Announcements

1. Remember to bring your evaluation pin #'s and Thinkpad's to lab this week.
2. Extra credit possibilities – send me email about this if you are interested
3. Continuing discussion of nuclear physics (Chapter 44)

   Description of nuclei – mass deficit

   Nuclear decay processes – half life – α,β,γ particles

   – units Ci, rad, rem

   Nuclear reactions – fission and fusion

Summary of some ideas about nuclear physics

•The basic forces that describe nuclei are stronger, shorter range, and more complicated than electromagnetic forces. Nuclear binding energies are typically 8 MeV/nucleon.

•Most nuclear decay processes are described by a simple rate equation

$$\frac{dN}{dt} = -\lambda N \quad \Rightarrow N(t) = N_0 e^{-\lambda t} = N_0 \left(\frac{1}{2}\right)^{t/T_{1/2}}$$

For example: $^{238}U \rightarrow {}^{234}Th + {}^{4}He$ $\quad T_{1/2}=4.5\times10^{9}$ yr.

•Radiation effects on humans and other sensitive forms of life and devices are due to the light decay products – α,β,γ particles

Radiation dose: Amount of radiation absorbed/unit mass

1 Gy = 1 J/kg of absorbed radiation = 100 rad

1 Sv = RBE x (dose in Gy units) = 100 rem

relative biological effectiveness

Guide to nuclear reactions

General rules

Total A (number of nucleons (Z+N)) is conserved

Total charge is conserved

protons and neutrons can convert to each other

$$n \rightarrow p + e^- + \bar{\nu} \leftarrow \text{antineutrino}$$

$$p \rightarrow n + \underbrace{e^+}_{\text{positron}} + \nu \leftarrow \text{neutrino}$$

Neutrinos were first detected in 1956 by Fred Reines and George Cowan, who showed that a nucleus undergoing beta decay emits a neutrino with the electron. Neutrinos are VERY weakly interacting and recent evidence suggests they have a mass of < 0.1 eV.

Examples of nuclear reactions

$^{14}_{6}C \rightarrow ^{14}_{7}N + e^{-} + \bar{\nu}$ Used for carbon dating

$$T_{1/2}\left(^{14}_{6}C\right) = 5730 \text{ yrs.}$$

$^{7}_{4}Be + e^{-} \rightarrow ^{7}_{3}Li + \nu$ Nucleus captures an electron

$^{11}_{6}C \rightarrow ^{11}_{5}B + e^{+} + \nu$ Positron emission

$^{12}_{5}B \rightarrow ^{12}_{6}C^{*} + e^{-} + \bar{\nu}$

$^{12}_{6}C^{*} \rightarrow ^{12}_{6}C + \gamma$

Beta decay followed by gamma decay

More nuclear reactions

$$ {}_1^1H + {}_3^7Li \rightarrow 2 \cdot {}_2^4He $$

Energy accounting :

for a general reaction of the type a+X→Y+b

energy released as kinetic energy of the products can be calculated:

$Q=(M_a+M_X-M_Y-M_\beta)c^2$

In this case, $Q=(1.007825+7.016003-2*4.002602)\ c^2$

$=17.348$ MeV

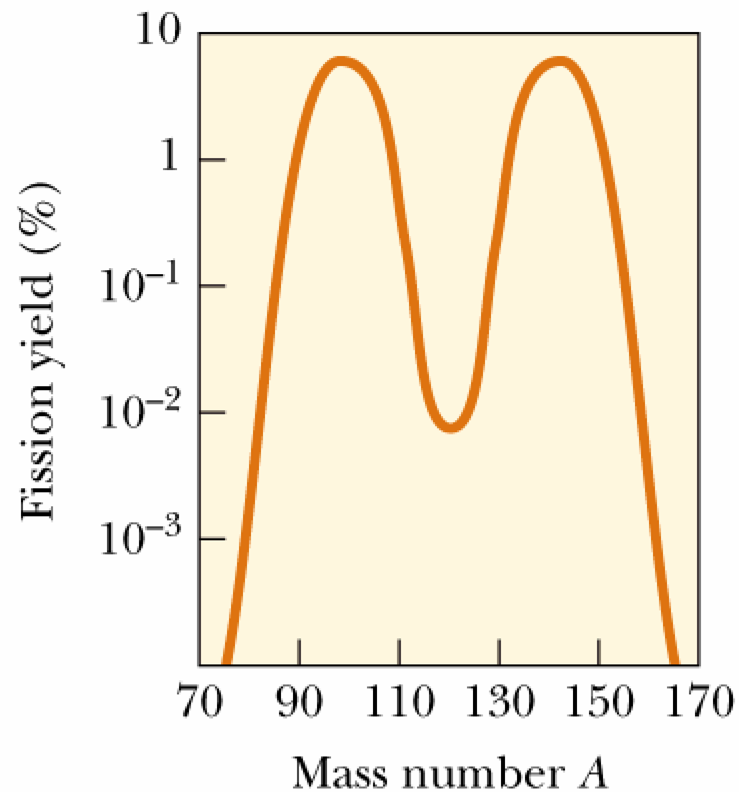
More nuclear reactions

$${}^{1}_{1}H + {}^{19}_{9}F \rightarrow \boxed{\;?\;} + {}^{4}_{2}He$$

$${}^{1}_{1}H + {}^{19}_{9}F \rightarrow {}^{16}_{8}O + {}^{4}_{2}He$$

Nuclear fission

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



Peer instruction question

Which of the following reactions is not possible?

$$(A)\, n + {}^{235}_{92}U \rightarrow {}^{140}_{54}Xe + {}^{94}_{38}Sr + 2n$$

$$(B)\, n + {}^{235}_{92}U \rightarrow {}^{132}_{50}Sn + {}^{101}_{42}Mo + 3n$$

$$(C)\, n + {}^{239}_{94}Po \rightarrow {}^{127}_{53}I + {}^{93}_{41}Nb + 3n$$

Online Quiz for Lecture 30
Nuclear reactions -- Apr. 20, 2005

Consider the following reactions and determine which one releases more energy

A. ${}^{1}_{0}n + {}^{235}_{92}U$ ---> ${}^{140}_{58}Ce + {}^{94}_{40}Zr + 2({}^{1}_{0}n)$

B. ${}^{1}_{0}n + {}^{235}_{92}U$ ---> ${}^{141}_{55}Cs + {}^{93}_{37}Rb + 2({}^{1}_{0}n)$

Which of these releases more energy per reaction? Some of the atomic masses for these processes are listed below:

- ${}^{1}_{0}n$ -- 1.00867u
- ${}^{235}_{92}U$ -- 235.04392u,
- ${}^{140}_{58}Ce$ -- 139.9054u,
- ${}^{94}_{40}Zr$ -- 93.9063u,
- ${}^{141}_{55}Cs$ -- 140.91963u,
- ${}^{93}_{37}Rb$ -- 92.92157u

Other fission reactions

$$n + {}^{238}_{92}U \rightarrow {}^{239}_{92}U \rightarrow {}^{239}_{93}Np + e + \overline{\nu}$$

$$ {}^{239}_{93}Np \rightarrow {}^{239}_{94}Pu + e + \overline{\nu}$$

"Natural abundances of U"

${}^{238}{}_{92}U$	99.27%	$T_{1/2}=4.47 x 10^9$ yr
${}^{235}{}_{92}U$	0.72%	$T_{1/2}=7.04 x 10^8$ yr

Energy applications of nuclear physics

$$\sum_i {}^{A_i}_{Z_i}N \rightarrow \sum_f {}^{A_f}_{Z_f}N$$

$$Q = \sum_f M\left({}^{A_f}_{Z_f}N\right) - \sum_i M\left({}^{A_i}_{Z_i}N\right)$$

Energy available to generate electricity

Two basic approaches:

- Fission n + “heavy nucleous” → smaller nuclei
- Fusion 2 small nuclei → larger nucleus

Fission: Some history –

1932 James Chadwick (England) discovered neutron

Enrico Fermi (Italy) discovered that neutrons could be absorbed by nuclei to form new elements

Lise Meitner, Otto Hahn, Fritz Strassmann, Otto Frisch (Germany) discovered fission of U

Example:

$$n+{}^{235}_{92}U \rightarrow {}^{236}_{92}U \rightarrow {}^{140}_{54}Xe+{}^{94}_{38}Sr+2n$$

$${}^{140}_{54}Xe \rightarrow {}^{140}_{55}Cs \rightarrow {}^{140}_{56}Ba \rightarrow {}^{140}_{57}La \rightarrow {}^{140}_{58}Ce$$

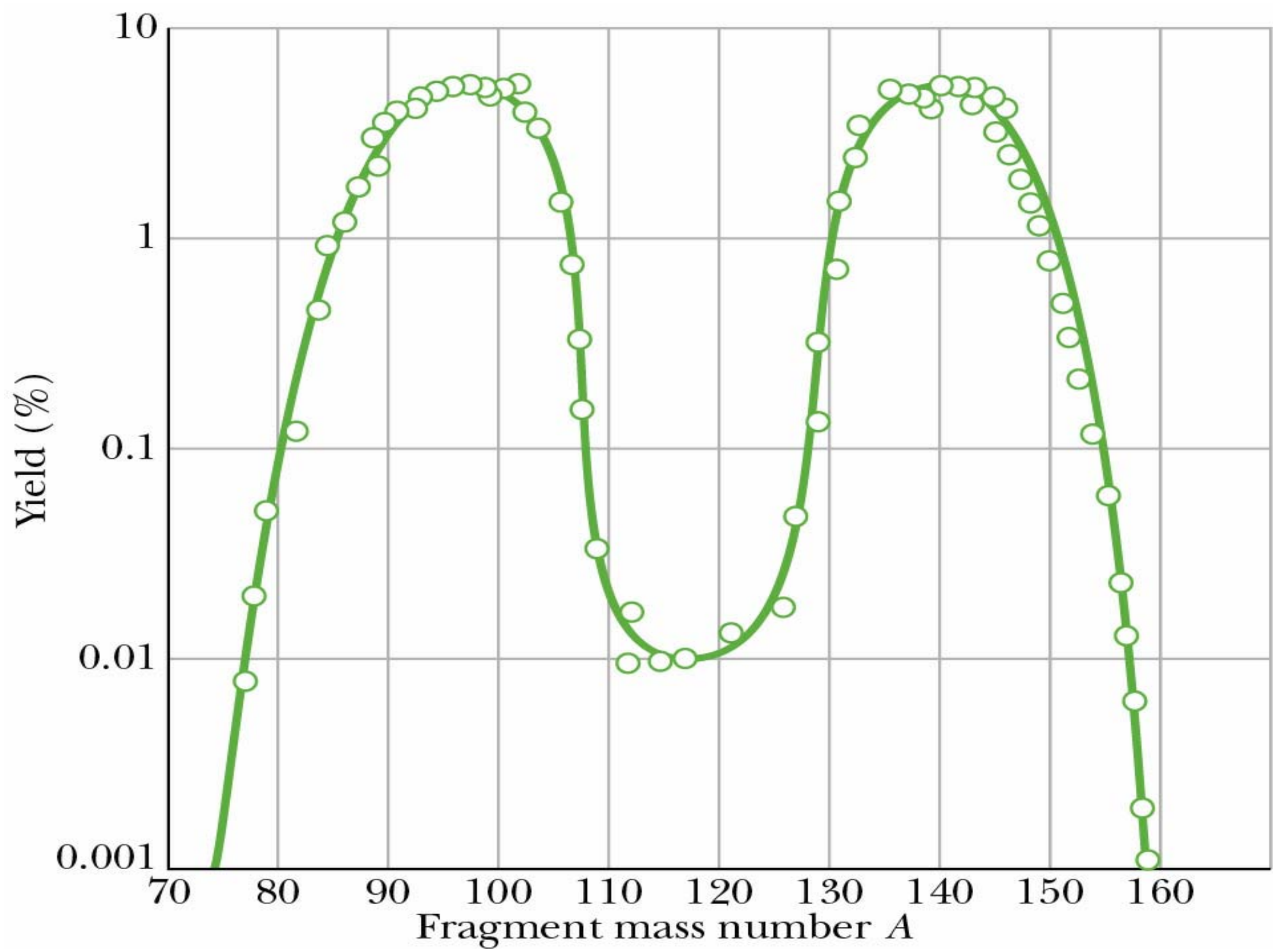
$$(\text{14s}) \quad (\text{64s}) \quad (\text{13d}) \quad (\text{40h}) \quad (\text{stable})$$

$${}^{94}_{38}Sr \rightarrow {}^{94}_{39}Y \rightarrow {}^{94}_{40}Zr$$

$$(\text{75s})(\text{19min})(\text{stable})$$

Q≈200 MeV

Other decay products for $n + {}^{235}_{92}U \rightarrow {}^{236}_{92}U$



Mechanism for power plant

Heat → mechanical energy → generator → electricity

Heat sources:

Chemical burning: oxygen + coal, oil, etc.

Nuclear burning: n + $^{235}_{92}U$

neutrons generated in the reaction are also used to fuel the reaction

2. HRW6 44.P.003. [53090] At what rate must ^{235}U nuclei undergo fission by neutrons to generate energy at the rate of 2.3 W? Assume that Q = 200 MeV.

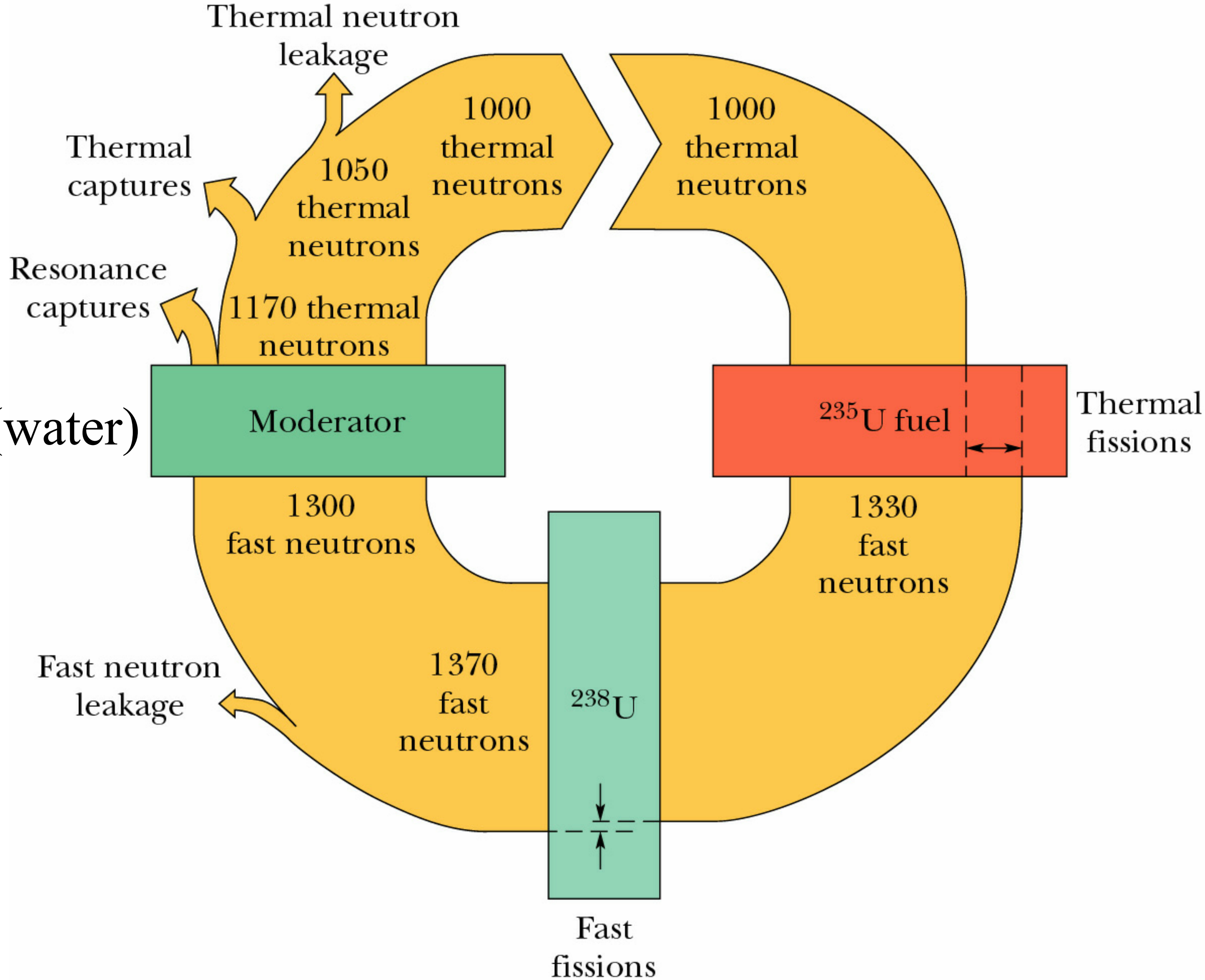
[ ] fissions/s

$$P = Q\left|\frac{dN}{dt}\right|$$

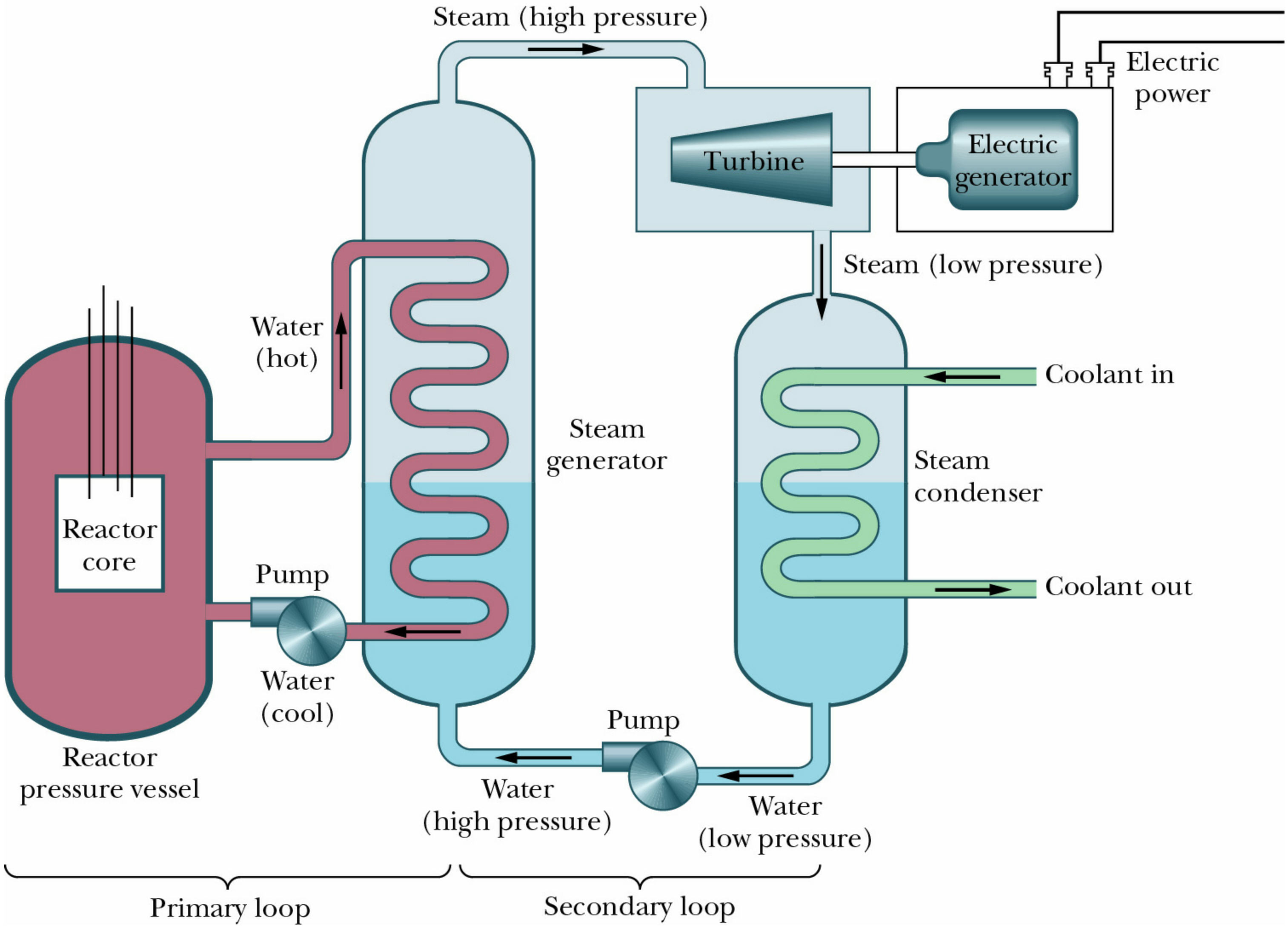
$$2.3\,J/s = 200\times10^{6}\,eV\cdot1.6\times10^{-19}\,J/eV\left|\frac{dN}{dt}\right|$$

Model for nuclear reactor – accounting for 1000 neutrons

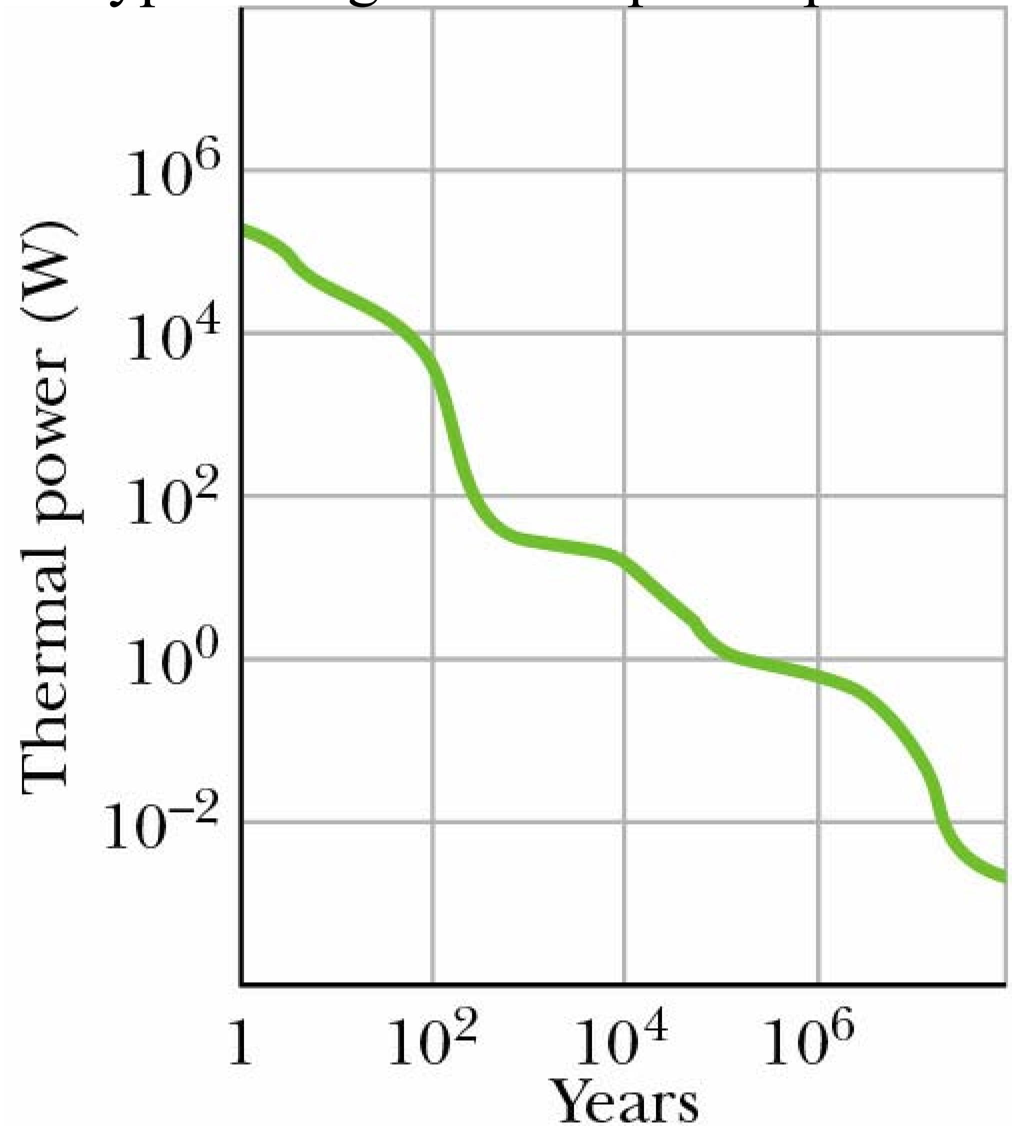
(water)



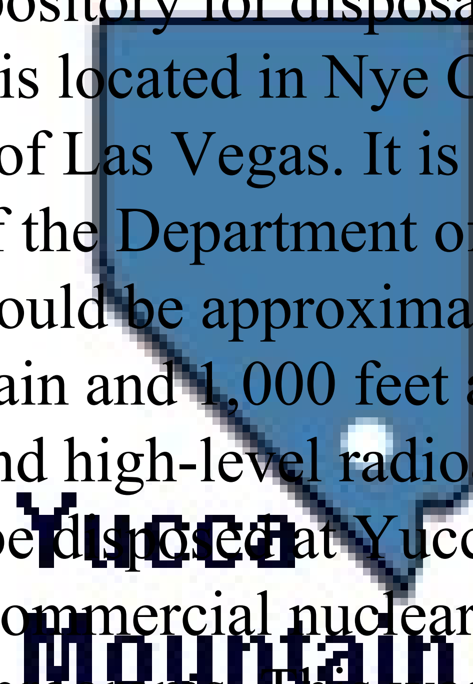
Simplified model of nuclear power plant



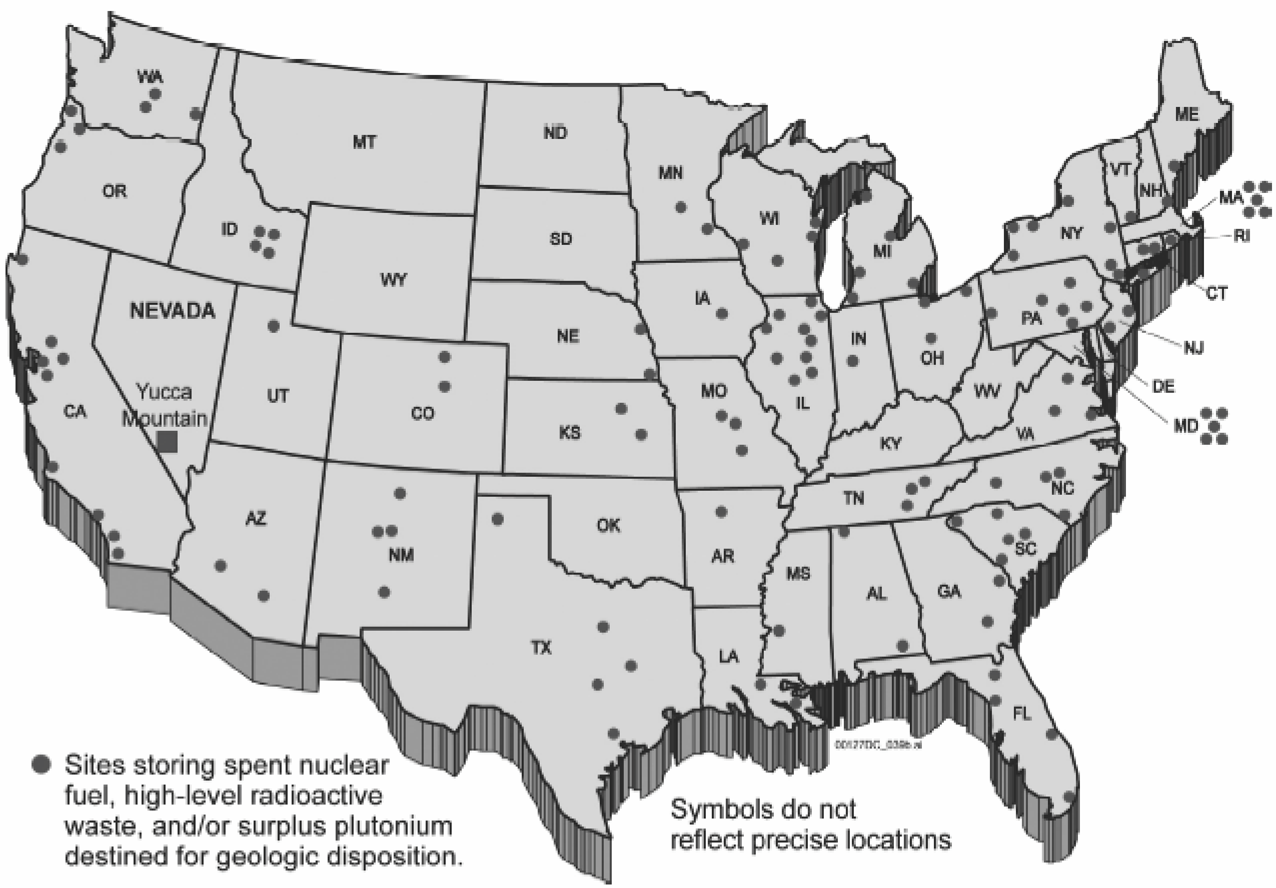
Thermal power release by radioactive wastes from one year's operation of a typical large nuclear power plant



Nuclear waste depository at Yucca Mountain, Nevada. -- Yucca Mountain is the Department of Energy's potential geologic repository designed to store and dispose of spent nuclear fuel and high-level radioactive waste. If approved, the site would be the nation's first geological repository for disposal of this type of radioactive waste. The site is located in Nye County, Nevada, about 100 miles northwest of Las Vegas. It is federally owned land on the western edge of the Department of Energy's Nevada Test Site. The repository would be approximately 1,000 feet below the top of the mountain and 1,000 feet above the ground water. Spent nuclear fuel and high-level radioactive waste make up most of the material to be disposed at Yucca Mountain. About 90% of this waste is from commercial nuclear power plants; the remaining is from defense programs. This waste is currently stored at facilities in 43 states.



Distribution of ~ 50,000 metric tons of radioactive waste



http://www.ocrwm.doe.gov/ymp/index.shtml

Fusion reactions

Summary of reactions in the sun:

$$^{1}H + {}^{1}H \rightarrow {}^{2}H + e^{+} + \nu \quad (Q = 0.42\ \mathrm{MeV})$$
$$e^{+} + e^{-} \rightarrow \gamma + \gamma \quad (Q = 1.02\ \mathrm{MeV})$$

$$^{1}H + {}^{1}H \rightarrow {}^{2}H + e^{+} + \nu \quad (Q = 0.42\ \mathrm{MeV})$$
$$e^{+} + e^{-} \rightarrow \gamma + \gamma \quad (Q = 1.02\ \mathrm{MeV})$$

$$^{2}H + {}^{1}H \rightarrow {}^{3}He + \gamma \quad (Q = 5.49\ \mathrm{MeV})$$

$$^{2}H + {}^{1}H \rightarrow {}^{3}He + \gamma \quad (Q = 5.49\ \mathrm{MeV})$$

$$^{3}He + {}^{3}He \rightarrow {}^{4}He + {}^{1}H + {}^{1}H \quad (Q = 12.86\ \mathrm{MeV})$$

Total energy release for each event: 26.7 MeV

This process has been occurring for $\approx 5 \times 10^9$ years and is expected to last for 10^9 more years

Fusion reactions which might be possible on earth:

$$^{2}_{1}H + ^{2}_{1}H \rightarrow ^{3}_{2}He + n \quad (Q=3.27\ MeV)$$

$$^{2}_{1}H + ^{2}_{1}H \rightarrow ^{3}_{2}He + ^{1}_{1}H \quad (Q=4.03\ MeV)$$

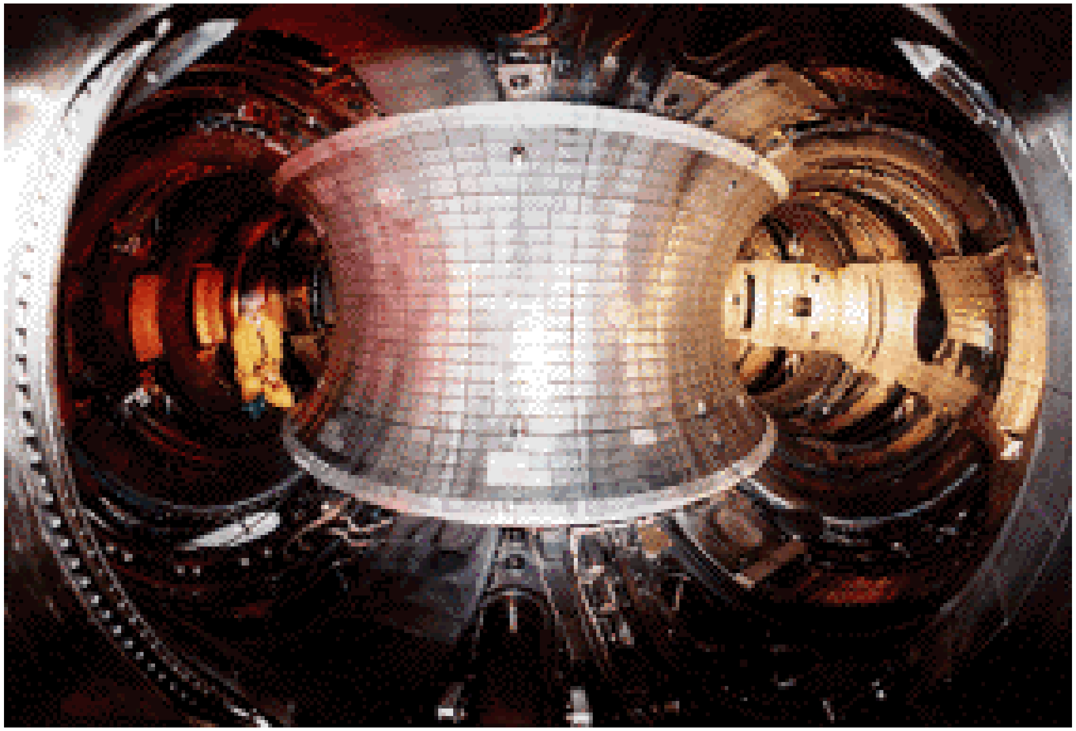
$$^{2}_{1}H + ^{3}_{1}H \rightarrow ^{4}_{2}He + n \quad (Q=17.59\ MeV)$$

Technological challenge: How to control the energetic reactants to effect net energy gain???

Magnetic confinement – "tokamak" design

Laser confinement – high powered lasers focused on fuel put into solid form

Images from the Tokamak Fusion Test Reactor at Princeton



	Advantages	Disadvantages
Fission	Technology has been demonstrated	Nuclear waste
Fusion	Less dangerous nuclear waste	Technology has not yet been demonstrated