Thermal and Nuclear Power Generation

Smith College, EGR 325
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photos mostly from M.A. El-Sharkawi, (c), University of Washington

Overview

- Thermal power plants
  - Thermodynamic cycles
  - Plant components
    - Boiler, turbine, generator
    - Governor
- Nuclear power plants

Discussion Questions

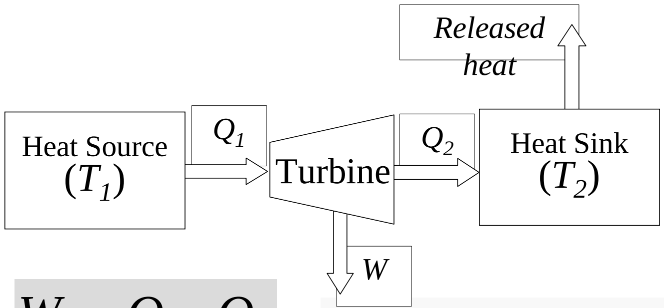
- Discuss the end-to-end conversion process in a steam plant
- Discuss the life cycle environmental damage from a steam plant
- Explain the thermodynamic cycles in a steam plant

Thermal Energy Constant

Fuel Type	**Thermal Energy Constant (Btu/kg)**
Petroleum Oil	45,000
Natural gas	48,000
Coal	27,000
Wood (oven dry)	19,000

1 Btu = 252 calories = 1.0544 kJoules

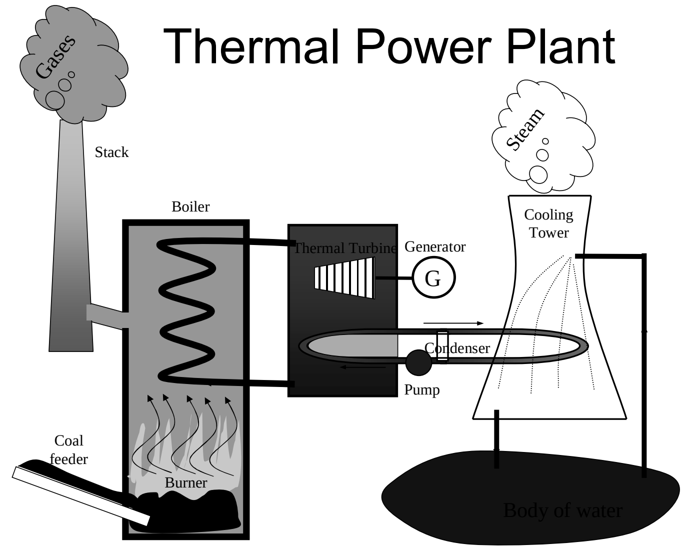
Second Law of Thermodynamics



$$W = Q_1 - Q_2$$
$$W = T_1 - T_2$$

$$\eta_{ideal} = \frac{W}{Q_1} = \frac{T_1 - T_2}{T_1}$$

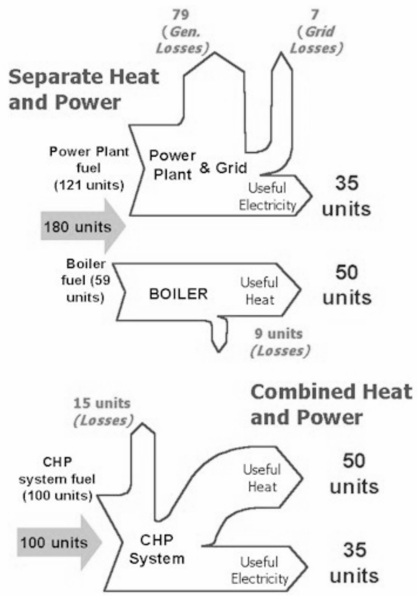
Thermal Power Plant



Compare a gas turbine to a steam turbine

Cogeneration, or Combined Heat & Power, CHP

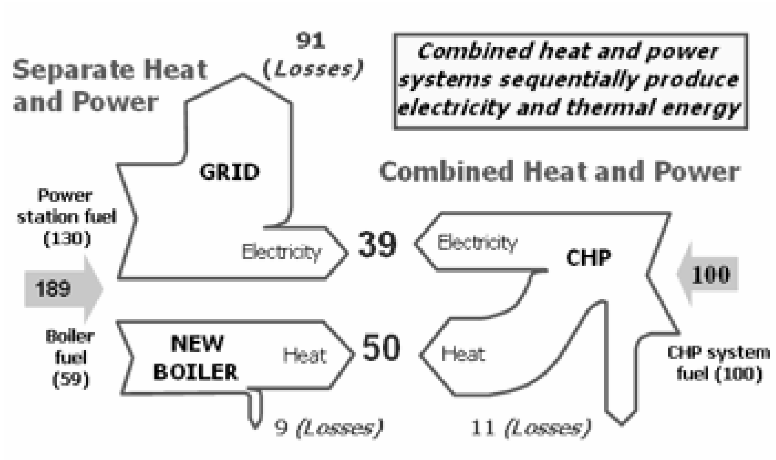
Cogeneration



http://www.sdenergy.org/ContentPage.asp?ContentID=48&SectionID=66

Cogeneration

http://www.eere.energy.gov/de/chp/chp_technologies/tech_basics.html

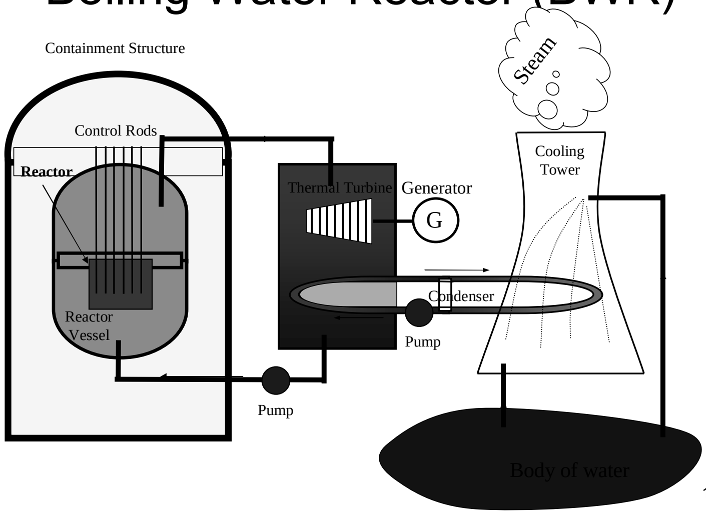


Cogeneration and Efficiency

- What is the increase in efficiency from using cogeneration, according to these figures?
- What types of locations are best suited to cogeneration?

Nuclear Power Plants

Boiling Water Reactor (BWR)



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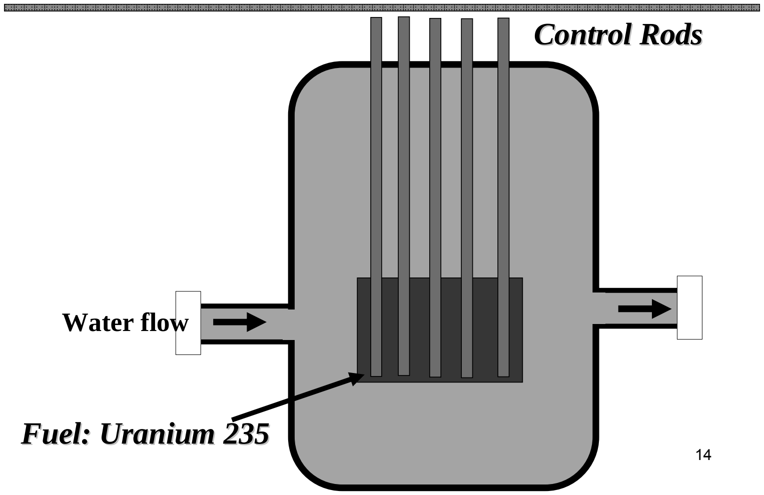
Reactor Vessel



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Types of Nuclear Power Plants

- ***Fission***
  - Nuclear fuel
  - The fission process – splitting atoms
  - Types of reactors
    - pressurized water reactors
    - boiling water reactors
- ***Fusion***
  - Two lighter elements are combined into a heavier element, and release energy in the process

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Nuclear Fuel

- Natural uranium is a mixture of three isotopes
  - $\mathbf{U^{234}}$, $\mathbf{U^{235}}$ (0.7%) and $\mathbf{U^{238}}$ (99.2%) (superscript is atomic mass)
- Only $\mathbf{U^{235}}$ can fission in nuclear reactor
- Enrichment process is used to increase the concentration of $\mathbf{U^{235}}$
  - For nuclear power generation, the concentration is ~ 3-5%
  - For nuclear weapons the concentration of U^{235} is 90%.

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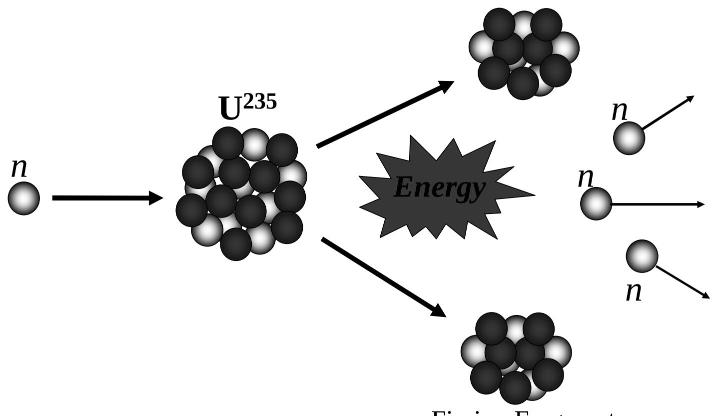
Fission Process



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Fission Process

- The newly released neutrons hit other uranium atoms causing additional fission processes
- As atoms are split
  - Some mass is lost
  - This lost mass becomes energy

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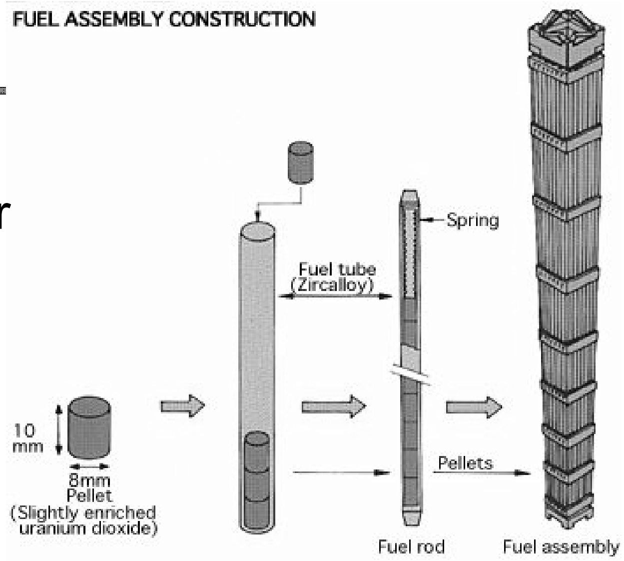
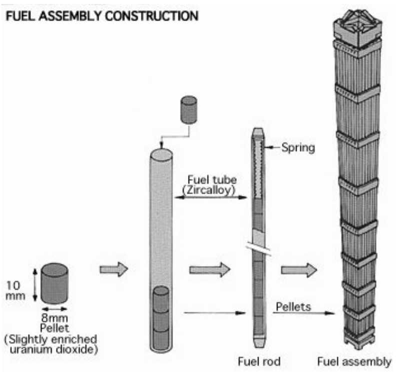
Nuclear Fuel



Nuclear Fuel

- U^{235} comes in the form of ceramic pellets about 10mm in size.
- The pellets are inserted into tubes and placed inside the reactor
- Each pellet contains the energy equivalent of
  - 2,000 lb of coal
  - 150 gallons of oil



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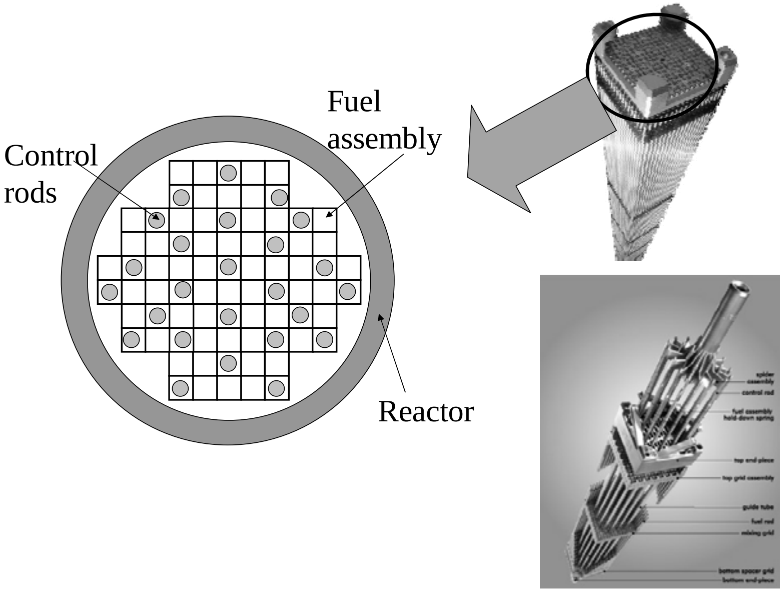

Example

- A nuclear reactor produces an average of 1GW of thermal energy annually.
  1. Compute the mass of U^{235} to produce an average of 1GW of thermal energy for a year.
  2. Compare the mass of the nuclear fuel with the equivalent mass of coal.

- Beware in text …
  - 1 kWs ≠ 1 kWh
    - Solution in text is incorrect
  - Energy units are J or kWh etc,
  - Power units are W, kW etc

- Problems with homework problems in chapter 3

Solution from text...

- The mass of U^{235} required to generate 1GW continuously for a year is

$$\frac{9.7762\times10^{26}\text{ events}}{25.4\times10^{23}\text{ events/kg}} = 385\text{ kg}$$

- 1 GW for 1 year requires 9.8×10^{26} fission events
- 1 kg of U^{235} can have 25.4×10^{23} fission events

Solution continued...

- 1 kg of coal produces 28,470 kWs
  (= 27,000 Btu/kg x 1.0544kJ/Btu)
  = _________ kWh of thermal energy ?

- To produce 1GW of thermal power per hour from coal, we need to burn ___________?

Solution continued...

- 1 kg of coal produces 28,470 kWs (7.9 kWh) of thermal energy
- To produce 1GW of thermal power per hour from coal, we need to burn

$$\frac{10^6\,\mathrm{W}}{8\,\mathrm{kWh/kg}} = 125\ \mathrm{kg/hr}$$

Solution continued...

- ... and continuing, there are 8760 hours in a year

$$8760 * 125 = 1.095 * 10^6\ \ \mathrm{kg/yr}$$

- Mass of coal/mass of uranium ≈ 3000

- *Or,* about 500 tons of coal are needed to produce the same energy from about 1 ton of Uranium !

What Happens To Used Fuel?

- "fission fragments“ left over after the atoms have split (cesium-140, rubidium-93) are radioactive.
- The fragments are cooled and stored in concrete pools lined with stainless steel.

Nuclear Fusion

- Two nuclei join to form a heavier nucleus
  - Heavy nuclei absorb energy to fuse
  - Light nuclei release energy when they fuse
    - Combine isotopes of hydrogen (deuterium and tritium), to form
    - Isotopes of helium

Nuclear vs. Chemical Reactions

- Nuclear reactions
  - Binding energy of nuclei
  - On the order of 17 MeV
- Chemical reactions
  - Energy holding electrons to the nucleus
  - On the order of 13.6 eV

Summary

- Thermal power plants
  - Boiler
  - Steam turbine
  - Electric generator
  - Cogeneration
- Nuclear power generation
- Next classes
  - When to use which type of generating facility
  - Economics of each type of plant