Radiation Exposure Emergencies.

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• On March 11, 2011, a 9.0-magnitude earthquake struck the east coast of Japan. Over 14,000 deaths
• Damage to the Fukushima Daiichi nuclear power plant
• This talk puts the emergency at the Japanese power plant into the context of the extensive literature on nuclear-reactor accidents by analyzing the mechanisms and major short-term and long-term health risks of radiation exposure
• Review the current medical treatment
• In addition, we briefly discuss the accidents at Three Mile Island in Pennsylvania in 1979 and at Chernobyl in Ukraine in 1986 because they illustrate the broad range of potential outcomes
MECHANISMS OF EXPOSURE

Nuclear Reactor Accidents
- (core) containing the fuel and the fission products may become damaged and allow radioactive elements to escape into the environment.

Types of Radiation Exposure
- Exposure from close proximity to radiation source
  - Beta radiation travels short distance and affects mostly skin
  - Gamma radiation can penetrate deeply

- External Contamination

- Internal Contamination

Mechanisms of Exposure
- Detonation of nuclear weapon requires highly enriched uranium or plutonium isotopes in concentrations and configurations not present in power plants.

- Dirty Bomb

Internal Contamination
Effective Doses of Radiation, According to Source of Exposure.

Types of Ionizing Radiation

The required conditions for Acute Radiation Syndrome (ARS):

- The radiation dose must be large (i.e., greater than 1 Gray)
- The dose usually must be external (i.e., the source of radiation is outside of the patient’s body).
- The entire body (or a significant portion of it) must have received the dose
- The dose must have been delivered in a short time

Acute Radiation Syndrome

- Based on the clinical experience of more than 800 patients who have been described in national and international registries of radiation accidents that have been predominantly medical in source (1)
- ARS has not been seen in general population in association with nuclear-reactor accident; all 134 patients with ARS at Chernobyl were either plant workers or members of the emergency response team (2)

Acute Radiation Syndrome – Chernobyl Experience

- 134 patients with ARS
  - All 134 had bone marrow depression
  - 19 had widespread radiation dermatitis
  - 15 had severe GI complications (1)
  - Cutaneous toxic effects are common because external low-energy gamma radiation and beta radiation are chiefly absorbed in the skin
  - Estimated skin doses in some patients were 10 to 30 times the bone marrow doses


Acute Radiation Syndromes

<table>
<thead>
<tr>
<th>Syndrome</th>
<th>Hematopoietic (Bone Marrow)</th>
<th>Gastrointestinal (GI)</th>
<th>Cardiovascular (CV)/Central Nervous System (CNS)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Prodromal Stage Latent Stage Manifest Illness Stage Recovery</td>
<td>Hematopoietic (Bone Marrow)</td>
<td>Gastrointestinal (GI)</td>
<td>Cardiovascular (CV)/Central Nervous System (CNS)</td>
</tr>
<tr>
<td>&gt; 0.7 Gy (&gt; 70 rads) (some symptoms may occur as low as 0.3 Gy or 30 rads)</td>
<td>Symptoms are anorexia, nausea and vomiting.</td>
<td>Symptoms are anorexia, nausea and vomiting.</td>
<td>Symptoms are extreme nervousness, confusion, severe nausea, vomiting, and watery diarrhea; loss of consciousness and burning sensations of the skin.</td>
</tr>
<tr>
<td>Hematopoietic (Bone Marrow)</td>
<td>Stem cells in bone marrow are dying.</td>
<td>Stem cells in bone marrow and cells lining GI tract are dying.</td>
<td>Patient may return partial functionality.</td>
</tr>
<tr>
<td>Gastrointestinal (GI)</td>
<td>Death occurs within a few hours after exposure.</td>
<td>Stage lasts about 2 days.</td>
<td>Stage lasts for minutes to hours.</td>
</tr>
<tr>
<td>Cardiovascular (CV)/Central Nervous System (CNS)</td>
<td>Stage lasts 1 to 6 weeks.</td>
<td>Stage lasts less than 1 week.</td>
<td>Symptoms may occur 5 to 6 hours after exposure.</td>
</tr>
</tbody>
</table>
| Overview of Medical Treatment for Radiation Injury

- 1. First aid and resuscitation
- 2. Medical and surgical stabilization
- 3. Definitive treatment of serious injuries
- 4. Prevention/minimization of internal contamination
- 5. Assessment of external contamination and decontamination
- 6. Treatment of other minor injuries
- 7. Containment of the contamination to the treatment area and prevention of contamination of other personnel
- 8. Minimization of external radiation to rescue and treatment personnel
- 9. Assessment of internal contamination
- 10. Treatment of internal contamination (this could be concurrent with many of the above)
- 11. Assessment of local radiation injuries/radiation
- 12. Counseling of patients about expected long-term effects and risks
- 13. Long-term follow-up of patients with significant whole-body irradiation or internal contamination
Treatment Priorities

• #1: Treat immediate life-threatening injuries (trauma, burns, etc)
• #2: Address Internal and External Contamination; Use Decontamination protocols
• #3: Treat Acute Radiation Illness if suspected
  – Treatment guided by estimated total dose;
  – This estimation is based on initial clinical symptoms, lymphocyte depletion kinetics and cytogenetic analyses (1,2)


Gastrointestinal Symptoms in assessing radiation injury severity

• GI symptoms (anorexia, nausea, vomiting, diarrhea)
• For GI symptoms the following estimation may apply:
  • <0.5 Gy: onset > 6 hours
  • <2 Gy: onset 2-6 hours
  • <4 Gy: onset <2 hours
  • <9 Gy: onset <30 minutes

Early laboratory indications of exposure to ionizing radiation.

Biologic effects resulting from radiation-induced damage to DNA molecules.
Acute Radiation Syndrome

- Treat GI complications supportively
- Cutaneous lesions – minimize inflammation with topical glucocorticosteroids and avoid secondary infections
- Treatment of the consequences of Bone Marrow Depletion:
  - Management of infections with antibiotics, antivirals, antifungals
  - Use of hematopoietic growth factors
  - Possible bone marrow transplantation (controversial)
  - 2 out of 13 patients after Chernobyl survived long-term
- Numerous organizations developed guidelines to treat ARS – these are publically available (1,2)


Long-Term Cancer Risk

- Studies of the Japanese atomic-bomb survivors showed clearly elevated rates of leukemia and solid cancers, even at relatively low total body doses. (1,2)
- Studies evaluating leukemia and nonthyroid solid cancers have not shown consistently elevated risks in the regions around Chernobyl (3,4)

Increase in Thyroid Cancer Risk in Children

- There is strong evidence of an increased rate of secondary thyroid cancers among children who have ingested iodine-131
- Increased risk by a factor of 2-5 per 1 Gy (1)
- Risk of thyroid CA among children who were given Iodine was 1/3 compared to children who did not receive iodine (2)
- Half-life of Iodine is 8 days, and local resources should not contain substantial iodine after 2-3 months
- To be effective, prophylaxis with potassium iodide should occur before or within a few hours of exposure
- Although potassium iodide can have toxic effects, the Polish experience with en masse administration of the drug after Chernobyl was reassuring (3)

You are working in a busy Emergency Department when the pre-hospital radio reports an explosion at a bus stop downtown. You get a notification/radio call that some of the victims will be delivered to your Emergency Department for treatment.

An earthquake struck, causing collapse of buildings and roads. It also damaged a nuclear plant, causing the leakage of radioactive material into the surrounding air and water. You expect hundreds of patients presenting to your ED.
What precautions would you use for the patients coming in?

A. Universal Precautions
B. Removal of the patient’s clothing and putting patient in a hospital gown after victims are delivered to the ER
C. Instruct EMTs/paramedics to remove victims’ clothing in the field and put victims in a hospital gown before delivering them to the emergency Department. Instruct paramedics to scan for radiation contamination with Geiger counters, if available, and for signs of chemical contamination
D. Answer C plus the use of decontamination room/Geiger counters and the use of Standard Precautions

Scope of Event

<table>
<thead>
<tr>
<th>Event</th>
<th>Number of Deaths</th>
<th>Most Deaths Due to</th>
</tr>
</thead>
<tbody>
<tr>
<td>Radiation Accident</td>
<td>None/Few</td>
<td>Radiation</td>
</tr>
<tr>
<td>Radioactive Dispersal Device</td>
<td>Few/Moderate</td>
<td>Blast Trauma (Depends on size of explosion and proximity of persons)</td>
</tr>
<tr>
<td>Low-Yield Nuclear Weapon</td>
<td>Large (e.g., tens of thousands in an urban area even from 0.1 kT weapon)</td>
<td>Blast Trauma Thermal Burns Radiation Exposure Fallout (Depends on Distance)</td>
</tr>
</tbody>
</table>

Dirty Bomb versus Nuclear Explosion (reactor or bomb)

- “Dirty Bomb” – primary damage is from blast; low level radioactive sources
- Nuclear Explosion/Leakage of Radioactive material – damage from both blast injury and possible high-level radiation

If you were a public health official or a paramedic addressing the mildly injured people at the bus stop, what instructions would you give?

A. Leave the immediate area by foot only; do not take public transportation
B. Go inside the nearest building if instructed by emergency personnel, and await further instructions. You will have a preliminary screen for evidence of radiological/chemical contamination.
C. Change clothes as soon as possible and store away dirty clothes in a plastic bag; these may be used as evidence by law enforcement.
D. Wash your skin with soap and water
E. All of the above
Key Points

- Contamination is easy to detect and most of it can be removed. Removal of clothing can reduce contamination up to 90%.
- It is very unlikely that ED staff will receive large radiation doses from treating contaminated patients.

Facility Preparation

- Activate hospital plan:
  - Obtain radiation survey meters.
  - Call for additional support: Staff from Nuclear Medicine, Radiation Oncology, Radiation Safety (Health Physics).
  - Establish area for decontamination of uninjured persons.
  - Establish triage area.
- Plan to control contamination:
  - Instruct staff to use universal precautions and double glove.
  - Establish multiple receptacles for contaminated waste.
  - Protect floor with covering if time allows.
  - For transport of contaminated patients into ED, designate separate entrance, designate one side of corridor, or transfer to clean gurney before entering, if time allows.

Protection from Contamination

- Follow universal precautions.
- Survey hands and clothing with radiation meter.
- Replace contaminated gloves or clothing.
- Keep the work area free of contamination.
- Personal radiation dosimeter

Time

Minimize time spent near radiation sources.

Distance

Maintain maximal practical distance from radiation sources.

Shielding

Place radioactive sources in a lead container.

Radiation Protection

Reducing Radiation Exposure

<table>
<thead>
<tr>
<th>Distance</th>
<th>Rate (R/hr)</th>
<th>Stay (hr)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 ft</td>
<td>12.5</td>
<td>24</td>
</tr>
<tr>
<td>2 ft</td>
<td>3.1</td>
<td>1.6</td>
</tr>
<tr>
<td>5 ft</td>
<td>0.5</td>
<td>10</td>
</tr>
<tr>
<td>8 ft</td>
<td>0.2</td>
<td>25</td>
</tr>
</tbody>
</table>

To Limit Caregiver Dose to 5

HOT LINE

Separate Entrance

Contaminated Area

Buffer Zone

Clean Area

Treatment Area Layout
Detecting and Measuring Radiation

- **Instruments**
  - Locate contamination - GM Survey Meter (Geiger counter)
  - Measure exposure rate - Ion Chamber
- **Personal Dosimeters - Measure doses to staff**
  - Radiation Badge - Film/TLD
  - Self-reading dosimeter (analog and digital)

Goals of Decontamination

- Prevent further spread of Radioactive Material (i.e. secondary contamination)
- Prevent further absorption and subsequent systemic toxicity to the patient
- Difference between Radiation Exposure and Contamination

Patient Management - Decontamination

- Carefully remove and bag patient’s clothing and personal belongings (typically removes 90 percent of contamination).
- Survey patient (including nares and mouth) and, if practical, collect samples.
- Handle foreign objects with care until proven nonradioactive 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 Process

- Use Personal Protective Equipment (PPE)
  *Protective clothing, gloves, shoe covers, face mask*
- Decon till patient is less than twice the amount of background radiation – use Geiger counter
- Wash skin and hair with soap and water; cut hair and nails prn; high-volume dilution with water
- Avoid excessive skin rubbing to protect skin barrier; use tepid water
- Avoid water in the presence of metallic Na, K, Li, Cesium, Rubidium; dusts of pure Mg, Phos, Sulfur, Strontium, Uranium, Zinc
Dirty Bomb Victim
A 35 year-old man was at a bus stop when the bomb exploded. He now complains of bruises on left thigh and several scratches on his hand. He changed his clothes before coming to your Emergency Department.

After the patient was thoroughly decontaminated at a Decontamination room of your Emergency Department, you obtain further history. The review of systems is otherwise negative.

<table>
<thead>
<tr>
<th>System</th>
<th>Findings</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vital Signs</td>
<td>Young man looking well.</td>
</tr>
<tr>
<td>Head</td>
<td>Pupils 3mm round and reactive to light. Oropharynx clear. Tympanic membranes normal. Moist mucous membranes</td>
</tr>
<tr>
<td>Neck</td>
<td>Clear to auscultation, no edema.</td>
</tr>
<tr>
<td>Cardiovascular</td>
<td>Regular rate and rhythm, no murmurs, rubs or gallops, cool extremities</td>
</tr>
<tr>
<td>General</td>
<td>Normal</td>
</tr>
<tr>
<td>Gastrointestinal</td>
<td>Normal bowel sounds, no rectal tenderness, no guarding or rebound.</td>
</tr>
<tr>
<td>Neurologic</td>
<td>Non-focal</td>
</tr>
<tr>
<td>Other</td>
<td>Wound: Several superficial scratches on left forearm, several bruises on left thigh</td>
</tr>
</tbody>
</table>

A 35 year-old man was at a bus stop when the bomb exploded. He now complains of bruises on left thigh and several scratches on his left hand. He changed his clothes before coming to your Emergency Department.

After the patient was thoroughly decontaminated at a Decontamination room of your Emergency Department, you obtain further history. The review of systems is otherwise negative.

What tests, if any, would you utilize in treating this patient?

A. None
B. General radiation monitoring and nasal swabs radioactivity measurement
C. Urine and fecal material to measure radioactivity
D. CBC with differential
E. CBC with differential, electrolytes, BUN, Cr, Glucose, liver function tests (LFTs)
F. B, C and D

Laboratory Results

<table>
<thead>
<tr>
<th>Lab Test</th>
<th>Value</th>
<th>Normal Range</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>WBC</td>
<td>5.5</td>
<td>4-10</td>
<td>K/mL</td>
</tr>
<tr>
<td>Hct</td>
<td>39</td>
<td>36-48 (women) 40-54 (men)</td>
<td>%</td>
</tr>
<tr>
<td>Plt</td>
<td>135</td>
<td>150-450</td>
<td>K/mL</td>
</tr>
</tbody>
</table>

Neutrophils: 70%
Bands: 0
Lymphocytes: 30%

Case Progression

- You get the report that radioactive Iodine may have been one of the components of the bomb that exploded at a bus stop.
In addition to the performed decontamination, how would you treat this patient?

A. DTPA (Diethylenetriaminepentaacetate)
B. NaHCO3 (Sodium Bicarbonate)
C. KI (Potassium Iodide)
D. Amifostine
E. None

Potassium Iodide (KI)

- Protects ONLY thyroid from cancer
- Works only IF radioactive iodine was involved in the exposure
- Works by preventing radioactive iodine uptake by the thyroid gland
- Must be taken prior to exposure or immediately after exposure to be effective
- Only 7% effective if given 24 hrs post exposure; however, helps if continual exposure (such as by ingestion) present
- A dose protects for 24 hrs

Treatment of Internal Contamination

- Radionuclide-specific
- 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-241/243</td>
<td>Ca- and Zn-DTPA</td>
<td>IV</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>

Medical Treatment of Radioactive heavy metals poisonings

- Aluminum reduces absorption of strontium
- Barium precipitates radium
- EDTA precipitates lead
- Penicillamine for lead, copper, cobalt
- Prussian blue for thallium, cesium, rubidium
- DTPA for plutonium, americium, curium
- Deferoxamine for plutonium, iron
- Water diuresis for tritium, Na, K
- Dimercaprol for mercury, arsenic, bismuth, chromium, nickel, lead

For expert assistance, contact Radiation Emergency Assistance Center in Tennessee (615) 481-1000 (24 hrs/day)
Internal contamination treatment

- Diluting agents: e.g. controlled water diuresis for tritium
- Blocking agents: e.g. Potassium Iodide (KI) for Iodine-131
- Chelating agents: e.g. Zn-DTPA and Ca-DTPA for plutonium and transuranics
- Gastric lavage: e.g. for cobalt contamination in special situation
- Pulmonary lavage: e.g. for plutonium in lungs in special situations
- Emetics: e.g. for cobalt
- Purgative/laxative/enemas: e.g. for cobalt

Patient with a sucking chest wound

- You get a call by paramedic stating that they are bringing you a patient with sucking chest wound who was close to the scene of the dirty bomb explosion
- How do you triage the patient?
  - A) Decontamination First, then treat pneumothorax
  - B) Treat pneumothorax first, then decon
Patient Management - Priorities

Triage
- Medical triage is the highest priority.
- Radiation exposure and contamination are secondary considerations.
- Degree of decontamination is dictated by number of and capacity to treat other injured patients.

Patient has shattered his tibia and requires surgery
- When should the patient go to surgery?
  - A) Within the next 24-48 hours
  - B) In 1 month after his condition stabilizes
  - C) In 3 months

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

Case Progression:
- The next day, the 35 year old patient who initially presented with bruises and scratches, presented with nausea and one episode of vomiting. He denies fevers, chills, diarrhea, abdominal pain, and upper respiratory symptoms. Review of systems is otherwise negative.

More labs are ordered with the following results:
- WBC 3.5
- Hct 40
- Platelets 230
- Absolute neutrophil count (ANC) 2050
What is the most likely diagnosis?
A. Gastroenteritis  
B. Cardiac ischemia  
C. Potassium Iodide side-effects  
D. Anxiety  
E. Radiation Injury

Case Progression:
• The patient returned next day for his CBC draw and monitoring. It is now approximately 48 hours after the bomb explosion.

  His nausea and vomiting had resolved after several hours yesterday, and he is now asymptomatic. His CBC today is:

  WBC 3.5 ANC 2020 Hct 40 Platelets 220

What is the patient’s prognosis?
A. Good  
B. Fair  
C. Poor  
D. Unknown

Summary
• Decontamination should not delay or impede stabilization of any patient.
• Removal of all clothing can reduce contamination on the patient up to 90%.
• Use Geiger counters and PPE: Decon till twice the amount of background radiation.
• Potassium iodide use and Chelating Agents; consult CDC website for medical countermeasures and doses.
• The prognosis of victims is proportional to their ANC counts at 48 hours and the timing and severity of their symptoms.
Resources

- Medical Radiobiology Advisory Team (MRAT) Armed Forces Radiobiology Research Institute (AFRRI), 301-295-0530, www.afri.usuhs.mil
  - Medical Management of Radiological Casualties Handbook, 2003; and Terrorism with Ionizing Radiation Pocket Guide
- Web sites:
  - http://emergency.cdc.gov/radiation/ - Response to Radiation Emergencies by the Centers for Disease Control and Prevention
  - www.acr.org - "Disaster Preparedness for Radiology Professionals" by the American College of Radiology, (search for “disaster” on website)
  - www1.va.gov/emshg - Medical Treatment of Radiological Casualties

References

- Kastengerg WE. Principal issues and future projects of nuclear energy.
- Sullivan MK, Donnelly B. Emergency Department Response to Terrorism, Top Emer Med. 2005; 27(1):50-77. (See “Forensic processes and actions,” pages 59-60.) (Subscription required)

References Cont

- Online Resources:
  - Weinstein JW. Isolation guidelines for hospitals. UpToDate.
Additional References:

- Procedures for Medical Emergencies Involving Radiation (PDF - 19 KB) (Health Physics Society)
- Patient Decontamination: Recommendations for Hospitals (PDF - 124 KB) (The Hospital and Healthcare System Disaster Interest Group and the California Emergency Medical Services Authority, July 2005, EMSA #233, Radiological Contamination, pages 11-16)
- Guide for the Selection of Chemical, Biological, Radiological, and Nuclear Decontamination Equipment for Emergency First Responders (PDF - 6.5 MB) (DHS, Draft, March 2007)
- Radiation Decontamination: 6 part audio-video demonstration (REAC/TS)
- Advanced Personal Protective Equipment (PPE) and Standard Precautions (PowerPoint® - 10 MB) (The New York City Department of Health and Mental Hygiene)
- Resources from National Council on Radiation Protection and Measurements (NCRP):
  - Responding to a Radiological or Nuclear Terrorism Incident: A Guide for Decision Makers (NCRP Report No. 165), Bethesda, MD 2011.
  - Population Monitoring and Decontamination Following a Nuclear/Radiological Incident (NCRP Scientific Committee 4-2), National Council on Radiation Protection and Measurements. (Report in preparation)

Acknowledgments

Some information/tables for this presentation was prepared by the Medical Response Subcommittee of the National Health Physics Society Homeland Security Committee.
The objectives of this session are:

- To review the differences in exposure and treatment between the dirty bomb victims and the victims of a nuclear plant malfunction or a nuclear blast
- To review the precautions to be used by the providers when treating patients in radiation emergencies
- To review the goals and the process of decontamination
- To review medical treatment options for radiation victims
- Methods of assessing prognosis of radiation victims