Lecture 1: RDCH 702 Introduction

- **Reading: Chart of the nuclides and Table of the isotopes (http://radchem.nevada.edu/docs/course%20reading/TOI.PDF)**
  - **Provide blog input when lecture completed**
    - → **Comments, questions, or statement that lecture completed**
    - → **http://rdch702.blogspot.com/**

- **Class organization**
  - **Outcomes**
  - **Grading**
- **Chart of the nuclides**
  - **Description and use of chart**
  - **Data**
- **Radiochemistry introduction**
  - **Atomic properties**
  - **Nuclear nomenclature**
  - **X-rays**
  - **Types of decays**
  - **Forces**

RDCH 702: Introduction

- **Outcomes for RDCH 702**
  - **Understand chemical properties in radiation and radiochemistry**
  - **Use and application of chemical kinetics and thermodynamics to evaluate radionuclide speciation**
  - **Understand the influence of radiolysis on the chemistry of radioisotopes**
  - **Understand and evaluate radioisotope production**
  - **Evaluate and compare radiochemical separations**
  - **Utilization of radioisotope nuclear properties in evaluating chemical behavior**
  - **Use and explain the application of radionuclides in research**
  - **Discuss and understand ongoing radiochemistry research**

Grading

- **Homework (5 %)**
  - **PDF provide at end of lecture**
    - **→ E-mail response directly after lecture**
- **Quizzes (12.5 % each)**
  - **Take home quiz**
  - **Develop tools for research (spreadsheets)**
- **Presentation (20 %)**
  - **Based on recent literature**
  - **End of semester**
  - **20-25 minutes**
- **Participation (12.5 %)**
  - **Blog response, skype, in class**
- **Class developed to assist and compliment research activities**

#	Date		Topic
1	Monday	27-Aug	Chart of the Nuclides
2	Wednesday	29-Aug	Chemical Speciation and Thermodynamics
3	Monday	03-Sep	Labor Day
4	Wednesday	05-Sep	Chemical Speciation and Thermodynamics
5	Monday	10-Sep	Quiz 1 (Chart of the Nuclides)
6	Wednesday	12-Sep	Nuclear Reactions
7	Monday	17-Sep	Nuclear Reactions
8	Wednesday	19-Sep	Origin of the Elements
9	Monday	24-Sep	Meet: Scinfinder and literature search (Poineau)
10	Wednesday	26-Sep	Quiz 2 (Speciation and Thermodynamics)
11	Monday	01-Oct	Electron orbitals and energy
12	Wednesday	03-Oct	Nuclear Models
13	Monday	08-Oct	Meet: Topic review with Prof. Poineau
14	Wednesday	10-Oct	Decay Kinetics
15	Monday	15-Oct	Decay Kinetics
16	Wednesday	17-Oct	Quiz 3 (Electron Orbitals and Decay Kinetics)
17	Monday	22-Oct	Dosimetry and Interaction of Radiation with Matter
18	Wednesday	24-Oct	Dosimetry and Interaction of Radiation with Matter
19	Monday	29-Oct	Isotope production
20	Wednesday	31-Oct	Meet: Topic review with Prof. Poineau
21	Monday	05-Nov	Quiz 4 (Dosimetry, Radiation Interaction, Isotope Production)
22	Wednesday	07-Nov	Separations
23	Monday	12-Nov	Separations
24	Wednesday	14-Nov	Separations
25	Monday	19-Nov	Separations
26	Wednesday	21-Nov	Meet: Separations and Nuclear Fuel Cycle with Prof. Poineau
27	Monday	26-Nov	In Reactor Chemistry
28	Wednesday	28-Nov	Reactors and Fuel Cycle
29	Monday	03-Dec	Application of Nuclear Material
30	Wednesday	05-Dec	Quiz 5 (Separations, Fuel Cycle)
31	Monday	Final	Presentations (TBD)

Radiochemistry Introduction

- Radiochemistry
  - Chemistry of the radioactive isotopes and elements
  - Utilization of nuclear properties in evaluating and understanding chemistry
  - Intersection of chart of the nuclides and periodic table
- Atom
  - Z and N in nucleus (10^{-14} m)
  - Electron interaction with nucleus basis of chemical properties (10^{-10} m)
    - → Electrons can be excited
      - * Higher energy orbitals
      - * Ionization
        - ➢ Binding energy of electron effects ionization
  - Isotopes
    - → Same Z different N
  - Isobar
    - → Same A (sum of Z and N)
  - Isotone
    - → Same N, different Z
  - Isomer
    - → Nuclide in excited state
    - → ^{99m}Tc

$$^{A}_{Z}ChemicalSymbol_{N}$$

Types of Decay

1. α decay (occurs among the heavier elements)

$$^{226}_{88}Ra \rightarrow ^{222}_{86}Rn + ^{4}_{2}\alpha + Energy$$

2. β^- decay

$$^{131}_{53}I \rightarrow ^{131}_{54}Xe + \beta^- + \overline{\nu} + Energy$$

3. Positron emission

$$^{22}_{11}Na \rightarrow ^{22}_{10}Ne + \beta^+ + \nu + Energy$$

4. Electron capture

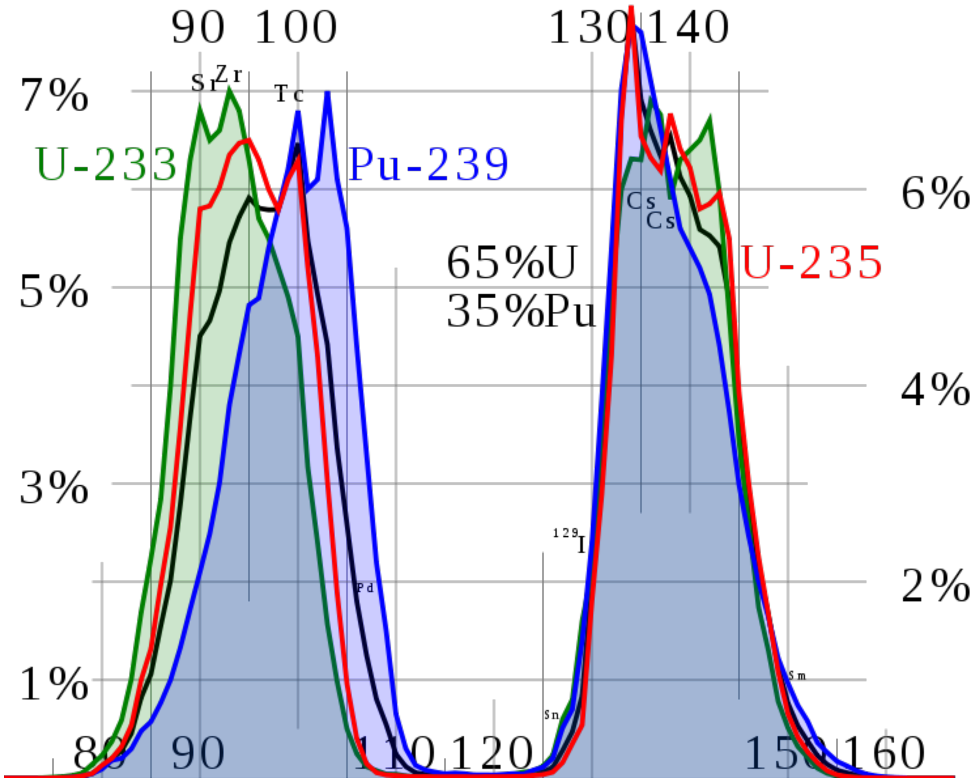
$$^{26}_{13}Al + \beta^- \rightarrow ^{26}_{12}Mg + \nu + Energy$$

5. Spontaneous fission

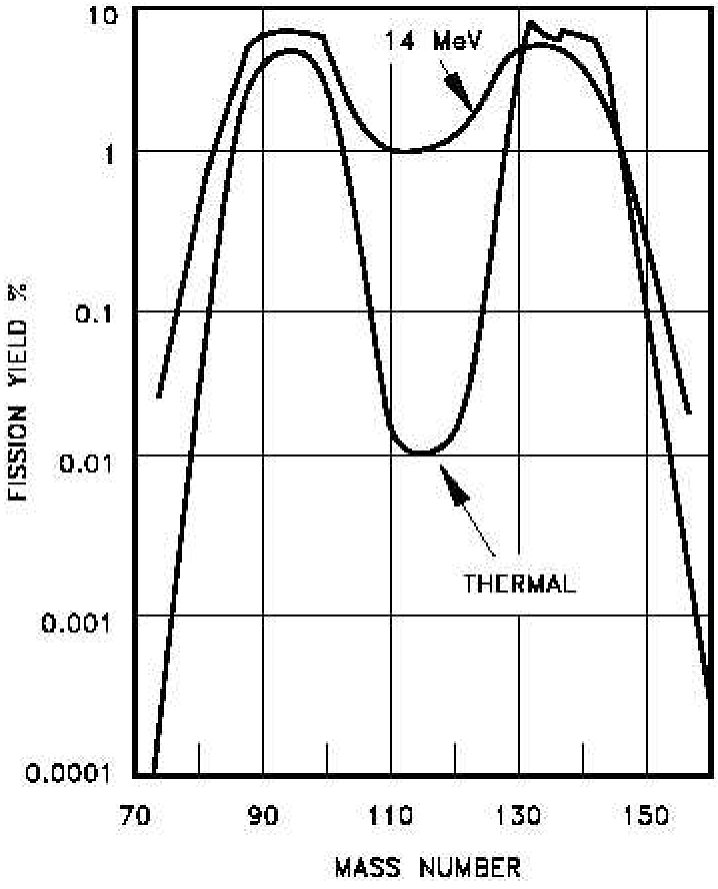
$$^{252}_{98}Cf \rightarrow ^{140}_{54}Xe + ^{108}_{44}Ru + 4^{1}_{0}n + Energy$$

Fission Products

- Fission yield curve varies with fissile isotope
- 2 peak areas for U and Pu thermal neutron induced fission
- Variation in light fragment peak
- Influence of neutron energy observed

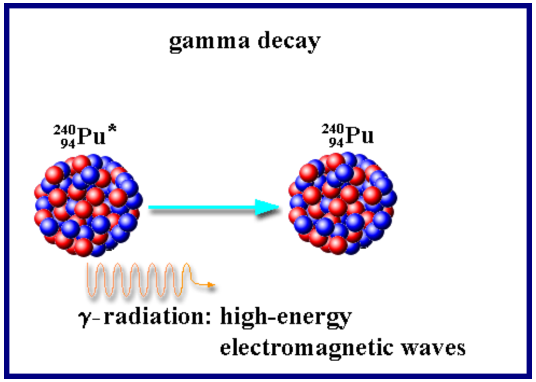


^{235}U fission yield



Photon emission

- Gamma decay
  - Emission of photon from excited nucleus
    - → Metastable nuclide (i.e., ^{99m}Tc)
    - → Following decay to excited daughter state
- X-ray
  - Electron from a lower level is removed
    - → electrons from higher levels occupy resulting vacancy with photon emission
  - De-acceleration of high energy electrons
  - Electron transitions from inner orbitals
  - X-ray production
    - → Bombardment of metal with high energy electrons
    - → Secondary x-ray fluorescence by primary x-rays
    - → Radioactive sources
    - → Synchrotron sources

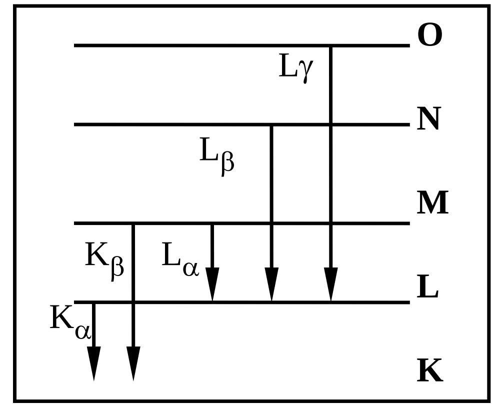


X-rays

- **Removal of K shell electrons**
  - **Electrons coming from the higher levels will emit photons while falling to this K shell**
    - → **series of rays (frequency ν or wavelength λ) are noted as K_α, K_β, K_γ**
    - → **If the removed electrons are from the L shell, noted as L_α, L_β, L_γ**
- **In 1913 Moseley studied these frequencies ν, showing that:**

$$\sqrt{\nu} = A(Z - Z_o)$$

- **where Z is the atomic number and, A and Z_0 are constants depending on the observed transition.**
- **K series, $Z_0 = 1$, L series, $Z_0 = 7.4$.**



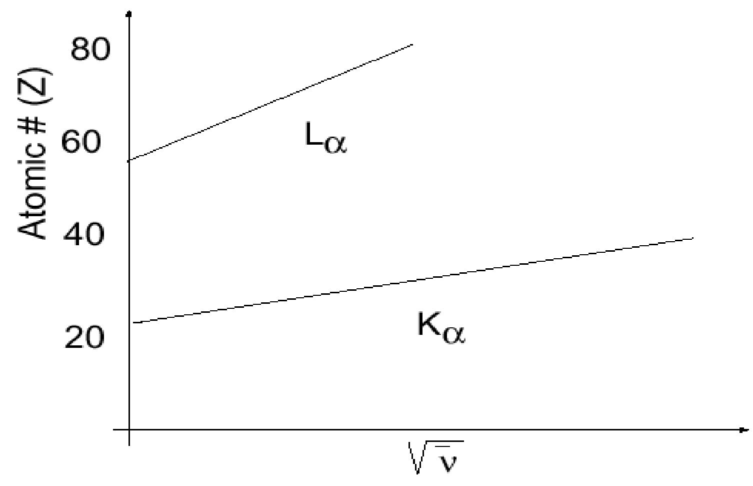
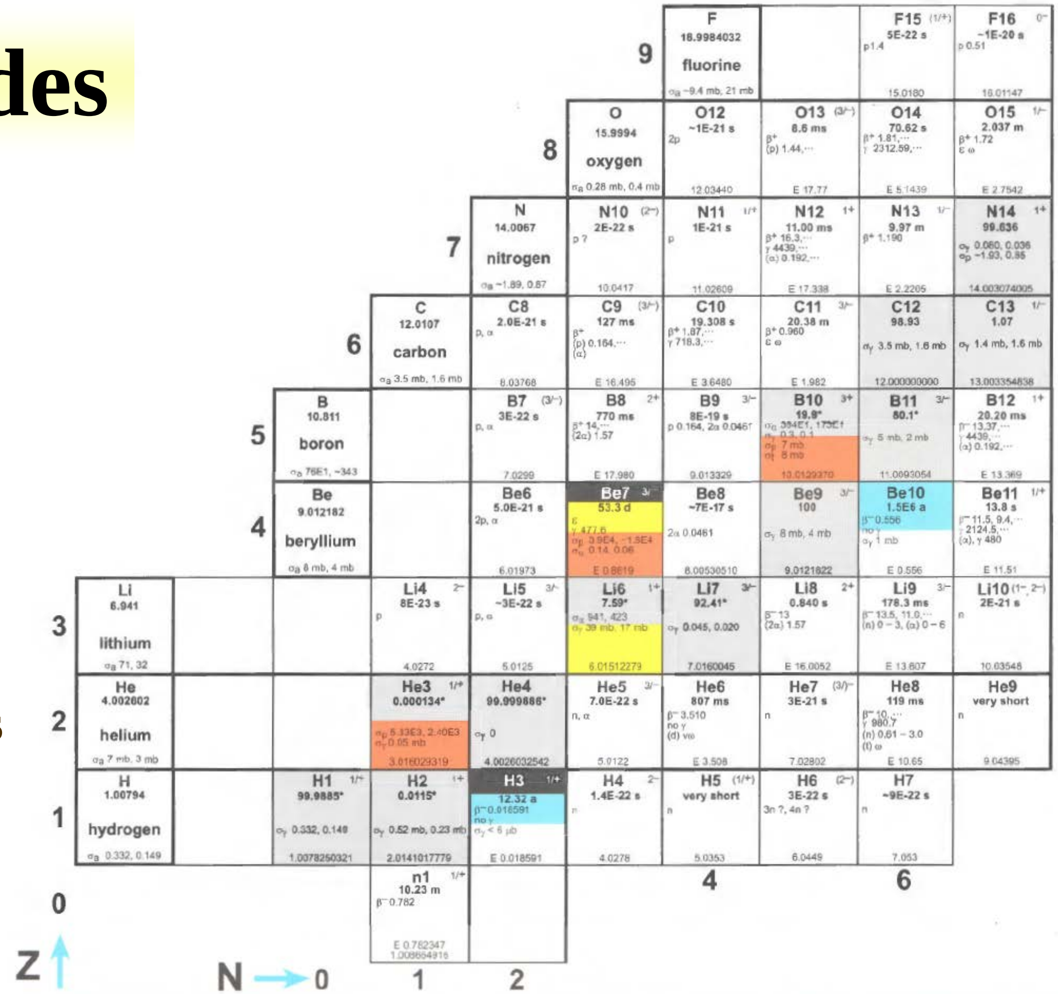


Figure 4 Moseley relationship for K_α and L_α radiation

Chart of the Nuclides

- Presentation of data on nuclides
  - Information on chemical element
  - Nuclide information
    - → Spin and parity (0^+ for even-even nuclides)
    - → Fission yield
  - Stable isotope
    - → Isotopic abundance
    - → Reaction cross sections
    - → Mass
- Radioactive isotope
  - Half-life
  - Modes of decay and energies
  - Beta disintegration energies
  - Isomeric states
  - Natural decay series
  - Reaction cross sections
- Fission yields for isobars



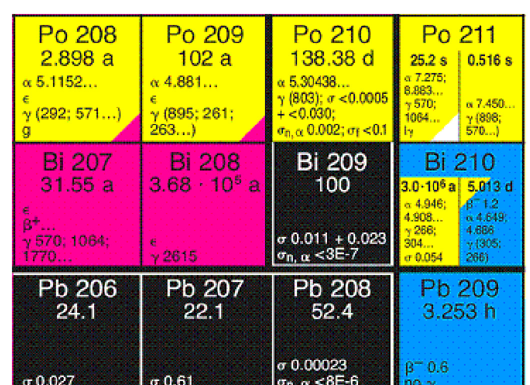


Chart of Nuclides

- **Decay modes**
  - Alpha
  - Beta
  - Positron
  - Photon
  - Electron capture
  - Isomeric transition
  - Internal conversion
  - Spontaneous fission
  - Cluster decay

Displacements Caused by Nuclear Bombardment Reactions

α – 3*n*	α – 2*n*	α – *n*
p – *n*	*p* – γ *d* – *n*	α – *n*, *p*
γ – *n* *n* – 2*n*	Original nucleus	*d* – *p* *n* – γ
γ – *p*, *n*	γ – *p*	*n* – *p*
n - α		

Relative Location of the Products of Various Nuclear Reactions

					α in
	β^- + *n* out	β^- out	*p* in	*d* in	H^3 in
		n out	Original nucleus	*n* in	
β^- + α out	H^3 out	*d* out	*p* out	β^+ out, EC	
	α out			EC + *p* out	

Chart of the nuclides

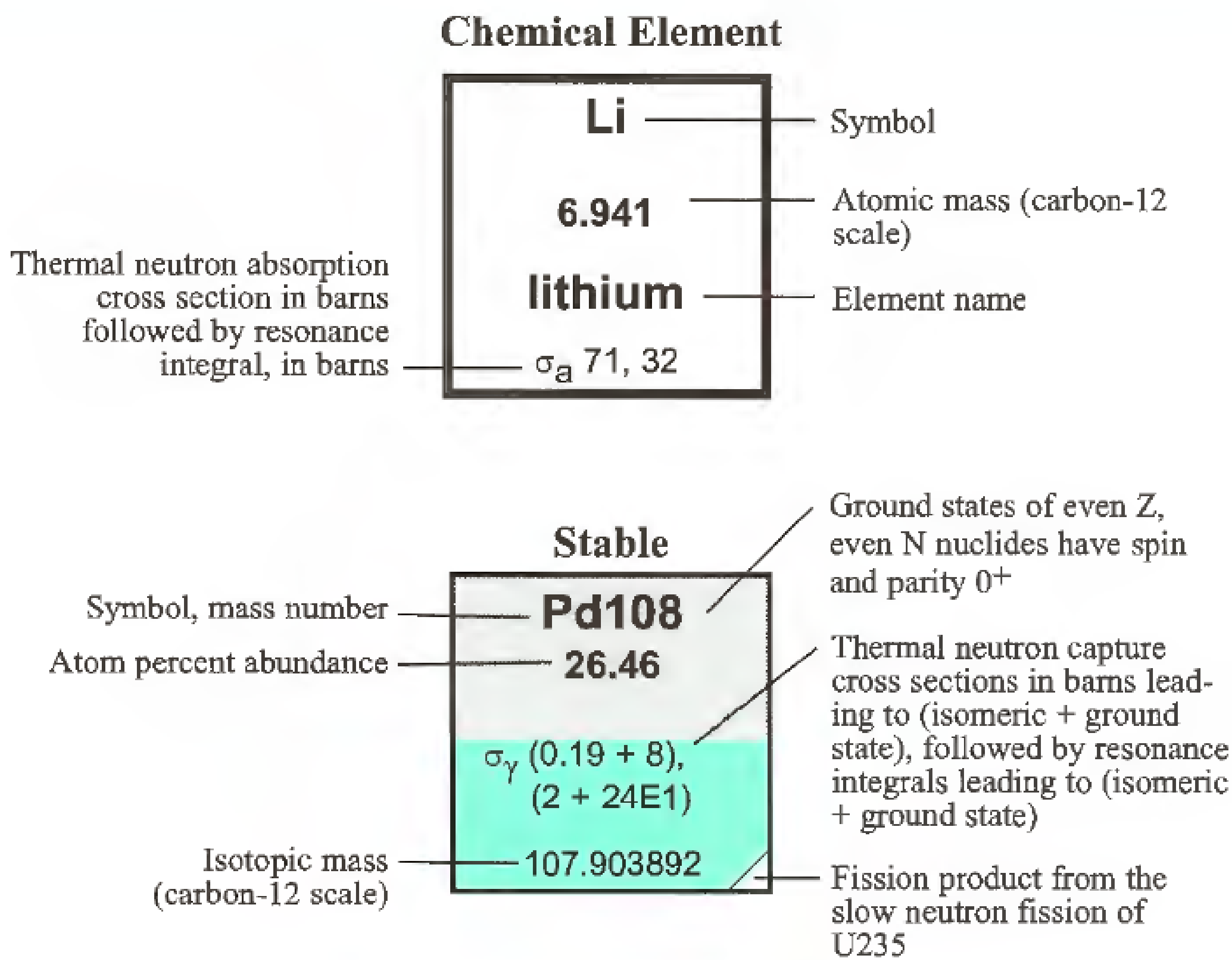


Chart of the nuclides

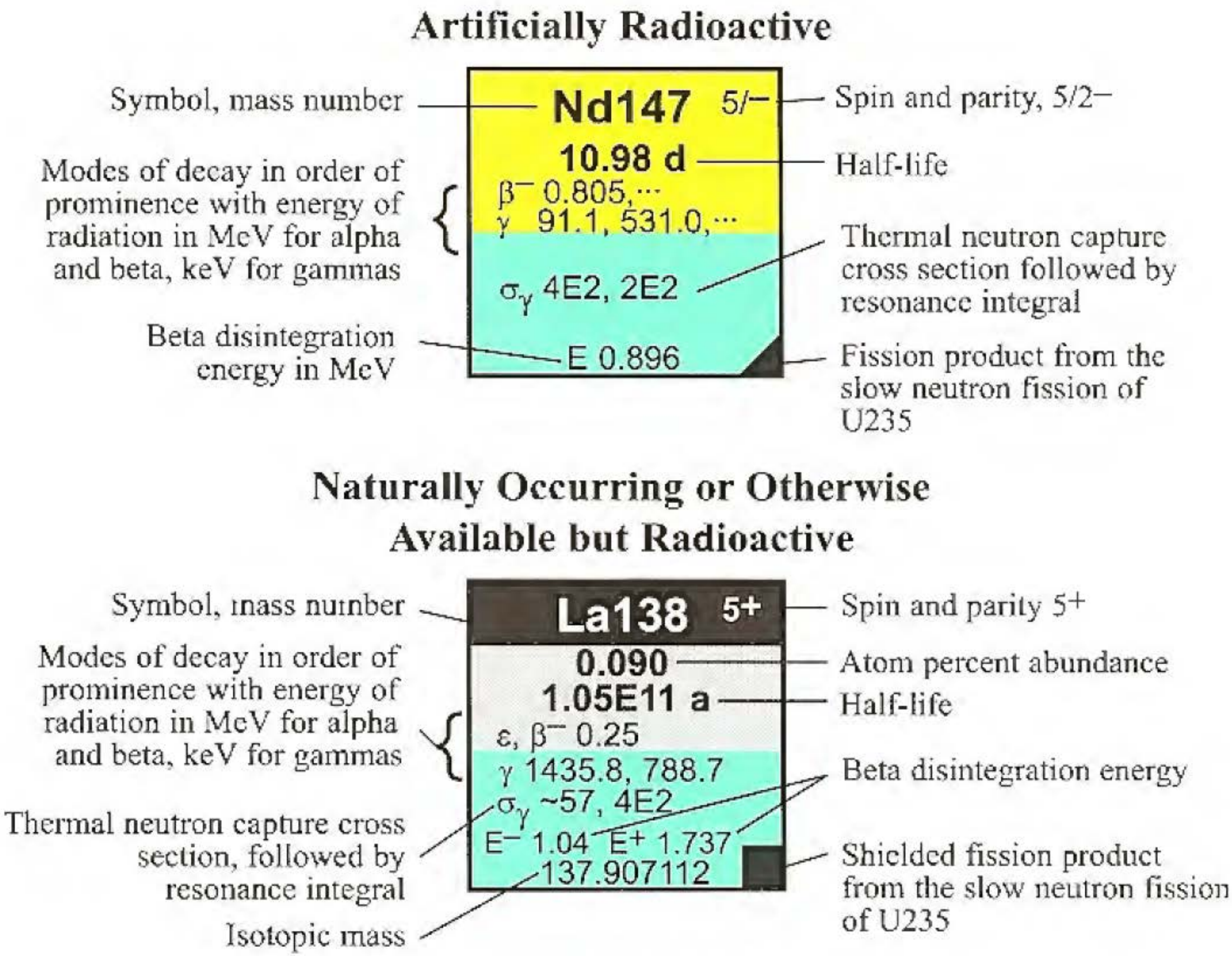


Chart of the nuclides

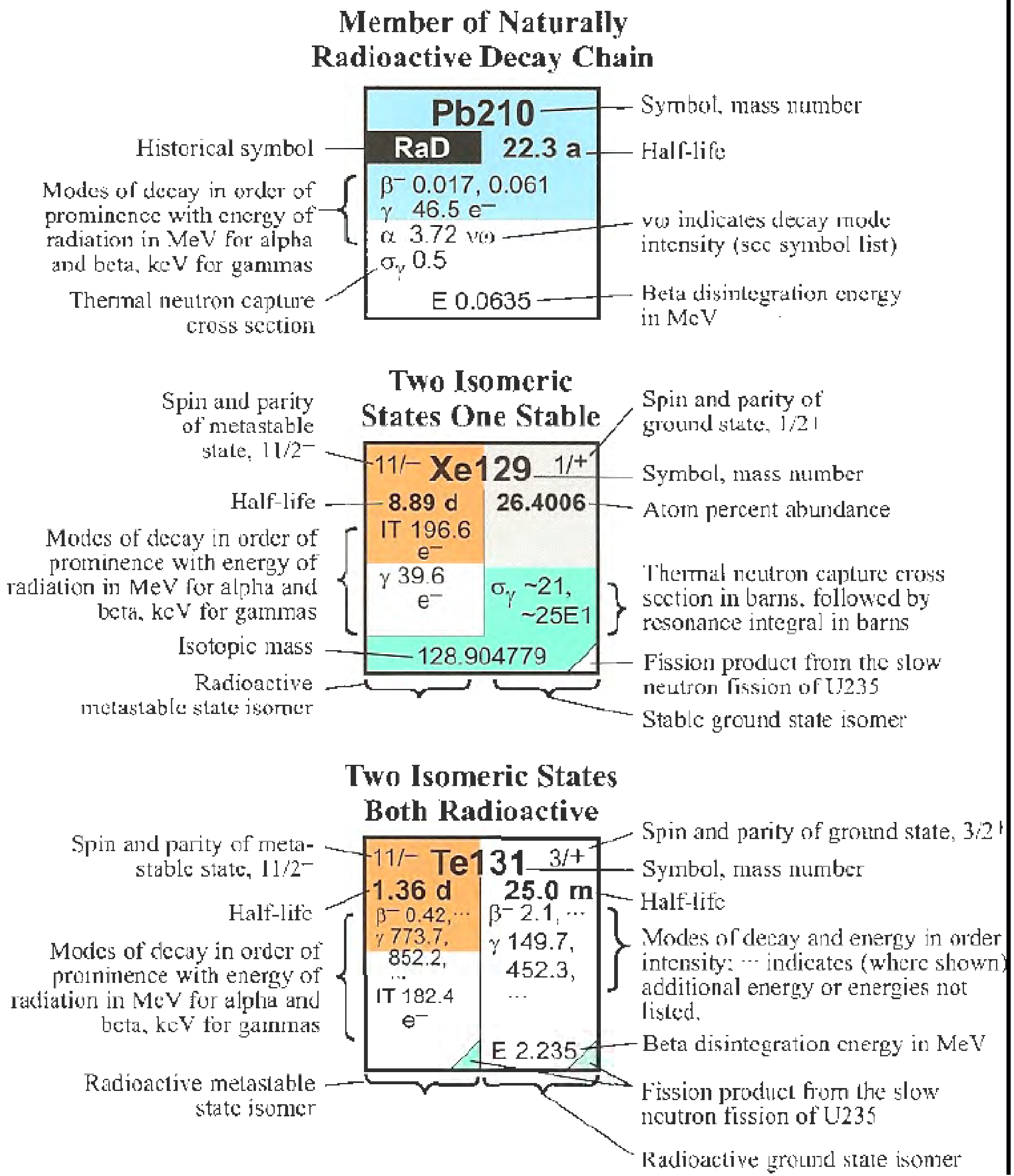
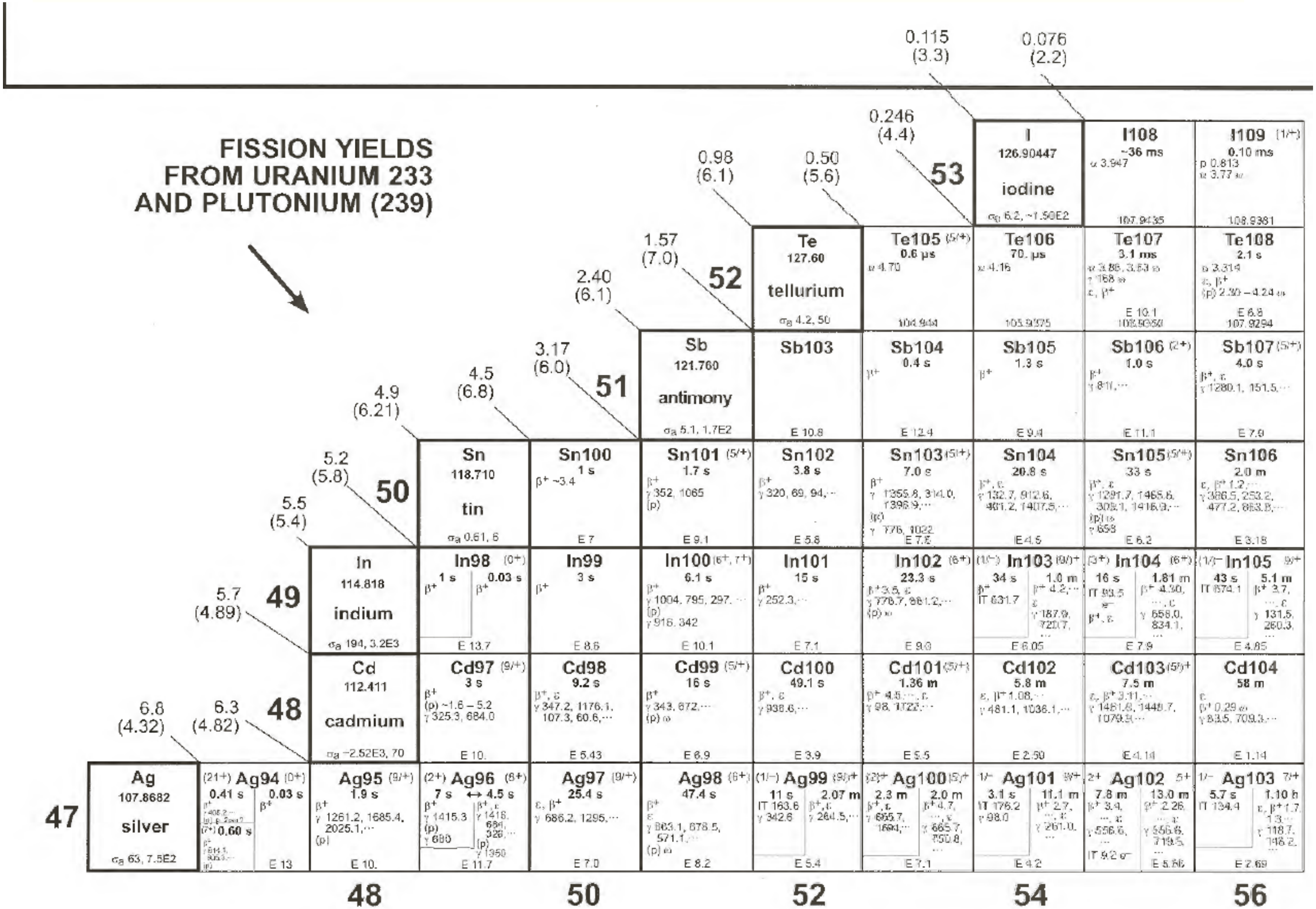
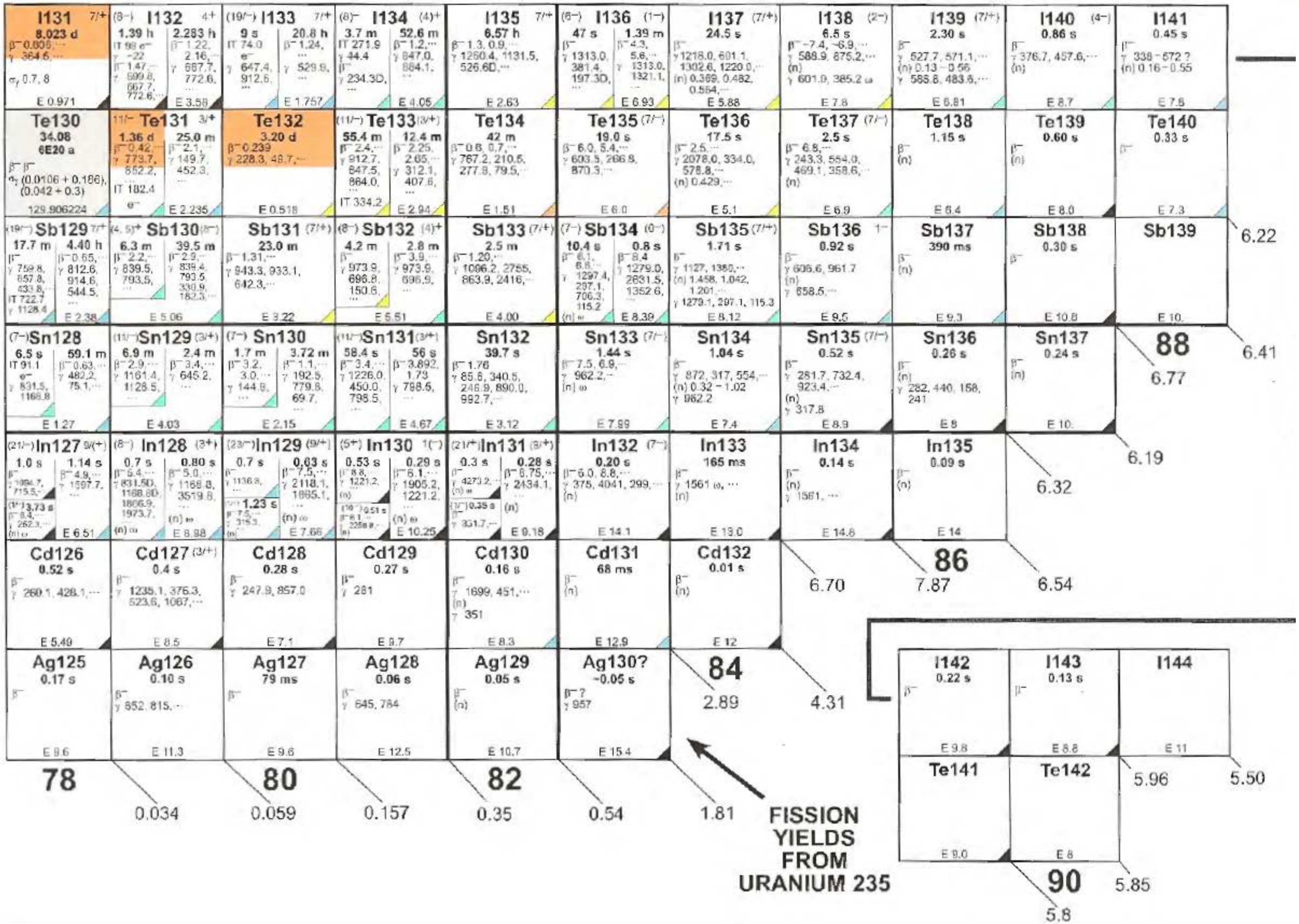


Chart of the Nuclide: Fission yields



Fission yields

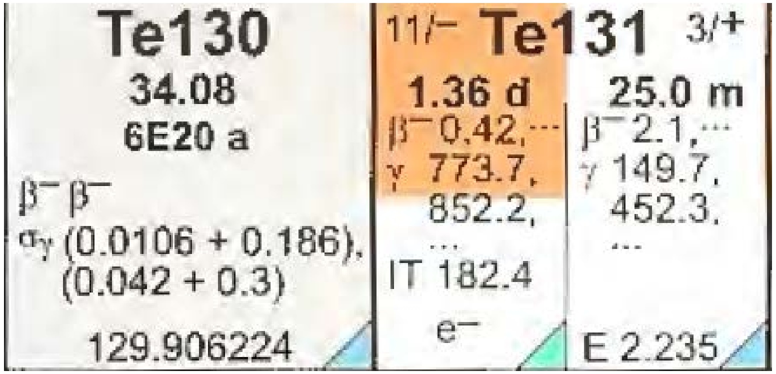


Terms and decay modes: Utilization of chart of the nuclides

- **Identify the isomer, isobars, isotones, and isotopes**
  - **^{60m}Co, ^{57}Co, ^{97}Nb, ^{58}Co, ^{57}Ni, ^{57}Fe, ^{59}Ni, ^{99m}Tc**
- **Identify the daughter from the decay of the following isotopes**
  - **^{210}Po (alpha decay, ^{206}Pb)**
  - **^{196}Pb**
  - **^{204}Bi (EC decay, ^{204}Pb)**
  - **^{209}Pb**
  - **^{222}At**
  - **^{212}Bi (both alpha and beta decay)**
  - **^{208}Pb (stable)**
- **How is ^{14}C naturally produced**
  - **Reactions with atmosphere (^{14}N as target)**
- **Identify 5 naturally occurring radionuclides with Z<84**

Chart of the Nuclides Questions

- **How many stable isotopes of Ni?**
- **What is the mass and isotopic abundance of ^{84}Sr?**
- **Spin and parity of ^{201}Hg?**
- **Decay modes and decay energies of ^{212}Bi**
- **What are the isotopes in the ^{235}U decay series?**
- **What is the half-life of ^{176}Lu?**
- **What is the half-life of ^{176}Yb**
- **How is ^{238}Pu produced?**
- **How is ^{239}Pu made from ^{238}U**
- **Which actinide isotopes are likely to undergo neutron induced fission?**
- **Which isotopes are likely to undergo alpha decay?**



- **What is the half life of ^{130}Te**
  - **What is its decay mode?**
- **What cross section data is provided for ^{130}Te?**

Table of the Isotopes

- **Detailed information about each isotope**
  - **Mass chain decay scheme**
  - **mass excess (M-A)**

    →Mass difference, units in energy (MeV)
  - **particle separation energy**
  - **Populating reactions and decay modes**
  - **Gamma data**

    →Transitions, % intensities
  - **Decay levels**

    →Energy, spin, parity, half-life
  - **Structure drawing**

Table of the isotopes

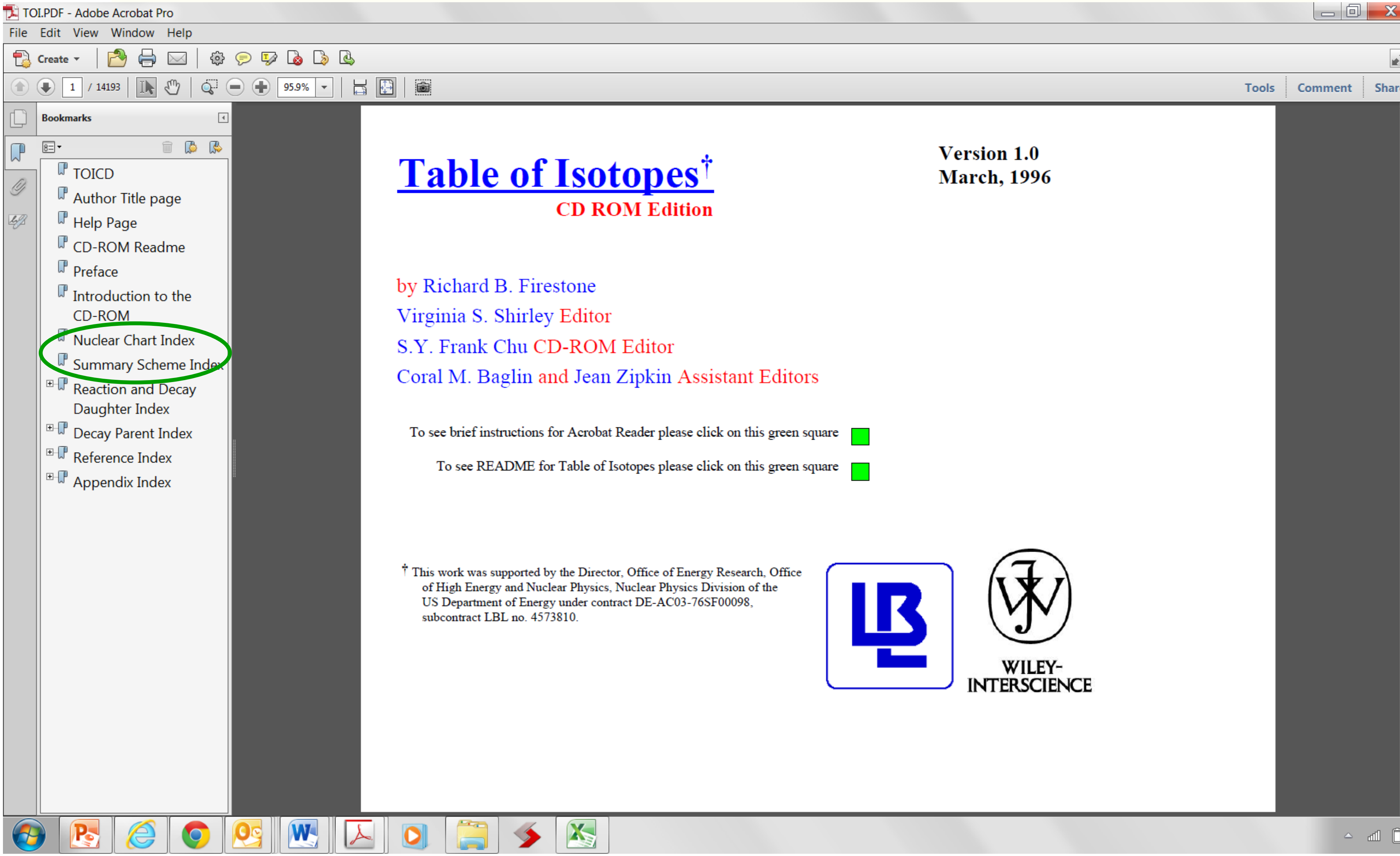
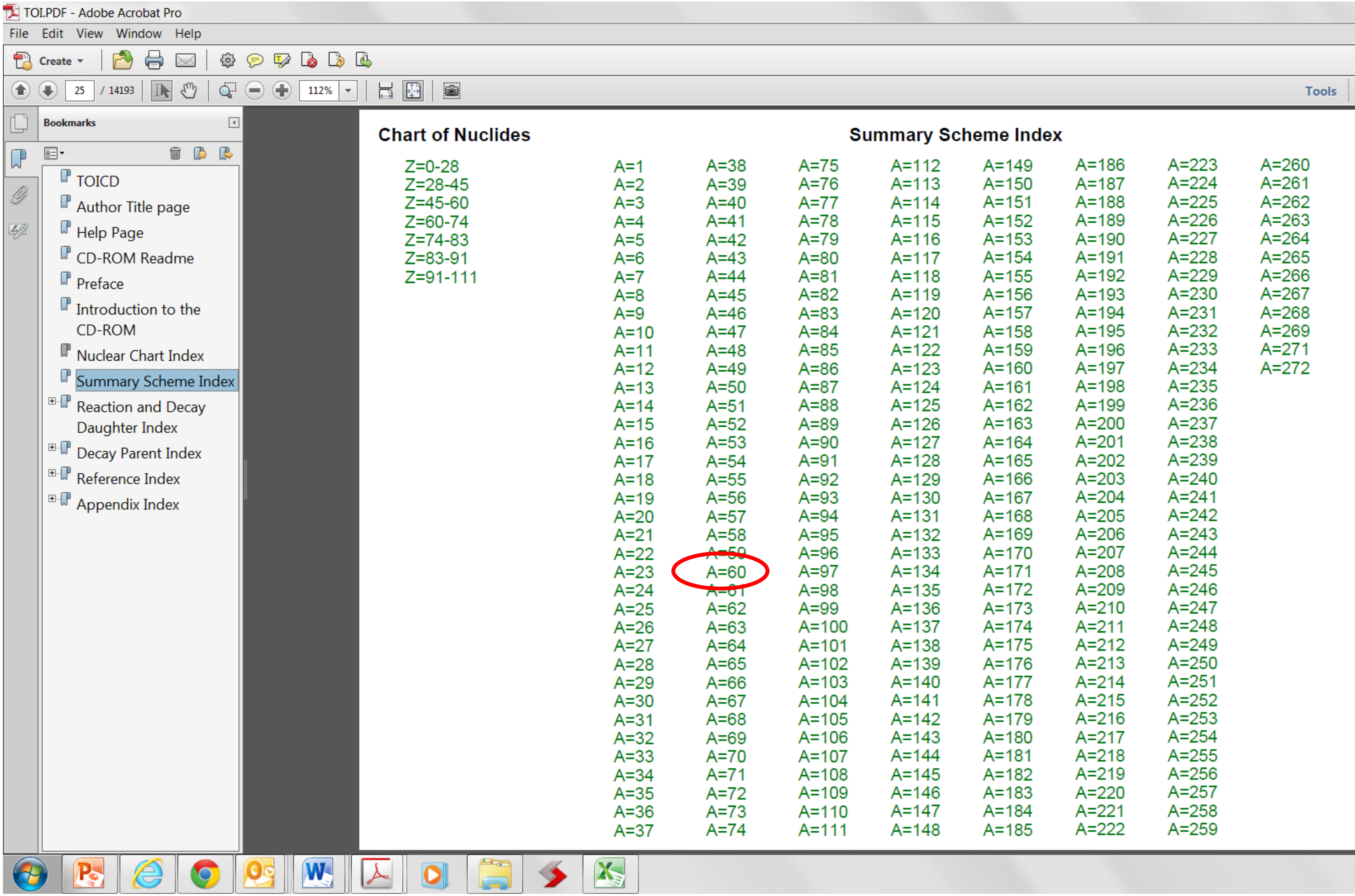


Table of the isotopes



$^{60}_{27}$Co

Δ: −61644.5 *14* S_n: 7491.93 *8* S_p: …
Q_{β^-}: 2823.9 *5*
σ_γ(for 0): 2.0 *2* b , σ_γ(for …): 58 *8* b

Populating Reactions and D…

- A ^{60}Fe β⁻ decay (57Ro54, 60M…
- B ^{60}Co IT decay (62Ha46, 63Sc14, … 71Pl02, 73Ha69)
- C ^{48}Ca(^{15}N,3nγ) (75Ki19, 77Wa10)
- D ^{57}Fe(α,p) (73Ma38)
- E ^{57}Fe(α,pγ) (75Ki19, 78Ta03)
- F ^{58}Fe(^{3}He,p) (72Se05, 73Ca07, 78Ta02)
- G ^{59}Co(n,γ), (pol n,γ) E=Thermal (66Sh15, 68Wa20, 69Ei01, 69Ko05, 69Me05, 69Sa10, 69Sm05, 72St05, 73Ho24, 73Re06, 78Bo08, 84Ko29)
- H ^{59}Co(n,γ) E=24 keV (84Ko29)
- I ^{59}Co(n,γ) E=132 keV (68Wa20, 69Sa10, 75Pr02)
- J ^{59}Co(d,p) (60En05, 64Bj01, 75Jo08, 75Ue01, 78Ro18, 78Ta02)
- K ^{61}Ni(d,^{3}He) (78Ta02)
- L ^{62}Ni(d,α), (pol d,α) (72Se05, 83Na12)

Levels and γ-ray branchings:

0, 5⁺, 5.2714 *5* y, *[ABCDEGHJKL]*,
μ=+3.799 *8*, Q=+0.44 *5*, %β⁻=100

58.59 *1*, 2⁺, 10.47 *4* m, *[ABCEFGHKL]*,
μ=+4.40 *9*, Q=+0.3 *5*, %IT=99.76 *3*,
%β⁻=0.24 *3*
γ_0 ***58.603*** *7* (I_γ 100) M3(+E4): δ<0.02

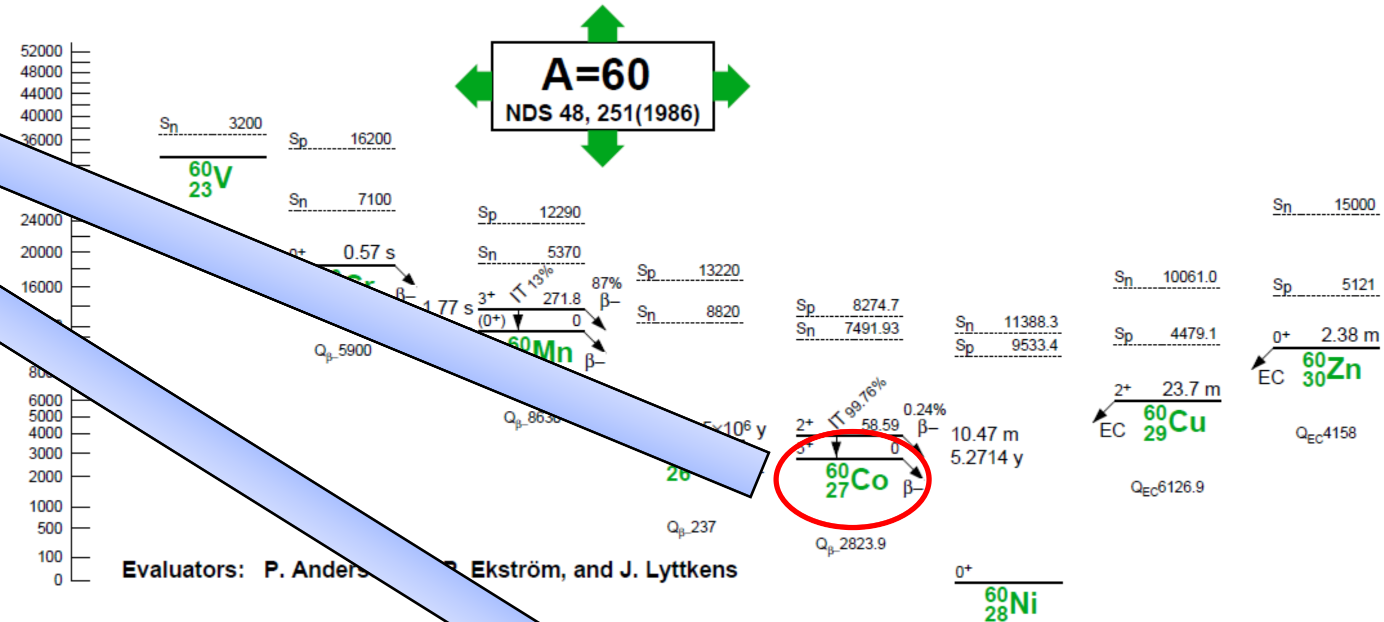
277.20 *2*, 4⁺, *[CEGHJL]*
γ_0 ***277.08*** *3* (I_γ 100) M1+E2

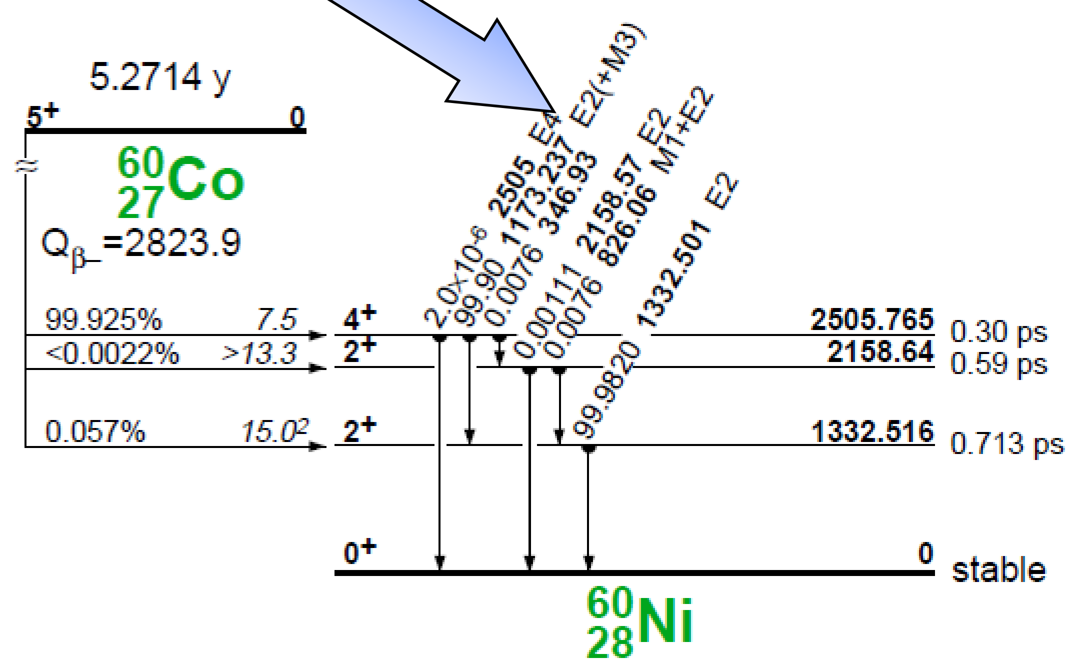
288.40 *2*, 3⁺, *[CEGHJKL]*
γ_{59} ***229.72*** *4* (I_γ 100) M1+E2

435.71 *4*, 5⁺, *[CEGHJKL]*
γ_{277} ***158.46*** *5* (I_γ 100.0 *7*) M1+E2
γ_0 ***435.71*** *5* (I_γ 64.0 *13*) M1+E2

γ(^{60}Ni) from ^{60}Co (5.2714 y) β⁻ decay *< for Iγ% multiply by 1.0>*

346.93 *7* (I_γ 0.0076 *5*)
826.28 *9* (I_γ 0.0076 *8*) M1+E2: δ=+0.81 *17*
1173.237 *4* (I_γ 99.90 *2*)
E2(+M3): δ=−0.0025 *22*
1332.501 *5* (I_γ 99.9820 *10*) E2
2158.77 *9* (I_γ 0.00111 *18*)
2505 (I_γ 2.0×10⁻⁶ *4*) E4





Half Lives

$N/N_o = e^{-\lambda t}$

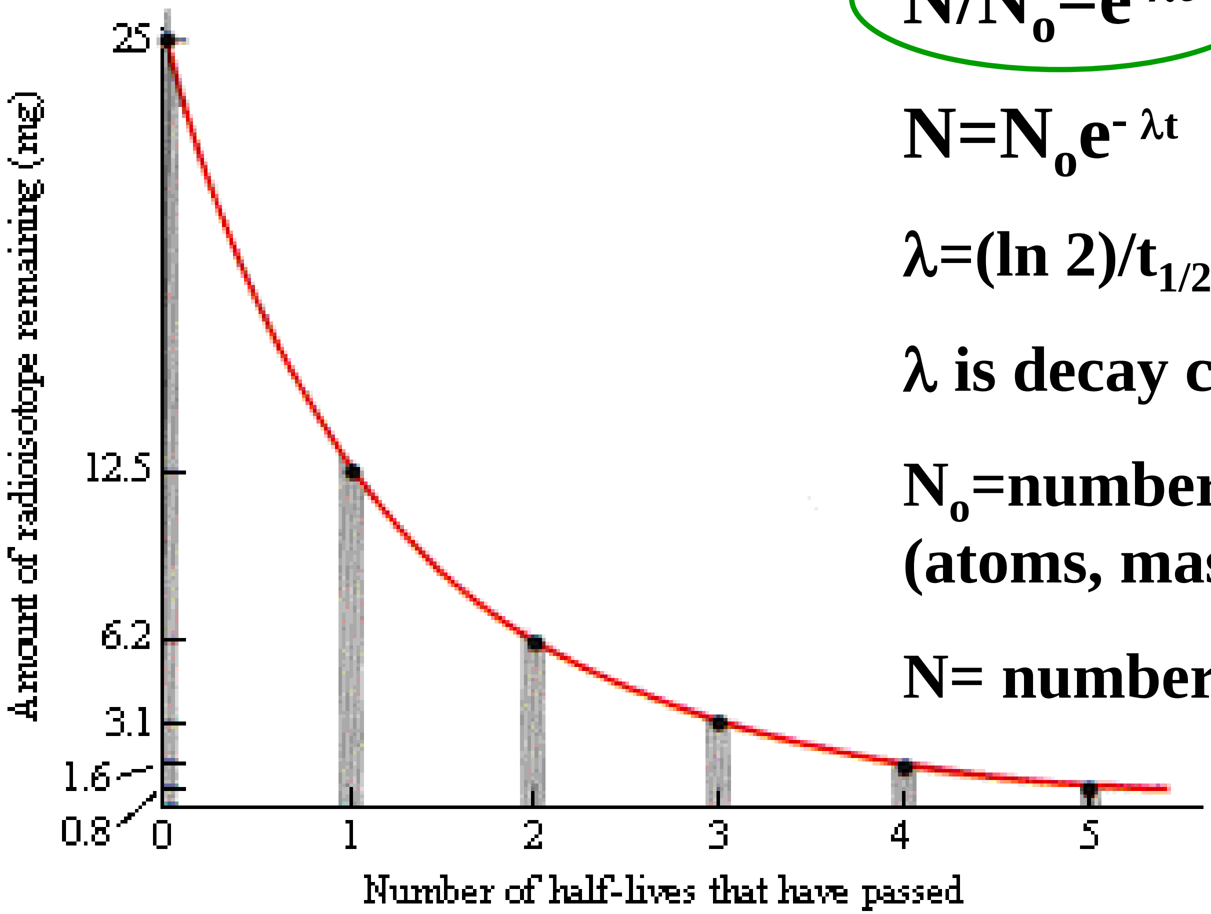
$N = N_o e^{-\lambda t}$

$\lambda = (\ln 2)/t_{1/2}$

λ is decay constant

N_o=number at time zero (atoms, mass, moles)

N= number at time t



Rate of decay of ^{131}I as a function of time.

Equation questions

- **Calculate decay constant for the following**

Isotope	$t_{1/2}$	λ	λ (s^{-1})
^{75}Se	119.78 days	5.79E-3 d^{-1}	6.78E-8
^{74m}Ga	10 seconds	6.93E-2 s^{-1}	6.93E-2
^{81}Zn	0.32 seconds	2.17 s^{-1}	2.17
^{137}Cs	30.07 years	2.31E-2 a^{-1}	7.30E-10
^{239}Pu	2.41E4 years	2.88E-5 a^{-1}	9.11E-13

- **^{75}Se example**
  - → λ= ln(2)/119.78 day = 0.00579 d^{-1}
  - → λ= 0.00579 d^{-1} *1d/24 hr * 1 hr/3600 s =6.7E-8 s^{-1}

Equation Questions

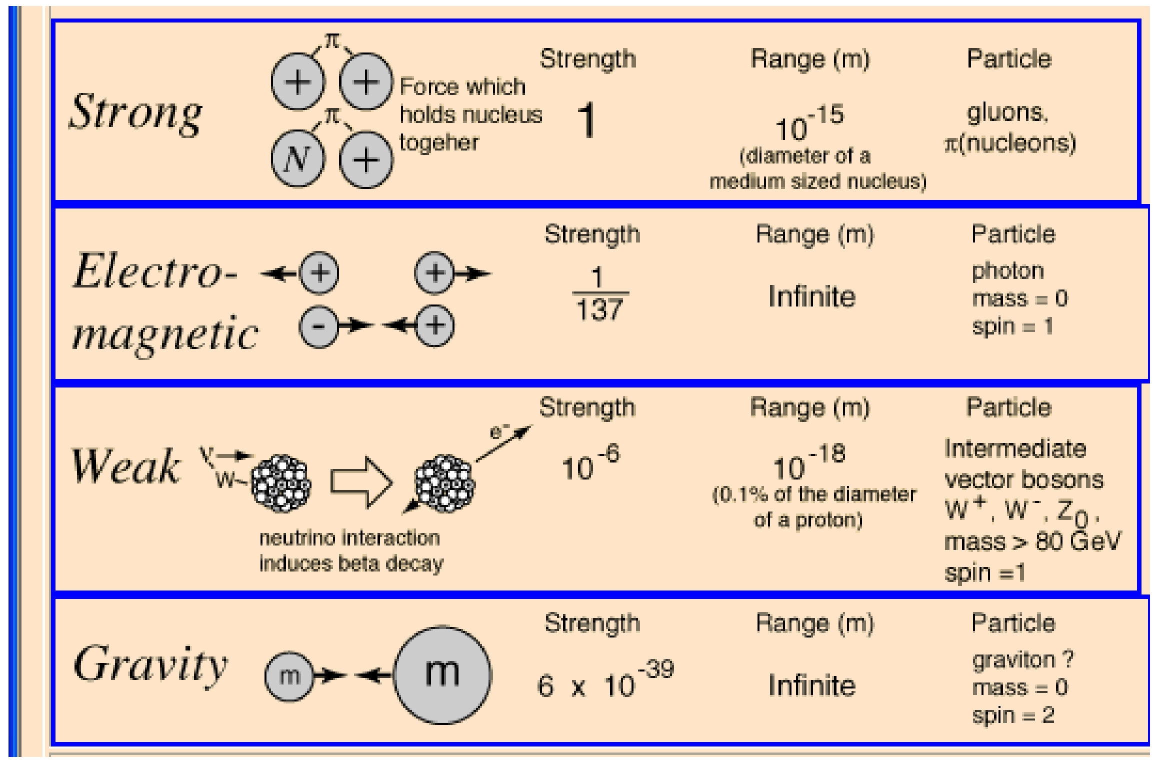
- What percentage of ^{66}As remains from a given amount after 0.5 seconds
  - Use $N/N_o=e^{-\lambda t}$
    - → $t_{1/2}$ = 95.6 ms; λ=7.25 s^{-1}
    - → $N/N_o=e^{-\lambda t}$ = $N=/N_o=e^{-7.25(.5)}$ = 0.0266 =2.66 %
      - * After 5.23 half lives
- How long would it take to decay 90 % of ^{65}Zn?
  - Use $N/N_o=e^{-\lambda t}$
  - 90 % decay means 10 % remains
    - → Set N/N_o=0.1, $t_{1/2}$ = 244 d, λ= 2.84E-3 d^{-1}
    - → $0.1=e^{-2.84E-3t}$
    - → ln(0.1)= -2.84E-3 d^{-1} t
    - → =-2.30/-2.84E-3 d-1 = t =810 days

Equation Questions

- **If you have 1 g of ^{72}Se initially, how much remains in 12 days?**
  - **$t_{1/2}$ = 8.5 d, λ=8.15E-2 d^{-1}**
  - **$N=N_o e^{-\lambda t}$**
  - **$N=(1\ g)\ e^{-8.15E-2(12)}$**
  - **N=0.376 g**
- **What if you started with 10000 atoms of ^{72}Se, how many atoms after 12 days?**
  - **0.376 (37.6 %) remains**
  - **10000(0.376) = 3760 atoms**

What holds the nucleus together: Forces in nature

- **Four fundamental forces in nature**
- **Gravity**
  - **Weakest force**
  - **interacting massive objects**
- **Weak interaction**
  - **Beta decay**
- **Electromagnetic force**
  - **Most observable interactions**
- **Strong interaction**
  - **Nuclear properties**



Particle Physics: Boundary of Course

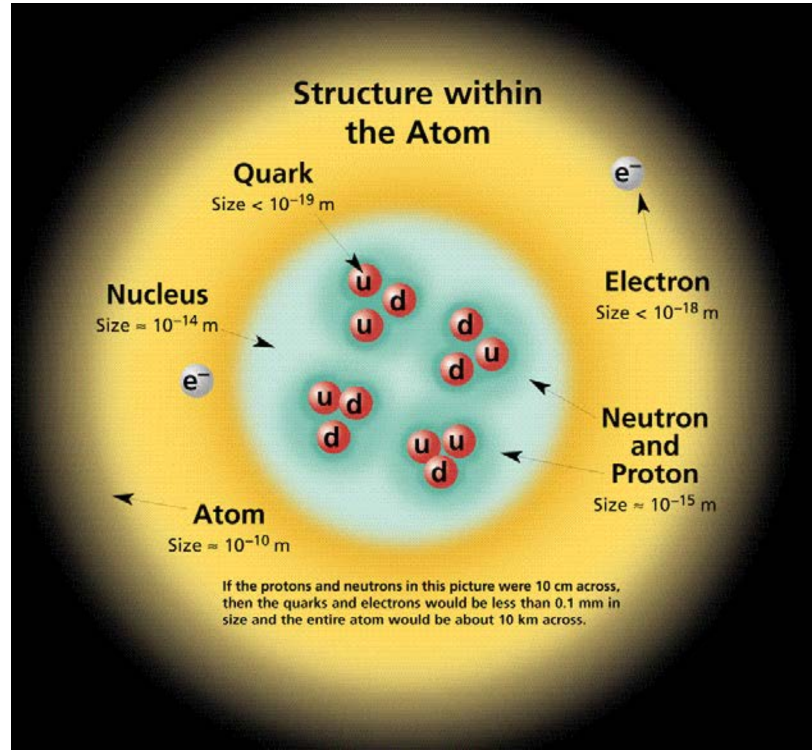
- **fundamental particles of nature and interaction symmetries**
- **Particles classified as fermions or bosons**
  - **Fermions obey the Pauli principle**
    - **→ antisymmetric wave functions**
    - **→ half-integer spins**
      - *** Neutrons, protons and electrons**
    - **→ Bosons do not obey Pauli principle**
      - *** symmetric wave functions and integer spins**
        - **➢ Photons**

Standard Model

FERMIONS matter constituents
spin = 1/2, 3/2, 5/2, ...

Leptons spin = 1/2			
Flavor		Mass GeV/c^2	Electric charge
ν_e	electron neutrino	$<1\times10^{-8}$	0
e	electron	0.000511	−1
ν_μ	muon neutrino	<0.0002	0
μ	muon	0.106	−1
ν_τ	tau neutrino	<0.02	0
τ	tau	1.7771	−1

Quarks spin = 1/2			
Flavor		Approx. Mass GeV/c^2	Electric charge
u	up	0.003	2/3
d	down	0.006	−1/3
c	charm	1.3	2/3
s	strange	0.1	−1/3
t	top	175	2/3
b	bottom	4.3	−1/3



- **Boson are force carriers**
  - **Photon, W and Z bosons, gluon**
  - **Integer spin**
- **What are the quarks in a proton and a neutron?**

Topic review

- **Definition of radiochemistry**
- **Types of radioactive decay**
- **Understand and utilize the data presented in the chart of the nuclides and table of the isotopes**
  - **Units for data**
  - **Relationships between isotopes**
  - **Fission yields**
- **Identify common fission products**
- **Define X-rays**

- **Read introduction to chart of the nuclides and table of the isotopes**

Study Questions

- **What are the course outcomes?**
- **What are 3 isotones of ^{137}Cs**
- **What are the different types of radioactive decay?**
- **Provide 5 radioelements**
- **Why is Tc naturally radioactive**
- **What are the stable isotopes of Sn?**
- **What is the beta decay energy of ^{90}Sr?**
- **Which has more stable isotopes, Cr or Fe?**

Questions

- **Comment on blog**
- **Respond to PDF quiz**