Induced nuclear reactions

What is induced fission

- Nuclear fission can be induced in some heavy nuclei by the capture of a neutron.
  - An Isotope that would otherwise be ‘more stable’ can be made less stable by adding a Neutron (changing the Isotope) in some Atoms

A fission reaction

- The now unstable nucleus breaks into 'daughter' nuclei and releases more Neutrons.
- An example of U235 becoming Ba and Kr is

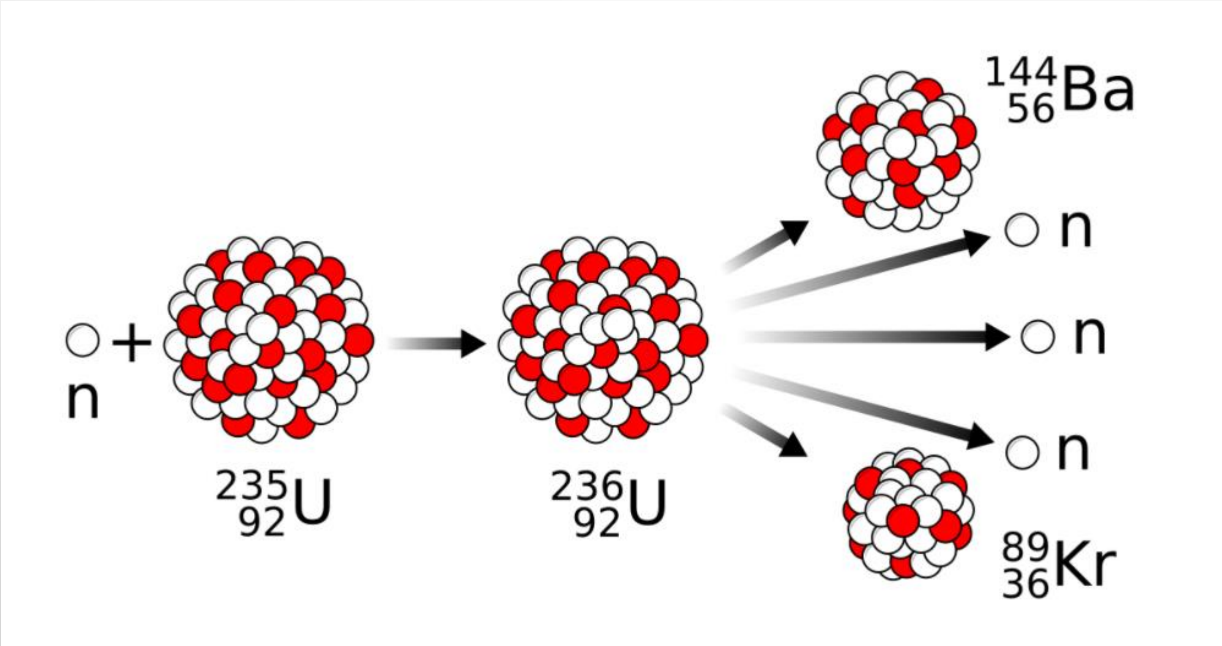


Image courtesy MikeRun

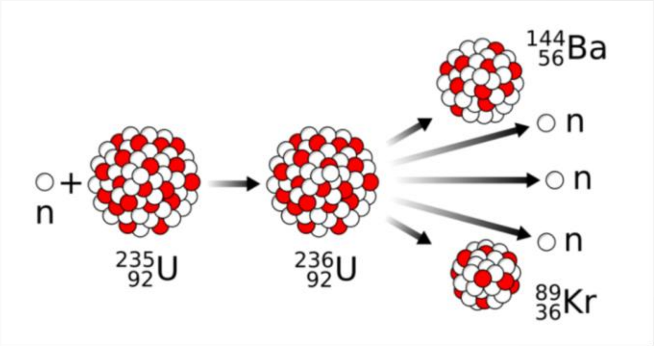
Myths and legends

- Many text books and videos present fission as if 1 neutron hits one U235 atom and the final outcome is always Ba and Kr and 3 neutrons.
- **Nah!**
- Firstly, probability plays a part in the exact daughter nuclei
- Second, nuclear fuel is never 'pure'
- Third, the energy in a nuclear reaction means the final outcome is along a continuum
- Fourth, once a reaction has started, the daughter nuclei are now targets in the fuel and they may capture Neutrons and fission
- Fifth, ….
  - This page shows **some** of the products of U235,236 fission https://en.wikipedia.org/wiki/Fission_products_(by_element)

In fact ....

- Nuclear reactors do not aim to produce a massive exponentially increasing fission reaction
- The balance in the reactor is set so that the main U235 fission is stable or just below stable (overall 1 fission produces slightly less than one more fission)
- This is because of the points made in Myths and Legends. As the reaction proceeds a number of daughter nuclei are produced which can also capture neutrons and decay producing energy
- This extra energy is part of the driver in a nuclear reactor

Super simplification



- First we need a sample of U235 (the fuel)
- U235 occurs naturally in uranium ores, so we can mine it
- But, it occurs in very small percentages compared to other less fissile uranium isotopes
- Two choices
  - Use lots of it and use lots of *Moderators* (Chernobyl / RMBK solution)
  - *Enrich* the fuel to increase the percentage of U235

Definitions

- *Moderators*
  - A Neutron needs to be travelling within a specific speed range when it hits an Atom to be absorbed into the Nucleus. Too slow and it doesn't get into the Nucleus, too fast and it goes straight through (note, these are quantum effects).
  - When a Neutron is released from an atomic Nucleus during fission, it is going too fast to be absorbed by another Atom.
  - A *Moderator*, slows the Neutron down so that it has a higher percentage chance of being captured, thus increasing the rate of reaction overall.
  - Yes – you read that right; a '*Moderator*' *increases* the rate of a nuclear reaction by *slowing* Neutrons and therefore increasing Neutron capture.

A bit more on Moderators

- It is not easy to find a Moderator. You need a compound that allows Neutrons to collide with it and the Neutrons
  - don't get absorbed forming stable Isotopes (these compounds are called Neutron Poison)
  - don't get absorbed forming unstable Isotopes (these compounds will fission and give other products that will affect the mix of isotopes)
  - Don't pass straight through, not getting slowed.

Definitions *enriching*

- Enrichment is increasing the percentage of the isotope desired for fission
- It is usually done in the gaseous state
  - The ore is centrifuged (spun) to remove the denser U238
  - Uranium must be in a gaseous form at low temperature. Thus, the ore is first converted to uranium hexafluoride
  - The centrifuge separates the components of the ore so that the densest end up at the outside, least dense in the inside

Back to fission

- Nuclear fuel (a metal rod, or pellet) is allowed to spontaneously decay
  - It can’t actually be stopped from its ‘normal’ decay
  - Thus, you don’t need to ‘start’ nuclear reactions
    - Just have two ‘pieces’ of fuel
    - Separate them with a moderator
    - And the neutrons emitted from one will be absorbed in the nuclei of atoms in the other

Different approach to spontaneous decay

- By itself, U235 will decay with a half life of 700 million years
- That doesn't seem like much, however
  - Every kilogram of U235 has approximately 2.56×10^{24} atoms
  - 1.8×10^{16} atoms decay every year
  - Or 570 million atoms decay every second
- The majority are travelling way to fast to induce further decay
- BUT
  - Add a moderator and the game changes completely
  - And, U236 at the point of catching that new neutron is significantly more unstable than it is in its normal state

Think that maths through

- In a millionth of a second up to 570 neutrons may be captured
- If they produce 570 x 3 = 1710 in that millionth of a second
- They could then produce 1710 x 3 = 5130 etc.
- In 1/100000 of a second we could have $570 \times 3^{10} = 33657930$ neutrons
- Each fission releases $3 \times 10^{-11} J$
- Thus in 1/100000 of a second we have released 0.001J of energy
- But it is exponential
  - In 1/10000 of a second we have $1.0 \times 10^{97} J$

Relax

- Not every emission is captured
- In reality only a small percentage are captured

- But, that is how atomic bombs work. The exponential increase in energy is so great that it goes ….

Nuclear bombs

- Scott Manley has an excellent YouTube series that explains how to make a "controlled" massive nuclear explosion
  - Going Nuclear - The Science Of Nuclear Weapons - Part 1 - Just a Theory
  - Going Nuclear - The Science Of Nuclear Weapons - Part 2 - Chain Reactions
  - Going Nuclear - Nuclear Science - Part 3 - Plutonium Implosion
  - Going Nuclear - Nuclear Science - Part 4 - The Incredible Shrinking Warhead
  - Going Nuclear - Nuclear Science - Part 5 - Hydrogen Bombs

Fusion

We will tackle fusion in its own lecture