. The Indian nuclear power programme has recognized and adopted the best practices in this area of the nuclear industry; therefore, since the inception of the nuclear power programme in the country, due regard has been given to this aspect through structured and systemic R&D initiatives. The key attributes of life extension programme essentially comprise of the following.

**4.2.4.1 Health Assessment – Development of Appropriate Tools**

Periodic health assessment is yet another important aspect of nuclear power, as it provides an early warning of any degradation in the components, equipment and systems in a nuclear power plant. These health assessment studies indeed provide the most current status of health of the equipment through comparison of the base line and in service data. The feedback obtained from these studies needs to be reviewed, assessed and addressed appropriately and timely. This also helps in implementing preventive and mitigative measures and also in planning ageing management/life extension. Special remote tools are needed for inspection of inaccessible core areas with high radiation fields and for carrying out repairs. These have been developed by NPCIL, BARC, and other institutions of the DAE. Some of them are: BARC Reactor Coolant Inspection System (BARCIS), Non-Intrusive Vibration Diagnostic Technique (NIDVT), and several other specialized cameras, manipulators, welding tools, etc. These tools have been helpful in pinpointing the exact locations, in determining the nature of repairs needed and in carrying out necessary repairs.

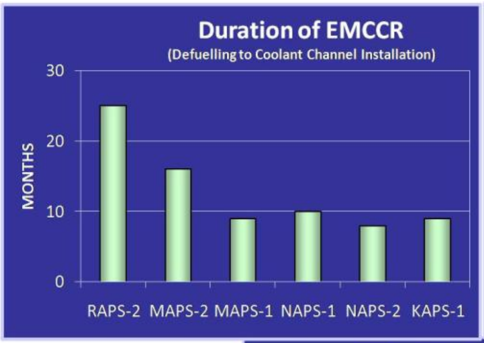
**4.2.4.2 Renovation & Modernisation**

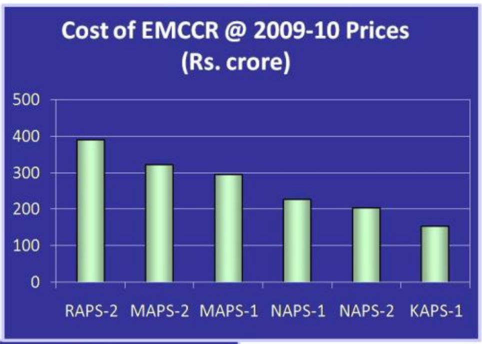
**EMCCR in PHWRs**

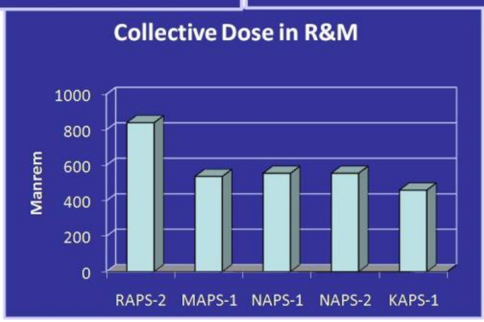
The coolant channels were initially constructed of Zircalloy-2 in PHWRs, and the health assessment studies carried out during operation, using the technique developed in-house, revealed that their life was limited due to alteration in the material properties under exposure to intense radiation, high temperature and pressure and a corrosive environment. The material degradation mechanism in Zircalloy-2 coolant channels was studied and these were replaced with Zirconium–2.5%Niobium – a better material with greater capabilities to withstand the severe conditions of operation,. The coolant tubes of Zircalloy-2 in six nuclear power reactors have been replaced by carrying out successfully en-masse coolant channel replacement (EMCCR) in Rajasthan Atomic Power Station-2, Madras Atomic Power Station-1&2 & Narora Atomic Power Station-1&2 and Kakrapar Atomic Power Station-1 using indigenous technology.

Glimpses of EMCCR

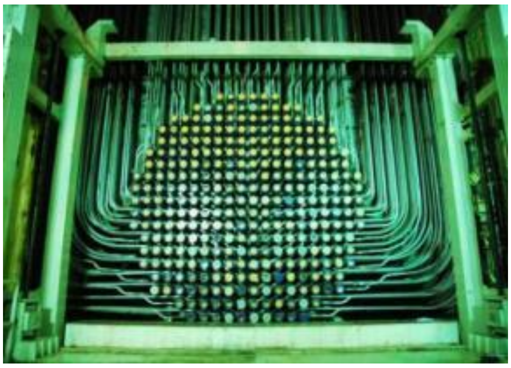
The time, cost and manrem (radiation dose) levels in EMCCR have been progressively reduced. This has been possible with experience and innovations introduced in tooling and execution of the jobs.



**EMFR in PHWRs**



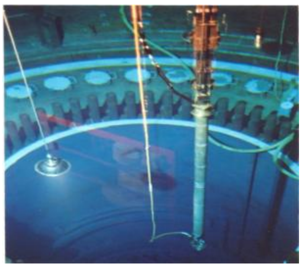
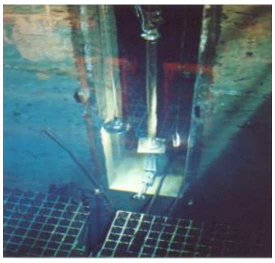
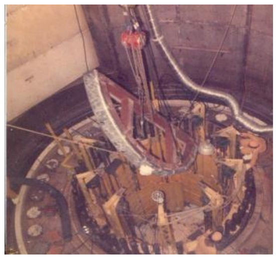
The feeders, made of carbon steel, are an important component of the primary heat transport (PHT) system in a PHWR. Feeder thinning on account of flow-assisted corrosion (FAC) was first noticed in 1995 in Candian PHWRs. The studies on FAC mechanism revealed that higher flow velocity at the bend portion of feeders along with the coolant pH of more than 10.5 contributed to accelerated FAC. The health assessment of feeders in Indian nuclear reactors showed lower FAC than Canadian PHWRs. This was attributed to maintaining of primary coolant pH in a narrow band of 10.2 to 10.4. However, to extend the life of the Indian PHWRs and synchronise this with EMCCR, en-masse feeder replacement (EMFR) was carried out for the first time in the world in a PHWR at Madras Atomic Power Station-1. After extensive studies, the existing carbon steel feeders were replaced with modified carbon steel feeders having 0.2%W/W chromium content – a material more resistant to FAC. EMFR was also, subsequently, carried out at Narora Atomic Power Station-1&2, Rajasthan Atomic Power Station-2 and Kakrapar Atomic Power Station-1.

**Replacement of Steam Generator Hairpin Heat Exchanger in MAPS**

Steam generator in a PHWR is an important equipment for being a boundary separating the radioactive fluid (the coolant) and the secondary side. The primary side (tube side) in steam generator is subjected to high pressure (87 kg/cm$^2$) high temperature (~293°c in 220 MW) heavy water coolant, and the secondary side on shell side, to a hostile environment resulting from the chemically treated DM water at 250°c and 40 kg/cm$^2$. Therefore, periodic health assessment and appropriate actions to ensure healthiness of SG is an important requirement in a nuclear power station. The detection and correction of leaky SG tubes at incipient stages is attempted essentially to prevent the escape of expensive and radioactive heavy water coolant and also to prevent contamination of secondary system.

The hairpin heat exchangers of the boiler in MAPS-1 had developed leakage in the tubes. Subsequent to detection of steam generator tube leakage, replacement for all boiler hairpin heat exchangers was carried out successfully in MAPS PHWR units. Based on detailed metallurgical examinations, improvement in future material selection for tubes was carried out by making a changeover from Monel-400 to Incalloy-800.

**Renovation & Modernisation and Safety Upgrade at TAPS-1&2**

The health assessment of Tarapur unit-1&2 has been carried out using the latest and advanced techniques developed indigenously. Reactor vessels and core shroud inspection and their structural integrity reviews were done successfully. Based on these studies, the plant life was extended by replacing the important equipment/components, which includes replacement of secondary steam generators (SSGs). In addition to this, safety upgrading of the units has also been completed successfully. The up-gradation was completed in a record time of 120 days, resulting in a life extension of 15 years. The Tarapur units are the only ones of their vintage in operation and are operating with availability- and capacity factors of near-100%.

**4.0 Technology Missions – In-core Repairs and Activities**

NPCIL has been faced with several special challenges necessitating repairs in the high radiation field core areas, which have been successfully addressed by developing appropriate remote tools and methodologies for executing the jobs, in mission mode. Some of the important such missions undertaken were:

- Repair of RAPS-1 End-shield
- Repair of RAPS-1 Over Pressure Relief Device (OPRD)
- Introduction of Spargers in MAPS-1&2
- Repair in Kaiga-3 End-shield
- Repair of leak in KAPS-1 Calandria Vault

**5.1Repair of RAPS-1 End-shield**

India's first PHWR developed end-shield leaks in the 1980s. The leak repair was performed successfully in 1983 in India's first PHWR operating reactor by developing special remote tools. The entire operation was supported by a full-scale mock-up and qualification of procedures.

**5.2 Repair of RAPS-1 Over Pressure Relief Device (OPRD)**


The Calandria Over Pressure Relief device (OPRD) is an 800-mm-diameter nozzle consisting of a stainless steel cover, which is held in position by shear pins. These pins break if the inside pressure in the calandria exceeds a pre-determined value of about 1.76 kg/cm$^2_{(g)}$. To ensure a pressure-tight seal between the cover and the flanges, a gasket made of soft nickel is used. In RAPS-1, it was this nickel gasket, which was damaged due to corrosive atmosphere in the calandria, leading to minor leakage of heleuim gas and heavy water from the calendria. After a thorough evaluation a technique to form a Cast-in-Situ metal seal using a special metal having low melting point was decided. Such a material was to remain in extremely high radiation fields of 50 to 100 thousand rad/hour inside the calandria. It, therefore, needed to be radiation-resistant so that it did not become hard and embrittled in service. Also, the material in question had to be non-adhesive to stainless steel. To match these characteristics, a special metal, Indium, which was produced only by Nuclear Fuel Complex, Hyderabad, was selected. This metal, at a purity of 99.9%, fulfilled all the conditions stipulated by Atomic Energy Regulatory Board.

The concept was of putting a backing metallic seal just inside the existing nickel seal in the OPRD. However, its crucial remote location at a place inside the calandria and availability of only a small 3.75-inch circular opening for approaching it created all sorts of difficulties in designing and developing the remotely handled tools, tackles and manipulators which could go to the inaccessible location and perform the operation in a perfect manner from a point above on the top of reactor deck. A number of such manipulators like metal indium pouring manipulator, temperature monitoring manipulator, indium forming manipulators, OPRD external heating manipulator and calandria internal and external CCTV (closed-circuit TV) manipulator, along with a lot of other tools and tackles were conceptualized and developed to meet the challenge.

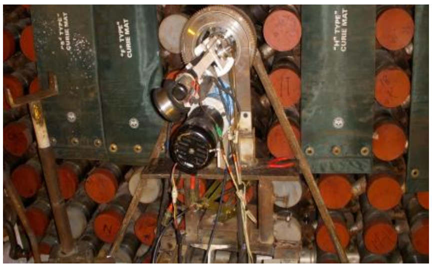
The repair was completed safely during 1996-97 in the first PHWR by well-planned remote operation in a very high radiation field.

### 5.3 Installation of Moderator Spargers in MAPS

The moderator inlet manifolds have been provided in earlier generation PHWRs (RAPS and MAPS) to maintain appropriate flow of moderator to dissipate its heat, thus limiting the temperature within the designed range. The manifolds provided in MAPS-1&2 failed in 1990, forcing operation of these reactors at reduced flow of moderator in calandria, essentially to maintain outlet temperature. This led to forced reduction in the rating of these reactors from 220 MW to 170 MW.

During the EMCCR of these units, an innovative technological solution, after detailed flow studies, was conceived, evolved and implemented. This involved replacement of three calandria tubes with perforated spargers. It was quite complex work in view of rolling of the sparger tubes on irradiated tube sheet and remote boring and grooving operation on the tube sheet. All tools, remotely air/electrically operated, were developed successfully and qualified on mockup. This operation restored the required moderator flow in the calandria and unit rating was restored to 220 MW.

### 5.4 Repair of End-shield in Kaiga-3



A light-water leak in O-10 channel of tri-junction weld joint between the calandria-side tube sheet, baffle plate and the lattice tube was detected and successfully repaired in Kaiga-3 south end-shield. The biggest challenge was to restrict the temperature of the nearby calandria tube rolling joint, which was only 2-3 mm away from the repair spot. Utmost care was exercised to avoid any damage to this rolled joint due to tools or heat input.

Economical general-purpose CCTV cameras were used. The innovative idea of developer technique with cyclic drying was used to pinpoint the exact leak location. Two sets of innovative, remotely operated tools and fixtures were conceptualized, engineered and manufactured. These were used for successful machining and repair of the defect remotely from a distance of about 3 m through a small opening of 150 mm.

Meticulous planning and dedicated efforts ensured repair of the leak in allotted time and manrem consumption.

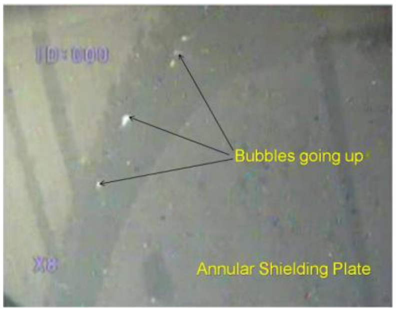
### 5.5 Repair of Leak in Calandria Vault of KAPS-1

**Calandria Vault and Leak Detection**

After initial few years of operation, light-water leakage was observed in the calandria vault (CV) of KAPS-1.

Effort on several occasions to detect and locate this leak using the available techniques did not help.

Calandria vault is a reinforced heavy concrete rectangular structure (13.7 m x 7.46 m x 16 m height) and houses core components such as calandria and end-shields. It is lined from inside with 5-mm-thick carbon steel plates, which are zinc-metalized on inner surface to prevent corrosion. The liner is integral with the vault concrete and consists of panels of carbon steel plates welded to grid work of structural steel members. In the north and south walls, end-shields are anchored and grouted. In the east and west walls, a number of penetrations are provided for various pipings, such as moderator cooling system pipes, vault water cooling system pipes, OPRDs etc. The vault is covered from top by 1.8-meter-thick concrete hatch beams. Calandria vault (CV) is filled with demineralised water, which provides shielding and it also cools the concrete. Vault water is circulated through CV cooling system to dissipate the heat. Radiation fields inside CV are very high even during shutdown (approximately 50000 rad/hr) and hence a manual access is not possible.

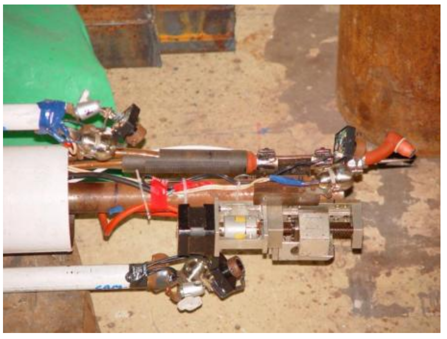



Detection of leak location and repair of defect was taken up during the en-masse coolant channel replacement (EMCCR) work of KAPS unit-1. Since radiation fields inside CV are very high, all the inspection and repair work was to be carried out remotely. It involved development of special tooling, inspection techniques, repair techniques, mock-up trials and qualification of techniques, actual repairs, examination and qualification of the repaired areas.

A half-scale mock-up of CV was designed and constructed. End-shield support plate and dry pack areas were simulated in the concrete wall of the mock-up. Artificial defects were created in the mock-up to simulate the defects in the liner.

Various techniques for leak-location identification, such as air-bubble leak test method, dye method, ultrasonic leak-detection method, thermography, etc. were tried on the mock-up. Out of all these methods, air-bubble leak test method was found to be most suitable for this leakage. For carrying out this test on CV, air was pushed under pressure in between the interface of CV liner and concrete and bubbles were observed in the vault water using remotely operated camera. For air pressurization, holes were drilled in the dry pack area below end-hield, where the water was leaking out. During the leak-location identification, the whole inner surface of the vault was viewed by providing cameras and light arrangements on the all four corners of the vault. Full scanning of the CV was carried out. Leaks were found in the lug-plate plug welds of end-shield (north) and in the weld between add-on liner (14-mm-thick) and the end-shield ring. Defects were characterized and root-cause analysis was done.

**Leak Repair**



To repair the end-shield lug-plate plug leak, schemes were made to approach the defect location from the fuelling machine vault (FM vault). Automatic TIG welding with AVC was designed and developed for making the repair weld. Remote welding tools were developed and mock-up trials were carried out to finalize the welding technique and the welding parameters. The repair was carried out by welding a separate plug at the leak location from FM vault side. Dye penetrants and vacuum box leak tests were carried out to qualify the repair welding.

The leak in the weld between add-on liner and end-shield ring, was taken up from inside the vault by lowering down the welding manipulator through the hole in the top hatch beam. Remotely operated tools for cleaning/grinding of the defect and soap bubble test were designed and developed. Automatic TIG welding with special procedure to suit the defect geometry and the surface condition was developed. Special-purpose manipulator to carry the welding fixture was designed and developed. The manipulator has the provision to locate and fix the welding fixture at the defect location in the 70-mm space in between endshield ring and annular shielding plate. The manipulator is lowered through the 110-mm-diameter hole in the top hatch beam and operated from the platform 3 meters above the top hatch to reduce the manrem consumption. Repair welding was successfully completed and soap-bubble leak test was carried out to qualify the repair weld.

The work of leak-location identification and repair of the leaks was a very challenging job. Development of remotely operated automatic welding tools and their manipulators was a highly specialized and complex job. It is a remarkable in-core repair work accomplished first time in PHWRs in the world.

## 6.0 Future Plans

### 6.1 The Needs

Although India is the fifth-largest producer of electricity, about 40 % of the population of the country does not have access to electricity today. The per capita consumption of electricity, which has a direct correlation with the Human Development Index, is very low at about 700 kWh per annum, about a fourth of world average and way below that of advanced countries. There exist shortages in energy and peak power in the range 10-15%.

Rapid economic growth is also critical to achieve developmental objectives and poverty alleviation. In fact, a sustained economic growth of about 8 to 10% is needed over the next few decades. As electricity is a key driver for economic growth, it is necessary that there is a massive augmentation in electricity capacity, apart from transmissions and distribution systems.

The Integrated Energy Policy of the country projects the need for an installed capacity of about 778 GW by the year 2032 for a growth rate of 8%, of which nuclear power is envisaged to be about 63 GW by 2032.

However, given India’s energy resource profile, it is inevitable that the long-term electricity needs have to come from nuclear energy. Thus, capacity addition in line with the three-stage programme of FBRs for the multiplier effect and followed by thorium-based systems for long-term sustainability of the capacity need to be pursued vigourously, while LWRs based on international cooperation will play an important role in the near term. The intergration of

LWRs into the three-stage programme, when spent fuel of LWRs is reprocessed to fuel the down-the-line FBRs is crucial for meeting the long-term electricity requirements.

### 6.2 Capacity Addition Plan up to 2032 and Beyond

The capacity addition plan in the medium term for reaching a capacity of 63,000 MW by 2032 envisages addition of indigenous PHWRs of 4200 MW based on natural uranium, 7000 MW from PHWRs based on reprocessed uranium from LWR spent fuel, 40000 MW from LWRs and the balance through 500-MW/1000-MW FBRs. Other reactors like the Advanced Heavy Water Reactor (AHWR), a technology demonstrator for thorium utilization and Indian LWR under development are also planned.

Beyond 2032, the main capacity addition is expected from metallic-fuel-based FBRs that are currently under development. The first of these reactors is expected to come on line in next two decades .

## 7.0 Key R&D Goals for Future

As discussed earlier, addition of new capacity and sustaining the existing capacity are key to having a large nuclear power capacity. While other issues like infrastructure, financing, industry capacity and capability are being separately addressed, the key will be development of technology. The development of cutting-edge, safe, reliable and affordable technology is the responsibility of the nuclear community – our responsibility. Sustained and focused R&D are the underpinnings of development of these technologies.

Some of the key R&D Goals are:

- **Development of Metallic FBRs**

Metallic FBRs are key to providing the multiplier effect, as they have a low doubling time. It is thus crucial to ensure the successful development of the metallic-fuel FBR and its fuel-cycle facility, including pyro-chemical reprocessing for low out-of-pile time of the fuel.

- **Development of the Third Stage and Beyond-Third-Stage technologies**

The demonstration of AHWR and its fuel-cycle facilities for thorium utilization and other thorium-burning systems, development of Accelerator Driven Systems (ADSs), Indian High Temperature Reactor (IHTR), molten-salt reactors, etc.

- **Waste-Management Technologies**

Sustainability of nuclear power depends on management of wastes. Thus, advanced technologies in partitioning and conditioning as well as disposal, including deep geological depository development, are priority area.

- **R&D for Sustaining Operating Capacity Longer**

New health-assessment techniques, development of better materials and manufacturing technologies, development of advanced, high burn-up, high reliability fuels, new cooling technologies for increased efficiency are the priority areas.

## 8.0 Conclusion

Indian nuclear power programme is fully developed and has graduated in all facets of nuclear power technology. The indigenous three-stage nuclear power programme is robust and on course. The challenge of large-scale nuclear power capacity addition in a rapid manner has, indeed, provided an opportunity for further enhancing country's capability in adopting and implementing diverse technologies.

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