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

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1. India’s Energy Picture

2. Indian SMRs
   a. PHWRS
   b. AHWR
   c. HTRs

3. Indian SMRs features and future goals
Electrical Power Capacity in India

![BARC Logo]

- **Coal**
- **Gas**
- **Hydro**
- **Solar**
- **Others**
- **Nuclear**
- **Wind**

<table>
<thead>
<tr>
<th>Year</th>
<th>Coal</th>
<th>Gas</th>
<th>Hydro</th>
<th>Solar</th>
<th>Others</th>
<th>Nuclear</th>
<th>Wind</th>
</tr>
</thead>
<tbody>
<tr>
<td>2012</td>
<td>221</td>
<td>537</td>
<td>1235</td>
<td>221</td>
<td>537</td>
<td>1235</td>
<td>221</td>
</tr>
</tbody>
</table>

**2012 | 2022 | 2040**

- **221**
- **537**
- **1235**

**GW**
India’s Nuclear Programme

Nat. U → U fueled PHWRs → Electricity

Dep. U → Pu → Pu Fueled Fast Breeders

Th → Pu Fueled Fast Breeders

U$_{233}$ → U$_{233}$ Fueled Reactors

H$_2$/ Transport fuel

Power generation primarily by PHWR
Building fissions inventory for stage 2

Expanding power programme
Building U$_{233}$ inventory

Thorium utilisation for
Sustainable power programme

Stage 1

Stage 2

Stage 3
# Operating Reactors

<table>
<thead>
<tr>
<th>Plant</th>
<th>Type</th>
<th>Capacity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tarapur Atomic Power Station</td>
<td>BWR</td>
<td>2X160</td>
</tr>
<tr>
<td></td>
<td>PHWR</td>
<td>2X 540</td>
</tr>
<tr>
<td>Rajasthan Atomic Power Station</td>
<td>PHWR</td>
<td>1X100, 1x200, 4x220</td>
</tr>
<tr>
<td>Madras Atomic Power Station</td>
<td>PHWR</td>
<td>2x220</td>
</tr>
<tr>
<td>Kaiga Atomic Power Station</td>
<td>PHWR</td>
<td>4x220</td>
</tr>
<tr>
<td>Narora Atomic Power Station</td>
<td>PHWR</td>
<td>2x220</td>
</tr>
<tr>
<td>Kakrapara Atomic Power Station</td>
<td>PHWR</td>
<td>2x220</td>
</tr>
<tr>
<td>Kudonkulum Atomic Power Station</td>
<td>PWR</td>
<td>2x1000</td>
</tr>
</tbody>
</table>
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

FBR 1 & 2

Reactor Assembly - PFBR

Fuel fabrication and reprocessing for FBRS
Evolution of Thorium Fuel Cycle in India

- Use of thorium in PHWR
- Thoria pellets irradiation in research reactor
- Dismantling of irradiated bundle and Post-irradiation examination
- Irradiated fuel reprocessing and fabrication
- KAMINI research reactor: $^{233}$U-Al Fuel
- AHWR critical facility
- Thorium extraction

ThEC: Thorium Energy Conference 2013

Gateway to Thorium Energy

Mumbai, India

Oct. 12-15
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
## Important Design Parameters of AHWR

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reactor Power</td>
<td>300 MWe (920MWth)</td>
</tr>
<tr>
<td>Fuel</td>
<td>54 pin cluster</td>
</tr>
<tr>
<td>Enrichment</td>
<td>(Th, $^{233}$U)MOX+(Th,Pu) MOX</td>
</tr>
<tr>
<td>Coolant</td>
<td>Boiling Light Water</td>
</tr>
<tr>
<td>Moderator</td>
<td>Heavy Water</td>
</tr>
<tr>
<td>Total No. of Channels</td>
<td>513</td>
</tr>
<tr>
<td>No. of Fuel Channels</td>
<td>452</td>
</tr>
<tr>
<td>Lattice Pitch</td>
<td>225 mm</td>
</tr>
<tr>
<td>Primary Shut down System</td>
<td>37 shut off rods ($B_4C$ absorber)</td>
</tr>
<tr>
<td>Secondary Shut down System</td>
<td>Liquid poison injection</td>
</tr>
<tr>
<td>No. of Control Rods</td>
<td>24</td>
</tr>
<tr>
<td>Passive Poison Injection</td>
<td>Poison injection through a passive valve</td>
</tr>
</tbody>
</table>

- Fuel [(Th, $^{233}$U) MOX]
- Fuel [(Th, Pu) MOX]
- Fuel [(Th, Pu) MOX] with Gd
- Displacer rod
- Displacer tube
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

AHWR Design Features

- Thorium based fuel
- Natural Circulation for core heat removal
- PCCS
- Passive decay heat removal
- PCIS
- 100 year design life
- Severe accident management
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)
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 $10^8 \text{n/cm}^2 \text{s}$
- Variable lattice pitch
- Cylindrical core($\varnothing3.3\text{m} \times 5\text{m} \text{height}$)
- 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
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 integral 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)

- Experiments have been conducted. Time for water seal formation is ~ 7s.
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.
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

**Status:**

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

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

Variation of loop temperature at high power experiment

Schematic of KTL

Experimental and comparison with other loops
Thermal-hydraulic studies on Molten Salt Breeder Reactor

Pebble Bed Test Facility

Molten ThF₄-LiF Salt loop

Molten Salt Natural Circulation loop (MSNCL)
Accelerator Driven Sub-critical 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 (LEHIIPA)

- Low Energy Beam Transmission line
- RFQ

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**

- 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.
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.
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.