What Is Radiation?
Natural Philosophy

Contemporary Description
Natural Philosophy

Contemporary Description

Elementary Particles
Natural Philosophy

Elementary Particles

Protons
Neutrons
He, C, Fe

Electrons
Positrons
Muons
Radiation

Any combination of elementary particles with sufficient energy to interact with and transfer energy to objects that intersect their path.
Excitation
Ionization
Radiation

Ionizing

Nonionizing
<table>
<thead>
<tr>
<th>Type</th>
<th>Penetration</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\gamma$</td>
<td>m</td>
</tr>
<tr>
<td>$\beta$</td>
<td>cm</td>
</tr>
<tr>
<td>$\alpha$</td>
<td>&lt;mm</td>
</tr>
</tbody>
</table>
Where does it come from?

Natural
- Sun
- Ground
- Food

Man made
- Hospital
- Reactors
- Weapons
What Is Radioactivity?
Types of Radiation Emitted

α
β
γ
<table>
<thead>
<tr>
<th>Unit</th>
<th>Activity</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Curie</td>
<td>37 billion d/s</td>
</tr>
<tr>
<td>1 µCurie</td>
<td>37 thousand d/s</td>
</tr>
<tr>
<td>1 pCurie</td>
<td>2 d/min</td>
</tr>
</tbody>
</table>
How long does it last?

Half-life

seconds  days  years  centuries
History

1895
Roentgen discovers X-rays

1896
Becquerel discovers Radioactivity

1896
Edison reports observed injury
What do you measure?

Absorbed dose

\[ D = \frac{\text{Energy}}{\text{Mass}} \]

rad  mrad  Gy  mGy
What do you measure?

1 Gy = 100 rad
1 rad = 1 cGy
Radiation

What do you measure?

Effective Dose

\[ H = \text{Dose} \times \text{Relative Risk} \]

rem  mrem  Sv  mSv
Radiation

What do you measure?

External

Internal

Effective Dose = External + Internal
How much radiation are persons receiving?

Natural Background in US ~ 3 mSv/y
1980

- **Medical**: 15%
- **Other**: 3%
- **Internal**: 11%
- **Terrestrial**: 8%
- **Cosmic**: 8%
- **Radon**: 55%
How much radiation are persons receiving?

Natural Background in US ~ 3 mSv/y

Natural Background in CO ~ 5 mSv/y
How much radiation are persons receiving?

Natural Background in US ~ 3 mSv/y

Medical exposures in US ~ 3 mSv/y

Total exposures in US ~ 6.3 mSv/y
Why is Radiation Bad for you?
Cellular Effects

Ionizing radiation can have a direct effect on the contents of a cell nucleus

Specifically it can damage DNA
Cellular Effects

Breaks in DNA

Some of these are repaired

Cell killing

Apoptosis  Mytotic death

Tissue Effects
Cellular Effects
Breaks in DNA
Some of these are repaired
Mutations
Chromosome Aberrations
Cancer
Cellular Effects

Tissues with proliferating (dividing) cells are more sensitive to radiation
Types of Radiation Injury

Acute Effects

Late Effects
Types of Radiation Injury

Acute Effects

Phases of Acute Exposure

Prodromal

Latent period

Appearance of syndromes
Types of Radiation Injury

Acute Effects

Prodromal

Nausea
Survival Probable

Vomiting
Survival Questionable

Diarrhea
Survival Unlikely
Types of Radiation Injury

Acute Effects

(2 to 5 Gy) total body

Hematopoietic syndrome

Blood forming organs

Death: 2 to 10 weeks
Types of Radiation Injury

Acute Effects

(5 to 20 Gy) total body

Gastrointestinal syndrome

Extensive bloody diarrhea

Death: 2 to 7 days
Types of Radiation Injury

Acute Effects

(> 50 Gy) total body

Neurological and cardiovascular failure

Survival: 1 to 2 days
Types of Radiation Injury

Acute Effects

$LD_{50}$

Mouse

$\sim 7$

Human

$\sim 4$

$LD_{50}$ increased with medical intervention
Types of Radiation Injury

Late Effects

Definite Effects

Severity proportional to dose

Cataracts $D_{\text{threshold}} \sim 5 \text{ Gy}$

Erythema $D_{\text{threshold}} \sim 7 \text{ Gy}$
Types of Radiation Injury

Late Effects

Stochastic Effects

Probability of occurrence is proportional to dose

Hereditary

Cancer
History

Before 1950
Focus on Definite effects

After 1950
Focus on Stochastic Effects
What is the risk for Radiation Carcinogenesis
How bad is radiation?

Cancer

Many causes of cancer:

Cannot determine cause of a diagnosed cancer

How do we know that radiation can cause cancer?
Radiation Biology

You can measure Dose
You do not have humans
Epidemiology

Hiroshima, Japan

Chernobyl
Epidemiology

You have exposed humans

You do not have measured dose

You must estimate dose

Dose reconstruction
Radiation Induced Cancer

Probability

Dose

Age at Exposure

Time since exposure

Sex
Radiation Induced Cancer

Probability

Dose
Risk Vs. Dose

Threshold
Risk Vs. Dose

Linear; No Threshold
Linear No Threshold (LNT)

The fact that we need a LNT model implies that the risk has to be be small.

There is no level of radiation that is safe because the risk is always greater than zero.
Radiation Induced Cancer

Probability

Time since exposure

Latent period

Leukemia: 1-10 years
Radiation Induced Cancer

Probability

Time since exposure

Latent period

Thyroid: 1-10 years
Radiation Induced Cancer

Probability

Time since exposure

Latent period

Female Breast: 10-20 years
Radiation Induced Cancer

Probability

Time since exposure

Latent period

Excess cancers still being identified for Japanese Bomb Survivors ( >60 years)
Radiation Induced Cancer

Probability

Age at exposure

Risk decreases with age at exposure
Radiation Induced Cancer

Probability

Sex

Breast, Uterus, Ovary

Prostate
## Radiation Induced Cancer

<table>
<thead>
<tr>
<th>Breast</th>
<th>Lung</th>
</tr>
</thead>
<tbody>
<tr>
<td>Colon</td>
<td>Bladder</td>
</tr>
<tr>
<td>Leukemia</td>
<td>Thyroid</td>
</tr>
<tr>
<td>Prostate</td>
<td>Ovary</td>
</tr>
<tr>
<td>Stomach</td>
<td>Uterus</td>
</tr>
<tr>
<td>Liver</td>
<td></td>
</tr>
</tbody>
</table>
## Radiation Induced Cancer

<table>
<thead>
<tr>
<th>Breast</th>
<th>Lung</th>
</tr>
</thead>
<tbody>
<tr>
<td>Colon</td>
<td>Bladder</td>
</tr>
<tr>
<td>Leukemia</td>
<td>Thyroid</td>
</tr>
<tr>
<td>Prostate</td>
<td>Ovary</td>
</tr>
<tr>
<td>Stomach</td>
<td>Uterus</td>
</tr>
<tr>
<td>Liver</td>
<td></td>
</tr>
<tr>
<td>Gall Bladder</td>
<td>Myeloma</td>
</tr>
<tr>
<td>Bone Surface</td>
<td>Kidney</td>
</tr>
<tr>
<td>Pancreas</td>
<td>Pharynx</td>
</tr>
<tr>
<td>Small Intestine</td>
<td>Bile Duct</td>
</tr>
<tr>
<td>Salivary Gland</td>
<td>N-H Lymphoma</td>
</tr>
<tr>
<td>Brain</td>
<td>Bile Duct</td>
</tr>
</tbody>
</table>
Radiation Induced Cancer

What is the best estimate of risk to a population of people?

Excess lifetime attributable to radiation

5% / SV  ~10^{-5} / mSV
Radiation Induced Cancer

New Questions

Is the fear of radiation proportional to dose?

Does the fear of radiation cause an increase of disease?
Thank you
Radiation Induced Cancer

LNT used for policy and regulations

Is there a threshold ???

Does a low dose to many persons result in unacceptable risks to the population ???
Radiation Protection Regulations

- Adult Occupational: 50 mSv/y
- Fetus: 5 mSv/Gestation
- General Public: 1 mSv/y
What should we do about this?

• Radiation Safety •
Objectives

Prevent occurrence of deterministic effects

Limit the risk of stochastic effects
Philosophy

Justification

Optimization

Limitation
What is Acceptable ?
The risk of fatality from occupational exposure to radiation should be no more that the risk of fatal accidents in industries that are recognized for having high standards of safety.
Radiation Limits

Occupational

Annual

Adults

50 mSv External + Internal

150 mSv Eyes

500 mSv Skin, extremeties
Radiation Limits

Occupational

Annual

Minors

? % of Adult Limits
Radiation Limits

Occupational

Fetus

Gestation period

5 mSv

Declared pregnancy
Radiation Limits

General Public

Annual

1 mSv

External + Internal
Natural Background Radiation

External

- Cosmic: 0.3 mSv/y
- Terrestrial: 0.3 mSv/y

Internal

- Body: 0.4 mSv/y
- Radon: 2.00 mSv/y

TOTAL: 3.00 mSv/y
Natural Background Radiation

External
- Cosmic: 0.3
- Terrestrial: 0.3

Internal
- Body: 0.4
- Radon: 2.00

TOTAL
- 3.00

TOTAL
- 5.00
Medical Examinations

- X-rays
  - Abdomen: 0.4 mSv
  - Chest: 0.06 mSv
  - Pelvis: 0.6 mSv
  - Dental: 0.03 mSv
- Mammography: 0.3 mSv
- CT (full body): 10 mSv
- Nuclear medicine: 20 mSv
# Radiation Induced Cancer

<table>
<thead>
<tr>
<th>Leukemia</th>
<th>Lung</th>
</tr>
</thead>
<tbody>
<tr>
<td>Colon</td>
<td>Stomach</td>
</tr>
<tr>
<td>Breast</td>
<td>Esophagus</td>
</tr>
<tr>
<td>Liver</td>
<td>Thyroid</td>
</tr>
<tr>
<td>Urinary Bladder</td>
<td>Bone Surface</td>
</tr>
<tr>
<td>Bile Duct</td>
<td>Brain</td>
</tr>
<tr>
<td>Gall Baldder</td>
<td>Myeloma</td>
</tr>
<tr>
<td>Ovary</td>
<td>Kidney</td>
</tr>
<tr>
<td>Pancreas</td>
<td>Pharynx</td>
</tr>
<tr>
<td>Small Intestine</td>
<td>Skin</td>
</tr>
<tr>
<td>Salivary Gland</td>
<td>N-H Lymphoma</td>
</tr>
</tbody>
</table>