Fission Reactors

Having seen the devastation of atomic bombs, scientists, including those who worked on the Manhattan project, campaigned against further nuclear weapon development. They wanted to turn the giant industries associated with the Manhattan project into peaceful applications, especially as an energy supply.

Basic Reactor Elements

Basic elements of fission reactors are listed. The diagram showing these elements is given below.

- reactor core for holding fission material or fuel
- moderator for slowing fast neutrons
- control rods holding neutron absorbers to control rate of fission
- monitoring system containing devices and indicators of operation
- energy transfer system to take the heat away

How Does That Nuclear Reactor Work?

The propulsion plant of a nuclear-powered submarine uses a nuclear reactor to generate heat. The heat comes from the fissioning of nuclear fuel contained within the reactor. Since the fissioning process also produces radiation, shields are placed around the reactor so that the crew is protected.

The nuclear propulsion plant in this ship uses a pressurized water reactor design which has two basic systems - a primary
system and a secondary system. The primary system circulates ordinary water and consists of the reactor, piping loops, pumps and steam generators. The heat produced in the reactor is transferred to the water under high pressure so it does not boil. This water is pumped through the steam generators and back into the reactor for re-heating.

In the steam generators, the heat from the water in the primary system is transferred to the secondary system to create steam. The secondary system is isolated from the primary system so that the water in the two systems does not intermix.

In the secondary system, the steam flows from the steam generators to drive the turbine generators, which supply the ship with electricity, and to the main propulsion turbines, which drive the propeller. After passing through the turbines, the steam is condensed into water which is fed back to the steam generators by the feed pumps. Thus, both the primary and secondary systems are closed systems where water is recirculated and renewed.

Since there is no step in the generation of this power which requires the presence of air or oxygen, this allows the ship to operate completely independent from the earth's atmosphere for extended periods of time.

Core and Fuel

- Uranium, m.p. 1403 K, phase transition, 933 K
- UO$_2$, m.p. 3138 K (suitable), UO$_2$ clad in Zircaloy or stainless steel.

Moderator

Moderators are compounds containing light nuclides such as H, D, He, C, O, F. Materials with low neutron-capture cross section are desirable. The following substances are commonly used as moderators.

- graphite,
- H$_2$O, D$_2$O
- He (100 Atm and 1273 K)
- Be (high temperature liquid metal).
- Na (773 to 873 K used in breeder reactor)
- BeF$_2$ + ZrF$_4$ (for GCR)

Control Rod Materials

Materials with high thermal-electron-capture cross section are desirable. Usually, cadmium, boron, carbon, cobalt, silver, hafnium, and gadolinium are common elements used in control rods. For example, the abundance and cross section of gadolinium are listed below:

<table>
<thead>
<tr>
<th>Mass Number</th>
<th>152</th>
<th>154</th>
<th>155</th>
<th>156</th>
<th>157</th>
<th>158</th>
<th>160</th>
</tr>
</thead>
<tbody>
<tr>
<td>Abundance %</td>
<td>0.20</td>
<td>2.15</td>
<td>14.73</td>
<td>20.47</td>
<td>15.68</td>
<td>24.87</td>
<td>21.80</td>
</tr>
</tbody>
</table>
Reactor Types

After the war, the United States set up a Civilian Power Reactor Program (CPRP) to coordinate the study of nuclear reactors for peaceful application of nuclear energy. The Atomic Energy of Canada, Limited was and still is the Canadian body for nuclear technology applications.

After WW II, CPRP was set up to find out the most economical and safe way to convert fission energy to electric energy. The Program decided to investigate the following eight types of power reactors:

- Fast Breeder Reactors (FBR)
- Aqueous Homogeneous Reactors (AHR)
- Heavy Water Moderated Reactors (HWR) (the CANadian Deuterium Uranium (CANDU) reactor)
- Pressurized Water Reactors (PWR)
- Boiling Water Reactors (BWR)
- Organic-Cooled Power Reactors (OCPR)
- Sodium Graphite Reactors (SGR)
- Gas-Cooled Reactors (GCR)

Breeder Reactor

For fear of running out of supply in the future, scientists and engineers tried to build fast breeder reactors (FBR) that produce more fuel than they consume while generating power.

The $^{233}$U cycle (or thorium cycle) makes use of the reactions,

\[ ^{232}\text{Th} + ^1_0\text{n} \rightarrow ^{233}\text{Th} \rightarrow ^{233}\text{U} + \beta^- \]

The $^{239}$Pu cycle (or the uranium cycle) makes use of the reaction

\[ ^{238}\text{U} + ^1_0\text{n} \rightarrow ^{239}\text{U} \rightarrow ^{239}\text{Pu} + \beta^- \]

The neutron-capture cross section is 2.7 b for $^{238}\text{U}$.

Reactor Links on the Internet

These links are available March, 2000. They, however, are subject to changes, because they are under the control of other companies.
• Westinghouse Energy Systems Whole systems of nuclear reactors designed, built, and managed by Westinghouse.

• Nuclear Links at Nuclear Engineering, the University of California at Berkeley.

• The McMaster Nuclear Reactor is a 2-MW pool-type distilled water reactor with enriched uranium fuel, up grated to 5 MW, flux of $1 \times 10^{14}$ neutrons cm$^{-2}$. Information is limited.

• The Integral Fast Reactor (IFR) page from the Department of Nuclear Engineering, University of California at Berkeley for informational purposes. The following diagram shows the concept of IFR on the site.

---

**Contributors**

• [Chung (Peter) Chieh](#) (Professor Emeritus, Chemistry @ University of Waterloo)