Nuclear Chemistry

IN THE NEWS
NUCLEAR POWER PLANT
HEAT ENERGY
TYPES OF REACTIONS
NUCLEAR DECAY – Types & Half life
BIOLOGICAL EFFECTS
OTHER INTERESTING STUFF

In the News: Clicker Question 1

- There is currently a nuclear emergency in Japan. The emergency was brought on because the flow of cooling water in nuclear reactors was interrupted. Cooling water interruptions were the cause of the following incidents as well:
  - A. There have been no other situations similar to the Japan situation
  - B. Cooling water was the initial problem at Chernobyl
  - C. Cooling water was the initial problem at 3 Mile Island
  - D. Cooling water was the problem at both Chernobyl and 3 Mile Island

IN THE NEWS

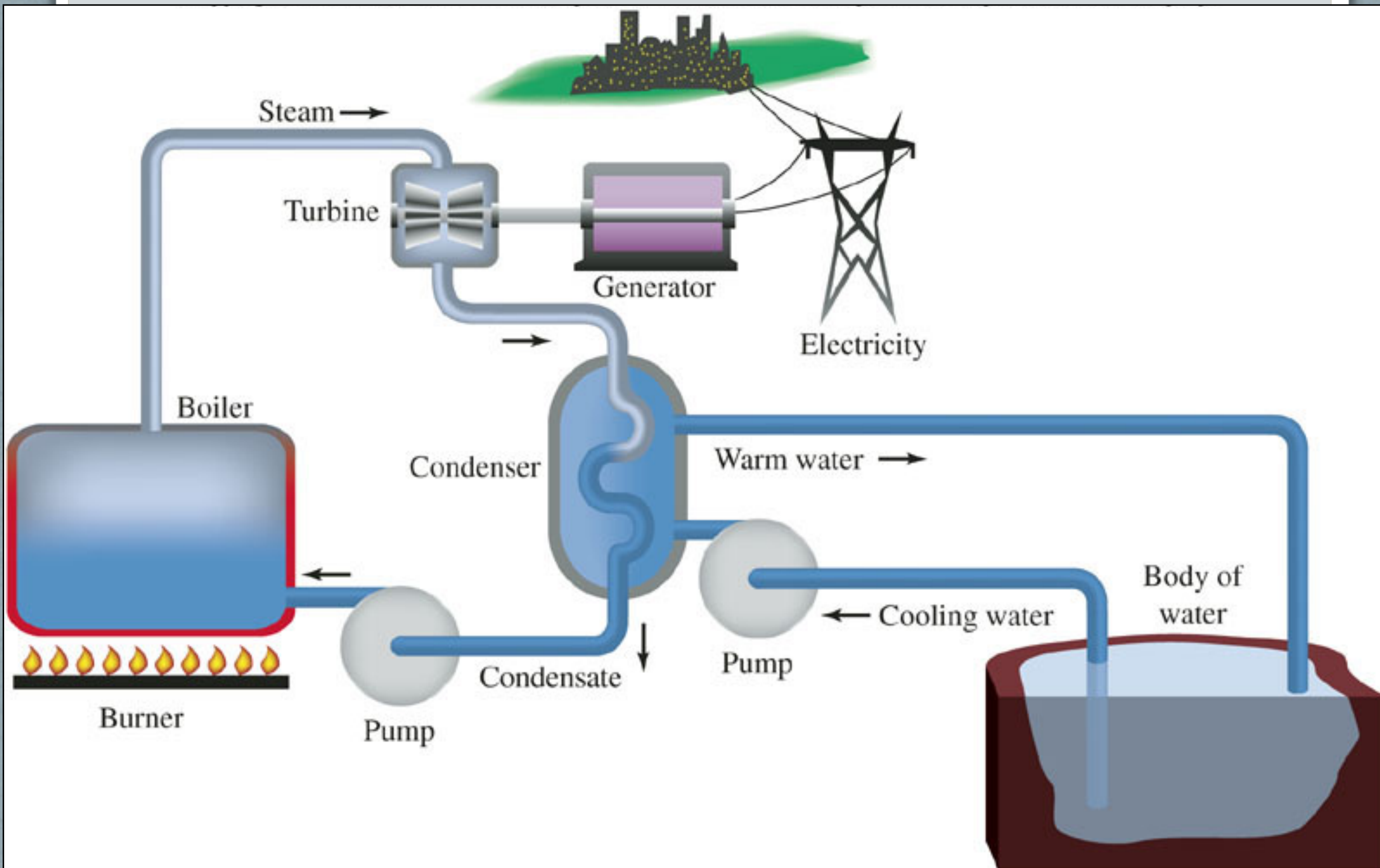
- http://video.nytimes.com/video/2011/03/11/world/asia/100000000718996/tc-031111.html

Nuclear Chemistry

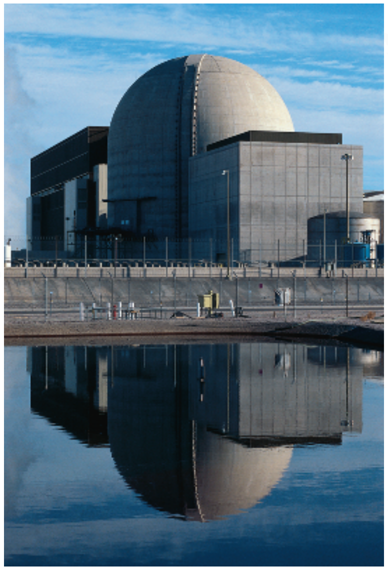
- http://www.youtube.com/watch?v=rBvUtY0PfB8

- Nuclear Power Plant
- Nuclear Reactions
- Energy
- Issues
- Radioactive Decay
- Biological Hazards

Diagram of a Conventional Power Plant



Schematic of a Nuclear Reactor



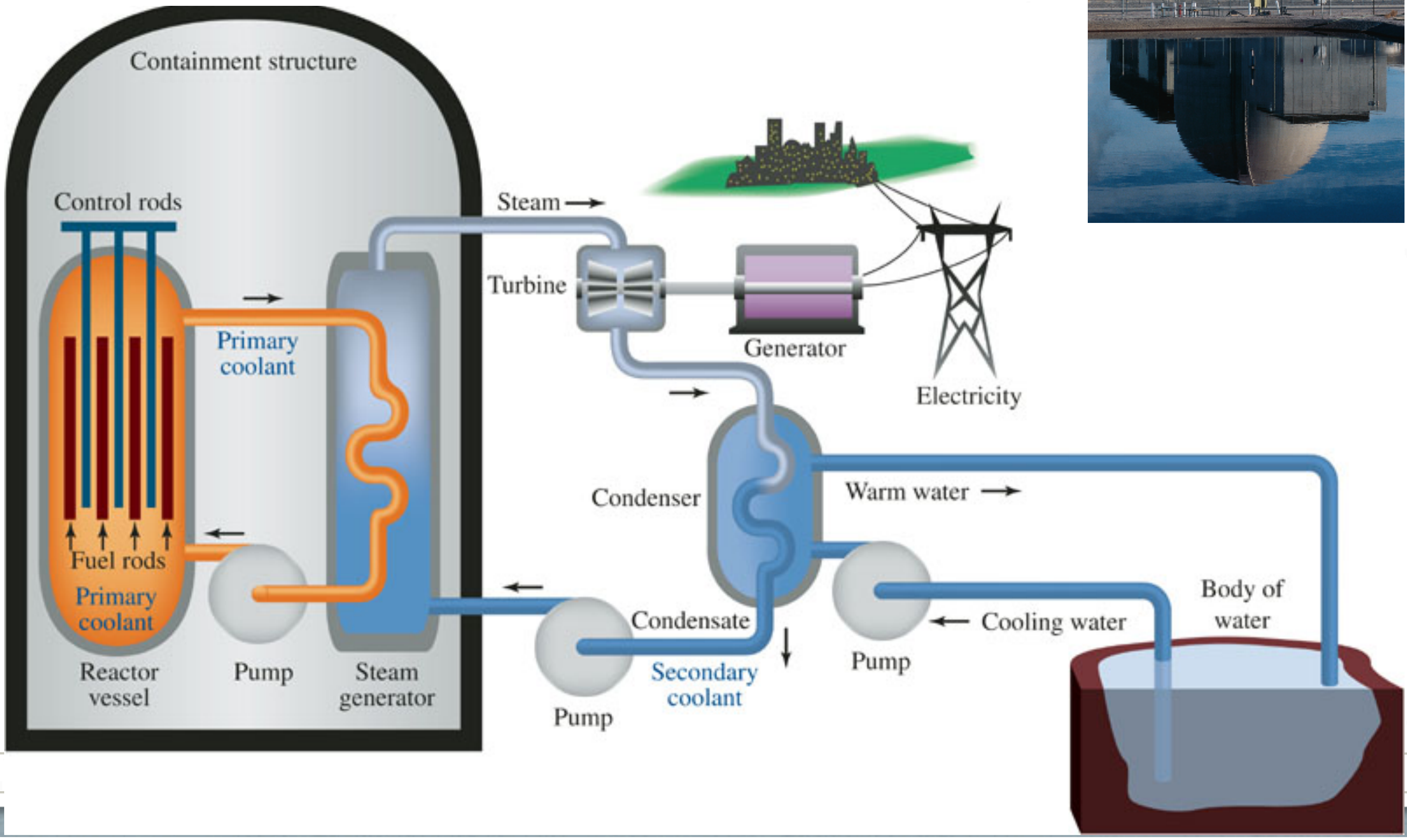
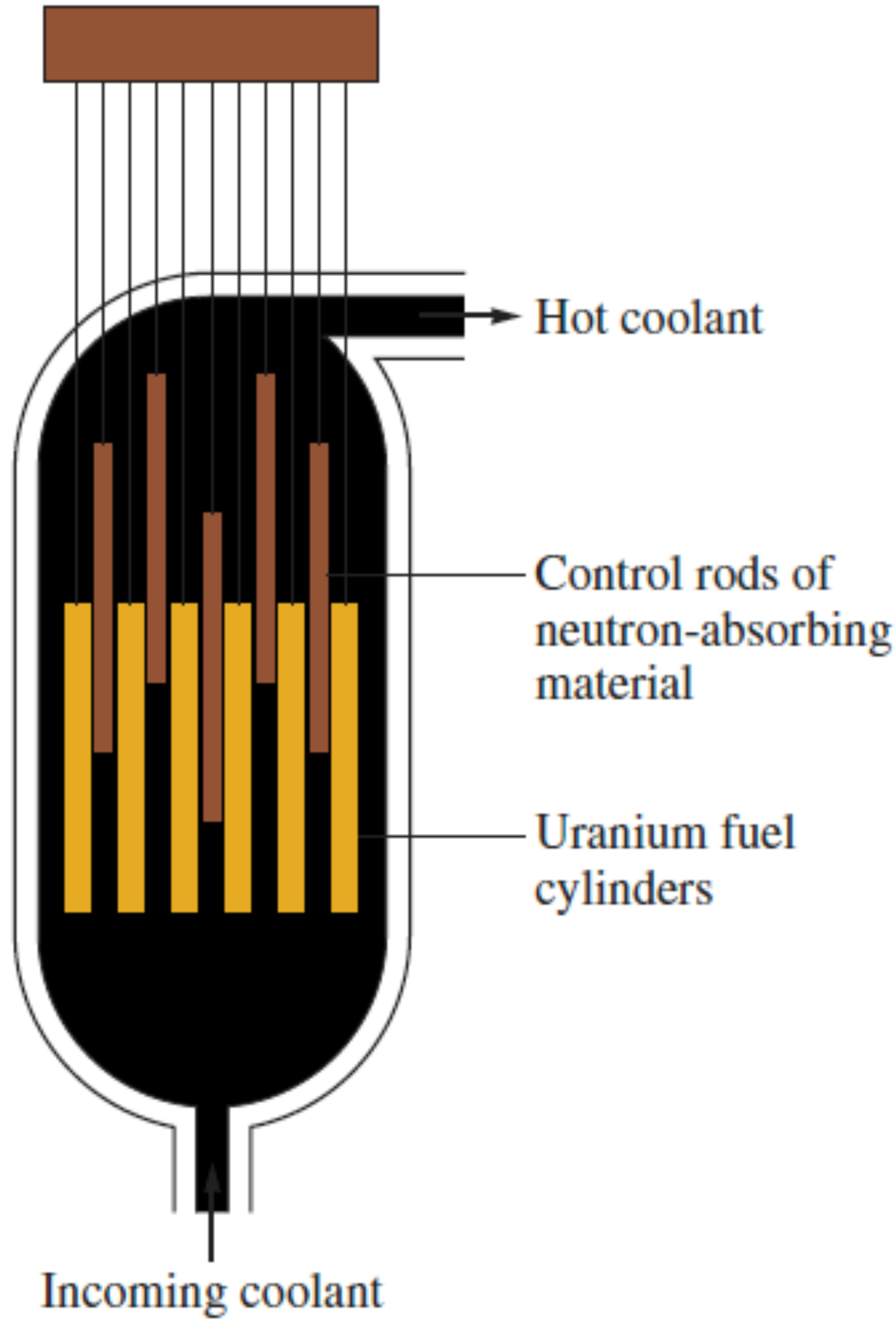


FIGURE 20.15

A schematic of a reactor core. The position of the control rods determines the level of energy production by regulating the amount of fission taking place.

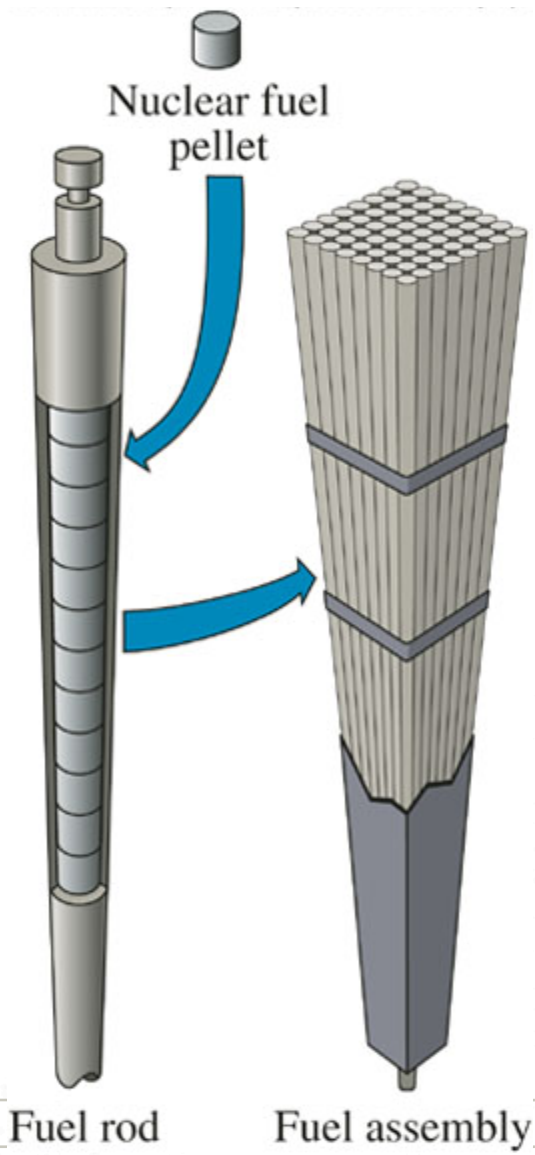


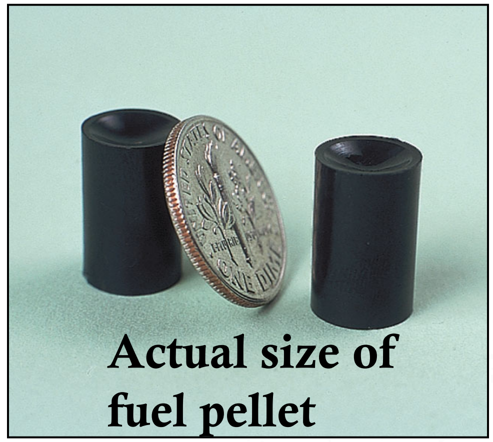
Nuclear power - Details

- Control rods – made from excellent neutron absorbers like cadmium or boron – moderate (control) the neutron intensity and the rate (speed) of the reaction.
- The primary coolant is the liquid that comes into contact with the reactor core, typically boric acid, H_3BO_3. It also moderates the neutrons' energy to make them more effective.
- The secondary coolant transfers the heat from the primary coolant as hot steam to drive a turbine generator.
- The steam is cooled back to liquid water and pumped back into the heat exchanger to continue the cycle.
- A considerable amount of waste heat is either given off as steam into the atmosphere or transferred to lakes, rivers or the ocean. There are important environmental considerations.

Basics of a Nuclear Reactor

An awesome source of electrical energy— but what to do with the spent nuclear fuel?





core

Cooling tower

Enriched Uranium

- Out of the ground - UO_2 and UO_3 mixed with other minerals in the form of rocks.
- 0.7 % U-235
- 3 % U-235
- 90 % U-235

Spent Fuel Cells

- Stored on site in pools of water, as they continue to cool down
- Packaged in ceramic containers and stored in barrels on site, until permanent storage facility is located

Proposed High Level Nuclear Waste Storage in Yucca Mountain, Nevada

A worker in one of the Yucca mountain tunnels

Clicker Question 2

- Did a nuclear explosion occur at the Fukushima plant?
- A) Yes, but only at 4 of the 6 reactors.
- B) No, but experts expect a nuclear explosion to occur if the situation isn't brought under control soon
- Yes, all of the reactors have had nuclear explosions to varying degrees
- No, there have been no nuclear explosions, nor do experts believe that a nuclear explosion will occur at the facility

Take a closer look at Fukushima power plant…

- Status of the 6 reactors:
- http://www.nytimes.com/interactive/2011/03/16/world/asia/reactors-status.html

Chernobyl-What Happened: April 26, 1986

Operator error – cooling water mistake

Explosion

9 tons of nuclear material blown into sky
100 times normal background radiation

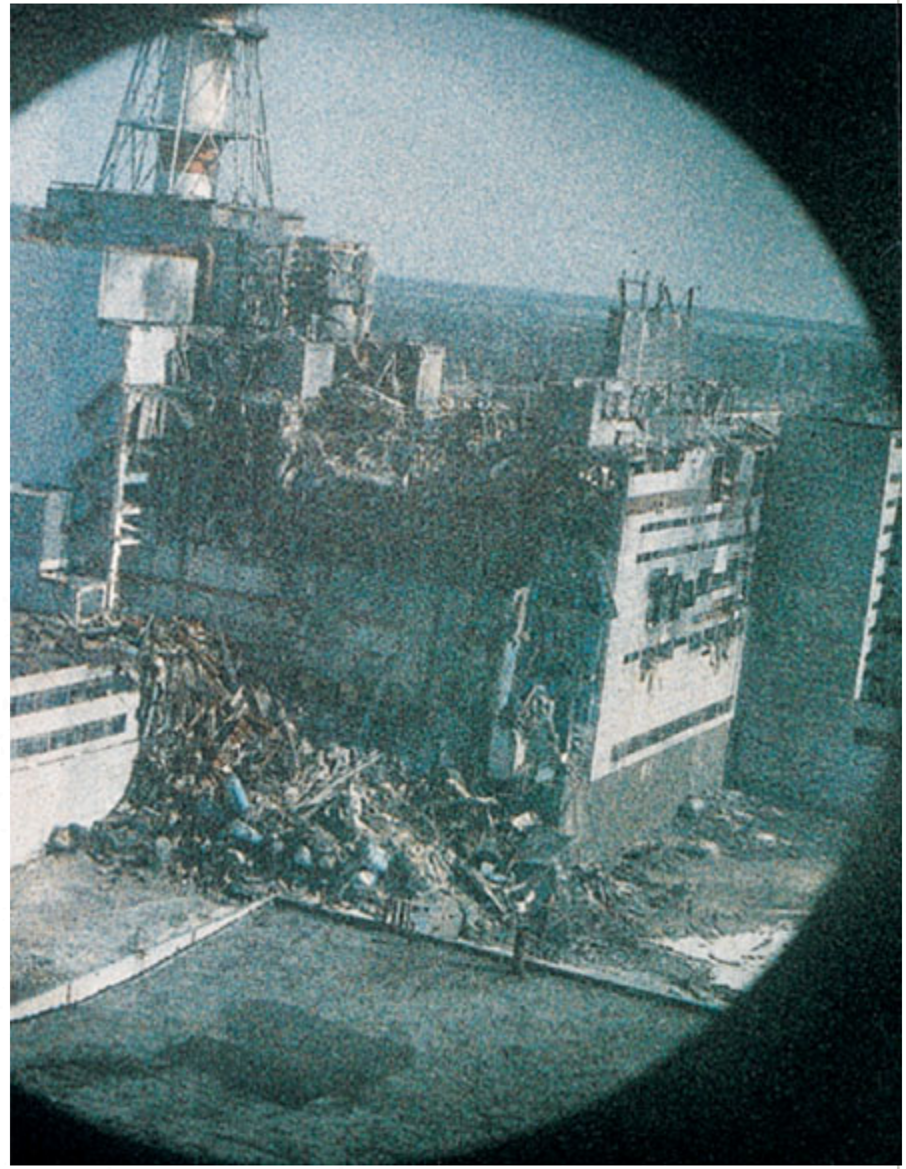
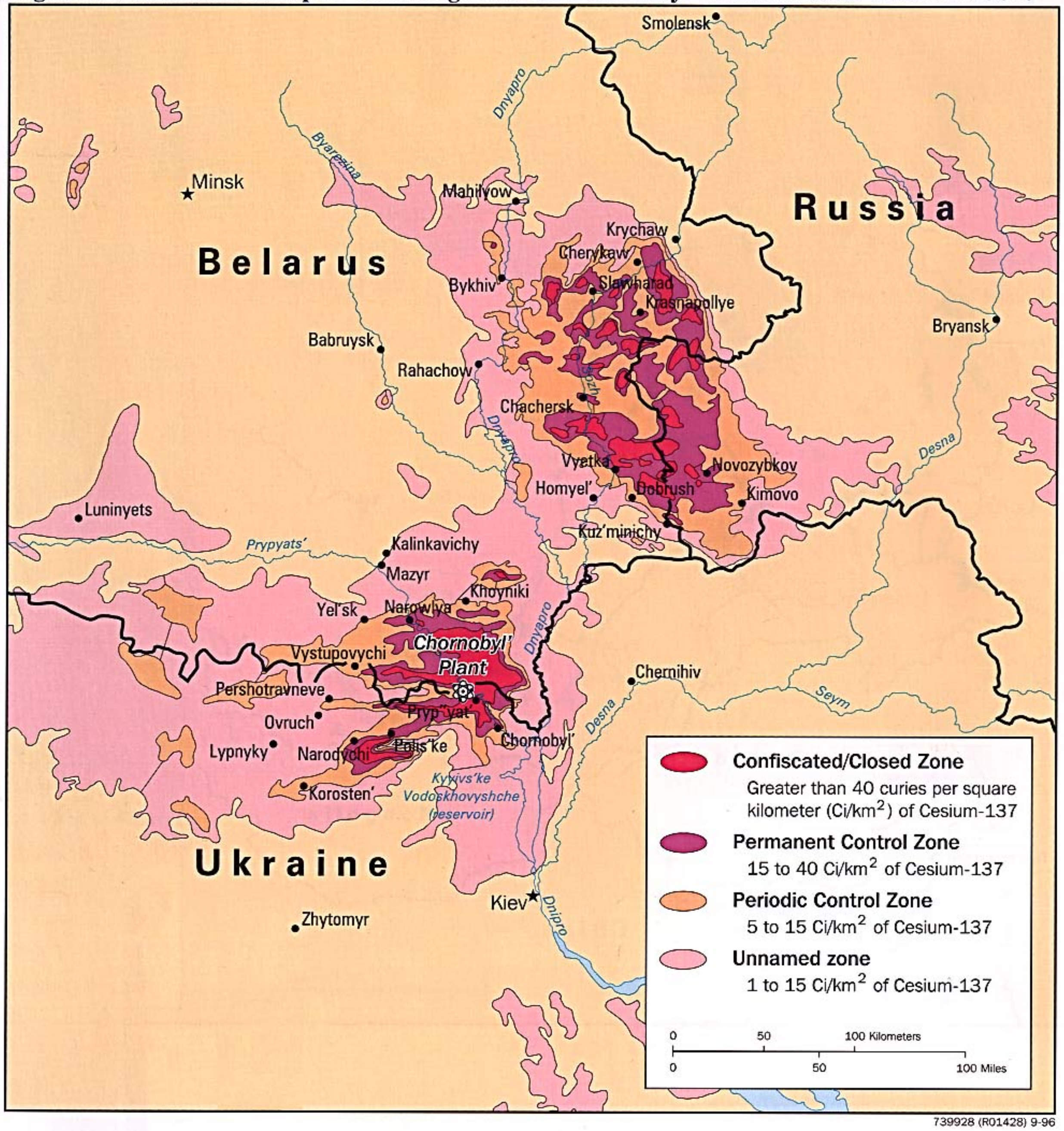


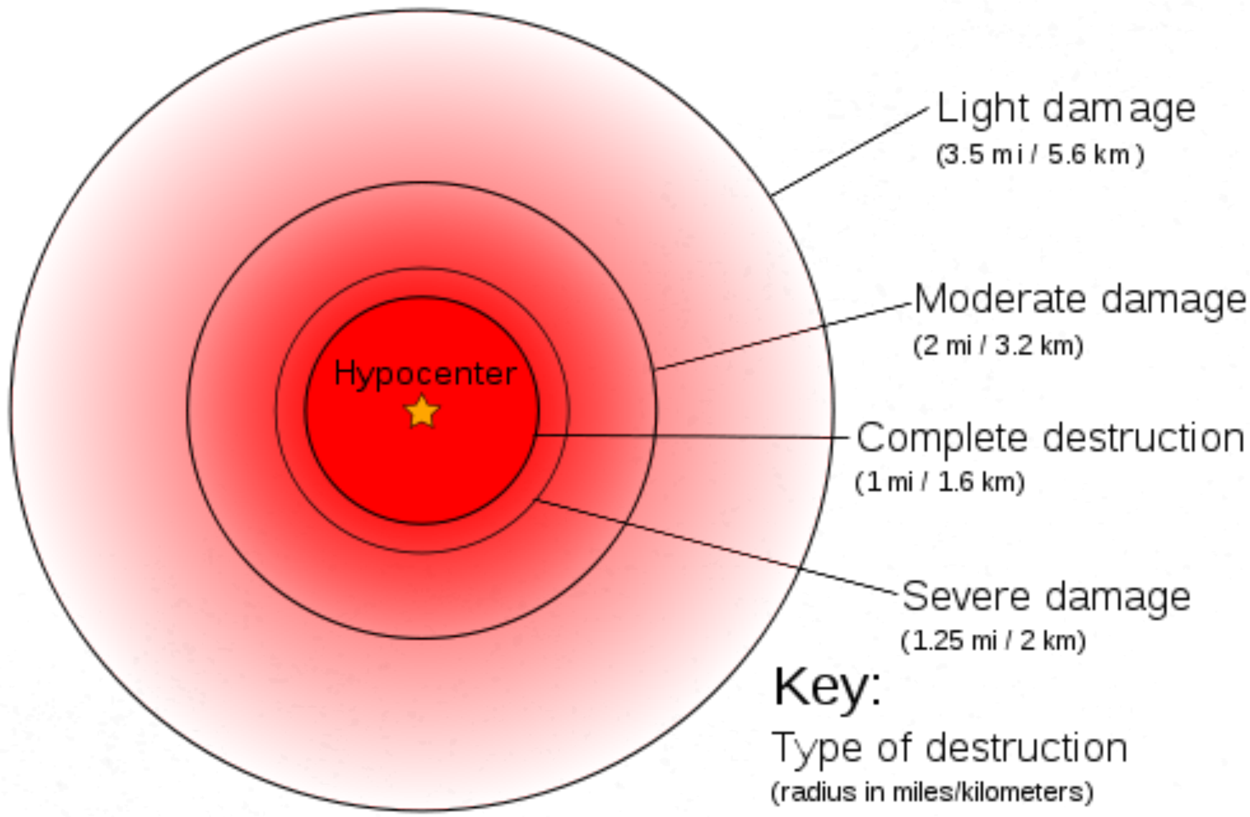
Figure 31. Radiation Hotspots Resulting From the Chornobyl' Nuclear Power Plant Accident



If a nuclear explosion would have happened at the power plant this is what it would have looked like:

http://www.globalsecurity.org/wmd/ops/hiroshima01.htm

Destruction Caused by Bomb



Nuclear or Chemical?

- A chemical explosion occurred.

Understand on a deeper level..

- Nuclear Fission Reaction

- Source of Energy

Where does the heat come from?

- To answer this question we need to take a closer look at a fission reaction …

Clicker Question 3

- During Fission reactions the number and type of atoms on the left hand side of the equation is
  - A) The **same** as the number and type of atoms on the **right** hand side of the equation, it's just that the atoms have rearranged (Law of Conservation of Mass).
  - B) The type of **atom** on the **right** hand side is the **same**, it is just the **number of atoms** that **changes**
  - C) The **type and number** of atoms on the **right** hand side **changes**.
  - D) Fission reactions don't have a left and right hand side, so this doesn't make sense

What does a nuclear reaction look like?

- Fission reaction is the type that is in the power plant, so let's take a look at that first.

- After we figure out what a fission reaction is, then we'll take a look at where all that energy comes from.

Fission - Animation

- http://www.youtube.com/watch?v=tQa4LONy9XM

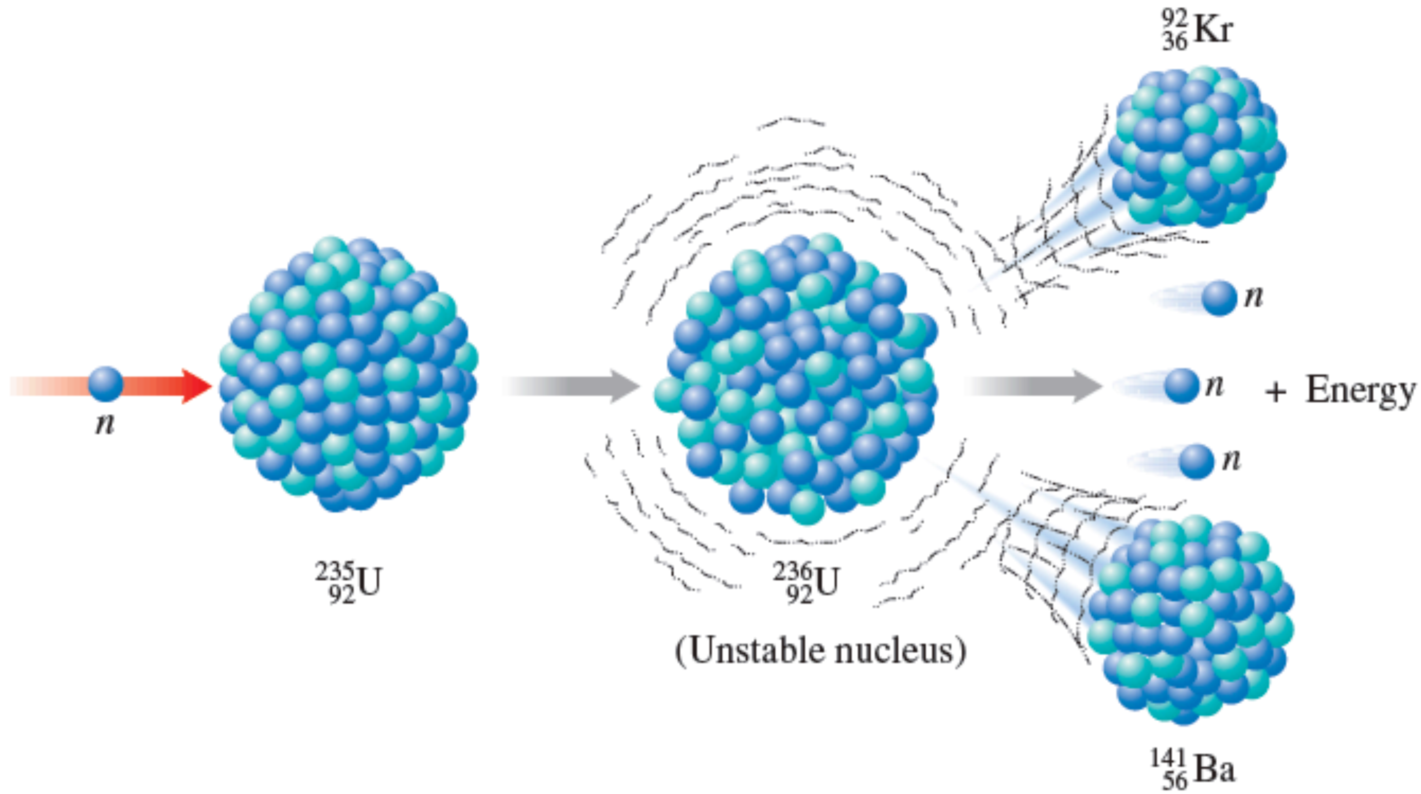


FIGURE 20.11

Upon capturing a neutron, the $^{235}_{92}U$ nucleus undergoes fission to produce two lighter nuclides, free neutrons (typically three), and a large amount of energy.

Write that as an equation:

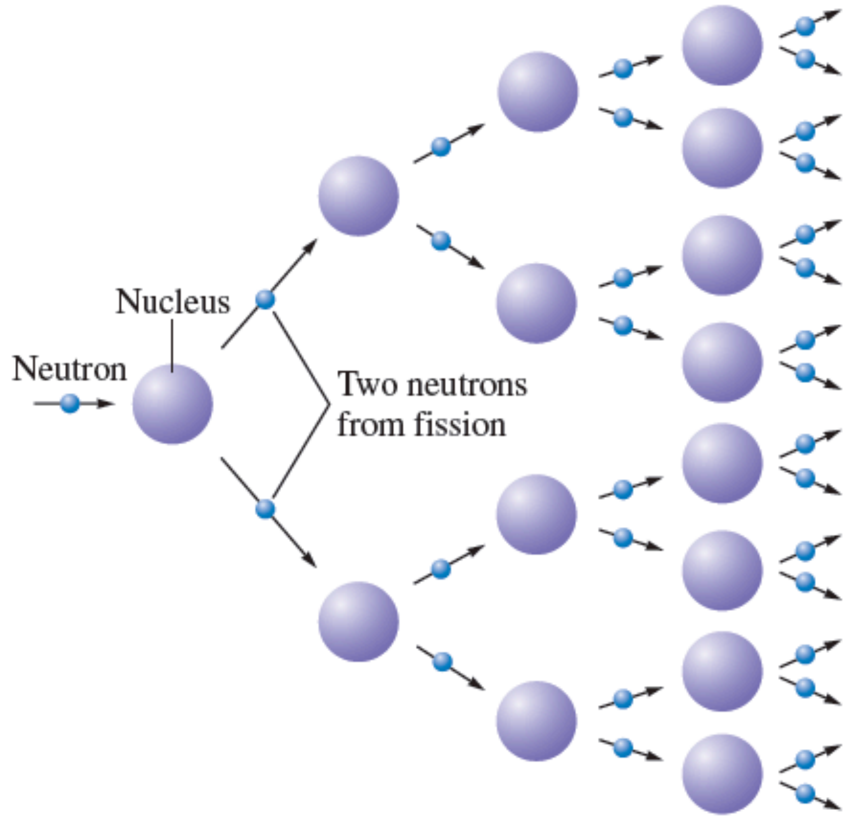


FIGURE 20.12

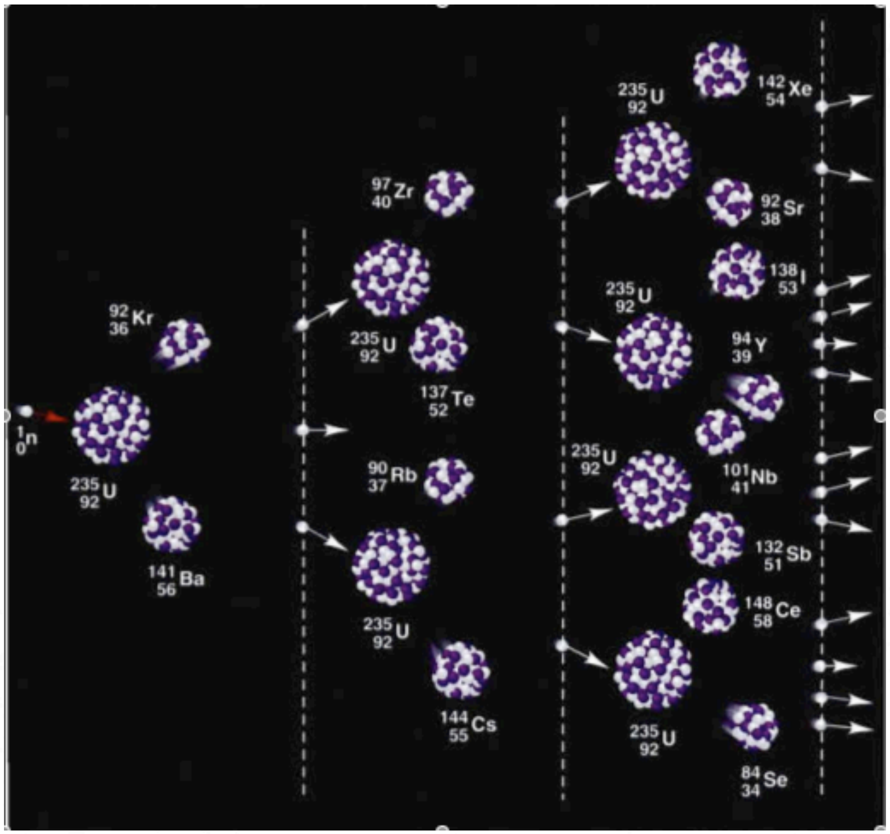
Representation of a fission process in which each event produces two neutrons, which can go on to split other nuclei, leading to a self-sustaining chain reaction.

Chemical Change vs Nuclear Change

$4\ C_7H_2(NO_2)_3CH_3\ (s) + 25\ O_2\ (g) \rightarrow 32\ CO_2\ (g) + 10\ H_2O\ (g) + 6\ N_2(g)$

$^{1}_{0}n + ^{235}_{92}U \rightarrow ^{141}_{56}Ba + ^{92}_{36}Kr + 3\ ^{1}_{0}n$

Some fission products



Write nuclear equations

What's all the fuss about I-131?

- Fission product
- Found in drinking water
- Found in ocean & soil samples
- What's the big deal
- Learn more about radioactive decay next time…

Balancing nuclear reactions

- Mass number is conserved and nuclear charge is conserved.
- $^{238}_{92}U \rightarrow {}^{234}_{90}Th$
- $^{1}_{0}n + {}^{235}_{92}U \rightarrow {}^{141}_{56}Ba + {}^{92}_{36}Kr$
- $^{1}_{0}n \rightarrow {}^{1}_{0}p^{+}$
- $^{14}_{6}C \rightarrow \quad + {}^{0}_{-1}e^{-}$

Balancing nuclear reactions

- Mass number is conserved and nuclear charge is conserved.
- ${}^{238}_{92}U \rightarrow {}^{234}_{90}Th + {}^{4}_{2}He$
- ${}^{1}_{0}n + {}^{235}_{92}U \rightarrow {}^{141}_{56}Ba + {}^{92}_{36}Kr + 3\ {}^{1}_{0}n$
- ${}^{1}_{0}n \rightarrow {}^{1}_{0}p^{+} + {}^{0}_{-1}e^{-}$
- ${}^{14}_{6}C \rightarrow {}^{14}_{7}N + {}^{0}_{-1}e^{-}$

Clicker Question 4

- The missing nuclide in the following nuclear reaction is:

$^{1}_{0}n + ^{235}_{92}U \rightarrow ^{80}_{38}Sr +$ ___ $+ 3\ ^{1}_{0}n$

A) $^{139}_{36}Ba$

B) $^{162}_{62}Sm$

C) $^{153}_{54}Xe$

D) $^{155}_{54}Xe$

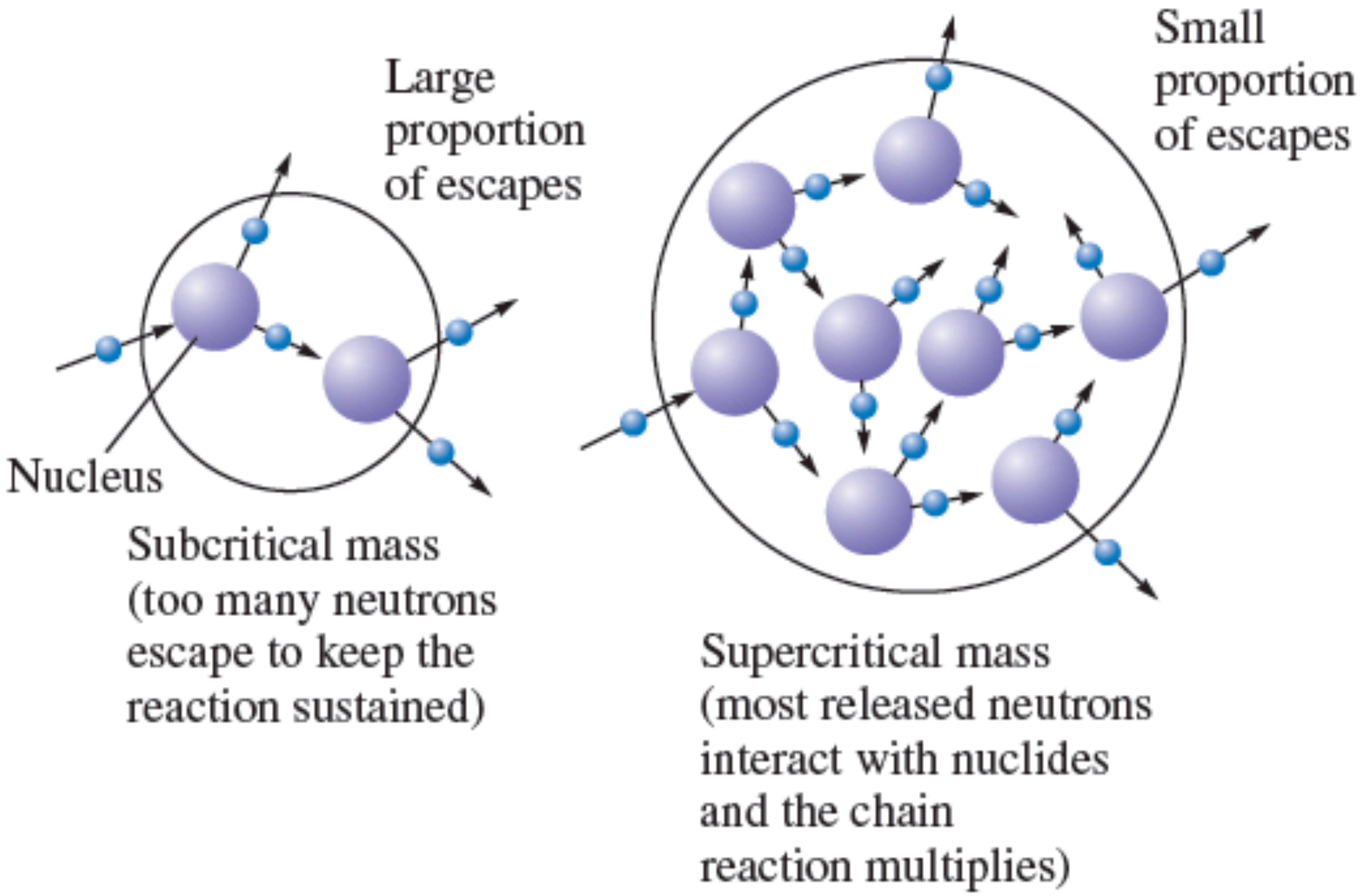


FIGURE 20.13

If the mass of fissionable material is too small, most of the neutrons escape before causing another fission event; thus the process dies out.

Nuclear Power Plant

- Heat is produced by nuclear change
- The fission reaction is a controlled chain reaction, so it keeps itself going and could get too hot
- Control rods absorb some neutrons to keep the reaction going, but not too fast
- As the fuel starts running low, control rods can be pulled back to allow for more neutron capture
- To generate a nuclear explosion, must have a critical mass (33 lbs) of U-235 come together.

How Does Fission Produce Energy?

$$^{1}_{0}n \rightarrow {}^{1}_{1}p^{+} + {}^{0}_{-1}e^{-}$$

Einstein had the answer…

$$E = mc^2$$

- This equation dates from the early years of the 20th century and is one of the many contributions of Albert Einstein (1879–1955).
- The symbol *c* represents the speed of light:

$$3.0 \times 10^8 \text{ m/s}$$

How Does Fission Produce Energy?

According to Einstein, if energy is given off across the change, some mass must be converted to energy,   Look at an example:

Formation of the NUCLIDE O-16 from the NUCLEONS:

Energy is released because **the sum of the masses of the fragments is less than the original mass**.

This 'missing' mass (about 0.1 percent of the original mass) has been converted into energy according to Einstein's $E=mc^2$ equation.

Matter converted to Energy?

Upon a spontaneous nuclear change a small amount of mass is converted to kinetic energy and is carried off by the products of the reaction. Increase of KE on a microscopic scale is perceived as thermal energy.

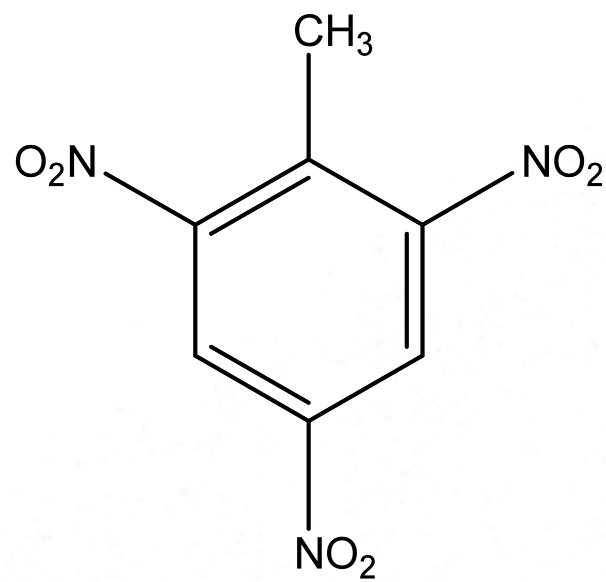
$$E = mc^2$$

Calculate the amount of energy released when 1.0 Kg of U-235 undergoes fusion

$${}^{1}_{0}n + {}^{235}_{92}U \rightarrow {}^{141}_{56}Ba + {}^{92}_{36}Kr + 3\ {}^{1}_{0}n$$

$$\Delta E = \Delta mc^2$$

TNT
(discovered in 1863 by Alfred Nobel)



1 kg of U-235, where only about 0.1% mass is converted to energy is equivalent to 33,000 tons of TNT

Clicker Question 5

Under conditions like those on the Sun hydrogen can fuse with helium to form lithium, which in turn can form different isotopes of helium and hydrogen

$$^{2}_{1}H + {}^{3}_{2}He \rightarrow [{}^{5}_{3}Li] \rightarrow {}^{4}_{2}He + {}^{1}_{1}H$$

2.01325 g 3.01493 g 4.00150g 1.00728g

What is the mass difference here? How much energy in joules in released?

Clicker Question 5 Answer

$^{2}_{1}H$ + $^{3}_{2}He$ → [$^{5}_{3}Li$] → $^{4}_{2}He$ + $^{1}_{1}H$

2.01325 g   3.01493 g   4.00150g   1.00728g

A) 1.764×10^{9} J/mol

B) 1.764×10^{12} J/mol

C) 1.764×10^{15} J/mol

D) 1.76×10^{18}J/mol

What happened at Fukushima?

- Nuclear reactor was shut down too fast.
- Control rods came down, but the reactor was still very hot.
- Power went out. Cooling water stopped flowing. Reactor got hotter and hotter, uranium fuel melted, housing of fuel rods melts, reaction continues to produce enormous amount of heat, breaks down water to H_2 gas, which is very explosive.
- Fission products are mostly unstable and undergo radioactive decay

Nuclear Chemistry

- http://www.youtube.com/watch?v=rBvUtY0PfB8

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Next time…

- Look at the fission products.
- Why are they unstable?
- What is radioactive decay or nuclear radiation?
- How can you predict if a particular isotope is stable?
- Can cooling down the isotopes, slow the radioactive decay? Can warming them, speed it up?
- What does nuclear stability have to do with the ability of an atom to undergo fission in the first place?
- What happens to your body when you are exposed to nuclear radiation?
- How can nuclear radiation be helpful?