MEDICAL GEOLOGY/GEOCHEMISTRY: An exposure

PILLALAMARRI ILA

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

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Session 2A, January 11, 2006

Objective

Jan 11:

10 AM - 11 PM Session 2A

- Review of radioactivity – radionuclides concepts
- Naturally Occurring Radioactive Materials (NORM)
  - Primordial-Cosmogenic-Anthropogenic
- Technologically Enhanced Naturally Occurring Radioactive Materials (TENORM)
  - TENORMs Contributors
  - TENORMs Radioactivity

11AM - 12PM Session 2B

- Radon:
  - Frequently Asked Questions (FAQs)
  - Myths and Facts
  - Radon potential maps of USA and Massachusetts
  - Radon in drinking water
  - Radon in indoor and outdoor air
  - Radon resistant new construction
  - Radon Detection

Review of Radioactivity – Radionuclides Concepts

- Atomic Nucleus
- Review of radioactivity and radionuclides concepts
- Radioactive Decay
- Units of Radiation Dose and Exposure

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)

$$A = Z + N$$

Review of radioactivity and radio-nuclides 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.

Isomer – Same N, Z, A but exists in an excited state for a period of time.

Ex: ${}^{60}_{27}Co_{33}$ (T ½ = 5.26 y) and ${}^{60m}_{27}Co_{33}$ (T ½ = 10.48 m).

Isotope – Same Z number, but different N.

Ex: ${}^{59}_{27}Co_{32}$ ${}^{60}_{27}Co_{33}$

Isobar – Same A number, but different Z.

Ex: ${}^{14}_{6}C_{8}$, ${}^{14}_{7}N_{7}$

Isotone – Same N number (also means same A-Z).

Ex: ${}^{14}_{6}C_{8}$, ${}^{15}_{7}N_{8}$, ${}^{16}_{8}O_{8}$

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

Radioactive Decay

Radioactivity is produced when unstable nuclei decay.

The disintegration of radio-nuclides releases excess energy in the form of nuclear radiations.

Radioactive decay takes place in several ways emitting radiation such as:

- Alpha rays
- Beta (negative and positive) rays
- Gamma rays
- Neutrons
- Neutrinos
- Proton decay
- Internal conversion electrons
- Characteristic x-rays
- Fission fragments

The heavy radioactive elements and their decay products predominantly emit three types of radiation:

Alpha rays, Beta rays, Gamma rays

Review of radioactivity and radio-nuclides …

Radioactive Decay

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 $^{234}_{92}U_{142}$ decays to $^{230}_{90}Th_{140}$ 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.

Review of radioactivity and radionuclides concepts …

Radioactive Decay

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

$$^{40}_{19}K_{21} \longrightarrow {}^{40}_{20}Ca_{20} + \beta + \gamma.$$

The radioactive isotope $^{40}_{19}K_{21}$ decays to $^{40}_{20}Ca_{20}$ 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.

Review of radioactivity and radio-nuclides concepts …

Radioactive Decay

- **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.

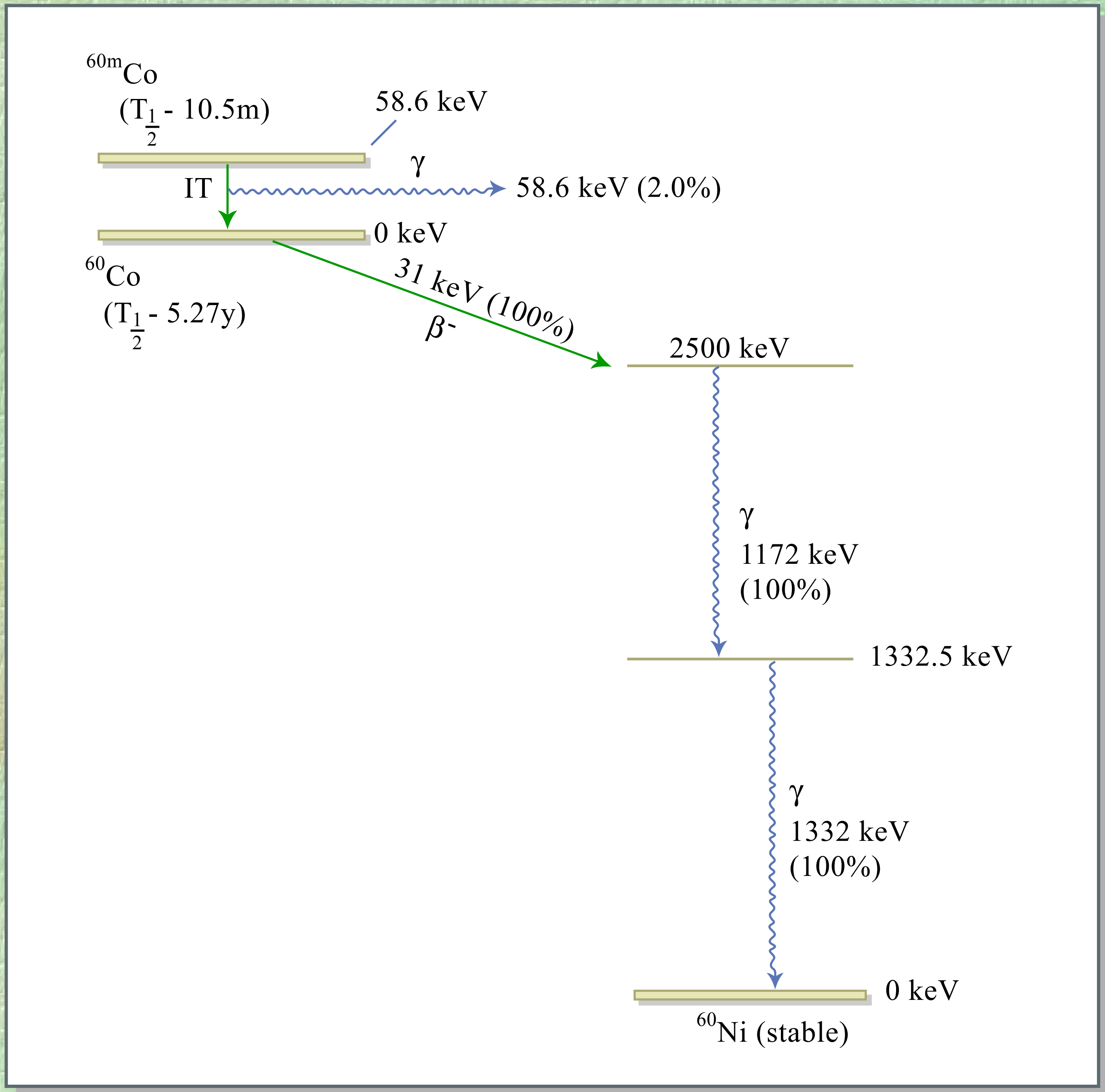

Figure by MIT OCW.

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

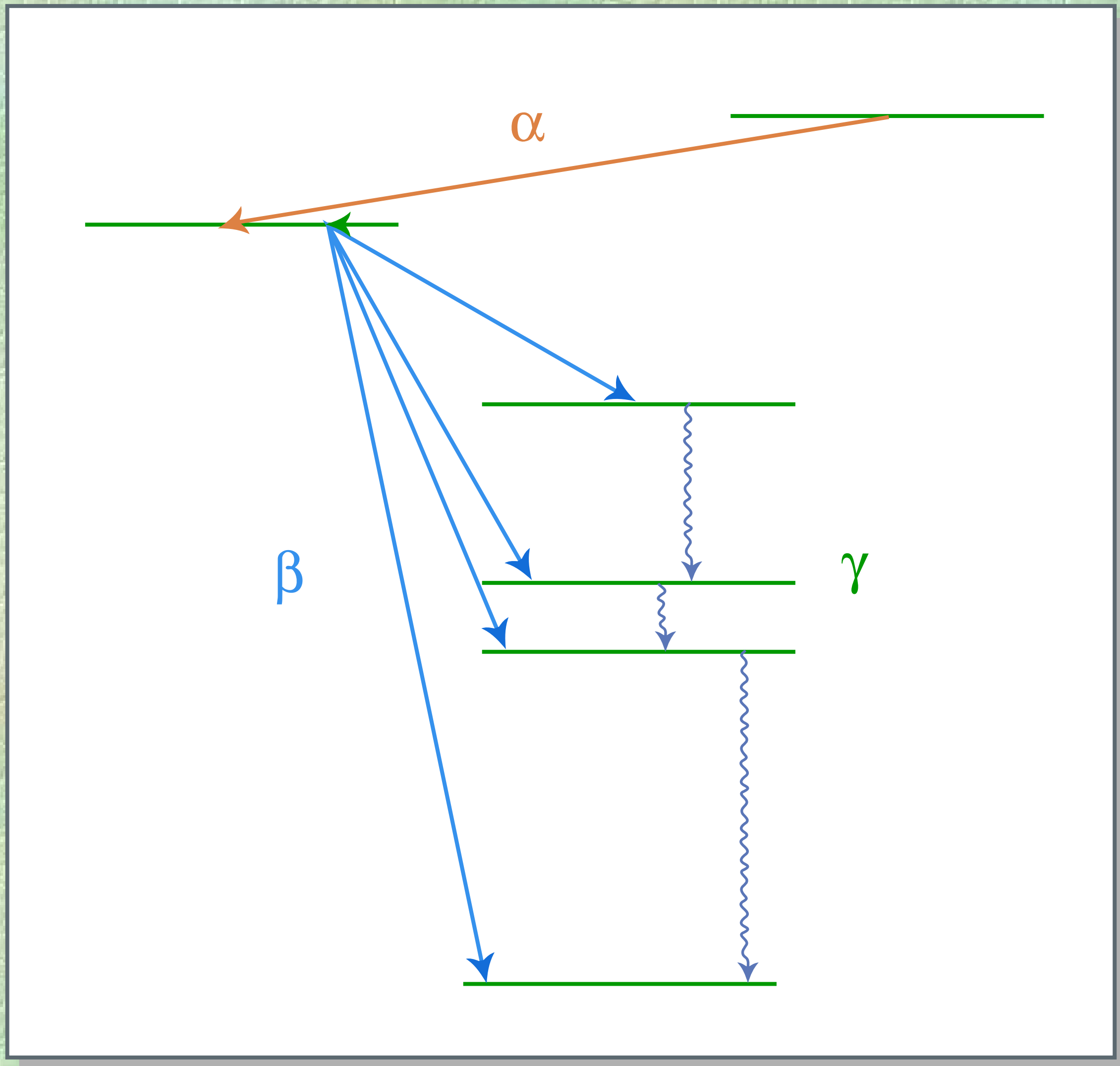

Figure by MIT OCW.

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

Review of radioactivity and radio-nuclides concepts …

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

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.

Ref: P126 Basic Nuclear Engineering; P 42 Environmental Radioactivity Merrill Eisenbud and Giesell.

Review of radioactivity and radio-nuclides concepts …

- **NORM** - Naturally Occurring Radioactive Material.

- **TENORM** -Technologically-Enhanced Naturally Occurring Radioactive Material.

Naturally Occurring Radioactive Materials (NORM)

- Primordial
- Cosmogenic
- Anthropogenic

Naturally Occurring Radioactive Materials

The earth is radioactive and the world we live in, the environment around is radioactive.

Radioactive elements can be categorized as

- Primordial – present even before or ever since the existence of the Earth.
- Cosmogenic - formed as a result of cosmic ray interactions.
- Anthropogenic - enhanced or formed due to technology, human activities.

Characteristics of Primordial elements

- long lived
- most half-lives of the order of millions of years;
- must have been left-over on the earth, because the radioactivity decays to very minute levels usually after 30 half-lives.

List of some more Primordial Radio-nuclides

^{209}Bi, ^{113}Cd, ^{142}Ce, ^{152}Gd, ^{174}Hf, ^{115}In, ^{138}La, ^{144}Nd, ^{176}Lu, ^{190}Pt, ^{192}Pt, ^{187}Re, ^{87}Rb, ^{147}Sm, ^{123}Te, ^{50}V

The uranium and thorium decay series

Detailed information of radioactive decay of ^{235}U, ^{238}U and ^{232}Th, and their daughter products, the corresponding half-life of each and the decay sequence are provided in many text books and web sites.

References:

1) Figure 13.1 ^{235}U radioactive decay chain.
Figure 13.2 ^{238}U radioactive decay chain.
Figure 13.3 ^{232}Th radioactive decay chain.
Chapter 13. Nuclear techniques for the determination of uranium and thorium and their decay products,
A hand book of silicate rock analysis, P. J. Potts.

2) http://www.health.state.ny.us/nysdoh/radon/chain.htm

Cosmogenic Radioactivity

Cosmic radiation:

- ❖**Primary cosmic radiation**
- ❖**Secondary cosmic radiation**

- Primary cosmic radiation:

  Extremely high energy particles (up to 10^{18} eV), and are mostly **protons**, and some larger particles.

  Major percentage of it comes from outside the solar system and exists throughout space.

  Some of the primary cosmic radiation is from the sun, produced during solar flares.

Table 3.
K, Th and U
Concentrations and activities in rocks and soils

Material	^{40}K		^{232}Th		^{238}U	
	%	Bq/kg	ppm	Bq/kg	ppm	Bq/kg
Igneous rocks						
Basalt (crustal average)	0.8	300	3.0-4.0	10.0 - 15.0	0.5-1	7.0 - 10.0
Granite (crustal average)	>4	>1000	17	70	3	40
Sedimentary rocks						
Shale sandstones	2.7	800	12	50	3.7	40
Clean quartz	<1	<300	<2	<8	<1	<10
Beach sands	<1	<300	6	25	3	40
Carbonate rocks	0.3	70	2	8	2	25
Continental crust (average)	2.8	850	10.7	44	2.8	36
Soil (average)	1.5	400	9	37	1.8	22
All rocks (range)	0.3 – 4.5	70 - 1500	1.6 - 20	7 - 80	0.5 – 4.7	7 – 60

Based on: Table 6-6, pp 140, Environmental Radioactivity from Natural, Industrial and Military Sources.

Cosmogenic Radioactivity

Cosmic radiation consisting of high speed heavy particles and high energy photons and muons permeates all of space, the source being primarily outside our solar system. The cosmic radiation interacts with the upper atmosphere, and produces cosmogenic radioactive nuclides. They can have long half-lives, but the majority have shorter half-lives than the primordial nuclides.

Cosmogenic Radioactivity …

- **The primary radiation that originate in outer space and impinge isotropically on top of the earth's atmosphere consist of**

  85% protons,

  14% alpha particles,

  1% of nuclei between atomic number Z from 4 to 26.

- **Primary radiation is highly penetrating with energies in the range 10^{10}eV to 10^{19} eV.**

- **The major source of cosmic radiation is galactic in origin and a small amount is of solar origin. However, solar flares (in cycles of 11 years) contribute significantly to cosmic radiation.**

Cosmogenic Radioactivity…

- Secondary Radiation:

  Not much of the primary cosmic radiation penetrates the Earth's surface. The vast majority of it interacts with the atmosphere. When the interaction takes place, it produces the secondary cosmic radiation, or that is detected on the Earth. The interactions produce other lower energy radiations in the form of photons, electrons, neutrons, muons, etc. which the surface of the Earth.

Cosmogenic Radioactivity …

- The atmosphere and the Earth's magnetic fields shield the Earth from cosmic radiation; thereby reduced amount reaches the Earth's surface. Thus the annual dose from cosmic radiation dependent on the **altitude** of the location.
- Dose from cosmic radiation to the U.S., to the average person is about **27 mrem per year**; **for** every 6,000 foot increase in elevation, the dose roughly doubles .

Cosmogenic Radioactivity …

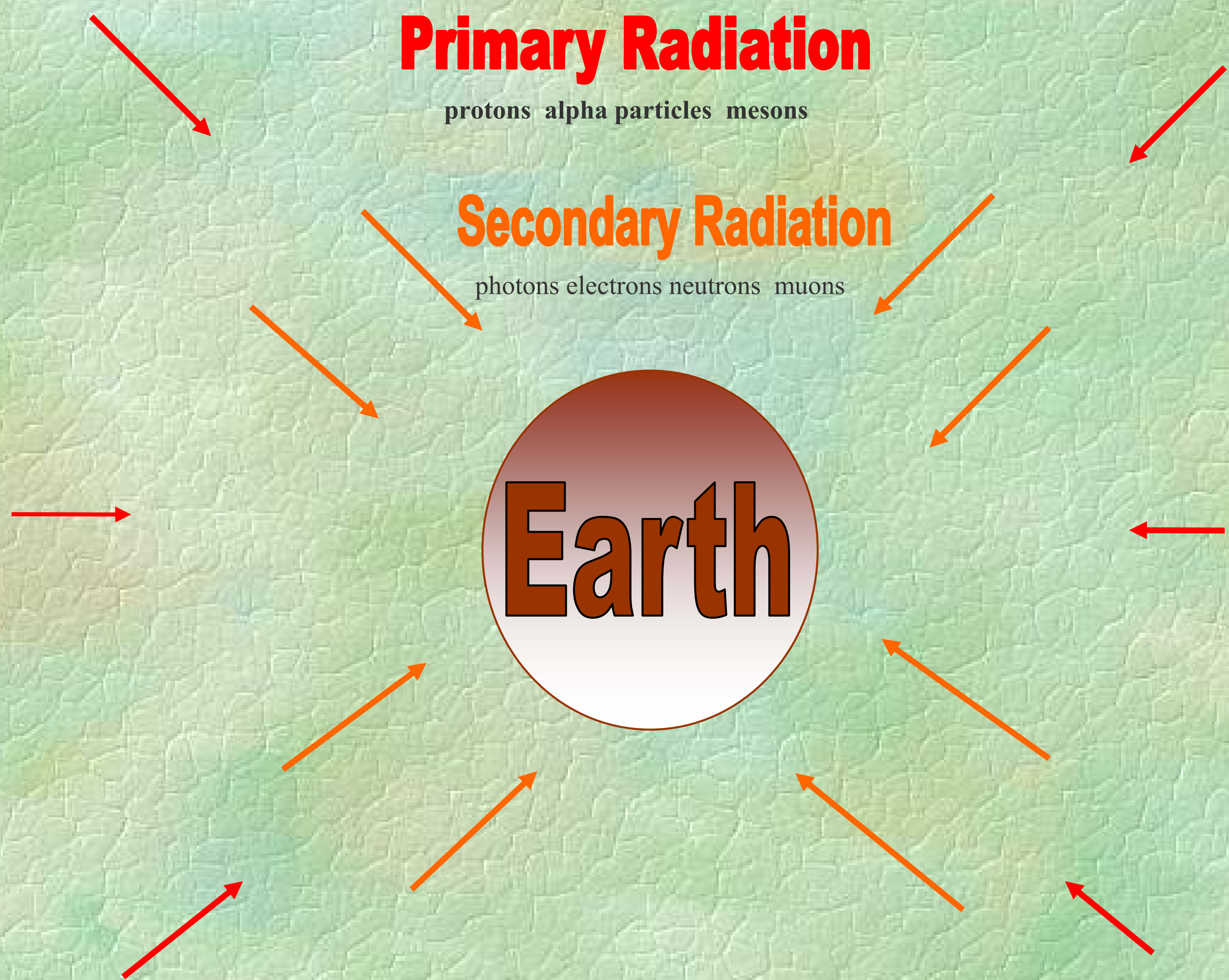

Figure 3 : Conceptual rendering of primary and secondary cosmic radiation isotropically surrounding the Earth. (not drawn to scale)

Cosmogenic Radioactivity …

- Typical Cosmic Radiation Dose rates:
  - 4 μR/hr in the Northeastern US
  - 20 μR/hr at 15,000 feet
  - 300 μR/hr at 55,000 feet
- There is only about a 10% decrease at sea level in cosmic radiation rates when going from pole to the equator, but at 55,000 feet the decrease is 75%. This is on account of the effect of the earth's and the Sun's geomagnetic fields on the primary cosmic radiations.
- Flying can add a few extra mrem to your annual dose, depending on how often you fly, how high the plane flies, and how long you are in the air.

Cosmogenic Radioactivity …

Table 4: Some commonly known cosmogenic radioactive nuclides and their activities

Radio -nuclide	Half-life
^{14}C	5730 yr
^{3}H	12.3 yr
^{7}Be	53.28 days

Based on http://www.physics.isu.edu/radinf/natural.htm

Cosmogenic Radioactivity …

- Some more cosmogenic radionuclides are ^{26}Al, ^{37}Ar, ^{39}Ar , ^{10}Be, ^{34m}Cl, ^{36}Cl, ^{39}Cl, ^{18}F, ^{80}Kr, ^{38}Mg, ^{24}Na, ^{22}Na, ^{32}P, ^{33}P, ^{31}Si, ^{32}Si, ^{35}S, ^{38}S,

Anthropogenic Radioactivity

The use of radioactivity for one hundred years, added to the natural inventories. The ban of above ground testing of nuclear weapons, reduced the amounts and also due to the shorter half-lives of many of the nuclides, have seen a marked decrease.

Table 5. Anthropogenic Radio-nuclides

Radionuclide	Half-life
^{3}H	12.3 y
^{131}I	8.04 d
^{129}I	1.57×10^{7} y
^{137}Cs	30.17 y
^{90}Sr	28.78 y
^{99}Tc	2.11×10^{5} y
^{239}Pu	2.41×10^{4} y

Note: Details may be obtained from Environmental radioactivity from natural, industrial, and military scources, 4th edition.

Natural radioactivity in soil

- Activity levels vary greatly depending on soil type, mineral composition and density. Activities for the ^{40}K, ^{232}Th, ^{238}U, ^{226}Ra and ^{222}Rn using typical numbers may be viewed on the web site:

http://www.physics.isu.edu/radinf/natural.htm

Natural Radioactivity in the Ocean

- Activity levels for the ^{40}K, ^{3}H, ^{87}Rb, ^{14}C in Pacific and Atlantic oceans using typical numbers may be viewed on the web site

http://www.physics.isu.edu/radinf/natural.htm

Technologically Enhanced Naturally Occurring Radioactive Materials (TENORM)

Contributors

&

Radioactivity

Technologically Enhanced
Naturally Occurring Radioactive Materials
TENORMs

- **NORM - Naturally Occurring Radioactive Material**

- **TENORM – Technologically Enhanced Naturally Occurring Radioactive Material.**

TENORM Contributors

Arranged alphabetically:

Coal Ash
Geothermal Energy Production Waste
Metal Mining and Processing Waste
Oil and Gas Production Scale and Sludge
Paper and Pulp Industry
Phosphate Fertilizers and Potash
Phosphate Industry Wastes
Scrap Metal Release and Recycling
Uranium Overburden and Mine Spoils
Waste Water Treatment Sludge

TENORM Sources and Concentrations

http://www.epa.gov/radiation/tenorm/sources.htm

http://www.epa.gov/radiation/tenorm/sources_table.htm

Note:

Please see "TENORM Sources" attached in the lecture notes table.

Please see "TENORM Sources Table" attached in the lecture notes table.

TENORM Summary http://www.epa.gov/radiation/docs/tenorm/402-r-00-001.pdf

- *Note: Please see "TENORM Summary" attached in the lecture notes table.*

Summary

- Radioactivty is all around us.
- Radioactive materials exist naturally and also are generated artificially.
- Technological activities enhance natural radioactivity.
- Radioactivity in the environment is from natural, industrial and military sources.

Internet Keywords

- Natural background radiation
- Cosmogenic radiation – primary secondary
- Table of isotopes
- Chart of nuclides
- NORM
- TENORM

References

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  A. R. Foster and R. L. Wright, Jr., Appendix B, pp 461,
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- For a list of NORM and TENORM related URLs
  http://www.thenormgroup.org/normrelatedlinks.html

- **US Environmental Protection Agency** **http://www.epa.gov/radiation/tenorm/sources.htm**
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