

Nuclear Power- A Successful High Technology Commercial Enterprise

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1.0 Introduction

India is home to over 16% of the world population. It is a vibrant, one trillion dollar economy growing at an annual rate of 8-9 %. Energy, especially electricity is a key driver for economic growth and a large growth in energy demand is projected. India, however, is not a very energy rich country and has just about 6% of the world's primary energy resources. Hence, no single source can meet the huge energy demand projected (1300 GWe by 2050). Hence all energy resources, including nuclear power have to be optimally deployed.

As, it was known that the country has modest resources of Uranium (61,000 tons of metal), the nuclear power in India was conceived initially to supplement other sources of power generation and specifically at locations away from coal mines. Since the country is having third largest Thorium reserves in the world (2,25,000 tons of metal), a sequential three-stage nuclear power programme was conceived to optimally utilize modest uranium and abundant thorium resources in a closed fuel cycle to enhance the energy potential of nuclear fuel.

Self-reliance has been the hallmark of the Indian nuclear power programme. Nuclear power in commercial domain in India has gone through distinct phases of Technology demonstration, Indigenisation, Standardization, Consolidation and Commercialization. Concerted efforts by Department of Atomic Energy (DAE) establishments have brought the country to a maturity in front end technologies i.e. exploration, mining, processing of ore, fuel fabrication, heavy water production etc. and back end technologies of spent

fuel reprocessing and waste management. Today, India has a sound R&D base with several developments in frontier technology, well-developed industry ready to meet any high technology challenge of manufacture & supply equipment and a fast-expanding nuclear power programme. Each of these phases has been no less than a revolution. The capabilities of operating nuclear power plants at high capacity & availability factors both, an excellent safety record, ability to construct projects with five years and expertise in in-core jobs have been demonstrated by NPCIL. The nuclear power plants in the country have so far generated about 270 billion units of electricity. The second stage of the three-stage programme is launched for commercial application through the 500 MWe Prototype Fast Breeder Reactor (PFBR) being constructed at Kalpakkam in Tamilnadu. This has marked a distinction to the country for having developed FBR technology.

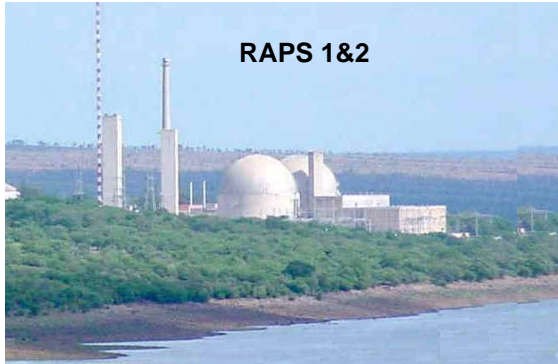
2.0 Technology Demonstration

As a first step to establish the techno-economic feasibility of nuclear power plants in India and to operate and maintain the nuclear power stations in regional grid system, two reactors were imported from the USA. These boiling water reactors (BWRs), set up at Tarapur in Maharashtra were supplied by General Electric Company, USA on turnkey basis and were commissioned. These reactors have served their intended purpose well and continue to be in safe & reliable operation at Capacity & Availability factors of over 90%, after about 38 years of their commissioning. These reactors are also source of cheap electricity, currently at 94 paise per unit.



Nuclear power today is economically competitive with coal thermal power 600-800 km away from coal pitheads. The average tariff of nuclear power during 2006-07 was Rs. 2.19 per unit which compares well with thermal power stations away from coal mines.

The foundation for the first stage of the three stage programme was laid



with the start of construction of RAPS-1&2, the first Pressurised Heavy Water Reactors (PHWRs) set up in technical collaboration with Atomic Energy Canada Limited (AECL). Indian engineers and scientists made significant contributions in the

construction and commissioning of this plant. Even in unit-1 (RAPS-1) some equipment and components were manufactured in India. In the second unit, the fabrication of critical nuclear components like end-shields, steam generators, calandria etc. was taken up indigenously.

The commissioning of RAPS-2 was entirely by the Indian scientists and engineers when the Canadian cooperation was discontinued in 1974.

3.0 Development of Indian Industry- Challenges

When nuclear power programme was shaping up in India in 1960s and early 1970s, the Indian industry was nascent. Some small and medium-size thermal power stations, some fertiliser and cement kilns, boiler drums and simple chemical reactors were the kind of manufacturing and fabrication jobs undertaken by the Indian industry at that time. The industry was new to the fabrication techniques and exacting code standards & requirements for nuclear components.



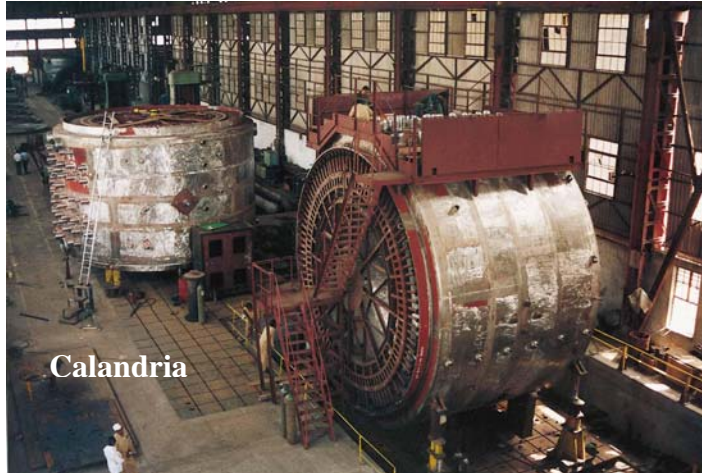
A major challenge before the nuclear establishment in India in the early days was to develop an indigenous industry capable of meeting the

requirements of the nuclear power industry. Efforts were directed at building an industrial base, which could support the stringent requirements of quality demanded by the nuclear industry

In addition, in many cases, the initial design and development activity was started in our laboratories and later passed on to the Indian industry. Special test facilities were created for qualifying products manufactured indigenously. Testing of large primary heat transport (PHT) pumps and motors is a case in point. Facilities available for the qualification of

electronic components, reliability analysis, etc. were extensively used. There has been considerable interaction in the field of metallurgy for material evaluation and qualification also.

Shops and tooling for manufacturing large reactor components like calandria and



Calandria



PHT Pump



Steam Generator

end-shields which required precision-machining were developed by joint efforts of the then PPED (now NPCIL), BARC & industries.

Developing manufacturing facilities for coolant channel components made from zirconium alloys was one of the most challenging tasks. The task was entrusted to Nuclear Fuel Complex (NFC), Hyderabad. NFC successfully met the challenge and supplied these coolant channel components for all the PHWR units except the first one at RAPS. The complete manufacturing cycle of these tubes has been evolved at NFC.

3.0 Journey of Indigenisation & Development of Commercial Nuclear Technology

Recognising the need and aspirations of self-reliance, the scientists and engineers of DAE/NPCIL absorbed the intricacies of the technology and initiated aggressively the indigenisation process as early as late sixties. The indigenous content in RAPS-1 was only about 55%, which increased to about 75% in RAPS-2. When the construction work on the twin-unit PHWR station Madras Atomic Power Station (unit-1&2) at Kalpakkam commenced in early 1970, several major modifications and upgradations were undertaken. Significant among them are partial double containment in Reactor building, improved design and materials for reactor components etc. over its predecessor at Rajasthan (RAPS-1&2). The design, manufacture of components and equipment, construction of plant and its commissioning was entirely by the indigenous efforts. RAPS-1&2 and MAPS-1&2 provided a very valuable experience and feedback in almost all fields of design, manufacturing, construction, commissioning and operation. Several teething problems were encountered during initial phases of operation of these units and overcome successfully.

3.1 Standardization & Consolidation

Based on the operational feedback, a decision was taken in the mid-1970s to standardise future 220 MWe stations. The design of the nuclear components required major modifications in line with then latest code

requirements, to improve the reliability and safety and a higher order of quality, inspection and manufacturing of the components as compared to earlier reactors.

Narora in Uttar Pradesh (UP), was selected for setting up the first of the standardised 220 MWe units. A significant number of developmental works were carried out in-house to meet the design safety and quality assurance requirements. These included a full double containment in reactor building, shell & tube type steam generators having egg-crate type tube supports design and use of advanced material, like Incalloy 800 as tube material, Reactor components and Primary Coolant Pumps with improved design, Emergency Core Cooling System(ECCS), Resin fixation systems for waste immobilization etc. Further, it was the first nuclear power station in country to have a closed loop condenser cooling system with cooling towers. Narora units were built and operated successfully after solving a number of operational problems. Successful operation of Narora units and experience gained thereof provided immense confidence and paved the way for setting up of a series of standardised 220 MWe units at KAPS and later units.

3.2 Expansion & Commercialization

The success of nuclear power in the commercial domain required its accelerated growth and operational flexibility. Recognising this, on September 17, 1987, Nuclear Power Corporation of India Limited (NPCIL) was formed from the erstwhile Nuclear Power Board, to launch nuclear power in the commercial domain. The units in operation and construction then (with the exception of RAPS-1) were transferred to NPCIL

In the late eighties, construction of four 220 MWe units was taken up concurrently, two at Rajasthan (units-3&4) and two at Kaiga (unit-1&2) with still improved features like compact layout, dome in dome type double containment with the Steam Generators fully inside the primary containment. The commissioning of these projects could be completed successfully in the year 2000. These units' operational performance at high Availability and Plant

Load factors matching the world standards indeed endorsed the maturity of 220 MWe PHWRs in the country.

After successful design and operation of 220 MWe PHWRs, the scaling up the unit size in accordance with the rising demand and matching with the grid capacity was undertaken. The design for the next generation PHWRs of 540 MWe size was

conceived and implemented at Tarapur units 3&4. As the 540 MWe reactor core was large, in addition to control rods for global control, zonal control systems comprising of light



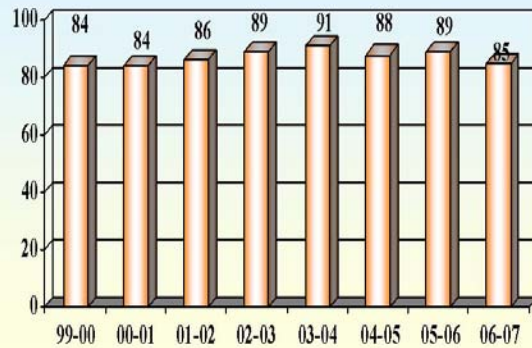
water columns for finer reactivity control were designed and introduced for the first time in Indian PHWRs. The construction of the reactors of 540 MWe capacity at Tarapur (TAPP-3&4) were launched in the year 2000 and completed ahead of schedule by about seven months in 2005/2006. The completion of the first of these units in less than five years was an international benchmark. In parallel, four more units of 220 MWe, at Kaiga 3&4 and RAPP 5&6 respectively were also launched in 2002 to enhance the existing capacity. While Kaiga-3 has already been completed (in five years) and is in operation, the other three are at an advanced stage of completion and expected to be in commercial operation during 2008/2009.

4.0 Performance & Achievements

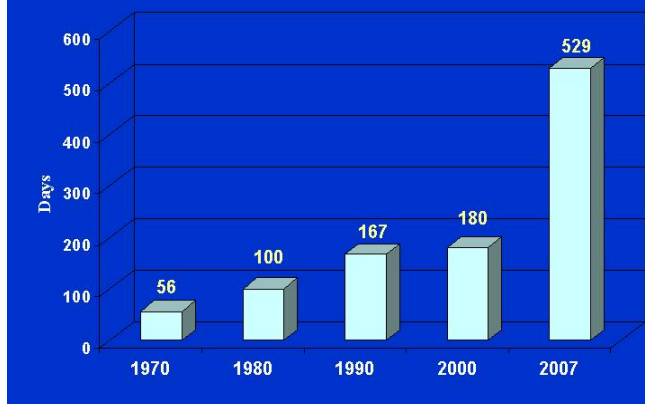
Indian nuclear power plants have progressively attained excellent operational performance comparable to international benchmarks with sustained efforts in operation and maintenance, development and nurturing of qualified human resources at various levels, which is a unique strength of the country today. In the year 2002,

Kakrapar Atomic Power Station (KAPS) was adjudged the world's best operating nuclear power plant among the PHWRs world over. Kaiga-2 completed 529 days of continuous operation recently. Prior to Kaiga-3, many other Indian reactors KAPS-1, NAPS-2 and RAPS-4 also registered

Availability Factor of NPCIL's Units



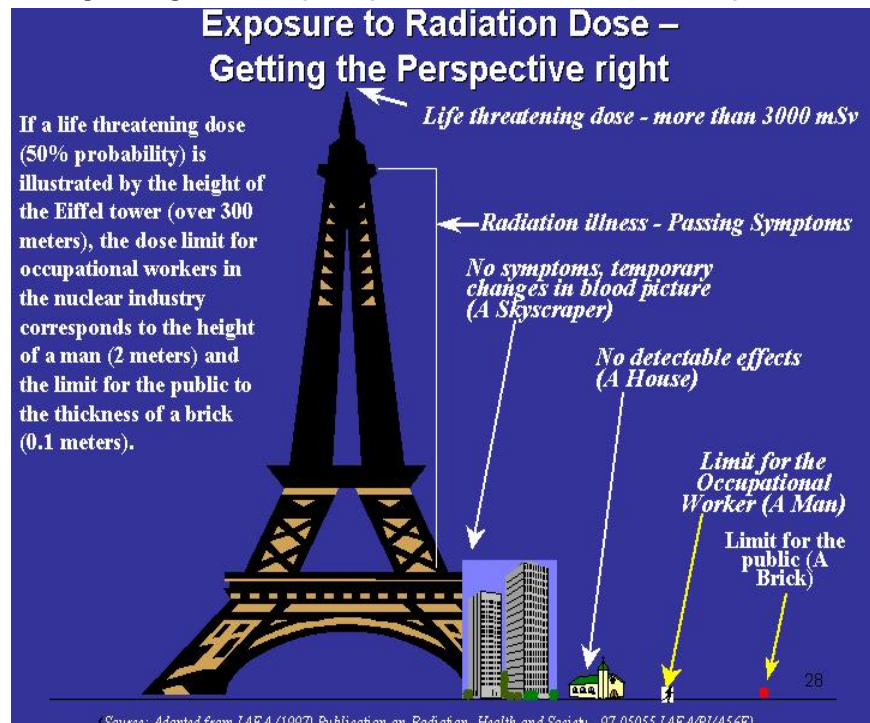
Longest Continuous Operation



continuous operation of nearly a year. The biennial shutdown durations have also been reduced to about 20 days by effective planning and management of shutdown activities. NPCIL units have been operating consistently at high Availability Factors of about 90%.

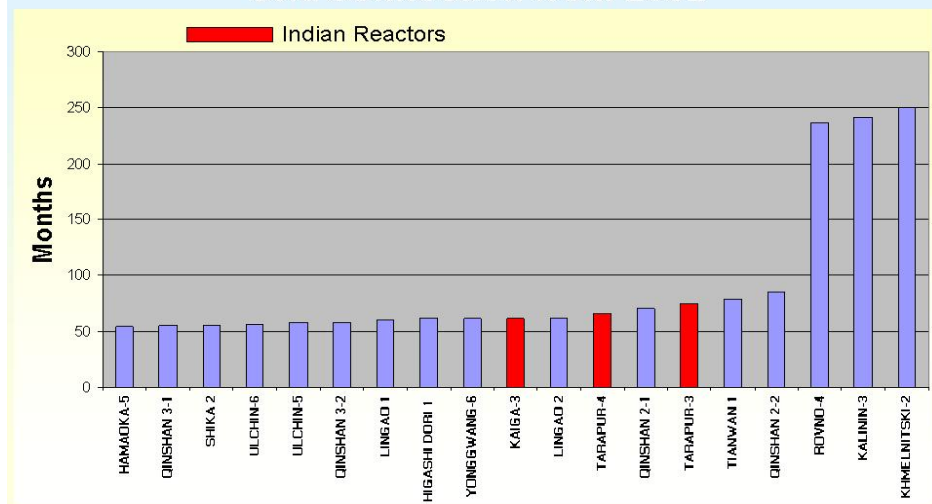
The safety track record of 277 reactor years of operation evidences the strong commitment to safety and demonstrates the strong safety culture of Indian nuclear industry. In Indian nuclear power plants, the radiation dose to occupational workers has been a small fraction of the limits prescribed by Atomic Energy Regulatory Board (AERB), the regulatory authority. The dose to the environment has been an insignificant fraction of the prescribed limit.

The limits prescribed by the AERB are more conservative than the international limits set by the International Commission on Radiation Protection (ICRP). The figure gives a perspective of radiation exposure – while the height of the Eiffel tower corresponds to a life threatening dose, the dose received as a result of nuclear power plant operation, by an occupational worker corresponds to that of the height of a man and that received by the public that of a brick.



On the construction front with the adoption of several innovative measures in contract management through mega package supply cum erection packages, use of advanced software in planning and monitoring, effective management practices, enhanced mechanization

Gestation period for Nuclear Power Plants From first pour of concrete to commercial operation Grid connection from 2002



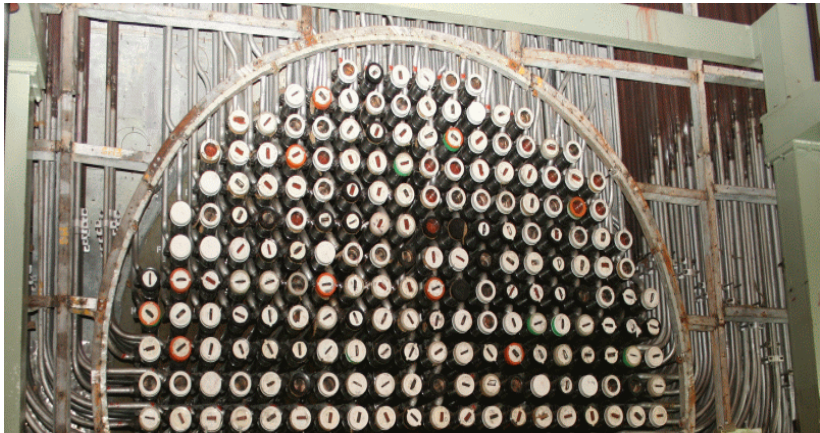
during construction, and open top construction with parallel construction and

commissioning activities, the gestation period of reactors has been brought down to five years. The achievement of criticality of TAPS-4, 540 MWe PHWR at Tarapur, Maharashtra, a first of a kind reactor, in less than five years, an international benchmark evidences yet strength of the country.

5.0 Innovations in Renovation & Modernisation

5.1 En Masse Coolant Channel Replacement (EMCCR)

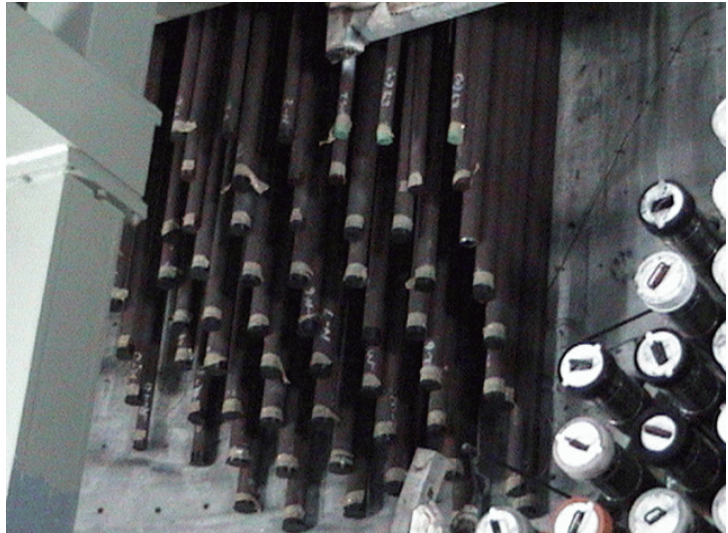
In the earlier design of PHWRs used at RAPS- 1&2, MAPS-1&2, NAPS-1&2 and KAPS-1 a zirconium alloy (Zircalloy 2) was used for coolant channels. It was considered the best available material at that time. However, in pile experience



brought out, the requirement of replacement of coolant tubes after 10 to 12 effective full power years in view of the modification of material characteristics especially the reduction in mechanical strength due to hydriding under radiation during service. These coolant channels constitute the core of a nuclear reactor and their replacement is akin to heart transplantation in human beings. The job of EMCCR at RAPS-2, attempted first time with indigenous technology, was completed successfully in a record time and all the coolant channels were replaced by an improved coolant tube material - Zirconium - 2.5% Niobium. This was for the first time in a developing country and only the second time in the world that such a highly complex technical project was completed. The job was completed using indigenously developed remotely handled tools. Similar EMCCR work been accomplished at MAPS 1&2 & NAPS-1, is underway at NAPS-2 and is planned at KAPS-1.

5.2 En Masse Feeder Replacement (EMFR)

Flow assisted corrosion leading to thinning of the carbon steel feeder elbows at the outlet of reactor was noticed in some Canadian PHWRs in 1996. A study and assessment was carried out in-house to detect any thinning of feeder pipes in Indian PHWRs. However, significant



thinning of feeders was not noticed in Indian PHWRs. The reduced degradation of feeders in Indian PHWRs was attributed to good chemical control and better operational practices in Indian reactors. For the earlier PHWRs RAPS-2 and MAPS-1&2, which had seen a long service life, a decision was taken to replace the feeders to extend their life. Hence at MAPS-1 the Enmasse Feeder Replacement (EMFR) was carried out along with the EMCCR work. This was for the first time in the world that feeders were replaced in a PHWR. EMFR has also been carried out at NAPS-1 and is underway at RAPS-2. India has thus acquired expertise in in-core jobs.

5.3 Safety & Performance Upgrades:

The long shutdowns for EMCCR/EMFR were used to carry out safety upgrades in parallel. These units were brought to the state of the art in terms of safety. Several major equipment, like the steam generators in MAPS 1&2 were also replaced to enhance the life of the plant and performance of equipment during these upgrades.

5.4 Ageing Assessment & Life Extension of TAPS 1&2

Tarapur units 1&2, commissioned in the year 1969 were licensed to operate for 25 years, in line with the practices prevalent then. NPCIL developed and carried out Probabilistic Safety Analysis (PSA) of TAPS 1&2

which found that the reactors were operating in the safe regime and met the current standards. However, based on the PSA studies and ageing management programme, systems upgradation and seismic upgradation were carried out in 2005/2006.

These included Replacement of existing 3x50% capacity Emergency Diesel Generators (DGs) with 3x100% capacity DGs, Introduction of Supplementary Control Rooms, Upgradation of Electrical, Fire Protection, Ventilation and Instrumentation and Control systems. Ageing assessment of civil structures was carried out and necessary reinforcement measures undertaken. Seismic strengthening of civil structures, safety systems, piping and equipment was carried out by providing additional anchorage & supports and anchorage and new seismically qualified DG buildings were constructed. The upgradation was completed in February 2006, one and half months ahead of schedule and the units brought on line. This unique life assessment, ageing management programme conceived, developed and carried out to achieve life extension of TAPS 1&2 indeed is yet another milestone in the history of the Indian nuclear power programme.

5.5 Unique Problems Addressal

While operating these reactors, a number of challenging problems have been satisfactorily addressed with the support of in-house R&D and industry.

- In 1981, a light water leak developed in one of the end-shields of RAPS-1. These leaks were successfully repaired.
- In RAPS-1 a leak of heavy water and helium cover gas emanating from the reactor cover called over pressure relief device (OPRD) was detected in 1994. This leak, in a highly radioactive area and difficult location, was successfully repaired using remote tools and a special metallic seal made of a metal with low melting point developed and tested indigenously.

- At MAPS, a very unique problem surfaced during 1989-90 when its moderator inlet-manifold was damaged. As a short-term rehabilitation measure, the moderator lines and its flow were re-routed. The plant could operate with this arrangement at 75% full power. Later, a new innovative design modification using sparger channels was implemented for the first time in the world, and the units brought back to their original rated capacity of 220 MWe.
- In 1990, cracks in the core shroud of the boiling water reactor (BWR) were detected in the USA. In view of this, it was decided to carry out core shroud inspection of BWRs at TAPS using specially developed remote tools like Grapple Operated Manipulator (GOM), under water CCTV system etc. This job was successfully accomplished. Life extension of TAPS-1&2 was carried out in 2006, which enabled it to operate for many years in future.

6.0 Conclusion

India has developed comprehensive capabilities in all aspects of nuclear power and reached a state of technological and commercial maturity. It is now poised for large-scale expansion. Nuclear power is currently competitive at locations away from coal mines but is likely to become location neutral in the near future. The electricity markets in the country are evolving and world is entering a nuclear renaissance. India has many opportunities to seize and nuclear power companies have to adopt new strategies in the emerging scenarios.

7.0 Acknowledgements

I duly recognize and thankfully acknowledge the contribution, of S/Shri N. Nagaich, Chief Engineer (CP&CC) and B.V.S. Sekhar, Additional Chief Engineer (Corporate Planning) in preparation of this paper.