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In the thermal reactor a moderator of some sort is used to slow down the neutrons so that fission can take place at thermal speeds. In the case of a reactor using U-235 along with U-238, it is just possible to produce a self-sustaining chain reaction. This is because U-238 is only fissionable by high energy neutrons and the inelastic scattering cross section of U-238 is dominant at high energies. Therefore the fast neutrons produced on fission have a very small chance of producing another fission.

Suppose that instead of moderating the neutrons in the reactor, part or all of the offending U-238 is removed. U-235 is fissionable at all neutron energies and so it is then possible to sustain a chain reaction on fast neutrons alone.

In a thermal reactor using natural uranium, the fissionable U-235 is being continually consumed, but because of the thermal capture in U-238, Pu-239 is produced. Pu-239 is, like U-235, fissionable at all neutron levels. In the typical natural uranium reactor about

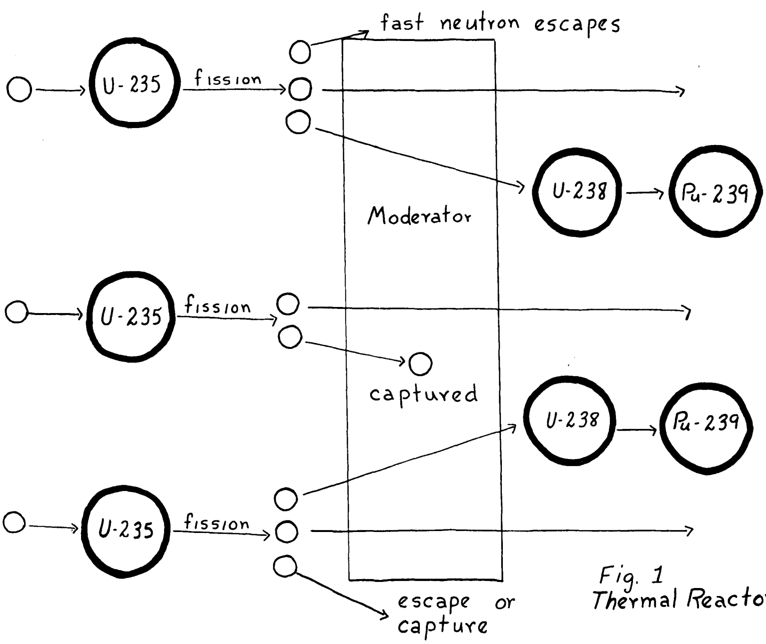

Fig. 1
Thermal Reactor

0.8 Pu-239 atoms are produced for each U-235 atom destroyed, so that in effect only 0.2 fissionable atoms are destroyed. This creates the question of the replaceability of U-235 by Pu-239.

It can readily be seen that this is not possible in a moderated reactor. Look at the number of neutrons produced per neutron absorbed in U-235. For thermal fission this is 2.08, but of these one is required to carry on the reaction so only 1.08 are usable for *all* other losses. These losses are defined as: capture in U-238; capture in moderator; and complete escape from reactor. Thus the capture of only one neutron would leave the impossibly low figure of 0.08 for the remaining losses. (Figure 1)

A like situation exists for thermal fission in Pu-239 where the number of neutrons produced per absorption is 2.07 so that it would not be possible using Pu-239 and U-238 to produce as much of the Pu-239 as would be used up by capture and fission. (Figure 2)

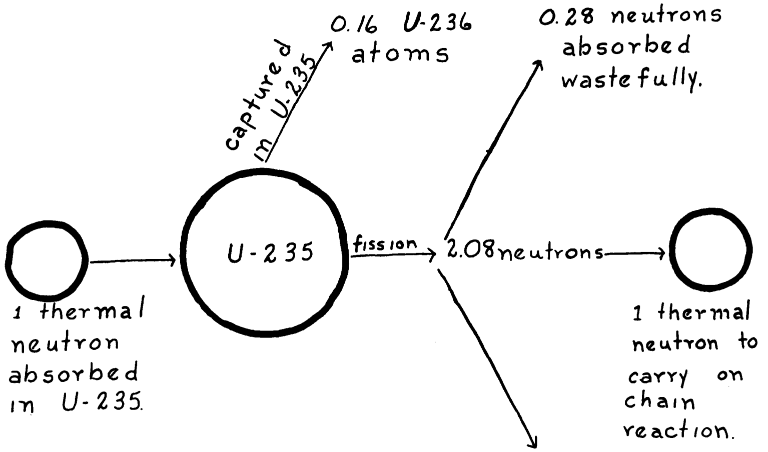

Fig. 2 - Thermal Fission conversion factor 0.8

The possibility of producing more fissionable material than will be used up becomes much more possible when the reactor is working on fast fission only. The neutrons produced per neutron consumed for fast neutrons at about 2 MeV energy for U-235, U-233, and Pu-239 were 2.3, 2.4 and 2.6, respectively, and so the possibility of gain factors above zero are real.

As stated above, one of the requirements for a fast reactor is that the neutron energy must be kept as high as possible so that the fissions take place at the highest possible energies. This is necessary because as neutron energy decreases, the fraction of neutrons captured in the fissionable material increases so that figures for neutrons produced per neutron absorbed decreases. This means that the size of a fast reactor core must also be limited so as not to contain an undue amount of material that will slow down neutrons. Therefore, in practice low-mass elements must be excluded as much as possible, and so the coolant and structural materials must have as high an atomic weight a possible and still be able to perform their primary functions efficiently. (Figure 3)

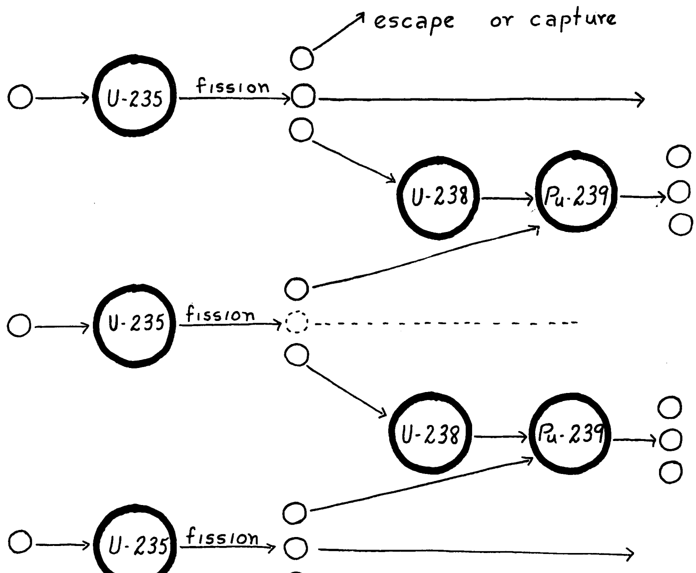

Fig. 3
Fast Fission Reactor

A further feature of the fast reactor is the high power density of the core. We can see this in comparing a fast and a thermal reactor using only U-235. The critical mass of U-235 in the fast reactor is much greater than in the thermal reactor for the same heat output. This is because of the low fission cross-section at high energies. However, at the same time the core size of the fast reactor will be smaller than that of the thermal reactor because of the absence of a moderator. This will mean that the cooling of the fast reactor must be done by a very efficient coolant, and liquid metals are favored in this respect because of their good heat transfer properties. Sodium or sodium-potassium alloy are possibilities and they also satisfy the nuclear requirements in that they are not particularly good slowing down media. Another problem comes from the large amount of heat to be removed per unit volume of core. The fuel must present as large a surface as possible to the coolant. This means that if fuel rods or tubes are used they must be very thin or thin walled, so there must be a number of them. (Figure 4)

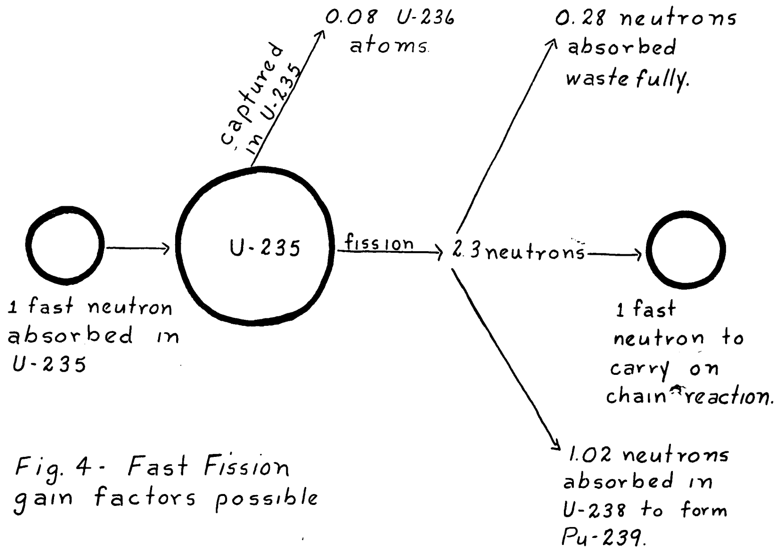

Fig. 4 - Fast Fission gain factors possible

The general agreement then, of the fast reactor, is a core containing the fissionable material in the form of rods or tubes surrounded by the fertile materials. This blanket of fertile materials must capture the neutrons as they escape from the core. It must also be capable of serving as a reflector and scatter the neutrons back into the core. Because it consists of heavy atoms it does not greatly reduce the neutron energy on scattering and so its action is different than the reflector in a thermal reactor.

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