



R&D Programme in BARC on AHWR-300 Design & Technology Development and Innovative Reactors

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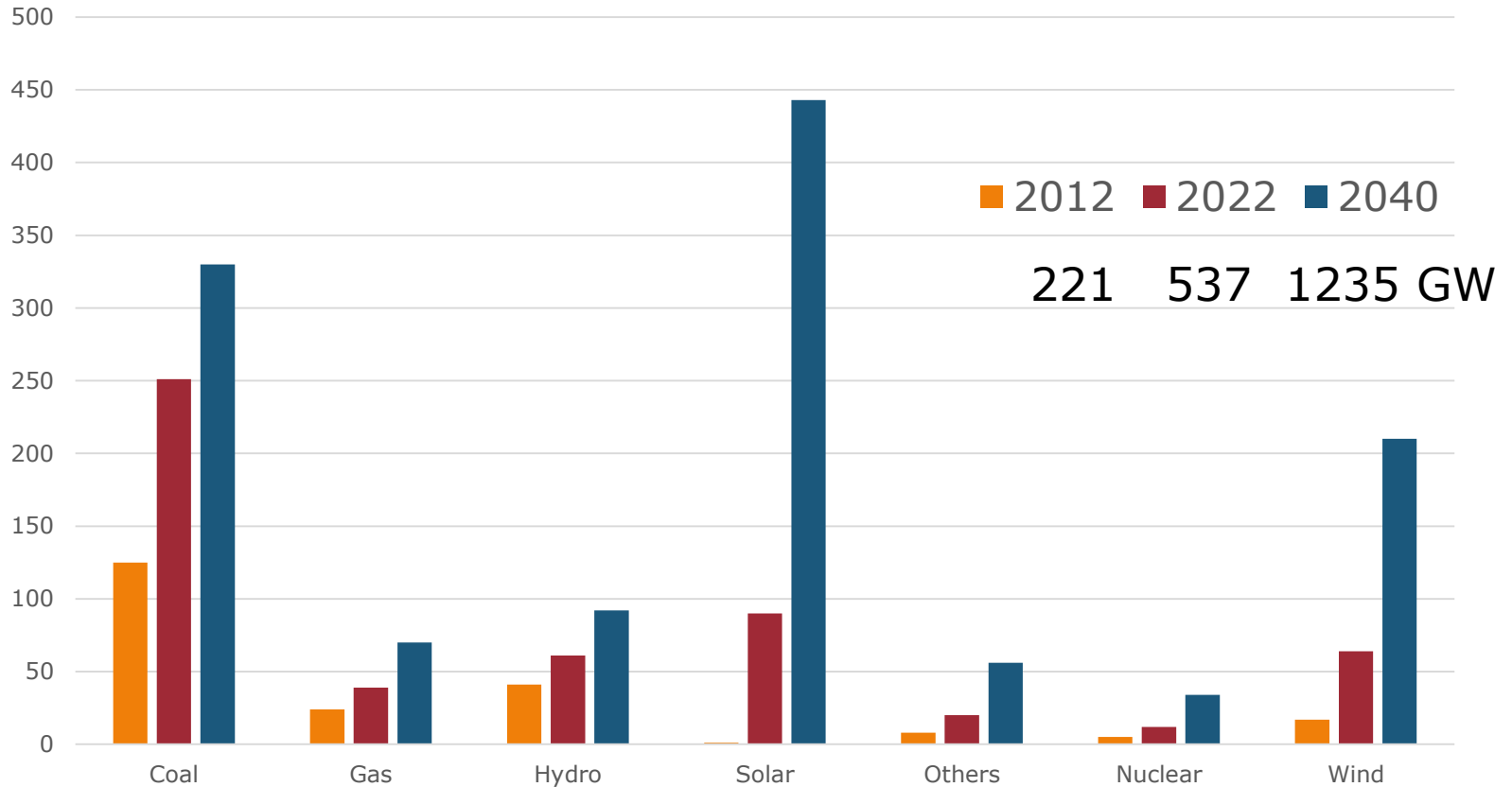
a. PHWRS

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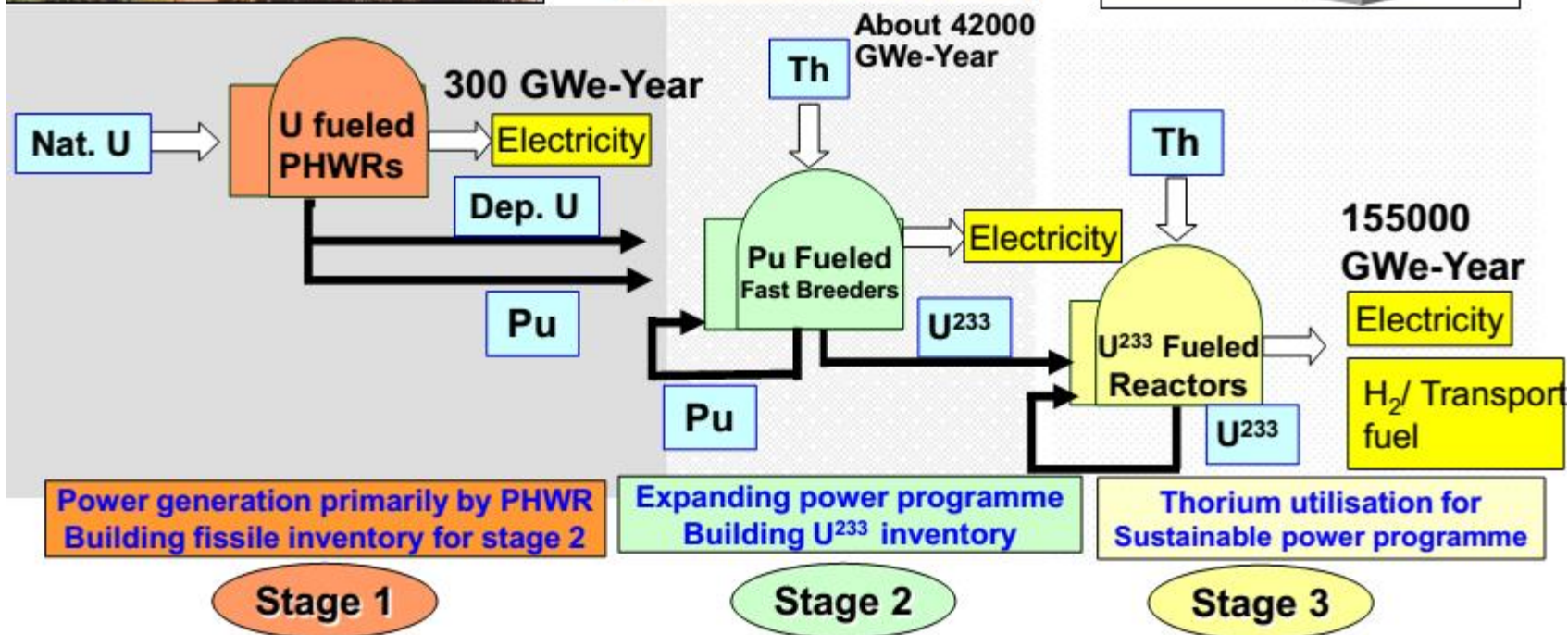
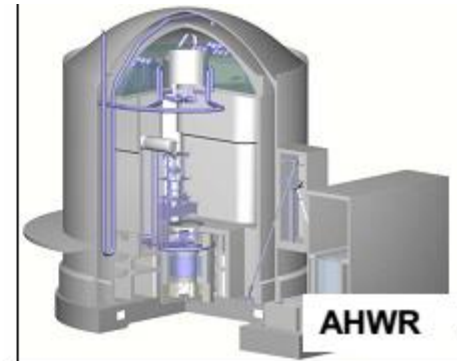
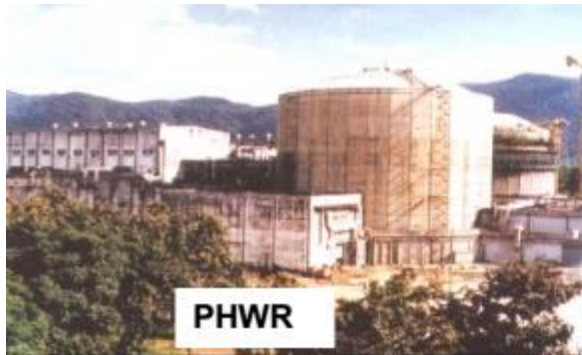
c. HTRs

3. Indian SMRs features and future goals

Electrical Power Capacity in India



India's Nuclear Programme



Operating Reactors

Plant	Type	Capacity
Tarapur Atomic Power Station	BWR PHWR	2X160 2X 540
Rajasthan Atomic Power Station	PHWR	1X100, 1x200, 4x220
Madras Atomic Power Station	PHWR	2x220
Kaiga Atomic Power Station	PHWR	4x220
Narora Atomic Power Station	PHWR	2x220
Kakrapara Atomic Power Station	PHWR	2x220
Kudonkulam Atomic Power Station	PWR	2x1000

Reactors under construction and planned

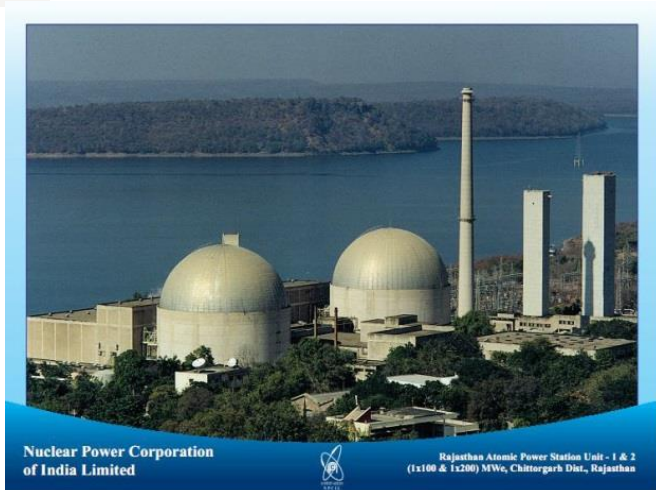
Under construction

- 4 units of 700MWe PHWR
- 2 units of 1000 MWe VVER
- 500 MWe PFBR under commissioning

- Reactors Planned

- New Fleet of ten 700 MWe PHWR
- 2 more units of VVER
- SMRs are the major workhorse of our indigenous nuclear power programme

1st Stage of India's Nuclear Programme - PHWRs



PHWR



NUCLEAR FUEL COMPLEX, HYDERABAD



WASTE MANAGEMENT AND REPROCESSING PLANT



700 MW PHWR UNDER CONSTRUCTION

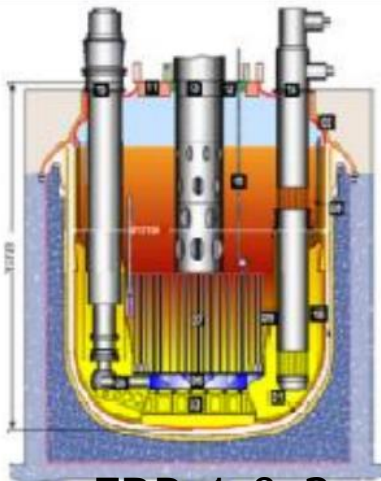
2nd Stage of India's Nuclear Programme- Fast Reactors



PFBRs under commissioning



Reactor Assembly - PFBR

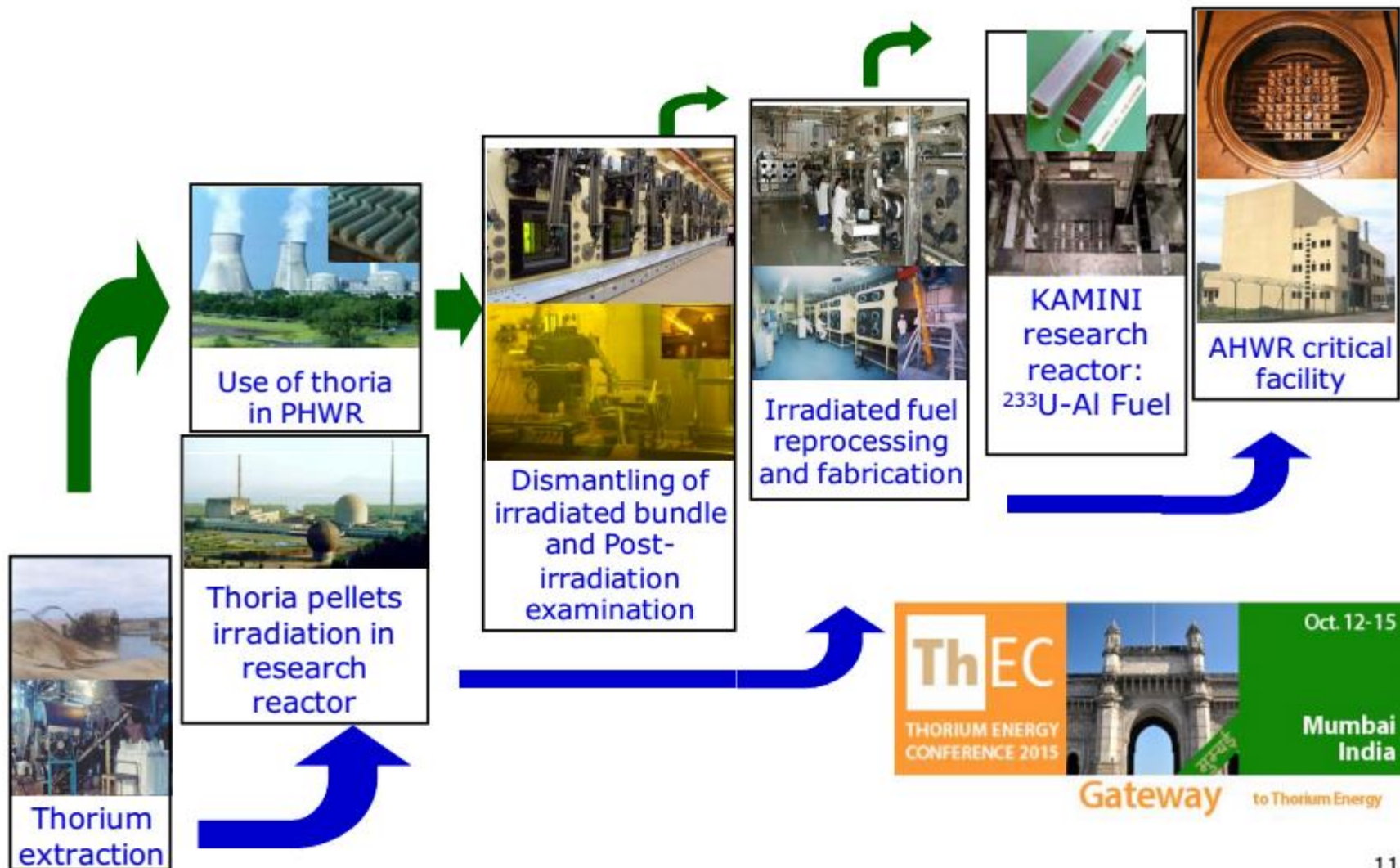


FBR 1 & 2



Fuel fabrication and reprocessing for FBRs

Evolution of Thorium Fuel Cycle in India

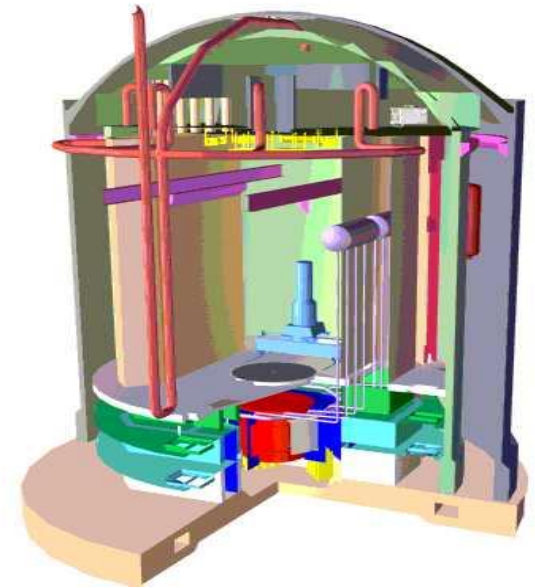


Advanced Heavy Water Reactor (AHWR)

The AHWR is a unique reactor designed for the large scale commercial utilisation of thorium and demonstration of integrated technologies of advanced reactors

Design objectives / Challenges

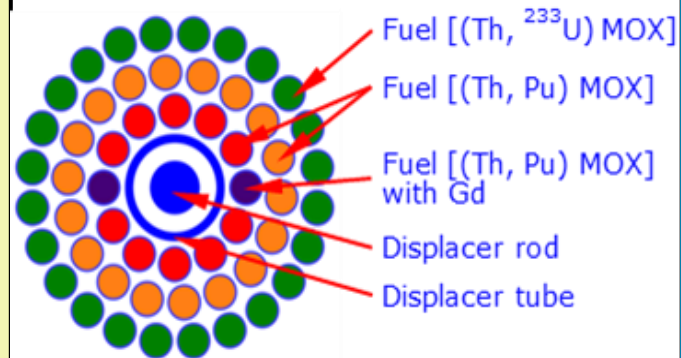
- Maximise the power from thorium
- Negative power coefficient in linear range of power
- Heat removal through natural circulation
 - Uniform coolant flow ; flat radial power distribution , short active core height
 - Low power density
 - Bottom peaked axial power/flux distribution
- Fuel cycle aspects
 - Self-sustenance in ^{233}U
 - Plutonium as make-up fuel ; minimise the Pu inventory and consumption
 - Maximise the burnup



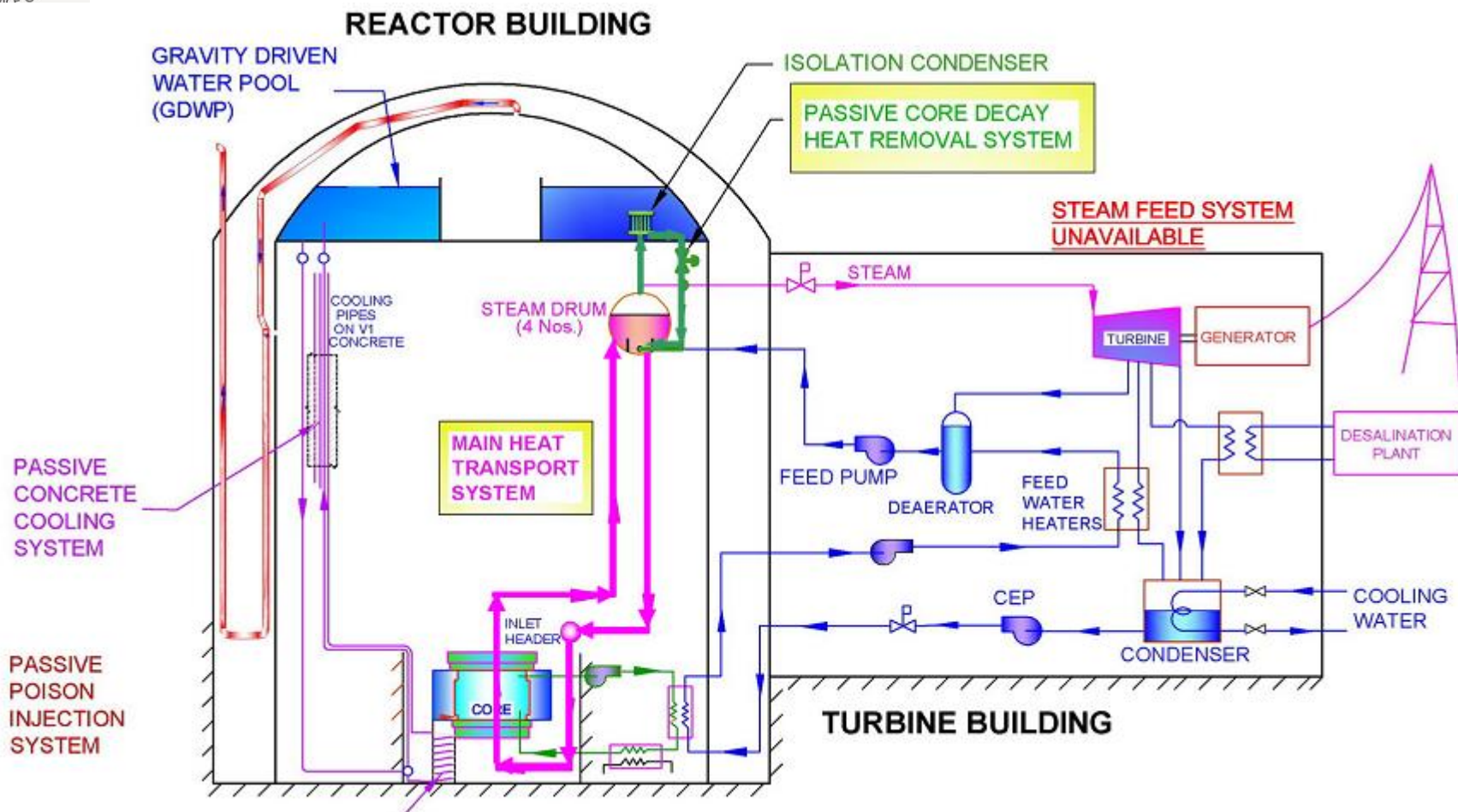
Advanced Heavy Water Reactor (AHWR)

Important Design Parameters of AHWR

Reactor Power	300 MWe (920MWth)
Fuel	54 pin cluster (Th, ²³³ U)MOX+(Th,Pu) MOX
Enrichment	Inner / Middle / Outer ²³³ U=3%,3.75%, Pu=3.25%
Coolant	Boiling Light Water
Moderator	Heavy Water
Total No. of Channels	513
No. of Fuel Channels	452
Lattice Pitch	225 mm
Primary Shut down System	37 shut off rods (B ₄ C absorber)
Secondary Shut down System	Liquid poison injection
No. of Control Rods	24
Passive Poison Injection	Poison injection through a passive valve

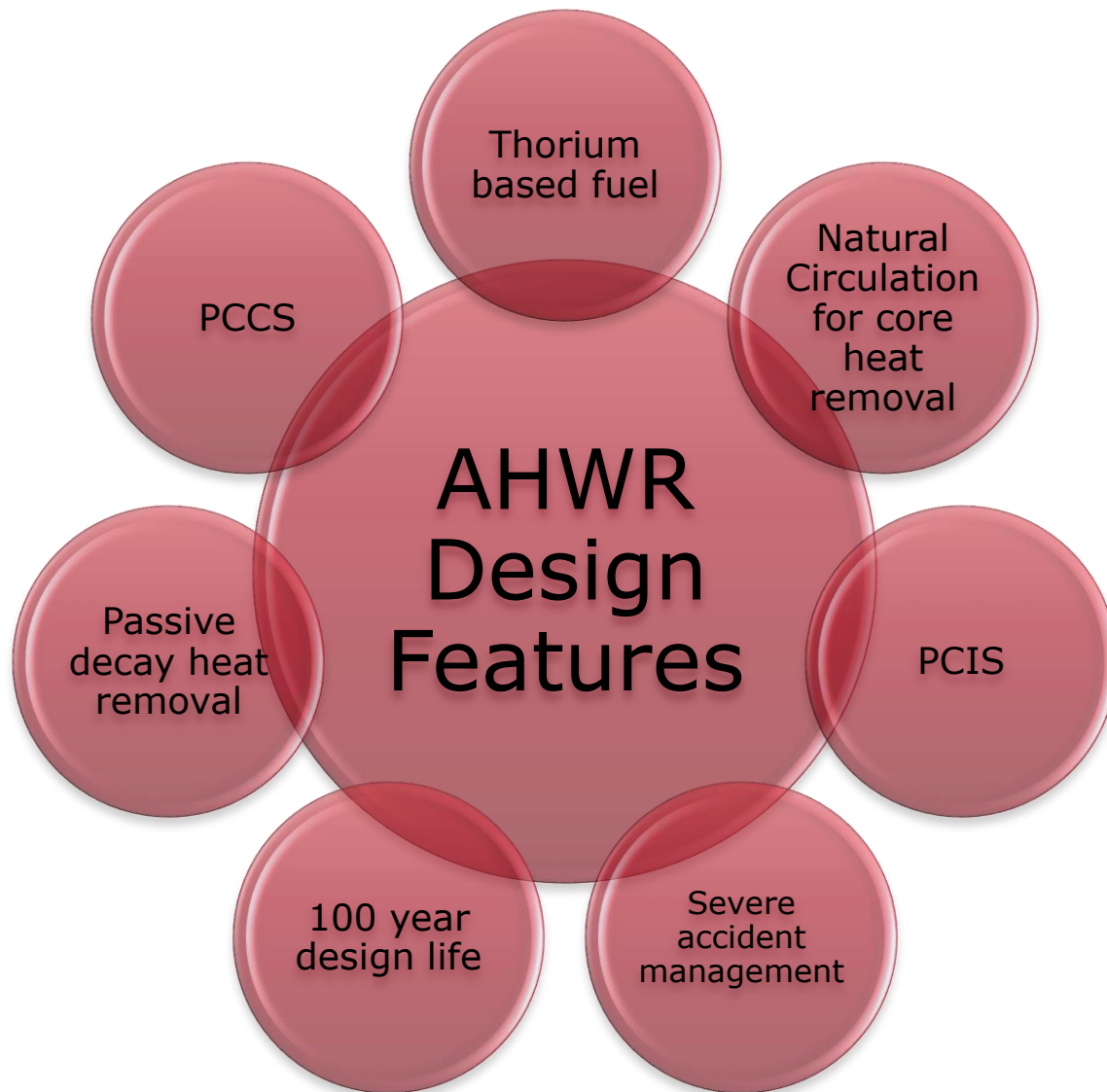


Natural Circulation in AHWR



Heat removal from core under both normal full power operating condition as well as shutdown condition is by natural circulation of coolant.

R&D Programme of AHWR





Experimental Facilities for AHWR Design Validation

BARC Facilities

- ▶ AHWR Critical Facility
- ▶ Integral Test Loop (ITL)
- ▶ Natural Circulation Loop (NCL)
- ▶ High Pressure Natural Circulation Loop (HPNCL)
- ▶ Flow Pattern Transition Instability Loop (FPTIL)
- ▶ Parallel Channel Loop (PCL)
- ▶ Passive Containment Isolation Test Facility (PCITF)
- ▶ Passive containment cooling test facility
- ▶ Passive concrete cooling test facility
- ▶ Boiling Water Loop (BWL)
- ▶ Moderator and liquid poison distribution test facility
- ▶ Isolation Condenser Test Facility (ICTF)
- ▶ Passive External Condensation Test Facility (PECTF)
- ▶ Air Water Loop (AWL)
- ▶ AHWR Thermal-Hydraulic Test Facility (ATTF)
- ▶ Fuelling Machine Test Facility (FMTF)
- ▶ Containment Systems Integral Simulation Test Facility (ConSIST)

IIT Bombay

- ▶ Thermal Hydraulic Test Facility (THTF)
- ▶ Freon Loop for CHF studies
- ▶ Passive Moderator Cooling System

IIT Kharagpur

- ▶ Facility for carry over and carry under studies
- ▶ Facility for Re-wetting experiments

Development Activities

- ▶ Fuel Rod Simulator (FRS) development (direct & indirect),
- ▶ Power decay and coast-down simulation
- ▶ Two-phase instrumentation (flow, void fraction, channel power)
- ▶ Passive valves (HSPV, AIPV, PPIV)

AHWR Critical facility

Critical Facility went critical on 7th April, 2008.

The facility has been designed for conducting lattice physics experiments to validate AHWR physics calculations.

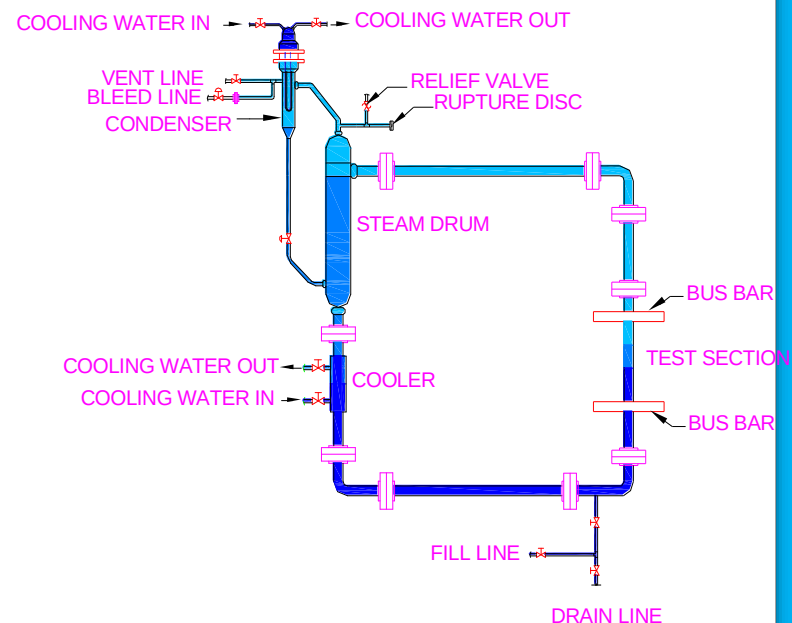
Features:

- Fission power of 100 W
- Neutron flux (avg.) of 10^8 n/cm² s
- Variable lattice pitch
- Cylindrical core (Ø3.3m x 5m height)
- Heavy water moderator & reflector
- 6 Cadmium shutoff rods
- Moderator dumping
- Variable core configuration



The validation exercise has raised the confidence level in calculation methodology and simulations of AHWR

High Pressure Natural Circulation Loop



Objectives

To study natural circulation
 steady state and stability
 behaviour at high pressure

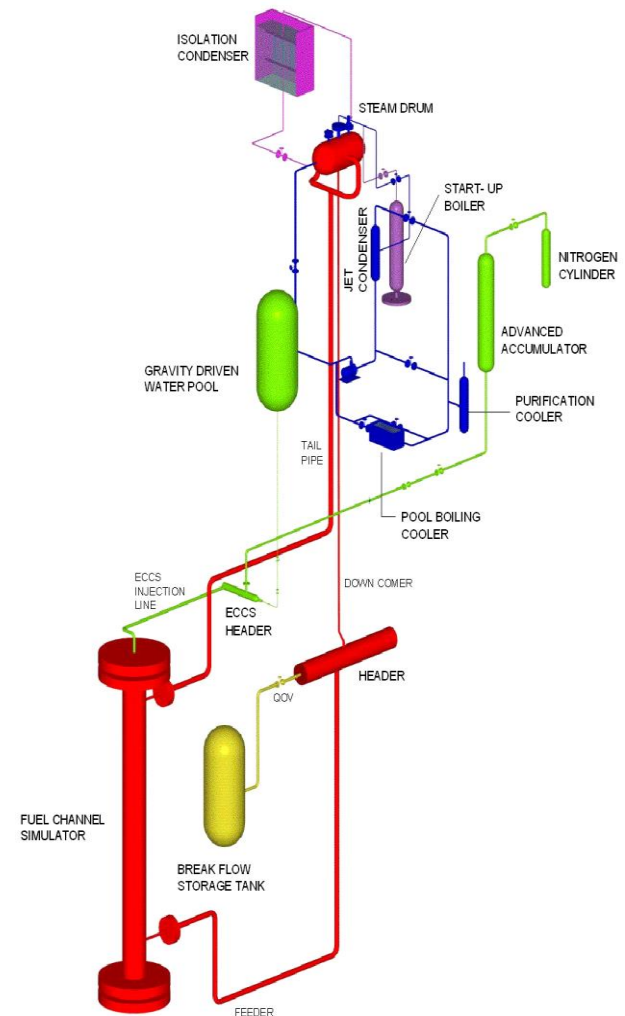
Validate in-house developed
 computer codes

Major Design Parameters

Design Pressure : 114 kg/cm²
Design temperature : 315 °C
Maximum Power : 80 kW
Loop Diameter : 50 mm
Elevation : 3000 mm
Heated Section : 1000 mm

Integral Test Loop (ITL)

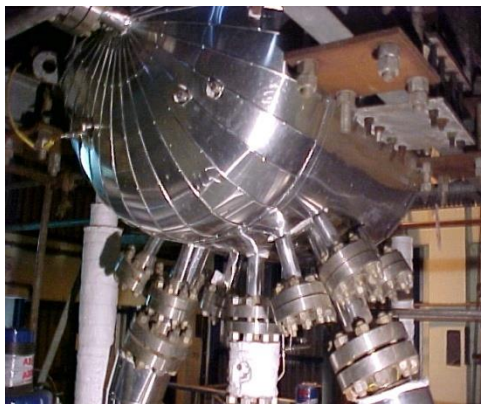
- A scaled test facility designed to simulate the Main Heat Transport and safety Systems of AHWR.
- Designed on the basis of power-to-volume scaling philosophy. The loop height is same at that of reactor. It simulates single channel of AHWR. Pressure and temperature are same as that in the reactor.
- Experiments conducted:
 - ✓ Start-up procedure
 - ✓ Performance evaluation of ECCS, GDWP and ICS.
- Served as a test bed for validating the
 - ✓ Design different equipments and instrumentation
 - ✓ Computer codes.



Integral Test Loop (ITL)



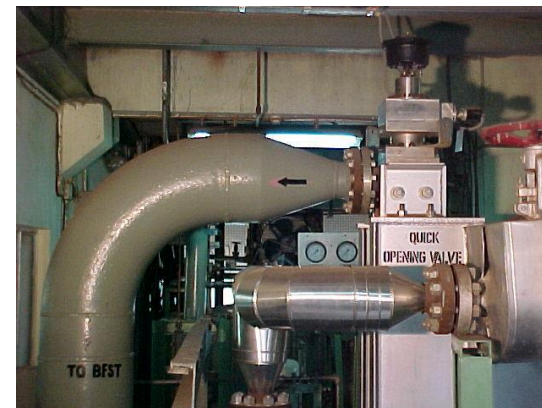
Inlet Header



Steam Drum



Fuel Rod Cluster Simulator



Quick Opening valve

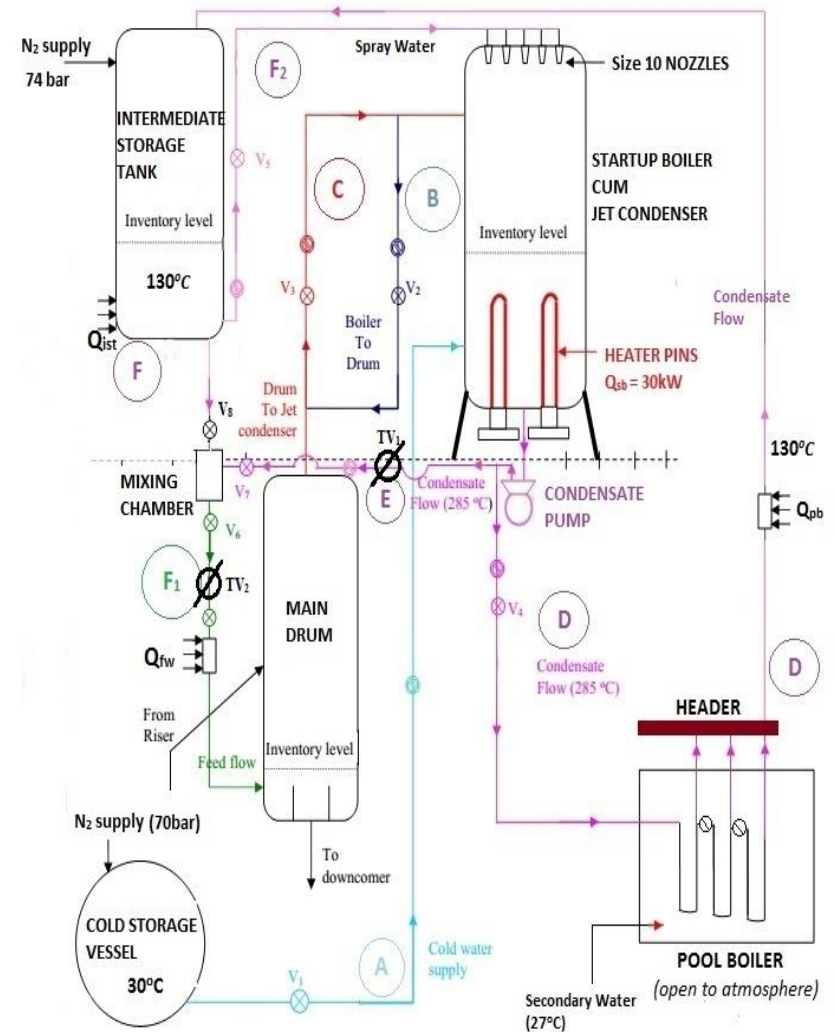
AHWR Thermal Hydraulic Test Facility (ATTF)

- ATTF is another scaled integral test facility designed on the basis of power-to-volume scaling philosophy. This test facility simulates the Main Heat Transport and safety systems of AHWR.
- This test facility simulates two full power channels of AHWR at full power temperature and pressure conditions.
- Elevation, pressure and temperature are same as that in the prototype.
- The main objectives of this test facility are generation of experimental data on parallel channel instability and evaluation of thermal and stability margins.
- AHWR fuelling machine will also be tested in this test facility.

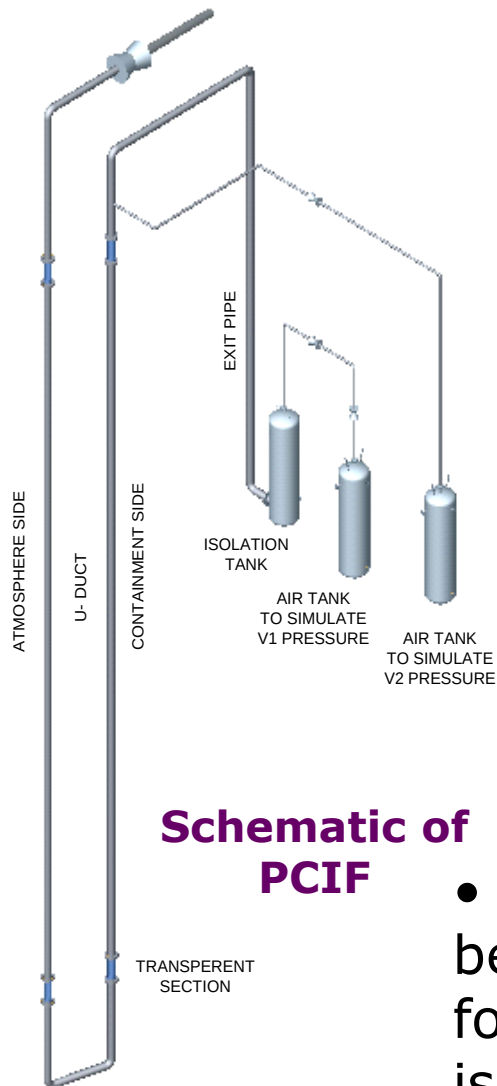
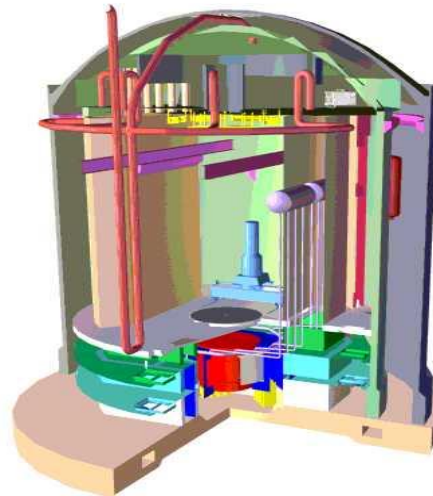


Thermal Hydraulic Test Facility (THTF) at IIT Bombay

- THTF is another scaled integrall test facility designed on the basis of Ishii scaling philosophy. This test facility simulates the Main Heat Transport system of AHWR.
- The main objectives of this test facility are generation of experimental data on parallel channel instability and CHF margins. In this facility simulating fluid, FC-84 (FREON) have been used

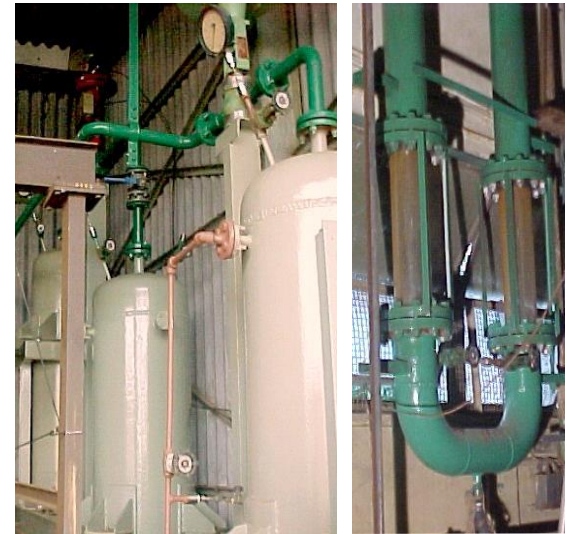


Passive Containment Isolation Test Facility (PCIF)

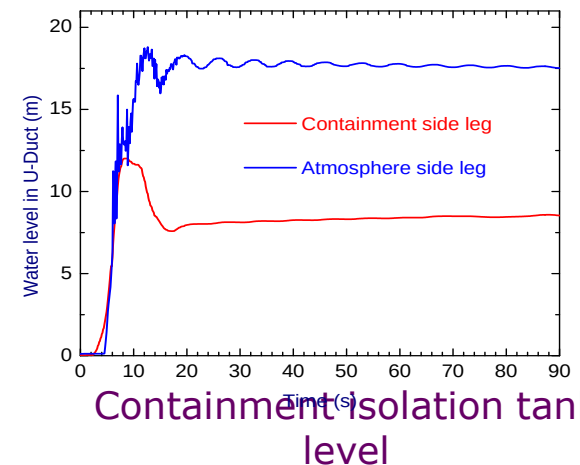


Schematic of PCIF

- Experiments have been conducted. Time for water seal formation is $\sim 7s$.

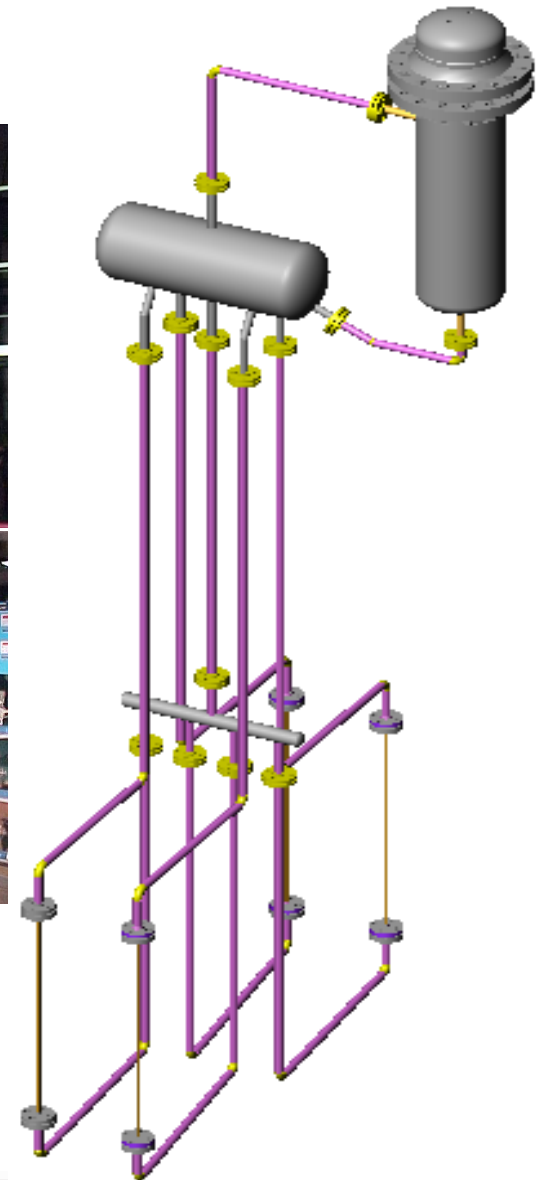
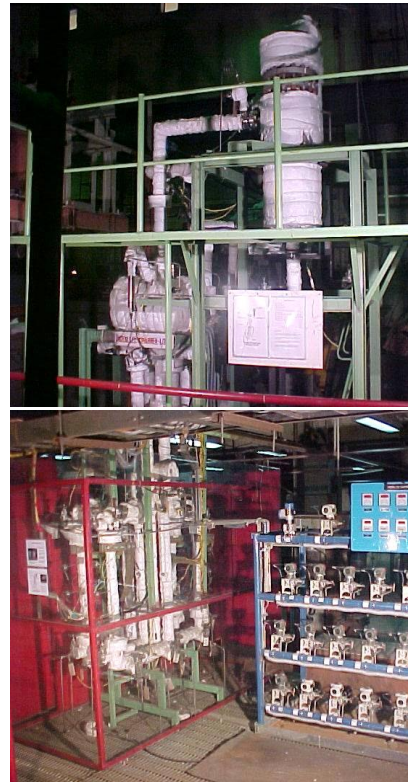


Passive Containment Isolation Facility (PCIF)



Test Facilities for Fundamental Studies on Natural Circulation Behavior

- The Parallel Channel Loop (PCL) was installed for studies on boiling natural circulation with multiple parallel channels at low pressures.
- Parallel channel instability was studied in this facility at low per and pressures.
- This facility was also used the simulation of void reactivity feedback.

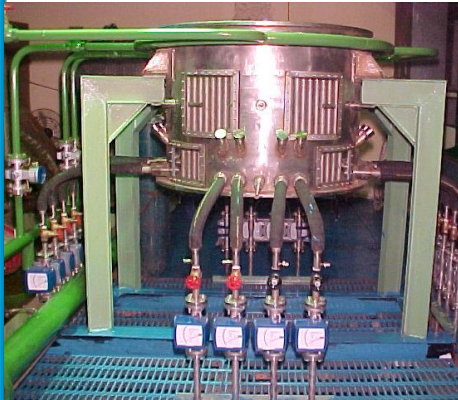


Moderator Flow and Liquid Poison Injection Studies inside Scaled AHWR Calandria Model

AHWR calandria is a vertical geometry and different from existing PHWRs. Hence, it is required to carry out experiments to validate the design

Objectives:

- (i) Moderator temperature and velocity distribution inside calandria
- (ii) Liquid Poison injection and its distribution inside calandria **with time**
- (iii) Validation of CFD model



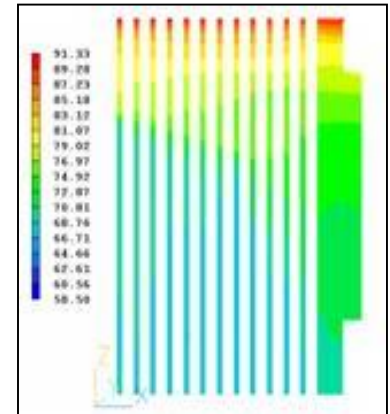
Experimental Setup



Power Supply



Control Panel



Temp. Distribution-CFD results

Status:

Experimental and CFD studies performed on moderator temperature & flow and liquid poison distribution inside the calandria.

Core Catcher Design Validation

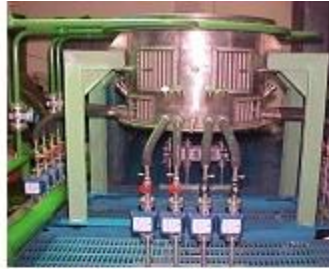
- A core catcher has been provided in AHWR for managing severe accidents involving core melt.
- To study the molten pool quenching behavior, a state-of-the-art test facility has been designed and commissioned at BARC.
- The bottom flooding concept used in AHWR core catcher design has been validated in this test facility.



Experimental Facilities for AHWR Design Validation



HPNCL



Moderator & liquid
poison distribution



PCCTF



PCITF



SDTF



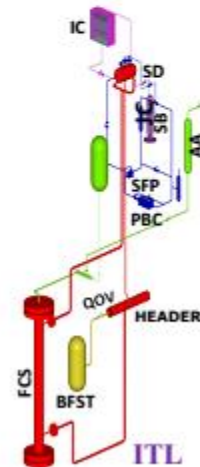
ATTF, Tarapur



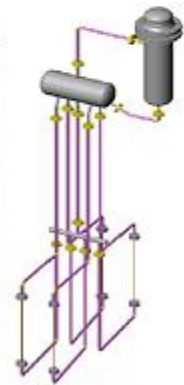
AHWR Critical Facility



Building housing ITL



FPTIL/CHIL



PCL

All the innovative and advanced features have been backed by extensive research and development programme. Various **integral** and **separate effect test** facilities have been setup for the design validation of these features.

Innovative Reactor Systems

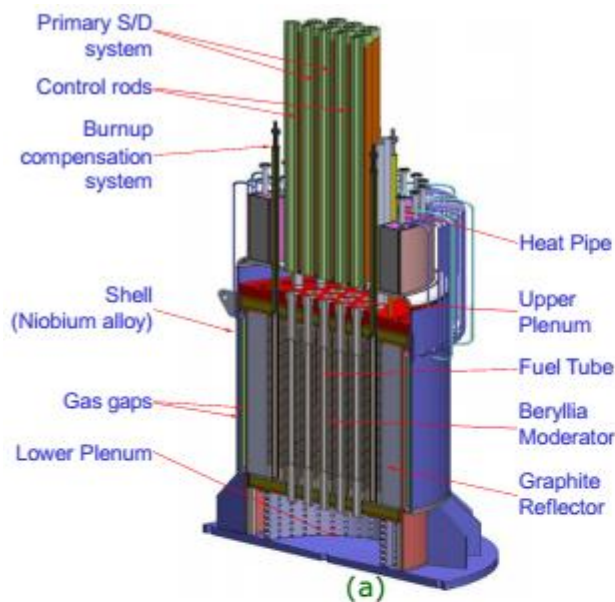
Indian High Temperature Reactor Programme ,

- Compact High Temperature Reactor (CHTR)
- Indian High Temperature Reactor (IHTR)
- IMSBR

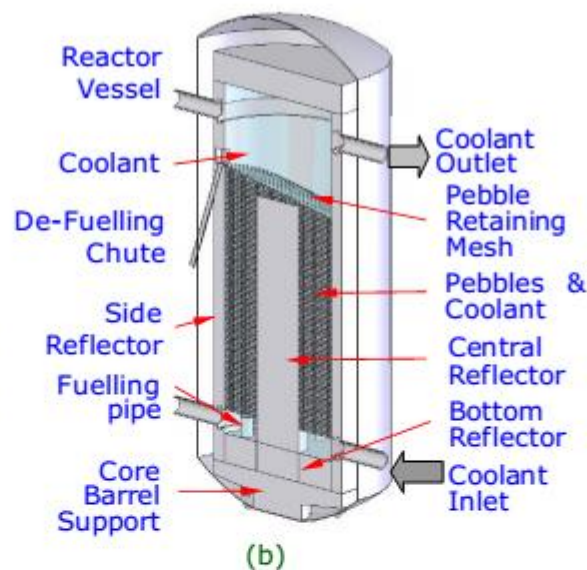
Rational Behind HTR Programme

- Hydrogen generation
- High efficiency
- Possibility of thorium utilisation
- Proliferation resistance

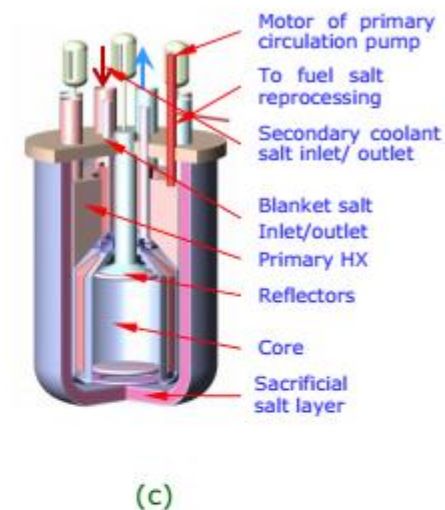
High Temperature Reactor Concepts



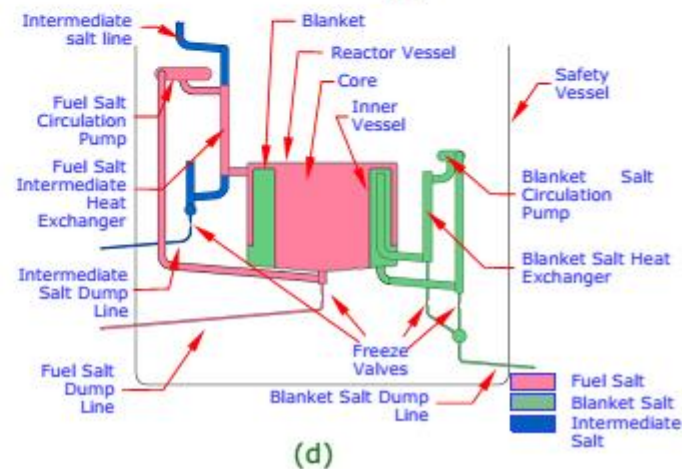
(a) Compact High Temperature Reactor, 100 kWt reactor for technology demonstration



(b) 600 MWth IHTR for large scale hydrogen production

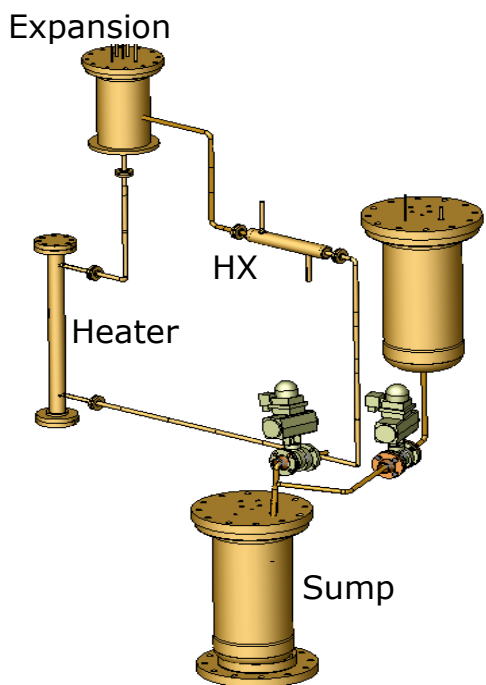


(c) And (d) Pool Type and Loop-In-Tank type IMSBR concepts under study as options for Third Stage

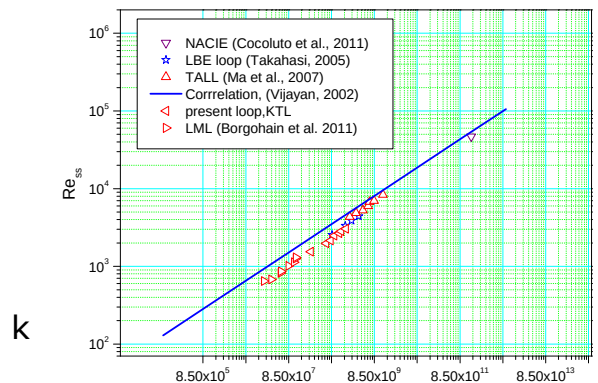


Thermal-hydraulic studies on Compact High Temperature Reactor

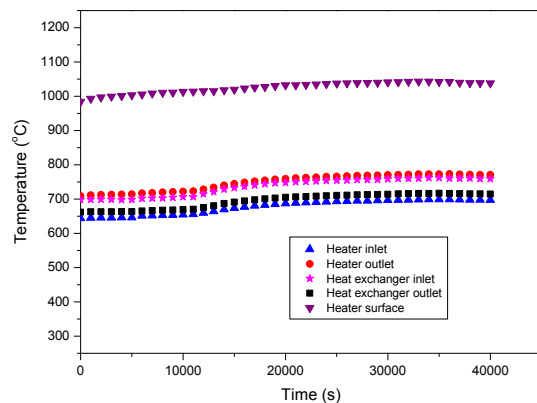
Lead Bismuth Loops



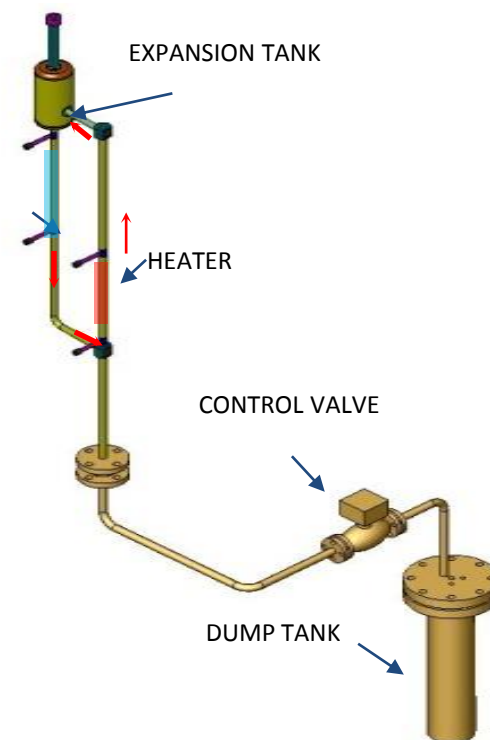
Schematic of LML



Experimental and comparison with other loops

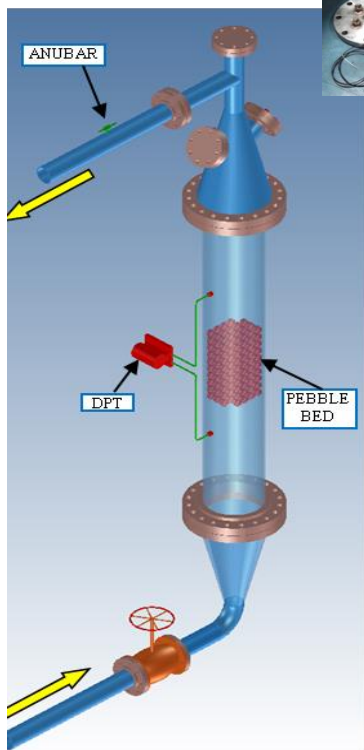


Variation of loop temperature at high power experiment

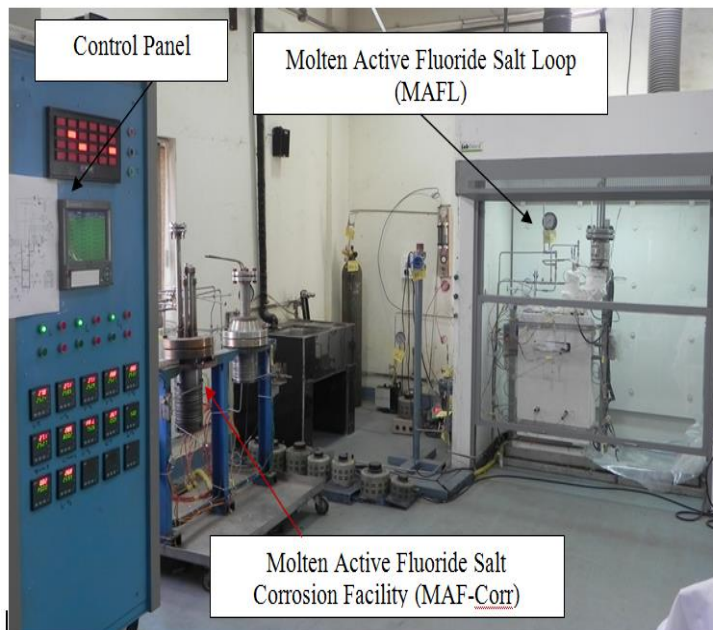


Schematic of KTL

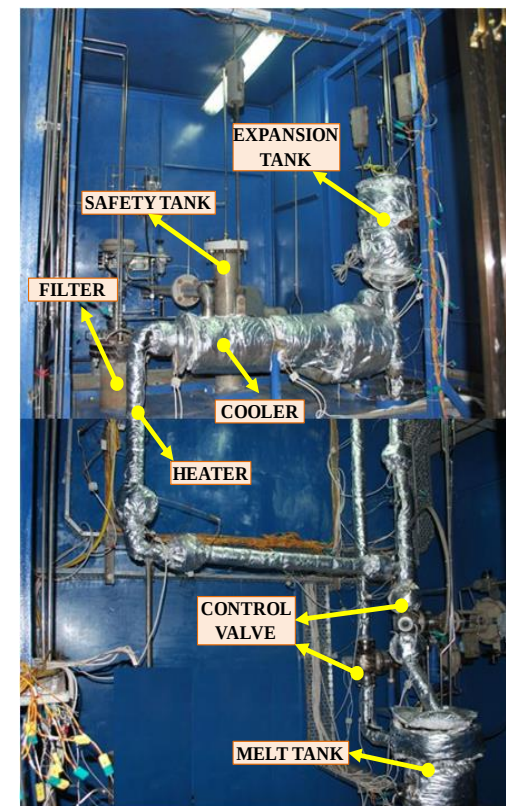
Thermal-hydraulic studies on Molten Salt Breeder Reactor



Pebble Bed Test Facility



Molten $\text{ThF}_4\text{-LiF}$ Salt loop



Molten Salt Natural Circulation loop (MSNCL)

Accelerator Driven Sub-critical System

Accelerator Driven Sub-critical reactor System (ADSS) is being developed for Thorium utilisation as well as for transmutation of nuclear waste in dedicated minor actinides burner reactor with inherent safety against power excursions. Development includes following three major elements

Development of a high current high energy proton accelerator

Stage-1: 30 mA 20 MeV Linac injector (LEHIPA)



Low Energy Beam Transmission line



RFQ



Drift Tube Linac



1.3 MW Klystron



60 kW RF System

Stage-2: 1 GeV and 30 mA superconducting linac:
A major program for augmentation of the infrastructure required for development of a 1 GeV linac has also been launched

Target development studies related to heat removal and window damage (irradiation creep and void swelling)



LBE thermal-hydraulic experimental test facility

Reactor program



Experimental sub critical facility

- Basic theoretical studies, advanced computer codes and compilation of nuclear data
- Experimental program for sub critical ADS, including sub criticality measurement and monitoring
- Several ADS concepts have been evolved: one way coupled, thorium burner, power producing Th breeder, Molten Salt Breeder ADS.



Indian Perspective on SMR Technology

India's indigenous reactor programme has been mainly based on SMRs,

- Pressurized heavy water reactors (PHWRs), such as PHWR-220, PHWR-540 and PHWR-700
- PFBR and FBRs
- AHWR-300

Advantage India,

- India is in a unique position as one of the few countries in the world with a comprehensive capability in the siting, design, construction, operation, renovation and modernization, and plant life extension for SMRs (PHWRs), with an industrial infrastructure, as well as human resources, currently in place.



Indian Perspective on SMR Technology

Future Perspectives of SMRs in India

Innovative small and medium sized reactors (SMRs) have several features that are expected to affect their future development and deployment in India.

These should have the following potential :

- Simpler designs and reduced demands for human intervention, resulting in fewer potentially unsafe actions;
- Construction close to population centres, due to enhanced safety;
- Using the capability and capacity of local industries to enable their participation in the design and construction of such reactors, and high adaptability to the standardization and modular construction approach;
- Potential to achieve low upfront capital costs.

Conclusions

- The Status and operation of Indian SMRs are briefed and the role of PHWRs in Indian Nuclear Programme is highlighted.
- The features of AHWR-300 are unique and R&D activities are done to validate the design.
- The conceptual design of innovative reactors systems are in progress and the R&D activities supporting the development are initiated.
- SMRs are the main pillars of India's indigenous nuclear programme and the future lies with the proper formulations of the design and deployment strategy