Safety Upgradation of Fast Breeder Test Reactor

A.Babu, S.Sridhar, K.Dinesh, V.Alagudurai, K.Vinolia, S.Varatharajan K.V.Suresh Kumar
abb@igcar.gov.in; sethu@igcar.gov.in; dink@igcar.gov.in; vad@igcar.gov.in; vinolia@igcar.gov.in; svr@igcar.gov.in; kvsuresh@igcar.gov.in

Indira Gandhi Centre for Atomic Research, Kalpakkam, India
Presented by **Error! Unknown document property name.**

Abstract

Fast Breeder Test Reactor (FBTR) has completed 30 years of operation and is relicensed for further operation up to 2018. FBTR undertook upgradation of systems, components & structures to enhance the safety level, based on the operational feedback, maintenance issues and obsolescence. Further, post Fukushima, an extensive retrofitting programme is underway to protect the plant against external events such as flood, Tsunami and seismicity. As per the upgradation programme, several major components have been replaced. These include the Neutronic channels, UPS, computers of the Central Data Processing System, main boiler feed pumps, five control rod drive mechanisms, control rods, central canal plug, deaerator lift pumps, reheaters of the steam water system, station batteries, DM plant, Nitrogen plant, starting air system of the emergency diesel generators, entire fire water system including pumps and isolation dampers of the reactor containment building. Due to obsolescence, 6.6kV MOCB were replaced with VCB and 415V electro-mechanical relays were replaced with numerical relays. Residual life assessment has been carried out for the non-replaceable components based on the operational history, the design limits for each component by which their capability for continued operation has been ensured.

As a part of seismic retrofitting programme, the adequacy of the systems to withstand SSE for safe shutdown, decay heat removal and containment integrity have been assessed. In particular, plant buildings, anchoring of electrical & instrumentation panels and sodium tanks and other capacities were verified and wooden battery stands of UPS and control power supply were replaced with seismically qualified metallic stands. A new seismically qualified service building is under construction for housing two seismically qualified DG sets and emergency switch gears. Seismic Instrumentation to measure seismic activity in safety structures as well as free-field close to the reactor is being procured. Supplementary control panel for monitoring the reactor during non-availability of main control room is being implemented.

This paper details the various measures implemented for enhancing the safety of FBTR which includes post Fukushima retrofits also.

Key words: Boiler Feed Pump, Sodium Pumps, Design Based Flood, Seismic Instruments

1.0 INTRODUCTION

Fast Breeder Test Reactor (FBTR) is a sodium cooled, PuC-UC fuelled fast reactor, located at Kalpakkam, India. The reactor achieved first criticality on 18th Oct. '85 with Mark-I core of 23 subassemblies (SA) rated for 10.5 MWt. The reactor core was progressively enlarged and TG was synchronized to the grid in July `97. The present core has 52 fuel subassemblies rated for 27.3 MWt and is generating 5.8 MWe connected to the national power grid. The peak fuel burn up achieved so far is 165GWd/t.

FBTR is a loop type reactor. Heat generated in the reactor is removed by two parallel hydro-dynamically coupled primary sodium loops, and transferred to the corresponding secondary sodium loops through Intermediate heat exchangers. Each secondary sodium loop is provided with two once-through steam generator (SG) modules. The steam from the SG in both the loops is fed to a common steam water circuit comprising a Turbine

Generator (TG) and a 100% Dump Condenser (DC). Usually the turbine is in operation. In the case of its non-availability, reactor operation could be continued by dumping the steam in the DC. Stainless steel (SS316) is the material of construction for reactor vessel, primary and secondary sodium circuits.

As part of Periodic Safety Review (PSR) for relicensing FBTR for continued operation, the systems, components and structures were subjected to a rigorous requalification and residual life assessment programmes. Based on this, FBTR has been relicensed to operate up to end of 2018. During the reassessment period, FBTR undertook major safety upgradation of the plant systems to replace obsolete & aged systems & components, enhance the safety margins as well as to protect the plant against post Fukushima type events. Further, all the plant buildings and plant systems connected with primary & secondary heat transport, decay heat chain and systems required for maintaining containment integrity were seismically qualified as per the current standards. Some of the major upgradation undertaken in the mechanical, electrical, Instrumentation & control and computer systems and the post Fukushima retrofits implemented are discussed below:

2.0 Mechanical systems

2.1 Engineered safety systems

FBTR has a dedicated sodium flooding system with auto flooding and manual flooding provisions to flood reactor vessel (RV) in case any leak occurs inside A1 cell where reactor is located. Auto flooding is initiated on low level, leak detector actuation and temperature of the A1 cell reaching the threshold on 2/3 logic. With manual flooding, 1.5 m^3 sodium is injected into RV. If the sodium level in RV could not be maintained by auto flooding, manual flooding is initiated by opening the valves located inside the containment building (RCB). In case of Designed Basis Events (DBE), RCB will become inaccessible and the flooding valves could not be accessed for manual operation. The flooding valves (auto & manual) are being relocated outside RCB.

The Preheating & Emergency Cooling System (PHEC) facilitates preheating of the RV & entire primary system by circulating hot nitrogen through the double envelope of the capacities and piping to maintain the primary sodium hot whenever electrical heat from secondary could not be transferred during Reactor shutdown. The system also serves the emergency cooling of the core to remove decay heat whenever forced sodium cooling is not available due to any reason. For putting the PHEC system to emergency cooling mode, the inlet/ outlet valves of the PHEC internal circuit located inside RCB which are kept closed are to be opened manually. During DBA, RCB become inaccessible and these valves could not be accessed. Replacement of these manually operated valves with pneumatically operated valves is planned.

2.2 Reactor assembly

The Control Rod Drive Mechanism which experienced leaks in their primary bellows were replaced with fresh spare mechanisms as and when leaks were observed. Five mechanisms were replaced so far. The control rods & their sleeves which have neared the fluence limit were also replaced with fresh ones. The central canal plug (CCP) with 1mm thermocouple which were prone to failure was also replaced with modified CCP of longer length with 4nos. 2 mm thermocouples.

2.3 Fire water system

The Fire water system comprised of a ring main of buried Cast Iron pipe construction. These pipe lines laid in the eighties were prone to leak very frequently. Leaks were found from the caulked joints and some from the pipes. Inspection of the pipeline indicated brittle nature of the pipe as corrosion has eaten away the iron content in the CI pipe leaving a graphite matrix. Longitudinal cracks of length more than 3 m also were observed on few occasions. The repair of the pipe line was posing a major challenge as no isolation valves were provided for segmental isolation. For any repair activity, the entire pipeline has to depressurised and emptied. The recurring leakage problems and pipe failures indicated total degradation of the piping system. Moreover, the fire water ring main has to be kept pressurised near the operating pressure as per the latest fire water standards, to prevent fatigue failure of pipe line due to frequent pressurisation and depressurisation. This was found to be not possible with the negative suction pumps which were provided with foot valves to keep the pumps primed. These foot valves were found passing or getting damaged when subjected to high pressure as mandated by the standard. In order to overcome these problems, it was decided to have fire water ring main with fully welded seamless carbon steel pipes laid above ground and existing fire water pumps were replaced with submergible type pumps of same capacity. Instead of one diesel driven pump & one motor driven pump, two diesel operated pumps and one motor operated pump were provided for better availability and redundancy.

2.4 Air conditioning system

The air conditioning of the plant was showing a degradation affecting smooth functioning and longevity of I& C systems and other sophisticated instruments and components. The quantum chilled water, FBTR gets from a centralised chilling plant located elsewhere was found to be less than the required. FBTR chillers were standby chillers of less capacity which can cater to a few areas. These chillers also became obsolete. FBTR went for a major revamping of the chilled water system by adding 550TR capacity chillers (2 nos. 150 TR screw chillers and 1no. 350 TR centrifugal chiller) to have a fully dedicated system. This was further augmented by installing 2 nos. High capacity high head chilled water booster pumps which deliver 360m^3/h at 45mlc head. The aged single skin air handling units (AHUs) of most of the areas were replaced with double skin AHUs and the ducts were cleaned using high vacuum system. The augmentation has helped in significant improvement in the air conditioning of the plant.

2.5 Secondary sodium system

In secondary sodium main circuit there was a communication line between surge tank and expansion tank through which hot sodium (490^{o}C) from surge tank flows to expansion tank where the sodium temperature is 290^{o}C. As the mixing of hot and cold sodium can create thermal ratcheting in the mixing zone inside expansion tank, it was posing as a major constraint in raising the sodium temperature near design value. The communication has been provided to facilitate venting of surge tank to expansion tank during sodium dumping. This line has been converted to a hot argon line with pneumatic valve in between to aid level maintenance in the surge tank.

2.6 Diesel fuel storage & transfer system

There were four underground MS storage tanks for storage of diesel and furnace oil, each having a capacity of 30kl each. One of these tanks which stored furnace oil developed leak. As a proactive measure all the tanks were replaced with corrosion resistant FRP tanks with double wall construction having leak monitoring arrangement. The storage capacity was also augmented to 120 KL to meet 15 days of DG operation. The piping was modified and the transfer pumps were provided with suction priming chambers and flame proof motors.

2.7 Steam water system

The steam water system of FBTR has undergone a major revamping programme. Originally the feed water heaters were of contact type and these were prone to level fluctuations leading to reactor trips. Also, the main boiler feed pumps were not suitable to withstand transients occurring during change of state of reactor. On several occasions, the pumps were found getting seized due to bearing damage. This was overcome by changing the existing pumps which were imported with indigenous pumps with increased NPSH margin.

Severe erosion damages were observed in the steam bypass & dump valves used for steam generator (SG) pressure and auxiliary steam header pressure as these valves were not conducive for two phase flow which prevails in the system during SG valving in and during reactor shutdown. These hydraulically operated valves were replaced with indigenous pneumatically operated valves. Operation of the valves with pneumatic actuators has been a main change taking into account of the fire safety issues of the use of hydraulic oil for high temperature valves.

3.0 I&C systems

3.1 Neutronic Instrumentation system

The first generation neutronic channels of FBTR, installed in 1984, had several issues like non-modular construction resulting in difficulty in maintenance, noise-pick up, absence of test facility, component obsolescence etc. Hence the complete neutronic channels of FBTR were upgraded with improved channels. The new channels also had several features like plug-in modules facilitating online maintenance, online test facility, tamper-proof access, micro-processor based reactivity computation etc. The cabling from neutron detectors to electronic channels was upgraded to super-screened cables which resulted in improved resistance to noise pick-up. Spurious alarms and trips from the nuclear channels were further improved by suitably modifying the grounding scheme for these channels.

3.2 Emergency Power Supply system

During surveillance checks on the Diesel Generator (DG), DGs failed to start on few occasions. These failures were attributed to malfunctioning of the components in the starting air system, including the directional control valves (DCVs), pressure regulator, start-stop lever etc due to carry over of moisture and oil in the starting air, due to the absence of an air-drier. Hence, the starting air system was upgraded with provision of dry filtered air and components with improved design, supplied by the OEM. In the new design, DCV has been replaced with spring-to-return pneumatic cylinder which ensures that the fuel rack is in work position in the absence of pneumatic supply. The new system also had provision for soft starting the DG, which greatly reduced unwanted stresses encountered during testing of DG. With these improvements, the reliability of starting the DG has significantly improved.

3.3 Auxiliary steam generating system

The package boiler of FBTR had issues while attempts were made to start after a prolonged period of shutdown. There were frequent spurious trips due to malfunctioning of the components. I

n addition, it was also difficult to locate the initiating fault due to the absence of diagnostic features. Due to component obsolescence, maintenance had become difficult. Hence, it was decided to upgrade the package boiler instrumentation with state-of-the-art PLC based system. As part of upgrading, new modulation mechanism and new feed-water bypass control valve were installed. Various pressure, temperature and level transmitters were upgraded, along with the UV flame detector. The PLC based control system provided all information in a single display, helping the operator to monitor the start-up process. The performance of the package boiler instrumentation has been satisfactory.

4.0 Electrical Systems

4.1 Transformers & distribution system

In FBTR electrical system, two 10 MVA, 33 kV / 6.6 kV main transformers, ten 6.6 kV / 433 V auxiliary load centre transformers and connected circuit breakers are in service for the past 32 years. There was no major fault or breakdown in this equipment. Taking into account their ageing factor and to increase the residual life further, the transformers were overhauled and reconditioned at the manufacturer's works. The servicing involved vacuum treatment for the core and windings, total replacement of oil, gaskets and radiator valves. As the original supplier of 6.6kV switchgear had phased out production, all the eighteen MOCBs (Minimum Oil Circuit Breakers) were replaced with state of the art VCBs (Vacuum Circuit Breakers). Similarly, existing electro-mechanical protective relays have become obsolete and started showing deterioration in their performance. Hence all these relays were retrofitted with state of the art numerical protective relays. Existing LT air circuit breakers (15 nos.) which have become obsolete were retrofitted with new model air circuit breakers of same make retaining the panels and cradles.

The two lengths of aged Paper Insulated Cables for the two incomer transformers of FBTR, which have been in service for more than thirty years, were replaced with joint less XLPE cables.

4.2 Control power supply

Due to degeneration in performance, the 220V, 1φ, 50Hz UPS (Uninterrupted Power Supply) was replaced in 1998 by a state of the art system. The tubular batteries in the 220V 1φ UPS, 220V, 48V & 24V DC control power supply systems and in the Ward Leonard drives have been replaced by high performance Plante cells. The batteries are being replaced with a periodicity of 10 years.

4.3 Lightning protection

36 nos. lightning masts and 52 nos. earth pits around the plant in the electrical grounding system were totally serviced and renovated. Motors/Generators in all systems including Sodium Pump Drives have been replaced by spares, whenever need arose. The machines taken out are serviced, rewound if required and kept as spares.

5.4 Reactor trailing cable system & power distribution to primary systems

Trailing cables in block pile are used to extend power supply to Small Rotating Plug (SRP) drive motor, SRP liquid metal seal heaters and other indications. The winding/unwinding and traversing through a torturous route were causing bending/unbending of these trailing cables leading to individual core failure. The trailing cable system consisting of a set of pulleys and counterweights was modified by eliminating all the sharp bends in the cable routing and by changing the orientation of the cable tower. After this modification, no cable failure has taken place.

Power cables had failed nine times in the penetration to RCB and the failures were found to be due to overheating as the spacing between cable joints was very short. Hence, the cable penetration joint assembly was redesigned by increasing the length (from 300 to 600 mm) and thereby giving more space between the individual cable core joints. Also a spacer disc to keep uniform radial clearance was introduced and a surveillance was introduced to test the joint for contact resistance. It may be noted that the cables in RCB do not see any radiation.

5.0 Computer systems:

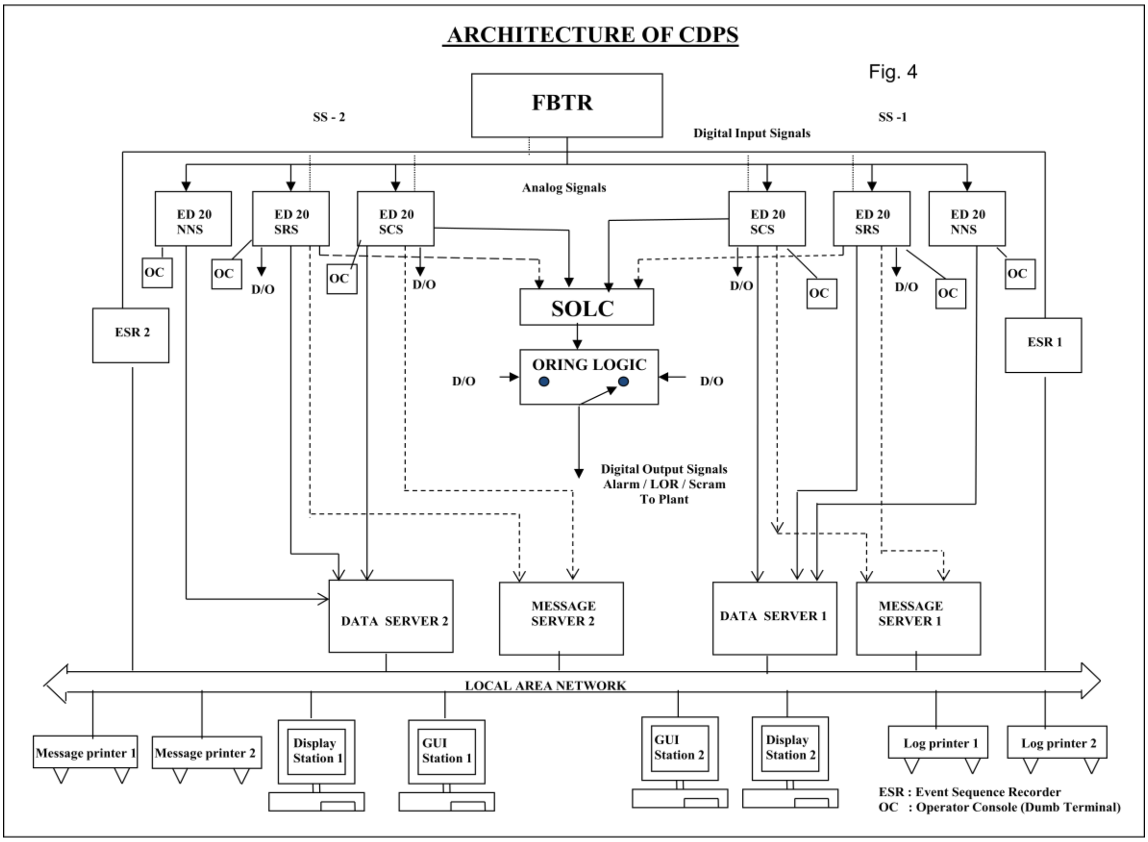
Fault tolerant Real time computer systems are used in FBTR for carrying out safety critical supervision such as supervision of fuel sub-assembly temperatures for any flow blockage, clad hot spot and undesirable power excursion and to take safety action in the event of detection of any one of them. Safety related supervision functions carried out by these real time computer systems in FBTR are Start-up check for Reactor, Discordance supervision, fine impulse testing of safety and Reactor protection logic, Steam generator leak detection, General supervision of process parameters against alarm limits, trip supervision and start-up check for fuel handling. These systems supervise and control over 640 analog and 320 digital signals from the plant.

Nearly 900 analog signals representing temperature, flow, pressure, level of sodium and neutronic signals are wired to computer-I. Nearly 600 important analog signals are duplicated to computer-II. The analog signals are classified as Fast scanned signals which are scanned every 0ne second, Medium scanned signals that are scanned every 20 seconds and slow scanned signals that are scanned every 5 minutes interval. In Computer-II there are no slow scanned signals. 500 digital signals representing neutronic trips for alarm, LOR and scram conditions etc. are wired to both computer systems. The analog signals are compared by CDPS against upper and lower threshold. If the signals exceed the threshold, then alarms are energized through digital outputs. The digital outputs of each computer are wired to 'ORING' logic. The ORed output is fed to the plant.

The computer systems were replaced in a phased manner taking into account of the obsolescence and failures. Originally, CDPS had two TDC 316 computers of 70's design. One of the 3rd generation TDC 316 computers were replaced with a 4th Generation PDP 11/84 computers in the late 80's. The system with J11 microprocessor @ 18MHz, had hardware floating point processor, 1MB ECC memory, 450 MB Hard disk, Magnetic tape, Floppy disc along with Analog I/O and Digital I/O subsystems. Here the analog signals were classified as fast with 1 second scanning interval and medium with 20 seconds scanning interval. The system used disc based RSX -11M real time multitasking, multi user operating system with compilers for FORTRAN –IV. The application software were developed in Fortran and all the application software were memory resident and were running in parallel under the control of operating system. Reactivity calculation, Hydrogen leak detection, Control Rod level discordance check, History dump during LOR or Scram, Operator console for functions like call a measure, trend, compute 'ai' constants for core thermocouple, Auto flooding condition check, Siphon break line check, Rate of raise of power check, Log power supervision etc. are done by the system. Due to the increased memory size, additional facilities viz. Graphical user interface for plant mimics, Graphical trend, History, dump on demand, classified logs etc. and History storage for messages were added.

In the year 1994, the second TDC 316 system was replaced with VME Bus based Motorola 68030 processor @25MHz, 4MB ECC memory, 540MB SCSI hard disk, Magnetic tape with Analog I/O and Digital I/O system. The system used Disc based Versa DOS real time, multi tasking, multi user operating system. The application programs as in PDP 11 were developed in ANSI C language. As in PDP 11 system, software simulator program was developed in C to test the application programs. Also an utility software was developed here to modify the software parameters online. Unlike PDP 11, the parameters in common memory can be modified online without the need to restart the software. A monitor program will give control to all the application programs sequentially depending on the interval in which application has to run. For instance core monitoring program runs every second, Fine impulse test program runs every 3 seconds interval, General supervision program runs every 20 second interval and so on.

The PDP 11 and Unipower-30 systems were connected in fault tolerant configuration such that PDP 11 system is online and Unipower-30 system was active standby. These systems were working satisfactorily. Due to ageing and difficulty in maintenance due to component obsolescence, it was decided to replace these systems one by one. Unipower-30 system was replaced in 2006 and PDP 11 was replaced in 2009 by identical Motorola 68020 @25MHz based real time embedded systems as shown in fig 4. The VME bus based CPU card has M 68882 FPP, 1 MB EPROM, 2 MB SRAM with EDAC facility, 128 KB EEPROM, programmable watchdog timer, 2 Nos. Hardwired TCP/IP ports and 4 Nos. RS 232C ports.



ARCHITECTURE OF CDPS

Fig. 4

During replacement, the safety critical functions are segregated from safety related and non-safety functions. Thus there are three ED-20 based embedded systems namely, SCS, SRS and NSS as shown in fig 4. Unlike earlier systems, now both systems are made identical with respect to no. of analog signals, digital input and output signals, functions, hardware etc. waterfall model was used and IEEE guidelines were followed for software development. Also the event sequence recorder is identical. The software is developed in C using tasking compiler and is downloaded to EPROM in the CPU. The configurable data are stored in EEPROM. While embedded system supervises and takes safety action, the non safety related functions like printing and displaying the messages, providing data to the graphical user interface are done by a dedicated industrial PC based systems. A dumb terminal is connected to the embedded systems for modifying the thresholds online under administrative control. The PC based GUI provides information for the operator and is password protected. The design of the system is such that no external system failure would affect the embedded system and any internal failure of the embedded system would initiate switch over to the standby system or order shut down to the plant as the case may be. Since there are no hard disk attached to the embedded system, and there is no operating system, the reliability of the system is high when compared to the earlier systems. Since the system uses in-house developed Hardware and software, problems like obsolescence and functional modification of software due to requirement change would not arise.

7.0 Seismic & post Fukushima retrofits

Seismic re-evaluation of FBTR has been carried out for a review based ground motion (RBGM) with peak ground acceleration (PGA) of 0.221g. All the main plant buildings and systems connected with core cooling, decay heat removal, maintenance of containment integrity & monitoring were qualified for the revised level. Seismic walk through was conducted throughout the plant and the deficiencies noticed were fixed. Un-anchored electrical panels, instrument panels, equipment & components were anchored to the floor. Re-evaluation of the anchors of the existing anchored tanks and components was done and inadequacy noticed was corrected. The wooden battery stands of UPS, 24V DC & 220V DC power banks were replaced with anchored seismically qualified metallic stands. The unreinforced masonry walls of the main building were strengthened by providing metallic reinforcement structures.

Fig.I: Easy fixes of loose components in RCB

Subsequent to the Tsunami of 2004, Reassessment of the design basis flood level (existing 8.5 m w.r.t. RL) of Kalpakkam was done. The revised flood level was estimated to be 12.01m with respect to RL. As FBTR Finished Floor Level (FFL) is 11.5 m, all the entry points to the plant were elevated to 12.1 m level by providing elevated ramps and bunds. As the estimated Tsunami level for kalpakkam site is 13 m, suitable removable Flood gates of 1m height is being provided at all the entry points. All the areas below ground level have been provided with dewatering pumps. The cooling tower has been provided with a bund of height 12.1m from RL all around as it is connected to the plant building through an underground tunnel and any flooding in the plant vicinity will flood the plant building through this path.

It was decided to have a back-up control room for FBTR, in case the main control room (MCR) is unavailable due to any reason. This Supplementary Control Panel (SCP) will help in bringing the reactor to a safe shutdown and in monitoring the vital plant parameters and ensure that decay heat is removed. The SCP will be located in turbine building, which is adjacent to control building, and is already seismically qualified. The SCP will be approachable by diversified paths. It is ensured that while all essential plant parameters and controls are brought to the SCP, the control desk is ergonomically designed to resemble the control desk in the MCR to help the operator in smooth operation of the plant. The sensors for the SCP will be dedicated ones where ever possible; suitable interfacing has been adopted to ensure no loading of signals which are shared by instrumentation channels of MCR and SCP. As an interim measure, facility to SCRAM the reactor as well as to monitor reactor power from an alternate location other than MCR has already been made.

Seismic Instrumentation to measure seismic activity in safety structures as well as free-field close to the reactor is being provided. Apart from continuously monitoring the seismic activity, the instrumentation will also alert the operator if any of the seismic sensors measure activity beyond threshold. Recording of seismic activity is trigger-based, covering both pre-event and post-event excursions.

Solar powered street lights were installed in strategic locations. Similarly solar powered LED lights were installed in control room, emergency diesel generator area and other strategic locations. Two mobile diesel generators of 140 kVA capacity each were procured to cater to the emergency loads in case of the non-availability of main emergency diesels.

For housing two seismically qualified Diesel Generator sets and emergency switch gear, a new seismically qualified flood safe building was constructed. DG sets & switch gears are in the advance stage of procurement and will be installed shortly.

8.0 CONCLUSION

With the major upgradation of plant systems and the completion of the balance ongoing jobs, the plant will be protected against seismic events and flooding and also will be meeting the current regulatory standards and is expected to get regulatory acceptance for operation up to 2028.