NucE 420
Radiological Safety
Dr. Jack Brenizer, Jr.
Class #1
NucE 420 - RADIOLOGICAL SAFETY

• INTRODUCTION

INSTRUCTOR:

JACK BRENIZER, JR.

DEPT. of MECHANICAL AND NUCLEAR ENGINEERING

PROFESSOR OF MECHANICAL AND NUCLEAR ENGINEERING
• BRENIZER’S CONTACT INFORMATION:
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• OFFICE HOURS:
  MONDAYS: 2:00 – 4:00 pm
  WEDNESDAYS: 10:00 am – 12:00 pm
  OTHER HOURS BY APPOINTMENT
• PLEASE TRY TO CALL DURING THESE TIMES ONLY. I WILL BE AT MY DESK WITH ALL THE COURSE MATERIALS AVAILABLE

• TA
  – Mr. Mat Berner
  – TEL: Office Hours: TBD
  – E-mail: mib5292@psu.edu
• SPECIAL NOTE FOR OFF-CAMPUS STUDENTS:

PLEASE SEND AN E-MAIL MESSAGE (BRIEF) to brenizer@engr.psu.edu WITH YOUR

1. NAME
2. E-MAIL ADDRESS
3. OFFICE AND HOME PHONE NUMBERS
4. YOUR BACKGROUND - INCLUDING WHY YOU ARE TAKING THIS COURSE AND WHAT YOU HOPE TO GET OUT OF IT
• REVIEW BEGINNING OF COURSE MEMORANDUM

• TEXT BOOK:
  – CEMBER - INTRODUCTION TO HEALTH PHYSICS
  – 4th edition

• REFERENCE BOOKS
  CRC: HANDBOOK OF CHEMISTRY AND PHYSICS
  KNOLL: RADIATION DETECTION AND MEASUREMENT
• REFERENCE BOOKS

ANOTHER USEFUL BOOK IS SHLEIEN'S

THE HEALTH PHYSICS AND RADIOLOGICAL
HEALTH HANDBOOK

• GOALS

• NUCLEAR ENGINEERING VERSUS MEDICAL
HEALTH PHYSICS

• GRADING
NucE 420 RADIOLOGICAL SAFETY (3)

Ionizing radiation, biological effects, radiation measurement, dose computational techniques, local and federal regulations, exposure control.

Prerequisite: NucE 301 or NucE 405
Topics:

(1) Introduction and Basic Considerations
(2) Radiation Dosimetry
(3) Radiation Biology
(4) Regulatory Guidelines and Requirements
(5) Health Physics Instruments
(6) Internal Radiation Protection
(7) External Radiation Protection
(8) Evaluation of Protection Measures
Grading:

Final course grades will be determined in the following manner:

- Homework Problems 25%
- Mid-semester Exam 25%
- Final exam 30%
- Report 20%
Examinations:

All examinations will be in-class exams.

The mid-term examination will be held in class on Wednesday, March 2, 2011.

The final exam will be held in the assigned time slot during the final examination period.

Report:

The reports will be due at the last class, Friday, April 29, 2011.
HOMEWORK:
• READ: CEMBER CHAPTERS 1, 2, 3, & 4
  – CHAPTERS 1 – 3: SHOULD BE ALMOST ALL REVIEW
  – CHAPTER 4: WILL BE REVIEW FOR MOST BUT NEW MATERIAL FOR A FEW

• PROBLEMS: CHAPTER 4, #'S:
  1, 2 (3rd express second part in mCi), 3, 4, 6, 12, 13, 19, 21, 24, 26, 27, 37 & 38

DUE IN BY: Monday, February 7, 2011
TALK FIRST ABOUT THE CONCEPTS OF HEALTH PHYSICS:

- MEASUREMENT OF TYPES AND QUANTITIES OF RADIOACTIVE MATERIAL

- ESTABLISHMENT OF RELATIONSHIPS BETWEEN RADIATION EXPOSURE AND BIOLOGICAL EFFECTS
• MOVEMENT OF RADIOACTIVE MATERIAL THROUGH THE ENVIRONMENT

• PROTECTION OF INDIVIDUALS FROM POTENTIALLY DAMAGING CONDITIONS
RADIOACTIVITY

SPONTANEOUS NUCLEAR TRANSFORMATION THAT RESULT IN THE FORMATION OF NEW ELEMENTS

- ALPHA DECAY

- BETA DECAY
  - BETA\(^{-}\) EMISSION
  - BETA\(^{+}\) (POSITRON) EMISSION

\[ \alpha \quad ^4\text{He} \quad \text{Dose} = \frac{dE}{dm} \]

\[ \beta^{-} \quad -1 \text{ charge} \]

\[ \beta^{+} \quad +1 \text{ charge} \]
• ORBITAL ELECTRON CAPTURE

• THE PROPERTIES OF RADIOACTIVITY ARE DETERMINED ONLY BY NUCLEAR CONSIDERATIONS

THIS IMPLIES:

– RADIOACTIVE PROPERTIES ARE NOT RELATED TO THE PHYSICAL OR CHEMICAL STATE OF THE ISOTOPE

– RADIOISOTOPE'S PROPERTIES W.R.T. DECAY CANNOT BE CHANGED
• PROPERTIES ARE DETERMINED BY THE

  – TYPE OF NUCLEAR STABILITY - i.e. THE NEUTRON/PROTON RATIO

  – MASS-ENERGY RELATIONSHIP AMONG

• PARENT NUCLEUS

• DAUGHTER NUCLEUS

• EMITTED RADIATION
Figure 3.5. Variation of binding energy per nucleon with atomic mass number.
Figure 3.6 Nuclear stability curve. The line represent the best fit to the neutron-proton coordinates of stable isotopes.
• LOOK AT CONCEPT OF PARENT AND DAUGHTER

• FOR EXAMPLE:

\[ ^{137}_{55}Cs \rightarrow ^{137}_{56}Ba^{*} + \beta^{-} \rightarrow ^{137}_{56}Ba + \gamma \]

• IS \(^{137}Ba^{*}\) RADIOACTIVE?
NUCLEAR POTENTIAL BARRIER

• PROBED THE NUCLEUS WITH PARTICLES TO DETERMINE RELATIONS WHICH EXIST BETWEEN NUCLEONS, NUCLEAR FORCE FIELDS, AND SUBNUCLEAR PARTICLES

• MAINLY CONCERNED WITH PROTONS AND NEUTRONS

• EXISTENCE OF AN ATTRACTIVE NUCLEAR FORCE DOES NOT APPEAR TO ALTER THE COULOMB FIELD RESULTING FROM PROTONS
• THE COMBINED FIELD APPEARS TO BE A COMBINED FORCE FIELD WHICH IS SIMPLY THE SUM OF THE TWO COMPONENTS

– **CLASSICAL**: A POTENTIAL BARRIER
  • CAN'T GET IN UNTIL $E > V_{\text{potential}}$

– **QUANTUM THEORY**: CAN TUNNEL THROUGH BARRIER

• PROBABILITY A FUNCTION OF PARTICLE ENERGY AND BARRIER THICKNESS
ALPHA EMISSION

- USE THE SYMBOL $\alpha$
- 2 PROTONS AND 2 NEUTRONS
- $^{4}_2He^{++}$

- ALPHA EMISSION OCCURS WHEN THE NEUTRON/PROTON RATIO IS TOO LOW
$^\text{210}_{84}\text{Po} \rightarrow ^\text{206}_{82}\text{Pb} + ^4_2\text{He}^{++}$

Or

$^\text{210}_{84}\text{Po} \rightarrow ^\text{206}_{82}\text{Pb} + \alpha$
<table>
<thead>
<tr>
<th></th>
<th>Neutron-to-Proton Ratio</th>
<th># of Neutrons</th>
<th># of Protons</th>
</tr>
</thead>
<tbody>
<tr>
<td>Po-210</td>
<td>126/84 = 1.5</td>
<td>126</td>
<td>84</td>
</tr>
<tr>
<td>Pb-206</td>
<td>124/82 = 1.51</td>
<td>124</td>
<td>82</td>
</tr>
</tbody>
</table>
• ALPHA EMISSION ONLY OCCURS NATURALLY FOR Z > 82
  – ONE EXCEPTION - $^{147}_{62}$Sm

• ELECTROSTATIC REPULSIVE FORCES IN HEAVY NUCLEI INCREASE MORE RAPIDLY THAN THE COHESIVE FORCES
  – MAY EVEN EXCEED THAT OF THE NUCLEAR FORCE
• EMITTED PARTICLE MUST HAVE SUFFICIENT ENERGY TO OVERCOME THE LARGE POTENTIAL BARRIER AT THE SURFACE OF THE NUCLEUS

• AS PREVIOUSLY DISCUSSED - TUNNELING RESULTS IN ALPHA PARTICLE ENERGIES MUCH LOWER THAN THE POTENTIAL BARRIER ENERGY
• FROM QUANTUM MECHANICAL CALCULATIONS

– \( E_\alpha(\text{min}) - 3.8 \text{ MeV} \)

– \( E_\alpha(\text{observed}) \geq 3.93 \text{ MeV} \)

(FOR HIGH ATOMIC NUMBER ELEMENTS)
• FOR THE GENERAL DECAY

PARENT → DAUGHTER + ALPHA +
MASS OF ELECTRONS +
TOTAL ENERGY RELEASE (OVER
AND ABOVE THE MASS-ENERGY OF
THE CONSTITUENT PARTS)

• EXAMPLE OF $^{210}$Po

$^{210}$Po $\rightarrow$ $^{206}$Pb + $^{4}$He$^{++}$ + 2 $m_{e}$ + Q

HERE Q = 0.0058 amu X 931 MeV/amu
WHERE DOES THIS ENERGY GO?

• SINCE BOTH PARTICLES ARE MOVING SLOWLY - NON-RELATIVISTIC

\[ \sqrt{\frac{2E}{m}} \]

\[ \sqrt{\frac{2E}{m}} \]

• CONSERVATION OF ENERGY:

\[ Q = \left( \frac{1}{2} M \times V^2 \right) + \left( \frac{1}{2} m \times v^2 \right) \]

\[ M = \text{mass of daughter; } m = \text{mass of } \alpha \]

• CONSERVATION OF MOMENTUM:

\[ M \times V = m \times v \]
• SOLVING FOR THE KINETIC ENERGY OF THE ALPHA PARTICLE YIELDS

\[
Q \quad KE_{\alpha} = \frac{Q}{1 + \frac{m}{M}}
\]

• NOW WE CAN SOLVE FOR EITHER

– THE KINETIC ENERGY OF THE ALPHA PARTICLE

OR
- THE KINETIC ENERGY OF THE DAUGHTER NUCLEUS

\[ KE_{\text{recoil}} = Q - KE_\alpha \]

• HOW CAN WE DETERMINE IF A REACTION WILL OCCUR?

  - LOOK AT THE N/P RATIO BEFORE AND AFTER THE REACTION, and

  - THE Q VALUE OF THE REACTION IS Q > 3.93 MeV?

  DOES N/P RATIO GO UP?
• ENERGY LEVEL DIAGRAMS

• AN INTERMEDIATE DECAY STEP MAY OCCUR IF THE ALPHA PARTICLE DOES NOT CARRY AWAY ALL OF THE AVAILABLE ENERGY

\[ \text{I.E. } KE_\alpha \text{ IS NOT EQUAL TO } Q \]

• IF THE DAUGHTER NUCLEUS IS LEFT IN AN EXCITED STATE IT MAY DECAY TO GROUND STATE VIA ADDITIONAL EMISSIONS
http://ie.lbl.gov/toi ; http://atom.kaeri.re.kr/

88-RA-226

AWR: 224.058502
Laboratories: INEL
Evaluation Date: JUN88
Evaluators: C.W.REICH
Comments:

226RA A DECAY

translated by Fred Mann (WHC)

Half life: 5.0491E+10 (2.2090E+08) s, or 1.60E+03 a
Ebeta: 3.7100E+03 (6.0000E+01) eV
Egamma: 7.2200E+03 (2.0831E+00) eV
Ealpha: 4.8606E+06 (0.0000E+00) eV
Spin & Parity: 0.0 plus
Isomer number: 0
Level number: 0

This nuclide has 1 decay mode(s):

Mode: alpha
Decay Q: 4.8707E+06 (2.5000E+02) eV

This nuclide has 4 radiation type(s):
Radiation type: gamma
Average decay energy: 6.5300E+03 (9.0000E+01) eV
Discrete spectrum normalization: 1.0000E-02 (0.0000E+00)
5 discrete lines given

<table>
<thead>
<tr>
<th>Energy</th>
<th>Normalization</th>
<th>Intensity</th>
<th>Energy errors</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.8610E+05</td>
<td>(1.0000E+02)</td>
<td>3.5000</td>
<td>(0.0500)</td>
</tr>
<tr>
<td>2.6227E+05</td>
<td>(5.0000E+01)</td>
<td>0.0049</td>
<td>(0.0005)</td>
</tr>
<tr>
<td>4.1460E+05</td>
<td>(5.0000E+01)</td>
<td>0.0003</td>
<td>(0.0000)</td>
</tr>
<tr>
<td>4.4937E+05</td>
<td>(1.0000E+02)</td>
<td>0.0022</td>
<td>(0.0000)</td>
</tr>
<tr>
<td>6.0066E+05</td>
<td>(5.0000E+01)</td>
<td>0.0005</td>
<td>(0.0000)</td>
</tr>
</tbody>
</table>

Radiation type: alpha
Average decay energy: 4.8606E+06 (2.0000E+02) eV
Discrete spectrum normalization: 1.0000E-02 (0.0000E+00)
5 discrete lines given

<table>
<thead>
<tr>
<th>Energy</th>
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<th>Intensity</th>
<th>Energy errors</th>
</tr>
</thead>
<tbody>
<tr>
<td>4.1600E+06</td>
<td>(2.0000E+03)</td>
<td>0.0003</td>
<td>(0.0000)</td>
</tr>
<tr>
<td>4.1910E+06</td>
<td>(2.0000E+03)</td>
<td>0.0010</td>
<td>(0.0001)</td>
</tr>
<tr>
<td>4.3400E+06</td>
<td>(1.0000E+03)</td>
<td>0.0065</td>
<td>(0.0003)</td>
</tr>
<tr>
<td>4.6017E+06</td>
<td>(2.0000E+02)</td>
<td>5.5500</td>
<td>(0.0000)</td>
</tr>
<tr>
<td>4.7844E+06</td>
<td>(2.5000E+02)</td>
<td>94.4500</td>
<td>(0.0000)</td>
</tr>
</tbody>
</table>

Radiation type: disc. electrons
Average decay energy: 3.7100E+03 (6.0000E+01) eV
Discrete spectrum normalization: 1.0000E-03 (0.0000E+00)
8 discrete lines given

<table>
<thead>
<tr>
<th>Energy</th>
<th>Normalization</th>
<th>Intensity</th>
<th>Energy errors</th>
</tr>
</thead>
<tbody>
<tr>
<td>8.7055E+03</td>
<td>(1.0000E+00)</td>
<td>9.6700</td>
<td>(0.1900)</td>
</tr>
<tr>
<td>6.6448E+04</td>
<td>(1.0000E+00)</td>
<td>0.1890</td>
<td>(0.0060)</td>
</tr>
<tr>
<td>8.7700E+04</td>
<td>(1.0000E+02)</td>
<td>6.8000</td>
<td>(0.2000)</td>
</tr>
<tr>
<td>1.6805E+05</td>
<td>(1.0000E+02)</td>
<td>1.1500</td>
<td>(0.0400)</td>
</tr>
<tr>
<td>1.6876E+05</td>
<td>(1.0000E+02)</td>
<td>7.4000</td>
<td>(0.2000)</td>
</tr>
<tr>
<td>1.7148E+05</td>
<td>(1.0000E+02)</td>
<td>4.2500</td>
<td>(0.1400)</td>
</tr>
<tr>
<td>1.8213E+05</td>
<td>(1.0000E+02)</td>
<td>3.4100</td>
<td>(0.0800)</td>
</tr>
<tr>
<td>1.8500E+05</td>
<td>(1.0000E+02)</td>
<td>1.1900</td>
<td>(0.0400)</td>
</tr>
</tbody>
</table>

Radiation type: x-rays
Average decay energy: 6.8500E+02 (1.1000E+01) eV
Discrete spectrum normalization: 1.0000E-03 (0.0000E+00)
5 discrete lines given

<table>
<thead>
<tr>
<th>Energy</th>
<th>Normalization</th>
<th>Intensity</th>
<th>Energy errors</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.4316E+04</td>
<td>(1.0000E+00)</td>
<td>8.5800</td>
<td>(0.1700)</td>
</tr>
<tr>
<td>8.1067E+04</td>
<td>(1.0000E+00)</td>
<td>1.9200</td>
<td>(0.0600)</td>
</tr>
<tr>
<td>8.3785E+04</td>
<td>(1.0000E+00)</td>
<td>3.1900</td>
<td>(0.1100)</td>
</tr>
<tr>
<td>9.4556E+04</td>
<td>(1.0000E+00)</td>
<td>1.1000</td>
<td>(0.0400)</td>
</tr>
<tr>
<td>9.7307E+04</td>
<td>(1.0000E+00)</td>
<td>0.3590</td>
<td>(0.0120)</td>
</tr>
</tbody>
</table>
Decay Equation

\[ _{88}^{226} \text{Ra} \xrightarrow{\alpha} _{86}^{222} \text{Rn} + \alpha_1 \]

94.3%  

\[ _{86}^{222} \text{Rn} \xrightarrow{\alpha_2} _{84}^{220} \text{Rn} + \gamma \]

5.7%  

\[ _{86}^{220} \text{Rn} + \alpha_2 + \gamma \]

\[ E_{\alpha_1} = 4.777 \text{ MeV} \]

100% 94.3%  

\[ E_{\alpha_2} = 4.591 \text{ MeV} \]

5.7%  

\[ E_{\gamma} = 0.186 \text{ MeV} \]