Fundamental Principles of Radiation

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Environmental Monitoring Programs
Nevada Site Specific Advisory Board (NSSAB)
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Fundamentals of Ionizing Radiation
What is an Atom?
Atoms
Atoms are the building blocks of ALL matter

A Helium atom is used in this example
Nucleons

**Neutron**

Mass is about 1 amu

**Proton**

Mass is about 1 amu

1 Atomic Mass Unit (amu) = 1.66 x 10^{-24} gram

Mass is about 0.0005 amu
Atoms

- Nuclear particles form atoms
- Similar atoms combine to form elements
- Elements combine to form molecules
- Molecules combine to form compounds
Isotopes

• The number of PROTONS defines the ELEMENT
• The number of NEUTRONS defines the ISOTOPE
• The isotopes of an element have similar chemical properties but different nuclear properties
  – Some isotopes are stable
  – Some isotopes are radioactive
Isotopes

Different Isotopes of Hydrogen

“Normal” Hydrogen or Protium
1 proton
0 neutron
1 electron
\( _1^1 \text{H} \)

Deuterium
1 proton
1 neutron
1 electron
\( _1^2 \text{H} \)

Tritium
1 proton
2 neutrons
1 electron
\( _1^3 \text{H} \)

“Normal” Hydrogen

Deuterium

Tritium
Isotopes and Atomic Notation

X = The symbol of the element

Z = The atomic number (# of protons)

A = The atomic mass number (# of protons + neutrons)

\[ Z \, X^A \]

Different Isotopes of Hydrogen

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- 1 proton
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Ionizing Radiation
Two Types of Radiation

- Non-Ionizing
- Ionizing
Non-Ionizing

Radiation that doesn’t have enough energy to form ions:

- Radar Waves
- Microwaves
- Laser
- Visible Light
Electromagnetic Spectrum

The Electromagnetic Spectrum is a large family of radiation that includes light, infrared, ultraviolet, X-rays, radio waves, and gamma rays.
Ionizing Radiation

Excess energy (from unstable atoms) capable of removing orbiting electrons from an atom, producing electrically-charged particles called ions. The “free” electron (- charge) and the remaining atom (+ charge) are the ions.
Stability of Nucleus

NUCLEI MAY BE STABLE OR UNSTABLE

Do any or all of the following:

- Emit particle
  - Alpha (α)
  - Beta (β)
  - Positron
  - Neutron
- Emit EM radiation
  - Gamma (γ)
- Grab electron
- Split (fission)
Alpha Particle Radiation

Daughter Nucleus
Th-231

Parent Nucleus
U-235

Alpha Particle
(Helium Nucleus)

\[ ^{4}_2 \alpha^{++} \]
Alpha Particle Radiation
(continued)

**Alpha**

- Large, highly positive charged **particle**
- Range in air about 1 - 2 inches
- Shielding can be a piece of paper, clothing or even the dead outer layer of skin
- Biological hazard is inhalation or ingestion
Beta Particle Radiation

Daughter
Nucleus
Calcium-40

Parent Nucleus
Potassium-40

Antineutrino

Beta Particle

$^{0}_{-1}\beta^{-}$
Beta Particle Radiation (continued)

**Beta**

- Small, negative charged **particle**
- Range in air is about 10 feet
- Shielding can be plastic, glass, metal foil, or safety glasses
- Biological hazard is inhalation or ingestion
- Externally, the eyes and skin are at risk
Gamma-Ray Radiation

Parent Nucleus
Cobalt-60

Daughter Nucleus
Ni-60

Gamma Rays
Gamma-Ray Radiation (continued)

**Gamma**

- Electromagnetic **waves** or photons that have no charge, similar to X-rays
- Range in air is several hundred feet
- Shielding is more difficult due to high penetrating power - dense materials (high Z number) such as concrete, lead, steel
- Biological hazard is whole body
Neutron Radiation

are very penetrating; therefore, they can affect all organs.

eyes are the most susceptible

slowed by hydrogenous materials and then absorbed by cadmium or boron

few natural emitters

reactors, research accelerators
Neutron Radiation
(continued)

**Neutron**

- Neutral *particle* ejected from nucleus
- Range in air is several hundred feet
- Shielding is better with materials that have high hydrogen content - water, plastic, boron, and even paraffin (low Z number)
- Biological hazard is whole body due to high penetrating power
Radioactivity is a natural and spontaneous process by which unstable radioactive atoms decay to a different state and emit excess energy in the form of radiation.

Half-life ($T_{1/2}$) is the amount of time required for radioactive material to decrease by one half; each radioisotope has a unique Half-life time period.
Units of Measure
# Units for Radiation Dose and Exposure

<table>
<thead>
<tr>
<th>Roentgen (R)</th>
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</tr>
<tr>
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<th>Rem (Roentgen Equivalent Man)</th>
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<tr>
<td>Unit for measuring effective dose (most commonly used unit)</td>
</tr>
<tr>
<td>Pertains to human body</td>
</tr>
<tr>
<td>Applies to all types of radiation</td>
</tr>
<tr>
<td>Takes into account the energy absorbed (dose) and the biological effect on the body due to the different types of radiation</td>
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\[ \text{Rem} = \text{Rad} \times \text{WF} \]
Not All Radiation is the Same

- Different radiation has different biological effects
- Radiation WEIGHTING FACTORS
  
  $\alpha = 20$
  $\eta = 5 - 20$
  $\beta = 1$
  $\gamma = 1$
Prefixes for Units

1 rem = 1,000 mrem (millirem)

1 mrem = 1,000 µrem (microrem)

*The same holds true for the new SI units, i.e.*, 

1 Sievert (Sv) = 1,000 mSv (millisieverts)

1 mSv = 1,000 µSv (microsieverts)
**Unit Conversions**

<table>
<thead>
<tr>
<th>Source Activity (disintegrations per unit time)</th>
<th>Exposure</th>
<th>Dose</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Old Units</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Curie (Ci) $= 37 \times 10^9$ dps</td>
<td>Roentgen (R)</td>
<td>Rem-roentgen equivalent man</td>
</tr>
<tr>
<td>$dps = \text{disintegrations per second}$</td>
<td>RAD or rad: radiation absorbed dose</td>
<td></td>
</tr>
<tr>
<td><strong>New SI Units</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Becquerel (Bq)</td>
<td>Gray (Gy)</td>
<td>Sievert (Sv)</td>
</tr>
<tr>
<td>$1 \text{ Bq} = 1 \text{ dps}$</td>
<td>$1 \text{ Gy} = 100 \text{ rad}$</td>
<td>$1 \text{ Sv} = 100 \text{ rem}$</td>
</tr>
<tr>
<td>$1 \text{ Ci} = 37 \text{ GBq}$</td>
<td>$1 \text{ rad} = 1 \text{ cGy}$</td>
<td>$1 \text{ rem} = 10 \text{ mSv}$</td>
</tr>
</tbody>
</table>

For gamma and x-ray radiation, a common “conversion factor” between exposure, absorbed dose, and dose equivalent is:

$$1 \text{ R} = 1 \text{ rad} = 1 \text{ rem}$$
Sources of Radiation
Natural Sources of Radiation

- Cosmic radiation
- Terrestrial radiation
- Radon
- Human body
Man-made Sources of Radiation

- Medical radiation
- Nuclear Power
- Consumer products
- Industry and Research
- Other minor sources
Average Doses from Radiation Sources

- Average person in the U.S. receives about 620 mrem each year
  - Natural sources = 310 mrem
  - Medical procedures and consumer products = 310 mrem

<table>
<thead>
<tr>
<th>Source</th>
<th>Dose (mrem)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Living near a nuclear power station (annual)</td>
<td>&lt;1</td>
</tr>
<tr>
<td>Chest X-ray (single procedure)</td>
<td>10</td>
</tr>
<tr>
<td>Terrestrial radioactivity (annual)</td>
<td>21</td>
</tr>
<tr>
<td>Radiation in the body (annual)</td>
<td>29</td>
</tr>
<tr>
<td>Cosmic (at sea level) (annual)</td>
<td>30</td>
</tr>
<tr>
<td>Mammogram (single procedure)</td>
<td>42</td>
</tr>
<tr>
<td>Cosmic (in Denver) (annual)</td>
<td>80</td>
</tr>
<tr>
<td>Head CT scan (single procedure)</td>
<td>200</td>
</tr>
<tr>
<td>Radon in average U.S. home (annual)</td>
<td>228</td>
</tr>
<tr>
<td>Upper gastrointestinal X-ray with fluoroscopy</td>
<td>600</td>
</tr>
<tr>
<td>(single procedure)</td>
<td></td>
</tr>
<tr>
<td>Whole body CT scan (single procedure)</td>
<td>1,000</td>
</tr>
</tbody>
</table>

Unaltered information taken from the 2015 NNSS Environmental Report
Sources of Radiation Exposure

Unaltered information taken from the 2015 NNSS Environmental Report
Biological Effects of Radiation Exposure
Exposure to radiation will cause **none** of these things to happen:

- You will not turn green
- You will not get super powers
- Radiation does not cause things to grow larger
- You will not glow in the dark
Two Categories of Radiation Dose

- Acute
- Chronic
Acute Radiation Doses

- An acute effect is a physical reaction due to massive cell damage.
- Damage caused by a large amount of radiation in a short period of time.
## Acute Radiation Dose Effects

<table>
<thead>
<tr>
<th>Effect</th>
<th>Dose (Rad)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Blood changes</td>
<td>25 – 100</td>
</tr>
<tr>
<td>Anorexia (loss of appetite)</td>
<td>150</td>
</tr>
<tr>
<td>Nausea</td>
<td>200</td>
</tr>
<tr>
<td>Fatigue</td>
<td>220</td>
</tr>
<tr>
<td>Vomiting</td>
<td>280</td>
</tr>
<tr>
<td>Epilation</td>
<td>300</td>
</tr>
<tr>
<td>Diarrhea</td>
<td>350</td>
</tr>
<tr>
<td>Mortality (w/o supportive care)</td>
<td>350</td>
</tr>
<tr>
<td>Mortality (with supportive care)</td>
<td>500</td>
</tr>
</tbody>
</table>
Chronic Radiation Doses

• Chronic radiation dose is typically a small amount of radiation received over a long period of time

• Example: the dose we receive from natural background radiation every day of our lives
Chronic Radiation Dose Effects

- The principal effect of chronic radiation dose is increased risk of contracting cancer.

- No increased risk of cancer has been observed in individuals who receive radiation dose at occupational levels (500 – 5,000 mrem/yr).

- No observable radiation effects in humans below a one-time dose of about 10,000 mrem.
Possible Effects of Radiation on Cells

When a cell is exposed to ionizing radiation, several things can happen:

- No damage
- Cells repair the damage and operate normally
- Cells are damaged and operate abnormally
- Cells die as a result of the damage
Factors Affecting Biological Damage from Radiation

- Total dose
- Dose rate
- Type of radiation
- Area of the body receiving the dose
- Cell sensitivity
- Individual sensitivity
Genetic Effects

There is no direct evidence of radiation-induced genetic effects in humans, even at high doses. Various analyses indicate that the rate of genetic disorders produced in humans is expected to be extremely low, on the order of a few disorders per million live born per rem of parental exposure.
## Comparison of Risks

<table>
<thead>
<tr>
<th>Health Risk</th>
<th>Estimate of Life Expectancy Lost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Smoking 20 cigarettes a day</td>
<td>6 years</td>
</tr>
<tr>
<td>Overweight (by 15%)</td>
<td>2 years</td>
</tr>
<tr>
<td>Alcohol consumption (U.S. average)</td>
<td>1 year</td>
</tr>
<tr>
<td>Agricultural accidents</td>
<td>320 days</td>
</tr>
<tr>
<td>Construction accidents</td>
<td>227 days</td>
</tr>
<tr>
<td>Automobile accidents</td>
<td>207 days</td>
</tr>
<tr>
<td>Home accidents</td>
<td>74 days</td>
</tr>
<tr>
<td>1 rem/yr from age 18 to 65</td>
<td>51 days</td>
</tr>
<tr>
<td>All natural hazards (earthquake, etc.)</td>
<td>7 days</td>
</tr>
<tr>
<td>Medical radiation</td>
<td>6 days</td>
</tr>
</tbody>
</table>
Radiation Protection
ALARA

As Low As Reasonably Achievable

As

Low
ALARA Exposure Practices

There are three basic practices used to maintain exposures to ALARA:

TIME Reduce Exposure Time
DISTANCE Increase Distance
SHIELDING Use Shielding
Time

**DOSE RATE:** Energy per unit time

**DOSE:** Total energy absorbed

Dose = (Dose rate) \times Time

Example of dose rate: 100 mrem/hr
DOSE RATE: Energy per unit time

DOSE: Total energy absorbed

Dose = (Dose rate) x Time

Example of dose rate: 100 mrem/hr

- If you stayed in this dose rate for an hour, what would your total dose be?
- What would your dose be after 15 minutes?
- If your allowed total dose is 75 mrem, what is your stay time?
Inverse Square Law

Double the distance … \( \frac{1}{4} \) the dose rate
Halve the distance … four times the dose rate
Shielding

Shielding: Material between you and the source

- Wax Bricks
- Lead
- Plastic
- Paper

Source
Shielding:
If you can’t be in the shielded booth...
...then stand behind the Doctor
Radiation Dose Limits*

Annual limit for occupational workers 5,000 Mrem
Annual limit for member of public 100 Mrem

* Limits for radiation exposure above background radiation (620 mrem/yr U.S. average from all sources)
ALARA

Radiation exposure to the work force and general public shall be controlled such that exposures are well below regulatory limits and that there is:

no radiation exposure without an equal benefit
Radiological Dose Assessment Goals
(NNSS Environmental Report Chapter 9)

- Limit = 10 mrem/year
  - Determine max dose to the public from air emissions

- Limit = 25 mrem/year
  - Determine max dose to the public from NNSS waste management sites

- Limit = 100 mrem/year
  - Determine max dose to the public from all exposure pathways combined

- Limits = <0.1 rad/day & <1 rad/day
  - Determine dose to terrestrial plants, aquatic animals and to terrestrial animals

Demonstrate Compliance with DOE Limits
Potential Exposure Pathways from NNSS Activities (Past and Present)
Dose to the Public from Natural Background Sources and from the NNSS

- 2015 dose to the public from all pathways is 2.91 mrem/year
  - Maximum dose from inhalation, ingestion, and direct exposure pathways that is attributable from NNSS operations
  - Well below DOE dose limit of 100 mrem/year
  - Indistinguishable from natural background radiation experienced by the public residing in communities near the NNSS

Unaltered information taken from the 2015 NNSS Environmental Report