Nuclear Theory - Course 227

PROMPT, DELAYED & PHOTO-NEUTRON PRODUCTION

The most important aspect of the design of a nuclear reactor is CONSERVATION OF NEUTRONS. Energy is released during fission and neutrons are used to cause Uranium-235 to fission. As many neutrons as possible must be conserved to cause fission, and the choice of moderator, reactor materials and the arrangement of fuel in a reactor are decided primarily with neutron conservation in mind.

As will be seen later, these neutrons have an important bearing on reactor control. This lesson will discuss the sources and types of neutrons in a reactor.

Production of Prompt Neutrons

In a nuclear reactor, energy is released during the fissioning of Uranium-235. The U-235 captures a neutron and becomes Uranium-236. The U-236 is so unstable that it splits or fissions into two parts known as fission products or fission fragments. At the instant the fission occurs, or very shortly thereafter, from one to three neutrons are released. On the average, two and one-half (2½) neutrons are released in this manner. These 2½ neutrons are released within one ten-millionth of a second of the U-235 fissioning and, therefore, they can be regarded as being produced <u>during</u> the fission process. This is why they are called PROMPT neutrons. U-235 fission can, therefore, be represented diagramatically as follows: -

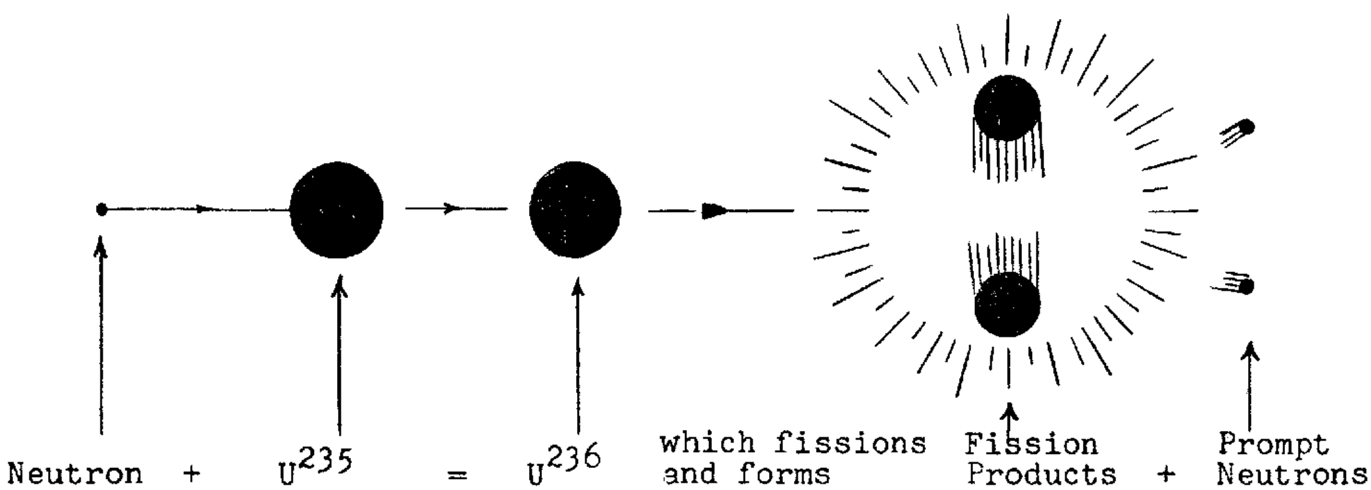

Fig. 1

The same process that is shown diagramatically in Figure 1 can also be represented by the following equations:

$$_{92}U^{235} + {_o}n^1 = {_{92}}U^{236} \longrightarrow {_{38}}Sr^{90} + {_{54}}Xe^{144} + 2\ {_o}n^1$$

$$_{92}U^{235} + {_o}n^1 = {_{92}}U^{236} \longrightarrow {_{35}}Br^{87} + {_{57}}La^{147} + 2\ {_o}n^1$$

The first equation shows Strontium and Xenon as the fission products, whereas the second equation shows Bromine and Lanthanum as the fission products. These are merely two of many such examples that can be given. In fact, the fission products can be any two of most of the elements as long as the equation balances.

The Fission Products

During the fission or splitting of U-236, the fission products can be any two of most of the isotopes of the elements. Some isotopes are produced, as fission products, during only a small fraction of the fissions. Other isotopes occur, as fission products, during a much greater number of fissions, e.g. Xenon-140 and Strontium-94 are fission products during 6% of all fissions that occur.

Most of these fission products, whether they occur frequently or otherwise, are unstable isotopes and, therefore, radioactive. They usually decay by emitting beta particles which are often accompanied by gamma rays. The daughter of the radioactive fission product is frequently radioactive and a whole decay series results.

The following illustrates the Sr-94 decay chain:

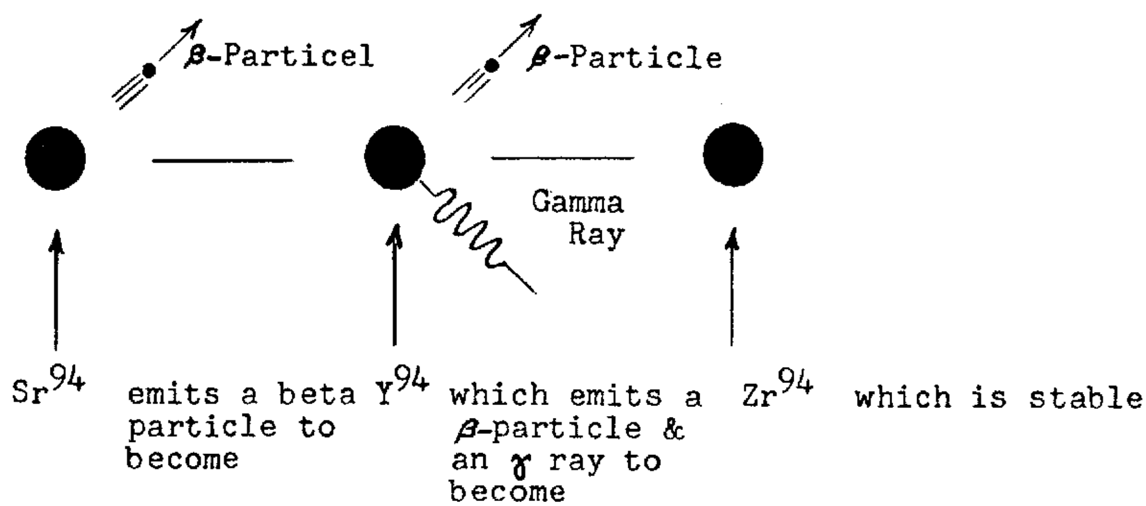

Fig. 2

or in equation form:

$$_{38}Sr^{94} \xrightarrow[\beta]{} {}_{39}Y^{94} \xrightarrow[\beta]{} {}_{40}Zr^{94}$$

Many such decay chains exist and many are larger than the one shown.

These fission products and their daughters are important in reactor operation. Their significance will be considered as various aspects of reactor operation are considered. One aspect will be considered in this lesson.

Production of Delayed Neutrons

Most of the fission products are radioactive. The example given above shows a fission product and its daughter decaying by beta particle and gamma ray emission; this is by far the most common method of decay.

However, there are some fission products or their daughters which are sufficiently excited or unstable to emit neutrons. For instance, Bromine-87, decays by beta emission to Krypton-87. The Kr-87, so formed, may be unstable enough to emit a neutron and become Kr-86. The following illustrates this decay chain diagramatically:

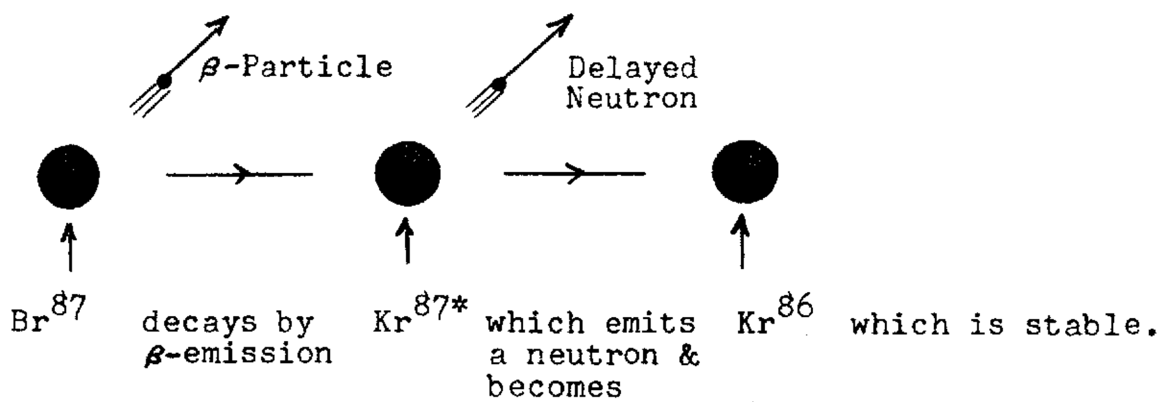

Fig. 3

or as an equation, it would be:

$$_{35}Br^{87} \xrightarrow[\beta]{} {}_{36}Kr^{87*} \xrightarrow[n]{} {}_{36}Kr^{86}$$

The asterisk, *, denotes that the Kr-87 is in a highly excited state.

The Kr-87 emits the neutron as soon as it has been formed but the rate at which the neutrons are emitted will depend on the rate at which the Kr-87 is formed. Now the Br-87 has a half-life of 55.6 secs and, therefore, these neutrons will appear to have an effective half-life of 55.6 secs as measured from the instant at which the fission occurs. In other words these neutrons are not emitted at the instant of fission, but their emission is delayed because of the delay in the decay of Br-87. They are therefore called DELAYED neutrons and the neutron is labelled as such in Fig. 3.

There are six groups of delayed neutrons with effective half-lives, varying from 0.05 secs to 55.6 sec. The delayed neutrons form 0.7% of the total neutrons produced as a result of fission, whereas 99.3% of these neutrons are prompt neutrons. Even though they form such a small percentage of the total, the delayed neutrons are very important in reactor regulation.

Production of Photo-neutrons

Prompt and delayed neutrons are produced as a result of fission. If no further fissions occur, no more prompt or delayed neutrons are produced. This is not the case with photo-neutrons.

Photo-neutrons are peculiar to reactors which have heavy water moderators or heat transport fluids. They are produced when gamma rays with energies greater than 2.2 Mev are captured by deuterium nuclei. Diagramatically the reaction would be represented as follows: -

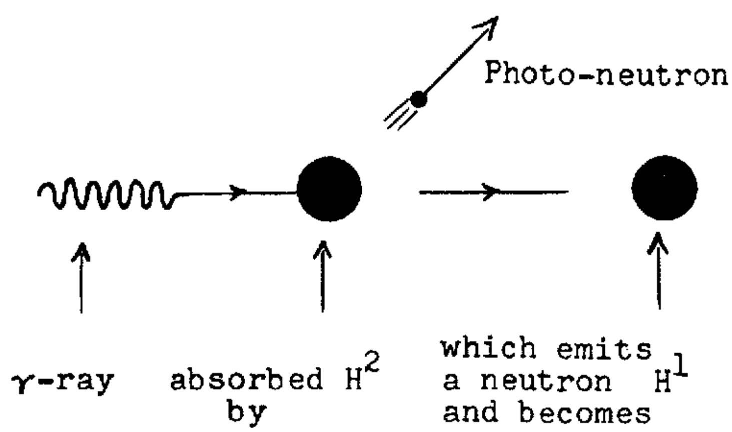

Fig. 4

The equation for this is: -

$${}_1H^2 + \gamma = {}_1H^1 + {}_0n^1$$

This photo-neutron is not produced in a graphite moderated reactor because no deuterium is present. The reaction is insignificant in light water moderated reactors due to the extremely low deuterium content.

Since gamma rays are emitted in the core, the heat transport system and in the moderator system, external to the core, photo-neutrons will be produced in all these systems. The important ones, though, are those produced in any heavy water moderator or heat transport fluid in the core. Even when the reactor is not operating, and prompt and delayed neutrons are not being produced, gamma rays from fission product decay will still produce photo-neutrons in any D_2O that might be present, providing a neutron source in the reactor to start the fission chain reaction.

ASSIGNMENT

1. (a) Name the three types of neutrons produced in a heavy water moderated reactor.

   (b) Which type is not produced in a graphite moderated reactor?

2. (a) Which two of the three types are produced as a result of fission?

   (b) What fraction of the total does each type represent?

   (c) Of the types produced as a result of fission, when and how are the ones produced in greater number, produced?

   (d) Explain how the ones, produced in smaller number, are produced and why they have the particular name that they have.

3. (a) If the third type of neutrons are not produced as a result of fission, how are they produced?

   (b) Why are these neutrons produced in the reactor core even when the reactor is not operating and the other two types are not being produced?

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