Exercises with Fission and Nuclear Reactors – Suggested Solutions

1) The mass number of a given nucleus increases by one unit when a neutron is captured. Table 6.1 gives information about mass excess for three important isotope pairs. Calculate the difference in average binding energy between the pairs of nuclide and discuss why the $^{238}U/^{239}U$ pair differs so greatly from the other two pairs in regards to utilization of nuclear energy.

Nuclide 1	**Mass Excess (keV)**	**Nuclide 2**	**Mass Excess (keV)**
^{235}U	**40915**	^{236}U	**42411**
^{238}U	**47306**	^{239}U	**50741**
^{239}U	**48585**	^{240}Pu	**50122**

It is noteworthy to notice the Q-value for the neutron capture and the change in binding energy per nucleon for each of the isotope pairs.

Nuclide pairs	Q-value for neutron capture (MeV)	Change in E_b/A (MeV)
$^{235}U/^{236}U$	6.58	-0.007
$^{238}U/^{239}U$	4.64	-0.015
$^{239}Pu/^{240}Pu$	6.53	-0.007

The nuclide pair $^{238}U/^{239}U$ have a significantly lower Q-value and a significantly bigger fall in E_b/A than the other pairs. This can be explained by the pair-pair configuration in the ^{238}U nucleus, which makes it less favorable to bind another neutron. On the other hand, for pair-odd nuclei it is much more favorable to bind another neutron to achieve a pair-pair configuration. This is shown from the cross sections for interaction with thermal neutrons (σ and σ_f).

2) Find the answers to the following questions:

1. **A specific thermal fission of ^{239}Pu gives ^{99}Y + 2 neutrons + X. Which nuclei is X?**
   $^{239}Pu + n \rightarrow {}^{99}Y + 2n + {}^{139}Cs$
2. **Calculate the Q-value for the above fission from a mass table.**
   Q-value: 191.42MeV
3. **Use a mass table to calculate the residual heat, that is the energy developed from disintegration after fission has taken place.**
   The energy which is released by disintegration after stability is
   ^{99}Y: $M(^{99}Y) - M(^{99}Ru) = 17.4$ MeV
   ^{139}Cs: $M(^{139}Cs) - M(^{139}La) = 6.5$ MeV
4. **A part of this energy is of no importance for the safety of the reactor, explain why.**
   2/3 of this energy will disappear with neutrinos. Some of the disintegrations have too long half-lives to have an effect on the reactor safety.

3) 1.0 g ^{239}Pu is irradiated with a neutron flux of 1.0 × 10^{14} n cm^{-2}s^{-1}. Assume that all the fissions have the same Q-value as the one calculated under 2.b.

1. **Calculate the developed effect from fission in plutonium during the irradiation.**
   1.0 g ^{239}Pu = 2.5×10^{21} atoms. Number of fissions per seconds is $\sigma\times\phi\times N_t$ = 1.89×10^{14}, which will give an effect of 3.6×10^{16} MeV (5811W).
2. **How much ^{240}Pu is formed after 100 days of irradiation?**
   The formation of ^{240}Pu: $\sigma\times\phi\times N_t$= 6.8×10^{13} s^{-1}. After 100 days of irradiation 0.232 g Pu will be made.

4) In a thorium breeder reactor, fissile ^{233}U is formed from fertile ^{232}Th.

1. **Write down the nuclear reaction and how the disintegration occurs.**
   ^{232}Th + n → ^{233}Th → ^{233}Pa → ^{233}U
2. **A specific thermal fission of ^{233}U gives ^{99}Y + 2 neutrons + X. Which nuclei is X?**
   ^{133}I
3. **Assume one ton thorium is irradiated with a neutron flux of 1.0 × 10^{14} n cm^{-2}s^{-1}. How long does it take to generate 100 grams of ^{233}U?**
   One ton ^{232}Th equals to 2.6×10^{27} atoms. The rate of formation for neutron capture (^{233}Th): $\sigma\times\phi\times Nt$ = 7.37×10^{24}cm^2×10^{14}n cm^{-2}s^{-1}×2.6×10^{27}atomer= 1.91×10^{18}atoms s^{-1} It will take 37 hours of irradiation to form enough ^{233}Th to give 100 g ^{233}U, but disintegration of ^{233}Pa to ^{233}U must be waited.
4. **What is the disintegration rate of this uranium?**
   100 g ^{233}U: $D=\lambda N$ = 3.56×10^{10} Bq (35.6 GBq)