Reactor-Boiler and Auxiliaries - Course 433

POWER REACTOR CONSTRUCTION

There are many different concepts for power reactors and even within the field of heavy water moderated, natural uranium fuelled reactors, there are many possible variations in design and construction. There are many common problems in the various methods used as well as special problems with each type that may require materials and systems not found in conventional stations. This lesson will introduce some of the variations and briefly discuss the basic objectives in the design.

Objectives in Reactor Construction

It has already been noted that the function of a reactor is to act as a furnace in the nuclear power station, that is, it must supply heat energy. The next step is to consider the basic objectives in how this energy is supplied without going into any details of the systems involved.

As an extreme case let us first consider the heat produced by a typical research reactor. Here the reactor may be cooled by water from a river or lake which enters the plant at say 50°F and leaves at less than 200°F. A great deal of heat may be removed this way but it is evident that this heat is of little or no use in a power station since these temperatures would not produce steam even at atmospheric pressure. To make this heat useful it must be available at a higher temperature and we now have our first objective: The heat supplied by the reactor must be at a reasonably high temperature (normally a minimum of 400 to 500°F).

The details of the neutron cycle and its effect on the chain reaction will not be dealt with in the level 4 lessons, but some understanding of the effect of neutron losses is necessary. Since the source of heat in the reactor is the fissions which occur in the chain reaction, it is obvious that there must be enough neutrons available to maintain the chain reaction.

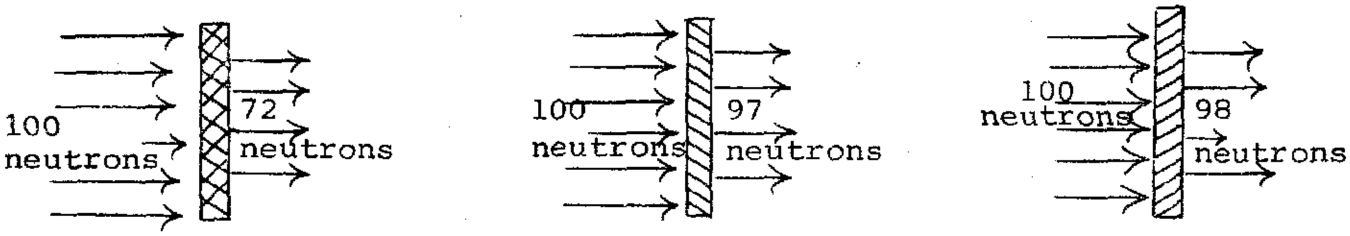
Two ways in which neutrons can be wastefully lost is by capture in the structural materials in the reactor and by escape from the reactor. If these are both kept to a minimum, then the chain reaction can be maintained even with fuel which has already given up a lot of energy from many fissions. This allows us to obtain the maximum energy from the fuel. Our second objective can therefore be stated: The reactor should be designed so that the maximum amount of heat energy can be obtained from the fuel.

Reactor Materials

Steel is the most common metallic structural material and finds many uses in reactor construction as elsewhere in industry. There are many different types of steel available depending upon the amounts of alloying materials present and, for example, if the application justifies the extra expense, corrosion resistant stainless steel could be used rather than a normal carbon steel. One major problem is encountered, however, when steel is to be used as a construction material in the reactor core. We noted previously that one of the major objectives was to keep neutron losses to a minimum and unfortunately, the iron in steel captures a relatively large number of neutrons. This almost eliminates steel from any use in the central part of the core, although the outer wall of the vessel may be made of steel without excessive neutron capture.

Other materials which are commonly used to improve the neutron loss situation are aluminum and zirconium or zirconium alloys (zircalloy). Aluminum is relatively cheap, and is quite useful, but does not stand up to high temperature. Since we require the heat energy to be at high temperature, the use of aluminum is limited. This has led to the development of zirconium alloys which are satisfactory in strength, neutron capture and temperature effects, and are therefore, commonly used for construction materials in the reactor core.

Figure 1 shows the relative neutron losses in passing through a piece of steel, aluminum or zirconium.



Steel Aluminum Zirconium

Fig. 1

Pressure Vessels and Pressure Tubes

The various materials used for moderators and heat transport fluids will be discussed in later lessons but one common material is water. Since water boils at 212°F at atmospheric pressure and we have said that the heat energy must be removed at 400 to 500°F to be efficient, then we must pressurize the water to prevent boiling at low temperatures. This high pressure water can be contained either in a high pressure vessel or in pressure tubes which run through a low pressure vessel.

A simple pressure vessel is shown in Figure 2. In this case, both the moderator and heat transport fluid are heavy water which flows first into the moderator region and then over the fuel carrying away the heat generated. The whole core is at high pressure and therefore, only thin walled tubes are required to guide the water over the fuel. The use of thin walled tubes keeps the neutron losses due to capture to a minimum. This type of system is most advantageous when the same liquid is used in both moderator and heat transport systems. If, for example, a reactor had D_2O moderator and H_2O heat transport system, it would be difficult to keep the two systems at the same pressure so as not to overstress the thin tubes. An even more important limitation on the pressure vessel when used with natural uranium is the difficulty in fabricating large pressure vessels. With presently available equipment, it is only possible to make pressure vessels large enough to result in about 100mw electrical output. This is not compatible with Canadian plans which call for stations of about 400-500mw electrical as a minimum economical size.

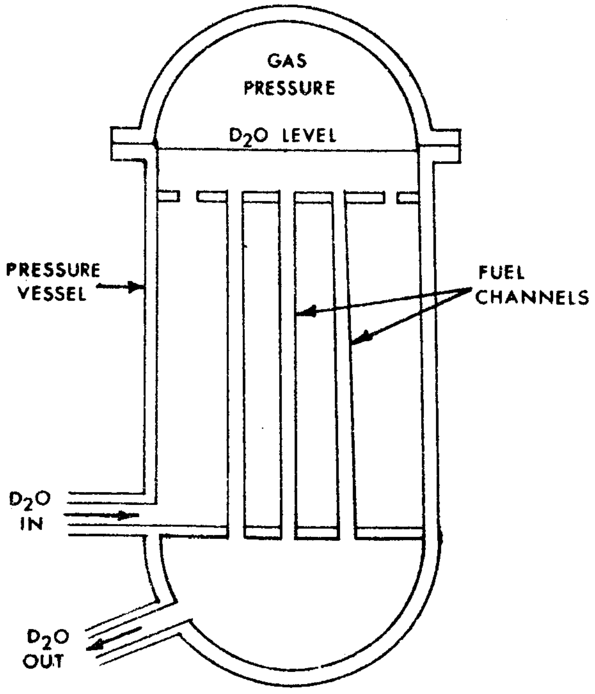


Fig. 2

The pressure tube type of design uses a low pressure calandria which serves as a container for the moderator.

A calandria is a vessel with a bundle of tubes running through it and could be field-erected of relatively thin material to any desired size. High pressure tubes which carry the heat transport fluid are then run through the calandria tubes. A simple reactor of this type is shown in Fig. 3.

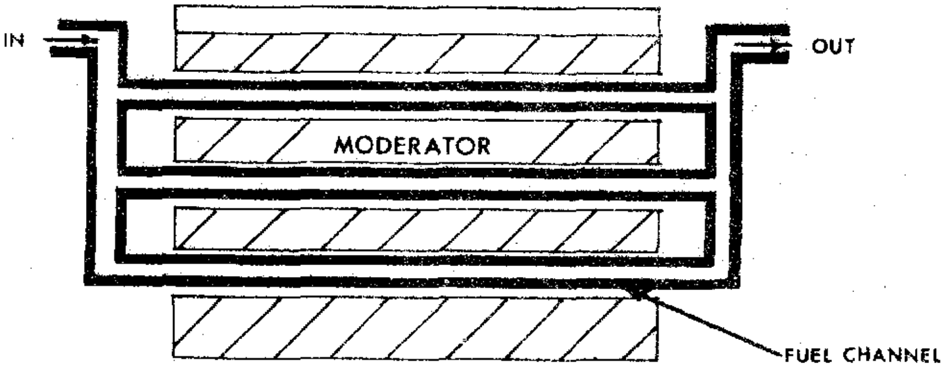


Fig. 3

In this case, the moderator would be D_2O but the coolant could be any other fluid without difficulty in keeping them separate, since the pressure tubes obviously give complete separation. The presence of the pressure tubes in the reactor core means there is more material which will capture neutrons unproductively and a material must be chosen which does not capture too many neutrons. As a result, zirconium alloys are often used as pressure tubes.

This design overcomes the main objection to pressure vessels, that is, size is not seriously limited. If a reactor is to be made larger, it is not difficult to simply add more pressure tubes and because the calandria is a relatively low pressure vessel, it can also be fabricated in larger sizes.

ASSIGNMENT

1. What are the two main objectives in reactor construction?
2. Why would zirconium be used as a structural material in a reactor when steel is cheaper and just as strong?
3. What is the main objection to developing natural uranium, pressure vessel reactors for the Ontario Hydro system?

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