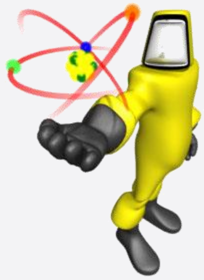


Nuclear Safety (Week 8 / Day 1)

Lecture #1: Overview of Radiation Safety

SAND2016-XXXX

Gulf Nuclear Energy Infrastructure Institute – 2016 Fundamentals Course

Mr. Brian Thomson
Sandia National Laboratories

*Sandia National Laboratories is a multi-program laboratory managed and operated by Sandia Corporation, a wholly owned subsidiary of Lockheed Martin Corporation, for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-AC04-94AL85000

Week 8 Learning Objectives

Learning Objectives:

- Understand the basics of radiation safety
- Understand the common causes of human error
- Understand the role and importance of Operational Radiation Protection and Environmental Monitoring Programs
- Understand the role and importance of emergency preparedness
- Understand the role and impact of human performance on the causes and/or consequences of the Three Mile Island, Chernobyl, and Fukushima Reactor Accidents

Week 8 / Day 1 Learning Objectives

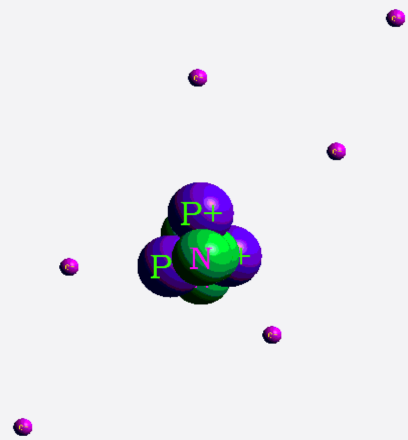
- To review basic information related to Radiation Safety, and how it relates to the safe use of nuclear power.
- To review key Human Performance Improvement (HPI) principles and how they relate to human and organizational performance.

Week 8 / Day 1 / Lecture #1 Outline

- Ionizing Radiation – the Basics
- Radioactivity, Radioactive Material, & Radioactive Contamination
- Measuring Radiation and Radioactivity
- Sources of Radiation
- Biological Effects of Radiation Exposure
- Monitoring for Radiation Exposure
- As Low As Reasonably Achievable (ALARA) – Concept & Implementation

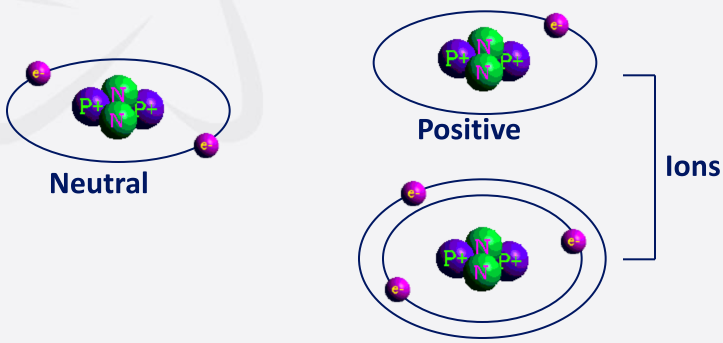
Atomic Structure

- Protons (positive)
- Neutrons (neutral)
- Electrons (negative)



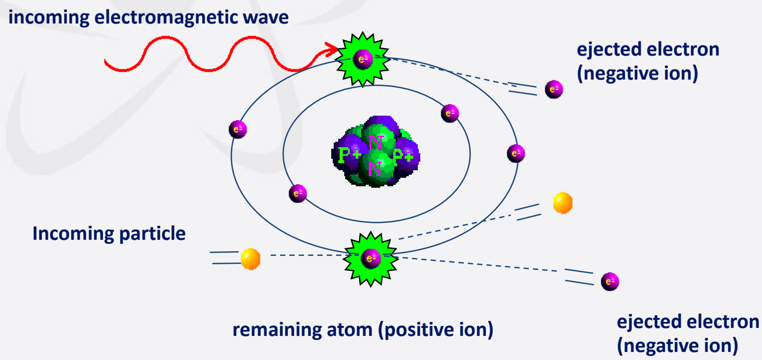
Ions

Ions are atoms with _positive_ or _negative_ charge



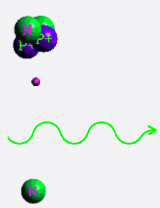
Ionization

The <u>process</u> of removing electrons from atoms



Ionizing Radiation

- Radiation that possesses enough energy to <u>cause ionization</u> in the atoms with which it interacts
- Released from unstable atoms and some devices in the form of rays or particles
- Examples:
  - Alpha (particle) α
  - Beta (particle) β
  - Gamma/x-ray (ray) γ
  - Neutron (particle) η



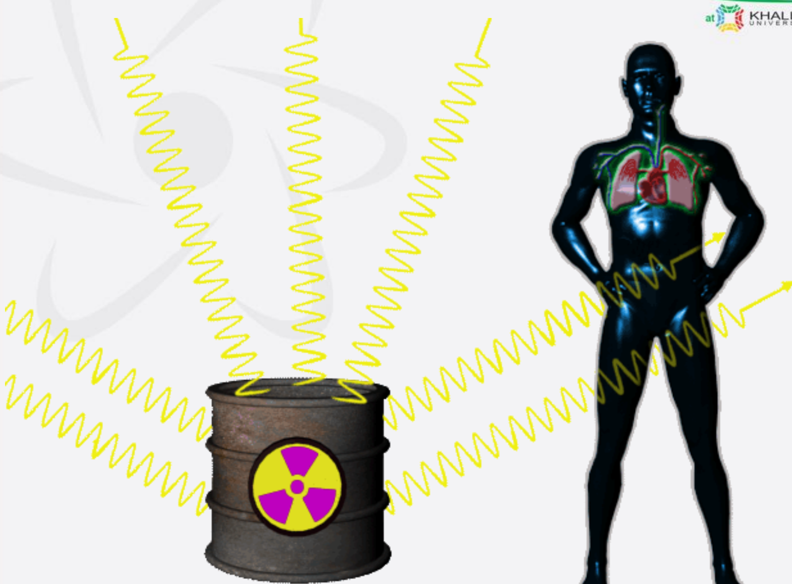
Non-Ionizing Radiation

- Radiation that does *not* have enough energy to ionize atoms with which it interacts
- Examples:
  - radio waves
  - infrared radiation
  - visible light
  - radar waves
  - microwaves

Radioactive Material vs. Contamination

- Recall: Radiation is energy
- Radioactive Material = the physical material emitting the radiation (energy)
- Radioactive Contamination = radioactive material that is uncontained and in an unwanted place
- Exposure to radiation will *not* cause you to become contaminated

Radioactive Material vs. Contamination (Cont.)



Radiation = Energy

11

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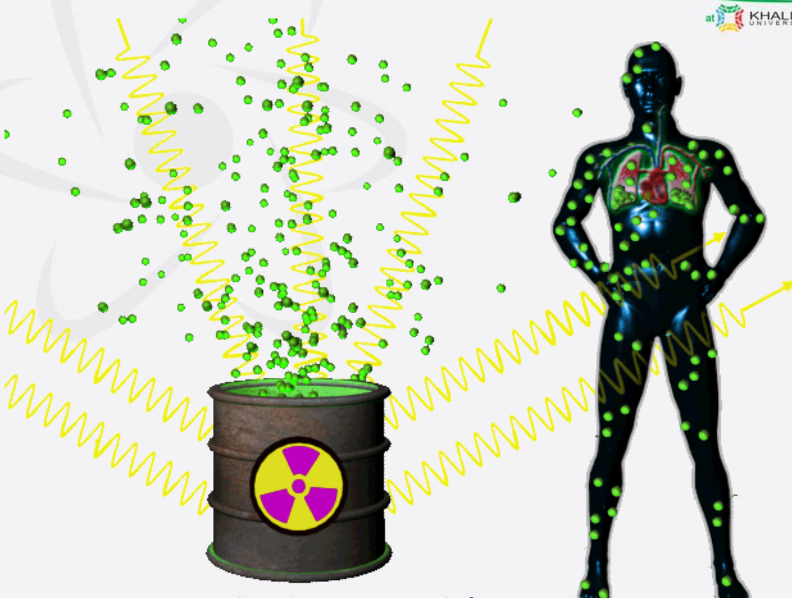
Radioactive Material vs. Contamination (Cont.)



Contamination = Material

12

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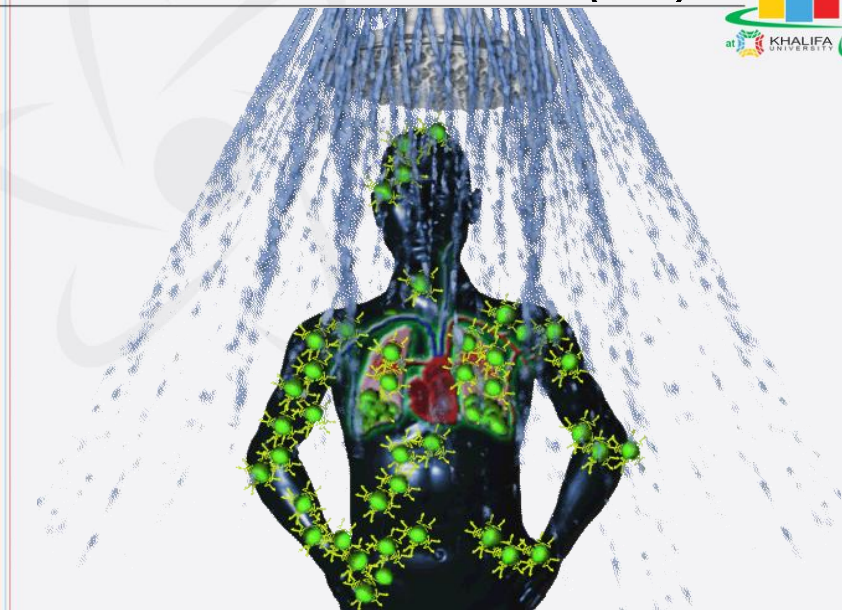
Radioactive Material vs. Contamination (Cont.)



External contamination is easily removed

Radioactive Material vs. Contamination (Cont.)

Internal contamination is NOT easily removed

Types of Radioactive Contamination

- Fixed

- Contamination that can not be readily removed from surfaces
- Detected by direct frisking of the item or surface

Types of Radioactive Contamination

- Removable

- Contamination that can be readily removed from surfaces
  - May be transferred by casual contact
  - Air movement may cause removable to become airborne
- Measured by wiping the area with a piece of paper and then counting the sample

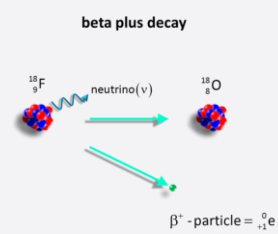
Types of Radioactive Contamination

- Airborne

- Contamination suspended in air - dusts, fumes, particulates, mists, vapors, or gases
- Radiation Protection personnel have equipment designed to sample the air for airborne contamination
  - Air is pulled through a filter paper, and the paper is counted using a contamination monitoring instrument

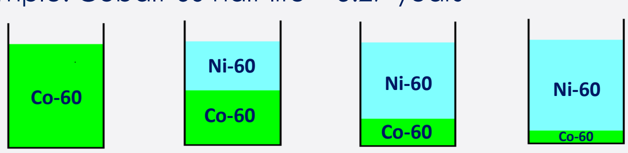
Radioactivity vs. Radioactive Half-Life

- Radioactivity - the *process* of unstable atoms becoming stable by emitting radiation



- Radioactive Half-Life - the time it takes for one half of the radioactive atoms present to decay

Example: Cobalt-60 half-life = 5.27 years



100 atoms today | 50 atoms after 5 yrs | 25 atoms after 10 yrs | 12 atoms after 15 yrs

Measuring Radiation

- Gray (Gy)

- SI Unit = Gray (Gy) an absorbed dose of 1 joule/kilogram.
- Unit for measuring absorbed dose in any material
- Applies to all types of radiation
- Does not take into account the potential effect that different types of radiation have on the body
- Gray is a very large unit
  - mGy (0.001 Gy)
  - µGy (0.000001 Gy)

1 Gy = 100 rad

Measuring Radiation

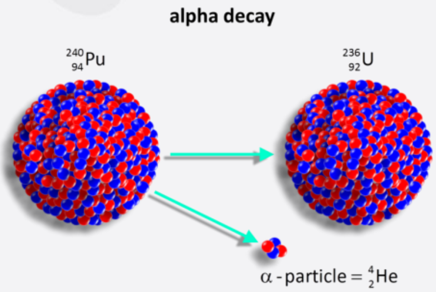
- Sievert (Sv)

- SI Unit = Sievert (Sv) unit for measuring dose equivalence
- Pertains to the human body
- Takes into account the energy absorbed (dose) and the biological effect on the body due to the different types of radiation
- Sievert is a very large unit
  - mSv (0.001 Sv)
  - µSv (0.000001 Sv)

1 Sv = 100 rem

Measuring Radioactivity

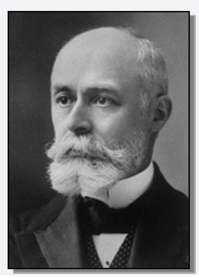
- A measure of the number of spontaneous disintegrations radioactive material undergoes in a certain period of time
- We measure the rate of decay, which leads us to the quantity of radioactive material present



Radioactivity Units

Basic Unit:

- Becquerel (Bq)
- 1 Bq = 1 disintegration per second (dps)
- dps = derived from instrument counts and counting efficiency



Henri Becquerel
1852 - 1908
Discovered
natural radioactivity

Contamination Units

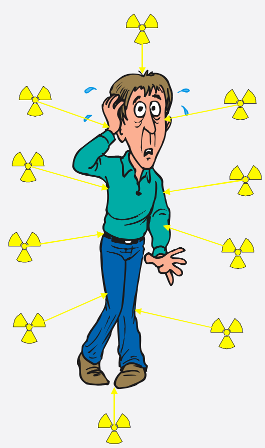
How spread out is the radioactive material?

$$\frac{\text{Radioactivity (Bq)}}{\text{Area (cm}^2\text{) or Volume (m}^3\text{)}}$$

Background Sources of Ionizing Radiation

Background = natural + man-made

We are *constantly* exposed to background radiation, from both natural and man-made sources



Natural Sources of Background Radiation

SOURCE	AVG DOSE
COSMIC - sun & outer space	30 - 39 mrem/yr (0.3 – 0.39 mSv/yr)
TERRESTRIAL - Earth's crust	21 - 48 mrem/yr (0.21 – 0.48 mSv/yr)
INTERNAL - our own bodies	28 - 40 mrem/yr (0.29 – 0.4 mSv/yr)
RADON - Uranium in the Earth	126 - 228 mrem/yr (1.26 – 2.28 mSv/yr)

https://en.wikipedia.org/wiki/Background_radiation

Man-Made Sources of Background Radiation

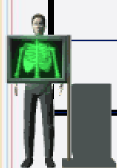
SOURCE	AVG DOSE
Medical	300 mrem (3 mSv)/yr (USA) 60 mrem (0.6 mSv)/yr (World)
Consumer Products	13 mrem/yr (USA) (0.13 mSv/yr)
Industrial Uses	< 1 mrem/yr (< 0.01 mSv/yr)
Atmospheric Testing	0.5 mrem/yr (World) (0.005 mSv/yr)

https://en.wikipedia.org/wiki/Background_radiation

Man-Made Sources of Background Radiation

- Medical

Radiation Therapy	600,000 mrem - tumor (6,000 mSv)
CAT Scan	5,800 mrem - head 1,500 mrem - lower spine (58 / 15 mSv)
Fluoroscope	5,000 mrem/min. - skin (50 mSv)
Mammogram	400 mrem - breast 0.2 mrem (low-dose screen) (4 / 0.002 mSv)
Dental X-Ray	0.5 - 1 mrem/shot - mouth (0.005 – 0.010 mSv)
Chest X-Ray	20 - 50 mrem/shot - chest (0.2 – 0.5 mSv)



Man-Made Sources of Background Radiation

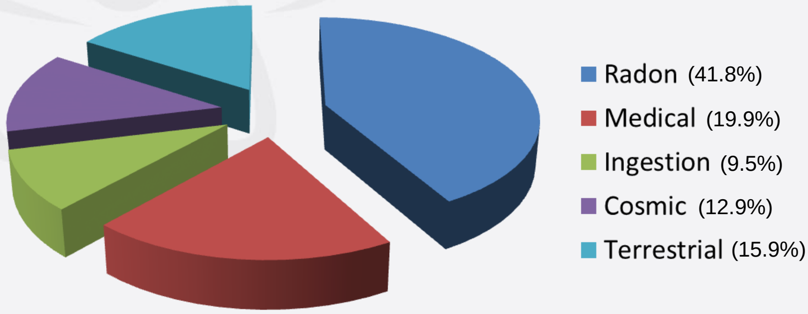
- Consumer Products

PRODUCT	AVG DOSE
Cigarettes (1.5 packs/day)	8,000 mrem/yr - lungs (80 mSv/yr)
Dental Porcelain (old)	60,000 rem/yr - gums (600 mSv/yr)
Tinted Glasses (old)	4,000 rem/yr - eyes (40 mSv/yr)
Building Materials	7 mrem/yr - whole-body (0.07 mSv/yr)
Radium Dial Watch	6 mrem/yr - whole-body (0.06 mSv/yr)
Smoke Detector	1 mrem/yr - whole-body (0.01 mSv/yr)

World Average

- Radiation Doses from Natural and Man-Made Sources

World Average Doses from Background Radiation



(Ref.: United Nations Scientific Committee on the Effects of Atomic Radiation, UNSCEAR 2008)

World Average (Cont.)

- Radiation Doses from Natural and Man-Made Sources

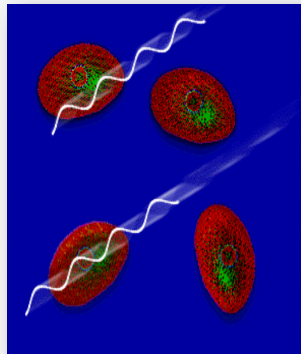
The average annual doses to the world population from all sources of radiation is estimated to be 3.01 mSv/year (301 mrem/year)

- Compared to 6.24 mSv/year (624 mrem/year) for the U.S.

Ref.: https://en.wikipedia.org/wiki/Background_radiation

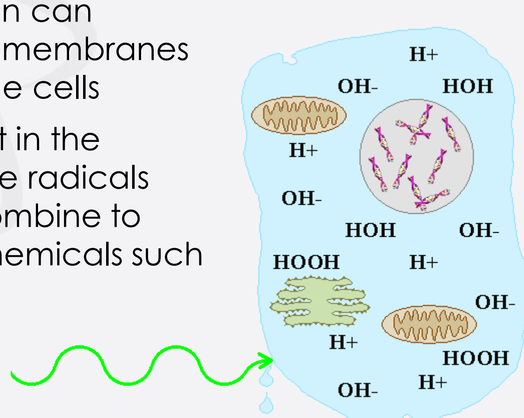
Radiation Risk

- Radiation exposure comes from a variety of natural and man-made sources
- The method by which radiation causes damage to human cells is by *ionization of atoms in the cells*
- Any potential radiation damage begins with damage to atoms



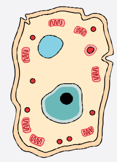
Cell Damage

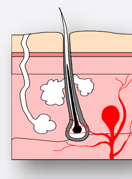
- Ionizing radiation can directly rupture membranes that surround the cells
- Ionizations result in the formation of free radicals which can recombine to form harmful chemicals such as H_2O_2



Cell Sensitivity

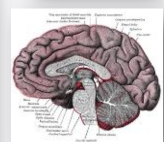
Some cells are more sensitive than others to environmental factors (viruses, toxins, ionizing radiation).





Highest Sensitivity:

- Actively dividing cells
- Non-specialized cells
- Examples: blood forming cells, hair follicles, cells that form sperm



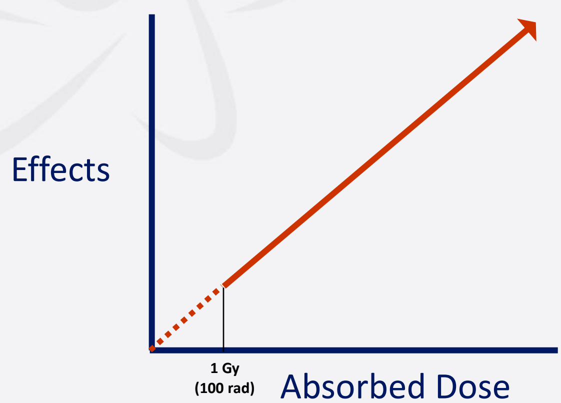
Lowest Sensitivity:

- Less actively dividing cells
- More specialized cells
- Examples: brain and muscle cells

Radiation Damage Factors

- Total Dose Received

In general, the greater the dose, the greater the potential for biological effects.



Radiation Damage Factors

- Dose Rate

The faster the dose is delivered, the less time the body has to repair itself.

$$\frac{3.6\ \text{Sv}}{50\ \text{y}} = \frac{72\ \text{mSv}}{\text{y}} \times \frac{1\ \text{y}}{50\ \text{w}} \times \frac{\text{w}}{40\ \text{h}} = \frac{36\ \mu\text{Sv}}{\text{h}}$$

→ ≈26% increased risk of being diagnosed with cancer*

versus

$$\frac{3.6\ \text{Sv}}{1\text{h}}$$

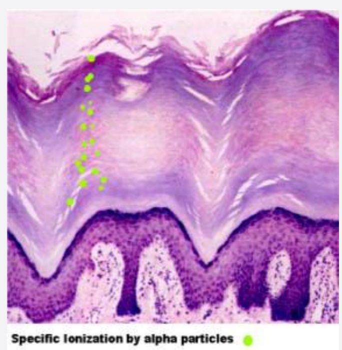
→ 50% chance of dying in 60 days without medical intervention

*BIER VII Phase 2

Radiation Damage Factors

- Type of Radiation

The specific ionization of X- and gamma rays does not create ion pairs as close together as particle radiation



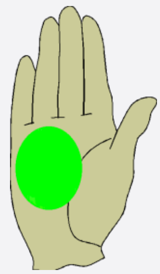
The specific ionization of particle radiation is higher as ionization occurs more frequently and at closer intervals along the path.

Radiation Damage Factors

- Area of the Body Exposed

- In general, the larger the area of the body that receives a dose, the greater the biological effect
- Extremities are less sensitive than blood forming and other critical organs

vs.



Radiation Damage Factors

- Individual Sensitivity

Age

- The human body becomes less sensitive to ionizing radiation with increasing age; however, elderly people are more sensitive than middle-aged adults

Genetic make-up

- Some individuals are more sensitive to environmental factors

Prenatal Sensitivity

Embryo/fetus cells are rapidly dividing, which makes them sensitive to many environmental factors including ionizing radiation.

Possible effects:

- Slightly Smaller Head Size
- Lower Birth Weight
- Increased Incidence of Mental Retardation
- Increased Risk of Childhood Cancer

Source: http://www.exilestan.com/tag/connection/

Source: http://www.scienceclarified.com/El-Ex/Embryo-and-Embryonic-Development.html

Acute vs. Chronic Radiation Dose

Potential biological effects depend on how much and how fast a radiation dose is received.

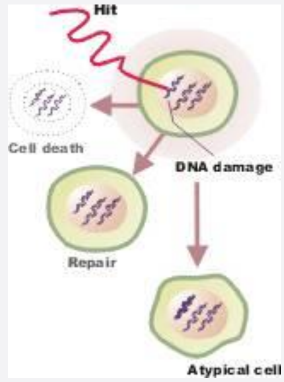
Radiation doses are grouped into:

- **Acute** - high dose of radiation received in a short period of time (seconds to days)
- **Chronic** - a small dose of radiation received over a long period of time (months to years)

Acute Radiation Dose

The body's cell repair mechanisms are not as effective for repairing damage caused by an acute dose.

- Damaged cells will be replaced by new cells and the body will repair itself, although this may take a number of months
- In extreme cases the dose may be high enough that recovery would be unlikely



Effects of Acute Radiation Exposure

AVG DOSE	DAMAGE
> 50,000 mSv (> 5000 rem)	Death Within 2-3 Days
> 5000 mSv (>500 rem)	Gastrointestinal Damage
3,200 - 3,600 mSv (320 -360 rem)	LD_{50}
2,000 - 5,000 mSv (200 – 500 rem)	Blood System Damaged
1,000 - 2,000 mSv (100 – 200 rem)	Radiation Sickness
250 - 500 mSv (25 – 50 rem)	Slight Blood Changes
20 mSv (2 rem)	Annual Limit

Chronic Radiation Dose

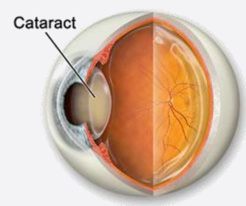
The human body is better equipped to tolerate chronic doses.

Typical examples include:

- The doses commonly received from natural background
- The doses commonly received from occupational exposure

Effects of Chronic Radiation Exposure

- Increased risk of cataract formation (eye doses > 4,500 mSv)
- Increased risk of developing cancer



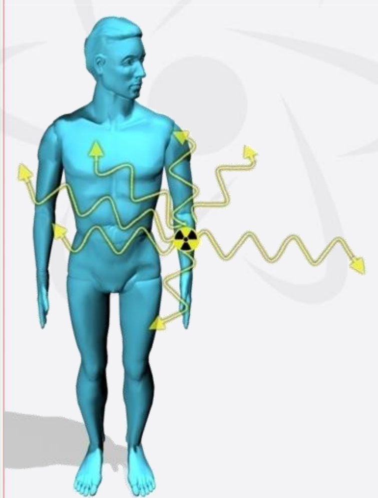
Source: http://www.sightsurgeryinternational.com/

Source: http://medicalpptonline.blogspot.com/2010/10/complicated-cataract-cataract.html

Source: http://tocancer.com/

Source: http://christienpaul.com/body/beat-cancer-without-chemo/

Monitoring for External Exposure



The body can be exposed to radiation from sources internal and external to the body.

External dosimetry is used to monitor exposure to radiation emanating from sources external to the body.

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Monitoring for External Exposure (Cont.)

EO01

- Personnel Monitoring Devices

Various types of dosimetry devices are used to measure personal dose received from exposure to external sources of radiation:

Whole-Body Dosimeter (TLD)

Electronic Personal Dosimeter (EPD)

Extremity Dosimeter

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Monitoring for External Exposure (Cont.)

- Whole-Body Dosimeter

The Thermoluminescent Dosimeter (TLD) is the primary device used to determine your occupational dose received from external sources.

Monitoring for External Exposure (Cont.)

- Electronic Personal Dosimeter (EPD)

- Used in some countries to supplement the whole-body TLD; *in other countries (e.g., Europe), the use of EPDs has replaced the use of whole-body TLDs*
- Sensitive to X-ray, gamma and beta radiation
- Measures dose and dose rate
- Provides dose and dose rate alarms
- Provides immediate, real-time, running of whole-body dose received

Monitoring for External Exposure (Cont.)

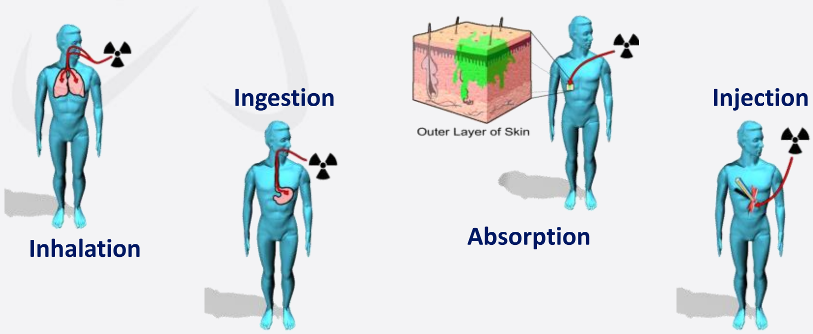
E001

- Extremity Dosimeters

- Normally consists of a (2)TLD chips, divided by a Tin shield, embedded in a finger ring
- One normally issued – worn on the most exposed extremity
- One per extremity can be issued – to be worn separately when in use
- Worn under protective clothing such as gloves

Internal Exposure Pathways

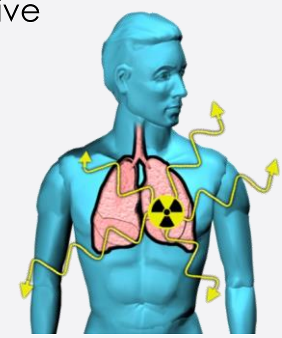
Internal dose results from radioactive material being taken into the body through:



Monitoring for Internal Exposure

E002

- Measure the amount of radioactive material present inside the body
- Calculate an internal dose
- Conducted to monitor workers for internal exposure to fission and activation products, Transuranics, tritium, etc.



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Monitoring for Internal Exposure (Cont.)

- Bioassay

- Whole-body Counting (In-vivo)
  - Does not measure low-energy betas (e.g., Tritium)

- Sample(s) provided for analysis (In-vitro)
  - Examples:
    - Urine (most common)
    - Feces
    - Hair
    - Blood

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Monitoring for Internal Exposure (Cont.)

- Personal Air Sampling

Personal air sampling equipment may be used to sample the air in the breathing zone for radioactive material.

Somatic Effects vs. Heritable Effects

Somatic effects appear in the exposed individual.

Examples:

- Cells may become cancerous
- Increased risk of cataract formation
- Possible life-shortening

Heritable (genetic) effects appear in future generations

- Not yet observed in human populations

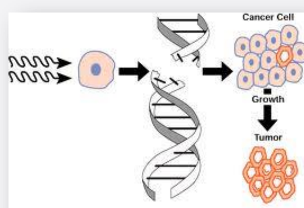


Figure 1. Development of cancer from mutation produced by ionizing radiation.

Source: http://itp.nyu.edu/~ad1790/blog/design-frontiers-final-project-proposal/

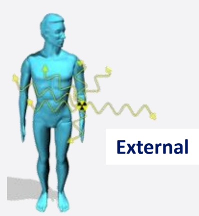
Cancer Risk from Radiation Exposure

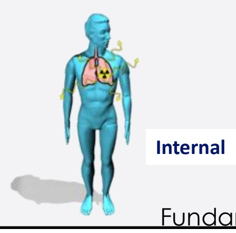
- Health effects observed in humans at acute doses in excess of 250 mSv
- No increase in cancer observed in individuals who receive a dose of ionizing radiation at occupational levels
- The possibility of cancer induction cannot be dismissed even though an increase has not been observed
  - Current rate of cancer death is about 10%*
  - An individual who receives 250 mSv over a working life increases his/her risk of cancer to about 19%

*World Cumulative risk average (age 0-64)

As Low As Reasonably Achievable (ALARA)

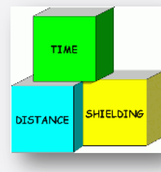
- Philosophy that strives to manage and control doses (individual and collective) to as low as is reasonably achievable
- Includes reducing both **external** and **internal** exposure
- Assumes that any exposure involves some risk
- No exposure without commensurate benefit





ALARA Implementation

- Basic protective measures used to reduce external doses:
  - minimizing **time**, maximizing **distance**, use of **shielding**, source reduction
- Basic protective measures used to reduce internal doses:
  - containments, robust contamination control program, personal protective equipment

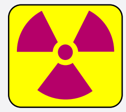


ALARA Implementation (Cont.)

- Personnel radiation doses are maintained ALARA through a combination of:
  - Administrative controls
    - radiological postings
    - warning labels and signals
    - work control documents
    - training
  - Engineered controls
    - safety interlocks
    - radiation shielding

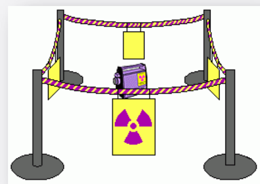
ALARA Implementation (Cont.)

- Radiological Postings



Alert personnel to the presence of radiological hazards

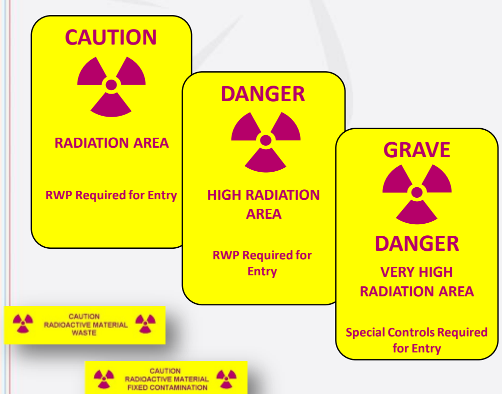
- hazards designated with a magenta (or black) standard radiation symbol on yellow background
- areas designated with yellow and magenta rope, chain, tape, or similar barrier material
- signs and physical barriers placed to be clearly visible from all entrances and accessible directions

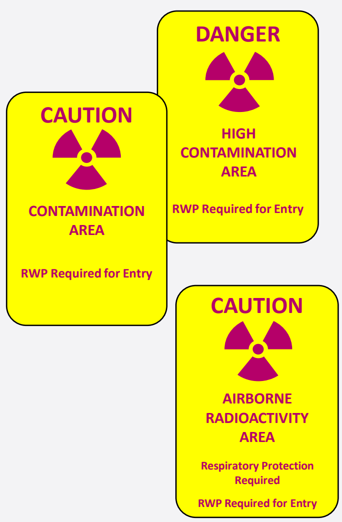


ALARA Implementation (Cont.)

- Radiological Postings and Labels

Examples:



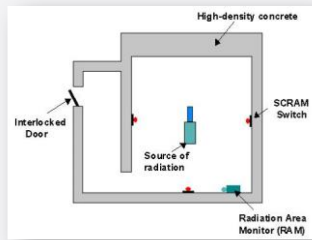


ALARA Implementation (Cont.)

- Engineered Controls

Radiation exposure in radiologically controlled areas is maintained ALARA *primarily* through facility established engineered controls:

- installed shielding
- containment systems
- facility design
- safety interlocks
- key- or code-controlled locks



ALARA Implementation (Cont.)

- Personal Protective Equipment (PPE)

Disposable Coveralls:

- The most commonly used
- Protects against skin, hair, and personal clothing contamination
- Frequently used with respiratory protection

Plastic Suits (with Supplied Air):

- Provides a high degree of protection
- Seldom needed - engineering comes first
- Slow to don, cumbersome, expensive
- Provides a source of breathing air

Questions?