Radiologic and Nuclear Threats

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Objectives

• At the completion of this presentation, attendees will be able to:
  – Discuss the clinical manifestations of internal contamination and acute radiation syndrome
  – Describe the diagnostic evaluation of internal contamination with radionuclides
  – Discuss the use of pharmaceutical countermeasures in the management of internal contamination
Scenario Presentation
Possible Scenarios

- Simple radiological device
- Improvised nuclear device (IND)
- Nuclear weapon detonation
- Nuclear power plant accident
- Radioactive dispersal device (RDD) including the “Dirty Bomb” scenario

Photo Credit Sandia National Laboratories and Wikipedia
“Dirty Bomb”

- Conventional explosive + radioactive material = “dirty bomb”
- Dispersal pattern variable
- Combined blast and burn injuries
- External and internal contamination
- Potentially large population affected
MECHANISM OF DISEASE
Ionizing Versus Non-ionizing Radiation

• Non-ionizing radiation (microwaves, UV):
  – Does not ionize other atoms or lead to the formation of free radicals

• Ionizing radiation interacts with human body through direct and indirect effects:
  – Directly
  – Indirectly
Radiation Damage

• Deterministic
  – Threshold dose
  – Local radiation injury
  – Acute radiation syndrome

• Stochastic
  – Random
  – Oncogenensis
  – Teratogenesis
Radiation Physics 101

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Radioactive Decay

- Atoms decay to reach a more stable state by emitting ionizing radiation in the form of particles or penetrating radiation (Gamma rays).
Types of Ionizing Radiation
Types of Ionizing Radiation

- Alpha particles
  - Positively charged, easily stopped by a thin paper, do not present an external hazard.
  - Inhaled/ingested, can result in significant organ damage.

\[
\begin{align*}
\text{parent: } & \quad ^{210}\text{Po} \\
\text{daughter: } & \quad ^{206}\text{Pb} + ^4_2\text{He}
\end{align*}
\]
Types of Ionizing Radiation

- Beta particles
  - Negatively charged electrons, can travel several centimeters through air. Stopped by clothes.
  - If internalized will cause problems.
  - “beta burn”

\[ ^{14}_6\text{C} \rightarrow ^{14}_7\text{N} + ^0_{-1}\text{e}^- \]
Types of Ionizing Radiation

– Gamma rays
  • Electromagnetic waves.
  • Gamma rays are the same as x-rays -- the difference is their source from within the atom: nuclear for gamma, extranuclear for X-rays.
  • Are a significant hazard (depending on duration of exposure, distance from the source, and type of shielding).
Types of Ionizing Radiation

- Neutrons
  - Neutron irradiation can turn previously nonradioactive materials radioactive.
  - Uncharged. Causes whole body irradiation like Gamma rays.
  - Emitted from fission reactions.
Radiation Units: S.I. Versus USA

<table>
<thead>
<tr>
<th>S.I.</th>
<th>Formula</th>
<th>USA</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Gray (Gy) =</td>
<td>100 x</td>
<td>RAD</td>
</tr>
<tr>
<td>1 Sievert (Sv) =</td>
<td>100 x</td>
<td>REM</td>
</tr>
</tbody>
</table>
2 Different yet Possible Overlapping Entities

<table>
<thead>
<tr>
<th>Exposure</th>
<th>Contamination</th>
</tr>
</thead>
<tbody>
<tr>
<td>Whole body</td>
<td>External</td>
</tr>
<tr>
<td>Partial body</td>
<td>Internal</td>
</tr>
</tbody>
</table>
Some Contaminated Patients are Exposed

Contaminated Victims

Exposed Victims
All Internally Contaminated Patients are Potentially Exposed
Contamination

External

Routes of Internalization

Inhalation

Ingestion

Injection or Wounds
Radiation Protection in Whole Body Exposure

- Time
- Distance
- Shielding
- Georgia Poison
Pick the Appropriate Personal Protective Equipment (PPE)!

WHEN CARING FOR THESE PATIENTS
Respiratory Protection

- Commonly available protective masks are generally sufficient pre-decontamination
- OSHA/NIOSH: Hospital staff taking care of patients in the pre-decontamination and decontamination areas, PAPRs or HEPA filter negative pressure masks are described as minimum
Personal Protection

• Standard Precautions
Radiation Detection in the ED

- Victims should be surveyed with Geiger-Müller counters.
- Standard G-M cannot detect radiation exposure; they detect external gamma, some beta, and no alpha unless using a specialized alpha probe.
- They can detect internal gamma, less beta, and no alpha regardless of the probe.

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Radiation Detection in the ED™

- Survey patient for radiological contamination and mark areas on body diagram.
- Remove contaminated clothes and label them.
- Except for an instance of highly-radioactive shrapnel, contamination should NOT deter medical staff from treating life-threatening injuries.
Radiation Survey in the ED and Decontamination
Radiation Detection

- Pocket dosimeters
- Film badges
- Thermoluminescent dosimeters (TLD)
DIAGNOSIS OF INTERNAL CONTAMINATION
Nasal Swabs

• A swab is collected from each nostril of individuals who have potentially inhaled radionuclides in the form of particulate matter.
• Each swab gets tested for the detection of radiation.
• The radiation present in the nasal cavities will reflect the presence of radionuclides in lower air spaces and subsequent internal contamination.
Nasal Swabs

• Not feasible in a mass casualty setting
• The negative and positive predictive values of radioactive nasal swabs in the case of $^{238}\text{Pu}$ relative to the CEDE was 41 and 59% respectively. For $^{239}\text{Pu}$, these values are 74 and 54% respectively.

In Vivo Measurements

• Whole body counters
• Chest counters for Plutonium and Uranium
• Wound monitoring instruments
Whole Body Dosimetry

- Using whole body counters or scanners that are potentially available at nuclear medicine departments.
- It is crucial to know when the contamination occurs as well as which radionuclide is involved.

www.bt.cdc.gov/radiation/clinicians/evaluation/index.asp
Diagnosis By Excretion (Bioassay) Sampling

• Collect urine or feces to measure excretion rates
• Challenging interpretation
  – Time when contamination occurred
  – Characteristics of inhaled or internalized radionuclides

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"Radiological Laboratory": Future Goals

• To rapidly (≤30 minutes per sample) analyze urine for the 22 priority radionuclides (alpha, beta and gamma emitters)
• To be able to achieve the analytical goals using a volume of ≤50 mL of urine
• To analyze the 22 priority radionuclides (e.g. $^{60}$Co, $^{137}$Cs, $^{241}$Am, etc.)
• To provide accurate and precise results in a short amount of time (>2000/day)
• CLIA’88 compliant
CDC’s Urine Radionuclide Screen

Urine Sample “Spot”

Gamma Radionuclide Screen

Alpha/Beta Radionuclide Screen/Quantification

Alpha (Long Lived) ICP-MS Screen

Gamma Radionuclide Quantification

Alpha Spectroscopy Quantification

Mass Spectroscopy Quantification

High Resolution Mass Spectroscopy Quantification

Np (V)

Pu (IV)

Np (VI)

Pu (VI)
Internal Contamination
Acute Radiation Syndrome

CLINICAL IMPACT AND CONSEQUENCES
Clinical Consequences of Internal Contamination

- **Acute and subacute**
  - End organ damage
  - Acute Radiation Syndrome
  - Multiorgan failure

- **Chronic**
  - Solid tumors
  - Leukemias
Radionuclides of Concern

• Transuranics
• Cesium-137
• Strontium
• Cobalt-60
• Polonium-210
Management Strategies

- Supportive care
- Decreasing absorption
- Decorporation and enhance elimination
- Long term monitoring
### Decorporation

<table>
<thead>
<tr>
<th>Displace Element</th>
<th>Chelate Element</th>
<th>Enhance Elimination</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Potassium Iodide</td>
<td>• DTPA</td>
<td>• Sodium Bicarbonate</td>
</tr>
<tr>
<td>• Ammonium Cl/Ca gluconate</td>
<td>• EDTA</td>
<td>• Forced Diuresis</td>
</tr>
<tr>
<td></td>
<td>• Prussian Blue</td>
<td></td>
</tr>
</tbody>
</table>

*No true radiation antidotes!
## Internal Contamination

<table>
<thead>
<tr>
<th>Radionuclide</th>
<th>Medication</th>
</tr>
</thead>
<tbody>
<tr>
<td>Iodine</td>
<td>KI (potassium iodide)</td>
</tr>
</tbody>
</table>
| Transuranics such as Plutonium & Americium | Zn-DTPA  
|                               | Ca-DTPA                              |
| Uranium                       | Bicarbonate                          |
| Cesium Rubidium Thallium      | Prussian Blue* [Ferrihexacyano- Ferrate (II)] |
| Tritium                       | Water                                |
Transuranics

- Used for Transuranics such as Plutonium and Americium.
- First dose should be Calcium DTPA followed by Zinc DTPA.
- Duration of therapy will be guided by urine or feces transuranic concentrations.
## DTPA Treatment of $^{239}$Pu

<table>
<thead>
<tr>
<th>Retention (% of Uptake)</th>
<th>Control</th>
<th>Treated with DTPA</th>
</tr>
</thead>
<tbody>
<tr>
<td>Liver</td>
<td>14.0</td>
<td>0.47</td>
</tr>
<tr>
<td>Skeleton</td>
<td>57.0</td>
<td>5.9</td>
</tr>
</tbody>
</table>
DTPA decorporation of $^{239}\text{Pu}$ (in rats): Decline in efficacy with delay to treatment

<table>
<thead>
<tr>
<th>Time to treatment</th>
<th>Liver</th>
<th>Skeleton</th>
</tr>
</thead>
<tbody>
<tr>
<td>1, 24, 48 hours</td>
<td>7</td>
<td>10</td>
</tr>
<tr>
<td>7 - 11 days</td>
<td>22</td>
<td>46</td>
</tr>
</tbody>
</table>

from Catsch, 1964
Cesium-137

- 46 Goiania pts contaminated with Cs-137 treated with Prussian Blue.
- Less than 1% is absorbed.
- Exchanges a cation and binds Cesium or Thallium.
- Decreases GI absorption and interrupts enterohepatic circulation.
Radiogardase®

- Insoluble form FDA approved in 2004. Available in CA or REAC/TS.
- Dosage is 3 g orally every 8 hours.
- Duration of therapy guided by feces Cs content
- AE: Constipation and blue stools, sweat, teeth
Radioactive Iodine Exposure

- Iodine Prophylaxis and Treatment
  - Potassium iodide (KI) is an effective, inexpensive thyroid-blocking agent.
Radioactive Iodine Exposure

Saturate the Critical Organ with the Stable Isotope

\[ _{131}^{131}\text{I} \]
Efficacy of KI is time dependent
ACUTE RADIATION SYNDROME (ARS)
Acute Radiation Syndrome (ARS)

- Deterministic effect
- Prodrone phase
- Hematopoetic syndrome
- Gastrointestinal syndrome
- CV/CNS syndrome
Approximate Time Course of Clinical Manifestations

Waselenko et al. Annals of Internal Med 140(12)
Prodrome

- Vague Sx: nausea, vomiting, headache.
- Help predict the dose: the higher the absorbed dose the earlier and the more frequent the Sx occur.

15 June 2004 Annals of Internal Medicine
Volume 140 • Number 12
Hematopoetic Syndrome (2-6 Gy)
Lymphocyte Depletion Kinetics

- Andrew’s nomogram helps estimate the dose of radiation.
- WBC with differential every 6 hrs for first 24-48 hours.
Cytogenetics

• Rate of dicentric chromosomes in peripheral lymphocytes.
• Available at REAC/TS.
• Takes a few days.
Management of the Hematopoietic Syndrome

- Complications: infection and bleeding.
- Treatment is supportive:
  - Reverse isolation
  - IVF
  - Blood products
  - Antibiotics
  - Colony stimulating factors such as filgrastim or G-CSF (300 mcg s.c per day)
  - Stem cell transplant
G-CSF: Animal Studies

Enhanced Survival of Acutely Irradiated (4Gy) Canines Following G-CSF Cytokine Treatments

Questions?

• Radiologic Threats
• Time, Distance, and Shielding
• Exposure versus Contamination
• Acute Radiation Syndrome