4. Geothermal Power

- Heat from the earth's interior (geothermal energy) that results from radioactive decay and gravitational pressures

Forms: Trapped ***steam*** or ***hot water***

- Can be harnessed in a few places. HOW?
  - The crust is drilled to allow the heat to escape, either as steam, or as very hot water.
  - Pipes carry the hot water to a plant, where some of the steam is allowed to "flash," or separate from the water.
  - That steam then turns a turbine - generator to make electricity.

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Geothermal Power: How It Works

- In a **flash steam power plant**, very hot water is depressurized or "flashed" into steam which can then be used to drive the turbine.

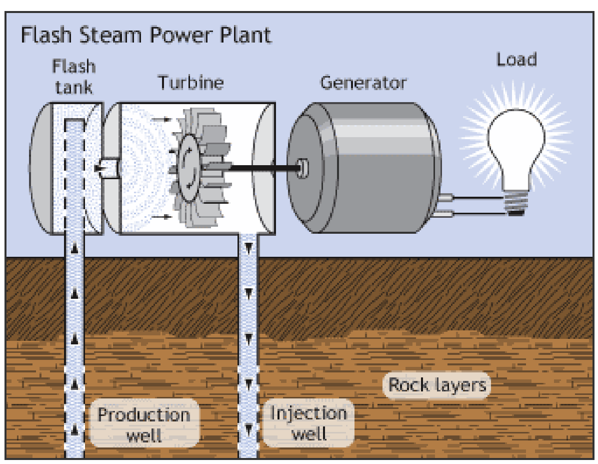

Image available at http://www.ucsusa.org/clean_energy/renewable_energy_basics/offmen-how-geothermal-energy-works.html

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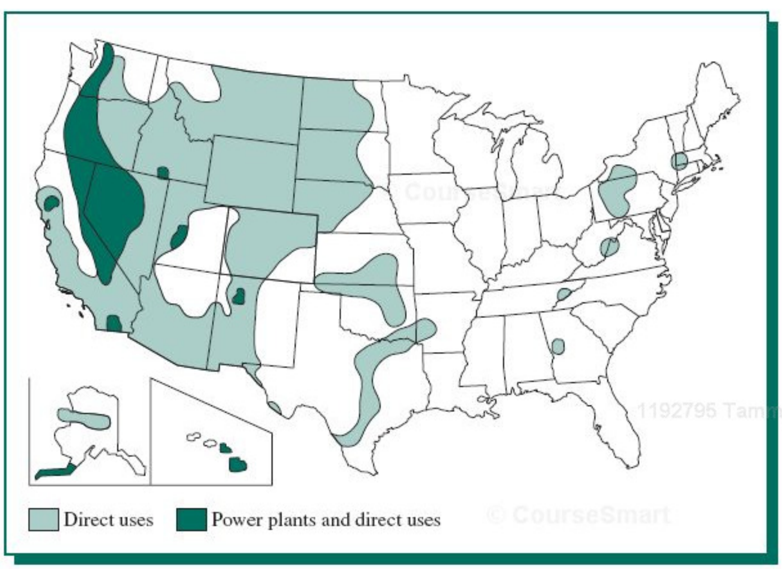
Geothermal Power – Cont.

Hot springs in Steamboat Springs area.

Source: National Renewable Energy Laboratory, Photographic Information Exchange.

FIGURE 8- 6 Regions of **potential sites for geothermal energy** production in the U.S. [Source: Geothermal Education Office, at http:// geothermal.marin.org.]



Geothermal Energy Sources in the U.S.

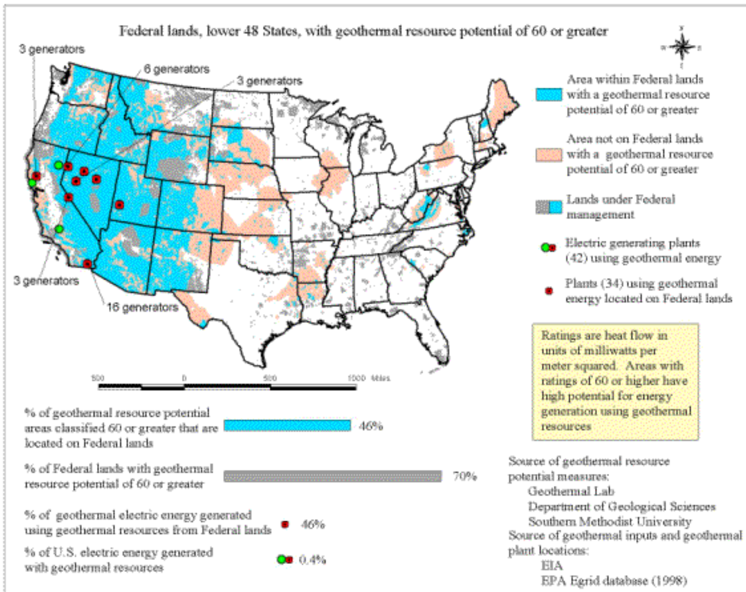


Image available at
http://www.eia.doe.gov/cneaf/solar.renewables/page/geothermal/geothermal.gif

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Geothermal Power – Cont.

Did you know that ….

… the capital of Iceland, Reykjavik, is heated mostly by geothermal energy?

Benefits **of Geothermal Power**

1) Environmental

- ❖ It offsets air pollution that would have been produced if fossil fuels were the energy source.

2) Cost

- ❖ Current cost is competitive w/ that of energy from fossil fuels

U.S. DOE, "Geothermal Energy -- Energy from the Earth's Core"
http://www.eia.doe.gov/kids/energyfacts/sources/renewable/geothermal.html

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Geothermal Power – Cont.

***Disadvantages* of Geothermal Power**

1) Emission of a few toxic gases

- Example is ***hydrogen sulfide, H_2S*** (rotten egg smell)

2) Corrosiveness of salt-water and disposal problems

- Hot water from the earth is usually more saline than ocean water

Highly corrosive; Disposal is a problem

3) Possible disruption of land

- Water withdrawal from geologically unstable region may cause land to subside

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Source: Suchocki, 2001, pp. 627-628

5. Biomass

Biomass power, also called biopower, is electricity produced from biomass fuels.

- ***Biomass*** = plant materials (ex. wood chips; crop residues) and animal products (ex. dung).

Uses **technology** that convert biomass fuels into electricity:

- Modern boilers
- Gasifiers
- Turbines
- Generators
- Fuel cells

Reference: U.S. Department of Energy, "Biomass Power," available at http://www.eere.energy.gov/de/biomass_power.html

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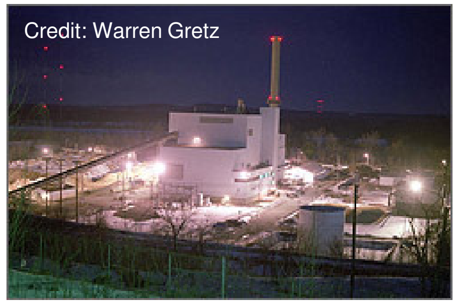
Biomass – Cont.

Credit: Daniel Peck



Wood chips made from energy crops, such as hybrid willows (left), provide raw material for a new gasifier at the McNeil Generating Station (right), a 50-MW wood-fired power plant located in Burlington, Vermont.

Image available at http://www.eere.energy.gov/de/biomass_power.html

Biomass: How It Works

The majority of biomass electricity is generated today using a steam cycle, as shown in Diagram 1. In this process, biomass is burned in a boiler to make steam. The steam then turns a turbine, which is connected to a generator that produces electricity.

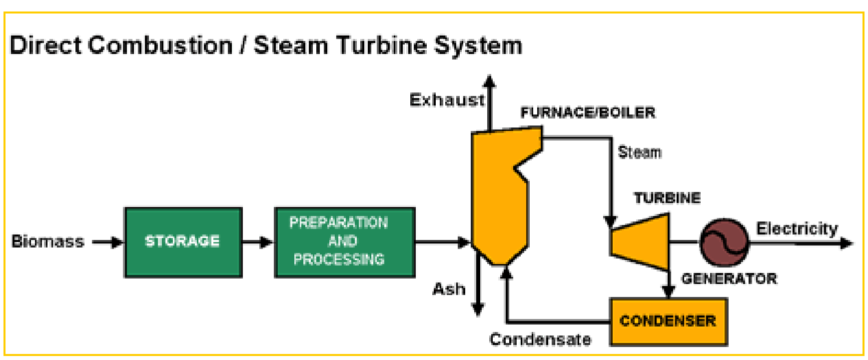


Diagram 1: In a direct combustion system, processed biomass is the boiler fuel that produces steam to operate a steam turbine and generator to make electricity.
Image available at http://www.eere.energy.gov/de/biomass_power.html

Biomass Gasification

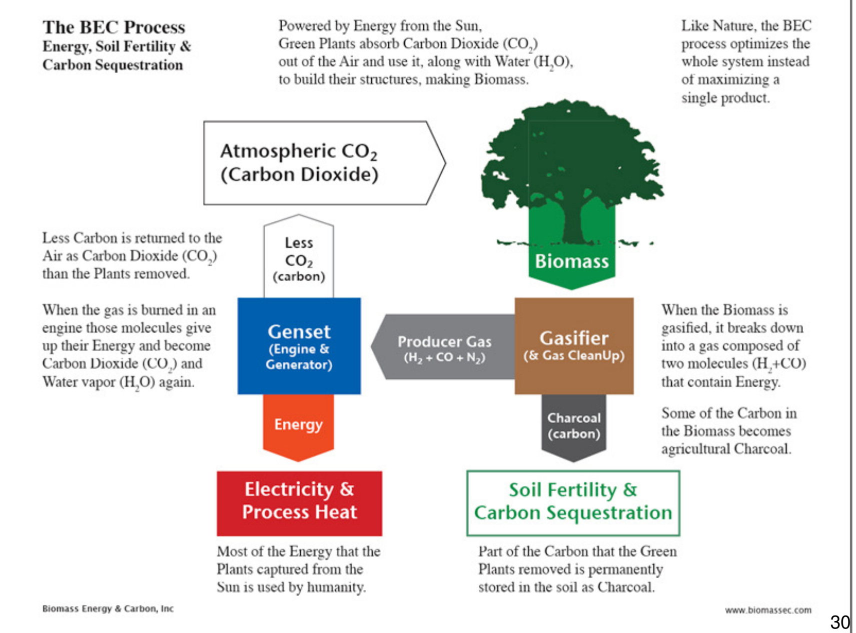


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Image available at http://www.biomassenergycorp.com/

Biomass Gasification

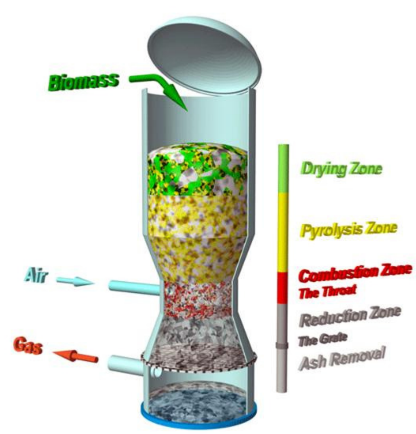
Gasifier

The Gasifier is essentially a chemical reactor where various complex physical and chemical processes take place. Four distinct processes take place in a gasifier:

- Drying of the fuel
- Pyrolysis
- Combustion
- Reduction

Biomass gasification produces:

- **H_2 & CO** = ***synthesis gas***
- **CH_4**



Reference: http://www.ecoprods.com/products-BIOMASS.htm

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Advantages of Biomass Power

1. Provides new market for the nation's farmers
2. Creates jobs
3. Biomass is ***available upon demand*** - the energy is stored within the biomass until it is needed.
   - Other forms of renewable energy are dependent on variable environmental conditions such as wind speed or sunlight intensity.
4. Biopower is a natural fit for the electric power industry
   - Can cofire biomass with coal and have fewer emissions that cause acid rain
5. Biopower makes productive use of "waste" such as crop residue and wood chips
6. Biopower is good for the environment
   - Renewable; helps reduce CO_2 emissions from fossil fuels

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Disadvantages and Challenges of Biomass Power

1. Higher costs
   - Generation costs > cost from fossil fuel generation
   - Biomass energy is less concentrated than fossil fuel
   - Less economical to transport over long distances
2. Need to develop high-yield, low energy-input crop farming practices
3. Need for more research to improve biopower technologies

Reference: http://www.eere.energy.gov/de/biomass_power.html

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Applications of Biomass

U.S. biopower plants have a combined capacity of 7,000 MW. These plants use roughly 60 million tons of biomass fuels (primarily wood and agricultural wastes) to generate 37 billion kWh of electricity each year. That's more electricity than the entire state of Colorado uses in a year. As with conventional power from fossil fuels, biopower is available 24 hours a day, seven days a week. Small, modular biopower systems with rated capacities of 5 MW or less can supply power in regions without grid electricity. These systems can provide distributed power generation in areas with locally produced biomass resources such as rice husks or walnut shells.

Cost

- A typical existing **coal**-fired power plant: ~ **2.3¢/kWh**.
- In today's direct-fired **biomass power plants**: ~ **9¢/kWh**.

Reference: http://www.eere.energy.gov/de/biomass_power.html

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Nuclear Energy from Fission

A nonrenewable energy source

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Background: Nuclear Power

What is radioactivity?

Radioactivity is the process by which some atoms emit radiation

- Involves a change in the nucleus (***nuclear change***)
- vs. ***chemical change*** **(reaction)** = involves rearrangement of electrons

Ex. of radioactive atoms: **Ra, Po, Pu, U**, etc.

Three forms of radioactivity:

- Alpha
- Beta, and
- Gamma radiation

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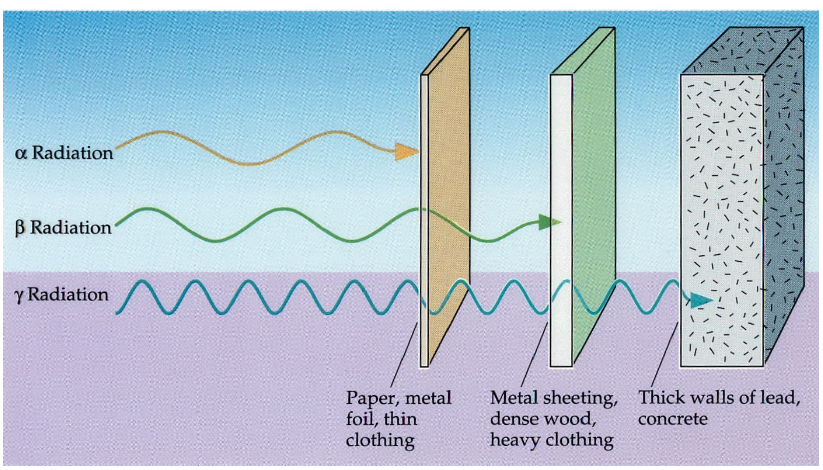

Alpha (α) radiation = least penetrating but is the most *ionizing*; most damaging to tissues/organs

Beta (β) radiation = highly energetic electrons; can be blocked by heavy clothing or dense wood

Gamma (γ) radiation = a form of light similar to x-rays; highly penetrating but least damaging of the three

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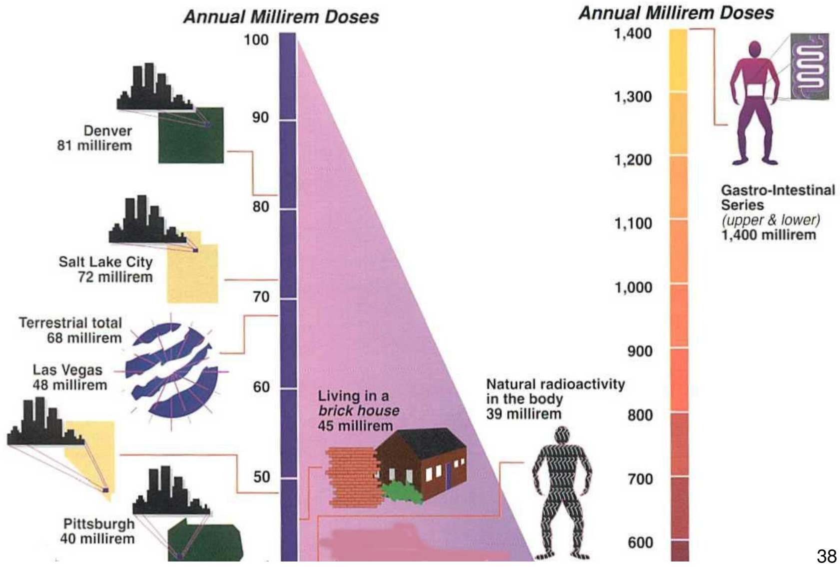
How much radiation are we exposed to?



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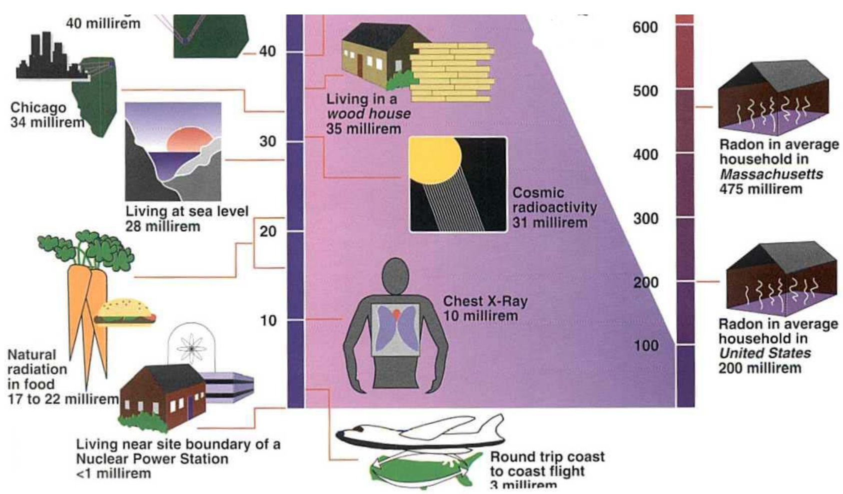
How much radiation are we exposed to?



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Annual Exposure to Radiation

We all know that radiation can kill us… eventually

But there are other more significant cause of death.

Radiation Risks in Perspective
Radiation Dose Comparisons

Natural Background	**Approximate MREM/Year**
Average U.S. Resident	300
Average Denver Resident	380
Radon in average households	
New York/New Jersey	360
Massachusetts	475
Medical Exposure	
Average U.S. Citizen	50
Typical Medical Examination	
Dental X-Rays *(Full Mouth)*	10 ~~3,000~~ *(Skin)*
Chest X-Rays	10 *(Bone)*
Gastro-Intestinal Series *(Upper & Lower)*	1,400 *(Bone)*
Occupational Exposure	
Average Pilgrim Station Radiation Worker *(since 1980)*	600 MREM/Year

Estimated Loss of Average Life
Expectancy From Various Health Risks

Health Risk	**Estimated Days of Life Expectancy Lost (average)**
Smoking 20 Cigarettes/Day	2370 *(6.5 years)*
Overweight *(by 20%)*	985 *(2.7 Years)*
All Accidents Combined	435 *(1.2 Years)*
Auto Accidents	200
Alcohol Consumption *(U.S. Average)*	130
Home Accidents	95
Drowning	41
Natural Background Radiation	8
Medical Diagnostic X-Rays *(U.S. Average)*	6
All Catastrophes *(Earthquake, Etc.)*	3.5
One REM Radiation	1

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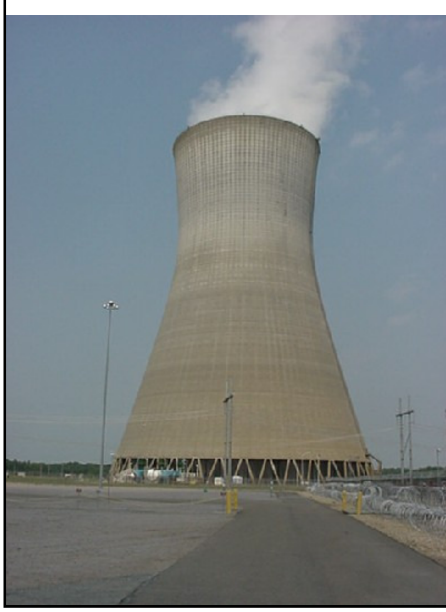
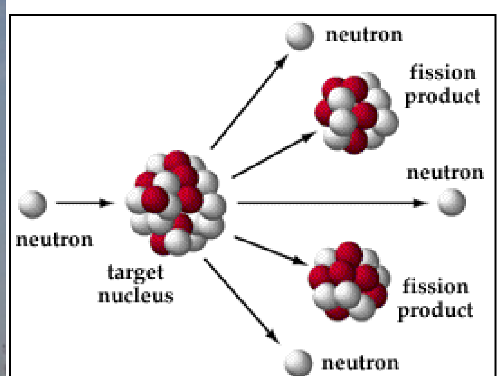
Background: Generation of Nuclear Power



Nuclear energy is an
alternative energy resource



\+ **heat**

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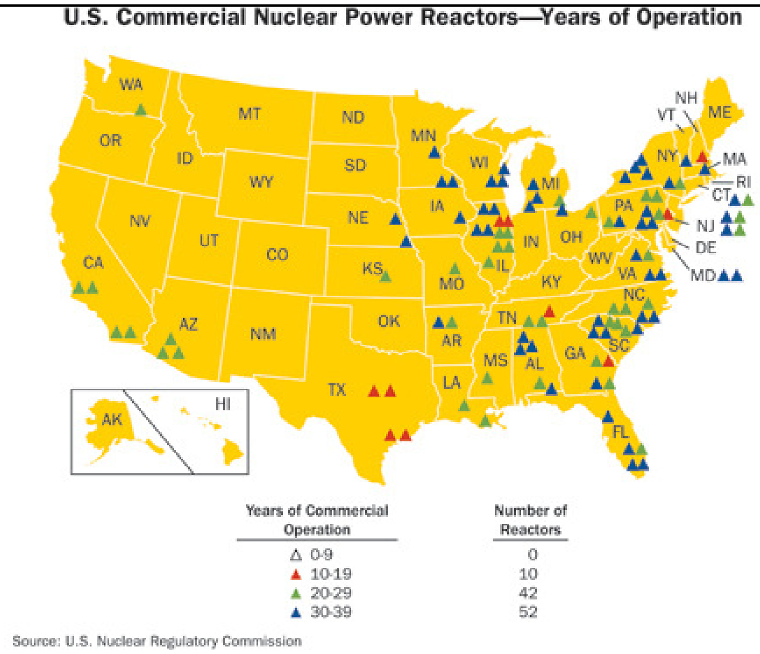

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Image available at http://www.nrc.gov/reactors/operating/map-power-reactors.html

Nuclear Reactor Design: The ***Boiling Water Reactor***

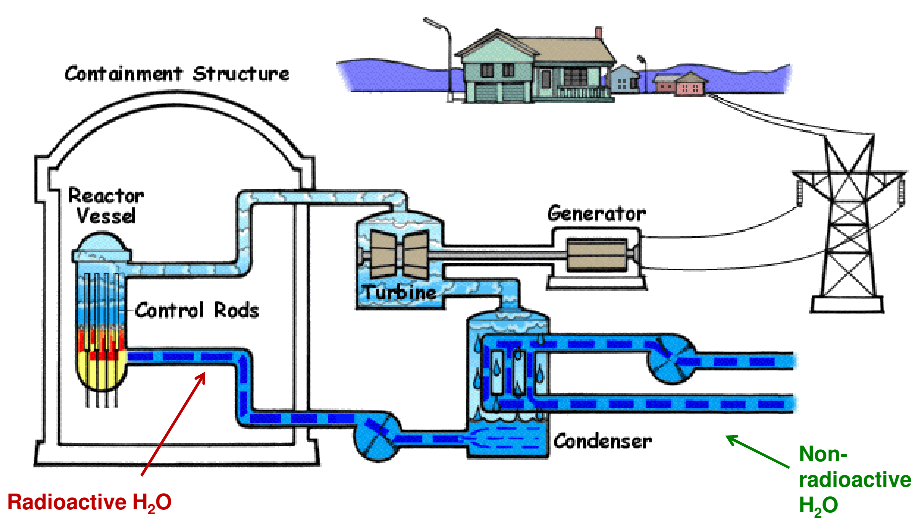

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Image available at http://www.nrc.gov/reading-rm/basic-ref/students/animated-bwr.html

Boiling Water Reactor **design**

Nuclear power plants operate on the same principle as coal-fired power plants in generating electricity. However, nuclear plants utilize the energy generated from ***fission*** (see previous slide) of radioactive elements (U-235 or Pu-239).

The uranium (or plutonium) is formed into ceramic pellets and placed in metal tubes called **fuel rods**. About 51,000 fuel rods are placed in the reactor vessel to make up the **nuclear core** -- the part of the plant that produces heat. When a uranium atom splits, or fissions, it gives off energy in the form of heat. To control the heat-producing process, **control rods** are used, which are *neutron-absorbing materials*. The control rods shut down the reaction when inserted between fuel rods. In addition, water flows through the core to act as **moderator** (used to slow the speed of neutrons without absorbing them) and coolant. As a **coolant**, water extracts heat from the core and is converted to steam, which is used to generate electricity.

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Boiling Water Reactor – Cont.

The condensed steam, now water, is pumped to the steam generators to repeat the cycle. The water in the condenser tubes picks up heat from the steam passing around the outside of the tubes. This heated water may be passed through a 140-meter high (459 feet) **cooling tower** before being returned to the lake or reused in the plant. The two (three in some designs) water systems are separated from each other to ensure that radioactive water does not mix with nonradioactive water.

There are 104 operating reactors in the United States. Of these, 69 are pressurized water reactors (PWR), and 35 are boiling water reactors (BWR).

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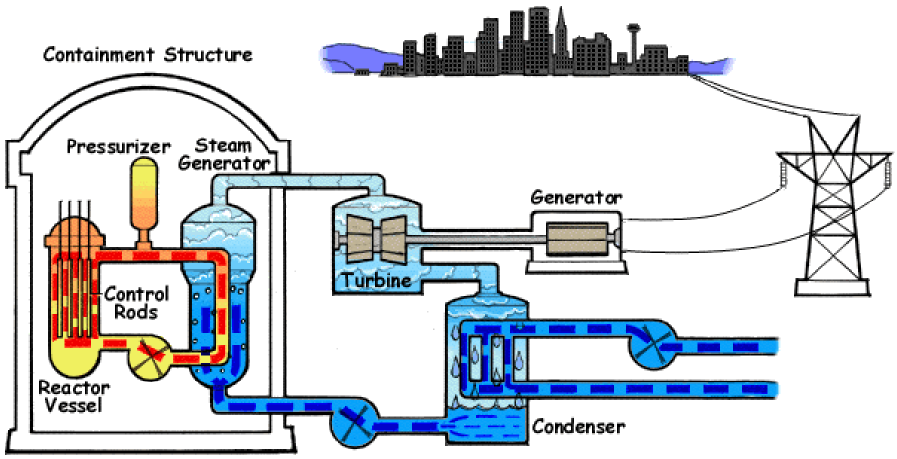
The Pressurized Water Reactor (PWR)



http://www.nrc.gov/reading-rm/basic-ref/students/animated-pwr.html

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In a **PWR** the primary coolant (water) is pumped under high pressure to the reactor core where it is heated by the energy generated by the fission of atoms. The heated water then flows to a steam generator where it transfers its thermal energy to a secondary system where steam is generated and flows to turbines which, in turn, spins an electric generator. In contrast to a boiling water reactor, pressure in the primary coolant loop prevents the water from boiling within the reactor.

PWRs currently operating in the U.S. are considered Generation II reactors.

Coolant

Light water is used as the primary coolant in a PWR. It enters the bottom of the reactor core at about 275 °C and is heated as it flows upwards through the reactor core to a temperature of about 315 °C. The water remains liquid despite the high temperature due to the high pressure in the primary coolant loop, usually around 153 atm.

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Nuclear Power

FACTS:

- Nuclear bombs need at least a **97% pure uranium** to produce a nuclear explosion from **uncontrolled fission**.

- **Fuel rods** *in power plants only contain* ***3% uranium***. It takes a lot of effort and technology to purify uranium from nuclear fuels.

- A nuclear bomb requires that the **subcritical mass** of either U or Pu be combined in about ***one-millionth*** (10^{-6}) ***sec*** to produce a **critical mass** that triggers nuclear explosion.
  - Impossible to attain within the design of a power-generating plant.

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FACTS - Cont.

- The nuclear reactions needed to reach bomb intensity requires **special containment**.
  - The reactor is not designed to contain this type of reaction.
  - If controls were lost, the heat would cause the core of the reactor to melt = ***meltdown***!

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Chernobyl vs. U.S. Nuclear Power Plants

Chernobyl reactor

Reactor no. 4 was a **light-water-cooled graphite-moderated** reactor. In this type of reactor, the neutrons released by the fission of uranium-235 nuclei are slowed down (moderated) by graphite so as to maintain a chain reaction.

Western nuclear experts have criticized this type of reactor primarily because it ***lacks a containment structure*** and requires large quantities of **combustible graphite** within its core. (See cross-section, Fig. 7)

NOTE: ***Graphite is a poor moderator***. Nuclear power plants in the U.S. use "heavy water" (deuterated), which is a good moderator. In addition designs in the U.S. include a secondary containment area.

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Chernobyl

On April 26, 1986, the world's worst nuclear-power accident occurred at Chernobyl nuclear power plant in the Soviet Republic of Ukraine. The accident occurred when technicians at reactor Unit 4 attempted a poorly designed experiment. The chain reaction in the core went out of control. Several explosions triggered a large fireball and blew off the heavy steel and concrete lid of the reactor. This and the ensuing fire in the graphite reactor core released large amounts of radioactive material into the atmosphere. A partial meltdown of the core also occurred.

http://www.atomicarchive.com/History/coldwar/page21.shtml

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Chernobyl

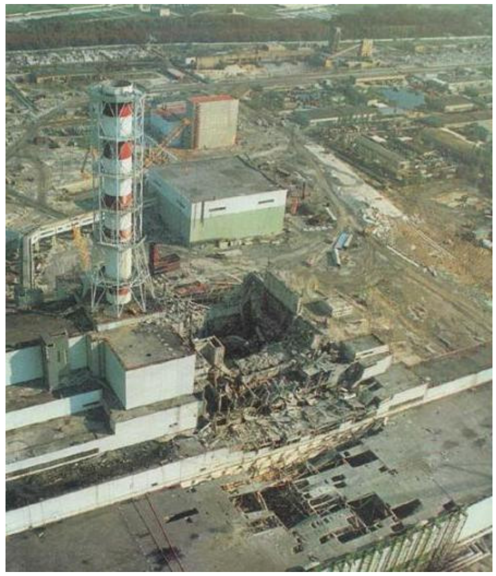

Image available at http://feww.wordpress.com/2009/03/18/all-is-not-well-at-chernobyl/

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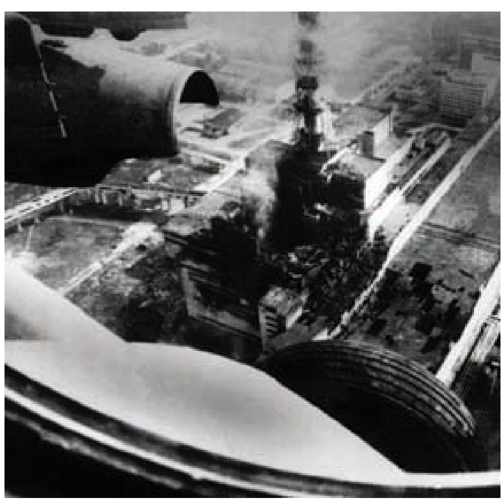

The explosion of the Chernobyl nuclear reactor

http://www.chernobyl.info/index.php

On 26 April 1986, at 1:23:44, reactor no. 4 of the Chernobyl nuclear power station exploded. One hundred times more radiation was released than by the atom bombs dropped over Hiroshima and Nagasaki.

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The 1986 Chernobyl accident

On 25 April, prior to a routine shutdown, the reactor crew at Chernobyl 4 began preparing for a test to determine how long turbines would spin and supply power to the main circulating pumps following a loss of main electrical power supply. This test had been carried out at Chernobyl the previous year, but the power from the turbine ran down too rapidly, so new voltage regulator designs were to be tested. A series of operator actions, including the disabling of automatic shutdown mechanisms, preceded the attempted test early on 26 April. By the time that the operator moved to shut down the reactor, the reactor was in an extremely unstable condition. A peculiarity of the design of the control rods caused a dramatic power surge as they were inserted into the reactor (see Chernobyl Accident Appendix 1: Sequence of Events).

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Chernobyl accident – *Cont.*

The interaction of very hot fuel with the cooling water led to fuel fragmentation along with rapid steam production and an increase in pressure. The design characteristics of the reactor were such that substantial damage to even three or four fuel assemblies can – and did – result in the destruction of the reactor. The overpressure caused the 1000 t cover plate of the reactor to become partially detached, rupturing the fuel channels and jamming all the control rods, which by that time were only halfway down. Intense steam generation then spread throughout the whole core (fed by water dumped into the core due to the rupture of the emergency cooling circuit) causing a steam explosion and releasing fission products to the atmosphere. About 2-3 sec. later, a second explosion threw out fragments from the fuel channels and hot graphite. There is some dispute among experts about the character of this second explosion, but it is likely to have been caused by the production of hydrogen from zirconium-steam reactions.

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Chernobyl accident – *Cont.*

Two workers died as a result of these explosions. The graphite (about a quarter of the 1200 tonnes of it was estimated to have been ejected) and fuel became incandescent and started a number of fires[f], causing the main release of radioactivity into the environment. A total of about 14 EBq (14 x 10^{18} Bq) of radioactivity was released, over half of it being from biologically-inert noble gases.

Reference: World Nuclear Organization,“Chernobyl Accident”, available at http://www.world-nuclear.org/info/chernobyl/inf07.html

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