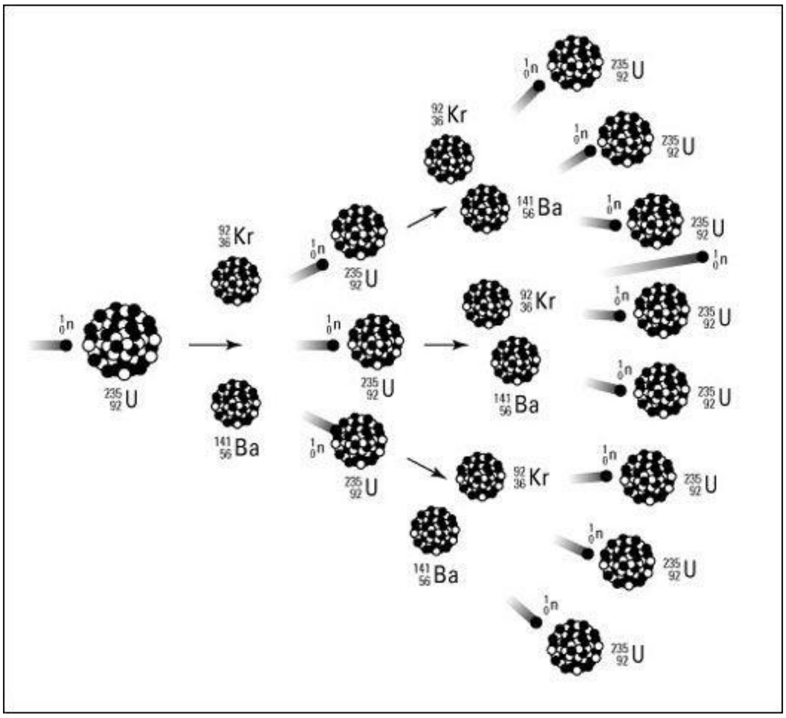
Energy from Nuclear Fission

You should remember from (I)GCSE that heavy nuclei, like ^{235}U can be fissioned (split) into two smaller fragments with 2 or 3 neutrons left over that can go on to cause further similar reactions in a chain. Diagrams like this should be springing to mind:



However, there are a few details that aren't often made very clear in textbooks, such as:

- Each fission event can and does create different fragments, not just the same two over and over again. The above diagram shows <u>every</u> ^{235}U nucleus fissioning into a ^{141}Ba and a ^{92}Kr nucleus. This is *incredibly* unlikely. In reality, the fission fragments are <u>most</u> likely to have mass numbers <u>around</u> 135 and 95.
- The number of separate neutrons emitted is also variable, with 2 or 3 neutrons being the most common number. Many diagrams and textbooks might have you believe that it was always one number or the other.

Energy is released

The binding energy curve shows that the fission products are lower down the curve than the parent nucleus, meaning they will also be lighter than the parent and therefore the fission process will release energy. We can calculate the mass defect of the process and hence the energy released.

[*Mathematical note: if you are using* $E = mc^2$ *in the following calculations, you will not get the right answers if you use* $c = 3 \times 10^8\ ms^{-1}$. *Mass defects are so small that you need to use a value with more sig figs to get correct answers. The full value is* $299\ 792\ 458\ ms^{-1}$]

1) The reaction in the above diagram:

$$^{1}_{0}\mathrm{n} + {}^{235}_{92}\mathrm{U} \rightarrow {}^{141}_{56}\mathrm{Ba} + {}^{92}_{36}\mathrm{Kr} + 3\,{}^{1}_{0}\mathrm{n}$$

Masses (in Atomic Mass Units):

Neutron: 1.00866 u
^{235}U: 235.04392 u
^{141}Ba: 140.833 u
^{92}Kr: 91.92616 u

Calculate:

a) The mass defect of this reaction, in u and kg ($1\mathrm{u} = 1.66 \times 10^{-27}$ kg)

b) The energy released in this reaction, in J and MeV

Nearly all of this energy is released as KE of the fission fragments (*i.e.* the Ba and Kr nuclei).

2) A similar reaction:

$$^{1}_{\ldots}\mathrm{n} + {}^{235}_{\ldots}\mathrm{U} \rightarrow {}^{\ldots}_{56}\mathrm{Ba} + {}^{90}_{\ldots}\mathrm{Kr} + 2\,{}^{\ldots}_{0}\mathrm{n}$$

(fill in the blanks)

Masses (in Atomic Mass Units):
^{144}Ba: 143.923 u
^{90}Kr: 89.920 u

Calculate:

a) The mass defect of this reaction, in u and kg

b) The energy released in this reaction, in J and MeV

3) Another possible reaction:

$$ {}^{\cdots}_{\cdots}\mathrm{n} + {}^{235}_{\cdots}\mathrm{U} \rightarrow {}^{148}_{\cdots}\mathrm{La} + {}^{\cdots}_{\cdots}\mathrm{Br} + \ldots {}^{1}_{0}\mathrm{n} $$

(fill in the blanks)

Masses (in Atomic Mass Units):

^{148}La: 147.93223 u ^{85}Br: 84.9156 u

Calculate:

a) The mass defect of this reaction, in u and kg

b) The energy released in this reaction, in J and MeV

4) A completely separate reaction

In the 1950s, the public were told that the UK was building nuclear reactors to generate electricity. Whilst this wasn't quite a complete lie, the main reason was to accumulate Plutonium in the core[1] to build nuclear weapons. Plutonium was easier to separate from everything else in the core than it is to separate ^{235}U and ^{238}U because Plutonium is a different element, so a chemical reaction can be used to separate it from everything else rather than requiring a centrifuge process.

^{239}Pu also releases neutrons when fissioned, so can be used to make a chain reaction. A possible fission reaction is:

$$ {}^{\cdots}_{\cdots}\mathrm{n} + {}^{239}_{\cdots}\mathrm{Pu} \rightarrow {}^{\cdots}_{\cdots}\mathrm{Zr} + {}^{137}_{\cdots}\mathrm{Xe} + \ldots {}^{\cdots}_{\cdots}\mathrm{n} $$

(fill in the blanks)

Masses (in Atomic Mass Units):

^{239}Pu: 239.052 u ^{100}Zr: 99.918 u ^{137}Xe: 136.912 u

Calculate:

a) The mass defect of this reaction, in u and kg

b) The energy released in this reaction, in J and MeV

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[1] Which forms when a ^{238}U nucleus absorbs a neutron and undergoes two Beta decays to become ^{239}Pu. The two beta decays occur with very short half-lives, but ^{239}Pu has a half-life of thousands of years, so it accumulates in the reactor core over time.