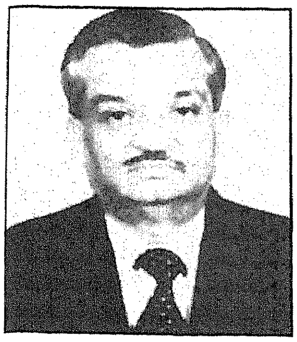

Nuclear Energy in India

by Dr Anil Kakodkar & Dr Ravi Grover

Introduction

In his presidential address at the International Conference on the Peaceful Uses of Atomic Energy in Geneva in August 1955, Homi J Bhabha, traced the growth of the civilisation, correlating it with the increase in energy consumption and the development of new energy sources. He emphasised [1]: "For the full industrialisation of the under-developed countries, for the continuation of our civilisation and its further development, atomic energy is not merely an aid, it is an absolute necessity. The acquisition by man of the knowledge of how to release and use atomic energy must be recognised as the third epoch of human history."

Bhabha and his colleagues commenced a detailed study on the needs and merits of India taking up R&D in atomic energy to meet its developmental needs [2 & 3]. The study concluded that 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. This conclusion is as true today as it was in the mid-fifties and led to the setting up of R&D facilities to pursue development of nuclear power and the ultimate construction of nuclear power plants.

All studies took cognizance of India's nuclear resource profile, and a three-stage nuclear power programme was formulated by Bhabha [4]. Pressurised Heavy Water Reactors (PHWRs) were chosen for the first stage of the nuclear power programme (Figure 2).

The decision to adopt PHWRs for India's nuclear power programme was based on best utilisation of our Country's limited uranium resources, higher plutonium yield which was considered necessary to lay the foundation of fast reactors to be set up in the second stage, freedom from import of enriched uranium which is necessary for light water reactors, and the then existing industrial capability in India to manufacture components required for the reactor systems.

Initially, to jump-start the nuclear power programme, two Boiling Water Reactors were set up at Tarapur near Mumbai. The reason for this choice lay in favourable performance guarantees for these reactors and the need to gain experience quickly in running nuclear power plants. These reactors are still in operation.

R&D Strategy

Having conceived a three-stage programme for setting up nuclear power reactors, the Atomic Energy Establishment was set up at Trombay in 1957 and was renamed as Bhabha Atomic Research Centre in 1967. Additional research centres and industrial units were progressively set up over the years by the Department of Atomic Energy (DAE) and DAE has been quite successful in deploying the results of R&D for the benefit of the nation. A list of the areas covered by such R&D efforts is as follows:

- Beneficiation and concentration of uranium and thorium ores to utilise indigenous resources.
- Process and technology for converting concentrates into both metallic and ceramic uranium fuels to be used respectively in research and power reactors.
- Technology for the production of heavy water for use in reactors using natural uranium.
- Development of processing routes for special nuclear materials, extractive metallurgy for toxic materials, purification processes, special-purpose equipment and machinery, and joining techniques.
- Setting up of research reactors and critical facilities.
- Study of reactor physics for thermal and fast reactors and design of different reactor systems and their comparative evaluation.
- Technology development for the design and manufacture of reactor equipment and components for PHWRs and research reactors.
- Reactor safety studies to continually improve safety of existing reactors and to incorporate latest concepts in new reactors at the design stage.
- Studies in life management of reactors and development of repair techniques.
- Fast reactor engineering, liquid sodium technology and technology development for setting up of fast reactors.
- Control and instrumentation for reactors, nuclear instrumentation, instrumentation systems for various metallurgical and chemical processes.
- Study of chemistry of heavy elements with a view to separating plutonium and other actinides from the spent fuel from reactors, leading to reprocessing technology on a commercial scale.
- Study of both radiochemistry and radio-metallurgical aspects of plutonium leading to recycling of the fissile material recovered from reprocessing for reuse in reactors.
- Study of chemistry required for the development of processes to decontaminate radioactive effluents and the development of technology for immobilising high-level wastes in stable vitreous matrices for long-term isolation of radioactivity from human biosphere, thus ensuring environment protection.

These efforts encompass every aspect of the nuclear fuel cycle and, as a result, India now has a solid base to expand its nuclear power programme as per requirements and availability of finance.

During the year 2002-03, nuclear power plants generated 19.358TWh of electricity and this was about 3.7% of total electricity generated in the country. In percentage terms, it may not be significant, but does signify the fact that we have been able to master this advanced technology. We are now poised for rapid growth of nuclear generating capacity in the country. In around four years from now, we should reach an installed capacity of around 4,500MWe with pressurised heavy water reactors, the mainstay of the first stage of our indigenous nuclear power programme, and another 2,320MWe with light water reactors making a total of around 6,800MWe (as against the present capacity of 2,770MWe).

In September 2003, the Government of India approved construction of a 500MWe prototype Fast Breeder Reactor marking the launching of the second stage of the nuclear power programme and successful implementation of this programme will open up a vast source of energy for the development of the country. Our medium term plan is to increase the nuclear installed capacity to about 20,000MWe by the year 2020.

Reactor Type & Location	Capacity
14 operational reactors at 6 sites: Tarapur, Rawatbhata, Kalpakkam Narora, Kakrapar and Kaiga	*2,820MWe
6 PHWRs under construction at: Tarapur (2x540MWe), Kaiga (2x220MWe), RAPS-5&6 (2x220MWe)	1,960MWe
2 LWRs under construction at: Kudankulam (2x1000MWe)	2,000MWe
PFBR under construction at: Kalpakkam (1x500MWe)	500MWe
Projects planned up to 2020: PHWRs (8x700MWe), FBRs (4x500MWe), LWRs (6x1000MWe), AHWR (1x300MWe)	13,900MWe
Total installed capacity at 2020:	**21,180MWe**
* includes 50MWe to be added after MAPS-1 upgrade	

Pressurised Heavy Water Reactors

The plans for setting up the first PHWR were finalised in 1964 and involved building a single reactor of 200MWe capacity at Rawatbhata, near Kota, in the state of Rajasthan (Figure 1), with the possibility of adding another unit later. The Canadian reactor at Douglas Point, on which RAPS-1 was modeled, was under construction then. Construction of RAPS-1 began in 1964.

The Douglas Point reactor began operation in 1966 and shortly after that an agreement was signed with Canada to build a second unit at Rawatbhata. Reactors at Rawatbhata were prototypes for India as was Douglas Point for Canada. There was a tremendous sense of satisfaction when RAPS-1 began feeding power into the grid in November 1972.

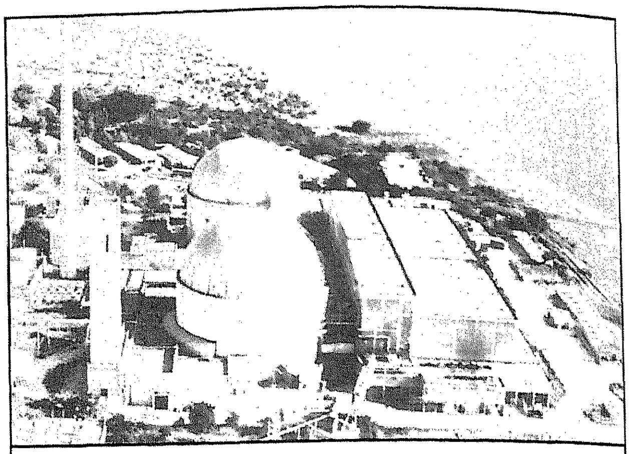

Figure 1: RAPS 1 & 2 Reactors at Rawatbhata

The reactors at Rawatbhata were followed by two reactors at Kalpakkam near Chennai (earlier called Madras). Certain bold changes were made in the design of the reactors at Kalpakkam (Figure 4). The huge dousing tank was eliminated and replaced by a suppression pool located in the basement of the building. A submarine tunnel, the first of its kind in India, was built to bring sea water to the plant. The reactors at Narora (NAPS) were built subsequently and incorporated several changes keeping in view the evolving safety requirements, seismicity, ease of maintenance, requirement of in-service inspection, improved constructability, improved availability and standardisation of design.

Subsequent 220MWe units are all similar to NAPS with certain modifications to reflect advances in technology and feedback from operations. The 540MWe units being built now at Tarapur incorporate further modifications and new concepts to match the latest trends over and above the 220MWe design. Units to be built in future will be of 680/700 MWe rating and will be a further evolution. In particular, these units are designed to allow partial boiling of the coolant in some of the channels.

In the standardised design, two independent, fast-acting, shutdown systems, operating on diverse principles, have been incorporated. In addition, to fast-acting shutdown systems, Automatic Liquid Poison Addition System (ALPAS) or Liquid Poison Injection System (LPIS) is incorporated. A separate shutdown cooling system consisting of two sets of equipment is also incorporated to reject decay heat during cold shutdown conditions. The emergency core cooling system of standardised 220MWe units consists of high-pressure heavy water injection from an accumulator, intermediate-pressure light water injection from accumulators, and long-term recirculation using the suppression pool.

The standardised design incorporates a primary containment (PC) surrounded by a secondary containment (SC) with a gap of about 2m. The PC is a pre-stressed concrete structure designed to withstand the peak pressure estimated to be reached in the unlikely event of a loss-of-coolant accident (LOCA). The SC is a reinforced concrete structure and envelops the PC. The space between the PC and the SC is maintained at a negative pressure during accident conditions by purging the air from the space to a stack after passing it through a set of filters. A passive pressure suppression system in the form of a 2.4m deep water pool is provided at the base of the PC for limiting the peak pressure in the containment following a LOCA. Equipment layout ensures decay heat removal by thermo-siphon and as a confidence-building measure, an experiment was carried out successfully at Narora to study the thermo-siphon characteristics of Indian PHWRs.

Over a period of fifty years, DAE have acquired considerable experience in the area of structural analysis and design of nuclear components. Several computer codes have been developed for physics design, in-core fuel management, system analysis during normal operating conditions as well as during postulated accident conditions, and for loading thorium fuel bundles for initial flux flattening.

At the time of evolving the strategy for establishing nuclear power generation technology in India, a very strong base was created within DAE for achieving self-sufficiency with respect to special material technologies necessary for the Nuclear Steam Supply System (NSSS). This includes the capacity to design and manufacture fuel, heavy water, pressure tubes, calandria tubes, and other Zircaloy components. Technology for the manufacture of equipment for the primary heat transport and moderator systems was developed in close interaction with several industrial houses.

This, in fact, highlights a very important difference between the nuclear power generation programmes of industrialised countries and India. In the advanced countries, the nuclear power programmes were supported by a manufacturing industry, which had already been well developed by virtue of defence, aerospace and petrochemical projects undertaken by them. In India, it was the demands placed by the nuclear power industry which was instrumental in the development of the capacity and capability of manufacturers and the growth of design consultants.

First-of-a-kind manufacturing of equipment and components was done in-house by the organisations of the DAE. Several test facilities were also set up for type-testing and calibration - some of these facilities are still in use.

With regard to the balance of plant equipment, R&D (as well as production) was entrusted to manufacturers already engaged in the thermal power industry and they have done a good job.

The interaction of the DAE with Indian industry has been responsible for introducing the highest level of quality control and surveillance in the manufacture of equipment and components to meet the requirements of codes such as ASME Section III. DAE has introduced a wide-range of hi-tech manufacturing techniques to industry in general

A nuclear power plant encompasses a large number of items ranging from small valves to large pumps and motors, to huge steam generators and the calandria assemblies. Several of them are located in high radiation environments that makes maintenance difficult. Most of the repair jobs therefore involve development of robotic and remote handling devices and any major maintenance activity is a challenge. Over the years, this capability has been achieved and, as a result, nuclear reactors in India are operating at high capacity factors. Coolant channels of some of the older PHWRs have been replaced in a very economic manner based on technology developed in-house.

Nuclear power technology in India has thus reached a state of maturity and the Department of Atomic Energy continues to take steps to further its development. These steps are aimed at further improving the safety and availability of operating stations, reducing the gestation period of plants under construction by using innovative management techniques, cost optimisation and development of new reactor systems. One of the components of the project gestation period is the time taken between hydrotest to commercial operation and NPCIL has been able to reduce it from 854 days for a plant (KAPS-2) commissioned in September 1995 to 161 days for a plant (RAPS-4) commissioned in December 2000 (Figure 5).

To further shorten the gestation period, for the plants now under construction, execution is being done by

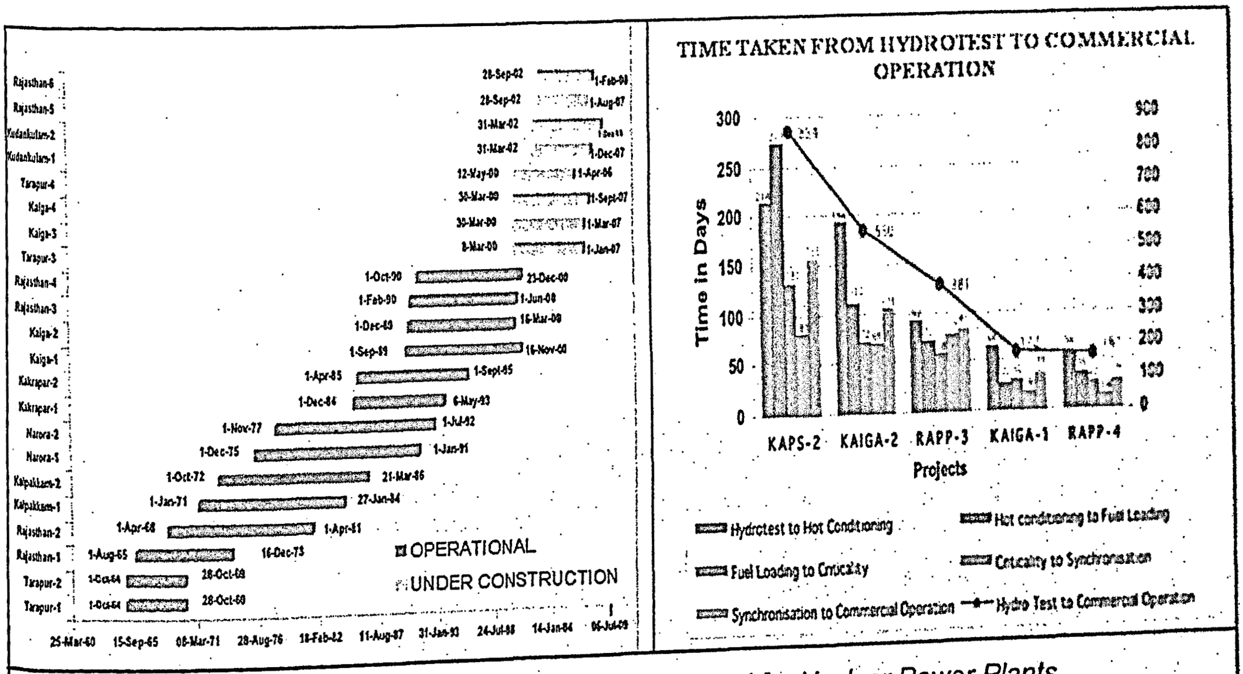

Figure 5: Reduction of the Gestation Period for Nuclear Power Plants

contracting-out packages of activities rather than single activities. This approach simplifies coordination, and therefore increases speed of execution of various works. In parallel to technical aspects, organisational aspects have also been evolving with time. First, Power Project Engineering Division was set up in 1967 and was entrusted with the responsibility for the PHWR programme. With continual expansion of the programme, the Nuclear Power Board was set up in 1984, which was converted into a company, Nuclear Power Corporation of India Limited (NPCIL), in 1987. Today NPCIL manages design, construction and operation of all nuclear power reactors in the country.

Indian industry is geared to manufacture equipment needed for the setting-up of nuclear power plants. Plants for the production of heavy water, fabrication of fuel and mining of uranium are under direct control of the Department of Atomic Energy and their performance during the recent years has been excellent. Heavy water plants are working at full capacity and continuously implementing measures to conserve energy. India's experience in managing the back-end of the fuel cycle is also noteworthy. Fuel reprocessing started in India early in the programme based on indigenous efforts. At present, India has three reprocessing plants to extract plutonium from spent fuel, the first at Trombay, the second at Tarapur and the third at Kalpakkam.

With total protection of the environment as an overriding consideration, management of the radioactive waste in the fuel cycle has received high priority in India's nuclear programme right from inception. Facilities for managing intermediate and low level wastes have been set up and are operating successfully along with every nuclear facility in the country. To treat high-level waste from reprocessing plants, waste immobilisation plants, incorporating hi-tech features like complete remote operation and maintenance, have been set up at Tarapur and Trombay. A facility for interim storage of vitrified waste has also been built at Tarapur. For ultimate disposal of high-level waste, research on setting-up an underground waste repository is in progress.

New Reactor Systems

With regard to the new reactor systems, Indira Gandhi Centre for Atomic Research (IGCAR) has completed the design and technology development of a 500MWe Fast Breeder Reactor and, as mentioned earlier, its construction has been sanctioned by the Government of India. Excavation has already started and the first pour of concrete is expected within a few weeks. Construction of this reactor marks the beginning of the second stage of the nuclear power programme based on fast breeder reactors, which has a significantly large potential as compared to the first stage (Figure 2).

To manage the fast breeder reactor programme, a new company called Bhartiya Nabhikiya Vidut Nigam (BHAVINI) - incorporating the technical expertise of IGCAR and the project management expertise of NPCIL - was set up in 2003.

The third stage envisages development of reactors based on thorium and, towards this end, BARC is developing an Advanced Heavy Water Reactor (Figure 3). There are basically four reasons for carrying out development of an AHWR system:

- Nuclear fuel resource available to us in plentiful quantities to sustain a large power programme is thorium and we must develop technologies for its utilisation as early as possible and keep interest in thorium-related R&D alive.
- The experience available in India with heavy water technology must rapidly translate into a system based on thorium. It would also help us to keep all heavy water related technologies in a state of readiness.
- Uranium-233, which is the fissile isotope derived from thorium, runs equally well in thermal as well as fast spectrum. Since India has a mature thermal reactor technology, there is a strong motivation to continue with this. At a later point in time, when the fast reactor technology has also fully matured, we can make a relative comparison. AHWR core can also be used as a passive blanket for Accelerator Driven Sub-critical Systems (ADS), which we propose to develop in the near future.
- The development of AHWR has given us an opportunity to incorporate several passive safety features in the design of this reactor, for example heat removal by natural circulation.

Successful completion of the development of AHWR technology will be a major milestone in our endeavour to utilise thorium. A detailed project report for AHWR has been prepared and its construction will be launched after obtaining all clearances.

India has also prepared a road map to develop accelerator driven sub-critical systems (ADS). As a first step towards this, a project to build a 100MeV, 10mA CW Proton Linac has been initiated. As part of a strategy to expand the role of nuclear energy source - an inevitable necessity in the future - the development of High Temperature Reactor technology has also been initiated in the form of a Compact High Temperature Reactor.

Concluding Remarks

Indian Atomic Energy programme has come of age. The programme has successfully delivered a self-reliant capability for its first stage involving setting-up of Pressurised Heavy Water Reactor Systems and associated fuel cycle plants. We have launched commercial Fast Breeder Reactor technology. It is time now for us to accelerate the development of the third stage, which would take us closer to our ultimate objective of exploitation of our vast thorium resources to address our long-term energy needs. On the basis of achievements so far, we can feel confident that this challenge will also be met.

The Indian economy is now on a fast track. Our dream to realise a quality of life for our people, commensurate with other developed countries, could now become a reality. One of the necessary prerequisites for this purpose would be the availability of electric power at the required level in view of direct correlation between per capita electricity consumption and per capita income. Assuming that energy intensity of the GDP will continue to decline as in the past several decades and the fact that being a tropical country, India does not need energy for heating, India would have to plan to reach a modest target of electricity generation of 5000kWhr per year per capita to provide a decent quality of life to its citizens.

India's population could rise to 1.45 ~ 1.5 billion by the year 2050. This would call for a total electricity generation of about 7,250 to 7,500 billion kWhr per year. This is an order of magnitude higher than the generation in the fiscal year 2002-03 and calls for developing a strategy for growth for electricity generation based on a careful examination of all issues related to sustainability including abundance of available energy resources, diversity of sources of energy supply and technologies, security of supplies, self sufficiency, security of energy infrastructure, effect on local, regional and global environment, health externalities and demand side management.

A recent study carried out at DAE examines all available energy resources in the country, the prospective plans of the various Departments of the Government of India and imperative to keep the energy import at manageable levels and constructs a scenario calling for a quarter of all electricity generation to be based on nuclear by the middle of the century. In reality, the share would inevitably have to be much higher. Clearly, realisation of such large nuclear power capacities would necessitate not only construction of a large number of fast breeder reactors and Thorium reactors but also the associated nuclear fuel recycle facilities.

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World First for BNFL Sellafield

BNFL Sellafield became the first non-reactor site to join the World Association of Nuclear Operators (WANO) at a signing ceremony on January 14th, 2004.

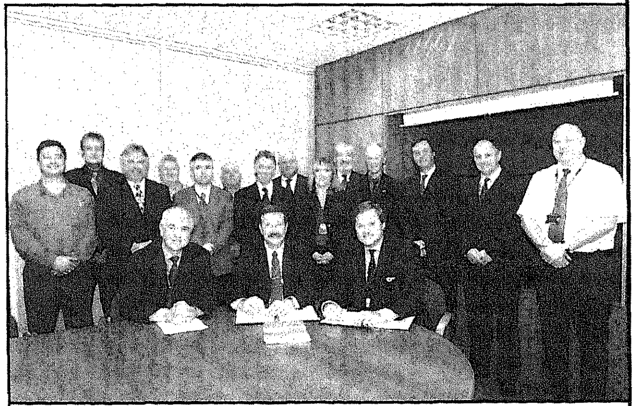
WANO is dedicated to improving the safety and reliability of nuclear power plants. Two years of co-operation between BNFL and WANO, including visits to Thorp and Sellafield's effluent treatment facilities, has demonstrated the benefits of extending WANO's review process to all nuclear plants. As a result, the Board of WANO have agreed to enter into a Partnering Membership Agreement with BNFL Sellafield.

The agreement was formally signed by Yves Canaff, Director of the WANO Paris Centre, and Lawrie Haynes, Chief Executive of BNFL's Government Services Group. Also present at the ceremony was Brian Watson, Director of Sellafield, and Paul Thomas, Director of Environment, Health Safety and Quality at BNFL.

Speaking ahead of the ceremony Lawrie Haynes said: "WANO's process for sharing worldwide best practise is widely recognised for its positive contribution to the safety and reliability of reactor operations. The work carried out at Sellafield demonstrates its value for all nuclear facilities, and everyone involved in these programmes should be proud of their contribution to continuous improvement of nuclear safety. It is only by sharing our experiences in this way that we can bring everyone to the standard of the world's best."

Yves Canaff said: "WANO was set up to help share good practice across power plant operators. Our visits to Sellafield have shown us that operators of both reactors and non-reactor nuclear plants can learn from each other. We are very pleased to welcome BNFL Sellafield to our organisation, and look forward to demonstrating the value of this relationship to other similar operators."

Speaking for BNFL Sellafield, Brian Watson said: "It is always a daunting experience to be the first of a kind, but the teams involved in the Sellafield visits worked tremendously hard to ensure a positive outcome for both parties. I believe this agreement puts us in an excellent position to drive forward the continuous improvements in safety and reliability that we and our stakeholders rightly expect."

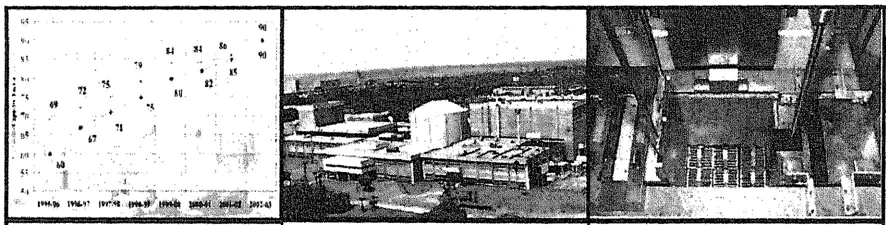


Yves Canaff (seated centre - Director of WANO Paris Centre) with left Brian Watson (Director of Sellafield) and right Lawrie Haynes (Chief Executive of BNFL's Government Services Group). Surrounding these three are members of BNFL project teams who have been working to secure membership of WANO.

WANO was established in 1987 to improve the safety and reliability of nuclear power plants. It does this by facilitating peer visits by mixed discipline teams drawn from its member organisations to stations operated by other members. This process ensures that both parties to the visit can share best practise and operating experience.

Every nuclear reactor operating company across the world is a member of WANO, and the sustained programme of review visits has yielded demonstrable improvements in safety and reliability world-wide.

For further information please contact the Sellafield Press Office on: 019467-85842.



Stage – I PHWRs

- **12- Operating**
- **6 - Under construction**
- Several others planned
- **Scaling to 700 MWe**
- **Gestation period being reduced**
- POWER POTENTIAL ≅ 10,000 MWe

LWRs

- 2 BWRs Operating
- **2 VVERs under construction**

Stage - II
Fast Breeder Reactors

- **40 MWth FBTR -** Operating since 1985 Technology Objectives realised
- **500 MWe PFBR- Under Construction**
- POWER POTENTIAL over 520,000 MWe

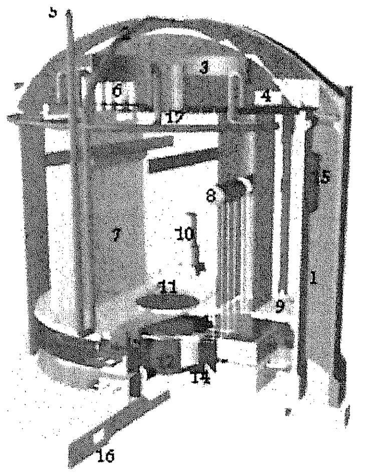
Stage - III
Thorium Based Reactors

- 30 kWth KAMINI- Operating
- 300 MWe AHWR- Under Development

POWER POTENTIAL IS VERY LARGE
Availability of ADS can enable early introduction of Thorium on a large scale

Figure 2: The Three-stage Nuclear Power Programme

Figure 3: Advanced Heavy Water Reactor



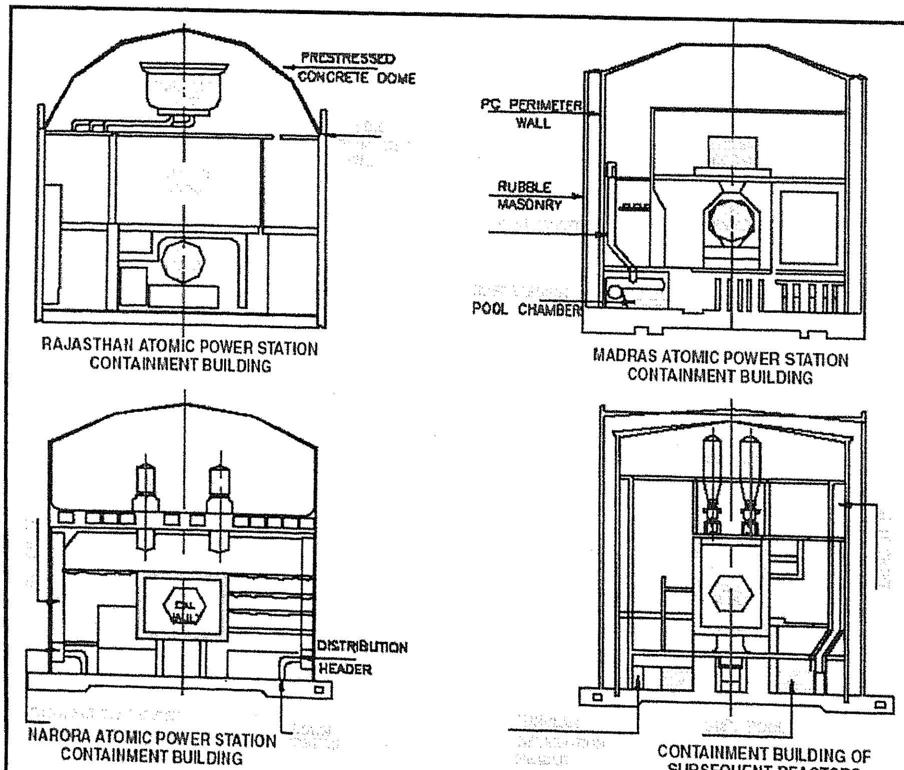
1 Secondary Containment
2 Primary Containment
3 Gravity Driven Water Pool
4 Isolation Condenser
5 Passive Containment Isolation Duct
6 Vent Pipe
7 Tail Pipe Tower
8 Steam Drum
9 100 M Floor
10 Fuelling Machine
11 Deck Plate
12 Calandria with End Shield
13 Header
14 Pile Supports
15 Advanced Accumulator
16 Pre - Stressing Gallery
17 Passive Containment Cooler

● BASIC DATA

FUEL :U-233/THORIUM MOX + Pu-239/THORIUM MOX
COOLANT : BOILING LIGHT WATER
MODERATOR : HEAVY WATER
POWER : 235 MW(e)

● ADVANCED SAFETY FEATURES

1. -Ve VOID COEFFICIENT OF REACTIVITY
2. SEVERAL ADVANCED PASSIVE SAFETY SYSTEMS
3. LARGE HEAT SINK ALLOWING 3 DAYS GRACE PERIOD



RAJASTHAN ATOMIC POWER STATION CONTAINMENT BUILDING

MADRAS ATOMIC POWER STATION CONTAINMENT BUILDING

NARORA ATOMIC POWER STATION CONTAINMENT BUILDING

CONTAINMENT BUILDING OF SUBSEQUENT REACTORS

Figure 4: Evolution of PHWR Technology