

PLANT LIFE MANAGEMENT EXPERIENCE AT TARAPUR ATOMIC POWER STATION

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Abstract

Tarapur Atomic Power Station, the longest serving Nuclear Power Plant in the Asian continent has completed 36 years of successful operation and generated more than 70 Billion units of electric power. Built in late sixties, with the state-of-the-art safety features prevailing then, TAPS through the process of evolution has become much more safer plant due to efforts of upgradation, renovation and refurbishment prompted by the station's operating experience, feed back from overseas reactors, lessons learnt from nuclear incidents, accidents and fresh review of design basis and safety analysis of the plant.

All components of a Nuclear power plant experience some degradation with time. The Reactor Pressure Vessels (RPV) designed for 40 effective full power years (EFPY) of operation have operated for less than 21 EFPY and the material condition is assessed to be fit for several more years of service. The condition of the containment and main plant buildings was assessed to be satisfactory. The Life Management Programme involved identification of key systems, structures and components (SSCs) that may experience degradation due to ageing, and take corrective measures through maintenance, repair and / or replacement. The identified components were classified as major critical components, important systems and other critical components. For each component mode of degradation was identified, ageing assessment was done and action plan was finalized. Replacement of some important equipment like 3X50% capacity Emergency Diesel Generators (EDG) with 3 X 100% capacity EDG, Salt Service Water (SSW) pumps, Control rod drive (CRD) pumps, Emergency Condenser tube bundles, Station battery has been done on the basis of condition monitoring and to obviate common cause failure and enhance the system reliability. Samples of Safety related cables were subjected to residual life assessment (RLA) and replacement action firmed up on the basis of the RLA findings. Condition survey of Main plant building at TAPS was done and based on the findings detailed repair and protective coating application on main plant building have been completed. The AMP of the safety related components is in place to ensure that integrity and functional capability are maintained at par with current standards of safety throughout the service life of the plant. The sterling performance of the plant, present trend of stability in operation after safety upgradations indicates its ability to outlive the design life of forty years.

Introduction

Tarapur Atomic Power Station (TAPS), the longest serving Nuclear Power Plant in the Asian continent has completed 36 years of successful operation and generated more than 70BU units of electric power. Tarapur Atomic Power Station (TAPS) consisting of two boiling water type reactors (BWR) was commissioned in the year 1969. The original capacity

of these reactors was 210 MWe each. After isolation of Secondary Steam Generators (SSGs) in 1985, both the units were rerated to 160 MWe each. These units are operating at rerated capacity since then.

It was an IGE turnkey project. Most of equipments were designed and fabricated to the manufacturing standards prevailing at that time. General Electric and its sub vendors supplied all the electrical components. The critical mechanical equipment namely Reactor pressure vessel was designed and supplied by M/s Combustion Engineering, feed water heaters by M/s SWECO, pumps by M/s Ingersol Rand, M/s Pacific and M/s Byron Jackson and piping, valves and fittings by M/s Crane Co. and ancillaries. All controls and instrumentations were supplied by General Electric and its sub vendors.

TAPS was built in late sixties, with the state-of-the-art safety features prevailing at that time. Since then the relevant safety standards for NPPs have been revised. The latest safety assessment of TAPS was done after 30 years of operation using relevant current standards and safety practices. Probabilistic Safety Assessment (PSA Level-1) carried out using all Postulated Initiating Events (PIEs) of the plant concluded that the Core Damage Frequency (CDF) is of acceptable level for earlier generation plants as per the guidelines of INSAG-8¹. A comprehensive safety review was done covering areas of Operating Experience, Ageing Management and a fresh review of Design basis and safety analysis of the plant as part of Safety Assessment for renewal of authorization of operation. The Seismic capability of safety related structures and equipment was reassessed based on walk through and plant seismic analysis. The comprehensive safety assessment brought out the limitations of the emergency power supply, sharing of systems and equipment between both units and vulnerability to common cause failure.

The Ageing Management Programme (AMP) identified key systems, structures and components (SSCs) that may experience degradation due to ageing, and formulated corrective measures through maintenance, repair and / or replacement. The Reactor Pressure Vessels (RPVs) are designed for 40 effective full power years (EFPYs) of operation and till date they have operated for less than 21 EFPYs. The assessment of material condition of the reactors concludes that they are fit for service for several more years. The condition of the containments and main plant buildings was assessed to be satisfactory. A good numbers of major equipment have been replaced to mitigate ageing. Primary system piping, process heat exchangers, feed water heaters, turbine extraction system piping, turbine blades, emergency condenser tube bundles, various pumps, station batteries, electrical cables, circuit breakers etc. are some of them. Obsolescence is another aspect of ageing of a plant. Replacement of obsolete equipment and components particularly in C&I is another area where much headway has been made.

Outage of both TAPS Reactors was also availed off from October 2005 to February 2006 and up gradations was carried out to address the safety areas identified by above reviews. Old 3 X 50% capacity Emergency Diesel Generators (EDGs) were replaced by 3 X 100% capacity EDGs to obviate common cause failure and enhance the system reliability. Safety related power and control circuits were segregated unit wise. This was achieved by installing two thousand meters of new cable trays and fifty thousand meters of new cables. Additionally, ten thousands meters of cable were re-routed. Unit wise segregation of Control Rod Drive (CRD) Hydraulic System, Shutdown Cooling System, Neutron Monitoring Power Supply System and incorporation of Independent Supplementary Control Rooms were the major upgradations

carried out. The enhanced safety levels and the stability in operation after safety upgradations indicate that the plant is capable to operate for several more years. .

Upgradation, Replacement and refurbishment of equipment have been done after detailed study and analysis so that current standards are met. Retrofitting the indigenously developed and fabricated equipment in a compact plant like TAPS was a difficult task and required lot of efforts and interaction with the manufacturer so that the developmental efforts do not compromise the quality.

An over view of such significant efforts are discussed in this paper.

Life Management

Ageing of TAPS Plant Systems, Structures and Components (SSC) important to safety has to be effectively managed to ensure integrity and functional capability throughout the service life. To achieve this, identification of key SSCs was done to detect degradation due to ageing and correct them through maintenance, repair and/or replacement. The Life Management Programme (LMP) of the SSCs has been developed with the objective of timely detection of any degradation that can weaken the basic safety function and planned mitigation. The **LMP** is designed for comprehensive and integrated management of ageing.

Identification of components to be included in Life Management Programme was done on the basis of the existing relevant documents.^{[7],[8],[9]&[10]} Plant operational experience and NRC review reports on the Calvert Cliff and Oconee NPPs application for extension of operating license were also referred.

Identified components have been classified as Major Critical Components, Important Systems and Other Critical Components. The components have been further classified as not replaceable, replaceable with re-engineering, and replaceable on routine basis. For each component the mode of degradation has been identified, ageing assessment has been done and action plan has been indicated.

The major critical components are those that have high safety significance, and that must remain functional during normal power operation and during those conditions for which the plant was designed. In general these are the components that will help contain or mitigate any release of fission product that may take place during normal operation, off-normal condition or design basis accident.

The major critical components identified for TAPS-LMP are the Containment, Reactor Pressure Vessel & Reactor Internals, Reactor Recirculation piping and rest of the Primary Pressure Boundary, Recirculation Pump Body, Control Rod Drive Mechanism, Safety Related Cables and Connectors, Reactor Pedestal & Vessel Stabilisers, Biological Shield & Secondary Steam Generator.

Among the major critical components, Reactor Pressure Vessel (RPV) is most important. From the RPV surveillance specimen programme, RPV material condition has been found satisfactory and has adequate fracture toughness to assure the safety of the Pressure Vessel till the end of service life^{[1],[2]&[3]}. The coolant water chemistry of the reactors has been very good throughout its past operating period, thus ensuring negligible deterioration of material of construction. Additionally Fatigue analysis for the reactor pressure vessel done taking into account the cumulative thermal and pressure cycles.^[4]

The Inspection programme of Reactor internals and support structures including core shroud exists. The condition of the Reactor internals is satisfactory. Fast neutron fluence assessment for Core shroud indicates that the fluence at the end of forty EFY will be less than the threshold values for causing Irradiation assisted stress corrosion cracking (IASCC). Detailed study assessing the fast fluence on other reactor internals concludes that significant operating margins are available.^[5] The primary system pressure boundary is inspected as per ISI Programme and has been found satisfactory. The generic issue of inter granular stress corrosion cracking (IGSCC) with SS304 material has been addressed and large portion of the piping has been replaced with improved quality material. Replacement of balance piping on the basis of ISI evaluation is a continuous process.

The important systems are the Engineered Safety Systems and other supporting systems necessary to operate the reactor in safe condition and to mitigate the consequences of serious accidents and prevent off-site exposure. The important systems identified for AMP are Core Spray System, Containment Spray System, Emergency Diesel Generator and EDG auxiliary systems, Emergency Ventilation System, Emergency Feed, Emergency Condenser, Biological Shield Cooling Water System, Reactor Building Cooling Water System, Salt Service Water System, Control Rod Drive Hydraulic System, Liquid Poison System, Compressed Air System, Station Battery, Reactor Protection System, Rx. Shutdown Cooling System, Class I, II & III Electrical Distribution System, Class-IV off site power distribution system for Engineered Safeguard System, Containment Isolation System, Auto Blow down System, Fuel pool and fuel pool cooling system, Reactor water clean up system & Fire detection and protection system

Important Systems (engineered safeguard system and other important support systems) are in good condition. The piping, valves, pumps and instruments are inspected, condition monitoring is done and actions are taken as required. Replacement of equipments is done on the basis of condition monitoring. Salt Service Water (SSW) pumps, Control Rod Drive hydraulic system main & booster pumps, Emergency Condenser tube bundles, Station battery are some equipments, which have been replaced. The old 3 X 50% capacity Emergency Diesel Generators (EDG) have been replaced with 3 numbers of 100% capacity EDG to obviate common cause failure and enhance the system reliability.

Other Critical Components are some important components necessary for safe operation of the plant and are not covered above. The critical components other than those listed above and identified for LMP are Reactor Relief Valves / Safety Valves, Secondary Steam Generators shell side Relief Valves, Primary Steam Isolation Valves (PSIVs), Start up Transformers, Primary Feed water Pumps and motors, Solenoid operated valves for CRD (SCRAM) system, Main Exhaust Fans, Drywell cooler fans, Instrument sensing lines of Reactor parameters, Civil Structures (Reactor bldg., Turbine bldg., Containment cooling bldg., foundations of important equipments & Stack.)

Other Critical Components like Reactor RVs/ SVs, Secondary Steam Generator (SSG) RVs, PSIVs etc. are checked/ inspected periodically as per programme and are maintained in good condition. The Reactor and SSG RVs are also being replaced with the new ones in phased manner. Reactor feed pumps, Plant main exhaust fans, emergency ventilation fans etc are inspected on routine basis and are covered in performance monitoring programme. These are in good condition. Safety related cables are visually inspected, IR checked and found to be satisfactory. A set of power and control cable samples removed from the location has been subjected to RLA and action is taken on the basis of the RLA findings.^[6] Additionally, Polarization Index (PI) checks have been introduced for assessing the cable condition.

Based on operating experience at TAPS and information from NPPs elsewhere, plant up-gradation has been done time-to-time. Addition of second station battery bank, second start up transformer, station black-out diesel generator, turbine supervisory instruments, Rod Worth Minimiser (RWM), Process disturbance analyzer, augmentation of fire protection system were some of the early major up-gradations carried out at TAPS.

Life Management Programme description

Effective Life Management of SSCs can best be accomplished under a systematic, umbrella type programme that co-ordinates existing activities relevant to managing ageing. The plant components identified for ageing management programme have been further classified in three categories:

1. Not replaceable,
2. Replaceable with re-engineering,
3. Replaceable

For each component, identification of modes of degradation has been done and the method for monitoring is indicated.

On the basis of monitoring and evaluation, ageing assessment for the components was done. In case ageing assessment for a component cannot be done from the monitoring methods, further assessment, surveillance and monitoring would continue. Accordingly, action plan for each component is finalised and included for ageing management.

1) LMP OF SIGNIFICANT SSC

The LMP of a few important SSCs is discussed in brief.

Containment

The primary containment of each TAPS reactor consists of a carbon steel drywell and carbon steel lined concrete chamber, the suppression pool and the common chamber. Drywell vessel weld joints inspection & shell thickness measurement is done periodically and no reduction in thickness has been observed. The drywell is provided with impressed current cathodic protection system for corrosion protection. All the penetrations are subjected to a structured inspection programme and replacement of expansion joints in drywell is done on the basis of examination results. A structured inspection programme exists for maintenance and overhaul of electrical & instrumentation penetrations.

Three nos. large vent pipes (9-feet 6 inches) from each drywell to suppression pool and the 76 nos. 24 inch size down comers entering the suppression have been inspected after emptying out the pools and condition was found satisfactory. The condition of all structures and liner plates inside Suppression pools and Common chamber were also thoroughly inspected and found to be healthy. The condition of the containment is also satisfactory.

Reactor Pressure Vessel

The RPV is cylindrical with hemispherical bottom head and flanged and gasketed upper head. The bottom head is welded to cylindrical shell. The cylindrical shell utilizes longitudinal weld seams in addition to girth (circumferential) welds. The low alloy high strength carbon steel body is clad from internal for minimizing corrosion. The Reactor Pressure Vessel (RPV) includes the vessel integral bottom head, vessel supports for mounting the vessel, the removable closure head, core support structure and nozzles. The RPV is designed and

constructed in accordance with ASME Boiler & pressure Vessel code, Section-I, 1962 edition and code cases 1270N & 1273N. As reactor vessel is not replaceable, its condition monitoring is very vital. It is covered by in-service inspection (ISI) of vessel and internals and surveillance testing of irradiated specimen for mechanical properties

The TAPS RPVs have Surveillance samples made from the steel of the same heat number which were drawn from the vessel base material, weld region and heat affected zone installed in both the vessels. These are being removed at periodic intervals and tested at the hot cells at RMD, BARC. The result (fracture toughness, RT_{NDT} , upper shelf energy) so far from the tests done indicates that there is sufficient fracture toughness, even at the end of 40 full power years. The conclusion from the experiments done so far indicates reasonable assurance for fracture toughness throughout the 40 full power years of operation for which TAPS reactor vessels are designed. It is worthwhile to mention that both units have been derated to 160 MWe from 210 MWe since 1985 and have been operated at these levels, which keep the neutron fluence level low.

Reactor Internals

The reactor internals including core spray piping and spargers and its attachments, top grid and its attachments, bottom grid and its attachments are examined visually during refuelling outages. No abnormality has been noticed. The reactor internal components namely core shroud, top grid, bottom support plate, steam dryer separator assembly are exposed to neutron flux. Fast neutron fluence assessment for all reactor internals conclude that the fast neutron fluence for forty full power years is less as compared to the threshold value for IASCC to set in.

RPV pedestal

Major degradation mode of concrete structure is strength reduction. Core sample were taken from the RPV pedestal concrete and tests were conducted including compressive strength and no significant degradation was found. The cube compressive strength obtained from the core test is more than the grade of concrete used. Also the specific gravity of more than 2.5 of concrete indicates dense concrete. Chemical analysis of concrete samples shows that chloride and sulphate contents are much less than limiting values. The pH value between 10 and 11 is acceptable. The cement content of 16.6% (assuming density of concrete as 2400 kg/m^3 and maximum cement as 400 kg/m^3) is acceptable. Microscopic analysis of concrete samples reveals that concrete at micro level is healthy.

Biological Shield

Biological shield is made of 5 feet thick concrete and has cooling coils passing through it. Sample Biological shield was taken and the results are indicative of good concrete.

Rx. Recirculation and primary piping

All primary pressure boundary systems were having material of construction of either SS 304 or SS-316 (except primary and secondary steam and feed water piping). These are class-1 piping as per ASME code. The generic issue related to failure of stainless steel piping was identified as IGSCC (Intragranular Stress Corrosion Cracking). Similar type of cracking was also experienced in overseas BWRs. To mitigate this, the pipings were replaced with better

corrosion resistant material (such as SS 316LN and SS304L/LN). Enhanced welding procedure such as last pass heat sink welding and use of preformed spools to reduce number of weld joints were introduced. The station has completed replacement of most of the susceptible primary system piping. Some of the piping had TGSCC (Transgranular Stress Corrosion Cracking) type of failure due to chloride content in thermal insulation applied on the pipelines

The stainless steel piping weld joints of class-1 system which are having IGSCC significance are being examined as per TAPS ISI Manual and ASME Sec XI requirements. All circumferential and longitudinal weld joints of the reactor recirculation loops A&B of both the units have been surface and volumetrically examined. No recordable indications have been found.

Other process piping

Degradation mechanism in process piping having two-phase fluid was identified as flow assisted corrosion and erosion and pitting. The piping was made of ASTM –A-106 GR-II carbon steel. The affected piping was replaced with superior ASTM-A-335 Chrome Moly (2.25% Cr-1% Moly) material, which is having better resistance to this environment. These piping are turbine steam extraction lines; boiler feed pumps minimum recirculation lines and spill lines of extraction system.

Circulating Water (CW) system piping:

The CW system piping and headers (approx two-meter dia) are fabricated from carbon steel plates. The system is used for circulating seawater through main condenser. Deterioration of the piping was experienced after two decades of operation. Major portion of piping and headers have been replaced.

Piping Expansion joints:

The piping coming from reactor through the primary containment has expansion joints. Based on the results of in-service inspection and experiences from other NPPs few expansion joints of primary containment penetration have been replaced. All the new expansion joints are indigenously designed.

Piping supports and hangers

All the piping and equipments are adequately supported for thermal, seismic and other loading condition as envisaged in ASME codes. The condition of these supports is regularly monitored during every refuelling outage for their integrity and setting.. As such no sign of degradation is noticed. Hydraulic seismic sway absorbers (snubbers) are provided to the recirculation pumps, piping and SSGs to accommodate dynamic loads imposed on the equipment. The function is to protect the equipment against dynamic load e.g. seismic loading. These are velocity sensitive instruments to minimize the movement of equipment and piping subjected to disturbing forces. These hydraulic type devices are having rubber elastomers as sealing material for hydraulic cylinder, snubber and adjuster valve and reservoir which are having limited life. The sealing elastomers for these snubbers have been developed from indigenous sources.

Re-circulation Pumps:

The reactor recirculation pump seals had frequent failures in the 1980s. To overcome this problem station modified the seal flushing and cooling arrangement and developed seal of simple and improved design from indigenous manufacturer. The additional seal cooling of demin filtered water is provided from CRD system, and thus the possibility of seal labyrinth pathways getting clogged was completely eliminated. After incorporating the above modification the seal's performance is satisfactory and unit outages related to pump seal failures are nil. Thermal fatigue resulted in failure of shaft of one of the pumps. The shaft severed below the pump bearing. Such type of failure was also reported by similar plants abroad. As a preventive measure station has replaced shaft of the pumps. These shafts have been developed from indigenous sources with improved design (better surface finish and less stress raisers). Delta ferrite measurements and in-situ metallography of the pump casing was done by AFD, BARC. No micro fissures were observed anywhere in the areas examined. The delta ferrite islands were observed in Austenite matrix at all the four locations where in-situ metallography was carried out.

On line diagnostic devices (vibration monitor) are now installed for these pumps.

Control rod drive mechanism

All the 69 drives in each of the units have been removed and reconditioned at least once. Based upon our past experience no failure has been noticed in the drive scram capability so far. Station has developed graphiter seals and other seals for CRD mechanisms.

Safety Related Cables and Connectors.

The degradation of cable can be due to thermal ageing of insulation, embrittlement and radiation effect. Visual inspection and Insulation Resistance (IR) checks are the monitoring methods used to assess the condition of the cable. Residual Life Assessment (RLA) studies of cables sample were carried out. Based on the results cable replacement programme is decided.

Core Spray & Containment Spray System

Internal inspection of all core spray & post incident pumps was carried out and condition was found satisfactory. All eight motors have been overhauled. Polarization Index (PI) checks of motor & cable is done along with pump inspection programme. All the system MOVs operability checks are done on monthly basis. MOVs major overhaul is done every ten years. MOVs current signature analysis is done based on operational observation. Condition of MOVs is satisfactory. The cables are checked for Insulation Resistance (IR) and found to be satisfactory. Instrumentation related to the system are calibrated and functional checks carried out and its performance is satisfactory.

Emergency Diesel Generator and EDG auxiliary systems up gradation

The old 3X 350 KW EDGs have been replaced with new 800 KW EDGs located in dedicated rooms in a seismically qualified new building. All the auxiliaries are new and hence sustain for a long operating period. Surveillance programme is in place to monitor its performance.

The specification for new EDGs was prepared as per IEEE-387 and vendors were qualified to supply the new EDGs. The EDGs were seismically qualified by analysis. Site acceptance tests were carried out for the EDGs as per IEEE-387-1995. The test carried out were Starting test, Load acceptance test, Rated load test, Load rejection test, Reliability test, Loss of site power test, Safety injection actuation signal test and Endurance test.

The cabling from the EDG to the load distribution buses was through seismically qualified cable trenches & cable trays. The cable laying was completed while units were operating and the end connection and testing was done when units were shutdown for upgradation. This resulted in considerable saving in outage period.

A PLC based Emergency Power Transfer Scheme (EMTR) was custom made to suit the requirement for the station. This serves the purpose of automatic tripping of non-essential loads and pick up of essential loads when off site power supply is lost. The logics of the scheme also address all postulated failures scenarios. All this was tested and qualified before restarting the units.

Segregation of Electrical Distribution System

This activity was one of the most challenging ones. When TAPS was built, the principle of segregation of safety related cables from non-safety related ones and also unit wise segregation of cables was not envisaged. So several cables were routed through same cable trays. A fire retardant compound was then pumped into these trays and the result was a solid block.

As part of the up gradations segregation of these cables had to be done. The power supply to several equipment was also required to be changed. This also involved significant amount of cabling through diverse routes.

A comprehensive study was made of all the cables and their routing. Based on the study and the requirements, detailed procedure was made for disconnection of cables, new cable laying, and connection to equipments and subsequent equipments testing. Whatever works could be done with reactors in operation were identified and completed prior to the outage. The actual cable disconnections etc. were carried out during the outage. Effort was made to carry out maximum activities simultaneously to save time. Post modification testing of equipments was done immediately for confirmation.

The work involved laying of more than 40 KM of cabling of more than 30 different types. Engaging skilled workers, providing effective supervision, detailed procedures and drawings, and continuous review, ensured the quality of the work.

Safety related cables

The cables used for safety related equipments can be classified broadly into two categories based on their locations - one inside the drywell and the other is outside. Basic difference between these locations is their environment. The drywell environment has high temperature, radiation and may have high humidity compared to outside environment.

Degradation of cable can be due to thermal ageing of insulation, embrittlement and radiation. Visual inspection, U bending test, water absorption test and Insulation Resistance (IR) checks are the monitoring methods used normally to assess the condition of the cable.

Residual Life Assessment (RLA) studies of cables inside drywell were carried out and based on the results some cables have been replaced.

The power cables outside the drywell are in good condition as seen from visual inspection and IR checks since they are not exposed to high radiation and temperature. Two samples from such locations were checked for RLA in BARC and were found in good condition. Polarization Index (PI) check has been introduced as additional conditional monitoring of the cable.

Emergency Ventilation System

The system performance checks are done on weekly basis. Secondary containment integrity is demonstrated by running the emergency ventilation fans prior to every refuelling outage. Efficiency of filters (particulate & iodine) is checked periodically as per technical specification. The filter assemblies are replaced based on efficiency test. The system performance is satisfactory. Internal inspection of the fans has been completed and the condition is good.

Emergency Condenser

Unit # 2 emergency condenser had experienced tube failure in year 1992. The failure analysis showed that tube had failed due to corrosion-assisted fatigue. Both the tube bundles of unit-2 were replaced with new bundles with improved tube material (SS 316 L) in the year 1996. Subsequently both the tube bundles of unit-1 have also been replaced in July 2001. The emergency condenser shell is also inspected from inside and found to be satisfactory.

The inspection of the EC piping is covered in the ISI programme. The steam and condensate piping inside the drywell (Class-1) have been inspected 100% in the 3rd inspection interval and the condition is satisfactory.

Reactor Building Cooling Water System

The RBCW system inspection is covered under the ISI manual. The pumps performance is monitored on monthly basis and it is found satisfactory. The heat exchangers had minor tube leak and they had been identified and plugged. The performance of heat exchangers is satisfactory.

Salt Service Water System

The pumps had served for the past 30 years in saline atmosphere and had shown sign of deterioration. All the pumps have been replaced with new ones. Piping is visually inspected and repair/corrective action taken up based on findings. Performance of the system is satisfactory.

Circulating Water (CW) system pumps

Extensive erosion of diffuser and failure of rubber bearings were the main problems experienced with the CW system pumps. The diffuser bowl assembly, impellers and other components have been successfully developed from local manufacturers and this effort is continuing. A special coating is now being applied on components subjected to seawater. Some of the spares, which were made of “Monel” material, were later on replaced with SS 316 /304 material as the original material was not available in India. The experience is satisfactory.

Station Battery

Each of the station batteries were relocated in dedicated rooms on seismically qualified stands during the upgradation outage. Weekly, monthly & quarterly surveillance programme is carried out on each battery bank. In weekly maintenance, voltage, specific gravity and temperature of pilot cells are monitored. In monthly & quarterly maintenance the above parameters are monitored for all the cells. Further half-yearly service load test is also carried out on each bank. The full capacity test of every bank is carried once in two years. The service life of each battery bank is around 10 years and the banks are replaced periodically.

Reactor Protection System

Performance monitoring of all RPS instruments is done on continuous basis. Performance trending has been done from year 1969 to 2000. Based on this study some of the instruments have already been replaced. The system cables are checked visually and by IR check and the condition is satisfactory.

Reactor Shutdown Cooling System

The performance of system is satisfactory. Earlier two of the three heat exchangers were used for fuel pool cooling. During system upgradation in 2005-06, this system was segregated from the fuel pool cooling system and now all three heat exchangers are used for shutdown cooling system. The system has been segregated unit wise too with two pumps and one HX serving each reactor. The third HX is a spare one and can be valved in for either reactor. The pumps are overhauled at regular intervals and their performance is monitored. Seat Leak tests of the MOVs are done during every refuelling outage for deciding corrective action if any. Tube failure was observed in one of the heat exchanger and three tubes were plugged. The condition of one heat exchanger has been checked by eddy current testing in 2005 and found to be satisfactory. The piping is inspected by visual, PT and UT as per ISI programme. The condition is found satisfactory.

Additional Control Rod Drive Hydraulic pumps & CRD hydraulic system unit wise segregation:

Each unit of TAPS is provided with a CRD hydraulic system for operating control rod drive system and for providing emergency feed to reactors. Each unit was having a train of two multistage pumps in series with a common standby train for both the units. In recent past gradual deterioration in the performance of the pumps was observed. Efforts to recondition could not be successful due to non-availability of spares. With lot of efforts, market survey and technical deliberations with indigenous manufacturers these pumps could be developed, manufactured and installed successfully.

The system has been segregated Unit wise by addition of one CRD hydraulic main feed pump and booster pump such that each unit has two CRD main feed pumps and two booster pumps. The piping was configured to segregate the system unit wise.

The power supplies to the equipments were provided from redundant sources.

Provision of Supplementary control Room:

Originally, TAPS was provided with all controls in the Main Control Room only. Safety evaluations on a global basis had concluded that a physically separate Supplementary Control Room (SCR) is required.

Based on this individual SCRs were provided for both reactors during the outage. Supplementary control room has been provided with the objective of accomplishing the following functions:

- a) Shutdown the reactor
- b) Maintain the reactor in a safe shutdown state.
- c) Ensure core decay heat removal for an extended period of time.
- d) Monitor all essential reactor parameters.

Sensors were identified to provide vital reactor information and indications were provided for them in SCR. Modifications were made in the existing circuitry to provide controls and indications in the SCR. All the modifications done were reviewed by experts before implementation. Testing of all the safety functions was done for commissioning the SCR. All Operating personnel were trained in operations from SCR prior to restart of the reactors.

Electrical Distribution System

The 220 kV Air Blast Circuit Breakers (ABCB) were provided for the generator transformers, startup transformers and feeders. All these breakers have been replaced by SF6 gas circuit breakers to address obsolesce. The 220 kV support post insulators have been phased out with high creepage distance insulators. Maintenance of all these equipments is carried out annually. The on line condition monitoring of 220 kV equipments is carried out by way of measuring the temperatures of current carrying clamps and insulators.

Fire detection and protection system

The fire protection system piping is laid underground and so far about 50 % of piping has been replaced. Fire hydrants and hose compartments each containing two lengths of 50 feet of 2.5-inch hoses is located around the building areas spaced about 150 to 200 feet apart. In side the building fire hose stations containing 75 feet long 1.5 inch with isolation valve, water nozzles etc. are provided at different locations. All the old hose in compartments have been replaced.

The Carbon dioxide supply for the protection of emergency diesel generator /air compressor room and turbine lube oil reservoir area was also replaced in the year 1997.

The ionization type conventional detectors has been further augmented by addressable type smoke detection system with optical, flame and heat type detectors covering all the vital areas in the plant.

Transformers

Transformer oil sample is tested for Break Down Voltage (BDV), crackle test and acidity test on monthly basis during monsoon period and quarterly basis during non monsoon period. Oil is also tested for physical properties and Dissolved Gas Analysis (DGA) on half yearly basis. Oil filtration is done periodically. Diagnostic testing of both the transformers had been done in July 2001 which included polarization index, capacitance and tan-delta measurement, partial discharge test and recovery voltage measurement. Condition is satisfactory on the basis of these analyses.

Primary Feed water Pumps and motors

The motor winding insulation was originally of class-B type. This has been changed to class-F type for better performance. Based on operating experience all the motors rewinding was done. The feed pump motor has been developed from indigenous vendor and many such motors has been developed and installed. Performance of the pumps is monitored on regular basis and performance tests are conducted during refuelling outage. Maintenance of the pumps is taken up based on performance tests findings. Also major overhaul of the pump/motor is taken up every five years. Condition is satisfactory. Efforts are on to develop spares from indigenous sources .

Feed water heaters

There are four feed water heaters in series. To improve the cycle performance and to run the units continuously for longer periods, availability of feed water heaters in the primary cycle plays a major role. These feed water heaters are vertical, channel-up, U-tube type and were supplied by M/s SWACO, USA. The material of construction of these feed water heaters is carbon steel shell and austenitic stainless steel tubes and internals made of carbon steel. These heaters were in operation since 1969 and subjected to various degradation mechanisms. This includes corrosion and erosion-corrosion (EC) of the heaters shell and fretting failures of tubes. The wet extraction steam caused erosion of shells and resulted in forced outages of units at times. The main Degradation mechanism found in the feed water heaters is mainly erosion corrosion due to heavy steam impingement and tube failure due to fretting vibration.

This phenomenon was noticed especially in primary feed water heaters. The damage was noticed in tube bundles due to direct impingement of steam resulting in tube leaks. Thorough review was made to improve the feed water heaters performance keeping the remnant life of the plant in view.

The development of these feed water heaters was taken up indigenously and all heaters were replaced with improved design in both the units. The performance of new heaters has improved thus the cycle performance also, as on date. All the feed water heaters except drain coolers have been replaced and replacement of drain cooler is also planned

2) Comprehensive Safety Review & Further Upgradation Program

The reactors have been designed for 40 effective full power year (EFPY) of operation and hence considerable numbers of years are left for continued operation. So far the reactors have

undergone about 21 EFY of operation. Based on studies and assessment of material condition of the reactors it was felt prudent to extend the life of the plant by another 20 years or so, and therefore, a Comprehensive Safety Review of the plant was carried out.

For considering operation of older nuclear power plant the regulatory process include continuous assessment and upgradation as well as discrete safety reviews such as Periodic Safety Reviews (PSRs). The key areas of PSR are review of operating history, comparison against current standards and review of ageing and degradation. In some countries PSR is considered as justification for continued operation of the plant beyond the design life. In some other countries the ageing management programme is the main safety related programme that forms the major consideration for the plant life extension.

For TAPS, the comprehensive safety review was done involving Operating Performance, Life Management Programme and Design Basis and Safety Analysis employing deterministic and probabilistic methods.

The salient recommendations of system modification were as follows:

- Upgradation of existing 3x50% capacity Emergency Diesel Generators by 3x100% capacity Emergency Diesel Generators.
- Segregation of electrical distribution system for Class-III (415 V AC), Class-II (120 V AC) & Class-I (250 V DC & 48 V DC) supplies into two zones with physical barrier.
- Redistribution of supplies to redundant loads from separate buses.
- Cable re-routing through diverse routes for redundant loads.
- Provision of Supplementary control room.
- Augmentation and unit wise segregation of Emergency Feed to reactors by addition of one pair of Control Rod Drive Hydraulic pumps.
- Unit wise segregation of Reactor Shutdown Cooling System and de-linking from Spent Fuel Pool Cooling system.
- Upgradation of Compressed Air System by providing additional dryer and powering of compressor by Class-III power supply
- Fire Protection system upgradation.

These recommendation have been implemented during upgradation outage of TAPS completed in 2005-2006.

3) Design Basis review

The review of Design Basis required identification of safety related systems, comparison of the safety features of the existing design with current standards, identification of deviations/non conformances and their safety impact and to recommend for, wherever required, viable alternatives to achieve safety comparable to current standards.

For system wise review against current standards a detailed review based on guidelines of US NRC Standard Review Plan NUREG 800 was performed. The standard review plan identifies the US NRC requirements as specified in general design criteria (GDC) of 10 CFR 50, to be met for specific systems based on the safety functions they perform. The area reviewed included conformance with single failure criteria/ redundancy, defense in depth, physical and functional separation of components and common cause failure vulnerability as applicable.

With respect to components / equipment of the identified systems, the review was performed with regard to their meeting the design parameter, and applicable design codes and standards. Insights from the results of PSA level –1 of TAPS was also used for the assessment.

4) Safety analysis review:

The existing accident analysis for TAPS was carried out in late sixties. With advancement of analytical methodologies and modifications carried out in the plant over a period of thirty years it was necessary to carry out fresh analysis as applicable. The identified analysis broadly covered (1) safety analysis of DBA including LOCA analysis for various break sizes in recirculation and steam lines, (2) fatigue analysis for reactor pressure vessel for integrity assessment and (3) probabilistic safety analysis level –1.

Condition Assessment of Civil Structures: (Reactor bldg., Turbine bldg., Containment cooling bldg. & Stack.)

Main plant building at TAPS comprises of Reactor Building, Turbine Building. Service Building, Suppression pool Building, Radwaste Building, Intake Structure and Stack are about 35 years old. Signs like minor cracks, reinforcement corrosion, spalling of concrete, etc were noticed on these plant buildings. This has necessitated conducting condition survey (including visual inspection, crack mapping, non-destructive test, chemical test, petrography etc) of main plant building.

Objective of the condition assessment was to estimate the durability, strength and stiffness with respect to the design requirements. The preliminary condition assessment was done based on the data obtained from the condition survey and testing. The items considered during condition assessment as per design requirements were functional requirements of the structural element, durability, design strength and stiffness requirements, affected strength and modulus of elasticity of the concrete, ductility and elastic limit of steel reinforcement.

Based on findings of detailed condition survey repair methodology was decided. This included the sealing of cracks and construction joints by polymer/ epoxy injection grouting, application of polymer-modified mortar after replacing the corroded reinforcement. After repair confirmatory NDT was done.

The Non Destructive Testing (NDT) techniques adopted for condition assessment were Visual inspection, crack mapping, crack propagation study peripheral entire area inside & outside, Cover meter test, Carbonation test, Impact Hammer test, Ultrasonic pulse velocity test, Half cell or surface potential, Electric radioactivity measurement test, Core extraction and compressive strength study, Petrography, Pull out test or internal fracture test and Chemical analysis

The tests concluded that the Compressive strength is 3000 psi and Specific Gravity > 2.5 (satisfactory). USPV test results were also satisfactory. After condition assessment, a protective coat of paint was applied on all the plant buildings. The structures are fit for several more years of service.

CONCLUSION

Replacement/ refurbishment of equipments and components showing sign of distress or ageing have been taken up successfully at TAPS. A well-planned life management programme is in place and being effectively implemented.

The major critical components namely Reactor Vessel and Containment, which are not replaceable, are in good condition. Other components are covered under surveillance and maintenance programme and repair or replacement can be taken up as required. Hence, the Life Management Programme of the safety related components is in place to ensure that integrity and functional capability are maintained throughout the service life of the plant.

Among its sister plants of similar vintage built in 1960s, TAPS is probably the only serving power plant and its performance indicators continue to be comparable to world median on all counts. The plant has generated more than 70 BU of energy at a very economical rate. A recently conducted comprehensive review of the plant including station-operating performance, ageing assessment & management, safety analysis and structural integrity studies concluded that the physical condition of the station is good enough for continued operation for several more years

TAPS has completed major up-gradation of safety related systems particularly the electrical systems to meet the current safety standards and practices. The result is that the plant now conforms to current standards of Safety and is now fit for long term operation With implementation of these upgradation plan and the ageing management programme in hand, the station is confident to continue operation safely and efficiently for several years to come..

ACKNOWLEDGEMENTS

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