Operation and Utilisation of Low Power Research Reactor Critical Facility for Advanced Heavy Water Reactor (AHWR)

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India has large reserves of Thorium and its utilisation for power production is an important feature of the long-term Indian nuclear power programme.

An Advanced Heavy Water Reactor (AHWR) has been designed and developed for maximum power generation from Thorium.

The design envisages using 54 pin MOX cluster with different enrichment of $^{233}$U and Pu in Thoria fuel pins.

Theoretical models developed to simulate neutron transport and the geometrical details of the reactor including all reactivity devices involve approximations in modeling, resulting in uncertainties.
With a view to minimise these uncertainties, a low power research reactor-Critical Facility (CF)- was built.

In CF cold clean fuel can be arranged in a desired and precise geometry.

Different experiments conducted in this facility greatly contribute to understand and validate the physics design parameters.

CF is a low power research reactor with a nominal power of 100 W with an average neutron flux of $10^8$ n/cm$^2$/sec.

Heavy water is used as moderator and as the reactor power is very low, no dedicated core cooling system is required.
CF Reactor Block Schematic
The reactor is essentially a vertical cylindrical tank made of Aluminium, provided at the bottom with graphite blocks as neutron reflector.

The reactor top has a revolving end plate with a few flanges to enable fuel handling operation.

Axial and radial radiation shielding is provided by concrete.

The fuel assemblies and shut off rods are suspended from the top of the reactor tank within lattice girders.

The lattice girders can be moved to change the pitch between the fuel assemblies.
CF has provision to study three types of core based on different fuel types, i.e.

1. 19 pin natural Uranium metal fuel cluster to constitute the reference core;
2. 54 pin (Th-Pu) MOX/(Th-\(^{233}\)U) Mox cluster to constitute the representative AHWR core;
3. 37 pin natural Uranium oxide fuel cluster to constitute the 540 MWe PHWR core.

Initially the reactor core is configured with natural Uranium fuel assemblies and later the AHWR type fuel assemblies will be loaded into the core.
## Core Layout

<table>
<thead>
<tr>
<th></th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>CAM</td>
<td>CF-16 Cu</td>
<td>CF-17 Cu</td>
<td>CF-18 Cu</td>
<td>CF-56</td>
<td>CF-38 Cu</td>
<td>CF-36</td>
<td>CF-41</td>
<td>CF-42</td>
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<tr>
<td>B</td>
<td>CF-38 Cu</td>
<td>CF-36</td>
<td>CF-41</td>
<td>CF-42</td>
<td>CF-43</td>
<td>CF-35 Cu</td>
<td>CF-40 Cu</td>
<td>ABS ROD</td>
<td></td>
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<tr>
<td>C</td>
<td>CF-58</td>
<td>CF-29 Cu</td>
<td>CF-10 SOR-1</td>
<td>CF-11 SOR-4</td>
<td>CF-12</td>
<td>CF-13 SOR-2</td>
<td>CF-30 Cu</td>
<td>CF-53 SOR-5</td>
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<td>D</td>
<td>CF-28 Cu</td>
<td>CF-55</td>
<td>CF-13</td>
<td>CF-2</td>
<td>CF-3</td>
<td>CF-4</td>
<td>CF-14</td>
<td>CF-49</td>
<td>CF-20 Cu</td>
</tr>
<tr>
<td>E</td>
<td>CF-30 Cu</td>
<td>CF-53</td>
<td>SOR-5</td>
<td>CF-5</td>
<td>CF-1</td>
<td>CF-6</td>
<td>SOR-2</td>
<td>CF-50</td>
<td>CF-21 Cu</td>
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<tr>
<td>F</td>
<td>CF-33 Cu</td>
<td>CF-52</td>
<td>CF-15</td>
<td>CF-7</td>
<td>CF-8</td>
<td>CF-9</td>
<td>CF-24</td>
<td>CF-51</td>
<td>CF-19 Cu</td>
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<tr>
<td>H</td>
<td>CF-34 Cu</td>
<td>CF-44</td>
<td>CF-45</td>
<td>CF-46</td>
<td>CF-47</td>
<td>CF-39 Cu</td>
<td>CF-54 Cu</td>
<td>CF-59</td>
<td>CF-60</td>
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<td>J</td>
<td>CF-59</td>
<td>CF-22 Cu</td>
<td>CF-23 Cu</td>
<td>CF-27 Cu</td>
<td>CF-60</td>
<td>ICD</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Operation & Experiments

- The facility was made critical in April 2008. Observed critical height (226.7 cm) was very much close to estimated critical height (226.5 cm).

- To validate the design intent of the reactor, following experiments were carried out:
  
  1. Measurement of Shut Off Rod (SORs) worth using dynamic test (rod drop method) – Measured value of all the six SORs was found 103 mk against estimated 105 mk. That of an individual SOR was found to be about 11 mk against the calculated value of 12 mk.
Operation & Experiments

2. Absorber Rod (AR) calibration - Total measured reactivity was found to be 3.6 mk against the calculated value of 3.7 mk. Variation of the reactivity load with position of AR was also determined.

3. Level coefficient measurement at critical height - Measured value of level coefficient was found to be 0.049 mk/mm whereas the evaluated figure was 0.05 mk/mm.

4. Measurement of Moderator Temperature Coefficient of Reactivity - It was measured and found to be 15.7 pcm/°C.
Operation & Experiments


7. Measurement of fine structure flux profile inside the central fuel cluster using the activation foils which were kept inside the dismantlable fuel cluster.

8. Irradiation of pin of natural Uranium and Thorium for measurement of gamma activity and thus to get the axial fission power profile.
Activation foils being installed within the fuel pin for measurement of fine structure flux profile
Integral experiments were conducted to study the variation of Thorium cross section in different nuclear data library.

In each of the integral experiment critical height was measurement with one experimental fuel cluster in the central location E-5 and five other locations of reference core.

1. Integral Experiments with Mixed pin [ThO$_2$- U] cluster
2. Integral Experiments with six pin [Th - 1%Pu] cluster
3. Integral Experiments with six pin [Th-LEU] sandwich cluster
4. Integral Experiments with nineteen pin [U-ThO$_2$-U] sandwich cluster
### Operation & Experiments

- Results of the integral experiments are tabulated below.

<table>
<thead>
<tr>
<th>Cluster Type</th>
<th>Critical height (cm)</th>
<th>E-5</th>
<th>F-4</th>
<th>F-3</th>
<th>F-2</th>
<th>B-3</th>
<th>F-1</th>
</tr>
</thead>
<tbody>
<tr>
<td>ThO₂-U Mixed pin</td>
<td>Evaluated</td>
<td>238.5</td>
<td>237.3</td>
<td>234.9</td>
<td>231.8</td>
<td>230.3</td>
<td>229.5</td>
</tr>
<tr>
<td></td>
<td>Observed</td>
<td>237.8</td>
<td>237.0</td>
<td>234.7</td>
<td>231.1</td>
<td>229.9</td>
<td>229.0</td>
</tr>
<tr>
<td>ThO₂ -1% PuO₂</td>
<td>Evaluated</td>
<td>232.9</td>
<td>233.5</td>
<td>232.3</td>
<td>229.9</td>
<td>229.6</td>
<td>228.9</td>
</tr>
<tr>
<td></td>
<td>Observed</td>
<td>233.3</td>
<td>233.4</td>
<td>231.7</td>
<td>229.8</td>
<td>229.5</td>
<td>229.0</td>
</tr>
<tr>
<td>ThO₂-LEU</td>
<td>Evaluated</td>
<td>234.2</td>
<td>234.7</td>
<td>233.2</td>
<td>230.9</td>
<td>230.4</td>
<td>229.6</td>
</tr>
<tr>
<td></td>
<td>Observed</td>
<td>235.2</td>
<td>235.6</td>
<td>234.4</td>
<td>231.7</td>
<td>231.4</td>
<td>230.5</td>
</tr>
<tr>
<td>U-ThO₂-U sandwich</td>
<td>Evaluated</td>
<td>236.8</td>
<td>235.3</td>
<td>232.3</td>
<td>228.3</td>
<td>226.7</td>
<td>225.2</td>
</tr>
<tr>
<td></td>
<td>Observed</td>
<td>235.2</td>
<td>234.1</td>
<td>231.5</td>
<td>227.9</td>
<td>226.5</td>
<td>225.3</td>
</tr>
</tbody>
</table>
Operation & Experiments

- The experiments carried out with all natural Uranium clusters enhanced the confidence in the methodology and computational tools.

- Measured values were found to be in good agreement with the calculated ones obtained by in-house developed computational tools.

- Measured critical heights in the integral experiments with Thorium based experimental cluster were found close to the calculated values.

- The experience gained in the experiments conducted in reference core (19 pin natural Uranium clusters) will be useful in planning and conducting the experimental program in CF with AHWR fuel clusters.
Besides the main objective, which is conducting experiments and validating the physics design parameters of AHWR, this reactor has facilities for testing neutron detectors and also to irradiate samples (Soil, Geological rock, Biological sample and Metallic alloys) for neutron activation analysis (NAA).

Neutron Activation Analysis (NAA) - NAA is one of the most widely used techniques for trace, minor, major elemental concentration determination in different samples due to properties like simultaneous multielement capability, high sensitivity, high selectivity, negligible matrix effect and non-destructive nature. Large sample analysis is advantageous for obtaining better analytical representativeness instead of replicate sub-sample analysis.
Large size samples (1 to 500 g) were packed in polythene. Small samples (100 to 500 mg) were also used. Samples were irradiated in graphite reflector position of CF for 4 h.

Higher masses of the samples (1 to 500 g) were used to obviate the error due to inhomogeneous distribution of analytes in small sub samples.
Concentrations of Fe, Cr, Ni, Mo, Mn, and As were determined in the austenitic stainless steel (using a sample of 5 g mass).

Ancient potteries, bricks obtained from excavated Buddhist sites of Andhra Pradesh, India were analyzed.

Large size (50 to 100 g) sample neutron activation analysis (LSNAA) of dross from Government Mint, Mumbai for analysing concentrations of Au and Ag.

Concentration ratios of elements such as Na, K, Cr, Mn, Fe, Co, Zn, As, Rb, Cs, La, Ce, Sm, Eu, Yb, Lu, Hf and Th with respect to Sc (internal mono standard) were calculated in the IAEA intercomparison sample.
**Other Utilisation of CF**

- **Neutron Detector Testing** - The graphite reflector region of the AHWR-CF has been used for testing of following types of detectors.

1. Boron lined proportional counters (0.1cps/nv to 30cps/nv)
2. Fission counters
3. High sensitivity ($^3$He) counters
4. Ion Chambers (Compensated/Uncompensated)

- CF is mainly used for characterizing the detector performances of pulse detectors as the maximum flux at the detector location is of the order of $2 \times 10^7$. 
Other Utilisation of CF

- The facility has the flexibility to maneuver the reactor power from shutdown power level to full power in finer steps of even 20 µW at lower power levels.

- This enables establishing the detector performance range very critically.

- The various parameters that are tested typically for pulse detectors are listed below:
  
  - Discriminator Bias characteristics.
  - HV characteristics.
  - Linearity of the flux measurement range.
  - Neutron sensitivity.
  - Performance immediately after exposure to high nvt at high flux.
  
  - Long term count rate stability.
  - Response time and repeatability of detector response.
  - Measurement of count rate loss at high neutron flux.
  - Gamma discrimination.
For DC detectors, the full measurement range may not be covered due to limited neutron flux at these locations.

The DC detectors are checked for their response and initial signal calibration characterization.

The designated locations (J-8) at the in-core position are also used for conducting detector life tests for high fluence with incident flux of the order of $10^8$ nv.

These locations can house the detectors for long duration and thereby characterizing the detectors of particular design for cumulative exposures under various detector bias conditions.
In a series of experiments, integral experiment were carried out using experimental fuel assembly (U-ThO$_2$ mixed pin cluster, Th-1% Pu cluster, Th-LEU cluster & U-ThO$_2$-U sandwiched cluster) at representative pile location.

Results of the experiments carried out enhanced the confidence in the methodology and computational tools.

Measured values were found to be in good agreement with the calculated ones obtained by in-house developed computational tools.

Apart from reactor physics experiments, facility is used to test and calibrate the neutron detectors.

It is also used to activate the samples (Soil, Geological rock, Biological sample and metallic alloys) for neutron activation analysis (NAA).
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- QUARTERLY PROGRESS REPORT of Electronic Division, BARC, from 2010 – 2012.
Thanks