<u>A6</u>

INTERIM REPORT

ON

Safety Evaluation of 700 MWe

Indian PHWRs at KAPP-3,4 and RAPP-7,8

POST FUKUSHIMA EVENT

INDEX

1.0 <u>Introduction</u>

1.1 **General**:

Indian PHWRs of 700 MWe are under construction at KAPP-3,4 and RAPP-7,8. These inland units have enhanced safety features with respect to standard IPHWRs and severe accident management provisions are included as part of design. NPCIL Obtained consent for First Pour of Concrete (FPC) for KAPP 3&4 on 20.11.2010 and the construction activities are progressing as per schedule. Application for next consenting stage, i.e Major Equipment Erection has been submitted to AERB. In RAPP 7&8, the major excavation is completed and application for FPC consent is under review at AERB.

700 MWe IPHWR units incorporate advanced safety features complying with current standards of redundancy, reliability, independence and prevention of common cause failures in its safety systems. Design takes care of Anticipated Operational Occurrences (AOO), Design Basis accidents (DBA) and Beyond Design Basis Accidents (BDBA) including severe accidents. The design includes provisions for withstanding external events like earthquake, flood, impact of explosion in vehicles carrying inflammable material on roads near NPP, fire, release of toxic gas from nearby industrial units / tankers moving through nearest district road.

In light of the accident at Fukushima, Japan, initiated by natural phenomenon, the design of 700 MWe IPHWR units is reviewed. The capability of 700 MWe design to withstand and mitigate extreme natural phenomenon which have very low probability of occurrence but potential for loss of significant operational and safety systems are assessed and necessary modifications are suggested to enhance the safety levels further.

1.2 **Site characteristics:**

Both KAPP-3,4 and RAPP-7,8 are inland sites. The cooling water requirements for the NPP units is drawn from nearby natural water body, which are fed from upstream rivers / dams. The design basis flood level is calculated based on existing regulatory requirements of consideration of upstream dam failure along with peak precipitation.

Relevant site wise parameters related to external flooding are given in the following table.

Parameters	RAPP-7,8	KAPP-3,4
Design Basis Flood Level RL - (m)	**361.61**	**50.3**
Safe Grade Level RL - (m)	**408** **(99.7 m EL)**	**51** **(99.7 m EL)**
Note: (i) The Diesel Fire water pumps are mounted on pedestals having a height of 325 mm above the 100 m elevation. (i.e 51.625 m RL in case of KAPP 3&4) **(ii) Emergency diesel generator sets are mounted on pedestals having a height of 300 mm above 100 m elevation. (i.e at 51.6 m RL in case of KAPP 3&4)**		

KAPS-1,2 units (220 MWe IPHWR) which are having a safe grade elevation of 51 m RL had successfully handled an external flood that has been caused due to multiple failures. After KAPS-1,2 flooding, the site was reviewed against external flooding and grade level of 51 m RL was assessed to be safe.

KAPP-3,4 and RAPP-7,8 are situated in areas which fall in Zone- 3 & 2 seismic zone respectively.

Relevant site wise parameters related to earthquake are given in the following table.

Parameters	RAPP-7,8	KAPP-3,4
Seismic Design Limits	**0.1 g**	**0.197 g**

The SSCs required for safety of NPPs are classified and qualified for appropriate earthquake levels. It has been evaluated that margin exists in the seismic design. The evaluations for KAPS-1,2 and RAPS-3,4,5,6 in the table below are applicable for KAPP-3,4 and RAPP-7,8 respectively.

Assessment of Seismic Margin

Station	Seismic Zone	Magnitude (Richter Scale)	Epicentral Distance (km)	Design PGA (g)	Conservative Margin (PGA) (g)
KAPS-1,2	III	6.5	30	0.2g	0.6 #
RAPS-3,4,5,6	II	6.0	40	0.1g	0.6 #

\# **Observation/performance based**- Design of new plants from NAPP onwards was done for allowable stress values. However, the actual stress values are much less than the allowable values. The actual Seismic Margin Assessment (SMA) on Peak Ground Acceleration (PGA) values are to be calculated referring to the analytical reports. But, based on the analytical values calculated for TAPP, RAPP and MAPP and performance of Kasiwaziki Kariwa and Shiko NPPs in Japan, GSECL's plant at Jamnagar and Panendhro, IFCO plant at Kandla, the SMA PGA will be about two to three times those of the analytical values.

Seismic instrumentation and protection:

The seismic instrumentation has been designed for monitoring seismic activity and automatic reactor trip on seismic event is being provided.

2.0 Scope and Objective:

The objective of this report is to compile findings of the review of consequences of occurrence of a similar situation like Fukushima Daiichi NPP in IPHWR 700 MWe units resulting in the unavailability of electric power and the designed water supply route and to recommend appropriate additional measures to mitigate the situation. This includes:

1. Evaluate the capabilities of the systems
2. Identify the required additional measures and infrastructure facilities and hook-up points to mitigate the consequences of beyond design basis scenarios.

3.0 Design Features of 700 MWe IPHWRs:

3.1 General:

Main technical parameters of 700 MWe IPHWRs (KAPP 3&4) are given in the following table:

Reactor thermal output	2166 MWth
Power plant output, gross	700 MWe
Power plant output, net	630 MWe
Power plant efficiency, net	29 %
Mode of operation	Base load
Plant availability target	90 %
Seismic design, SSE	0.214 g
Primary Coolant material	Heavy Water
Secondary Coolant material	Light Water
Moderator material	Heavy Water
Thermodynamic Cycle	Modified Rankin
Type of Cycle	Indirect
Core damage frequency	10^{-5} / Reactor Year
Large early release frequency	10^{-6} / Reactor Year
Occupational radiation exposure	20 mSv / Year (Average in any consecutive 5 years)
Operator Action Time	30 minutes, generally
Steam flow rate at nominal conditions	3844 t/h
Steam pressure/temperature	44 kg/cm^2(g)/256.3^oC
Feed water temperature at SG inlet	180.0 ^oC
PHT system Volume	206 m^3
Primary coolant flow rate	28.9 $x10^6$ kg/h
Reactor operating pressure at ROH	100 kg/cm^2(g) nominal
Quality at coolant channel exit	Up to 3 %
Core coolant inlet temperature	266.0 ^oC

Core coolant outlet temperature	310.0 ^oC
Mean temperature rise across core	44.0 ^oC
Active core height	594 cm
Equivalent core diameter	638.4 cm
Average linear heat rate	27.4 kW/m
Average fuel power density	235 MW/m^3
Average core power density	12.1 MW/m^3
Fuel material	Natural UO_2
Cladding tube material	Zircaloy-4
Outer diameter of fuel rods	1.308 cm (cladding OD)
Rod array of a fuel assembly	37 elements arranged in 4 concentric rings
Number of fuel assemblies	4704 fuel bundles in 392 channels.
Enrichment of reload fuel at equilibrium core	Natural Uranium (0.7% U-235)
Fuel cycle length	12 months
Average discharge burn up of fuel	7000 MWD/t
Control rod absorber material	Cadmium sandwiched in SS
Soluble neutron absorber	Natural boron (during initial phase) and Gadolinium Nitrate
Inner diameter of Calandria shell	7800 mm
Wall thickness of Calandria shell	32 mm
Base material of Calandria shell	Austenitic SS-304L
Number of coolant channels	392
Coolant Channel inside diameter	103.4 mm
Core length	5.940 m
Coolant Channel material	Zr - 2.5% Nb Alloy (Cold Worked)
Type of Steam Generator (SG)	Mushroom type with Integrated Steam Drum
Number	4
Total tube outside surface area	3370 m^2

Number of SG tubes	2489
Tube outside diameter	19 mm
Tube material	Incoloy-800
Type of Primary Coolant Pump (PCP)	Vertical Centrifugal, Single Stage
Number	4
Head at rated conditions	221 m
Flow at rated conditions	2.44 m^3/s
Pump speed	1490 rpm
Volume of Pressuriser	45 m^3
Liquid / Vapour ratio in pressuriser	80:20
Heating power of heater rods	1.37 MW
Moderator volume	282 m^3
Inlet/outlet temperature	53.0 ^oC / 76.0 ^oC
Containment Type	Prestressed Inner Containment Wall (ICW), Reinforced Outer Containment Wall (OCW)
Containment Overall form (spherical/cylindrical)	Cylindrical Double Containment with Dome
Containment Dimensions (diameter/height)	ICW: 49.5 m diameter 53.1 m height OCW: 54.74 m diameter 55.565 m height
Containment Design pressure	1.6 kg/cm^2(g)
Active/passive systems for core cooling	Active: Shutdown Cooling System Passive: Through natural circulation through SGs and Passive Decay Heat Removal system. Emergency Core Cooling System under LOCA.

3.2 Safety Systems:

Safety systems provided in 700 MWe IPHWRs for fundamental safety functions under normal operating conditions and accident conditions are as follows

Reactivity Control

Reactor shutdown is achieved by two diverse and fast acting shutdown systems. The shutdown systems are so designed that the first shutdown system is preferred mode of shutdown.

Serial Number	Purpose	Device / Equipment
1.	First Shutdown System	Shutdown System#1
2.	Second Shutdown System	Shutdown System #2

Reactor regulating system is used for normal power maneuvering including fast reduction of power as a setback action. The devices used for power control purpose are given below

Serial Number	Purpose	Device / Equipment
1.	Control and Regulation	Liquid zone control system
2.	Xenon override	Adjuster rods
3.	Power Reduction	Control rods

Core Cooling

Multiple means are provided for core cooling under various plant states. These include main as well as backup systems.

Purpose	Device / Equipment
<u>Under normal operating condition</u>	
i) Power operation	
Primary	Primary coolant pumps
Secondary	Steam generators (SG) fed by main boiler feed pumps
ii) Hot Shutdown Condition	
Primary	Primary coolant pumps
Secondary	Steam generators fed by main/ auxiliary boiler feed pumps
iii) Cold Shutdown Condition	
Primary	Shutdown Cooling Pumps
Secondary	Process Water in Shutdown Cooling heat exchangers.
<u>Under accident condition</u>	
i) Station Blackout	
Primary	Thermosyphoning
Secondary	Re-circulating steam generators secondary side inventory after cooling in passive decay heat removal system (PDHRS). As a backup, fire water supplied from diesel engine operated pumps independent of station power supplies can also be injected into PDHRS or steam generators after their depressurization.
ii) Loss of Coolant Accident	Through Emergency core cooling system (ECCS) (i) 2 X 100 % trains of High pressure H_2O injection (Accumulator) (ii) 2 X 100 % trains of Low pressure long term recirculation by ECCS pumps Fire water direct injection to the core is provided through ECCS path as backup.

3.3 Containment of Radioactivity

Type	Double containment with primary containment of pre-stressed concrete (with steel liners) and secondary containment of reinforced concrete. Both are of dome shape.
Engineered Safety Features	Containment spray system – for containment cleanup and cooling after accident Secondary containment purge and recirculation system – to maintain negative pressure in secondary containment space Primary containment controlled discharge system- to reduce primary containment pressure on long term basis.

3.4 Emergency Power Supply Systems:

700 MWe IPHWRs are connected to the grid through two separate systems of 400KV and 220 KV.

Standby Power Supply System consists of Class-III, Class-II and Class-I Power Supplies. These Standby Power Supplies feed all the safety related loads of the station. These are divided into the Division-I and Division-II for distributing redundant safety related loads. The redundant loads are so distributed that each division can independently meet the emergency load requirement. Each division is independent and physically separated from the other.

on-site emergency DG sets is classified as Class-III power supply system. Auxiliaries connected to this power supply system can tolerate short time power supply interruption (approximately two minutes). 4 numbers of 4000kW, 6.6kV diesel generator sets are provided. DG#1 and DG#3 are located in SAB-A and DG#2 and DG#4 are located in SAB-B. Each diesel generator set along with its auxiliaries is housed in independent rooms. Any one out of four diesel generator sets is adequate to meet the system demands under all postulated conditions. Onsite underground water proof fuel oil storage sufficient for 1 DG operation for 7 days at 4000 kW is always ensured.

3.5 Service Water System (Providing Ultimate Heat Sink):

All the safety related loads are cooled by closed loop process water system, which in turn rejects heat to atmosphere through service water system. The design of process water and service water in 700 MWe IPHWRs is improved w.r.t. earlier units by having these systems in two independent loops. DG sets are cooled by service water. These systems and buildings in which equipment of these systems are located are designed and qualified as seismic category-1.

3.6 Spent Fuel Storage And Cooling System:

In 700MWe IPHWRs, Spent Fuel Storage Bays (SFSB), one for each unit, are located inside the reactor auxiliary building outside Reactor Building. It has the capacity to store spent fuel bundles of 10 years reactor operation and one emergency full core unload. These spent fuel storage pool are having tank in tank concept. Water inventory inside the SFSB is about 4500 m^3. Present estimation indicates the following

Sr. No.	Parameters	Normal Heat load of 10 years Spent fuel inventory (days)	Normal heat load + emergency heat load of one core.(days)
1	Time to reach 100 °C	5.5	3.4
2	Time to reach min. shielding height	25.5	15.35
3	Time to reach top fuel exposure	42	25.5

3.7 Design Basis Flood Level:

The maximum flood water level estimated is 50.3 m RL for KAPP 3&4 and 361.61 m RL for RAPP 7&8.

The safe grade elevation for KAPP 3&4 is 51 m RL (99.7 m elevation) and that for RAPP 7&8 is 408 m RL. Internal flooding of buildings due to external flood is ruled out by appropriately sealing all the pipe penetrations under the safe grade elevation. The floor elevation of all buildings at ground level is at 51.3 m RL (100 m elevation). All the cable penetrations are made approximately 500 mm above safe grade elevation (51 m RL).

The same philosophy has been adopted for RAPP 7&8 also with a safe grade elevation of 408 m RL.

Since both the sites at Kakrapar and Rajastan are inland sites, Tsunami is not postulated.

3.8 Existing On Site Water Inventory:

1. Seismically qualified underground IDCT basins (Both units together) contain 28000 Cub M of pre treated water which includes Ultimate Heat Sink (UHS) inventory. (In RAPP 7&8, separate SSE qualified Emergency Makeup Water Pond (EMWP) is provided to cater to the UHS inventory)

2. Seismically qualified underground Fire water sumps (Both units together) contain 4000 M^3 of pre treated water.

3. Seismically qualified ACST (Both units together) contain 650 M^3 water.

4. ECCS sump inside Reactor Building contain 1100 m^3 of DM water

5. Deaerator storage tanks (Not Seismically qualified) contain 500 m^3 of DM water (Both units together)

6. NDCT basins (Not seismically qualified) contain approximately 1,80,000 M^3 of raw water (Both units together).

7. DM water storage tanks (Not seismically qualified) contain 560 M^3 of DM Water (Both tanks together).

8. Condensate Storage Tanks (Not seismically qualified) contain 500 M^3 of DM water (Both units together).

9. Domestic water over head tank (Not seismically qualified) contains 180 M^3 of treated water (Both units together).

10. Over head DM water storage tank (Not seismically qualified) contains 50 M^3 of DM Water (Both units together).

3.9 Decay heat removal provisions:

3.9.1 Core cooling during loss of Class-IV power supply

During loss of Class-IV power conditions, reactor is shutdown automatically and core cooling is achieved by natural circulation of primary coolant system through steam generators. Heat removal from SG takes place initially through atmospheric discharge valves. After starting of the EDG sets, Auxiliary boiler feed pumps supply feed water to SGs. Subsequently shutdown cooling system can be valved in and in this mode core cooling can be maintained for long period.

3.9.2 Core cooling during SBO:

In case of simultaneous loss of Class-IV and Class-III power supply, reactor is shutdown automatically and core cooling is achieved by natural circulation of primary coolant system through steam generators. 700 MWe IPHWRs incorporates passive decay heat removal system (PDHRS) which cool and re-circulate SG secondary side inventory. PDHRS having 600 m^3 DM water inventory (4 x 150 m^3) can maintain SG inventory for about 6 hours without any make up. There is design provision to supplement PDHRS inventory by fire water system and this mode of cooling can continue for long period. In addition feature of fire water injection into SGs is also available as a back-up to PDHRS.

3.10 Design Basis Accident (DBA):

Safety analysis of various design basis accidents have been carried out including loss of coolant accidents (LOCA) covering a spectrum of primary coolant pipe break sizes. With ECCS available, acceptance criteria are met for all LOCA conditions. All equipments in ECCS system are provided with class III / II power supply. A sump with an inventory of 1100 m^3 is provided at the basement of the Containment to provide suction to ECCS pumps.

Containment spray system is available for post accident containment clean up and cooling to depressurize the containment. CSS pumps are provided with Class-III power. The CSS pumps also take suction from the same ECCS sump.

3.11 Multiple Failure Conditions:

Safety analysis of various multiple failure conditions have been carried out (viz. LOCA with Loss of ECCS, LOCA with Failure of containment isolation) and the Radiological Impact Assessment shows that no counter measures in public domain are required in these cases.

4.0 Additional Design provisions under consideration

Following safety features exist in the design of 700 MWe IPHWR to mitigate the consequences of an accident or to prevent escalation of accident severity. In addition to the present design provisions, some measures are under consideration and are indicated below. These additional measures will be further reviewed in detail and the feasibility will be checked before implementation.

	Design Feature	Design Status for IPHWR 700 MWe
Augmentation of services		
1	Water availability / utilization for various accident conditions.	On site water inventory is given in section 3.7. Additional design provisions under consideration -Appropriate hook up arrangement with quick connectors to utilize the onsite water resources as explained in section 3.8. -Fire tenders for the backup of diesel driven fire water pump. - Bore holes inside plant boundary. - Other water sources near plant.

2	Alternate power supply	4x4000kWe emergency diesel generators exist. Additional design provisions under consideration – -Additional power packs / power sources for monitoring, emergency loads, lighting, etc.
3	Automatic Reactor Trip	Additional design provisions under consideration - Automatic Reactor trip on Seismic event.
Measures to prevent escalation of accidents		
1	Passive Decay Heat Removal System (PDHRS)	Design provision exists for 6 hrs without make up. In addition, provision exists for water addition to PDHRS tank by fire water backed by fire tenders or portable pump. Hook Up system exists.
2	Emergency Core Cooling System	Design provision exists for water addition by fire water backed by fire tenders or portable pump. Hook Up system exists.
3	Steam Generators	Design provision exists for water addition to SG by fire water backed by fire tenders or portable pump. Hook Up system exists.
4	Spent fuel storage bay	Additional design provisions under consideration - Hookups for make up to SFSB in case of loss of power supply.
Mitigative measures to arrest accident at different stages		
1	Water make up to calandria	Design provision exists for water addition to Calandria by fire water backed by fire tenders or portable pump. Hook Up system exists.
2	Water make up to calandria vault	Design provision exists for water addition to Calandria vault by fire water backed by fire tenders or portable pump. Hook Up system exists.
3	Water make up to end shields	Design provision exists for water addition to end shield by fire water backed by fire tenders or portable pump. Hook Up system exists.
5	Hydrogen management through passive autocatalytic recombiner	Better hydrogen dispersion from FM vaults to pump room areas during accident conditions by providing openings between these areas. Additional design provisions under consideration: - Design provision for Passive Autocatalytic Recombiner (PAR)

5.0 Preparation of Procedures and training of operators:

Procedures to handle extreme events utilizing systems mentioned above will be made and training imparted at appropriate time.

6.0 Conclusion

700 MWe 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 possibility of upstream dam failure. Core cooling is achieved by natural circulation, a complete passive system in the event of total unavailability of off-site/ on-site power supply. A passive decay heat removal system is provided to preserve inventory in SG for continued natural circulation. Various systems backing one another are provided to maintain natural circulation. The inventory in SFSB ensures fuel will not get uncovered for about 25 days. 700 MWe Indian PHWRs are capable of handling any postulated external natural events. However, some considerations as indicated under section 4.0 are being reviewed in detail for feasibility of implementation.