QUESTIONS ABOUT RADIATION AND HEALTH

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A presentation to the Northern New Mexico Citizens Advisory Board

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What will be covered?

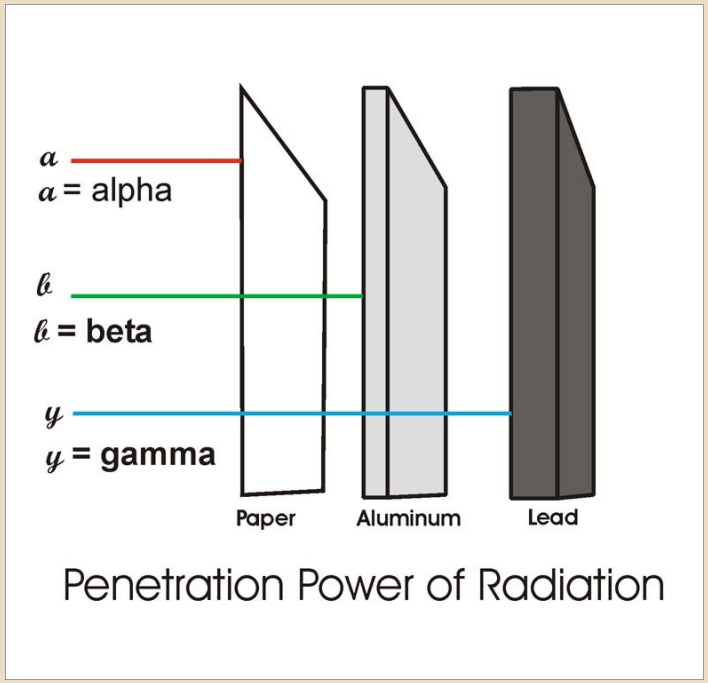
- Types of radiation
- What is ionizing radiation (IR)?
- How does exposure occur?
- Biological effects of IR
- How is dose calculated?
- Health effects of IR
  - Non-cancer
  - Cancer

Types of Radiation

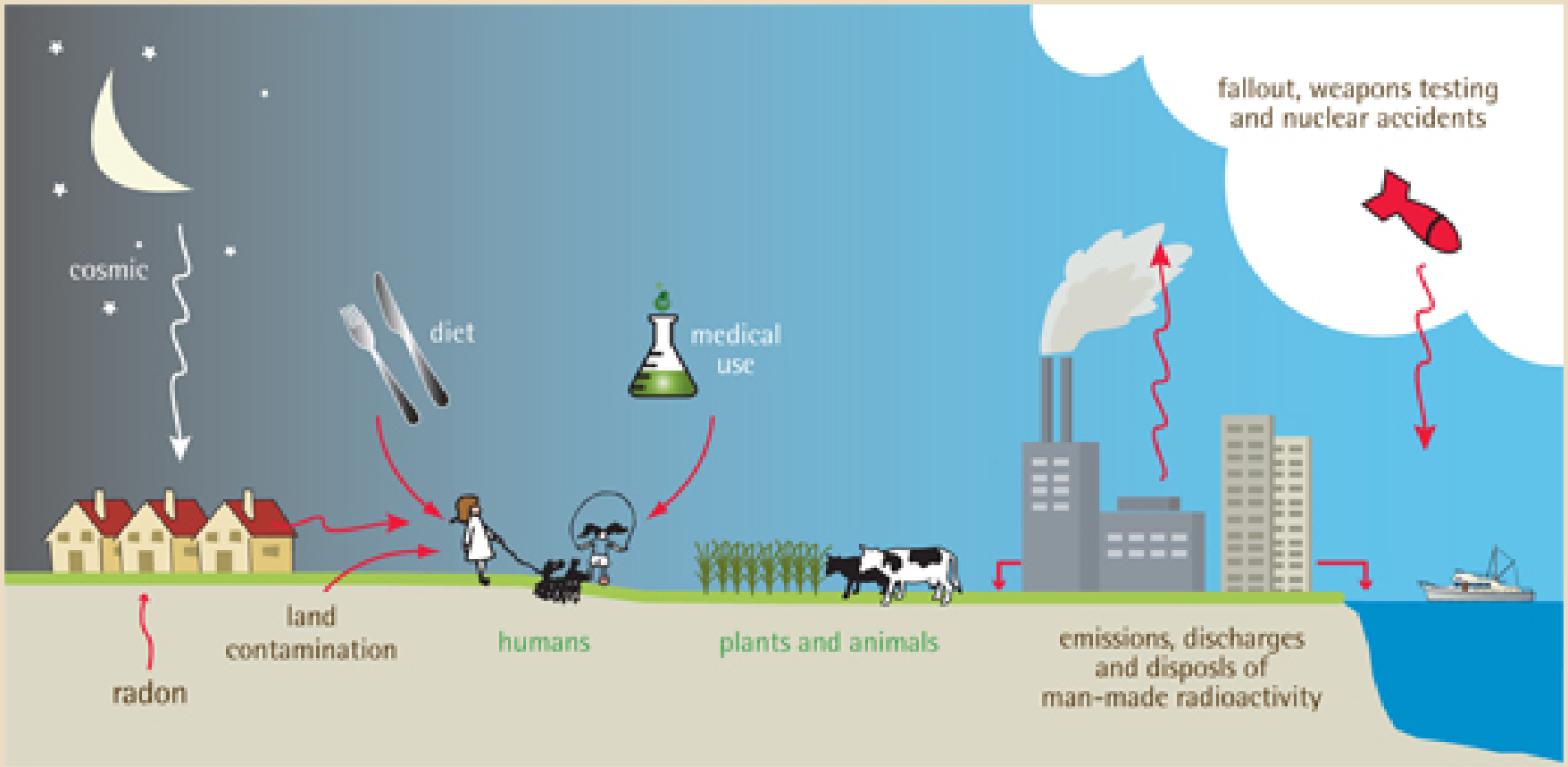
- Ionizing radiation (focus of this presentation)
- Non-ionizing radiation
  - Microwaves
  - Ultrasound
  - Ultraviolet radiation/light
  - Laser-emitted
  - Infrared radiation
  - Visible light

What is Ionizing Radiation?

- Alpha (α) radiation or particles – stopped by paper
- Beta (β) radiation or particles – stopped by glass/aluminum
- Gamma (γ) rays or electromagnetic radiation – most stopped by lead



Sources of Ionizing Radiation Exposure



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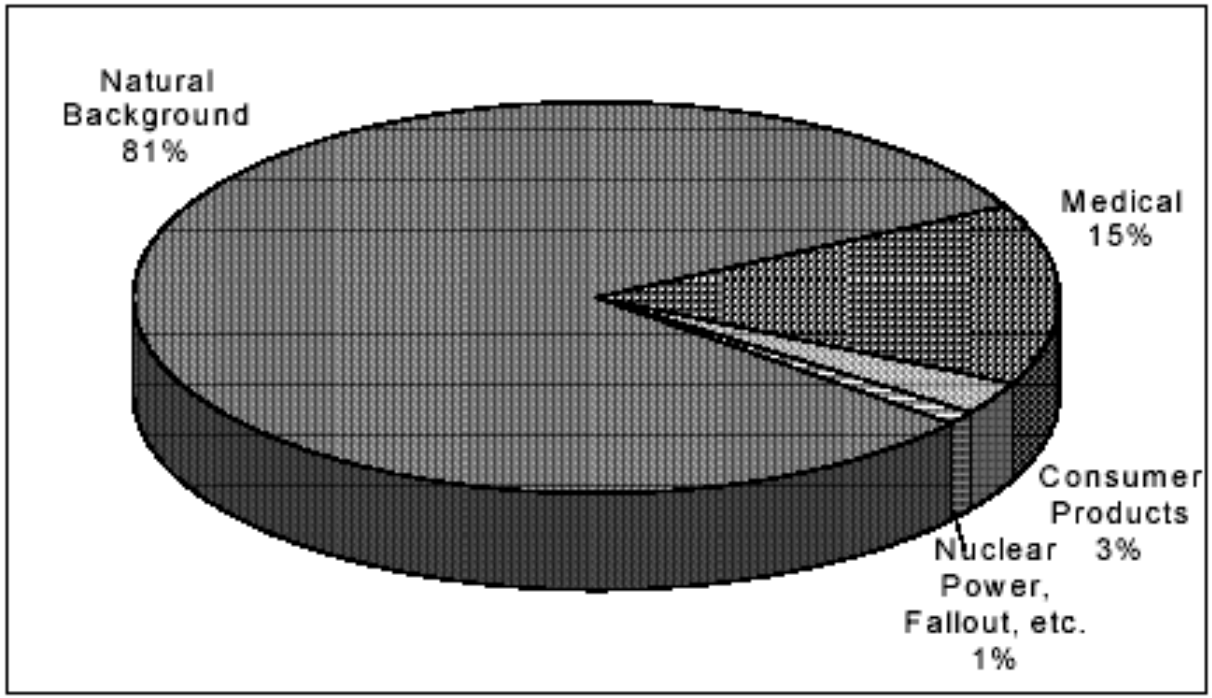
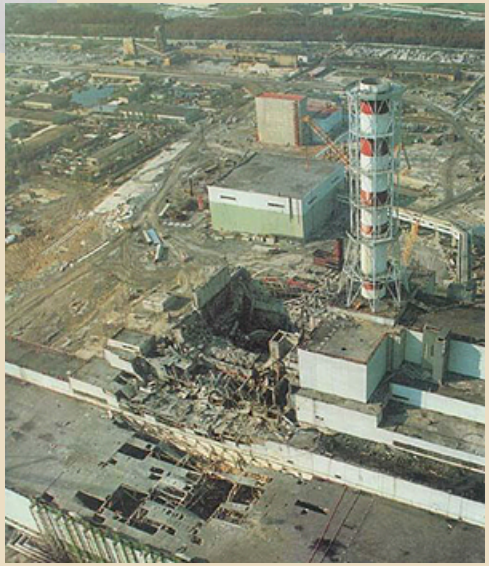


Figure 1-1. Sources of Radiation Exposure to the Average U.S. Citizen
(adapted from NCRP 1987a)

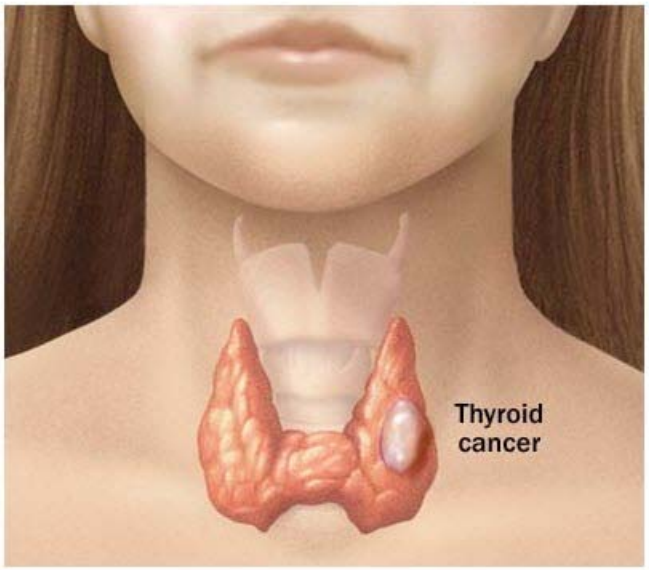
How does exposure to IR occur?

- External (e.g., X-rays, γ-rays)
- Internal (result from ingestion, inhalation, dermal absorption, or injection of radionuclides)
- Difference between internal and external sources largely related to:
  - the distribution of dose within and among body organs
  - the duration of exposure
    - an internal source might stay in the body for a long time and irradiate tissues
    - once the external exposure is over, there is no longer delivery of ionizing radiation within body cells.

Sources of External Exposure to Radiation



Sources of Internal Exposure to Radiation



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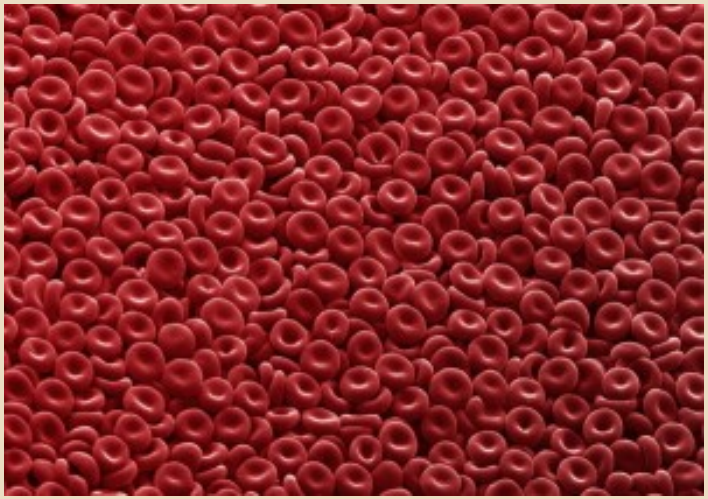
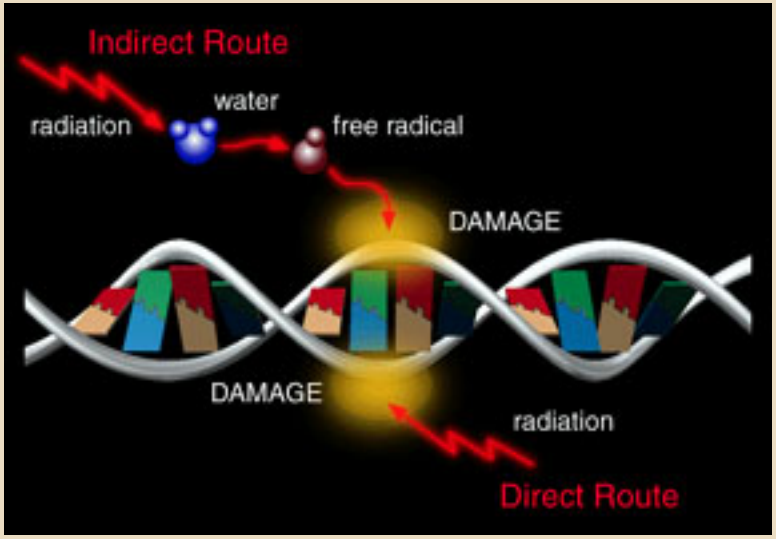
Radioactive material sealed in needles, seeds, wires, or catheters is placed directly into or near a tumor.



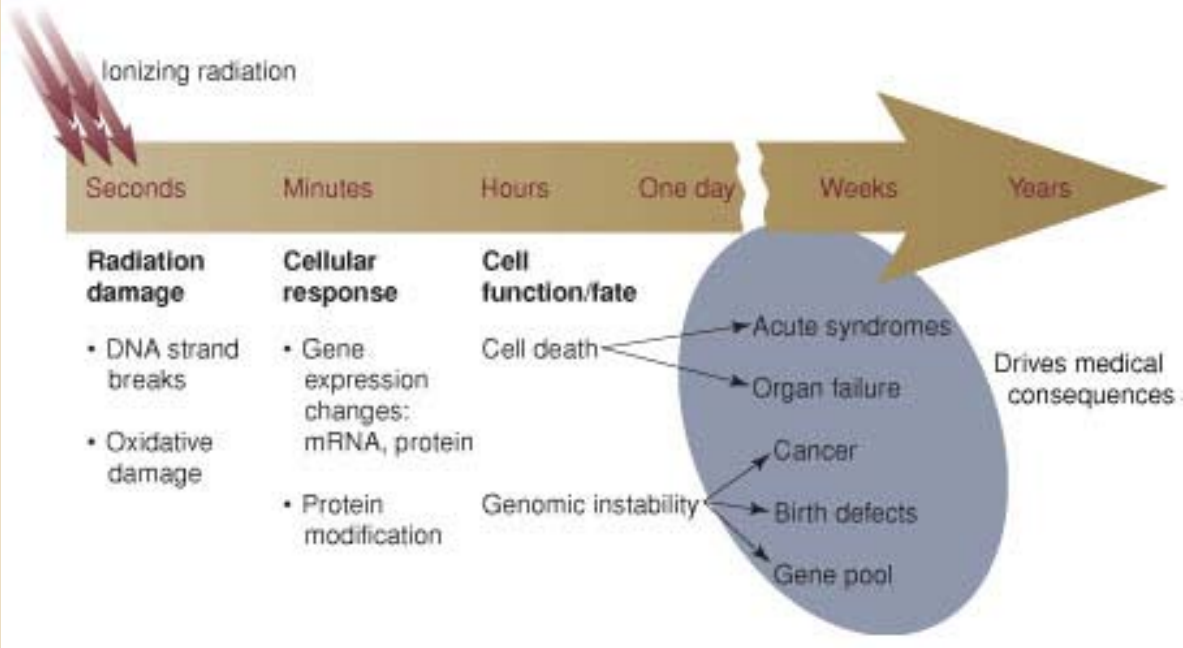
Polycythemia vera is a rare blood disease in which your body makes too many red blood cells.

Biological Effects of Exposure to IR



- The biological effects, however, depend not only on the total absorbed dose but also on the local density of ionization.

Biological Effects of Exposure to IR



- In general, cell death and other effects result largely from unrepairable DNA damage or DNA damage that is inadequately repaired.

α-radiation Biological Effects

- Not an external radiation hazard (except to skin) because it is poorly penetrating.
- Once α-particle-emitting radionuclides are in the body they can become a health hazard.

X-, γ-, β-radiation Biological Effects

- X- and γ- radiations can generally penetrate sensitive organs of the body.
- The higher-energy β-radiation can penetrate to about 10 mm into tissue and it can pose both an external hazard and an internal hazard when emissions occur within the body.

Measuring Radiation Dose

Dose Quantities

Absorbed dose

energy "deposited" in a kilogram of a substance by the radiation

Equivalent dose

absorbed dose weighted for harmful effects of different radiations

(radiation weighting factor w_R)

Effective dose

equivalent dose weighted for susceptibility to harm of different tissues

(tissue weighting factor w_T)

- For β- and γ-radiation, absorbed dose = equivalent dose
- For α-radiation, equivalent dose=20 times absorbed dose

Tissue weighting factors

Tissue or organ	Tissue weighting factor
Gonads	0.20
Lung	0.12
Bladder	0.05
Breast	0.05
Thyroid	0.05
Skin	0.01

Approximate Doses of Ionizing Radiation to Individuals

- Average annual dose to a person in the US is about 360 mrem (3.6 mSv).
- An individual's exact dose depends on many factors, including:
  - Flights:

    LA to NY Round Trip

    = 2.5 mrem per person

  - Where you live:

    26 mrem/yr (sea level)

    OR

    26 + 40 mrem/yr (6000 – 7000 ft)

Factors Affecting Radiation Dose and Fate in the Body

- The passage of ionizing radiation through the body results in the deposition of energy within the irradiated tissue volume.
- The amount of any kind of radiation energy deposited depends on:
  - Length of time over which the individual is irradiated
  - Strength of the source
  - Physical nature of the radiation (e.g., X- or γ-rays, α-, β- or other particles, cosmic rays)
  - Distance to radiation source

Main Routes of Internal Exposure to Radionuclides

- **Inhalation:**
  - Radioactive **gases** such as radon or tritium, **vapors** or **particulate materials** enter the body when inhaled
- **Ingestion:**
  - Radionuclides may be ingested **in food** and **drink**
    - Following the ingestion, radionuclides are **absorbed** mainly **from the small intestine**
    - This process is facilitated by the small intestine's immense surface area of about 200 m2 provided by the epithelial villi
- **Dermal absorption**
  - **Entry** through **intact** skin or wounds

Biodistribution of elements in human adults

Element	Principal deposition sites (% entering blood)	Retention half-time*
Hydrogen (Tritium)	Similar concentration in all tissues	~ 10 days
Carbon	Similar concentrations in all tissues; dependent on type of compound	Up to 40 days
Phosphorus	Skeleton (30%)	> 20 years
Strontium	Skeleton (25%)	≥ 20 years
Iodine	Thyroid (30%; range, 5–55%)	80 days

*Retention half-time is the time it takes for the element to leave the body. This is different than the physical half-life, which is the time it takes the element to decay.

Biodistribution of elements in human adults

Element	Principal deposition sites (% entering blood)	Retention half-time
Cesium	Similar concentrations in all tissues	50–200 days
Plutonium	Liver (30%), skeleton (30%)	~ 20 years, > 20 years
Radon	Similar concentrations in all tissues except fatty tissues, where it is higher	Hours (varies by organ/tissue)
Radium	Skeleton (25%)	≥ 20 years
Uranium	Skeleton (~ 10%)	≥ 20 years
Polonium	Liver (~ 30%), kidney (10%), red bone marrow (10%)	~ 50 days
Americium	Liver (50%), skeleton (30%)	2–3 years, > 20 years

Elimination from the Body

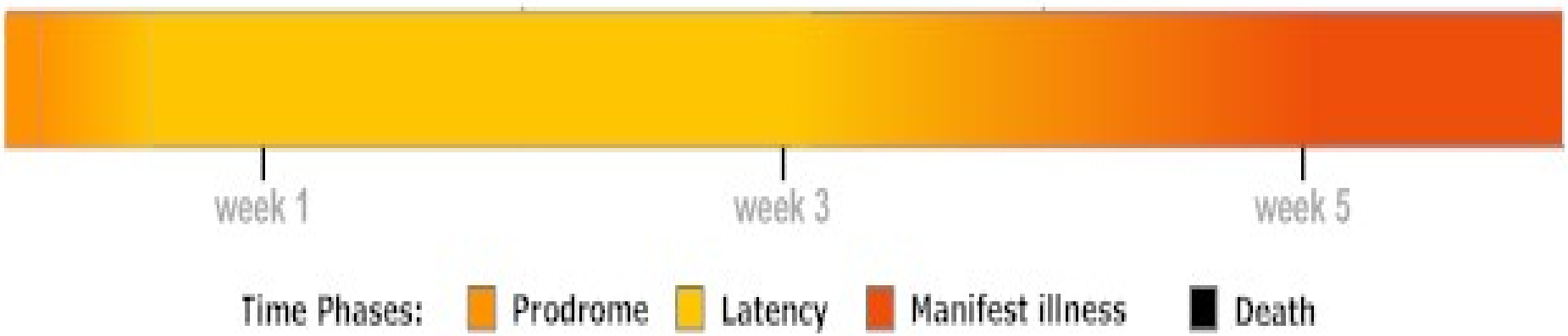
- Exhalation
- Excretion in urine, feces, sweat, saliva, and potentially in milk

Health Effects from Exposure to Ionizing Radiation

Primary Health Effects from Ionizing Radiation Exposure

- Acute effects (high amounts):
  - Skin burns, cataracts, hair loss, birth defects, cancer, teratogenic effects such as mental retardation (a complex central nervous system functional abnormality).
  - Damage to blood-forming organs, gastrointestinal tract, and central nervous system can result from serious accidents involving nuclear materials.
  - Very high doses (e.g. 500 rem or more) may cause death in many, but not all individuals, depending on the degree of medical intervention.
- Long-term health effects:
  - Genetic mutations (none observed in humans)
  - Cancers

Time Phases of Acute Radiation Syndrome (ARS): Absorbed Dose Range 1-2 Gy (100-200 rads)



Predominant Manifestation of ARS*
(Dose Range 1-2 Gy)

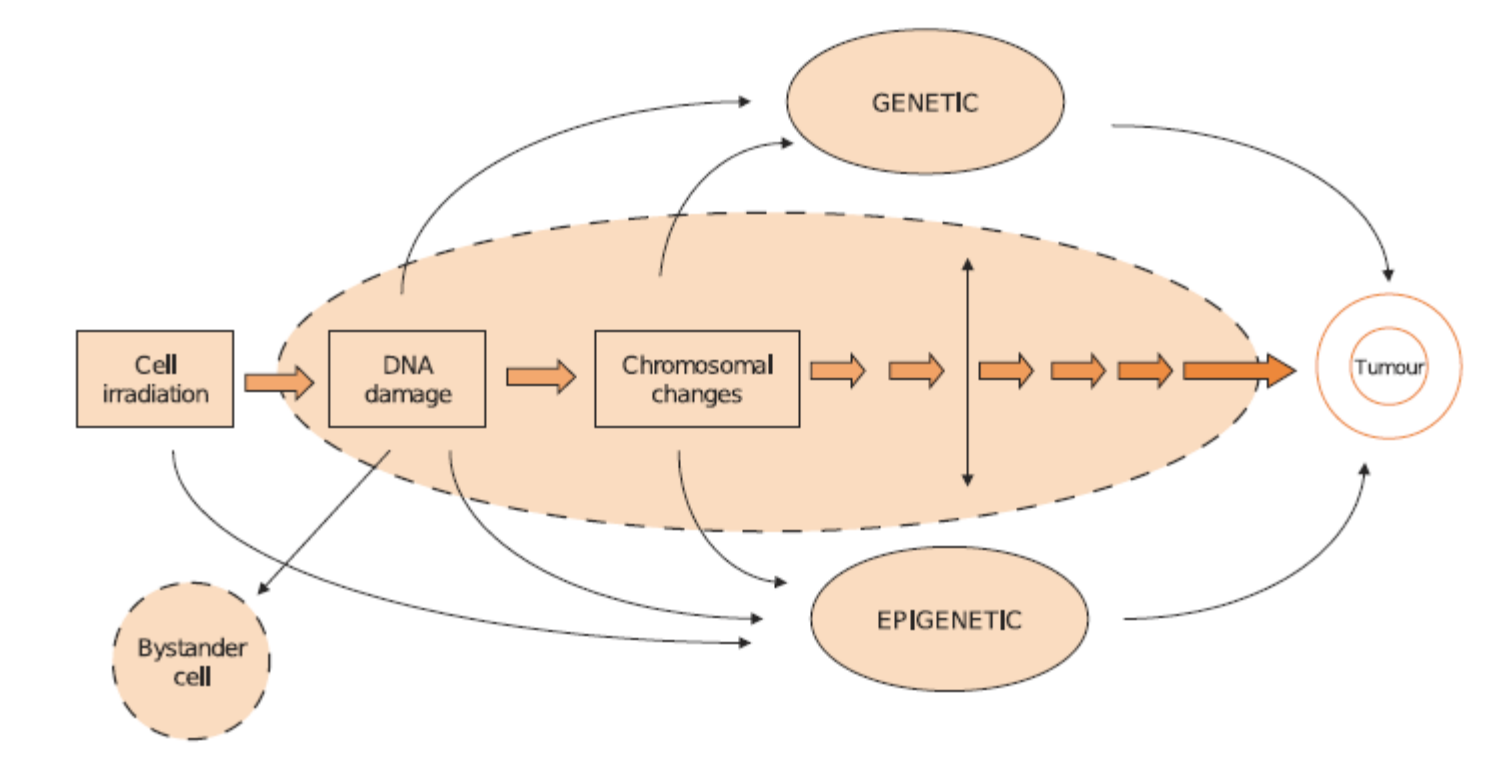
- Hematopoietic (highest contribution)
- Gastrointestinal (much lower contribution)
- Neurovascular (much lower contribution)

*See handout

Cancers Associated with Ionizing Radiation Exposure

All types of ionizing radiation can cause cancer in humans.

Mechanisms of Carcinogenesis: Ionizing Radiation*



*A review of human carcinogens. Part D: Radiation / IARC Working Group on the Evaluation of Carcinogenic Risks to Humans (2012: Lyon, France)

Cancers Associated with X- and γ-Radiation

- Sufficient evidence in humans:
  - Salivary gland, esophagus, stomach, colon, lung, bone, basal cell of the skin, female breast, kidney, urinary bladder, brain and central nervous system, thyroid, and leukemia (excluding chronic lymphocytic leukemia)
- Limited evidence in humans
  - Liver, pancreas, ovary, prostate, and multiple myeloma

Human Cancers Associated with α-emitters Exposure

- Radon-222 (and its decay products):
  - Sufficient evidence in humans: lung cancer
  - Limited evidence in humans: leukemia
- Radium-224:
  - Sufficient evidence in humans: bone sarcomas
- Radium-226:
  - Sufficient evidence in humans: bone sarcomas and paranasal sinuses and mastoid process
- Radium-228:
  - Sufficient evidence in humans: bone sarcomas

Human Cancers Associated with α-emitters Exposure

- Thorium-232:
  - Sufficient evidence in humans: primary liver cancer, leukemia (excluding chronic lymphocytic leukemia), cancer of the extrahepatic bile ducts and gallbladder
  - Limited evidence in humans for cancer of the pancreas and prostate (medical use of Thorium)
- Plutonium-239:
  - Sufficient evidence in humans: lung, liver, and bone
  - Limited evidence in humans: multiple/unspecified sites
- Underground hematite mining with exposure to radon:
  - Sufficient evidence in humans: bone sarcomas

Human Cancers Associated with β-emitters Exposure

- Short-lived radioisotopes of iodine (including iodine-131) exposure during childhood and adolescence:
  - Sufficient evidence in humans: thyroid
  - Limited evidence in humans: for iodine-131 and cancer of the digestive tract and salivary gland, leukemia, and bone and soft tissue sarcoma
- External and internal exposure to fission products, including strontium-90:
  - Sufficient evidence in humans: solid cancers, leukemia and/lymphoma, multiple/unspecified sites
- Tritium:
  - Inadequate evidence in humans

Human Cancers Associated with β-emitters Exposure

- Cesium-137 alone or in combination with external radiation:
  - Inadequate evidence in humans (sufficient evidence in experimental animals for the carcinogenicity)

Other Non-cancer Health Effects of IR at Low Doses

- Hereditary effects:
  - IR can produce mutations in the DNA or reproductive cells, which may be expressed as harmful hereditary effects in subsequent generations (animals)
  - A statistically significant excess of these effects not detected in irradiated human populations, (including the Japanese atomic bomb survivors)
  - EPA model suggests low risk of genetic diseases (compared to cancer risk) at low doses of radiation (1mGy) to both parents prior to conception

Other Non-cancer Health Effects of Ionizing Radiation at Low Doses

- Cardiovascular Disease:
  - Association well established at high radiation doses (> 5 GY; >500 rads) (as those sometimes administered therapeutically)
  - Direct damage to the structures of the heart and the coronary arteries (NAS, 2000; UNSCEAR, 2006; Little et al., 2008). [The association not statistically significant at doses under 0.5 Sv (Shimizu et al., 2010)]

Other Non-cancer Health Effects of Ionizing Radiation at Low Doses

- Cataracts:
  - Association well established
  - The suggested mechanism involves radiation damage to dividing cells in the lens and subsequent differentiation and migration of the cells, leading to opacities
  - Anywhere from 0.5 Gy to 2 Gy
  - Evidence of opacity formation following chronic low-dose rate γ –radiation exposure

Beryllium Exposure & Health Problems

Beryllium in the Environment

- Physical and chemical properties
  - Lighter than aluminum but 40% more rigid than steel
  - Excellent electrical and thermal conductivities
  - Very permeable to X-rays
  - Very high affinity for oxygen (results in high resistance to corrosion)
- Use
  - Beryllium alloys: automobiles, computers, sports equipment, and dental bridges
  - Pure beryllium metal: nuclear weapons (a neutron source after bombardment with α-particles or γ-rays), aircraft, X-ray machines, and mirrors

Human Exposure

- General population:
  - Air
    - Natural (about 95% of atmospheric beryllium comes from windblown dust; about 5 % - from volcanic activity)
    - Combustion of coal and fuel oil, municipal waste incineration, burning of solid racket fuel)
  - Food:
    - Average of 13 µg/L in fruit juices;
    - Rice, head lettuce, and potatoes: 80 ug/kg, 330 ug/kg, and 0.3 µg/kg, respectively)
  - Water: range of 0.01-1.22 µg/L
  - Cigarette smoke
- Industries & occupations: specialty metallurgy workers, avionics, electronics, nuclear industry, fire prevention, telecommunication industry

Potential Health Effects

- Skin contact:
  - Contact dermatitis
  - Insoluble materials embedded under the skin: chronic granulomatous skin lesions
- Inhalation:
  - Acute beryllium disease/pneumonitis, tracheobronchitis
  - Beryllium sensitization, berylliosis or chronic beryllium disease (CBD)
  - Cancer of the lung (sufficient evidence in humans)