Chem 1B Objective 15:
Identify radiation types and understand nuclear chemistry reactions.

Key Ideas: Many applications of particle radiation and nuclear reactions: nuclear power plant, nuclear medicine, radioactive dating.

Particle radiation includes alpha particles and beta particles.

Radioactive isotopes undergo radioactive decay to produce particle radiation.
E.g., carbon-14 is a beta emitter.

Radioactive decay is a 1st order rate process. Relate rate constant to half-life.

RADIATION!!

Is Radiation SAFE?

Is Radiation DANGEROUS?

Have you ever been *EXPOSED* to Radiation?

“Regular” Chemical Reactions Involve Electrons

Electron “cloud” occupies a very large volume around the nucleus.

Electron transitions (emission) between energy states (energy levels) produce **Electromagnetic Radiation** (**light**).

Electrons are responsible for bonding.

Bonds break and form in a chemical reaction.

Most chemical reactions release Energy.

Nuclear Reactions Involve the Nucleus

Nucleus contains protons and neutrons in a *very small space*, which are held together by the *strong nuclear force*.

Nuclear reactions produce **Particle Radiation** (**alpha** particles and **beta** particles and **neutrons**).

Nuclear reactions (fission and fusion) produce **A LOT OF ENERGY**!

What We Need To Know About Radiation

What is radiation? Identify the two types of radiation.

Objective: Write nuclide symbols.

Name	Radiation Type	Nuclide Symbol	Source
alpha			
beta			
x-rays			W = 0.02 nm (med) Cu = 0.157 nm (crys)
gamma			Co-60 = 1 pm (med)
neutron			Cf-252
positron			Na-22

$^{0}_{1}e$ $\quad$ $^{0}_{-1}e$ or $^{0}_{-1}\beta$ $\quad$ $^{4}_{2}He^{2+}$ $\quad$ $^{1}_{0}n$

What We Need To Know About Radiation

What is radiation? Identify the two types of radiation.
Objective: Write nuclide symbols.

Mass number   charge

$$^{4}_{2}\mathrm{He}^{2+}$$

Atomic number   Atomic symbol

Alpha particle is a *Helium nucleus*
2 protons = atomic number
2 neutrons = mass number - # of protons
0 electrons = # of protons - charge

What We Need To Know About Radiation

What is radiation? Identify the two types of radiation.
Objective: Write nuclide symbols.

Name	Radiation Type	Nuclide Symbol	Source
alpha	particle	${}^{4}_{2}He^{2+}$	Alpha emitters
beta	particle	${}^{0}_{-1}e$ or ${}^{0}_{-1}\beta$	Beta emitters
x-rays	EM	X-ray	W = 0.02 nm (med) Cu = 0.157 nm (crys)
gamma	EM	${}^{0}_{0}\gamma$	Co-60 = 1 pm (med)
neutron	particle	${}^{1}_{0}n$	Cf-252
positron “anti-matter”	particle	${}^{0}_{1}e$	Na-22

What We Need To Know About Radiation

Where does radiation come from?
http://science.howstuffworks.com/nuclear1.htm
http://www.scifun.org/chemweek/Radiation/Radiation.html

Source	Annual Exposure per Capita in U.S., mrems/year
Natural background radiation	130
Medical x-rays	90
Weapons test fallout	5
Nuclear power plants	< 0.01

What is the largest external source of radiation?
What is the largest internal source of radiation?

Radiation Dose Chart http://www.ans.org/pi/resources/dosechart/

What We Need To Know About Radiation

Radiation units:

Unit of activity: 1 **Curie** = 3.7×10^{10} disintegrations per second

Roentgen: measure of x and gamma ray ionization in air.

Roentgen equivalent, physical (**rep**) - measure of x, gamma, and particle radiation.

Radiation Absorbed Dose (**rad**): 1 rad = 10^{-2} J/kg of tissue

Roentgen equivalent, man (rem): **rem** = rad x RBE

RBE = ***Relative Biological Effect*** depends on radiation type and relative penetrating power of radiation type.

What We Need To Know About Radiation

Objective: What type of radiation should you avoid?

Greatest penetrating power: x and gamma rays
Least penetrating power: alpha particles

Highest RBE: alpha particles - ionizing radiation (RBE = 20)
Lowest RBE: beta particles, x-rays (RBE = 1)

http://www.whatisnuclear.com/articles/radioactivity.html

What We Need To Know About Radiation

Is radiation dangerous?

Objective: how to protect yourself from radiation?

Source	Radiation Type	Protection
Sun (solar)		
EMF (from power lines)		
CT scan (X-rays)		
PET scan		
Ultrasound		
Tc-99 (γ-rays)		
MRI		
U-235 (α emitter)		
C-14 (β emitter)		

Paper skin Al foil Pb shield concrete

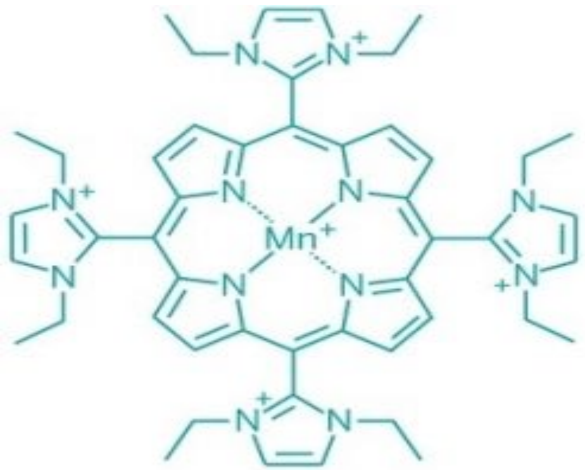
What We Need To Know About Radiation

Is radiation dangerous?

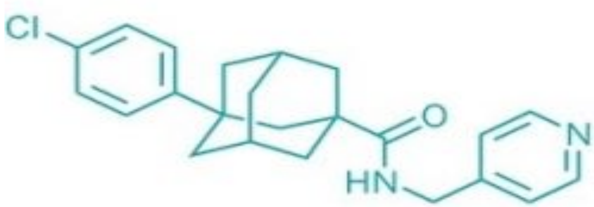
Objective: how to protect yourself from radiation?

Source	Radiation Type	Protection
Sun (solar)	EM	Sunscreen (SPF)
EMF (from power lines)	EM	
CT scan (X-rays)	EM	Pb shield
PET scan	particle	Al foil
Ultrasound	EM	
Tc-99 (γ-rays)	EM	concrete
MRI	EM	
U-235 (α emitter)	particle	skin, paper
C-14 (β emitter)	particle	Al foil

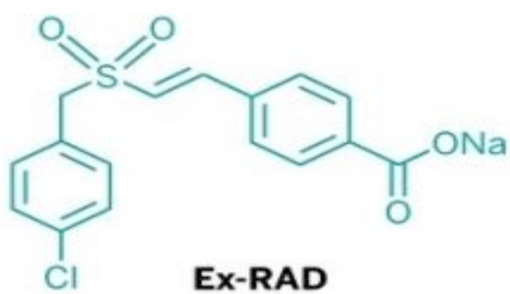
The LD 50/30 is in the range from 400 to 450 rem (4 to 5 sieverts) received over a very short period. LD 50/30 is he dose of radiation expected to cause death to 50 percent of an exposed population within 30 days. http://www.nrc.gov/reading-rm/basic-ref/glossary/lethal-dose-ld.html



AEOL-10150



ABC294640



Ex-RAD

http://cen.acs.org/articles/90/i26/Drugs-Never-Used.html

Acute Radiation Syndrome (ARS)

Radiation can damage all the major organ systems in the body. It hits rapidly dividing cells, such as those in the bone marrow and gastrointestinal tract, which are the most radiation sensitive. Damage to the bone marrow, called hematopoietic-ARS, causes a drop in the production of blood cells, resulting in anemia, bleeding, and a susceptibility to infections.

AEOL-10150 protects healthy tissue during cancer radiation therapy by neutralizing radicals.
ABC294640 inhibits sphingosine kinase, which regulates cell proliferation and activation
Ex-RAD protects hematopoietic and GI tissues from radiation injury when given either before or after exposure.

What We Need To Know About Radiation

Radioactive means a *radioactive isotope* *<u>undergoes radioactive decay</u>*.

<u>Objective</u>: Which isotopes are radioactive?

(i) Z > 83 (are these isotopes alpha or beta emitters?)

(ii) Odd # of protons and Odd # of neutrons (only 5 are stable)

(iii) Band of stability

(Darleane C. Hoffman, Director of the Glenn T. Seaborg Institute at thte Lawrence Berkeley Laboratories, predicts reaching an "island of stability" beyond atomic number 120.)

(iv) Magic numbers:

for protons: 2, 8, 20, 28, 50, 82, 114 (discovered 1998, Fl-289, $t_{1/2}$ = 2 s)

for neutrons: 2, 8, 20, 28, 50, 82, 126

What We Need To Know About Radiation

Objective: determine # of neutrons and protons in an isotope

Determine the number of protons and neutrons in each common radioactive isotope.

a. Carbon-14

(i) 14 p, 14 n   (ii) 6 p, 14 n   (iii) 6 p, 8 n

b. Potassium-40

c. Uranium-235

What We Need To Know About Radiation

Two Types of particles are emitted during radioactive decay:

Alpha particles (for heavy elements)

Beta particles (for light elements).

*Radioactive decay is a **first order** rate process.*

Rate Law: $\text{rate} = -\dfrac{\Delta\,[N]}{\Delta\,\text{time}} = k\,[N]^1$

(-) sign refers to rate of disappearance (disintegration) of radioactive isotope

k = rate constant

$$\text{Half-life} = t_{1/2} = \frac{0.693}{k}$$

What We Need To Know About Radiation

Objective: write a nuclear equation

Carbon-14 is a beta emitter with a half-life of 5,700 years. Write a balanced nuclear equation that shows the radioactive decay of this isotope.

$$ {}^{14}_{6}\mathrm{C} \;\; ---- > \;\; {}^{0}_{-1}\mathrm{e} \;\; + \;\; ?? $$

U-238 is an alpha emitter with a half-life of 4.5 billion years. Write a balanced nuclear equation that shows the radioactive decay of this isotope.

Which isotope, C-14 or U-238, would you keep under your bed?

Which substance do you want under your pillow?

Isotope	% abundance	Emission	Half-life	Source
K-40	0.0118	β	1.28×10^9 yr	body
I-131	~0	β	8 days	^{235}U fission
I-127	100		Stable	
C-12	98.9		Stable	
C-13	1.10		Stable	
C-14	Trace	β	5730 yr	
Am-241	~0	α	458 yr	Smoke detector

Smoke detector contains 1/5000 g Am-241. Typical detector emits 0.9 microcuries.

^{40}K is an Internal Radiation Source

Objective: calculate radiation exposure

In a 70 kg human, there is 140 g of potassium. A very small amount of this potassium is radioactive potassium-40. The relative abundance of radioactive potassium-40 is 0.012%. Potassium-40 is a beta emitter with a half-life of 1.28 billion years. The mass destroyed per disintegration is 2.822×10^{-31} kg.

a. Write a balanced nuclear equation that shows the radioactive decay of potassium-40. What is the order of this reaction (and any radioactive decay reaction)?

b. Calculate the number of potassium-40 nuclei in a 70 kg human.

c. Calculate the radiation exposure in mrem/year from potassium-40.

Radiation exposure in mrem/year from K-40

Radioactive decay is a 1st order reaction:

$k = 0.693/t_{1/2} =$

rate = k N =

= # of K-40 nuclei that disintegrate in 1 year

In nuclear decay reaction, mass destroyed ==> ***energy released***

$E = mc^2$

Mass destroyed from one K-40 nucleus disintegration

= 2.822×10^{-31} kg/nucleus

Energy from one K-40 nuclei disintegration

= $(2.822 \times 10^{-31}\ \text{kg})(3.00 \times 10^{8}\ \text{m/sec})^2 = 2.54 \times 10^{-14}$ J/nucleus

Energy from number of K-40 nuclei that disintegrate in 1 year

= $(2.54 \times 10^{-14}$ J/nucleus)(# of nuclei that disintegrate in 1 yr) =

Convert E to rad to rem:

1 rad = 10^{-2} J/kg of tissue

Roentgen equivalent, man (rem): **rem** = rad x RBE

^{14}C is an Internal Radiation Source

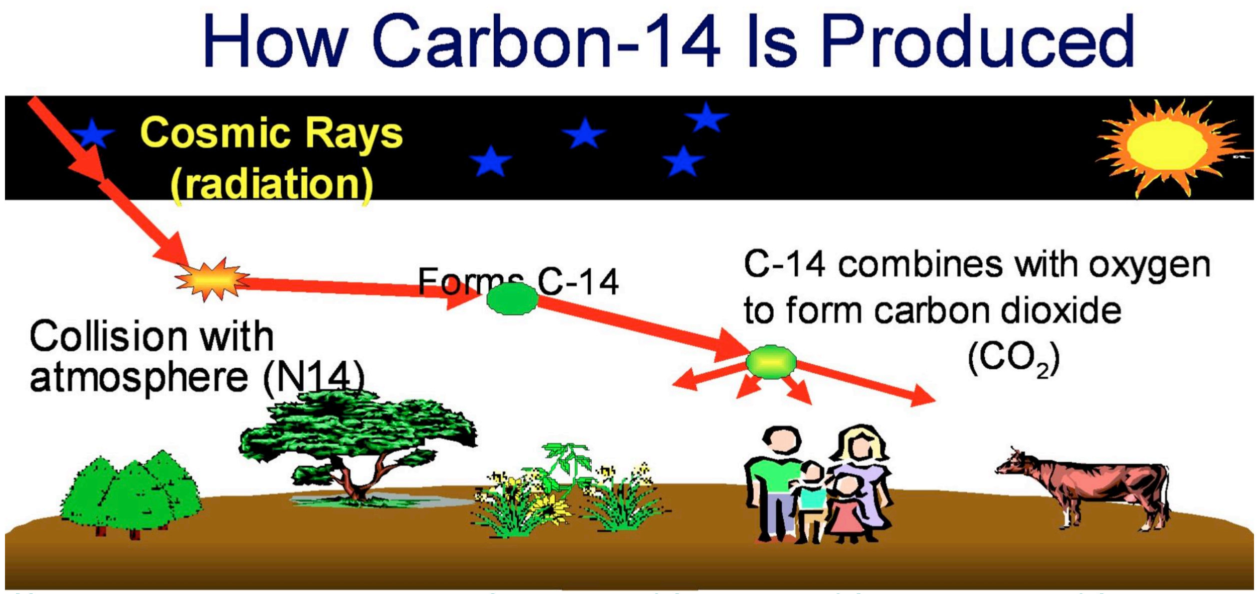
In a 70 kg human, there is 1.6×10^4 g of carbon. A very small amount of this carbon is radioactive carbon-14. The relative abundance of radioactive carbon-14 is 1 carbon-14 in 10^{12} C. Carbon-14 is a beta emitter with a half-life of 5730 years. The mass destroyed per disintegration is 7.85×10^{-32} kg.

a. Write a balanced nuclear equation that shows the radioactive decay of carbon-14. What is the order of this reaction and any radioactive decay reaction?

b. Calculate the number of carbon-14 nuclei in a 70 kg human.

c. Calculate the radiation exposure in mrem/year from carbon-14.

How Is Carbon-14 Used to Date Fossils?



http://www.weneedice.com/articles%20Has%20carbon%20dating.html

Cosmic ray collides with atom to form a neutron.
Neutron collides with N-14 to form C-14.

Write a nuclear equation that shows how C-14 is produced.
What other product is produced?

In living organisms, ratio of C-12 to C-14 is constant. But, when organism dies, no new C-14 taken in so ratio changes.

http://thrivinghighschool.wordpress.com/category/science/

Radon is an External Radiation Source

1. Where does radon come from?
Radioactive decay series, Chang, Table 21.3, p. 717

Radioactive decay can be used to determine the age (**date**) of old artifacts
Uranium: a radioactive clock
http://scifun.chem.wisc.edu/CHEMWEEK/PDF/Uranium_Clock.pdf

2. Why is radon a concern in homes?

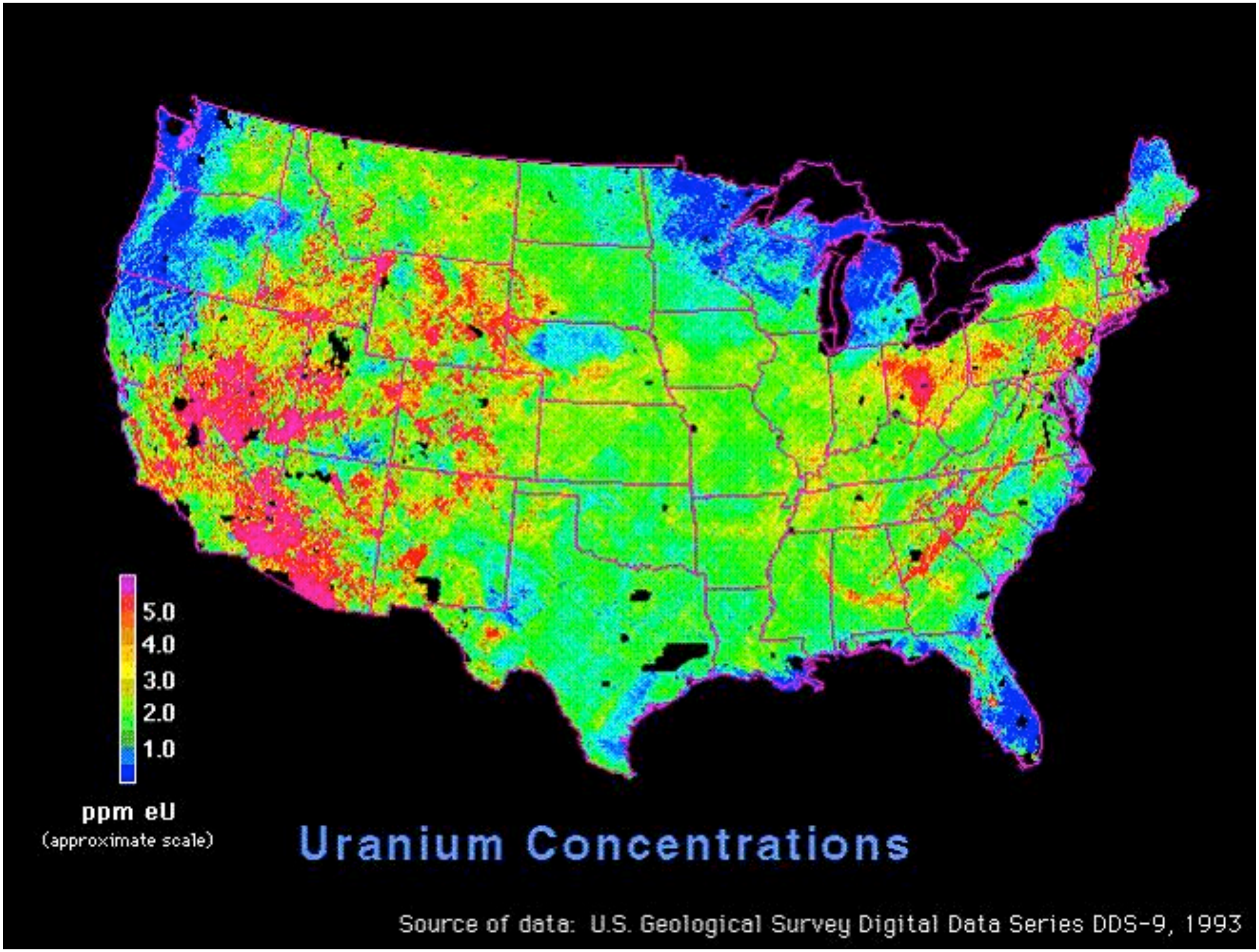
3. How much radon is in your house?
"radon map of California"
http://www.epa.gov/radon/zonemap.html
http://energy.cr.usgs.gov/radon/rnus.html
http://eetd.lbl.gov/newsletter/cbs_nl/nl12/cbs-nl12-radon.html
Radon test kits: http://www.wpb-radon.com/radon_Test_kits.html

4. Is it better to be exposed to an radioisotope with a long or short half life? Also, consider alpha or beta emission.

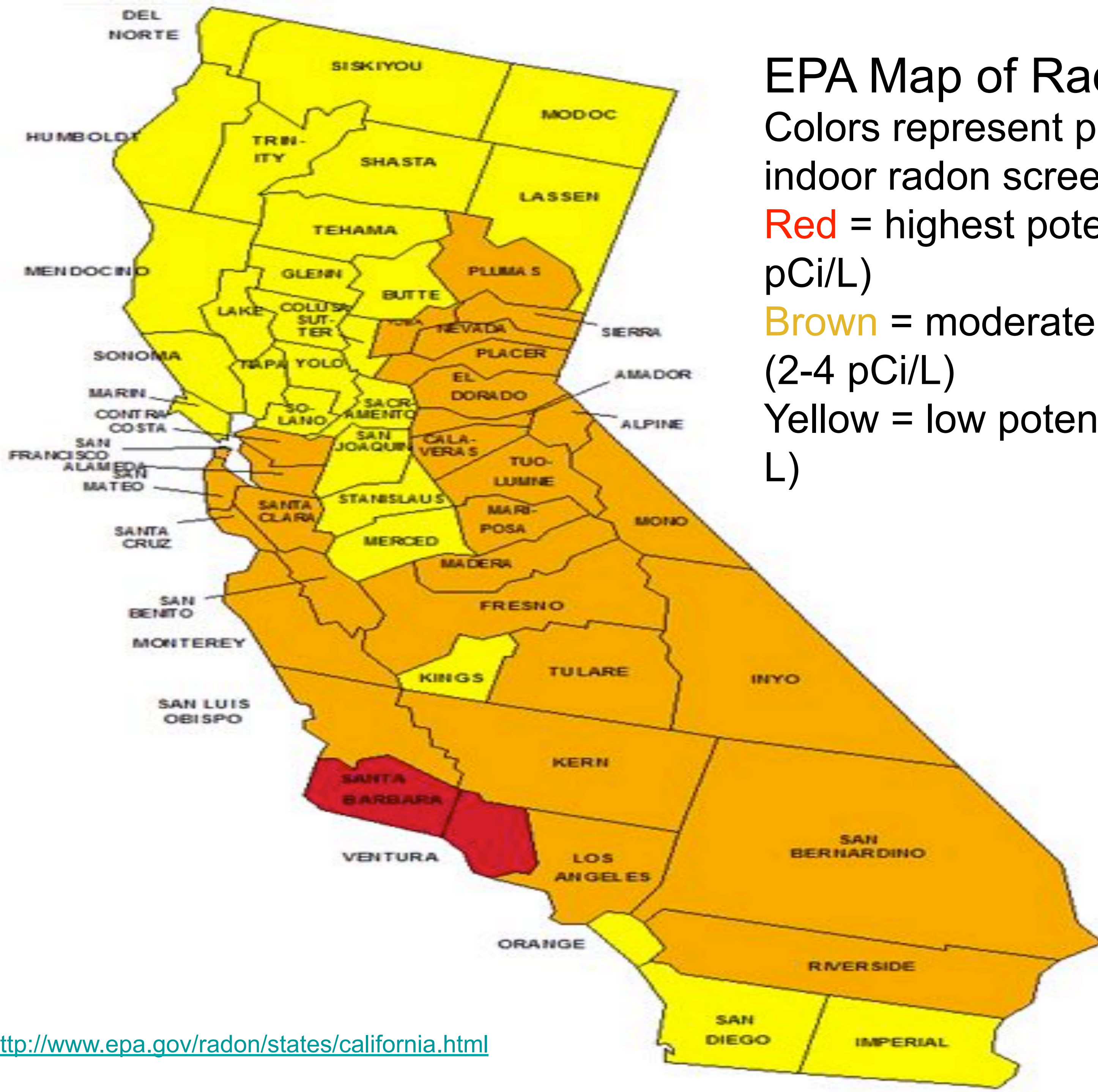
^{238}U Radioactive Decay Series

http://www.health.state.ny.us/environmental/radiological/radon/chain.htm

Symbol	Element	Radiation	Half-Life	Decay Product
U-238	Uranium-238	alpha	4,460,000,000 years	Th-234
Th-234	Thorium-234	beta	24.1 days	Pa-234
Pa-234	Protactinium-234	beta	1.17 minutes	U-234
U-234	Uranium-234	alpha	247,000 years	Th-230
Th-230	Thorium-230	alpha	80,000 years	Ra-226
Ra-226	Radium-226	alpha	1,602 years	Rn-222
Rn-222	Radon-222	alpha	3.82 days	Po-218
Po-218	Polonium-218	alpha	3.05 minutes	Pb-214
Pb-214	Lead-214	beta	27 minutes	Bi-214
Bi-214	Bismuth-214	beta	19.7 minutes	Po-214
Po-214	Polonium-214	alpha	1 microsecond	Pb-210
Pb-210	Lead-210	beta	22.3 years	Bi-210
Bi-210	Bismuth-210	beta	5.01 days	Po-210
Po-210	Polonium-210	alpha	138.4 days	Pb-206
Pb-206	Lead-206	none	stable	(none)



http://energy.usgs.gov/OtherEnergy/Uranium.aspx



EPA Map of Radon Zones

Colors represent predicted indoor radon screening level

Red = highest potential (> 4 pCi/L)

Brown = moderate potential (2-4 pCi/L)

Yellow = low potential (< 2 pCi/L)

http://www.epa.gov/radon/states/california.html http://cen.acs.org/articles/90/i36/Extracting-Uranium-Seawater.html

9/3/12, CEN, p. 60 "Extracting Uranium From Seawater"

SEAWATER AT A GLANCE

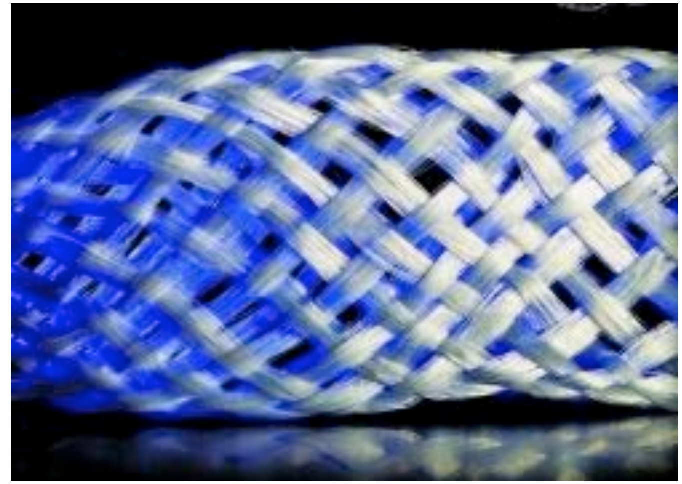
Total U in oceans:
4 billion tons

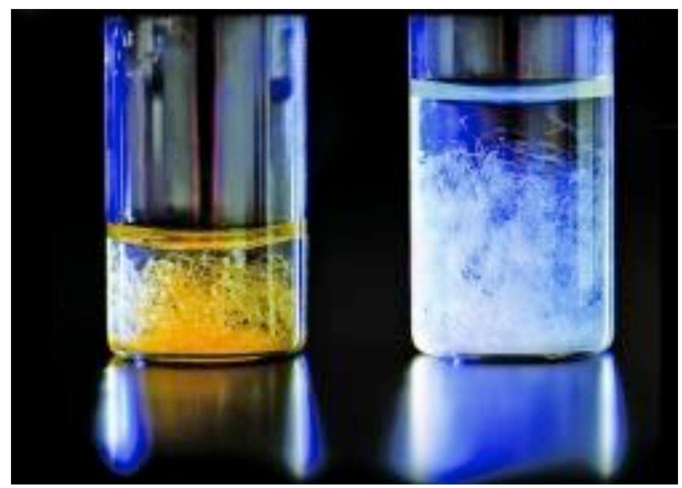
Metals 10^5 to 10^7 times more abundant than U in seawater:
Na, K, Mg, Ca

U concentration in seawater:
3.3 µg/L (ppb)

pH of seawater:
8.0–8.3

Worldwide U production in 2011:
50 thousand tons





A new high-surface-area polyethylene fiber functionalized with selective chelating groups can be braided into various forms and left dangling in the ocean to soak up uranium, which causes the white fibers to change colors.

A Nuclear Fission Reaction Releases a Lot of Energy

U-235 has an abundance of 0.7% and undergoes induced fission:

$^{235}U + ^{1}n \text{ --> } ^{236}U \text{ --> } ^{141}Ba + ^{92}Kr + \_\_\_ \ ^{1}n + \gamma + 200 \text{ MeV energy}$

<u>The energy released from the fission of U-235 is used to make electricity and in an atomic bomb.</u>

http://periodictable.com/Elements/092/

1 eV = 1.6×10^{-19} J
200 MeV = 3.2×10^{-11} J

U-235 Fission Reaction Releases a Lot of Energy

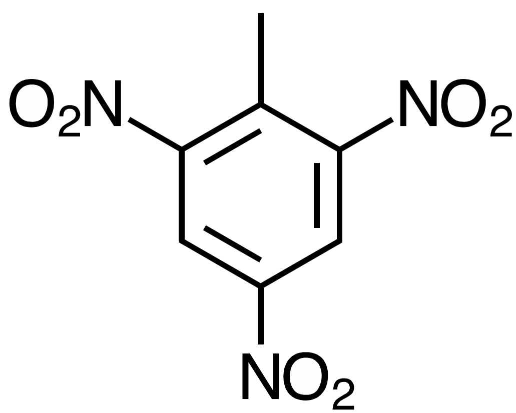
The natural abundance of U-235 is 0.7%. U-235 has to be enriched to 90% for an atomic bomb. An atomic bomb undergoes *uncontrollable* chain reaction. The first atomic bomb was equivalent to 20 kton of TNT.

a. Calculate the energy from 20 kton of TNT. (Hint: see ΔH)

b. What is meant by "chain reaction"?

c. What is critical mass?

d. Calculate the mass of U-235 that is equivalent to 20 kton of TNT.



Mass of U-235 that is equivalent to 20 kton of TNT

Problem solving method (*work backwards*):
Mass of U-235 --> moles of U-235 --> nuclei of U-235

Need to know how much E is released when one U-235 undergoes fission (200 MeV = 3.2×10^{-11} J/nuclei)

Need to know how much E is released when 20 kton of TNT explodes

Mass of U-235 that is equivalent to 20 kton of TNT

<u>Problem solving method</u> (*work backwards*):

Mass of U-235 --> moles of U-235 --> nuclei of U-235

Need to know how much E is released when one U-235 undergoes fission

(200 MeV = 3.2×10^{-11} J/nuclei)

Need to know how much E is released when 20 kton of TNT explodes

$$2\ C_7H_5N_3O_6 \rightarrow 7\ CO + 7\ C + 5\ H_2O + 3\ N_2$$

1 ton of TNT releases	4.18×10^{9} J
20 kton of TNT releases	8.14×10^{13} J
E released from U-235 fission	8.14×10^{13} J
E released from one U-235 fission	3.2×10^{-11} J
# of U-235 nuclei	
Moles of U-235 nuclei	
Mass of U-235 nuclei	

Density of U = 19.05 g/cm^3 ==> critical mass = 52 cm^3

or sphere of d = 5 cm

U-235 Fission is Used in a Nuclear Power Plant for Electricity

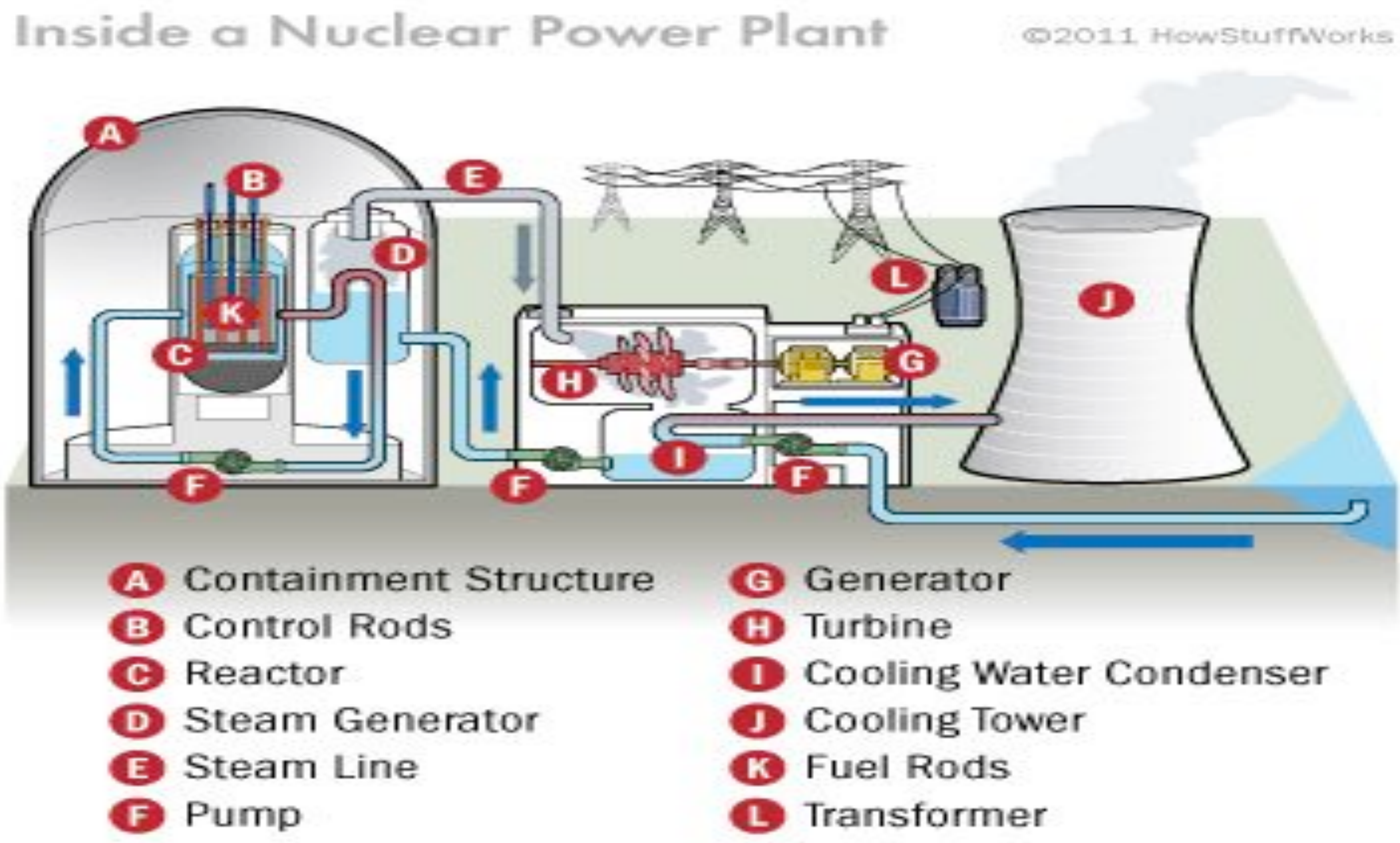
Uranium has to be enriched to 2-3% (nat. abundance = 0.7%) for a nuclear power plant. The chain reaction is controlled in a nuclear power plant.

a. Describe how a light water nuclear power plant works.
http://science.howstuffworks.com/nuclear-power1.htm
Identify the substance(s) and function of:
(i) Fuel rods
(ii) control rods
(iii) moderator
(iv) coolant.

b. How does the plant work to produce electricity?

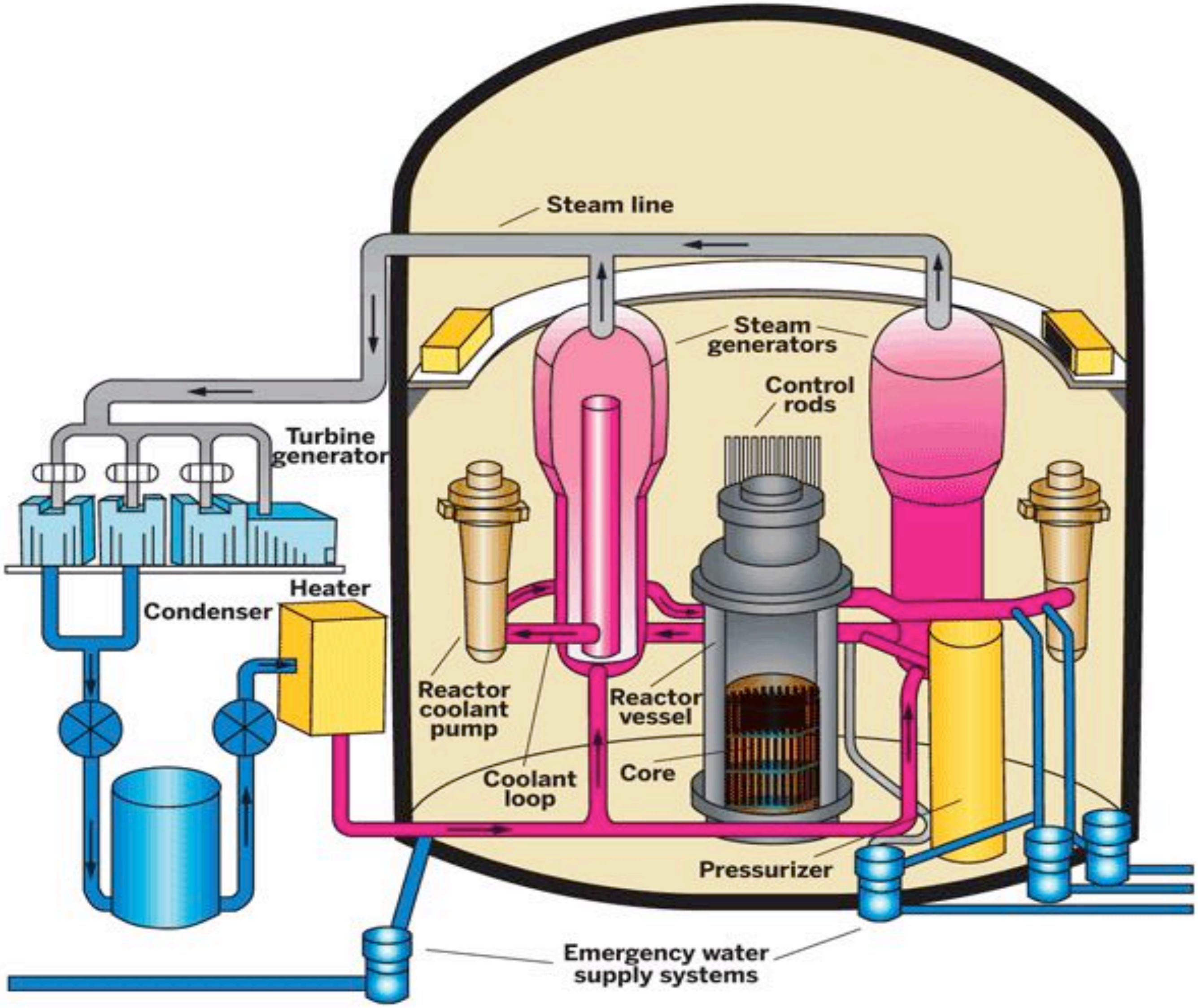
c. What is one advantage of nuclear power? What is one disadvantage of nuclear power?

Nuclear Power Plant Demo game:
http://www.ida.liu.se/~her/npp/demo.html



http://science.howstuffworks.com/nuclear-power2.htm http://cen.acs.org/articles/87/i34/Coming-Back-Nuclear-Energy.html:

Coming Back To Nuclear Energy: A resurgence of interest in new power plants is driving discovery of advanced materials. See videos of reactors



Materials are being developed to prevent corrosion and radiation damage.

Would you want a Nuclear Power Plant in your backyard?

http://www.pbs.org/wnet/need-to-know/environment/is-the-next-fukushima-in-your-backyard/16489/

Would you want a Nuclear Power Plant in your backyard?

Compare the Nuclear Power Plant Design of:

- Three Mile Island (1979)

http://www.world-nuclear.org/info/Safety-and-Security/Safety-of-Plants/Three-Mile-Island-accident/#.UZHeIIJCY6E

- Chernobyl (1986)

http://www.world-nuclear.org/info/chernobyl/inf07.html

- Fukushima Daiichi (2011)

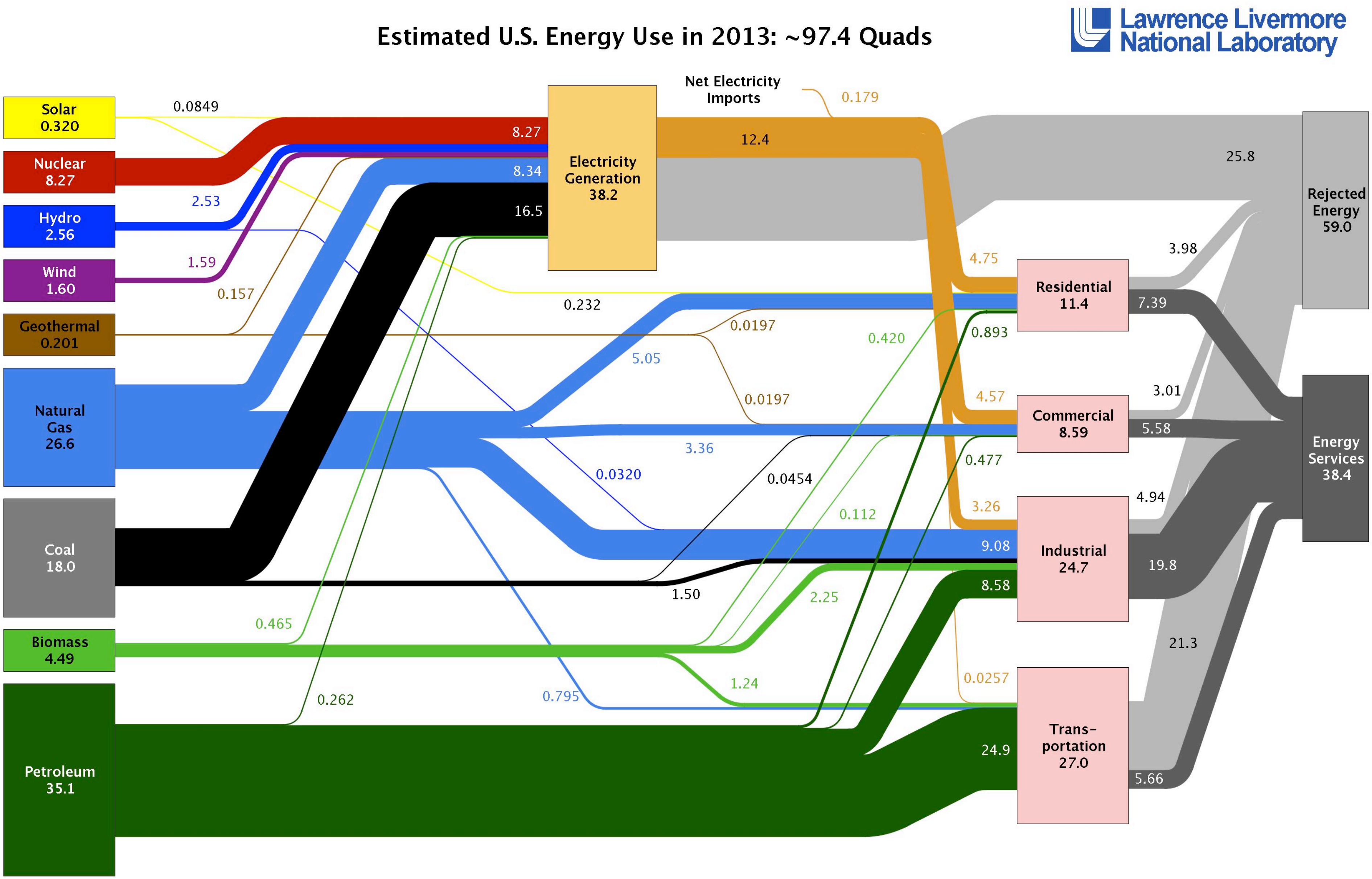
http://www.world-nuclear.org/info/inf18.html
http://www.washingtonpost.com/wp-srv/special/world/japan-nuclear-reactors-and-seismic-activity/

http://themoderatevoice.com/103674/explainer-nuclear-power-meltdowns-and-why-japan-is-not-chernobyl/
http://news.nationalgeographic.com/news/energy/2011/03/1103165-japan-nuclear-chernobyl-three-mile-island/

The scientific community believes the earth's climate is changing due to **global warming**.
Global warming is caused by the burning of fossil fuels.

Which fuel is cleaner?
Compare fossil fuels: Coal and Natural Gas
To Nuclear
To Hydroelectric
To Solar and Wind.
Give reasons.

(See The World's Foremost Environmentalist Weighs In On Nuclear Power, SOURCE: http://www.washingtonpost.com/wp-dyn/content/article/2006/04/14/AR2006041401209.html)



Source: LLNL 2014. Data is based on DOE/EIA-0035(2014-03), March, 2014. If this information or a reproduction of it is used, credit must be given to the Lawrence Livermore National Laboratory and the Department of Energy, under whose auspices the work was performed. Distributed electricity represents only retail electricity sales and does not include self-generation. EIA reports consumption of renewable resources (i.e., hydro, wind, geothermal and solar) for electricity in BTU-equivalent values by assuming a typical fossil fuel plant "heat rate." The efficiency of electricity production is calculated as the total retail electricity delivered divided by the primary energy input into electricity generation. End use efficiency is estimated as 65% for the residential and commercial sectors 80% for the industrial sector, and 21% for the transportation sector. Totals may not equal sum of components due to independent rounding. LLNL-MI-410527

https://flowcharts.llnl.gov/content/energy/energy_archive/energy_flow_2013/2013USEnergy.png

Comparison of Electricity Sources (2003)

Source	% electricity in US	Number of Facilities in US	Cost, Cents per kW hr (2003 data)*	Baseload	CO_2 emissions in US/% of total	Other emissions	Radiation	Waste
Coal	50	600	1.8 to 2.0	Constant	2 billion tons/36%	64% SO_2 26% NOx 33% Hg	Negligible (from uranium and thorium)	1000 tons ash/day, heavy metals, As, Ba, Be, B, Cd, Cr, Tl, Se, Mo, Hg. Waste kills 24,000 Americans per year.
Natural gas	25		5.2 to 15.9	Constant				
Nuclear	20	104	1.4 to 1.9	Constant	Very low (about same as wind power)		Negligible (100x lower than coal)	Radioactive isotopes with short half lives; rest recycled. No deaths to public in 50 years of operation.
Hydro-electric	5		0.25 to 2.7	Constant	Very low			
Solar, wind	<1		Solar: 13.5 to 42.7 Wind: 4.6	Intermittent and unpredictable	Very low			

Source: California Energy Commission

Comparison of Electricity Sources (2016)

Source	% elect ricity in US	Number of Facilities in US	Cost, Cents per kW hr (2016 data)*	Baseload	CO_2 emissions in US/% of total	Other emissions	Radiation	Waste
Coal	30	600	9.5	Constant	2 billion tons/36%	64% SO_2 26% NOx 33% Hg	Negligible (from uranium and thorium)	1000 tons ash/day, heavy metals, As, Ba, Be, B, Cd, Cr, Tl, Se, Mo, Hg. Waste kills 24,000 Americans per year.
Natural gas	34		7.5	Constant				
Nuclear	20	104	9.5	Constant	Very low (about same as wind power)		Negligible (100x lower than coal)	Radioactive isotopes with short half lives; rest recycled. No deaths to public in 50 years of operation.
Hydro-electric	6.5		7	Constant	Very low			
Solar, wind	6.5		Solar: 11 Wind: 8	Intermittent and unpredictable	Very low			

Source: https://www.eia.gov/energyexplained/index.cfm?page=electricity_in_the_united_states, http://www.renewable-energysources.com/

Coal is the Main Source of Electricity in the World

http://cen.acs.org/articles/88/i40/Chemistry-Energizes-China.html

UPSTART

China is ramping up alternative energy in addition to coal

ELECTRICITY GENERATION CAPACITY, GIGAWATTS	2007	2015	2020	2035
U.S.				
All types	**995**	**1,069**	**1,082**	**1,216**
Coal-fired	313	325	326	337
Wind	16	64	64	69
Solar	1	1	1	1
CHINA				
All types	**716**	**1,021**	**1,242**	**1,924**
Coal-fired	496	625	750	1,233
Wind	6	39	63	130
Solar	0	4	6	6
WORLD				
All types	**4,428**	**5,005**	**5,470**	**7,009**
Coal-fired	1,425	1,545	1,671	2,366
Wind	93	277	347	486
Solar	8	45	53	64

SOURCE: DOE, International Energy Outlook 2010

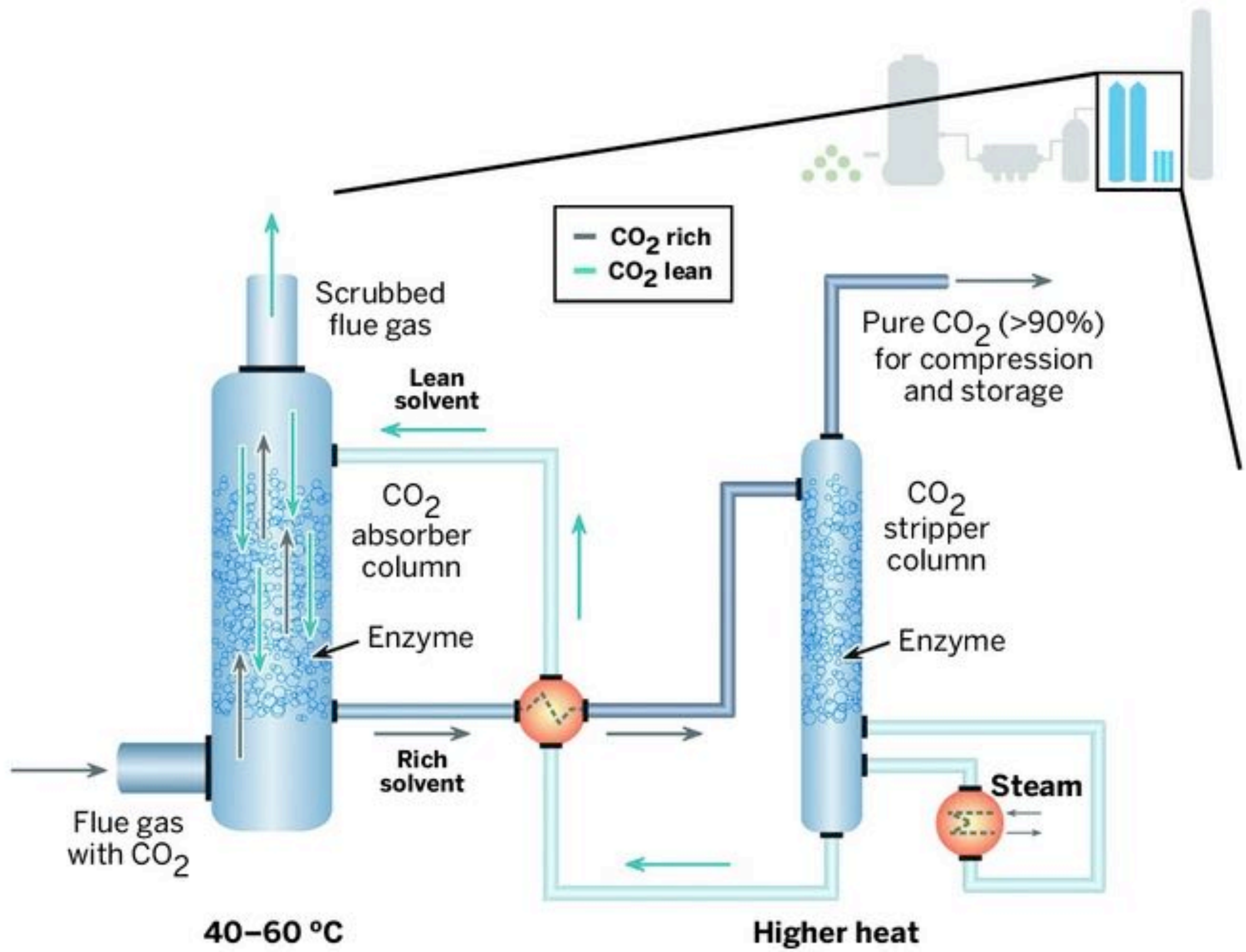
Coal represents 94% of China's fossil energy reserves (3rd behind U.S. and Russia). (CEN 6/13/11, p. 22)

Coal emits 75% more CO_2 than natural gas and 25% more than oil

Coal emits 90 times as much SO_2, twice as much CO_2, and more than five times as much NO_x per unit of electricity (CEN 6/4/12, p. 27) http://cen.acs.org/articles/90/i47/Lurching-Toward-Low-Pollution-Coal.html

11/19/12, CEN, p. 12 “Lurching Toward Low-Pollution Coal Power”

2014: new standards to limit emissions of Hg, SO_2, NO_x, .. from coal



2/2/14: Coal Ash Spill in Dan River, North Carolina

http://www.cnn.com/2014/02/09/us/north-carolina-coal-ash-spill/

30,000 – 50,000 tons spilled. Ash contains As, Se, Cd

2nd spill into Dan River on 2/14/14.

12/22/08: Coal ash dam in Kingston, TN breaks and spills 1.1 billion gallons

http://www.nytimes.com/2008/12/25/us/25sludge.html?pagewanted=all&_r=0

AT A GLANCE Three installations, three directions for the U.S. solar economy.

http://cen.acs.org/articles/91/i50/New-Race-Solar.html

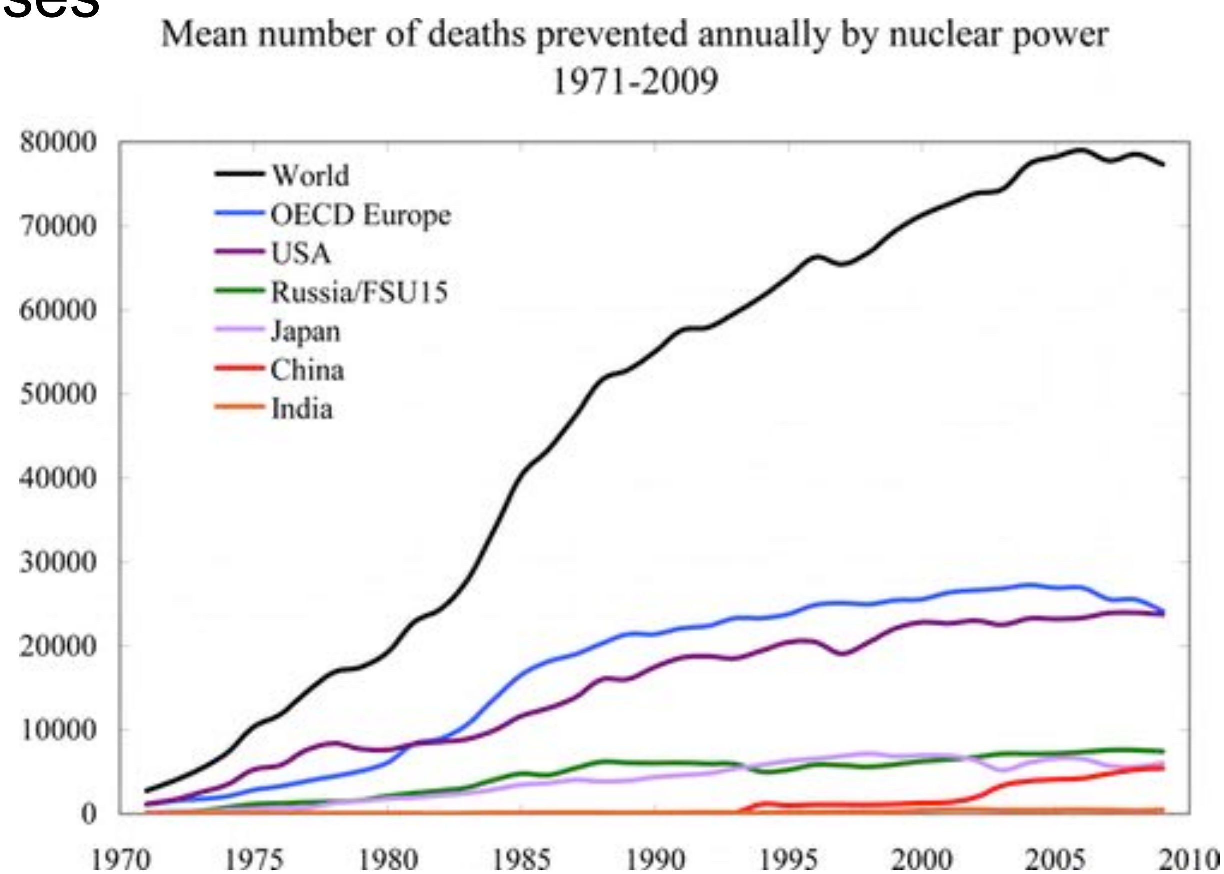
	Abengoa Solar Solana Project	California Valley Solar Ranch	Ivanpah Solar Electric Generating System
Location	Gila Bend, Ariz.	San Luis Obispo, Calif.	California Mojave desert on California-Nevada border
Type	Concentrated solar power	Photovoltaic	Concentrated solar power
Output capacity	280 MW	250 MW	392 MW
Start-up date	October 2013	October 2013	First of three towers began operating in 2013
Storage capacity	Yes: thermal energy storage system, provides electricity for six hours without generation	No	No
Design	32,700 collector assemblies, each with 28 curved parabolic trough mirrors	88,000 photovoltaic-panel-tracking devices	More than 300,000 flat mirrors that focus sunlight on three towers
Electricity purchase agreement	Arizona Public Service	Pacific Gas & Electric	Pacific Gas & Electric and Southern California Edison
Cost	$2.0 billion with $1.5 billion DOE loan guarantee	$1.6 billion with $1.2 billion DOE loan guarantee	$2.2 billion with $1.6 billion DOE loan guarantee
Owner(s)	Abengoa, a global company based in Spain	NRG Energy and SunPower, a solar cell company	BrightSource Energy, NRG Energy, Google, and Bechtel
Facility footprint	3 sq miles, including storage facilities	3 sq miles of development on 6.5 sq-mile site	6.2 sq miles on Bureau of Land Management land

“Power to Save The World”, Gwyneth Cravens, 2007

* Nuclear power emits no gases because it does not burn anything; it provides 73% of America's clean-air electricity generation, using fuel that is tiny in volume but steadily provides an immense amount of energy.
* Uranium is more energy-dense than any other fuel. If you got all of your electricity for your lifetime solely from nuclear power, your share of the waste would fit in a single soda can. If you got all your electricity from coal, your share would come to 146 tons: 69 tons of solid waste that would fit into six rail cars and 77 tons of carbon dioxide that would contribute to accelerated global warming.
* A person living within 50 miles of a nuclear plant receives less radiation from it in a year than you get from eating one banana. Someone working in the U.S. Capitol Building is exposed to more radioactivity than a uranium miner.
* Spent nuclear fuel is always shielded and isolated from the public. Annual waste from one typical reactor could fit in the bed of a standard pickup. The retired fuel from 50 years of U.S. reactor operation could fit in a single football field; it amounts to 77,000 tons. A large coal-fired plant produces ten times as much solid waste in one day, much of it hazardous to health. We discard 179,000 tons of batteries annually--they contain toxic heavy metals.
* Nuclear power's carbon dioxide emissions throughout its life-cycle and while producing electricity are about the same as those of wind power.
* Nuclear plants offer a clean alternative to fossil-fuel plants. In the U.S. 104 nuclear reactors annually prevent emissions of 682 million tons of CO_2. Worldwide, over 400 power reactors reduce CO_2 emissions by 2 billion metric tons a year.

http://cen.acs.org/articles/91/i14/Nuclear-Power-Prevent-Deaths-Causes.html

4/8/13, CEN, p. 8 "Nuclear Power May Prevent More Deaths Than It Causes"



Nuclear power in place of fossil-fuel energy sources, such as coal, has prevented some 1.8 million air-pollution-related deaths and 64 gigatons of carbon emissions globally over the past four decades (Environ. Sci. Technol., 2013, 47 (9), pp 4889–4895)

http://cen.acs.org/articles/91/i13/Nuclear-Retirement-Anxiety.html
4/1/13, CEN, p, 14 "Nuclear Retirement Anxiety"
Cleaning up a retired nuclear reactor is a long, costly, and complex process.

Rancho Seco (Sacramento)
900-MW reactor 1975 to 1989
Shutdown cost > $500 million
Took nearly 20 years to decommission.
22 casks stored on-site.

1. Owner shuts down plant and notifies Nuclear Regulatory Commission, starting the 60-year decommissioning time clock. Within two years, the plant owner issues a plan that includes goals, a timeline, and a cost estimate.
2. Reactor fuel is removed from core and spent fuel is removed from on-site storage pool. Both are placed in concrete and steel canisters that are constructed on-site. Highly radioactive material is removed from the reactor pressure vessel and is also stored on-site in canisters. The pressure vessel itself is kept intact to be shipped to a low-level waste disposal facility.
3. Millions of pounds of concrete and other debris are broken down and shipped to a low-level waste and hazardous waste disposal site.
4. Spent fuel and other more radioactive wastes remain on-site in casks resting on a cement slab, waiting to be moved after selection and construction of a national high-level radioactive waste facility.
5. When completed, site must be decontaminated and available for general use with radiation below a standard of less than 25-millirem annual exposure.

http://cen.acs.org/articles/90/i52/Technical-Solution-Nuclear-Waste.html

12/24/12, CEN, p. 2 Letters: Technical Solution To Nuclear Waste

Storage of raw wastes, regardless of method or site, is not the optimum way to handle the problem. The answer is to recycle the waste to reduce possible hazards and at the same time recover useful by-products.

In the early 1970s at Argonne National Lab, a group including E. Philip Horwitz was researching a practical answer to this problem. The approach taken was to first separate the waste into individual components using ion-exchange chromatography. Because the waste materials were too "hot" for traditional polymer-based ion-exchange particles to remain stable, separations were developed with liquid ion-exchangers supported on porous silica microspheres. The Horwitz group proposed that the waste components be separation-classified so that appropriate elements could be recycled for production of nuclear energy; useful, short half-life elements (e.g., platinum) would be stored until no longer radioactive; and "hot," long half-life materials would be encased in ceramic blocks for stable long-term underground storage. Technical papers describing the excellent separation work by the Horwitz group support the viability of this approach.

The ion-exchange approach was so successful in the lab that efforts were initiated to set up demonstration plants to show that the method could be scaled up for possible large-scale processing. Unfortunately, in 1974 an oil crisis struck the U.S. (Some may remember the difficulty in obtaining gasoline for automobiles.) Apparently in response to that crisis, the Argonne team was suddenly told by the Commerce Department to abandon nuclear waste research and focus on fossil fuels.

New nuclear fuel formulations could extract more energy and reduce nuclear waste.

http://cen.acs.org/articles/88/i37/Nuclear-Efficiency.html

NUCLEAR REACTOR TYPES

Generation IV technology differs from contemporary reactors in coolant, temperatures, fuel, and cladding

SYSTEM	COOLANT	OUTLET TEMPERATURE	FUEL	CLADDING
GENERATION II/III				
Pressurized or boiling water reactor	Water	300 °C	UO_2, mixed UO_2/PuO_2	Zirconium alloy
GENERATION IV				
Supercritical-water-cooled reactor	Supercritical water	600 °C	UO_2, mixed UO_2/PuO_2	Ferritic-martensitic steel, nickel-iron-chromium alloy
Very high temperature reactor	Helium	1,000 °C	UO_2, mixed UO_2/UC	SiC, ZrC
Molten salt reactor	Fluoride salts	1,000 °C	UF_4 (dissolved in the coolant)	None
Gas fast reactor	Helium, carbon dioxide	850 °C	Mixed UC/PuC	Ceramics
Sodium fast reactor	Sodium	550 °C	U-Pu-Zr; mixed UO_2/PuO_2, UC/PuC, UN/PuN	Ferritic-martensitic steel
Lead fast reactor	Lead or lead/bismuth	800 °C	Mixed UN/PuN	Ferritic-martensitic steel, ceramics, alloys

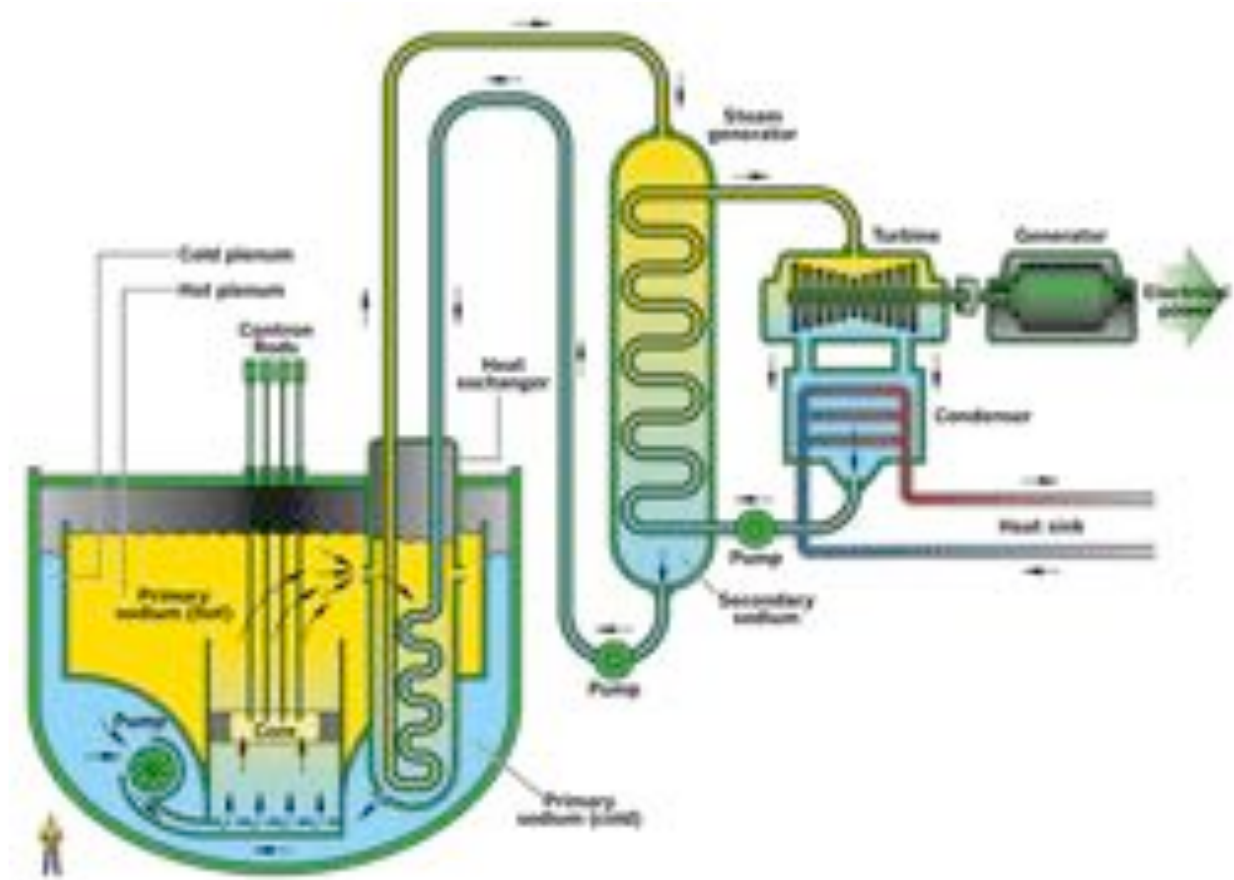
SOURCE: *MRS Bulletin* (**2009**, *34*, 10)

“The four classes of Generation IV reactors work on the same basic principles as previous-generation reactors, but they operate at higher temperatures and may differ in terms of coolant, fuel assemblies, and neutron energy.”

FUTURE GENERATION

In a sodium-cooled fast reactor, molten sodium absorbs the heat from nuclear fission reactions to produce steam that, in turn, is used to generate electricity.

http://cen.acs.org/articles/88/i37/Nuclear-Efficiency.html



http://cen.acs.org/articles/90/i50/Snap-Together-Nuclear-Power.html

12/10/12, CEN, p. 42 “Snap-Together Nuclear Power”

A 360-MW, two-reactor, small modular nuclear power plant will be buried 150 feet underground, covered by a 10-foot concrete slab, and will look like a 30-acre WalMart store from the surface.

CEN, 3/8/10, p. 31 nuclear power policy and purex reprocessing process

CEN, 11/16/09, p. 44 Thorium as nuclear fuel

CEN, 9/13/10, p. 29 New nuclear fuel formulations and reactor types. Generation IV uses higher outlet T and coolant.

CEN, 11/9/09, p. 47
Plutonium-238 used for fuel for deep space exploration

CEN, 5/3/10, p. 56
Revigator water jar - inside of jar is lined with carnotite (contains U). Rn gas released to water to treat and cure arthritis, flatulence, and senilty.

CEN, 5/28/12, p. 30
Heavy water nuclear reactors. Make D_2O by using exchange technology with H_2S or NH_3.

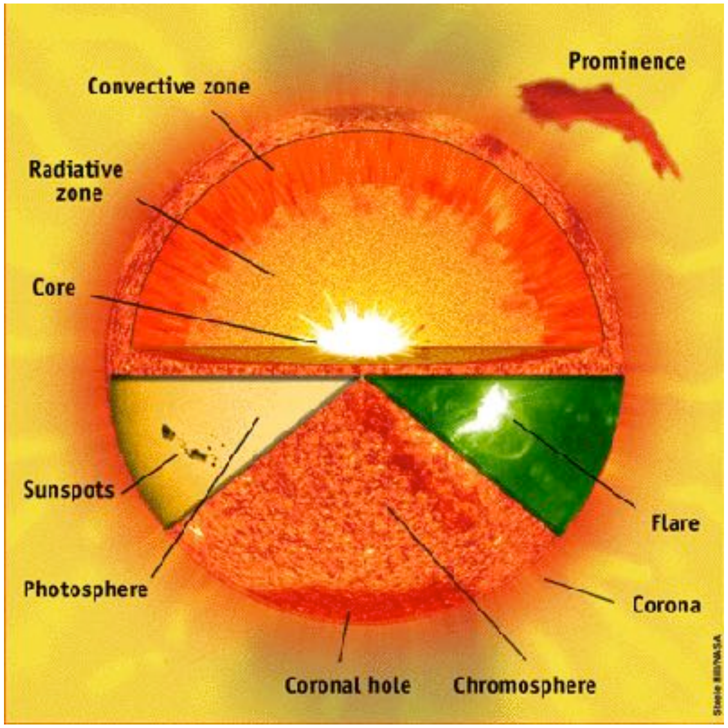
Nuclear Fusion Occurs In the Sun and Releases A Lot of Energy

Fusion reactions in the sun www.howstuffworks.com/sun2.htm
What is the temperature inside the sun?

Nucleosynthesis and Big Bang: how bigger elements are made from smaller elements.
http://www.meta-synthesis.com/webbook/32_n-synth/nucleosynthesis.html

Nuclear fusion reactors:
http://science.howstuffworks.com/fusion-reactor1.htm
At what temperature does a fusion reactor operate?

Nuclear Fusion Occurs In the Sun and Releases A Lot of Energy



Fusion reactions in the sun

www.howstuffworks.com/sun2.htm

What is the temperature inside the sun? 15 million K

$^{1}H + {}^{1}H \rightarrow {}^{2}H + {}^{o}p$ + neutrino

$^{1}H + {}^{2}H \rightarrow {}^{3}He$ + gamma

$^{3}He + {}^{3}He \rightarrow {}^{4}He + 2\,{}^{1}H$

Nuclear Fusion Occurs In the Sun and Releases A Lot of Energy

Nucleosynthesis and Big Bang: how bigger elements are made from smaller elements.

http://www.meta-synthesis.com/webbook/32_n-synth/nucleosynthesis.html

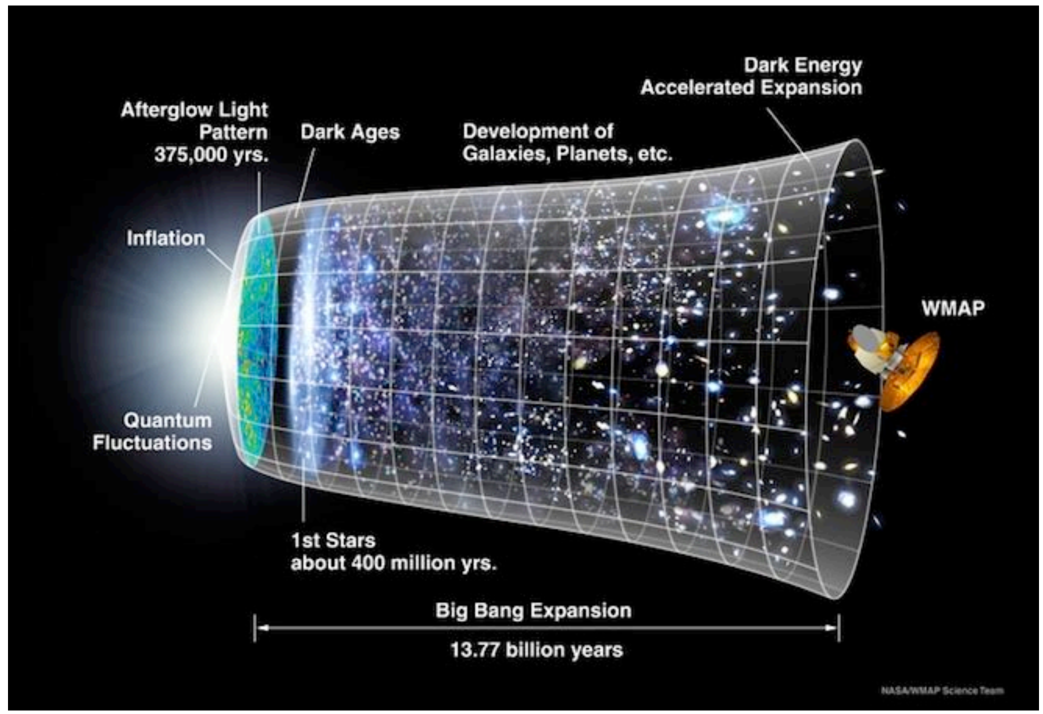
$^{1}H + {}^{0}e \rightarrow {}^{1}n$

(free neutron half life = 617 sec)

$^{1}H + {}^{1}n \rightarrow {}^{2}H$

^{2}H is very reactive and produced light elements:

^{1}H, ^{2}H, ^{3}He, ^{4}He, ^{7}Li

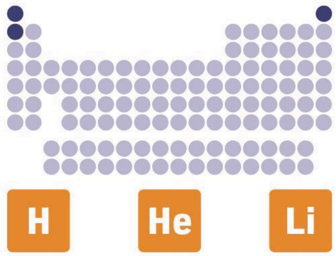


Gravity $\rightarrow$ stellar nucleosynthesis $\rightarrow$ heavier elements to Fe

THE ORIGINS OF THE ELEMENTS

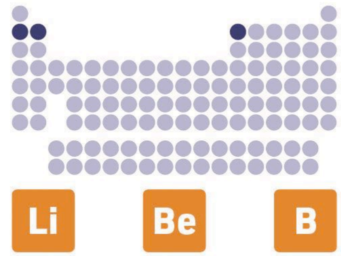
The 118 elements in the periodic table don't all have the same backstory. Here, we examine how different elements were created, according to physicists and chemists.

THE BIG BANG



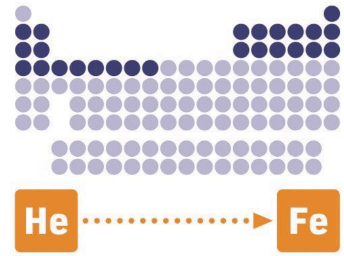
The lightest elements were made by nuclear reaction chains between 10 s and 20 min after the big bang. Hydrogen and helium in particular were made in large amounts.

COSMIC RAYS



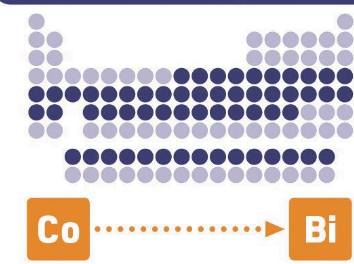
When cosmic rays in space hit the nuclei of elements like carbon or nitrogen, they cause those elements to fragment into lighter elements like lithium, beryllium, and boron.

FUSION IN STARS



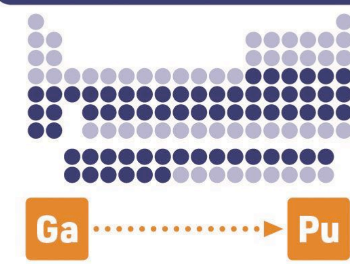
Fusion reactions inside stars generate the energy that stars radiate. They produce elements from helium up to iron. Creating heavier elements isn't possible through fusion.

THE S-PROCESS



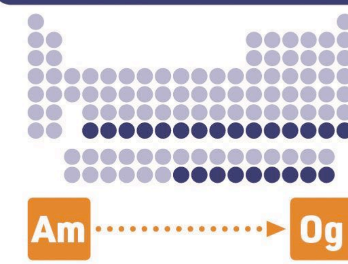
The slow neutron-capture process (s-process) occurs in aging stars over thousands of years. Atoms capture neutrons and undergo β decay to produce new element isotopes.

THE R-PROCESS



In the rapid neutron-capture process (r-process), atoms capture many neutrons at once and undergo β decay to form new element isotopes. It occurs in neutron star collisions.

SYNTHETIC ELEMENTS



The heaviest elements have been created artificially on Earth in nuclear reactors or particle accelerators. These elements are unstable and decay into lighter elements rapidly.

Note: Elements are highlighted where isotopes of that element are created by the process discussed. Not all isotopes created are stable.

Nuclear Fusion Occurs In the Sun and Releases A Lot of Energy

Nuclear fusion reactors:

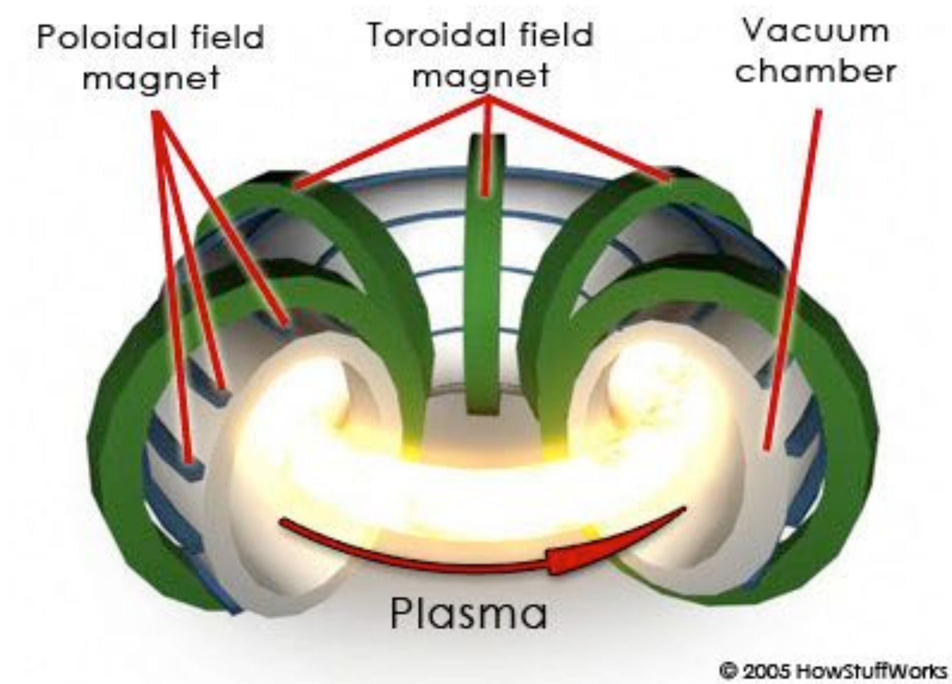
http://science.howstuffworks.com/fusion-reactor1.htm

At what temperature does a fusion reactor operate?

T = 100 million K

$^{2}H + {}^{2}H \rightarrow {}^{3}He + {}^{1}n$

$^{2}H + {}^{3}H \rightarrow {}^{4}He + {}^{1}n$



Radioactive Isotopes Are Used in Nuclear Medicine for Diagnosis and Therapy:

http://health.howstuffworks.com/nuclear-medicine.htm

Isotope	Half-life	Medical application
Ce-141	32.5 days	Gastrointestinal tract diagnosis; measuring myocardial blood flow
Ga-67	78 hr	Abdominal imaging; tumor detection
Ga-68	68 min	Detect pancreatic cancer
P-32	4.3 days	Treatment of leukemia, polycythemia vera (excess red blood cells), pancreatic cancer
I-125	60 days	Treatment of brain cancer; osteoporosis detection
I-131	8 days	Imaging thyroid; treatment of Graves' disease, goiter, and hyperthyroidism; treatment of thyroid and prostate cancer
Sr-85	65 days	Detection of bone lesions; brain scans
Tc-99m	6 hr	Imaging of skeleton and heart muscle; brain, liver, heart, lungs, bone, spleen, kidney, and thyroid; *most widely used radioisotope in nuclear medicine.*

Radioactive Isotopes Are Used in Nuclear Medicine for Diagnosis and Therapy:

http://health.howstuffworks.com/nuclear-medicine.htm

1. Would you expect a larger radiation dose to be used in diagnosing disease or treating disease?

2. In boron neutron capture therapy (BNCT), the boron-10/ neutron capture reaction is used to produce ionized lithium-7, 2.4 MeV of energy, weak gamma radiation, and a type of particle radiation. The energy released in this reaction is principally kinetic energy.
a. What type of particle radiation is produced? Write a nuclear equation that suppports your answer.
b. What therapy is BNCT used for? What is one problem with BNCT?