Nuclear Engineering 150 – Discussion Section
Team Exercise Solutions #3

Problem 1

A reactor is operating for a long time at some known power density P_0. Then, it instantaneously changes power to some power density P_1. One fission product of interest is ^{135}Xe, though it has a neglible yield from the initial fission reaction. ^{135}Xe precursors ^{135}Te and ^{135}I are produced with a combined yield of approximately 6%, before decaying via β^- decay to ^{135}I and ^{135}Xe respectively. Find the number density of ^{135}Xe as a function of time after the power change. (Your solution may be left as variables)

Nucleus	Half-life	Thermal σ_a
^{135}Te	19.0 s	~ 0
^{135}I	6.6 hr	~ 0
^{135}Xe	9.2 hr	2.6×10^6 barns

Problem 1 Solution

We will create the following simple decay chain graphic, built from the information provided in the problem, to visualize the processes described in the problem.

GRAPHIC GRAPHIC

Starting off, since this is a problem related to decay, we will start from the usual equation for changes in a quantity of radionuclides.

$$\frac{dN}{dt} = \text{production} - \text{losses}$$

First, we find the neutron production. We are told that after the transition, the reactor is now generating with power density P_1.

The amount of ^{135}Xe is dependent on its parents, ^{135}Te and ^{135}I. Since the half-life of ^{135}Te (19.0 s) is practically insignificant in comparison to the multi-hour half-lives of its daughters (to be exact, $T_{1/2,\mathrm{Te135}} = 0.08\, T_{1/2,\mathrm{I135}}$ and $T_{1/2,\mathrm{Te135}} = 0.06\, T_{1/2,\mathrm{Xe135}}$), we can treat it as instantaneously decaying into iodine.

Now, we can recognize ...

Problem 2

a) Find the excitation energy in ^{236}U when a neutron with zero kinetic energy is absorbed by ^{235}U.

b) Find the excitation energy in ^{239}U when a neutron with zero kinetic energy is absorbed by ^{238}U.

c) The activation energy for ^{236}U is 6.2 MeV and the activation energy for ^{239}U is 6.6 MeV. Will fission occur in each of these cases? Identify 235U and 238U as fissile or fissionable and explain.

d) A ^{238}U nuclei absorbs a 2 MeV neutron and fissions into ^{132}Sn, ^{106}Mo, and a neutron. If the neutron is produced with 2.5% of the total energy released in the reaction, does it have enough energy to fission another ^{238}U atom?

Nucleus	Mass
n	1.00866492 amu
^{106}Mo	105.918137 amu
^{132}Sn	131.917816 amu
^{235}U	235.043930 amu
^{236}U	236.045568 amu
^{238}U	238.050788 amu
^{239}U	239.054293 amu

Problem 2 Solution

a.)

The total mass-energy of the excited ^{236}U atom is the sum of the masses of the reactants: the ^{235}U atom and the neutron.

$$\begin{aligned} m(^{236}\mathrm{U}^*) &= m(^{235}\mathrm{U}) + m_n \\ &= 235.043930 \text{ amu} + 1.00866492 \text{ amu} \\ &= 236.052595 \text{ amu} \end{aligned}$$

The excitation energy of ^{236}U is the difference between the total mass-energy of the system and the rest-mass of ^{236}U (multiplied by c^2, converting the mass-energy in amu to MeV).

$$\begin{aligned} E_{\text{ex}} &= \left[m(^{236}\mathrm{U}^*) - m(^{236}\mathrm{U})\right] c^2 \\ &= [236.052595 \text{ amu} - 236.045568 \text{ amu}]\, c^2 \\ &= (0.007027 \text{ amu})c^2 \\ E_{\text{ex}} &= 6.545 \text{ MeV} \end{aligned}$$

b.)

The total mass-energy of the excited ^{239}U atom is the sum of the masses of the reactants: the ^{238}U atom and the neutron.

$$\begin{aligned} m(^{239}\mathrm{U}^*) &= m(^{238}\mathrm{U}) + m_n \\ &= 238.050788 \text{ amu} + 1.00866492 \text{ amu} \\ &= 239.059453 \text{ amu} \end{aligned}$$

The excitation energy of ^{239}U is the difference between the total mass-energy of the system and the rest-mass of ^{239}U (multiplied by c^2, converting the mass-energy in amu to MeV).

$$\begin{aligned}
E_{\text{ex}} &= \left[m(^{239}\text{U}^*) - m(^{239}\text{U})\right] c^2 \\
&= [239.059453 \text{ amu} - 239.054293 \text{ amu}]\, c^2 \\
&= (0.005160 \text{ amu})c^2 \\
E_{\text{ex}} &= 4.806 \text{ MeV}
\end{aligned}$$

c.)

The 6.545 MeV excitation energy of the ^{236}U is greater than the 6.2 MeV activation energy of the fission process for that nucleus. This means that even when a ^{235}U nucleus absorbs a neutron with zero kinetic energy, fission is possible—^{235}U is fissile. ^{238}U does not exhibit this property. When ^{238}U absorbs a neutron and forms ^{239}U, the excitation energy of 4.806 MeV is less than the activation energy of 6.6 MeV for fission to occur. This means that the absorbed neutron must have more than about 1.8 MeV of kinetic energy to trigger fission, and so ^{238}U is fissionable.

This process is given by the equation...

d.)