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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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

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

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

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

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

Onset: 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

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

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

Gilan, Iran

- Resulting in severe radiation burns to the chest

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 dependant on the energy and type of radiation

Natural Background

Primarily radon and gamma rays from the atmosphere
- Ground
- Building Materials
- Air
- Food
- Universe
- Elements within our own body

Electromagnetic Radiation

<table>
<thead>
<tr>
<th>IONIZING</th>
<th>NONIONIZING</th>
</tr>
</thead>
<tbody>
<tr>
<td>Frequency (Hz)</td>
<td></td>
</tr>
<tr>
<td>$10^{13}$</td>
<td>$10^{12}$</td>
</tr>
<tr>
<td>Gamma rays</td>
<td>X-rays</td>
</tr>
<tr>
<td>$10^{-11}$</td>
<td>$10^{-10}$</td>
</tr>
</tbody>
</table>

Manmade Sources

Used in medicine, research, and industry
- X-ray equipment
- Radioactive materials
Assumes everyone receives two diagnostic x-ray exams per year
Key Point:

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

Key Point:

Not all radiation is equal.

Background Radiation Around the World

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

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

Biologic Factors
- Oxygen Effect
  - Tissue is more sensitive in the presence of oxygen
- Recovery
- Age

Penetrating Distances

Radiation Sensitivity and Age
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.

Radiation Doses and Dose Limits

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

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>1.5x10^6 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>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 - 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 Õ edema
- Elevated intracranial pressure
- Death within hours

**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

**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

**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

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

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

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 (³²P) or Club Soda
- Toothpaste

### 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

### 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 (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>
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<tr>
<td>24 - 48 Hours</td>
<td>~3 Months</td>
<td>After adequate hematopoietic recovery</td>
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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

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 NaI, 300 mg tablet
- SSKI (1 g / ml), 5 - 6 drops in water

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-241/242</td>
<td>Ca- and Zn-DTPA</td>
<td>IV infusion</td>
</tr>
<tr>
<td>Plutonium-239/240</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cobalt-60</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

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)
<table>
<thead>
<tr>
<th>Prussion Blue</th>
<th>DPTA chelation</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Blocks intestinal absorption of Cs-137</td>
<td>• Plutonium</td>
</tr>
<tr>
<td></td>
<td>• Americium</td>
</tr>
<tr>
<td></td>
<td>• curium</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Penicillamine</th>
<th>Other adjuncts</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Radioactive heavy metal poisoning (lead)</td>
<td>• Filgrastim and sargramostim to treat neutropenia</td>
</tr>
</tbody>
</table>
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

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></td>
<td></td>
<td>Increased risk of childhood cancer</td>
</tr>
<tr>
<td>All</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

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%

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