honors (not AP®)

Nuclear Fission & Fusion

Unit: Atomic and Nuclear Physics

MA Curriculum Frameworks (2016): HS-PS1-8

AP® Physics 2 Learning Objectives: N/A

Mastery Objective(s): (Students will be able to…)

- Identify nuclear processes as “fission” or “fusion”.
- Describe the basic construction and operation of fission-based and fusion-based nuclear reactors.

Success Criteria:

- Descriptions account for how the energy is produced and how the radiation is contained.

Language Objectives:

- Explain how fission-based and fusion-based nuclear reactors work.

Tier 2 Vocabulary: fusion, nuclear

Notes:

Fission

fission: splitting of the nucleus of an atom, usually by bombarding it with a high-speed neutron.

When atoms are split by bombardment with neutrons, they can divide in hundreds of ways. For example, when ^{235}U is hit by a neutron, it can split more than 200 ways. Three examples that have been observed are:

$$^{1}_{0}n + ^{235}_{92}\text{U} \rightarrow ^{90}_{37}\text{Rb} + ^{144}_{55}\text{Cs} + 2\,^{1}_{0}n$$
$$^{1}_{0}n + ^{235}_{92}\text{U} \rightarrow ^{87}_{35}\text{Br} + ^{146}_{57}\text{La} + 3\,^{1}_{0}n$$
$$^{1}_{0}n + ^{235}_{92}\text{U} \rightarrow ^{72}_{30}\text{Br} + ^{160}_{62}\text{Sm} + 4\,^{1}_{0}n$$

Note that each of these bombardments produces more neutrons. A reaction that produces more fuel (in this case, neutrons) than it consumes will accelerate. This self-propagation is called a chain reaction.

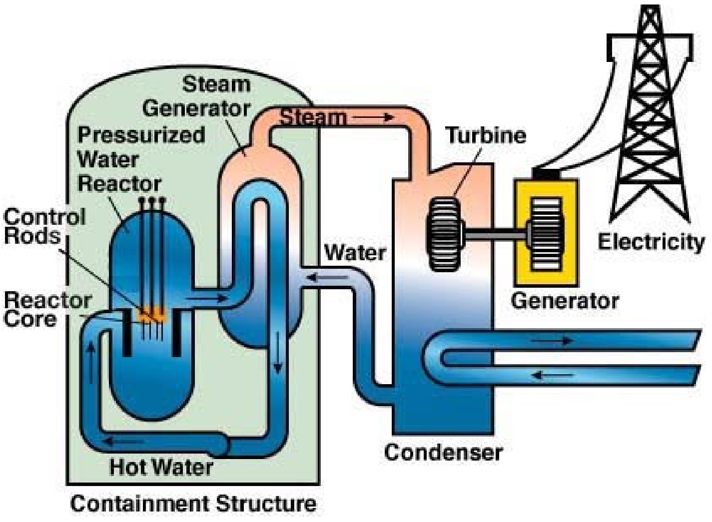
Note also that the neutron/proton ratio of ^{235}U is about 1.5. The stable neutron/proton ratio of each of the products would be approximately 1.2. This means that almost all of the products of fission reactions have too many neutrons to be stable, which means they will themselves undergo $\beta-$ decay.

Use this space for summary and/or additional notes:

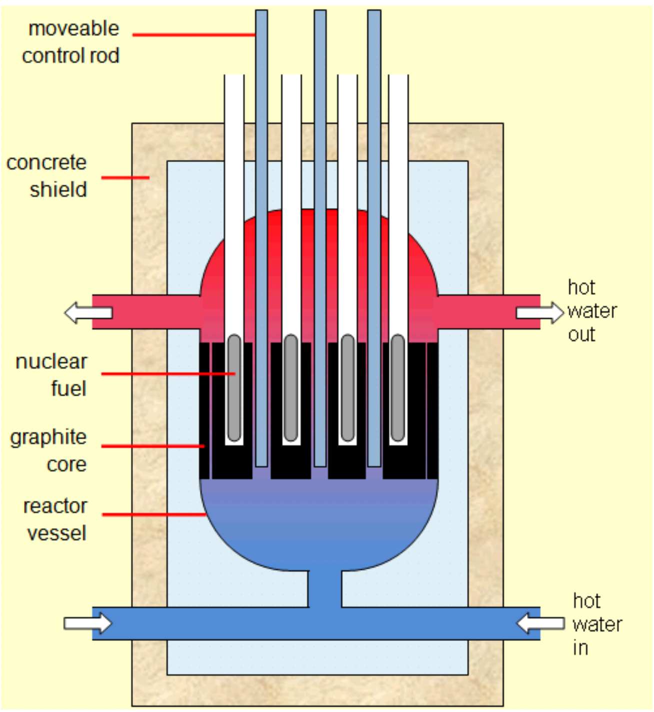
honors (not AP®)

Nuclear Fission Reactors

In a nuclear reactor, the heat from a fission reaction is used to heat water. The radioactive hot water from the reactor (under pressure, so it can be heated well above 100 °C without boiling) is used to boil clean (non-radioactive) water. The clean steam is used to turn a turbine, which generates electricity.



The inside of the reactor looks like this:



The fuel is the radioactive material (such as ^{235}U) that is undergoing fission. The graphite in the core of the reactor is used to absorb some of the neutrons. The moveable control rods are adjusted so they can absorb some or all of the remaining neutrons as desired. If the control rods are all the way down, all of the neutrons are absorbed and no heating occurs. When the reactor is in operation, the control rods are raised just enough to make the reaction proceed at the desired rate.

Use this space for summary and/or additional notes:

honors (not AP®)

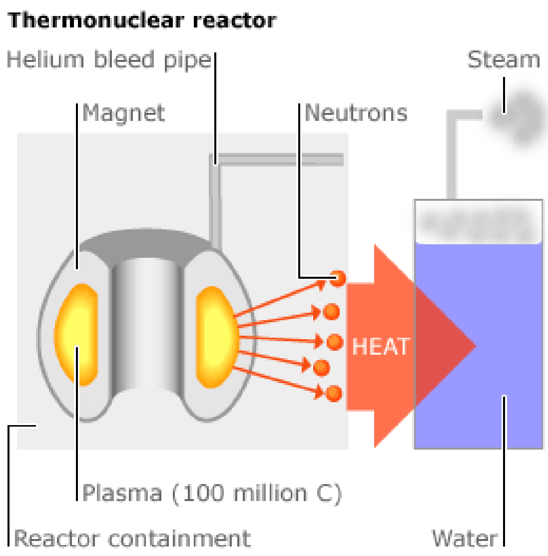
Fusion

<u>fusion</u>: the joining together of the nuclei of two atoms, accomplished by colliding them at high speeds.

Nuclear fusion reactions occur naturally on stars (such as the sun), and are the source of the heat and energy that stars produce.

On the sun, fusion occurs between atoms of deuterium (^{2}H) to produce helium:

$$^{2}_{1}\text{H} + ^{2}_{1}\text{H} \rightarrow ^{4}_{2}\text{He}$$



The major challenge in building nuclear fusion reactors is the high temperatures produced—on the order of $10^{6} – 10^{9}$ °C. In a tokamak fusion reactor, the starting materials are heated until they become plasma—a sea of highly charged ions and electrons. The highly charged plasma is kept away from the sides by powerful electromagnets.

At the left is a schematic of the ITER tokamak reactor currently under construction in southern France.

MIT has a smaller tokamak reactor at its Plasma Science & Fusion Center. The MIT reactor is able to conduct fusion reactions lasting for only a few seconds; if the reaction continued beyond this point, the current in the electromagnets that is necessary to generate the high magnetic fields required to confine the reaction would become hot enough to melt the copper wire and fuse the coils of the electromagnet together.

After each "burst" (short fusion reaction), the electromagnets in the MIT reactor need to be cooled in a liquid nitrogen bath (−196 °C) for fifteen minutes before the reactor is ready for the next burst.

Use this space for summary and/or additional notes: