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SAFETY EVALUATION OF

INDIAN NUCLEAR POWER PLANTS PHWRs

AT RAJASTHAN ATOMIC POWER STATION (RAPS-2)

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1.0 INTRODUCTION

Rajasthan Atomic Power Station 1&2 is 200 MWe twin units Pressurized Heavy Water Reactor (PHWR). It uses natural uranium oxide as fuel and heavy water as primary coolant & moderator. The heat generated due to fission in the fuel is removed by primary coolant and transmitted to de-mineralized light water in Steam Generators to produce steam. This steam is then fed to turbine to produce electricity.

At present, RAPS-1 fuel is removed from the reactor completely and stored in Spent Fuel Bay. PHT, moderator and all other system have been drained & dried and are kept under preservation mode. RAPS-2 first criticality was achieved on 08.10.1980 and is presently operating at full power with imported fuel under IAEA safeguard. These units are vintage PHWR of 1st generation CANDU type with simple and compact design with single shut down system, once through cooling water and single containment.

During 1996-98, RAPS-2 was shutdown to replace all the coolant channels (EMCCR) from Zr-2 to Zr-2.5% Nb material to address the creep & hydrogen embrittlement related issues. In addition to this a number of safety up-gradations were carried out which includes introduction of high pressure emergency injection to PHT System, provision of light water injection to PHT system, additional diesel generator set to take care of maximum flood level of 1179.5 Feet EL. etc. etc. to strengthen the safety & core cooling provisions. Again during 2008-09 the coolant channel feeders were also replaced.

RAPS-2 being the first generation CANDU Type reactor design, the standard safety features of reactor was reviewed during EMCCR and the necessary modifications were carried out; therefore, these issues presently were not reviewed.

The existing design envisaged loss of class III power supply failure for a maximum period of 20 minutes. During this period, Main DGs or flood DG will be started and power to essential loads will be restored. To take care of maximum expected flood level and power supply failure, a detail Emergency Operating Procedure for use of operator is already in place.

2.0 POSTULATED EVENT

Task force reviewed the safety of RAPS-2 plant to maintain the essential safety functions considering extended loss of power supply. During the review, task force has envisaged following scenarios which may likely to impair availability of motive power or incapacitating the designed water supply routes:

i) Earth quake
ii) Gandhi Sagar dam break
iii) Rana Pratap Sagar (RPS) Dam break
iv) All the three events at i), ii) and iii) above

RAPS site is situated on the bank of reservoir of Chambal river, therefore, event like Tsunami is not anticipated. In the event of high intensity cyclone or tornado, at the most loss of class IV power is expected and class III power through diesel generator is expected to function normal as per design intent.

Out of the above, the occurrence of earthquake leading to Gandhi Sagar Dam break followed by Rana Pratap Sagar (RPS) Dam break as in item no 2.(iv) above will be the extreme scenario which may impair power supply and incapacitate certain designed safety features . Therefore this event is reviewed for prolonged core cooling provisions without motive power availability. The impact of other event will be of lesser magnitude. It is noted that maximum flood level under this scenario will be 1179.5 feet EL above MSL. Subsequent to the flood resulting from failure of Gandhi Sagar Dam, RPS dam is assumed to have failed resulting in fast reduction in reservoir level & finally water may be available only in patches in the form of small ponds in the original river bed.

3.0 ASSUMPTIONS

In this review, following assumptions are considered:

i) RAPS-2 was operating at full power prior to earth quake event.
ii) Reactor tripped on auto/manual along with Class IV failure at the time of earthquake as it has failsafe features on loss of power and air.
iii) Scenario of an earthquake associated with break in Gandhi Sagar Dam resulting in flooding of plant area in about 30 minutes (flooding up to 1179.5 ft is expected in about 2 hours) and subsequently break in RPS dam is considered for this review.
iv) For the purpose of this review it is assumed that class III power is not available after earth quake even through flood DG#5.

v) Class II power will be available for 20 minutes till the battery bank gets exhausted.

vi) Reactor building is accessible and associated systems are available as they are re-evaluated for seismic ground acceleration – Peak Ground Acceleration (PGA) of 0.22g

vii) Pump house and its equipments including fire & stand by water pumps are assumed to be not available due to earthquake and/or flooding.

4.0 REVIEW OF EVENT

4.1 Important Steps of Postulated Event

- Reactor Trip on auto on class IV failure or trip manually on earth quack alarm / direct information
- DG startup failed
- Ensure Class II load continue/resumed.
- Start crash cooldown in case class III not resumed in 6 Minutes or event is known/confirmed earlier.
- Conserve class II power.
- Line up portable fire fighting pump for makeup water.
- Action for T/G (Early coast down, Hydrogen Purging Etc.)
- Start flood DG 5 (within 20 minutes)
- Restart important load for core cooling

The details of event progression are given in Annexure-I.

4.2 Essential Safety Functions

4.2.1 <u>Reactor Shutdown</u>

Reactor Shutdown function will be achieved by moderator dump system due to fail safe features (On loss of power or air supply).

4.2.2 <u>Containment function</u>

Containment isolation is not expected, however this will take place on loss of control power or air as it has a failsafe feature. If required these dampers can also be closed manually.

4.2.3 Reactor Core Cooling

Following reactor shutdown with Class-IV failure, PHT pressure will fall down to < 55 Kg/sq cm. and reactor core cooling will be provided by thermo siphoning mode. At six minutes due to non availability of Class-III power supply, operator will initiate crash cool down as per existing EOP (water inventory in boiler is only for 45 minute cooling). Following crash cool down, when secondary system pressure goes down below 4 kg/cm^2 existing BFP-4&5 (Class-II) will provide feed water to the boilers. Provision exists to feed the water to boilers from dousing tank of unit-2, however the water can be fed after the steam pressure to the boiler reduces to less than static head of dousing tank water level. Meantime Diesel operated pumps can also be connected to feed the water to boilers. Parallel action will also be taken to coast down T/G & purging of Hydrogen from Generator. Meanwhile Flood DG (DG # 5), installed at higher elevation will be started to feed all essential loads. Therefore SBO is limited to the extent of starting the flood DG# 5 & connecting to bus, which was essentially installed for the purpose.

In light of the accident at Fukushima, Task force reviewed the above provisions to identify various means of prolonged & sustained core cooling from the time of reactor trip under postulated severe natural scenario not taking the credit of resumption of class III even by flood DG # 5.

Based on the assumptions & review, weaknesses were identified & recommendations are proposed for improvements for sustained core cooling under postulated event & listed below:

Weakness observed in existing systems/procedure

After detailed review of systems and existing EOP of SBO (Station Black Out), task force noted that systems and procedures are available at site to assure core cooling with respect to postulated scenario. Provision of flood DG and portable diesel operated pumps exist with connection point for make up of water to boilers, PHT system and dousing tank, however following areas need further improvements:

i) With the postulated scenario of loss of class II power after 20 minutes, need for cooling of PHT, moderator, end shield etc is to be further addressed for enhancement.
ii) Though portable diesel operated pumps are available however their adequacy and reliability to pump water to SG and PHT system needs to be assessed, demonstrated and to be improved upon.

iii) Following initiation of manual crash cool down, boiler pressure is expected to fall down to 4 kg/cm^2 only. Further, make up to the boilers as envisaged through BFP# 4&5 (class-II operated pumps) and through dousing tank. This may pose difficulties in makeup due to limited pressure of BFP 4&5 and static head of dousing tank.

iv) In the postulated scenario water in the RPS reservoir is expected to fall up to river bed. There is no defined source to ensure the availability of water. There is need to ensure the source of water for at least 7 days cooling requirement.

ECCS actuation is depending upon initiation of conditioning signal (Boiler Room Pressure >0.25 psig) which will prevent PHT system shrinkage requirement during SBO under the assumed scenario.

Initiation of crash cool down is operator decision dependent.

4.4 Recommendation for Improvement

After detailed review of all systems with respect to identified weakness in item 4.2 above, the task force has identified the augmentation of following areas so that cooling water can be pumped to boilers to ensure fuel cooling by thermo-syphoning:

i) Augmentation of water sources
ii) Augmentation of Feed/ make up capability
iii) Extension of power sources
iv) Improvement in the system
v) Augmentation of Long term resources

Unit-1 core is defueled and all the main and auxiliary system water is removed and system equipments are in preservation state. It was therefore considered prudent to make use of some of the Unit-1 system equipment for augmenting the resources of shortcomings noticed above. These changes are considered to be short term in nature and can be implemented quickly.

4.4.1 Augmentation of Water Sources

There is need to identify an additional storage for supplying cooling water to SGs, PHT systems, end shields, Moderator System and Dousing tank through diesel/diesel generator/battery operated pumps through diverse routes. It is proposed to consider the following:

- RAPS-1 dousing tank of 1800 Cu. Mt capacity can be used for storage of water (Through RAPS-1 ECCS injection line using diesel/diesel generator/battery operated pumps, water can be pumped to RAPS-2 Boilers, PHT, end shield, dousing tank and moderator system as per details and schematic in Fig-1. The advantage of this tank is that after the depressurization of boilers, water can be filled by gravity to unit-2 Boilers.)
- RAPS-1 Deaerator storage tank and HLRFT tanks are also available for use. (It is therefore proposed to keep them filled and provision can be kept ready with fire hydrant fittings for connecting to fixed as well as portable diesel/battery/diesel generator operated pumps to essential systems)
- Suitable alternate hook up arrangements to use residual inventory of unit-2 HLRFT & DM Storage tanks
- River bed water in patches: Even if all the above provision exhausted and/or not available, water available in river bed can be pumped through portable diesel operated pumps available at RAPS site. These pumps can be connected to fire water header and/or proposed system augmentation. Hookup provision for pumping to fire water system already exists near river bank. From the fire water header water can be transferred to any of the above provision through fire hydrants of nearby location.

4.4.2 Augmentation of Cooling Water Make-up Capability

- A suitable hook-up arrangement in all the water resources identified above is to be provided. Similarly all the systems which need the feed for core cooling, the hook-up points are to be suitably provided. Three numbers of diesel/battery/diesel generator operated pumps are to be installed in parallel at suitable location so the feed from above identified resources can be pumped on demand (Fig-1).
- In addition to provision of diesel operated pumps, three additional portable diesel operated pumps suitable to pump water to boilers against 4 Kg/cm2 should be made available at RAPS-2.
- It is also proposed to install/replace one electrical driven fire fighting pump of unit-1 to diesel driven pump.

4.4.3 Extension of Power Sources

- Feasibility of manual interconnection between Class-I 250 V DC batteries , Class II supply & flood DGs of Unit-1 System to Unit-2 System
- Availability of emergency portable lightings other than existing Class-I battery operated lights may be augmented in sufficient numbers (Including head lights)
- Few numbers of portable electrical generator sets for emergency hookups

4.4.4 Improvement in the Systems

- Automatic reactor trip on sensing of earthquake
- Conditioning signal for ECCS actuation should be removed. This will ensure high pressure injection on PHT low pressure signal (< 55 Kg/sq. cm(g)) in line with other PHWR units and will prevent void formation in PHT system.
- An alternate and diverse route for pumping water to systems through diesel/battery/diesel generator operated pumps.
- In RAPS-2 cobalt adjustor rods to be replaced with stainless steel adjustor rods.
- Feasibility of automatic crash cool down after six minutes may be explored to avoid operator decision dependency.
- To ensure continuous availability of air to essential load for long duration (MAL, EAL and PAL) a diesel operated compressor should be hooked-up to Bullet tank.
- Control room Ventilation/cooling back up from DG source
- Automatic closer of boiler blown valves to conserve water in boilers.
- Generator hydrogen purging arrangement should be suitably modified to make provision for purging above the maximum flood level.
  - The existing EOP should be reviewed and updated with respect to postulated scenario and all concerned officials are to be trained periodically to handle such events.

4.4.5 Augmentation of Long term resources

- Up-gradation of Class-II system by replacing MG sets with seismic qualification UPS and to be located above design flood level.
- Portable instruments to monitor level, pressure, temperature & flow for various safety related parameters.
- Issues related to hydrogen management viz. Detection, purging & re combination etc should be studied & suitably addressed. The study should include the areas of hydrogen accumulation in different pockets such as feeder cabinet, FM vault, containment, calandria vault etc.
- Additional provision can be considered in unit-1 deaerator to pressurize up to 50 psia to feed the water to boiler as a passive system.
- Common infrastructure facilities at Rajasthan site such as management of radiological emergency, fire station facilities & capabilities, transport, communication etc etc needs to be reviewed and augmented for effective handling of emergency within plant, site and public domain.

- Feasibility of making the bund at the main outfall to retain water for emergency feed in the event of failure of RPS Dam
- Accident Management Guidelines & Resources

5.0 CONCLUSION

The existing system is adequate to mitigate DBA (Design Basis Accident) events, SBO (Station Black Out) for limited period and simultaneous occurrence of external events like earth quake up to SSE (Safe Shutdown earth Quake), Gandhi Sagar Dam Break, RPS Dam Break. However, with the implementation of measures recommended above, RAPS-2 core cooling can be sustained for long period in the event of non-availability of motive power and the designed water supply routes are in-capacitated.

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SCENARIO PROGRESSION AT RAPS-2

UNDER SEVERE NATURAL EVENT

<u>**B2**</u>

SCENARIO PROGRESSION AT RAPS-2 UNDER SEVERE NATURAL EVENT

1.0 SCENARIO

The scenario of event progression such as in Fukushima where cooling water and electrical power source got incapacitated was developed for RAPS-2, step-by-step details of which are discussed below:

1.1 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 thermosyphoning with available inventory in boilers. Class III power is resumed through main DG's. Boiler inventory, which provides heat sink, is maintained by auxiliary boiler feed pumps. Alternatively Shut down cooling circuit can be valved in. Containment ventilation is maintained by normal design provisions. The Class IV power can be drawn from RPS Hydel Power Station through existing dedicated line.

1.2 Class-III Power Supply Failure

Under this condition (SBO), core cooling is maintained by thermosyphoning with available inventory in boilers. As the event progresses boilers inventory start depleting. As per existing EOP flood DG is started within 20 minutes before Class I battery bank exhausted. This will restore essential class III load like S/D pump, Aux PPP, Aux feed water pump, moderator pump, end shield pump, generator hydrogen seal oil pump etc. Thus core cooling is not expected to get affected.

1.3 Flood DG Failure

Under this condition core cooling is maintained by thermosyphoning with available inventory in boilers. Crash cooling is initiated. As the event progresses SGs inventory start depleting. When boiler pressure decreased to less than 4 kg/cm2 BFP 4 &5 start and feed the water to boilers. Mean time Portable Diesel Pump is hooked up to feed the water to boilers.

After 20 minutes battery bank will exhaust which will lead to loss of Class I & II power. Boiler inventory will get exhausted within 45 minutes. A provision exists for injecting fire water in to boiler. After depressurization of SGs further feed will be given to the boiler by portable Diesel pumps . Thus core cooling is dependent on availability of water and portable diesel pumps. Therefore these resources are proposed to be augmented.

1.4 Availability of Cooling Water Inventory

Existing cooling water sources are available either in deaerator, HLRFT, DM storage tank, Dousing Tank. Further the water can also be drawn through RAPS 3&4 NDCT through existing connection in RAPS-2 area. Provision exists to draw water directly from RPS reservoir.

However, in the postulated scenario RPS reservoir may not have water and also there is no other identified source of water for connecting to portable diesel operated pump. Therefore the alternate source of water storage are proposed in the recommendation

1.5 Availability of Pumping Mode

As there are many alternate sources are available for supply of power to the pumps for feeding water to the SG and other cooling systems, however in the postulated scenario, there is no motive power available to the essential pumps, once the batteries get exhausted. Necessary recommendations are proposed for an alternate source of power as well as by additional diesel operated pumps. The detailed recommendations for handling emergency under this scenario are given in the report.