Radiation Poisoning

Outline

Radiation Safety
- Possible scenarios
- Radiation Basics
- Decontamination procedures

Medical Aspects of Radiation
- Biologic effects
- Radiation sickness
Radiation Safety

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Diagnostic Medical Physicist
Department of Radiology
The Ohio State University Medical Center

Possible Radiation Emergency Scenarios

- Medical
- Terrorist use of nuclear materials
- Catastrophic event
### Medical Radiation Event

- 40 year old male underwent a coronary angiography, coronary angioplasty and secondary angiography due to complications, followed by a coronary artery by-pass graft.
- All procedures occurred on March 29, 1990

Appearance of skin injury post-procedure:
- (a) 6-8 wks
- (b) 16-21 wks
- (c) 18-21 wks


### Medical Radiation Event

- Acquisition protocols were not set properly resulting in excessive exposures
- Cedar Sinai (L.A.): 200 patients overexposed during 18 month period
- Providence St. Joe (L.A.): 34 patients overexposed during 20 month period
- Glendale Adventist Medical Center (L.A.): 10 patients overexposed during 10 months
- 8x national average for exposure

**Medical Radiation Event**

- Radiation Oncology

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**Terrorist Use of Nuclear Material**

- Radiological Dispersal Device (i.e. “dirty bomb”)
- Combine radioactive material with explosive device
- Blast effect plus radioactivity
### Terrorist Use of Nuclear Material

Improvised Nuclear Device or Nuclear Weapon
- An actual nuclear detonation
- Allegation that 50 to 100 one kiloton suitcase nuclear weapons unaccounted for from former Soviet Union
- Various rogue or terrorist supporting states

### Catastrophic Event

#### Reactor Accidents
- Three Mile Island - 1979
- Chernobyl – 1986
- Tokaimura, Japan – 1999 (uranium processing facility)
- Fukushima, Japan – 2011

#### War Veterans
- Operation UPSHOT-KNOTHOLE
- Exposures ranged from 0.4 – 31 mSv (equivalent to 5 – 390 chest x-rays)
Catastrophic Event

- Goiânia, Brazil
- 1985: Private radiotherapy clinic closed down
- 1987: Teletherapy head stolen
- Unit dismantled, Cs-137 source capsule ruptured causing major contamination
- 50.9 TBq (1375 Ci) caesium-137 teletherapy machine left in abandoned clinic

Goiânia, Brazil

- 112,000 people monitored
- 249 people contaminated
- 49 people 0.1 - 6.2 Gy
- 4 people died
  - 6 y old girl
  - 18 y old man
  - 22 y old man
  - 38 y old mother

Used with permission from Brian Dodd, BD Consulting, HPS Past President
## Catastrophic Event

- Gilan, Iran
- 1996: Ir-192 source used for industrial radiography falls out of shielded container
- Manual worker picks up source and puts it in chest pocket

Used with permission from Brian Dodd, BD Consulting, HPS Past President

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## Gilan, Iran

- Resulting in severe radiation burns to the chest
### Radiological Accident Statistics (1944-2000)

- ~ 400 reported accidents
- ~ 3000 exposed persons
- > 100 deaths, more than half involving patients
  - In addition, orphan sources can be mixed up with scrap causing contamination problems
  - Illicit trafficking involves orphan sources but very few orphan source incidents are due to illicit trafficking events

### The Basics of Radiation

Ionizing radiation is electromagnetic energy or energetic particle emitted from a source. Ionizing radiation is able to strip electrons from atoms causing chemical changes in molecules.
Ionizing Radiation

- Ionizing radiation is emitted by
  - Radioactive material
  - Machine generated (x-rays, LINACS)
- Biological effects from ionizing radiation are dependent on the energy and type of radiation

Electromagnetic Radiation

<table>
<thead>
<tr>
<th>Frequency (Hz)</th>
<th>IONIZING</th>
<th>NONIONIZING</th>
</tr>
</thead>
<tbody>
<tr>
<td>$10^20$</td>
<td>Gamma rays</td>
<td>$10^{15}$</td>
</tr>
<tr>
<td>$10^{18}$</td>
<td>X-rays</td>
<td>$10^{14}$</td>
</tr>
<tr>
<td>$10^{16}$</td>
<td>Ultraviolet rays</td>
<td>$10^{13}$</td>
</tr>
<tr>
<td>$10^{10}$</td>
<td>Visible light</td>
<td>$10^{12}$</td>
</tr>
<tr>
<td>$10^5$</td>
<td>Infrared light</td>
<td>$10^{11}$</td>
</tr>
<tr>
<td>$10^{-7}$</td>
<td>Radio waves</td>
<td>$10^{10}$</td>
</tr>
<tr>
<td>$10^{-6}$</td>
<td>Micro-waves</td>
<td>$10^9$</td>
</tr>
<tr>
<td>$10^{-10}$</td>
<td>Wave length (m)</td>
<td>$10^{-2}$</td>
</tr>
<tr>
<td>$10^{-11}$</td>
<td>Light waves</td>
<td>$10^{-1}$</td>
</tr>
</tbody>
</table>
Natural Background

Primarily radon and gamma rays from the atmosphere
- Ground
  - $^{222}$Rn
- Building Materials
- Air
- Food
  - $^{238}$U and $^{232}$Th from drinking water
- Universe
  - Gamma rays generated in supernova
- Elements within our own body
  - $^{14}$C

Health Risks from Exposure to Low Levels of Ionizing Radiation: BEIR VII Phase 2, 2006

Manmade Sources

Used in medicine, research, and industry
- X-ray equipment
- Radioactive materials

Assumes everyone receives two diagnostic x-ray exams per year

Health Risks from Exposure to Low Levels of Ionizing Radiation: BEIR VII Phase 2, 2006
Key Point:

Every individual receives low levels of radiation every day of their life.

Background Radiation Around the World
Key Point:

Not all radiation is equal

Particulate Ionizing Radiation

- Alpha particles: two protons and two neutrons
- Beta particles: release gamma
- Neutrons: causes other substances to become radioactive
## Gamma or X-Ray (Photons)

- High energy rays
- Very penetrating
- Difficult to shield
- Can be produced from radioactive decay and a nuclear weapon explosion or reactor accident
- PPE will not protect against photon radiation

### Penetrating Distances

<table>
<thead>
<tr>
<th>Particle</th>
<th>Paper</th>
<th>Plastic</th>
<th>Lead</th>
<th>Concrete</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alpha ($\alpha$)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Beta ($\beta^-$)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Gamma and X-rays</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Neutron ($\nu$)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Radiosensitivity

Physical Factors

• Linear Energy Transfer (LET)
  - Measure of the rate at which energy is transferred from ionizing radiation to soft tissue.

• Relative Biologic Effect (RBE)
  - Ability to produce biologic damage

Fractionation

Biologic Factors

• Oxygen Effect
  - Tissue is more sensitive in the presence of oxygen

• Recovery

• Age

Radiation Sensitivity and Age

![Graph showing radiation sensitivity and age](image)
Law of Bergonie and Tribondeau

- Stem cells are radiosensitive. The more mature a cell, the more resistant to radiation it is.
- The younger the tissue and organs, the more radiosensitive they are.
- When the level or metabolic activity is high, radiosensitivity is also high.
- As the proliferation rate for cells and the growth rate for tissue increase, the radiosensitivity also increases.

Measures of Radiation Exposure

- Rad = Radiation Absorbed Dose: measures amount of energy actually absorbed by a material (i.e. tissue)
- Rem = Roentgen Equivalent Man: measures biologic damage of radiation; takes into account dose and type of radiation involved
- In most situations, 1 Rem = 1 Rad
- 1 Gray (Gy) = 100 Rads
- 1 cGy = 1 Rad
- 1 Sievert = 100 Rems
- 1 millisievert = 0.1 Rem
## Radiation Doses and Dose Limits

<table>
<thead>
<tr>
<th>Activity</th>
<th>Dose Limit (mrem)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flight from Los Angeles to London</td>
<td>5</td>
</tr>
<tr>
<td>Annual public dose limit</td>
<td>100</td>
</tr>
<tr>
<td>Annual natural background</td>
<td>300</td>
</tr>
<tr>
<td>Fetal dose limit</td>
<td>500</td>
</tr>
<tr>
<td>Barium enema</td>
<td>870</td>
</tr>
<tr>
<td>Annual radiation worker dose limit</td>
<td>5,000</td>
</tr>
<tr>
<td>Heart catheterization</td>
<td>45,000</td>
</tr>
<tr>
<td>Life saving actions guidance</td>
<td>50,000</td>
</tr>
<tr>
<td>(NCRP-116)</td>
<td></td>
</tr>
<tr>
<td>Mild acute radiation syndrome</td>
<td>100,000</td>
</tr>
<tr>
<td>( \text{LD}_{50/60} ) for humans</td>
<td>350,000</td>
</tr>
<tr>
<td>(bone marrow dose)</td>
<td></td>
</tr>
<tr>
<td>Radiation therapy</td>
<td>6,000,000</td>
</tr>
<tr>
<td>(localized &amp; fractionated)</td>
<td></td>
</tr>
</tbody>
</table>
Radioactive Material

• *Radioactive material* consists of atoms with unstable nuclei

• The atoms spontaneously change (decay) to more stable forms and emit radiation

• A person who is *contaminated* has radioactive material on their skin or inside their body (e.g., inhalation, ingestion, shrapnel, or wound contamination)

• A person exposed to radiation may, or may not, be contaminated.

• Not all radioactive materials are equal

Types of Radiation Hazards

• *External Exposure* - whole-body or partial-body (no radiation hazard to ED staff)

• *Contaminated* -
  - external radioactive material: on the skin
  - internal radioactive material: inhaled, swallowed, absorbed through skin or wounds
**Radiation Exposure Types**

<table>
<thead>
<tr>
<th>Irradiation</th>
<th>External Contamination</th>
<th>Internal Contamination</th>
</tr>
</thead>
</table>

**Examples of Radioactive Materials**

<table>
<thead>
<tr>
<th>Radionuclide</th>
<th>Half-Life</th>
<th>Activity</th>
<th>Use</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cesium-137</td>
<td>30 yrs</td>
<td>1.5x10⁶ Ci</td>
<td>Industrial radiography</td>
</tr>
<tr>
<td>Cobalt-60</td>
<td>5 yrs</td>
<td>15,000 Ci</td>
<td>Cancer Therapy</td>
</tr>
<tr>
<td>Plutonium-239</td>
<td>24,000 yrs</td>
<td>600 Ci</td>
<td>Nuclear Weapon</td>
</tr>
<tr>
<td>Iridium-192</td>
<td>74 days</td>
<td>100 Ci</td>
<td>Industrial Radiography</td>
</tr>
<tr>
<td>Hydrogen-3</td>
<td>12 yrs</td>
<td>12 Ci</td>
<td>Exit Signs</td>
</tr>
<tr>
<td>Strontium-90</td>
<td>29 yrs</td>
<td>0.1 Ci</td>
<td>Eye Therapy Device</td>
</tr>
<tr>
<td>Iodine-131</td>
<td>8 days</td>
<td>0.015 Ci</td>
<td>Nuclear Medicine</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Therapy</td>
</tr>
<tr>
<td>Technetium-99m</td>
<td>6 hrs</td>
<td>0.025 Ci</td>
<td>Diagnostic Imaging</td>
</tr>
<tr>
<td>Americium-241</td>
<td>432 yrs</td>
<td>0.000005 Ci</td>
<td>Industrial radiography</td>
</tr>
<tr>
<td>Radon-222</td>
<td>4 days</td>
<td>1 pCi/l</td>
<td>Environmental Level</td>
</tr>
</tbody>
</table>
# Medical Aspects of Radiation

**Richard Nelson, MD**  
Vice Chair  
Department of Emergency Medicine  
The Ohio State University

## Acute Radiation Syndrome (ARS)

- Group of symptoms that develop after total body irradiation (> 100 rads)
- May occur from either internal or external radiation
- Four important factors are:
  - High Dose
  - High Dose Rate
  - Whole Body Exposure
  - Penetrating Radiation
ARS - Phases

1. **Prodromal Phase** - occurs in the first 48 to 72 hours post-exposure and is characterized by nausea, vomiting, malaise and anorexia. At doses below about 500 rads last 2 to 4 days. The earlier the symptoms, the worse the exposure.

2. **Latent Phase** - follows the prodromal phase and lasts for approximately 2 to 2 1/2 weeks. During this time, critical cell populations (leukocytes, platelets) are decreasing as a result of bone marrow insult. The time interval decreases as the dose increases.

3. **Illness Phase** - period when overt illness develops

4. **Recovery or Death Phase** - may take weeks or months
### Prodromal Phase and Prognosis

- If time to emesis is < 4 hours: exposure at least 3.5 Gy
- If time to emesis is < 1 hour: exposure at least 6.5 Gy

### Acute Radiation Sickness

- Skin/hair
- Gastrointestinal tract
- Hematopoietic system
- Central nervous system
## ARS - Skin

<table>
<thead>
<tr>
<th>Response</th>
<th>Epilation</th>
<th>Erythema</th>
<th>Dry</th>
<th>Moist</th>
<th>Desquamation</th>
<th>Necrosis</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>300</td>
<td>600</td>
<td>1000</td>
<td>&gt;1500</td>
<td>&gt;5000</td>
<td>&gt;5000</td>
</tr>
</tbody>
</table>

- **Day 9**
- **Day 11**
- **Day 16**
- **Day 24**
ARS - Gastrointestinal Syndrome

• Radiation > 600 rads
• Damages intestinal lining
• Nausea and vomiting within the first 2 - 4 hours
• May develop diarrhea
• Associated with sepsis and opportunistic infections
• At 10 days could develop bloody diarrhea resulting in death
ARS - Hematopoietic Syndrome

ARS Blood Counts

- 48 hour absolute lymphocyte count > 1200: good prognosis; 300 - 1200: significant radiation exposure; <300: probably lethal
- Absolute granulocyte counts: should be followed with higher-level exposures; nadir occurs at 8 to 30 days post-exposure
- Other parameters: platelet counts, reticulocyte counts, numbers of dicentric chromosomes in blood and bone marrow
**ARS - Central Nervous System**

- Seen with radiation dose > 1,000 rads
- Microvascular leaks → edema
- Elevated intracranial pressure
- Death within hours

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**Prehospital Care**

- Information is critical: type of exposure, internal vs. external vs. whole vs. partial body, radioactive materials involved
- Decontamination if time permits
  - remove and bag clothing
  - soap and water cleansing of exposed skin
  - retain wash water
- Emphasis on treating life-threatening injuries
# Evaluation & Treatment - Hospital Care

- Activate hospital plan
- Establish triage area (separate entrance)
- Plan to control contamination (don’t count on patients already being decontaminated)
  - Prepare area by cover/marking floor, control ventilation
  - Prepare staff by issuing protective clothing
  - Prepare for surveying; call radiation safety officer
  - Establish area for storage of waste
  - Plan for decontamination of non-traumatized patients

## Patient Management: Triage

Triage based on:
- Injuries
- Signs and symptoms - nausea, vomiting, fatigue, diarrhea
- History - Where were you when the bomb exploded/ how close?
- Contamination survey with G-M meter
Patient Management: Priorities

Triage

• Medical treatment is the highest priority
• Radiation exposure and contamination are secondary considerations
• Degree of decontamination dictated by number of, and capacity to treat, other injured patients

Protecting Staff from Contamination

• Use universal precautions
• Survey hands and clothing with radiation meter
• Replace gloves or clothing that is contaminated
• Keep the work area free of contamination

Key Points

• Most contamination is easy to detect and most of it can be removed
• It is very unlikely that ED staff will receive large radiation doses from treating contaminated patients
### Staff Protection Levels of PPE

- **Level A** – IDLH environments, fully encapsulated, requires SCBA
- **Level B** – Chemicals or substances with inhalation hazard, requires SCBA or SAR
- **Level C** – Known contaminants, requires air-purifying respirator

### Decon Agents - 1

- **Dry Removal**
- **Soap / Shampoo**
- **Household Bleach 1:10** (Sodium Hypochlorite)
- **Waterless Cleansers**
### Decon Agents - 2

- Povidone-Iodine
- Lava Soap
- Cornmeal / Tide 50:50
- Vinegar (\(^{32}\text{P}\)) or Club Soda
- Toothpaste

### Decontamination

- Irrigate open wounds and cover with sterile dressing
- Soap and water showering (including hair)
- Effective for mixed radiation/chemical contamination
- Refer for any surgery
### Patient Management: Decontamination

- Carefully remove and bag patient’s clothing and personal belongings (typically removes 75-95% of contamination). This may have been done at the scene.
- Survey patient and, if practical, collect samples (skin/wound swabs)

### Patient Management: Decontamination

- Handle foreign objects with care until determined non-radioactive with survey meter
- Decontamination priorities:
  - Decontaminate wounds first, then intact skin
  - Start with highest levels of contamination
- Change outer gloves frequently to minimize spread of contamination
Patient Management: Decontamination (cont.)

- Cease decontamination of skin and wounds
  - When the area is less than twice background, or
  - When there is no significant reduction between decon efforts, and
  - Before intact skin becomes abraded.

Patient Management: Decontamination (cont.)

- Contaminated thermal burns
  - Gently rinse. Washing may increase severity of injury.
  - Additional contamination will be removed when dressings are changed.

- Do not delay surgery or other necessary medical procedures or exams...residual contamination can be controlled
Special Considerations

- High radiation dose and trauma interact synergistically to increase mortality.
- Close wounds on patients with doses > 100 rem.
- Wound, burn care and surgery should be done in the first 48 hours, or delayed for 2 to 3 months (> 100 rem).

<table>
<thead>
<tr>
<th>Emergency Surgery</th>
<th>Hematopoietic Recovery</th>
<th>Surgery Permitted</th>
</tr>
</thead>
<tbody>
<tr>
<td>24 - 48 Hours</td>
<td>~3 Months</td>
<td>After adequate hematopoietic recovery</td>
</tr>
</tbody>
</table>

Patient Management: Psychological Casualties

- Terrorist acts involving toxic agents (especially radiation) are perceived as very threatening.
- Mass casualty incidents caused by nuclear terrorism will create large numbers of worried people who may not be injured or contaminated.
- Provide psychological support to patients and set up a center in the hospital for staff.
# Patient Management: Psychological Casualties

- Establish triage (monitoring and counseling) centers to prevent psychological casualties from overwhelming health care facilities
- Staff counseling centers with physicians with a radiological background, health physicists with instrumentation and psychological counselors

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# Patient Management: Treatment of Internal Contamination

- Radionuclide-specific, and time sensitive
- Most effective when administered early
- May need to act on preliminary information
- NCRP Report No. 65, Management of Persons Accidentally Contaminated with Radionuclides

<table>
<thead>
<tr>
<th>Radionuclide</th>
<th>Treatment</th>
<th>Route</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cesium-137</td>
<td>Prussian blue</td>
<td>Oral</td>
</tr>
<tr>
<td>Iodine-125/131</td>
<td>Potassium iodide</td>
<td>Oral</td>
</tr>
<tr>
<td>Strontium-90</td>
<td>Aluminum phosphate</td>
<td>Oral</td>
</tr>
<tr>
<td>Americium-241/</td>
<td>Ca- and Zn-DTPA</td>
<td>IV infusion</td>
</tr>
<tr>
<td>Plutonium-239/</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cobalt-60</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
### Potassium Iodide

- Blocks thyroid uptake of Iodine-131 (a beta emitter)
- Treat within 4 Hours (no utility >12 hours)
- Has no protective effect on anything else
- Soviets administered KI 72 hours after Chernobyl, and had thousands of cancers
- KI or Nal, 300 mg tablet
- SSKI (1 g / ml), 5 - 6 drops in water

NCRP Report No 65, p 83-86, 104

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### Radiostrontium Contamination Therapy

- Al Phosphate (100 ml) reduces absorption as much as 85%
- Ba Sulfate is also effective
- Na Alginate inhibits uptake by 80–90% (10g po)
**Prussion Blue**

- Blocks intestinal absorption of Cs-137

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**Penicillamine**

- Radioactive heavy metal poisoning (lead)
### DPTA chelation

- Plutonium
- Americium
- Curium

### Other adjuncts

- Filgrastim and sargramostim to treat neutropenia
Localized Radiation Effects – Organ System Threshold Effects

- **Skin - No visible injuries** < 100 rem
  - Prompt - erythema, epilation >500 rem
  - Moist desquamation >1,800 rem
  - Ulceration/Necrosis >2,400 rem

- **Cataracts**
  - Acute exposure >200 rem
  - Chronic exposure >600 rem

- **Permanent Sterility**
  - Female >250 rem
  - Male >350 rem

Chronic Health Effects From Radiation

- **At low doses, radiation is a weak carcinogen**

- **Risk of fatal cancer due to radiation exposure is estimated as ~ 4% per 100 rem**

- **A dose of 5 rem increases the risk of fatal cancer by ~ 0.2%**

- **A dose of 25 rem increases the risk of fatal cancer by ~ 1%**
# Fetal Irradiation

*No significant risk of adverse health effects below 10 rem*

<table>
<thead>
<tr>
<th>Weeks After Fertilization</th>
<th>Period of Development</th>
<th>Effects</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt;2</td>
<td>Pre-implantation</td>
<td>Little chance of malformation</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Most probable effect, if any, is death of embryo</td>
</tr>
<tr>
<td>2-7</td>
<td>Organogenesis</td>
<td>Reduced lethal effects</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Teratogenic effects</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Growth retardation</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Impaired mental ability</td>
</tr>
<tr>
<td>7-40</td>
<td>Fetal</td>
<td>Growth retardation with higher doses</td>
</tr>
<tr>
<td>All</td>
<td></td>
<td>Increased risk of childhood cancer</td>
</tr>
</tbody>
</table>

## Key Points

- Early symptoms are an indication of the severity of the radiation dose
- Pre-planning to ensure adequate supplies of PPE and survey instruments
- Rescue and treatment protocols vary little for radiation contamination
- Treatment of medical/surgical emergencies takes priority
- Donning PPE and decontaminating patients minimizes exposure risk
- Treatment requires a unified effort