APES CHAPTER 12 NOTES (MRS. BAUCK): NONRENEWABLE ENERGY RESOURCES

"Our country's leaders have three main choices: Taking over someone else's oil fields; carrying on until the lights go out and Americans are freezing in the dark; or changing our life style by deep conservation while heavily investing in alternative energy sources at higher costs."
— Charles T. Maxwell (consultant to oil companies and the U.S. Government on oil policy)

"The world is not running out of oil—at least not yet. What our society does face, and soon, is the end of abundant and cheap oil on which all industrial nations depend."
— Dr. Colin Campbell and Dr. Jean Laherrere (petroleum geologists)

MODULE 34: Patterns of Energy Use

I. Energy Use Timeline

A. overview timeline of energy sources

additional info from http://instituteforenergyresearch.org

1) *fire power*: ~1,000,000-500,000 B.C. – controlled use of fire for cooking, warmth, light, etc.
2) *animal power*: ~6000 B.C. – domestication of cattle; mules used to transport cargo, etc. (~4500 B.C. – invention of the ox-drawn plow in Mesopotamia)
3) *wind power*: ~3500 B.C – Ancient Egyptians invented the sail
4) *solar power* (direct): ~3000 B.C. – Ancient Egyptians, Chinese, Phoenicians, Greeks, and Romans used solar power to evaporate water to obtain salt and to dry crops
5) *coal power*: ~1000 B.C.– coal used in China
6) *water power*: 100 B.C. – water wheels used in what is now Turkey
7) *wind power*: 65 B.C. – windmills used in Greece
8) *Industrial Revolution* (late 1700s, early 1800s… typically 1760-1830) – machinery development; initiated by the invention of *steam engine*
9) Late 1800s: development of the *internal combustion engine, oil-well drilling, and refinement of crude oil*
10) *electric power*: 1879 – Thomas Edison invented electric light bulb
11) *nuclear power*: 1952 –world's first nuclear reactor operational for commercial power (Pennsylvania)
12) *solar power* (indirect): 1954 – first silicon solar collectors constructed (U.S.)
13) *oil power*: 1959 – first drilling in the U.S. for oil (Pennsylvania) by Colonel Edwin Drake
13) other info…
    - 1970 – first the major oil find is discovered (U.K. North Sea)
    - 1973 – internet developed
    - 1980 – first solar-cell power plant is operational (Utah)
    - 1989 – World Wide Web established

II. Nonrenewable energy use in the U.S. and the world

A. **fossil fuels**—*substances derived from fossilized biological material that is millions of years old*

B. **nonrenewable energy**—*source of energy with a finite supply, OR source of energy that is used faster than it is replenished*

C. energy units (some overlap with Ch. 2)
  1) W = Watt
    a) **1 W = 1 J/s = 1 Nm/s (N = kgm/s^2)**
      - 1 W ≈ 3.412141630 BTU/h
      - 1 horsepower ≈ 745.700 W
      - 1 horsepower (electrical British) = 746 W
      - 1 horsepower (electrical European) = 736 W
      - 1 horsepower ("metric") = 735.498 75 W
    b) **kilowatt hour (kwh)** *is the amount of energy expended by a one kilowatt device over the course of one hour* (kw x hour)
  2) **J = Joule**
    a) 4.184 J = 1 cal
    b) **GJ = gigajoule (10^9 J)**… burning ~8 gallons of gasoline
    c) **EJ = exajoule = 10^9 GJ = 10^{18} J**
    d) (U.S. only) quad = quadrillion = 10^{15} BTU
  3) **BTU or Btu = British Thermal Unit =** *the amount of energy used to raise the temperature of one pound of water one degree Fahrenheit.*

D. energy vs. power
  1) **energy**—*the ability to affect matter, do work, and/or transfer heat*
  2) **power**—*the rate at which matter is affected, work is done, or heat is transferred* **ENERGY = POWER x TIME**

E. worldwide fossil fuel energy use
  1) main stats
    a) China is #1 and U.S. is #2 for total annual energy consumption
    b) Canada is #1 and U.S. is #2 for per capita annual energy consumption
    c) Over 80% of global fuel consumption is fossil fuels
  2) **commercial energy sources**
    a) substances that produce energy; bought and sold
    b) coal, oil, natural gas; sometimes wood and animal waste
  3) **subsistence energy sources**
    a) substance that produce energy, gathered as needed by people
    b) wood/sticks, straw, animal waste

F. U.S. energy use patterns
  1) amount consumed yearly, in descending order: oil, natural gas, coal, renewable, nuclear
  2) end use, in descending order: industrial, transportation, residential, commercial

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III. Forms of Energy for Multiple Purposes

A. Energy efficiency calculations
  1) **energy efficiency** % = *(energy output / energy input) x 100*
  2) **energy return on energy investment (EROEI)** = *energy obtained from fuel / energy invested to obtain fuel*
  3) efficiency **α** EROEI
  4) system efficiency and environmental impact are important to consider

B. Transportation
  1) U.S. energy from transportation, in descending order: passenger car, airplane, bus, motorcycle and commercial train (tie)

C. **CAFE = Corporate Average Fuel Economy**
From NHTSA:

> "The National Highway Traffic Safety Administration (NHTSA) regulates CAFE standards, and the U.S. Environmental Protection Agency (EPA) measures vehicle fuel efficiency. Congress specifies that CAFE standards must be set at the 'maximum feasible level' given consideration for technological feasibility, economic practicality, effect of other standards on fuel economy, and the need of the nation to conserve energy."

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IV. Electricity generation = ~40% of U.S. energy use

A. electrical power production

1) **energy carrier**—*something that can move energy to an endpoint*
2) **primary energy source**
    a) an energy source *existing on its own*
    b) can contribute to another (the secondary) being produced
    c) examples: c*oal, oil natural gas, solar energy, nuclear energy, geothermal energy*
3) **secondary energy source**
    a) an energy source *dependent upon another source* for production
    b) example: *electrical power*
4) *1831 – invention of the generator* by Faraday; a moving magnet will cause a current in a coil of wire (example: flashlights that are shaken for power)
5) **turbine**—a *wheel* made of curves "vanes" on a rotating spindle
6) *generator*—a machine converting mechanical energy to electrical energy
7) *turbogenerator*—a turbine and a generator together
8) **capacity**—*maximum electrical output of a power plant*
9) **capacity factor—** *the fraction of time a power plant is operating in a year* (sometimes shut down for maintenance, refueling, and repairs)
10) **electrical power grids**
    a) three main *power grids* of the continental U.S., with sub-regions
        - Eastern Interconnected System (Eastern Interconnect)
        - Western Interconnected System (Western Interconnect)
        - Texas Interconnected System (Texas Interconnect)
    b) **electrical grid**—*network of interconnected transmission lines, linking multiple power plants with end users*
11) fluctuations in demand
    a) *baseload*—constant supply of power available
    b) *peak*—highest demand
    c) *reserve capacity*—additional sources of power, drawn upon during peak hours
    d) *brownout*—*reduction* in power
    e) *blackout*—*loss* of power

B. Electricity is clean energy?

a) Using electricity creates no new pollution…
b) but its production has effects on the environment because it has to be produced from using a primary source
c) efficiency
    - thermal production of electricity is only ~*30% efficient*

- heat is lost in travel from the firebox and in the spent steam (conversion losses)
- *cooling towers* are used to condense the steam

C. matching sources to uses

1) categories of primary energy use: transportation, industrial, commercial/residential, to generate electric power
2) how to decrease consumption: conservation, increase efficiency, demand management

D. **cogeneration** or **combined heat and power (CHP)**

> from http://www.energy.rochester.edu/cogen/chpguide.htm :
>
> "Cogeneration… is an enormous and growing market… The common feature in all cogeneration systems is the *prime mover*, which will either convert waste heat into power or generate heat and power from a single energy input. Prime movers can either be reciprocating engines (such as an automobile engine, which produces both power and heat) or a turbine. Turbines can be powered by steam, hot air, and occasionally other media. Combustion turbines have a compressor, combustor, and hot air turbine in a single unit. Prime movers can be combined in a variety of ways to increase energy utilization. One common method is to use the waste heat from an engine or combustion turbine to generate steam, which is then used to power a steam turbine. A simple cycle plant has a single prime mover, and a combined cycle plant will have two in series."

- *combined-cycle natural gas unit*—two turbines: the first (gas turbine) fueling the second (steam turbine)

E. sustainable energy options

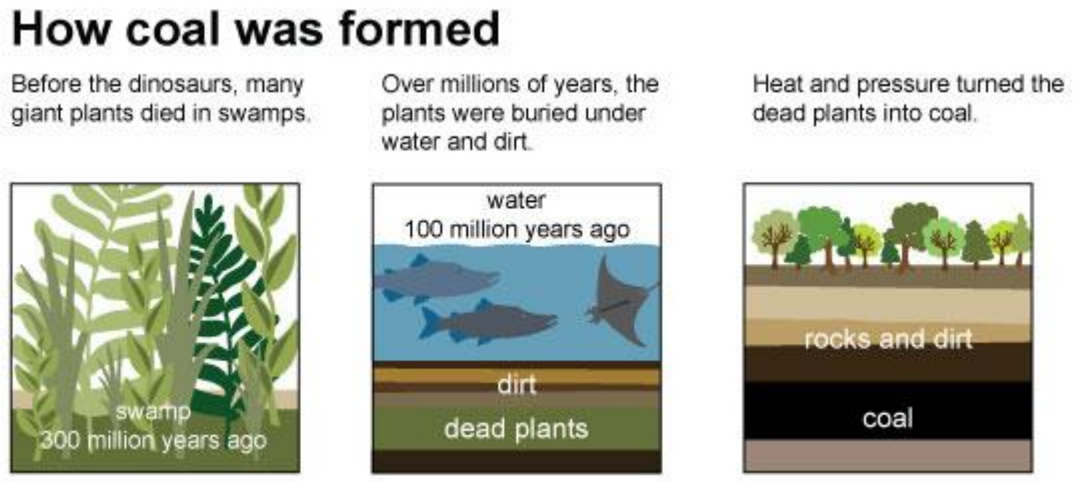
1) conservation through *improving vehicles*
2) other vehicular options: carpooling, mass transit, walking, bicycle
3) conservation through state-adopted *deregulation*—the process by which governments remove restrictions on business in order to (in theory) encourage the efficient operation of markets
4) conservation through *improvements in appliances* and *light bulbs*: increased energy efficiency and lower energy costs (may cost more to buy)
5) conservation through *new building codes*—improved insulation, windows…
6) conservation through the *internet*: emails, telecommuting, online shopping…
7) non-fossil fuel energy sources: *nuclear power, solar power, geothermal energy, hydroelectric, wind…*

MODULE 35: Fossil Fuel Resources

I. General info - how fossil fuels are formed

A. decreased detritus formation in ocean depths (lack of O_2)
B. *compaction of dead organic matter* below layers of sediment
C. conversion by heat and pressure to *fossil fuels: coal, oil, and natural gas*
D. fossil fuels can still form but are considered *nonrenewable resources* because the replacement rate cannot keep up with demand

II. Coal (some info from www.coal.org and https://www.eia.gov/energyexplained/index.php?page=coal_home)



Source: Adapted from National Energy Education Development Project (public domain)

A. *peat (peat moss)*—partially decomposed organic material, precursor to coal formation

B. types of **coal** (*solid fossil fuel from organic material millions of years old*)
   1) **anthracite***:* hard*;* metallic luster; ~90% C; least plentiful; "smokeless"
   2) **bituminous***:* soft; black; usually 20-% moisture; *most common U.S. coal*, thermal/steam coal
   3) subbituminous*:* dull black, usually 20-30% moisture
   4) **lignite** ("brown coal")*:* brown-black, higher moisture, lower C, used to generate electricity

C. progression of coal formation:

PEAT → LIGNITE → BITUMINOUS → ANTHRACITE

D. advantages of coal
   1) relatively inexpensive
   2) relatively easy to mine on surface
   3) relatively easy to process and refine
   4) relatively easy to transport and store

E. disadvantages of coal
   1) release of CO_2 from combustion
   2) issues with *tailings* (mining waste)
   3) subsurface mining does more damage
   4) SO_2 emissions from burning higher-S coal
   5) trace amounts of Hg, Pb, As in coal can be released when burned
   6) release of PM from burning
   7) chemicals used to "wash" coal can be environmentally hazardous

* * *

III. Petroleum Oil https://www.eia.gov/energyexplained/index.php?page=oil_home

A. general terms
   1) **petroleum**—*underground liquid fossil fuel containing hydrocarbons, water, and sulfur*
   2) **crude oil**—*liquid petroleum extracted from the ground*

B. crude oil reserves vs. production
    1) *oil resources*—total amount of crude oil remaining
    2) *estimated reserves*—amount of crude oil *expected* to exist
    3) *exploratory drilling*—a method of finding crude oil deposits
    4) *oil field*—underground area containing oil deposits
    5) *proven reserves*—an estimate of *how much oil can be extracted in an economically feasible way* from an oil field
        a) **1 barrel of oil = 42 gal**
        b) proven reserves listed as *probabilities* (P*x*), like P50
    6) *production—"harvesting" the oil or natural gas form the field by extraction*
        a) *nonconstant extraction rate from pore spaces in sedimentary rock*
        b) *gusher*—quick flow from an oil well; not lasting
        c) *primary recovery—conventional* pumping
        d) *secondary / tertiary recovery—forcing* the oil up into the wells by injection of steam or brine into the reservoir

C. advantages of petroleum
    1) relatively easy to transport and store
    2) cleaner-burning than coal

D. disadvantages of petroleum
    1) oil leaks from drill sites
    2) oil tanker accidents (Deepwater Horizon 2010, Exxon Valdez 1989)
    3) trace amounts of Hg, Pb, As in coal can be released when burned

E. adjusting to higher prices
    1) increase domestic production of oil
        a) open **ANWR** (**Arctic National Wildlife Refuge**) and similar areas to oil/gas exploration
        b) add more coal-fired power plants
        c) monetary assistance to other countries' oil/gas development
        d) extend Alaska gas pipeline to the lower 48 states

from http://www.alyeska-pipe.com/default.asp
"The 800-mile-long Trans Alaska Pipeline System (TAPS) is one of the largest pipeline systems in the world. It stretches from Prudhoe Bay on Alaska's North Slope, through rugged and beautiful terrain, to Valdez, the northernmost ice-free port in North America. Since pipeline startup in 1977, Alyeska Pipeline Service Company, the operator of TAPS, has successfully transported over 15 billion barrels of oil."

    2) decrease consumption
        a) increasing fuel efficiency standards for vehicles and appliances
        b) improving building insulation
        c) development of alternative energy sources
    3) protect against another OPEC boycott by a massing a *strategic oil reserve*

F. **OPEC**—*Organization of Petroleum Exporting Countries*
    1) member countries: Algeria, Angola, Congo, Ecuador, Equatorial Guinea, Gabon, Indonesia, Iran, Iraq, Kuwait, Libya, Nigeria, Qatar, Saudi Arabia, the United Arab Emirates, and Venezuela
    2) OPEC formed a *cartel*, working together to raise prices

G. problems of growing U.S. dependency on foreign oil
    1) costs of purchase
    2) risk of supply disruption: Middle East conflicts, wars
    3) resource limitations

a) geologists are searching using computer mapping
b) global usage: *900 BB (billions of barrels)* used, most in 20th century
c) proven reserves:

http://www.eia.doe.gov/emeu/international/reserves.html

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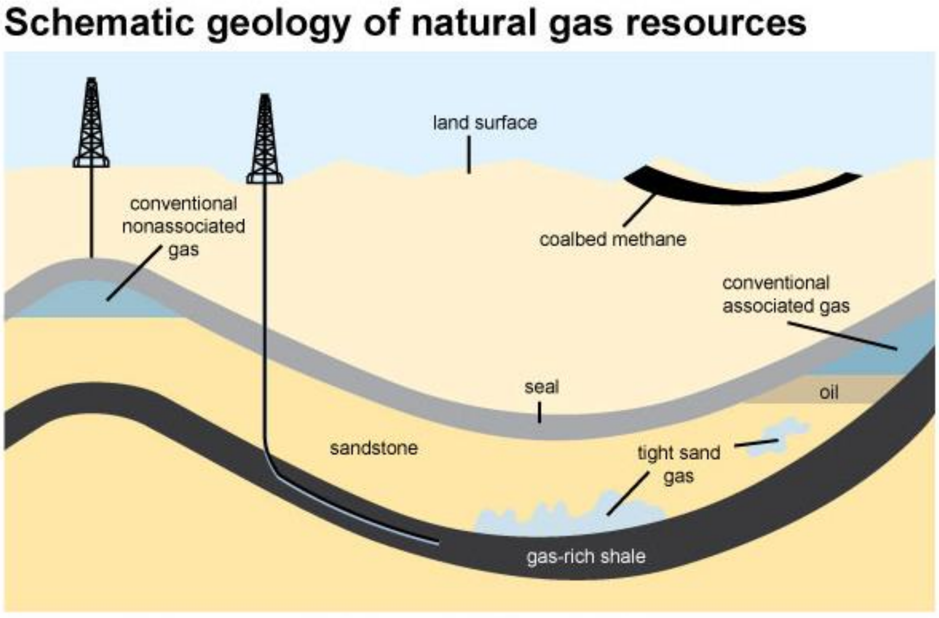
IV. Natural Gas

https://www.eia.gov/energyexplained/index.php?page=natural_gas_home

A. **natural gas**—*fossil fuel source formed beneath the surface, comprised of multiple compounds*



Source: Adapted from *United States Geological Survey factsheet 0113-01* (public domain)

B. **LNG = Liquefied Natural Gas**
  1) a synthetic oil made from cooling natural gas to -260° F to liquefy it
  2) used in transporting natural gas, since it takes up 1/600 of the volume
  3) U.S. imports most of its LNG

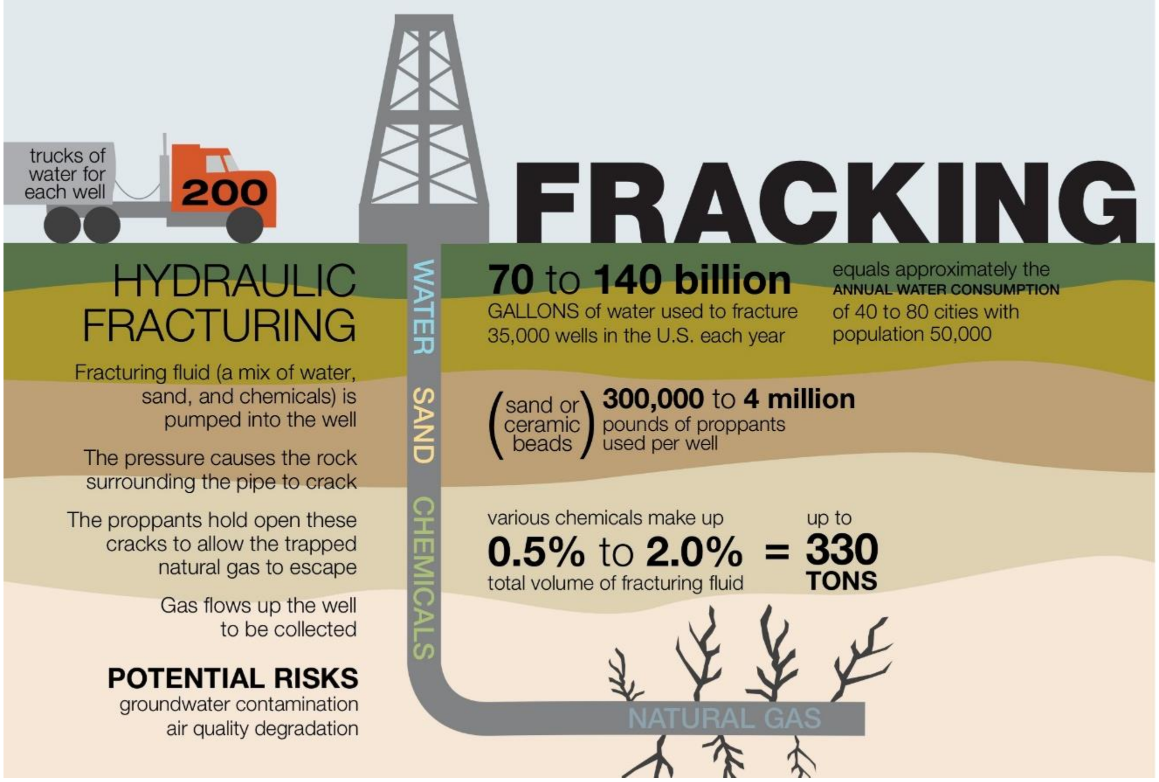
C. **LPG = Liquefied Petroleum Gas** (Autogas)
  1) mainly propane, propylene, butane, and butylene in various amounts
  2) a by-product of natural gas processing and petroleum refining

Typical Composition of Natural Gas (www.naturalgas.org)	
Methane CH_4	70-90%
Ethane C_2H_6, Propane C_3H_8, Butane C_4H_{10}	0-20%
Carbon Dioxide CO_2	0-8%
Oxygen O_2	0-0.2%
Nitrogen N_2	0-5%
Hydrogen sulfide H_2S	0-5%
He, Ne, Xe	trace

D. advantages of natural gas
  1) easily used for heating and cooking

2) used to manufacture nitrogen-based fertilizer
3) “cleanest burning” fossil fuel – almost no SO_2 or PM emissions

E. disadvantages of natural gas
1) most gas is inaccessible – need pipelines
2) unburned CH_4 is a GHG
3) *hydraulic fracturing (“fracking”)* issues



Source: napavalley.edu

V. Oil Sands, Oil Shale, and Liquefied Coal
A. **oil sands** (tar sands) – *slow-flowing, viscous deposits of bitumen mixed with sand, water, and clay*
1) **bitumin** *is a tar-like hydrocarbon*
2) when heated, the bitumen “melts;” can be collected and refined into a crude oil-like product
3) U.S.— limited oil sand deposits in Utah
4) Alberta, Canada has the world’s largest oil sand deposits

from www.oilsandsdiscovery.com :

“An estimated 1.7 to 2.5 trillion barrels of oil are trapped in a complex mixture of sand, water and clay. The most prominent theory of how this vast resource was formed suggests that light crude oil from southern Alberta migrated north and east with the same pressures that formed the Rocky Mountains. Over time, the actions of water and bacteria transformed the light crude into bitumen, a much heavier, carbon rich, and extremely viscous oil. The percentage of bitumen in oil sand can range from 1%-20%.”

B. **oil shale**
  1) *sedimentary* rock containing *kerogen* (solid waxy hydrocarbons)
  2) when heated, the rock releases vapor that can be recondensed into a crude oil-like product
  3) impractical: too small of a yield (1/2 barrel oil impractical— too small of a yield (1/2 barrel oil per ton of rock)

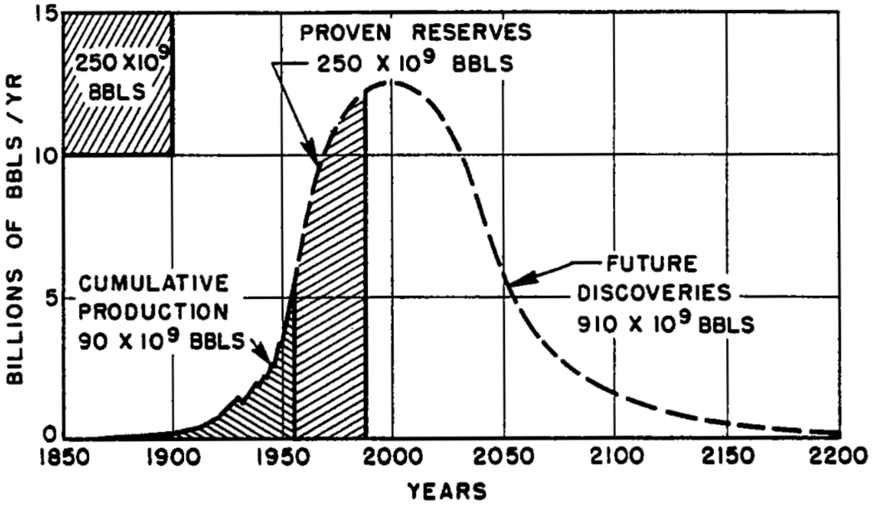
C. liquid coal (coal liquefaction)
  1) **CTL** – *coal-to-liquid process*
  2) too many GHG released in processing – not a feasible fuel for the future

VI. Nonrenewable resources and the future

A. **energy intensity**—*energy use per unit of GDP (gross domestic product)*

B. Hubbert's curve (1969)
  1) in *1970*, new exploratory drilling began to turn up *no new oil deposits*
  2) shift from oil-independent status to being dependent on imported oil
  3) *bell curve* named for geologist M.K. Hubbert
  4) based on his prediction, U.S. oil production would peak around 1965-1970

C. **peak oil**—*the point at which the world's oil will be used up*



MODULE 36: Nuclear Energy Resources

I. Nuclear Power background info

A. benefits of nuclear power
  1) does not produce Greenhouse gases (GHG); "clean burning"
  2) does not deplete fossil fuels
  3) not affected by prices of crude oil, etc.

B. Global statistics on nuclear power

http://www.world-nuclear.org/information-library/current-and-future-generation/plans-for-new-reactors-worldwide.aspxv

(2019) " Today there are about 450 nuclear power reactors operating in 30 countries plus Taiwan, with a combined capacity of about 400 GWe. In 2017 these provided 2506 billion kWh, over 10% of the world's electricity. About 50 power reactors are currently being constructed in 15 countries—notably China, India, Russia and the United Arab Emirates."

C. U.S. statistics on nuclear power
  1) 30 states have nuclear reactors
  2) *~100 commercial nuclear generating units in the U.S.*
    a) most are **pressurized water reactors (PWRs)**
    b) also **boiling water reactors (BWRs)**
  3) latest updates from EIA (U.S. Energy Information Administration): http://www.eia.gov/energyexplained/index.cfm?page=nuclear_use
  4) EIA issues and trends: http://www.eia.gov/nuclear/

D. Florida statistics from http://www.eia.gov/nuclear/state/florida/ : St. Lucie, Turkey Point

E. general terms (SEE ATOM REVIEW NOTES)
  1) review basic nuclear chemistry: proton, neutron, electron, nucleus, isotope, mass number, atomic number, atomic mass, half-life, fission, fusion
  2) *MW(e) = Megawatt electric*
  3) U.S. Nuclear Regulatory Commission (NRC) gives approval for operation

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II. How Nuclear Power Works

A. from mass to energy
  1) types of nuclear reactions
    a) **fission**—*one larger atom is split into two smaller atoms*
      - *fission products*—the lighter atoms resulting from the reaction (also called *daughter products*)
    b) **fusion**—*two smaller atoms are joined (fused) to form one larger atom*
    c) *chain reaction*—a domino effect; a repeating reaction cycle
  2) characteristics of nuclear reactions
    a) *mass of products < mass of reactants* (violates Conservation Laws)
    c) massive energy is released (1 kg is enough to be a full-scale bomb)
    d) $E = mc^2$
    e) **isotopes** are involved: *different forms of the same element, having different numbers of neutrons*

fission reaction

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

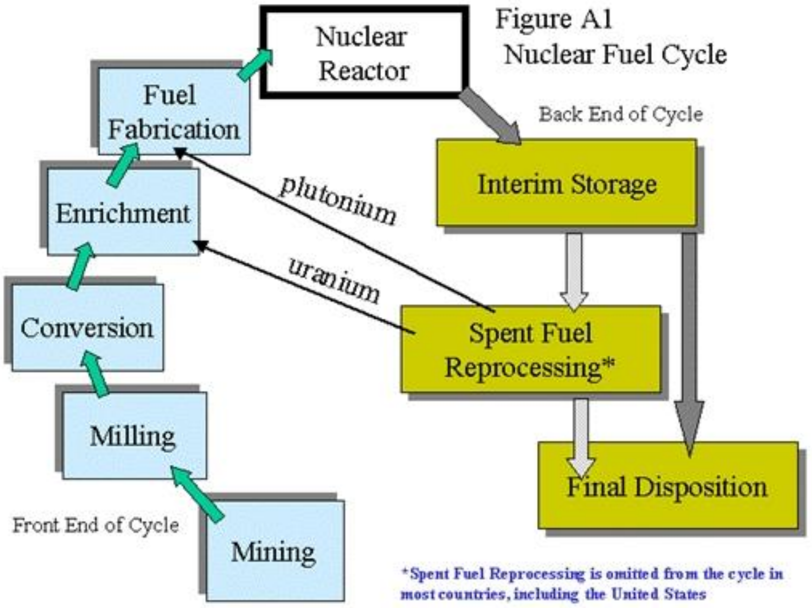
neutrons can cause more rxns.--- chain reaction

  3) fuel for nuclear power plants
    a) uranium (U) ore is mined and refined, made into *UO_2 (uranium dioxide), also generically called MOX (mined oxide fuel)*
    b) *enrichment*—separating the isotopes (U-238 and U-235)
  4) parts of nuclear reactors
    a) *reactor core*, containing tubes called **fuel elements** or **fuel rods**
    b) **control rods,** interspersed between the fuel elements, contain neutron-absorbing material
    c) *moderator*—material that *slows down the neutrons* (such as water); can be referred to as the *coolant*
      - *"light water" = regular H_2O*
      - *"heavy water," D_2O, contains deuterium (H-2)*
    d) *reactor vessel* holds everything

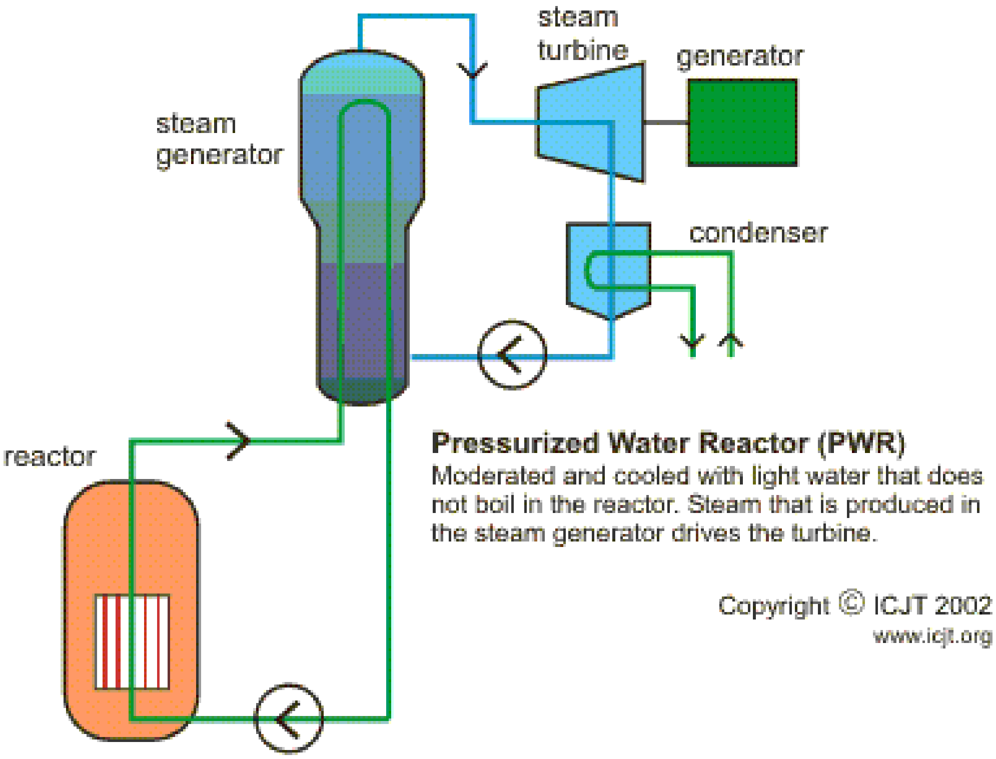
5) types of nuclear reactors
  a) *WATER*
    - *Pressurized Water Reactors (PWR) - important*
    - *Boiling Water Reactors (BWR) - important*
    - Advanced Boiling Water Reactor (ABWR)
    - Advanced Light Water Reactor (ALWR)
    - Light Water Cooled Graphite Moderated Reactor (LWGR)
    - Pressurized Heavy Water Moderated Reactor (PHWR)
  b) *LIQUID METAL*
    - Advanced Liquid Metal Reactor (ALMR)
    - Integral Fast Reactor (IFR)
  c) *GAS*
    - Modular High Temperature Gas Cooled Reactor (MHTGR)
    - Gas Cooled Reactor (GCR)
    - Advanced Gas Cooled Reactor (AGR)

6) nuclear power plant basics
  a) heat generated by the reactor boils water
    - water can be allowed to flow through the reactor
    - double-loop method
      * water is heated to 316 °C (600 °F) but is pressurized (155 atm) so it can’t boil
      * superheated water flows through a heat exchanger to boil unpressurized water
  b) water is converted to steam
  c) steam powers turbogenerators
  d) *meltdown*—actual melting of the core materials, causing explosions
  e) *LOCA* – loss of coolant accident

NUCLEAR FUEL CYCLE http://www.icjt.org



PRESSURIZED WATER REACTOR (PWR) - important



Pressurized Water Reactor (PWR)
Moderated and cooled with light water that does not boil in the reactor. Steam that is produced in the steam generator drives the turbine.

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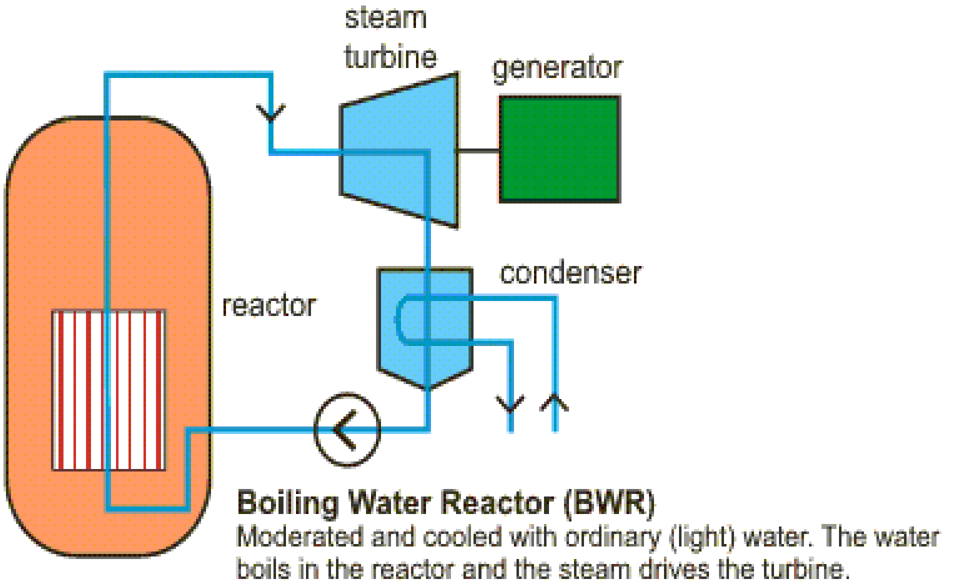
BOILING WATER REACTOR (BWR) - important



Boiling Water Reactor (BWR)
Moderated and cooled with ordinary (light) water. The water boils in the reactor and the steam drives the turbine.

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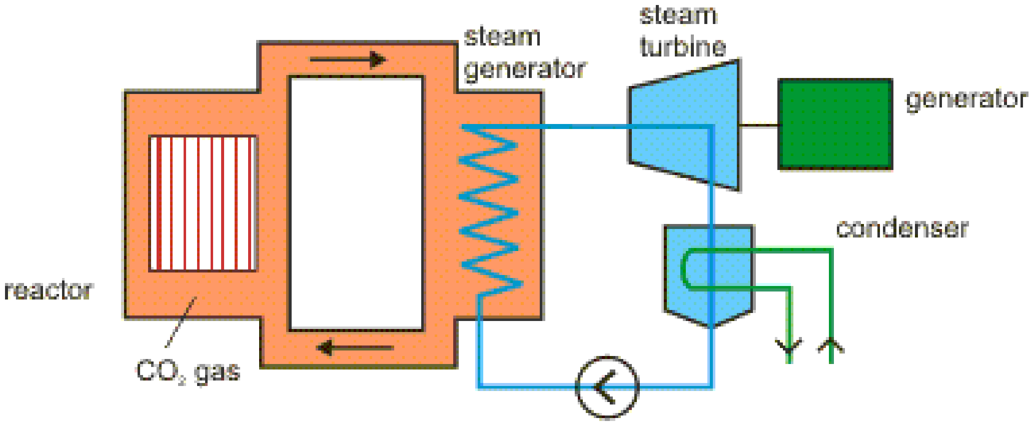
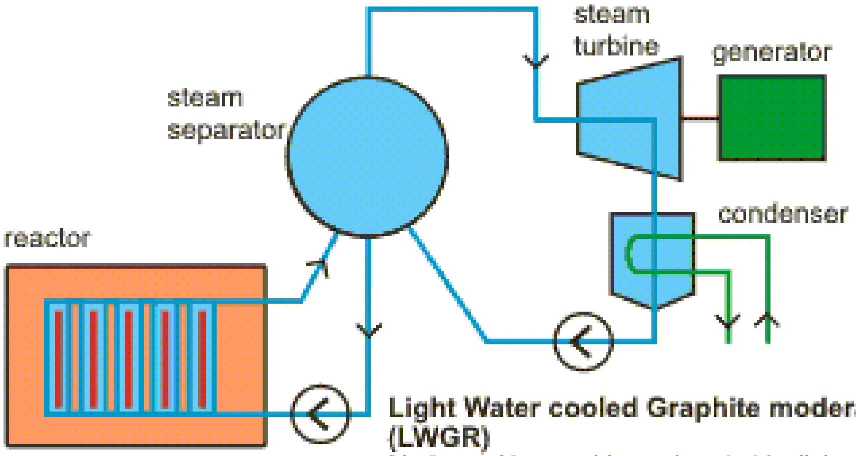
GAS COOLED REACTOR (GCR)



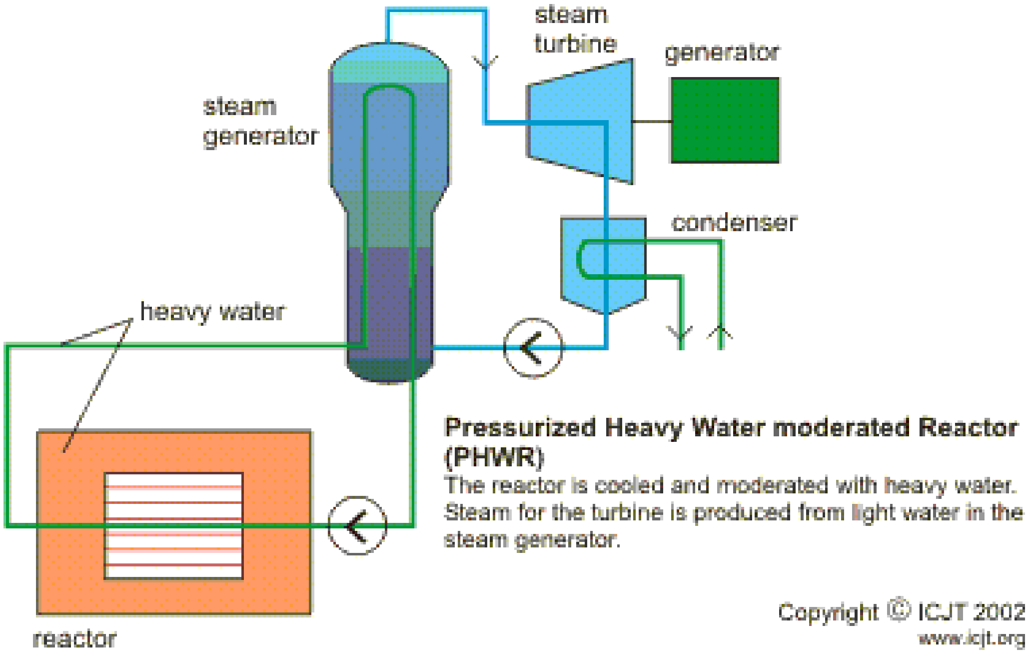
Gas Cooled Reactor, Advanced Gas cooled Reactor (GCR in AGR)
Graphite is used as the moderator and carbon dioxide is used as the coolant. Hot CO2 heats up and boils water into steam that drives the turbine.

LIGHT WATER COOLED GRAPHITE MODERATED REACTOR (LWGR)



Light Water cooled Graphite moderated Reactor (LWGR)
Moderated by graphite and cooled by light water that boils in the reactor. The steam drives the turbine.

PRESSURIZED HEAVY WATER MODERATED REACTOR (PHWR)



Pressurized Heavy Water moderated Reactor (PHWR)
The reactor is cooled and moderated with heavy water. Steam for the turbine is produced from light water in the steam generator.

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more reactors: **ADVANCED LIGHT WATER REACTOR (ALWR) –** p. 21
PEBBLE-BED MODULAR REACTOR (PBMR) – p. 22
LIQUID METAL FAST BREEDER REACTOR (LMFBR) – p. 23

RADIOACTIVITY SYMBOL

B. comparison of nuclear power with coal power emissions

1000 MW plants, 1 year of operation

	NUCLEAR (tons)	COAL (tons)
fuel needed	30	3,000,000
CO_2	none	7,000,000
SO_x, NO_x, PM, etc.	none	300,000
radioactive gases	trace	none
solid wastes	250 **	600,000
accidents	widespread	localized

** highly radioactive

III. Hazards and Costs of Nuclear Power

A. radioactive emissions

1) general info from…
www.darvill.clara.net/nucrad/index.htm and www.epa.gov

a) *radioisotopes (radioactive isotopes or radionuclides)*—unstable isotopes which spontaneously release particles (see b)

b) **half life** (t ^{½}) — *the time it takes for half the amount of a radioisotope to decay* (wide range—from a fraction of a second to thousands of years)

c) *radioactive emissions*—possible products of nuclear decay:

i.) **alpha particle = α**
- *made of He nuclei (2 protons, 2 neutrons); positively charged*
- alpha decay example:

$$^{241}{}_{95}\mathrm{Am} \rightarrow {}^{237}{}_{93}\mathrm{Np} + {}^{4}{}_{2}\mathrm{He}$$

ii.) **beta particle = β**
- *made of electrons; negatively charged*
- beta decay example:

$$^{3}{}_{1}\mathrm{H} \rightarrow {}^{3}{}_{2}\mathrm{He} + {}^{0}{}_{-1}\mathrm{e}$$

iii.) **gamma ray = γ**
- *made of electromagnetic (em) radiation, no charge*
- pure energy; wavelengths (λ) of 0.03-0.003 nm!
- gamma decay example:

$$^{3}{}_{2}\mathrm{He} \rightarrow {}^{3}{}_{2}\mathrm{He} + \gamma$$

d) emissions are also called ionizing radiation

e) *radioactive waste (radwaste)*—emissions from the nuclear reactions as well as indirect products (elements)

f) radioactivity units:

Curie: *1 Ci = 3.7×10^{10} decays per second*
This is roughly the activity of 1 gram of the ^{226}Ra isotope, a substance studied by the pioneers of radiology, Marie and Pierre Curie.

The curie has since been replaced by an SI derived unit, the **becquerel (Bq),** *which equates to one decay per second.*

1 Ci = 3.7×10^{10} Bq and 1 Bq = 2.70×10^{-11} Ci

Roentgen Equivalent Man (rem)— a unit of equivalent dose relating the absorbed dose in human tissue to the effective biological damage of the radiation)

Sv = sievert = SI derived unit of dose equivalent, attempting to reflect the biological effects of radiation; J of energy / kg of tissue *1 sievert = 100 rem*

Gray (Gy) = the SI unit of absorbed dose and physical effects; same unit equivalent as Sv
1 gray = 100 rad

Rad = unit of radiation dose, *meaning* "**r**adiation **a**bsorbed **d**ose." It is superseded in the SI system by the gray; the U.S. is the only country that still uses the rad.

2) biological effects of radioactive emissions
   a) *stochastic effects*—a long-term, low-level (chronic) exposure
      - stochastic = likelihood that something will happen
      - increased exposure makes the effects more likely to occur but do not influence the type or severity
      - cancer, genetic mutations
   b) *nonstochastic effects*—acute, short-term, high-level exposure
      - becoming more severe as the exposure increases
      - burns, radiation sickness (nausea, weakness, hair loss, skin burns or diminished organ function)

Exposure (rem) *	**Health Effect**	**Time to Onset**
5-10	changes in blood chemistry	variable
50	nausea	hours
55	fatigue	hours
70	vomiting	hours
75	hair loss	2-3 weeks
90	diarrhea	weeks
100	hemorrhage	weeks
400	death	within 2 months
1,000	destruction of intestinal lining	1-2 weeks
1,000	internal bleeding	1-2 weeks
1,000	death	1-2 weeks
2,000	damage to central nervous system (CNS)	minutes
2,000	loss of consciousness	minutes
2,000	death	hours to days

3) sources of radiation: cosmic radiation, natural elements in the crust, X-rays, radon in homes, fallout from testing
4) government guidelines = 1.7 mSv/yr exposure, except for X-rays

B. **radioactive wastes** (“**radwaste**”)
   1) *reprocessing*—recovery and recycling of isotope products of nuclear reactions to be used as fuel again (not done in U.S.)
   2) types of radioactive waste
      a) *low-level waste*
         - mixed (hazardous and radioactive) waste
         - waste from commercial or government activities
         - waste exempted or deferred from regulation by the Nuclear Regulatory Commission
         - waste containing natural radioactivity

    - certain types of cleanup or decommissioning waste
    - can take 100-500 years to become safe
  b) *high-level waste*
    - byproduct of producing nuclear materials for defense uses
    - stored in forms such as sludge, liquid, or pellets which must be solidified before disposal
    - produced when spent nuclear fuel is reprocessed by dissolving it in strong chemicals to recover unfissioned uranium and plutonium (not done in U.S.)
    - generally contains highly radioactive elements, such as cesium, strontium, technetium, and neptunium.
    - takes thousands of years to become safe

From https://www.epa.gov/radiation

Commonly Encountered Radionuclides				
Name	Atomic Number	Radiation Type		
		Alpha	Beta	Gamma
Am-241	95	●		●
Cs-137	55		●	●
Co-60	27		●	●
I-129 &-131	53		●	●
Pu (plutonium) - important	94	●	●	●
Ra	88	●		●
Rn	86	●		
Sr-90	38		●	
(Technetium) Tc-99	43		●	●
Tritium (H-3)	1		●	
Thorium (Th)	90	●		●
U - important	92	●		●

from www.chemicalelements.com

Isotope Half Life

U-230	20.8 days	Pu-236	2.87 years
U-231	4.2 days	Pu-237	45.2 days
U-232	70.0 years	Pu-238	87.7 years
U-233	159,000.0 years	**Pu-239**	**24,100.0 years**
U-234	247,000.0 years	Pu-240	6560.0 years
U-235	**7.0004 x 10^8 years**	Pu-241	14.4 years
U-236	2.34 x 10^7 years	Pu-242	375,000.0 years
U-237	6.75 days	Pu-243	4.95 hours
U-238	**4.47 x 10^9 years**	Pu-244	8.0 x 10^7 years
U-239	23.5 minutes	Pu-245	10.5 hours
U-240	14.1 hours	Pu-246	10.85 days

3) disposal
  a) short-term – hold the materials on site
  b) long-term
    - non-corrosive containers sealed in glass blocks

        - buried deep underground in a stable area
        - enclosed in concrete and dumped in ocean

4) military radioactive wastes
    a) radioactive waste is leaking from Russian nuclear submarines
    b) more waste will be generated by dismantling old weapons
    c) technical problems with finding safe storage and disposal sites
    d) financial problems covering the costs of security, decommissioning, decontamination and clean-up

5) high-level nuclear waste disposal – *Yucca Mountain*
    http://www.yuccamountain.org/
    a) located in a remote desert on federally protected land within the secure boundaries of the Nevada Test Site in Nye County, Nevada
    b) ~ 100 miles NW of Las Vegas
    c) supposed to be a *geologic repository*—packaged waste stored in underground tunnels deep below the surface
    d) project is presently stalled

> "Federal funding for DOE's repository program is currently nonexistent… the U.S. Department of Energy (DOE) has spent at estimated $8 billion studying the site and constructing the exploratory tunnel beneath Yucca Mountain. Moreover, to actually construct and operate a repository at Yucca Mountain, DOE's own estimate suggests the cost could reach $97 billion. …Today the Yucca Mountain site has been abandoned and nothing exists but a boarded up 5p-mile exploratory tunnel; there are no waste disposal tunnels, receiving and handling facilities, and the waste containers and transportation casks have yet to be developed."

C. potential for accidents

1) *Chernobyl* (former USSR; Ukraine, 4/26/86)

https://www.nationalgeographic.com/travel/destinations/europe/ukraine/exclusion-zone-chernobyl-ukraine/

    a) summary
        - power plant located 80 miles north of Kiev; had 4 reactors
        - safety systems were disabled while running tests on a nearby generator
        - reactor overheated, chain reaction went out of control, steam built up and blew the steel and concrete top off the reactor
    b) causes
        - known design weaknesses going unchecked
        - design flaw– unstable at low power: heats up too quickly
        - procedural violations: cooling system was disabled; 6-8 control rods were in place instead of at least 30
        - breakdown in communication between the test team and the reactor team
    c) effects
        - 31 died right away
        - *increased thyroid cancer from I-131, and Cs-137*
        - increased other types of *cancer*
        - increased cases of *anxiety, depression, PTSD*
        - last reactors of the power plant shut down in 2000
        - lack of public trust

2) Fukushima (3/11/11) http://www.world-nuclear.org/information-library/safety-and-security/safety-of-plants/fukushima-accident.aspx

- a) summary
  - Japan
  - produced 1/10 the radiation of Chernobyl
  - released I-131 (8-day half-life) and Cs-137 (30-yr half-life)
- b) causes
  - occurred after earthquake and tsunami
  - tsumani broke reactor's connection to the power grid
  - reactors overheated – meltdown of all three
- c) effects
  - close monitoring of 3700 plant workers
  - seawater monitoring
  - airborne radiation spread
  - hindered access to site and equipment – storm damage

3) *Three Mile Island 2* (TMI-2) http://www.threemileisland.org/
(near Middletown/Harrisburg, Pennsylvania, 3/28/79)

- a) summary
  - steam generator shut down due to lack of feedwater
  - valve opened to let out excess steam but did not close
  - equipment did not show that the valve was still open
  - partial meltdown of the core
- b) causes
  - design problems
  - equipment malfunctions
  - miscommunication
- c) effects
  - lack of public trust
  - very low exposure to 2,000,000 people in the area
  - stricter standards of design, inspection, backup equipment, and human experience/ skill, troubleshooting
  - reactor shut down permanently

D. Safety and nuclear power

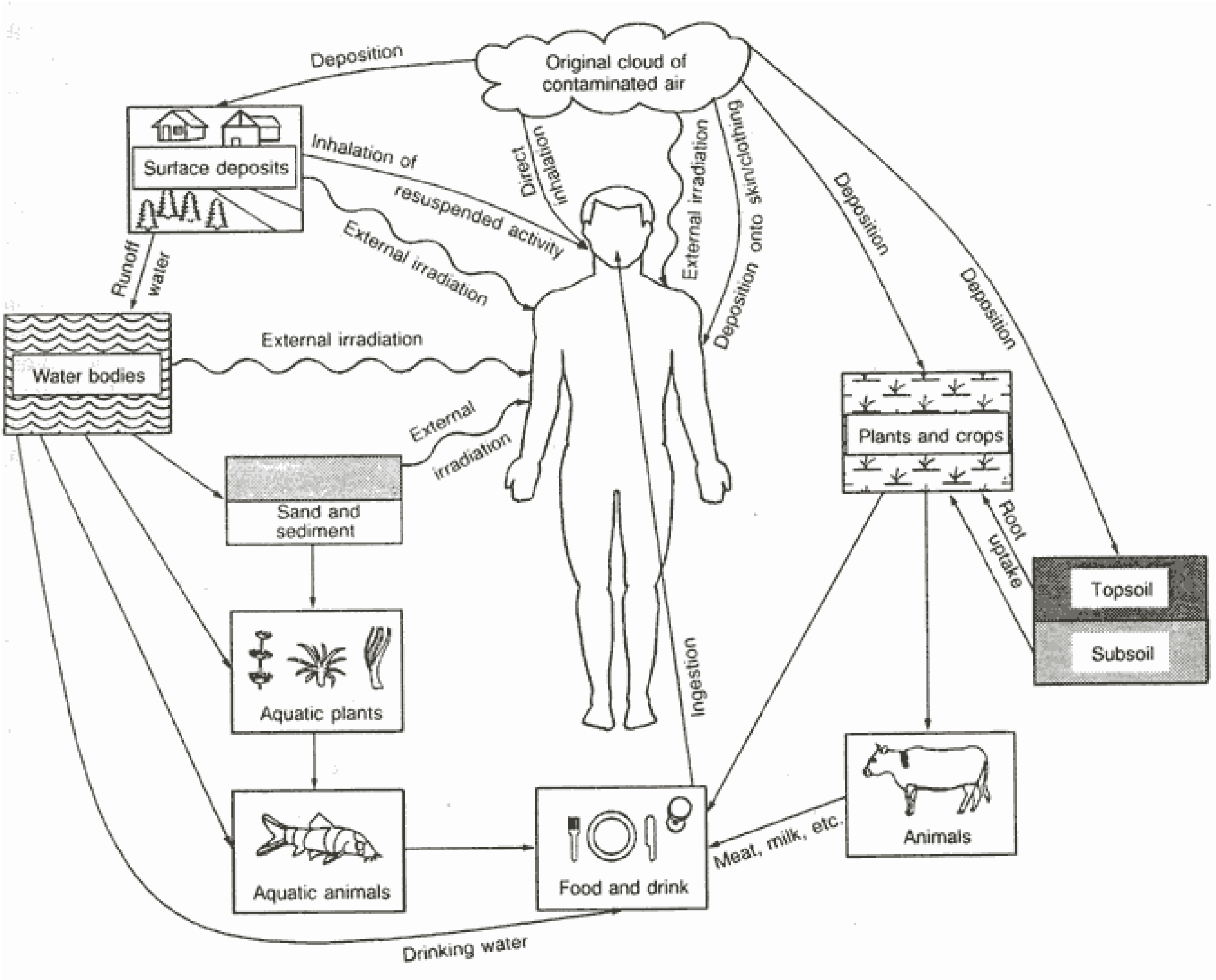
1) **active safety**—human-controlled actions, external power, equipment signals
2) **passive safety**—design components
3) new generations of reactors
   - a) Generation I – built in the 1950s-60s; most are decommissioned
   - b) Generation II – most currently operating reactors
   - c) Generation III – smaller, simpler designs; passive safety features
     - Example: **ALWR – advanced light water reactors** prevent a *LOCA (loss of coolant accident)* – see notes p. 21
   - d) Generation IV – **PBMR (pebble-bed modular reactor) –** see p. 22

From www.pbmr.com

"The PBMR is a High Temperature Reactor (HTR), with a closed-cycle, gas turbine power conversion system. Although it is not the only HTR currently being developed in the world, the South African project is internationally regarded as the leader in the power generation field. Very high efficiency and attractive economics are possible without compromising the high levels of passive safety expected of advanced nuclear designs.

The PBMR essentially comprises a steel pressure vessel which holds the enriched uranium dioxide fuel encapsulated in graphite spheres. The system is cooled with helium and heat is converted into electricity through a turbine."

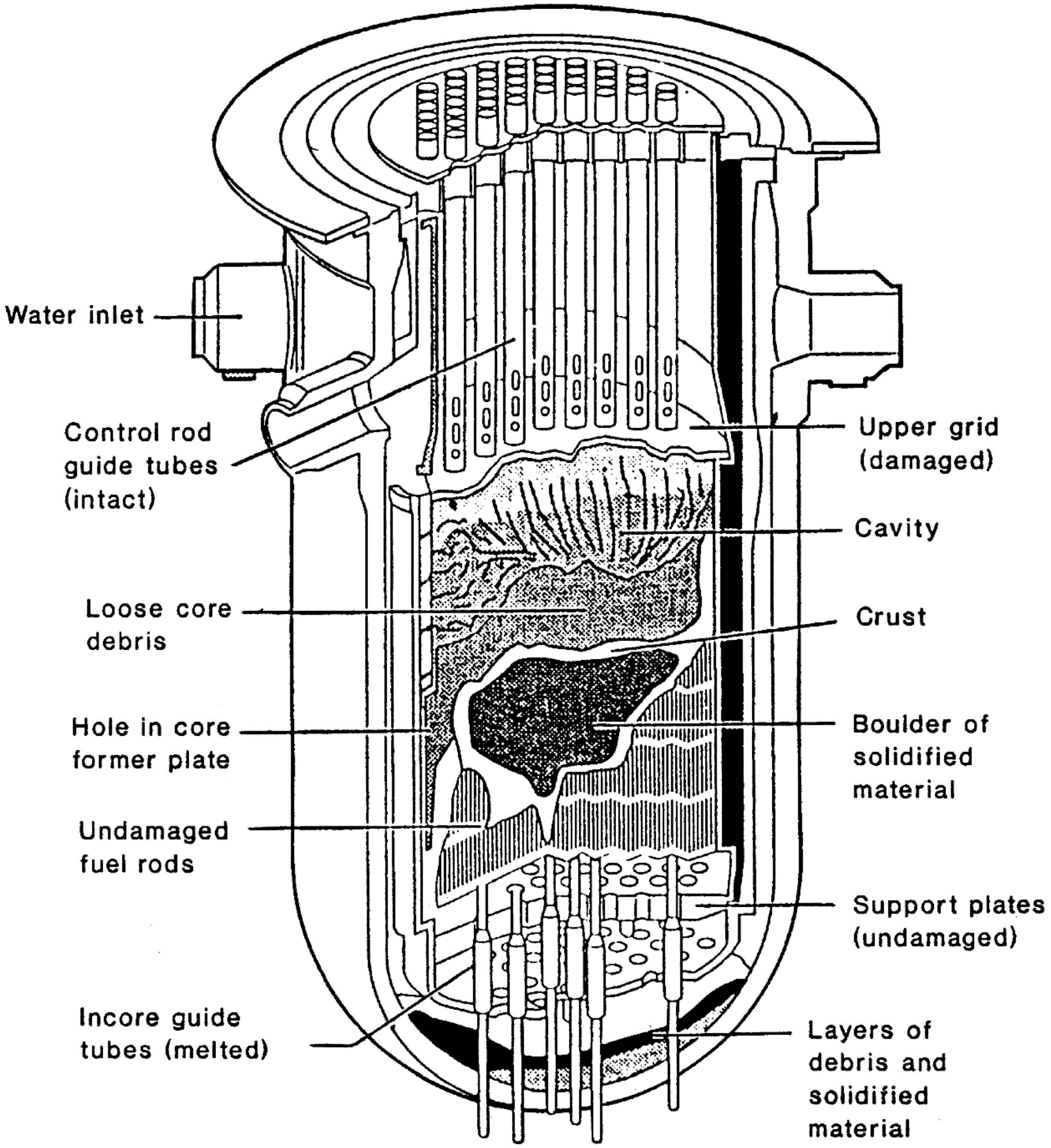
E. Economic problems with nuclear power
  1) power plants lasting an average of only 17 years
    a) **embrittlement**— the reactor parts themselves become brittle
    b) **corrosion**—chemically eaten away; causes cracks in the pipes
  2) **decommissioning** (closing down) a power plant is costly (hundreds of millions of dollars)
  3) technical problems



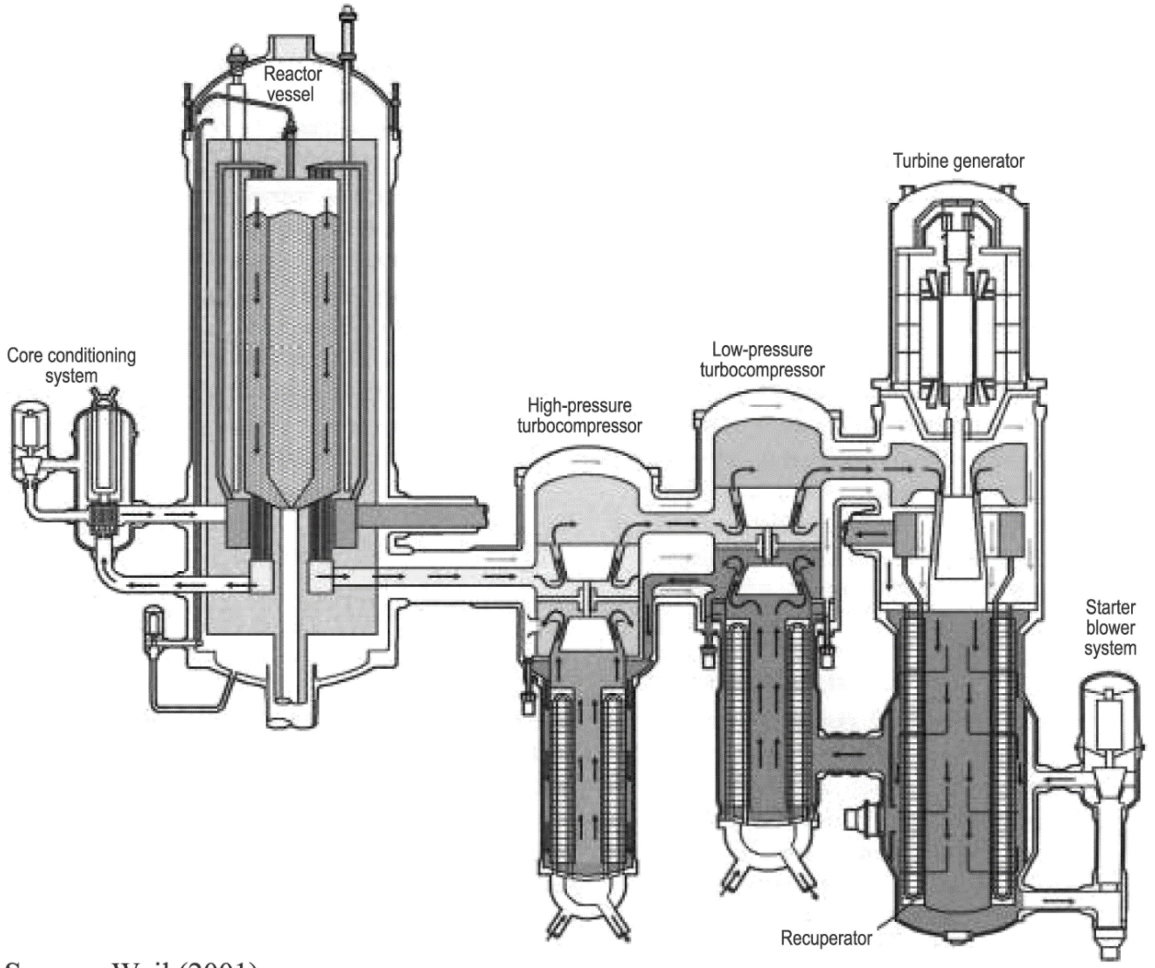
Main environmental pathways of human radiation exposure
[Source : IAEA technical report ISBN 92-0-129191-4 Vienna 1991]

ADVANCED LIGHT WATER REACTOR (ALWR)

Source: G.P.U. Nuclear



PEBBLE-BED MODULAR REACTOR (PBMR)



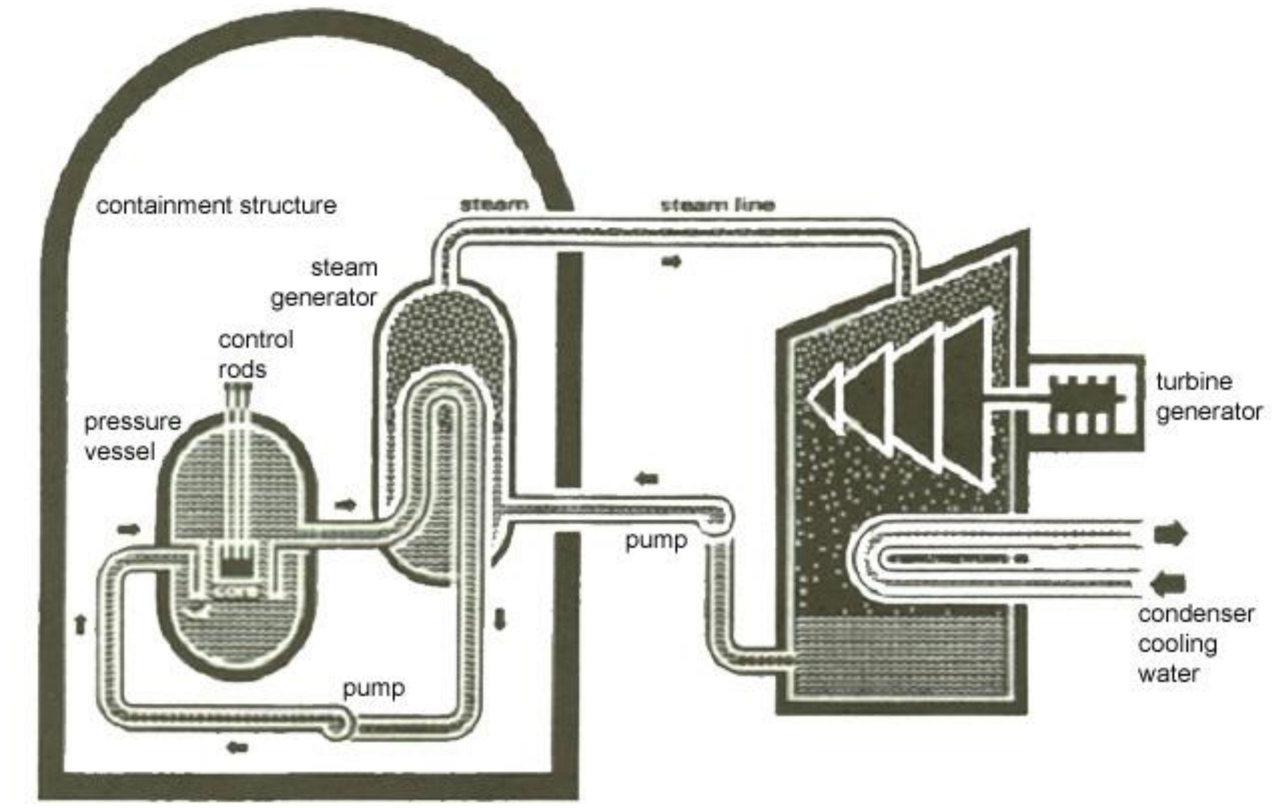
Source: Weil (2001)

IV. More Advanced Reactors
  A. *breeder reactors* **(**liquid metal fast breeder reactors)
    1) *uses U-238 to absorb extra neutrons; becomes Pu-239*

example of breeder reactions

$$^{1}_{0}n \;+\; ^{238}_{92}U \;\rightarrow\; ^{239}_{92}U \;\rightarrow\; \underset{\text{beta decay}}{^{239}_{93}Np \;+\; ^{0}_{-1}e} \;\rightarrow\; \underset{\text{beta decay}}{^{239}_{94}Pu \;+\; ^{0}_{-1}e}$$

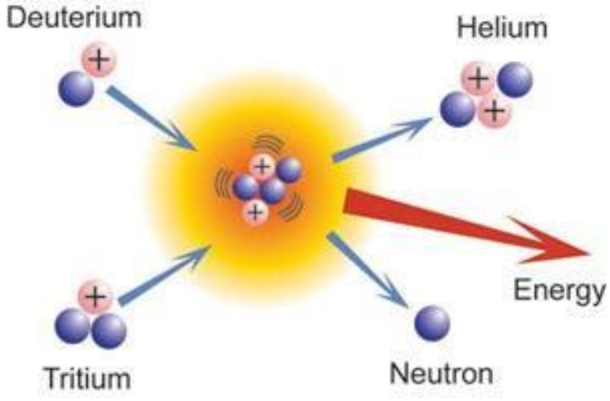
    2) *almost all naturally occurring U is U-238*; this makes good use of it since it is nonfissionable
    3) meltdowns would be very serious since Pu-239 has a long half-life
    4) France and Japan—only countries with commercial breeder reactors
       1 g Pu = 1 ton oil that would be burned to produce power
    5) U.S. has small, military breeders



Liquid metal fast breeder reactor (LMFBR)

B. fusion and fusion reactors
  1) general fusion info
    a) **fusion**—the joining of nuclei of two smaller atoms to form one larger atom
    b) stars are nuclear reactors (sun converts H to He)
  2) *hot fusion*—deuterium (H-2) fusion, done in plasma
     ”http://library.thinkquest.org/17940/texts/fusion_dt/fusion_dt.html
    a) reaction results in equal quantities of tritium and neutrons
    b) produces large amount of heat energy
    c) “heavy hydrogen” isotopes *deuterium (D; H-2)* and *tritium (T; H-3)* are used in a **d-t reaction**
      - *T does not occur in nature* and is made in the lab (radioactive)
      - *D can be extracted from seawater* – heavy but not radioactive
    d) fusion requires 3,000,000 °C as well as high pressure—usually *ignited by a fission reaction*!

HOT FUSION from www.iter.org :



3) problems with fusion
    a) would use too much energy to get started
    b) how to contain the hydrogen at such high temps without the structure itself disintegrating
4) possible techniques
    a) Tokamak design, using a magnetic field
    b) laser fusion, using frozen hydrogen
    c) Z machine, using electricity
5) **ITER: International Thermonuclear Explosion Reactor** www.iter.org
    a) international project involving China, European Union, Switzerland, Japan, Republic of Korea, Russian Federation, U.S.
    b) located in France
    c) hydrogen plasma at 150 million °C – 10x higher than sun's core! (remember that plasma is a hot, electrically charged gas)
    d) Tokamak device that uses magnetic fields to contain and control the hot plasma
    e) will produce 500 MW of fusion power
    f) construction is underway and the first plasma operation is targeted for December 2025, with full operation targeted for 2035
    g) more hot fusion options… http://pesn.com/2009/10/28/9501583_Focus-Fusion-1_success/

6) cold fusion (1989)
    a) could theoretically run at room temperature
    b) hypothetical process would occur in a unique solid structure without significant energy being applied
    c) hypothetical products would be mainly helium with very few neutrons and occasional tritium
    d) *cold fusion dismissed by most scientists as "pseudoscience"*