Pressurized Heavy Water Reactor

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In this lecture, we shall discuss about the essential components and working of Pressurized Heavy Water Reactor (PHWR)

At the end of this session, the learners will be able to
(i) list the components of PHWR
(ii) list the differences between a PWR and PHWR
(iii) understand the arrangement of fuel elements in calandria

1 Pressurized Heavy Water Reactor (PHWR)

The pressurized heavy water reactor utilizes natural uranium as the fuel and heavy water as both moderator and coolant. The use of heavy water as moderator facilitates the use of natural uranium as the fuel. The cycle diagram of coolant in PHWR is similar to that in a PWR with the difference being the use of heavy water as primary coolant. A schematic diagram of working of a PHWR plant is shown in Figure 1.

![Schematic diagram of Pressurized Heavy Water Reactor](image-url)

**Fig 1. Schematic diagram of Pressurized Heavy Water Reactor (Redrawn from Ref. [3])**
1.1 PHWR Core

CANDU (Canada Deuterium Uranium) type reactors are the common form of PHWR. The core configuration of CANDU is different from that of a PWR. UO$_2$ pellets (12.2 mm diameter and 16.4 mm long) are stacked in zircaloy tube to form fuel rods of 13.1 mm diameter and 490 mm long. These rods are arranged in concentric circles with a pitch of about 14.6 mm to form an assembly of 102 mm diameter and 495 mm long that houses 37 fuel rods. A number of such fuel assemblies are inserted into pressure tubes of calandria.

Calandria is a low-pressure horizontal vessel, consisting of circular channels arranged in a regular fashion and immersed in moderator (heavy water). The pressure tubes (containing fuel assemblies) are loaded in the channels of calandria with the coolant (heavy water) flowing around the zircaloy tubes inside the pressure tubes. This extracts the heat released during fission and transfers the same to the secondary coolant (light water) that boils to generate steam.
The Indian PHWR (220 MWe) consists of a calandria that contains heavy water (moderator) at near ambient pressure and temperature. About 306 pressure tubes made of zircaloy are inserted in the calandria. Each pressure tube contains 12 fuel bundles. Each fuel bundle has 19 fuel rods and is 495 mm long weighing about 16 kg. A schematic diagram of arrangement of fuel pellets in zircaloy tubes to form fuel bundle, their loading inside pressure tubes and the placement of pressure tubes in calandria are shown in Figure 2.

![Fig 2. Arrangement of fuel pellets in fuel bundles and pressure tubes](image)

The power cycle adopted in PHWRs is the two-coolant cycle (indirect cycle). Heavy water acts as both coolant and moderator, similar to the roles of light water in pressurized water reactor. However, the heavy water used as coolant alone is at high pressures. The moderator (also heavy water) is at lower pressure. Another difference between coolant system of PWR and PHWR is the use of different coolant material for primary and secondary circuits. The primary coolant is heavy water, while the secondary coolant is light water. The annular region between the coolant tube and pressure tube is filled with an annulus gas like carbon dioxide. The primary coolant passing thorough the coolant tubes removes the heat generated by fission from the fuel rods. In the steam generator, heavy water transfer heat to light water that undergoes evaporation to produce saturated steam. The steam then expands in a turbine generator producing electricity. The spent steam is condensed in condenser and returned to the steam generator for extraction of heat from heavy water.

The calandria has provisions for accommodating liquid poisons in tubes at specific locations in the calandria. The moderator also acts as neutron reflectors. Therefore, control of neutron flux and hence the reactor power can be achieved by controlling the level of moderator. In nutshell, calandria represents the most important assembly of PHWRs as fuel, coolant, moderator, control rods etc. are all present in it. One of the important aspects of CANDU reactors is the facility for online refueling without shutting down the reactor. The spent-fuel bundles can be replaced by the bundles of fresh fuel during the normal operation of the reactor.
There are two primary coolant loops with one pump used for each loop. Four steam generators (@ two steam generators per loop) are used. The primary coolant pumps themselves maintain the primary coolant pressure and hence PHWRs do not require pressurizer. The operating conditions in a typical PHWR are given in Table 2.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
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</thead>
<tbody>
<tr>
<td>Primary coolant pressure (MPa)</td>
<td>10</td>
</tr>
<tr>
<td>Primary coolant inlet temperature (°C)</td>
<td>267</td>
</tr>
<tr>
<td>Primary coolant outlet temperature (°C)</td>
<td>310</td>
</tr>
<tr>
<td>Secondary coolant inlet temperature (°C)</td>
<td>187</td>
</tr>
<tr>
<td>Secondary coolant outlet temperature (°C)</td>
<td>260</td>
</tr>
<tr>
<td>Steam generator pressure (MPa)</td>
<td>4.7</td>
</tr>
</tbody>
</table>

2 References/Additional Reading