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SAFETY EVALUATION OF

INDIAN NUCLEAR POWER PLANTS PHWRs

AT MADRAS ATOMIC POWER STATION (MAPS)

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1.0 Introduction

Madras Atomic Power Station housing two PHWRs of 220 MW(e) rating each is located in the east coast of Tamil Nadu about 65 Km south of the city of Chennai. Unit 1 reactor went into commercial operation in January 1984 and Unit 2 in March 1986. The eastern coast where MAPS is located is prone to cyclonic storms and the elevations of the different buildings in the plant are built taking into account adequate margins for higher storm surges. The plant had witnessed the Indian Ocean Tsunami on December 26, 2004 when Unit-2 was operating at near full power and was shut down safely following loss of cooling water pumps in the sea water pump house. The pump house operating floor is located about 2 meters below the level of the main plant buildings and is connected by a submarine tunnel about half a kilometer long to the intake well. During 2004 Tsunami, one of the Process sea water pumps on class-IV power supply continued to operate. However, due to debris brought in by Tsunami the travelling water screen was getting choked and had to be cleaned. The pump operated intermittently for cleaning the screens and in the intervening period fire water addition to process water system, through the design provisions was resorted to maintaining once through cooling. It should be borne in mind that subsequent to Tsunami, improvements have been effected and a tsunami bund has been added as part of the PFBR out fall channel which combines with MAPS outfall. This is expected to absorb considerable energy from the tsunami wave and result in lesser wave height when it reaches the structures on the shore.

During EMCCR campaigns in MAPS-1&2 , several upgradations have been carried out like, segregation of cable routes to reduce the probability of common cause failure, new Power UPS system in separate building at higher elevation to replace the motor generator sets which were initially used for class-II power, Upgradation of 240VAC control power supplies with additional redundancies upgradation of cable fire safety and fire alarm systems etc..

In MAPS, during loss of electric power conditions, core cooing is achieved by natural circulation of primary heat transport system heavy water through steam generators. This is a complete passive system for removal of decay heat. Steam generator secondary side inventory is to be replenished in order to maintain natural circulation. Hence multiple provisions are available to maintain SG secondary inventory under all possible conditions to ensure core cooling. As the decay heat reduces with time, the quantity of water requirement to replenish SG inventory also reduces.

2.0 SCOPE AND OBJECTIVE

The Task Force has covered the terms of reference given in the Office Order. The expected condition of design water supply routes and power supply routes have been studied in depth and maintaining the cooling in beyond design basis scenarios.

3.0 EXISTING DESIGN FEATURES

3.1 Important Plant Specifications and location

Important Elevations

Mean sea level	6.096 m
Pump house operating floor	8.63 m
Turbine building ground floor	10.668 m
Reactor Building ground floor	35 feet eq. 10.668 m
Spent fuel pool	10.668 m
Additional DG-5	12.518 m
2 diesel fire fighting pumps	12.768 m
6.6 KV & 415 V switchgear	10.668 m
Class-II and Class-III switchgear	20.668 m
Batteries and Power UPS	Above 18.3 meters except for Unit 2 UPS 1 400KVA for which battery can remain operable for flooding upto 15.2 m.

3.2 Design Decay Heat Removal Provisions

i) 2 x 100% BFPs (class IV) located at 10.668 meters elevation (TB ground floor)
ii) 2 auxiliary BFPs (class III) 2.5% capacity with 60 Kg/cm^2 discharge pressure located at 10.668 meters
iii) 1 emergency BFP (class III) 2.5% capacity with 16 Kg/cm^2 discharge pressure located at 15.668 meters.
iv) Gravity feed to steam generators from deaerator storage tank (valves at 15.668 meters)

v) Firefighting water addition to steam generators – one connection each for north and south banks of steam generators with electrically operated valves (class II) at boiler room near steam generators. High pressure emergency injection system with 30 Te D_2O accumulator at 60 Kg/cm^2 (shared between both units and located west side of Turbine Building 2).

vi) Firefighting water addition to emergency injection header from moderator pumps (east side of reactor buildings

vii) Firefighting water back up to H.P. process water system (valves inside reactor building at 35 feet – ground floor)

viii) Process sea water heat exchangers at 10.668 m in TB, and process sea water pumps/Emergency class III process sea water pumps at 8.63 m at sea water pump house.

ix) H.P process water to shut down cooling heat exchangers (Pumps at 10. 668 m elevation in Turbine building)

3.3 Additional Provisions

i) Firefighting water addition to PHT storage tank (East side of Reactor buildings near small break out panel)

ii) Firefighting water back up to shut down cooling heat exchangers (connection near the heat exchangers at boiler room).

iii) Second fire water connection to SGs, outside the turbine building at the auxiliary transformer annex on the west side of Turbine buildings at about 11.5 m elevation)

3.4 Seismic and Flood Design Status

The main plant buildings have been analyzed for 0.22 g (6.0 Richter scale at 20 Km distance). All emergency power equipment and deaerator storage tank and piping have been strengthened during the exercise and have been qualified for the above earthquake conditions.

The design basis flood level is about 10.45meters from storm surge point of view. The main diesel generators are located at 10.668 meters with an additional DG located at 12.518 meters which is common for both the units and can be connected to any bus in either of the units. Similarly two diesel driven fire fighting pumps had been relocated during plant up gradation at 12.768 m. During 2004 Tsunami, the level reached in pump house interior was about 10.45 meters and the surrounding areas around pump house about 10.55 meters. No water entered any of the main plant buildings.

4.0 BEYOND DESIGN BASIS NATURAL EVENT SCENARIO FOR WHICH PLANT SYSTEMS ARE ANALYSED

For the purpose of checking the availability of plant systems during external natural events, the design basis flood and safe grade elevation worked out for Prototype Fast Breeder Reactor at Kalpakkam site, which is at present under construction is taken.

For a period of 1000 years, the original safe grade level for PFBR was designed as 14 m. However, since the original raft construction before Tsunami wave, inundated by Tsunami water, the raft had to be redone taking the original raft as datum. In view of this, the finished grade level for PFBR became 15.4 meters. All safety related structures of PFBR are located at 15.4 meters or above. For MAPS, study report in 1981 by CWPRS, taking into account 1977 severe cyclone at Andhra, the safe grade level from cyclonic storms had been arrived at as 10.45 m. Hence for the purpose of this analysis, a flood level of15 meters is taken. If at a later date, this figure gets revised on further review, the new figures can be adopted, to revise the analysis.

In addition, no credit is taken for time available from tsunami alert and actual occurrence of tsunami, though in a more realistic scenario tsunamigenic earthquakes are expected to occur only beyond Andamans, and there will be about 2 to 3 hours' time available to shut down and cool down the reactors in a normal manner. Equipment below this elevation of 15 meters in turbine building, sea water pump house and firewater pump house are not given any credit in the cooling down of the reactors. Class-II and Class-I power supplies, Class-II MCCs, 48VDC and 240VAC control power supplies are expected to be available since they are located at higher elevation. Main control room is expected to be inhabitable.

For the above, beyond design basis scenario, the review provides for maintaining core cooling without any significant augmentation from outside for a period of **ten days.**

5.0 ASPECTS CONSIDERED

After detailed discussions, the minimum requirements to be addressed for core safety and spent fuel safety has been arrived at as given below:

- Make up and cooling of Primary Heat Transport System
- Make up to secondary side of Steam Generators
- Make up to moderator system including calandria
- Make up to end shields

- Make up to calandria vault in case of standardized PHWRs having water filled calandria vault
- Hook up provisions from outside the Reactor Building for the above water addition requirements from alternate sources other than the designed water routes
- Augmentation of on site water sources to be designed to be intact following tsunamis
- Mobile pumping equipment/Other methods that do not require power
- Alternate Power sources for the mobile pumping equipment
- Periodic Spent fuel bay make up

6.0 REVIEW OF EXISTING SYSTEMS AND EVENT PROGRESSION

Following tsunami strike, in case of the projected scenario of flooding upto 15 meters elevation, Class IV and Class III power supplies will be lost. Crash cool down should be initiated immediately but not later than 6 minutes from class IV power failure. The SG secondary side pressure is expected to reach about 3 Kg/sq.cm at around 20 minutes and PHT temperature around 150^{o}C. Immediate addition of water to SG secondary should be resorted to through proposed alternate methods of pumping deaerator water .This is discussed separately. ECCS system should be lined up when class II is available (for about 30 to 40 minutes) and PHT pressure should be maintained at about 60 Kg/sq.cm. Subsequent make up to secondary side should be done using augmented water sources through hook up points proposed.

The aspects to be considered are discussed below item wise:

6.1 PHT

For maintaining PHT system inventory and cooling, provisions to be made to add light water to the headers directly at higher pressure of about 50 Kg/sq.cm. Mobile fire tenders having suitable pump capacity are known to be available and should be finalized at detailed engineering stage.

6.2 SG Secondary

Immediately during crash cool down, water addition to secondary side have to be started. Possible methods are-

i) Through a new pump capable of pumping 60 cubic meters hour at 100 meters head to be installed at 20.668 elevation and powered from class II taking water from deaerator
ii) Connecting a dedicated pressurized tank of 100 to 150 cubic meters capacity located at H.P. Heater Floor

Subsequently, water should be added from deaerator by pressurizing with nitrogen. Suitable features using liquid nitrogen cylinders to be worked out. The current role of emergency process water storage tank at turbine building roof is to be reviewed and if acceptable should be disconnected from process water system and dedicated for water addition to deaerator.

For longer SBO scenario, augmentation in the form of suitably designed under ground concrete tank of 750 cubic meters capacity with suitable auxiliary tanks and motive equipment is to be done.

6.3 Moderator and Calandria

In MAPS type of reactors calandria sprays will not be available after moderator pump stops on loss of class II supply after about 30 to 40 minutes. Hook up provisions should be engineered to add light water and fill up dump tank and calandria. It is suggested to use the existing fire fighting line connection available to emergency injection line from moderator pump discharge from outside Reactor building, by suitable additional quick connect type, hook up points.

6.4 End Shield

At present provision exists to add fire fighting water to end shields but the connections and valves are inside reactor building. Spare Embedded Parts have been identified in primary containment wall and can be used to install a hook up point outside RB to add water to end shield. In addition the existing provision to add water to PHT storage tank should be strengthened suitably. This should be addressed at the time of detailed engineering.

6.5 Summary of Additional Hook-up Points

i) To PHT system through ECCS route directly to headers for injecting under pressure (Possible location is in the ECCS inlet headers to each Reactor building).

ii) To Secondary side through existing feed water line fire water addition facility to feed water headers outside RB. (to be compatible for quick connection from mobile pumps).

iii) To moderator and calandria through an additional hook up facility in the existing fire fighting connection to moderator pump discharge.

iv) New line to end shield from outside RB with necessary isolations and suitable for mobile pump connection.

v) Suitable line with quick connect arrangements for mobile pumps water addition to spent fuel storage bay.
vi) Hook up using quick connect couplings should be provided in the existing fire fighting water addition facility to SG secondary outside the turbine building.

6.6 Augmentation of Water Sources

i) New Underground concrete storage tank of 750 cubic meter capacity along with 25 cubic meter capacity tank which can be pressurized to 10 kg/sq.cm.
ii) Additional 100 to 150 cubic meter capacity tank at HP heater floor (to be kept pressurized to 10 Kg/sq.cm)
iii) Reengineering of process water emergency storage tank for using its inventory to make up Deaerator/Steam Generators.

6.7 Alternate Pumping Equipment

The suggested methods are

i) Mobile fire tenders which can up at 10 kg/sq.cm as well as at about 40 to 50 kg/sq.cm . It is understood such system pumps are available and to be suitably engineered. At least two dedicated tenders are required for every twin unit site.
ii) Truck mounted diesel driven pumps of suitable capacity
iii) Liquid nitrogen power packs to drive water from tanks by pressurizing
iv) CNG driven pumping equipment
   - The type and quantity will be decided while detailing.

6.8 Alternate Power Sources

i) Truck mounted diesel generators of 150KW capacity, air cooled, with suitable starters to connect to mobile electric pumps or existing small pumps.
ii) Truck mounted CNG driven diesel generators
iii) Fixed diesel generators with air cooling located at higher elevations with suitable fuel storage and quick hook up provisions to various loads (with starting equipment).
iv) Solar powered small lighting grids for all important areas
v) Sufficient number of portable emergency lights kept charged and ready to operate.

6.9 Spent Fuel Storage Bay Make up

The spent fuel bay is located at 10.668 meters elevation (ground floor) and suitable hook up provisions to be provided to transfer water from tankers taking water from on site reservoirs which are about 750 meters away on the west side. But this will be required only after a period more than 10 days by which time arrangements can be made to make up.

7.0 RECOMMENDATIONS

7.1 Short Term Recommendations

- Provision of medium size air cooled power packs either driven by CNG or diesel and can be mounted in a truck or diesel driven pumps mounted in a truck.
- Provision of small pumps with requisite head deriving power from the power packs to pump water to SG and other applications.
- Engineering to delink the process water emergency storage tanks from the process water system and using for making up deaerator inventory.
- Strengthen existing firewater line to add water to PHT storage tank and add separate line from outside RB to add water to end shield . Suitable hook up connections for connecting water from other sources like mobile diesel driven pumps are to be add
- Battery operated measurement provisions for the following:

– Levels in steam generators
– Level in ECCS accumulators
– Deaerator Level
– PHT storage tank level
– Temperatures in PHT system
– Area Pressures in Reactor building
– Radiation fields in Reactor building

- Keep adequate portable emergency lamps at higher elevation duly charged

7.2 Long Term Recommendations

- Provision of Reactor trip on seismic event (exceeding OBE)
- Provision of pump to transfer water from deaerator to SG immediately after crash cool down and hooking up to class II.
- Engineering underground concrete tank of 750 cum. and other accessories including pumps and liquid N_2 battery./CNG power pack + 20m^3 transfer tank.

- Engineer and procure 100 cu.m tank suitable for 10 Kg/sq.cm and locate it at HP heater floor.
- Provision of solar powered lighting for different buildings.
- Provision for hydrogen management devices for worst case scenario.
- Engineering of liquid nitrogen packs for delivering nitrogen a 10 bars pressure minimum.
- Study and engineering of methods to use suppression pool water inventory.

8.0 CONCLUSION

MAPS is designed for external events like flood. Many upgradation jobs have been carried out during the EMCCR of both units of MAPS. DG-5 and two diesel driven fire fighting pumps have been kept at a higher elevation and core cooling can be provided for a scale of Tsunami which occurred in 2004. The spent fuel bay is at the ground floor, and the inventory is sufficient for a period more than 10 days provided there is no structural damage. The recommendations given in this report have been evolved for handling the scenarios for more severe Tsunamis which can inundate up to a height of 5 meters from the ground floor of main plant buildings. With the recommendations of the report taken into account the core cooling and spent fuel integrity can be maintained even in the postulated flooding scenario.

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SCENARIO PROGRESSION AT MAPS–1&2

UNDER SEVERE NATURAL EVENT

SCENARIO PROGRESSION AT MAPS–1&2 UNDER SEVERE NATURAL EVENT

1.0 INTRODUCTION

The mean sea level at MAPS is 6.096 meters. From the storm surges point of view the required elevation is 10.45 meters. However, the ground floor elevation of main plant buildings is at 10.668 meters. The site had witnessed Indian Ocean Tsunami in December 2004 when the water level reached was maximum of about 10.5 meters surrounding the areas of sea water pump house. The pump house operating floor is at 8.63 meters and many of the sea water pumps (condensing cooling water, Process sea water, emergency process sea water) became inoperable following Tsunami. The level reached in pump house was about 10.45 meters. No water entered any of the main plant buildings.

In case of flooding due to external events the following scenarios can be envisaged:

2.0 CLASS IV POWER AVAILABLE

On loss of condenser cooling water pump house due to tsunami, the condenser vacuum will drop and TG will trip on low vacuum. The reactor should be tripped manually and crash cool down is to be initiated. Feed water supply to SGs by BFPs followed by ABFPs are available to maintain SG secondary side inventory. After cooling down to 150 deg.C, PHT Shutdown Cooler is valved in and system is further cooled down to below 50 deg. C. H.P. process water system is circulating through shutdown coolers. Since sea water heat sink is not available fire fighting water is valved in to process water system through the designed route and cooling maintained on once through mode. At MAPS, during Tsunami, one of the Process sea water pumps was still available but could not be operated continuously due to choking of travelling water screens by weeds and debris brought in by Tsunami. The above mode of cooling with fire fighting water was resorted to till Process sea water pump could be stabilized. All other circuits like moderator, Shield systems were cooled by the above mode.

3.0 CLASS-IV BECOMING UNAVAILABLE

After resumption of class-III, HP process water pump will resume and HP process will be connected to LP process water system automatically. Since process sea water pumps are on Class-IV and Emergency Process sea water pumps being at lower level are submerged cooling has to be continued with fire fighting water. Since the electrical driven fire water pumps are on Class-IV, diesel driven fire water pumps have to be operated. Enough water storage for 7 days operation is available at on-site reservoir (9 million gallons) and even assuming no make-up this can be extended to few more days during the shutdown. All other systems like moderator and end shield can be operated, since Class-III is available. The on-site diesel storage will also be available for 10 days (3 tanks of 56 Kiloliters each). This can be extended by optimizing the equipments which are run, as per the actual requirement. All other monitoring will be available.

4.0 CLASS-III BECOMING UNAVAILABLE

All 5 diesel generators become unavailable due to submergence. Crash cool down will be initiated. ECCS will be lined up to maintain PHT pressure. FM supply pump will be stopped to conserve energy. On a long term when inventory in ECCS accumulator runs out, light water should be added to reactor headers through proposed mobile pumps at high pressure of 50 Kg/cm^2.

For water addition to secondary sides of SG, the proposed new pump at higher elevation will be run on class-II till it lasts and maximum possible amount of water will be transferred to SGs from Deaerator storage tank. Alternatively, the proposed pressurized 100cu. M capacity tank at HP heater floor to SGs can be utilized. Subsequent use of Deaerator water will be done by nitrogen pressurization from proposed liquid nitrogen batteries.

Augmentation of water resources is planned through the above mentioned additional tank at HP heater floor and Emergency process water storage tank in Turbine building roof. The Deaerator water is expected to last for 24 hours and can be further supplemented by the above mentioned provisions. For long term cooling an underground concrete storage tank of 750 cu.m capacity is proposed, with an Auxiliary tank of 20 cu.m located below it. This tank will be designed to be pressurized up to 10 Kg/cm2 through nitrogen for transfer of water to Steam generator. Diesel or CNG driven mobile power packs can also be used along with submersible pumps to pump this water. The connection to Steam generators will be through the fire water addition facility to feed water headers located outside Turbine building.

After moderator pump stops after class-II runs out, it is proposed to fill the calandria and dump tank with light water through a suitably engineered connection from outside RB. Inventory addition requirement if any to PHT storage tank, can be met through the connections available already from fire water system. The proposed additional hook up facility outside RB can be used for addition of water to end shield.

Spent fuel storage bay can be made up as and when required by tankers from reservoir at the west end of the plant.

Solar powered lighting is proposed for all important areas of the plant.

5.0 LOSS OF INDICATIONS

Due to power supply loss all indications will be lost. Battery operated indicators should be engineered to measure some important parameters like levels in steam generators, ECCS accumulator, Deaerator, PHT storage tank and temperatures in PHT, pressures in RB and radiation fields in Reactor building.