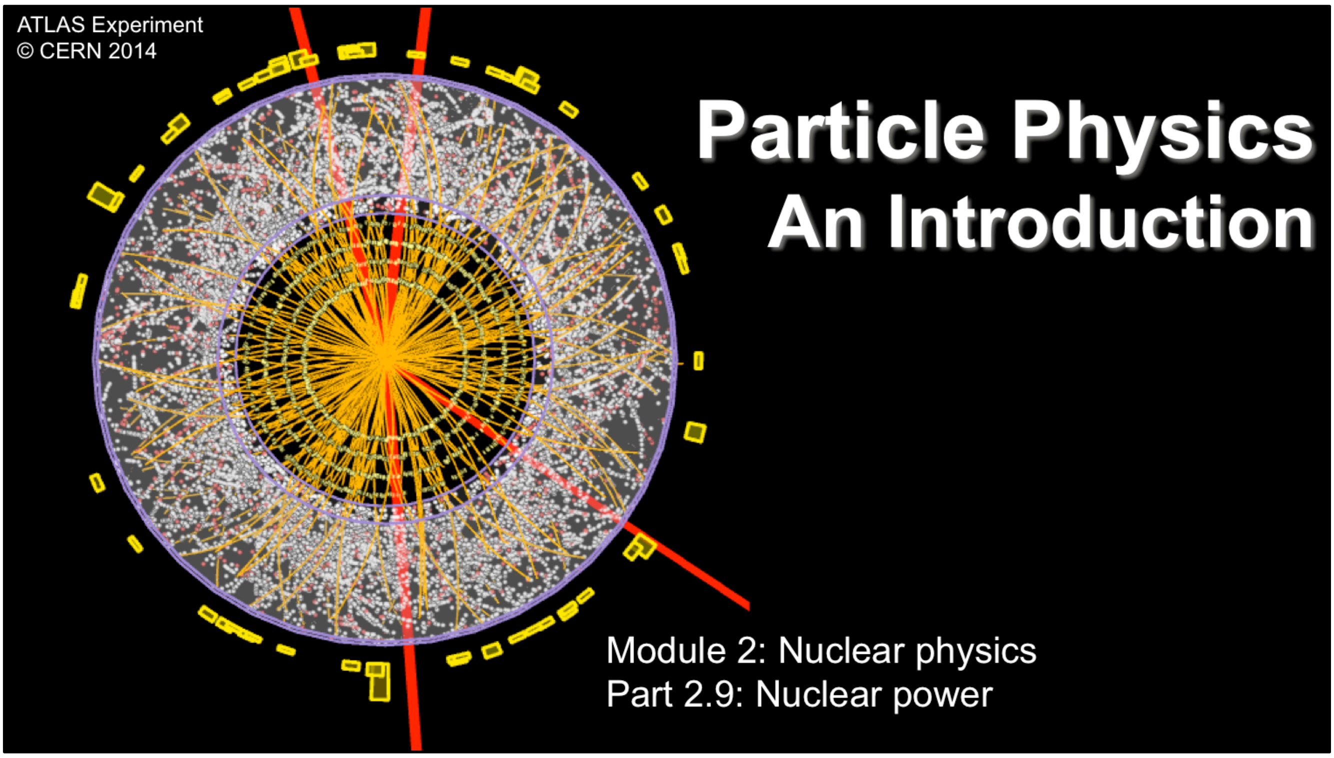
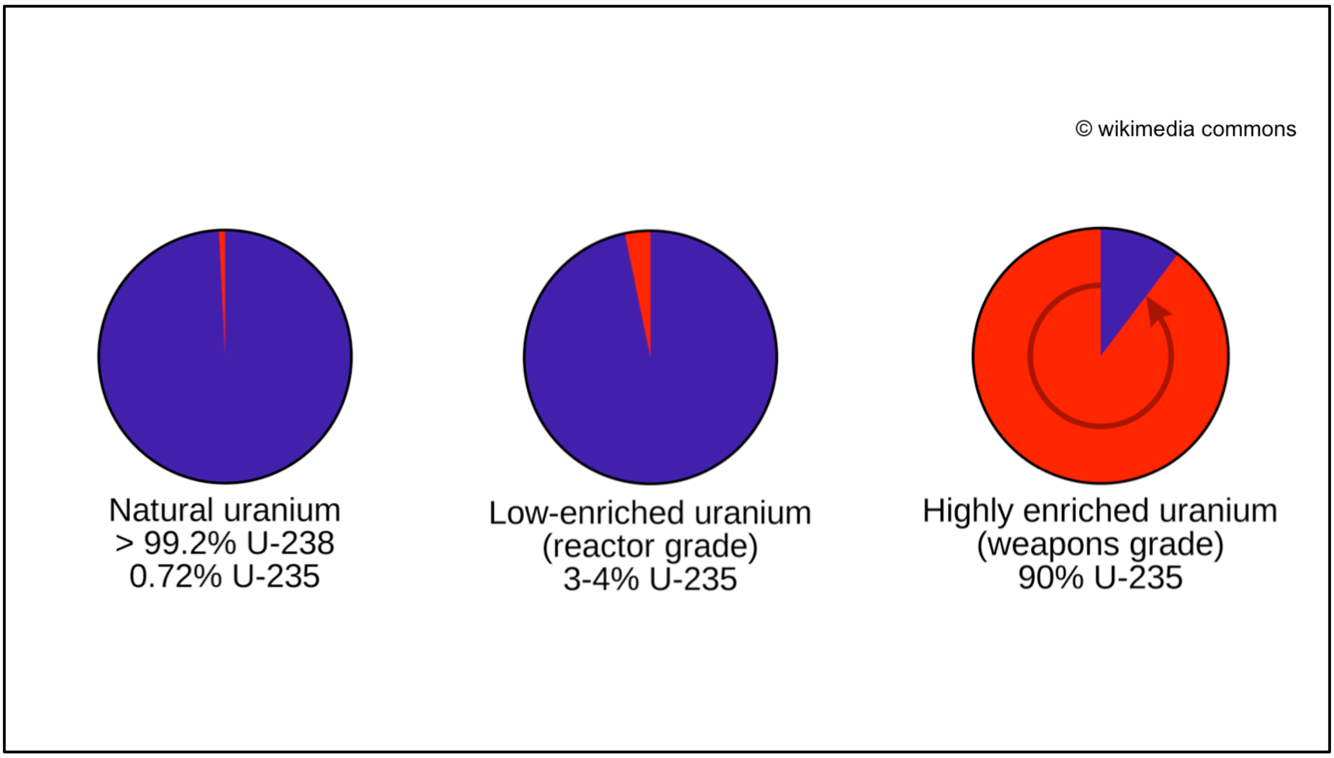


During this second module, we deal with nuclear physics and its applications.

In this 9th video we will continue discussing the transformation of a portion of nuclear binding energy into heat through fission.

After following this video, you will know how fission is used and controlled in nuclear power plants.



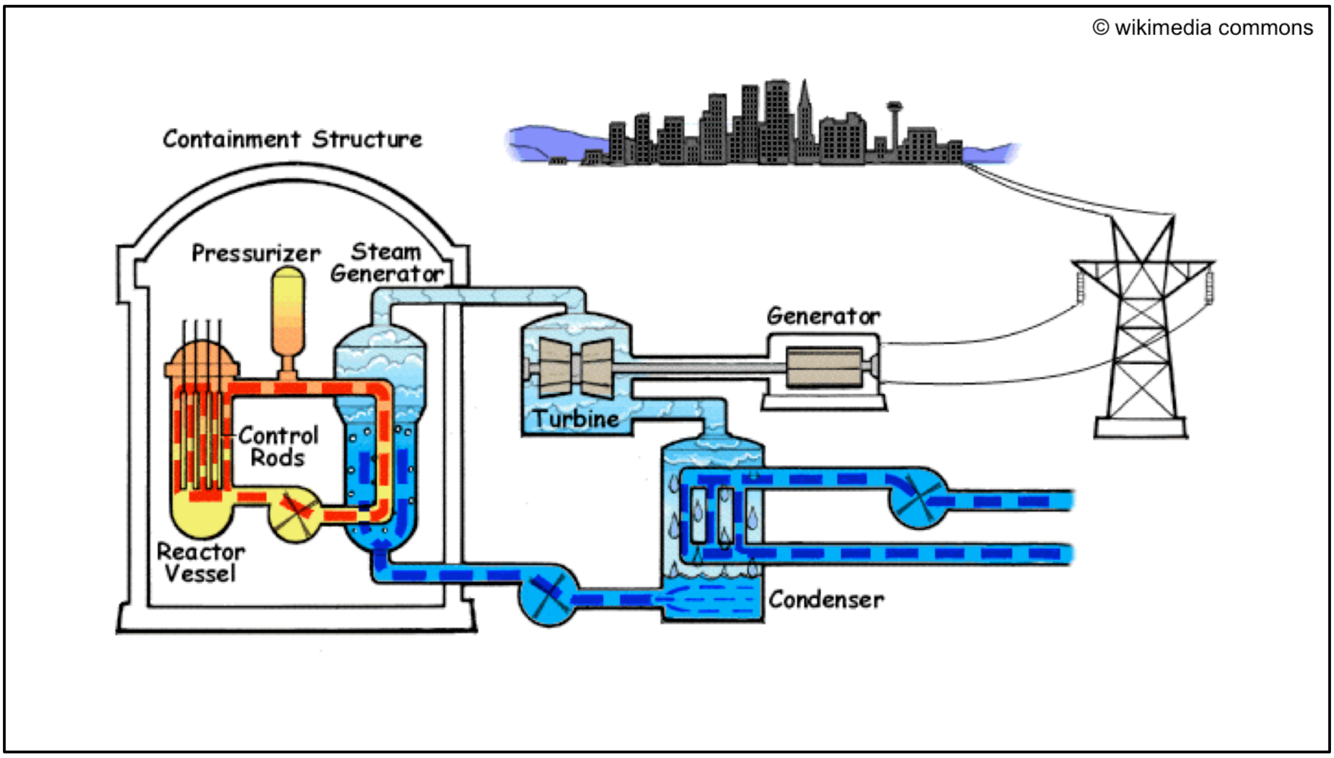
- **Natural uranium** is a mixture of 0.7% ^{235}U and 99.3% ^{238}U. 235U has a five times shorter half-life (7×10^8 y) than ^{238}U (5×10^9 y), the natural mixture therefore has only a small fraction of ^{235}U.
- **Enriched uranium** is a material in which the ^{235}U component has been increased by an isotope separation process. This separation uses the small difference in mass between the isotopes to separate them, e.g. in a gas centrifuge filled with UF_6. In these cylindrical ultracentrifuges, rotation generates an enrichment of the light isotope towards the axis, and the heavier isotope towards the periphery. The devices are used in parallel and in series to obtain the required quantities and levels of enrichment.

- Enriched uranium is a critical component for both **civil and military applications.** A nuclear bomb usually contains at least 85% ^{235}U, but a simple and ineffective weapon can already be obtained with a minimum of 20%.

IAEA

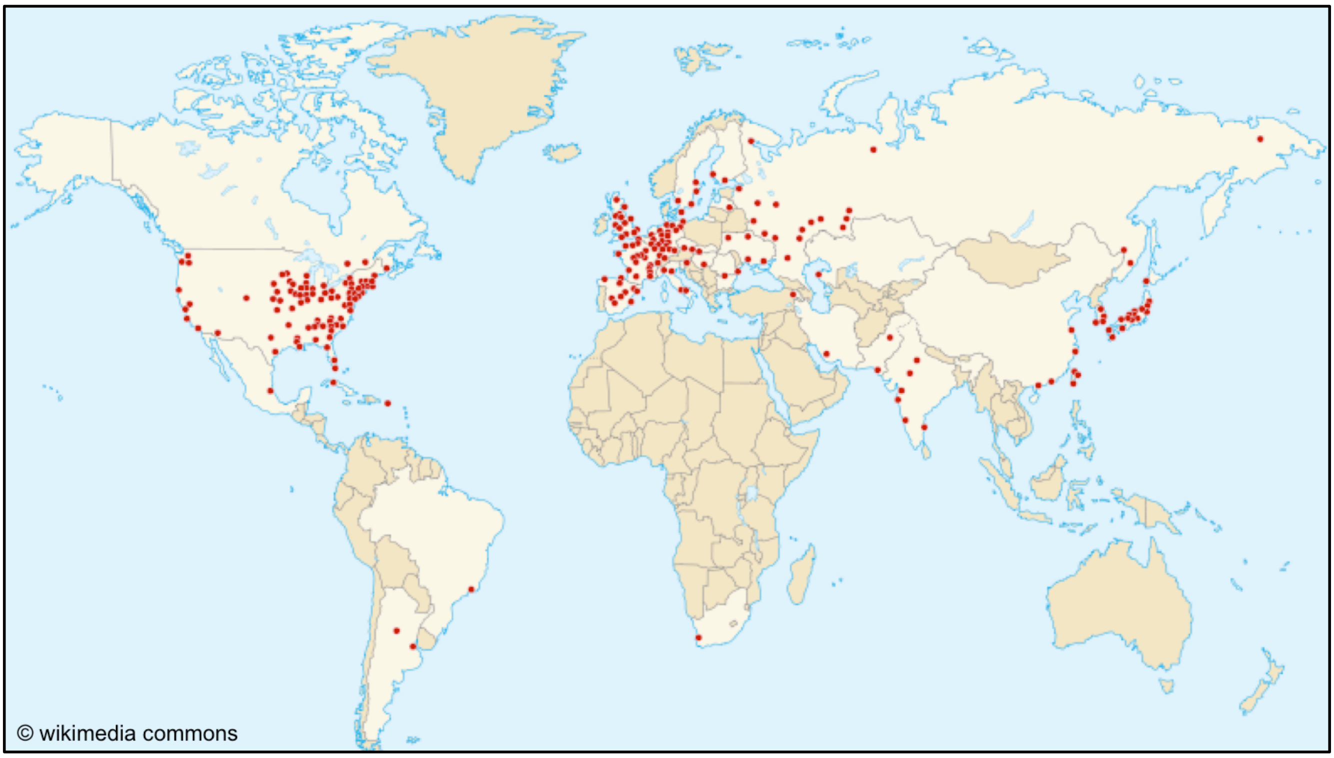
International Atomic Energy Agency

- The **International Atomic Energy Agency**, IAEA, attempts to monitor and control the production and storage of fissile materials.

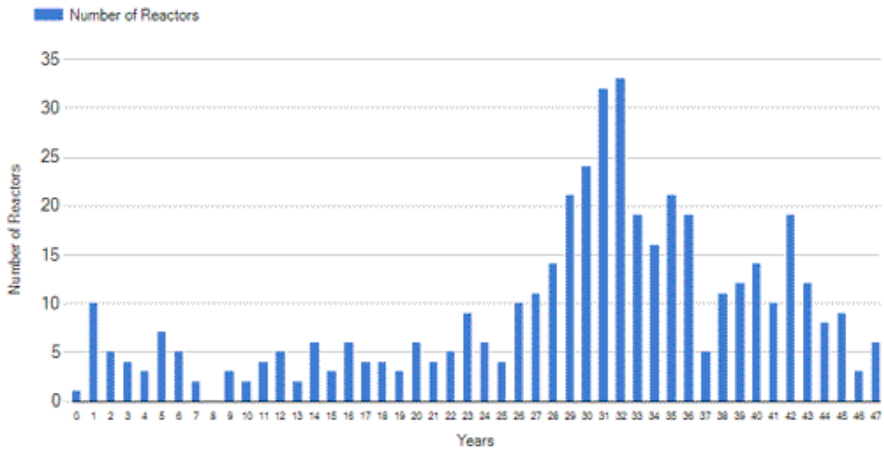


- In the controlled environment of a nuclear reactor, the **chain reaction with k = 1** can be used as a sustained source of energy.
- The **reactor core** contains: **fuel rods** with the fissile material; **control rods** with a neutron absorber; and a **moderator** to reduce the neutron kinetic energy and thermalize them.
- **Thermal neutrons** incident on natural uranium are radiatively captured by ^{238}U and will not cause fission. That's why one uses **uranium enriched to 3-5% of ^{235}U** as fuel in nuclear reactors.
- The **control rods** in a reactor regulate the neutron rate. They are often made of **cadmium** which has a high cross section for neutron absorption. By inserting or removing the rods one manages the **flow of neutrons** and therefore the reaction rate, to keep $k \cong 1$ and therefore a constant power source.
- The role of the **moderator** is to slow down neutrons by scattering, to increase their probability of capture (and therefore increase the fission rate). A material with small absorption cross section is chosen. Water (H_2O) is used in **light water reactors** often found in Western countries. In **research reactors** designed to produce a large flux of neutrons, one also uses heavy water (D_2O) because the cross section for neutron capture in deuterium is smaller than in hydrogen. In reactors of the **RBMK** type, like the Chernobyl power plant, **graphite moderator rods** are used in addition.

- In a **nuclear power plant** the reactor core is immersed in a **cooling liquid** (usually water). Its goal is to collect the heat generated by the core.
- Through a **heat exchanger**, the cooling water is used to produce steam, which will in turn drive **turbines** to generate electricity. At the exit of the turbines, the steam is condensed and recycled. The residual heat is often removed through cooling towers or dumped into rivers.
- The second goal of the coolant is to keep the **core temperature** under control and prevent a meltdown of the core.
- The whole is surrounded by a **containment building** to avoid contamination of the environment by radiation.
- At the **beginning of a cycle**, the value of *k* is set to be slightly above 1 until the desired power level is reached. At this point *k* will be reduced to 1 to have a **stable power source**.



- We already calculated the impressive **maximum energy yield** related to nuclear fission.
- Ignoring the efficiency of power plants and other losses, **1g of uranium is equivalent to 3 tons of coal** in heat output.
- This explains the important usage of this energy source in developed countries. On March 31, 2014, **435 reactors were operating in 31 countries** worldwide with a total installed capacity of 372 GW net; 72 reactors were under construction.
- In 2012, about **10% of global electrical energy** was produced by nuclear power plants.



Number of nuclear reactors worldwide by age as of 2016-02-04 (IAEA 2016)

Source: European Nuclear Society, IAEA

- However most nuclear reactors are **over 20 years old**. The economic crisis in 2008 and the Fukushima nuclear accident caused a decrease in production of nuclear electricity by 4% in 2011 compared to 2010.
- Countries such as Germany, Belgium, Switzerland and Taiwan have announced the **end of their usage** of nuclear power. Other countries no longer engage in nuclear power.
- According to Wikipedia, the construction of 18 reactors appear **several years late**, 9 are under construction since more than 20 years.
- However, the **fight against global warming** and the necessary reduction of **fossil fuels** may change this impression that nuclear fission is a power source in decline.

In the next video we present the principles of nuclear fusion as a source of heat and see how it works in stars and in future plants.