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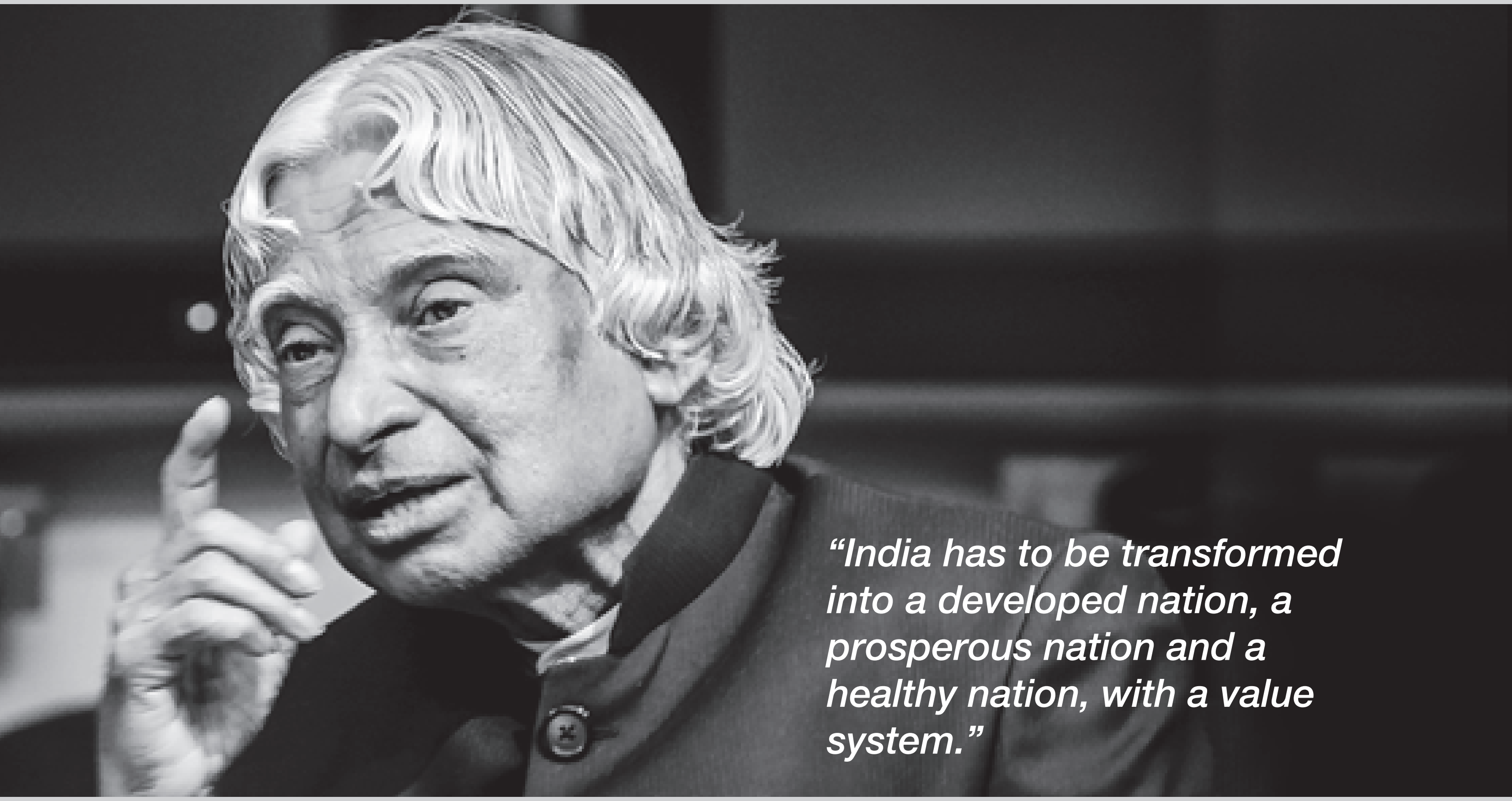
An International Journal of Nuclear Power

Former President, Bharat Ratna Dr. APJ Abdul Kalam

A Tribute



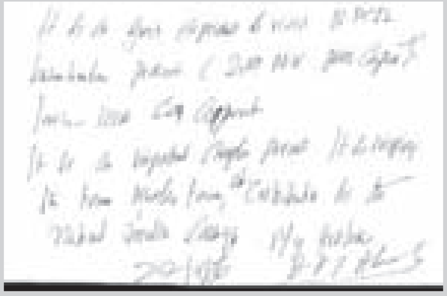
"India has to be transformed into a developed nation, a prosperous nation and a healthy nation, with a value system."

Bharat Ratna Dr. APJ Abdul Kalam, former president of India and an eminent scientist, inspired millions, while his guiding vision, love for the nation and professionalism shaped many of India's most memorable scientific and technological success stories. He played a vital role in India's several strategic defense initiatives as well as civilian space programs, including the development of India's first Satellite Launch Vehicle, SLV III, way back in 1980.

He was an ardent supporter of nuclear power. During one of his visits to KKNPP in 2011, he said that he was completely satisfied with the safety features of the reactors, and further added that KKNPP was a boon to future generations.

"Man needs his difficulties because they are necessary to enjoy success."

"Let us sacrifice our today so that our children can have a better tomorrow."



Dr. APJ's reflections of the KKNPP

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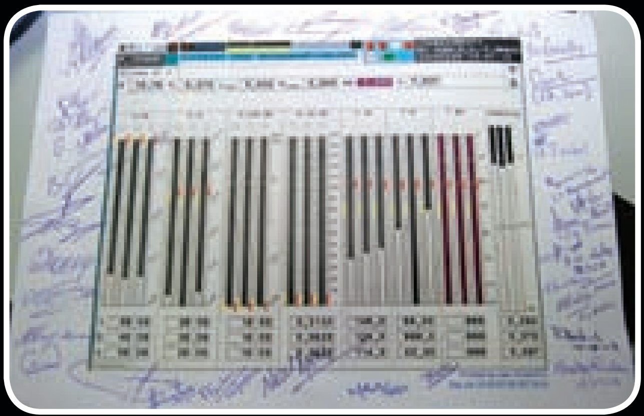
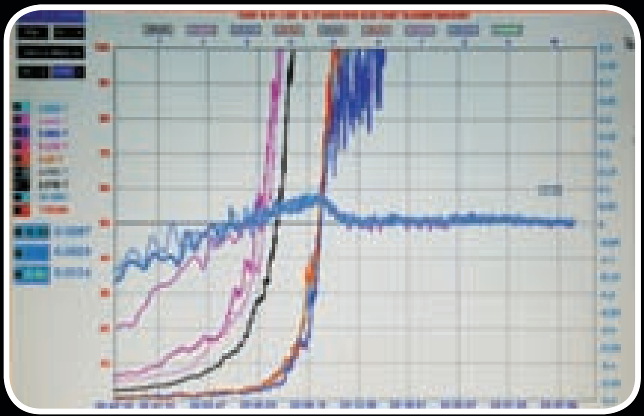
Kudankulam-1 in the service of the nation

First Criticality: The Beginning of the Magic of Fission Chain Reaction

Unit-1 of KKNPP attained its first criticality on July 13, 2013



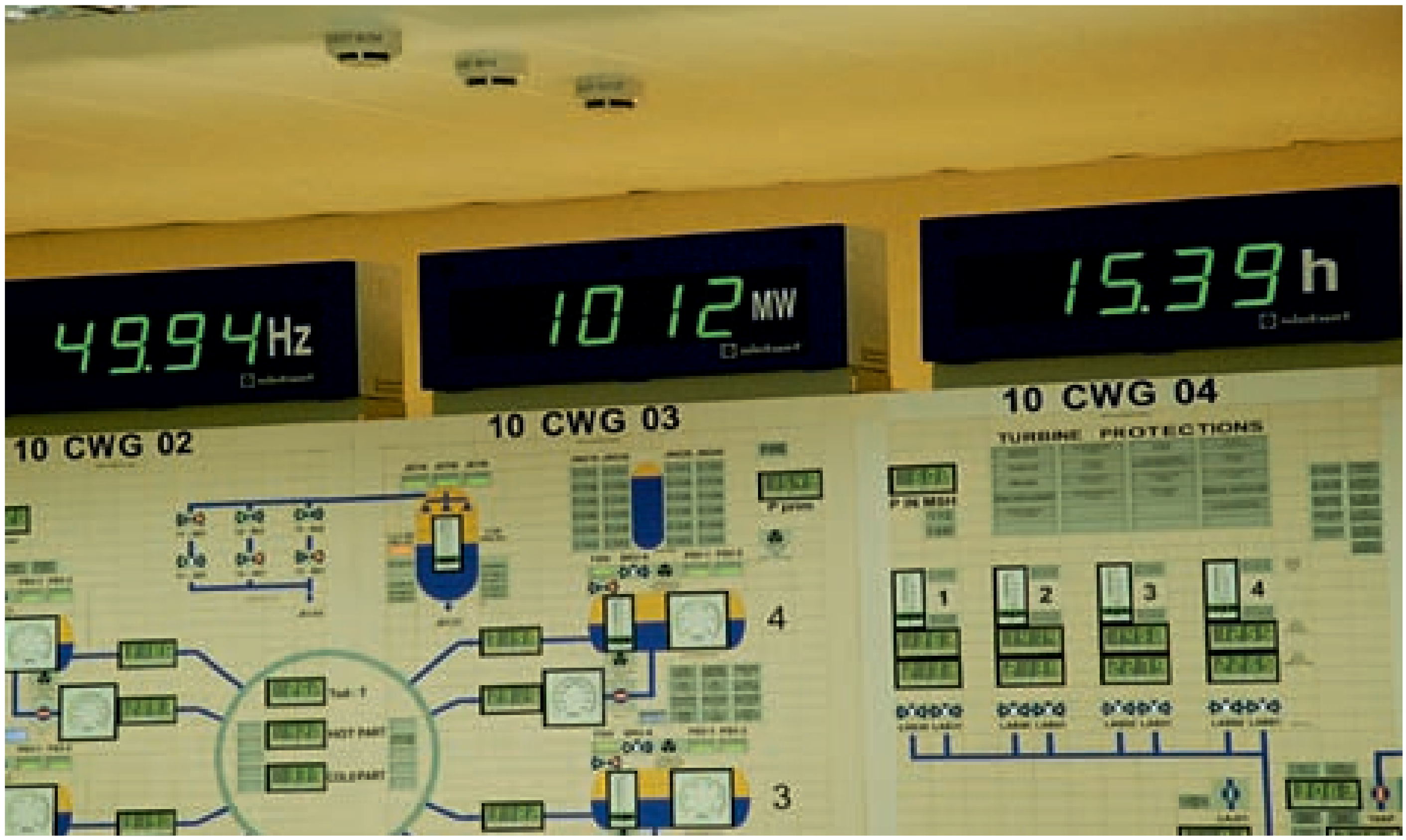


At a gigantic 1000 MW each, Kudankulam units-1&2 are the “largest-ever” nuclear reactors in India till date.

With KKNPP-1 achieving commercial operation on December 31, 2014, India has 21 nuclear power reactors and it ranks 7th in the nuclear-power-producing nations of the world in terms of number of reactors.

Power from Kudankulam is shared between the beneficiary states in the Southern Grid, viz., Tamil Nadu, Karnataka, Kerala, Puduchery and Andhra Pradesh.

Ready. Steady. Go.



Full-Power Operation

KKNPP unit-1 attained its rated full power of 1000 MW at 1320 hrs. on June 7, 2014. The power level was gradually raised in steps in accordance with the clearances accorded by the Atomic Energy Regulatory Board (AERB). At each successive step, various tests were conducted and the respective clearances for the next step obtained from the AERB. At full power, stipulated tests were conducted and the reports submitted to the AERB for review and final clearance for continued operation of the unit at full power. Total gross generation of electricity from KKNPP-1 during October 22, 2013 to June 24, 2015 was 6873 million units.

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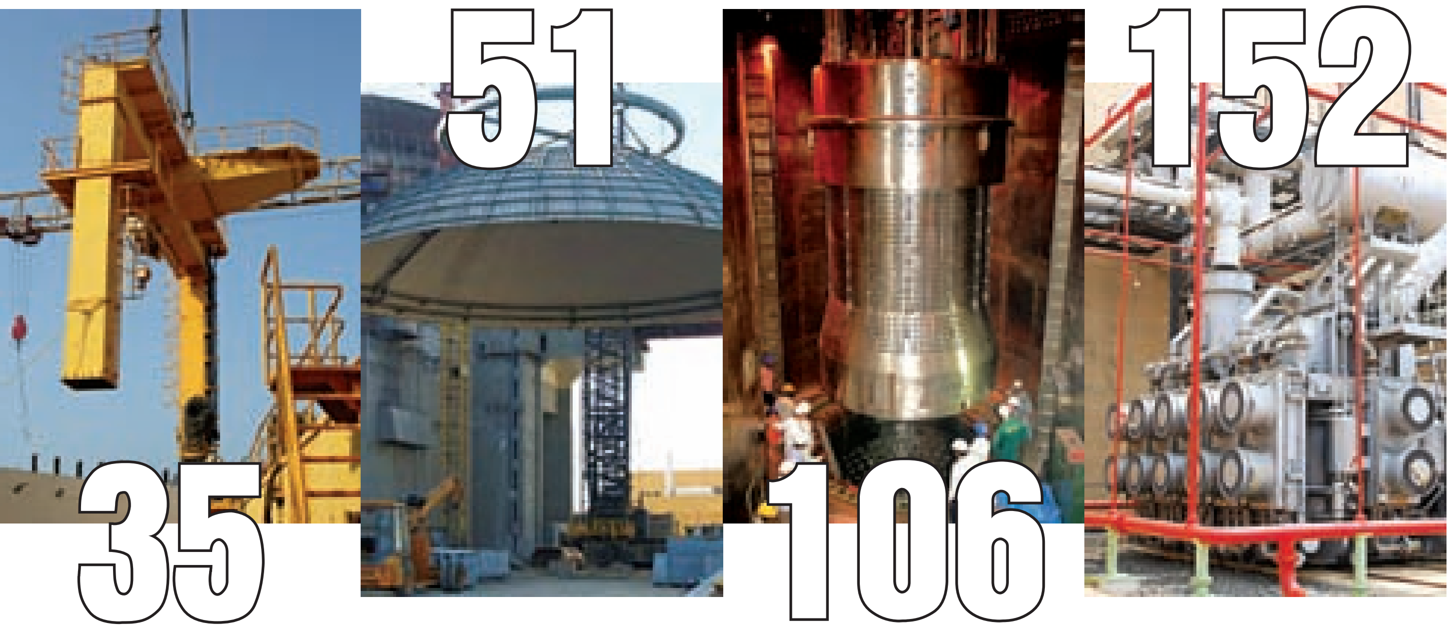

Articles (Continue)

KKNPP:
A Project of Several 'Firsts' in India

With a project description studded with superlatives, KKNPP has to its credit many 'firsts' in India.





The KKNPP VVERs are based on proven technology and impeccable safety that has been demonstrated with more than 65 VVERs built till date worldwide. And for India, they bring these several 'firsts':

- Indian nuclear power project on technical cooperation basis with the Russian Federation
- Time-tested VVER units now in India
- 1000-MW nuclear reactors, largest in the country till date
- Passive Heat Removal System (PHRS), which does not require electricity or water for cooling of the fuel in the reactor
- Core catcher
- Hydrogen recombiners
- Hermetically sealed containment liner
- Un-bonded concrete pre-stressing system
- Single-unit 1000-MW turbine
- Single-unit 1000-MW generator
- Largest gas-insulated switchgear (400-kV) in the country
- Unique facility for fish protection in the water intake structure

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Editorial

Amritesh Srivastava
Editor

Inflection Point

A reactor design of such technological sophistication that it is considered one of the best in the world. An armour of safety systems so meticulous and effective that it elevates the existing proven safety paradigm to an even higher level. Passive safety systems so ingenious that they can actuate without operator intervention and function based on natural principles, without requiring the use of external motive power like electricity – thus ensuring safety even during extreme circumstances. A reactor size so humongous that each reactor of 1000 MW is easily the largest-single power generation unit (nuclear or any other kind) in the country. That's Kudankulam Nuclear Power Plant for you – the confluence of the finest 'adjectives'– and an engineering marvel!

When the 1000-MW KKNPP-1 – the first unit of Kudankulam Nuclear Power Project-1&2 (KKNPP-1&2) – began commercial power generation at 0001 hrs. on December 31, 2014, it added a glorious chapter to the annals of nuclear power generation in India. Established in technical collaboration with the Russian Federation, the KKNPP reactors are a shining example of Indo-Russian cooperation in peaceful uses of nuclear energy. These state-of-the-art reactors are based on proven, time-tested VVER-type reactor design, with more than 65 VVER reactors built globally.

The KKNPP site will ultimately have six reactor units, i.e., four more in addition to the existing two at the site. The second Kudankulam reactor unit (KKNPP-2) is already at an advanced stage of commissioning, while the pre-project work for KKNPP-3&4 units has already begun.

A grand achievement of Indo-Russian cooperation, KKNPP lays the cornerstone for a series of large-size Pressurised Water Reactors belonging to Light Water Reactor category that have been planned ahead in the country. KKNPP, thus, will always be remembered as the harbinger of large-size LWRs in India.

The commercial operation of KKNPP-1 has taken the installed nuclear power generation capacity in India from 4780 to 5780 MW. The second KKNPP unit will soon add another 1000 MW to the tally. Also, four indigenous Pressurised Heavy Water Reactors of 700 MW each – two at Kakrapar in Gujarat and two at Rawatbhata in Rajasthan – are at advanced stages of construction. These will add 2800 MW.

More PHWR-type indigenous reactors as well as LWR-type reactors based on international cooperation have been planned.

Obviously, nuclear power in the country is staged for a sharp upswing in this coming decade and beyond. And at this cusp of time, Indian nuclear power generation is at a take-off stage – an inflection point.

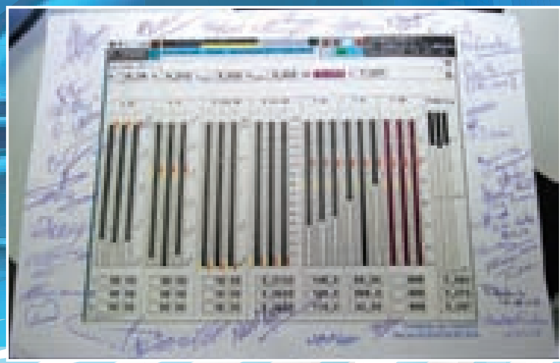
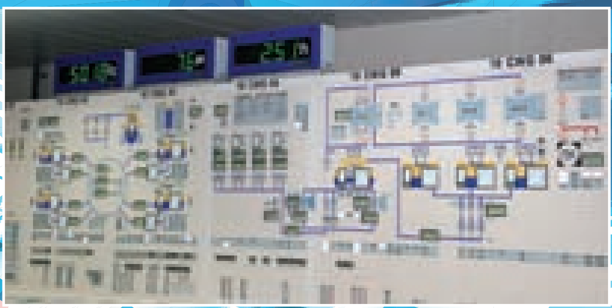
Happy Reading...

Amritesh Srivastava

Down The Memory Lane





An Overview of VVER Type of Reactors: A Journey Since the 1960s

R. Kamath, ACE (Project LWR – Electrical), KKNPP-3&4

Ever since Kudankulam Nuclear Power Project (KKNPP) came into existence in our country, the term "VVER" has entered the lexicon of nuclear India in a big way and this article takes an overview of VVER, in brief – about its origin, history and progress since its inception way back in 1960s.

VVER (or sometimes also mentioned as WWER) is the popular acronym for **'water cooled, water moderated energy reactor',** originally designed and developed by the erstwhile Soviet Union (now the Russian Federation). The term VVER is actually derived from the Russian term, 'Voda Vodyanoi Energeticheskya Reaktor' (voda in Russian language means water).

VVER reactors are a series of Pressurised Water Reactors (PWRs), originally designed by OKB Gidropress – a subsidiary of ROSATOM – Russian state nuclear corporation, while the nuclear power stations employing VVER technology have been developed by the power plant design institutions within ROSATOM, such as Moscow ATOMENERGOPROEKT (AEP), St. Petersburg AEP and Nizniy Novogorod AEP. Significantly, Kudankulam Nuclear Power Project (KKNPP) design has been mainly developed by the Moscow unit of AEP, although Gidropress and other associated research institutes of Russian Federation such as Kurchatov Institute have all been actively involved in the concerned systems of VVER nuclear power plants, in close coordination with AEP – the main and general designer for Kudankulam nuclear reactors.

Origin and History

Generation-I VVER Reactors (1960–1966)

ROSATOM's VVER reactors are among the world's most common and widely used PWRs, using light water both as coolant as well as moderator, and hence the name VVER. It was first developed by ROSATOM subsidiary OKB Gidropress in the Soviet era, and is now being developed further by various units of AEP in Russia, with pioneering new features.

However, it is pertinent to note some significant differences between the VVER and other PWR types of reactors, both in terms of design as well as materials used. Some of the distinguishing features of VVER include the following key differences:

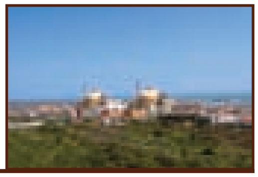
- Use of Horizontal Steam Generators
- Use of Hexagonal Fuel Assemblies
- Use of high-capacity Pressurisers

The First VVER Unit: V-210

The first-ever construction of a VVER nuclear power plant in the world started way back in 1960s in Novovornezh, Russia, and since then, it has been long way forward for VVER type of reactors. Indeed, about 67 reactors have since been constructed in many parts of the world, such as Armenia, Bulgaria, China, Czech Republic, Finland, Hungary, India, Iran, Slovakia,

The control room of KKNPP

The control room of KKNPP



Ukraine and, above all, Russia – where it originated.

The first-ever VVER unit was commissioned in 1964, at Novovornezh Nuclear Power Plant in the Voronezh region of Russia. This unit was then called as V-210 and the second unit at Novovornezh-2 was called as V-365, wherein, initially, these numbers referred to the corresponding electrical output of the main generator of the unit.

Although these two units have since been decommissioned, Novovornezh site continues to remain at the core and fulcrum of VVER design and development, with many new units of VVER, either under operation or under construction at this stage, serving as a reference unit for upcoming units elsewhere or as a testing ground for new VVER units.

Generation-II VVER Reactors (1966-1980)

The successful commissioning and operation of the above two units at Novovoronezh virtually set the platform and provided the solid basis for further development of more powerful reactors. Accordingly, VVER-440 Model V-230, the most common design, delivering 440 MW of electrical power was designed and developed at the same Novovoronezh site in the form of Novovoronezh units-3&4. The V-230 model employed six primary coolant loops, each with a horizontal steam generator. Later on, a modified version of VVER-440, Model V-213, was developed, which was a product of the first nuclear safety standards adopted by the Soviet designers of that era. This model included additional safety features such as emergency core cooling and auxiliary feed water systems as well as upgraded accident localisation systems.

These VVER-440 units have been safely operating in many European Union nations such as Slovakia (Bohunice-1 to 4, Mohovce-1 & 2), Hungary (Paks-1 to 4), Bulgaria (Kozloduy-1 to 4), Czech Republic (Dukovany-1 to 4) and Finland (Loviisa-1&2).

Significantly, the design of Finnish Loviisa Plant was accomplished in the year 1971-72, by taking into account of the General Design Criteria (GDC) for nuclear power plants, issued by United States AEC in year 1971. All VVER plants after this have been designed to meet these safety standards and that explains why the safety features of all operating VVER-440 units and the other PWR types of similar era are quite similar. The reliability of the above design has been amply demonstrated by the fact that their regulators have approved the life extensions of decades to these operating plants. The Loviisa NPP in Finland, with two VVER-440 reactors, has thus been able to create one of the best lifetime performance records in the world.

Generation-III and Generation-III+ VVER Reactors (1980 onwards)

Based on the experience and success of Generation-II reactors, the design and development of Generation-III reactors was taken up and VVER-1000, which came to known as the flagship of VVER design, was developed through this effort. The VVER-1000 was developed after 1975, with a four-process-loop system housed in a containment with additional safety features such as containment spray steam suppression system, automatic control, passive safety systems, and many other containment localisation systems associated with Western third generation nuclear reactors of that time.

By far, VVER-1000 remains the most common VVER design worldwide and as on date, there are 31 VVER units which are in operation, including unit-1 of Kudankulam, with a cumulative operational experience of about 500 reactor-years.

The VVER-1000 plants in operation are broadly categorised into 3 groups as given below:

a) Novovoronezh-5, which was commissioned in 1980, as Pilot plant

b) A small series of 4 units commissioned during 1983-1986

c) Standard series of 23 units, commissioned during 1985-2011

VVER-1000 / V-320

The above mentioned standard series VVER-1000 units were called as V-320 type, the design of which was completed in the early 80s and implemented at 8 sites in Russia and Ukraine, as well as in Bulgaria (Kozloduy-5&6) and Czech Republic (Temelin-1&2). The safety record of VVER-1000 plants has been very good and no major incident with any significant safety impact has been reported so far.

VVER-1000 / AES 91 (V-428)

The experience gained from the operating plants of VVER-1000/ V-320 type further helped the evolution of an improved design in the form of AES-91, also known as VVER-1000 / V-428, which was developed by AEP Institute based in St. Petersberg. The Taianwan AES-91 units in China, which were commissioned in the year 2007, were the first reactors in the world to have core catchers installed inside the reactor building.

It is very significant that the AES-91 design with VVER-1000 / V-428 reactor was accepted for construction in China in 1997, as while conforming to Chinese requirements, the design of these reactors also incorporated recommendations from more than 20 expert reviews conducted by International Atomic Energy Agency (IAEA) between the years 1995 to 2005.

When compared to V-320 design, V-428 incorporated the following improvements:

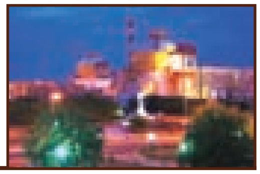
- 4 x 100% Redundancy in main plant safety systems
- Improved physical separation of redundant safety systems
- Core catcher
- Passive hydrogen re-combiners
- Advanced reactor circulating coolant pumps to remain leak-tight even during loss of power

VVER-1000 / AES-92 (V–412 & V-466)

The AES-91 design was closely followed by the development of AES-92 type of design, also known as VVER-1000/V-412 and V-466 by AEP Institute based at Moscow, with incorporation of all the above safety features along with additional passive safety features.

Significantly, Kudankulam NPP units adopted the above mentioned AES-92 (or VVER-1000/V-412) type of design. Kudankulam unit-1 achieved its criticality in July 2013 and attained commercial operation in December 2014. Presently, Kudankulam unit-2 is at an advanced stage of commissioning.

Similar to AES-91 design, the AES-92 design is developed with extensive use of passive safety



system features such as double containment for reactor building, 8 additional hydro accumulators for passive core flooding and 12 heat exchangers for passive decay heat removal systems (PHRS) without operator intervention.

Both AES-91 and 92 were conceptualised based on a preferential use of active safety systems to manage design basis accidents and the optimal combination of active and passive systems to manage more serious accidents. While incorporating these safety features, emphasis was laid on deploying passive means of decay heat removal systems, addressing the impact of common cause failures as well as realistic assessment of probabilities of operator errors.

In addition to the advanced safety features, the design of these units deployed the concept of Beyond Design Basis Accident (BDBA) management based on a balanced combination of passive and active safety systems. In addition, a plant of AES-92 design is also certified to conform to the technical requirements of European Operating Organisations (European Utility Requirement – EUR).

VVER-1200 / AES-2006

VVER-1200 / AES-2006 is the latest evolution in the long series of VVER reactors. The development of the design of these units began in mid-2000s. The main aim of the development of this design was to optimise the cost of nuclear power plants and increasing the safety of the nuclear power plant without substantially changing the basic configuration of nuclear steam supply systems. The reactor is basically an evolution of the VVER-1000 type design with increased power output of about 1200 MW (gross) along with the provision of additional passive safety features. In order to achieve this, the thermal power of the plant has been increased to 3200 MW and additional safety systems have been introduced for management of beyond design basis accidents (BDBA). Along with operating experience and feedback received from VVER-1000 plants, the lessons learnt from Tainwan plant in China also came handy for the development of this design. These units also meet all the international safety requirements for Generation III+ nuclear power plants.

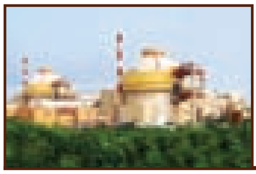
VVER-1200 / AES-2006 type is broadly classified into two categories, as given as follows:

1. Version V-491 developed by AEP, St. Petersberg on the basis of AES-91 design developed for Tainwan plant, China
2. Version V-392 M developed by AEP, Moscow, on the basis of AES-92 design developed for Kudankulam plant, India

Construction of the first AES-2006/ V-491 units is currently underway in Russia at two sites, namely, Sosnovyi Bor (Leningrad II) and two units in the Kaliningrad of Baltic region. In addition, this design has also been chosen for construction of new units at Ostrovets in Belarus and additional units have also been proposed for Temelin 3&4 in Czech Republic and Hanhikivi in Finland.

Construction of first AES-2006/ V-392 M units are currently underway in Russia in Novovoronezh (Novovoronezh – Phase II) and in addition, this design has also been offered to Akkuyu Project in Turkey.

In addition, agreements have also been signed for the construction of four units in Turkey and two units in Belarus.



VVER of the Future – VVER-TOI

VVER-TOI stands for Typical, Optimised with enhanced Information and this design is being conceptualised and developed to create a standardised VVER power plant, optimised both in terms of technology as well as economics, aimed at developing a new Generation III+ reactors based on VVER technology, with a number of target-oriented parameters using modern information and management technologies.

The above design is being developed by AEP institute based in Moscow, based on AES-2006 / V-392 M design. This design also represents a further evolution of VVER-1200 design and it will be designated as V-510.

The evolution of VVERs at a glance is given along with timeline in Table-1

Conclusion

The entire gamut of issues related to the evolution of design and development of VVER type of nuclear power reactors since the first VVER in 1960s shows a strong and robust process of design evolution of one of the flagship PWRs belonging to Light Water Reactor category. Notably, there has been a continuous trend of implementing constant improvements in the design features and increased emphasis on enhancing the safety aspects of the nuclear power plant, largely based on the lessons learnt during the construction as well as feedback received from the plants in operation. Increased emphasis on passive safety systems has been the hallmark of new generation VVERs.

Needless to say, it has indeed been a long journey of technological advances and improvements ever since VVER V-210 came into existence and the journey is continuing, rather strongly, to ensure increased safety and reliability of VVER nuclear power plants across all installations.

The very fact that as many as 67 units of VVER reactor units have been constructed in many parts of the world so far and another 13 are currently under construction is a proof of the strength and core competence of the VVER design, which has indeed come a long way ever since the first VVER unit was constructed way back in 1960s. Based on their inherent strengths and with many more units expected to be set up in the coming years, VVERs are poised to make even bigger impact on the global nuclear power generation.

R. Kamath, *SO/H, presently working as ACE (Project LWR – Electrical), KKNPP–3&4, is an electrical engineer.*

He joined KK Project, NPCIL-HQ in 1989. He has contributed to the review and finalisation of Technical Assignment (TA) of electrical systems of the plant as well as the finalisation of DPRs, PSAR, etc.

Since 2002, he has been working in the Electrical Construction Group of KKNPP site. The works handled by him include major electrical equipment such as 220kV and 400kV GIS and GIBD, 24/400kV GTs, Unit and Reserve Auxiliary Transformers, etc. as well as 10MW KKNPP windfarm.

Emergency Core Cooling Systems Integrated Test

Aneesh D.M., Control Engineer, KKNPP

Introduction

Each of the Kudankulam Nuclear Power Project (KKNPP) reactors consists of four trains of independent active Emergency Core Cooling Systems (ECCS), each of which is capable of mitigating the events of Loss of Coolant Accident (LOCA) followed by primary coolant pipeline rupture.

The following are the Active Emergency Core Cooling systems:

1. **Emergency and planned cooling down of primary circuit and spent fuel storage pond cooling system (JNA 10–40):** This is a low-pressure ECCS system and ensures sub-criticality, long-term core cooling of the reactor and minimises the release of radioactive iodine (I-131) from any possible failed fuels.

2. **High-pressure boron injection system JND10-40:** This is a high-pressure ECCS system makes up primary circuit during a postulated small-break LOCA and large.

3. **Containment spray system JMN10-40:** Reduces the primary containment pressure and ensures that radioactivity is confined within the primary containment by binding iodine-131.

On April 29, 2012, KKNPP unit-1 successfully demonstrated the capability of its active safety systems by successfully conducting the ECCS Integrated Test. This was a major milestone of the project, involving meticulous efforts from the entire KKNPP Operation and Maintenance staffs as well as employees from other Indian nuclear power plants.

Necessity of ECCS Integrated Test

Unit-1 hot run was completed and integrated performance of reactor and associated systems were found acceptable. Before unloading the dummy fuel from the reactor, integrated performance of active safety systems with its associated logics were to be verified.

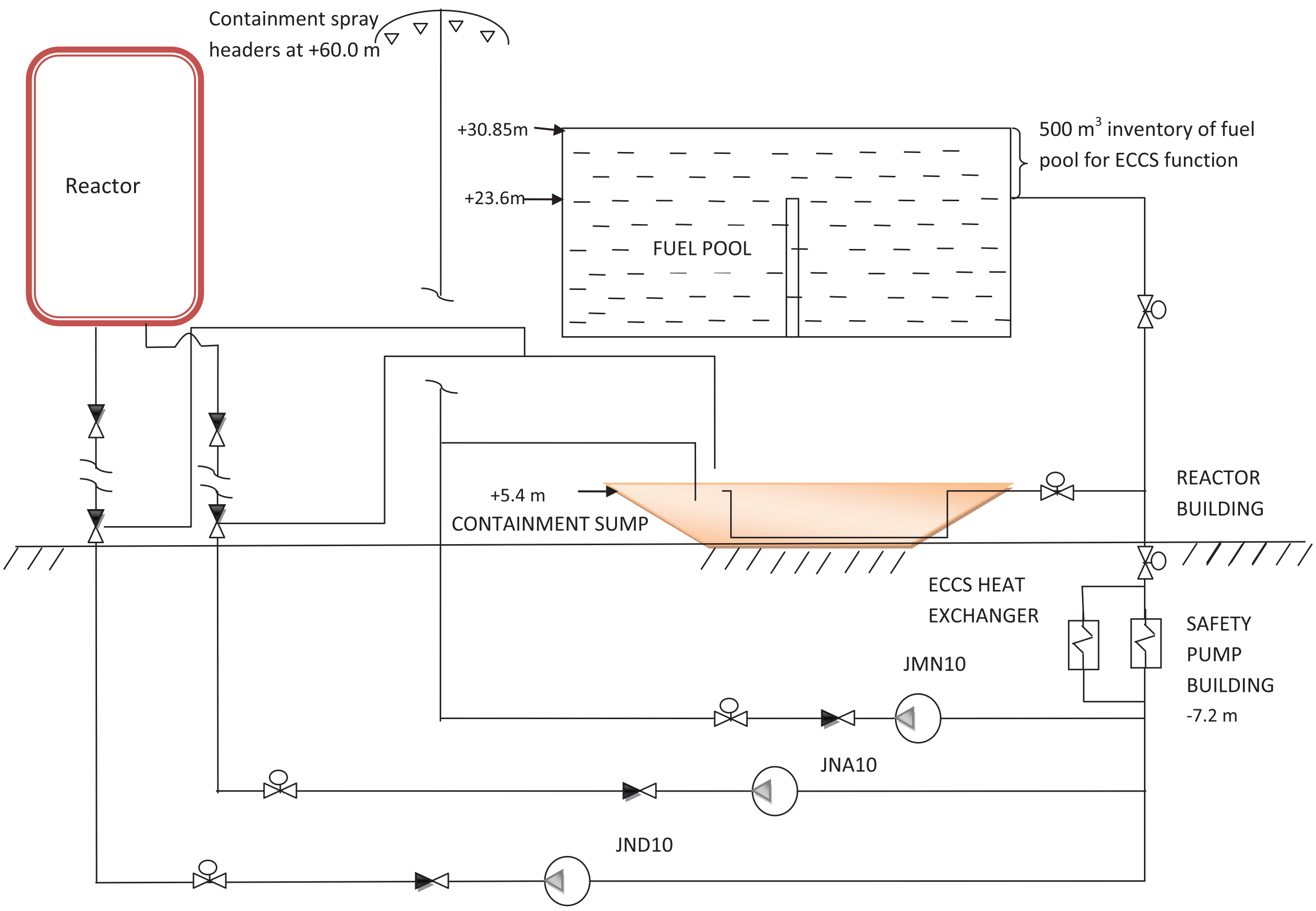
Design of ECCS

Emergency core cooling systems are designed to discharge borated water into the reactor core and for containment spraying initially from spent fuel pool. After reduction of level in spent fuel pool, suction of pumps automatically changes over to containment sump.

Major Technical Challenges / Aims of ECCS Integrated Test

1) Due to lower elevation of containment sump with respect to fuel pool and high discharge flow from in safety system pumps, absence of cavitation had to be demonstrated to validate the design. Capability of pumps to operate near their lowest NPSH limit was to be verified.

2) Response of electrical and instrumentation systems was to be verified during



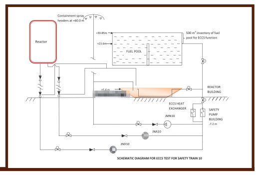
Schematic diagram with relative elevations for the ECCS test

the starting and operation of equipment.

Preparation for the Test

After the completion of system flushing, process instrumentation, commissioning of valves and safety system pumps were commissioned and commissioning results were found acceptable. As flushing of main coolant pipelines was already completed and normal operating equipments inside primary containment were commissioned, field modifications were made in safety system pipelines for diverting the discharge water to floor (which in turn flows to containment sump) for preventing the entry of water into the main coolant pipelines. Thorough cleaning of primary containment, including containment sump, was done under departmental staff supervision. Repainting of sump was done. Healthiness of Instrumentation systems was ensured by logic checks.

After filling of the containment sump up to 400 m^3 (inventory expected to reach sump during a postulated large-break LOCA), water samples were taken and sample results were found acceptable. Absence of air ingress into safety system pipelines during the opening of containment sump valve by operating one train of JNA10-40 system at rated flow



rate was demonstrated as a part of the test. Additional instruments were installed to measure the pump suction pressures during suction change over. Automatic changeover of one train of JNA10-40 system from fuel pool cooling mode to emergency mode on initiation of 'Primary LOCA' signal was demonstrated as a part of the test.

Operator prohibition for 30 minutes was kept bypassed for stopping of equipment in case of abnormal situations.

Execution of ECCS Test

Associated supportive systems were made ready as per the requirement. All 4 ECCS channel pumps and associated valves were kept according to the normal plant operation status (All equipment were paused except one – the JNA pump, which was operating in fuel pool cooling mode). Maintenance and operation staffs were placed at important locations for monitoring of safe operation of equipment. Primary LOCA Push Button for all four safety trains were pressed simultaneously from Main Control Room. Automatic actions and important parameters were checked from main control room as well as field. All the 16 safety pumps operated simultaneously for a period of 30 minutes.

Conclusion

Simultaneous and automatic starting of safety system pumps (JNA10-40, JMN10-40, and JND10-40) on primary LOCA signal initiation and upon fuel pool level lowering to 13.365 m, automatic changeover of safety system pumps suction from fuel pool to containment sump took place.

No cavitation or gas locking signs were observed during simultaneous operation of safety system pumps with suction from containment sump and were found to be stably operating at rated flow rate. The lowest compound pressure gauge reading during testing was observed to be 0.3 $bar_{(g)}$.

Also, NPSH available for safety system pumps during accident scenario, by extrapolation of test results, were found to be more than minimum acceptable NPSH required for the pumps.

In summary, this was by far the most challenging commissioning test conducted at KKNPP till that date, which required foolproof coordination, communication, preparation and execution of the test.

Aneesh D. M., *an electrical engineer, joined NPCIL as an executive trainee in the 16th batch in 2007. After the completion of his induction training, he was involved in the commissioning of Emergency Core Cooling Systems of KKNPP. He has been involved in the commissioning of all the safety system pumps as well as the commissioning tests and demonstration of cavitation-free simultaneous operation of twelve pumps by the ECCS test. He is currently a Control Engineer in general shift operation and looks after primary side coordination jobs and solid waste management systems of KKNPP.*

Erection and Commissioning of Polar Crane at KKNPP

Arun P. Nair, SO/F, KKNPP; **Kapil Aggarwal,** ASCE, KKNPP-2;
P. A. Suresh Babu, Chief Engineer (QA), KKNPP

1.0 Introduction

The polar crane (crane with circular movement) at Kudankulam Nuclear Power Project (KKNPP) has a capacity 350/190 tons. It moves on a circular rail of type KR-140 inside the reactor building at an elevation of +43.9 meters. The span of crane is 42 meters and is made up of 2 main girders having boxed structure reinforced by diaphragms. The lifting height of 350/190 tons is 22 m. The two main girders are connected at the ends by end girders. Low-alloy structural steel 10KhSND and high-strength structural steel WELDOX 700E were used for crane construction. The crane is provided with one main trolley, one auxiliary (slave) trolley and one main gantry, supported on main girders. The main trolley houses main hoist of 350/190-ton capacity and one service hoist of 10-ton capacity. Auxiliary trolley (slave trolley) houses one auxiliary hoist of 32 tons capacity and one service hoist of 10-ton capacity on the gantry. Gantry supported on main girders is provided with service hoist of 10-ton capacity. The service hoists are used for the maintenance of the crane itself and for shifting the small loads

A view of polar crane before installation of dome on the reactor building

Steam generator being erected using polar crane

Bridge assembly with main and auxiliary hoist

(up to 10 tons) inside the reactor building. The power supply to the crane is supplied from the panel kept at the top of the containment. The power cables from this panel are connected to the panel located on the main gantry platform. The crane is also provided with a dome service platform, which is used for the maintenance of the containment dome for any repairs.

Polar crane is designed for lifting and handling of various equipment inside reactor building during maintenance and refuelling, i.e. it is used for handling of reactor head and upper block, handling of protective tube unit (PTU), core barrel, spent fuel and fresh fuel cask etc. It is a component for normal operation and important for safety. Polar crane relates to seismic category I as per PNAEG -5-006-87 and to class 1N as per PNAEG -01-011-97.

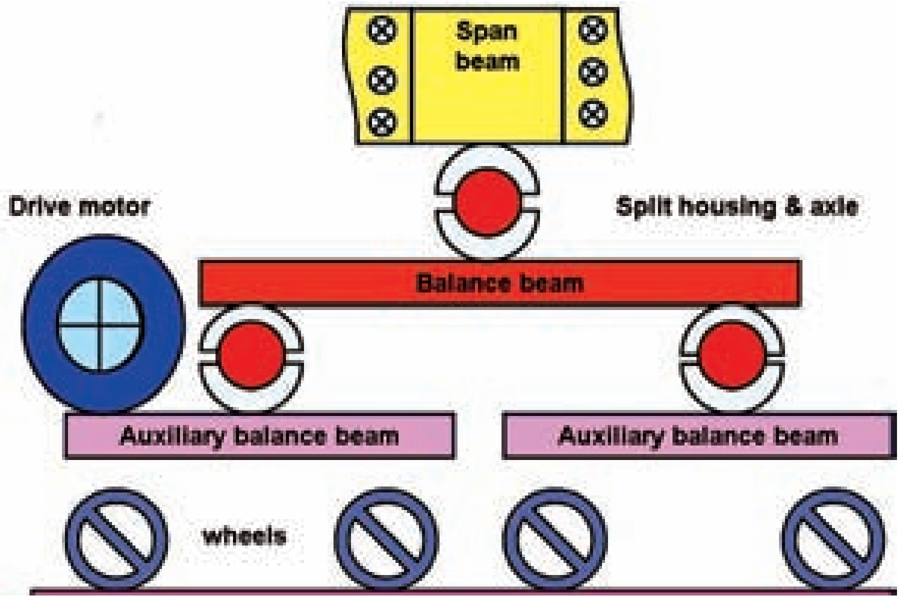


Figure 1: Bridge travel drive carriage

Polar crane operates in two modes:

- Assembly mode: During plant construction stage for erection. During this the restriction zones are not effective.
- Operation mode: For lifting of reactor internals, fresh and spent fuel cask during refuelling shutdown. Restriction zones are active, i.e. movement of loads above reactor and fuel pool is prohibited.
- The crane can also be used during maintenance of equipment such as steam generator (SG), reactor coolant pump (RCP) in case of requirement during shutdown.

2.0 Description of Various Components and Important Mechanisms of Polar Crane

The polar crane was manufactured by M/s Uralmash Plant JSC in Russian Federation. The crane is equipped with:

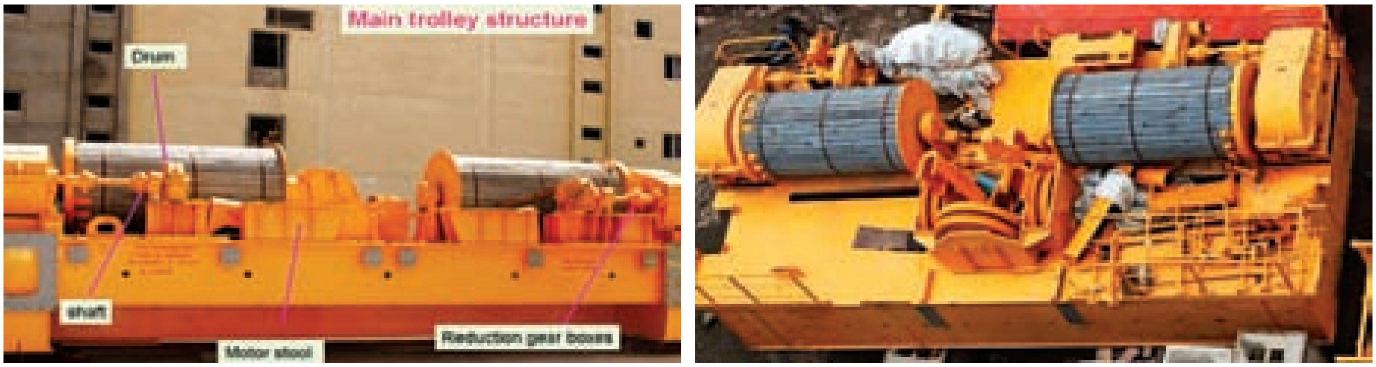
- The main hoist mechanism of 350/190t (350t hoist is used during erection for installation of equipment and 190t hoist is used during the service life of the reactor plant). Number of cycles for 350t is limited due to span beam capacity (prevent permanent deflection in span beam). So that 350t capacity is used during erection period and it can be used in future for replacement of steam generator if required. Same hoist is used for both 350 t and 190 t. It is selected by selecting switch on control desk.
- Auxiliary hoist mechanism of 32 t of load lifting capacity for handling small equipment and fresh fuel cask.
- Three electric hoists mechanism of each 10t load lifting capacity installed on the main trolley frame, on the auxiliary trolley frame gantry and on the crane bridge gantry.

The crane equipment includes the following main components/ mechanisms.

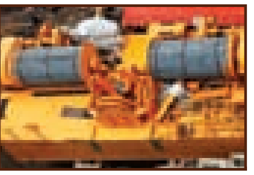
2.1 Bridge with Travel Mechanism

The bridge is a welded metal structure consisting of two span beams, two end beams, fixing devices and gantry. The span beam consists of three sections of welded metal structure of box section made of rolled plates and reinforced with longitudinal angles and vertical diaphragm. Two span beams and two end beams form a rigid frame with the help of straps and high-strength bolt joint.

Movement of the bridge over the rail is achieved with the help of four bridge travel drive carriages.



Main hoist trolley prior to its installation



Crane being assembled at the manufacturer's facility

Drive carriages are provided in each corner of the crane span beams, which consists of main balance beam, idle carriage, drive carriage, motor reduction gear. Main balance beam rests on the idle and drive carriages with the help of two split housings and two liners. Each carriage consists of two flangeless wheels, mounted on shafts running in rolling bearing supports. To exclude slip of wheel relative to the rail, wheels have conical form and are installed at an angle. The drive carriage includes motor reduction gear, which is put with its hollow output shaft on wheel shaft.

To keep the crane on rail track horizontal rollers are installed in housings on one side of the crane. Each housing accommodates two horizontal rollers. The rollers are designed to take horizontal loads both under normal service conditions and during earthquake. Scraper is installed on the carriage to remove unwanted material lying on the circular rail.

2.2 Main Hoist Trolley

Main hoist trolley consists of main hoist mechanism, frame, travel mechanism, grapples, brackets, high strength bolts, split housing and axle. The trolley frame rests on four carriages. Each of these carriages is supported by two double-flanged wheels. Double flange running wheels are mounted on the wheel shafts running in rolling bearings. A motor reduction gear is put with its hollow output shaft on wheel shaft. The frame

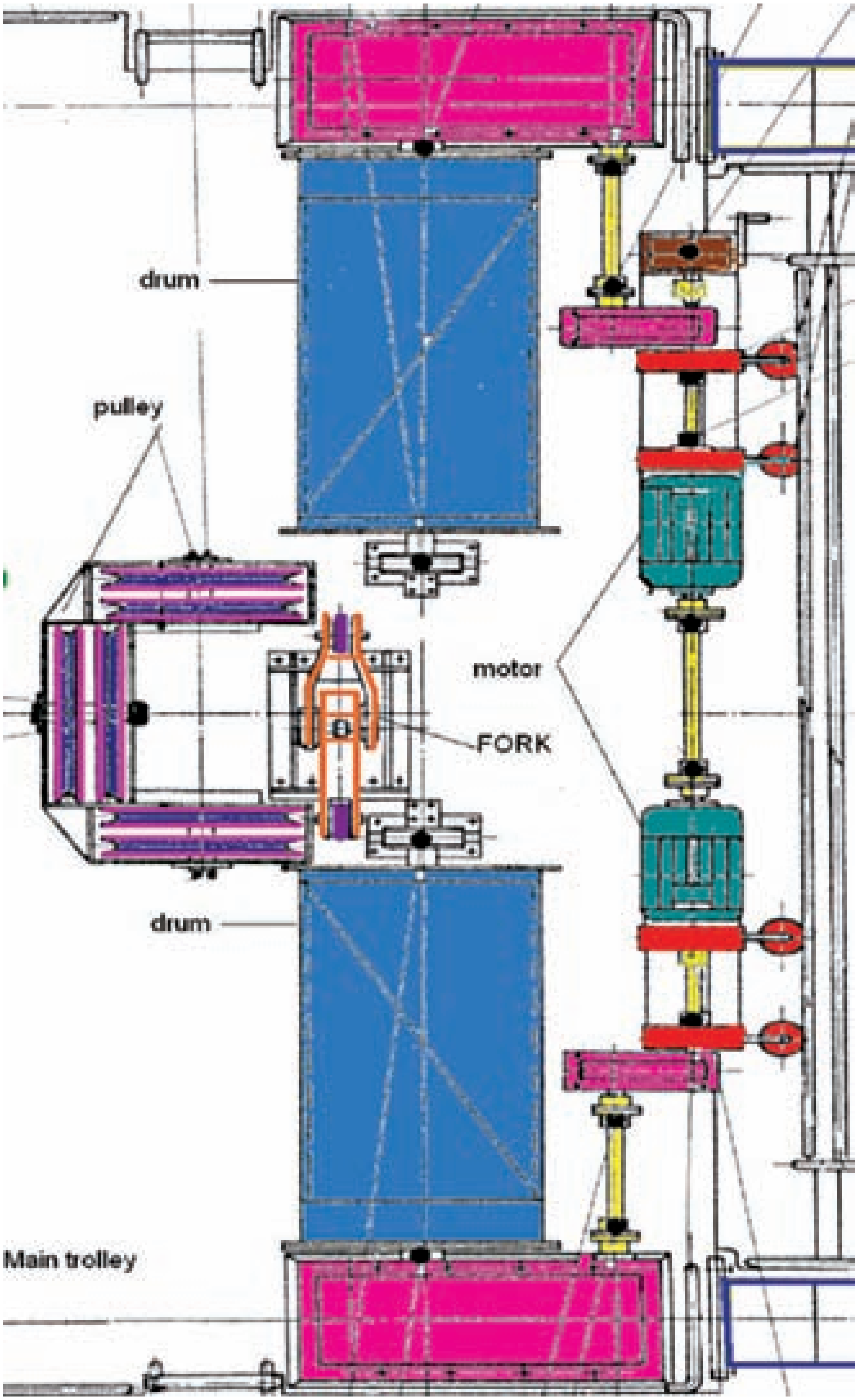
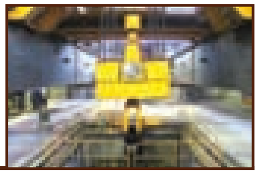


Figure 2: Main hoist mechanism



with running wheels is connected to the trolley frame with the help of split housing and axle. To exclude oil leakage to reactor operating floor, tray made of plates in the form of pan is installed under the motor-reduction gear.

2.3 Auxiliary Hoist Trolley

Auxiliary hoist trolley is connected to the main hoist trolley by means of two hinged joints. Auxiliary hoist trolley travels with the main hoist trolley, i.e. it doesn't have separate drives for movement of auxiliary trolley. It consists of auxiliary hoist mechanism, frame, split axle boxes, bearings, axle, running idle wheels and grapples. Auxiliary trolley wheels are flangeless; its position on the rail is determined by flanges of the main hoist trolley wheels and hinges connecting the trolleys.

The grapples fixed to the trolley are intended to hold trolley on the rails during earthquake. The side surfaces of the grapples function as stops to determine the extreme positions of the trolley while traveling along the bridge.

2.4 Main Hoist Mechanism

Main hoist mechanism is installed on the frame of the main trolley and includes two drum units, main hoist levelling unit and upper sheaves. The drums are driven by electric motors through reduction gears connected in series. To synchronise drum rotation, electric motors are connected by means of intermediate shaft. Each of intermediate shafts accommodates two electro-hydraulic brakes. The main hoist mechanism is equipped with hand drive to bring the load in safe position in case of interruption in power supply. When the motor drive is used, the half-coupling of hand drive is disengaged from the half-coupling on the hoist drive reduction gear. When the need arises, engagement is done using lead screw mechanism and to operate electro-hydraulic hoist drive brakes is released.

The main hoist mechanism incorporates fork swing (rotation) mechanism, suspension and axle extension mechanism. The fork is installed on the sheave suspension traverse via thrust bearing. The traverse in its turn rests on the suspension with its trunnion via bearings. Such design permits the fork to rotate around its axis and to rock together with the traverse relative to its axis. The sheave

Main fork mechanism at the manufacturer's facility and reeving being carried out at the site

Cable supplying power to the polar crane routed through the top inner containment

suspension connects with the main hoist mechanism drums by means of ropes through a system of sheaves and tackle blocks and serves for lifting and lowering of loads. The fork has an axle to hold the loads and is actuated by electric drive, in addition to this manual drive is also provided.

2.5 Dome Service Platform

Dome service platform is used for the maintenance of inner surface of the containment dome. It consists of two trusses inside which platforms and stairs are installed. One end of the platform rests on the crane bridge and the other end is installed on the bridge gantry.

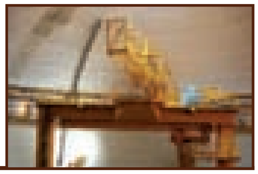
2.6 Power Supply to Crane

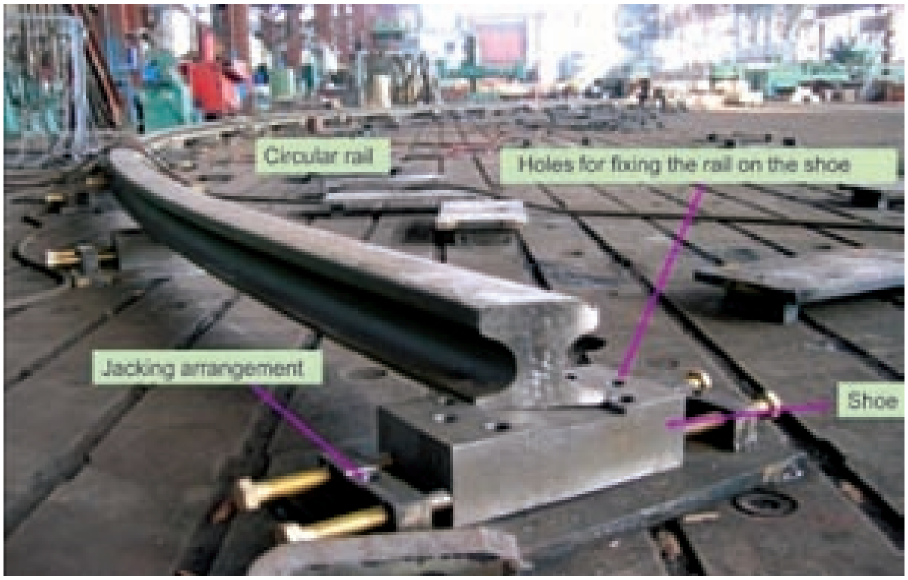
380V supply to the crane equipment is fed through the power supply line, which connects the containment dome and the crane. The mechanism with its platform rests on the bridge gantry. The current supply line from the bridge to trolley incorporates flexible cables. Assembly of the cable loop is carried out on the cable cars running over I-beam monorail.

2.7 Crane Circular Rails

The polar crane is supported on crane girder beam. These are 15 such beams of 8.76m arc length, each subtending an angle of 24° at the centre of polar crane. Each beam is supported on 3 brackets. Thus, these are 45 brackets supporting the crane runway girder. The radius of the circle formed by crane girder is 21.0 m.

Dome service platform with gantry in the foreground





Crane rail being checked at the manufacturer's facility

The crane beams are resting over the bearing plates of thickness t35, 100 x 660mm size. The contact surface of the bearing plate with the bottom plate of crane beam, the contact surface between web plate/diaphragm and the bottom plate of the crane beam are machined (plane surface) to ensure 100% contact.

The crane railings in 30 segments are arranged in circular ring of a 42m diameter, while a gap of 1.5 mm between each segment is provided to compensate for thermal expansion. Each rail segment is placed over eleven shoes welded to the crane beams and secured by bolts and strips to the shoes.

3.0 Pre-erection Activities

After receipt of the equipment, its visual inspection was carried out. Completeness of the equipment as per packing list was verified. De-preservation of components such as nuts, bolts and washers was carried out by submerging them into a tank with boiling water and then while being still hot into a tank with a mixture of petrol and oil. The crane erection was a part of mega package (M6) contract.

A levelled clear assembly area of 50m x 18m was identified in front of the reactor building for bridge structure and carriage of the polar crane. A separate space of size 10m x 24m was identified for assembly of gantry and the trolley.

4.0 Erection

The erection of the polar crane comprises ground assembly, mechanical erection as well as electrical and instrumentation systems.

4.1 Ground Assembly

The ground assembly works are as follows:

- Main bridge assembly
- Bridge drive mechanism assembly

Crane rail being erected on the crane beam inside the containment at +43.9 m

Crane rail KR-140 with shoes being erected

- Assembly of roller pedestal with horizontal rollers
- Assembly of main and auxiliary trolleys
- Assembly of bridge gantry and hoist
- Assembly of auxiliary trolley gantry

4.1.1 Main bridge assembly

The crane was manufactured by M/s. Uralmash, Russia, and shipped to Kudankulam. The main girder was received in 3 separate pieces. To align these pieces, the ground was levelled. For getting a levelled surface, 24 concrete blocks each weighing around 4 to 5 tons were shifted to the location and the top of the concrete blocks was levelled. All the 3+3 pieces of the main girder were aligned on these concrete blocks. After checking the camber and bow of the girder using Total Station, the girders were joined together by high-strength friction grip (HSFG) bolts. Initially, the bolts supplied by the manufacturer were failing while tightening to the full torque. Similar bolts were than taken from unit-2 crane and tried, but the result was the same.

Polar crane girders being aligned on the ground

HSFG bolt joint, during alignment and after final cleaning, tightening and painting

This issue was taken up with the manufacturer and new bolts were supplied from the manufacturer. The new bolts were de-preserved and bolts were cleaned off of all traces of oil and grease. For HSFG bolts, the contact surfaces should be grit-blasted before joining.

The clearances between the contact surfaces recommended by the manufacturer were very tight to obtain the correct value of friction between the surface of the strap plate and the beam. A procedure was prepared for the sequence of bolt tightening. After grit blasting, the bolts were put into the bolt holes and it was initially tightened manually using spanners. Then it was tightened in a step-wise manner to full torque value using hydraulic torque wrench. The bolt tightening was completed within 72 hours after the de-preservation of the bolts. After the QA inspection, the joints were painted. After completing the ground assembly of the main beams the rail, staircase, platforms, hand railing, festoon structure and other structural items were assembled on them to reduce the time for erection. In unit-1, these items were assembled and erected separately, whereas in unit-2, these items were assembled on ground itself.

4.1.2 Bridge drive mechanism assembly

After shifting the drive carriages and drive mechanism from stores it was thoroughly inspected. After inspection, the drive carriage mating parts, split pins, couplings, etc. were de-preserved by removing the paint and coatings. The gearboxes were assembled with

Crane girder being lifted to +43.9m inside RB using the Demag crane

Crane end girder installation in progress using tower crane

the drive carriages (wheels). The drive mechanism and balancing beams were assembled with main beams.

4.1.3 Assembly of roller pedestal with horizontal rollers

The roller pedestals received from the manufacturer were first taken to the workshop for dismantling the rollers and rollers casing. After dismantling, these were machined to suit the circular rail alignment and wheel size. In unit-1, the machining was done after erection, whereas in unit-2, all machining was done at ground in a local workshop to reduce the erection and assembly time significantly. After machining, the same was assembled on ground for checking the clearances. The roller pedestal assembly was erected separately from the main beam assembly.

4.1.4 Assembly of main and auxiliary trolleys

Main and auxiliary trolley was shifted to the site and thorough inspection of material was carried out. After inspection, the drive mechanism was assembled with trolleys and alignment of wheels were checked. This alignment was matched with the rail on the main girder assembly, which was already erected. After this, the hoisting mechanisms were assembled on the trolley. In unit-2, the seismic arrestors were also attached with the trolleys and oil in gearboxes were filled at the ground itself to reduce the erection time.

4.1.5 Assembly of bridge gantry and hoist

For assembly of bridge gantry, both the legs of the gantry were placed on the levelled concrete blocks. After checking the gantry span, diagonal the gantry beam with platform, monorail and hoist was assembled with it. The joints were same as in bridge assembly

Crane girders and end girders installed at +43.9m inside reactor building

Gantry structure being installed

and connected with HSFG bolts. After fixing all the accessories, i.e. platforms, staircase, hand rails, cabling of hoist, etc., the gantry structure was made vertical for installation of main electrical panel on it.

4.1.6 Assembly of auxiliary trolley gantry

Assembly of auxiliary trolley gantry was done in the same way as bridge gantry. It was also assembled on the concrete blocks.

4.2 Mechanical Erection

Maximum material of the polar crane was erected by using DEMAG or Liebherr cranes kept near the reactor building. All erection works were taken up as per the schedule, prepared prior to erection. The crane was erected inside the reactor building before completion of crane beams erection. As and when the six diagonally opposite crane beams were ready, the crane girders were installed and erection works inside the reactor building initiated. Therefore, the crane erection works and CRB works could be taken up in parallel. Before the erection of the main girder, the centre of the crane and each wheel position were marked exactly on the rail.

After completing the ground assembly, one main girder was erected inside the reactor building by using Demang crane and held on the circular rail. By using two tower cranes, 2 end beams were lifted simultaneously and assembled with this main girder by using temporary bolts. Then the second girder was lifted and brought closer to end beams and with the help of all the 3 cranes, the flange holes were matched and assembled along with strap plates by temporary bolts. After the geometrical checking, viz., span, diagonal and level of the formed rectangle, the bolt insertion and tightening as per the sequence was done. This made the bridge assembly ready. After joining together the assembly was checked for camber, diagonals and rail alignment. This entire assembly was completed within 72 hours to take the HSFG joints. Subsequently, the erection and welding of roller pedestals were done.

The centre of the crane was matched with the centre of the reactor building. The readings of the crane centre at different positions were taken using Total Station. On getting clearance from QA regarding dimensions of the bridge assembly, the clearance for the erection of first part of the containment dome was given.

Next, the erection of other assemblies was taken up. This included assembly of trolleys, gantries, dome service platform, etc. The trolleys were erected first. After the erection of trolleys, the clearances between wheels flanges and rail were taken. The trolleys were moved on the rails for checking any misalignment in the rails. On clearing both the trolleys, the erection of main gantry was done. The gantry structure was

Dome service platform being lifted to be installed on the polar crane

The '360°rotating' polar crane used for handling and erecting bulky ODC equipment items in the reactor building

The '360°rotating' polar crane used for handling and erecting bulky ODC equipment items in the reactor building

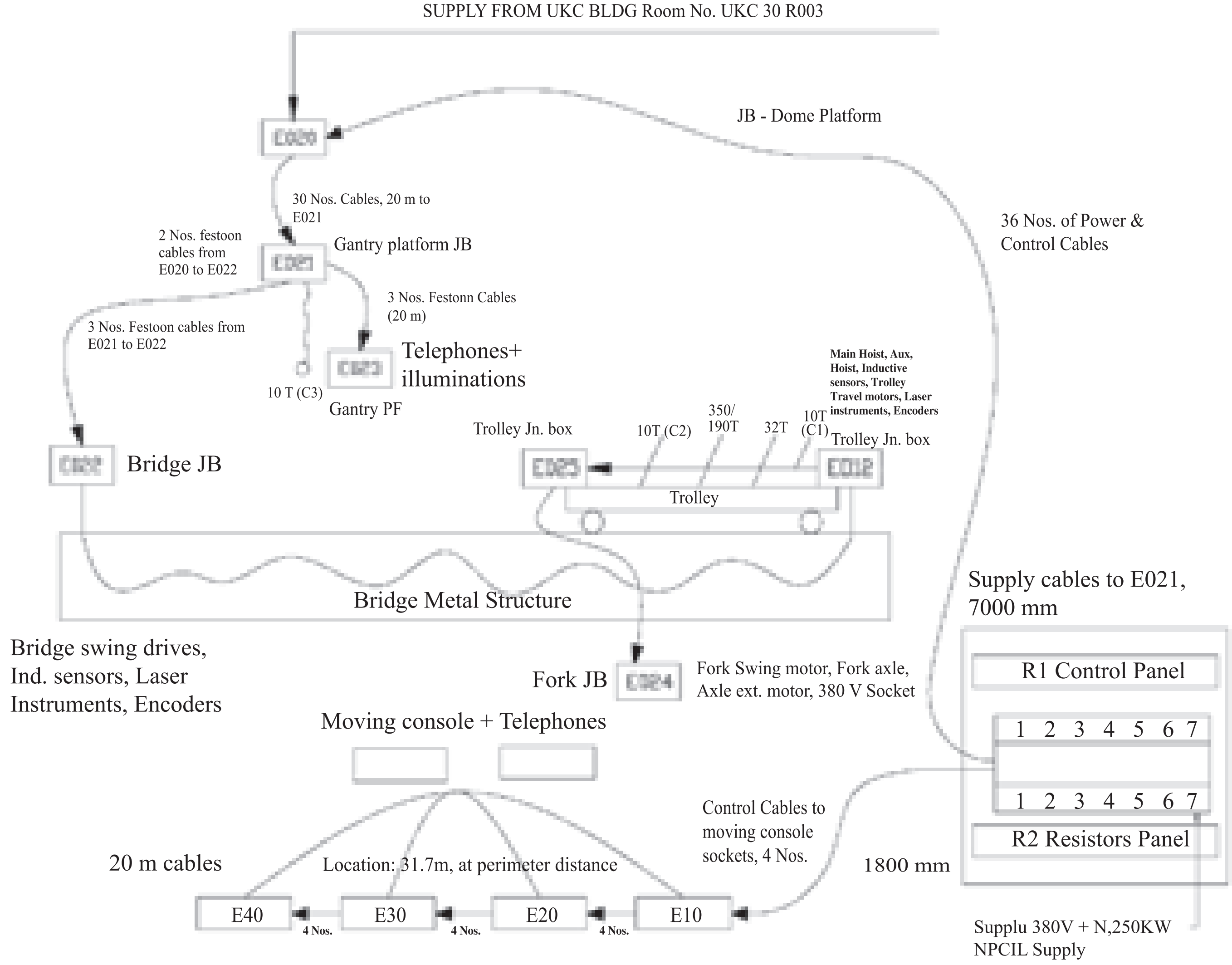


Figure 3: An electrical schematic diagram of 350/190T polar crane

lifted and placed on the main bridge and aligned. After alignment, it was bolted to the flanges provided on the main girder. The flanges de-preservation was done 24 hours prior to the erection.

After completing the main gantry erection, the erection of dome service platform was done. The dome service platform installation point was marked on the main girder based on the actual alignment dimensions of the crane. The actual dimensions of the crane and reactor building dome were noted from the site and an AutoCAD model of the crane was made. Based on this model, the correct location of the fixing point of dome service platform was identified. The dome service platform was erected and clearance for the second part of the reactor building dome was given.

On completing the erection of second part of dome, the dome service platform was lifted and its supports were welded to the main gantry platform. On completing the works of dome service platform, the cabling works of the crane started. Also clearance was given for erection of final top part of the reactor building dome. The power supply panel to the crane was erected with the third part of the dome.

On completion of erection, the after-erection alignment and electrical cabling, etc. works started. This also includes rope reeving of main and auxiliary hoists. The main hook of the crane was shifted inside the reactor building through equipment airlock and kept at 31-m elevation. It was made vertical with the help of auxiliary hoist and other service hoists provided in the crane. After rope reeving of main hoist, it was

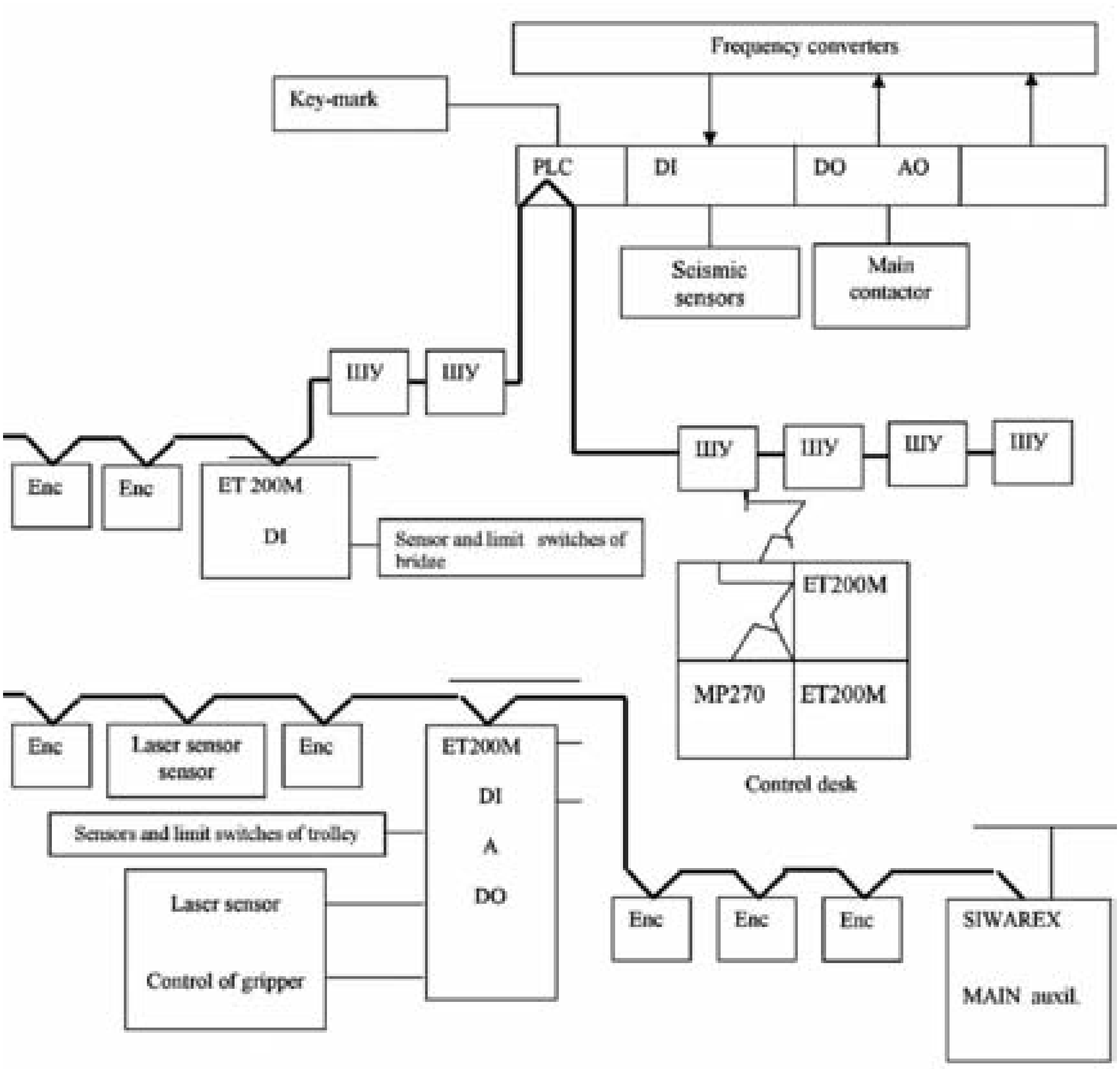


Figure 4: Block diagram of the control system

Load test in progress using steel slabs kept on a pre-tested platform

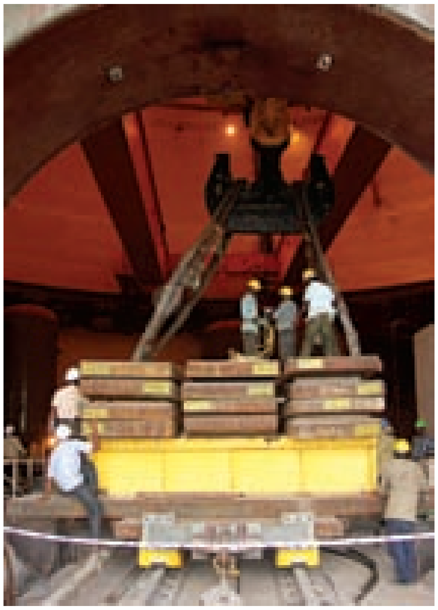
noted that the main hook was not straight. The reason for this was due to wrong reeving diagram given in the passport. The reeving was done again with the modified reeving diagram issued by the equipment manufacturer.

Main hoist reeving activities in progress

4.3 Electrical and Instrumentation Systems

The major electrical equipment that were installed and commissioned on this crane are: electric motors (20 nos.) for bridge, trolley, hoist movement, fork rotation, etc., thruster brakes, limit switches, panels, junction boxes, contactors, lighting, etc.

Major instrumentation & control (I&C) equipment are programmed logic circuit (PLC) units for bridge and trolley control, control panels, encoders, inductive proximity switches, laser measuring device, control desk, load sensors, etc.



Loads being shifted to +31.7m inside the RB using skip transfer trolley

Electrical cable-laying was started soon after the main erections were

Deflection being monitored during the crane static test

over. When the cabling was in progress, dome part-2, part-3 and crown were erected. As the electrical works were sequenced along with the dome erection, soon after the dome part-3 erection, E20 panel was erected on the top of gantry and cabling work was taken up. After the electrical cabling, instrumentation cabling was done. The following improvements were made to expedite the E&I works:

- Power supply cables on the main gantry were laid prior to lifting
- Festoon cables were cut and were kept inside girder
- Electrical panels were mounted on the trolley and main girder
- Cable trays were installed at various points before the erection itself. Thus considerable amount of time was saved during the electrical works

Power and resistor panels for the polar crane are located in reactor auxiliary building (UKC). The crane control desks are provided in multiple locations. The crane can be controlled either from the reactor operating floor at +31.7m inside reactor building or from UKC at +20m.

The crane control system has a two-level structure, which ensures fulfilment of the requirements of fail-safe and safety. The block diagram of the control system is shown in Figure 4.

The lower level provides for communication with the object to be controlled and fulfils the functions of acquisition and primary processing of signals from sensors and of diagnosis of the state of sensors, actuators and communication lines, of grouped (multi-operation) and local control

of crane mechanisms and ensures the interaction interface with the upper level.

The upper level provides for generalised processing of information and ensures interface of interaction for the operator and the system, fulfils the functions of operator's information support, data base input, of display, logging and documentation of works relating to the direct control of the crane and ensures interface of interaction with the lower level.

The lower and upper levels of the control system are made on the basis of PLC Simatic 7-400.

5.0 Commissioning and Load Test

After energising and making the crane operational, various loads were lifted for commissioning and running in test of various hoists and crane rails. Before the arrival of the manufacturer's personnel pre-commissioning checks were completed in full scope and all the relevant reports were kept ready. Final fine-tuning, testing of logics and software loading, crane movement checks, load tests were done along with the manufacturer's representative. To avoid the difficulty of putting/removing the D shackles along with slings, special custom-made 200-ton capacity endless slings were procured, which was found to be very useful for the load testing.

As part of final acceptance tests, static and dynamic tests of the crane were carried out. Load test was taken up after the complete rail shoe and jack bolt welding. The static test is carried out at 125% of the rated load. The 190t hoist was

Polar crane dynamic test in progress

Seismic arrestors installed at ground before lifting to +43.9 m

tested at 238t and the 350t hoist was tested at 437t. The test is considered successful if the elastic deflection is <56 mm and there is no permanent deflection after removal of test loads. Test loads were placed on platform, which was also qualified for 450t prior to load test. During load testing, all the required electrical parameters were monitored from the UKC control room and were recorded. Other parameters such as hoisting speed, travel speed, braking distance, etc. were also checked and recorded. The sequence of the test was as follows.

1) No-load test

All the movements of the crane were tested without load. The main hoist was lowered and lifted three times and bridge was rotated 3 times. During the test, all the required electrical and mechanical parameters were checked and were recorded.

2) Load test with nominal load of 350 tons

During the test, load was raised and lowered thrice and the crane was also rotated thrice. All the required parameters were checked and recorded.

3) Static test with a load of 437 tons (@125%)

A 437-ton load was lifted and held for a duration of 10 minutes. During the test, both deflection and brake slip was monitored. Deflection was measured using Total Station and a manual arrangement. After the test, no permanent deflection was observed. After the test slings were removed and Ramson Hook

was disengaged from the main fork to check for signs of any damage.

4) Dynamic test with 110% load (385 tons)

A 385-ton load was raised and lowered thrice and the bridge was also rotated thrice. All the combined motions like bridge rotation and trolley movement, bridge rotation and main hoist movements, trolley movement and hoisting were checked during this test and all the required parameters were monitored and recorded. After the test, the crane was inspected thoroughly for signs of any damage.

6.0 Improvements Made in Unit-2 Crane Erection

Based on the experience gained during erection of polar crane in unit-1, various improvements were made while erecting polar crane in unit-2.

In order to speed up the ground assembly works, the following improvements in the erection procedure were made.

a) Bolt tightening was done by hydraulic torque wrench.

b) In order to avoid the interference of the main wheel with the roller pedestal wheel, the main wheel assembly was dismantled at ground and the wheels and roller pedestals were machined in the workshop. After machining, the same were assembled and erected.

c) The height of the platforms at the end of the trolley was reduced prior to lifting to avoid fouling with the end girder when the trolley is taken to the end. Moreover, balancers and main wheels were assembled and tied with main beams for reducing the erection time.

d) Main hoist alignment was completed prior to lifting and gearbox oil was filled. Doing this activity at ground reduced a lot of time. Persons could work more comfortably at ground level outside reactor building. Moreover, shifting of oil drums inside the reactor building was avoided, which saved time and chances of spillage. Material handling at ground was easier than doing it at 42m elevation inside the reactor building.

e) The main hook of the crane was taken inside the reactor building in vertical position in the stand, which reduced the time to make it vertical and rope reeving was made easy. Rope reeving of the main hoist was done by giving temporary power supply to the motors, as permanent power supply from design source was not available. Also special handles were made for rope adjustment in both the rope drums of main hoist.

f) Seismic arrestors of the trolley were erected with trolley itself before installing the trolley on the crane girder.

7.0 Review and Acceptance

Activities at each stage were jointly reviewed by Nuclear Power Corporation of India Limited (NPCIL) and Russian federation (RF) specialists at the site. After completion of each stage, the required reports such as alignment reports, torque reports, NDT reports, etc. were prepared. These reports were reviewed by various agencies, including manufacturer/ Russian representative. Based on the satisfactory results of each stage activities, clearances were given for next stage assembly. All the reports, including ground assembly, erection, commissioning and load testing, were included in the CCC for future reference.

8.0 Conclusion

Polar crane is a special crane with a capacity of 350/190 tons, which moves on a circular rail inside the reactor building at an elevation of +43.9 meters with a span of 42 meters. The total weight of the crane is approximately 500 tons and the crane was received in several parts in 135 different packages from the Russian Federation.

It is worth mentioning here that after the commissioning of the polar crane, it has been used almost 24x7 till the start-up of unit-1. Similarly, it has been a workhorse in unit-2 as well.

Arun P. Nair, *SO/F, joined NPCIL in 2001 as SO/D. After joining KKNPP O&M Group, he was deputed to the Russian Federation for an eight-month training. Thereafter, at KKNPP, he was involved in the commissioning of cooling water systems and erection of various load-lifting equipment, and later in the first approach to criticality, power raise, first synchronisation and various aspects of phase-B & C experiments for unit-1. He is ASCE, KKNPP unit-2, where he is presently involved in the preparatory works for unit-2 hot run. He is also the recipient of 'NPCIL High Performance - Young Executive Award' for the year 2007, for his contribution in the erection and commissioning of load lifting equipment at KKNPP.*

Kapil Aggarwal, *SO/F, holds a post-graduate degree in Mechanical Engineering from Tula State University, Russia. After joining NPCIL in 2001 at KKNPP Directorate Mumbai, he was deputed to Russian Federation for eight months, to undergo training for operational personnel at NVTC. Thereafter, at KKNPP, he was involved in the commissioning and testing of fuel handling systems, refueling machine and erection of load lifting equipment of KKNPP-1&2 and later in the first criticality of unit-1, low-power tests, full-power operation of unit-1 and stable operation at full power. He has been felicitated with 'NPCIL High Performance - Young Executive Award' for the year 2006. Presently, he is ASCE (unit-2) at KKNPP.*

P.A. Suresh Babu, *SO/H+, is CE (QA), KKNPP. He is a mechanical engineer. He is from BARC's 32nd batch for in-plant training. After the successful completion of one year of training at RAPS, he was posted at MAPS in 1989. In 2003, he shifted to KKNPP, where since 2010 he has been functioning as Head, QA, with overall responsibilities of Site QA functions of KKNPP 1-4.*

Some of his significant contributions have been in the design change of latch ball screw assembly, modification of excess flow check, full core defueling of MAPS-2 and EMCCR-elated works of FHS and the commissioning of FHS, erection and commissioning of polar cranes, trestle cranes, turbine building cranes and fuel building crane, ILRT and hydro test in both units at KKNPP as well as PSI of unit-1.

Erection of KKNPP Dome Liner

Jayesh Kurwa, ACE (FLWR), NPCIL

The reactor-building dome for each of the Kudankulam Nuclear Power Project (KKNPP) reactors is hemispherical in shape with a diameter of 44 m. The dome is made from 6-mm-thick carbon-steel plate (except crown portion, which is made of 10mm-thick plate). From the limitations on fabrication, transportation and erection point of view, the dome was fabricated in 4 parts. The technical parameters for each part are given in Table-1.

Table-1: Technical Parameters of the Dome

Part	Dimension	Weight	Remarks
1	At bottom Φ 44 m x 5.6 m height and at top Φ 43.564 m	68 MT	Consisting of 15 panels equispaced at 24° each
2	Φ at bottom 45.564 m x 7.6 m height and at top Φ 35.224 m	100 MT	Consisting of 15 panels equispaced at 24° each
3	Φ at bottom 35.224 m x 8.065 m height and at top Φ 6 m	130 MT	Consisting of 15 panels equispaced at 24° each
4	Crown Φ 6 m x 1.410 m height	6 MT	Fabricated as a single part from 15 segments combined together

For fabrication and erection, separate procedures, quality plans and job hazard safety analysis were carried out. Checklists were prepared and filled and verified before lifting of each part of the dome. Trial assembly between part 2 and 3 of the dome was carried out on the ground. The dome radius and height were measured at number of locations by optical alignment equipment.

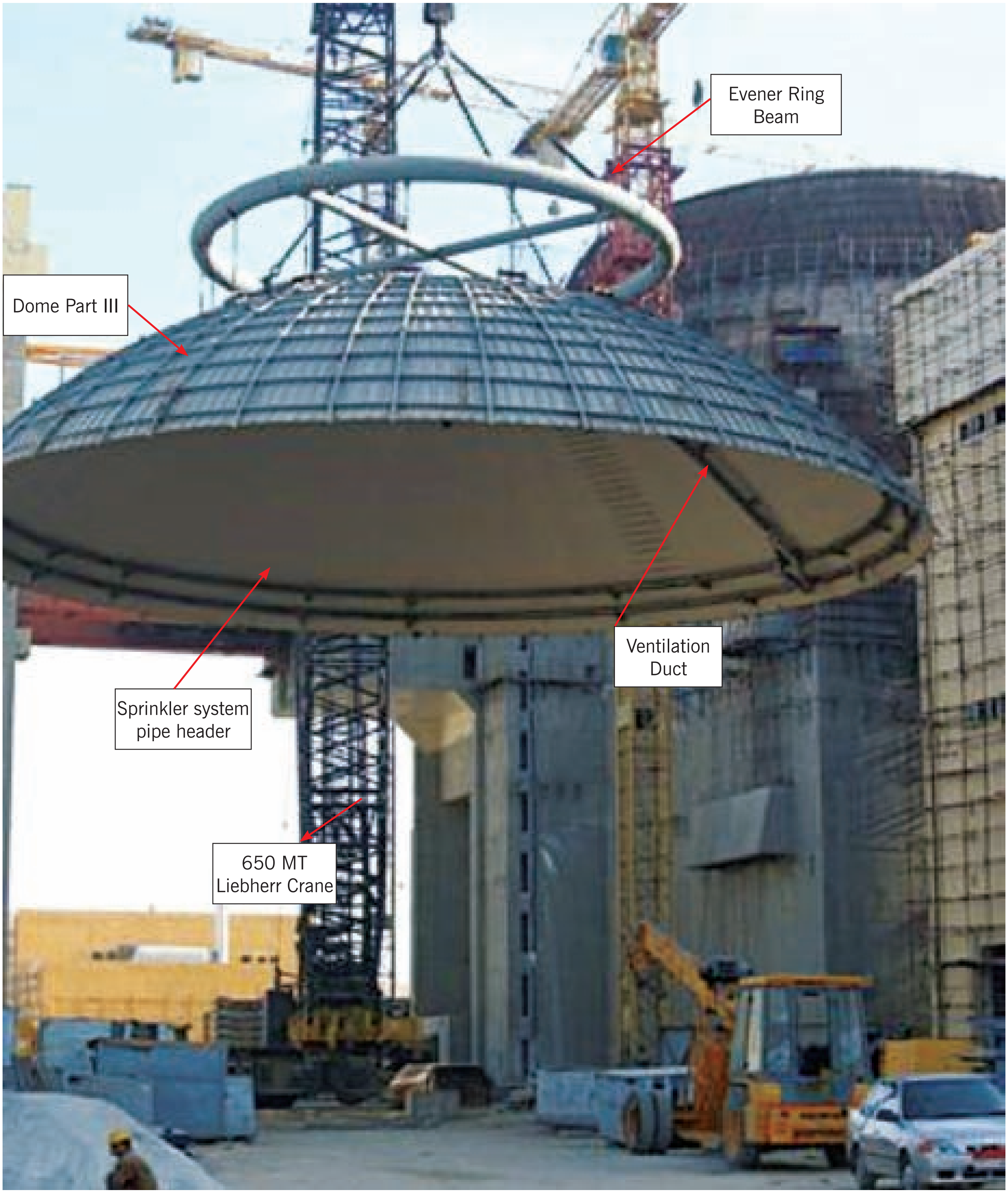
For erection of dome part 2 and 3, a separate tubular evener beam (weighing 22 MT) was fabricated. All the joints of evener beam were subjected to Non-Destructive Examination (NDE), i.e. (100% Radiographic Testing (RT) of pipe weld joints, Ultrasonic Testing (UT) and Dye Penetrant Testing (DPT) of various components.

The most important aspect of erection was from the point of erection of dome part-3, in which sprinkler system pipe header weighing 22 MT, ventilation duct weighing 0.5 MT and electrical embedded parts (EPs) were installed/erected. The total weight for erection of dome Part-III was about 180 MT. This included dome liner weight, sprinkler system header weight, ventilation duct, electrical EPs, and also the weight of evener beam, slings and D-shackles), which was very close to the crane capacity (Liebherr crane 650 MT) at a working radius of 43.3 m. Before each lifting, load test was carried out.

There was a factor of wind velocity restriction for the erection, which was being monitored on hourly basis from two days prior to the erection day.

On the crown portion, an additional member of polar crane – the electrical panel cage – was to be welded, which was a formidable

Dome Part-II – lifting from ground for erection



Dome Part-III erection

A view of Part-III dome seating from polar crane inside the reactor building

task to achieve to the required mating profile. The erection time for dome part-2 and 3 was 6 hours each. Upon seating of dome on the stools, temporary fixing was carried out and, subsequently, fine adjustment for alignment and proper seating were done. Thereafter, welding fit-up and circum-welding between Part-I to Part-II, Part-II to Part-III and Part-III to crown were separately carried out. The requirements of working drawings on any shift of centre, radius and total elevation were stringent and were achieved well within specified parameters.

With meticulous planning and flawless execution, the work was completed in a safe manner within the specified parameters and in a minimum time period.

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Tertiary dome with Passive Heat Removal System ducts during construction phase

Tertiary dome with Passive Heat Removal System ducts during construction phase

Underwater Cutting of Caisson Gate Structures at KKNPP

R.R. Kamath, ACE (HTS), KKNPP-3&4

Introduction

In Kudankulam Nuclear Power Project (KKNPP), a once-through cooling system is used, where the cooling water is drawn from the sea and after removing the heat from the condenser, the water is discharged back into the sea. To facilitate the intake of the seawater at the design location (at a point of about 1.2 km from the shore) and depth (10.5 m), a unique design of caisson structures has been provided. There are 4 caisson units – 2 adjoining units (dimensions 36 m x 15 m x 12.45 m) and 2 water passage units (46 m x 15 m x 12.45 m). These structures were cast in the dry area within the temporary dyke, and after the completion of their construction, they were floated, towed and installed at their final design locations. The water passage units have large openings (total 10 openings in each caisson of dimension 6 m x 5.4 m) for inlet of seawater. These openings were temporarily closed using fabricated structural steel gates weighting approximately 16 MT (dimensions 6 m x 5.4 m 1.5 m), which were held in place by a system of turn buckles at the top and pivot pins of 100mm diameter at the bottom. Additional anchor fasteners were provided at eight locations using three M20 bolts each, embedded in caisson wall. These gates were also designed to act as the buoyancy tanks during towing operation. After successful installation of the water passage units, these gates were to be removed by a special underwater cutting operation.

As these gates were of large dimensions as well as weighing about 66 MT (including the water ballast inside) and as the working environment was very tough due to the open sea/wind conditions, several safety measures were also required to be incorporated in the work. Moreover, as this type of specialised underwater cutting operation was being carried out for the first time in NPCIL projects, there was no past experience of the work, and hence the work was really challenging.

Feasibility Study for Gate Removal

As per the Working Documentation supplied by the Russian designers, the gates were supported by 2 hinge assemblies at the bottom and 2 turn-buckles at the top. Hence the gates had to be removed by loosening the turn-buckles at the top and releasing the gates from the bottom pins. Then these gates were to be pulled by a marine craft and to be brought to the shore for lifting out of water. However, as these gates were submerged in the seawater for a long period, it was assessed that the removal of the gates from the pins would not be possible due to severe corrosion and consequent bonding of the metal surfaces of the pin and gate. Moreover for additional safety, 24 anchor fasteners were provided on the sides of each gates. Hence it was not possible to remove the gates as per the drawings. Further, the gates were submerged at a depth of about 9 m below the seawater level, with the bottom clearance of only about 350 mm from the bed, which was a constraint for the access.

Hence a thorough review of the methodology to be adopted for removal of the gates was done. In this regard, many of the specialist underwater cutting agencies, including experts from Indian Navy, were contacted. Finally, it was concluded that the only feasible method to remove these gates was to cut the structural members holding the pins by accessing from either sides of the gate and detaching the gate from the body of the caisson. Then the gate would be lifted by a crane placed on the top of the caisson. However, this cutting operation would have to be carried out totally under water.

Figure 1: Exothermic electrode

Overview of Underwater Cutting Process

There were two underwater cutting processes then approved for the use of Navy. They were:

1. Oxygen-arc cutting
2. Shielded metal-arc cutting

Of these, oxygen-arc (oxy-arc) was preferred because it cuts plain and low-carbon steel easily and due to its ease of use.

Two types of electrodes (also called rods) were used for oxy-arc cutting:

1. Exothermic electrode
2. Steel-tubular electrode

Of these, the exothermic is preferred, as it would burn independently after an arc is struck and oxygen is flowing.

Principle of Underwater Cutting using Oxy-Arc Method

Oxygen-arc cutting is defined as oxygen cutting process, in which metal is severed by means of the chemical reaction of oxygen with the base metal at elevated temperatures. The heat of the arc brings the metal to its kindling temperature, and then a high velocity jet of pure oxygen is directed through a tubular cutting electrode at the heated spot. The metal oxidizes and is blown away. The tip of the electrode, which is exposed to both heat and oxidation, is consumed in the process and must be replaced frequently.

These electrodes provide excellent cutting results and can be used with a constant current DC welding generator set on straight polarity (electrode negative) supplying current to the electrode. With the work grounded, the electrode will ignite as it touches the work.

Hence, Oxy-arc cutting method using exothermic electrodes is used at KKNPP. (See Figure 1 for exothermic electrode.)

The exothermic electrodes consist of seven small rods inside a thin steel tube. One of the seven rods is a special alloy that burns independently after an arc is struck and oxygen is flowing through the tube. The remaining six rods are made of mild steel. The electrode is insulated with electrical tape for providing electrical insulation to the diver and to provide waterproofing for the electrodes. The electrode is 22 inches long, with a 10-mm outer diameter and a bore diameter of 2 mm. The exothermic electrode melts almost any material with its 10,000° F-plus tip heat.

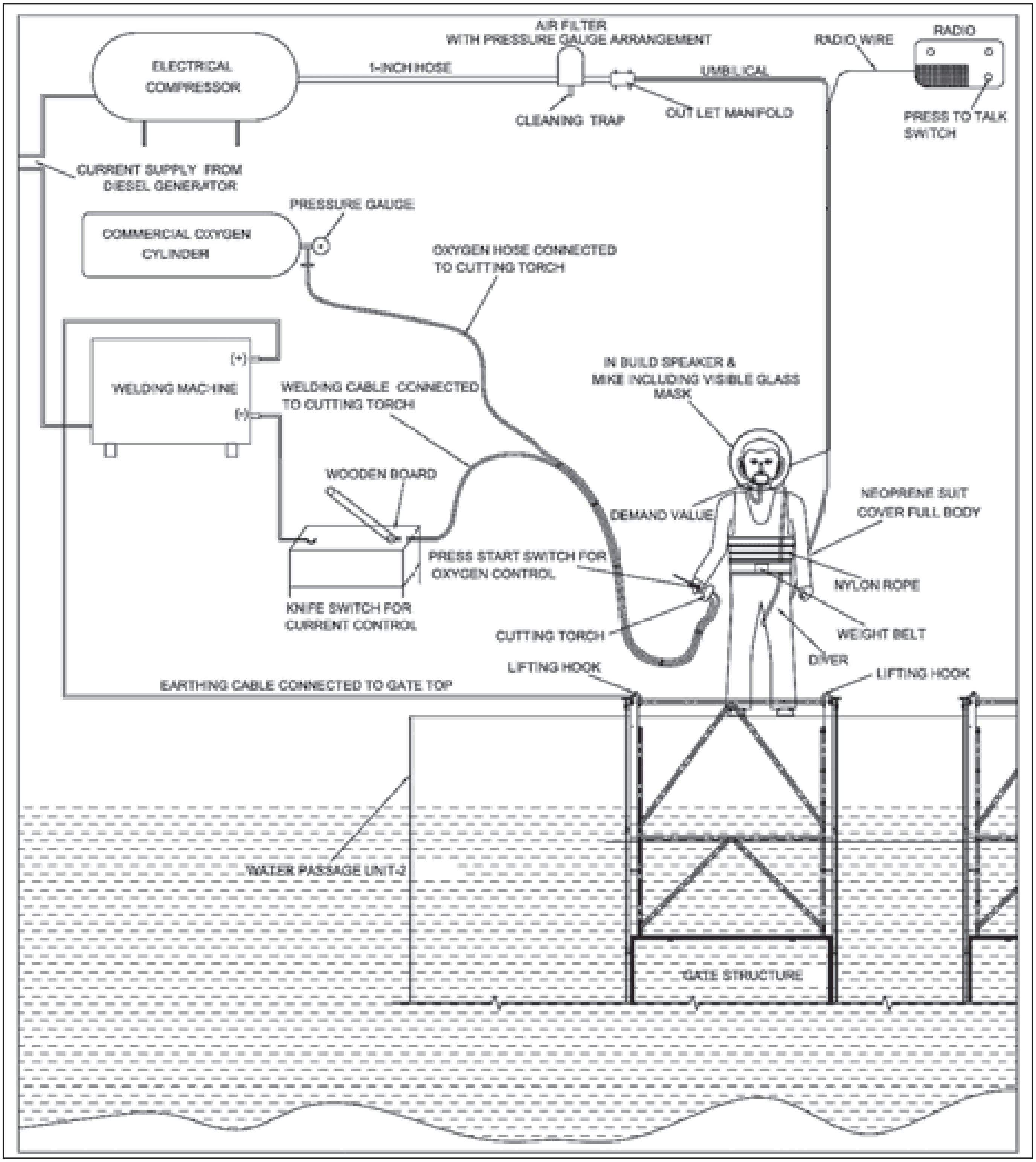


Figure 2: Typical arrangement of the underwater cutting setup

Equipment and other materials used for the underwater cutting works were as follows:

Equipment

a) On Land

1) Air compressor
2) Air distribution panel
3) Breathing air filter
4) Diver air radio
5) DC welding generator
6) Commercial oxygen cylinder
7) 150MT crawler crane (Kobelco crane)
8) TFC 280 – 75 MT crane
9) Trailor – for shifting
10) Wheel-mounted (TIL) crane for unloading
11) Dumper (For cylinder, packing wood shifting)
12) Weigh bridge

Underwater

1) Exothermic cutting torch
2) Cutting cables
3) Knife switch
4) Grounding clamp
5) Welding lens
6) Breathing apparatus
7) Under water communication system
8) Safety harness
9) Underwater lighting system
10) Umbilical – (gas hose)
11) Diver's protective apparel (including Neoprene suit)

b) Underwater Cutting Equipment

1) Cutting torch
2) Cutting cables
3) Knife switch

Underwater Cutting Consumables

1) Underwater cutting rods – 10 mm diameter., 22 inch long
2) Commercial oxygen
3) Packing wood

Floating Craft

1) Tug boat/75 HP country boat
2) 75 MT Barge-mounted crane

Typical arrangement of the underwater cutting setup is given in Figure 2.

Underwater Cutting Methodology Used at KKNPP

As described above, the work involved high technical knowledge and the sequence of operation were to be completed in the specific time.

After the successful grounding of the water passage unit-2, concrete ballasting was carried out. Once the entire compartment concerting level reached up to El. 0.000 m from El. -9.050 m, the gate cutting operation was commenced.

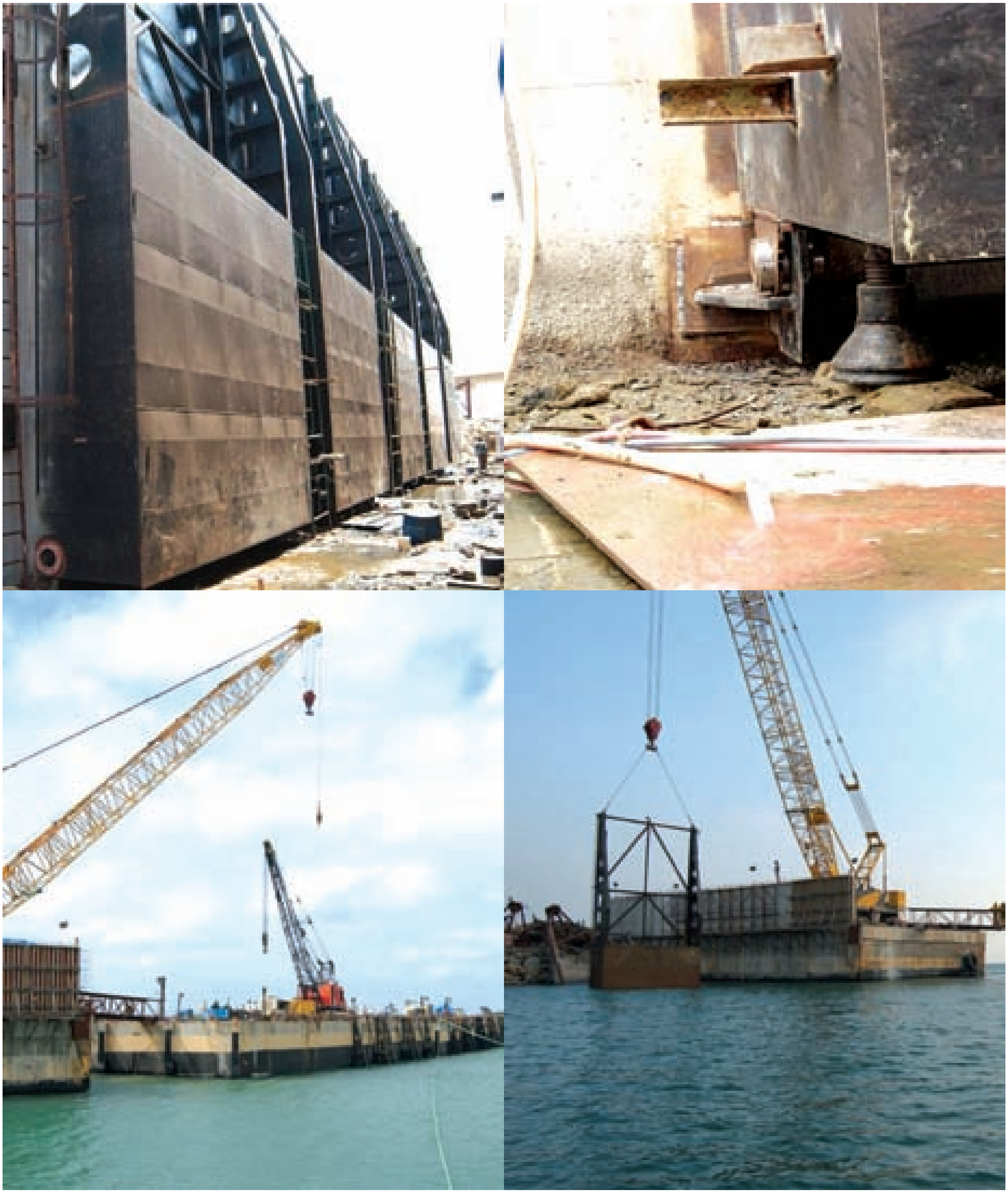
Before carrying out the actual cutting work, underwater survey of the site was carried out for finalising the methodology of cutting the gates. Based on the survey, it was decided to carry out the cutting operation in the following sequence:

1) Securing the gate structure before cutting
2) Cleaning of cutting area
3) Making suitable number of openings on the sides of the gates for balancing the buoyancy
4) Cutting the pins and/or the whole assembly
5) Cutting and removing the additional anchor bolts
6) Removal of the gates from the caisson structure

The detailed procedure adopted for removal of the gates is explained below.

Securing the gate structure before cutting

The gates were held with the 75 MT crane with wire slings at the top of gates, in addition to the turnbuckles already provided. The turnbuckles were also supported by additional stiffening members below them. Wooden beams were



Caisson during construction stage

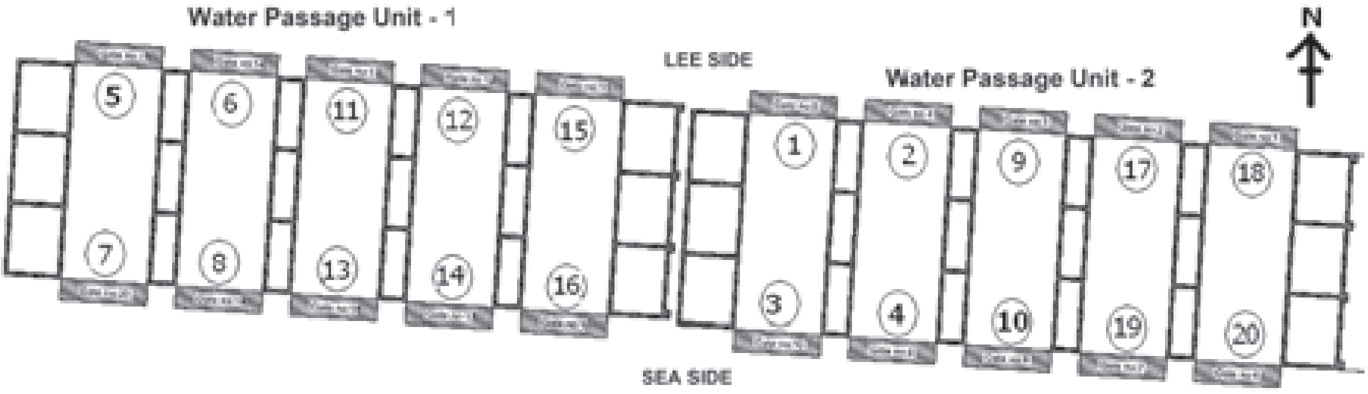


Figure 3: Sequence of removal of gates in caisson structures

placed under the gates on the seabed so that the load of the gates could get transferred to the wooden beams when the pins get removed.

As the gates were huge in size and very heavy, it was essential to make adequate arrangements for securing them before making any attempt to cut the pins/assembly/anchors etc. Without proper arrangements, there was a distinct possibility of the gates to topple on the divers during cutting operations. Also the gate was only hinged at top against the horizontal loads through the top turnbuckle and this support could not possibly take the weight of the gate. Hence it was decided that these turn buckles be additionally supported by ISMC 250 and 10-mm-thick plate and before cutting the side hinges of the gates, the gates be held by crane. Three wooden beams of size 1.4 m in length and 400 mm in width (thickness depended on site condition) were placed and packed tightly through wedges by divers (one each at both the ends and one at the centre) at the bottom of gate above the sea bed, so that if any load comes from the gates while cutting and removing the pins/ assembly/anchors, the same would be transferred to the wooden beam.

Cleaning of cutting area

As the area to be cut was submerged in seawater for a long of time, a considerable amount of bio-fouling had occurred. In order to facilitate underwater cutting, all bio-fouling was to be removed from the area where cutting was to be taken up, with the help of divers using scrappers and wire brush.

Making suitable no. of openings on the sides of the gates for balancing the buoyancy

As the gates contained about 50 cu.m of water, it was necessary that the weight be balanced as the gates get progressively lifted up from the sea. Hence, it was decided to make a few openings on either side of the gate for balancing the buoyancy and self-weight for a safe and easy lifting operation. Hence, before starting the gate-cutting operation, at first 4 openings of 300 mm x 250 mm were made to drain out the water while lifting.

Cutting the pins and/or the whole assembly

As it was difficult to fuse the pivot pins that held the gate in position, it was decided to cut and remove the hinge assembly. Accordingly, the hinge assembly was cut and the gate was separated from the caisson structure at the bottom.

Cutting and removing the additional anchor bolts

After the cutting of bottom assembly from the gate (2 nos.),

the gate was immediately held by surface-placed (caisson top) crawler crane of 150 MT capacity. The cutting operation of the additional anchorages on the sides (total 24 nos.) was taken up one-by-one from bottom to top. It was decided to cut the plate around the bolt head and leave the bolts embedded in the concrete as it is. On completion of the above works, the load of the gates would be transferred to the wooden beams under the gates, while holding it using crane from the top of the gate assembly. After the completion of removal of entire side anchor hinges, the top turnbuckles (2 nos.) and additional support given below the turnbuckle (10 mm plate – 2 nos.) were cut and removed by normal gas cutting method while continuously holding the gate by crane.

Removal of the gates from the caisson structure

Once all the cutting work was completed, the sliding and lifting of the gate assembly was done with the help of the crawler crane. The gate assembly was lifted from its position and moved out of the caisson area. Then the gate assembly was moved slowly towards the east arm of breakwater dyke, with half the gate submerged in the seawater. Once the gate assembly reached near the east arm area, it was lifted from the seawater gradually by maintaining the balance, by allowing the water to drain out from the gate structure through the openings made, and was placed safely on the east arm of breakwater dyke.

Cutting and removal of each gate was done successfully following the above procedure. It was necessary that before placing the next caisson, at least two passages (4 nos. of gates) were required to be removed so as to reduce the water current on the caisson being placed. Hence, there was a very tight schedule for removal of the gates. The order of the gate cutting and removal followed is given in Figure 3.

Shifted gates on the east arm were cut into required sizes and loaded on to the trailers using crawler crane and transported and deposited at KKNPP store. The entire gate removal operation was completed in a period of 50 days.

Safety Measures

Job Hazard Analysis was prepared and approved for the work and all the safety precautions and checklists were used for safe execution of the work.

Before commencement of the job, detailed discussions were held with the specialised agency and all the aspects of the methodology were reviewed. Underwater videography of the mockup work was carried out to ascertain the feasibility and safety of the methodology being adopted. Only after satisfactory mockup study, the actual methodology of work was finalised and the work was commenced.

The work was carried out under Package C-VI (construction of hydro-technical structures).

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Main Coolant Piping (MCP) Welding Works at KKNPP

J.D. Kurwa, ACE(FLWR), NPCIL; **S. Chandrasekhar,** SO/E, KKNPP; **S. Sarvanan,** SO/E, KKNPP

The reactor coolant system or the Nuclear Steam Supply System (NSSS) consists of the Reactor Pressure Vessel (RPV), Main Coolant Pipeline (MCP), Reactor Coolant Pump (RCP), Steam Generator (SG), Emergency Core Cooling System (ECCS) stages 1 and 2, Quick Boron Injection System (QBIS), Pressuriser (PRZ), reactor internals and connections to the process parameter monitoring devices etc.

The VVER-1000 Pressurised Water Reactor (PWR) MCP integrates connecting the four valveless loops, each consisting of RCP and SG by five main coolant pipe spools to the RPV. The low-alloy steel pipeline spools of 990-mm OD and 70-mm wall thickness, inclusive of 5-mm-thick stainless steel (SS) internal cladding to withstand a test pressure of 25 MPa, are welded to the equipment to make the closed MCP loops. The

Primary Heat Transfer Circuit

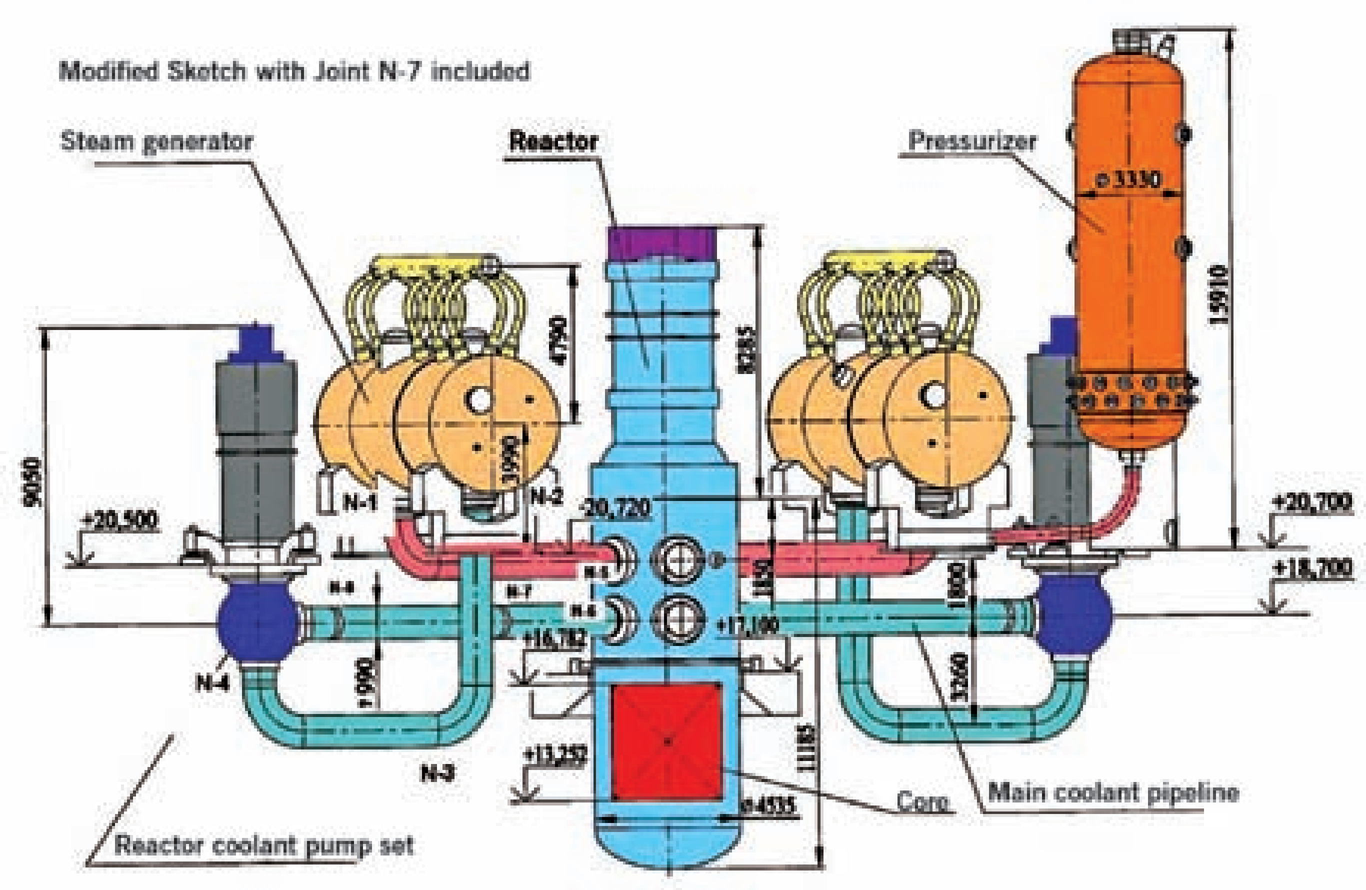
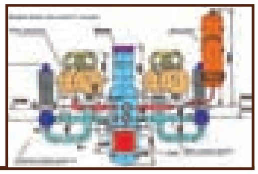


Figure 1: N1-N8 – 8 weld joints per loop. In all, 4 loops and 32 weld joints



entire main circulating pipeline is supportless and connected to two floating equipment, namely, SGs and RCPs. The hot water gaining enthalpy from the RPV is lead in the 850NB MCP from the RPV outlet (Hot Leg) to the SG inlet. After heat exchange to the secondary fluid in the SG, the fluid is lead to the SG outlet connected to the RCP inlet by MCP from the bottom, the RCP outlet leading the primary fluid to the RPV inlet (Cold Leg). The PRZ takes care of pressure surges and is connected to one of the hot leg loops of the MCP. The RPV with four each inlet and outlet nozzles are welded to MCP.

Main coolant piping is one of the most critical works in the nuclear power plant. Kudankulam Nuclear Power Project (KKNPP) being the first PWR in India, this critical work was carried out for the first time in Indian nuclear industry for a thick, low-alloy steel-clad pipe. (Refer Table-1 for chemical composition). As such the entire technology was to be qualified before taking up the actual work. A total of 32 weld joints (8 of each of RPV-MCP, SG-MCP, RCP-MCP and MCP-MCP joints per loop) are involved for each Unit (Refer to Figure 1) The NSSS plan layout is shown in Figure 2.

Table-1: Chemical Composition

1) Base Metal																
Sl. no.	Base Metal	Car-bon	Silicon	Manga-nese	Chromium	Nickel	Molybde-nium	Copper	Sulphur	Phosphorus	Arsenic	Cobalt	Tin	Antimony	P+Sn+Sb	Vanadium
1	**15X2HMФA-A** (RPV)	0.13-0.18	0.17-0.37	0. 3-0.6	1.8-2.3	1.0-1.5	0.5- 0.7	0.08	0.012	0.01	0.01	0.03	0.005	0.005	0.015	0.10 -0.12
2	**10ҐH2MФA** (SGandCoolant Pipe)	0.08-0.12	0.17-0.37	0.7-0.9	0. 3	1.7-2.0	0.4-0.7	0. 3	0.02	0.02	-	-	-	-	-	0.04
3	**06X12H3Д** (RCP)	0.06	0.3	0.6	12-13.5	2.8-3.2	-	0.8-1.1	0.025	0.025	-	-	-	-	-	-
2) Filler Metal																
Sl. no.	Filler Metal	Car-bon	Silicon	Manga-nese	Chromium	Nickel	Molybde-nium	Copper	Sulphur	Phosphorus	Arsenic	Cobalt	Tin	Antimony	Niobium	Vanadium
Wire																
1	Cb-08g2s	0.05-0.11	0.7-0.95	1.8-2.1	0. 2	0.25	-	-	0.025	0.030	-	-	-	-	-	-
2	Cb-01X12H2 **-ВИ**	0.025	0.15-0.5	0.2-0.7	11-13. 5	1.6 -2.5	-	-	0.02	0.03	-	-	-	-	-	-
Electrode																
3	PT-30	0.06-0.1	0.17-0.37	0.7-1.3	-	1.3-1.8	0.45-0.75	-	0.02	0.025	-	-	-	-	-	-
4	**ЦL-51**	0.035	0.35	0.15-0.6	Dec-15	1.8-2.5	-	-	0.025	0.030	-	-	-	-	-	-
5	**ЦL-25/1**	0.12	1.0	1.0-2.7	23-27	11.5–14.0	-	-	0.020	0.030	-	-	-	-	-	-
6	**EA-898/21b**	0.10	0.7	1.6-2.5	17.5-20.5	9.0-10.5	0. 3	-	0.025	0.025	-	-	-	-	0.7-1.2	-
Note: Single values are considered as Maximum																
Filler metal – 1 & 3 for Welding jt. Nos.1, 2, 3, 5, 6 & 7																
Filler metal – 2 & 4 for Welding jt. Nos. 4 & 8																
Filler metal – 5 & 6 for Cladding jt. Nos. 1 to 8																

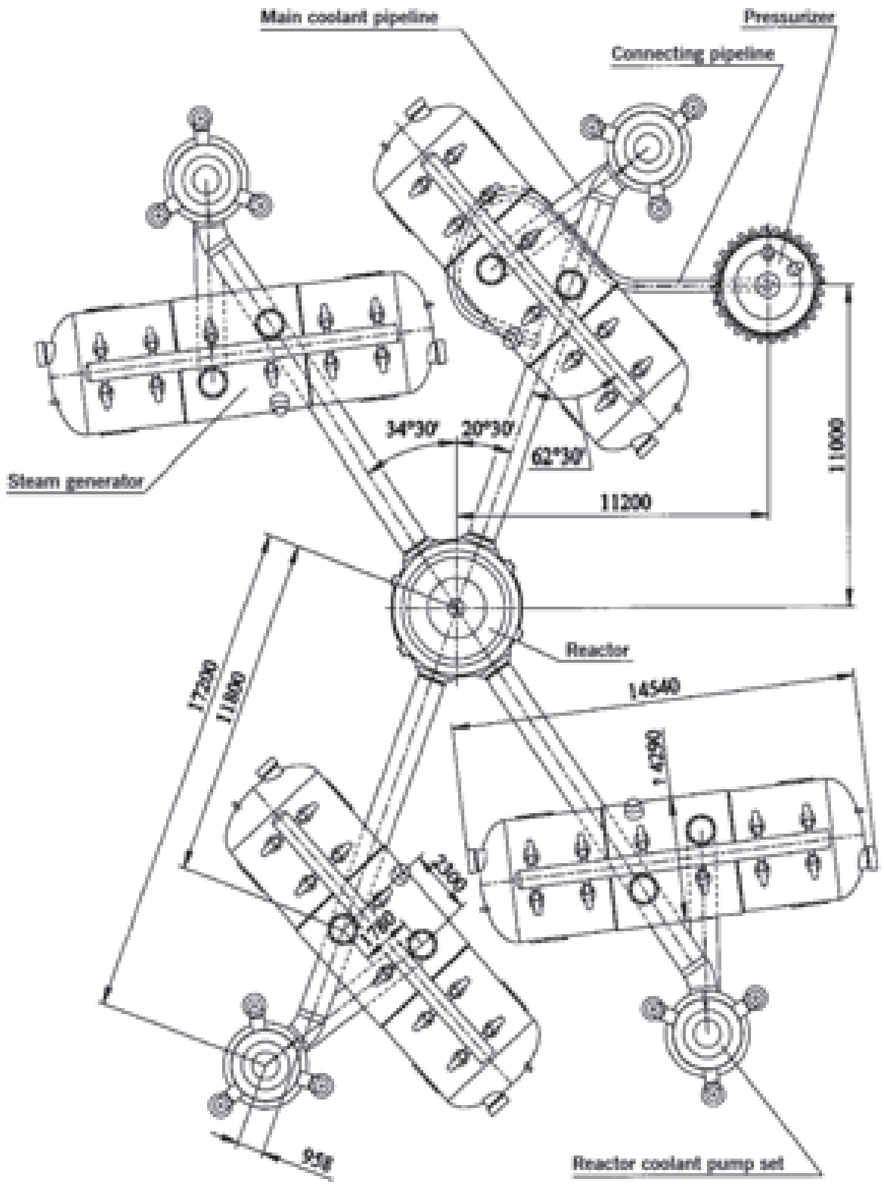


Figure 2: A typical view of the NSSS equipment layout

For successful qualification of processes and welders, followed by successful completion of works, the following activities were planned and executed for MCP welding. Stringent requirements were to be met for each joint at RPV, RCP, SG and pipe-to-pipe joint.

1. Induction and training of welders: Highly experienced welders, based on their previous experience records, were inducted for this work. Since only a limited number of pipe pieces were supplied from Russian Federation (RF) for qualification of welders and technology, the welders were initially trained on high wall-thick Indian pipes using Russian electrodes. Similarly the pipe fitters and grinding personnel also were trained on these Indian pipe spools initially before taking up qualification work on RF-supplied qualification spools. A number of joints were made as part of this training to develop confidence and competence of welders, fitters and other skilled workers related to the job.

2. Development of pre-heating and post-weld heat treatment induction machines and heating pads: Two types of heating are used for pre-heating and post-weld heat treatment of MCP weld joints. Resistance heating is used for MCP-MCP and RCP nozzle-MCP joints, whereas induction heating is used for RPV nozzle-MCP and SG nozzle-MCP joints. Very stringent requirements for heat treatment were to be met in terms of time and temperature limits in the area/zone of heating. Special custom-built resistance-heating pads for resistance heating and low-frequency induction heating machine with flexible inductors

Table-2: Various Procedures Established for MCP Works

Sl. No.	Description
1	Procedure for welding of main coolant piping
2	Heat treatment of pipe-to-pipe and RCP casing-pipe joints
3	Heat treatment of RPV-pipe and SG-pipe joints
4	Visual and measuring examination of MCP piping
5	Methodology for handling and lowering MCP spools
6	Procedure for welder performance certification testing of MCP welding
7	Procedure for technology certification of MCP welding
8	Procedure for liquid penetrant testing of MCP welding
9	Procedure for radiographic testing of MCP welding
10	Procedure for ultrasonic testing of MCP welding
11	Procedure for erection and alignment of MCP spools
12	Methodology for hot radiography

cooled with water for induction heating were developed exclusively for MCP welding works and subjected to extensive qualification tests before putting on the job.

3. Development of procedures: Number of procedures were identified specifically for MCP welding works and established after elaborate discussions with RF specialists. Various procedures established for MCP works are described in Table-2.

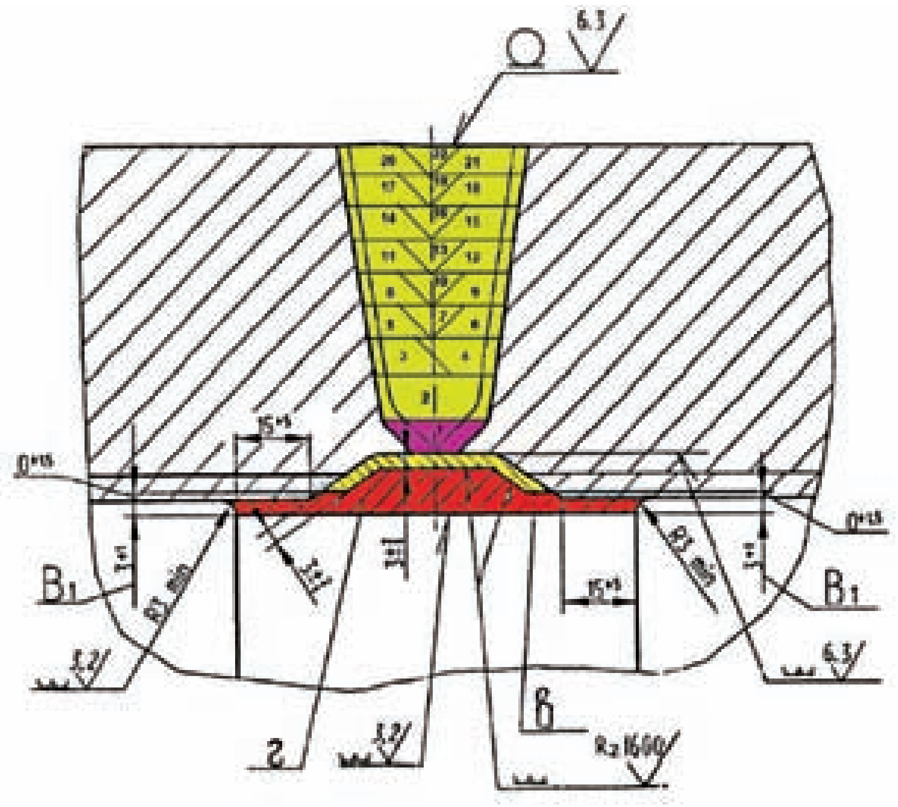
4. Qualification of technology and welders: Technology and welder qualification activities were taken up after extensive training of welders. Actual parameters specified for each type of joint were simulated for the technology and welder qualification. A large number of destructive and non-destructive testing was carried out for qualifying the technology and welders.

5. Execution at site: Following activities were involved in the execution of MCP welding works.

5.1 Initial erection of spools: Identified spool pieces were taken to respective locations and supported accurately on temporary structures weighing 272 MT designed specially with allowances for thermal expansions and shrinkages.

5.2 Measurement of nozzle coordinates: The coordinates of nozzles of main equipment like RPV, SG and RCP were measured using optical instruments.

5.3 Trimming, weld edge preparation and NDT of pipe spools: Based on the survey results of equipment nozzle coordinates, the lengths of spools were calculated and trimmed taking into account shrinkage value, using special purpose cutting and beveling machine. Weld edge preparation as per drawing was also carried out using these machines with the help of special templates. Dye Penetrant Test (DPT) was carried out for the weld edges to rule out any defects.



Cb08g2s – Root Run -10 mm thick (GTAW)

PT-30 – Fill Pass - 55 mm thick (SMAW)

ЦЛ-25/1–Dissimilar cladding - 2 to 5 mm thick (SMAW)

EA-898/21Б – SS cladding -10 mm thick (SMAW)

Figure 3: A typical weld joint

5.4 Alignment of spools and weld joint fit-up: The prepared spools were aligned as per drawing requirements and fit-up prepared for the weld joint. The fit-up requirements considering the narrow gap welding and tolerances on radial, angular mismatches and root gap uniformity are stringent. Fit-up was cleared for welding after visual and measurement inspection by QA group of contractor and execution and QA groups of Nuclear Power Corporation of India Limited (NPCIL). The weld fit-up is inspected by RF specialists also.

5.5 Root welding: Root welding is carried out by Gas Tungsten Arc Welding (GTAW) process using specified filler wire up to 10 mm.

5.6 Inspection of root weld: Root pass is inspected visually and by Penetrant Test (PT) from both outside and inside of the pipe before releasing for pre-heating and further welding by Shielded Metal Arc Welding (SMAW) process.

5.7 Pre-heating and Post-weld Heat Treatment (PWHT): Pre-heating of the weld joint is carried out as per the procedure by resistance pad heating method or by induction heating method as per the requirement of joint. Specified heating methodology, temperature limits and other details for pre-heating, and post-weld heat treatment for different weld joints are shown in Table-3.

5.8 Intermediate inspections: Intermediate inspections are carried out for the weld joints at the following stages

- Visual inspection after every pass
- Radiographic Testing (RT) after completion of 50% weld (in hot condition)

Table - 3: Various Details for Pre-heating and Post-Weld Heat Treatment for Different Weld Joints

Joint	Description	Type of heat treatment	Pre-heat temperature (in °C)	Intermediate tempering temperature (in °C)	Post-weld heat treatment (PWHT)
N5, N6	RPV-MCP	Induction	220-270	620-660 for 3 hrs.	620-660 for 7 hrs.
N1, N2	SG-MCP	Induction	220--270	NA	620-660 for 8 hrs.
N3, N7	MCP-MCP	Resistance	220-270	NA	640-660 for 8 hrs.
N4, N8	RCP-MCP	Resistance	200-250	610-630 for 5 hrs.	625-650 for 8 hrs.

- PT after final pass / after intermediate tempering in cold condition
- RT after final pass, after intermediate tempering in hot condition and after final tempering in cold condition
- Hot radiography was conducted successfully on MCP weld joints after qualifying the procedure, materials and the process, for the first time in India

5.9 Heat treatment: Intermediate tempering and post-weld heat treatment for the weld joints were carried out as per the details shown in the Table-3. Stringent requirements were to be met for temperature, time limits and cooling rates as allowable tolerances on the specified value was very small and no failure of equipment during the process is allowed. On RPV nozzle transition zone, RCP nozzles and SG nozzles very stringent requirement had to be met.

Induction heating for RPV to MCP joint

Steam generator nozzle welding – mounting of induction coils for inter pass, intermittent tempering and PWHT

5.10 Final Inspection: The following final inspections are carried out for the weld joints after PWHT

- Visual testing (VT)
- Penetrant testing (PT)
- Radiographic testing (RT)
- Ultrasonic testing (UT)

5.11 Cladding: After final inspection of weld joints, the clad welding is carried out for the joints inside the pipes/ nozzles. Inspection of cladding is carried out as follows.

- PT after each layer
- UT after completion of cladding

Due importance was given for industrial safety aspects and all necessary arrangements, first-aid facility and evacuation methodologies were worked out in detail for confined area work with a mock up carried out.

5.12 Hydro testing of weld joints: Hydro testing of MCP weld joints is carried out along with hydro testing of primary circuit at 24.5MPa.

5.13 Preservation: Preservation of weld joints is carried out after completion of all inspection activities.

5.14 Statistical Data: For each weld joint, including cladding, 28 layers of welding with 116 passes consuming about 180 kg welding consumable

with two welders welding simultaneously in opposite direction per joint continuously from outside. At a time maximum four joints welding in different loops was achieved with accurate planning with available resources. It takes about a month for completion of welding, heat treatment and inspection process for each joint. It took 10 months to complete KKNPP unit-1 (KKNPP-1) MCP and with experience gained KKNPP unit-2 (KKNPP-2) took 8.5 months to complete the welding works. There was no industrial safety related incident.

RCP to pipe welding – resistance heating

A new welding sequence as compared to that was adopted by Russian side was evolved and successfully executed. This was appreciated by Russian organisations for welding, metallurgy and general designer of reactor plant.

Completed RPV N-5 weld joints

Challenges Faced

1. Development of technology and its qualification was a Herculean task as for the first time qualification with cladded pipes was taken up in NPCIL. It took almost a year to qualify the technology parallel with the other equipment required for welding and heat treatment and some time for welders to weld with Russian consumables.
2. For pre-heating and heat treatment especially induction heating system development

was a herculean task for our specific use, and was successfully developed by a Mumbai-based agency, and was tested on full-scale mock ups of RPV and SG nozzles to meet the required parameters, as some of the parameters were very stringent in nature and required to be controlled. As the parameters of heat treatment were stringent, failure of equipment during entire cycle is not tolerable and hence spare equipment has to be kept ready and is to be connected to the system within shortest possible time. In case of RPV joint PWHT, a cooling fan of the capacity 40,000 m^3/hr with a specially designed discharge hood was installed inside RPV to maintain the temperature gradient across the wall of nozzle whose thickness varying between 300 mm to 70 mm at the weld joint having stringent temperature requirement during soaking time.

3. Job specific special resistance heating pads and system with required capacity were specifically developed.

4. Development of hot RT technique and the fixtures was another challenging job, as it has to be done in such a way as not to damage the source and entry has to be made inside the equipment/ pipe in hot condition near the joint. All the necessary arrangements were made to prevent any damage to heating elements, radiography source as well as burn injury to the personnel carrying out RT.

5. During welding of RPV nozzles, the horizontality of RPV top sealing face is to be maintained and controlled to be within 0.1mm and that for RCP top face less than 0.5mm, requiring frequent sequencing of the welding. Also the movement at the other end of pipe was to be controlled in order to prevent misalignment and also mismatch with the equipment nozzles while welding.

6. Cladding of completed welds joints from inside especially in joints N1, N2, N3 and N7 was a difficult task as it has to be done in a confined space and joint location having different profiles for each type of joint, as entry is to be made inside the equipment.

7. Welding and weld repairs were another challenge, as they had to be carried out in hot condition and in such a manner not to damage the heating elements and cause personnel injury. The number of weld repairs was very minimal (less than 0.001%) in the total volume of material deposited.

8. During execution of the job problems were faced with supplied welding electrodes in the form of taper burning and were resolved in the course of execution of the job.

9. Maintaining of required environment with strict control on chlorides and humidity was a challenging job and was ensured by providing of temporary ventilation with High-efficiency particulate arrestance (HEPA) filters, and specially procured air conditioners of 48TR with flexible ducts supplying the cold air to different areas inside Reactor Building (RB) and inside confined area.

10. Equipment failures faced during heat treatment (both induction and resistance) were a real challenge and were resolved in shortest possible time and thus avoided the violation of technical requirements which otherwise called for technical justifications and analysis by the Designers and Metallurgical Organisation of Russian Federation. Special work instructions were developed to tackle such situations.

Detailed planning was done for each activity and work was executed successfully within the time schedule with 1/10th of the cost quoted by a foreign organisation.

S. Chandra Sekhar, *Sr. Executive Engineer, is a B.Tech graduate in mechanical engineering. He joined NPCIL in the year 2003. At KKNPP, he has worked as execution engineer in the Reactor Group and has been involved in the erection of nuclear steam supply system (NSSS) equipment, including primary coolant piping. He has made significant contribution to the works related to primary loop equipment, piping, welding, heat treatment, and customised insulation of NSSS.*

S. Saravanan, *a mechanical engineer, joined NPCIL, Kakrapar Project in 1990. He joined KKNPP QA group in 2001 and was involved in the inspection activities of NSSS equipment and pipeline erection work at reactor units-1&2. He was deputed for QS works to Izhora plants in the Russian Federation for 6 months during the manufacturing of KKNPP NSSS system components. He holds NDT Level-III certification in ultrasonic testing. He also has an MS degree in manufacturing management.*

Jayesh Kurwa, *B.E. (Mechanical), joined NPCIL in 1989 and worked at the KKNPP-1&2 up to 1991 and then at KAPS-1&2 up to 1999. During his tenure at KKNPP from 2004 to 2014, he was responsible for construction and erection of equipment and pipelines inside reactor building and auxiliary building. His main contribution was in installing and welding of thick cladded pipes for main coolant pipelines and NSSS pipelines, in addition to dome liner fabrication and erection. He has extensive experience in PSI, ISI, containment tests, NDEs as well as Russian Federation Codes and Standards. Presently, he is ACE (Future LWRs) at headquarters, NPCIL.*

Distortion and Residual Stress Control in Welding of Secondary-Cycle System Pipeline at KKNPP-1&2

R. Santhosh Kumar, SO/E (QA), KKNPP-1&2; **R. Sudhakarbabu,** SO/E (QA), KKNPP-1&2;
Sunil M. Pelagade, SO/E (QA), KKNPP-1&2

Introduction

Distortion and residual stress control during welding of hook-up joints of the secondary-cycle pipeline with dynamic equipments has been always a challenging job, especially when the equipment is condensate extraction pumps, electrically driven feed pumps, turbine driven feed pumps and main steam turbines. The control of these entities is required for reducing the stresses on equipment nozzles, in turn to increase the life of the equipment.

The typical case of interconnecting piping between booster pump and main feed water pump has been taken for presentation in this article. The layout includes the U-loop piping starting from booster pump to main feed pump, which have 8 pre-fabricated piping blocks. The dimensions of the blocks are 530mm diameter and 28mm thickness. The erection and welding of all these blocks were completed sequentially, keeping final hook-up block (block no. 5) un-erected in the loop. The final hook-up block involved erection and welding of two consecutive joints in a manner that the distortion and residual stresses in the equipment nozzle remained within acceptable limits. The efforts for minimising the distortion and residual stresses are reflected in this article.

The pipeline being discussed is feed water pipeline connecting the booster pump to main feed water pump as indicated in the schematic (Figure 1). This pipeline connects to the suction nozzle of main feed water pump. The pipeline has been provided with two guide-sliding supports and four hanger supports to transfer its load to structures. The dimensions and conditions of the pipeline, which it will be subjected to during operation are as are shown in Table-1.

The detailed layout of the pipeline is given in Figure 2, indicating the location of supports and routing.

Table-1: The Dimensions and Conditions of the Pipeline

Medium: Demineralised (DM) water	Material: 15^{0}C (Carbon steel)
Flow: 3000 T/h	Pressure: 25 kg/cm^2
Outer diameter: 530 mm, Thickness: 28 mm	Temperature: 186°C
Load due to mass of booster pump: 8.2 T	Weight of pipeline: 10.4 T

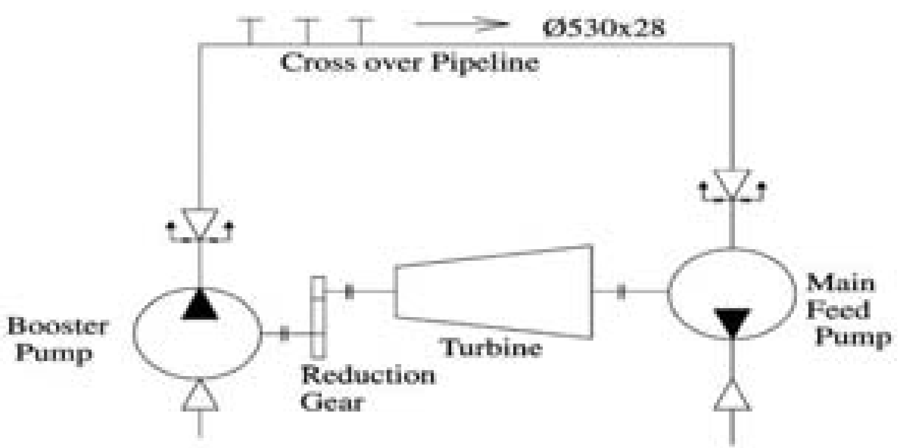


Figure 1: Schematic for pumps and their interconnecting pipelines

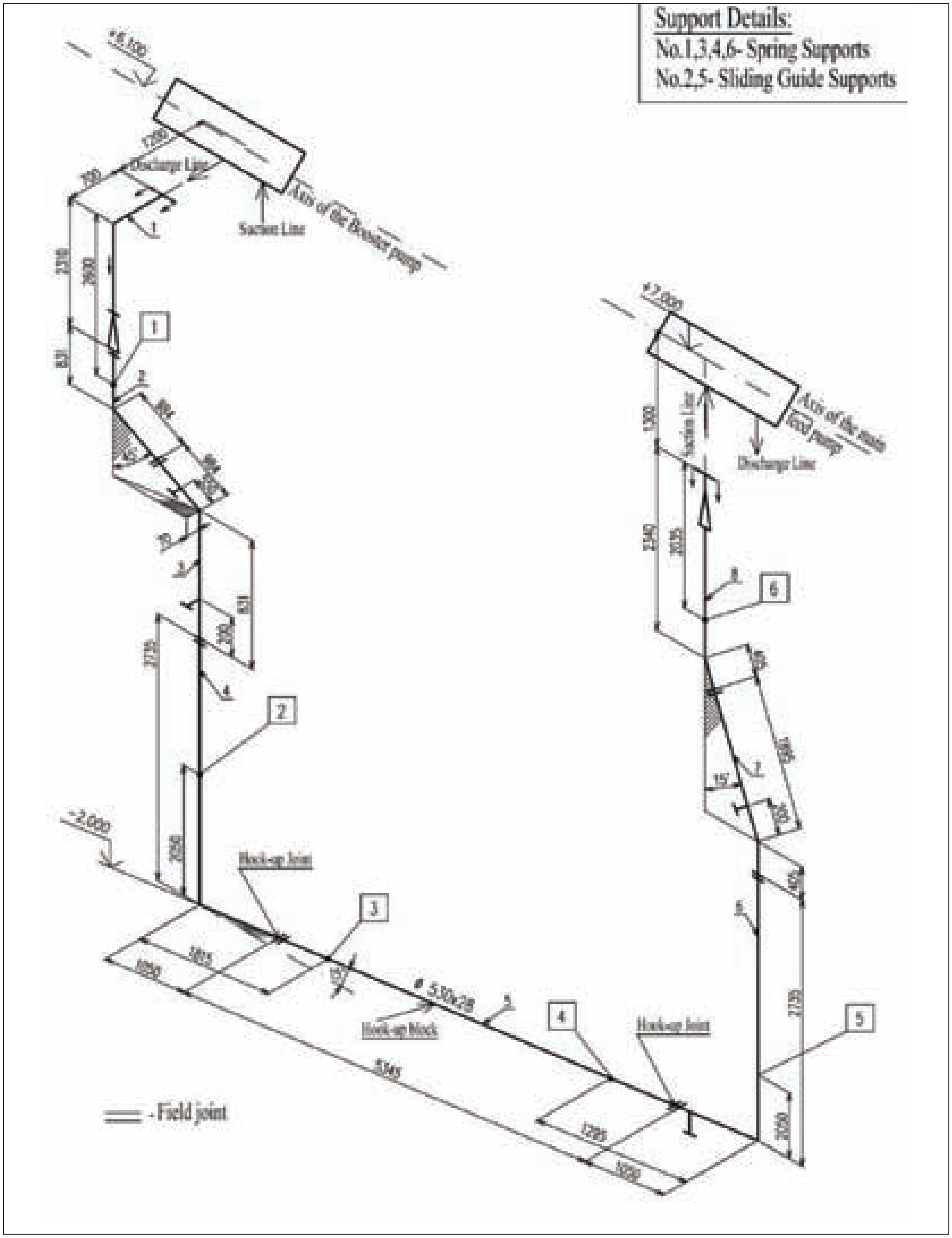
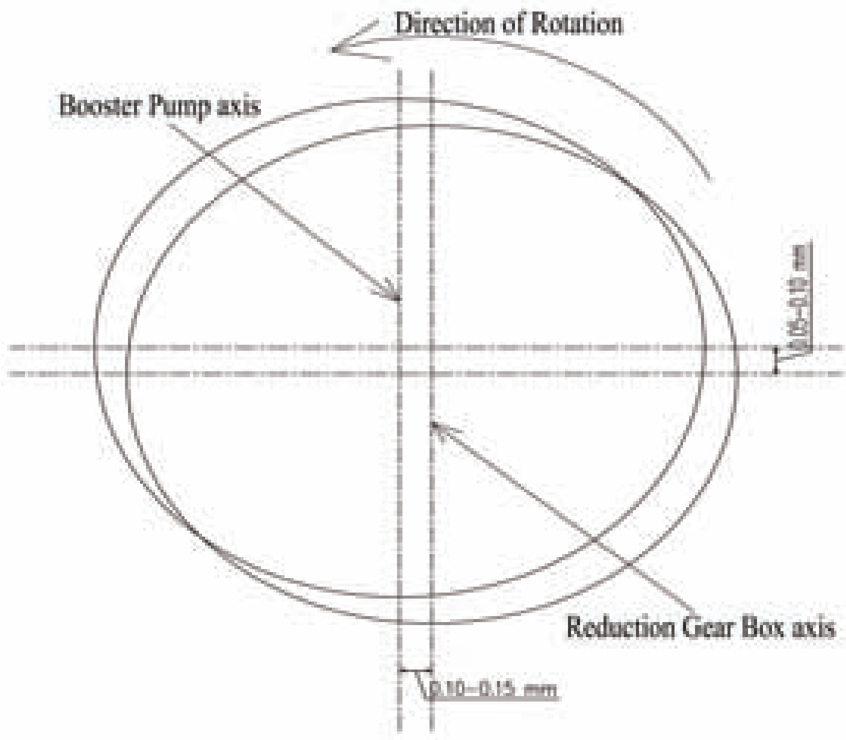


Figure 2: Layout of interconnecting pipeline between booster pump and main feed pump



Note:
The above requirements indicate the values for radial alignment.
The axial alignment values are 0.03mm (0.1mm per 1000mm length).

Figure 3: Alignment requirements for pumps

Table-1: Chemical Composition and Physical Properties of the Base Metal of Piping

a) Chemical composition (wt %)

C	Si	Mn	Cr	Ni	Cu	S	P
0.12-0.18	0.7-1.0	0.9-1.3	Not more than 0.3	Not more than 0.3	0.3	0.025	0.035

b) Mechanical and physical properties

UTS (MPa)	Yield point (MPa)	Relative Elongation (%)	Relative contraction (%)	Toughness J/cm²	Coefficient of thermal expansion at 20°C	Thermal conductivity	Modulus of elasticity
Not less than 490	294	18	45	59	10.8E-6/°K	36W/mK	200 GPa

Aim

1) To achieve the alignment requirement of the pumps after welding of hook-up joints (as indicated in Figure 3).

2) To achieve minimum residual stresses in the pipeline and nozzle of the pump, and uniform loading on the base frame of the pump (indicator of residual stresses) within 100 kg.

Pre-requisites

The following activities were completed as pre-requisites.

1) All the joints except hook-up joints were welded and inspected by applicable NDT methods and results were confirmed satisfactory.

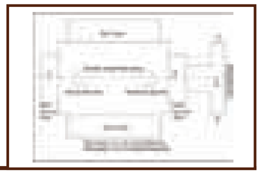
2) All supports were erected and kept in locked condition.

3) Installation of the hook-up block was completed and it was made ready for welding.

4) The locations for installation of precision dial gauges were identified as indicated in Figure 4 and installation was completed. The locations for installation of dynamometers were also identified in Figure 5.

5) The availability of Welding Procedure Specification (WPS) and Procedure Qualification Record (PQR) applicable for this welding was ensured.

6) Approved welding and erection procedure briefing



to the concerned people was made especially in respect of distortion control.

7) Qualified welders, consumables and welding machines meeting the specifications were ensured.

Understanding the Base Metal of Piping

The material of the piping is 15rc as per Russian specification. It is a grade of low-alloy carbon steel. The physical and mechanical properties are the indicators for the distortion control ability (See Table-1).

The Means Adopted for Controlling Distortion

1) The joint configuration for all the weld joints considered was J-groove (as indicated in Figure 6). The consideration of J-groove was based on the fact that it would contribute minimum shrinkage stresses, which would finally result in minimum shrinkage stresses because of zero root gap and minimum bevel angle (15°).

2) The welding of all the blocks except block no. 5 was completed in the free state of nozzles of both the pumps. The location of final hook-up joints was much distance away from the nozzles, which resulted in minimum stresses because of welding on pump nozzles, and thereby in the reduction in distortion. Figure 2 clearly indicates the relative positions of the hook joints and nozzle joints.

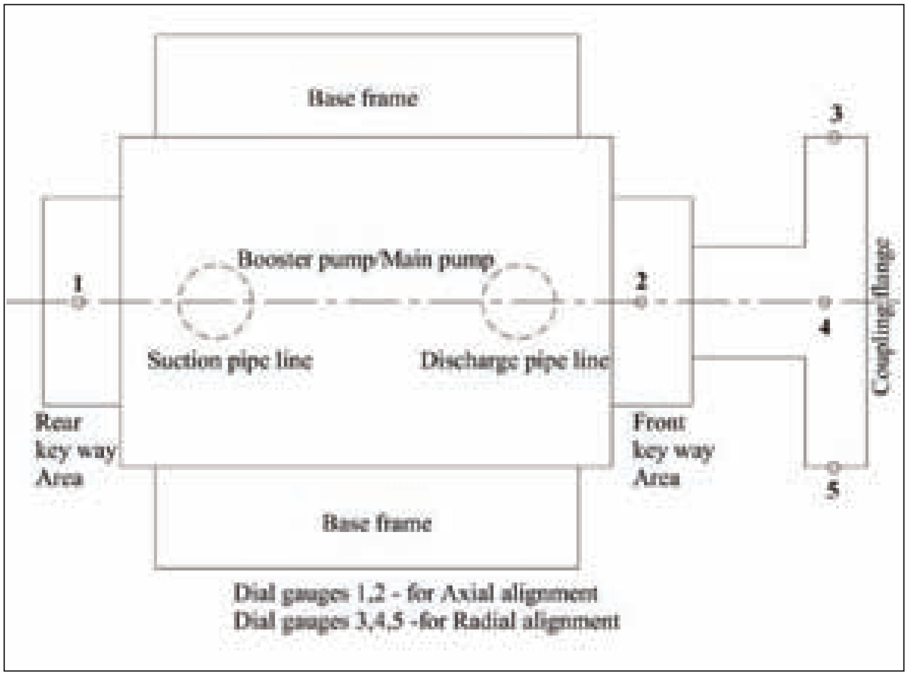
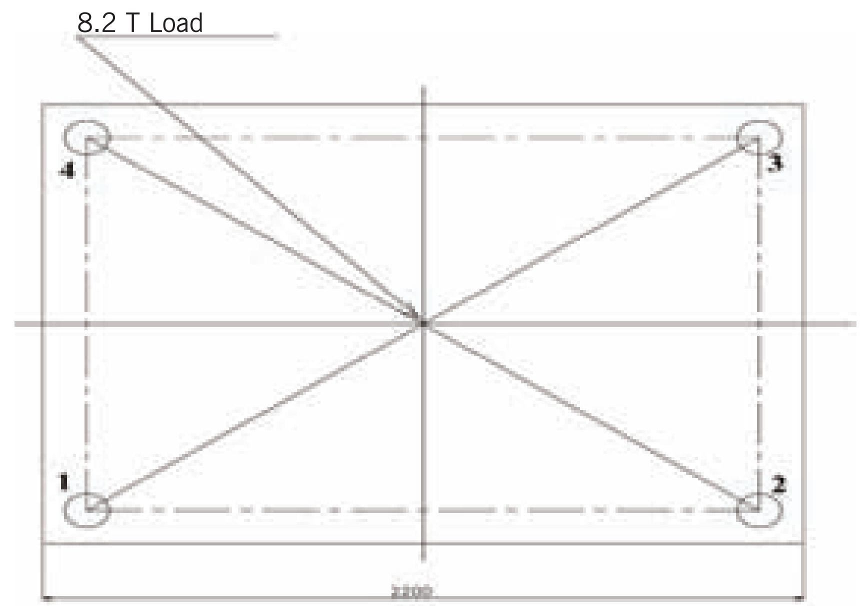


Figure 4: Position of dial gauges



Note: 1, 2, 3, 4 are the positions of dynamometers

Figure 5: Location of dynamometers on base frame of pump

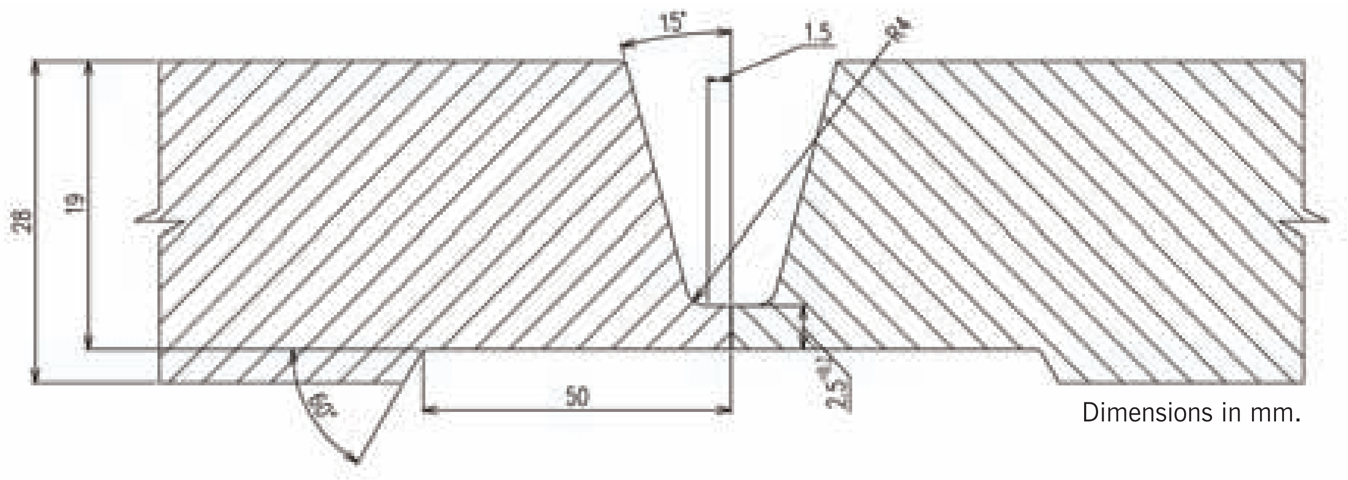
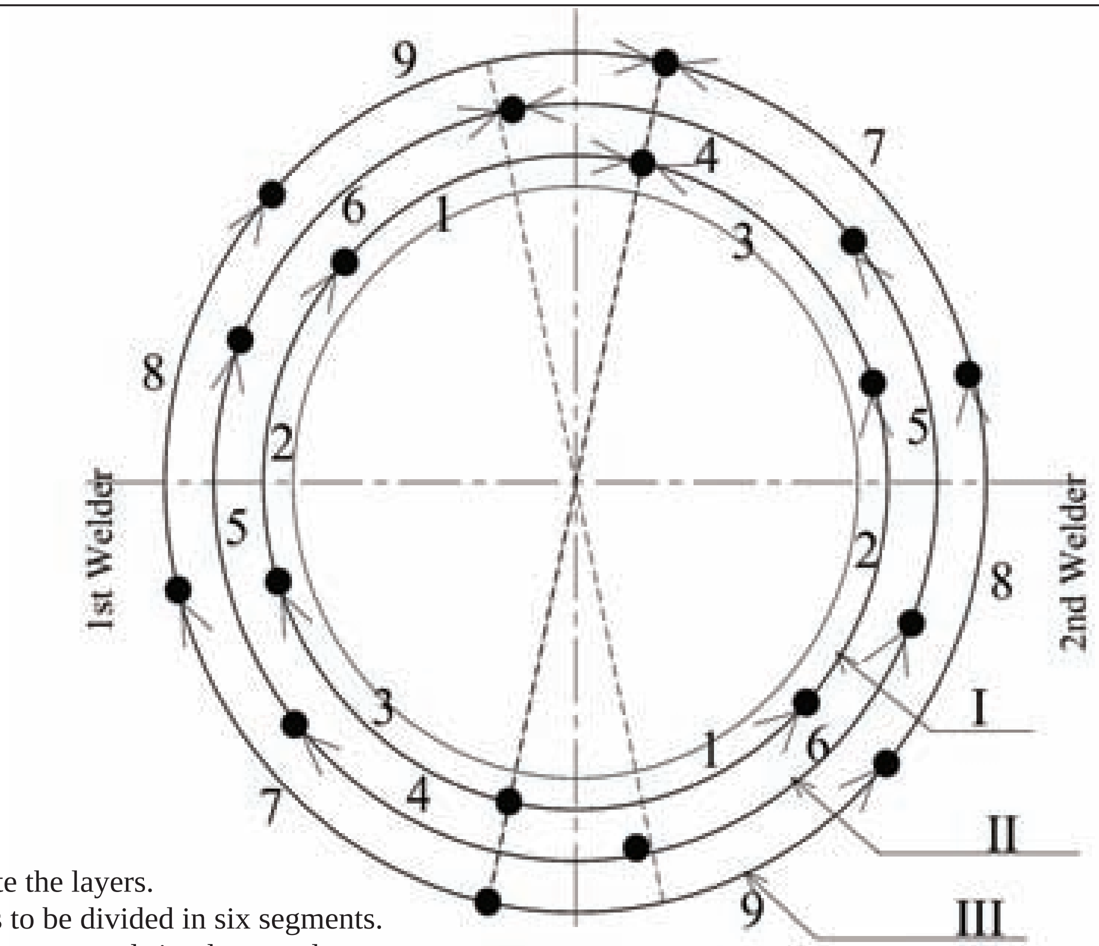


Figure 6: Weld joint configuration



Note:
1. I,II,III- Indicate the layers.
2. Each layer has to be divided in six segments.
3. Two welders are engaged simultaneously.

Figure 7: The welding sequence adopted

Table-1: The Sequence of Activities

Booster pump, turbine and feed pump shafts were ensured to be in decoupled condition.
↓
The pre-alignment checks of pumps with turbine were performed.
↓
Ensured that the spring values of hanger supports to erection condition. Subsequently,the springs of all hanger supports were locked to make it rigid
↓
The welding of one joint was initially taken up, keeping the other in fit-up condition and dial gauges installed in vertical, horizontal and axial directions.
↓
The root and hot pass of the joint was made using TIG process in a sequence as indicated in Figure 7. The joint was divided in six segments and simultaneously two welders were deputed for welding in opposite segments following back-step welding sequence.
↓
During the root and hot pass, the dial gauge readings were continuously monitored and readings were recorded. The readings recorded were within acceptable limits with respect to limits imposed in Figure 3.
↓
Inspection was performed using VT and PT Non-Destructive Testing (NDT) methods.
↓
Subsequent layers were performed by SMAW process in a pre-defined sequence till 50% of the welding was finished.
↓
The temporary cleats were removed after achieving 50% of weld thickness.
↓
The dial gauge readings were observed with deviation with respect to radial alignment requirement.
↓
The cause of deviation was found to be uneven metal deposition as indicated in Figure 8.
↓
The area was gouged where the deposition was more and brought to uniform deposition condition, which resulted in acceptable dial gauge readings.
↓
Welding started for the remaining 50% weld thickness, following the same sequence and uniformity in deposition till it was finishes or the dial gauge readings crossed the acceptable limit for distortion.
↓
Once the welding was finished, weld inspection was carried out using NDTs (VT, PT, RT, UT).
↓
Similar sequence was followed for the other joints, monitoring the dial gauge readings after every layer of the joint.
↓
Weld inspection of the other joints was also carried out using different NDT methods (VT, PT, RT, UT).
↓
The loading on the base frame of the pump was checked using dynamometers, and it was observed that the difference in the readings was well below the acceptable one, which confirmed that the stresses were within acceptable limits.

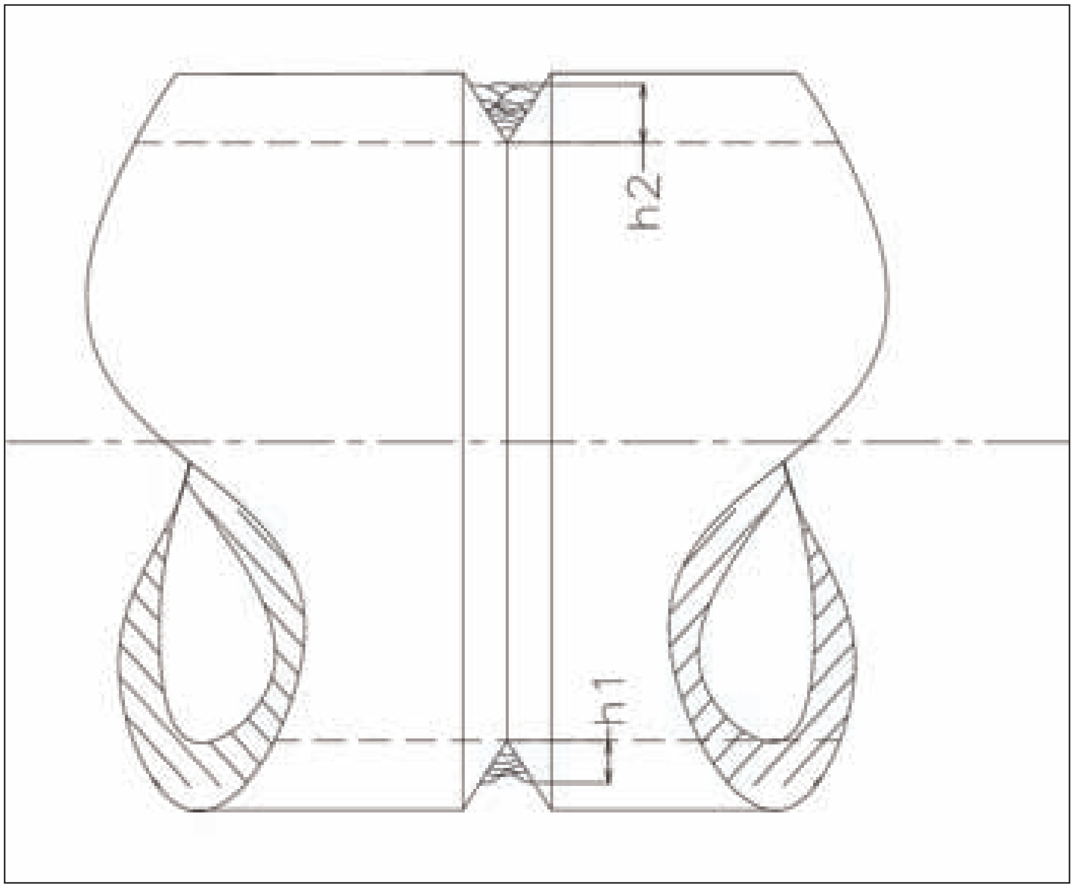


Figure 8: Variation in weld deposition causing the distortion

3) The welding process adopted was manual TIG for first two layers and subsequently all the layers by manual SMAW process, which contributed minimum distortion in the initial passes/layers of welding. TIG process contributed concentrated heating instead of acting as a spread heat source, which resulted in less distortion.

4) Control of the following welding process parameters contributed to minimising distortion.

- Electrode diameter (maximum 4 mm)
- Interpass temperature (maximum 120° C)
- Control of speed of welding to minimise the spread of heat
- Minimum number of passes/layers
- Weaving of each pass was not more 3 times the diameter of electrode
- Height of each layer were within 6–10 mm
- Interlayer starting points were separated by 16 to 20 mm

5) Restraint was applied using the cleats to the welds before the start of welding. The application of the restraint reduced the amount of distortion. A total of six cleats were used for making fit-up of the joint.

6) The dominant cause of distortion in circular butt welds is transverse shrinkage. A back-step welding sequence was followed with symmetrically simultaneous welding for

controlling the transverse shrinkage. Based on a stepwise algorithm, the sequence of activities that were followed is depicted in Table-1.

7) All the welded joints were subjected to NDT inspection. The methods of inspection were VT, PT, RT and UT in 100% scope. The welded joints were made by highly skilled welders and strict adherence to procedures was followed so that there would be no weld repairs needed. It is the gouging and repairing of the joints that causes more shrinkage distortion.

Conclusion

The welding of both the joints of the final hook-up block was completed satisfying the following:

a) The radial and angular alignment requirement of the pump coupling was achieved.

b) Both the weld joints were evaluated by NDTs and found acceptable meeting the specifications.

c) Uniform loading on the base frame of the pumps and load values were within specified limits (100 kg).

d) Load run, load tests and subsequent operation of the pump was found to be satisfactory.

References

1) ASM Handbook Volume 6

2) Welding Engineering and Technology by R.S. Parmar

3) Manufacturer Documents and working drawings

R. Santhosh Kumar *joined KKNPP-1&2 in 2007 after the completion of diploma in mechanical engineering. He has work experience in QA section, for the regular QA related activities of various packages like Indoor and outdoor piping and equipment of common service system, seawater systems equipment and pipeline in seawater pump house and chlorination plant and erection and commissioning of turbine, generator, condenser auxiliary system, including piping and equipment at KKNPP-1&2.*

R. Sudhakarbabu, *a mechanical engineer, joined KKNPP in 2007. He has rich construction experience on major secondary cycle system equipment of KKNPP-1&2. He was also involved in the successful completion of the initial construction activity to the stage of commissioning activities of several equipment and systems at KKNPP-1&2.*

Sunil M. Pelagade, *an engineering graduate, joined NPCIL Training School in 2003 for his induction training. After his initial years at TAPS-3&4, he was transferred to KKNPP, where he joined the QA section as QA engineer. He has experience in pre-fabrication, erection, inspection and testing of cranes, hoists, trollyes and elevators. He has been QA engineer for erection and commissioning of various equipment and systems (M-3 Package) at KKNPP-1&2. He also won "Young Executive Award" in the year 2012.*

Internal Coating of Seawater Pipelines at KKNPP-1&2

V. Sankara Narayanan, ACE (BoP), KKNPP-3&4

Introduction

Cooling water required for condenser, essential and non-essential process loads of KKNPP-1&2 is drawn from the sea (Gulf of Mannar) through an intake structure with fish protection facility. The seawater drawn at a distance of 1.2 km from seashore passes through the fish protection facility, underground tunnel (UPN) and forebay (UPU) reaches the suction of condenser cooling water pumps (PAC), essential load cooling water pumps (PEC) and non-essential load cooling water pumps (PCC). These pumps supply seawater for various cooling requirements of the plant. The essential load colling water pumps (PEC) are located inside a separate building called UQC, and the non-essential cooling water pumps (PCC) and condenser cooling water pumps (PAC) are located inside a building called (UQA) in the sea water pump house.

The condenser cooling water pumps (PAC) supply seawater for main condenser cooling using 2200mm-diameter carbon steel (CS) underground pipelines with internal coating to turbine buildings. The essential load cooling water pumps deliver seawater through CS piplines with internal coating (laid inside tunnels) to reactor building to take care of essential safety loads such as shutdown colling etc., and safety building (UKD) to take care of emergency diesel generator cooling and safety chiller cooling. The non-essential cooling water pumps (PCC) deliver seawater through underground-buried HDPE pipelines/CS pipelines with internal coating to non-safety chiller, compressor and other non-essential loads in turbine and other buildings.

Corrosion Protection of Seawater Pipes

The design and supply of seawater system pipes can be categorised as given below based on anti-corrosive protection:

1. Essential load pipelines (PEB), condenser cooling and non-essential load pipelines

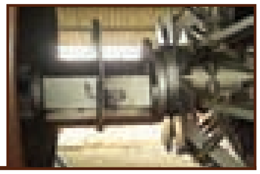
   a) Pipes above 600mm diameter are made of CS pipes with internal coating and butt weld joint

   b) For essential load pipelines (PEB): pipes below 600mm up to 200mm diameter are made of CS pipes with internal coating with anodic protectors (sacrificial anode) at the butt weld joints (no coating in the joints)

   c) For other pipe lines: Pipelines below 600mm diameter are made of CS material with internal coating with flange joints (coated)

   d) Pipelines of sizes 108 to 14mm are made as tubes and are made of titanium

For all the CS pipes, internal coating is performed with Copen Hycote 162HB solvent-free two-



part epoxy coating system to a thickness of 1000 microns. This system was applied as per the requirements of working drawings of seawater systems.

The Selection Process of Coating System

The Russian Federation (RF) designer has specified the internal surface of seawater pipelines to be coated with 'POLAK EP-21' as per RF standards. The coating life specified was 40 years. Search for identifying equivalent coating systems available in Indian/ International market was performed and suitable coating systems were identified.

A committee consisting of execution, QA, and field engineering departments was constituted to go through the various coating systems and submit a report. The committee, after analysing various parameters, recommended the following coating systems for approval of Russian Designer.

1. Copen hycote 162 HB, a two-component solvent-free epoxy coating system – 500 to 1000 micron thickness based on various applications
2. 100% solids high-build polyurethane – 2000-micron thickness

Approval of the RF designer was obtained for both the above systems.

Internal Coating of Condenser Cooling Water Pipelines

The condenser cooling water pumps located in pump house (UQA) supplies seawater to the condenser located in turbine building through 2200mm diameter concrete pipeline with 12mm CS liner. The pipeline is underground and the CS pipe is coated with anticorrosive coating. The internal coating with Copen hycote162 HB was started for this 2200-mm-diameter CS pipe for the first time in KKNPP. The process is briefly explained as follows.

Process Qualification of Coating System

The work of coating was awarded to a local contractor through a public tender, who procured the Copen Hycote coating from the manufacturer E Wood Ltd, England. The technical requirements of the coating and application were clearly indicated in the specification of the tender.

Pre-qualification of the coating system and establishment of application procedure was a prime requirement. The coating material supplied by E wood Ltd. was sent for testing in various laboratories like IIT Chennai, for conducting tests. The process qualification report (PQR) tests conducted are as follows.

a. Compatibility of seawater application
b. Water vapor permeability
c. Impact resistance
d. Compressibility
e. Recoverable elongation
f. Flexibility
g. Abrasion resistance
h. Accelerated weathering
i. Water absorption
j. Salt spray / Salt fog resistance
k. Cathodic disbandment
l. Scrub resistance
m. Humidity resistance
n. Bacteria resistance
o. Mould resistance
p. Scratch resistance
q. Flame spreading resistance

Based on the results of the test report the coating along with method of application was qualified. The procedure was also established based on the same.

Surface Preparation of Pipes

The internal surface of the pipes was grit-blasted with iron grits (Grit - G 16) to the surface finish SA 2½ as per ISO 8501-1. As the pipe diameter was 2200 mm, manual grit blasting was adopted, including weld joints of the pipe. The blast surface was tested for surface anchor profile of 75 microns using press '0' film, which measures and records the profile. Chlorine contamination test was also performed on the surface.

Application of Coating

Copen Hycote is a two-component coating system, the components of which need to be mixed at hot conditions between 35-65 °C. The base and the activator need to be mixed in the proportion of 2:1. Plural feed hot airless spray-painting machine was used for heating, mixing and applying the coating on the internal surface of the pipe. The application was done manually using the spray gun. A single coat of 500 microns was applied on the internal surface of the pipe.

Field Testing of Coated Surface

The following field tests were conducted on the coated surface as per the approved Quality Assurance Plan (QAP).

PAB pipeline assembly

1. Wet film thickness of Coating
2. Dry film thickness of Coating
3. Adhesion Test - to find out bonding strength of the coating
4. Holiday Test - to find out any discontinuity in the coating
5. Shore hardness test

If any failure is noticed in the tests, repair of the coating is performed. As per the approved procedure, a patch of 50 mm x 50 mm or higher area is over-coated in the holiday area / low-thickness area after roughening the surface.

Periodical Checking of the Coated Surface

The coating of PAB pipelines in Essential Cooling Water System was done in the year 2004. Unit-1 PAB pipelines were flooded with seawater in 2009. The coating was checked periodically and found to be in good condition. There has been no problem in these bigger diameter pipes till date up to 2014.

Internal Coating of Essential and Non-essential Cooling Water Pipelines

This seawater system has CS pipes with diameters of 80 to 1100 mm. Below 150mm diameter, titanium pipes are used in safety-related

An aerial view of breakwater dyke of KKNPP-1&2

An aerial view of breakwater dyke of KKNPP-1&2

area and in other areas below 80 mm, titanium pipes are used.

Site Grit Blasting and Painting Shop

The applicator (contractor) established a grit-blasting and painting shop at KKNPP for internal coating of pipelines. The shop had one semi-automatic grit-blasting machine with vacuum cleaning set-up. The photographs in Annexure-1 show the arrangements in the shop as well as the application of coating to the internal surface.

The pipe is placed stationary on the machine platform and the nozzle travels rotational and axial movements inside the pipe, blasting the grits on the internal surface. The grit and the dust were removed using vacuum created from the other end. Pipes with diameters up to 750 mm were blasted using this machine. Pipes with bigger diameters were blasted manually.

Surface finish up to SA 2½ as per ISO 8501-1 was achieved. The surface profile (roughness) achieved was 60 to 75 microns. The following tests were performed in the shop.

Painting machine inauguration

1. Grit blasted surface finish was checked with standard comparators after blasting and offered to NPCIL
2. Surface roughness was checked with press ‘O’ films
3. Chlorine contamination test was also performed on the surface

Internal Coating Machine

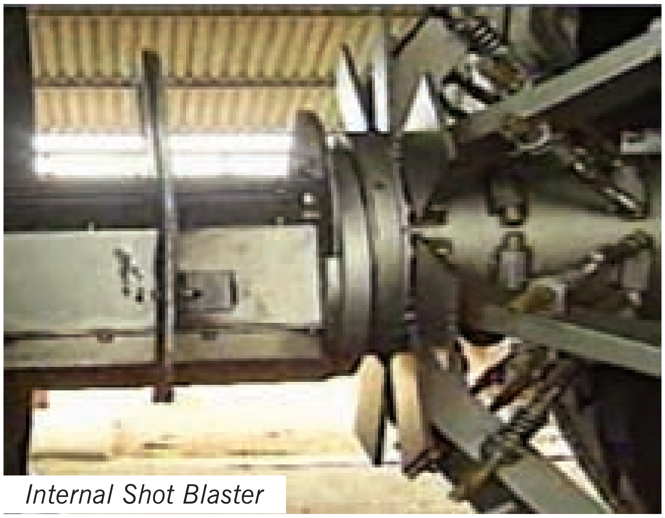
After grit blasting the surface to acceptable level, the pipe will be transferred to internal coating machine using cranes. The internal coating machine is also semi-automatic in which pipe is placed on a stationary platform and the painting nozzle travels inside pipe coating the surface through a rotating spray nozzle.

The coating received as two components as base and activator. These received in drums are preheated in the painting machine and attached to dual feed hot plural spray equipment. The components are supplied in correct proportion and temperature and mixed in the equipment and pumped to the rotating nozzle. The nozzle rotates and coats the paint on the surface. The coating thickness is achieved by the travelling speed and rotating speed of the nozzle. A minimum of 1000-micron coating thickness is achieved. Coating thickness is measured in wet condition and varies from 1000 to 1300 microns.

Field Tests on the Coating

The coating is subjected to similar tests as applicable to condenser cooling water pipelines.

Annexture-1: A) Pipe Coating with Solvent-Free Liquid Epoxy



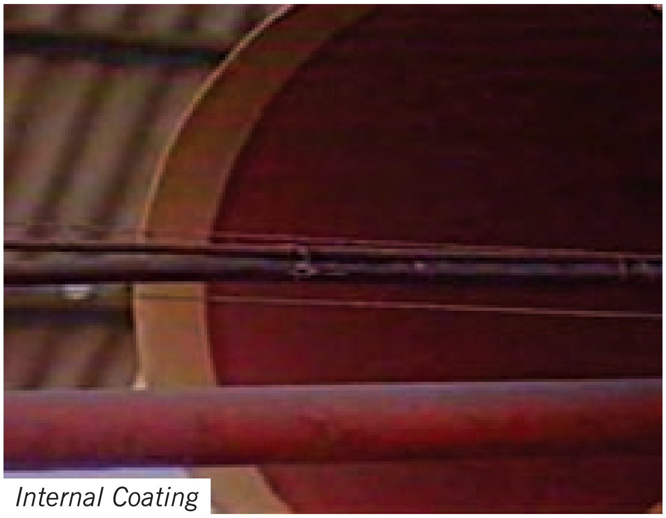
Internal Shot Blaster

Internal Shot Blasting

Heating & Mixing of Activator & Base

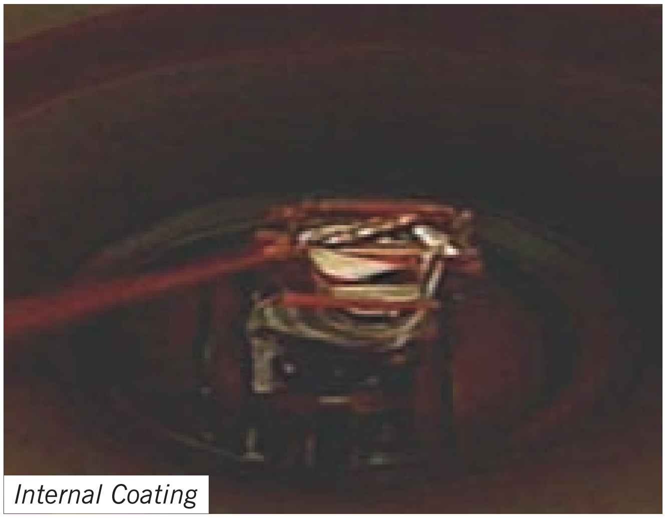
Internal Coating Boom

Internal Coating

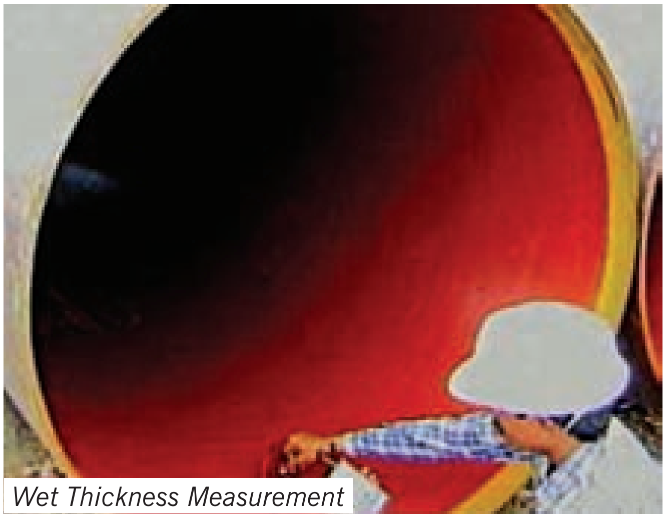


Internal Coating

B) Coated Pipes Testing and Stacking

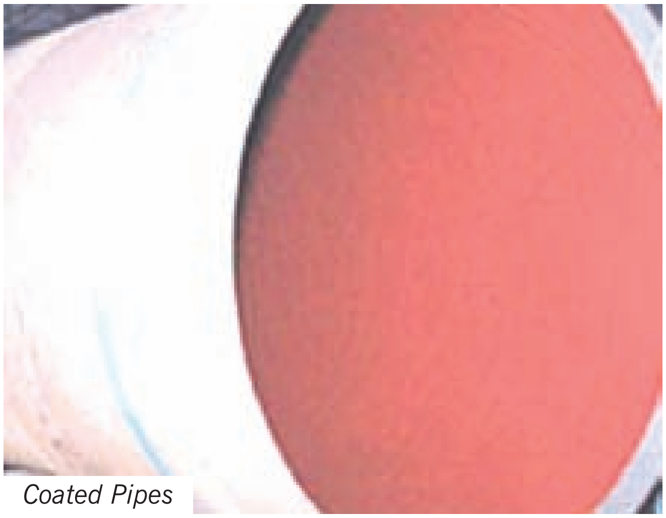


Internal Coating



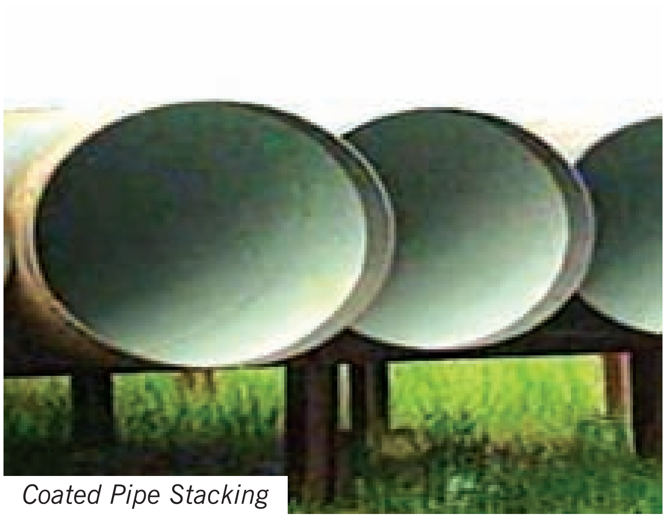
Wet Thickness Measurement

Coating Repair Marking



Coated Pipes

Coated Pipe Stacking



Coated Pipe Stacking

Annexture-A **Internal Pipe Coating - Polyglass / Corroglass**

Fabricating Requirements

1.1 Flange faces are to be rebated in order that the coating can be carried from the pipe bore out across the inner part of the flange face. This procedure will afford protection of the weld seam and prevent crevice attack between flaoge joints. Where possible, flange rebates are to be machined prior to fabrication and in accordance with Figures 1, 2 and 3.

1.2 All welds are to be reasonably smooth and should be slag and spatter free.

1.3 Accessible sharp edges in areas to be coated shall be ground to a minimum radius of 1.5mm

1.4 Pipe spools should be flanged at both ends and at any branch connections where field fit welds are to be carried out after coating Refer to Spee PS2 for further information.

1.5 In order to prevent damage to the coating through the fitting of threaded plugs etc., this type of arrangement should be avoided wherever possible. Where tapped bosses and saddle connections are fitted these should be manufactured from a non-corodible metal for the service environment, the coating will then be terminated overlapping the non-corrodible insert.

Flange	Dimension A	Dimension C
Flat face	20 mm or within 3mm of bolt hole to bore, whichever the lesser	1.5 mm
Raised face	10 mm or half width of raised portion, whichever the lesser	1.5 mm
RTJ	Full width of inner land to 'O' ring groove	1.5 mm

Figure 1

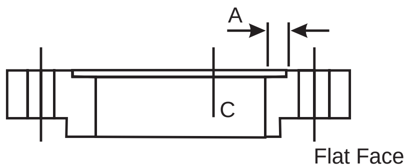


Figure 2

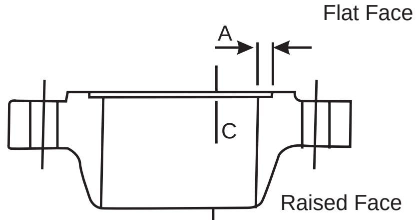
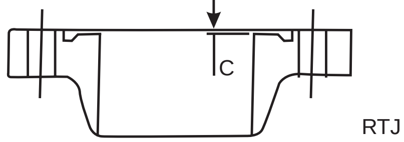


Figure 3



Coating of other Fitting and Flanges

Coating of pipe-fittings, flanges and nozzles were performed manually using the painting machine and the nozzle. Coating of flanges surfaces were critical due to the flatness requirement to be achieved.

Pre-requisites for the Coating

The pipes and fittings are checked and prepared based on the following pre-requisites before coating.

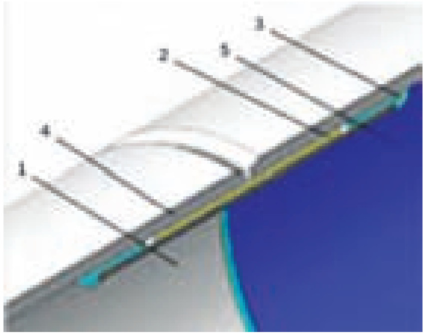
1. The surface are made smooth, without any projections, deep pitting corrosion, rolling discontinuities.
2. The weld joints are ground smoothly, avoiding sharp edges, crevices. Weld spatters have to be removed.
3. The flange edges should be chamfered / ground to a radius of 1.5 to 3 mm to avoid sharp corners.
4. Any rust, mill scales to be removed by grit blasting.
5. Grease, oil and other imparities to be removed using proper solvents.
6. The steel surface must be dry and humidity of the atmosphere should not be more than 85%.
7. Salts like chlorides must be removed by powder washing prior to blast cleaning.

Coating of Field Weld Joints

The pipes up to 12m lengths were coated in the shop and transported to erection site. After erection and

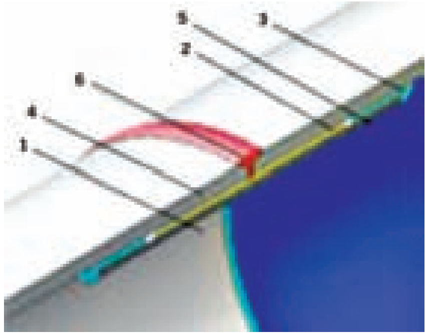
Annexture-B

Internal Coating of Pre-Manufactured Steel Fittings and Spools



Joint before Welding

1 - Inner surface of coated pipe
2 - Thermal protection
3 - Mastic Epoxy
4 - Steel pipe
5 - THRU KOTE(R) connection system coated with same material of steel pipe



Joint after Welding

1 - Inner surface of coated pipe
2 - Thermal protection
3 - Mastic Epoxy
4 - Steel pipe
5 - THRU KOTE(R) connection system coated with same material of steel pipe.
6 - Weld

welding of the joint in field the weld joint also was coated with Copen hycote coating. For pipes of 600mm diameter and above, coating was done manually in the field. For pipes of safety category II, i.e. for essential cooling water pipelines below 600mm diameter, anodic protectors (zinc anode) were welded in the pipelines to compensate for the uncoated welded joints. For pipes of Cat-III, flange joints were introduced for pipes below 600mm diameter.

Normally, the shop-coated pipes have 50mm uncoated surface on the edges. After welding of the pipes the surface is prepared by grinding and power needles are used to achieve the surface roughness. Then the coating is applied using brush on the weld joint. The required quantity of paint is heated, mixed and prepared and applied using brush.

Experience with the Coated Pipes

In the pipes with diameter of 600 mm and above, the coatings have been found to be good and have not failed. Some failures have occurred in the nozzle joints (nozzle sizes up to 100 mm) in these lines. In all other diameter pipes also, failures have occurred in nozzles, and in some bends and flanges. An analysis was carried out on the failures and improvements were suggested as given below.

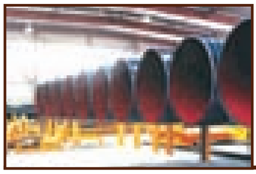
Improvements Suggested for Internal Coated Pipes

It was recommended that the design of seawater pipeline system be made taking into practical problems and limitations of coating application. Fabrication and erection improvements were also indicated. The recommendations were as below:

a) For applications involving pipelines of 150 mm or below, it was recommended to go for using titanium pipes, instead of using internally coated CS pipes.

b) The branches from seawater CS pipes shall be a minimum of 75 mm in diameter. The instrumentation tubing shall be connected through a suitable titanium adopter.

c) Flange joints shall be avoided, as the coating of flange surfaces cannot be observed to the maximum quality achievable on the internal surface of pipes.



Surface coating thickness variation, cracks at the bolt holes and outer ends of flanges cannot be avoided. This leads to failures of coating during tightening of flange joints. Every time flange is opened, the same has to be repainted.

d) Otherwise the flanges designed to meet coating requirements shall be selected and supplied. User data of Corro-coat for special flange is enclosed as Annexure 'A' for reference. Flanges are to be supplied with chamfered inner radius edges so that proper painting thickness can be achieved. However sharp edges have to be rounded as per coating specification requirement before painting if supplied with sharp corners. Hence flange design needs to account for this thickness reduction.

e) Other technologies of joints available for pipes below 600mm diameter, such as pre-coated sleeves/couplings shall be analysed for suitability as part of design and supplied along with pipeline. Relevant figures from a Thru-kote catalogue is enclosed as Annexure 'B' for reference.

f) Modifications in the seawater-coated pipelines like adding nozzles or changing 1/2“ nozzles to 3” at later date again adds to the failure rates.

g) External surface of pipes shall not be applied with Copen Hycote coating as a lot of handling damages occurs, leading to rejection of coating. For seawater pipes, the first pass and hot pass of the welding shall be performed by TIG welding as followed in KKNPP. This will provide better profiles in the inner surface.

h) Supply of prefabricated pipes with welding by SMAW method from Russian Federation was a problem in KKNPP units-1&2. The same shall be avoided in future projects. All the weld joints shall be done at the project site, so that proper weld profile for painting requirements can be achieved in weld area or the manufacturer shall be instructed to achieve the required weld profile.

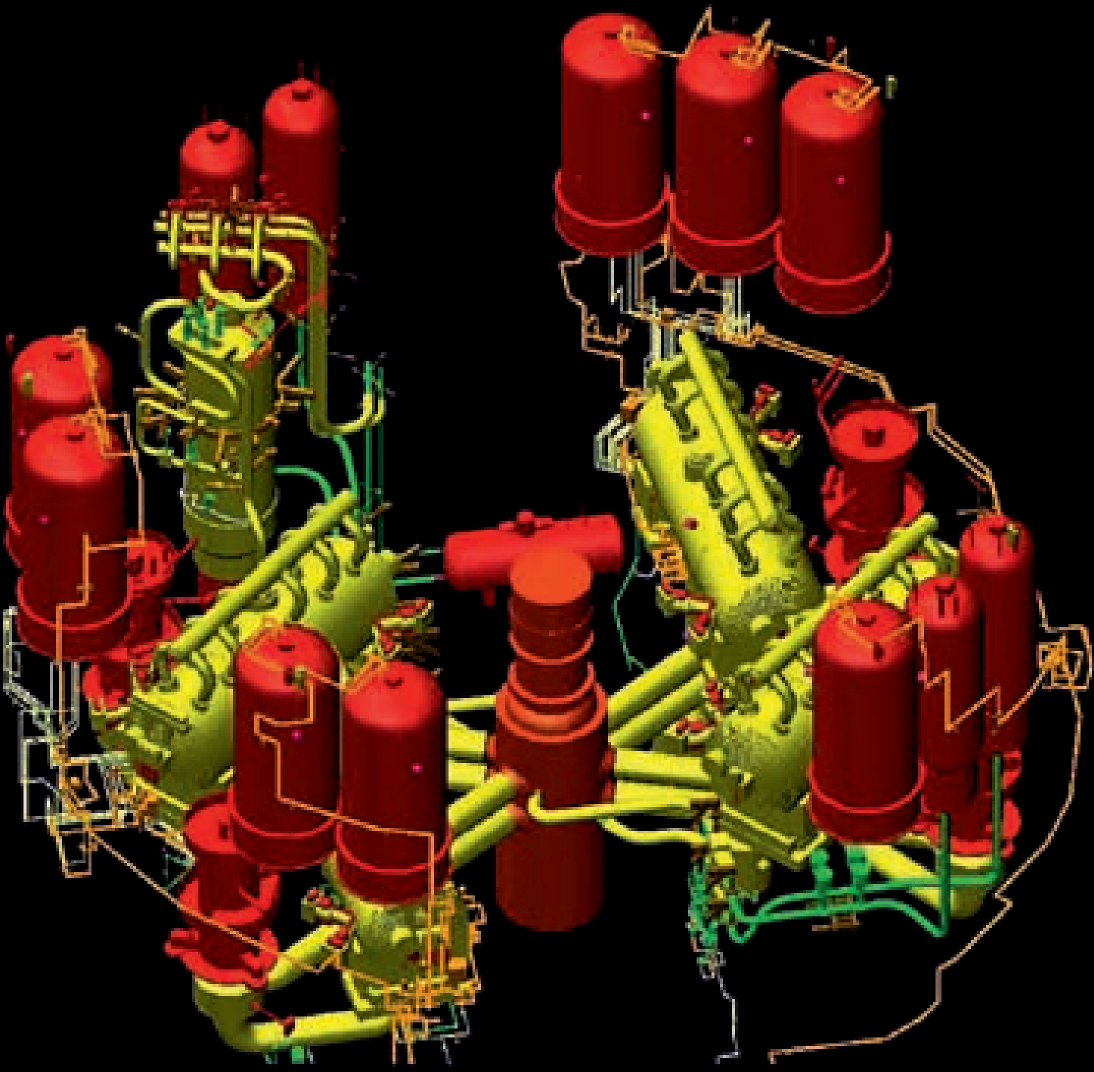
i) During handling after coating, end caps shall be provided to the ends of the pipes.

V. Sankara Narayanan *is a B.E. (Mechanical) graduate. He joined NPCIL in 1988 and was in-charge of the fabrication and erection of seawater system package at Kudankulam Nuclear Power Project-1&2. He has been involved in the commissioning of unit-2 seawater system and the erection and commissioning cranes and hoists, as well as in critical works like main coolant pipe welding, condenser erection, etc. In the initial years, among his significant contributions is the development of the heavy material handling plans like dome erection of KKNPP-1&2 with 650-ton crane. Presently, he is ACE (Balance of Plant), KKNPP-3&4.*

KKNPP
An Engineering Marvel

Project Highlights

The glorious feat of KKNPP is a tribute to the ingenious design, meticulous planning, coordinated teamwork and impeccable execution. Presented here are some salient aspects and highlights of the project.



A 3D rendering of the VVER

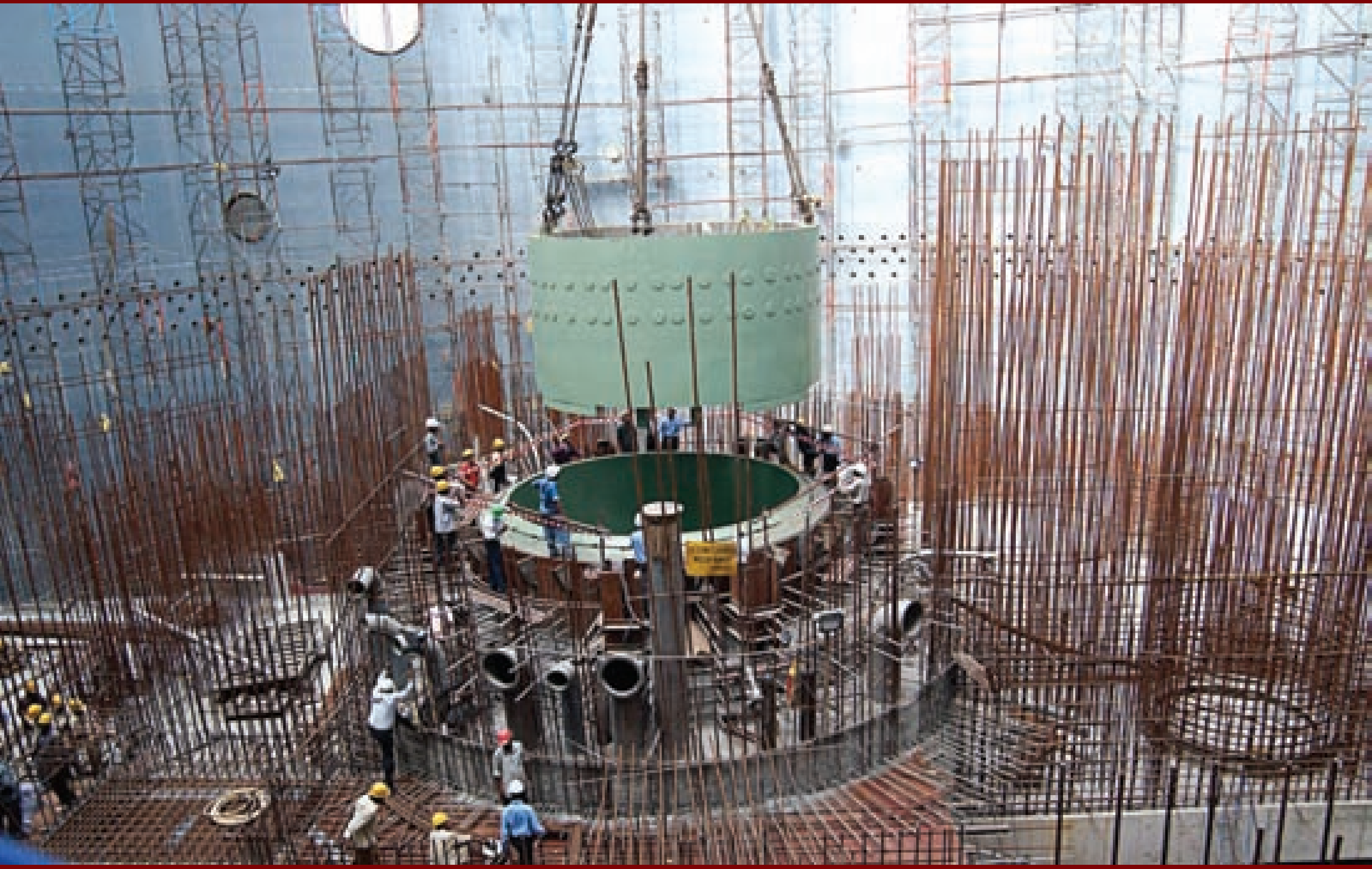
VVER: How It Works

Heat in a nuclear power reactor is produced by the controlled fission chain reaction in the nuclear fuel. The heat is used to raise steam that drives turbo generator to produce electricity. In VVER, slightly enriched uranium is used as fuel. The fuel assemblies are placed in the reactor core, which is housed in reactor pressure vessel (RPV). In VVER, water is used both as coolant and moderator. The coolant removes the heat from the reactor. The reactor plant has three major loops. The coolant circuit, or nuclear steam supply system (NSSS), comprises the reactor, primary coolant pump, steam generator and associated pipes. Four such circuits are connected to the RPV. Since the boiling point of the water is 100°C and the temperature of the coolant rises to 322°C in the reactor, the coolant is kept pressurised to inhibit its boiling, by a pressuriser connected to one of the loops.

The hot coolant transfers its heat in the steam generator, to the water circulating in another loop called 'secondary' cycle. Thus, the steam generator has two sides, the primary and the secondary side. The secondary circuit comprises steam generators, turbines, moisture separator and reheater, condenser, feed water pump, de-aerators, associated pipelines and other equipment. The secondary circuit is also a closed loop and does not contain radioactivity. However, it is still isolated from the environment.

The steam produced in the steam generator is fed to a set of turbines, which drive the generator to generate electricity. The steam from the turbine is exhausted into a condenser, where it is cooled and condensed. The condensate is pumped back to the steam generator. Condenser cooling is accomplished by a third loop, condenser-cooling system, which draws cooling water from the Gulf of Mannar. It is this third circuit that is exposed to the environment and is also devoid of radioactivity.

Construction Highlights



Civil construction and equipment erection taking place simultaneously, depicting the challenges of VVER-type reactor construction

Concreting and Structures

Unique Concrete Pre-stressing System

A first-of-its-kind un-bonded pre-stressing system for concrete – Freyssinet 55C15 – has been adopted at KKNPP. This pre-stressing system has a unique feature in that it also allows re-stressing in future. The pre-stressing system for KKNPP reactor containment buildings consists of 128 tendons (60 vertical U tendons and 68 horizontal full-round tendons). Each tendon consists of 55 strands of 150 sq. mm, each stressed at a load of 11.5 MN (meganewton) per tendon.

Reactor Building Raft

The huge reactor building raft (concrete foundation) was laid in just 93 days instead of the usual 6 to 7 months for this type of reactors, which was a remarkable achievement in reducing the project gestation period.

Hermetically Sealed Containment Liners

The reactor containment building of KKNPP has some first-ever features in the form of 'liners'. The 'inner' containment (IC) of the reactor building is made of pre-stressed reinforced concrete and has a diameter of 44 m, a height of 67 m and a wall thickness of 1.2 m. Its hemispherical dome has a 'hermetically sealed' carbon-steel liner inside it, installed in 3 parts. This dome liner is a 'first' for a nuclear power plant (NPP) in India. The walls and the floor of the inner containment have carbon steel liner plates, which is another 'first' for an Indian NPP. The 'outer' containment (OC) has a wall thickness of 60 cm, a diameter of 52 m and a height of 70 m.

Inner Containment Dome Top	+67 m
Outer Containment Dome Top	+70 m
PHRS Deflector Top Level	+80 m
IC Inner Diameter	44 m
OC Outer Diameter	52 m

Tertiary Dome for PHRS

The KKNPP is first in the country to have a tertiary dome for the reactor buildings. The tertiary dome houses the air ducts for the passive heat removal system (PHRS) based on the thermo-siphoning effect and starts above +52 m, while its top reaches a level of +80 m, and is supported with concrete and metal-structure rib walls inside, with left-in shuttering.

Core Catcher

A massive core catcher (also called melt core catcher) weighing 101 MT lies installed beneath each of the two KKNPP reactors. A core catcher is a vessel designed to prevent any molten fuel from escaping to the bottom of the reactor building and to the environment in a highly unlikely event involving reactor fuel meltdown. While the molten fuel continues to be cooled by the virtue of heat-absorbing material present in the core catcher cavity, the surroundings of the core catcher are designed to allow flooding with water to enable further cooling. Indeed, the twin KKNPP units are the first reactors in India to have this unique safety device.

PHRS – A Unique Passive Safety Feature of VVER

Tertiary dome with passive heat removal system ducts during the construction phase

Innovative Project Management

Sourcing of Equipment and Cost Optimization

Based on the fact that the VVER-1000 type KKNPP reactors were the first such reactors to be set up in India, a decision was made to source the equipment from the Russian Federation, based on the stringent engineering requirements and specifications, and especially since the Russian Federation offered a soft loan in the form of equipment supply. This decision to source the equipment rather than building it indigenously was to achieve the twin target of reduction in project gestation period as well as cost optimization.

Fuel Supply

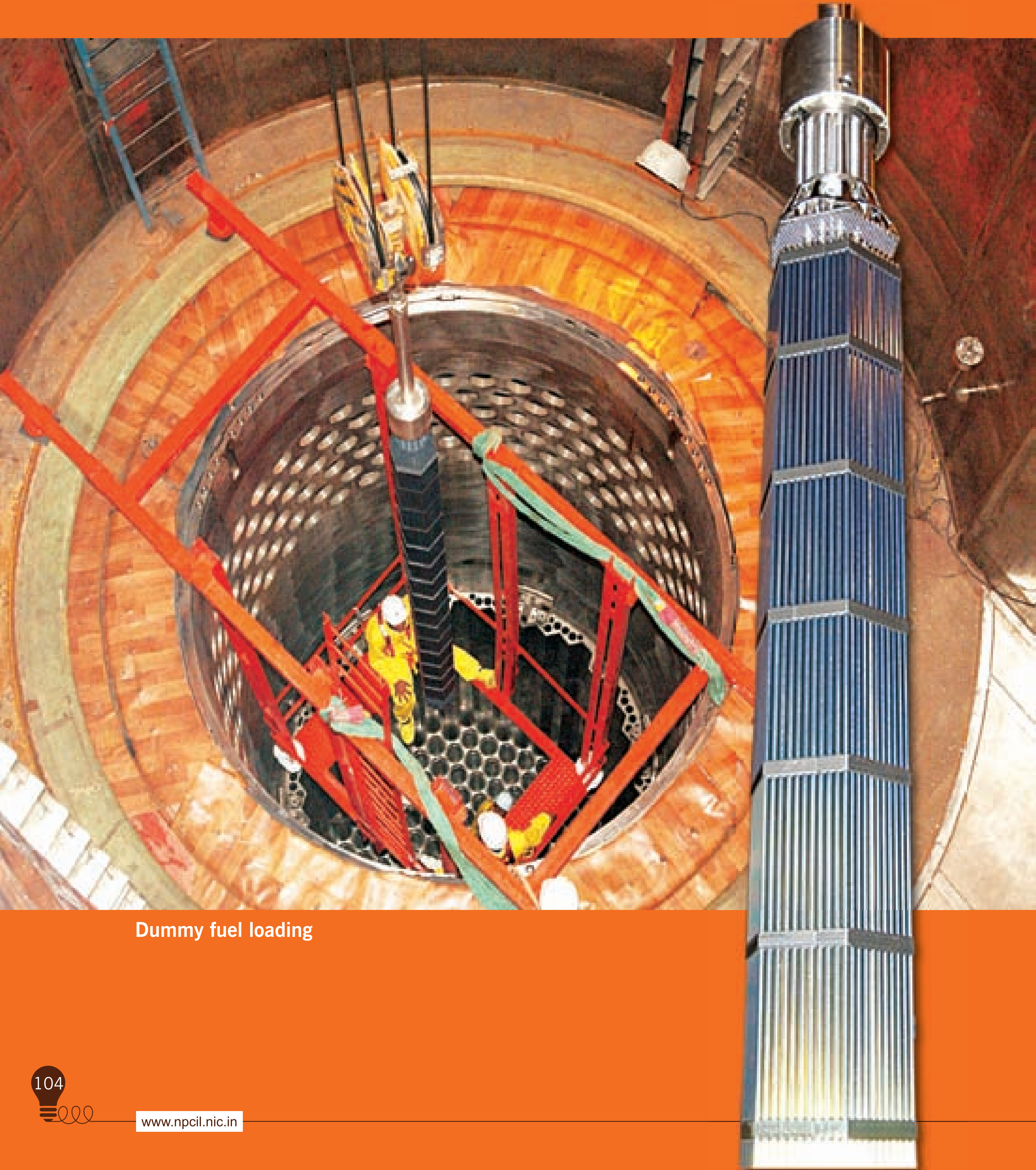
Lifetime supply of fuel has been ensured through an arrangement with the Russian Federation.

Specialised Training and Human Resource Development

In addition to the one-year nuclear training through the Nuclear Training Centre (NTC) at KKNPP and through periodic and ongoing training programs, a specialised training was imparted to Indian engineers and O&M (Operation & Maintenance) personnel using a full-scope training simulator supplied by ATOMSTROYEXPORT (ASE) from the Russian side. The full-scope simulator is capable of providing interactive training by simulating the entire spectrum of plant processes, controls and instrumentation.

As per the pre-defined division of work, the Indian side carried out the construction, erection and commissioning of the entire plant under the technical supervision of Russian experts.

Fuel-Handling System Highlights



Dummy fuel loading

Fuel Assemblies

The V-412 VVER-1000 reactors of Kudankulam use slightly enriched uranium fuel. The fuel assemblies are hexagonal-array type, and there are 163 fuel assemblies constituting the reactor core. Each fuel assembly comprises 331 locations (slots). Out of the 331 locations in the fuel assembly, Zr-Nb tubes loaded with fuel occupy 311 locations, while the balance 20 locations house control rods and instrumentation tubes. The fuel rods are zirconium-niobium (Zr-Nb) tubes in which fuel pallets are encapsulated.

Fuel	Sintered UO_2
Clad thickness	0.69 mm
Clad material	Zr–1%Nb
Helium gas filled to pressure	2±0.25 MPa

Core Refuelling

The reactor undergoes a refuelling process once each year, wherein one-third of the reactor core is replaced with fresh fuel. The refuelling process begins with shutting down the reactor and bringing down its pressure to atmospheric pressure. The temperature of the coolant is reduced to 60-70°C. Thereafter, the top cover of the reactor pressure vessel (RPV) is removed. This is done after removing the connections to the top cover and detaching the protective tube assembly. An overhead crane then lifts the top cover of the RPV. The removed spent fuel from the core is transported to the cooling ponds after ascertaining their leak tightness. The remaining two-thirds fuel assemblies are re-arranged in the core as per the design intent. The fresh fuel, which has already been shifted from fresh fuel storage area to the holding pond, is lowered into the vacant positions.

The entire operation is carried out under a protective layer of borated water. The reactor pit or cavity is filled with borated water, providing more than 3-meter-thick layer of water above the fuel assemblies.

Spent Fuel Storage

The spent fuel from the reactor core is stored within the reactor building for an initial cooling period, after which it is shifted to spent fuel bay outside the reactor building. The storage pools are at all times filled with pure, demineralised borated water, which is constantly recirculated. These high-integrity concrete pools are lined with stainless steel sheets.

Assembly of upper portion of RPV underway

Reactor Pressure Vessel

Reactor Pressure Vessel (RPV) is the heart of a nuclear power plant. The RPV of Kudankulam reactors measures 19.45 meters in height and 4.5 meters in diameter and weighs 316 metric tons. It is a 200-mm-thick cylindrical vessel made of low-alloy high-strength steel, with inner cladding of austenitic stainless steel.

The RPV houses fuel assemblies, the control rods and a host of other mechanisms and connections. Light water, which is the coolant, enters and exits through the coolant inlet and outlet, respectively, connected to the upper part of the RPV. The coolant entering through the inlet is directed downwards and enters the core barrel through the perforations present on it. The coolant circulates through the reactor core and absorbs the heat in the core produced by the chain reaction taking place in the nuclear fuel, and then this hot coolant moves out of the outlet. From here, the hot coolant reaches steam generators. The light water is demineralised to eliminate the adverse effect of minerals naturally present in water. A fixed quantity of boric acid is added to this demineralised water. The demineralised water acts as a moderator and a reflector. The boron in the boric acid is a neutron absorber and it thus helps in controlling the reactivity, i.e. the rate of fission chain reaction.

While the RPV has a detachable top cover, the vessel head is a leak-tight chamber that facilitates building-up of pressure necessary to prevent the boiling of the coolant (water) at a lower temperature.

The other reactor internals include 'protective tube unit' that keeps the core in position and guides the control rods into the core; core baffle – sandwiched between core barrel and core – for shielding the RPV from irradiation, support systems for fuel assemblies, instrumentation and control, provisions for the placement and retrieval of specimen that are irradiated, etc.

The top of the RPV is crowned with 121 reactor control drives. The control rods containing neutron-absorbing materials control the rate of chain reaction, in other words, the power of the reactor. These rods are held by electro-magnetic clutches and are referred to as 'control protection and safety absorber rods' (CPSAR). The increased number of control rods afford greater control and allow quick termination of the fission chain reaction.

The reactor pressure vessel is connected to four steam generators directly and the coolant returns via main circulating pumps. These pumps, four in number, one for each steam generator, pump reactor coolant from the steam generators into the RPV. The hot coolant flows in a closed-loop primary circuit called the primary circulation circuit or the Nuclear Steam Supply System (NSSS). Once the heat of the coolant (in the primary circulation circuit) is transferred to light water (in a separate secondary circuit) to raise the steam, the coolant is flowed back by the circulatory pumps to the RPV. The primary circulation circuit is kept physically isolated from the secondary system because the coolant in the primary circuit carries slight radioactivity. The secondary circulation circuit is non-radioactive.

Steam Generators

The steam generators of KKNPP have a unique horizontal design. Each reactor at KKNPP has four steam generators. These steam generators are horizontal 'shell and tube' type heat exchangers. A nest of U-shaped tubes is housed inside the shell. The horizontal design of the steam generators allows it to hold large quantity of secondary side water, which acts like a large reservoir even if the feed water supply is terminated in an unlikely situation. The horizontal layout of the steam generator has another advantage that even with significant reduction in the level of the secondary side, the heat removal capacity of the steam generator is not impaired. These steam generators also have large evaporation surfaces implying low steam velocities on contact. The steam generators have provisions for an auxiliary feed water supply should the main feed water supply be disrupted in an abnormal condition. The emergency heat removal from the secondary side is accomplished by an emergency cool-down system powered by diesel generators. The system comprising heat exchangers and pumps is a closed loop system using the inventory of steam generators, thus requiring no feed-water.

The steam produced in the steam generator is fed to a set of turbines, which drive the generator to generate electricity. The steam from the turbine is exhausted into a condenser, where it is cooled and condensed. The condensate is pumped back to the steam generator.

A Modular Approach to Reactor Dome Construction

Reactor building containment dome before concreting

Scaling New Heights in Safety

Safety is deep-rooted in every aspect of Indian nuclear power plants and it indeed begins right from design, siting (site selection), construction, commissioning and operation.

Taking the safety paradigm to even greater heights, KKNPP-1&2 are among the safest nuclear reactors ever designed in the world.

Safety Systems

Highlights

Some of the unique safety features of KKNPP reactors are:

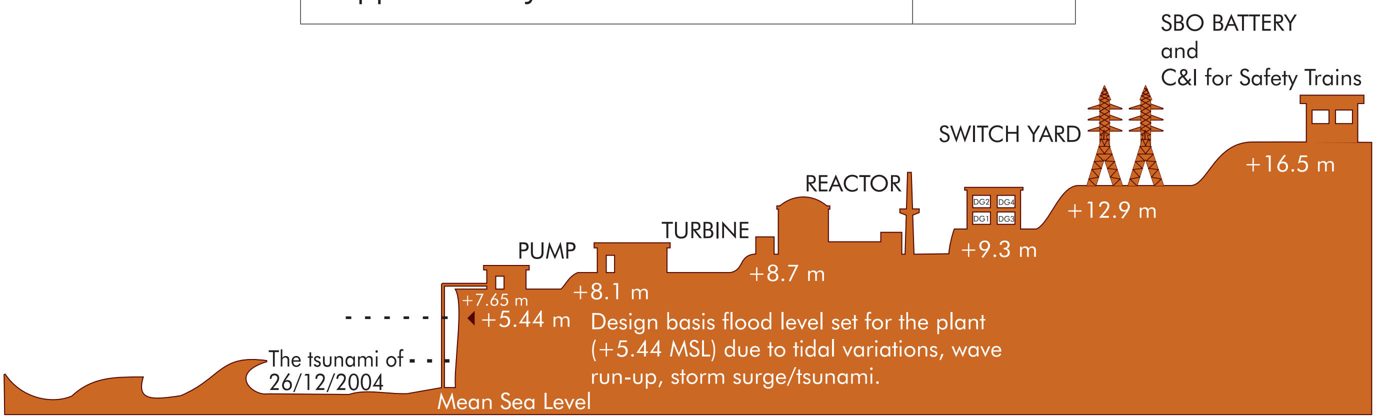
- Hermetically sealed double containment – first time with carbon-steel liner
- Unique Passive Heat Removal System (PHRS) to provide emergency core cooling through passive removal of decay heat
- Fully quadruplicated (4x100%) redundancy of safety systems
- Larger number of control rods (121) for increased safety margins
- Additional shutdown systems for the reactor, like quick boron-injection system.
- Hydro accumulators
- Hydrogen recombiners
- Core catcher

Safety Against Natural and External Hazards

Kudankulam site is located in the least earthquake-prone zone, i.e. Zone-II, which is the lowest seismic hazard zone in the country as per the earthquake resistant design code of India [IS 1893 (part 1) 2002]. The plant is designed to withstand severe earthquakes, and safe margins of peak ground acceleration for operation and shutdown have been factored in the plant design. Also, the site does not have any active faults in its vicinity. The plant site is also located far off (about 1500 km away) from the tsunamigenic fault (a tsunamigenic fault is where tsunamis originate). This means a tsunami originating there would lose much of its strength by the time it travels all that distance and reaches (if at all) the shores of Kudankulam. Higher site elevation from mean sea level as well as the elevated location of plant systems and equipment provide adequate safety margins to avoid design basis flooding of the plant. Leak-tight doors with gaskets are provided in reactor and other safety-related buildings to prevent any water ingress even in the hypothetical event of a 'higher than design basis' tsunami. The robust double-containment is designed to withstand an aircraft impact.

As compared to the Design Basis Flood Level of 5.44 meters, the elevation levels of important facilities at KKNPP with respect to mean sea level are:

Reactor building ground floor	8.7 m
Safety diesel generator sets	9.3 m
Switchgear for safety trains	9.3 m
Group I battery bank	12.9 m
Station blackout battery	16.5 m
Control instruments for safety trains	16.5 m
Supplementary control room	9.7 m



Mean sea level and relative elevations of structures at KKNPP

Safety is an over-riding priority in nuclear power plants. Based on an advanced design, the state-of-the-art KKNPP reactors incorporate a unique combination of 'active' and 'passive' safety systems, taking the safety paradigm to an even higher level. The Kudankulam reactors truly represent a pinnacle of technological achievement and are indeed among the safest in the world.

The plant's 'overlapping' safety features are based on the philosophy of 'defence-in-depth,' and follow the principles of 'redundancy' and 'diversity'. For example, the plant has fully quadruplicated (4x100%) redundant safety systems, where only one is sufficient. This is an example of redundancy. The principle of diversity is used for avoiding common-mode failure. For example, power supply to safety-related systems and equipment is provided by more than one grid feeders. These are further backed up by on-site quadruplet diesel generators and then again by battery backups.

Apart from the 'engineered' safety systems, the advanced reactor design imparts 'inherent' safety to the reactors. The negative void coefficient characteristic of the reactor causes the reactor to shut down if there is a loss of water from the reactor core. Whereas, the negative power coefficient characteristic of the reactor ensures that any abnormal increase in reactor power is self-terminating.

A Glimpse of Active and Passive Safety Systems

Active safety systems provide robust safety functionality immediately in case of any unlikely scenario of emergency. Complementary to the active systems, the passive safety systems work even in station blackout conditions, that is, even if there is a total unavailability of electricity to the plant. This is possible because passive safety systems do not require any electricity-dependent trigger for actuation, but rather rely on the unfailing natural principles such as gravity, inertia/conservation of momentum, pressure differential, convection, etc.

Here is a glimpse of some of the KKNPP safety systems.

Reactivity Control

Control Rods: Ingenious mechanisms ensure reliable operation. Take for example the control rods, which are used to control the reactivity. The control rod mechanisms located atop the reactor pressure vessel (RPV) are used for driving the control rods 'in' to different extents in order to reduce the reactivity and, consequently, the power output of the reactor. Electromagnetic clutches hold these rods and, upon loss of electricity, these clutches are 'de-energised,' which causes the control rods to fall freely into the reactor core under the force of gravity, making the reactor sub-critical in a matter of 2 to 4 seconds. A larger number of control rods (121) provide increased safety margins.

Quick Boron Injection System: It is yet another fast-acting system to shut down the reactor. Boron is a neutron absorber that is used (in the form of boric acid) to bring the reactivity to a halt. This system, based on the principle of diversity, acts as a backup system to the above mentioned 'control rod' mechanism for achieving reactivity control and quick shutdown. There are two components of the quick boron injection system – active and passive. The system injects concentrated boric acid solution into the reactor coolant circuit using pumps (active functionality), but this system can work even in case of failure of power to the pumps, as these are then driven by 'flywheels' connected to the pumps. The flywheels have a passive functionality, as they work on the principle of inertia (conservation of momentum). The conserved energy drives the pumps for a time period that is sufficient enough to achieve the injection of the boric acid solution.

Emergency Core-Cooling System (ECCS)

Emergency Core-Cooling System (ECCS) is employed in case of an unlikely scenario to flood the reactor core with ECCS water containing boric acid. ECCS has two components: passive ECCS and active ECCS. The passive ECCS does not require any pump or power supply and can function even during a highly unlikely scenario station blackout conditions. This passive part of the ECCS consists of special accumulator tanks that are connected using independent nozzles to reactor pressure vessel (RPV) from an elevated location above the RPV. If there is a loss of coolant, the coolant pressure falls.

The moment the pressure of the coolant falls below a preset value (that is, less than the tank pressure), the stored borated water starts flowing into the reactor core. There is also a provision of another passive system holding additional water at an elevated location above the RPV, which releases water slowly for an extended period during an emergency, to keep the core flooded. The passive ECCS is backed up by an active ECCS that uses pumps and derives its functionality from 4 channels of high-pressure and 4 channels of low-pressure subsets. The system is designed to remove residual heat for a longer duration. This system uses additional water resource of spent fuel pond and further switches on the suction to containment sump.

Containment Spray System

The reactors have a provision of containment spray system, which removes the heat released into the reactor containment, for example, in case of a break in the coolant pipeline resulting in release of steam inside the containment. The sprinkler system is automatically activated the moment pressure inside the containment crosses a predetermined value. The system has two redundant channels of sprinklers that spray water in the space within the containment dome. By condensing the steam, the containment spray system limits the temperature and pressure peaks to values at which containment integrity is assured. The spray water also contains chemicals to bind fission products, thus confining any radioactive fission products that may be released inside the containment building during a primary system leak.

Passive Heat Removal System (PHRS)

Passive Heat Removal System (PHRS) is a unique safety feature of KKNPP. The system is designed to provide emergency reactor core cooling even in the worst-case scenario of total loss of electrical power at the plant, including loss of grid power and backup power. This amazing level of safety is achieved through passive 'thermo-siphoning' and it works on the natural principle of convection, using air ducts. Heat from the reactor is transferred to the large quantity of water present on the secondary side of the steam generators and this water in turn is cooled by atmospheric air in the coolers provided at a height on the outside of the outer containment. The hot air rises naturally and is removed through outlet ducts, while cooler air enters through inlet ducts. A natural circulation is established and heat is removed without using any power at all.

Hydrogen Recombiners

Hydrogen Recombiners located in the containment building are another example of passive safety at KKNPP. They work on the principle of chemical catalysis (using 'palladium' metal as catalyst) and do not require any operator intervention or electricity whatsoever. These set of passive devices recombine hydrogen generated by metal-water reaction at high temperatures during an unlikely extreme event, and thus a hydrogen-gas explosion (which actually happened at Fukushima) would not happen.

Core Catcher

Core Catcher is yet another passive safety device implemented for the first time in any reactor in India. It is a massive steel tank-type containment device located beneath the reactor core in each of the KKNPP reactor buildings, In the worst-case scenario, even if the highly improbable event of fuel meltdown occurs, the core catcher would literally 'catch' any molten fuel escaping through the bottom of the reactor. The core catcher also contains ferrous oxide and aluminium oxide bricks that would absorb the heat and themselves melt, and thus bring the temperature down, while also causing the fuel to form lumps, thereby preventing any seepage of radioactive material either to the bottom of the plant or into the ground. For additional cooling, the area outside the core catcher is flooded with water.

Core catcher being lowered into position during reactor building construction

Strengthening the Safety Paradigm

Post-Fukushima, a Task Force was constituted by NPCIL to carry out safety assessment of KKNPP-1&2. The Task Force reviewed the core cooling capability of KKNPP during a postulated Beyond Design Basis Accident (BDBA) of tsunami resulting in incapacitation of motive power and the designed cooling water supply route. It was concluded that KKNPP design has:

- Passive safety systems to ensure reactor shutdown, core cooling and radioactivity confinement even in the case of an extended unavailability of electric power and the designed cooling water supply route
- Hydrogen management and molten core long-term cooling systems are also available to ensure the integrity of the containment systems
- Grade levels of all the main buildings have margins from conservatively arrived values of Design Basis Flood Level (DBFL)

However, as a means to further enhance the defense-in-depth safety paradigm and to take the level of safety to the next level, some additional measures were taken to cope up with rare severe multiple natural events having very low probability, like the one that took place at Fukushima, to take care of hypothesised extended Station Blackout (SBO) conditions.

- A separate 8000 m^3 water storage tank at a higher elevation
- Scheme for make-up of water to intermediate component cooling system
- Scheme for make-up of water to spent fuel pools
- Scheme for charging water to secondary side of SGs
- Schemes for injection of borated water make up to primary circuit from a separate 160m^3 borated water storage tank outside of Reactor Building (RB)
- Scheme for providing backup power supply from Mobile Diesel Generator for valves and plunger pump

Commissioning Highlights

The '360° rotating' polar crane used for handling and erecting bulky ODC equipment items in the reactor building

An Overview of Commissioning

Among a battery of pre-commissioning tests that were conducted to validate the integrity and tolerance of equipment, structures and systems in context of their design parameters, here are some prominent ones in respect of KKNPP-1, the first of the two KKNPP reactor units.

Integrity Test of Reactor Containment Building

An important pre-commissioning requisite is to demonstrate the structural strength and integrity of the reactor containment building. This was successfully tested by pressurising the reactor building to a level of pressure much higher than that during normal operation. For this the inner containment was pressurised to 4.60 kg/cm^2, several times compared to atmospheric pressure even though during operating condition the pressure would be slightly negative (very close to atmospheric pressure).

Hydro Test

Hydro test of the primary and secondary circuits of Nuclear Steam Supply System (NSSS) was successfully conducted to validate the strength and leak tightness of the circuits. The hydro test for the reactor primary circuit was carried out at 24.5 MPa (250 kgf/cm^2), 40% above the normal operating pressure and involved the testing of reactor pressure vessel, steam generators, reactor coolant pumps, pressuriser, main coolant piping, quick boron-injection system tanks and various reactor-process and safety-system equipment, piping and tubing. The primary circuit was tested at a higher temperature (not less than 90°C). All the required auxiliary systems, like the seawater cooling systems, component cooling systems, water chemistry control systems, make-up water systems, pressurising systems, power supply systems, control systems and the main control room were made operational prior to start of the hydro testing. The trial run of all the four reactor coolant pumps (RCPs) was also successfully completed earlier. The secondary circuit was tested at 110 kgf/cm^2 a few days later.

Hot Run

Hot run is one of the major exercises taken up before achieving the first criticality of a reactor. The hot run of KKNPP-1 was conducted in two steps. In the first step, the clearance to raise primary circuit temperature up to 130°C was obtained from AERB, upon which the reactor coolant pumps (RCPs) were started, the primary circuit temperature was raised to 130°C, and the RCP combination tests were completed over several days. Then, in the second step, upon AERB gave clearance to raise the temperature above 130°C, the temperature was gradually raised till the primary circuit temperature reached 260°C and pressure 15.7 MPa. Then steam blow-down was commenced. Steam flushing was completed after a week. The primary circuit temperature reached 260°C and pressure 15.7 MPa, while the main steam header temperature reached to 260°C and pressure 6 MPa.

The Journey to Sustained Power Operation

The commissioning process of the reactor unit involves a large number of safety and performance tests carried out in the primary circuit (reactor side) and secondary circuit (turbine side) systems, safety systems, electrical systems, etc. to ensure that the systems are performing as per the design intent.

Commissioning activities are divided into three main phases: Phase A, Phase B and Phase C. Phase-A commissioning activities mainly focus on the individual equipment and system commissioning. The strengths of the primary and secondary circuits are tested by means of hydrotest, while containment strength test is also carried out in this stage.

The integrated performance of all the systems is then carried out with 'dummy fuel' to simulate actual fuel in the reactor. The thermal hydraulic performance of the entire nuclear power plant is evaluated in this stage of 'hot functional test (hot run)', done at the rated operating parameters.

In Phase-B commissioning, the nuclear fuel is loaded in the reactor and the primary system circuit is heated up to nominal parameters and physical start-up of the reactor is carried out to attain the first criticality of the reactor.

Phase-C commissioning activities comprise three sub-stages, viz., Phase C1, Phase C2 and Phase C3 that focus on evaluation of the system performance to various transients with respect to the acceptance criteria.

In Phase C1, the reactor power is raised up to 50% of full power and the generator is synchronised with the grid. Various tests pertaining to reactor systems, secondary feed water and turbine generator systems are performed with generator synchronised to the grid. Phase C2 encompasses reactor power raise to 75% full power and carrying out various tests of reactor and turbine systems with the generator synchronised to the grid. In Phase C3, the reactor power is raised in steps, first up to 90% and then to 100%. In this phase also, several transient and dynamic tests are carried out on the reactor and turbine generator systems, with the generator synchronised to the grid.

The tests carried out at KKNPP during the commissioning phases are very exhaustive; some are enumerated below:

- Containment strength test, to assess the leak tightness of the Primary containment
- Primary and secondary circuit hydrotests, to assess the integrity of the system
- Reactor systems functional tests by switching off the Reactor Coolant Pumps in various combinations, to assess the Reactor Core Hydraulic characteristics
- Integrated operation of all the four trains of the Emergency Core Cooling System and Containment Spray System, to assess the performance of safety systems
- Natural circulation test to assess the formation of the natural convective heat transfer under total loss of core circulation
- Low-power physics tests and xenon stabilisation tests, to assess the neutronic behaviour of the reactor
- Electrical systems functional tests like Emergency power transfer tests of the diesel generators, net load rejection test and satisfactory operation of the Turbo-Generator under house load
- Turbine systems functional tests like Electro-Hydraulic Governing System integrated tests and Load Throw-off test
- Control Systems and Instrumentation functional tests like Neutron Flux Monitoring Equipment tests, Monitoring and Diagnostic System tests and Automatic Power Controller tests

Such multifaceted battery of tests are performed in line with international practices, to ensure the operability of the nuclear power plant in a safe manner under all postulated operating states and to ascertain the endurance capability of the equipment.

The Magic of Fission Chain Reaction Begins

Attainment of First Criticality

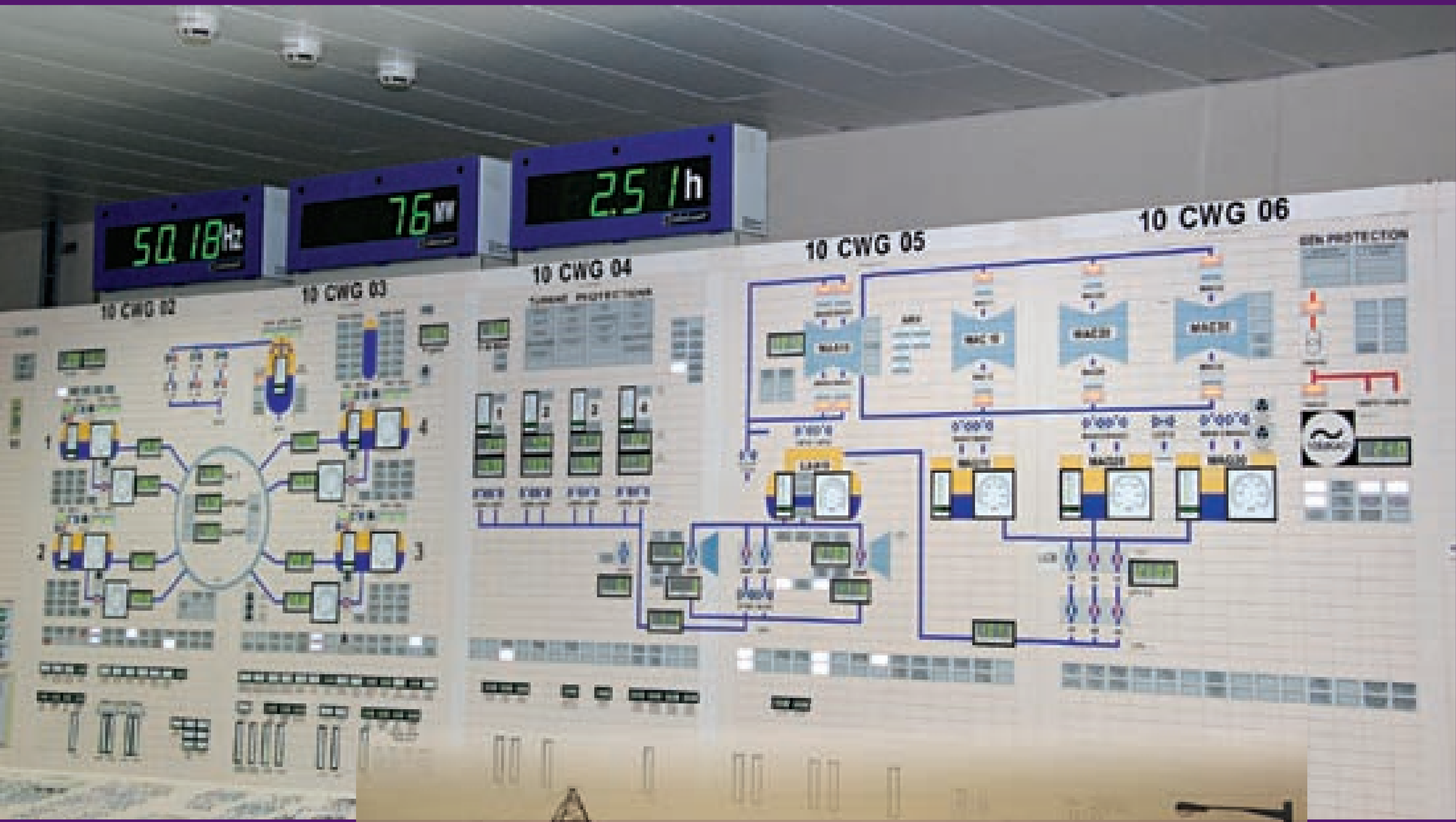
KKNPP reactor unit-1 (KKNPP-1) achieved its first criticality on July 13, 2013.

Criticality is the event of a nuclear reactor reaching a self-sustained controlled chain reaction. This means no external source of neutrons is required to sustain fission in the reactor core. Criticality inside the nuclear reactor is the first requirement for producing useful amounts of energy from the reactor.

This important milestone for KKNPP unit-1 was achieved at 2305 hrs. after the 'boron dilution process' allowed the neutron concentration to go up and start nuclear fission, generating heat. Prior to this, the reactor with fuel was filled with concentrated borated water.

The entire process of the first criticality was achieved with text-book precision.

Power Flows to the Grid



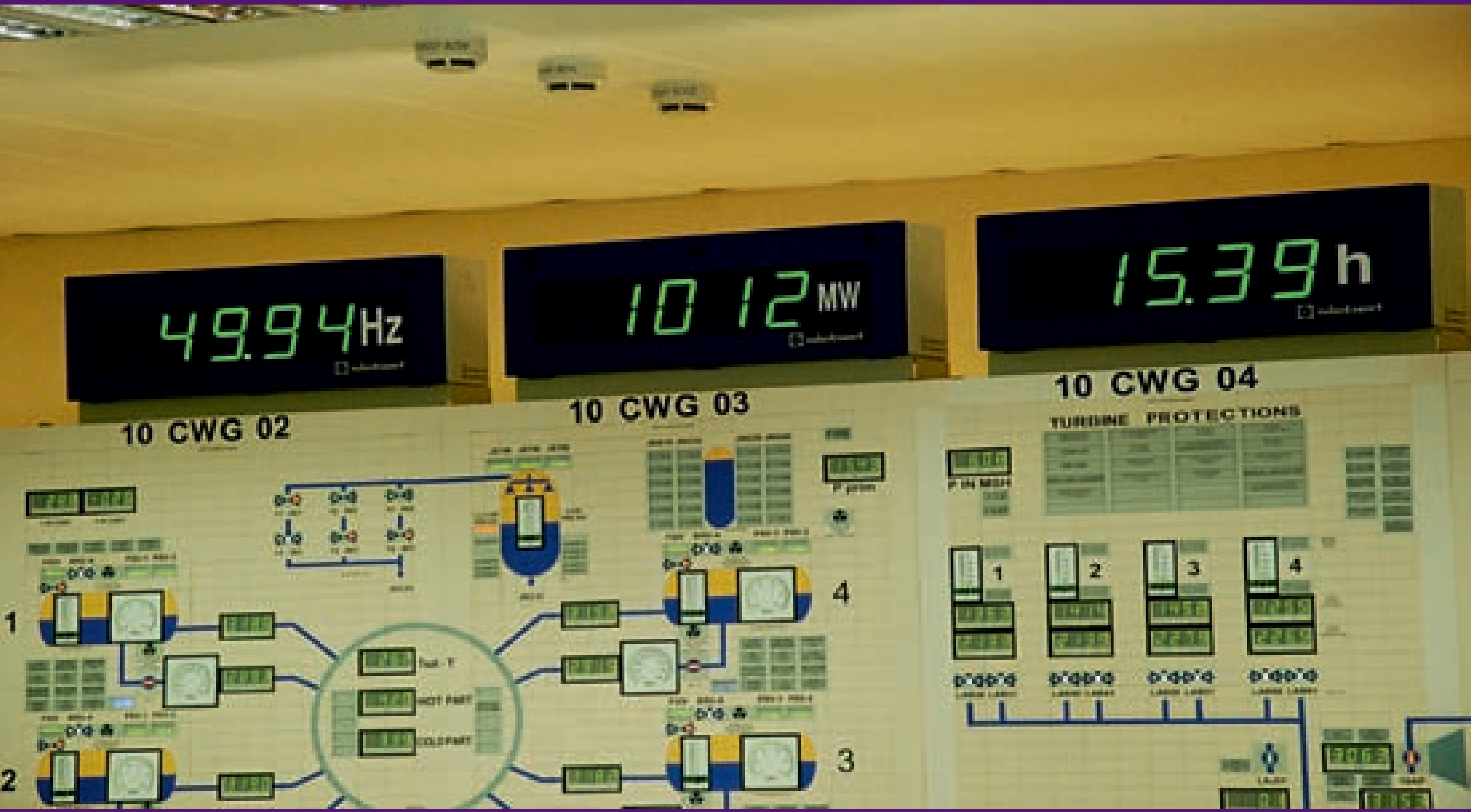
Synchronisation to Southern Grid

KKNPP-1 was connected and synchronised to the Southern Grid for the first time on October 22, 2013.

In the early hours, at 0245 hrs., the first unit generated 75 MW, which was gradually increased up to 160 MW. Subsequently, power was successfully transmitted to the southern grid.

Power from Kudankulam is shared between the beneficiary states in the Southern Grid, viz., Tamil Nadu, Karnataka, Kerala, Puduchery and Andhra Pradesh.

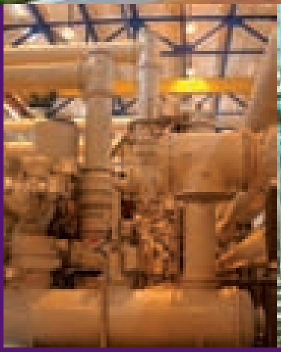
Ready. Steady. Go.

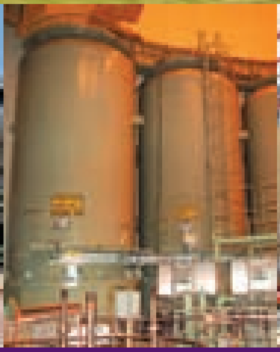


Full-Power Operation

KKNPP unit-1 attained its rated full power of 1000 MW at 1320 hrs. on June 7, 2014. The power level was gradually raised in steps in accordance with the clearances accorded by the Atomic Energy Regulatory Board (AERB). At each successive step, various tests were conducted and the respective clearances for the next step obtained from the AERB. At full power, stipulated tests were conducted and the reports submitted to the AERB for review and final clearance for continued operation of the unit at full power.

A Dream Come True





The wait is over. The 1000-MW KKNPP-1, India's 21st nuclear power reactor unit, which also has the distinction of being the largest power generation unit (nuclear or any other kind) in the country, achieved the milestone of commercial operation at 0001 hrs. on December 31, 2014. With this, the installed nuclear power generation capacity in India has now reached 5780 MW. The unit has brought power and smiles to millions of homes. The total gross generation of electricity from KKNPP-1 during October 22, 2013 to June 24, 2015 was 6873 million units.

This sterling technological achievement of Indo-Russian cooperation has opened a golden chapter in the history of nuclear power generation in India. KKNPP-1&2, the maiden twin-unit (2 x 1000 MW) Pressurised Water Reactor type nuclear power project in the country, has set the cornerstone for a series of large-capacity (1000 MW and more) nuclear power reactor units to be set up in India in the coming years, with international cooperation. These will supplement the first stage of our own indigenous nuclear power programme consisting of Pressurised Heavy Water Reactors (PHWRs), to speed up power generation in the country and thereby energising faster economic growth and development – for a better tomorrow.

Nuclear Training Centre

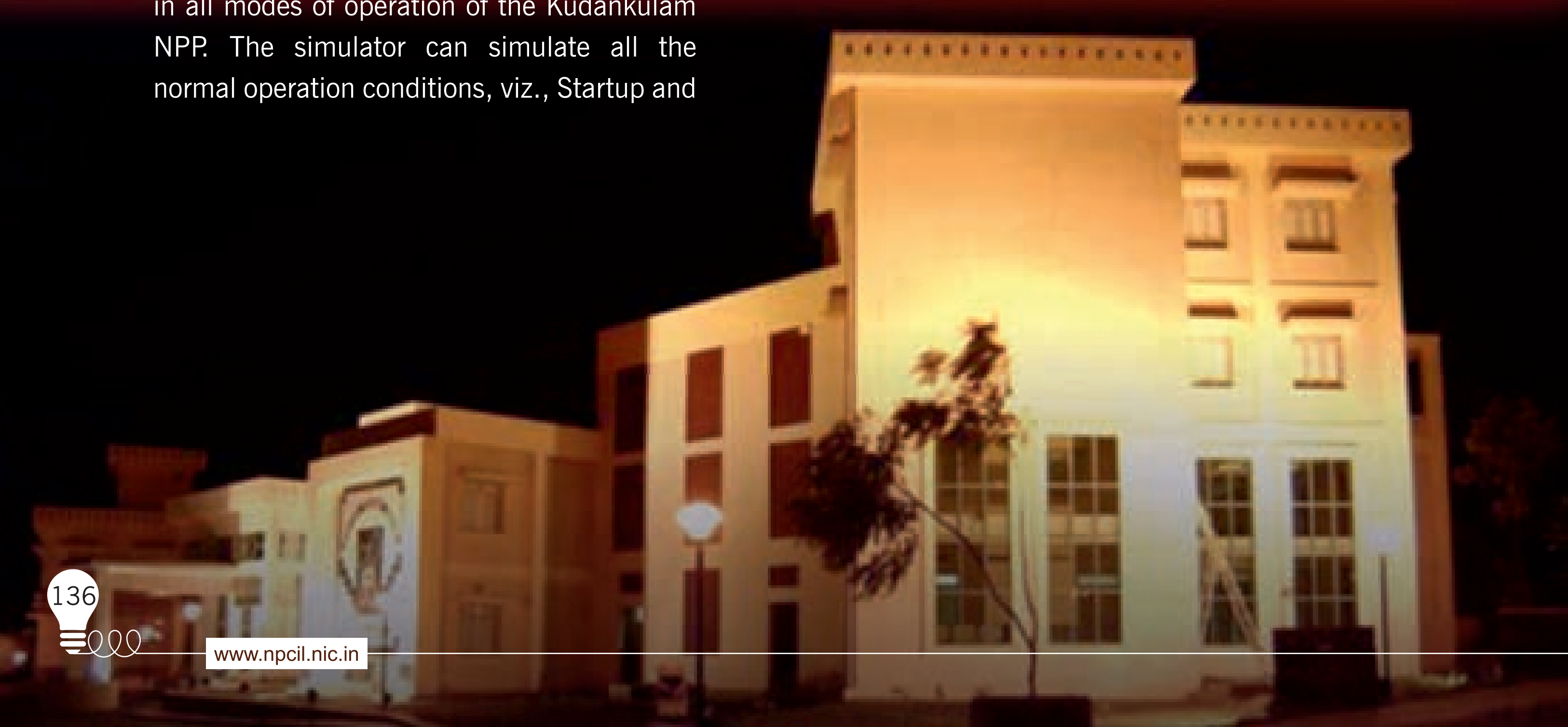
Developing Human Capital for Today and Tomorrow

Like in any dynamic organization, human resources form the backbone of NPCIL. Training is central to developing a pool of competent individuals forming specialised teams that work in perfect unison towards achieving organizational goals of today and tomorrow. At NPCIL, this is accomplished through unique training and skill development programmes, in which Nuclear Training Centres (NTCs) play a dominant role.

NTCs are well established, fully equipped training centres with latest pedagogy, training infrastructure, structured documentation and training aids, and above all, a large pool of experienced faculties.

The ISO-9001:2000 certified NTC at KKNPP has a 'PWR-specific' training centre equipped with state-of-the-art models, mockups and reference plant simulator. The full-scope Replica Training Simulator (KKFSS) at Kudankulam Nuclear Power Project is Intended for training of operation engineers in all modes of operation of the Kudankulam NPP. The simulator can simulate all the normal operation conditions, viz., Startup and shutdown, as well as abnormal operations, including accident conditions for training purpose. The KKFSS design is based on KKNPP unit-1 as the reference unit.

The training simulator has the capability to simulate plant startup from cold and hot conditions, maneuvering through power ranges and attaining full power. Similarly, power decrease, shutdown and cool-down of the unit can be simulated. Also, transient and emergency operating conditions such as Anticipated Operational Occurrences, Design Basis Accidents and Beyond Design Basis Accidents can also be simulated. The simulation capability also includes unlikely accident conditions such as station blackout, loss-of-coolant accident in primary circuit, complete loss of feed water, uncontrolled withdrawal of control rod group at power, failure of reactor emergency protection system, loss-of-coolant accident in primary circuit with station blackout, etc.



Evolution of Electrical Systems of KKNPP: An Engineering Journey

R. Kamath, ACE (Project LWR – Electrical), KKNPP-3&4

Kudankulam Nuclear Power Project (KKNPP), by all accounts, is a monumental achievement in the Indian nuclear power history, the foundation of which was actually laid way back in year 1988, on November 20, 1988, through Inter Governmental Agreement (IGA) signed between erstwhile Soviet Union and India.

The electrical systems at Kudankulam Nuclear Power Project, like any other systems of the project, underwent a series of evolutions and developments before taking the final shape – both in terms of design documentation as well as implementation of the electrical systems through successful completion of erection, testing and commissioning of the electrical systems of KKNPP reactor units-1&2.

This article endeavours to bring out this entire process, from the beginning of this evolution after the signing of IGA (Inter-Governmental Agreement) for KKNPP between the erstwhile Soviet Union and India in 1988 to the synchronization of unit-1 generator, covering the development of entire gamut of issues through the years.

1 Technical Assignment (TA)

Technical Assignment (TA) is one of the first and foremost technical documents, which was finalised based on the series of extensive discussions with the then Soviet/ Russian specialists. The document contained the basic details of the terms, definitions, classifications, general design and technical requirements of various major systems and equipment, including engineered safety features of the plant, which were to be fulfilled during the design elaboration of the plant. The operational conditions of nuclear power station under various load and grid characteristics were also broadly discussed and the technical requirements of the equipment to withstand such load variations and regulations were also enumerated as baseline criteria for development of detailed design engineering.

In addition, normative documents and international regulations/ standards/codes etc. to be followed and complied during the design elaboration were also discussed and finalised in this document. The reference plants in the then Soviet Union were also deliberated and listed in the technical assignment.

TA for E al Systems of KKNPP

For electrical systems, brief details of systems (both normal and emergency) and equipment covering extra high voltage (EHV) / medium voltage (MV) / low voltage (LV) switchgear, transformers, diesel generator sets, types of batteries, etc. were all discussed and mutually agreed upon between the two sides. The major technical features and requirements of all these systems and equipment, including the selection of voltage levels applicable for KKNPP, were also deliberated and mutually agreed upon.

Significantly, the basic guidelines for long and short-term regulation characteristics covering regulation of output during operation as well as under 'normal grid' and 'grid disturbance' period were discussed through finalisation of power curve for the generator. In addition, the voltage regulation requirements under various conditions of the plant, including generator characteristics, its capability curve, its response to various grid conditions were all discussed and requirements from Indian side were stipulated in the TA.

Some of the major technical requirements, related to electrical systems, which were discussed and agreed upon between the two sides at the time of 'finalisation of TA' are listed as below

a) Basic scope of the detailed engineering and design aspects covering characteristics of plant electrical systems and equipment, including their interaction with other systems of plant and grid

b) Voltage levels for electrical auxiliary systems as well as for power evacuation

c) Basic groups (class) and types of power supply along with interruption time allowed, if any, for each group of power supply

d) Basic guidelines about the system and equipment capability and environmental conditions under which the systems and equipment are supposed to operate

e) Permissible voltage and frequency tolerances

f) Applicable standards and qualification requirements

g) Special features of power output system equipment; in view of the coastal and saline conditions prevailing at KKNPP, it was proposed to have gas-insulated type of switchgear for both 220 and 400kV systems

h) Decision on having 'three single-phase units' of generator transformers, in view of limitation of size and capacity of the transformers as well as selection of type and range of tap changer, type of neutral grounding systems (solid grounding), etc.

i) Selection of type of tap changing method for Reserve and Unit Auxiliary Transformers along with range and the neutral grounding method (resistance grounding); it was also stipulated that impedance of the transformers shall be so chosen that effective value of the sub-transient short-circuit current value does not exceed 40 kA and asymmetrical short circuit value does not exceed 100 kA. The systems were to be designed taking into account of the contribution of electrical motors to the short-circuit currents in the event of any fault.

j) Basic requirements of Diesel Generator (DG) sets and its auxiliary systems, including the stipulation of its qualification as per IEEE–387 and type of fire-fighting systems in the DG rooms.

k) Type of MV / LV Switchgear and Motor Control Centers (MCC).

l) Type of battery and battery charger/ rectifier, inverter systems, etc., including provision of separate 24 hours

battery for station blackout (SBO) conditions

m) Type of switching scheme for power evacuation, i.e., nuclear power plant (NPP) connection to power grid. In view of the requirement of operational flexibility and reliability point of view for a power plant of this magnitude, one-and-a-half breaker scheme was adopted for 400kV Gas-Insulated Switchgear (GIS) system and for 220kV system, 'two main bus' scheme was stipulated. A basic single-line drawing showing the above two schemes were also drawn and mutually agreed upon as a baseline drawing for further development during the detailed design engineering stage.

n) Basic technical requirements during the automatic changeover of power supply source at 6kV bus from unit systems to reserve and vice versa, were also stipulated along with permissible voltage drops on the system.

o) Basic guidelines and requirements of normal and emergency auxiliary power supply systems were also mentioned, which would serve as guiding document for development of detailed design engineering, with emphasis on identification of the loads required to be fed from safety system or related power supply. In order to meet the above criteria, a requirement of 4th DG set (in addition to the 3x100% DG arrangement generally followed at that point of time in Russian NPPs) was also and stipulated accordingly.

p) The basic design criteria regarding segregation of equipment layout, cabling routes, tray systems, separation, etc. was also enumerated, which would guide the detailed design engineering by the Russian side.

q) The technical requirements regarding the broad type of cables to be used for cabling systems of KKNPP, along with fire barrier systems to be used were also specified.

r) Requirements of various auxiliary systems such as lighting systems, receptacle network, grounding, space heaters etc. were also discussed and stipulated accordingly.

s) The methodology of interconnection of Generator output to Transformers through Isolated Phase Bus Duct (IPBD) and various system operation conditions for the same were deliberated and requirements were stipulated.

t) The technical requirements of generator, its auxiliary systems and the generator performance characteristics under various grid voltage and frequency variations, to be conformed during the design development were all discussed and agreed upon.

u) Above all, the scope, contents and type of drawings / documentations / analysis reports etc., which need to be developed during the detailed design engineering stage, were also deliberated and listed in the document.

All the above requirements were to be taken into considerations by the Russian designers during the detailed design development and engineering of the plant electrical systems and its equipment and compliance of the same had to be ascertained by Indian side.

It is also pertinent to note that the original Technical Assignment (TA) was discussed and finalised during the initial discussions held in year 1989-90, which were however discussed again (after the revival of the project talks between two countries in 1998) and necessary amendments to include the additional and up-to-date technical requirements were added in the revised / amended TA signed between the two sides in the year 1998.

All the above TA documents were reviewed, compared and analysed through an exhaustive study of the salient features provided in the reference NPPs, new Russian plants which were under operation and construction at that point of time, along with stipulations recommended in various codes, guidelines, standards such as IAEA, USNRC, 10 CFR, AERB manuals, IEC/IEEE standards, Indian Electricity Rules, etc. Invariably, the prevailing design features of relevant systems and equipment in indigenously-developed PHWR plants were also referred and compared before finalisation of the same.

2.0 System Studies Report

'Power Systems Studies Report' on transmission line systems connected with any power plant is an important basic document for development of detailed design engineering, particularly the engineering part related to the power evacuation systems, voltage regulation etc. In this, various studies are carried out to identify the transmission systems for KKNPP based on the load flow and short-circuit studies. In addition, it is also used for identifying the step-up voltage, transmission corridors, number of outlets and the system for providing the start- up power. The impact of sudden load throw-off or sudden load injection, over-voltage studies etc. is also carried out along with various stability analysis.

The first power system studies report on the transmission systems associated with KKNPP was carried out by Central Electricity Authority (CEA) in the year 1991-92 on consultancy basis based on the then transmission systems prevailing in the southern grid, and through these studies, following transmission lines were finalised:

1. Kudankulam–Trivandrum: 400kV D/C line
2. Kudankulam–Madurai: 400kV D/C line
3. Madurai–Annur: 400kV D/C line
4. Annur–Salem: 400kV S/C Line

However the above report had to be re-validated due to the stalling of discussions on KKNPP project during the period 1992-98. Hence, CEA was requested again to evolve suitable transmission line systems for evacuation of power from KKNPP in the year 1999. Since the generation situation in southern grid had undergone substantial change in the nearby grid as well as in the transmission systems planned earlier for KKNPP, the systems studies had to be carried again in the context of changed generation and load scenario.

Physical inspection of turbine prior to installation

Physical inspection of turbine prior to installation

The new report brought out the following major conclusions related to KKNPP, which were to be carried further for detailed design development.

1. The power generated at KKNPP may be stepped up to 400kV and transmitted into the southern region grid through six transmission lines.
2. Start-up power supply to KKNPP was planned to be provided at 220kV level.
3. 220kV and 400kV buses were to be interconnected through two 315MVA Interconnecting Auto Transformers.
4. Provision of 2x80 MVAR Shunt Reactors at KKNPP Bus to control the voltages under light load conditions.
5. Transmission lines thus finalised as per 1998 report were as follows:
    a) KKNPP–Trivandram: 400kV D/C lines
    b) KKNPP–Kayathar: 400kV D/C lines
    c) LILO of Kayathar–Trivandraum at KKNPP: 400kV, S/C lines
    d) KKNPP–Nagercoil S/S: 220kV S/C line
    e) Nagercoil–Kayathar S/S: 220kV S/C line
    f) KKNPP–Tuticorin: 220kV S/C line

The above system study in 1998 was subsequently followed up with another revised power systems studies by Power Grid Corporation of India Ltd. (PGCIL). In this report in the year 1999, it was finalised to evacuate the KKNPP power through only 4 lines of KKNPP–Tirunelveli using quad conductors, perhaps for the first time in this part of the southern grid. Results of various stability, short-circuit studies and dynamic over-voltage studies were also carried out to assess the likely grid scenario under various conditions and found to be in order by the grid authorities.

The outcome of above systems studies reports were shared with General Designers of the project, to incorporate the necessary changes needed in the detailed design engineering as well as in the various equipment specifications, such as 220kV and 400KV Gas-Insulated Switchgear systems etc.

3.0 Detailed Project Report (DPR) Packages

This is the third, and by far one of the most important, stages in the evolution of electrical system design and development for KKNPP. The primary responsibility of preparation of Detailed Project Report (or popularly known as DPR) was with Atomenergoproekt (AEP), the general design institute for KKNPP. For each discipline, the packages to be submitted by the General Designer were identified in advance along with the schedule for its submission.

The DPR packages thus submitted by AEP had to be reviewed, commented and mutually discussed before its finalisation.

To begin with, the DPR contract was signed in 1998, and as per the terms and conditions of the contract signed between the two sides, the list of various DPRs to be submitted were finalised and submission of the same commenced soon in the year 1999-2000.

There were a total of nine DPR packages related to electrical systems as listed below:

- E-1: Concept and regulatory basis of the systems: 400kV and 220kV switchgears, lighting, grounding and lightning protection
- E-2: Concept and regulatory basis of the system: communication and signaling
- E-3: Concept and regulatory basis of the systems: Power output systems, auxiliary power supply systems, cabling, relay protection, generator and its excitation
- E-4: Design materials of 400kV and 220kV switchgears, generator and its excitation system, lighting system, grounding and lightning protection
- E-5: Design materials of power output system, auxiliary power supply system, cabling, relay protection and automatic switching systems
- E-6: Design materials of communication and signaling
- E-7: Design materials of layout solutions of transformers, 400kV and 220kV switchgear and auxiliary power supply systems equipment
- E-8: Design materials of auxiliary buildings at NPP site and structures of auxiliaries
- E-9: Design materials of high-frequency communication and telemetering

The entire DPR finalisation was split into two parts. While the first part covered the conceptual and regulatory basis of the systems and equipment (i.e. E–1, E–2 and E–3 packages), the second part of the DPR (i.e. E–4, E–5, E–6, E–7, E–8 and E–9 packages) covered design materials, detailing of the systems and equipment described in the first part of the DPR.

DPR documents thus submitted covered virtually every important systems and equipment of all discipline. In this report, the basic technical specifications/parameters and qualification requirements were also discussed and finalised. The information thus covered in the DPR packages offered was sufficient enough to discuss the techno-commercial issues between the two sides later, so that it was possible to make and realise realistic cost estimate.

Along with DPR packages, Preliminary Safety Analysis Reports (PSARs) packages were also prepared for all the systems, contents of which were reviewed in detail by each group and finalised in consultation with concerned specialist groups. PSARs on all the various systems / equipment, thus finalised, were submitted to AERB for their review and acceptance, before carrying out any initial activity or actual construction works of NPP at site.

In case of electrical systems, S–8 PSAR document was thus prepared and finalised after a series of discussions with Russian side and then submitted to AERB in the year 2000-01. The comments given by AERB after their detailed review were also discussed later on with General Designers and necessary changes/revisions, wherever needed, were also incorporated in the PSAR packages, before its re-submission and clearance by regulatory authority.

In case of electrical systems, all the nine packages and PSAR

S–8 package were exhaustively reviewed and salient features and parameters given in the DPR packages were checked and compared for its suitability and adaptability in the Indian context, keeping in view of various stipulations in the Indian regulatory documents and standards.

The main technical specifications and parameters of the electrical equipment such as type of switchgear/transformers, its rating/ capacity, voltage ratios, continuous current capacity, S–C breaking capacity, type of system grounding, type of control, monitoring and relay protection (CMRP) schemes, type of battery banks, type of cables to be used etc. were all discussed and finalised between two sides, during the DPR stage and recorded in the relevant packages.

An exclusive DPR package was devoted to the finalisation of the layout plans, basic floor layout, equipment layout, cable gallery layout etc. of not only electrical buildings, but also of those buildings which have electrical panels / installations, cable galleries etc.

Along with DPR packages, some of the relevant codes /guidelines and GOST standards referred for framing the above documents and its contents were also obtained from the Russian side, as a reference tool for the purpose of review as well as for future reference/records.

Thus, in accordance with the provisions of the main agreement, DPR contract, Techno-Commercial Offer (TCO) was discussed and agreed upon between the two sides and the General Framework Agreement (GFA) was signed mutually with elaboration of various terms and conditions of understanding and responsibilities to be shared and followed by the two sides for the implementation of the project. In line with this GFA, various contracts for elaboration of Working Documentation (WD) and supply of long-delivery as well other equipment (called as Balance of Plant – BOP) were all discussed and mutually agreed upon between the two sides.

4.0 Elaboration of Working Documentation (WD) Contract

After the finalisation of DPR / PSAR packages on various systems and equipment, techno-commercial contract was signed between the two sides along with GFA, paving the way towards setting up of India's first 1000MW power plant. The stage was thus also set for finalisation of the list of documents and drawings to be submitted by General Designer of the plant.

For KKNPP, the main responsibility of design and its detailed engineering was in the scope of the Russian side and elaborate discussions were therefore held to finalise the nature and list of documents to be submitted, not only for facilitating the tender documentation preparation for awarding the erection contracts, but also for carrying out the actual works at the site.

Accordingly, one of the first activities after formal agreement for setting up of nuclear power plant at KKNPP site was finalisation of engineering drawings contract, in which various WD to be submitted during the course of project execution were all listed along with their schedule for submission.

The above list was extensively reviewed vis-à-vis the then planning schedule drawn for the project and discussed with Russian side. All the necessary WD packages were listed and identified for electrical systems covering the entire gamut of works to be done at the site, right from the equipment layout, basic single line diagrams to voluminous cable logs/schedules and termination drawings etc.

All these packages were uniquely numbered with their title and likely quarter/year of submission and schedule drawn for the same was duly monitored and pursued.

The above submission for electrical systems included single line drawings, layout drawings, control and relay protection schemes, power and control cable logs/ schedules, termination schedules/ drawings/albums, cable metal structure layouts, cabling route plans, lighting and welding receptacle network drawings, including outdoor street lighting layout as well as indoor and outdoor grounding grid systems drawings etc.

All these drawings were reviewed in detail at headquarter (HQ) and by a small team of design engineers posted at NPCIL Representation Office in Russian Federation (NRRF), Moscow and wherever needed, interactions were carried out with Russian side, both at the site, HQ and at NRRF office, Moscow. Only after due clearance, the drawings were released for erection works at site.

In case of electrical systems, first priority buildings/systems were identified such as 220kV Gas-Insulated Switchgear, Reserve and Common Station Auxiliary Power Supply systems (covering transformers and 6kV switchgear), DM water systems, fire water systems etc. and all the electrical drawings related to these buildings were sought first, so that works related to these systems can be taken up first. Within the particular building drawings, priority was given to equipment layout, cable metal structure layout, lighting and welding receptacle layout etc. so that, the same can be erected before the commencement of main equipments such as GIS, 6kV and 0.4 kV switchgear, protection panels etc. The above drawings were subsequently followed by cable logs/schedules, cable termination drawings, control schematic drawings etc. which were all needed not only to take up the works at site, but were also crucial for taking up pre-commissioning and commissioning activities of the systems to be made ready first.

The changes to be made in the above drawings were issued in the form of Design Change Notices (DCNs) by the representatives/ specialists of General Designers based at Kudankulam site, which were again reviewed by Field Engineering (FE) Groups and cleared for implementation at site.

5.0 Equipment Delivery Contracts

Similar to the Engineering WD contract mentioned above, separate contracts were signed for delivery of various equipment/components of nuclear power plant being built at Kudankulam. From reactor pressure vessel to steam generator, from 220kV / 400kV gas-insulated switchgear to 220V battery banks, from process pipelines to cable trays and from cables to various loads such as motors / valves / heaters etc., the scope of supply of

Table-1: Quantum of Works Executed during the Erection Works of Main Plant Electrical Systems

Sl. No.	Name of the Equipment	Type and Technical Specification in Brief	Qty / Nos. / Special Feature, if any	Make
1	**400kV Switchgear**	Gas-Insulated Switchgear (GIS); 400kV, 3150A, 40kA, One-and-half CB scheme	6 Bays (India's largest 400kV GIS switchyard)	SIEMENS, France
2	**400kV and 220kV Bus duct**	Gas-Insulated Bus Duct (GIBD) connecting GT and 400kV GIS, through long tunnels; 400kV, 2000 A	~ 3300 m (Longest 400kV GIBD installation in the country and one of the longest in the world too)	SIEMENS, France
3	**Generator Transformer**	1 Phase, 24 / 400kV, 417 MVA Generator Transformer; OFAF, Off Circuit Tap Changer, Solidly grounded neutral	7 nos. with 3 nos. / each unit and 1 common S/B for both the units (Largest 1 Phase GT, in terms of capacity, erected in the country)	Zaporozhe Transformer (ZTR), Ukraine
4	**Reserve / Common station Auxiliary Transformers**	3 Phase 220 / 6.3 / 6.3 kV, 63 MVA RAT/ CSAT; OLTC with a tap range of + 7.5% to – 15% with steps of ±1.25%; Short-circuit voltage / impedance: 10.5%; Vector group: Yn / yn0 / yn0; Oil natural, Air forced (ONAF); NGR – Neutral Res. Grounded	4 nos. RATs (2 nos./Unit) + 1 no. CSAT, common for both units	Zaporozhe Transformer (ZTR), Ukraine
5	**Unit Auxiliary Transformers**	3 Phase, 24 / 6.3 / 6.3kV, 63MVA UAT; OLTC with a tap range of +10% to–15% with steps of ±1.25%; Short-circuit voltage / impedance: 11.5±0.5; Vector Group Δ / yn1/yn1; ONAN / ONAF, NGR - Neutral Res. grounded	4 nos. of UATs (2 nos./each unit)	Zaporozhe Transformer (ZTR), Ukraine
6	**Interconnecting Transformers and Shunt Reactors**	400 / 220kV, 315 MVA Interconnecting Autotransformers; 3 x 27 MVA, 400kV Shunt Reactors	2 nos. of ICTs/ 6 nos. of Shunt Reactors	Zaporozhe Transformer (ZTR), Ukraine
7	**6kV Switchgear**	SF_6 type 6kV Switchgear, 6kV, 3150/2000/ 630 A CBs, 40kA, Numerical SIPROTEC Relays for Normal Systems and Static Relays for Emergency Power Supply Systems	6kV – 4 nos. of normal and emergency buses / each unit; two 6kV Reliable buses / each unit + Common Station 6kV Buses; In total, ~ 500 nos. of cabinets, (taking into account of 6kV S - G cabinets in Normal / Reliable/ Common and Emergency Auxiliary Power Supply Systems)	Electroshield – SAMARA, RF

Sl. No.	Name of the Equipment	Type and Technical Specification in Brief	Qty / Nos. / Special Feature, if any	Make
8	**Diesel Generator Set**	6kV, 6.3 MW Diesel Generator Sets as a standby source for emergency power supply systems; Ungrounded neutral, 0.8 P.F, 1000 rpm; Brushless Excitation, starting time of not more than 12 sec;	4 x 100%; Total = 10 sets; 4 nos./ each unit for EPSS; 2 nos. of RPSS Sets, common to both the units	Alstom, France / SEMT Pielstic Diesel Engine & Leroy Somar Alternator
9	**Auxiliary Transformers**	Dry Type, 6 / 0.4 kV, 1 / 0.4 MVA Aux. Transformers, Dyn11; 8% & 5% S – C Imp. for 1 / 0.4 MVA, F Type Insulation; Solidly grounded;	Total ~ 101 nos.	ZTR, Ukraine and NTT / SIEMENS, Germany
10	**LV Switchgear / MCCs / ACDBs / DCDBs etc.**	0.4 kV / 220 V Switchgear Panels / Motor Control Centers, with different current ratings from 1600 A to 630 A and less; 40kA for 1 sec. S – C Capacity	LV Switchgear / MCC Panels; ~ 1500 panels	LV Switchgear / MCCs: Progress – RF; ACDB / DCDBs: Electron, RF
11	**Hermetic Cable Penetration Units**	6kV and 0.4kV / 220 V Hermetic Cable Penetrations for routing the cables inside the Reactor Building	~ Total 766 nos. (~ 383 nos./unit)	ELOX – Prom, RF / Ukraine
12	**Rectifier / Inverters**	Rectifier: 132kVA, 380V I/P V & 220V DC O/P, with a charger current rating of 100 A to 630 A Inverter: 20, 40 & 60 kVA; 220V DC I/P & 220V / 380 V AC O/P	NOPS: 2 Rectifiers / Unit; RPSS: 4 Rectifiers & 8 Inverters / Unit; EPS: 12 Rectifiers & 24 Inverters / Unit; SY: 2 Rectifiers & 2 Inverters (Common for both units) Total: 38 nos. of Rectifier for both Units Total: 56 nos. of Inverter Units for both units	GUTOR, Germany
13	**Battery Banks**	For RPSS & EPSS Battery: 220V DC, 1500Ah, 2 hours; SBO Battery: 220V DC, 1500 Ah, 24 hours; Normal CPS Back up: 110V DC, 1500 Ah, 2 hours SY Battery (Common): 220V DC, 1500 Ah, 2 hours	NOPS: 2 Battery Banks / Unit; RPSS: 4 Battery Banks/Unit; EPSS: 12 Battery Banks/Unit; SY Battery: 2 Battery Banks (Common for both units) Total: 38 nos. for both Units	GUTOR, Germany

Sl. No.	Name of the Equipment	Type and Technical Specification in Brief	Qty / Nos. / Special Feature, if any	Make
14	**Cable Metal Structures**	Cable Metal Structure works comprising of erection of both open as well as closed type G. I / Painted Cable trays/ ducts with its supporting consoles, racks etc. Cable ducts / boxes for routing the cables over trestle & in high enthalpy area	Unit-1: ~ 1600 MT Unit-2: 1600 MT Common: 1500 MT Total: 4700 MT	Gidroelectromonthaz (GEM) / Electron, RF
15	**Cabling**	6kV / 0.4kV and 220 V Power and Control cables of around 110 types with varied size, cross section, ranging from 0.5 sq. mm to 500 sq. mm	HV Power: ~ 300 km LV Power: ~ 1500 km Control: ~ 11200 (incl. I & C Cables) Lighting/Com. Cables: 1500 km Total Qty laid / units-1&2 incl. Common is ~ 13,500 km	Podolsk, RF; Azov, RF VNIIKP, RF Uncomtech, RF Nexans, France
16	**Lighting Fixtures**	Indian make Lighting Fixtures are used with usage of separate Lighting Transformer of Capacity 400kVA, 6kV / 415 V to supply Indian make Lighting Fixtures of different types	~ 50,000 Lighting Fixtures (for KKNPP Units-1&2 together)	Philips, India

all these mechanical, electrical and instrumentation system equipment were in the Russian side and in order to streamline the delivery, separate contracts were signed with Russian side, listing the various equipment, sub-supplies, approximate quantity, their weight, main parameters, KKS codes etc. along with likely delivery schedule or month/quarter/year.

The above schedule was also reviewed, discussed and finalised in line with the then plan/schedule drawn for commissioning of KKNPP units. The equipment required for the priority systems were identified and conscious efforts were made to get a commitment for the advanced delivery schedule of some of these priority equipment.

Significantly, although most of the electrical equipment were to be supplied from the Russian Federation, there were some specialised electrical equipments such as gas-insulated switchgear, diesel generator sets, hermetic cable penetrations, generator circuit breakers, battery cells etc., which were to be arranged from countries other than Russia and hence, in order to streamline different source supplies, the equipment contracts were segregated into three separate sub-contracts, for covering a) equipment to be supplied by Russian Federation, b) Equipment to be supplied by CIS countries such as Ukraine and c) Equipment to be supplied by Third countries

A view of 1-phase, 24/400kV, 417MVA generator transformer

(other than the Russian Federation and Ukraine), as detailed further below:

a) Major electrical equipment delivered from Russian Federation

- 220kV Gas-Insulated Switchgear and Bus Duct: 9 bays
- 6kV and 0.4kV Switchgear panels and Motor Control centers, AC and DC Distribution Boards: ~ 2000 panels
- Power and Control Cables: ~ 14,000 km
- Cable Metal Structure and Cable trays: ~ 5,000 MT
- Control, Monitoring, Relay and Protection Panels: ~ 100 nos.
- Fire Barrier Materials, including fire-protection paint

b) Electrical equipment delivered from CIS countries

- 220/6kV, 63MVA Reserve and Common Station Auxiliary Transformers: 5 nos.
- 220/6kV, 63MVA Unit auxiliary transformers: 4 nos.
- 24/400kV, 417MVA Generator transformers: 7 nos.

- Hermetic Cable Penetrations installed in the Inner Containment (IC) wall of Reactor Building: 760 nos.
- 6kV / 0.4kV Auxiliary Transformers: 101 nos.

c) Electrical equipments delivered from third countries, other than the RF and CIS countries

- 400kV Gas-Insulated Switchgear and Gas-Insulated Bus Duct: 6 bays (SIEMENS, France)
- 6kV, 6.3 MW Diesel generator sets: 10 nos. (Alstom, France)
- 220V and 110 V Battery banks: 38 nos. (GUTOR, Germany)
- Rectifier / inverter panels: 38/56 nos. (GUTOR, Germany)

While framing the contours of the contract, list of documents, which are to be submitted either before or along with equipment were also discussed at length and agreements on the same were reached. Important documents such as seismic and environmental qualifications, type test reports etc. of all the electrical equipment were all collected either before inspection or during the mandatory initial inspection of the equipment carried out before its delivery to the site.

As such, dedicated Quality Assurance (QA) engineers were posted at NRRF office in Moscow

A view of 400kV gas-insulated switchgear (GIS) to review, verify and oversee the inspection and verification of required documents to be sent along with equipment. In most of the major cases, final acceptance testing was witnessed at the factory, before the dispatch of the materials to the site, in the presence of representative of Russian regulatory agencies, who were involved during the entire process of manufacturing, right from the beginning stage to the final stage of inspection, including packing and delivery of equipment to the site.

6.0 Erection contract at site for execution of erection works

Erection work is one of the most important aspects of any project implementation and plays a very significant role in the entire cycle of scientific achievement. More so, when volume and magnitude of erection works involved are huge and gigantic as it was in case of KKNPP, when compared to any other nuclear power project or for that matter, any power project under implementation in our country.

Be it civil, mechanical, electrical and instrumentation, the quantum of works, be it, in terms of volume of concreting in civil, inch diameter erection of pipelines in mechanical or the quantum of cabling lengths running into thousands of km in electrical and instrumentation, the magnitude of works involved

A view of 400kV gas-insulated bus duct (GIBD) tunnel connecting 400kV GIS and GT

A view of 400kV transmission line outlets of KKNPP

in each discipline was huge and unparalleled. As such, since the supply of all these equipment, except civil structural materials such as cement, reinforcement steel etc., were all in the scope of the Russian supply, the site works were basically related to erection of materials issued as free issue materials to the contractor. All such erection works, in each discipline, required huge mobilisation of resources and manpower, which were duly accomplished to complete the erection works successfully. Erection of each and every major equipment was a project within a project by itself due to the sheer size, nature, volume, weight and significance of the equipment being erected. It is appropriate therefore to know, in brief, how it was accomplished, despite heavy odds and constraints, usually associated with site erection works, coupled with the vagaries of supply chain management vis-à-vis planned activity at site.

As mentioned above, since the supply of almost all mechanical, electrical and instrumentation equipments were in the scope of Russian side, the scope of erection contracts was limited to erection, testing and pre-commissioning of the equipment, which were issued as 'free issue material' to the contractor. A labour intensive contract of this kind was very unique, as except civil engineering contracts, there were no supply part involved in erection of mechanical, electrical and instrumentation equipment, other than erection accessories required in some cases. The execution of the works thus needed huge mobilisation of resources of plant and machineries as well as manpower, often necessitating the requirement of specialised machineries and qualified manpower to execute the intended works.

In view of the specialisation and requirement of well-experienced agency, which can manage a huge resource mobilization needed to execute the works, a pre-qualification of potential bidders was thus carried out in all the disciplines (civil, mechanical and electrical), with the available tender inputs given by the Russian side. Pre-qualification of civil engineering bidders was carried out in the year 2001 and the process for selection of same in case of mechanical and electrical systems was carried out subsequently in the year 2003-04 as per the prescribed procedure(s) laid down. The basic purpose of pre-qualification was to review, analyse and shortlist the capable and potential bidders who could execute the works efficiently and in the process, could also save the precious time, which otherwise would have been consumed in the detailed main tendering process. The above pre-qualification was thus followed by main tendering process, through which erection contracts were awarded to successful bidders. In case of electrical systems, the works involving Erection, testing and pre-commissioning of Main Plant Electrical Systems of units-1&2 was thus awarded on the successful bidder in the year 2004. All the construction works, involving the above, through the above mentioned contracts were successfully completed and the related systems were handed over to the concerned O&M groups. Subsequently, all these electrical systems of both the units were successfully commissioned and are currently in service.

An indicative list of the quantum of works executed during the erection works of main plant electrical systems is given in Table-1.

7.0 A Brief on Electrical Systems of KKNPP

The electrical systems for 2 x 1000 MW Kudankulam NPP mainly consists of power output system and station auxiliary power supply system.

Power Output System

The electrical power is generated at 24 kV, 3-phase, 50 Hz by turbo generator and the same is stepped up through 24/400kV generator transformer. As per the original evacuation systems, power was to be evacuated through six 400kV transmission lines, however, due to usage of high-capacity quad conductors by Power Grid Corporation of India Limited (PGCIL), power is being evacuated now through 4 nos. of 400kV transmission line system over two double circuit towers emanating from one end at KKNPP switchyard.

For reserve source of offsite power supply, KKNPP is connected to two 230kV substations, through two 220kV transmission lines with loop-in–loop-out (LILO) arrangement. The 400kV and 220kV buses at KKNPP are interconnected

Turbo-generator hall of KKNPP-1

Turbo-generator hall of KKNPP-1

by means of two, 3-phase interconnecting autotransformers of 315MVA capacities each. The generated power is however evacuated through only 400kV transmission lines. However, since 400kV and 220kV systems are interconnected, technically, power can flow through 220kV lines, in case of any requirement of such situation, subject to clearance from grid system authorities, depending on the prevailing generation / load scenario and permissible technical conditions.

The generator for the KKNPP is rated with a power capacity of 1000 MW, 3-phase, 50 Hz, p.f. 0.9 at the voltage of 24 kV.

The generator transformer capacity is determined based on the necessity to evacuate the full power output of the generator. Due to the limitations imposed by the size, weight and transportation problems, 3 single-phase 24/400kV generator transformers are considered with a rating of 3 x 417 MVA each.

The generator is connected to generator transformers through isolated phase bus duct with 24kV, 30kA generator circuit breaker connected between generator and generator transformer. The generator is synchronised with 400kV network using GCB. The provision of GCB allows the scheduled start-up and shutdown of power unit from the 400kV network.

Indoor SF_6-gas-insulated switchgear with one-and-a-half circuit breaker scheme for 400-kV switchgear and two main bus scheme for 220kV switchgear is adopted in view of the salinity and coastal conditions prevailing at KKNPP site.

Offsite Power System

Parameters and conditions of power system operation are the main factors, which support the continuous and cost-effective operation of NPP. Modes of operation and parameters of the grid of which the NPP is a part, define conditions of operation for NPP units and its reliability.

The power system of India includes all the states of the country – from Tamil Nadu in the southern part of the country, Jammu and Kashmir in the North, Gujarat in the west and Arunachal Pradesh and Manipur in the northeast. The overall installed capacity of India's power stations, by the time of commissioning of power unit-1 of Kudankulam, had exceeded 250 GW (to be precise, the total installed capacity was 258701 MW as on January 31, 2015, as per the CEA site) and the annual power generation by all India's power stations at this stage was likely to be more than 880 billion units.

Thermal power stations contribute a major share to total generation capacity of India, which use coal/oil as fuel (over 65%). Hydroelectric power stations account for approximately 18% and the overall installed capacity of NPPs is around 2-3%.

Structurally, India's power system consists of five regions – South, West, North, East and Northeast regions. All these regions are linked to each other by high-voltage AC electrical transmission lines with voltage levels of 220 and 400 kV, and also with the help of HVDC transmission lines in some regions. In the recent times, 765kV transmission line systems have also been planned and recently, Power

Grid Corporation of India Limited has energised 765kV Raichur-Sholapur transmission line, which has been interconnected with the national grid.

The grids of separate regions and India's transmission systems as a whole are formed mainly by double-circuit power transmission lines with a voltage of 400 kV. In the majority of regions, power transmission line networks normally stretch over 300 km. More 765kV AC transmission lines are also planned now for power transmission in the northern region.

The Southern region of India consists of states, Tamil Nadu, Kerala, Andhra Pradesh, Karnataka and Union territory of Pondicherry. The installed power capacity of the southern region stations is around 60 GW, which amounts to be more than 1/4 of the total installed power capacity of India's power stations. The southern regional grid is connected to the western and eastern regional grids. The southern regional grid is formed by the 400kV single and double circuit transmission lines.

The design of grid for the southern region, developed by the Central Electricity Authority of India (CEA) is based on the projection of development of India's power sector, including a considerable number of constructions of 765/400kV transmission lines. The design of

A view of 220kV gas-insulated switchgear (GIS)

A view of 400kV / 220kV, 315MVA interconnecting autotransformer with 220kV gas-insulated bus inlets over supporting trestle (connected between 220kV GIS and ICT)

southern regional grid thus projects sufficient availability of 400kV and 220kV transmission lines as presented in the study report by PGCIL.

The design of grid for the southern region, developed by the Central Electricity Authority of India – CEA is based on the projection of development of India's power sector, including a considerable amount of construction of 400kV transmission lines. Analysis of network of the southern regional grid showed that, under the normal conditions, the capacity margin of these networks in case of transmission lines transmit the power in rated capacity, will not be less than 100%. The switching off of any element in the supply line will not thus cause any reduction of capacity and will not pose any limitation on operation of KKNPP.

KKNPP will be one of the six biggest power stations of India's southern region. The 400kV grid development plans of the power grid of Tamil Nadu state, and the southern region as a whole, thus envisage connecting the KKNPP to the nearby junction substations of 400 kV for the power evacuation of station's two units (2x1000 MW) through four 400kV power transmission lines and two 220kV power transmission lines as a reserve offsite power supply source.

Transmission Line Systems of KKNPP

The capacity of the grid system of the southern region thus provides a reliable offsite reserve power supply system for two units of KKNPP, both under normal mode as well as under maintenance or during the initial operation and commissioning stage.

KKNPP reserve auxiliary transformers are thus supplied from 220kV gas-insulated switchgear system. KKNPP design thus envisages external reserve power supply sources as reliable reserve power supply in case of non-availability of 400kV lines. Additional reliability is ensured by connecting such sources with two independent transmission lines, which can be operated on account LILO systems available, in case of failure of any one 220kV power source.

Line loading limits are considered as per report by PGCIL as given in Table-2.

Static stability calculations are made after finalization of the actual structure of grid of the southern region in view of evacuation of the KKNPP. All the factors are taken care, which limit the capacity of power transmission lines, and the managing grid facilities.

Studiesforcapacitiesoftransmission lines from the KKNPP shows that, if projected lines and the southern regional grid are available in full strength, the KKNPP rated power output will be evacuated with static stability margin of not less than 50%.

If one circuit of 400kV transmission line evacuating KKNPP power output is switched off, then static stability margin at full power output is reduced to approximately 20%. If two circuits of one of 400kV transmission line are switched off, then static stability margin at full power output will be reduced to approximately 10%.

Table-2: Line loading limits considered as per PGCIL report

Voltage level	Conductor envisaged	Thermal limit
400 kV	Quad ACSR "Moose"	About 3200 Amperes at 85 °C
230 kV	ACSR Zebra	About 649 Amperes at 75 °C

Thus, the capacity of the intended grid of the southern region will provide reliable operation for two units, 1000 MW each, of KKNPP, both under normal mode and under maintenance with standard margin of static stability. Growth of the local consumption and increase in 230kV transmission line load, will lead to the increase in static stability margin both, in the full operation of grid and in maintenance mode of the grid.

As mentioned above, the KKNPP design further envisages external reserve power supply sources for long-lasting emergency power supply in case of switching off of 400kV lines. Such sources are connected with two independent 230kV transmission lines.

In light of the above, it was envisaged to connect the KKNPP to Tuticorin thermal power station by a single circuit 230kV transmission line and to Shenbagaramanpudur (SR Pudur) substation by another single circuit 230kV transmission line. Shenbagaramanpudur substation in turn is connected to Kayathar substation, which is considered to be a second source.

A view of 6kV/0.4kV switchgear and auxiliary transformer in emergency auxiliary power supply system

A provision of interconnection of 400kV and 230 kV transmission systems at the KKNPP is available through two interconnecting autotransformers of 400/220 kV, with a capacity of 315 MVA each. It facilitates the following operational benefits:

- Normal auxiliary power supply can be restored through interconnecting autotransformers, generator transformer and unit auxiliary transformers from 230kV grid, in case of 400kV grid failure.
- Reserve auxiliary power supply as well as common station auxiliary power supply will be made available through interconnecting autotransformers and reserve auxiliary transformers and common station auxiliary transformer respectively, in case of 230kV grid failure.

The following transmission lines are thus envisaged for KKNPP

400kV System

1) 2 Double circuit lines between KKNPP – Tirunelveli of ~ 100km*

2) Two 400kV lines / bays at KKNPP are presently kept as spare bays for future use

   *Note: Out of these 4 nos. of 400kV lines originally established between KKNPP site and Tirunelveli 400kV PGCIL substation, one line has recently been diverted out of 400kV

Tirunelveli substation and taken directly to Madurai substation, with transmission line length of about 240 km.

220kV System

1) LILO line between Tuticorin–Kudankulam NPP–R S Pudur (while the distance between Tuticorin line, which is coming from Tuticorin TPS, and the KKNPP site, is around 80 km; the distance between KKNPP site and R S Pudur LILO Junction end is about 17 km.)

2) One single circuit line at KKNPP switchyard is kept as spare bay for future use

Onsite Power Systems

Station Auxiliary Power Supply System

The main function of the station auxiliary power supply system is to ensure the availability of sufficient power during all modes of operation, so that established allowable design limits and design conditions for cooling the reactor core and maintaining the containment integrity, including prevention of any significant release of radioactive material to the environment, and to ensure that the other necessary functions during the postulated accidents are not exceeded.

For starting up as well as for normal shutdown, station auxiliary power is drawn from the 400kV network, through generator transformer and unit auxiliary transformers with

A view of 6kV, 6.3MW diesel generator set in emergency auxiliary power supply system building

A panoramic illuminated night view of KKNPP site

the generator circuit breaker open. Station auxiliary power during normal plant operation is drawn from the tap-off to 24kV bus duct through unit auxiliary transformers.

The reserve power supply is derived from 220kV grid through 220/6.3kV reserve auxiliary transformers and is used as back up power during non-availability of power supply from unit auxiliary transformers.

The common station auxiliary power supply feeding the common station auxiliary loads is derived from 220kV grid through 220/6.3kV common station auxiliary transformer.

Station auxiliary power supply system envisaged for KKNPP is comprised of and categorised as per their functional requirement as given below:

- Normal auxiliary power supply system, including common station auxiliary supply system
- Reliable auxiliary power supply system of normal operation
- Emergency auxiliary power supply system for safety systems

Load Distribution Criteria

The loads are distributed among the 6kV, 0.38kV and 220V DC buses, taking into account of following factors:

- Power rating

- Necessity to provide the redundancy

Based on the above, the following distribution of loads is envisaged:

- Motors rated above 200 kW are designed to be fed from 6kV switchgear
- Motors rated at 200 kW and below up to and including 11 kW are designed to be fed from 0.38kV switchgear
- Motors rated below 11 kW are fed from 0.38kV Motor Control Centers (MCC)
- Heaters of the pressure compensator systems are designed to be fed from 0.38kV switchgear/MCC
- 6 kV motors and 6/0.4kV auxiliary transformers are evenly distributed among 6kV buses
- 380V motors and other loads are distributed evenly among 0.38kV buses
- Inverters and other loads are distributed evenly among 220V DC buses

Permissible Voltage and Frequency Variations

All the electrical equipment of auxiliary power supply system are designed to operate satisfactorily at the following voltage and frequency variations continuously at their rated capacity.

Rated voltages: 6 kV, 380V and 220V

Rated frequency: 50 Hz

Voltage variation: $\pm$10%

(+10% -15% 220 V DC)

Frequency variation: $\pm$5%

Combined Voltage and frequency variation: $\pm$10%

Permissible Harmonic Contents

The maximum harmonic contents permissible in auxiliary power supply system are as follows:

- System voltage up to and including 1 kV: 8%
- System voltage above 1 kV: 5%

All the equipment will be capable of withstanding above harmonic contents without affecting their normal operation.

Normal Auxiliary Power Supply System

Normal auxiliary power supply system is designed to provide the electrical power supply of auxiliary loads of normal operation which allow interruption of power supply for the time of automatic switching to reserve supply and do not require the obligatory availability of power supply after the operation of reactor trip and also intended normally to provide the supply to reliable auxiliary power supply system and emergency auxiliary power supply system in all modes of NPP, except the condition of non-availability of normal auxiliary power supply from unit auxiliary transformers and/or reserve auxiliary transformers.

Four 6kV buses are envisaged per unit which normally derive the power either from the unit generator or from 400kV grid through generator transformer and a set of two 3-winding, 63MVA, 24/6.3kV unit auxiliary transformers. These 6kV buses are backed up by power supply from 220kV grid through a set of two 3 winding, 63 MVA, 220/6.3kV reserve auxiliary transformers.

A view of switchyard control room for control and monitoring of 220kV and 400kV power output systems

The 0.4kV buses derive power from each of these 6kV buses through 6/0.4kV auxiliary transformers and are backed up by power supply from common standby 6/0.4kV auxiliary transformers.

The 6kV power supply derived either from the unit generator or from 400kV grid through GT and UATs is referred as normal auxiliary power supply. Power supply derived from 220kV grid through reserve auxiliary transformers as back-up to 6kV buses of normal auxiliary power supply system is referred as reserve auxiliary power supply. The reserve auxiliary power supply can be switched on to 6kV buses of normal auxiliary power supply system automatically through Automatic switching (Automatic fast transfer) scheme or manually, in case of loss of normal auxiliary power supply. The normal as well as reserve auxiliary power supply capacity is sufficient to feed the unit auxiliary loads for generation of power and also to ensure the safe shutdown of NPP unit.

Unit Auxiliary Transformers

Two unit auxiliary transformers per unit with a capacity of 63 MVA each are envisaged as a normal auxiliary power supply source. The capacity of 63 MVA of each unit auxiliary transformer is based on the load (57 MVA) coming on each of these transformers for power unit operation and shut down excluding common station service loads.

The unit auxiliary transformers are connected on the high voltage (HV) side, to the tap-off from 24kV isolated phase bus duct (IPBD) connecting the generator and generator transformer. The tap-off connection is taken between the generator circuit breaker (GCB) and the generator transformer. On-load tap changer is provided on 24kV side to control the voltage in the range from +10% to –15% with steps of ±1.25%.

24/6.3 kV Unit auxiliary transformers are provided with 6.3kV split (two secondary) windings, each of them connected to 6kV bus of normal auxiliary power supply system. Each of this bus is provided with the incomer connection from the reserve auxiliary transformer for automatic fast transfer of power supply.

Reserve Auxiliary Transformers

Two reserve auxiliary transformers per unit with a capacity of 63MVA each are envisaged for the reserve power supply to normal auxiliary power supply system. The capacity of each reserve auxiliary transformer is designed to replace any one of the unit auxiliary transformers of the unit for the full power unit operation and shutdown.

The reserve auxiliary transformers are connected on the HV side to the 220kV (GIS) connecting the 220KV transmission lines. On-load tap changer is provided on 220kV side to control the voltage in the range from +7.5% to –15% with steps of ±1.25%. 220/6.3kV Reserve auxiliary transformers are provided with 6.3kV split (two secondary) windings and each of them is provided to connect to 6kV bus of normal auxiliary power supply system.

The system is provided for automatic switching of 6kV reserve auxiliary power supply to normal auxiliary power supply system buses on loss of supply.

Common Station Auxiliary Transformer

A Common station auxiliary transformer with a capacity of 63 MVA has been provided for supplying the common station service loads for two units. The capacity of common station auxiliary transformer is based on the total load of (around 42 MVA) of the systems of services, which are common for both the units required for unit operation. The capacity of this transformer is selected as 63 MVA so as to match with reserve auxiliary transformer.

The common station auxiliary transformer is connected on the HV side to the 220kV GIS. On-load tap changer is provided on 220kV side to control the voltage in the range from +7.5% to –15% with steps of ±1.25%. 220/6.3kV Common station auxiliary transformer is provided with 6.3kV split (two secondary) windings and each of them is connected to 6kV bus of common station auxiliary power supply system. These 6kV buses are backed up by the supply from reserve auxiliary transformers of both the units.

Reliable Auxiliary Power Supply System

Reliable auxiliary power supply system of normal operation is designed to provide electric power supply to the auxiliary loads of NPP, which are required to maintain the important and expensive equipment in operation (e.g. generator), which allows interruption of power supply for the time of the switching over to reserve auxiliary power supply from the reserve auxiliary transformers or from the power supply from common station diesel generators.

The system is designed to provide the power supply even in case of loss of normal auxiliary power supply system.

The reliable auxiliary power supply system consists of two sections, which provide the auxiliary power supply to the mutually redundant process system loads, which are required to preserve the important and expensive equipment in operation.

Each section of the reliable auxiliary power supply system is provided with equipments such as 6.3MW, 6kV common station diesel generator sets, 6kV switchgear, associated 6/0.4kV auxiliary transformers, 0.4kV switchgear / motor control center (MCC), 6kV and 0.4kV switchgear panels, rectifiers, 220V DC batteries, D.C. Distribution Boards (DCDB), inverters etc.

Emergency Auxiliary Power Supply System

Emergency auxiliary power supply system is designed to supply the electric power to the loads of safety systems as well as safety related systems performing control and supervision over the operation of the these systems.

The equipments of emergency auxiliary power supply system are capable of performing its intended function before, during and subsequent to safe shutdown earthquake (SSE) conditions.

The emergency auxiliary power supply system is designed, taking into account the impact of the ambient conditions and consequences of the human activity such as missile strike, aircraft strike etc. The emergency auxiliary power supply system is designed to preserve its operating capacity both during the event/ incident and after the incident.

The emergency auxiliary power supply system is designed to perform its functions in any operating modes, including loss of power supply from the normal auxiliary power supply system. In this mode, the emergency auxiliary power supply system ensures independence from the offsite power supply system by opening the tiebreakers and automatic start-up of diesel generators and connection of the diesel generator to buses of emergency auxiliary power supply system.

The emergency auxiliary power supply system corresponds to the structure of the safety process system, and therefore, the system is designed correspondingly as four-channel system (4 x 100%). Each channel of the emergency auxiliary power supply system is designed to provide electrical power to the loads of the respective channel of the safety process system and the corresponding safety control system. All channels of the emergency auxiliary power supply system are identical.

The emergency auxiliary power supply system meets the single-failure criteria i.e. it is capable of fulfilling its functions, which requires its operation on all initiating events due to the failure of one of the important elements of one channel, coinciding with the failure of second channel as a result of independent failure of active or passive component of that particular channel (irrespective of initiating event) and the non-availability of third channel due to repair or maintenance of any active element of third channel.

The emergency auxiliary power supply system provides independent operation of each of the four channels due to electrical independence and the physical separation of the electrical equipments.

Each channel of the Emergency auxiliary power supply system is provided with components such as 6kV, 6.3MW diesel generator sets, 6kV switchgear, 6/0.4kV auxiliary transformers, 6kV and 0.38kV switchgear panels, 0.38kV switchgear/motor control centers (MCC), rectifiers, 220V DC batteries, D.C. Distribution Boards (DCDB), invertors etc.

Diesel Generator Systems

The diesel generator and its auxiliary equipment are designed to be capable of fulfilling their functions by taking into account the impact of the ambient conditions and consequences of the human activity such as missile strike, aircraft strike etc.

In the normal operation mode of the NPP, the functions of electrical power supply system of the diesel power plant ensures continuous availability of the diesel generator, to be able to start up and continuously operate at rated load without any attendance of the duty personnel for duration of 240 hours. During this period suitable action to replenish the diesel fuel will be taken.

The automatic start-up is performed by the signal of loss of voltage on 6kV bus of the emergency auxiliary power supply system. The provision is made for the remote start-up of the diesel generator from the main control room and supplementary control room. The start-up is also provided from the local control panel of the diesel generator. The day fuel tank capacity is 8 hrs. for each DG set, with Intermediate tank capacity of 100 cu.m, sufficient enough for 2 days of operation for each DG and the common fuel storage reservoir capacity is designed to be sufficient for 5 days operation of each unit.

Cabling and Cable Penetrations

Power and control cables are selected by voltage rating, voltage drop, short circuit rating and its duration and admissible load taking into account of laying conditions with application of de-rating factors for admissible current loads as a function of ambient temperature in the location of their laying.

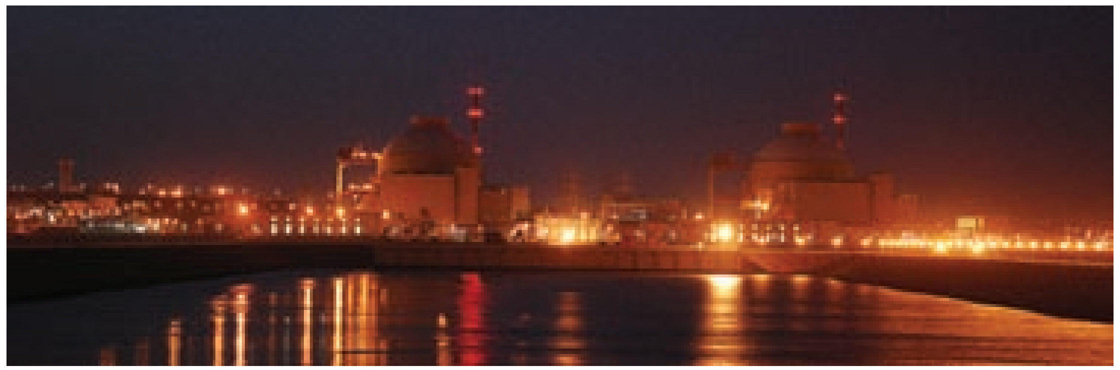
The power and control cables of emergency auxiliary power supply system will be selected, rated, qualified for service considering normal operation as well as fault conditions. These cables are also qualified for environmental conditions taking into account the cumulative radiation effects, if applicable and thermal aging expected throughout their design life including design basis events.

All safety system cables inside and outside containment are equivalent to fire survival (FS) cables according to their characteristics. The 0.4kV and 220V cables have 90 minutes fire rating.

Cables of the auxiliary power supply system for any voltage rating are laid, as a rule, in cable supporting structures i.e. cable racks, open metal trays, closed trays or in closed metal ducts of low cross section. Special cable rooms are provided to lay numerous cable lines such as underground cable tunnels, shafts, metal ducts, semi-floors and trenches or buried hume pipes etc.

Special hermetically sealed electrical penetrations are used to pass cables to the containment. These penetrations provide gas-proof and leak-tight penetration of one or several circuits while passing through protective containment of reactor. Thus, the integrity of containment on parameters of leak-tightness and passage of electrical circuits is totally ensured. A total of 383 hermetic cable penetrations, first-of-its-kind in

A glittering night view of Kudankulam-1&2



A glittering night view of Kudankulam-1&2

Indian NPPs, have been used for each unit of KKNPP, which provide hermetically-sealed condition for routing the cable lines inside / outside the reactor building.

Cabling in KKNPP was one of the most demanding and challenging task in view of the huge magnitude and quantum of the cabling spread across a vast area of units-1&2. The job is compounded further due to the huge inventory of around 100 assorted types of cables, with over 500 types and different sizes of the cables, ranging from 0.5 sq. mm to 500 sq. mm. The job involved not only close monitoring of the actual progress of the cabling works at site, but also required a real time updating of the database on the cabling done at site on every day, on-line assessment of cable stock at site, follow up of short supplied cables with Russian side, etc. when compared to the cable logs/working documentation issued for the cabling works to be done at site.

Cabling in all the main plant buildings are taken up after detailed study of routes and fronts / cable available, daily planning, etc. so that, important systems and loads are connected and released for commissioning in time, in line with project schedules and targets set. The job also involved identification of engineering mismatches of the cable logs with cable metal structures, if any, prior to taking up cabling works, and prompt disposal of the same in close coordination with General Designer (AEP) / ASE / FE etc. at site, so that the scheduled works at site are not affected. The detailed study and assessment of the cables required for the works were made on a daily basis and necessary actions were initiated and discussed with Russian side to arrange the short-supplied cables from their side.

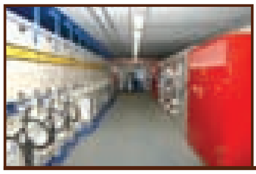
The quantum of cabling done at KKNPP site would surely go down as one of the largest quantum of cabling works ever done in our country, with the total quantity of cables almost touching 13500 km (approximately), at the end of units-1&2 works together (including common station cabling works). Most of these cabling works had to be taken up in long-winded tunnels below the grade level, connecting various main plant buildings. The successful completion of this colossal cabling works spread across several normal as well as safety tunnels in the plant site, by itself, was a major accomplishment in the history of electrical system equipment erection works of Indian NPPs.

Grounding System

Grounding grid network is laid in the plant area so as to provide the safety of the personnel as well as to the equipment, structures, etc. by equipment grounding. Conductors of adequate size are chosen to carry the maximum ground fault current. The grounding grid is so laid that step and touch potentials are kept within safe values under any fault conditions. Almost 70,000 meters of 70 sq. mm copper conductors have been laid as a part of outdoor grounding grid network, covering the entire area of KKNPP units-1&2. The grounding system is designed to provide electrical safety to the personnel and equipment in the zone of electrical systems/equipment and beyond their limits and to divert the ground impulse currents from lightning protection systems as well as provide grounding of neutral of generators, transformers and protection circuits etc.

Lighting System

In KKNPP, lighting systems are provided in various main plant



buildings, structures, tunnels and outdoor areas for KKNPP in the form of normal lighting, emergency lighting and evacuation lighting. Dedicated lighting transformers with voltage rating 6 kV / 0.415 V are provided so that, lighting fixtures of Indian make with voltage rating of 220/230 V could be used in all buildings. Design of lighting circuits have been carried out in a manner to ensure availability of lighting in all locations even under failure of normal lighting system. In addition evacuation lighting with exit-type lighting fixtures have been provided in all entry/exit points of buildings/tunnels etc., as applicable.

A panoramic night view of illuminated KKNPP site.

Conclusion

To sum up, it can be well said that from the initial discussion (TA) stage to whatever is accomplished today, Electrical Systems at KKNPP have indeed seen transformational and remarkable strides in scaling the KKNPP to greater heights as well as shaping the contours of KKNPP units. It has been sure a long engineering journey since the initial discussions began over two decades ago and it is indeed gratifying that after a series of discussions and significant contributions by several specialists and experts from both sides, an outstanding achievement of this sorts could be realised. Significantly, all these electrical systems are today in successful operation and service at both the units of KKNPP and this must be a tribute to all those who have toiled, worked hard and contributed untiringly towards this accomplishment at one stage or other, directly or indirectly, during the design, engineering, development, construction, commissioning and now during the O&M phase.

For the entire KKNPP team involved in the above works since its inception to synchronization and commercial operation, it has thus been a unique engineering journey of electrifying achievements and memorable moments at KKNPP. Every unit of electricity generated at this 'temple of power' located in the southern-most tip of our country and fed into the southern grid of our nation speaks volumes of it!

References

1) TA on Electrical Systems
2) DPR Packages (E–1 to E–9) on Electrical Systems of KKNPP
3) PSAR / FSAR Package S–8 on Electrical Systems of KKNPP
4) CEA / PGCIL Reports on KKNPP transmission systems

R. Kamath, *SO/H, presently working as ACE (Project LWR – Electrical), KKNPP–3&4, is an electrical engineer. He joined KK Project, NPCIL-HQ in 1989. He has contributed to the review and finalisation of Technical Assignment (TA) of electrical systems of the plant as well as the finalisation of DPRs, PSAR, etc.*

Since 2002, he has been working in the Electrical Construction Group of KKNPP site. The works handled by him include major electrical equipment such as 220kV and 400kV GIS and GIBD, 24/400kV GTs, Unit and Reserve Auxiliary Transformers, etc. as well as 10MW KKNPP windfarm.

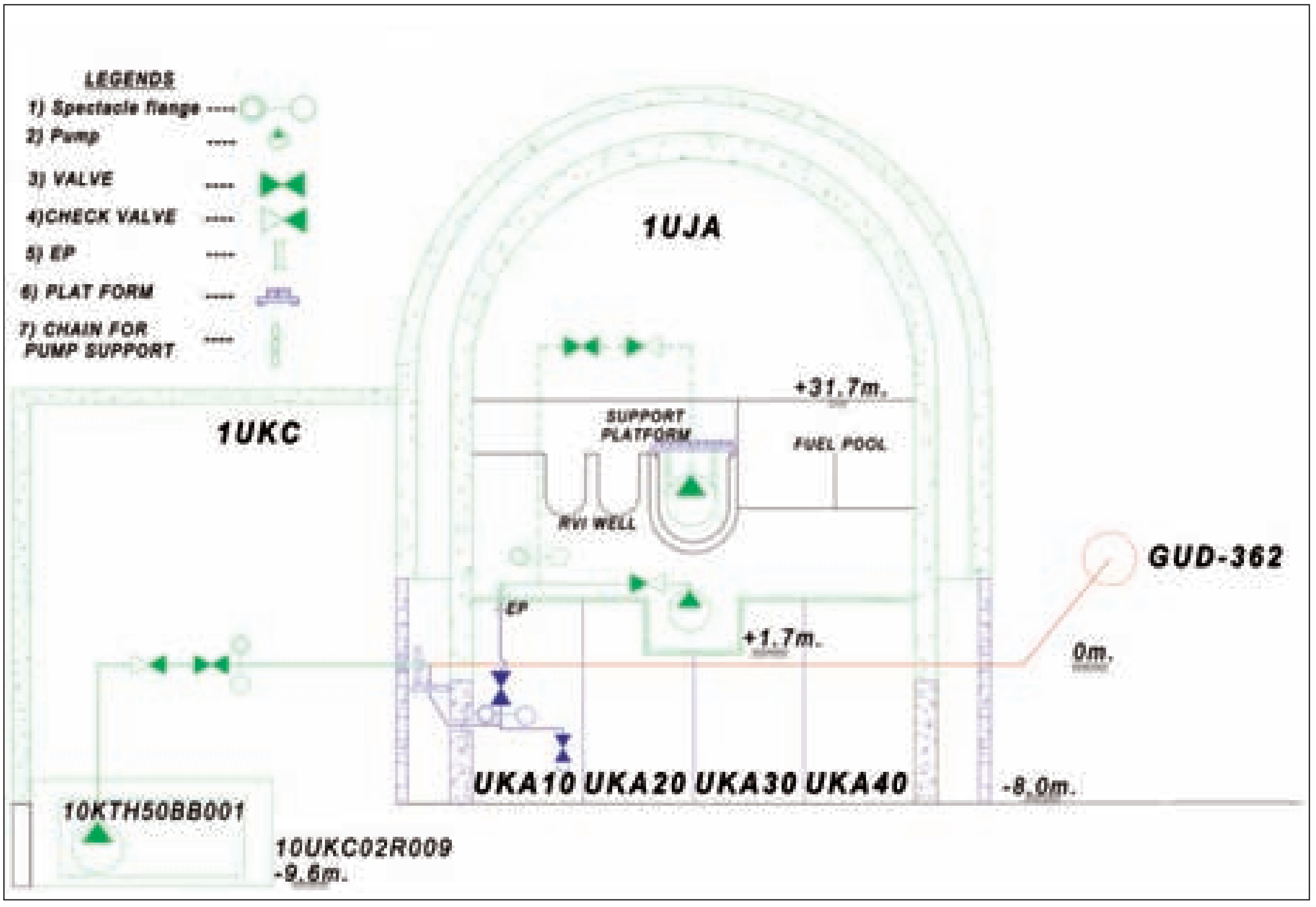
Commissioning Experience of Chilled Water and Primary System of KKNPP

Sunil V.P., Shift-Charge Engineer, KKNPP-1

At Kudankulam Nuclear Power Project (KKNPP), the responsibility of commissioning of different systems was distributed among the O&M engineers well in advance. As per that division of responsibility, the major systems to be commissioned by our sub-group were reactor coolant system, Chilled Water System and passive Emergency Core Cooling System (ECCS).

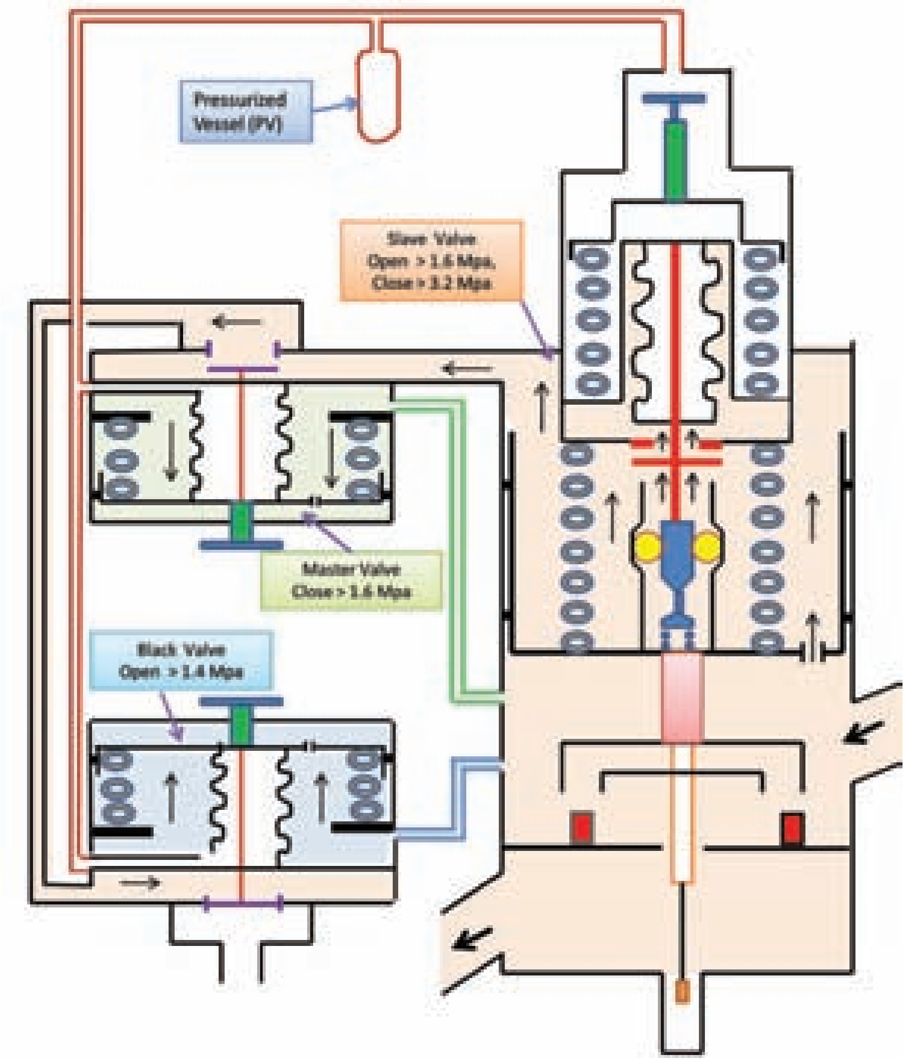
At that point of time, not much about the system other than the KKS code [codes by which structures and systems of Kudankulam Nuclear Power Project (KKNPP) are identified] was known to us and there was only a brief knowledge about the functioning of the systems.

Once the responsibilities were fixed, the respective groups started collecting the information from the huge bulk of detailed documents supplied by the designers. Initially we identified the documents that we were supposed to prepare



Simplified schematic arrangement of de-watering scheme

System pressure < 1.4 MPa



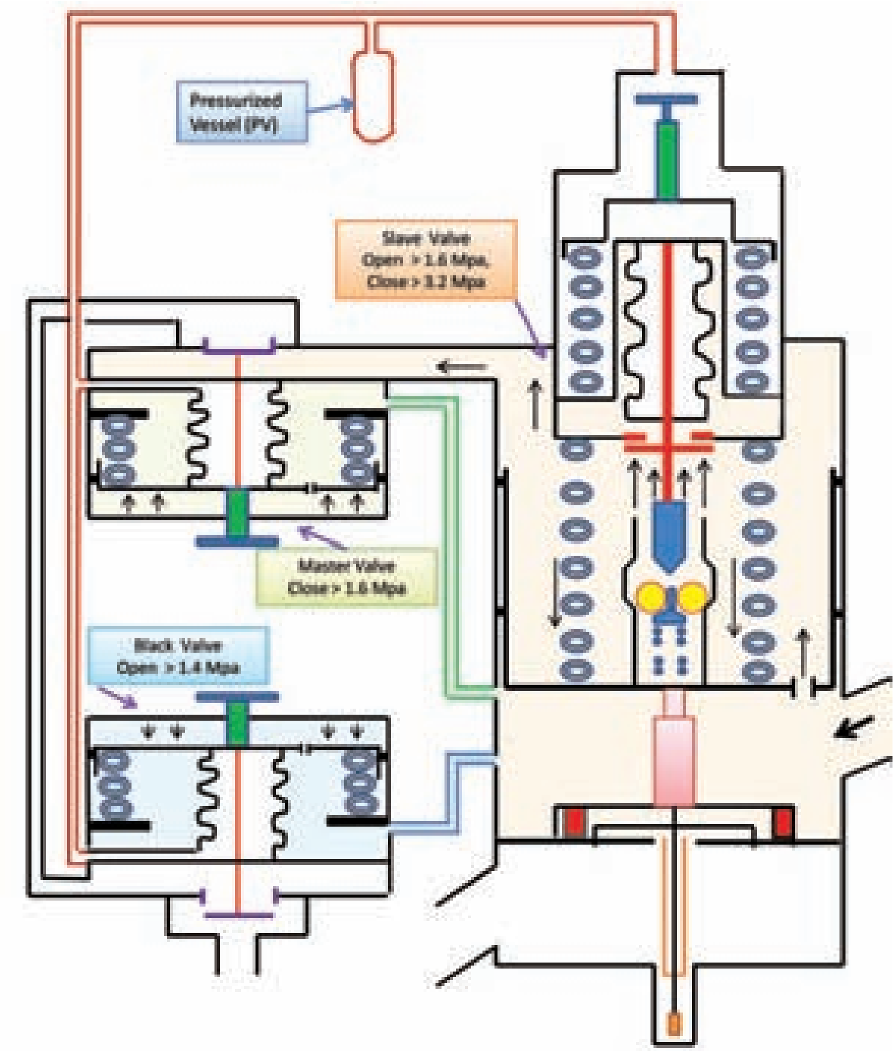
Double check valve during LOCA with SBO

and the information required to prepare them. Then we searched for the information in the supplied documents and the documents where we needed more information inputs were kept aside for obtaining from designers/suppliers/manufacturers.

With this background work, we were deputed to Russian federation for operation training in VVER plants. During this training, we could further obtain operational information related to the various systems of the VVER.

After completion of training, we were posted at KKNPP site, where we could work in construction environment so that the commissioning requirement could be fine-tuned to suit erection schedules

First among the commissioning activities which our sub-group took up was hydro test of coolers of Reactor Coolant Circulation Pump (RCP) motors. The RCP motors and pumps were brought to site as disassembled components. As per the stipulations of the

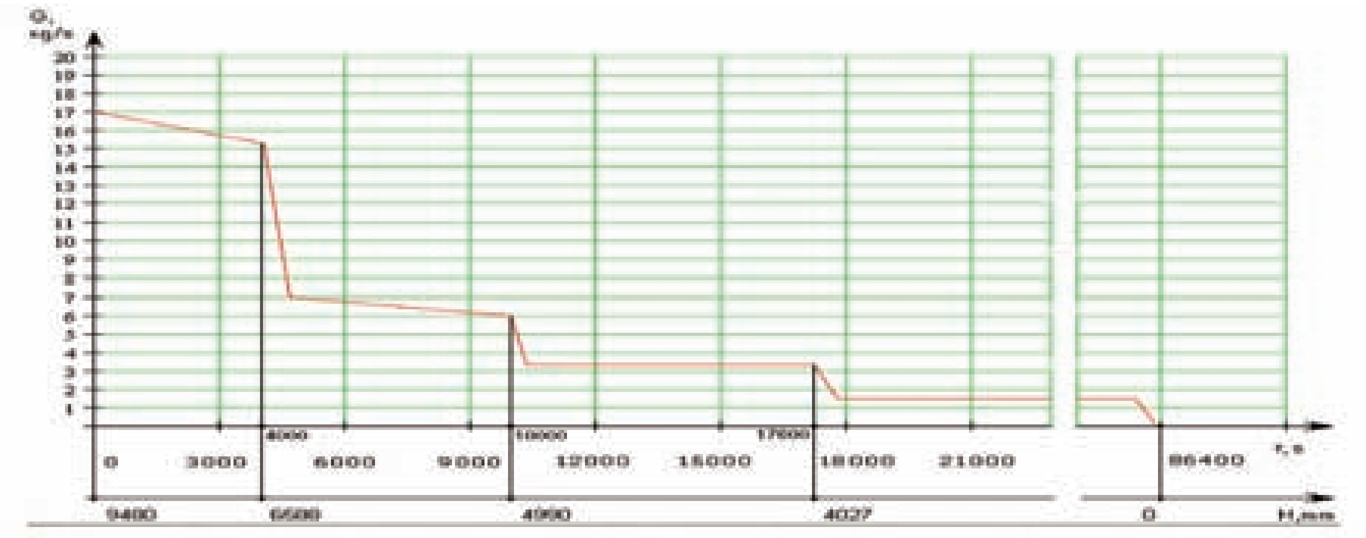


Double check valve during normal condition

manufacturers' documentation (known as passport), prior to assembly, the heat exchangers were to be subjected to hydro test. A setup was made in an inactive workshop and all the coolers were hydro-tested prior to the assembly of motors. Later on, the pipelines used for cooling and lubricating were cleaned in the workshop prior to assembly. The pipelines were shipped with a protection layer in inner surface and outer surface to prevent corrosion. They were cleaned physically using a cloth soaked in white spirit attached to steel cables. This type of cleaning yielded excellent results, which was evident from the results of oil samples taken during the first operation of motor on 'no load' and subsequent results of auxiliary circuit during load test of pumps.

In KKNPP, the instrumentation tubing is done without any mechanical joint, right from the main pipe or equipment up to transmitter. There is no root valve near main piping. The tubings are provided with small automatic isolation devices known as tripping device, similar to excess flow check

Number of the stage	Stage I	Stage II	Stage III	Stage IV
Duration of the stage (seconds)	0-4000	4001-10000	10001-30000	30001-86400
Boric acid flow from one accumulator, kg/s	5,0	2,5	1,65	1,07



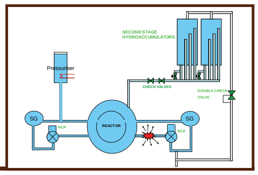
Flow rates at each stage (Flow vs. Time)

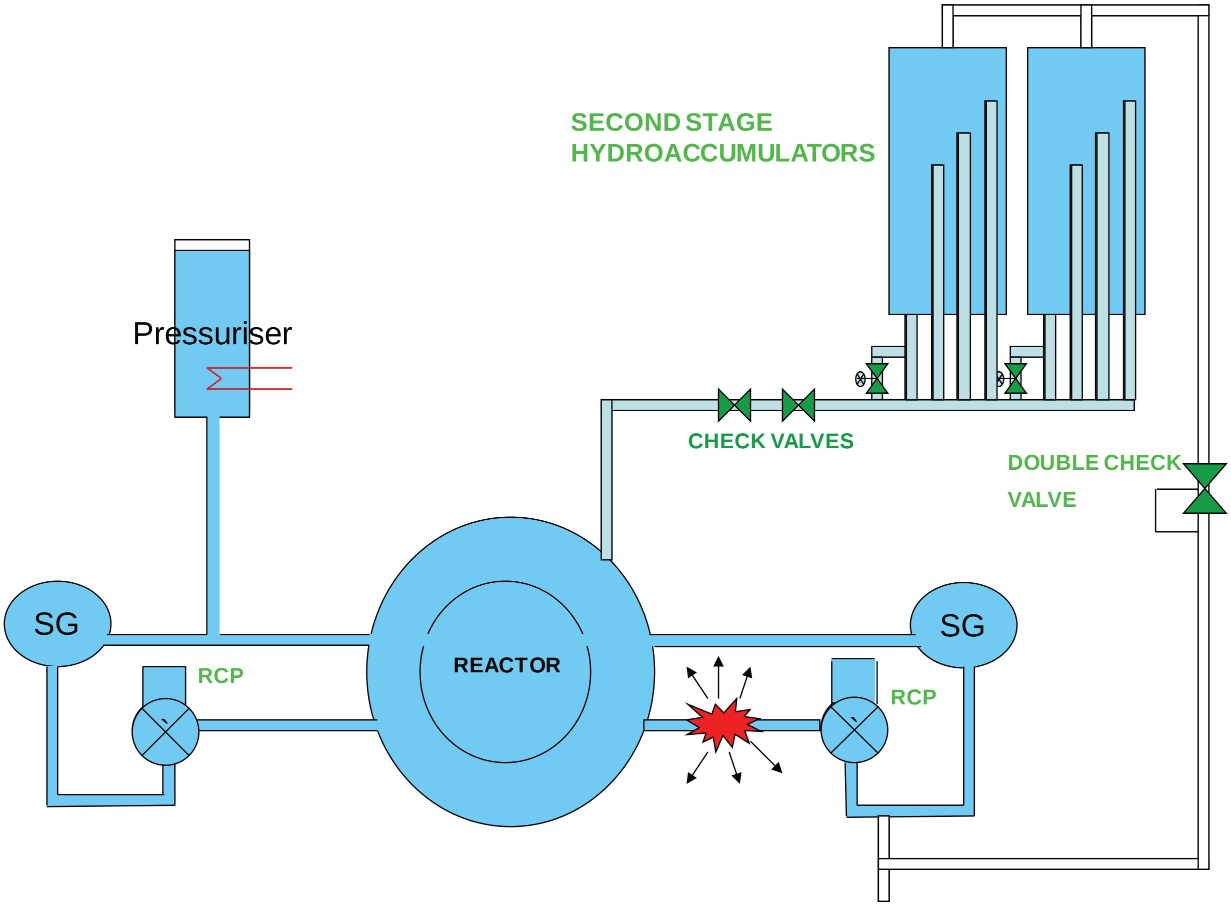
valves provided in PHWR fuel handling systems. However, their working principle is different from excess flow check valves. As per the manufacturer's recommendations, they need to be tested prior to erection and the value of the flow at which they actuate should be recorded, and checked to be within limits. They were in hundreds and test setup was made in DM plant for testing them.

By this time, piping jobs were in progress at erection side. Many systems had piping without flange joints. So open loop and closed loop flushing of systems were to be planned beforehand to avoid any cutting of pipelines for flushing after erection. Elaborate flushing schemes were prepared and with the concurrence of designers at headquarter (HQ), field engineering (FE) had worked out the engineering and erection agencies executed the schemes.

For safety related and non-safety related chilled water system strainers were provided near pump and bypass pipes were provided at the entry to respective buildings. The lines inside buildings were flushed either by supplying water from inside to outside the building or by arranging hoses near to air handling units (AHUs) and diverting to outside. Headers of chilled water inside non-safety chiller building were manually cleaned from inside, since adequate velocity could not be generator by open-loop flushing to remove debris. The end plates of the headers were welded after cleaning from inside, as they were of 800mm diameter.

As of flushing of reactor systems, the systems connected to primary systems are flushed into the main coolant pipelines or the reactor itself. To prevent clogging of small tubings, they were not hooked up prior to flushing into the reactor. The reactor internals were removed and one pump was installed to





Second Stage Hydro Accumulator - 1 Channel

dewater the flushed water from the reactor. The sequence of flushing of systems connected to the main coolant pipe lines was decided based on the location of the nozzle so that the systems which already had been flushed would not get contaminated by the water flushed from other systems. Presence of adequate water was ensured in reactor pressure vessel so that the impact of any debris falling in to reactor would be reduced to avoid damage to the liner on RPV. In addition to this, a rubber liner was also provided at the bottom of the RPV. With this arrangement, even emergency and planned cooling system were flushed, with water pushed at the rate of $900m^3/hr$.

After the completion of this process, the inner surface of main coolant pipelines were cleaned and dried, since they had to remain without medium till the hot run of the system. The RPV also was cleaned by wiping and was cleared for hook-up of small tubing and reactor internal erection.

The final flushing of the primary system was done along with operation of RCPs. One temporary line was erected from the blowdown line to the storm water drain. Through this line, continuous blowdown was done while 3 RCPs were operating in combination. The chemistry of the primary circuit blowdown water was continuously monitored and stage-by-stage temperature of the primary system was raised to 80°C, depending on chemistry indices. After attaining appropriate chemistry, blowdown to storm water drain was stopped and temperature was raised.

Other than flushing of systems interlock, checking of equipment and integrated testing of systems were also challenging. RCPs are provided with two circuit breakers on 6KV side. There were around 47 protections (including inhibition to start based on auxiliary readiness) for each RCP. In that, some were based on 2/3 logic. To test the interlocks, the breakers had to operate a number of times. To limit this imitators, mimicking operation of breakers was developed and hooked up at the breaker end and logic tests were carried out.

RCPs have a shaft-driven pump to supply oil during operation of pump and emergency oil tank to supply oil during coast down. In addition to this, each RCP have two motor-operated canned rotor pumps, which are submerged in oil inside the tank.

Electrically-operated pump is in operation only during start-up till it accelerates to nominal speed. Hence these lube-oil pumps were provided with normal operating power supply without battery back-up (Group 1). However during uncoupled condition, the coast-down time of motor was around 20 minutes, during which the emergency oil tank was not sufficient to cater. During 'no load' test if Class IV (Group II) supply fails, there should be a foolproof mechanism to supply oil till motor comes to a standstill. Since spare cable EP were not available for extending battery backed-up, supply from outside was not possible. Hence one MCC which supplied group I supply to one valve inside containment was modified to an 'isolator only' type of cell and inside containment starter was arranged near lube-oil pump to start in case of emergency. With this arrangement, RCP motor was tested on 'no load' a number of times, including for trim balancing.

The second-stage hydro accumulators are designed to supply boric acid to cool the core for up to 24 hours with varying flow rates. At the beginning of injection, flow rate would be high and this comes down in steps. This was achieved by providing standpipes inside the tanks and orifices in the pipelines. When the test was conducted in some of the stages, the flow rates did not meet the design criteria and the total time requirement of 24 hours was also not being met. The test was repeated after changing orifice.

Subsequent modifications carried out have resulted in attaining the required flow rate for the required duration.

Sunil V.P., *a mechanical engineer. is from the 3rd batch of NPCIL. He had been involved in the commissioning and operation of KAPS-2 and KGS-1&2. Thereafter, he shifted to the Directorate of LWR. Subsequently, he underwent training in operation of VVER and joined the Commissioning Group of KKNPP. He was in-charge of the commissioning of reactor systems and passive safety systems of reactor plant. He has Level 1 licence for operation and is working as shift-charge engineer at KKNPP-1.*

Ferrying of over-diamensional consignments (ODCs) from the jetty


Ferrying of over-diamensional consignments (ODCs) from the jetty

Pre-Service Inspection at KKNPP

Ponraj N., SA/E, KKNPP; **Jogesh P. Padia,** SO/E (QA), KKNPP; **K.A. Raman,** PE (QA), KKNPP

1. Introduction

Kudankulam Nuclear Power Project (KKNPP) is the first-of-its-kind Light Water Reactor (LWR) of VVER 1000 type constructed at Kudankulam in collaboration with the Russian Federation (RF). Various challenges were met during construction, commissioning and operation activities in line with the RF standards. Challenges were also faced in finalising and executing the inspection activities, including the Pre-Service Inspection programme for the Kudankulam Nuclear Power Project units-1&2 (KKNPP-1&2). The formulation of the PSI programme and its implementation at KKNPP-1&2 is detailed below.

2. PSI/ISI Programme Formulation and Its Scope

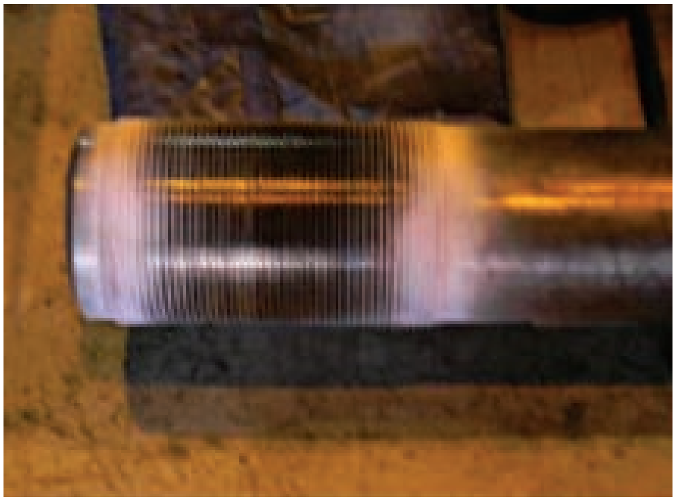
The Pre-service Inspection (PSI) and In-service Inspection (ISI) programme for primary and secondary cycle system of KKNPP-1&2 is based on the design documents, the existing practices of reference plant and

Table-1: Systems Identified for PSI/ISI of KKNPP-1&2

Sr. No.	System Description	KKS Code
1.	Reactor pressure vessel	JAA
2.	Reactor core barrel	JAC
3.	Core baffle	JAC
4.	Protective tube unit	JAC
5.	Upper unit	JAB
6.	Steam generator (SG)	JEA
7.	Pressurizer	JEF
8.	Emergency core cooling system (ECCS) Accumulator (Stage-I)	JNG
9.	Relief tank	JEG
10.	Separating bellow	JAA
11.	Reactor coolant pump	JEB
12.	Air vent elbow	JAB
13.	Leak detection device of the reactor main joint	JAA
14.	ECCS accumulator (Stage-II)	JNG
15.	Quick boron injection system (QBIS) Tank	JDJ
16.	Passive heat removal system (PHRS) heat exchanger	JNB
17.	Pipelines for QBIS connection	JDJ
18.	Main coolant pipeline	JEC
19.	Pressurising system piping	JEF
20.	ECCS pipeline 1st stage (JNG10-40)	JNG
21.	Pipelines of emergency gas removal system	KTP
22.	The system for emergency and scheduled cooling down of the primary circuit and fuel storage pool cooling	JNA
23.	High-precision (HP) emergency injection system and Emergency boron injection system	JND10-40 and JND50-80
24.	Chemical and volume control system	KBA
25.	Distillate system	KBC10-30
26.	Primary drains and controlled leaks system	KTA
27.	2nd stage ECCS piping system	JNG50-80
28.	Main feed water piping system	LAB
29.	Main steam piping system	LBA
30.	High temperature purification system of primary coolant	KBE10-40
31.	SG Emergency cool down and blow down system	JNB10-40
32.	Fuel pond water supply for purification system	FAL

RPV head

CPSAR nozzle weld PT inspection



RPV stud PT inspection

RPV stud UT inspection

RPV nut PT inspection

RPV nut VT inspection

Sr. No.	System Description	KKS Code
33.	Fuel pool piping system	FAK
34.	Spray system	JMN
35.	Passive heat removal system (PHRS) pipeline	JNB 50-80
36.	Component cooling water system	KAA
37.	Core catcher	JKM
38.	Passive catalytic hydrogen recombines	JMT-JMU
39.	JNG (50-80) ECCS 2nd stage passive core flooding system double check valve JNG50-80 AA 601 (DCV)	JNG50-80 AA 601
40.	Steam discharge to atmosphere valve (BRU-A) LBK51AA201, LBK52AA201, LBK53AA201, LBK54AA201	LBK
41.	Primary containment liner	-
42.	Makeup line to spent fuel storage (Post-Fukushima enhance system) through external source	JKM
43.	Makeup line to steam generator (Post-Fukushima enhance system) through external source	LAB32, 42, 52, 62
44.	Makeup line to borated tank KBA91BB001 (Post Fukushima enhance system)	KBA91
45.	Makeup line to primary system KBA90 (Post-Fukushima enhance system) through external source	KBA90
46.	8000 m^3 raw water tank (Post-Fukushima enhance system) outlet manifold	GKE

other normative documents. The various requirements of relevant Russian PNAE G codes and Atomic Energy Regulatory Board (AERB) codes were also taken as guidelines while formulating the programme. The PSI/ISI programme based on the above Topical document as a working programme applicable for KKNPP-1&2 is elaborated by a committee, with members from the site and NPCIL headquarter (HQ). This was reviewed and concurred by the RF and AERB. The inspection requirements are also in line with guidelines stipulated by the manufacturer of the equipment.

Governing/guiding documents used for PSI/ISI programme manual:

- FSAR St 2.47 (Topical report 'In-service inspection of metal of reactor plant equipment and pipelines')
- PNAE G-7-008-89 (Regulations for design and safe operation of the atomic power plant equipment and pipelines)
- AERB Safety Guide No. AERB/NPP/SG/02

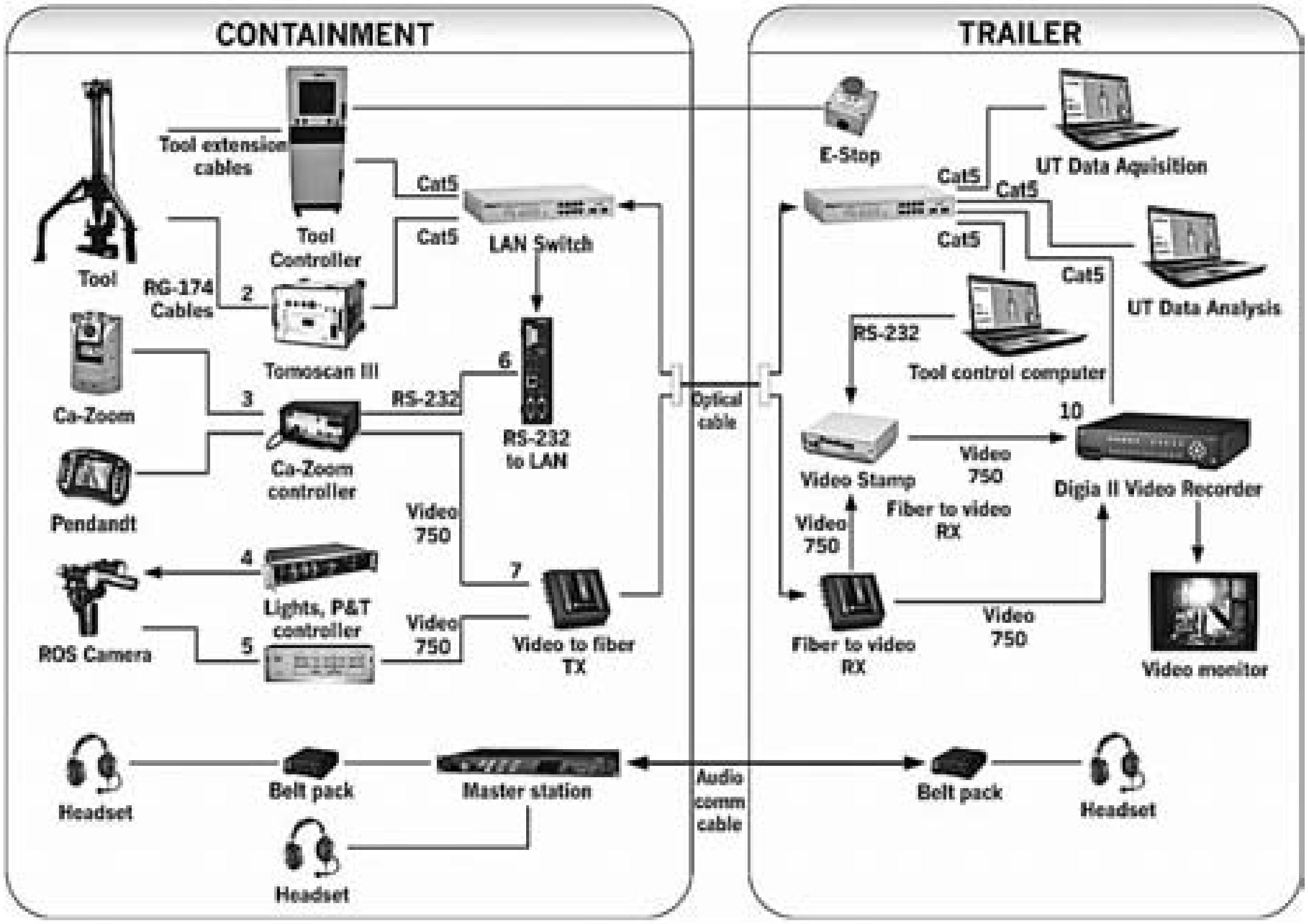
2.1. List of Systems Identified for PSI

Based on the review and as mentioned above, systems listed in Table-1 were identified for PSI/ISI and scope of inspection and frequency was mentioned in the finalised PSI/ISI manual for KKNPP-1&2.

2.2. Planning and Implementation of PSI Programme

The PSI is carried out at various stages, viz., manufacturing, construction and commissioning to generate the baseline data for the future ISI programme.

The PSI was performed before the commencement of operation to collect baseline data and executed mainly in two stages, viz., hydro test and after hot run of the system. The inspection was carried out as per the approved procedures and technique sheets and test results were documented in the approved format.



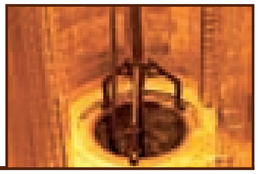
General scheme of RPV inspection system

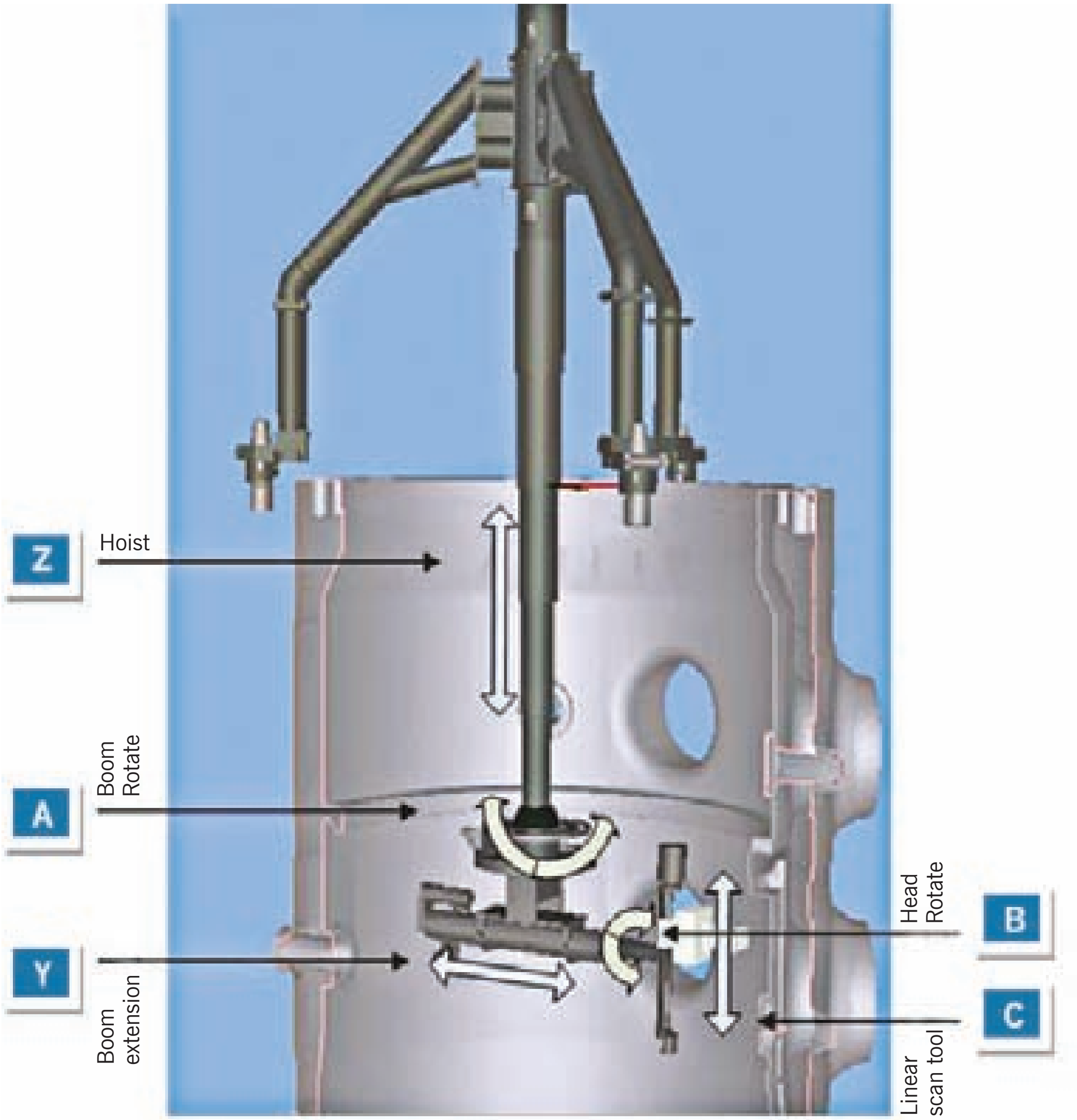
Various non-destructive testing (NDT) procedures for visual testing (VT), penetrant testing (PT), magnetic particle testing (MT), radiographic testing (RT), ultrasonic testing (UT) and eddy current testing (ET) were prepared by Nuclear Power Corporation of India Limited (NPCIL) for inspection activities by manual inspection as well as by remote automatic inspection. These procedures were further reviewed by AERB PSI/ISI task force. The other necessary documents such as technique sheets for various weld joint configurations and base metal inspection were also prepared for each NDT techniques as applicable, by NPCIL and reviewed by AERB task force.

2.3. Manpower Training and Assessment

The manpower involved in the inspection programme was experienced and trained and certified by national and international body for Non-Destructive Examination (NDE) certification, viz., Indian Society for Non-Destructive Testing (ISNT) or American Society for Non-Destructive Testing (ASNT).

All the inspection personnel, including the contractor manpower and departmental personnel conformed to





Central mast manipulator mounted onto the reactor vessel

Four-axes movement of the RPV inspection system

different certification level requirement in various NDE methods as per the testing requirement. The training and qualification details were documented, forming part of PSI/ISI records. The inspection personnel were authorised by Head QA on the basis of their proficiency in each inspection method and experience. Training and competency check on the mock-ups were carried out as per requirement.

Mock-ups/calibration blocks: Special mock-ups were prepared for functional testing of remote automatic inspection systems and for validation of the procedures for VT, UT and ET. For

RPV inspection system on unit-1 RPV during PSI

manual inspection, various calibration blocks similar to the one being tested were used for sensitivity calibration.

3. Inspection Methodology

The Inspection was carried out manually as well as using the robotic inspection system as envisaged in the inspection program. The training and qualification on these robotic inspection systems were also carried out on mock-up trials, including the various functional tests of the inspection system under the supervision of original equipment supplier.

3.1. Manual NDT Inspection

a) Visual testing (VT)

b) Penetrant testing (PT)

c) Magnetic particle testing (MT)

d) Ultrasonic testing (UT)

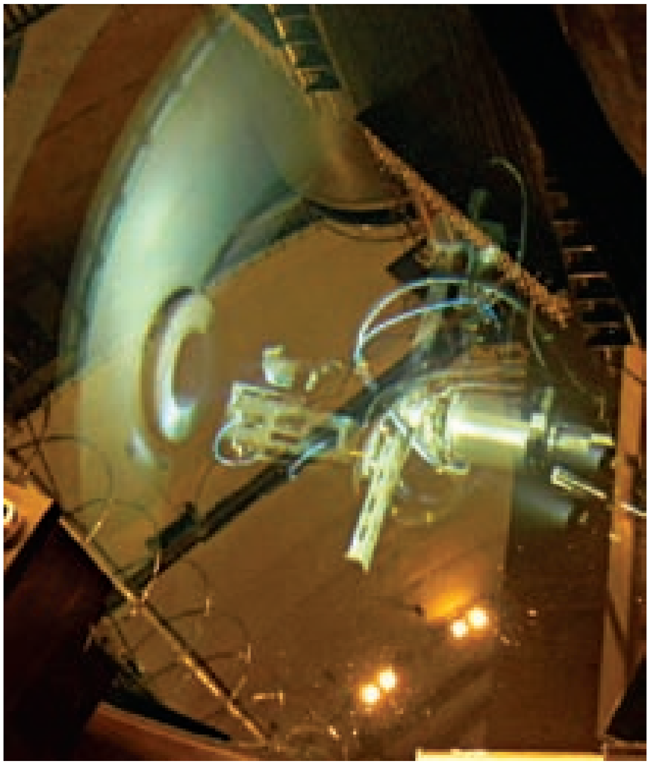
e) Radiography testing (RT)

f) Ultrasonic thickness gauging ($UT_{Thickness\ gauge}$)

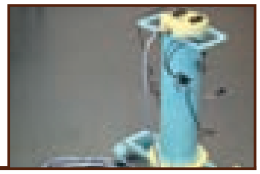
3.2. Automated/Remote NDT Inspection

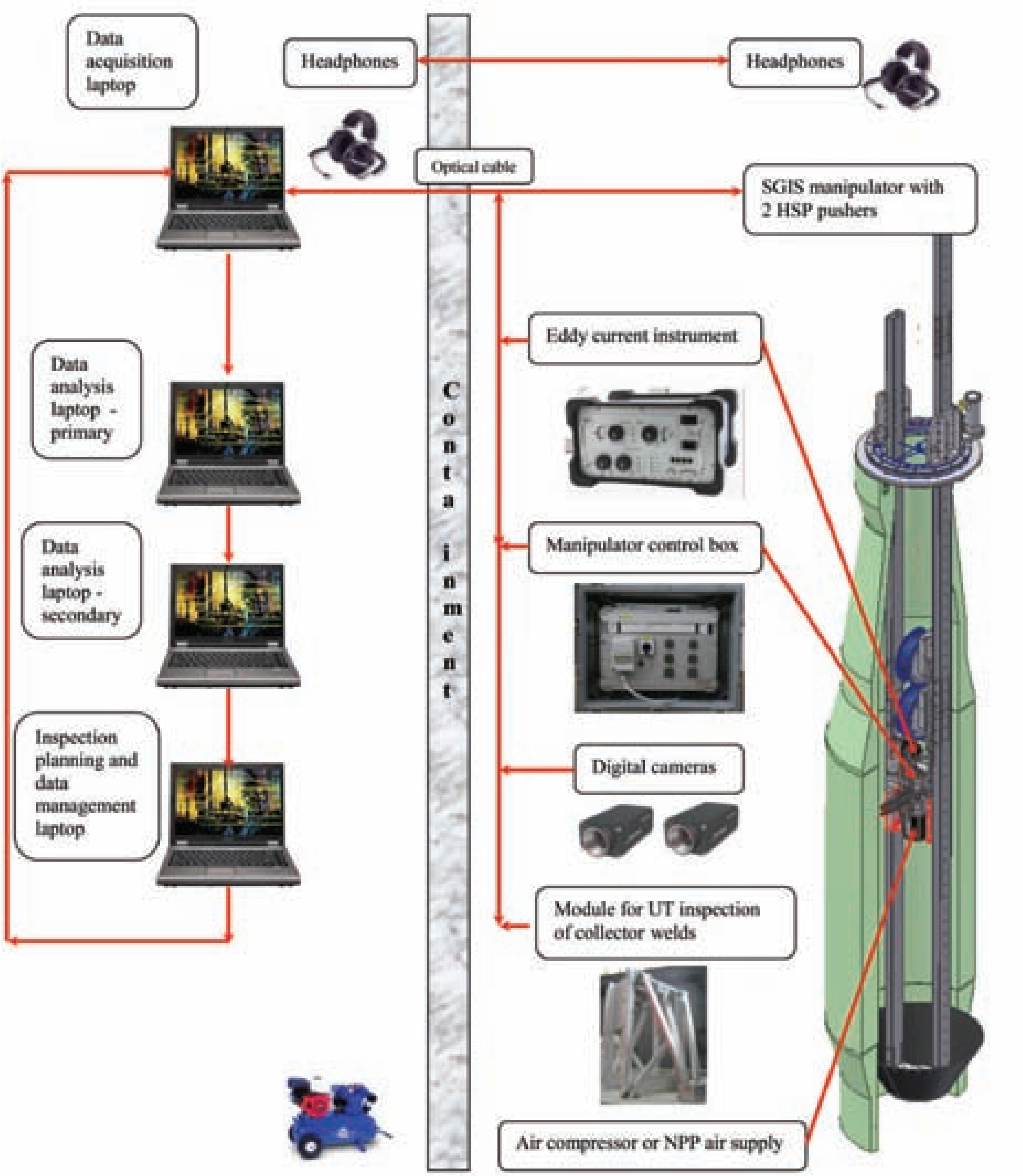
Automated systems are highly sophisticated with the software based, computer controlled, remotely operated manipulator, data acquisition system, data analysis and reporting system. Most of the mechanical components are custom made, highly precision-machined to get the required accuracy for the inspection and with the dedicated custom made application software for the entire operations.

The following five automated inspection systems

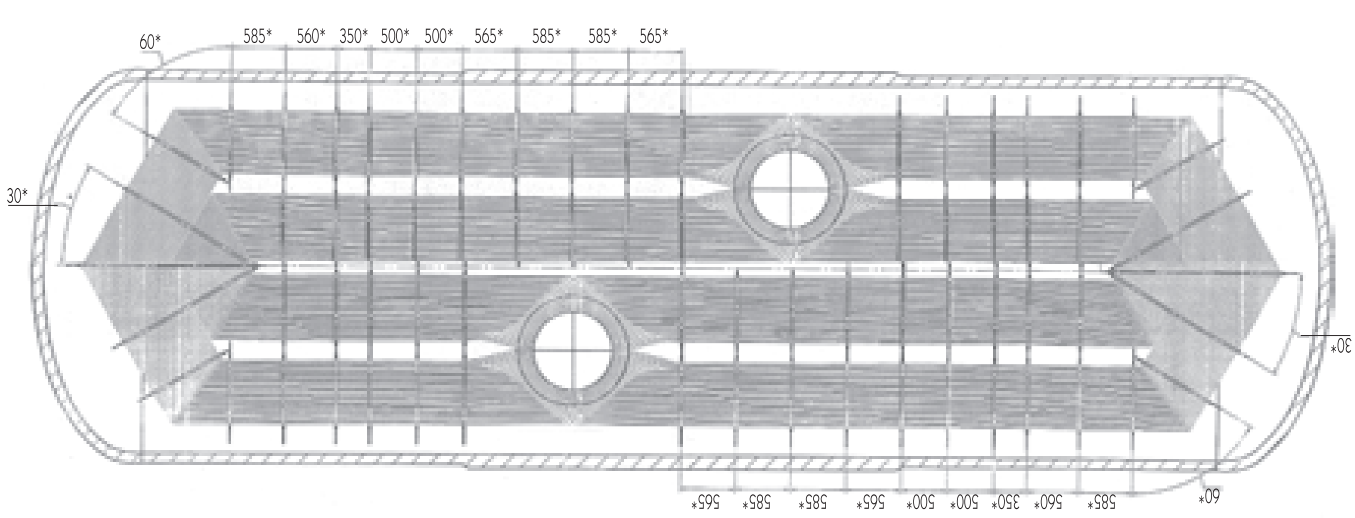


Under water televised visual inspection during unit-1 PSI





General scheme of SG inspection system



SG tube layout

have been supplied to KKNPP for the metal inspection of rector equipment and piping system as a part of the main contract.

1. RPV inspection system
2. SG inspection system (SGIS)
3. Piping weld UT inspection system
4. RPV internal inspection system from outside
5. RPV stud hole inspection system

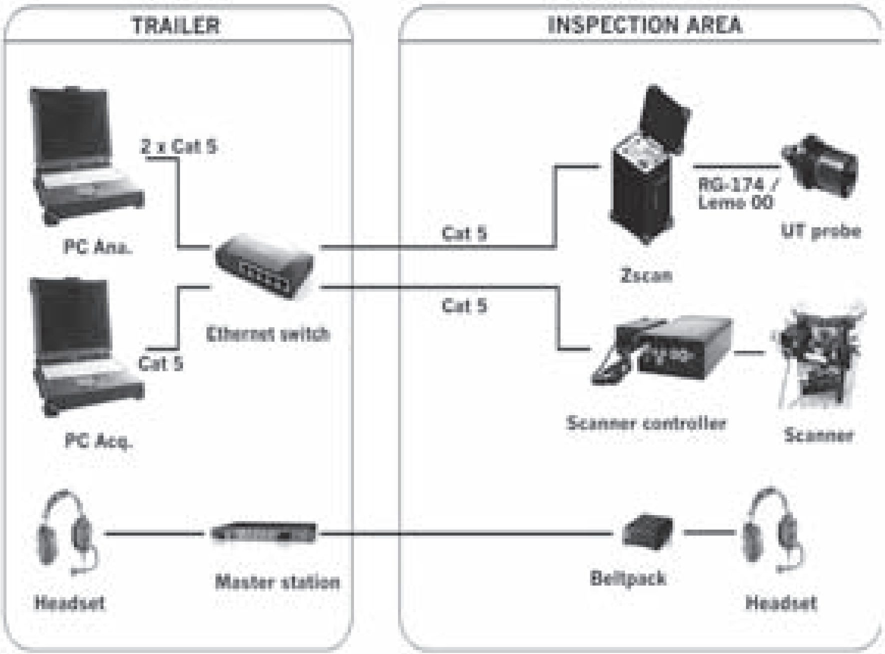
ECT inspection during unit-1 PSI

Boobbin flexible probe

3.2.1. Preparation for remote auto inspection

The inspection systems/ tools were supplied in semi-assembled condition for easy transportation. All the auto inspection system equipment were assembled and made ready at the site for site acceptance tests. Mock-up facilities for piping inspection were prepared with calibration blocks embedded in the pipe spool cut out for various diameter piping.

For SG inspection system qualification, collector mock-up with representative tube locations (for ET) were made along with collector weld joint UT calibration block embedded in the mock up. One full-size half-tube lay out was also used to ensure capability of pusher puller to execute the severest tube lay out. For RPV UT probes functional checks, special trolley mounted mock-up facility with UT sensitivity calibration blocks were used. Full-scale integrated functional tests were carried out in the field in line with site acceptance test procedures on the field equipment for final validation before actual testing.



General scheme of SG inspection system

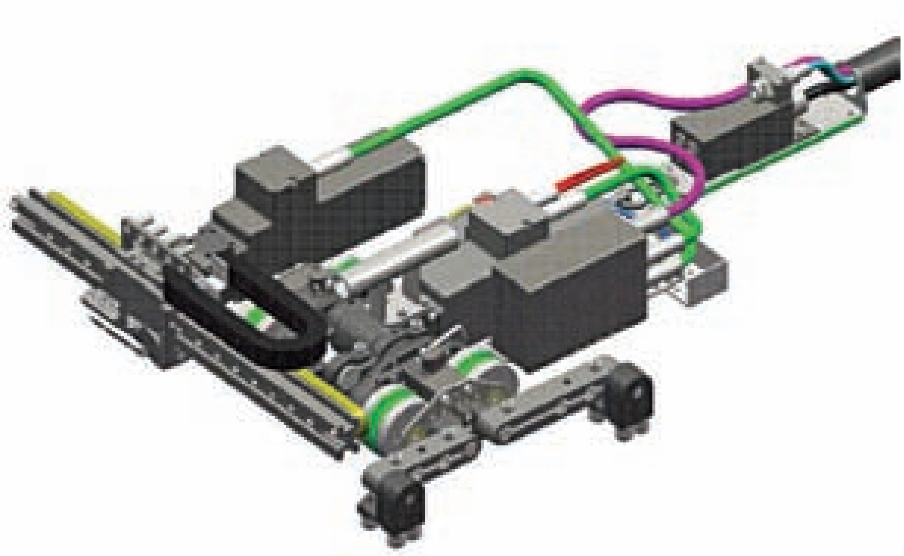
3.2.2. RPV Inspection System (RPVIS)

This remote automated under water inspection system consists of 2 inspection modules namely ultrasonic inspection (UT) and televised visual testing (TVT) modules. For reactor pressure vessel, 6 shell weld joints and base metals, including cladding, nozzles and core belt regions, are inspected by UT and TVT from inside. Weld joints and base metals of RPV internals (core barrel and baffle assembly) are inspected by TVT from inside. This system works on sophisticated electric and pneumatic actuator/drive, which is operated through PC-based remote mode away from RPV.

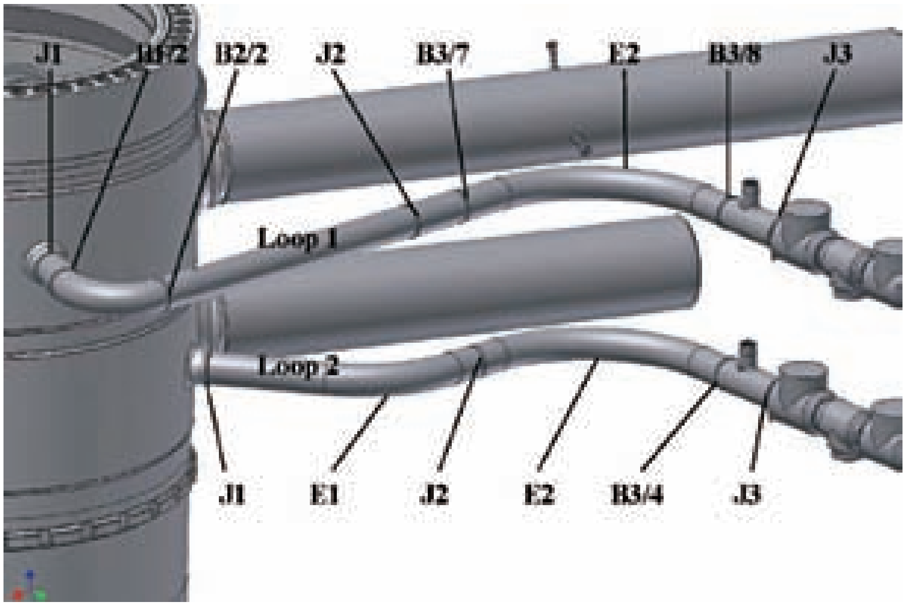
The manipulator is mounted on the reactor main flange with the help of support tripod and guide pins, which are installed in the RPV vessel flange. The manipulator along with the inspection attachment is lowered into the guide pins by the polar crane. The inspection system has four axes of movement:

1) Vertical movement (hoist),
2) Boom rotation (boom rotate about the vertical axis),
3) Horizontal (inspection boom extension) and
4) Head rotation, which allows the circumferential scan of nozzles

The hoist, a vertical multi-section telescoping tube, provides travel along the pressure vessel centerline. Vertical motion is cable driven



Inspection crawler



JNG pipeline schematic weld joint locations

by an electrically-powered hoist drive located on the top of the tube assembly. Vertical travel is measured by a resolver mounted in the hoist drive assembly.

The inspection boom, a horizontal, electrically-driven telescoping tube, is mounted at the bottom of the hoist and rotates in a horizontal plane perpendicular to the vertical hoist centerline. It is driven by an electrically-powered drive (boom rotate) about the hoist. A resolver measures the angular position of the inspection boom about the hoist as the boom is rotated.

A resolver also measures the lateral extension position of the telescoping boom. A mounting flange at the outer end of the inspection boom telescoping section carries an attachment rotator (head rotate) and inspection attachments used to inspect. An optical encoder measures the position of the electrically-driven head rotate.

The vessel wall surfaces are scanned vertically by raising or lowering the hoist to move the inspection attachment along the wall or alternately by precision drive (C-axis drive) and circumferential scan is done by rotating the boom about the hoist. Nozzles are inspected by special attachment connected to head rotate mechanism and rotating the inspection attachment about the nozzle centerline using the head rotate drive.

Before inspection, functional testing of the manipulator and calibration of probe with sensitivity calibration block (primary) carried out in separate trolley mounted crawler at workshop/NDT lab and calibration settings are confirmed once again at location in Reactor Building (RB) central hall before start of work. The secondary calibration block is used in situ for the periodic response check during the field inspection.

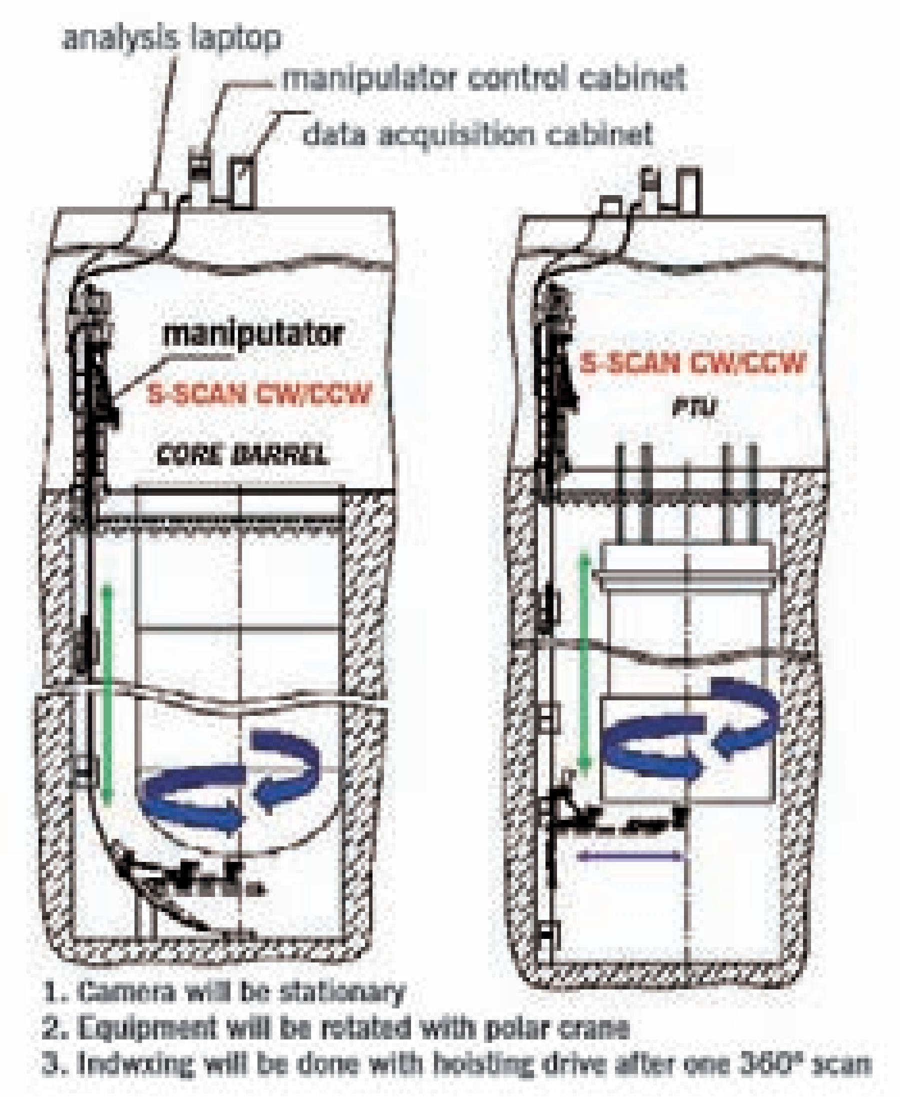
Data acquisition is done by 7 probes using the multichannel UT inspection system. Data analysis is done using ultra

Elbow UT inspection during unit-1 PSI

vision software. Special UT probes shear type, longitudinal angle beam probes and also TRTL probes are used for the UT of RPV welds and base metal.

3.2.3. SG Inspection System (SGIS)

This remote inspection system consists of four modules, namely, eddy current test module with bobbin probe (for tube inspection), eddy current test module with MRPC probe (for collector ligament inspection), ultrasonic inspection module (for primary collector weld joint) and TVT module (visual inspection on tube sheet and collector).



General scheme for inspection of core barrel and PTU

Inspection crawler

The system primarily consists of base plate, mast, carriage with elevating mechanism, high-speed double pusher (HSP), probe drum system, pneumatic and control box with cable system and lower expandable platform (for FME control, centering vertical mast and bottom support of the manipulator). Manipulator is resting on the SG collector flange with the help of mating flange of the manipulator. Dowel pins on the manipulator flange helps for easy installation. This system works on sophisticated electric and pneumatic actuator/drive which is operated through PC-based remote control system away from SG. Separate software is used for data acquisition, data analysis and data base management

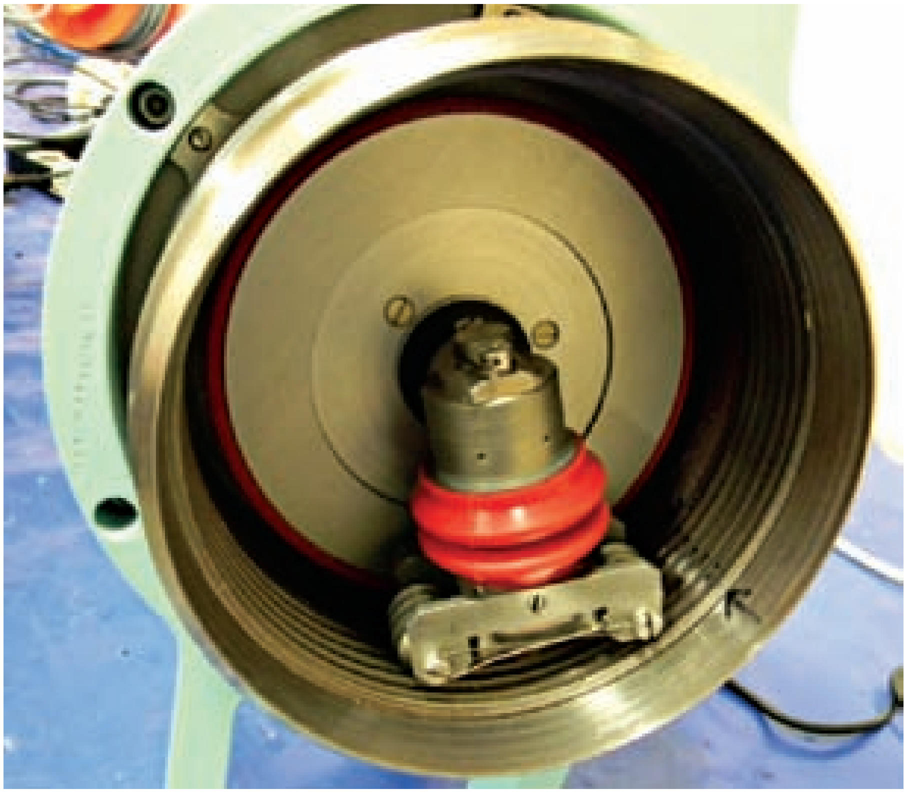
(DBM). Inspection system has the feature of easy removal and installation of different inspection module according to the inspection plan.

SG has 10978 tubes, in horizontal layout. It has two collectors (hot and cold). SS 321 equivalent SG tubes are running from hot to cold in two layouts, and there are 5 bends in a U tube and hence special probes are used to execute the bends. The system is capable of driving two probes at a time with two pushers. Special MRPC drive module is used to inspect the ligament portion including the rolled area of the tube in the tube sheet region. The collector (circular tube sheet) portion has one weld joint at top which is inspected by the manipulator using UT module and multi channel U system MS5800.

3.2.4. Piping auto UT Inspection System

This inspection system is meant for remote automatic ultrasonic inspection of reactor pressure boundary pipeline circumferential welded joints and adjacent base metals (HAZ) and elbows.

Inspection system manipulator



Standard calibration block and ECT probe

The system is very complex, which includes PC-based control system and data acquisition system, robotic crawler system and multi-channel ultrasonic flaw detector unit. Water is used as the couplant for piping inspection. This is arranged through a dedicated water tank in the field located at reactor central hall. The water from this tank is fed through a long flexible hose to the inspection crawler in the field.

This system is in modular form so that it can be easily

ECT data acquisition during unit-1 PSI

RPV stud hole inspection system during unit-1 PSI

dismantled, transported from one location to other location at various elevations inside reactor building to test the various piping components taking care of field congestions and easy handling.

For the piping inspection, various probe configurations of about 7 probes were designed and optimised to suit to various piping weld joint sizes and configurations in the field. The probes are mounted on the frame arrangements, to be assembled in each case, to suite to the various field configurations as per the inspection scope.

3.2.5. TVT system for reactor internals from outside surfaces

Reactor internal under water inspection system is based on televised visual inspection method. This system consists of a manipulator with travelling mechanism, a radiation resistance camera, electric and control system, data acquisition station. Functional tests and sensitivity calibration are carried out before starting inspection. During the disassembly of RPV, reactor internals (core barrel along with core barrel and PTU) are placed in the reactor internal inspection well. Inspection well has installed guides to travel the manipulator over the entire length of equipment being inspected. The manipulator has three modes of drives, namely, hoist, carriage and console. The hoist drive works on a simple rope drum with winch, which is intended to position the camera in vertical coordinate (Z-axis). The carriage is a linear motion drive and radiation-resistant camera housing is mounted on carriage. The carriage is mounted on the console. It can turn -900 (vertical) to 00 (horizontal). Dedicated drive mechanism with encoder and limit switch facility is provided in various drives.

It has only the vertical linear motion along the guide in the inspection well and inspection along the circumference is achieved by rotating the reactor internals with the help of polar crane fork swing mechanism. VT calibration comparator is used for the initial setting of the inspection system parameters such as illumination, depth of view and field of view and analysis software set-up.

3.2.6. RPV main flange stud hole (thread) ET inspection system

This is a custom-made automatic inspection system for single frequency eddy current testing of RPV main flange stud hole threads. There are 54 stud holes of size M170x6 of depth about 200 mm. It aims to detect discontinuities along entire length of the thread. It is provided with inline reference calibration standard for analysis purpose. The system consists of one portable type manipulator and PC-based data acquisition station, with long extension cables for facilitating data acquisition from reactor central hall. Flaw signals are compared with reference signal from calibration standard for evaluation of indications.

Pre-service inspection of unit-1 was carried out and the baseline data was generated for all the equipment, pipeline and supports as per the approved programme. After the review at the site, PSI data was submitted to NPCIL-HQ for independent review and subsequently submitted to AERB PSI/ISI task force.

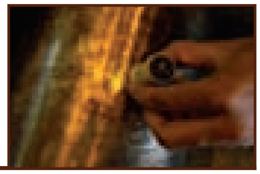
The test results were recorded in hard copy in the report format concurred by the task force. Soft data of field inspection was also stored in hard disc/DVDs. The preservation of records/ reports is carried out as per the established procedure. The original copy of the database is stored in 'KKNPP document centre' and the duplicate copy is stored in site QA section for ready reference. A soft copy is also available at HQ.

The PSI programme audit was conducted at site level by internal audit team and external audit was conducted by HQ-QAD team. AERB task force members were present at the site during the inspection of RPV.

Conclusion

The finalization of PSI programme was successfully completed by the efforts of NPCIL and AERB task force after several review meetings. The codal requirement of KKNPP was totally different compared to the existing PHWR practices. Familiarising with the applicable RF codes and VVER-type reactor PSI/ISI activities and finalisation of the PSI/ISI programme was a demanding task. PSI was mainly executed in 2 stages, viz., post-hydro test and post-hot run. The quantum of manual inspection was huge, e.g., 2000m of PT, 1800 m of UT, 150m of RT and 1900 studs (VT, PT, MT and UT) etc. In addition to manual inspection, automatic inspection of RPV, RPV internals, SG and nuclear piping by

Hard copies of unit-1 PSI records



the robotic system was an equally challenging task in the tight project schedule. Report preparation, review and submission to AERB were done progressively, which enabled the faster review and quicker obtaining of the stage-wise clearances. All the PSI records in hard form and soft form are kept in the library for the future reference and soft copy at HQ. Copies of PSI records are also kept with QA section for ready reference.

The authors acknowledge with thanks for the contribution of NPCIL and AERB task force for the finalisation and execution of PSI works at KKNPP unit-1. The support from execution, O&M, HQ and other NPCIL units is worth mentioning for the timely execution of this mammoth task of PSI in unit-1. This has once again proved the saying “Coming together is beginning. Keeping together is progress. Working together is success”.

***Ponraj N.**, SA/E has a diploma in mechanical engineering. He joined in NPCIL as KKNPP Scientific Asssistant Batch-II trainee in the year 2004. After the successful completion of his induction training, he joined the KKNPP QA group. He has NDT Level-II certification for VT, PT, MT, UT and ECT. At KKNPP, he has been involved in QA activities related to the fabrication and erection of Nuclear Steam Supply System (NSSS) piping, including Main Coolant Piping (MCP) welding and equipment erection as well as PSI activities at KKNPP-1&2. He is a recipient of NPCIL Group Achievement award for MCP welding works.*

***Jogesh P. Padia,** SO/E (QA), is a B.E. (Mechanical) graduate. He joined NPCIL as a 14th batch Engineer Trainee in the year 2005. After the successful completion of his induction training, he joined the KKNPP QA group. He has ISNT Level-III certification in RT and Level-II in VT, PT, MT, UT and ECT. At KKNPP, he has been involved in QA activities related to the fabrication and erection of Nuclear Steam Supply System (NSSS) piping, including Main Coolant Piping (MCP) welding and equipment erection as well as PSI activities at KKNPP-1&2. He is a recipient of NPCIL Group Achievement award for MCP welding works.*

***K.A. Raman,** PE (QA) is a B Tech (Mechanical) graduate. He jointed NPCIL as NPCIL Batch–II Engineer trainee at MAPS. After his induction training, he joined the KGS-1&2 construction QA group. Since then, he has been involved in construction QA related works of primary and secondary side piping and equipment erection, and later, O&M WA group at KKNPP. Another area of his work is PSI and ISI activities of KGS-1&2 and establishing NDT facilities for ISI. He has ISNT certification Level-III in RT, UT and Level-II in VT, PT, MT and ET methods.*

Media Reflections

nkulam N-plant begins to generate powe

Media, Delhi
Wednesday 23rd October 2013, Page: 13

thern grid gets first flow from Kudankulam

Kudankulam begins power production

Tribune, Delhi
Wednesday 23rd October 2013, Page:

Power generation begi at Kudankulam N-pla

CHENNAI, OCTOBER 22
India's atomic power plant operator Nuclear Po

Dainik Jagran, Delhi
Wednesday 23rd October 2013, Page: 12

कुडानकुलम संयंत्र में उत्पाद

Deccan Chronicle, Hyderabad
Wednesday 23rd October 2013, Page: 6

Power generation increased to 160 MW fro

NUCLEAR POWER

KNPP goes live on South

DNA, Mumbai
23/10/2013

Kudankulam starts produ

Chronicle, Delhi
23rd October 2013, Page: 9

Kudankulam begins output of nuke power

REUTERS/PRESS TRUST OF INDIA
New Delhi

INDIA started pumping electricity for the first time from its much-delayed Kudankulam nuclear power plant in the southern state of Tamil Nadu on Tuesday, with an initial output of 160 mw, the government said in a statement.

Statesman, Delhi
Wednesday 23rd October 2013, Page: 1

Kudankulam Unit I synchronised

STATESMAN NEWS SERVICE
Chennai, 22 October

The first unit of the Kudankulam Nuclear Power Plant (KNPP) in Tamil Nadu was today synchronised with the southern power grid.

"The synchronisation of Unit 1 of the Kudankulam Nuclear Power Plant was done at 2.45 a.m. It is generating 75 MWe", KKNPP site director Mr R S Sundar said. The power generation will be raised to 500 MWe, 750 MWe and 1000 MWe in stages. At every stage, various tests are conducted and the technical parameters verified. Based on the results of the tests at each of the stages and with AERB clearances, subsequent stages are reached.

MWe. But Power System Operation Corporation Limited (POSOCO)'s website mentions that the secondary system failed."

Even if synchronization is successful they cannot start commercial operation immediately.

Hindustan, Delhi
Wednesday 23rd October 2013, Page: 9

कुडनकुलम परमाणु संयंत्र मिली दक्षिण ग्रिड को बिज

Rashtriya Sahara, Delhi
Wednesday 23rd October 2013, Page: 10

एटमी बिजली का ताजा झोंका

Asian Age, Mumbai 23/10/2013 P-5

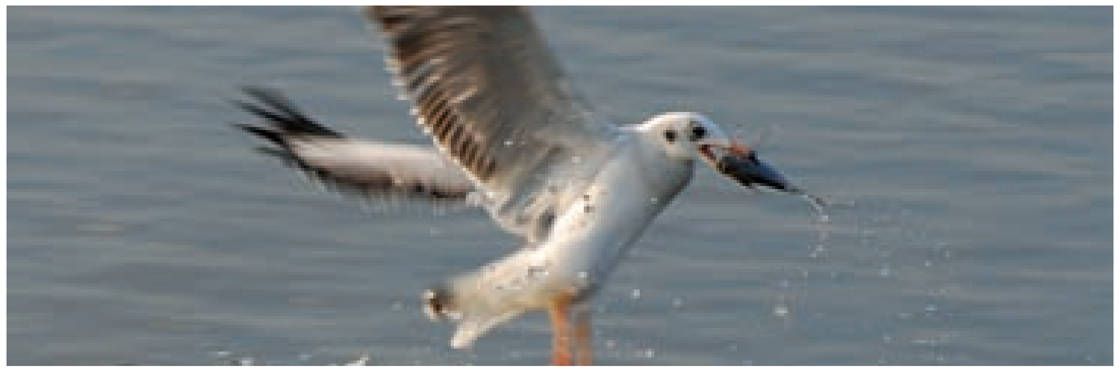
Kudankulam-1 begins to generate

M. ARULOLI
TIRUNELVELI (TN), OCT. 22

The first unit of the Kudankulam nuclear power project

The readings will be submitted to the Atomic Energy Regulatory Board after whose clearance

Preserving nature for posterity



Preserving nature for posterity

Plants Under Operation

UNIT-LOCATION	REACTOR TYPE	PRESENT CAPACITY (MW)	DATE OF COMMENCING COMMERCIAL OPERATION
TAPS-1, Tarapur, Maharashtra	BWR	160	October 28, 1969
TAPS-2, Tarapur, Maharashtra	BWR	160	October 28, 1969
TAPS-3, Tarapur, Maharashtra	PHWR	540	August 18, 2006
TAPS-4, Tarapur, Maharashtra	PHWR	540	September 12, 2005
RAPS-1,* Rawatbhata, Rajasthan	PHWR	100	December 16, 1973
RAPS-2, Rawatbhata, Rajasthan	PHWR	200	April 1, 1981
RAPS-3, Rawatbhata, Rajasthan	PHWR	220	June 1, 2000
RAPS-4, Rawatbhata, Rajasthan	PHWR	220	December 23, 2000
RAPS-5, Rawatbhata, Rajasthan	PHWR	220	February 4, 2010
RAPS-6, Rawatbhata, Rajasthan	PHWR	220	March 31, 2010
MAPS-1, Kalpakkam, Tamil Nadu	PHWR	220	January 27, 1984
MAPS-2, Kalpakkam, Tamil Nadu	PHWR	220	March 21, 1986
NAPS-1, Narora, Uttar Pradesh	PHWR	220	January 1, 1991
NAPS-2, Narora, Uttar Pradesh	PHWR	220	July 1, 1992
KAPS-1, Kakrapar, Gujarat	PHWR	220	May 6, 1993
KAPS-2, Kakrapar, Gujarat	PHWR	220	September 1, 1995
Kaiga-1, Kaiga, Karnataka	PHWR	220	November 16, 2000
Kaiga-2, Kaiga, Karnataka	PHWR	220	March 16, 2000
Kaiga-3, Kaiga, Karnataka	PHWR	220	May 06, 2007
Kaiga-4, Kaiga, Karnataka	PHWR	220	January 20, 2011
KKNPP-1, Kudankulam, Tamil Nadu	VVER	1000	December 31, 2014
Total		**5780**	

**Owned by DAE*

Plant Under Commissioning

PLANT	CAPACITY (MW)
KKNPP-2, Kudankulam, Tamil Nadu	1x1000 LWRs
Total	**1000**

Projects Under Construction

PROJECT	CAPACITY (MW)
KAPP-3&4, Kakrapar, Gujarat	2x700 PHWRs
RAPP-7&8, Rawatbhata, Rajasthan	2x700 PHWRs
Total	**2800**
PFBR** Kalpakkam	1x500 FBR

***Being implemented by BHAVINI*

ASIA
Rising on World Nuclear Map...

While Asia constitutes only one-third in terms of numbers of operating nuclear power plants today, the picture will be distinctively different in future. Asian region is poised to become a world leader in nuclear power development. Of the 67 units currently under construction in the world, about three-fourths (47 units) are in Asia. Similarly, of the 168 units planned world over, 117 will be set up in Asia.