RFSS Lecture 1: Introduction Part 1

- **Readings:**
  - Chart of the nuclides
    → Class handout
  - Table of the isotopes
  - Modern Nuclear Chemistry: Chapter 1
    → [http://radchem.nevada.edu/docs/course%20reading/Nuc%20&%20Radchem%203rd%20Ed%20Friedlander.pdf](http://radchem.nevada.edu/docs/course%20reading/Nuc%20&%20Radchem%203rd%20Ed%20Friedlander.pdf)

- Class organization
- Outcomes
- Grading
- Resources
  - Chart of the nuclides book (bring to class everyday!)
  - Electronic resources
    → Web pages, pdfs, apps, programs, blog

- History of radiation research
- Chart of the nuclides and Table of the isotopes
  - Description and use
  - Data

- Radiochemistry introduction
  - Atomic properties
  - Nuclear nomenclature
  - X-rays
  - Types of decays
  - Forces (limit of course instruction)
Introduction

• Course designed to increase potential pool of researchers for the nuclear fuel cycle
  ▪ Nuclear fuel
  ▪ Separations
  ▪ Waste forms
  ▪ Nuclear forensics and the fuel cycle
  ▪ Safeguards
  ▪ Nuclear reactors
• Course will emphasize the role of radiochemistry in the nuclear fuel cycle
• Interest students in radiochemistry
  ▪ Provide route to radiochemistry research
    → Graduate research in radiochemistry
Course overview

• Radiochemistry includes physics of radioactive decay and chemistry of radioisotopes
  ▪ Intellectual intersection of the periodic table and chart of the nuclides
    → Emphasis on elements with only radioactive isotopes
      * Tc, actinides

• Course topics
  ▪ Chart of the nuclides
  ▪ Details on alpha decay, beta decay, gamma decay, and fission
  ▪ Methods and data from the investigation of nuclear properties
  ▪ Fundamental chemical properties in radiation and radiochemistry
  ▪ Radioisotope production and
  ▪ Radiochemistry in research and technology

• Textbooks and published literature are used a reading material
  ▪ Available as PDFs
    → Linked to web page

• Input from students valued
  ▪ Expect participation and assistance with course development
  ▪ Output should enhance on-line course
Outcomes

1. Understand, utilize, and apply the chart of the nuclides and table of the isotopes to radiochemistry and nuclear technology
   - Bring chart of nuclide to class
   - Understand chart of the nuclide structure
   - Access and utilize presented data
   - Use Table of the Isotopes

2. Understand the fundamentals of nuclear structure
   - Why do nuclei have shapes other than spherical
   - Relationship between shape and behavior

3. Understand chemical properties of radioelements
   - Focus on actinides
     - Filling of 5f electron orbitals
   - Technetium, promethium
     - Radioelements Z<83
Outcomes

4. Comprehend and evaluate nuclear reactions and the production of isotopes
   - Use chart of the nuclides
     → Cross section data
   - Reaction particles
     → Neutrons, alpha, ions, photons
   - Reaction energies
     → Mass differences

5. Comprehend types and descriptions of radioactive decay
   - Expected decay based on location of isotope in chart of the nuclides
   - Decay modes relationship with half-life
Outcomes

6. Utilization of radiochemistry in research
   - Evaluation of concentration
   - Behavior of radioelements
   - Exploitation of isotopes

7. Investigate modern topics relating radiochemistry to the nuclear fuel cycle
   - Research basis in laboratory
   - Literature review
   - Presentation of results
Grading: Lecture course

• Pop-quizzes at end of lecture (20 %)
  ▪ Based upon presented information
  ▪ PDF form submission

• Five comprehensive quizzes (15 % each)
  ▪ Based on topic covered in lecture and pop quizzes
  ▪ Take home and submitted on PDF
    → Work material submitted separately in electronic format
  ▪ Goal of quizzes is demonstrating material comprehension
  ▪ Quizzes will be iterated after submission
    → Students will have opportunity to correct answers
    → 1st due date for all quizzes
    → answers posted after 1st due date
    → Opportunity to resubmit changes after posting of answers

• Participation (5 %)
Grading: Fuel Cycle Laboratory

- 3 groups for initial laboratories
- Write up for 3 laboratories (10% each)
  - Radiation Safety
  - Alpha and Gamma spectroscopy
  - Oxide pellet synthesis
  - U solvent extraction
    → One report from each group
- Report on research (35%)
  - Publication manuscript form
- Presentation of research (35%)
  - 15 minute presentation at end of course
- Research requires plan of the week
  - Radchem.nevada.edu
Laboratory Modules

• Radiation safety, laboratory walkthrough
  ▪ 1st module taken by all students
    ➔ Orientation of laboratory

• Alpha and gamma spectroscopy
  ▪ Inverse square law
  ▪ Isotopes
  ▪ Decay energy branching
  ▪ Calibration
  ▪ Measuring samples
Laboratory Modules

- Radiochemical separations
  - Solvent extraction with tributylphosphate
  - UV-Visible spectroscopy of U
  - Determination of distribution coefficient
- Formation of oxide ceramics
  - Precipitation from salts
  - ZrO$_2$
  - Basis for formation of nuclear fuel
- Focus on concepts useful for the nuclear fuel cycle
Grading: Laboratory

- Reports format from manuscript preparation
  - Abstract
  - Introduction
    -> Background
    -> Why is the research performed
  - Experimental
    -> Methods
    -> Equipment
  - Results and discussion
    -> What was observed, what does it mean
  - Conclusion
    -> Restatement of main discussion points
    -> Answers question posed in introduction
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<td>1300-1700: Unsealed Sources Training (1st floor HRC)</td>
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<td>Tuesday 16 June</td>
<td>Online Lectures: Nuclear Properties, Decay Kinetics</td>
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<td>1030: Group Photo (Baepler Xeriscape Garden)</td>
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<td>Meeting: Chart of Nuclides, Nuclear properties, decay kinetics, alpha decay</td>
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<td>Online lecture: Beta decay</td>
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<td>Online lecture: Nuclear Models</td>
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<td>Lecture Dr. Michael Simpson, University of Utah: Pyroprocessing in the NFC</td>
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<td>Tour University of California Irvine: Nuclear Reactor</td>
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<td>Tour General Atomic, Lecture: Nuclear Forensics</td>
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<td>Online lecture: Nuclear Reactions</td>
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<td>Online lecture: <strong>Americium and Curium chemistry</strong></td>
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<td>Skype Presentation Dr. James Laidler, ANL: Fast Reactors and Gas-cooled Reactors</td>
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<td>Skype Presentation Dr. James Laidler, ANL: Fuel Design, and History of Reprocessing</td>
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<td>Online lecture: <strong>Chemistry of reactor fuels</strong> Quiz 4</td>
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<td>Tour to the Nevada Nuclear Security Site NNSS</td>
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<td>Lecture Dr. Ralf Sudowe, UNLV: Radiation interaction Meeting: Reactors, Fuel, Forensic</td>
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<td>Monday 20 July</td>
<td>Lecture Dr. Jenifer Braley, Co School of Mines: Advanced Recycling &amp; Nuclear Fuel Separation</td>
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<td>Lecture Dr. Ralf Sudowe, UNLV: Detectors</td>
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<td>Lecture Dr. Gary Cerefice, UNLV: Waste forms &amp; repositories, UNLV, geological repositories</td>
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<td>Lecture Dr. Thomas Hartmann, UNLV: Fuels, Vitrification &amp; waste forms Quiz 5</td>
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<td>Friday</td>
<td>26 Jun Research, reporting, and presentation development</td>
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<td>29 Jun Report and presentation development, presentation practice</td>
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Course Resources

• Chart of the nuclides book
  ▪ Bring everyday

• Reading material and resources
  ▪ Modern Nuclear Chemistry
  ▪ Nuclear and Radiochemistry
  ▪ Table of the Isotopes
  ▪ Radiochemistry of Nuclear Power Plants with Light Water Reactors
  ▪ Technetium
  ▪ Uranium to Curium Chemistry
    → [http://radchem.nevada.edu/classes/rfss/readings.html](http://radchem.nevada.edu/classes/rfss/readings.html)

• Course blog
  ▪ Completion of online course, homework, labs, quizzes
  ▪ [http://rfssunlv.blogspot.com/](http://rfssunlv.blogspot.com/)
Course Resources

• National Nuclear Data Center
  ▪  Q-value calculator
  ▪  Chart of the nuclides
  ▪  Nuclear Wallet Cards

• Table of the Isotopes
  ▪  http://ie.lbl.gov/toi/

• Nuclide tool (growth and decay)

• JCHESS speciation code
  ▪  http://radchem.nevada.edu/classes/rdch702/lectures%20and%20chapters.html

• Isotope Browser app
  ▪  Host of information available at http://www.iaea.org/

• Nuclear Fuel Cycle information
  ▪  Used for DOE-Nuclear Energy project on fuel cycle options
  ▪  https://connect.sandia.gov/sites/NuclearFuelCycleOptionCatalog/SitePages/a/homepage.aspx
History of Radiation Research

- 1896  Discovery of radioactivity
  - Becquerel used K₂UO₂(SO₄)₂•H₂O exposed to sunlight and placed on photographic plates wrapped in black paper
  - Plates revealed an image of the uranium crystals when developed
- 1898  Isolation of radium and polonium
  - Marie and Pierre Curie isolated from U ore
- 1899  Radiation into alpha, beta, and gamma components, based on penetration of objects and ability to cause ionization
  - Ernest Rutherford identified alpha
- 1909  Alpha particle shown to be He nucleus
  - Charge to mass determined by Rutherford
- 1911  Nuclear atom model
  - Plum pudding by Thomson examined
  - Rutherford developed planetary model
- 1912  Development of cloud chamber by Wilson
- 1913  Planetary atomic model expanded (Bohr Model)
  - Application of quantum mechanics
- 1914  Nuclear charge determined from X rays
  - Determined by Moseley in Rutherford’s laboratory
History

• 1919  Artificial transmutation by nuclear reactions
  ▪ Rutherford bombarded $^{14}\text{N}$ with alpha particle to make $^{17}\text{O}$
• 1919  Development of mass spectrometer
• 1928  Theory of alpha radioactivity
  ▪ Tunneling description by Gamow
• 1930  Neutrino hypothesis
  ▪ Fermi, mass less particle with $\frac{1}{2}$ spin, explains beta decay
• 1932  First cyclotron
  ▪ Lawrence at UC Berkeley
• 1932    Discovery of neutron
  ▪ Chadwick used scattering data to calculate mass, Rutherford knew A was about twice Z. Lead to proton-neutron nuclear model
• 1934    Discovery of artificial radioactivity
  ▪ Jean Frédéric Joliot & Irène Curie showed alphas on Al formed P
• 1938    Discovery of nuclear fission
  ▪ From reaction of U with neutrons, Hahn and Meitner
• 1942    First controlled fission reactor
  ▪ Chicago Pile
• 1945    First fission bomb tested
  ▪ Trinity Test
• 1947    Development of radiocarbon dating
## Radioelements

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### *Lanthanides*

| 58 Ce | 59 Pr | 60 Nd | 61 Pm | 62 Sm | 63 Eu | 64 Gd | 65 Tb | 66 Dy | 67 Ho | 68 Er | 69 Tm | 70 Yb | 71 Lu |

### **Actinides**

| 90 Th | 91 Pa | 92 U | 93 Np | 94 Pu | 95 Am | 96 Cm | 97 Bk | 98 Cf | 99 Es | 100 Fm | 101 Md | 102 No | 103 Lr |
Technetium

- Confirmed in a December 1936 experiment at the University of Palermo
  - Carlo Perrier and Emilio Segrè.
  - Ernest Lawrence (UC Berkeley) mailed molybdenum foil from cyclotron deflector
  - Succeeded in isolating the isotopes $^{95,97}\text{Tc}$
  - Named after Greek word τεχνητός, meaning artificial
  - University of Palermo officials wanted them to name their discovery "panormium", after the Latin name for Palermo, Panormus
  - Segre and Seaborg isolate $^{99m}\text{Tc}$
Promethium was first produced and characterized at ORNL in 1945 by Jacob A. Marinsky, Lawrence E. Glendenin and Charles D. Coryell.

Separation and analysis of the fission products of uranium fuel irradiated in the Graphite Reactor.

Announced discovery in 1947.

In 1963, ion-exchange methods were used at ORNL to prepare about 10 grams of Pm from used nuclear fuel.
Np synthesis

- Neptunium was the first synthetic transuranium element of the actinide series discovered
  - isotope $^{239}\text{Np}$ was produced by McMillan and Abelson in 1940 at Berkeley, California
  - bombarding uranium with cyclotron-produced neutrons
    $\rightarrow 238U(n,\gamma)239U$, beta decay of $239U$ to $^{239}\text{Np}$ ($t_{1/2}=2.36$ days)
  - Chemical properties unclear at time of discovery
    $\rightarrow$ Actinide elements not in current location
    $\rightarrow$ In group with W
- Chemical studies showed similar properties to U
- First evidence of 5f shell
- Macroscopic amounts
  - $^{237}\text{Np}$
    $\rightarrow 238U(n,2n)237U$
    * Beta decay of $^{237}U$
    $\rightarrow$ 10 microgram
Pu synthesis

• Plutonium was the second transuranium element of the actinide series to be discovered
  ▪ The isotope $^{238}\text{Pu}$ was produced in 1940 by Seaborg, McMillan, Kennedy, and Wahl
  ▪ Deuteron bombardment of $^{238}\text{U}$ in the 60-inch cyclotron at Berkeley, California
    → $^{238}\text{U}(^{2}\text{H}, 2n)^{238}\text{Np}$
  * Beta decay of $^{238}\text{Np}$ to $^{238}\text{Pu}$
  ▪ Oxidation of produced Pu showed chemically different
• $^{239}\text{Pu}$ produced in 1941
  ▪ Uranil nitrate in paraffin block behind Be target bombarded with deuterium
  ▪ Separation with fluorides and extraction with diethylether
  ▪ Eventually showed isotope undergoes slow neutron fission
Am and Cm discovery

• First produce in reactor via neutron capture
  ▪ neutron capture on $^{239}\text{Pu}$
  ▪ $^{239}\text{Pu} + n \rightarrow ^{240}\text{Pu} + n \rightarrow ^{241}\text{Pu} \rightarrow ^{241}\text{Am} + \beta^-$
  ▪ Also formed $^{242}\text{Cm}$

• Direct production
  ▪ $^{241}\text{Am}$ from $^{241}\text{Pu}$ produced by $^{238}\text{U} + ^4\text{He}$
    → Also directly produced from He on $^{237}\text{Np}$ and $^2\text{H}$ on $^{239}\text{Pu}$
  ▪ $^{239}\text{Pu}(^4\text{He},n)^{242}\text{Cm}$
    → Chemical separation from Pu
    → Identification of $^{238}\text{Pu}$ daughter from alpha decay

• Difficulties in separating Am from Cm and from lanthanide fission products
  ▪ Trivalent oxidation states

• See publications announcing discovery on web page
Bk and Cf discovery

- **Required Am and Cm as targets**
  - Needed to produce these isotopes in sufficient quantities → **Milligrams**
  - Am from neutron reaction with Pu
  - Cm from neutron reaction with Am
- **Production of new elements followed by separation**
  - $^{241}\text{Am}(^{4}\text{He},2n)^{243}\text{Bk}$ → Cation exchange separation
  - $^{242}\text{Cm}(^{4}\text{He},n)^{245}\text{Cf}$ → Anion exchange
- **Where would the heavier actinides elute?**

Dowex 50 resin at 87 °C, elute with ammonium citrate
Einsteinium and Fermium

- Debris from Mike test
  - 1st thermonuclear test
    - [Video](http://www.youtube.com/watch?v=h7vyKDeS)
  - New isotopes of Pu
    - 244 and 246
    - Successive neutron capture of $^{238}\text{U}$
    - Correlation of log yield versus atomic mass
  - Evidence for production of transcalifornium isotopes
    - Heavy U isotopes followed by beta decay
    - Successive neutron capture to form Es and Fm
      - Similar to r-process in nucleosynthesis
- Ion exchange used to separate new elements
Md, No, and Lr discovery

- 1st atom-at-a-time chemistry
  - $^{253}\text{Es}(^{4}\text{He},\text{n})^{256}\text{Md}$
- Required high degree of chemical separation
- Use catcher foil
  - Recoil of product onto foil
  - Dissolved Au foil, then ion exchange
- Nobelium controversy
  - Expected to have trivalent chemistry
    - Actually divalent, filled 5f orbital
    * Divalent from removing 7s electrons
  - 1st attempt could not be reproduced
    - Showed divalent oxidation state
  - $^{246}\text{Cm}(^{12}\text{C},4\text{n})^{254}\text{No}$
    - Alpha decay from $^{254}\text{No}$
    - Identification of $^{250}\text{Fm}$ daughter using ion exchange
- For Lr $^{249, 250, 251}\text{Cf}$ bombarded with $^{10, 11}\text{B}$
- New isotope with 8.6 MeV, 6 second half life
  - Identified at $^{258}\text{Lr}$
End of Lecture 1, Part 1

• Readings:
  ▪ Chart of the nuclides
    ➔ Class handout
  ▪ Table of the isotopes
  ▪ Modern Nuclear Chemistry: Chapter 1
    ➔ http://radchem.nevada.edu/docs/course%20reading/Nuc%20&%20Radchem%203rd%20Ed%20Friedlander.pdf

• Class organization
• Outcomes
• Grading
• Resources
  ▪ Chart of the nuclides book (bring to class everyday!)
  ▪ Electronic resources
    ➔ Web pages, pdfs, apps, programs, blog
• History of radiation research
RFSS Lecture 1: Introduction Part 2

- Readings:
  - Chart of the nuclides
    → Class handout
  - Table of the isotopes
  - Modern Nuclear Chemistry: Chapter 1
    → http://radchem.nevada.edu/docs/course%20reading/Nuc%20&%20Radchem%203rd%20Ed%20Friedlander.pdf
- Class organization
- Outcomes
- Grading
- Resources
  - Chart of the nuclides book (bring to class everyday!)
  - Electronic resources
    → Web pages, pdfs, apps, programs, blog
- History of radiation research
- Chart of the nuclides and Table of the isotopes
  - Description and use
  - Data
- Radiochemistry introduction
  - Atomic properties
  - Nuclear nomenclature
  - X-rays
  - Types of decays
  - Forces (limit of course instruction)
Radiochemistry terms and concepts

• 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} \text{ m})
  ▪ Electron interaction with nucleus basis of chemical properties (10^{-10} \text{ 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
    → ^{99}\text{m} \text{Tc}
Types of Decay

1. α decay (occurs among the heavier elements)

\[ ^{226}_{88}Ra \rightarrow ^{222}_{86}Rn + ^4_2 \alpha + \text{Energy} \]

2. β⁻ decay

\[ ^{131}_{53}I \rightarrow ^{131}_{54}Xe + \beta^- + \bar{\nu} + \text{Energy} \]

3. Positron emission

\[ ^{22}_{11}Na \rightarrow ^{22}_{10}Ne + \beta^+ + \nu + \text{Energy} \]

4. Electron capture

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

5. Spontaneous fission

\[ ^{252}_{98}Cf \rightarrow ^{140}_{54}Xe + ^{108}_{44}Ru + 4^1_0 n + \text{Energy} \]
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

\[ ^{235}\text{U fission yield} \]
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 $\nu$ or wavelength $\lambda$) are noted as $K_\alpha$, $K_\beta$, $K_\gamma$
    → If the removed electrons are from the L shell, noted as $L_\alpha$, $L_\beta$, $L_\gamma$

- In 1913 Moseley studied these frequencies $\nu$, 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, $Z_0 = 7.4$. 

![Diagram of X-ray emissions from electron transitions]

**Figure 4** Moseley relationship for $K_\alpha$ and $L_\alpha$ 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 the nuclides

**Chemical Element**

- **Li** (Symbol)
- **6.941** (Atomic mass (carbon-12 scale))
- **lithium** (Element name)
- **$\sigma_a 71, 32$** (Thermal neutron absorption cross section in barns followed by resonance integral, in barns)

**Stable**

- **Pd108** (Symbol, mass number)
- **26.46** (Atom percent abundance)
- **$\sigma_\gamma (0.19 + 8), (2 + 24E1)$** (Isotopic mass (carbon-12 scale))
- **107.903892** (Fission product from the slow neutron fission of U235)
- **Ground states of even Z, even N nuclides have spin and parity 0+**
- **Thermal neutron capture cross sections in barns leading to (isomeric + ground state), followed by resonance integrals leading to (isomeric + ground state)**
Chart of the nuclides

Artificially Radioactive

Symbol, mass number

$\text{Nd}^{147}$

Spin and parity, $5/2^-$

Half-life

$10.98 \text{ d}$

Modes of decay in order of prominence with energy of radiation in MeV for alpha and beta, keV for gammas

$\beta$: 0.805 ...

$\gamma$: 91.1, 531.0, ...

$\sigma_\gamma$: $4E2$, $2E2$

Fission product from the slow neutron fission of U235

Beta disintegration energy in MeV

$E$: 0.896

Naturally Occurring or Otherwise Available but Radioactive

Symbol, mass number

$\text{La}^{138}$

Spin and parity $5^+$

Atom percent abundance

$0.090$

Half-life

$1.05E11 \text{ a}$

$\sigma$: $57$, $4E2$

Beta disintegration energy

$E$: $1.04 \times 10^1 + 1.737$

Isotopic mass

$137.907112$

Thermal neutron capture cross section, followed by resonance integral

$1435.8$, $788.7$
### Member of Naturally Radioactive Decay Chain

<table>
<thead>
<tr>
<th>Element</th>
<th>Symbol, mass number</th>
<th>Half-life</th>
<th>Modes of decay</th>
<th>Energy of radiation</th>
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<td>Pb210</td>
<td>§</td>
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<td>β+ 0.017, 0.061</td>
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<td></td>
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<td>γ 46.5 e−</td>
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<td>E 0.0635</td>
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**Historical symbol:**
- Indicates the radioactive decay mode and intensity.
- Beta disintegration energy in MeV.

### Two Isomeric States One Stable

<table>
<thead>
<tr>
<th>Element</th>
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<th>Atom percent abundance</th>
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**Spin and parity of metastable state, 5/2−**
- Stable ground state.
- Fission product from the slow neutron fission of U235.

### Two Isomeric States Both Radioactive

<table>
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<th>Symbol, mass number</th>
<th>Half-life</th>
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<td>γ 149.7, 452.3, ...</td>
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<td>E 2.3285</td>
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**Spin and parity of metastable state, 3/2−**
- Stable ground state.
- Fission product from the slow neutron fission of U235.
Chart of the Nuclide: Fission yields

FISSION YIELDS FROM URANIUM 233 AND PLUTONIUM (239)

<p>| | | | | | | |</p>
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Fission yields

FISSION YIELDS FROM URANIUM 235
Terms and decay modes: Utilization of chart of the nuclides

- Identify the isomer, isobars, isotones, and isotopes
  - $^{60m}\text{Co}$, $^{57}\text{Co}$, $^{97}\text{Nb}$, $^{58}\text{Co}$, $^{57}\text{Ni}$, $^{57}\text{Fe}$, $^{59}\text{Ni}$, $^{99m}\text{Tc}$
- Identify the daughter from the decay of the following isotopes
  - $^{210}\text{Po}$ (alpha decay, $^{206}\text{Pb}$)
  - $^{196}\text{Pb}$
  - $^{204}\text{Bi}$ (EC decay, $^{204}\text{Pb}$)
  - $^{209}\text{Pb}$
  - $^{222}\text{At}$
  - $^{212}\text{Bi}$ (both alpha and beta decay)
  - $^{208}\text{Pb}$ (stable)
- How is $^{14}\text{C}$ naturally produced
  - Reactions with atmosphere ($^{14}\text{N}$ 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 $^{84}\text{Sr}$?
• Spin and parity of $^{201}\text{Hg}$?
• Decay modes and decay energies of $^{212}\text{Bi}$
• What are the isotopes in the $^{235}\text{U}$ decay series?
• What is the half-life of $^{176}\text{Lu}$?
• What is the half-life of $^{176}\text{Yb}$
• How is $^{238}\text{Pu}$ produced?
• How is $^{239}\text{Pu}$ made from $^{238}\text{U}$
• Which actinide isotopes are likely to undergo neutron induced fission?
• Which isotopes are likely to undergo alpha decay?

• What is the half life of $^{130}\text{Te}$
  ▪ What is its decay mode?
• What cross section data is provided for $^{130}\text{Te}$?
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 Isotopes

CD ROM Edition

Version 1.0
March, 1996

by Richard B. Firestone
Virginia S. Shirley Editor
S.Y. Frank Chu CD-ROM Editor
Coral M. Baglin and Jean Zipkin Assistant Editors

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Table of the isotopes

<table>
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<th>Chart of Nuclides</th>
<th>Summary Scheme Index</th>
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<td>Z=0-28</td>
<td>A=1 A=38 A=75 A=112 A=149 A=186 A=223 A=260</td>
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<td>Z=28-45</td>
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<td>A=37 A=74 A=111 A=148 A=185 A=222 A=259</td>
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</table>
Half Lives

\[ \frac{N}{N_0} = e^{-\lambda t} \]

\[ N = N_0 e^{-\lambda t} \]

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

\( \lambda \) is decay constant

\( N_0 = \) number at time zero (atoms, mass, moles)

\( N = \) number at time \( t \)

Rate of decay of \( ^{131}\text{I} \) as a function of time.
Equation questions

- Calculate decay constant for the following

<table>
<thead>
<tr>
<th>Isotope</th>
<th>$t_{1/2}$</th>
<th>$\lambda$</th>
<th>$\lambda$ (s$^{-1}$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$^{75}\text{Se}$</td>
<td>119.78 days</td>
<td>5.79E-3 d$^{-1}$</td>
<td>6.78E-8</td>
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<tr>
<td>$^{74}\text{mGa}$</td>
<td>10 seconds</td>
<td>6.93E-2 s$^{-1}$</td>
<td>6.93E-2</td>
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<tr>
<td>$^{81}\text{Zn}$</td>
<td>0.32 seconds</td>
<td>2.17 s$^{-1}$</td>
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<tr>
<td>$^{137}\text{Cs}$</td>
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<tr>
<td>$^{239}\text{Pu}$</td>
<td>2.41E4 years</td>
<td>2.88E-5 a$^{-1}$</td>
<td>9.11E-13</td>
</tr>
</tbody>
</table>

- $^{75}\text{Se}$ example
  $\Rightarrow \lambda = \ln(2)/119.78 \text{ day} = 0.00579 \text{ d}^{-1}$
  $\Rightarrow \lambda = 0.00579 \text{ d}^{-1} \times 1 \text{ d}/24 \text{ hr} \times 1 \text{ hr}/3600 \text{ s}$
  $= 6.7E-8 \text{ s}^{-1}$
Equation Questions

• What percentage of $^{66}$As remains from a given amount after 0.5 seconds
  - Use $\frac{N}{N_0} = e^{-\lambda t}$
    \[ t_{1/2} = 95.6 \text{ ms}; \lambda = 7.25 \text{ s}^{-1} \]
    \[ \frac{N}{N_0} = e^{-\lambda t} = N/N_0 = e^{-7.25(0.5)} = 0.0266 = 2.66\% \]
    * After 5.23 half lives
• How long would it take to decay 90 % of $^{65}$Zn?
  - Use $\frac{N}{N_0} = e^{-\lambda t}$
    - 90 % decay means 10 % remains
      \[ \text{Set } \frac{N}{N_0} = 0.1, t_{1/2} = 244 \text{ d}, \lambda = 2.84 \times 10^{-3} \text{ d}^{-1} \]
      \[ 0.1 = e^{-2.84 \times 10^{-3} t} \]
      \[ \ln(0.1) = -2.84 \times 10^{-3} \text{ d}^{-1} t \]
      \[ t = \frac{-2.30}{-2.84 \times 10^{-3} \text{ d}^{-1}} = 810 \text{ days} \]
Equation Questions

• If you have 1 g of $^{72}$Se initially, how much remains in 12 days?
  - $t_{1/2} = 8.5 \text{ d}$, $\lambda = 8.15 \times 10^{-2} \text{ d}^{-1}$
  - $N = N_0 e^{-\lambda t}$
  - $N = (1 \text{ g}) e^{-8.15 \times 10^{-2}(12)}$
  - $N = 0.376 \text{ g}$

• 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

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

- History of nuclear physics research
- Discovery of the radioelements
  - Methods and techniques used
- Types of radioactive decay
  - Define X-rays and gamma decay
- Understand and utilize the data presented in the chart of the nuclides and table of the isotopes
- Utilize the fundamental decay equations
- Identify common fission products
Study Questions

• What are the course outcomes?
• What were important historical moments in radiochemistry?
• Who were the important scientists in the investigation of nuclear properties?
• What are the different types of radioactive decay?
• What are some commonalities in the discovery of the actinides?
• Provide 5 radioelements
Pop Quiz

- Respond to PDF quiz
- Provide comments in blog when complete