A4

SAFETY EVALUATION

OF INDIAN NUCLEAR POWER PLANTS

STANDARD INDIAN PRESSURIZED HEAVY WATER REACTOR (IPHWR)

SAFETY EVALUATION OF INDIAN NUCLEAR POWER PLANTS
STANDARD INDIAN PRESSURIZED HEAVY WATER REACTOR (IPHWR)

1.0 INTRODUCTION

The safety assessment of Standard Indian Pressurized Heavy Water Reactor (IPHWR) units (220 MWe & 540 MWe) was taken up by the Task Force constituted by CMD, NPCIL vide Office Order No. NPCIL/CMD/COM/03/2011 dated 15.3.2011 to review the design features of IPHWRs to ensure core cooling in view of the recent accident, earthquake followed by tsunami at Fukushima Nuclear Power Plant in Japan on 11-03-2011.

IPHWR is the standardized design, indigenously designed, developed and implemented progressively at NAPS1&2, KAPS1&2, KGS1-4, RAPS-3-6 and TAPP3&4. Of these, NAPS 1&2, KAPS 1&2, KGS 1-4 and RAPS 3-6 are 220 MWe reactors, inland sites. TAPP 3&4 is 540 MWe and is a coastal site reactor.

Standardized IPHWRs are designed for external events like flood, fire and earthquake. The lessons learnt through the thorough review of the events at our stations (given below) leading to subsequent recommendations are embedded into the design after appropriate vetting by regulatory body.

- Fire Incident at NAPS rendering total loss of power (off site and on site) for several hours (successfully handled on the strength of Design Provisions and appropriate Operator Actions)
- Flood Incident at KAPS
- Tsunami Incident at MAPS and TAPS

The valuable feedback arising out from above led to strengthening in design as brought below:

- Addressing the issues related to common cause failures with respect to power supplies, pathways for cooling water supplies and strengthening the availability of heat sinks
- Grade level of all units is decided considering the maximum flood level w.r.t. tsunami at coastal site and possibility of dam failure for inland sites.

- The availability of essential equipment for core cooling during postulated flood event including the location of DGs have been addressed in all the plants.

The earthquake design of IPHWRs is for 0.2g (for NAPS 0.3g) acceleration during SSE condition. During the Bhuj Earthquake (7.6 Richter scale) in Gujarat, an acceleration of 0.15 g was reported at a distance of 150 km from the epicenter. During this period KAPS continued to operate. Seismic event considering the Indian seismotectonic map and estimated tsunami wave height generated on account of postulated seismic event (level of 9 on Ricther scale) due to Makran fault is less than 2 meters. Hence, both seismic and flood is not a threat for all standardized PHWR stations as these have already been considered as design input for plants or back fitted as applicable.

There is a process of in depth review with respect to advances in the National and International Safety Standards every 10 Years for all the Operating Stations as per regulatory requirements. Accordingly over a period of time all the above standardized PHWR Stations have been upgraded to latest standard of safety.

In IPHWRs, core cooling is achieved by natural circulation, a complete passive system for removal of decay heat. In order to maintain natural circulation various systems backing one another are provided. Steam Generator (SG) inventory is to be replenished in order to maintain natural circulation. Hence a defense in depth approach has been used to maintain SG inventory under all possible conditions, to ensure core cooling. As the decay heat reduces with time, the requirement to replenish SG inventory also reduces.

The Spent Fuel Storage Bay (SFSB), which is seismically designed, is another area where the spent fuel is being stored. The large pool of water available in it can sustain for more than a month without make up.

On these strengths, the accident which occurred at Fukushima is not having implication on nuclear safety in IPHWRs .The current study has been under taken as the system of review of international events, to examine for any strengthening required with respect to the experience feedback.

2.0 SCOPE AND OBJECTIVE

The task force covered the intent as mentioned in the order and checked the strength and adequacy of design pathways in view of the Fukushima accident and also made a check on the availability of beyond design basis water supply pathways. The EOPs also have been visited to check for any augmentation. On the basis of the feed back of the accident and the review, the recommendations are generated for further enhancement of the Plant Safety.

3.0 EXISTING DESIGN FEATURES

Existing design features for the condition of Class IV supply failures and deterministically postulated Class III supply failures are examined as given below:

3.1 Class-IV Power Supply Failure

In case of loss of off site power including Class IV power, reactor shutdown is achieved automatically. Core cooling is maintained by natural circulation in Primary Heat Transport (PHT) System. Steam Generator inventory, which provides heat sink, is maintained by auxiliary boiler feed pumps (ABFPs). Alternatively Shut down cooling circuit can be valved in. Containment pressure and its cooling is maintained by normal design provisions. The ABFPs and Shut down Cooling Pumps are powered by 3x100% DGs in 220 MWe units and 4x50% DGs in 540 MWe (TAPP-3,4). These DGs are tested weekly to ensure their availability when demanded.

Relevant site wise parameters are given in the following table.

Parameters	**RAPP-3,4,5,6**	**NAPS-1,2**	**KAPS-1,2**	**KGS-1,2,3,4**	**TAPS-3,4**	**Remarks**
Seismic Design Limits	0.1g	0.3g	0.2 g	0.2g	0.2g	
Flood Level RL-(m)	359.6	180.8	48	38.9	28.81	
Grade Level RL-(m)	384	187	51.3	40	32 (6.3m above MSL)	* protective rock bund 7.03 m above MSL in TAPP-3,4
(EL-m)	(100)	(100)	(100)	(100)	(100)*	
DG Elevation(EL)	100	100	100	100	100	100

Estimated tsunami wave height generated on account of postulated seismic event (level of 9 on Ricther scale) due to Makran fault is less than 2 meters. Present elevation of DGs at TAPS-3,4 is adequately above.

3.2 Class-III Power Supply Failure

Notwithstanding the above strengths, deterministically the DGs are considered not available rendering Class III power and all design pathways for cooling water supply unavailable.

Continued core cooling under such Beyond Design Basis Condition is addressed through replenishment of Steam Generator (SG) Inventory by water addition through fire water system. As no power is available arrangement has been made to supply water using Diesel Driven Pumps through water supply line dedicated for the purpose. The system, water inventories and diesel oil provisions are discussed below.

3.2.1 Availability of Water Inventory

There are 3 nos. of Diesel Driven Fire Water Pumps available for emergency use. These pumps can supply water to SGs at 3.5 kg/cm^2(g). Water inventory of 500 m^3 (for twin unit) in fire water sump and 800 m^3 in Induced Draft Cooling Tower (IDCT) sump of each unit is available in case of 220 MWe PHWRs. For TAPS#3,4 inventory of 4000 m^3 is available in fire water sump. In addition to this about 5000 m^3 inventory (for twin unit) is available in emergency make up water pond for RAPS# 3,4,5,6 and cooling water discharge tunnel for KGS# 1,2,3,4. These inventories can extend the capability of decay heat removal to beyond 30 days (except for NAPS & KAPS). For NAPS & KAPS, the inventory is sufficient to remove decay heat for about 7 days. There is a need to provide additional inventory for KAPS# 1,2, NAPS#1,2 and TAPS# 3,4 units for extended decay heat removal capability. The IDCT basin and fire water sump along with pumps are SSE qualified for all the Stations. The available inventory (SSE qualified) break up is as follows:

- 500 m^3 in fire water sump for twin units of 220 MWe
- 800m^3 in IDCT basin per unit (i.e. total 1600 m3 for twin unit) for 220 MWe
- 5000 m^3 in Emergency make up pond (for twin units) of RAPS #3-6 and cooling water discharge tunnel (for twin units) of KGS# 1-4
- 4000 m^3 in (open) fire water reservoir for two units for TAPS 3, 4

The extended source of inventory near the stations is identified as follows:

The plants located inland (RAPS# 3,4,5,6, KAPS # 1,2, NAPS # 1,2, KGS # 1,2,3,4) are having large water reservoirs/river in the vicinity. Temporary arrangement for drawing cooling water from this source is practiced and also has been rehearsed in the past. It is seen that requisite water flow, can be arranged within a short time(of around 30 minutes). The process need to be embedded in EOP as a further defense in depth.

3.2.2 Fire Water System

The fire water system catering to the requirement of replenishing the water to SGs is SSE qualified. There are three diesel driven pumps and one Class-III operated pump, each with a discharge capacity of 275 m3/hr with rated head of 8 kg/cm2(g). This system is capable of handling safety loads (SG secondary, ECCS direct core injection, ECCS HX , Moderator pumps and HX, Shutdown HX ,End shield cooling) and fire loads.

3.2.2.1 Availability of Diesel Oil

For operating the Diesel Driven Fire Water Pump, 200 liter diesel inventory is required for 8 hours. An amount of 250 Kilolitre diesel inventory is stored in the Diesel Storage Tanks. Considering the consumption of 0.6 Kl/day by fire water pumps, the availability of diesel inventory is adequate. These storage tanks are underground and designed to with stand flooding in the area.

3.2.3 Power Source For Monitoring And Emergency Lighting

Class I & II power supply can be maintained for about two hours following SBO making all the lights instrumentation logics and indications available for such time. It is suggested that arrangement may be made to have limited power supply for extended period to monitor following parameters:

- Reactor Power measurement
- Moderator level
- SG inlet temperature and level
- Reactor Outlet and Inlet Header pressure and temperature
- Stack release
- Containment Pressure and Temperature
- SFSB level and temperature
- Area Radiation monitor

3.3 Spent Fuel Cooling Provisions

In SFSB (designed for SSE condition), a water level of about 7.5 m for 220 MWe and 8.3 m for 540 MWe reactor is always maintained and the spent fuel is submerged with a water column of 5 m above the fuel. Total water inventory of about 3000-4000 m^3 for 220 MWe and 5600 m^3 for 540 MWe reactors is available in the pool. It is re-circulated and cooled by Class IV/Class III powered pump. In case of loss of cooling, water will start boiling in about three days. The water inventory is sufficient to prevent the overheating of the fuel for more than 30 days.

Tank in tank concept has been provided in plants RAPS 3-6 & KGS 1-4 to strengthen the leak detection.

3.4 Emergency Power Supply/Power UPS

UPS and battery for emergency power supply are located for NAPS1&2, KAPS1&2, KGS 1,2,3&4 and RAPS 3,4,5&6 in control building at 106.5 meter elevation and for TAPS3&4 located at 100 meter and are qualified for SSE. It is expected that for a period of two hours power supply for various indication & emergency cooling will be available during SBO.

4.0 REVIEW OF EXISTING EOPs

Existing EOPs for SBO and loss of feed water were also revisited and found to be ok. However as a precaution to handle the tsunami scenario additional observations have been included in the recommendations.

5.0 RECOMMENDATIONS

5.1 Short Term Recommendations

i) Reactor trip on seismic event (exceeding OBE) needs to be provided.
ii) Availability of additional batteries for monitoring important plant parameters and emergency lights should be ensured in standard SBO kit.
iii) Surveillance programme for safety related fire water lines is to be established to ensure their healthiness.
iv) Vent pipes on underground diesel storage tanks should be extended to ensure no water ingress in case of flooding / tsunami.

v) Provision for hand pumps for transferring diesel oil from underground diesel storage tank to day tank of diesel fire water pumps.

vi) All JBs along with terminal boxes of motors should be surveyed and ensured for leak tightness to avoid impact of flooding.

vii) Water bodies and diesel/ petrol pump stations should be identified in the vicinity of each station and the information should be recorded in EOP as a measure of defense in depth.

viii) Fire tenders (already available at stations) and portable diesel driven pumps/ connectors need to be stored in seismically qualified building at suitable higher elevation as a measure of defense in depth.

ix) Surveillance procedure including operability and schedule for stock checking and for keeping equipment such as batteries, emergency lights, fire tenders and portable diesel driven pumps to be used in emergency, need to be prepared.

x) Periodical refresher training to the station staff to ensure quick response to such scenarios needs to be implemented.

xi) Tee joints with quick connectors at identified locations of fire water and feed water systems to be established as hooking points for injecting water as measure for defense in depth.

xii) Enough numbers of connecting hoses & miner’s hat should be ensured to be available.

xiii) In TAPS–3&4, 4000 m^3 SSE qualified existing reservoir should be covered to prevent possible ingress from Tsunami induced water.

xiv) All the fire water lines for safety related loads needs to be included in ISI program

5.2 Long Term Recommendations

i) Examine the use of suppression pool inventory with power pack operated pumps

ii) An appropriate instrumentation scheme along with requisite power source should be implemented to monitor the following important parameters for extended off-site and on-site power failure.

- Reactor Power measurement
- Moderator level
- SG inlet temperature and level
- Reactor Outlet and Inlet Header pressure and temperature
- Stack release
- Containment Pressure and Temperature
- SFSB level and temperature
- Area Radiation Monitor

iii) For managing BDBAs/ severe accident, provisions are needed to prevent / arrest accident, additional Hook up points for injecting water into the following

- ECCS for TAPS – 3&4
- Calandria (Moderator)
- Calandria Vault

Following provisions are also need to be made:

- Hydrogen detector
  - H_2 Autocatalytic Re-combiner

iv) SSE qualified water reservoir of 5000 m^3 capacity for NAPS, KAPS and TAPS 3-4 needs to be provided.

v) The inventory in SFSB is adequate to keep spent fuel submerged in water for 30 days without any make up. Provision to be made to supply make up water to SFSB for spent fuel cooling in case of any postulated loss of inventory.

vi) Bore holes inside plant boundary should be identified to transfer water to fire water sump.

vii) Bio growth (mangroves) for TAPS-3,4 can be examined.

viii) Severe Accident Management Guidelines should be made available.

ix) Solar powered batteries can be considered for emergency lighting, monitoring and engineering to recharge the battery bank.

6.0 CONCLUSION

IPHWRs are designed for external events like flood, fire and earthquake and the grade level of all units are decided considering the maximum flood level with respect to tsunami at coastal site and possibility of dam failure for inland sites. Core cooling is achieved by natural circulation, a complete passive system in the event of total unavailability of off-site/ on-site power supply. Various systems backing one another are provided to maintain natural circulation. The inventory in SFSB ensures fuel will not get uncovered for about 30 days. The Indian siesmotectonic map is way different than that of Japan and seismic event of the magnitude of Fukushima along with that level of Tsunami is not expected here. However Indian PHWRs are capable of handling any postulated event of loss of power and flood events. Some recommendations have been evolved as further defense in depth.

This page is intentionally left blank.

B4

SCENARIO PROGRESSION AT STANDARD INDIAN PHWRs

(NAPS ONWARDS)

UNDER SEVERE NATURAL EVENT

SCENARIO PROGRESSION AT STANDARD INDIAN PHWRs (NAPS ONWARDS) UNDER SEVERE NATURAL EVENT

1.0 INTRODUCTION

Indian PHWR (IPHWR) units at NAPS-1,2; KAPS-1,2; RAPS-3,4,5,6; KGS-1,2,3,4 and TAPS-3,4 are of standard Indian design. Out of these units, TAPS-3,4 are coastal stations, whereas all other are inland sites. Design Basis Flood Level (DBFL) for NPPs is calculated, on the basis of postulation of upstream dam failure for inland sites and storm/ tsunami (whichever is governing) for coastal sites. Structures, Systems and Components (SSCs) of NPPs are located above this level and up to this level of flood, all design provisions related to fulfillment of fundamental safety functions are available. Both these events (i.e. dam failure / tsunami) could result from earthquake, therefore availability of this information can be made use of in better managing the incident. For inland sites this information is available from state authorities and for coastal sites from India Tsunami warning System co-ordinated by Indian National Centre for Ocean Information Services (INCOIS), Hyderabad. These communications and annunciating the information in control rooms is recommended to be formalized in the form of a system.

IPHWRs are having sensors for detecting seismic activity and annunciate the same in control room. With recommendation of providing seismic trip corresponding to appropriate ground acceleration, the operating NPPs would be automatically tripped on sensing a seismic event. As this action is taken at a level lower than SSE level, even in case of beyond design basis external event, shutdown of the reactors can be achieved as both the shutdown systems are inside plant buildings (located at higher elevation and are fail safe). The same applies to systems for maintaining long term sub-criticality (wherever required). Therefore, in case of beyond design basis external event, there is no concern related to reactor shutdown and maintenance of sub-criticality and this safety function is successfully achieved.

Practically there would be a certain time gap (of the order of around one hour) between seismic activity and the effects of dam failure / tsunami are felt at the NPP. This time can be gainfully utilized for bringing the operating units to cold shutdown state and mobilizing other resources. On getting the information from appropriate authorities as an immediate operator action, crash cool down would be initiated in operating units.

2.0 REACTOR CORE COOLING

In the above mentioned scenario the core cooling can be achieved as follows with/without power supply.

3.0 CLASS IV POWER SUPPLY FAILURE

As a result of earthquake, Class-IV power supply cannot be credited and unit can be brought to cold shot down utilizing auxiliary boiler feed pumps and shut down cooling pumps. These pumps and their power supply from emergency diesel generators are seismically qualified and would be available. With crash cool down initiated units can be brought to cold shutdown state within one hour.

4.0 CLASS III POWER SUPPLY FAILURE WITH AVAILABILITY OF WATER RESOURCES

At this stage, if water level at site exceeds the design basis flood level then emergency diesel generators could become unavailable (either due to their location or un availability of cooling water), then the power supply to the systems maintain units in cold shutdown state would be lost. This situation would essentially lead to a Station Black Out (SBO) situation and depending upon severity of the incident and effects on plant systems and facilities, SBO may be extended for a longer duration. This would result in heating up of fuel as direct cooling is lost. In such situation (i.e. SBO, caused by extreme external event or otherwise), Steam Generators (SGs) secondary side can be supplied with water from fire fighting pumps. On primary side flow will be maintained through natural circulation, which is an inherent feature of IPHWRs. For supplying water to steam generators, they need to be depressurized by blowing off-steam through atmospheric discharge valves, with atmosphere as the ultimate heat sink. These fire fighting pumps have their own diesel engines and do not depend on station power supplies for their operation.

5.0 AVAILABILITY OF WATER INVENTORY

The water inventory for use by these fire fighting pumps is kept in seismically qualified storage (and can be augmented by water supply from other on-site seismically qualified storage (refer annexure A4). Therefore, if fire water pumps and their water inventory survive in the beyond design basis external event then core cooling can be maintained as indicated above. Indian PHWRs also have a provision to supply fire water to end shields under such situations from fire fighting pumps. If water inventory becomes un-usable then the inventory can be made available through identified on-site water storages. These storages are not designed for core cooling but can be made use of in such situation. The water inventory can be augmented by utilizing fire water tenders. If fire fighting pumps become unavailable then water can still be supplied (to steam generators/ end shields) through mobile fire water pumps as recommended.

With heat sink ensured, core cooling can be continued for extended duration and there is no concern for radioactivity release as the fuel temperature is kept under control.

6.0 CLASS III POWER SUPPLY FAILURE WITHOUT THE AVAILABILITY OF WATER RESOURCES

In case water from fire water pumps cannot be supplied, then all designed core cooling provisions would be lost and situation could worsen. In such a scenario, steam generators inventory would last for a limited period (this time will depend when fire water supply is interrupted as it is dependent on decay heat in the core). After dry out of steam generators, the natural circulation maintained for core cooling will be broken and effectively there would be no heat removal from the fuel. This would result in excessive heat up of fuel and the scenario could further aggravate. However in this situation with recommendation of utilizing suppression pool water inventory for feeding to steam generators, core cooling would start again and with available huge inventory of suppression pool, core cooling can be continued for fourteen days. On primary side inventory addition would be done from emergency core cooling line after making it through. With success of this action there is no concern of radioactivity release.

7.0 SPENT FUEL COOLING

The spent fuel is stored in a large pool of water and water cover over spent fuel could be maintained for at least thirty days (refer annexure A4). With recommendation of augmenting spent fuel pool water inventory, the spent fuel safety is ensured for extended duration and there would be no release of radioactivity from these stored spent fuels.

8.0 SCENARIO PROGRESSION IN CALANDRIA / CALANDRIA VAULT

IPHWRs have large water inventory in calandria and calandria vault water and they would provide heat sink, when steam generator heat sink becomes unavailable. However, due to complete loss of power supplies, these systems are also devoid of any cooling and they continue to get heated up and these inventories may finally boil off. However, with recommendation of supplying water to calandria and calandria vault through appropriate hook up arrangements these inventories can be made up and decay heat removal can continue. These actions will prevent any possibility of core damage and the resultant threat to the containment due to hydrogen generation would also be taken care of. With containment integrity maintained there is no concern of radioactivity release.

9.0 LOSS OF INDICATION

For a prolonged power supply failure, plant controls and indications (which are provided by backup batteries) too would last only till the battery autonomy period. In an extended scenario of power supplies unavailability, plant indications would be lost. With recommendation of battery capacity enhancement / charging the essential plant indications and lighting in essential plant areas (refer annexure A4) can be maintained. In addition recommendations are also made to strengthen the existing design capabilities with respect to on-site water sources and power supplies.

10.0 CONCLUSION

The above analysis shows that a situation caused by extreme external event resulting in beyond design basis situation can be handled with recommended up gradations / modifications and the event progression can be stopped at appropriate stage and radioactivity release can be avoided. These recommendations also follow the defense-in-depth approach where failure in mitigation at one stage can be handled by a backing up provision.