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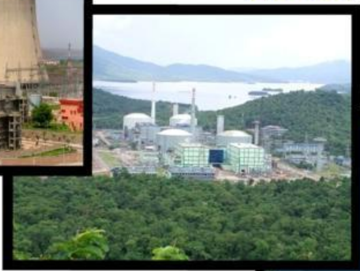
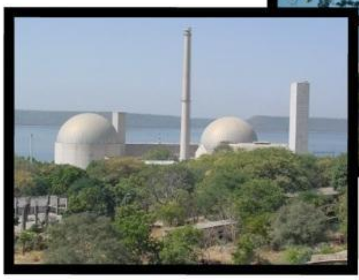



Safety Evaluation of Indian Nuclear Power Plants Post Fukushima Incident

(Interim Report)



Nuclear Power Corporation of India Limited

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NPCIL

SAFETY EVALUATION OF INDIAN NUCLEAR POWER PLANTS POST FUKUSHIMA INCIDENT

Interim Report

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EXECUTIVE SUMMARY

An unprecedented earthquake of magnitude 9 (Richter scale) followed by a Tsunami of height much larger than the value considered in design of Fukushima Dai-ichi Plant had hit north eastern part of Japan on March 11, 2011.

There are 13 nuclear power plants, all of Boiling Water Reactor type located in the affected zone. Six of the units are located at Fukushima Dai-ichi (3 under operation and 3 under shutdown), 4 at Fukushima Dai-ini and 3 at Onagawa all operating. The severe earthquake resulted in the disruption of the grid resulting into non-availability of offsite power. All the operating plants were automatically shut down on sensing the earthquake. The decay heat removal system started functioning normally as per design requirements. The Tsunami which hit the affected area about half an hour later, resulted into submergence of the emergency power supply systems at Fukushima Dai-ichi leading to total loss of on-site power supply, termed as station blackout condition. The decay heat removal could not be resumed, which ultimately resulted in the fuel assemblies getting uncovered. This led to overheating of the fuel. Metal water reaction between zirconium and water resulted in generation of hydrogen. In the process, the reactor containment vault pressure increased and reached upto almost two times the design pressure. It was decided to vent the reactor containment vault to prevent damage to it. During the depressurization, hydrogen and steam leaked into the secondary containment resulting in hydrogen explosion. Spread of radioactivity necessitated evacuation of public in the nearby areas extending up to 20-30 Kms to prevent exposure of the public. The event was initially rated as Level 5 on the International Nuclear Event Scale. The rating was subsequently revised to Level 7. However, the total radioactivity released during this incident was about 10% of that released during the Chernobyl accident in 1986. There was also degradation in the cooling provisions of spent fuel pool in Unit-4 resulting in spent fuel getting uncovered. The situation is still evolving.

NPCIL was in constant and continuous contact with World Association of Nuclear Operators (WANO), International Atomic Energy Agency (IAEA), Japan Atomic Industrial Forum (JAIF) and also NPCIL representative posted at WANO, Tokyo Centre. The scenario has been developed based on information obtained from these sources. WANO quickly provided a Significant Operating Experience Report highlighting generic aspects to be checked out at all Nuclear Power Plants.

Considering the severity of the situation at Fukushima resulting out of severe multiple natural events leading to loss of operational and safety system in Dai-ichi plant, it was decided to comprehensively review and re-evaluate the readiness at our nuclear power plants for dealing with extreme events. For this purpose, four task forces were constituted covering different types of reactors, namely, Boiling Water Reactors at Tarapur Atomic Power Station, Pressurized Heavy Water Reactors with dousing and single containment at Rajasthan Atomic Power Station, Pressurized Heavy Water Reactors with suppression pool and partial double containment at Madras Atomic Power Station and subsequently built standardized Pressurized Heavy Water Reactors from Narora Atomic Power Station onwards having double containment, suppression pool, and calandria filled with heavy water, housed in a water filled calandria vault. The stations were asked to conduct walk down and inspect all important provisions required to withstand flood and fire events. The reports of the four task forces have been discussed in detail by Operations, Design and Safety directorates together with the top management at NPCIL HQ. The reports of the task forces have been collated and presented in this report along with the existing safety features and practice of safety management in force in our nuclear power plants. It may be noted that present review and re-evaluation is an interim measure and is based on the present understanding of the Fukushima event. This exercise is required to be updated at a later stage when the detailed chronological events of Fukushima become available.

The important design features of the Indian NPPs including the boiling water reactors have provisions to handle complete loss of power, differing from Fukushima Dai-ichi plant.

In the context of scenario at Fukushima, it may be recalled that pertinent incidents at Indian nuclear power plants, like prolonged loss of power supplies at Narora plant in 1993, flood incident at Kakrapara plant in 1994 and Tsunami at Madras plant in 2004 were managed successfully with existing provisions.

An in depth safety analysis and review of these events was carried out and lessons learnt were adequately utilized for taking corrective measures in all the operating as well as under construction plants.

Similarly, to assess safety of our reactors in light of International events in nuclear industry like Three Mile Island and Chernobyl, detailed independent safety review of events were conducted and key lessons learnt were implemented in all plants.

Present review and re-evaluations conducted indicate that adequate provisions exist at Indian nuclear power plants to handle station blackout situation and maintaining continuous cooling of reactor core for decay heat removal. However, to further augment the safety levels and improve defense in-depth, salient recommendations which have been made for short and long term implementation are given below:

- Automatic reactor shutdown initiation sensing seismic activity
- Inerting of the TAPS-1&2 containment
- Increasing the duration of the passive power sources/battery operated devices for monitoring important parameters for a longer duration
- Provisions for hook up arrangements through external sources, for adding cooling water inventory to Primary Heat Transport (PHT) system, steam generators, calandria, calandria vault, end shields and Emergency Core

Cooling System (ECCS) as applicable and also the provisions for mobile diesel driven pumping units

- Augmentation of water inventory and the arrangement for transfer of water from the nearby sources if required
- Revision of Emergency Operating Procedures (EOPs) to include additional provisions recommended
- Organize structured training programs to train plant personnel on modified EOPs
- Additional Shore protections measures at Tarapur Atomic Power Station and Madras Atomic Power Station which are located on the sea coasts, as deemed necessary
- Additional hook up points for making up water to spent fuel storage pools wherever necessary for ensuring sufficient inventory

A detailed implementation programme is being worked out to address all the identified requirements.

SAFETY EVALUATION OF
INDIAN NUCLEAR POWER PLANTS
POST FUKUSHIMA INCIDENT

1.0 PREAMBLE

Under adverse rare natural event of undersea mega thrust earthquake of magnitude 9 on Richter scale, followed by Tsunami hitting Fukushima Dai-ichi Nuclear Power Plants in Japan accompanied by seismic aftershocks, the existing safety features were challenged resulting in local radiological consequences. Preliminary information on event progression indicates that all operating reactors in the region were automatically shutdown sensing earthquake and brought to subcritical state within seconds and core cooling was established. Earthquake had cut off the off site power feed to the plants. However, later, a tsunami of much higher intensity than the design basis impaired the onsite power as well, owing to flooding of emergency diesel generators. Complete loss of Onsite and Off-site power also called as station black out, jeopardized reactor core cooling process. Consequent fuel heat up to higher temperatures led to exothermic metal water reaction (chemical reaction), partial damage of the fuel, and resulted in hydrogen build up in reactor vessel and containment. Subsequently, containment pressure started rising, necessitating containment depressurization by venting. This venting resulted in hydrogen entering into the reactor building, accumulating near the roof, forming explosive concentrations levels. The consequent explosion partially damaged the reactor building which serves as a secondary containment and resulted in local radiological consequences. Following the release of radio activity, laid down radiation emergency procedures were followed. Event management unfolded new challenges of sustained core cooling and emergency preparedness under adverse conditions, to ensure public safety.

At Fukushima Dai-ichi, the event got exacerbated by loss of cooling and consequent over heating of fuel, which resulted in generation and escape of hydrogen. When this hydrogen reached explosive concentration, explosion took place in the reactor building, damaging its roof. The main learning point from this incident as well as the earlier incident at TMI is to prevent fuel temperature rise and hydrogen generation, by assuring uninterrupted core cooling. This has been the focus in all our plants, where several redundant systems are provided for core cooling to build Defence-in-Depth.

NPCIL immediately took a decision to revisit the safety provisions and Emergency Operating Procedures existing at its plants to check for their adequacy as well as to further improve them, wherever required.

The scenario at Fukushima is still evolving and NPCIL is keeping a close watch on the progress of events. This interim report is prepared based on the understanding derived from the information available so far and will be re-visited at a later time when further details are available. The quick exercise conducted as of now has identified areas requiring further strengthening of the Defense-in-Depth, to arrest progression of such events and has identified short term and long term recommendations.

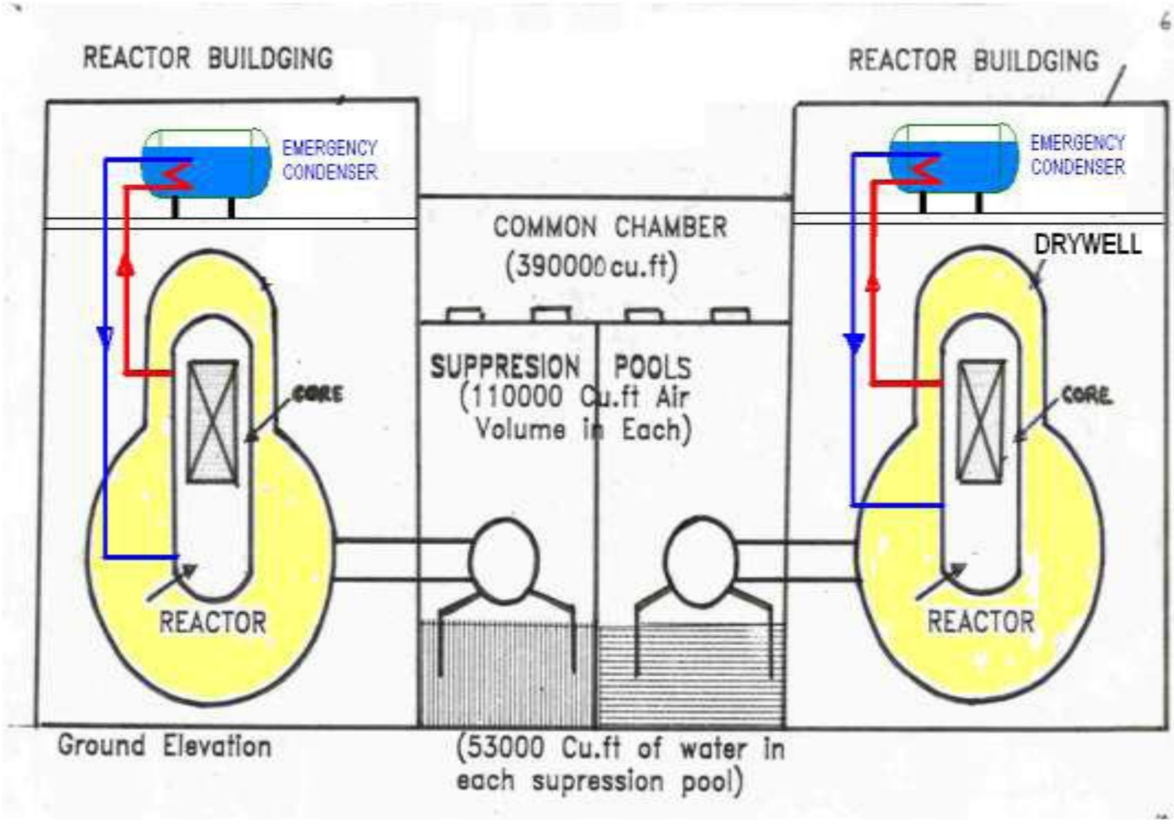
In line with the actions by International Nuclear Community, walk downs have been performed at all NPCIL Stations, mitigating provisions available to handle severe natural events including loss of onsite and offsite power have been inspected and ensured to be in a state of readiness.

The important design features of the Indian NPPs in the present context include provisions to handle complete loss of power and are brought out below:

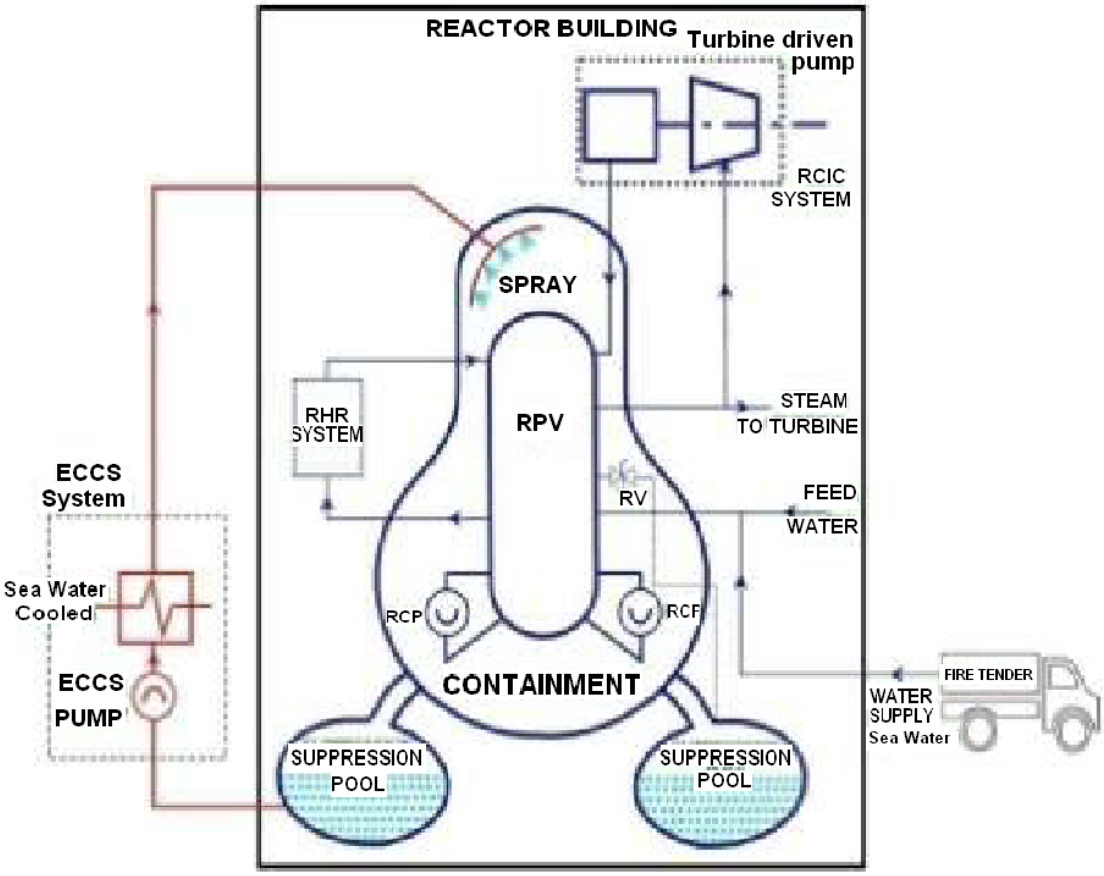
i) Boiling Water Reactors at TAPS 1&2

- Passive decay heat removal feature in the form of emergency condenser which performs without the need of any motive equipment or requiring electric power, discharging the decay heat into the atmosphere
- Ten times higher free space in the dry well and wet well including the common chamber (as compared to Fukushima reactor) which will accommodate larger amount of non-condensable gases and as a result, the pressure increase in the containment will be lower.

Containment (TAPS-1,2)



Fukushima Reactor



ii) Pressurized Heavy Water Reactors (Refer Sketch in Item - 4)

- Decay heat removal by **natural recirculation** (without requirement of pumping) of primary heat transport coolant through steam generators, which are located at higher elevation than the reactor.
- Provision to add water to secondary side of steam generators through diesel operated firefighting pumps/ mobile firefighting pumps.
- Heat sink for the fuel in the form of low temperature moderator in reactor vessel (calandria) and water filled calandria vault in standardised PHWRs.

The licensed and qualified manpower at NPCIL's plants are well trained to use the Emergency Operating Procedures formulated at all the plants based on the above provisions to deal with scenarios under station black out, flood and tsunami events.

1.1 Safety: An Ever Evolving Feature in NPCIL

NPCIL, as a part of its safety culture, has institutionalized a process of national/ international event(s) tracking, their safety review for applicability in Indian nuclear power plants. It is to bring out that the safety provisions in Indian nuclear power plants have been re-evaluated on a number of occasions.

In the context of scenario at Fukushima incident, it may be recalled that pertinent incidents as mentioned below were managed with existing provisions at Indian NPPs. Prolonged loss of power supplies at Narora Atomic Power Station consequent to turbine fire incident in 1993 had no radiological impact on environment as the event was successfully handled using existing design provisions and emergency procedures. However, key recommendations of safety review broadly included the fire prevention measures, avoiding common cause failure of all power supplies and additional mitigating measures for assured core cooling and were implemented.

- Flood incident at Kakrapara Atomic Power Station due to heavy rains together with non-operation of weir control for adjoining water pond caused the flooding at the plant in 1994, inundating turbine building basement equipment. On-site power supply facilitated core cooling using fire water, a backup to process water since offsite power supply failed. Salient recommendations included administering preventive measures such as provision of multiple flood barriers at all entry points, sealing of inlet openings below design flood level and updating emergency operating procedures.
- In Tsunami event of December 26, 2004 at MAPS due to earthquake at Sumatra fault, essential safety requirements of plant shut down, maintaining cooling of reactors and isolation of containment were met. However, recommendations of review that included early warning system for tsunami, provision of additional cooling water sources for longer duration cooling were implemented.

These events were analyzed in depth; lessons learnt requiring corrective measures were implemented not only for affected sites but also at other stations and projects under construction as an established practice of enhancing safety levels for all plant

Similarly, to assess safety of our reactors in light of events in nuclear industry worldwide, detailed independent safety review of events was conducted and key lessons learnt were implemented in all plants.

The events at Three Mile Island, USA and Chernobyl, Ukraine (then Soviet Union) had brought out many learning points which were studied and incorporated in our reactors. Following NPCIL reactors were already operational at the time of these incidents.

Unit	Month & Year of Commissioning
TAPS-1	Oct-1969
TAPS-2	Oct-1969
RAPS-1	Dec-1973
RAPS-2	Apr-1981
MAPS-1	Jan-1984
MAPS-2	Mar-1986

TAPS-1&2 and RAPS-1 were commissioned before TMI incident which took place in 1979. The Chernobyl accident took place in April, 1986 when TAPS-1&2, RAPS-1&2 and MAPS-1&2 were operational.

Strengthening measures arising from the lessons learnt out of national and international events in NPPs are embedded in the design of Indian nuclear power plants and back fitted at the operating stations. As such, NPCIL stations are designed to withstand earthquake, tsunami, flood and fire to mitigate Fukushima-like event. The current review is intended to identify further measures to enhance the existing safety provisions to a higher level.

1.2 Findings of First Level Evaluation

Fukushima event was initiated by the beyond design severe seismic event (9.0 Richter scale) followed by tsunami. It is seen from the Indian scenario that Indian seismo-tectonic map is different from Japan. The location of Tsunamigenic faults in Indian context and seismic map of India reveals that simultaneous occurrence of earthquake and Tsunami/ flooding is not expected.

The safety features of Indian NPPs are designed for earthquake with return period of 10,000 years. Similarly regulatory guidelines for postulating maximum flood potential/ tsunami/ cyclone and storm surge are taken into consideration for fixing the design plinth level of the plant and safety systems. A system of continuous review of various incidents/operating experience at national/international level is in force and back fits to address the findings are periodically incorporated in our nuclear power plants. Indian NPPs are designed, constructed, commissioned and operated meeting the Safety System norms brought out in the Indian Regulatory documents for Siting, Design, Safety Analysis, Construction and Operation at par with the international standards. The effects of natural external events such as earthquake, cyclone, storm surge and Tsunami events are the considerations in siting requirements of Indian NPPs along with many others lie vicinity of water resources, availability of heat sink, etc which are detailed out separately in the report.

A first level assessment has been carried out on the mitigating provisions available in the current design for Indian NPPs. The status is summarized in the accompanying tables bringing out the margins available with regard to various events. The extreme external natural events considered are earthquake and Tsunami/ floods. Other event considered is complete loss of Off-site and On-site power. It can be seen that Indian NPPs have adequate design provisions to cope up with these events. It may be noted that for TAPS-1&2, RAPS-1&2 and MAPS-1&2 plants the original design did not consider Tsunami and upstream dam break conditions. The designs were revisited and additional provisions were retrofitted during the safety upgrade campaigns taken up earlier.

Assessment of Seismic Margin

Station	Seismic Zone	Magnitude (Richter Scale)	Epicentral Distance (km)	Design PGA (g)	Conservative Margin (PGA) (g)
TAPS 1,2	III	5.7	16	0.2g	0.337 to 1.83 @
RAPS-1,2	II	6.0	40	0.1g	0.233 to 2.26 @
MAPS-1,2	II	6.0	20	0.156 g	0.233 to 2.26 @
NAPS-1,2	IV	6.7	12	0.3g	0.6 #
KAPS-1,2	III	6.5	30	0.2g	0.6 #
KGS-1,2,3,4	III	5.7	12	0.2g	0.6 #
RAPS-3,4,5,6	II	6.0	40	0.1g	0.6 #
TAPS-3,4	III	5.7	16	0.2g	0.337 to 1.83 @

@ **Seismic requalification based-** These values are based on analysis conducted during the seismic re-evaluation of the plants based on permissible stress values. Very few components are close to the low PGA values, majority are close to 0.6g PGA.

\# **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 SMA 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.

Postulated flood levels and margins

Station	Original designed flood level (in meter)	Revised levels taken for assessment (in meter)	Emergency power DGs elevation (in meter)	Margin available (in meter)
TAPS-1&2	29.33	31.10*	32.30	1.20
RAPS-1&2	354.20	359.60**	356.6 (Original DGs) 366.6 (Retrofitted DG)	 7.00
MAPS-1&2	8.96	10.50*	10.67 (Original DGs) 12.5 (Retrofitted DG)	0.17 2.00
NAPS-1&2	180.80	Design is adequate-revision not required	187.30	6.50
KAPS-1&2	50.30	Design is adequate-revision not required	51.30	1.00
RAPS-3&4	359.60	Design is adequate-revision not required	384.30	24.70
RAPS-5&6	359.60	Design is adequate-revision not required	393.30	33.70
KGS-1&2	38.90	Design is adequate-revision not required	41.30	2.40
KGS-3&4	38.90	Design is adequate-revision not required	41.60	2.70
TAPS-3&4	31.10	Design is adequate-revision not required	32.30	1.20

* For TAPS-1&2, Tsunami is considered for revision of flood level for assessment.

** For RAPS-1&2, Upstream dam break is considered for revision of flood level for assessment.

Station Black Out (SBO) Handling Measures

Station	Availability of Class-II Duration (hours)		On-site Water Sources available as Heat Sink Capability (in days)		Availability of make-up provision	Spent Fuel Storage Bay Water Inventory for Maximum Heat Load (in days)
	Power Battery	Control Battery	Seismically Qualified	Non-Seismic		
TAPS-1,2	8	12	> 30	>30	Yes	Fuel pool - 7 AFR* pool - 7
RAPS-1,2	16 **	8 ***	7	>30	Yes	Fuel pool - 7 AFR* pool - 30
MAPS-1,2	16 **	8 ***	7	>30	Yes	30
NAPS-1,2	16 **	8 ***	7	>30	Yes	30
KAPS-1,2	16 **	8 ***	7	>30	Yes	30
KGS-1,2,3,4	16 **	8 ***	>30	>30	Yes	30
RAPS-3,4,5,6	16 **	8 ***	>30	>30	Yes	30
TAPS-3,4	16 **	8 ***	>30	>30	To be provided	30

*   AFR - Away From Reactor

**   With appropriate load shedding and catering to essential loads

*** With appropriate load shedding and catering to essential indications and logics

Estimated tsunami wave height that will be generated at the two coastal sites on account of postulated seismic event (level of 9.0 on Richter scale) due to Makran fault at TAPS and Sumatra fault at MAPS have been considered. The other plants are inland sites. The highest seismic potential of 9 in Richter scale exists in Himalayan region. None of our nuclear plants are located at a site with potential of more than 7 in the Richter scale.

Main reason for the accident event progression at Fukushima is the impairment of the core cooling after shutdown and consequently, decay heat from the reactor could not be adequately removed. This aspect was the central theme of evaluation of the Indian Nuclear Power Plants (NPPs). The Task Forces revisited the provisions and facilities at every unit along with feedback obtained from the Stations through Plant Walk down exercises bringing out the actual status of the systems, components and features.

The Task Forces have given recommendations with a view to add further Defence-in-Depth.

SAFETY ASPECTS OF
NUCLEAR POWER PLANTS (NPPs)
IN INDIA

2.0 Fleet operated by NPCIL

NPCIL is operating twenty nuclear power plants comprising two Boiling Water Reactors (BWR) of 160 MWe each, sixteen Indian Pressurized Heavy Water Reactors (IPHWRs) of 220 MWe each and two IPHWRs of 540 MWe each. Four units of 700 MWe IPHWRs and two units of Russian WWERs- Pressurized Water Reactors (PWRs) of 1000 MWe each are under construction. The present total installed capacity of nuclear power in India is 4780 MWe. The accumulated experience of safe operation through these reactors is 330 reactor years.

2.1 Safety Features considered during selection of a site for Nuclear Power Plants in India

Safety is given prime and overriding importance at all stages of a Nuclear Power Plant (NPP) at every stage viz. in site selection, reactor design, construction and operation. The Sites for Indian nuclear power plants are selected based on the criteria such that these plants can be constructed and operated safely and provide protection to plant personnel, public and environment against impact of radiological consequences under operating conditions as well as accidental conditions. The Site selection considers the impact of external natural hazards viz. seismic, rain precipitation, storm surges and tsunami (for coastal site), flooding due to upstream dam break (for inland sites), geological hazards, loss of ultimate heat sink as well as external human induced hazard like those from oil refinery, chemical plant, flight corridor, armament depots etc.

The effect of these site parameters on engineer-ability of the plant in the context of external natural and man induced events is assessed. For an external event (or combination of events) the choice of values of these parameters which dictate the plant design is determined to ensure that buildings, structures, systems and components important to safety will maintain their integrity and will not suffer loss of function during and after the event. Design provisions against external events (man made and natural) are based on the data obtained from various National Organizations, Institutes, and R&D centers of repute.

Some of the design considerations for these external events are as follows: -

i) Design basis flood for inland sites is evaluated considering combinations of maximum probable precipitation (rainfall) and floods due to upstream dam breaks. Site grade elevation is set at a level higher than the design basis flood level. Meteorological data of precipitation for 100 years is used for arriving at maximum precipitation at design basis flood level.

ii) Site Specific design basis ground motion i.e. peak ground acceleration, response spectrum and spectrum-compatible time history is evaluated from seismo-tectonic considerations. These are used for design of various structures, systems and components (SSCs) to withstand earthquake.

iii) Impact of Tsunami, cyclone, storm surge, and wave run up for coastal sites

iv) Fire hazard is evaluated and safety of various SSCs is ensured against fire

v) Consideration of severe weather conditions

vi) Consideration of aircraft crash by locating site away from flying corridor

2.2 Site Specific Requirements of NPPs Considering External and Internal Events

The NPPs are designed considering internal events originating from within the plant and external events impacting from outside. The frequency and the severity of external events and phenomena, natural and man-induced that could affect the safety of the plant are assessed and design provisions are made to safely handle such events. The location of plant site ensures that the site-plant interaction does not introduce radiological risk of an unacceptable magnitude. In nature, generally, environment and public are continuously exposed to radiation and radionuclide from natural sources of both terrestrial and extraterrestrial origin and it is ensured that the impact due to nuclear plant operation does not cause any significant addition.

The radiological impact assessment of site is done considering the meteorological data with respect to wind speed and direction, atmospheric stability, dispersion of radioactive material through atmosphere. Finally, site specific off-site emergency preparedness plans are developed considering the demographic data (periodically updated), evacuation routes, shelter, transportation and consideration of exclusion zone and sterilized zone.

The design of Indian nuclear power plants take into account a wide range of postulated initiating events from low probability high consequences events to high probability low consequences events to ensure that radiological consequences of postulated events are well below acceptable levels for public safety. The design of nuclear power plants considers engineered safety systems for mitigating Design Basis Events, such as Loss of Coolant Accident (LOCA), and natural events occurring due to seismic, cyclone wind, floods caused by heavy precipitation, upstream dam break for inland sites and tsunami/ storm for coastal sites and fire. A postulated event falling beyond this range is called as Beyond Design Basis Event, and such an event may require Emergency Operating Procedures outlining additional provisions and measures to handle it safely.

2.3 Design Considerations for Natural Events - Seismic, Flooding, Cyclone, Tsunami, etc.

The Indian nuclear power plants are located in Indo-Gangetic plains and peninsular India in seismic Zone 3 or lower except for Narora Atomic Power Station (NAPS) which is in Zone 4. These seismic zones are lower as compared to Zone 7 of Fukushima as per United States Geological Survey (USGS). Indian Nuclear Power Plants (NPPs) are designed to withstand earthquake with adequate safety margins commensurate with their site specific design basis ground motion, worked out conservatively. In addition, it is a mandatory requirement for setting up nuclear power stations that there should be no active ground faults within 5 kilometers of plant area. The Atomic Energy Regulatory Board (AERB) requires that safety significant structures, systems and equipment be designed to take into account even rare and extreme seismic event. For each nuclear power plant an in-depth seismic analysis is carried out and the plant is designed and constructed to withstand the maximum projected earthquake that could occur in its area without any breach of safety system. For example, a site that features clay over bed rock will respond differently during an earthquake than a hard rock site. Taking all these factors into account, maximum ground motion at the plant location is determined and the plants are designed accordingly.

During earthquake at Bhuj region (Gujarat) on January 26, 2001, plants at KAPS and TAPS continued to operate as these are designed for Safe Shutdown Earthquake (SSE) level. These catastrophic natural events are primarily region and location specific, based on tectonic and geological fault line locations, which calls for site specific assessments avoiding extrapolations.

For inland sites the cooling water sources are lakes/rivers (with or without cooling towers) while for coastal sites the sea water is used as ultimate heat sink for cooling the reactors and to remove the residual heat. The `Grade Level' for NPPs is designed to cater to the potential of external flooding emanating from heavy precipitation or dam break at the upstream end for inland sites and design basis Tsunami wave height or cyclone storm surges for coastal site.

Fire and explosions which could occur as a consequence of the natural event are also taken into design considerations of an NPP to ensure effectiveness of shut down and cooling of the reactor as well as isolation of the containment from environment.

2.4 Design Considerations for Provisions of Defence-in-Depth

The NPP is designed with redundant, diverse and physically separated safety systems and components following principles of multiple barriers/ Defence-in-Depth to achieve the essential safety functions of reactor shutdown, continuous core cooling and containment of radioactivity. The design provides multiple safety barriers between fuel and public such as fuel cladding, pressure retaining boundary and containment along with the exclusion zone as part of Defence-in-Depth philosophy to ensure that the radiation release is well below the prescribed dose to public during normal operation and reference dose during accident conditions.

2.5 Operational Practices of NPPs

Operation of the nuclear power plants of NPCIL is carried out, within the requirements of Technical Specifications, a document approved by AERB, by formally trained and licensed personnel. All the key control room positions are manned by trained and licensed graduate engineers. The plant is operated as per approved procedures and following the operational limits and conditions for various system parameters laid down in the technical specifications for operation. Overriding priority is accorded to safe operation of the plants, safety of occupational workers, members of public and protection of environment. The operating personnel are periodically relicensed and are also imparted periodic training/retraining on full scope simulator.

2.6 Internal Safety Review Process for Operating Stations

NPCIL is an organization having expertise in areas of design, construction, commissioning, safety analysis, operation, quality assurance, training, research and development and management of human resources of nuclear power plants. All essential aspects of nuclear industry are available in-house under a single umbrella. The broad concepts of Defence-in-Depth and As Low As Reasonably Achievable

(ALARA) with respect to radiation exposure during normal plant operation are the main guiding principles followed in design and operation of plants.

One of the noteworthy features of the Indian nuclear power plants is the strong internal safety review mechanism combined with multitier regulatory safety review system. These mechanisms work in synergy, facilitating in bringing out any latent weaknesses quite early and corrective actions are initiated with overriding priority. A well structured practice to learn lessons from operational experiences at our plants as well as from international nuclear industry is in place. Prompt Operational Experience Feedback is thus a key area where emphasis is laid. Whenever any outage or event with significant learning point occurs in a plant, the information is compiled at headquarters and flash reports are issued to all stations, to ensure that the experience gained is immediately put to use to prevent recurrence of such an event elsewhere. Similarly detailed OPEX (Operation Experience Feedback) reports are generated and sent to stations for disseminating the information to all concerned. At Station Level, OERC (Operation Experience Review Committee) thoroughly reviews Operation Experience Feedback from other stations, international experience feedback reports from IAEA, WANO, COG and other such agencies, and, identifies actions to be taken. These identified actions are further reviewed in Station Operation Review Committee before implementation.

System exists at sites, to conduct regular job observations, to ensure that all good practices are put to use and potential pitfalls are identified and corrected. Focused self assessments are conducted in identified areas to identify areas for improvement. A well structured program exists at all sites to identify and correct Low level Events and Near Miss Events and draw lessons from them. Regular Team Building workshops are conducted to foster the culture of team working and synergize the efforts of all participating team members.

The Corporate Management System at NPCIL incorporates a network of Quality Assurance processes to sustain high level of safe performance. For operating stations; Technical units, Technical Audit Engineer, QA units, Root Cause Analysis teams, Aging management, Training and qualification, Health Physics and industrial safety etc are certain elements of this system.

2.6.1 Safety Review at NPCIL:

The internal safety review of station operation and safety performance is conducted by various safety review committees given as under:

2.6.1.1 Station Operation Review Committee (SORC)

SORC is the station level review committee, which meets regularly and discusses:

- station performance,
- review of any off normal occurrences, equipment failures, significant events, and low level events,
- infrequently performed operations,
- review and approval of engineering changes, referral of safety related changes for design review and monitoring of implementation of regulatory recommendations

The Station Director is the Chairman of SORC, which consists of heads of operations, maintenance, technical services and includes technical audit engineer and health physicist. The deliberations of this committee are provided to Corporate Office and regulatory body.

2.6.1.2 Safety Review Committee for Operations at Head Quarters

In addition, high level safety review committee at NPCIL Corporate Office conducts review of the various safety proposals, related engineering changes, events during operation and safety issues thoroughly and follows the resultant action plan.

2.6.1.3 Station Level Self Assessment

A review of the various operation aspects based on set performance objectives and criteria is done once in a year by a group of Senior Engineers from the Station and with a representative participating from Headquarters. The observations and findings of this review are addressed by the Station Management. The review report also undergoes a scrutiny at Headquarters.

2.6.1.4 Corporate Review

A comprehensive review of all functional and cross-functional areas of plant operation is carried out by a team constituted by Headquarters. Normally, Station Director from any other station is the Team Leader. This team conducts an in-depth review in line with the methodology followed in international peer reviews by World Association of Nuclear Operators (WANO).

The results of the Corporate Review are thoroughly reviewed by an Apex Committee for Review of Operating plants Safety Status (ACROSS). This is headed by a senior level Director and consists of other management personnel. The recommendations of this Committee are closely monitored for implementation.

The comprehensive review mechanism comprising the internal review processes existing at the Indian nuclear power plants bring to light the strength and robustness of systems and processes, which ensure that safety culture is all pervading through the organization and a structured review mechanism of all safety related issues exist.

2.7 External Review Mechanism

2.7.1 Regulatory Review

This consists of

- Site Clearance
- Review of Design/Safety Analysis
- Oversight on construction
- Authorization for operation
- Life management / upgradation
- Oversight of operation and review of operational incidents

The regulatory process consists of a three tier review; the first by the Unit Level Safety Committees, the second by Safety Review Committee for Operating Plants and at the apex level by the Atomic Energy Regulatory Board. In addition, a regulatory inspection by a team from the Atomic Energy Regulatory Board (AERB) is carried out once in every six months for each NPP. The implementation of the recommendations of the regulatory review is monitored by the Unit level Safety Committees.

Other statutory authorities such as Pollution Control Board, Central Electricity Authority, Department of Explosives, Inspectorate of Boilers, Ministry of Environment and Forests also have oversight in their respective areas.

2.7.2 Periodic Safety Review of Operating Stations by AERB

AERB while maintaining a regular oversight on safety, evaluation of events and incorporation of improvements also conducts a Periodic Safety Review (PSR) once every ten years for each plant to revalidate the license for operation of the Station. A midterm review at every five years is conducted to supplement the process. This review evaluates sufficiency of safety of the units in line with prevailing safety standards and safe operating practices so as to keep in pace with advances in technology prior to reauthorization of operation.

2.7.3 Peer Reviews

Peer reviews of all the Operating Plants is conducted periodically by World Association of Nuclear Operators (**WANO**) as well as by internal Peer groups.

WANO has a standard performance objectives and criteria which serves as the basis for such reviews. High priority is accorded by NPCIL to address all the Areas for Improvement (AFI) identified by the Peer Review Teams, who observe closely the performance of individuals and system by being at plant for about three weeks. Plants which are in the start-up phase are also peer reviewed. All the NPCIL Stations have been subjected to peer review once and many of them have also completed the second round of peer review.

2.8 Emergency Preparedness

Detailed off site emergency preparedness manuals are available at all our plants, which are prepared in consultation with the District Administration. The procedures laid out are checked for their effectiveness during field exercises which are conducted once every two years by district authorities. During the exercises the adequacy of the infrastructure available in the neighborhood for effective implementation of the emergency plans are checked. Based on the feedback, improvement of access roads, provision of adequate shelters and communication facilities and other logistic support required during off site emergencies are taken up.

It is noted that a similar plan has been executed in Japan following the event at Fukushima involving evacuation and monitoring and controls on food etc. The emergency preparedness plans will also be revisited by NPCIL after additional feedback from Fukushima event is available.

In this context of handling safety related events, an on line Computerized Operating Plant Information System and an Emergency Response Center facility is available at Headquarters so that experienced senior engineers can provide technical support to the station, whenever needed.

2.9 Safety Review of New Projects

NPC Safety Review Committee for Projects and Design at Headquarters evaluates the safety features and its standards during design. It ensures that current standards of safety are incorporated in the design. In addition to this a three tier safety review is also done by AERB before authorizing the construction of the plant. This includes:

- Siting clearance
- Review of Design/Safety Analysis
- Oversight during construction in the form of stage wise clearance for activities like equipment erection.
- Authorization for commissioning
- Start up.

2.10 Safety Upgradation of Plants

Bringing up the safety level of Operating Nuclear Power Plants is top priority for NPCIL. Lessons learnt from operating experience at NPCIL Plants as well as at Plants in other parts of the world are used as inputs for safety upgrades. The mechanisms as covered help to identify areas for improvement. Safety Upgrades are carried out during long outages of the plant for maintenance as well as life extension activities, complying with the regulatory recommendations.

ANALYSIS OF FUKUSHIMA EVENT

3.0 Initiation of the Fukushima accident

Unprecedented Earthquake of Magnitude 9.0 on Richter scale on March 11, 2011 at 14:46 Japan Standard Time (JST) off the northeast coast of Japan, the largest earthquake in 300 years, resulted in safe shut down of the plants. However the earthquake was followed by a Tsunami of 14 m height and significant aftershocks which incapacitated the electric power sources and impaired core cooling of Fukushima Dai-ichi Nuclear Power Plants.

3.1 Event Scenario

The Fukushima Nuclear Power Plant consists of six boiling water reactors (BWRs): Unit 1 (460 MWe), Unit 2 (784 MWe), Unit 3 (784 MWe), Unit 4 (784 MWe), Unit 5 (784 MWe) and Unit 6 (1100 MWe). Units 4, 5 and 6 had been shut down prior to the earthquake for planned maintenance.

NPCIL has been in constant touch with various agencies like WANO, IAEA, JAIF and NPCIL representative at WANO, Tokyo Centre to be updated with the developments at Fukushima. The probable path of progression of events at Fukushima has been re-constructed with the current understanding from the information received so far.

On sensing the earthquake, the operating reactors (Units 1, 2 & 3) were shut down automatically. Power grid of the northern Japan region failed. After automatic shutdown, decay heat was continuously removed by core cooling system operated by on site power from emergency diesel generators. Containment was isolated by closing all non-safety penetrations and plant was at safe shutdown state within one hour.

However, a tsunami with considerable height hit the plant at 15.41 hrs. The Plant was designed for withstanding Tsunami height up to 6.5 m. As a result, sea water flooded Diesel generators and essential service water building that cools the generators, causing failure of power supply from Diesel generators. Common Cause failure of Power supply led to Station Blackout and failure of emergency core cooling system. Station Batteries and Reactor Core Isolation Cooling System (RCIC) were available for a short period until batteries exhausted. RCIC pumps lost power supply when the battery supply ran out resulting in loss of decay heat removal function. Consequently, the decay heat continued to boil off the coolant inventory in Reactor Pressure Vessel (RPV) raising its pressure. Generated steam continued to be relieved into wet well, through relief valves raising wet well temperature. Water level in the RPV reduced exposing fuel rods, raising clad temperatures, and initiated metal water reaction accompanied by generation of hydrogen. Accident progression was stopped by restoring the water supply to Unit 1 to 3 on March 12, 2011, March 14, 2011 and March 13, 2011 respectively.

Significant amount of generated hydrogen pushed into the wet-well through wet-well vacuum breakers into the dry-well. Dry-well pressure rose to 8 bars which is double the designed pressure. The containments were pre-inerted with nitrogen. Depressurization of the containments of Unit 1 to 3 was done on March 12, 2011 and, March 13, 2011 respectively, by venting containment atmosphere. Depressurization of primary containment reduced the pressure but released the hydrogen, noble gases and small amounts of aerosols (Cesium 137 and Iodine 131) into the service floor of Reactor Building which acts as a secondary containment. Hydrogen explosion took place and secondary containment was damaged in Unit 1 on March 12, 2011 and in Unit 3 on March 14, 2011 . However, in Unit 2 Hydrogen explosion took place in wet-well chamber on March 15, 2011.

The fuel damage in reactors and spent fuel pools caused volatile fission products noble gases, Cesium and Iodine (airborne aerosols form) to be released to the environment in a gradual manner. The spread of radiation was restricted to mostly a few parts of Japan. Minor/negligible increase was reported by neighboring countries. However, on account of the long distances involved, no effect is expected in India. The current status of the Reactors is that the cores of Unit 1, 2, 3 are damaged. Secondary containment buildings were damaged due to various explosions/ fires in Unit 1 to 4. Reactor vessels were cooled with borated sea water in all Units with mobile pumps and it was reported that containment in Unit 1 was flooded. Further, cooling of the reactors is being carried out by releasing steam to the atmosphere leading also to releases of fission products along with.

Japanese have worked to cool the reactor by pumping sea water, spent fuel pools by fire tenders and water cannons for spraying water for cooling the fuel.

3.2 Radiological Consequences and Counter Measures

The radiological status at plant site and surrounding areas are being monitored continuously by the Japanese Authorities and the radiation levels are continuously showing a down trend. In the case of Chernobyl accident, due to the explosion of the reactor and subsequent fire, the radioactive debris were suddenly ejected to significantly higher altitudes and got dispersed over an widespread area. In the Fukushima incident the activity released initially was on account of hydrogen explosion in Reactor Building leading to release of steam with radioactive products. Some of the radioactivity release from Fukushima is also from the spent fuel pools. This radioactivity is getting dispersed over a localized area surrounding the plant. Temporary evacuation of the public has been done by the Japanese authorities over 20 to 30 Km radius.

For Unit 4, the scenario seems to be different as unit was under refueling shut down, wherein the entire core was stored in Spent Fuel Pool located on Reactor service floor. The unavailability of motive power resulted in loss of Fuel Pool cooling. As a result, the stored fuel inventory got heated, on evaporation of water and water level in the pool going down. Exposure of spent fuel to air resulted in metal water reaction which further heated up fuel. The hydrogen generated during the process formed an explosive mixture and resulted in explosion damaging the roof of the Reactor Building in which the spent fuel pool is located.

REVIEW OF INDIAN NPPs

BY TASK FORCES

4.0 Review of Indian NPPs in light of Fukushima event

In wake of the rare severe natural event at Fukushima, resulting in loss of significant operational and safety systems due to natural events, earthquake, flood, tsunami and consequential fire and explosions, a comprehensive safety review/ evaluation for all operating plants has been carried out by Task Forces constituted by NPCIL. These task forces have analysed the Fukushima event based on the current scenario (information available through various International agencies) and preliminary recommendations have been made as summarized in this section. These recommendations may undergo changes as the event is still evolving in Fukushima. The recommendations have been reviewed for the purpose of harmonizing the choice of common hardware and implementation approach, where desirable. The implementation details are being worked out and may vary with respect to detailed features such as quantification of equipment namely pumps, power supply etc. Actions to work out the engineering of the proposals are being initiated. Submission will be made to regulatory body for final review and clearance of the proposals.

It has been ensured that the plants are adequately designed to withstand site specific seismic conditions. Seismic instrumentation has been provided at all the sites to alert the operator, and take appropriate actions as per Emergency Operating Procedures. The task forces have recommended hooking up these instruments for automatic tripping of the reactor (except NAPS and KAPS where automatic reactor trip already exists). All the plant grade levels are higher than the design basis flood levels for the respective plants. Emergency power supplies are located above the design flood levels at all the plants. At RAPS-2 and MAPS-1&2, where the diesel generators were not above the design flood level, one diesel generator was provided at higher elevation during the last plant up-gradation.

While all the above provisions are available, the present study assumes rare combination of events and their extent which may challenge the onsite power and design cooling provisions as it happened in Fukushima event.

The summary of assessment made and the key recommendations made by the task forces for enhancing safety levels are brought out.

Recommendations Common to all Stations:

The four task forces after evaluating the four different designs of reactors in NPCIL fleet have come out with certain recommendations which are common to all the types of NPCIL reactors.

These are:

- ***Provision of automatic reactor trip on seismic event*** at all plants except where it is already available (NAPS & KAPS)
- ***Additional options for Power sources for cooling:-***
  - Additional Diesel operated fire tenders and diesel operated pumps to enable water addition at high and low pressures to the different systems based on the need.
  - Diesel driven electric generators (air cooled and not requiring external cooling) to cater to power needs.
  - Use of nitrogen gas from liquid nitrogen tanks to passively pressurize water tanks and transfer the water to systems at required pressure.
- ***Water sources***
  - Provisions to use water from suppression pool except in RAPS-2
  - Qualifying existing water storages/tanks in the plants like deaerator storage tanks, for earthquake resistance

- Conditioning signal override facility for ECCS in PHWRs where it is not available.

- ***Hydrogen management*** provisions in containment
- Additional Battery operated devices to monitor important plant parameters
- Providing shore protection structures to withstand tsunami at coastal plants where they are not available
- Review of Emergency Operating Procedures for external events and retraining of operator
- Alternate make up provisions for spent fuel pool during extended station black out
- Feasibility of providing solar powered lighting
- Provision of boreholes at suitable locations to augment water supply.
- Provision of suitably designed flood proof enclosure and doors for important safety related electrical power sources
- Review of containment venting provisions at suitable points to vent the containment structure to stack

4.1 Safety Evaluation of BWRs at TAPS-1&2

The Tarapur Atomic Power Station (TAPS-1&2) is located on the West Coast of India on the Arabian Sea. The reactors are Boiling Water Reactors (BWRs) of General Electric, USA design. The reactors became critical in 1969.

After completing 35 calendar years of successful operation, a detailed study and review of all the safety systems of the plant has been done in 2004 and upgrades in various systems have been carried out in the period 2004-2006, in order to enable the plant to meet the current safety standards and requirements. Enhancement of the capacity of the diesel generators for supplying emergency power, Provision of a dedicated diesel generator for meeting the Station Black out scenario, provision of additional redundancy in safety equipments, battery bank at higher elevation and diversity in cable routing form part of the safety upgrades.

In the light of the information available from Fukushima incident, the various requirements for handling severe external events involving extended station black out period have been revisited. It has been confirmed that, Reactor shut down system, Primary system isolation, primary containment isolation, passive emergency condenser system for decay heat removal for 6 hours without any intervention, and station batteries which can supply emergency power for minimum 8 hours will remain unaffected. Sufficient water inventory will be available on site to meet the cooling requirements during the above conditions.

In addition to the applicable common recommendations made above, additional specific recommendations for the TAPS 1&2 station are

- Pre-inerting of Primary Containment with nitrogen
- Provision for high point vent for the reactor pressure vessel to depressurize the vessel
- Provisions to ensure diesel generator meant for station blackout conditions to operate under beyond design flood scenario
- Provision of hook up points for injecting water in the feed water line to the reactor, shell side of emergency condenser low pressure core spray system and containment spray systems from outside RB
- Alternate provisions for replenishment of water in spent fuel pool inside the Reactor Building and Away From Reactor storage facility
- Provision of tsunami alert mechanism

4.2 Safety Evaluation of PHWRs at RAPS-1&2

Rajasthan Atomic Power Station 1 & 2 consists of 200 MWe twin units Pressurized Heavy Water Reactor (PHWR). These units are PHWRs of 1st generation CANDU with once through cooling water system, and single containment design. At present, RAPS-1 fuel is removed from the reactor completely and stored in Spent Fuel Bay. PHT, moderator and all other systems have been drained & dried and are kept under preservation mode. RAPS-2 first criticality was achieved in 1980 and is presently operating at full power.

The postulated scenario for flood event for these reactors is the break in Gandhi Sagar Dam which lies upstream of the plant. The availability of power supplies and safety systems under the above flooding conditions has been evaluated.

The Reactor protection system will promptly shut down the reactor. Core cooling can be maintained by natural circulation on the primary side through the steam generators. Provisions are available to add water to the secondary side of steam generators through hook up points.

RAPS unit 1 is under shut down and fuel has been unloaded from the reactor. It is proposed to utilize the water storages and power sources available in the unit for Unit 2 during exigencies, by suitable inter connections.

Station specific recommendations in addition to applicable common recommendations are:

- Making a bund at the outfall to retain water, to cater to the conditions of downstream dam break which will result in loss of inventory in the lake as an alternate to the pits in the lake which are assumed to retain water

- Provision of suitable interconnections between unit 1 and unit 2 water sources (Dousing Tank, Deaerator Storage Tank, High Level Reserve Feedwater Tank)

- Inter connection between, unit 1 and unit 2 flood Diesel Generators, Class II supplies and batteries

- Provision of hook up points for adding water to calandria, end shields from outside reactor building.

4.3 Safety Evaluation of PHWRs at MAPS-1&2

Madras Atomic Power Station housing two PHWRs of 220 MWe rating each is located at Kalpakkam on the east coast of Tamil Nadu. This coast is prone to cyclonic storms and the elevations of the different buildings in the plant are built taking into account the 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 and cooling maintained after 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. 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.

Tsunami in the coastal area can initiate from an earth quake at the fault line near Sumatra, which is the only known fault in this region. This is more than 1300 km away from the coast. From the earlier experience of tsunami which was generated from an earthquake of 9.2 (Richter Scale) intensity it is seen that there will be a time of about 3 hours after the onset of earthquake for the tsunami wave to reach the plant. The plant has got tsunami alert system and provision of alert messages from INCOIS, Hyderabad. There will be adequate time for shutting down the reactor and cool down the reactor fast and bring down the primary coolant temperature to below

100 deg C. However provisions available to cater to extended station black out conditions, the existing system provisions have been revisited.

It is confirmed that reactor protection system will shut down the reactor promptly. Core cooling will be through natural circulation of primary coolant through the steam generators. Provision exists to add firefighting water from inside the reactor building as well as from outside the reactor building. The plant has one diesel generator of 1750 kW capacity which is located two meters above grade level of the plant., Two diesel firefighting pumps are also available at about 2.2 meters above the grade level. The diesel generator has got provisions to be cooled by connecting the firefighting water from the diesel operated firefighting pumps.

Plant Specific recommendations in addition to the applicable common recommendations are:

- Provision of underground raw water tank, in addition to the on site reservoir.
- Provision of hook up points for adding water to calandria, end shields from outside reactor building.
- Studying feasibility of providing pressurized water tanks at a higher elevation in turbine building.

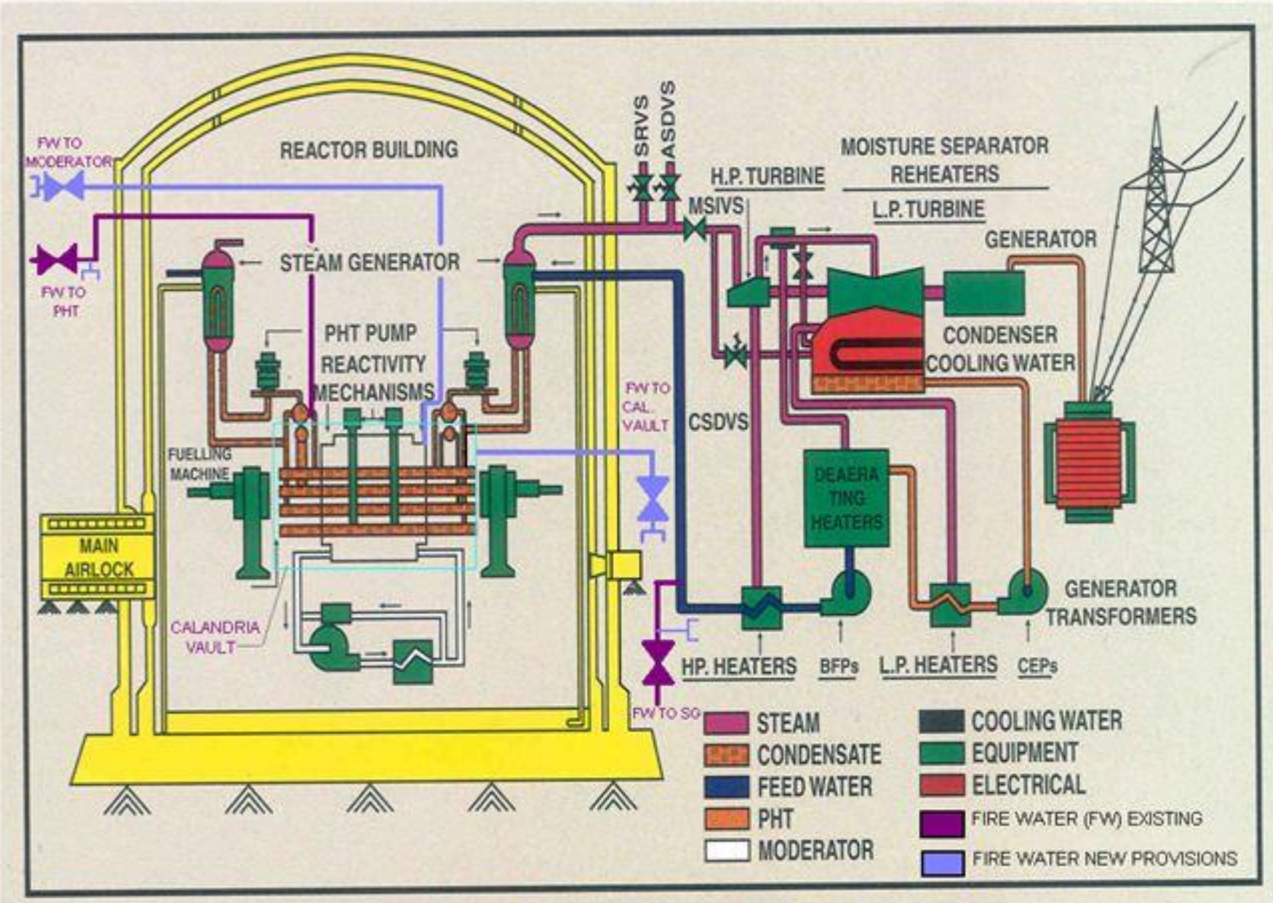
4.4 Safety Evaluation of Standard PHWRs NAPS onwards

IPHWR is the standardized design indigenously designed, developed and implemented progressively at NAPS 1&2, KAPS 1&2, KGS 1-4, RAPS 3-6 and TAPP 3&4. Detailed evaluation of the plant design and safety provisions has been carried out for the severe natural event scenario for these plants

The standard PHWRs are provided with two diverse fast acting shut down systems. The moderator remains filled in calandria even during shut down and the calandria is surrounded with a water cooled calandria vault. These will add to the heat sinks already available, to remove decay heat from fuel.

Recommendations made specific to plants in addition to the applicable common recommendations are:

- Provision of hook up of water supply to ECCS from external sources at TAPS 3&4
- Provision of seismically qualified water reservoirs of 5000 cubic meter capacity at NAPS, KAPS and TAPS 3&4
- Hook up points for adding water to calandria and calandria vault and end shields at all standard PHWRs.



Schematic Diagram of Indian PHWR

SUMMARY AND

ROAD MAP FOR IMPLEMETATION

5.0 Summary

The Indian Nuclear Power Plants are designed constructed and operated to withstand environmental hazards including earthquake, flood, fire etc. The design for each NPP Site is worked out as per the stipulations of relevant Codes and Guides of Atomic Energy Regulatory Board. The safety of public and environment is ensured using the defense in depth approach.

For mitigating the rare severe natural event similar to Fukushima earthquake, additional design features such as providing core cooling with additional means of power source at Site are recommended to bring plant to a safe shutdown state and maintain the same in a prolonged period. In addition, procedures and guidelines for severe natural event handling, emergency preparedness, conducting staff training and simulating mock up drills for all operating Nuclear power plants will be extended.

For each type of Nuclear Power Plant analysis has been done for scenario of rare severe natural event i.e. severe earthquake, tsunami or dam break and consequential failure / unavailability of power and cooling provisions for a prolonged period. The analyses indicate that each plant can be brought to safe shut down state without any radiological consequences to public or environment and maintained in safe condition for prolonged length of time with incorporation of the recommendations.

5.1 Road map for implementation

The recommendation of the task forces have been reviewed and discussed. Action plans for the near term and long term are being worked out. As brought out earlier, this report is an interim one. As the event at Fukushima further unfolds and additional information is available, the recommendations will be revisited and changes, if any, will be incorporated.

The broad road map is given in the accompanying table.

ROAD MAP FOR IMPLEMENTATION OF RECOMMENDATIONS

Sl. No.	Recommendations	Action Plan	Implementation Time
1.	Automatic reactor shutdown initiation sensing seismic activity	a) Finalization of specification for instrumentation b) Equipment availability at sites, and finalization of scheme c) Obtaining Regulatory approval and implementation at sites	a) 15 days b) 6 months c) 3 months **Total - 9 months**
2.	Inerting of the TAPS-1&2 containment	a) Engineering b) AERB approval c) Equipment availability d) Implementation	a) 4 months b) 2 months c) 12 months d) Next refueling outage
3.	Increasing the duration of the passive power sources/battery operated devices for monitoring important parameters for a longer duration		6 months
4.	Provisions for hook up arrangements through external sources, for adding cooling water inventory to Primary Heat Transport (PHT) system, steam generators, calandria, calandria vault, end shields and Emergency Core Cooling System (ECCS) as applicable and also the provisions for mobile diesel driven pumping units	a) Engineering b) Regulatory Review c) Equipment availability at site and implementation	a) 4 months b) 2 months c) 6 months **Total- 12 months**

5.	Augmentation of water inventory and the arrangement for transfer of water from the nearby sources if required	a) Engineering of the water transfer arrangement b) Finalization of inventory augmentation and provisions (Tanks, Diesel driven pumps etc) c) Implementation of finalized arrangements	a) 4 months b) 2 months c) 6 months **Total- 12 months**
6.	Additional Shore protections measures at Tarapur Atomic Power Station and Madras Atomic Power Station which are located on the sea coasts, as deemed necessary	a) Finalization of height of shore protection b) Engineering c) AERB approval d) Implementation	a) 3 months b) 3 months c) 2 months d) 6 months **Total-14months**
7.	Additional hook up points for making up water to spent fuel storage pools wherever necessary for ensuring sufficient inventory	a) PHWR b) BWR	a) 6 months b) Next refueling outage
8.	Revision of Emergency Operating Procedure	a) First level review as per existing provisions b) Revision incorporating additional recommended provisions	a) Under progress b) After implementation of additional provisions
9.	Re-training of plant personnel		Subsequent to EOP modification