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

Fuel Cycle:

- **DFRP**: From 2016
- **CORAL**: Since 2003
- **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

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

**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

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

Temperature at Tip of Nozzle

Variable Flow

Servo motor controlled

Interfaced with gas jet system

Supports for ball screw setup on top of sub assembly

Moving Platform with ball screw setup

Gas Jet System

Ball Screw : Moving Platform

Servo motor system

Main Control Room Thermocouple readings

Core Thermocouples

Moving Platform with ball screw setup

Control Plug

Validation of all core temperature monitoring thermocouples by Continuity check & Rate of sensing
Gas Jet system for Validating Core Temperature Monitoring Thermocouples

Validation of all core temperature monitoring thermocouples

Supports for ball screw setup on top of sub assembly

IR camera image

MCR readings

Core Thermocouples

Hot air blower with controller

MCR
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.
Simulator Room and Main Control Room

Simulator Room

Main Control Room

Operators Training
Reactors Operation

- Mandatory trainings such as sodium handling, electrical authorization, human performance, safety culture, etc. - completed.
- Classroom training for clearing checklist of various systems given.
- Simulator training - completed in April 30, 2015
- Written examination – in progress
- Walkthrough tests – planned to be completed by second half of July ‘15.
- Interview by AERB appointed committee in July, 2015.
- Full-fledged licensed operating crew - by Aug, 2015

- Main Control Room is being manned in round the clock shift by engineers, undergoing training to qualify for Level – I, II & III positions.
Status of FBR-1&2

Dr. P. Chellapandhi

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

<table>
<thead>
<tr>
<th></th>
<th>Homogeneous</th>
<th>Axial Heterogeneous</th>
<th>Radial Heterogeneous</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Top blanket removal</td>
<td>Top blanket removal</td>
<td>Axial blankets removal</td>
</tr>
<tr>
<td></td>
<td>H/D ratio reduction</td>
<td>Blanket in core centre</td>
<td>Blanket SA inside core</td>
</tr>
<tr>
<td></td>
<td>Addition of FSA &amp; BSA</td>
<td>Addition of FSA</td>
<td>Addition of FSA</td>
</tr>
</tbody>
</table>

### Diagrams

- **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

### Table

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

* Higher diameter chosen to have flexibility to adopt axial / radial hetero core at any stage
Evolution of Reactor Assembly Design

- 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 → Independently in top shield supported on RV
- RA Support Skirt: In tension → In compression

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.
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 (490° C 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. Offset 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

- 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
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.
Passive Shutdown Systems

Enhanced Safety Features

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

To prevent ULOFA

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

3a. SLD in CSRDM

3b. TSEM in DSRDM

3c. Hydraulically Suspended Absorber Rod (HSAR)
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.
## Dose Limits

<table>
<thead>
<tr>
<th>Event/Accident</th>
<th>Frequency</th>
<th>Limiting Dose at Plant Boundary</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Whole Body (Thyroid Child)</td>
</tr>
<tr>
<td><strong>Design Basis Events</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Category-1 Normal Operation including operational transients ($\leq 1$)</td>
<td>1.0 mSv/y</td>
<td>0.1 mSv/y</td>
</tr>
<tr>
<td>Category-2 Events of Moderate Frequency (1- 10$^{-2}$)</td>
<td>5 mSv/ event (50)</td>
<td>0.1 mSv/ event</td>
</tr>
<tr>
<td>Category-3 Events of Low Frequency ($\sim 10^{-2}$- 10$^{-4}$)</td>
<td>30 mSv/ event (300)</td>
<td>1.0 mSv/ event</td>
</tr>
<tr>
<td>Category-4 Events of Low Frequency ($\sim 10^{-4}$- 10$^{-6}$)</td>
<td>100 mSv/ event (500)</td>
<td>5.0 mSv/ event</td>
</tr>
<tr>
<td><strong>BDBE</strong></td>
<td>Frequency $\leq 10^{-6}$</td>
<td>250.0 mSv/ event (2500)</td>
</tr>
<tr>
<td>Summary</td>
<td></td>
<td></td>
</tr>
<tr>
<td>-----------------------------</td>
<td></td>
<td></td>
</tr>
<tr>
<td>• First criticality of PFBR project in 2015</td>
<td></td>
<td></td>
</tr>
<tr>
<td>• Closure of PFBR Fuel Cycle by 2022-23</td>
<td></td>
<td></td>
</tr>
<tr>
<td>• FBR-1&amp;2 to be commissioned in 2023-24</td>
<td></td>
<td></td>
</tr>
<tr>
<td>• Metallic Demonstration Fast Reactor by 2025</td>
<td></td>
<td></td>
</tr>
<tr>
<td>• A serial construction of CFBRs (Oxide and Metal) from 2030 onwards</td>
<td></td>
<td></td>
</tr>
<tr>
<td>• In order to achieve the goal with excellence in the mission several R&amp;D institutes &amp; academic institutes and industries have been involved.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>• 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</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
THANK YOU