Characteristics and types of fast reactors

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In this lecture we shall discuss some of the salient characteristics of fast reactors and their types.

At the end of this lecture, the learners will be able to

(i) list the salient characteristics of fast reactors
(ii) list the types of fast reactors
(iii) list the advantages of pool-type fast reactors over loop-type reactors

1 Salient characteristics of fast reactors

Fast reactors generate energy from nuclear fuel through their irradiation with fast neutrons. In a thermal reactor, neutrons produced as a result of neutron absorption in fuel possess high kinetic energy of the order of MeV. These are slowed by elastic collision with moderator resulting in thermal neutrons with energies as low as 0.025 eV. Since the fast reactor utilizes fast neutrons, moderation is not required. To be precise, moderation is undesirable in a fast reactor. Hence fast reactors do not contain moderating materials like water, heavy water and graphite in the core.

The fission cross section of U-235 in fast spectrum is low, compared to that of Pu-239. Hence Pu-239 is used as the main fissile isotope, though enriched U-235 is used at the start to initiate the chain reaction.

Fast reactors are normally configured for breeding. This requires absorption of neutrons by a blanket of fertile material. Also neutron losses in structural components are to be minimized. Hence layers of blankets containing fertile material are used, to ensure that more fuel is breed than that burnt, qualifying the definition of a breeder.

The most common coolants like water and heavy water cannot be used as coolants in a fast reactor. Non-moderating materials like Helium and liquid metals like sodium, lead, lead-bismuth eutectic qualify to be coolants owing to their non-moderating nature.

Based on the coolant, fast (breeder) reactors are further classified as follows:

(i) sodium cooled fast reactor
(ii) lead cooled fast reactor
(iii) helium cooled fast reactor

Both sodium cooled fast reactor and lead cooled fast reactor are called Liquid Metal Cooled Fast Breeder Reactor (LMFBR).
Due to better transport and neutronic properties, sodium is the most preferred choice for coolant. One of the advantages of using sodium as coolant is the possibility of achieving a **high coolant (sodium) outlet temperature**, while maintaining a pressure much lower than those maintained for light water and heavy water reactors. This is due to the high boiling point of sodium even at atmospheric pressure. Hence problems associated with high pressures are circumvented to a large extent.

Sodium cooled fast breeder reactors use two cycles of coolant flows. The primary circuit involves the circulation of sodium through the core. Relatively low temperature sodium enters the core at the bottom and leaves at the top at higher temperature. This sodium, called primary sodium is radioactive due to exposure to neutrons while passing through the core.

Another circuit involves heat transfer between the radioactive primary sodium and secondary sodium in separate heat exchangers. The secondary sodium in turn transfers heat to water in steam generator, thus producing steam. The use of secondary coolant between primary coolant and steam is aimed at preventing contact of radioactive sodium with water in case of leakage. While it is to be noted that sodium-water reaction itself is exothermic and needs to be prevented, contact of radioactive sodium with water would also involve concerns with radioactivity. Hence preventing contact between radioactive sodium and water eliminates the radioactivity concerns.

### 2 Types of sodium cooled fast breeder reactor

There are two types of sodium cooled fast breeder reactor: loop-type reactor, pool-type reactor. This classification is based on the location of (primary) heat exchanger used for transferring heat from primary sodium to secondary sodium.

#### 2.1 Loop-type fast reactor

The schematic diagram of a loop-type fast reactor is shown in Figure 1. In loop-type reactor (see figure 1), the heat exchanger used for heat transfer from primary to secondary sodium and the primary sodium pumps is located outside the reactor vessel, but still within the biological shield.
2.2 Loop-type fast reactor

In pool-type reactor (see figure 2), the primary heat exchanger and pumps for primary sodium are placed inside the reactor tank. As a result, the diameter of reactor tank is higher for the pool design compared to that of loop design.
Also, the thermal inertia of sodium is higher in pool type reactors compared to that in loop-type reactors. For example, when there is a drop in the rate of circulation of primary sodium in the core, the temperature of the coolant due to this transient will slowly increase from the steady-state temperature due to higher heat capacity (product of specific heat and mass). Hence the higher mass of sodium in the pool contributes to the higher thermal inertia.

Other advantages of pool type reactors over loop type reactors are:

(i) Radioactive materials are confined within a single vessel
(ii) Availability of independent and dedicated sodium loop for removing decay heat reliably
(iii) Reduction in the amount of external piping
(iv) No penetrations leading to higher structural integrity of the vessel
(v) Lower neutron dose
(vi) Sodium leakage will not result in Loss of Coolant Accident (LOCA) leading to higher reliability

3 Reference/Additional Reading