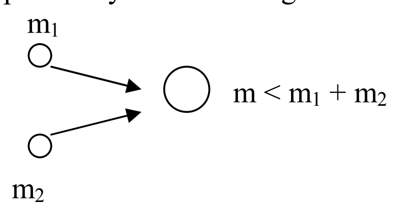
Lecture 6 Feb 9, 2012.
Environmental science FFY471, Env physics FYP350

Elements from the first lecture on
Nuclear energy

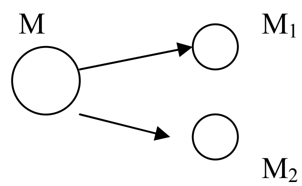
There are two kinds of nuclear reactions leading to energy production:
- fusion, to merge of light atoms to heavier
- fission, to split heavy atoms into lighter

Fusion



The energy gain in the merger is $(m_1+m_2)\,c^2 - mc^2$

Fission



The energy gain in the splitting is $Mc^2 - (M_1 + M_2)c^2$

Per mass unit the energy gains in the processes are vary large. Larger in fusion than in fission.

There is still no technical solution on the fusion reactions, in the sense that we can produce energy from fusion reactors. In the two lectures on nuclear energy we will not discuss fusion any more and concentrate on fission energy.

Basic fission reaction
The conventional fuel atom in a nuclear reactor is the U-235 atom. If this atom is hit by a neutron of the right velocity it can split into two fission products and a number of neutrons. The energy released is as kinetic energy in the fission products.
When the fission products slow down, they heat up the reactor material. Water is passing through the reactor and, usually, brought to boiling. The steam then pass through a turbine with a generator and electrical energy is produced.

The critical phenomenon in the nuclear reactor is the “neutron economy”. Neutrons must be produced in a proper amount and have a proper velocity distribution in order to have operating nuclear reactor.

We will discuss the nuclear energy from a figure of the nuclear fuel cycle.

The fuel cycle starts with the mining of uranium (resources of the energy) , the processing of the ore coming out of the mine and, after several steps, the uranium fuel is delivered to the reactor. The fuel burn in the reactor for some years and is then spent fuel, which lead to waste disposal. So the three points of major interest associated to the fuel cycle are:
- nuclear energy resources - reactor operation - waste disposal

The fuel. The possible energy resources for a reactor.

The most common fuel is U-235.
Plutonium-239, Pu-239, can also burn in a reactor, but Pu-239 do not exist as a energy resource on the earth.

U-235 and Pu-239 (and U-233) are fissile elements. That means that the split into fragments when hit by a neutron. Then there are fertile elements, which can absorb neutrons and be transformed to fissile elements.
Fissile elements can then be produced in a reactor, when running on other elements. This kind of fuel production is called breeding.
Examples of fertile elements are Th-232 (Thorium-232), U-234 and U-238.

In summary, the fission energy resources on earth are uranium and thorium.
Thorium is about three times more abundant in the earth crust than uranium.

Today uranium and U-235 is the sole fuel for nuclear reactors.

Uranium resources
Present annual usage in the world   70 000 tonnes

Concentration in the earth crust   3 ppm

Global resources with a price below a conventional level is 5,5 million tonnes

Known recoverable resources

Australia	1 673 000 tons	31%
Kazakhstan	651 000 tons	12%
Canada	485 000 tons	9%
Russia	480 000 tons	9%

If a higher price is accepted for uranium the reserves will increase by a factor of 10 or so.

Thorium resources
Concentration in earth crust   6 ppm
Known and estimated resources   4,4 mill tonnes

Australia	489 000 t	19%
USA	400 000 t	15%
Turkey	344 000 t	13%
India	319 000 t	12%

The uranium resources with present consumption will last for about 70 years, based on present recoverable resources. If thorium and breeding are introduced in the reactor technology the will probably be fuel for nuclear reactors in the order of thousand years.

Natural uranium contain 99,3 % of U-238 and 0,7 % of U-235. In the most common type of reactors, light water reactors, the fuel is U-235. That means that natural uranium must be enriched to about 3-4 % of U-235.

The fuel element

The fuels to a reactor is delivered in long thin rods. They contain about 97% U-238 and 3% U-235. After 3-4 years in the reactor most of the U-235 has been consumed and the used fuel rods from the reactors have a typical composition of
95% U-238, 3,7% stable fission products, 0,8% plutonium, 0,4% radioactive fission products and 0,1 % other transuraniums than plutonium.

These spent rods makes up the high level waste.

Ionizing radiation

Radioactive materials emit ionizing radiation as α–, β– and γ-radiation.
That the radiation is ionizing means that it causes ionization events in the penetrating material.
α-radiation is He-nuclei.
β-radiation is electron or positrons.
γ-radiation is electromagnetic radiation of short wavelength.

Radiation quantities and effects

Activity, the number of decays per second, is given in the unit Becquerel (Bq).
1 Bq = 1 decay per second.

Absorbed radiation energy per mass unit of absorbing substance defines the quantity dose with the unit Gray (Gy).
1 Gy = 1 J/kg

Equivalent dose is a way to represent the biological effects of ionizing radiation. It is given in the unit Sievert (Sv) and the sievert value is given from the dose multiplied with a quality factor.

Typical radiation values

The background radiation on the earth is about 1 mSv.
An average Swedish citizen receives about 3 mSv per year, most of the radiation from radon.

The lethal dose equivalent is 3-5 Sv.