Reactor-Boiler and Auxiliaries - Course 433

FUEL

The fuel in a reactor is the source of heat, but in producing the heat, it is not "consumed" in the same sense as burning fossil fuel. From basic nuclear physics, we know that the heat released in the reactor fuel, is due to the decrease in mass during the fission process. However, the total decrease in mass for a fuel slug coming from a power reactor is only about 1%, so that the weight before irradiation is roughly equal to the weight after irradiation. Aside from the possibility of some deformities such as wrinkles or bowing, the majority of fuel removed from the reactor will look just like the fuel which is being put into the reactor. The main difference is that the spent fuel is highly radioactive, so that a person handling fuel 1 hour after removal from the reactor, would receive a lethal dose in 30 to 40 seconds, if no shielding were provided. This time would be reduced to 2 to 3 seconds for fuel taken directly from the centre of the central channels in a reactor.

Fuel Materials

The fuel material must be one which will fission readily under neutron bombardment. The most common material (and only naturally occurring fuel) is Uranium-235. Only 0.7% of natural uranium is U-235 and the remaining 99.3% is U-238 which does not fission readily. As a result, there are many neutrons lost by capture in U-238 in a reactor using natural uranium fuel. This capture occurs most often when the neutrons have an intermediate energy, that is, whey they are partially slowed down from fast to thermal energies. You will recall, from the lesson on moderators, that one desirable property of a moderator was to slow down neutrons quickly. This is because they will not remain too long at intermediate energies, where capture in U-238 is most likely. Fortunately, these captures in U-238 produce U-239 which decays radioactively, to Plutonium-239 (Pu-239), another fuel material. The Pu-239 will then fission if struck by a neutron and thus add to the heat energy produced by the fuel.

When natural uranium is used as the fuel material, it may be in the form of pure uranium metal, metal alloys, uranium carbide or uranium oxide. The metal has the advantages of having no added neutron absorbers, and the maximum density. These properties result in uranium metal being the best fuel with respect to maintaining the chain reaction. However, pure uranium metal distorts under irradiation and reacts quickly with hot water, so that it is not normally used in power reactors. Adding an alloy to the uranium will improve on these disadvantages, but the alloying materials then wastefully capture neutrons. This waste of neutrons would probably result in a necessity to use uranium which has been ENRICHED, ie, the concentration of U-235 has been artificially increased above 0.7%. The equipment required to enrich fuel is extremely expensive and, at present, is used only in the U.S.A. on a large scale. A better method is to use uranium oxide or uranium carbide which are stable materials, and can still be used as natural uranium. The most common power reactor fuel at present is uranium di-oxide (UO_2).

Sheathing Materials

The fuel must be enclosed in a sheath to hold the fuel together, and prevent the radioactive fission products from escaping into the heat transport system. This sheathing material must meet approximately the same requirements as the reactor pressure tubes which were discussed in an earlier lesson. That is, they must stand the high temperatures and pressures without failure or serious corrosion, and they should capture a minimum number of neutrons. Again stainless steel would be a good choice if it were not for excessive neutron capture. For a natural uranium reactor, other materials are required, and the most common material in Canadian designs is a zirconium alloy. Even with zirconium which doesn't capture too many neutrons, there is still a strong incentive to keep this material to a minimum. This results in using a sheath which is as thin as possible without having too many failures in the reactor. At present, fuel sheathing is generally about 0.015 inches thick.

Fuel Fabrication

As well as choosing the materials to be used in the fuel, it is necessary to decide on the shape and size of the fuel. Some of the shapes which have been used are shown in Fig. 1.

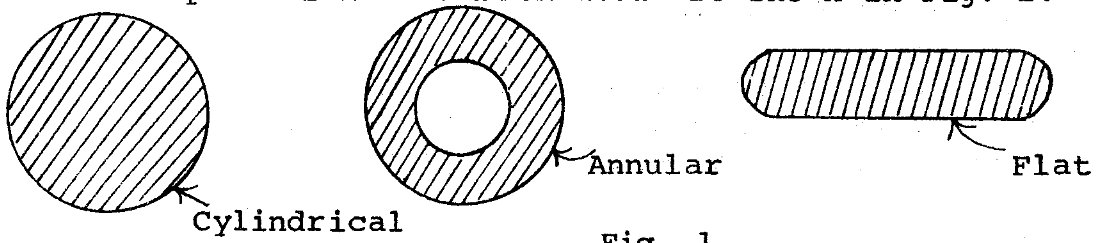

Fig. 1

The annular shape is rather difficult to fabricate and the sheathing material on the flat is inclined to bulge under pressure and eventually fail. The most common shape is therefore, the cylinder which is a stable, easily fabricated shape.

If we decide to use the cylindrical shape, we must now decide upon the size of each ELEMENT. If the size of the pressure tube has been fixed, the fuel could be made in one single element with the coolant around the outside only, or it could be divided into a BUNDLE of several elements as shown in Figure 2.

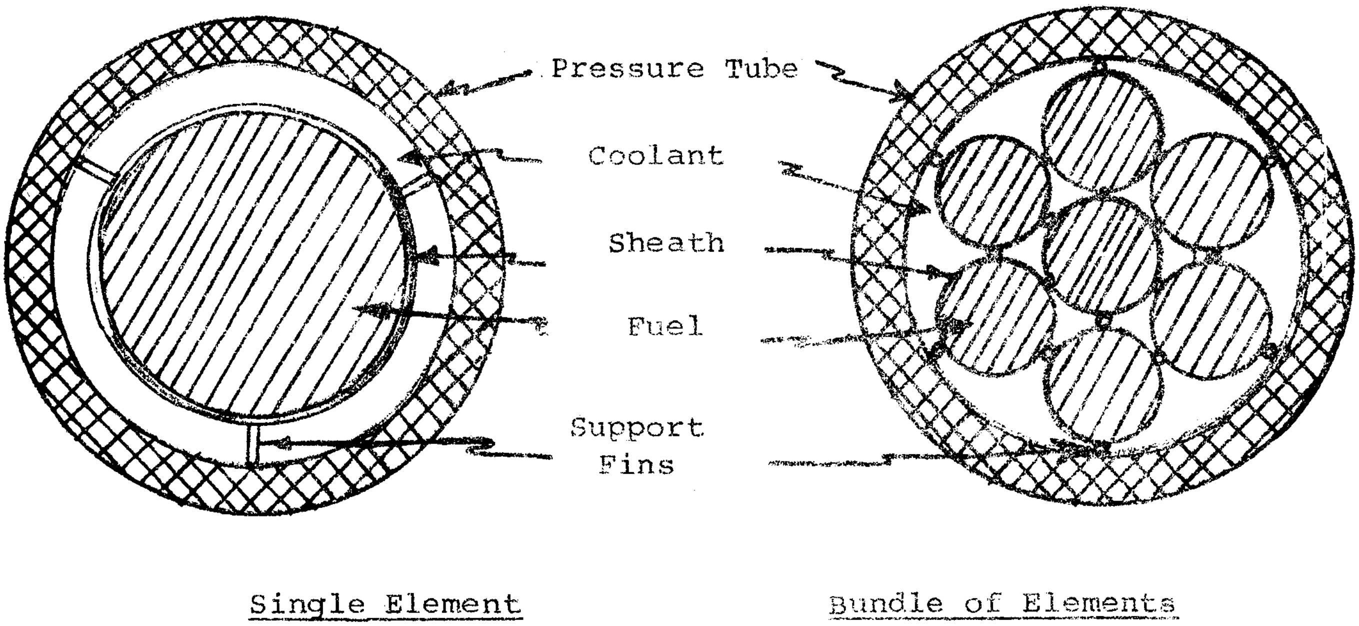

Fig. 2

The reason some cross-sectional subdivision may be required, is to improve the heat removal from the fuel. The centre of the single element in Figure 2 will be hotter than the centre of any of the smaller elements for the same total heat production, since the heat has to be transferred along a longer path. This central temperature in a large fuel element at high power would likely exceed the temperature at which damage occurs. Subdivision must be kept to a minimum, however, since increased subdivision introduces more sheathing material for the same amount of fuel. For example, if we consider Figure 2 and make the diameter of the large element 2.65" and the diameter of the seven small elements 1", then the cross-sectional areas are:

Single Element	7- Element
$A = \frac{\pi d^2}{4} = \frac{3.14 \times 2.65^2}{4}$	$\text{Area} = \frac{7\pi d^2}{4} = \frac{7 \times 3.14 \times 1^2}{4}$
$= 5.5$ sq in	$= 5.5$ sq in

The amount of fuel is therefore, the same in each case. The amount of sheathing however, depends on the total circumference, which is:

Single Element	7-Element
$C = \pi d = 3.14 \times 2.65$	$C = 7\pi d = 7 \times 3.14 \times 1$
$= 8.3$ in	$= 22$ in

We have therefore, increased the amount of sheathing by nearly three times by subdividing from a single element to 7 elements.

Cross-sectional subdivision may therefore, be summarized as follows:

1. Subdivision is an advantage from the point of view of heat removal. Some subdivision in power reactor fuel is nearly always required for this reason.

2. Subdivision is a disadvantage because it introduces extra sheathing material which captures neutrons. For this reason, it should be kept to a minimum, compatible with the requirement noted above.

It may also be necessary to divide the fuel into short bundles rather than one which extends the full length of the channel. This will make the handling easier, and the fuelling machine smaller. As in the case of cross-sectional subdivision, the number of bundles per channel should be kept to a minimum so that extra structural material (such as end caps at the end of each element) is not added to the reactor.

ASSIGNMENT

1. Is any benefit obtained from the neutrons captured in U-238 and if so, what is it?

2. What are two disadvantages of uranium metal as a fuel?

3. Is stainless steel a good material for natural uranium fuel sheaths and why?

4. What is the reason for cross-sectional subdivision of reactor fuel and why should it be kept to a minimum?

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