
NEUTRON FLUX SPECTRUM

The number of neutrons that exist at a given energy level varies. A plot of either the fraction of neutrons or the neutron flux at a given energy versus the energy level is called a neutron energy spectrum. The neutron energy spectrum varies widely for different types of reactors.

EO 4.1 STATE the average energy at which prompt neutrons are produced.

EO 4.2 DESCRIBE the neutron energy spectrum in the following reactors:

- a. Fast reactor
- b. Thermal reactor

EO 4.3 EXPLAIN the reason for the particular shape of the fast, intermediate, and slow energy regions of the neutron flux spectrum for a thermal reactor.

Prompt Neutron Energies

The neutrons produced by fission are high energy neutrons, and almost all fission neutrons have energies between 0.1 MeV and 10 MeV. The neutron energy distribution, or spectrum, may best be described by plotting the fraction of neutrons per MeV as a function of neutron energy, as shown in Figure 2. From this figure it can be seen that the most probable neutron energy is about 0.7 MeV. Also, from this data it can be shown that the average energy of fission neutrons is about 2 MeV. Figure 2 is the neutron energy spectrum for thermal fission in uranium-235. The values will vary slightly for other nuclides.

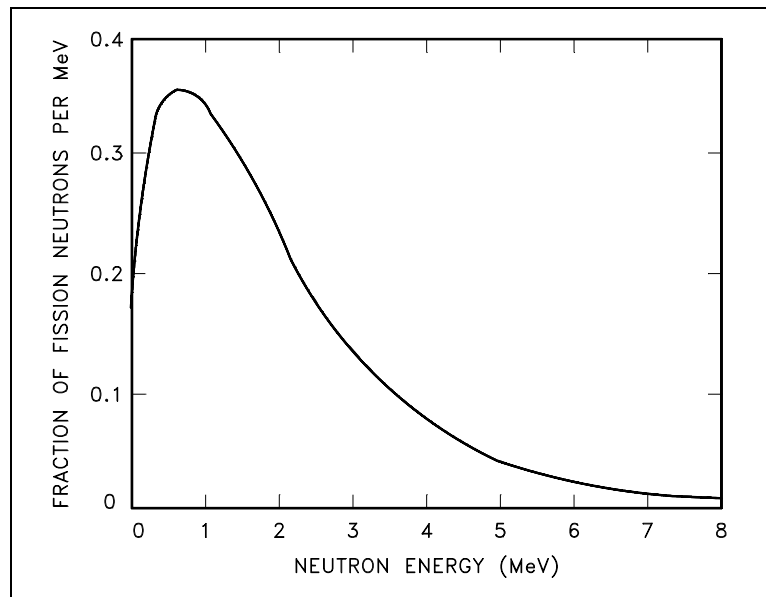


Figure 2 Prompt Fission Neutron Energy Spectrum for Thermal Fission of Uranium-235

Thermal and Fast Breeder Reactor Neutron Spectra

The spectrum of neutron energies produced by fission varies significantly from the energy spectrum, or flux, existing in a reactor at a given time. Figure 3 illustrates the difference in neutron flux spectra between a thermal reactor and a fast breeder reactor. The energy distribution of neutrons from fission is essentially the same for both reactors, so the differences in the curve shapes may be attributed to the neutron moderation or slowing down effects.

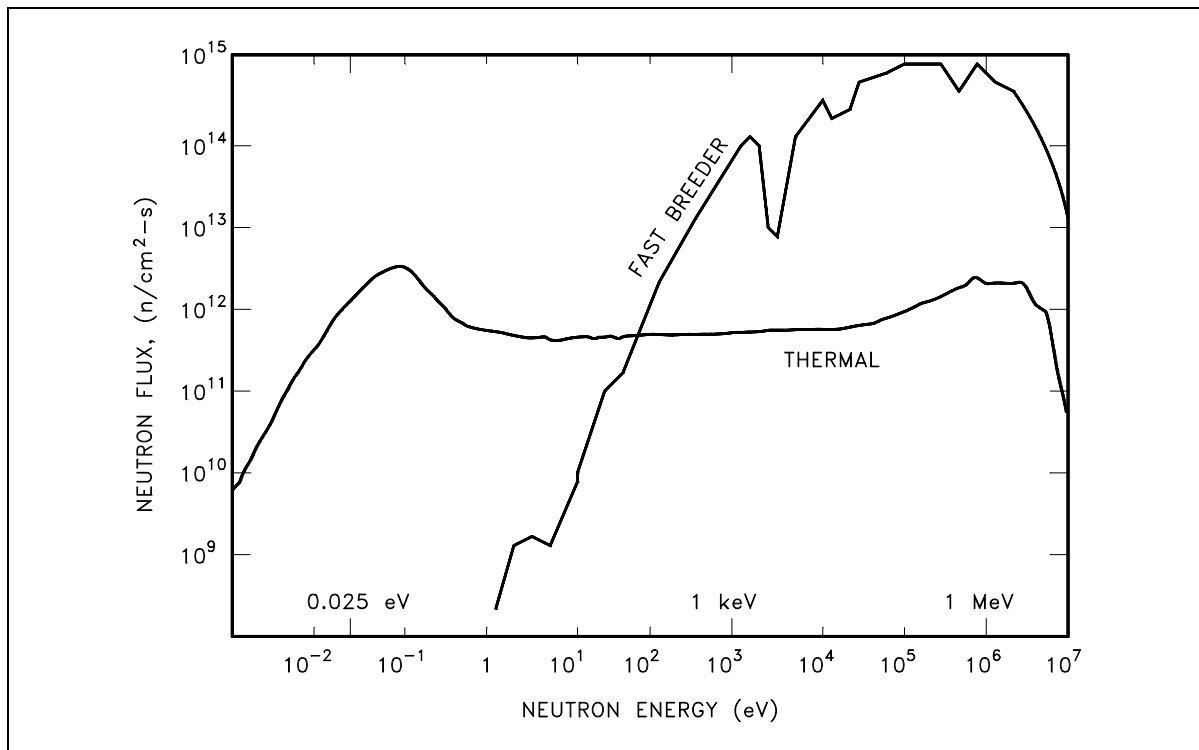


Figure 3 Comparison of Neutron Flux Spectra for Thermal and Fast Breeder Reactor

No attempt is made to thermalize or slow down neutrons in the fast breeder reactor (liquid metal cooled); therefore, an insignificant number of neutrons exist in the thermal range. For the thermal reactor (water moderated), the spectrum of neutrons in the fast region (> 0.1 MeV) has a shape similar to that for the spectrum of neutrons emitted by the fission process.

In the thermal reactor, the flux in the intermediate energy region (1 eV to 0.1 MeV) has approximately a $1/E$ dependence. That is, if the energy (E) is halved, the flux doubles. This $1/E$ dependence is caused by the slowing down process, where elastic collisions remove a constant fraction of the neutron energy per collision (on the average), independent of energy; thus, the neutron loses larger amounts of energy per collision at higher energies than at lower energies. The fact that the neutrons lose a constant fraction of energy per collision causes the neutrons to tend to "pile up" at lower energies, that is, a greater number of neutrons exist at the lower energies as a result of this behavior.

In the thermal region the neutrons achieve a thermal equilibrium with the atoms of the moderator material. In any given collision they may gain or lose energy, and over successive collisions will gain as much energy as they lose. These thermal neutrons, even at a specific temperature, do not all have the same energy or velocity; there is a distribution of energies, usually referred to as the Maxwell distribution (e.g., Figure 2). The energies of most thermal neutrons lie close to the most probable energy, but there is a spread of neutrons above and below this value.

Most Probable Neutron Velocities

The *most probable velocity* (v_p) of a thermal neutron is determined by the temperature of the medium and can be determined by Equation (2-13).

$$v_p = \sqrt{\frac{2 k T}{m}} \quad (2-13)$$

where:

- v_p = most probable velocity of neutron (cm/sec)
- k = Boltzman's constant (1.38×10^{-16} erg/°K)
- T = absolute temperature in degrees Kelvin (°K)
- m = mass of neutron (1.66×10^{-24} grams)

Example:

Calculate the most probable velocities for neutrons in thermal equilibrium with their surroundings at the following temperatures. a) 20°C, b) 260°C.

Solution:

- a) Calculate the most probable velocity for 20°C using Equation (2-13).

$$\begin{aligned} v_p &= \sqrt{\frac{2 k T}{m}} \\ &= \sqrt{\frac{2 \left(1.38 \times 10^{-16} \frac{\text{erg}}{\text{°K}} \right) (293 \text{°K})}{1.66 \times 10^{-24} \text{ g}}} \\ &= 2.2 \times 10^5 \frac{\text{cm}}{\text{sec}} \left(\frac{1 \text{ m}}{100 \text{ cm}} \right) \\ &= 2200 \frac{\text{m}}{\text{sec}} \end{aligned}$$

- b) Calculate the most probable velocity for 260°C using Equation (2-13).

$$\begin{aligned}v_p &= \sqrt{\frac{2 k T}{m}} \\&= \sqrt{\frac{2 \left(1.38 \times 10^{-16} \frac{\text{erg}}{\text{°K}} \right) (533^\circ\text{K})}{1.66 \times 10^{-24} \text{ g}}} \\&= 2.977 \times 10^5 \frac{\text{cm}}{\text{sec}} \left(\frac{1 \text{ m}}{100 \text{ cm}} \right) \\&= 2977 \frac{\text{m}}{\text{sec}}\end{aligned}$$

From these calculations it is evident that the most probable velocity of a thermal neutron increases as temperature increases. The most probable velocity at 20°C is of particular importance since reference data, such as nuclear cross sections, are tabulated for a neutron velocity of 2200 meters per second.

Summary

The important information in this chapter is summarized below.

Neutron Flux Spectrum Summary

- Prompt neutrons are born at energies between 0.1 MeV and 10 MeV. The average prompt neutron energy is about 2 MeV.
- Fast reactors have a neutron energy spectrum that has the same shape as the prompt neutron energy spectrum.
- Thermal reactors have a neutron energy spectrum that has two pronounced peaks, one in the thermal energy region where the neutrons are in thermal equilibrium with the core materials and another in the fast region at energies where neutrons are produced. The flux in the intermediate region (1 eV to 0.1 MeV) has a roughly $1/E$ dependence.
- The neutron flux spectrum for the fast energy region of a thermal reactor has a shape similar to that of the spectrum of neutrons emitted by the fission process.
- The reason for the $1/E$ flux dependence at intermediate energy levels in a thermal reactor is due to the neutrons' tendency to lose a constant fraction of energy per collision. Since the neutrons lose a greater amount at the higher energies, the neutrons tend to "pile up" at lower energies where they lose less energy per collision.
- The neutron flux spectrum for the slow region of a thermal reactor contains a peak at the energy where the neutrons are in thermal equilibrium with the atoms of the surrounding material.