RADON RESEARCH IN MULTI DISCIPLINES: A REVIEW

PILLALAMARRI ILA

Earth Atmospheric & Planetary Sciences
Neutron Activation Analysis Laboratory
Massachusetts Institute of Technology
Cambridge, MA 02139

IAP 2007: 12.091 Credit Course: January 17- 25, 2007

Session 1, January 17, 2007

COURSE OUTLINE

I. Fundamentals of radon physics: review
II. Radon research in geology
III. Radon research in radiation biology
IV. Radon research in medicine
V. Radon research in health physics
Earth & Planetary Science
Radon research in multi disciplines - summary
Student Presentations
Radioactivity Laboratory demonstration

DETAILED COURSE WORK

The course work involves the following:

1. January 17, 19, 22, 24, 26 1-3 PM
   5 sessions each of 2 hours - 25%
2. Study assignments – 4 - 20%
3. Project
   Literature Survey – Writing a report - 30%
4. Project Presentation - 25%

Required percentage to pass this course is 95%
Grading: P/F

Session 1
Radon &
Radiation Physics
Review

Objective 1 of 2

1. Radioactivity and Radiation Review
   1.1 Alpha, Beta and Gamma radiation
   1.2 Ions and ionizing radiation

2. Radon characteristics –
   Uranium 238 decay series

3. Radon decay products –
   Radon 222 decay sequence

Objective 2 of 2

4. Dynamic Equilibrium
5. Equilibrium Ratio
6. Measurement Units
   - 6.1 Picocuries per liter & Becquerel per cubic meter
   - 6.2 Working Level and Working Level Month
7. Facts of Radon – An Overview

http://ocw.mit.edu/OcwWeb/Earth--Atmospheric--and-Planetary-Sciences/12-091January--IAP--2006/LectureNotes/index.htm Session2a.pdf

1. Review of radioactivity and radionuclides concepts

Atomic Nucleus

Material

Compounds

Elements

Atoms

(Neutrons + Protons) + Electrons
{Nucleus}

Element X is depicted by

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

A = Mass Number
N = Neutron Number
Z = Atomic Number (Proton Number)

$$A = Z + N$$

1. Review of radioactivity and radionuclide concepts …

Radio-isotopes & Radio-nuclides

	Mass	Charge
Neutron	1.008665 u	No electrical charge
Proton	1.007277 u	Positive charge
Electron	0.000548 u	Negative charge

(Ref: Basic Nuclear Engineering, A. R. Foster and R. L. Wright, Jr., Appendix B, pp 461)

Nuclides: Characterized by atomic number Z and mass number A.

Isotope – Same Z number, but different N.

Ex: $^{59}_{27}\mathrm{Co}_{32}$, $^{60}_{27}\mathrm{Co}_{33}$.

Nuclides: **Stable and Radioactive**

Radioactive Nuclides: **Naturally occurring and Artificially produced** .

1.1 Alpha, beta and gamma radiation

Alpha decay followed by gamma decay:

Alpha particle is $^{4}_{2}He_{2}$.

$$^{234}_{92}U_{142} \longrightarrow {}^{230}_{90}Th_{140} + \alpha + \gamma .$$

The unstable isotope $^{234}_{92}U$ decays to $^{230}_{90}Th$ by alpha and gamma radiation. The atomic number decreases by 2 and mass number by 4.

Alpha decay of ^{234}U to ^{230}Th

Z ↓						
92	U 231 4.2 d	U 232 68.9 y	U 233 1.592E5 y	U 234 2.455E5 y 0.0055	U 235 7.038E8 y 0.720	
91	Pa 230 17.4 d	Pa 231 3.28E4 y	Pa 232 1.31 d	Pa 233 26.967 d	Pa 234 1.17m | 6.7h	
90	Th 229 7340 y	Th 230 7.538E4 y	Th 231 25.52 h	Th 232 1.405E10 y 100	Th 233 22.3 m	
	139	140	141	142	143	N ←

Table 1: Alpha decay of ^{234}U to ^{230}Th (shown in the format of chart of nuclides).
The atomic number Z reduces by 2.
The neutron number N reduces by 2.
The mass number A reduces by 4.

1. Review of radioactivity and radio-nuclides concepts …

1.1 Alpha, beta and gamma radiation …

Beta decay followed by gamma decay.

Beta particle is electron ejected by excited nuclei. Their charge can be positive or negative.

$$^{40}K \longrightarrow {}^{40}Ca + \beta + \gamma .$$

19 21 20 20

The radioactive isotope ^{40}K decays to ^{40}Ca by beta and gamma radiation. Neutrinos are also emitted. A neutron is transformed into proton. The atomic number increases by 1 and mass number remains unchanged.

Beta decay of ^{40}K to ^{40}Ca

Z ↓							
20	Ca 37 0.181 s	Ca 38 0.440 s	Ca 39 0.859 s	Ca 40 96.941	Ca 41 1.3E5 y	Ca42 0.647	
19	K 36 0. 342 s	K 37 1.23 s	K 38 0.926 s | 7.63 m	K 39 93.258	K 40 1.28E9 y 0.012	K 41 6.73	
	17	18	19	20	21	22	N ←

Table 2: Beta decay of ^{40}K to ^{40}Ca (shown in the format of chart of nuclides).
The atomic number Z increase by 1.
The neutron number N reduces by 1.
The mass number A remains unchanged.

1. Review of radioactivity and radio-nuclides concepts …

1.1 Alpha, beta and gamma radiation …

- Gamma rays (γ) are emitted when an excited nucleus de-excites, by the transition from an excited energy state to a lower energy state. Gamma-rays have well defined energies and their emission often is accompanied by nuclear reactions and nuclear decays.

- Alpha particles (α) are ^4He particles with two protons and two neutrons. The atomic number (Z) of the resultant nucleus is reduced by two units, the mass number is reduced by 4 units.

- Negative Beta particles (β^-) or negatrons are emitted when neutron is transformed into a proton during the nuclear transformation.

  Negative beta particles are electrons formed during nuclear transformation, hence are of nuclear origin.

  The atomic number (Z) of the resultant nucleus is one unit greater, but the mass number is unchanged.

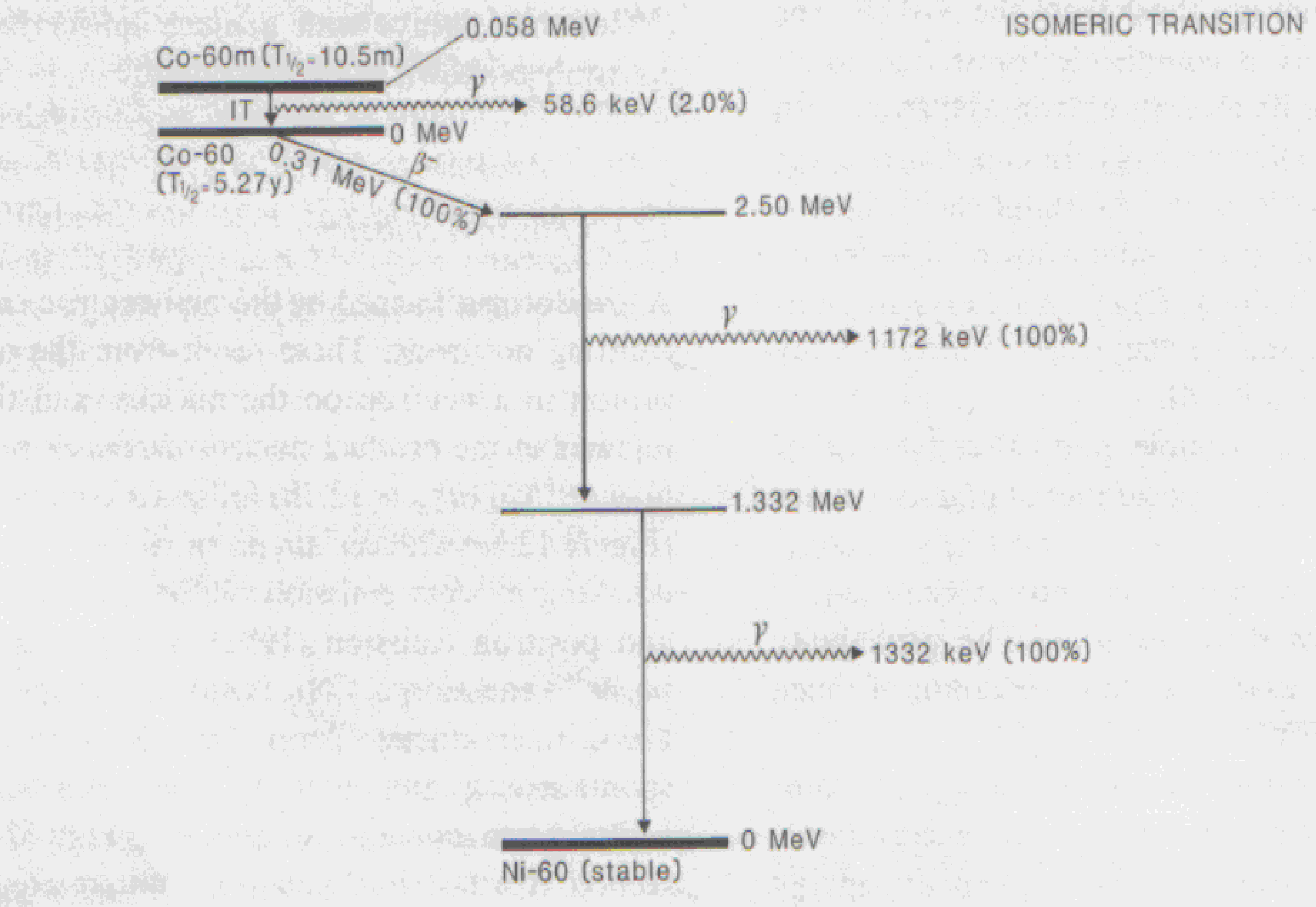


Figure 1: Gamma and beta decay scheme of ^{60m}Co and ^{60}Co.

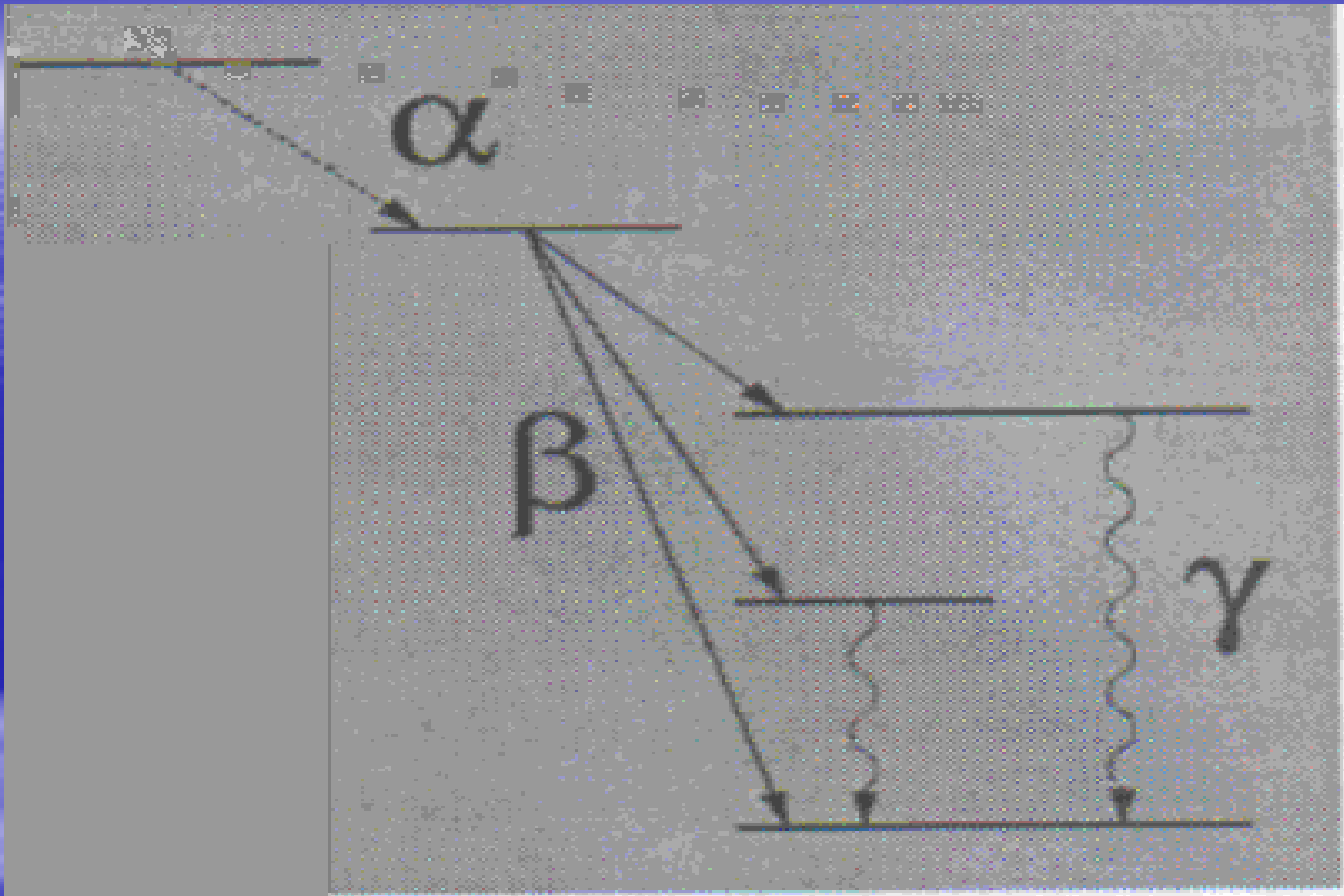


Figure 2: Pictorial depiction of simultaneous alpha, beta and gamma emissions

1.2 Ions and ionizing radiation

- Atoms normally contain the same number of electrons in orbit as protons in the nucleus. This provides an overall neutral charge to the atom.
- Ions are formed when radiation in the form of alpha, beta and /or gamma and X-rays knock out an electron from an atom along the travel path. This results in free electron (of negative charge) and a positive ion.

1.2 Ions and ionizing radiation …

- This ionization is hazardous to health.
- Ionization of atoms and molecules of human cells can cause damage to that cell.

  Ionization of water molecules within or surrounding cells can result in the formation of hydrogen peroxide – a poison to cell.

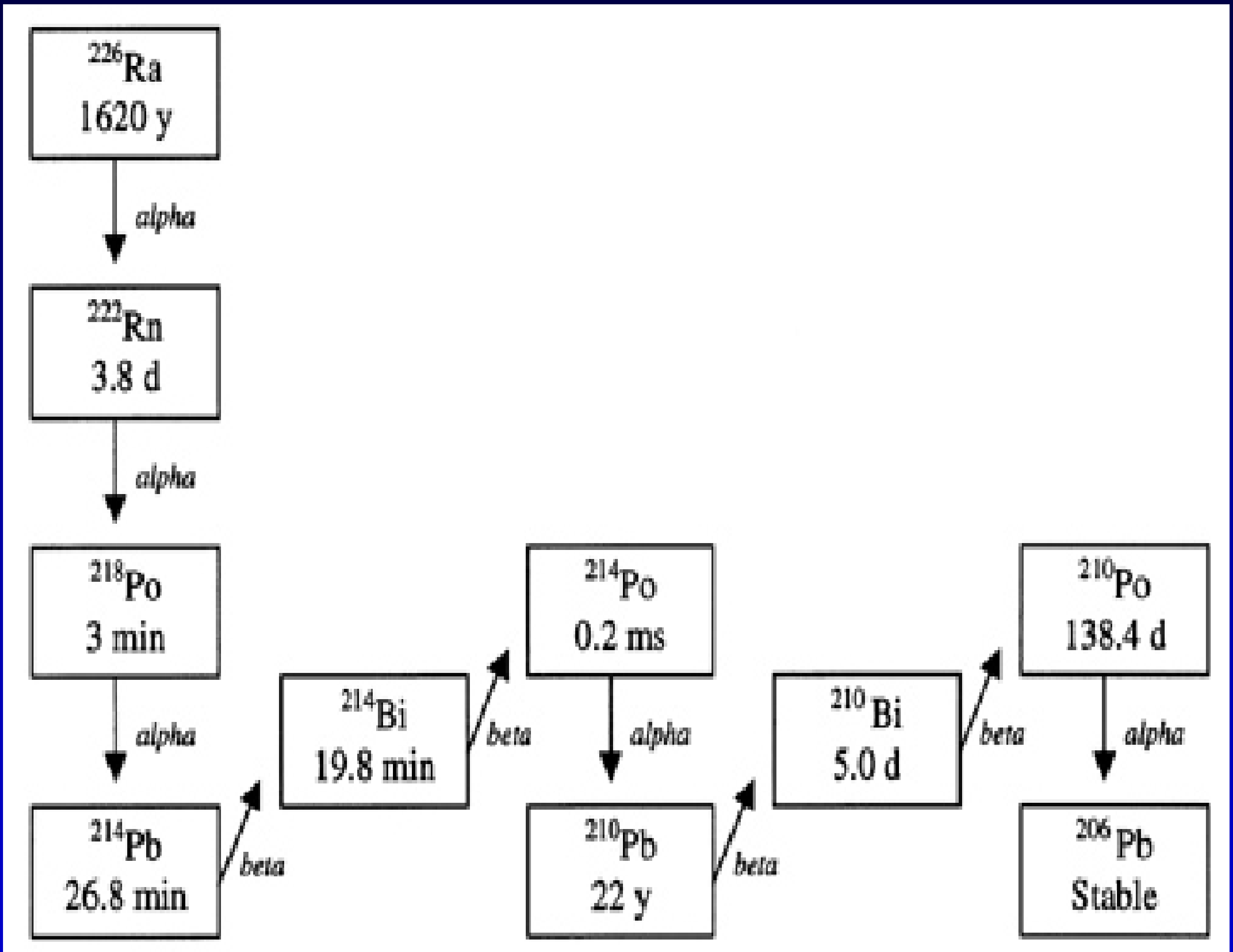
1. Review of radioactivity and radio-nuclides concepts …

- **NORM** - Naturally Occurring Radioactive Material. Radon is naturally radioactive gas.
- **TENORM** -Technologically-Enhanced Naturally Occurring Radioactive Material.

2. Uranium Decay Series

- Uranium 238 “Parent”
- Protoactinium 234
- Uranium 234
- Thorium 230
- Radium 226
- Radon 222
- Polonium 218
- Lead 214
- Bismuth 214
- Polonium 214
- Lead 210

3. RADON DECAY sequence



- ^{226}Ra
- ^{222}Rn…
- …^{206}Pb

Courtesy of Environmental Protection Agency, USA

3. RADON PROGENY

"Radon Decay Products"

- Decay products of ^{222}Rn
- Eight decay steps yield α, β & γ
- Electrically charged: attracted to surfaces including particulate
- Can be inhaled and cause exposure

Courtesy of Environmental Protection Agency, USA

4. Dynamic Equilibrium

- Radon enters a building. Radon is a radioactive gas, so it constantly decays into its daughter products (RDPs). Also, radon may not be entering the building at a constant rate, for example with intermittent ventilation or movement in the building.
- Also, the RDPs that are getting generated inside the building, part of them may be suspended in the air within, some percentage may settle on the surfaces.

4. Dynamic Equilibrium …

- Once the radon entry rate into a building changes, time is needed for radon and RDP levels to stabilize. Otherwise their concentrations may be constantly changing.
- 12 hours is normally sufficient time frame for reaching the dynamic equilibrium. Dynamic equilibrium is the steady state of radon and RDP levels within the environment.

5. Equilibrium Ratio Assumption

- The RDPs are metallic, radioactive and highly electrostatic. So, not all RDPs created from the decay of radon will remain in air (environment). A percentage will get attached to the surfaces called plate out. Some will be ventilated out. The relationship between indoor radon air and the radon decay products is called the Equilibrium Ratio (ER).
- ER varies from 0.3 to 0.7

5. Equilibrium Ratio (ER) …

- Usually the equilibrium ratio is not measured when radon is tested/measured.
- ER factor is usually assumed.
- ER factor is useful in the conversion of pCi/L to working level (WL) units.
- pCi/L = (WL x 100) / Equilibrium Ratio

6. Measurement Units

Units of Radiation Dose and Exposure

- Radioactivity is measured in unit of disintegration per second (dps).

  1 Becquerel is 1Bq = 1 dps

  1 Curie is 1Ci = 3×10^{10} dps

6. Measurement Units …

Units of Radiation Dose and Exposure

- The amount of radiation is usually referred to as **Dose**.
- **Dose** is different from **Exposure**.
- The quantities and units of Radiation Dose and Exposure are not simple but are complex involving various parameters such as type of radiation, absorbed dose (D), quality factor (Q), any modifying factor (N), etc.
- After going through an evolution in a period of more than a half a century, the current units designated by SI (Système International)

Unit of Dose Equivalent is 1Sievert = 1 Sv (1 Joule/kg)

Unit of Dose is 1 Gray = 1Gy (1 Joule/kg)

1 Gy = 100 rad; 1 rad = 0.01 Joule/kg

1 Sv = 100 rem; 1 rem = rad x quality factor

Note: rad refers to any material and any radiation.

6.1 pCi/L and Bq/m^3

Radioactivity is measured in units of disintegrations per second (dps).

Units of Activity
1 Becquerel (Bq) = 1 disintegration per second
1 Curie (Ci) = 3.7 x 10^{10} disintegrations per second
1 picoCurie (pCi) = 0.037 disintegration per second

Radon concentration is measured in pCi per liter of air (or water) or Becquerel per meter cubed.

6.2 Working Level (WL) & Working Level Month (WLM)

- 1 Working Level (WL) is any combination of short-lived radon decay products in one liter of air that will result in the ultimate emission of 1.3×10^5 MeV of potential alpha energy.

- This number is chosen based on the fact that approximately the alpha energy released from the decay products in equilibrium with 100 pCi of Radon 222.

- 1 WL = 2.08×10^{-5} Jm^3

- Radon Daughter Products are measured in WL

6.2 Working Level (WL) & Working Level Month (WLM) …

Dose to workers in work place environment is calculated in units of concentrations of radon daughter products, namely Working Level units.

WLM is the exposure dose in working level months for the exposure period. The exposure dose in WLM is calculated from the equation:

WLM (Working Level Month Exposure) =

WL x Exposure Time (in hours) / (170 (hours/month))

Where

WL = pCi/L x Equilibrium Ratio / 100

Note: While reporting the WLMs, the value of equilibrium ratio should always be reported.

Frequently Asked Questions (FAQs) about Radon

What is radon?

- Radon is a radioactive element
  Atomic Number 86

- There are between 20 and 28 radio-isotopes of radon - 20 cited in the chemical summary, 28 listed in the table of isotopes.
  Sources: Condensed Chemical Dictionary, and Handbook of Chemistry and Physics, 69th ed., CRC Press, Boca Raton, FL, 1988.

- Three well known isotopes of radon are:
  ${}^{222}_{86}Rn_{136}$ called Radon; half-life 3.824 d
  ${}^{220}_{86}Rn_{134}$ called Thoron; half-life 55.6 s
  ${}^{219}_{86}Rn_{133}$ called Actinon; half-life 3.96 s

Radon is …

- Toxic, colorless, odorless and radioactive noble gas
- Denser than air
- Naturally occurring radioactive gas
- Ubiquitous in nature: Being or seeming to be everywhere at the same time
- Member of Uranium decay series
- Direct decay product of Radium-226
- Decays to daughter radioactive elements

Why is Radon important?

- Radon is present everywhere, all around us.

- Radon

  cannot be seen with naked eye,

  cannot be smelled,

  cannot be aware easily of its presence .

- Radon

  becomes harmful to health at unacceptable concentration levels.

Harmful Radon Daughter Products (RDPs)

- Radon 222 has a half-life of 3.8 d.
- Radon 222 decays to a series of four radioactive decay products:

Polonium 218	(half-life 3.05 m)
Lead 214	(half-life 26.8 m)
Bismuth 214	(half-life 19.8 m)
Polonium 214	(half-life 163.7 micro s)

These decay product isotopes are heavy metals. Of the four decay products, especially Polonium 218 and Polonium 214 are the main sources of health hazard because they emit alpha rays.

Alpha particles, even though cannot penetrate skin, they are about 20 times more damaging than other type of ionizing radiation when deposited internally, for example by inhalation.

How Is Radon Measured?

- Radon is measured in picoCuries per liter of air (pCi/L). While no level of radon exposure is considered safe, EPA has set an action level at 4 pCi/L.
- If radon test in a home shows levels at or above 4 pCi/L, the home should be fixed.

How much is too much?

Action Guide (4 pCi/L)

Consider Action (2 - 4 pCi/L)

7. Facts of Radon – An Overview

- http://ocw.mit.edu/OcwWeb/Earth--Atmospheric--and-Planetary-Sciences/12-091January--IAP--2006/LectureNotes/index.htm Session2a.pdf
- http://www.epa.gov/radon/radonqa1.html

(URL verified January 31, 2007)

Summary

I Talked about

- Alpha, Beta and Gamma radiation
- Ions and ionizing radiation
- Uranium 238 decay series
- Radon 222 decay sequence
- Radon, Thoron and Actinon isotopes
- Radon Daughter Products
- pcI/L and Bq/m^3 ; WL and WLM
- Action level for radon
- Dynamic Equilibrium and Equilibrium Ratio
- Parameters that effect the action level

Internet key words

- radon, radon progeny, decay chain series, radon potential, radon daughter products, radon risk, dynamic equilibrium, equilibrium ratio,

action levels, working level WL,

working level month WLM

References & Further Reading

- **Brenner, D. J.; Sachs R. K.**
  Domestic radon risks may be dominated by bystander effects – but the risks unlikely to be greater than we thought, Health Physics 85(1): 103-108; 2003.

- **Cavallo, A.; Hutter, A.; Shebell, P.**
  Radon progeny unattached fraction in an atmosphere far from radioactive equilibrium Health Physics 76(5): 532-536, May 1999.

References & Further Reading

- Kristof, JW.; Hanna, A.; Hadjinicolaou, J.;
  Soil gases and building foundations
  International Journal for Housing Science and Its Applications
  30(1): 69-80; Special Issue 2005.

- Kovler, K.
  Radon exhalation of harden in concrete: Monitoring cement hydration and prediction of radon concentration in construction site
  Journal of Environmental Radioactivity
  6(3): 354-366; 2006.

References & Further Reading

- Leonard, B.
  Radioisotope deposition on interior building surfaces: Air flow and surface roughness influences,
  Nuclear Technology 152(3): 339-353; December 2005.

- Lopez, F.O.; Canoba, A.C.
  Passive method for the determination of the equilibrium factor between ^{222}Rn gas and its short period progeny,
  Journ of Radioanal and Nucl Chem. 258(2): 269-74; Nov 2003.

References & Further Reading

- Nielson, K. K.; Holt, R. B.; and Rogers, V. C.
  Site-specific characterization of soil Radon potentials [electronic resource] : project summary,
  Cincinnati, OH: United States Environmental Protection Agency, Research and Development, National Risk Management Research Laboratory, 1996.
  http://purl.access.gpo.gov/GPO/LPS35300

- Rabi, J. A.;Da Silva, N. C.
  Radon exhalation from phosphogypsum building boards: Symmetry constraints, impermeable boundary conditions and numerical simulation of a test case
  Journal of Environmental Radioactivity 86(2): 164-175; 2006.

References & Further Reading

- Sciocchetti,G.; Cotellessa,G.; Soldano, E.; Pagliari, M ,
  A new technique for measuring radon exposure at working places,
  Radiation Measurements 36(1-6):199-203; Sept 2003.

- Tokonami, S.; Takahashi, H.; Kobayashi, Y.; Zhuo, W.; Hulber, E.
  Up-to-date radon-thoron discriminative detector for a large scale survey,
  Review of Scientific Instruments 76(11): 113505; 2005.

References & Further Reading

- Cember, H,
  Introduction to Health Physics,
  McGraw-Hill Publishing Co.;
  3 Rev. Edition , 1994.
  ISBN 0071054618
- **Dowd, SB., Tilson, ER.,**
  Practical Radiation Protection and Applied Radiobiology,
  Philadelphia, PA: W.B. Saunders 1999.
  ISBN 0721675239

References & Further Reading

- Eisenbud, M.,
  Environmental Radioactivity,
  Academic Press, Inc., 1971.
  ISBN: 012235150

- Foster, AR., Wright, RL.,
  Basic Nuclear Engineering,
  Boston: Allyn and Bacon 1983.
  ISBN: 0205078869