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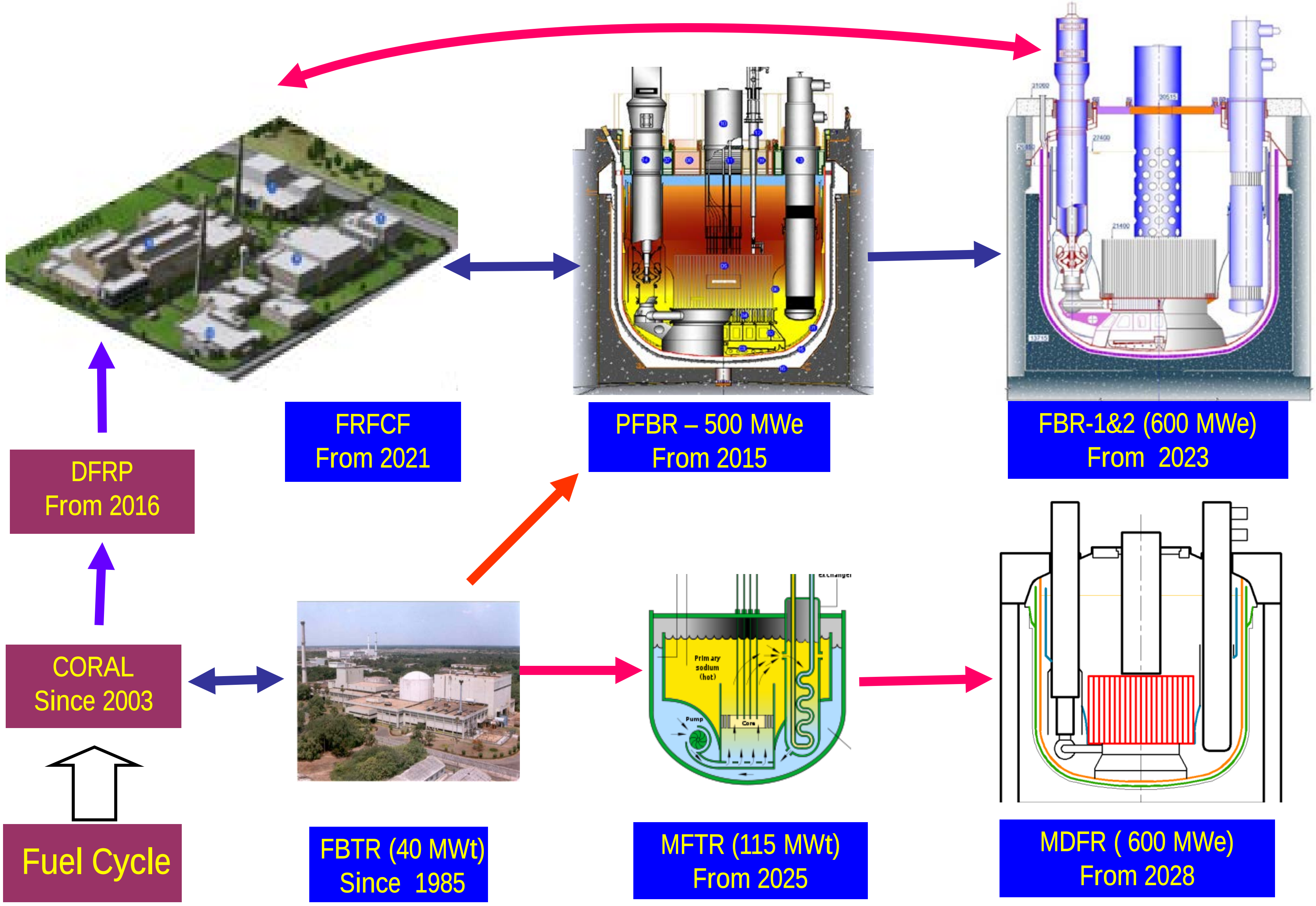
BHAVINI

Status of PFBR

Dr. P.Chellapandi

Fifth Joint IAEA-GIF Technical Meeting / Workshop
on Safety of Sodium Cooled Fast Reactors
23-24 June 2015, Vienna

FBR and Associated Fuel Cycle Programme (up to 2030)



FRFCF
From 2021

PFBR – 500 MWe
From 2015

FBR-1&2 (600 MWe)
From 2023

DFRP
From 2016

CORAL
Since 2003

Fuel Cycle

FBTR (40 MWt)
Since 1985

MFTR (115 MWt)
From 2025

MDFR (600 MWe)
From 2028

Schematic of PFBR Flowsheet

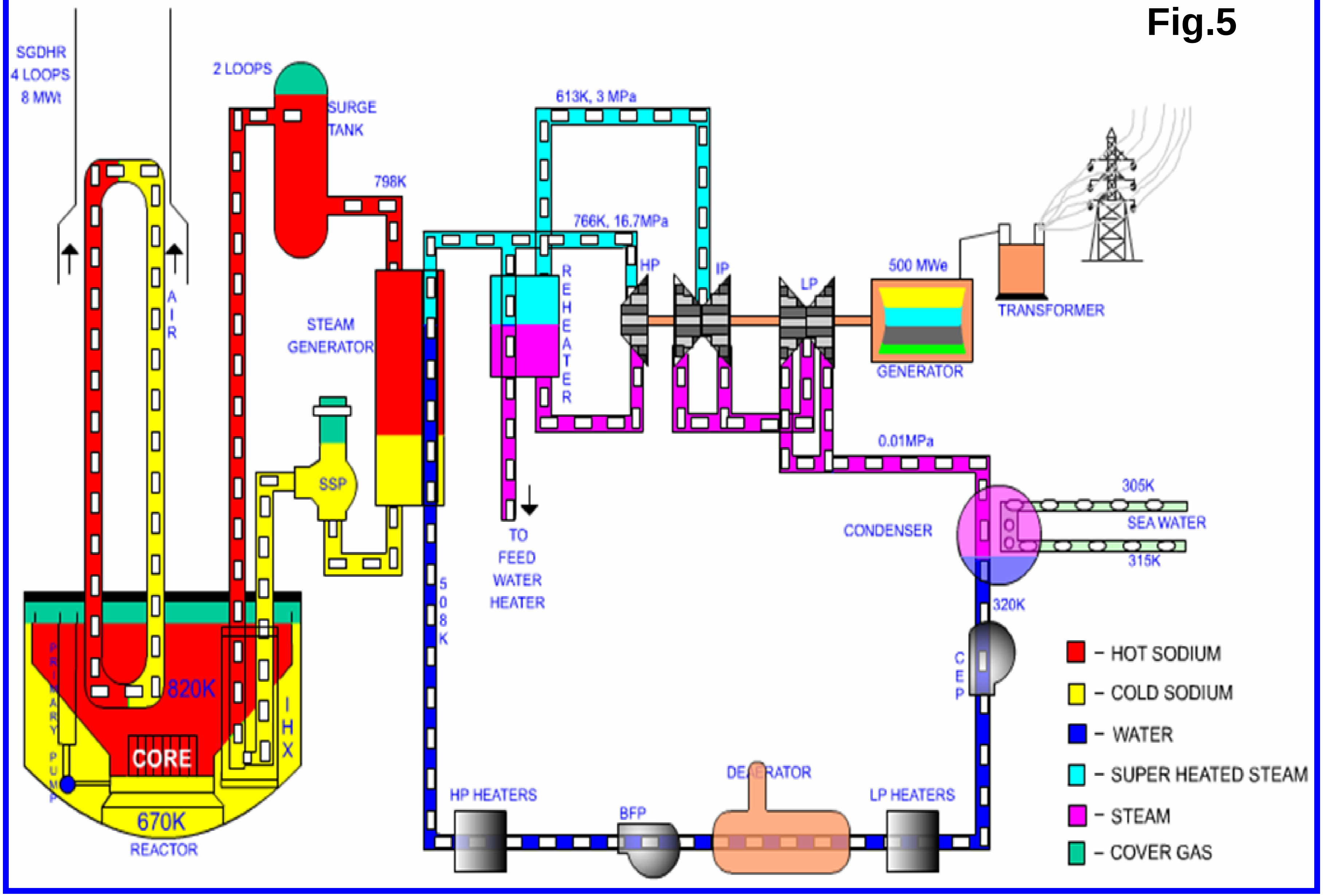


Fig.5

Current Status of PFBR Project

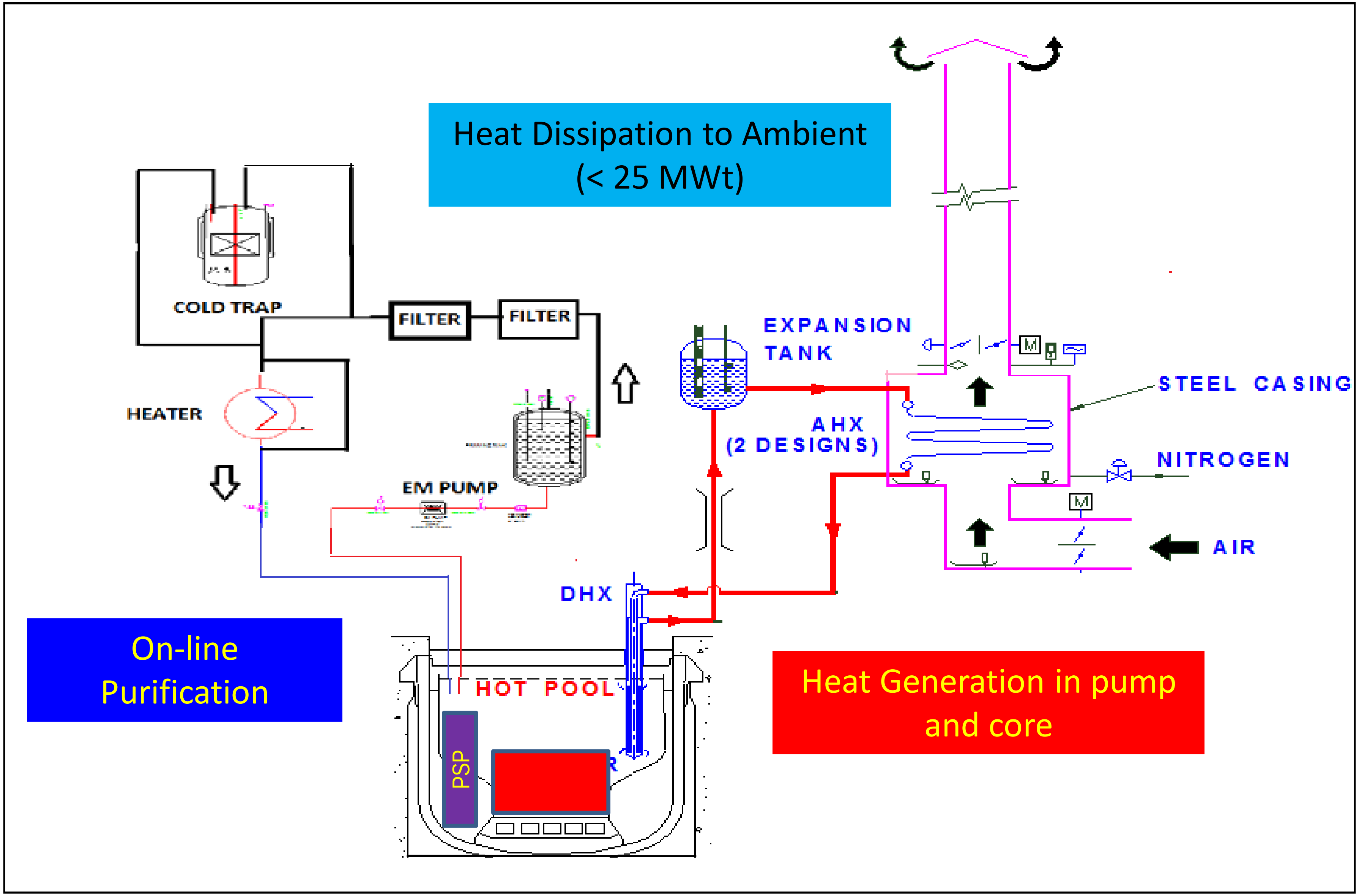
- **Construction activities completed**
- **Energy Conversion System is ready including: Sea water intake structure, electrical transmission line to feed to southern grid**
- **Pumps and drives, Fuel handling mechanisms, shutdown systems, etc. have been commissioned**
- **Reactor assembly internals have been kept in poised condition filled with nitrogen for pre-heating.**
- **Secondary system filled with argon and kept under pressure after achieving the specified purity levels**
- **Reactor operation team consisting of six crews has been formed for the round the clock shifts. As a part of operators qualifying & licensing program, training is provided in full scope simulator.**
- **Periodic regulatory inspection recommendations of the committee constituted by AERB, were implemented systematically and submitted to the Project Design Safety Committee.**
- **Awaiting clearance from Atomic Energy Regulatory Board (AERB) for (1) Sodium Charging, (2) Fuel Loading and (3) First Criticality**

PFBR Commissioning and Power Raising: Overall Planning

Sodium Filling & Purification	Isothermal Tests (~400ºC)	First criticality with Critical Facility	To reach 50-60% % power operation
▪ In-situ performance of mechanisms in reactor assembly at room temperature ▪ Sodium melting and charging into purification circuit ▪ In-situ performance of Electromagnetic pumps and Cold traps & and sodium purification ▪ Sodium filling in the circuit	▪ Pump operation ▪ Vibration checking ▪ Performance of mechanisms in sodium ▪ Overall heat balance with core, pump and decay heat removal systems ▪ Improving sodium purity further	▪ Switch over from initial purification to permanent purification circuit ▪ Isolation of secondary sodium circuit ▪ Replacing dummy subassemblies with adequate No. of fuel subassemblies ▪ Validation of reactor physics codes and data	▪ Replacing the dummy subassemblies with additional fuel subassemblies ▪ Coupling of secondary sodium and steam by-pass systems ▪ Completion of essential trial runs ▪ Connect to the southern grid

First Criticality in Sep 2015 and Power Operation by Dec 2015

First Approach to Criticality



Heat Dissipation to Ambient
(< 25 MWt)

On-line
Purification

Heat Generation in pump
and core

Trailing cable system

At SRP – 0° & LRP - 0°

At SRP – 0° & LRP - 180°

At SRP – 0° & LRP - 360°

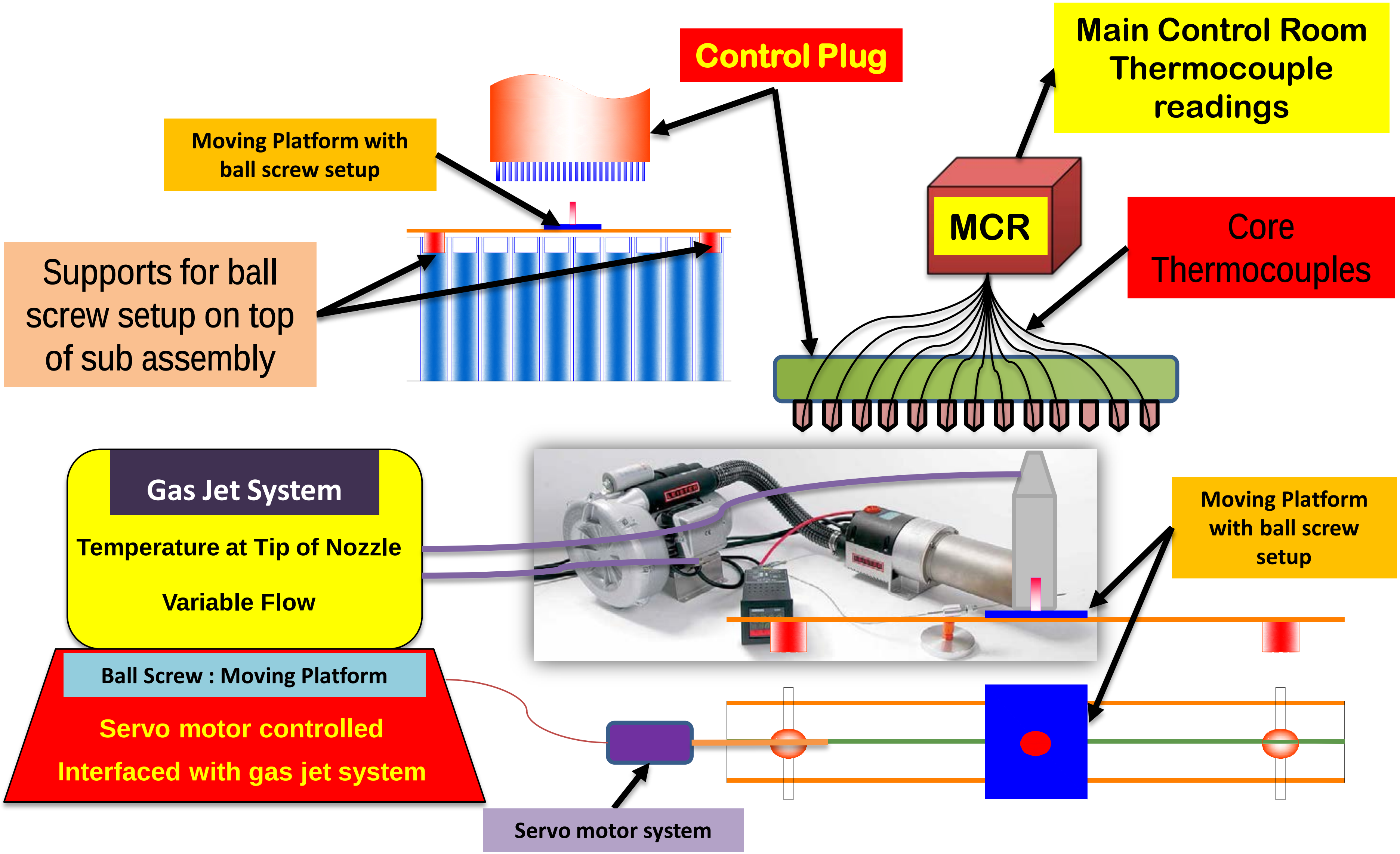
At SRP – 180° & LRP - 360°

Sucessfully implemented the experimental feed back to use Teflon bushes at the interface of cables and discs to avoid cable damage and smooth sliding of cables within discs and Strengthening of the hanging structure to facilitate fail safe design.

Cleaning of Reactor Assembly Internals

Reactor assembly internals have been kept in poised condition for pre-heating. In order to ensure complete cleanliness of reactor internals including dummy sub-assemblies, innovative techniques/tools were developed particularly for removing the dust and activity has been completed.

Gas Jet system for Validating Core Temperature Monitoring Thermocouples



Moving Platform with ball screw setup

Control Plug

Main Control Room Thermocouple readings

MCR

Supports for ball screw setup on top of sub assembly

Core Thermocouples

Gas Jet System

Temperature at Tip of Nozzle

Variable Flow

Ball Screw : Moving Platform

Servo motor controlled

Interfaced with gas jet system

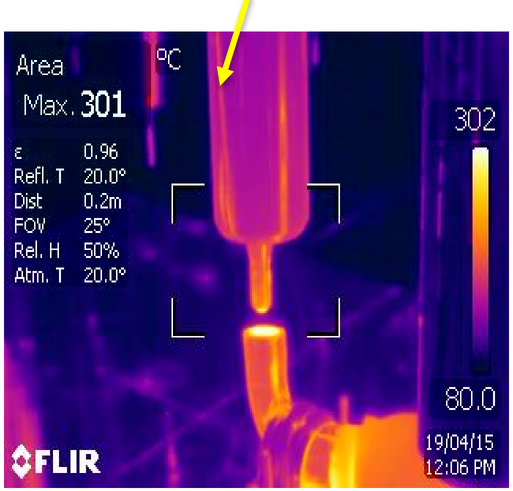
Moving Platform with ball screw setup

Servo motor system

Validation of all core temperature monitoring thermocouples by Continuity check & Rate of sensing

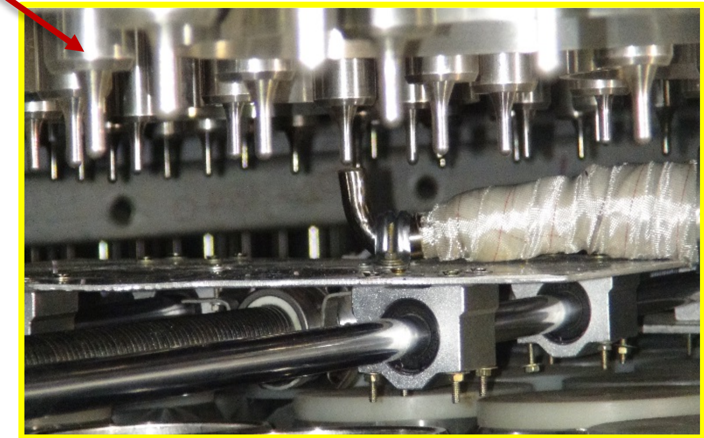
Gas Jet system for Validating Core Temperature Monitoring Thermocouples

Core Thermocouples

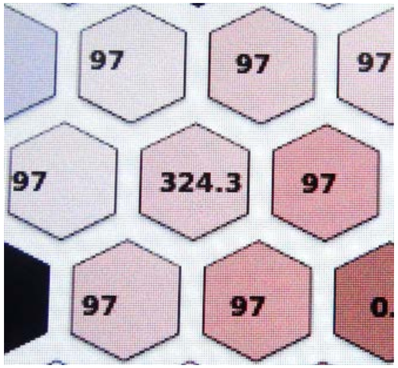


IR camera image

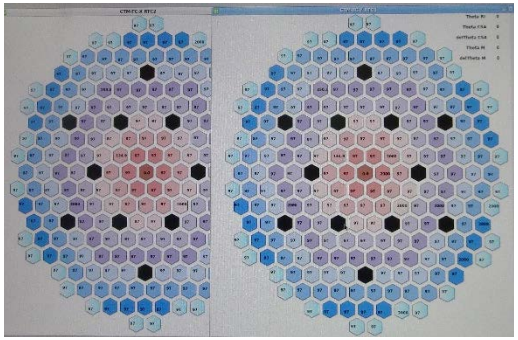
Validation of all core temperature monitoring thermocouples



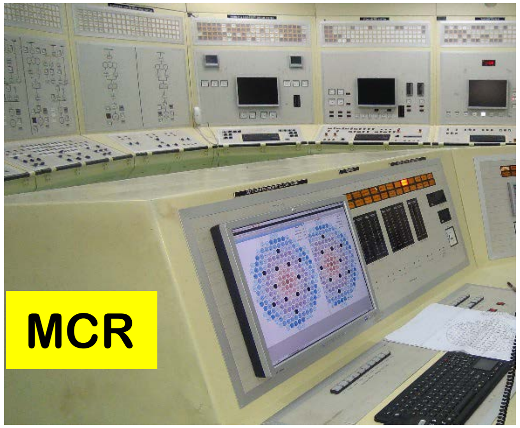
Supports for ball screw setup on top of sub assembly



MCR readings



Hot air blower with controller



MCR

Dummy Fuel Handling Mock-drill

Installation and commissioning of all necessary instrumentation for the fresh fuel handling scheme starting from transfer cask to placing into the ex-vessel transport port have been completed. Further, as a part of technical demonstration, a full-scale mock-up drill has been carried out with the transfer of dummy fuel sub-assemblies within DAE campus from BHAVINI entry gate to Fuel Building.

TRANSFER POT MOVEMENT FROM EVTP TO IVTP and VICEVERSA

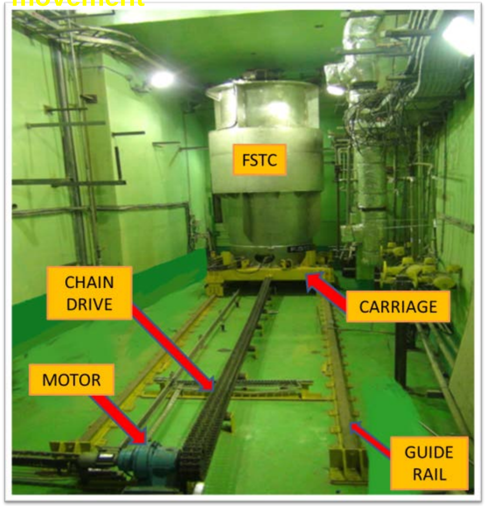
Fuel Transfer Cask Movement From Interface Gate To Fuel Building

MOVEMENT FROM INTERFACE GATE

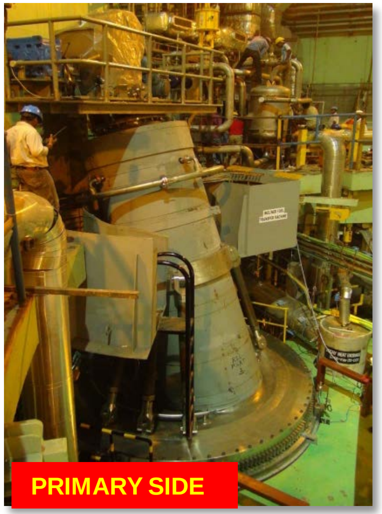
TRAILER PARKED IN FUEL BUILDING

FUEL CASK PARKED ON CARRIAGE

Fresh SA transfer chamber movement



IFTM PARKED



PRIMARY SIDE

SECONDARY SIDE

Simulator Room and Main Control

Simulator Room

Main Control Room

Operators Training

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Status of FBR-1&2

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Major Design Targets for FBR-1&2

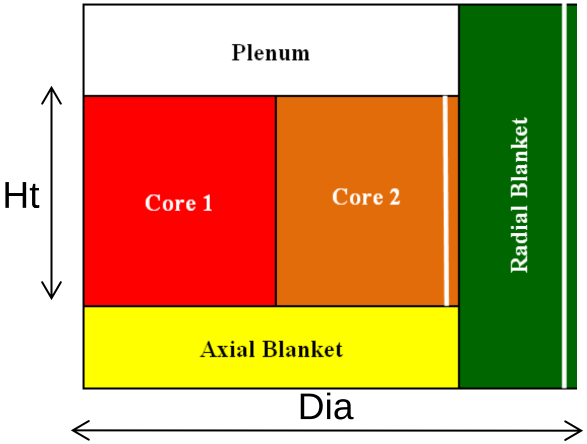
- Enhanced safety demonstration to practically eliminate severe accidents
- Core design with higher Breeding Ratio (BR)
- Detailed safety analysis with pessimistic combination of events
- No major R&D requirement for the design as well as Technology development beyond those planned for 500 MWe reactors
- Competitive Cost (reduction of capital cost & construction time):
- Unit Energy Cost (UEC) ≤ targeted for 700 MWe PHWR

600 MWe advance MOX Fuelled reactor is the preferred choice<

Core Concepts to Achieve Targets (SVR < 1 $ & BR ~ 1.2)

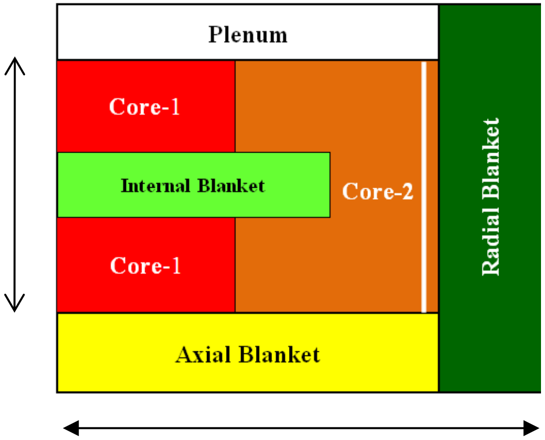
Homogeneous

- Top blanket removal
- H/D ratio reduction
- Addition of FSA & BSA



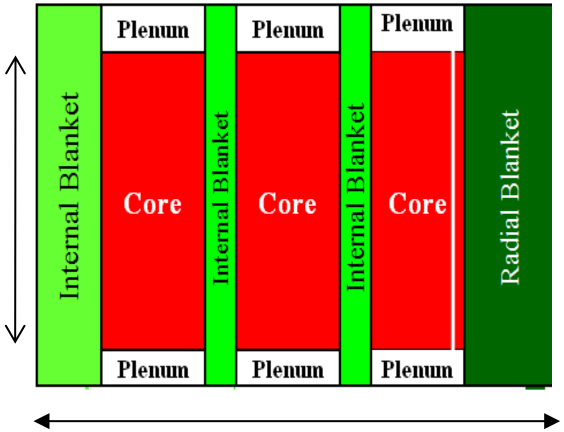
Axial Heterogeneous

- Top blanket removal
- Blanket in core centre
- Addition of FSA



Radial Heterogeneous

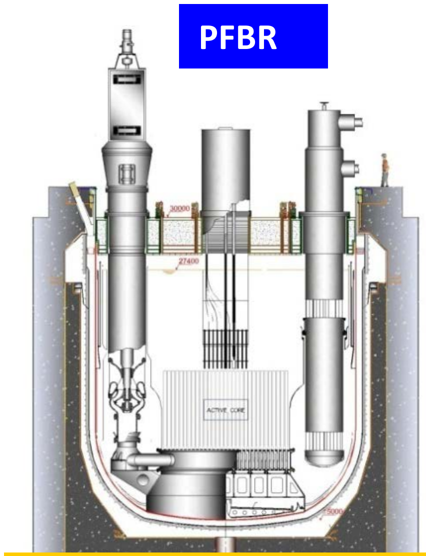
- Axial blankets removal
- Blanket SA inside core
- Addition of FSA



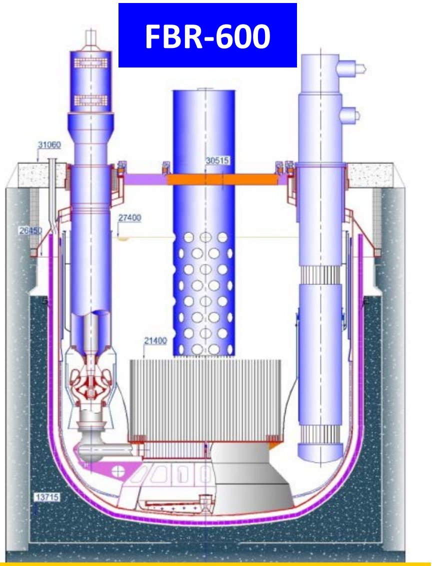
Core Ht -mm	700	700 (+300 blanket) / 1000	1030
Dia - mm	3600 (core + blanket)	3375 (core + blanket)	3400 * (core + blanket)
Enrichment	Core1: 19% / Core2: 28.5%	Core1: 28.7% / Core2: 30%	29.5% (single zone)
SVR	< 1 $	0.8 $	0.75 $
Implication	Core dia is higher & Low BR Not preferred	Computational complexity & Strict fabrication control (mix-up)	To be optimized further

**** Higher diameter chosen to have flexibility to adopt axial / radial hetero core at any stage***

Evolution of Reactor Assembly Design

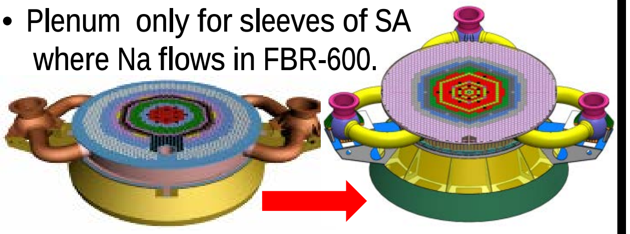

PFBR

- Core diameter (m) : 6.1 → 6.615
- MV dia (m) x ht (m) : 12.9 x 13.1 → 12.9 x 14.385
- No. of Primary pumps : 2 → 3
- Primary Sodium mass : 1150 t → 1270 t
- CP & SRP : CP on SRP → Integral
- MV - SV Gap (mm) : 300 → 250 (implication on ISI)
- SV - RV Gap (mm) : 220 → 55 (Nearly embedded)
- RA dia (m) x ht (m) : 13.9 x 15.5 → 13.79 x 17.245
- Shielding Concrete : Embedded in top shield → Independently supported on RV
- RA Support Skirt : In tension → In compression


FBR-600

MV-Main Vessel; CP-Control plug; SRP-Small Rotatable Plug; SV–Safety Vessel; RA–Reactor Assembly; RV- Reactor Vault

- Plenum for all SA sleeves in PFBR.
- Plenum only for sleeves of SA where Na flows in FBR-600.

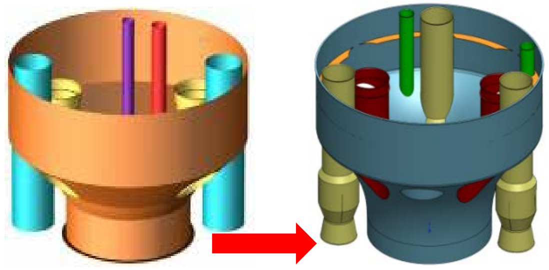

Grid Plate & Primary Pipes

Bolted constrn. → Welded constrn.

4 Pipes (2x2) → 6 Pipes (3x2)

Larger plenum → Smaller plenum

Hard facing on Mating Flanges → No hard facing

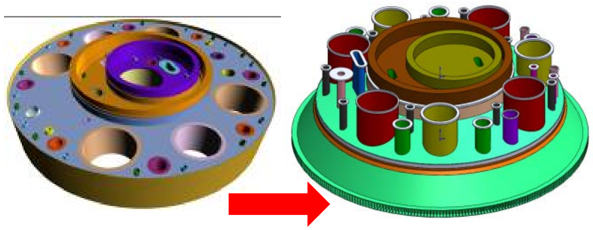

Inner Vessel

Conical step → Single torus

15-20 mm → 15 mm uniform

Bolted with GP → Welded with GP

Design to prevent buckling → Buckle free shape


Top Shield

Box structure → Shell structure

Plugs: Box → Thick Plates

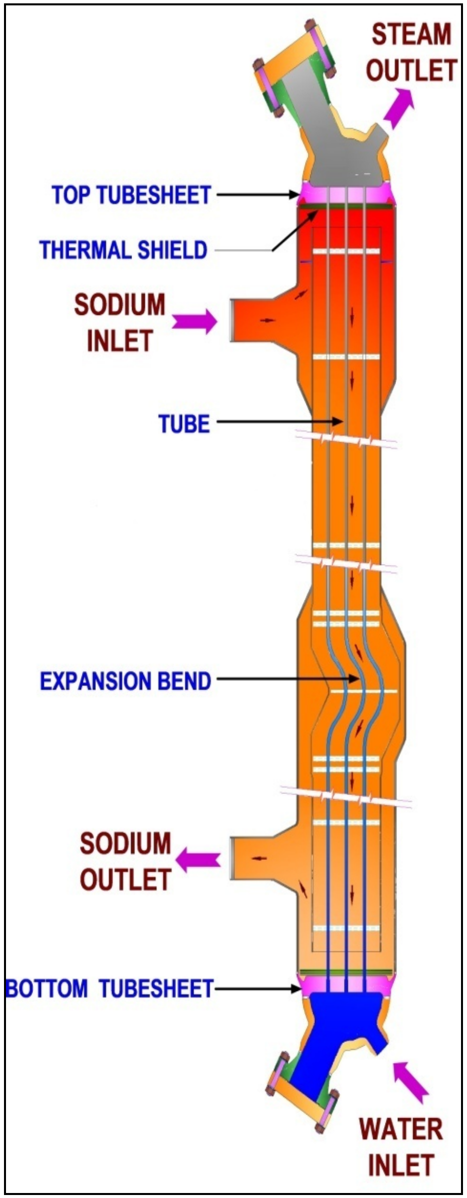
Carbon steel → Stainless steel

MV-RS Junction: Welded Tee → Forged ring

Steam Generators

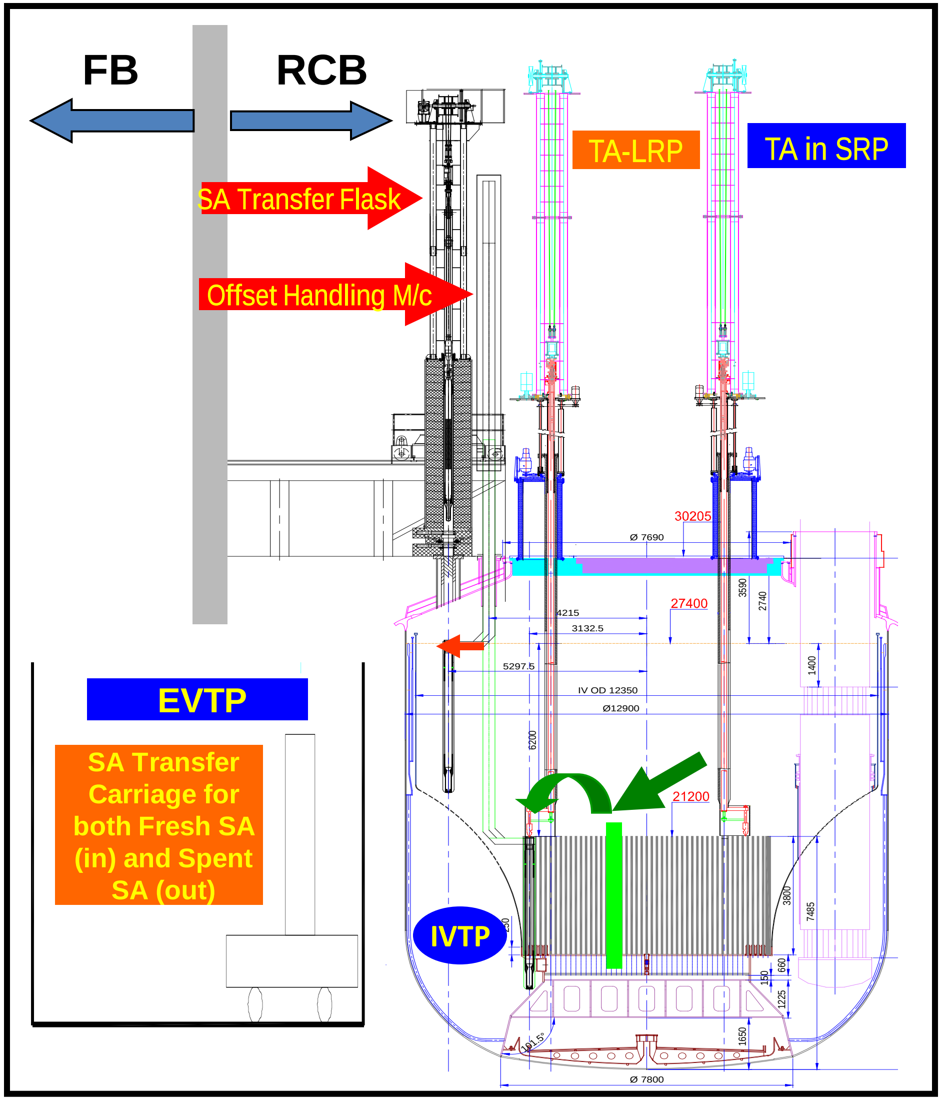
- ✓ Concept similar to PFBR;
- ✓ Number of tubes is same as PFBR (547)
- ✓ Longer tube length : 30 m (23 m for PFBR)
- ✓ No. SG modules: 3 per loop (4 per loop for PFBR)
- ✓ 20% higher power (158 to 250 MWt / SG)
- ✓ Higher steam temperature: 510 °C (490ºC for PFBR)

- ✓ SG with 23m tube: (8 + 4 + 1) = 13 units
- ✓ SG with 30m tube: (8 – 2 + 1) = 7 units
- ✓ Reduced no. of tubes and consequent reduction of tube sheet joints improves reliability and significant reduction in manufacturing time (~45 %)



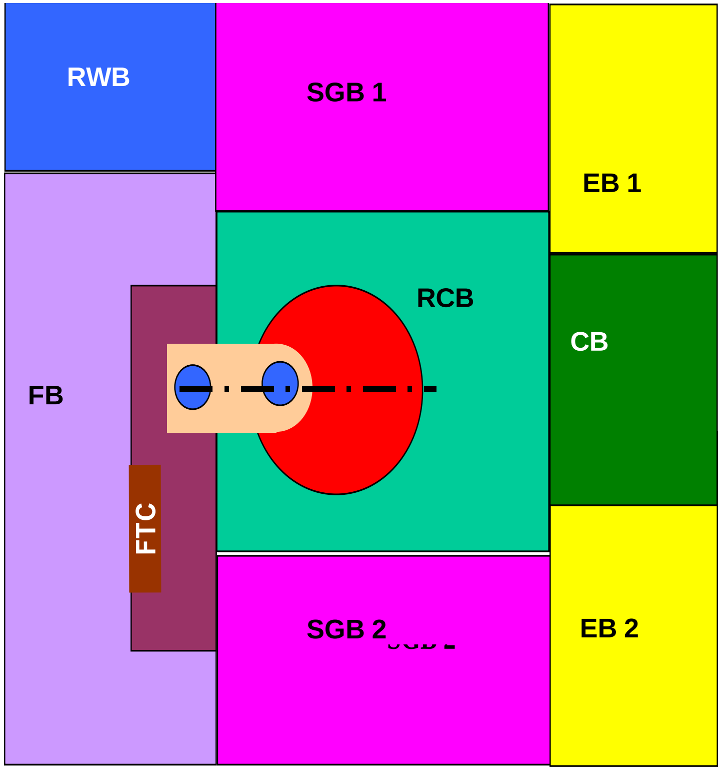
Fuel Handling Scheme

- In-Vessel Transfer from Active Core to Storage Space:
  - One Transfer Arm *(No Change)*
- From Storage space to IVTP in Grid Plate:
  - By the same TA in PFBR and by a separate TA in FBR-600 *(additional TA)*
- From the IVTP to EVTP:
  - Directly by IFTM in PFBR and the same is accomplished by three items viz. Off-set Handling Machine, SA Transfer Flask and a carriage in FBR-600 *(slight additional time needed)*
- Subsequent transfer is same as PFBR

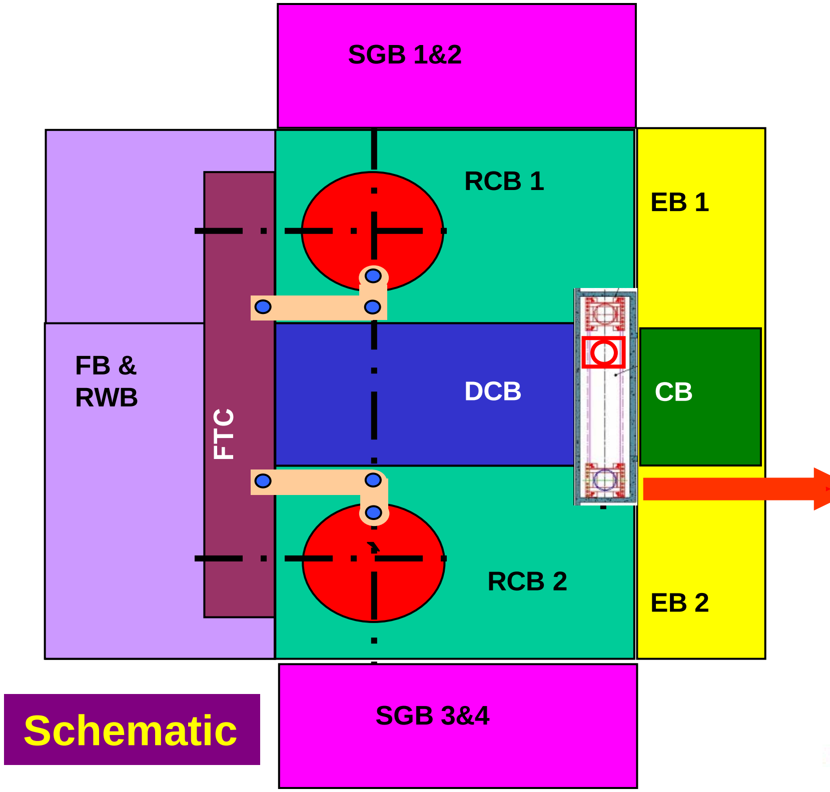


- **Equipment in Fuel Building identical to PFBR**
- **Handling time is nearly same for FBR-600 (230 minutes per SA on an average)**

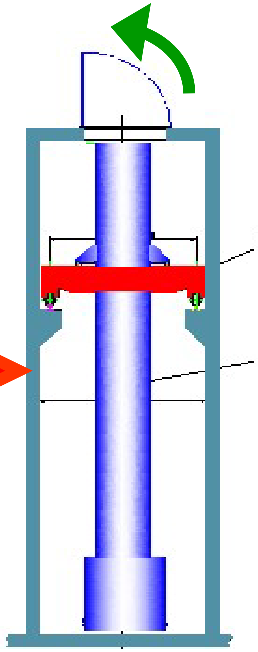
Sharing of Facilities in FH System



PFBR : Single Unit Layout



FBR 600 : Twin Unit Layout



Traverser

- FH for each FBR in twin unit concept will be carried out with some specific time shift
- All equipment in Fuel Building shared between Twin units
- Additional systems for FBR-600: A separate decontamination Building (DCB) to enable sharing of special handling equipment and a traverser to facilitate transfer of PSP, IHX etc using Shielded Flasks

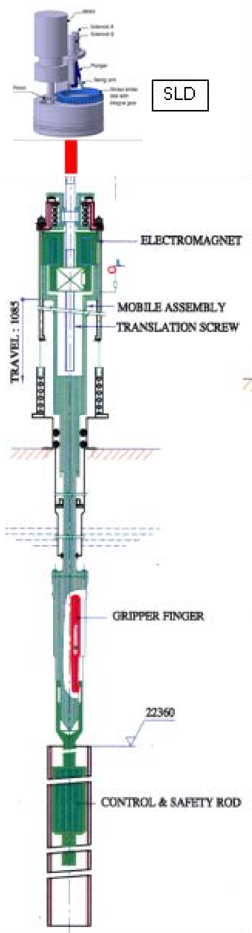
Enhanced Safety Features of FBR-1&2

- **The safety level to be in consonance and conforming to the evolving national and international safety standards (approaching to Gen-IV SDC)**
- **Higher level of safety through introduction of inherent design features in the core, additional passive and diversified means of shutdown and decay heat removal**
- **Engineering of critical structures with high reliability, redundancy with provision of In-Service Inspection**
- **Coolability of core debris and maintenance of primary system and containment integrity to minimize large and early offsite radioactivity release.**
- **Robust severe accident management measures**

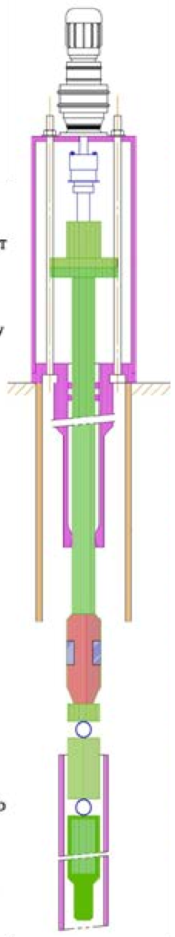
- Small inter-vessel space so that the Decay Heat Removal Exchangers inlet window will be sufficiently immersed in the hot pool in case of main vessel leak
- Independent supports for main vessel and Safety Vessel
- Safety vessel should withstand mechanical loads from earthquakes whilst retaining leaked sodium for a long time.
- Additional DHR circuits in secondary circuit with air as ultimate heat sink
- Sufficient margins against earthquakes.

- Ultimate shutdown system based on B4C granules/Li injection for taking care of re-criticality
- Core catcher for credible core debris and Post Accident Heat Removal purpose,
- Introduction of thermo-fluid in the concrete vault cooling circuits and special heat exchangers for heat removal from vessel inter-space.

Enhanced Safety Features

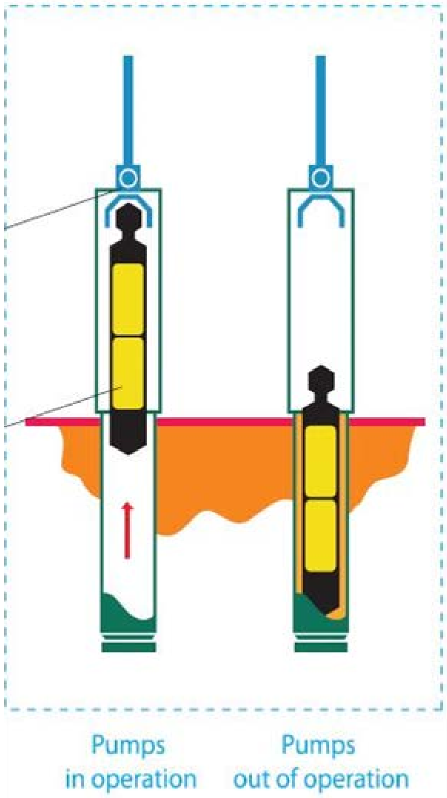


3a. SLD in CSRDM



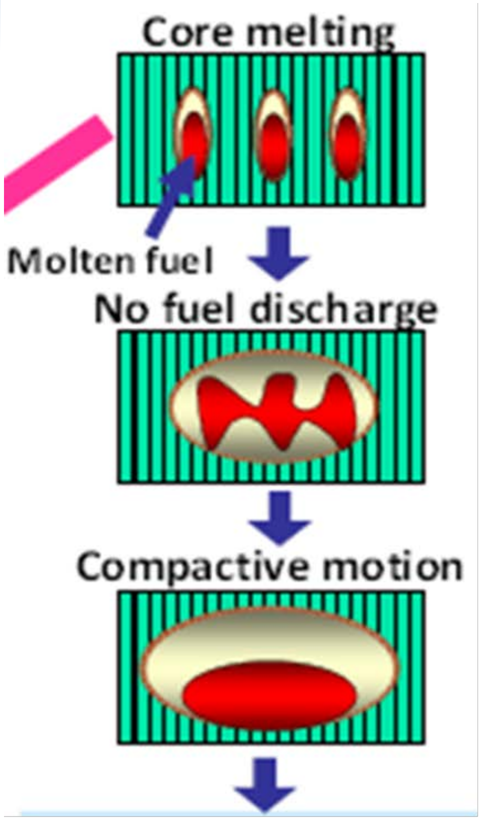
3b. TSEM in DSRDM

To prevent ULOFA

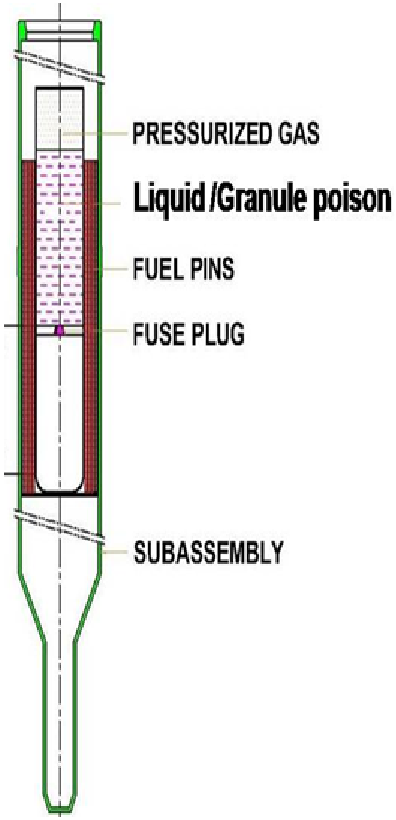


3c. Hydraulically Suspended Absorber Rod (HSAR)

Passive Shutdown Systems



Large reactivity insertion and re-criticality within core: Two options to prevent: remove a portion of molten materials or injection of poison

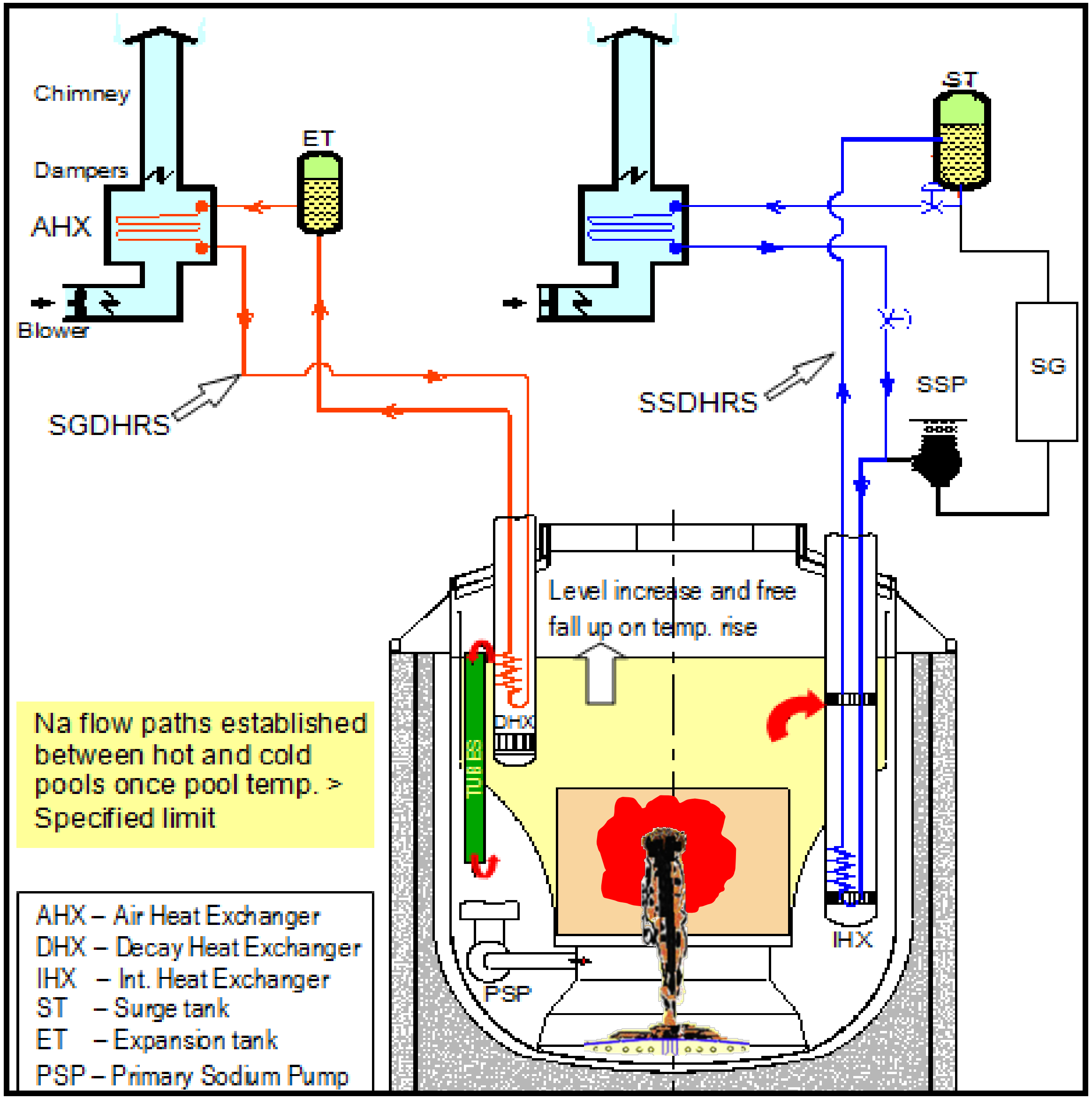


Poison will automatically flow once the thermal seal melts during overheating / small scale melting of fuel and prevents re-criticality event

To prevent re-criticality

Judicious Combination of Active & Passive DHRS

- For accomplishing DHR during FH, ISI and most of DBEs, DHRS (4x10 MWt) will be introduced in the secondary sodium circuits (SSDHR) instead of OGDHR
- For taking care of DHR during SBO and DECs, SGDHRS will be retained.
- For PAHR condition, a few pipes penetrating through inner vessel under consideration to augment the flow paths (large perforation) created during fuel melt-through scenario to provide adequate natural circulation



Level increase and free fall up on temp. rise

Na flow paths established between hot and cold pools once pool temp. > Specified limit

AHX – Air Heat Exchanger
DHX – Decay Heat Exchanger
IHX – Int. Heat Exchanger
ST – Surge tank
ET – Expansion tank
PSP – Primary Sodium Pump

Dose Limits

Event/Accident	Frequency	Limiting Dose at Plant Boundary	
		Whole Bod (Thyroid Child)	New Limits
Design Basis Events	Category-1 Normal Operation including operational transients ($\leq$ 1)	1.0 mSv/y	0.1 mSv/y
	Category-2 Events of Moderate Frequency (1- 10^{-2})	5 mSv/ event (50)	0.1mSv/event
	Category-3 Events of Low Frequency (~10^{-2}- 10^{-4})	30 mSv/ event (300)	1.0 mSv/event
	Category-4 Events of Low Frequency (~10^{-4}- 10^{-6})	100 mSv/ event (500)	5.0 mSv/event
BDBE	Frequency $\leq 10^{-6}$	250.0 mSv/ event (2500)	20.0 mSv/event

Summary

- First criticality of PFBR project in 2015
- Closure of PFBR Fuel Cycle by 2022-23
- FBR-1&2 to be commissioned in 2023-24
- Metallic Demonstration Fast Reactor by 2025
- A serial construction of CFBRs (Oxide and Metal) from 2030 onwards
- In order to achieve the goal with excellence in the mission several R&D institutes & academic institutes and industries have been involved.
- History of design, manufacturing and erection experiences is well documented to adopt for the future applications towards achieving economic competitiveness of the technology with the enhanced safety

THANK YOU