Week 1, Lecture 3 – Overview

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Introduction

-- General Properties of Nuclei

-- Chart of Nuclides

-- Nuclear Processes, overview

--- decay equations

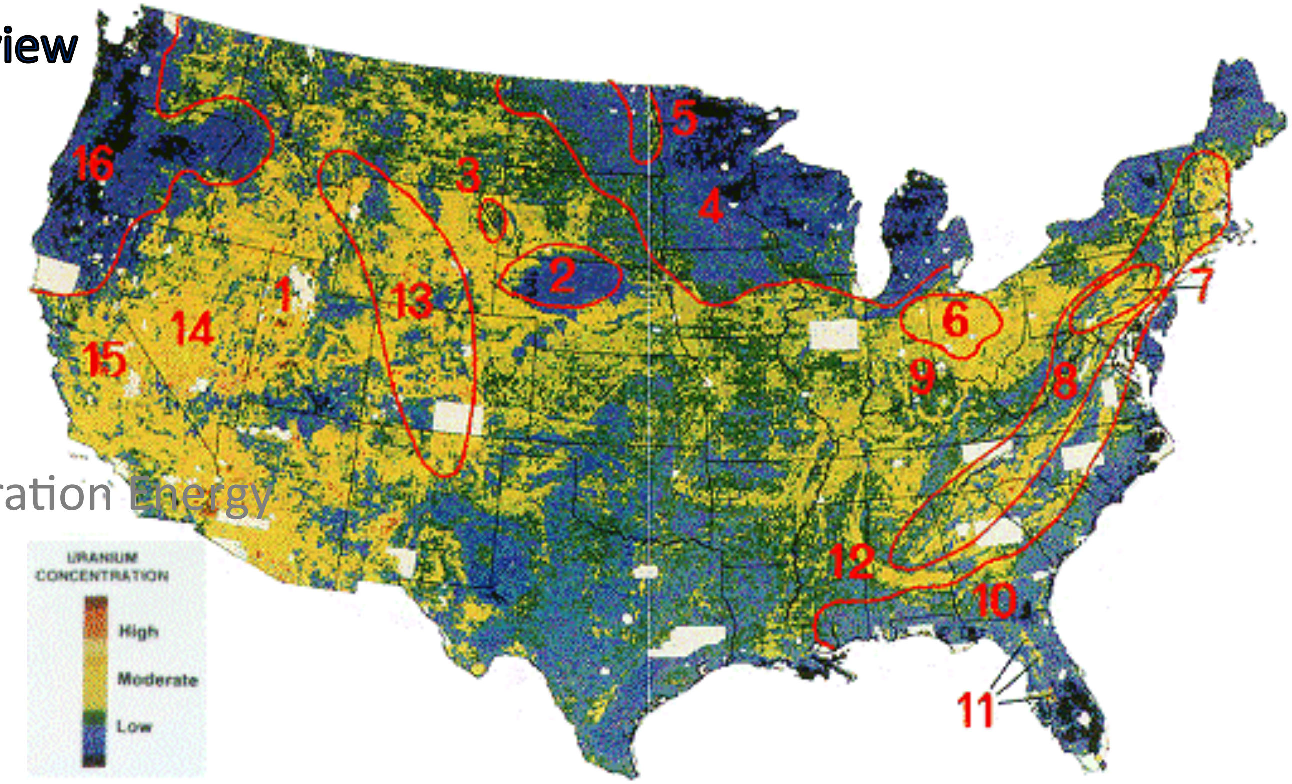
--- conservation laws

-- Nuclear "Activity"

Mass and Energy

-- Einstein's cliché

-- Binding Energy viz. Separation Energy



Map of U.S. Natural Radioactivity from U.S. Geological Survey
http://geology.about.com/library/bl/maps/blusradiationmap.htm

Nuclear Processes - 3

Internal Processes …

relaxation of excited states via photon emission:

e.g., proton, neutron excited states, nuclear vibration or rotation

radioactive decay (often leads to nuclear and/or atomic excitation)

1) Nucleus has too much Coulomb energy
   nuclear conversion/change through the "strong force" … alpha decay, fission
2) Nucleus is unbalanced with respect to neutron/proton number
   nuclear conversion/change through the "weak force" … beta-decay, -, + , capture

$$^{99}_{42}Mo \rightarrow {}^{99m}_{43}Tc^{1+} + e^- + \overline{\upsilon}_e + Q_{\beta-} \quad T_{1/2} = 73hr$$

β - decay: Electron & antineutrino are created

$$^{11}_{6}C \rightarrow {}^{11}_{5}B^{1-} + e^+ + \upsilon_e + Q_{\beta+} \quad T_{1/2} = 20\,\text{min}$$

β + decay: antielectron & neutrino are created

$$^{50}_{23}V \rightarrow {}^{50}_{22}Ti^{1-} + e^+ + \upsilon_e + Q_{\beta+} \quad T_{1/2} = 150Py$$

$$^{50}_{23}V \rightarrow {}^{50}_{22}Ti + \upsilon_e + Q_{EC}$$

$$^{201}_{81}Tl \rightarrow {}^{201}_{80}Hg + \upsilon_e + Q_{EC} \quad T_{1/2} = 73hr$$

EC decay: electron is destroyed & neutrino is created

The Conservation Laws

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(Natural) Law is a concise statement of observed facts in a natural process.

Quantities that are conserved in (all) nuclear reactions:

1) Total energy (including the mass al la Einstein, $E=mc^2$)

   Total Energy = Kinetic Energy + Potential Energy + "Mass Energy"

2) Momentum, both linear and angular

   Linear momentum, $\vec{p} = m\vec{\mathrm{v}}$
   Angular momentum = orbital motion ($\vec{p} = m\vec{\mathrm{v}} \otimes \vec{\mathrm{r}}$) + spin

3) Electrical charge (protons and electrons are charged, of course)

4) The total number of nucleons and separately the total number of leptons

   Nucleons: proton, neutron
   Leptons: electron, electron-neutrino [anti-electron, anti-electron-neutrino]

Aside: Activity

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^{99m}Tc -- 800 MBq is typically administered during diagnostic procedures.

What does MBq refer to, how many atoms is this?

Radioactive sources are characterized in terms of the number of decays per unit time. This is thus called the ACTIVITY. The historical unit of activity is the "Curie" (Ci) that is defined as 3.700… $x10^{10}$ decays/s (the approximate decay rate of 1 gram of 'natural' radium separated from uranium ore).

The modern (SI) unit of activity is the "Becquerel" (Bq) that is 1 decay/s or simply 1 s^{-1}

Thus: 800 MBq (mega-Becquerel) = 800 $x10^6$ decays/s = 8.00 $x10^8$ /s

The activity: $A = \lambda N$

How active are you?

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Calculate the activities in a typical person (70 kg) given the following data:

Nuclide	Mass (μg)	Half-life	Activity	Decay Mode
238-U	90	4.5×10^{9} y		
232-Th	30	1.40×10^{10} y		
40-K	17	1.248×10^{9} y		
226-Ra	31	1600 y		
14-C	0.022	5700 y		
3-H	0.06 pg	12.32 y		
218-Po	0.02 pg	3.05 m		

How active are you?

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Calculate the activities in a typical person (70 kg) given the following data:

Nuclide	Mass (μg)	Half-life	Activity	Decay Mode
238-U	90	4.5×10^{9}y	30 pCi (1.1 Bq)	Alpha Emission
232-Th	30	1.40×10^{10} y	3 pCi (0.12Bq)	Alpha Emission
40-K	17	1.248×10^{9}y	120 nCi (4.5 kBq)	Beta Minus
226-Ra	31	1600 y	30 pCi (1.1 Bq)	Alpha Emission
14-C	0.022	5700 y	0.1 μCi (3.7 kBq)	Beta Minus
3-H	0.06 pg	12.32 y	600 pCi (22 Bq)	Beta Minus
218-Po	0.02 pg	3.05 m	1 μCi (0.2 MBq)	Alpha Emission

$$A = \left(\frac{\ln 2}{T_{1/2}}\right)\left(\frac{mN_A}{MM}\right)$$

A	Mass (ug)	T 1/2 (yr)	λ (s^-1)	N	Activity (Bq)	Activity (nCi)
238	90	4.50E+09	4.8899E-18	2.28E+17	1.11E+00	3.01E-02
232	30	1.40E+10	1.5718E-18	7.79E+16	1.22E-01	3.31E-03
40	17	1.25E+09	1.7632E-17	2.56E+17	4.51E+00	1.22E-01
226	31	1.60E+03	1.3753E-11	8.26E+16	1.14E+06	3.07E+04
14	0.022	5.70E+03	3.8605E-12	9.46E+14	3.65E+03	9.87E+01
3	6.00E-08	1.23E+01	1.7861E-09	1.20E+10	2.15E+01	5.81E-01
218	2.00E-08	5.81E-06	0.00378769	5.52E+07	2.09E+05	5.66E+03
		Sec/year =	N_A			
		3.15E+07	6.02E+23			