

Activity 17 Solutions: Nuclear Energy Use

As you watch the videos in class today, look for a pro-nuclear or anti-nuclear bias on the part of the video producers, narrators, and interviewers. Which ones had a very evident bias?

While most of the video clips seem to have no blatant bias, a few do. The video clips of the breeder reactor (made in the 1960's) seem pro-nuclear, while Donahue seems anti-nuclear as does the clip of the Simpsons. The clip about nuclear waste disposal seems to have a pro-nuclear bias.

17.1 Electrical Energy from Nuclear Reactors

1) Fission Reactions

- a) What happens to a uranium-235 (${}_{92}^{235}\text{U}$) nucleus during a fission reaction?

Fission involves the breaking apart of large nuclei into smaller nuclei. A uranium-235 nucleus splits into smaller fission fragments.

- b) What reaction products are released when a U-235 nucleus fissions?

Fission fragments, fast-moving neutrons, and energy are released.

- c) What is a nuclear chain reaction?

The neutrons released by a fissioning uranium-235 nucleus are slowed and absorbed by other U-235 nuclei, causing these nuclei to fission and release neutrons.

2) Components of Nuclear Fission Reactors

- a) What is the purpose of the moderator in a nuclear reactor? What are two of the substances that may be used as moderators?

The moderator slows down neutrons so that these neutrons can be absorbed by uranium-235 nuclei, causing the nuclei to fission.

- b) What is the purpose of control rods in a nuclear reactor?

Control rods absorb neutrons to slow down the rate of fission reactions.

- c) List three other components of a nuclear reactor.

Fuel rods provide the uranium-235 nuclei.

Coolant keeps the radioactive material from overheating.

The containment system encloses the nuclear reactor and prevents radioactive material from escaping in the case of an accident.

- d) How is the thermal energy from uranium-235 fissions converted into electrical energy?

A heat exchanger transfers thermal energy from the fission reactions to a container of water. The water is converted into steam. The steam pressure turns turbines, which spin magnets near coils of wire in the generator.

3) Nuclear reactor fuel

- a) Which uranium isotope is most common in naturally occurring uranium ores?

Uranium ore is about 99.3% uranium-238.

- b) Which isotope is required for fission reactions?

Uranium-235 is required for fission reactors.

- c) What is meant by "enriched" uranium?

Enriching uranium ore increases the percentage of uranium-235 by separating off and taking away uranium-238 from the naturally-occurring uranium.

17.2 Reactor Safety

4) Chernobyl Nuclear Reactor

- a) What was the result of the loss of coolant at the Chernobyl nuclear reactor?

A mishandled safety exercise (exacerbated by a critical design flaw) caused an uncontrolled fission chain reaction. The water coolant boiled into steam molecules, which dissociated into atoms of hydrogen and oxygen. These atoms recombined explosively, blowing the lid off the reactor core and causing the graphite moderator to catch on fire.

- b) What was the main safety concern immediately after the accident?

Initially, there was concern that there might be enough fuel concentrated below the reactor core to undergo another uncontrolled chain reaction. The fuel was found to have mixed with sand and glassified and was not concentrated enough to sustain such a reaction.

- c) Presently, what is the greatest danger at Chernobyl?

Presently, the greatest danger is that the massive reactor lid could fall and cause a great deal of radioactive dust to escape through the holes in the sarcophagus and spread into the atmosphere.

5) Types of nuclear accidents: meltdowns and uncontrolled chain reactions

- a) What was the result of the loss of coolant at the Three Mile Island nuclear reactor?

A loss of coolant left the fuel rods partially exposed for 40 minutes. The heat generated by these fuel rods caused a partial meltdown of a portion of the reactor core.

- b) What is the difference between a meltdown and an uncontrolled chain reaction? Which situation is worse?

An uncontrolled chain reaction, which occurred at Chernobyl, is a more dire circumstance than a meltdown, which occurred to a limited extent at Three Mile Island. Loss of coolant in a Chernobyl-type reactor may result in an uncontrolled chain reaction, in which the fission rate accelerates out of control, and may result in an explosion or meltdown. A meltdown may even occur without an uncontrolled chain reaction due to the remaining heat generated by the decaying fission fragments.

- c) What could be done to the fuel in a nuclear reactor so that the reactor could function normally after a loss of coolant?

A meltdown or uncontrolled chain reaction can be prevented if the uranium fuel is in small pieces coated with heat-resistant ceramic material. The ceramic pellets are spread out to dissipate heat. The German reactor shown in the video is cooled with helium gas. However, other coolants could work as well with ceramic-coated fuel.

17.3 Types of Conventional Nuclear Reactors

6) Three types of reactors

- a) Reactors can be classified on the basis of the moderator and coolant used. What are the three main types of nuclear reactors?

Reactors that use fuel rods and are graphite moderated and water cooled. (Chernobyl type)

Reactors that use fuel rods and are water moderated and water cooled.

Reactors that use widely separated ceramic-coated fuel pellets. These reactors are graphite or water moderated and may be water cooled or gas cooled.

- b) Which of these types is the most dangerous?

Graphite moderated, water cooled reactors are the most dangerous because they can experience uncontrolled chain reactions if the water coolant is lost.

- c) What is the safest type of nuclear reactor?

Reactors using small heat resistant, ceramic-coated pellets of fuel are the safest. The fuel is distributed in small amounts so that the reactor cannot reach a dangerously high temperature. Such reactors can use water or gas as the coolant and can shut down safely in the case of a loss of coolant.

- d) Does the U.S. have the newest, safest nuclear reactors? Why or why not?

The reactors in operation in the U.S. are water moderated and cooled reactors, which are much safer than the Chernobyl type reactors but not as safe as the newer reactors, which use small pellets of fuel.

The reason that the U.S. does not have the newest, safest reactors is that no new nuclear reactors have been built in the U.S. since the Three Mile Island accident.

- e) Group Discussion Question: What is the benefit of using water as both the moderator and the coolant in a nuclear reactor?

7) *Consequences of using nuclear power*

- a) How does the price of environmental and health risks from nuclear power plants compare to the price of these risks from coal-burning power plants?

The risk from nuclear power plants is low when reactors are operating properly. However, the risk is unpredictable because a single nuclear accident can cause much damage. The risk from coal-burning plants is high in terms of greenhouse gas and acid rain emission. However, these risks are predictable.

- b) Compare the advantages and disadvantages of nuclear power with other energy sources.

Nuclear reactions can produce a million times more energy than chemical reactions, such as burning fossil fuels. Nuclear power plants do not produce greenhouse gases or acid rain. However, there can be problems with the safety of nuclear reactors and the safe disposal of nuclear waste disposal.

17.5 Radioactive Waste Disposal, Part 1

8) *Storing nuclear waste*

- a) How does the video suggest that radioactive nuclear waste be stored?

Spent radioactive fuel rods would be sealed in canisters to be buried underground in waste disposal sites.

- b) How long will it take for radioactive waste to reach radiation levels on the order of natural background radiation?

Keep in mind that there is high level radioactive waste, such as spent fuel rods, and low level radioactive waste coming from many other sources. According to the video clip seen in class, higher level radioactive waste will become less radioactive by a factor of 30,000 in 1000 years and in 10,000 years will be less radioactive than uranium ore (such as that seen in class).

- c) What problems can you foresee in trying to find a place to store it for this length of time?

10,000 years is a long time! We may choose a storage facility to be in a relatively uninhabited, geologically stable region, but who is to say what that region will be like 10,000 years from now.

17.6 Breeder Reactors

9) Breeder reactor fuel

- a) What is the fuel used in a conventional nuclear reactor?

The relatively scarce U-235 (Only 0.7% of natural uranium is the U-235 isotope.)

- b) What fuel is used in a breeder reactor?

Plutonium-239. Breeder reactor fuel is 85% plentiful uranium-238 and 15% plutonium-239.

- c) Why don't breeder reactors need a moderator?

Fast neutrons can induce fission in plutonium-239, so no moderator is needed to slow down the neutrons.

- d) What is the main advantage of a breeder reactor over a conventional reactor?

Breeder reactors use the fission of plutonium-239 and the accompanying fast neutrons to turn uranium-238 into plutonium-239. In this way, breeder reactors produce more plutonium-239 than the amount of plutonium used to operate the reactor.

The supply of uranium-235 used by conventional reactors is limited. The uranium-238 used by breeder reactors is much more plentiful than the uranium-235 used by conventional reactors.

- e) What is a potential danger of reactors that breed more plutonium than they use?

Unlike the byproducts of conventional reactors, the plutonium produced in breeder reactors can be converted into nuclear weapons.

17.7 Radioactive Waste Disposal, Part 2

10) Storing nuclear waste

- a) Where are spent radioactive fuel rods currently stored in the U.S.?

Currently, the spent fuel rods are stored at the site of the nuclear reactor in which they were used.

- b) Where does the U.S. government propose storing spent fuel rods?

Spent radioactive fuel rods would be sealed in canisters and buried inside tunnels in Yucca Mountain, Nevada.

- c) What are some potential dangers to this storage plan?

Some scientists believe that radioactive waste stored in Yucca Mountain would be susceptible to damage from earthquakes and underground water. Some scientists believe the stored fuel could explode.

- d) Why would any community want to store nuclear waste?

Storing nuclear waste would provide income to a community from jobs and licensing fees.

17.7 Fusion Reactions

11) Fusion Reactions

- a) What happens during a fusion reaction?

Fusion involves the joining of smaller nuclei to make larger nuclei. Hydrogen nucleus (a proton) can fuse with neutron to form deuterium. Two deuterium nuclei can fuse into a helium nucleus.

- b) In which reaction is more energy released – fission or fusion? Why is more energy released?

More energy is released during a fusion reaction because the difference in mass (and, thus, binding energy) between the reactants and their products is greater in a fusion reaction.

- c) Where do fusion reactions occur?

In the core of stars and in some nuclear bombs

- d) What would be the advantage of generating electricity using a fusion reaction rather than a fission reaction?

Hydrogen is plentiful on Earth (from water) and the reaction produces a very high energy yield.

- e) What is the main difficulty with sustaining a controlled fusion reaction?

Temperatures of nearly a million degrees are required to provide the activation energy, and that is too hot for any material to hold the reactants. The reactants must be held in place using very strong magnetic forces and this isn't a trivial problem.