It is to be kept in mind that in the consideration of the competition of fission with other processes, it is not sufficient to consider energies alone, as we have done. For fission, one must not only have the energy rise to the top of the barrier, but is is also necessary that this energy be concentrated in the proper modes of motion for fission. This may take some time, so that competing processes may occur at the expense of fission. Since the number of modes, and hence of useless nonfission modes, increases with excitation energy, it may, therefore, be very likely that the reason photofission with ~ 100-Mev gamma rays on lower nuclei has not been observed is because the energy does not get concentrated in a proper mode before it is lost by some other way than fission.

8.3 THE FISSION PROCESS – RESULTING PARTICLES

When a nucleus fissions there are, in addition to the two fragments, a number of other particles observed. They are neutrons, beta particles, gamma rays, and often fast alpha particles. Some of these are observed to accompany the fission process, and others are emitted at various times following the fissioning itself.

The fission fragments themselves have been studied in great detail*. The distribution of fission fragments for U^{235} as a function of mass, shown in Figure 53, consists of two nearly identical peaks with maxima at mass numbers 96 and 140. If U^{235} is fissioned by a neutron, and in the course of fissioning two neutrons are emitted, then the mass number corresponding to *equal* splitting would be A = 117. The observed yield for equal splitting (A = 117) is only 0.01%, whereas the maximum yields (at A = 96 and 140) are about 6.5%. In each case, the fission fragment formed is unstable (see Figure 49) because of the excess of neutrons. For example, the nucleus with mass number 140, yield 6.3%, finishes up as stable Ce^{140} after a sequence of beta decays:

$$\underset{(Z=54)}{Xe^{140}} \xrightarrow[16s]{} Cs^{140} \xrightarrow[short]{} Ba^{140} \xrightarrow[12.8d]{} La^{140} \xrightarrow[40.0h]{} \underset{(Z=58)}{Ce^{140}} \qquad (8\text{-}11)$$

A large number of such "fission product chains" have been identified.

It should be noted that the distribution of masses also gives the distribution of the relative kinetic energies of fission fragments. This follows from the conservation of momentum. If E_1 and E_2 are the kinetic energies of the fission fragments M_1 and M_2, then conservation of momentum requires that $M_1V_1 = M_2V_2$ or $\sqrt{2M_1E_1} = \sqrt{2M_2E_2}$. Thus $M_1/M_2 = \sqrt{E_2/E_1}$, so that the heavier of a pair of fission fragments has the smaller kinetic energy. The absolute value of the energy E_1 corresponding to the mass M_1 follows from the fact that the total energy $E_1 + E_2$ is a constant (~ 160 Mev) and the total mass $M_1 + M_2$ is a constant (~ 234 m.u.).

The neutrons emitted in fission are classed as either "prompt" or "delayed". The term "prompt" means that the neutrons leave the fission fragment after its formation in times shorter than we can measure. An estimate of 10^{-15} second can be made by considering the fission product as the splitting of a drop. The final fragments are not of spherical shape (Figure 54), so there will be a considerable vibrational energy associated with oscillations about the equilibrium (spherical) shape of the fragment. This excitation energy may be sufficient to evaporate a neutron, especially since neutron binding energies in fission fragments are small because of the excess of neutrons. For example, assume that U^{235} is made to fission by a neutron, and two fragments with A = 118 and Z = 46 appear. Using the formula for M(A,Z), equation (8-8), one can calculate binding energies for various nuclei of weight A = 118:

*See "Nuclei Formed in Fission: Decay Characteristics, Fission Yields and Chain Relationships" issued by the Plutonium Project in J. Am. Chem. Soc. 68: 2411(1946) and Rev. Mod. Phys. 18: 513(1946).

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