INSAC-2024: November 20, 2024

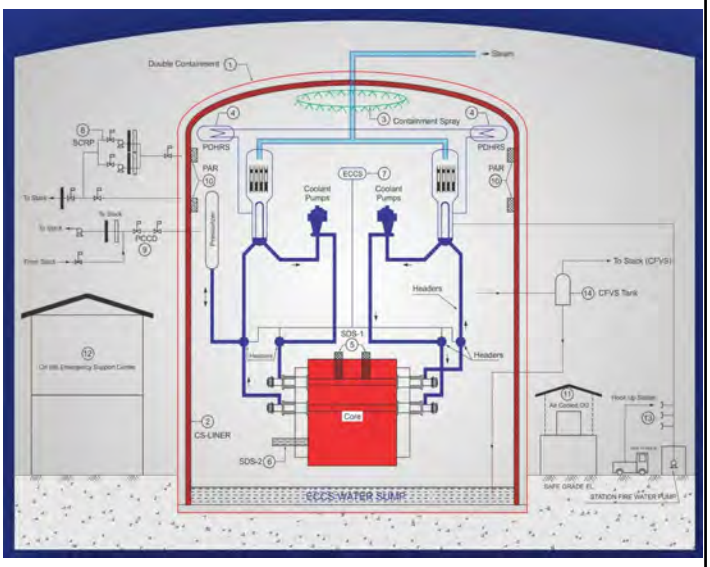
Experiences in Safety reviews & Licensing of 700 MWe PHWRs

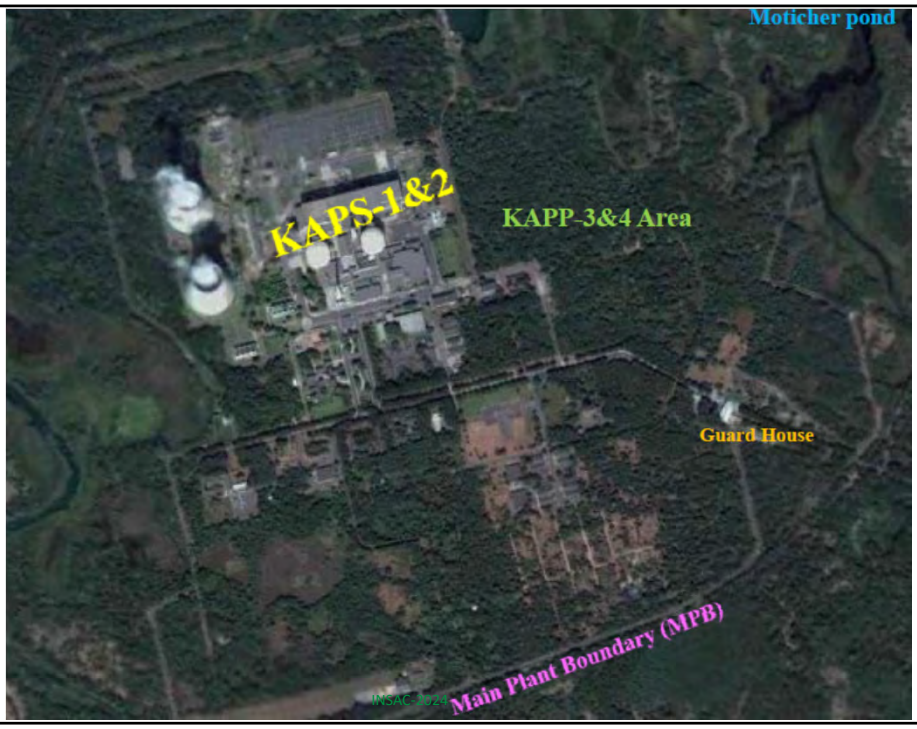
- Mayank Verma -

Atomic Energy Regulatory Board

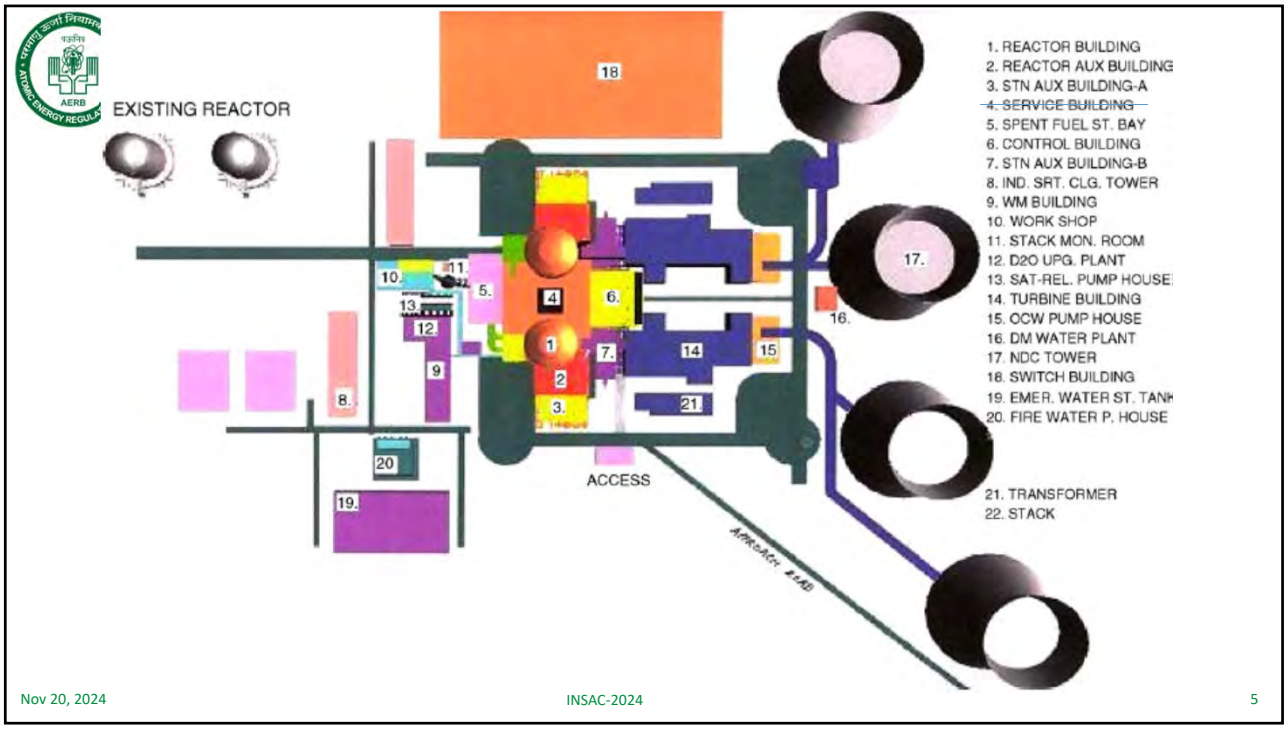
India's first 700 MWe PHWRs: Kakrapar Atomic Power Project 3&4

- Co-located with 2x220 MWe, KAPS-1&2
- Siting, Construction, Commissioning permissions were granted by AERB, following its multi-tier review process, to operate up to the rated power levels
- AERB granted Permission to operate at full power in Aug 2023 (KAPP-3) & Aug 2024 (KAPP-4)
- Regulatory oversight through periodic reporting, Site observers & Regulatory Inspections

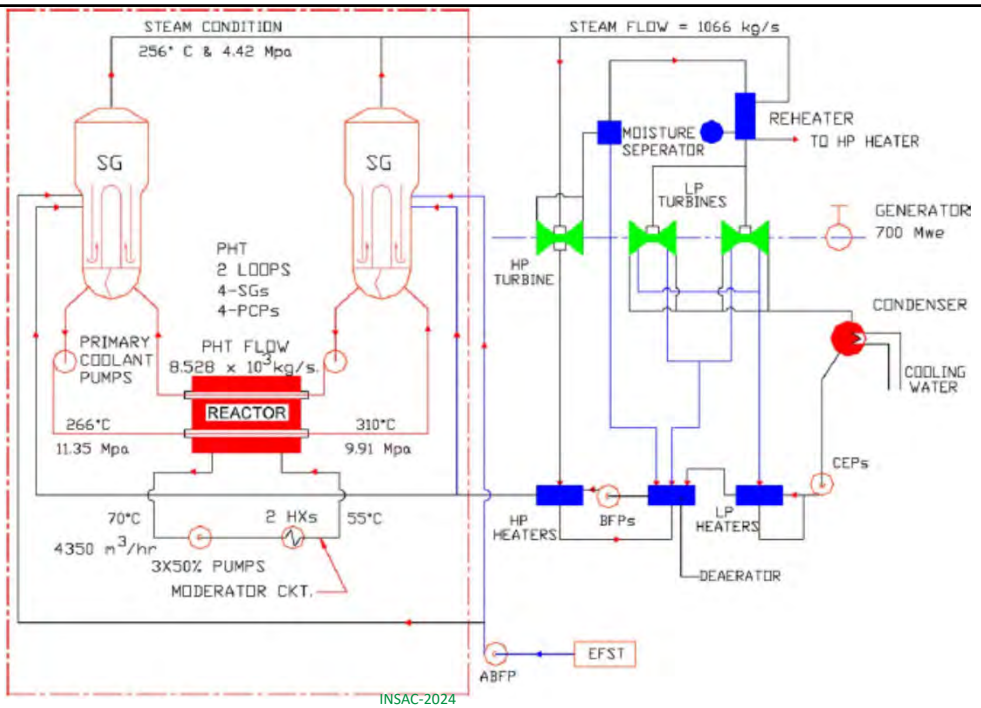



Moticher pond
KAPS-1&2
KAPP-3&4 Area
Guard House
Main Plant Boundary (MPB)


Kakrapar Atomic Power Station
Recently viewed
Anudisha Building
Google



Simplified Schematic



Current Status of KAPP-3&4

KAPP-3

- First Biennial Shutdown (since Sept 18, 2024) is nearing completion
- Operated 524 FPDs, 2.11 HOYs (as on Oct 2024)
- First Synchronization: Jan 10, 2021
- First Criticality: Jul 22, 2020

KAPP-4

- Operating at ~95%FP
- Operated 155 FPDs, 0.62 HOYs (as on Oct 2024)
- First Synchronization: Feb 20, 2024
- First Criticality: Dec 17, 2023

Key design features

Standard design is based on 540 MWe TAPS-3&4, except some salient changes:

- PHT main circuit: 2 identical loops with feeders in interleaving geometry.
- Partial boiling of the coolant at the coolant channel exit
- Salient changes due to partial boiling:
  - Higher PHT temperatures at RIH & ROH
  - Core flow marginally increased
  - Pressurizer volume increased
  - Two ROHs of the same loops are interconnected to avoid flow instability
  - Feeder sizing optimized to have uniform quality at channel exit
  - SG design is modified with increased drum height

Key design features

- Reactor control using
  - Ionization chambers at low power
  - Self Powered Neutron Detectors (SPNDs) in the low power range
  - Both in the intermediate range
- Bulk power estimates are corrected using selected channel temperature and flow measurements made on the primary side in pre-boiling regime Above this the secondary side measurements are used to verify the thermal output of the core.
- Regional Overpower Protection Systems: Protection against localized overpowers. Reactor bulk power high trip parameter is replaced by Regional Overpower Protection (ROP) trip parameter.

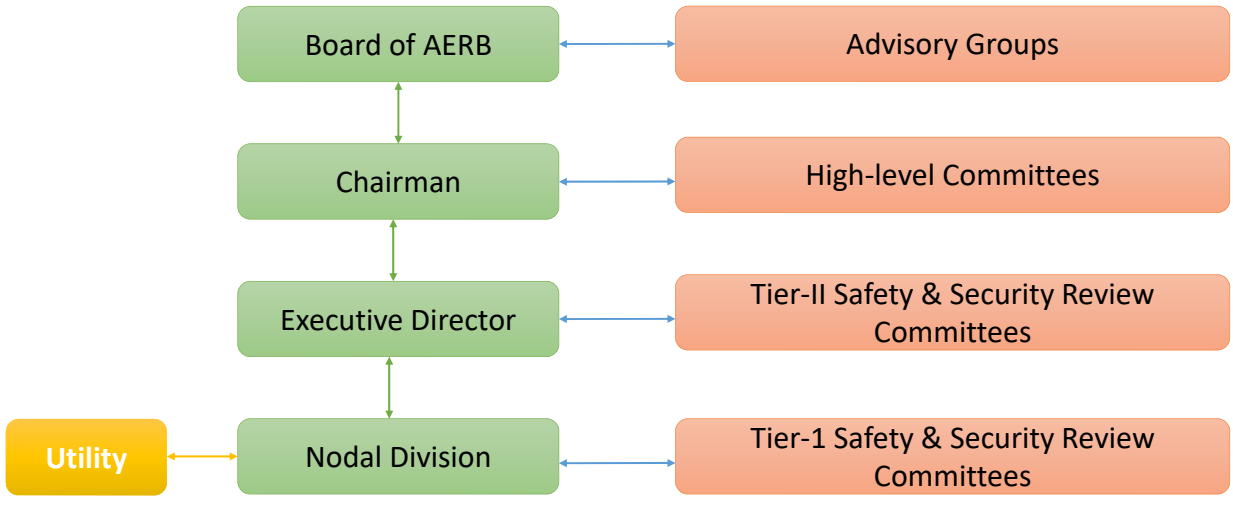
Key design features

- Bulk power regulation and flux tilt control is by modulating the water level in LZC.
- CTM setback will be available pre-boiling. Reactor setback based on bundle power high and spatial power tilt are also available.
- 12 fuel bundles per channel
- Air cooled Diesel Generator: Emergency power supply during extended SBO
- Primary Containment is lined with Carbon Steel liner to reduce the leak rate.
- Design Life of the plant is considered to be 40 years, subject to review at appropriate stage.
- FOAKs…

Regulatory History of KAPP-3&4

- Site Evaluation Report was submitted in Feb 2006
  - Site Evaluation Committee was constituted
- Design Basis Information was first submitted to AERB in May 2006
- KAPP-3&4 Preliminary Safety Analysis Report PSAR (Sec 1, 2, 3) were first submitted to AERB in Jun 2006
  - Subsequently, other sections were submitted in stages
- PDSC (KAPP-3&4) was constituted in May 2006. Scope was extended to RAPP-7&8 in Dec 2009. Scope was further extended to GHAVP-1&2 in Apr 2015: Held 90 meetings
  - Just before the start of Commissioning of KAPP-3&4, the PDSC (KAPP-3&4, RAPP-7&8 and GHAVP-1&2) was reconstituted as PDSC-PHWR, responsible for design safety reviews of all 700 MWe PHWRs: Held 84 meetings till date
- Based on the Commissioning experience the Final Safety Assessment Report (FSAR) of KAPP-3&4 was submitted recently in Nov 2024.

Multi-tier Review Process of AERB



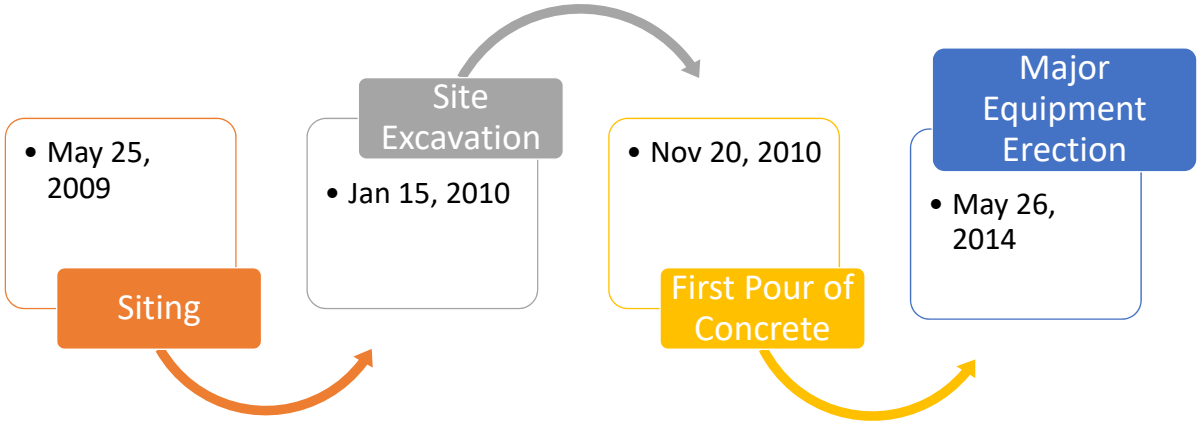
Working groups / Specialist groups

- WG-1 (Radiation Shielding)
- WG-2 (Mechanical Design)
- WG-3 (Moderator System)
- WG-4 (PHT System)
- WG-5 (Fuel & FHS)
- WG-6 (Process Water & Rx Aux)
- WG-7 (Control & Instrumentation)
- WG-8 (Electrical System)
- WG-9 (Ventilation & ESFs)
- WG-10 (Reactor Physics)
- WG-11 (Radiation prot & waste mgmt.)
- WG-12 (QA, PSI/ISI)
- WG-13 (Containment Analysis)
- WG-14 (TG & Auxiliaries)
- WG-15 (Accident Analysis)
- WG-16 (Fire Hazard Analysis)
- WG-17 (IV&V)
- WG-18 (Commissioning)
- WG-19 (Technical Specifications)
- TFs: Layout, Common MCR, EQ, Safety Classification/ seismic categorization, Trip coverage, Drop load, Containment test, EPP, 4x100%DG
- CESC & its WGs

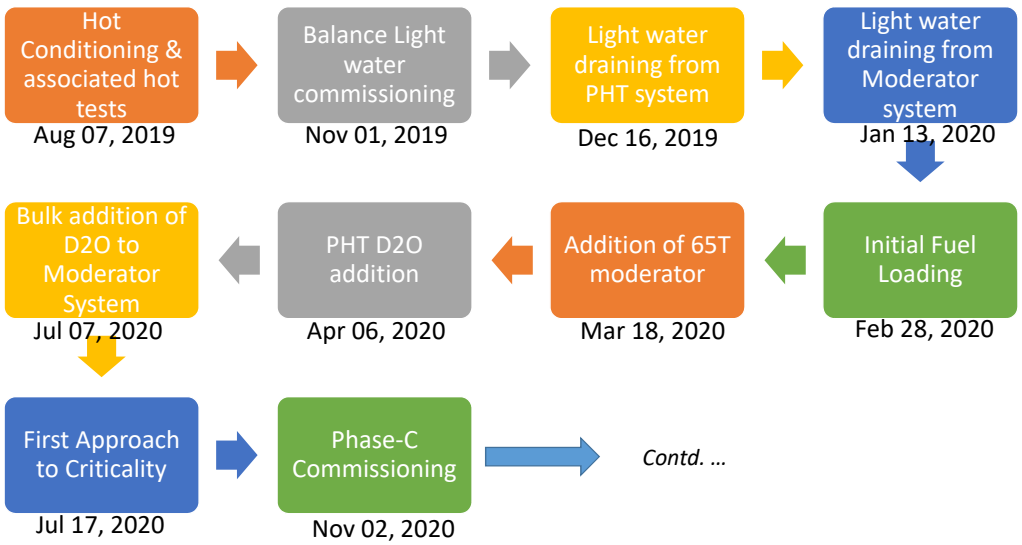
Consents for NPPs

Stage	Activity/ Sub-stages
Siting	Location of NPP at a proposed Site
Construction	Site Excavation
	First Pour of Concrete
	Major Equipment Erection
Commissioning	Phase-A (without fuel)
	Phase-B (with fuel)
	Phase-C (power raise)
Operation	Periodic Safety Reviews

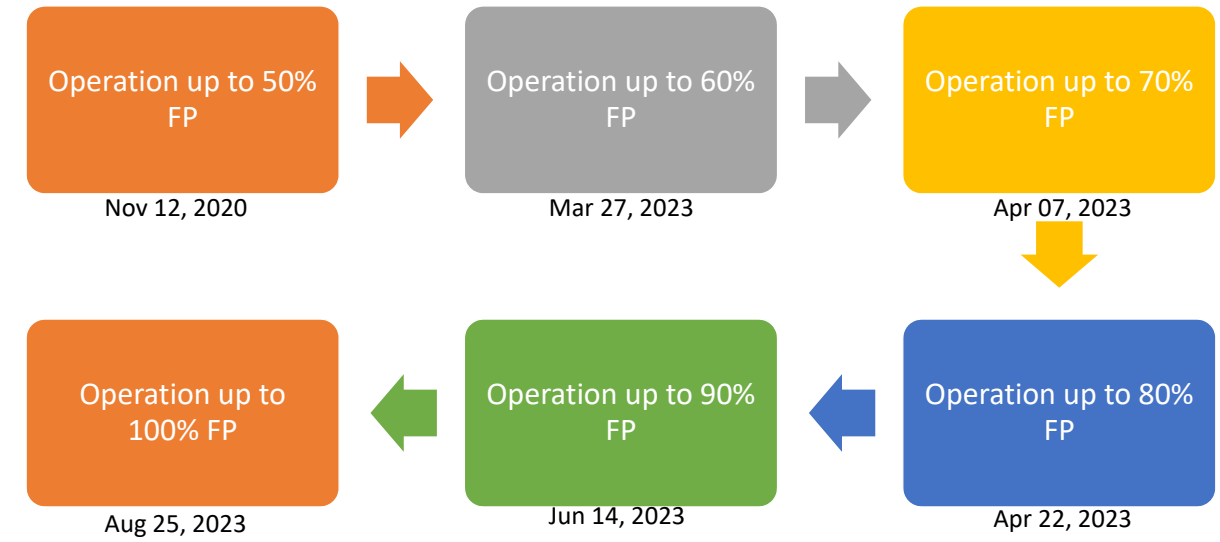
Regulatory Permissions for KAPP-3&4



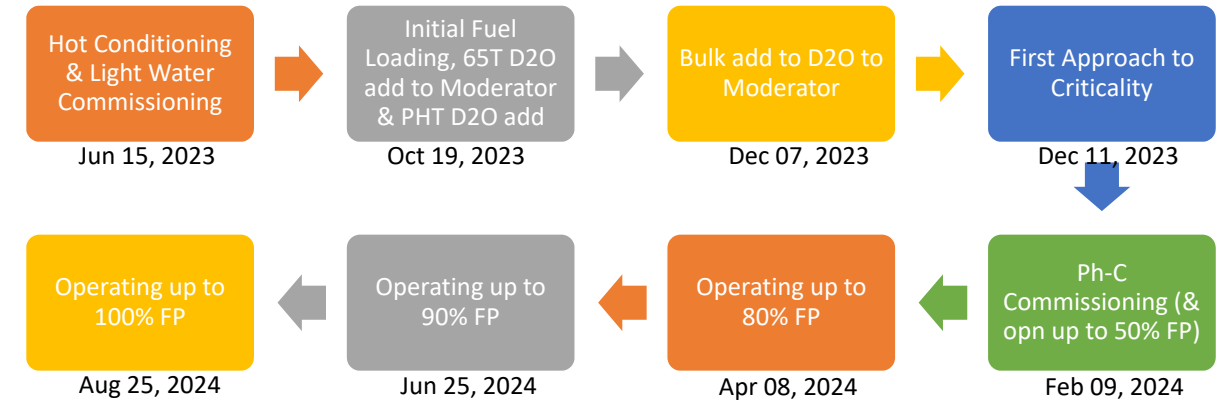
KAPP-3 Commissioning



KAPP-3 Ph-C Commissioning



KAPP-4 Commissioning



Key Challenges

- First of a kind systems / features
- Issues in Siting, Design, Construction, Commissioning
- New / Revised Regulatory Documents: AERB/SC/D (2009, 2014), SC/S (2014), SG/D-19 (2018), SM/RIA (2019), SG/O-2 (2024), Under review SC/G, SG/G-1, SC/QA, SG/QA
- Change of guard (2010-2024):
  - At NPCIL HQ & Site
  - At AERB
- Advent of AERB's Integrated Management System (2015)
- AERB's Safety Review & Licensing process: Reliance on Committees → Strengthening in-house competencies
  - Maximum in-house Review Groups
  - Committees Recommendatory in nature
- Regulatory Inspection: Focus on issues → Focus on Systemic deficiencies
- COVID: Commissioning of KAPP-3

FOAK systems / features in 700 MWe PHWRs

- **PHT Partial boiling**
- **Feeder Interleaving**
- **Primary Containment Liner**
- **Passive Decay Heat Removal System**
- **Containment Spray System**
- **Super Heavy Concrete**
- **Mobile Transfer Machine**
- **Regional Overpower Protection System**
- **Containment Filtered Venting System**
- **Passive Catalytic Re-combiner Devices**

Followed rigorous reviews of experiments, analyses, Literature, mock ups and Commissioning tests.

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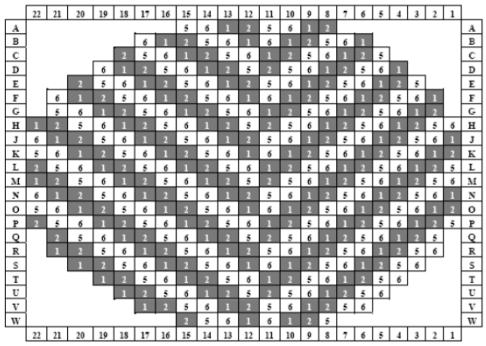
PHT Partial Boiling

- Partial boiling at coolant channel outlet to extract 19 % more power from 540 MWe core
- ROH inter-connection of same loop to avoid any flow instability
- Higher PRZ volume to accommodate swelling
- Rx Thermal Power measurement from secondary side parameters
- Periodic lowering of Rx power to pre-boiling regime to detect channel flow blockage
- Size of feeders increased
- End shield thickness reduced

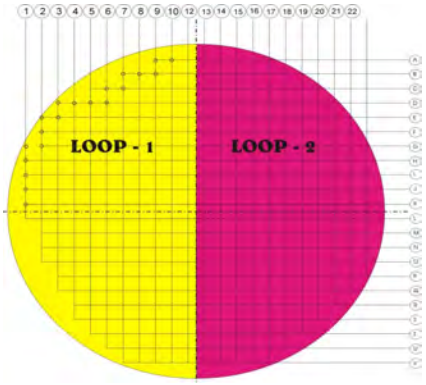
PHT feeder Interleaving

- Reactor headers length is increased to distribute feeders throughout the Core.
- Interleaved configuration has higher safety margins
  - Reduction in peak power (Void gets distributed across the core during LOCA)
  - Increase in Prompt Criticality Margin
  - Reduction in adiabatic heat deposition on Fuel pins
  - Lower sheath temperature and lower clad oxidation

Interleaved core of 700 MWe Design



TAPS-3&4 Core Configuration



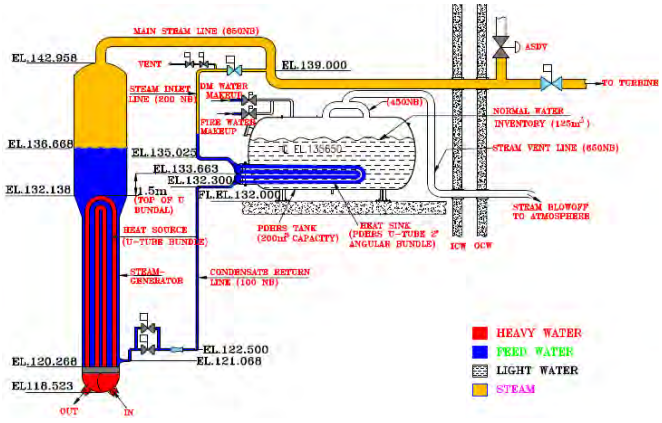
Containment Liner

- PC is provided with 6mm thick CS integral liner
- Pre-fabricated Ring Liner at KAPP-3&4: Minimum dimensional deviations
- Leak rates:
  - Unlined containments: 0.3% v/v per hour
  - KKNPP-1&2: 0.3% v/v per day
  - 700 MWe PHWRs: 1% v/v per day

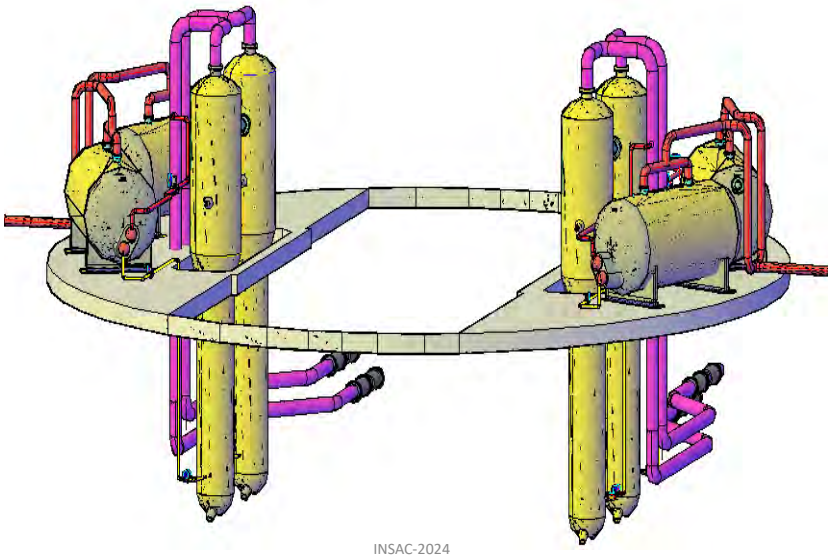
Prefabricated ring liner at KAPP-3&4

Passive Decay Heat Removal System (PDHRS)

- Additional safety feature to maintain SG inventory during SBO condition.
- Valves on condensate return line opened remote manually within 15 minutes in case of SBO.
- EC inventory adequate for 8 hours following SBO.
  - Provision for Fire water injection in PDHRS tanks



Schematic layout of PDHRS

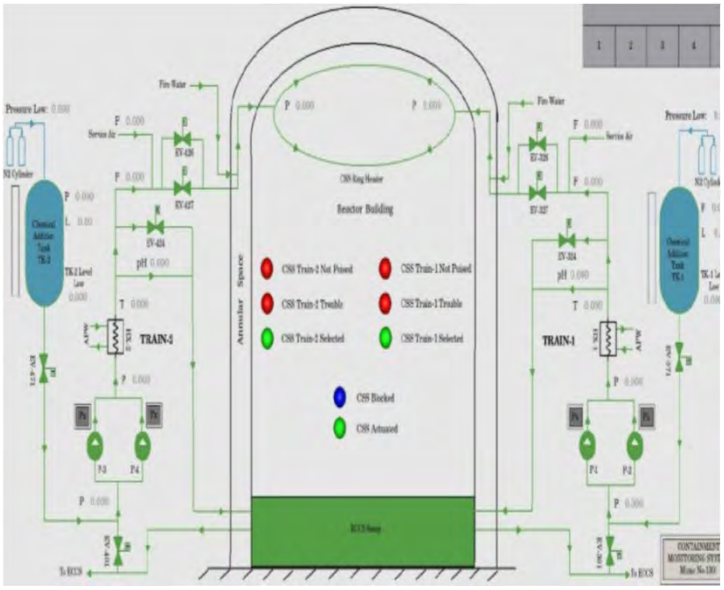


Containment Spray System

For removal of Fission products & containment cooling / depressurization

Substitutes

- PCFPB
- Suppression pool, Distribution Header & Vent Shafts
- RB Coolers (not designed for accident cond.)

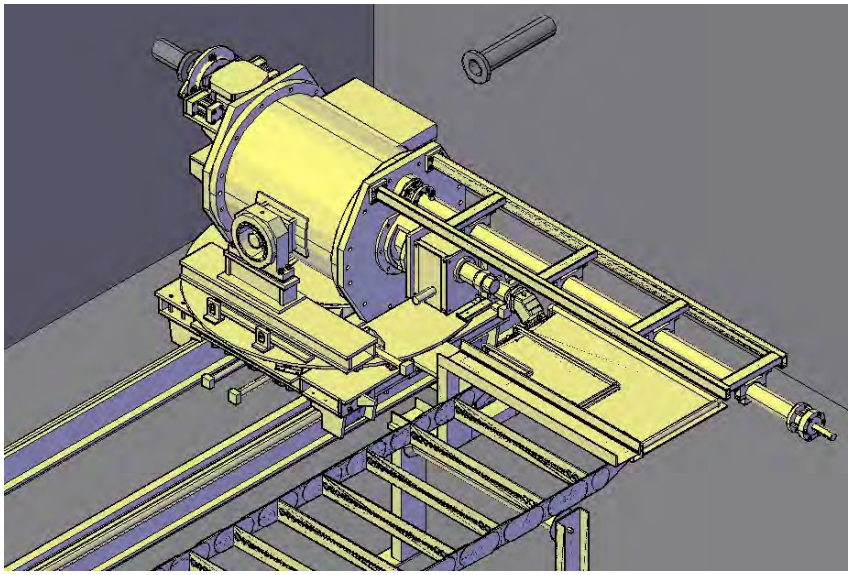


Super Heavy Concrete

- Required for compact layout of 700 MWe NPPs
- Density: 4.2 gm/cc
  - Used 4.1 gm/cc (small quantity) at TAPS-3&4
- Used in following locations of 700 MWe PHWRs:
  - FT Room
  - Access tunnel (pump room)

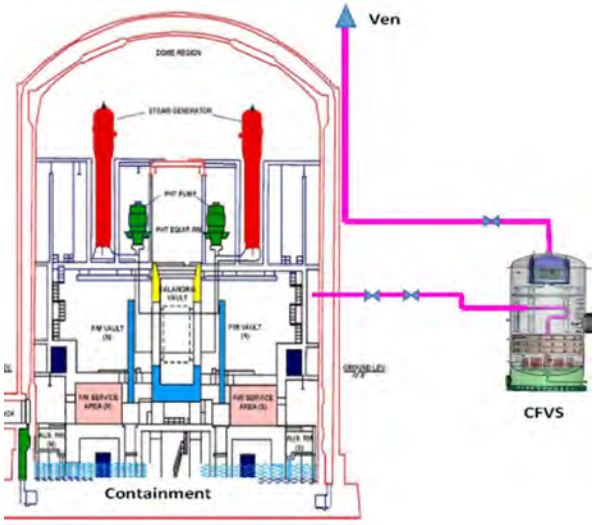
Mobile Transfer Machine

- Improved design for fuel transfer
- Eliminates/ combines the following systems of 220/540 NPPs:
  - Shuttle transfer station
  - Shuttle transport tube
  - Transfer Magazine
- Eliminates D_2O from FT system
- Common Machine for both N/S sides & discharges spent fuel bundles into the TLB.



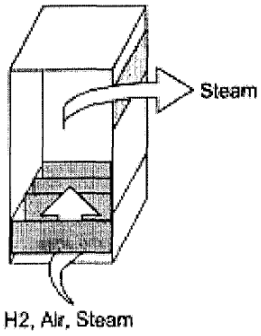
Containment Filtered Venting System (CFVS)

- Will be operated @1.55kg/cm^2 containment pressure, after ensuring hydrogen concentration < 4% v/v.
- Decontamination Factor:
  - Particulates and Elemental Iodine = 100
  - Organic Iodine = 10



Passive Catalytic Re-combiner Devices

- In DBA, PCRDs are not required as hydrogen management will be taken care by layout. In BDBA, PCRDs will start working at ~2% hydrogen concentration.



Post-Fukushima Safety Upgrades

- External hook up points: SG, PHT, ECCS, ES, Calandria, CV, SFSB, CSS, PDHRS, ECCS sump
- Containment Filtered Venting System (CFVS)
- Passive Catalytic Recombiner Devices (PCRD)
- Automatic reactor trip during a seismic event
- Fixed Air Cooled DG sets located in BDBE qualified NFSB
- Mobile driven trailer mounted pumps, fire tenders, fixed submersible pumps at SRPH
- Hydrogen & Steam Concentration Monitoring system (HSCMS)
- Severe Accident Parameter Monitoring System (SAPMS)
- On-Site Emergency Support Centre (OESC)
- Real time Online Decision Support System (RO-DSS)

Key issues resolved in Siting / Design

- Three Zone Concept: Zone 2 → Zone-1 (inactive) & 3 (active)
- End shield thickness reduced: Facilitate layout of higher sized feeders & easy replacement of single channel
- Common Main Control Room
- Shutdown cooling pumps and HX brought down from pump room to accessible area and PRC area respectively.
- Shortfall in Exclusion Zone, major District Road passing near to Site boundary wall
- Fishing activities in Ponds within Exclusion Zone: No fishing zone declared in coordination with Gujarat Government
- Dam break analysis suggested lowering of roads in 3 stretches
- Low Trajectory Turbine Missile Zone: CB, SAB in LTTM zone of KAPP-3&4, IDCT, SRPH, FWPH in LTTM zone of KAPS-2. Now only once IDCT (out of two loops)

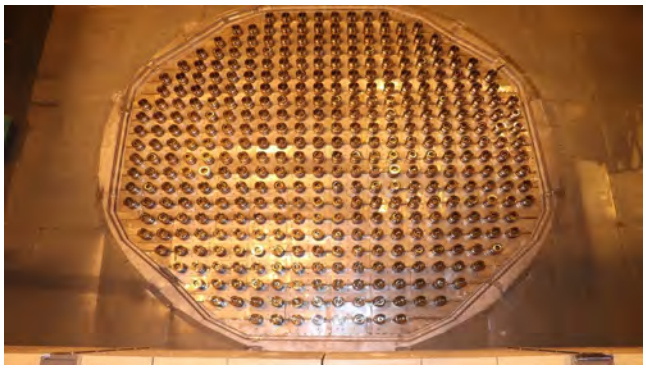
Key issues resolved in Construction

- Excessive chipping of End shield support structure for removal of angles for template used for locating anchor bolts
- Shift of Calandria vertical reference plane due to error in transferring Centre line markings to top hatch floor
- Calandria Vault top hatch beam manufacturing & QA was inappropriate
- Moderator HX cover studs were defective (found during Site PSI, missed during Manufacturing)
- Requalification of long-procured equipment
- Basis of Acceptance for the safety critical equipment
- Compliance to Factories Act, 1948 and AER(F)R 1996
- ASNT/ISNT Level-II certification

Key issues resolved in Commissioning

- Commissioning of FOAK systems
- Finalization of Trip Set points
- PSI of Supports as per ASME Sec XI IWF-2200
- Temperatures beyond design in high enthalpy areas of Reactor Building
- Consideration of internal leakages in PHT system during Station Black out condition
- Issues in Delayed Neutron Monitoring System SVs leading to incapacitated failed fuel detection
- Foreign material in feeder inlet orifice
- Reduced capacity of Deaerator Relief Valves
- Channel temperature monitoring system RTDs faulty

KAPP-3&4



FM Vault

Turbine

KAPP-3&4

Main Control Room

Fuel handling control panels

GHAVP-1&2

GHAVP FWPH

GHAVP Geotech investigations

KGS-5&6

KGS-6 NB area

KGS-5&6 Main plant area

Thank you

for your attention…

mayankverma@aerb.gov.in