MEDICAL MANAGEMENT FOR NUCLEAR/RADIOLOGIC EVENTS

Frank Guyette, MD, MPH
Department of Emergency Medicine
University of Pittsburgh
Overview

- Nuclear Scenarios
  - Detonation Issues
  - Reactor Issues

- Radiation Injury
  - Acute Radiation Syndrome
  - External Contamination
  - Internal Contamination
Scenario: Washington Mall
Effective Range for Blast Energy
1 kT Weapon

Effective Range for Blast Energy

1 kT Weapon

Penetrating Wounds

White House

55 m/sec

DYNAMIC OVERPRESSURE

ED50

4.3 m/sec

LD50

11 m/sec

The Mall

Washington Monument

550 m

550 m

750 m

### Effective Range for Thermal Energy

**Infrared**

<table>
<thead>
<tr>
<th>Distance (m)</th>
<th>Thermal Energy (cal/cm²)</th>
<th>Burn Severity</th>
</tr>
</thead>
<tbody>
<tr>
<td>700</td>
<td>7</td>
<td>3° Burn</td>
</tr>
<tr>
<td>800</td>
<td>4</td>
<td>2° Burn</td>
</tr>
<tr>
<td>1200</td>
<td>2</td>
<td>1° Burn</td>
</tr>
</tbody>
</table>

Detonation Altitude - 300 m

5.9 km  Flash Blindness
16.7 km  Retinal Burns
46 km  Daytime Visibility
50.8 km  Nighttime Flash Blindness
Energy Partition

**Standard Fission / Fusion**

- Blast: 50%
- Initial Radiation: 5%
- Fallout: 10%
- Thermal: 35%
- Initial Radiation: 5%

Radiation Physics 101

- Ionizing Radiation
  - Electromagnetic energy or particle emitted from a source.
  - Capable of stripping electrons from atoms, causing chemical changes in molecules.
Radiation Types

Types of ionizing radiation:
- Alpha
- Beta
- Gamma
- Neutrons
Ionizing Radiation

Any Radiation Consisting of Directly or Indirectly Ionizing Particles or Photons

- Alpha
- Beta
- Gamma
- Neutron

1 m Concrete
Alpha Particles

- Composed of 2 neutrons and 2 protons.
  - Ionized helium atoms.
  - Highly ionizing.
  - Component of nuclear fallout.

- Travel several cm in air and a few microns in tissue.
  - Stopped by thin paper or clothing.
  - Threat is inhalation or absorption of alpha emitter in wounds.
Beta Particles

- High energy “electron” emitted from nucleus.
- Can have wide range of energies depending upon the particular emitter radionuclide.
- Moderately penetrating
  - Up to a few meters in air
  - Millimeters in tissue
- PPE provides some protection.
Gamma (X-Ray) Particles

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

- **rad**
  - Radiation absorbed dose.
  - Defined as the deposition of 0.01 joule of energy per kilogram of tissue.
  - Basic unit for measuring radiation.
Exposure Measurements

- **rem**
  - Roentgen equivalent man.
  - Reflects the type of radiation absorbed and the likelihood of damage from a particular type of radiation dose.

- **Sv**
  - 1 rem = 0.01 Sv = 10 mSv
  - 100 rem = 1 Sv
Ionizing Radiation
Any Radiation Consisting of Directly or Indirectly Ionizing Particles or Photons

- Alpha
- Beta
- Gamma
- Neutron

1 m Concrete
Natural Background Radiation

- Everyone is constantly exposed to background radiation.
  - Represents radiation incorporated into food, water, earth crust.
  - Solar radiation.
- Estimated annual background radiation is 360 millirem (3.6 milliSv) per year.
Radiation Effects

- **Stochastic**
  - Random result of exposure.
  - eg. Cancer.

- **Deterministic**
  - Dose-response effect of exposure.
  - eg. Acute Radiation Sickness.
# Radiation Exposures

<table>
<thead>
<tr>
<th>Activity</th>
<th>Radiation level</th>
</tr>
</thead>
<tbody>
<tr>
<td>Daily life</td>
<td>2 milli-Sieverts/year</td>
</tr>
<tr>
<td>Chest X-ray</td>
<td>0.1 milli-Sievert</td>
</tr>
<tr>
<td>Chest CT scan</td>
<td>5 milli-Sieverts</td>
</tr>
<tr>
<td>Cross-country airplane flight</td>
<td>0.5 milli-Sieverts</td>
</tr>
<tr>
<td>Threshold for radiation sickness</td>
<td>1,000 milli-Sieverts (1 Sv)</td>
</tr>
<tr>
<td>Threshold for an increase in cancer risk</td>
<td>100 milli-Sieverts</td>
</tr>
</tbody>
</table>
Safe Level of Exposure

- No level of radiation is considered safe
- The American Cancer Society estimates that the whole lifetime risk of developing a cancer for each individual is approximately 42%.
- Exposure to 100 mSv could increase that risk by approximately 1 more percentage point.
Whole Body Dose Limits

- **Occupational**
  - 2 rem per year averaged over 5 years.
  - Not to exceed 5 rem in any 1 year.

- **General Public**
  - 0.1 rem per year
Exposure Types

- The magnitude of this risk and the types of cancer associated vary with:
  - the dose
  - the type of radiation
  - the route of exposure (e.g., ingestion vs. external)
  - the time over which the exposure occurred
Radiation Exposure Types

Irradiation

External Contamination

Internal Contamination
Irradiation

- External irradiation
  - whole-body
  - partial-body
- Occurs when all or part of the body is exposed to penetrating radiation.
- *Individual is not radioactive.*
Contamination

- Contamination by radioactive materials
  - external: deposited on the skin.
  - Internal: inhaled, swallowed, absorbed through skin, or introduced through wounds.
- Patient continues to emit radioactive particles.
Incorporation

- Incorporation of radioactive materials
  - uptake by body cells, tissues, or organs (bone, liver, kidney, etc)
- Cannot occur unless contamination has occurred.
Acute Radiation Sickness (ARS)

- Group of symptoms that develop after total body irradiation (> 1 Sv).
- May occur from either internal or external radiation.
- Four important factors are:
  - High Dose.
  - High Dose Rate.
  - Whole Body Exposure.
  - Penetrating Radiation.
## Symptoms of Radiation Exposure

<table>
<thead>
<tr>
<th>Estimated whole body radiation dose</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Sv</td>
<td>Threshold for acute radiation symptoms</td>
</tr>
<tr>
<td>3-4 Sv</td>
<td>Threshold for possible death without treatment</td>
</tr>
<tr>
<td>5-6 Sv</td>
<td>Threshold for possible death with treatment</td>
</tr>
<tr>
<td>&gt;8 Sv</td>
<td>Death likely, even with treatment</td>
</tr>
</tbody>
</table>
Factors that effect Dose (TDS)

- The dose of radiation absorbed by a person depends on:
  - strength of the radiation source
  - the individual’s distance from the source
  - the amount of protective shielding
  - the duration of the exposure.
Health effects of the Dose

- The health effects of radiation depend on:
  - the type of radiation
  - the dose of radiation absorbed
    - the time over which the exposure occurs
  - the exposure pathway (e.g., ingestion, inhalation, external)
  - the specific parts and percentage of the body exposed
ARS = Whole body irradiation

- Exposure to the same radiation source, if limited to only a relatively small part of the body—the feet, for example—may cause nothing more than superficial burns of the skin.
- Japanese workers
Phases of ARS

- Occurs in 4 phases.
- Phase 1
  - Prodromal phase
  - Occurs in the first 48 – 72 hours post-exposure.
  - Characterized by:
    - N/V
    - Anorexia
  - At doses less than 500 rads, lasts 2-4 days.
Phases of ARS

- **Phase 2**
  - Latent phase.
  - Lasts for approximately 14 – 17 days.
  - During this phase, critical cell populations (e.g., leukocytes, platelets) decrease due to marrow insult.
  - Time interval decreases as the total body dose increases.
Phases of ARS

- Phase 3
  - Illness Phase.
  - Period during which overt illness develops.
    - Infection
    - Bleeding
    - Electrolyte Imbalance
    - Diarrhea
    - Changes in mental status
    - Shock
Phases of ARS

- Phase 4
  - Recovery phase.
  - May occur over weeks to months.
Acute Radiation Syndromes

- Systemic Effects of Radiation:
  - Hematologic
  - Gastronintestinal
  - Pulmonary
  - Cutaneous
  - Neurovascular
- Combined Injury
ARS Hematopoietic Syndrome

- Hematopoietic system is earliest indicator of severity of radiation exposure.
- Both rapidity and degree of decline in cell counts provides information.
- Pancytopenia is associated with fever, sepsis, and hemorrhage.
Lymphocyte Counts (Exposure Screening)

- Absolute lymphocyte count at 48 hours is a good indicator of prognosis.
  - > 1200: Unlikely patient has received a lethal dose.
  - 300 – 1200: Significant exposure has occurred and patient should be hospitalized with barrier protection.
  - < 300: Potentially lethal dose.
Hemogram
(300 rem TBI Exposure)
Andrews Lymphocyte Nomogram

- Absolute Lymphocyte Count over 48 hours
- Confirms Significant Radiation Exposure

<table>
<thead>
<tr>
<th>48 hr. lymphocyte count</th>
<th>Est'd radiation dose</th>
<th>Prognosis</th>
</tr>
</thead>
<tbody>
<tr>
<td>1000-1500 cells/mm³</td>
<td>1-2 Sv</td>
<td>Good</td>
</tr>
<tr>
<td>500-1000/mm³</td>
<td>2-4 Sv</td>
<td>Fair</td>
</tr>
<tr>
<td>100-500/mm³</td>
<td>4-8 Sv</td>
<td>Poor</td>
</tr>
<tr>
<td>&lt;100 mm³</td>
<td>&gt;8 Sv</td>
<td>Death, even with treatment</td>
</tr>
</tbody>
</table>
ARS – GI Syndrome

- Seen with doses > 600 rads.
- Such doses damage 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.
GI effects and triage

- A crude form of triage can utilize the time from exposure to onset of GI symptoms.
- Following a dose higher than 2 Sv, most people will vomit.
- If vomiting ensues within 4 hours of exposure, urgent medical evaluation and treatment is likely needed.
ARS – CNS Syndrome

- Seen with radiation dose > 1,000 rads.
- Probably due to diffuse microvascular leaks.
  - Result in the development of cerebral edema.
  - Elevated intracranial pressure.
- Patient rarely lives long enough to develop other manifestations.
  - Death within hours.
ARS - Skin

- Various skin changes occur depending upon the radiation dose.
- Injuries tend to progress with dose and demonstrate a threshold effect.
- Early erythema is an important finding.
  - May develop within a few hours, but may appear to resolve in only a few hours.
Early erythema after Nagasaki detonation
Skin Effects

- > 300 rads  Epilation 17-21 days
- > 600 rads  Erythema
- >1000 rads  Dry desquamation 2-4 weeks
- > 1500 rads  Moist desquamation 2-8 weeks
- >5000 rads  Necrosis days to months
Epilation after Nagasaki detonation
Moist Desquamation after Occupational Exposure
Causes of Burn Deaths

- Direct result of accident 13%
- Infection 45%
- Organ system failure 41%
- Iatrogenic intervention 1%
Hospital Management of Irradiated Patients

- Activate local (hospital) plan.
  - Radiation Safety Officer
  - Michael Sheetz
  - 412-624-2726
  - msheetz@pitt.edu

- Establish triage area.
  - Ideally avoid facility contamination.
Contamination Mitigation

- Plan to control contamination.
  - Prepare area by cover/marking floor, control ventilation.
  - Prepare staff by issuing protective clothing.
  - Prepare for surveying.
  - Establish area for storage of waste.
  - Plan for decontamination of non-traumatized patients.
Decontamination Equipment

- Hospital Surgical Gown (waterproof)
- Cap, Face Shield, Booties (waterproof)
- Double Gloves (inner layer taped)
- Dosimeters, Survey Meters

- Drapes
- Plastic Bags
- Butcher Paper
- Large Garbage Cans
- Radiation Signs and Tape
Decon Agents - 1

- Dry Removal
- Soap / Shampoo
When Do I Stop?

- When No More Comes Off!
- Stop Levels:
  - 1 mR/h beta
  - 1000 dis/min alpha (air proportional counter w/ 60cm² Window)
  - If Committed Dose will Not Exceed 15 rem/yr to Skin
- Isolate w/ Bag & Continue Decon Next Day

NCRP #65, p117
Radiation Protection Principals

- Time
- Distance
- Shielding
- Quantity
Radiation Protection

- **Time**
  - Radiation dose is dependent on time of exposure

- **Distance**
  - Inverse square rule applies

- **Shielding**
  - 18 cm of lead required for high energy EMR
Radiation - Quantity

- Real time dosimeter
  - Set at level of exposure (25 Rads)
  - Alarms at set level of absorption
  - Expensive, but only need one per team
Radiation Dose Evaluation?

- Monitor Patient
  - Geiger-Mueller counter to evaluate contamination
Patient Arrival

- Carefully remove and bag victim’s clothing and personal belongings.
- Survey patient and conduct biological sampling.
- Contaminated patients require decontamination.
- If patient has a wound, decontaminate it first, then decontaminate skin.
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.
Internal Contamination and Incorporation

- Various medications can be used to limit uptake or facilitate removal of radioactive material.
  - Numerous medications are approved by the FDA.
  - Certain drugs are investigational and can be used in an emergency (i.e. Radiogardase [Prussian Blue] and DTPA)
- REAC/TS
Therapies for Incorporation (Iodine)

- Iodine ($I^{131}$)
- Degradation product of Uranium fission
- Fallout from Nuclear Reactors and Fission Weapons
- Children are at highest risk

Treatment
- Infants 16mg
- Children < 3 32mg
- Children < 150lbs 65mg
- > 150 130mg tablet
Chelation Therapy

- Exposure to Radioactive Cesium or Thalium
- Reactor Fallout, Dirty Bomb
- Prussian Blue
  - Works to increase hepatic or enteric clearance
  - Administer daily until stool and urine are no longer radioactive
- Dosage
  - Adults 3g orally TID
  - Children 1g orally TID
Chelation

- Plutonium, Americium, or Curium
- TNWs, Reactor Fallout, Industrial applications
- Pentetate Calcium Trisodium (Ca-DTPA)
  - Must be administered within 24 hrs of exposure
  - May exacerbate Asthma
  - Binds and increases rate of elimination
  - Dosage
    - Adults 1gm over 3-4 min
    - Children 14mg/kg do not exceed 1gm
Chleation

- Plutonium, Americium, or Curium
- TNWs, Reactor Fallout, Industrial applications
- Pentetate Zinc Trisodium (Zn-DTPA)
  - Must be administered within 24 hrs of exposure
  - Reduces Magnesium and Manganese levels
  - Binds and increases rate of elimination
  - Dosage
    - Adults 1gm over 3-4 min
    - Children 14mg/kg do not exceed 1gm
Elimination Enhancement

- Uranium
- TNWs, Reactor Fallout, Industrial applications
- Sodium Bicarbonate increases the elimination of Uranium and may prevent kidney damage.

Dose
- Adults 4gm PO then 2gm every 4 hours until urine pH is 8-9, or isotonic IV drip at 125cc/hr.
- Children 84-840mg PO per day divided into q6 hr dosing
- Monitor stool for uranium content.
ARS and Trauma

- Radiation and Trauma = ↑ Mortality.
- Wound and burn care, surgery, and orthopedic repair should be done in the first 48 hours or delayed for 2 to 3 months.
Surgical Recommendations

- Based on Immunocompetence Status
- Life-Saving / Major Surgery within 36 - 48 h
- Elective Procedures until 45 - 60 days Following Hematopoietic Recovery
What is Fallout?

- A complex mixture of over 200 different isotopes of 36 elements
- 2 oz of fission products formed for each kT of yield.
- Size < 1 micron to several mm.
Early Fallout

- That which reaches the ground during the first 24 hours after detonation
- Early fallout fraction 50-70% of total radioactivity
Delayed Fallout

- Arrives after the first day, very fine invisible particles which settle in low concentrations over a considerable portion of the earth’s surface
- 40% of total radioactivity
Three Mile Island Accident

- Three Mile Island Unit 2 nuclear power plant near Middletown, PA
- March 28, 1979
- The most serious in U.S. commercial nuclear power plant operating history
- Led to no deaths or injuries to plant workers or members of the nearby community
Chernobyl Accident

- 26 April 1986 at the Chernobyl nuclear power plant
- was the most severe ever to have occurred in the nuclear industry
- All together, over 600,000 workers were involved in the clean up and response efforts
Chernobyl Accident

- The Chernobyl accident caused many severe radiation effects immediately.

- Among the approximately 600 workers present on the site:
  - 2 died within hours of the reactor explosion.
  - 134 suffered from acute radiation sickness.
    - Twenty eight workers died in the first four months after the accident.

- Another 200,000 recovery received doses of between 0.01 and 0.50 Gy.
The basic clinical picture was that of a distinctive acute radiation sickness caused by gamma-irradiation of the whole body and by beta-irradiation of extensive areas of the skin surface.
Effects of Fallout

- Combined effect of radiation from several sources:
  - (a) short-term external gamma/beta radiation from the gas emission cloud
  - (b) external gamma/beta radiation from fragments of the damaged reactor core
  - (c) inhalation/ingestion of gases/dust containing a mixture of radionuclides;
Chernobyl Accident

- Average doses to Ukrainian and Belarusian evacuees were 17 mSv and 31 mSv, respectively.
- Individual exposures ranged from a low of 0.1 to 380 mSv
- since 1986, and to date there is no strong evidence for radiation-induced increases of leukemia or solid cancer (other than thyroid cancer).
Thyroid Cancer

- A large number of children and adolescents who in 1986 received substantial radiation doses in the thyroid after drinking milk contaminated with radioactive iodine.
- To date, about 4,000 thyroid cancer cases have been detected among these children.
- Although 99% of these children were successfully treated, nine children and adolescents in the three countries died from thyroid cancer.
At Fukushima, radioactive iodine and cesium—both beta-emitters—have been detected in vegetables, the result of radioactive dust settling on leaves.

Trace levels of radioactive iodine and cesium have been detected as far away as California and Massachusetts.
- *Uranium 235 (U-235)* is the nuclear reactor fuel
- *Plutonium (Pu-239)*
- *Cesium (Cs-137)* is a fission product of U-235
  - emits beta and gamma radiation
  - rapidly excreted by the body
  - half-life is 31 years.
Iodine and Thyroid Cancer

- *Iodine 131 (I-131)* a fission product of U-235
  - emits beta and gamma radiation
  - After inhalation or ingestion - concentrated in the thyroid gland
    - used as a treatment for thyroid Dx
    - in lower doses, I-131 causes thyroid cancer, primarily in children
    - uptake of I-131 can be effectively blocked by pretreatment with potassium iodide
  - half-life of I-131 is only 8 days
4 Golden Rules of Toxicology

(Adapted from Kent Olson, MD FACEP)

- Treat the Patient before the Poison
- Prevent or Reduce Exposure
- Enhance the Elimination of the Agent
- Consider Specific Adjuncts and Antidotes
Radiation Accidents can Pose Toxicology Problems

- The Dose makes the Poison
- Acute (Threshold Effects)
- Long-Term Toxicity

- Irradiation (Whole body) vs Contamination
Internal Contamination Involves 4 Stages

- Deposition Along Route of Entry
- Translocation
- Deposition in Target Organ
- Clearance
RN Therapeutic Interventions

- Plutonium / Transuranics - DTPA
- Cesium - Insoluble Prussian Blue
- Uranium - Alkalization of Urine
- Radioiodine - Radiostable Iodine
- Tritium - Radiostable Water
- Fission Products (Fallout) - Combination
DTPA (Pentatate Trisodium) Administered for Soluble $^{239}$Pu Within One Hour

<table>
<thead>
<tr>
<th>Organ</th>
<th>Control Retention</th>
<th>DTPA Treated Retention</th>
</tr>
</thead>
<tbody>
<tr>
<td>Liver</td>
<td>14%</td>
<td>0.47%</td>
</tr>
<tr>
<td>Skeleton</td>
<td>57.0%</td>
<td>5.9%</td>
</tr>
</tbody>
</table>
Insoluble Prussian Blue Effective for Cs-137

- Binds ions in the gut
- Biological half-life reduced to 1/3
- Not systemically absorbed
- Side effects - constipation, GI upset at higher doses (20 g/day)
Uranium - Alkalinize Urine

- $^{235}\text{U} - 186$ keV Gamma
- Eff Half Time Depends on Solubility
- At Normal Enrichment Levels, Primary Renal Toxicity
- Maintain Urine pH 7.5 to 8
- Use Bicarbonate tablets (Do not use Alka Seltzer from old texts!)
Iodine - Block

- $^{131}\text{I}$ - Eff Half Life = 7.6 days
- Treat within 4 Hours (Best 1 Hour Before Exposure!)
- KI 130 mg tablet
- SSKI (1 g / ml) - 5 - 6 drops in water
Tritium - Dilute

- Beta Emitter - 5.7 keV (18 keV Max)
- 2% Binds to Cellular Components
- Essentially Occupies TBW Space
- Force Fluids 3 - 4 L / day
  - Reduces Half-Time by 1/3 - 1/2

NCRP Report No 65, p 105-106
Radiostrontium Contamination Therapy

- Al Phosphate (100 ml) Reduces Absorption as much as 85%
- Ba Sulfate
- Na Alginate Inhibits Uptake by Factor 8 - 10
  - 10 g po
- Ca Competes with Sr given po / IV
- Ammonium Chloride po provides Synergy for max effect
Fission Products (Fallout) from Safety Series 47

- Wounds – Apply potassium rhodizonate (1 g)
- Inhalation / Ingestion - Calcium Alginate (10 g)
- Potassium Iodide (130 mg)
- Prussian Blue (1 g)
- DTPA (1 g)

Current Traveler’s Guidelines

- Current traveler screening guidance has been implemented at all US points of entry (air, land, and maritime)
- Any traveler with radiation contamination detected at levels of $\geq 2$ times background will be provided the opportunity for further public health follow-up
Current Traveler’s Guidelines

- *Travelers contaminated at levels ≥20 times background*: CDC will immediately contact the state radiation control program using the roster provided by the Conference of Radiation Control Program Directors (CRCPD)
Current Traveler’s Guidelines

- The follow-up assessment should consist of four main activities:
  - Ensure the effectiveness of external decontamination
  - Assist in completion and review the Epidemiologic Assessment form with the traveler and assess potential for internal contamination
  - Perform a thyroid count
  - Evaluate the need for bioassay, and collect a urine sample if necessary
Current Traveler’s Guidelines

- urine samples of contaminated travelers:
  - Travelers who have lived or travelled within a 50 mile radius of the Fukushima nuclear power plant
  - Travelers ≤18 years of age or who are pregnant
  - Travelers with an elevated thyroid count (i.e., distinguishable from background)
  - Travelers with an elevated count (i.e., distinguishable from background) taken at back of chest
  - Travelers with high levels of concern
Current Traveler’s Guidelines

Key Points

- Irradiation vs contamination
- Health Effects:
  - the type of radiation
  - the dose of radiation absorbed
  - the exposure pathway (eg, ingestion, inhalation, external)
  - the specific parts and percentage of the body exposed
- ARS and triage
- Resources: HP, REACTS