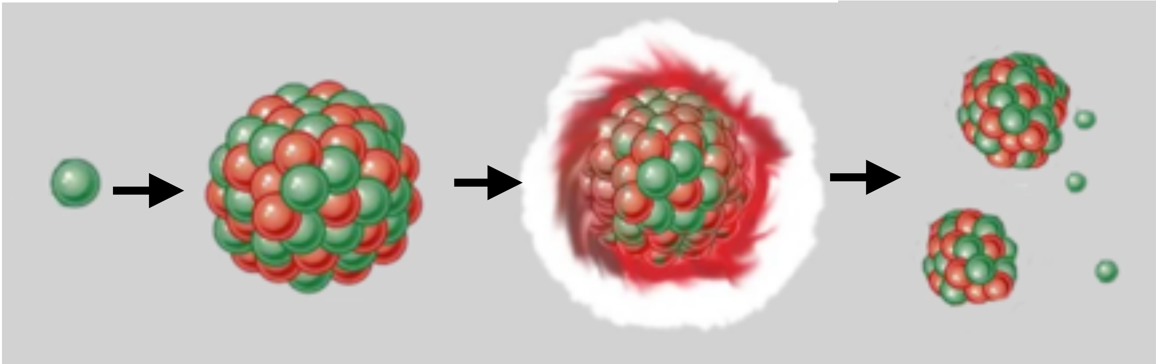
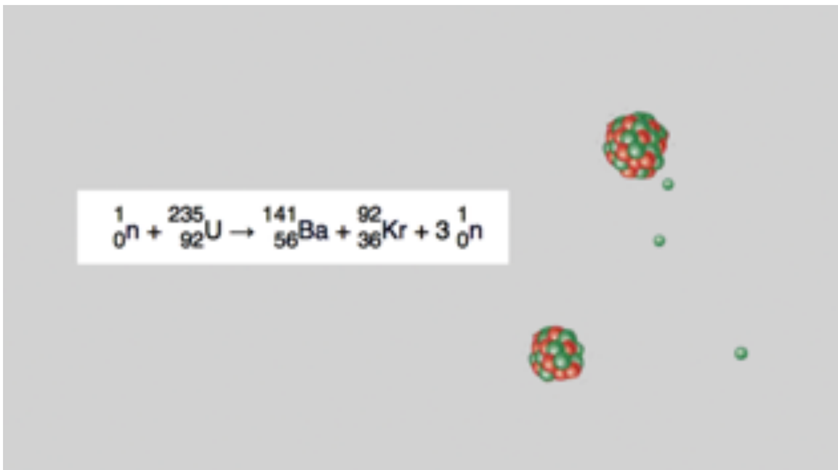


Nuclear Fission is the splitting of the nucleus of an atom into two or more parts by hitting it with a small particle, almost always a neutron (a proton would be repelled from the positive nucleus and an electron would have too little energy).
The isotope most commonly used to produce energy from nuclear fission is Uranium 235.
If a neutron strikes the uranium nucleus with the “right” amount of kinetic energy the neutron enters the nucleus and destabilises it. The nucleus then splits into two large parts and releases a large amount of energy.
The right amount of kinetic energy to give the best possible split for the most energy is about the same as the neutron would have if it were at room temperature. It would be travelling at about 2.2Km per second, these neutrons are called “thermal neutrons”.



Introducing nuclear fission
The Fizzics Organization
www.fizzics.org

A typical result of fission of Uranium 235 is shown here, but it is certainly not the only possible outcome. There are many.

Nuclear fission and binding energy
The Fizzics Organization
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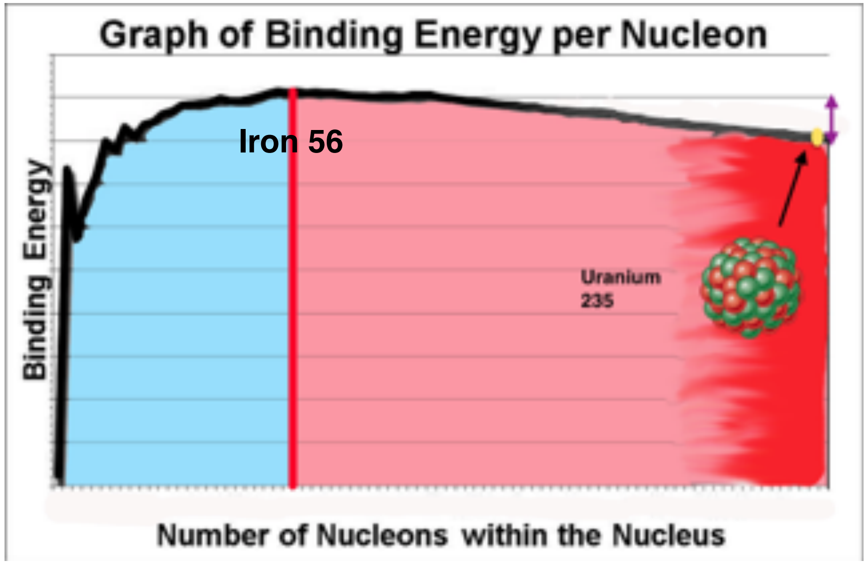
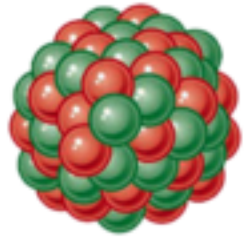


Uranium 235

$^{235}_{92}U$ 92 protons
235 - 92 = 143 neutrons
92 electrons



235 is the nucleon number

The graph shows how the binding energy, that is the amount of energy that holds the nucleus of atoms together, varies with the size of the nucleus.
Smaller atoms, on the line with the blue shading, release energy if they are fused together.
Larger atoms on the line with the red shading, can release energy if they are split - that especially applies to very big atoms like uranium (with the deep red shading).
The most stable atom is iron 56, at the peak of the curve.

If a uranium atom were to be split into two fairly equal parts there would be energy released due to the change in binding energy, as shown by the arrow on the graph. This doesn't look much but remember the arrow shows the change of energy for each nucleon in the nucleus and there are 235 of them.

The energy change is so large that the mass of the parts after splitting is slightly less than the mass of the atom and extra neutron in the first place.

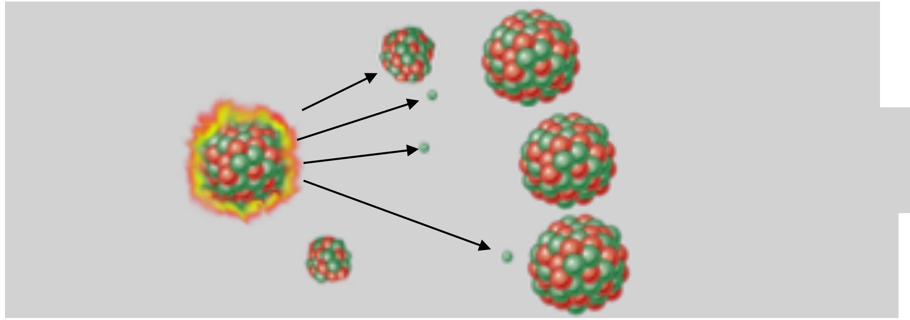
That loss of mass is converted to energy a calculation you can do using the famous equation $E = mc^2$

Before you do that you have to convert the mass to kilograms and the energy produced is about 3.24×10^{-11} J

If one kilogram of uranium 235 underwent fission the total energy produced would be about 83.14 TJ
Now a one kilogram cube is about 37 mm (just under 1.5 inches) on each edge.
To produce an equivalent amount of energy we would have to burn around **10,000 tonnes of coal**

Calculating the energy change

The mass of the uranium atom before it is split up plus the mass of the neutron that hits it is more than the mass of all the bits which are produced. This loss of mass is converted into energy.
At this small scale masses are measured in atomic mass units (amu)



Before

Mass of Uranium 235 is	235.043930 amu
Mass of a neutron is	1.008665 amu
Total	236.052595 amu
After	
Mass of Barium 141 is	140.914411 amu
Mass of krypton 92 is	91.926156 amu
Mass of 3 neutrons	3.025995 amu
Total	235.866562 amu

Change = 236.052595 - 235.866562

A loss of 0.186033 amu
This is for one atom.

We can work out how many atoms there are in one kilogram

Avogadro's constant is the number of particles in a mole of the substance. A mole is the atomic mass (235 in this case) expressed in grams. So a mole of uranium is 0.235Kg. Avogadro's number is always the same it is 6.02×10^{23}.
So if we have 1 kg of uranium in a fuel rod we have 1000/235 = 4.25 moles and this contains $4.25 \times 6.02 \times 10^{23} = 2.56 \times 10^{24}$ atoms and so there are **2.56×10^{24} uranium nuclei in 1 Kg of uranium 235.**

Now if we managed to split all of the atoms in one kilogram of uranium (that wouldn't happen in a reactor, they are not that efficient) the change in mass would be:
0.186033 amu x 2.56×10^{24}

= 4.76×10^{23} amu

One amu =$1.66053892 \times 10^{-27}$
so the mass lost in Kg is
$1.66053892 \times 10^{-27} \times 4.76 \times 10^{23}$
which is only 7.9×10^{-4} Kg
which looks very small, less than one gram

but if this is converted to energy we get
E =Mc²
$E = 7.9 \times 10^{-4} \times 3 \times 10^{8} \times 3 \times 10^{8}$

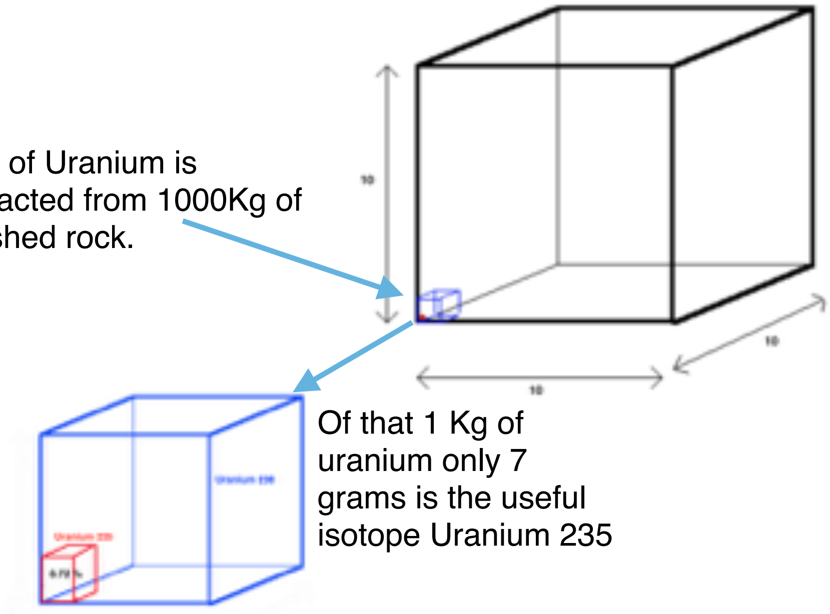
which comes to 7.11×10^{13} joules, which is a lot!

This is a very rough calculation making several assumptions. In reality there are many other ways the atom can split and it is not most certainly possible to split every atom in the fuel.

Fuel for nuclear fission
The Fizzics Organization
www.fizzics.org

Uranium mines are huge. Before the uranium can be extracted the rock has to be crushed. There is only a small percentage of uranium in the ore, generally about 0.1 to 0.25%

1Kg of Uranium is extracted from 1000Kg of crushed rock.



Of that 1 Kg of uranium only 7 grams is the useful isotope Uranium 235

To partly separate the two isotopes they are turned into a lid that will flow usually a gas, uranium hexafluoride. The two isotopes are then separated in a huge centrifuge, however, the difference in density is so small that the separation is far from complete. The concentration of uranium 235 may be around 50%.

Uranium 235
Uranium 235

Have identical chemical properties

The only difference is a slight one of density.

To be useful in a nuclear power station the fuel must have a high percentage of uranium 235 but because the isotopes of uranium have absolutely identical chemical properties the only way of (partly) separating the two is by using the difference in density.

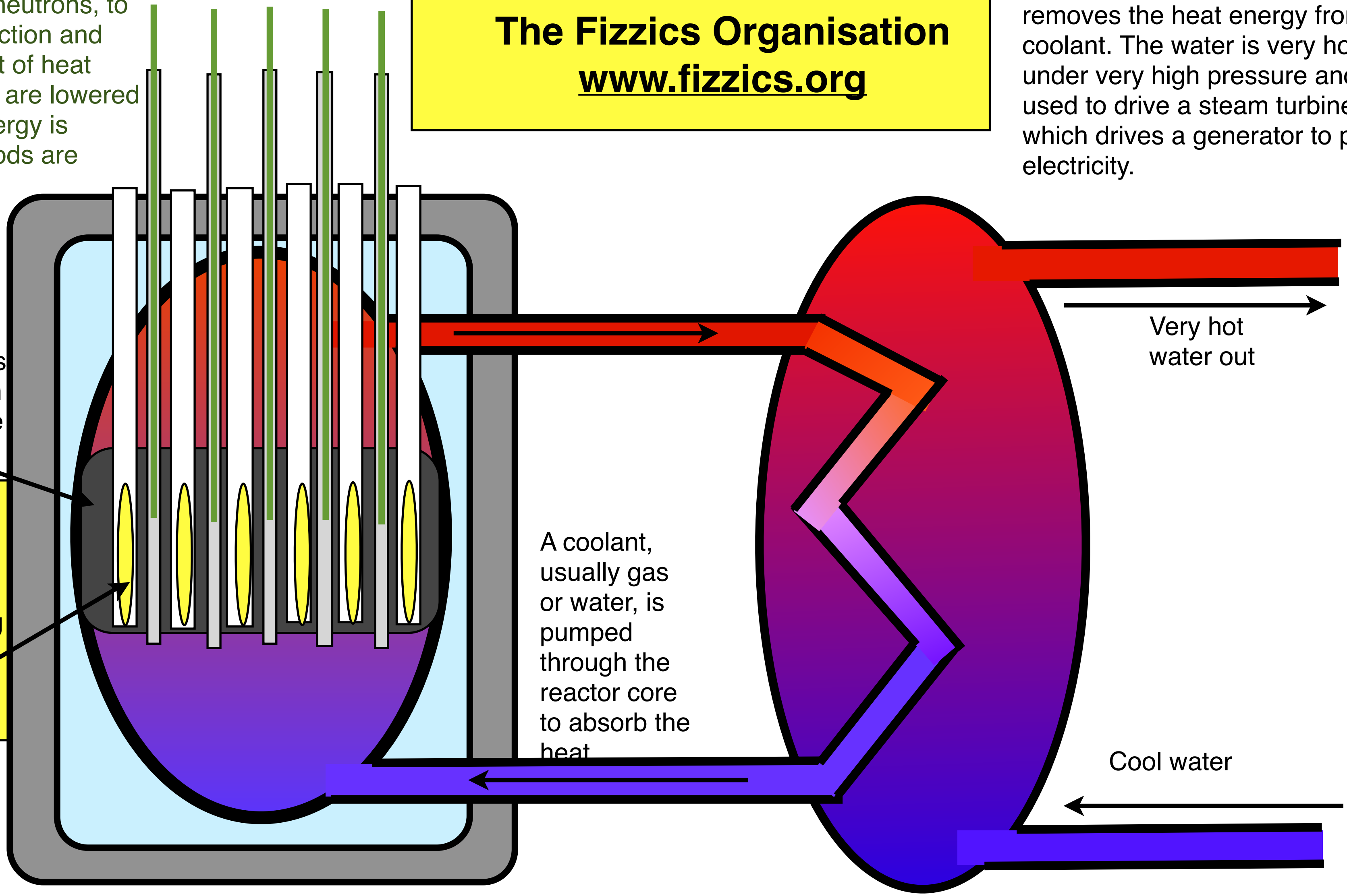
A nuclear reactor
The Fizzics Organisation
www.fizzics.org

The control rods contain boron which will absorb neutrons, to slow down the reaction and reduce the amount of heat produced the rods are lowered further, if more energy is needed then the rods are raised

Water in the heat exchanger removes the heat energy from the coolant. The water is very hot and under very high pressure and is used to drive a steam turbine, which drives a generator to produce electricity.

The graphite is a moderator. It slows the neutrons down so they react more effectively

The fuel is usually uranium 235 or plutonium 239. The neutrons split the atoms producing new elements and a large amount of energy.



Nuclear power

- •Causes no atmospheric emissions
- •A flexible and reliable source of energy
- •Fuel can be recycled to some extent
- •Low cost power production once a power station is set up
- •The fuel is easy to transport

BUT

- •There is a chance of high risk disaster due to accident, earthquake or tidal wave
- •The waste produced is highly radioactive and will remain so for a long time
- •Leaks can cause contamination of the environment
- •The power station is expensive to build
- •The lifetime of a nuclear power plant is limited and it is expensive to demolish at the end of its life.