Medical Management of Nuclear or Radiological Emergencies

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Situations for radiation exposure

- A *planned exposure situation* is a situation of exposure that arises from the planned operation of a source or from a planned activity that results in an exposure due to a source.

- An *emergency exposure situation* one that arises as a result of an accident, a malicious act or any other unexpected event, and requires prompt action in order to avoid or to reduce adverse consequences.

- An *existing exposure situation* is a situation of exposure that already exists when a decision on the need for control needs to be taken.
## Radiation emergency

<table>
<thead>
<tr>
<th>Classification</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Nuclear</strong></td>
<td>An <em>emergency</em> in which there is, or is perceived to be, a hazard due to the energy resulting from a nuclear chain reaction or from the decay of the products of a chain reaction</td>
</tr>
<tr>
<td><strong>Radiological</strong></td>
<td>An <em>emergency</em> in which there is, or is perceived to be, a hazard due to a radiation exposure</td>
</tr>
</tbody>
</table>
## Potential victims of a radiation emergency

<table>
<thead>
<tr>
<th>Condition</th>
<th>Exposed individuals</th>
</tr>
</thead>
<tbody>
<tr>
<td>Accident</td>
<td>Radiation workers</td>
</tr>
<tr>
<td></td>
<td>Individuals of the public (other workers included)</td>
</tr>
<tr>
<td></td>
<td>Responders</td>
</tr>
<tr>
<td>Medical mishap</td>
<td>Patients</td>
</tr>
<tr>
<td>Malevolent act (&quot;Incident&quot;)</td>
<td>Individuals of the public</td>
</tr>
<tr>
<td></td>
<td>Responders</td>
</tr>
</tbody>
</table>
Radiation exposure

- External
  - Whole-body
  - Local

- Radioactive contamination
  - External
  - Internal
Possible consequences of a radiation emergency

- Radiation emergencies are not common, but may lead to:
  
  - Medical (acute / late), psychosocial, environmental, and economical impacts!
  - Examples:
    - Chernobyl NUCLEAR accident
    - Goiânia RADIOLOGICAL accident
    - Fukushima NUCLEAR accident
Response to radiation emergencies

• Based on the same principles that regulate the response to other emergencies, but...
Ionizing radiation specificities

- Ionizing radiation is not perceived by the human senses, but
- May be fairly easily detected
- The health community in general is not aware of the radiation-induced health manifestations...
Data: 1944 - 2015

<table>
<thead>
<tr>
<th>Condition</th>
<th>Number</th>
</tr>
</thead>
<tbody>
<tr>
<td>“Significant” emergencies</td>
<td>~500</td>
</tr>
<tr>
<td>Exposed people</td>
<td>~3,000</td>
</tr>
<tr>
<td>Deaths</td>
<td>~140</td>
</tr>
</tbody>
</table>
Radiation emergencies: involved activities

<table>
<thead>
<tr>
<th>Activity</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>industry</td>
<td>35</td>
</tr>
<tr>
<td>irradiators</td>
<td>27</td>
</tr>
<tr>
<td>medicine</td>
<td>12</td>
</tr>
<tr>
<td>laboratory</td>
<td>10</td>
</tr>
<tr>
<td>NI/other</td>
<td>8</td>
</tr>
<tr>
<td>reactors</td>
<td>5</td>
</tr>
<tr>
<td>education</td>
<td>2</td>
</tr>
<tr>
<td>military</td>
<td>1</td>
</tr>
</tbody>
</table>
### Significant past radiological emergencies

<table>
<thead>
<tr>
<th>Year</th>
<th>Place/Region</th>
<th>Radionuclide, circumstances</th>
<th>Number of exposed persons</th>
<th>Number of deaths</th>
</tr>
</thead>
<tbody>
<tr>
<td>2000</td>
<td>Brazil</td>
<td>$^{60}\text{Co}$</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>2000</td>
<td>Egypt</td>
<td>$^{192}\text{Ir}$</td>
<td>7</td>
<td>2</td>
</tr>
<tr>
<td>2000</td>
<td>Thailand</td>
<td>$^{60}\text{Co}$</td>
<td>&gt;10</td>
<td>3</td>
</tr>
<tr>
<td>2001</td>
<td>Panama</td>
<td>radiotherapy</td>
<td>28</td>
<td>6</td>
</tr>
<tr>
<td>2001</td>
<td>Poland</td>
<td>radiotherapy</td>
<td>5</td>
<td>0</td>
</tr>
<tr>
<td>2001</td>
<td>Georgia</td>
<td>$^{90}\text{Sr}$</td>
<td>3</td>
<td>1</td>
</tr>
<tr>
<td>2001</td>
<td>Bolivia</td>
<td>$^{192}\text{Ir}$, transport</td>
<td>59</td>
<td>0</td>
</tr>
<tr>
<td>2002</td>
<td>Bolivia</td>
<td>$^{192}\text{Ir}$</td>
<td>4</td>
<td>0</td>
</tr>
<tr>
<td>2002</td>
<td>Venezuela</td>
<td>$^{137}\text{Cs}$</td>
<td>3</td>
<td>0</td>
</tr>
<tr>
<td>2006</td>
<td>Senegal &amp; Ivory Coast</td>
<td>$^{192}\text{Ir}$</td>
<td>4</td>
<td>0</td>
</tr>
<tr>
<td>2006</td>
<td>Venezuela</td>
<td>$^{60}\text{Co}$, transport</td>
<td>3</td>
<td>0</td>
</tr>
<tr>
<td>2006</td>
<td>Belgium</td>
<td>$^{60}\text{Co}$</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>2006</td>
<td>UK</td>
<td>$^{210}\text{Po}$</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>2009</td>
<td>Ecuador</td>
<td>$^{192}\text{Ir}$</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>2010</td>
<td>Venezuela</td>
<td>$^{192}\text{Ir}$</td>
<td>3</td>
<td>0</td>
</tr>
<tr>
<td>2010</td>
<td>India</td>
<td>$^{60}\text{Co}$</td>
<td>7 (?)</td>
<td>1</td>
</tr>
<tr>
<td>2012</td>
<td>Peru</td>
<td>$^{192}\text{Ir}$</td>
<td>3</td>
<td>0</td>
</tr>
<tr>
<td>2014</td>
<td>Peru</td>
<td>$^{192}\text{Ir}$</td>
<td>3</td>
<td>0</td>
</tr>
<tr>
<td>$\Sigma$</td>
<td></td>
<td></td>
<td>146</td>
<td>14</td>
</tr>
</tbody>
</table>
IAEA - Incident and Trafficking Database (ITDB)  
– January 1993 to December 2013

• 2447 “incidents”
  ▪ 424 involved unauthorized possession and related criminal activities
  ▪ Incidents included in this category involved illegal possession, movement or attempts to illegally trade in or use nuclear material or radioactive sources
    ▪ Sixteen incidents in this category involved high enriched uranium (HEU) or plutonium
Radiation Dispersal Device – RDD

http://www.remm.nlm.gov/rdd.htm

• "Dirty Bomb" = Explosive method of dispersion

• Explosion produces radioactive and nonradioactive shrapnel and radioactive dust

• Explosion causes
  • Radiation contamination, commonly
  • Radiation exposure only in certain circumstances
  • Physical injury
  • Burns
  • Panic, fear
Radiation Exposure Device - RED

http://www.remm.nlm.gov/red.htm

- Whole-body and/or local exposure
  - ARS / CRS
- Important psychological impact

A 150 Ci (5.55 TBq) $^{192}$Ir under seat planted source

Doses rates from 280 to 7,000 mSv/h
“Medical” response insertion

- All hazards plan
- National radiation emergency plan
  - Medical response
    - Pre-hospital
    - Local hospital
    - Reference center
  - Source control
  - Contamination control
  - Waste disposal
  - Public communication

Public communication
“Medical” response to radiation emergencies

Response action levels

- Local hospital
- Tertiary (reference) center
- Police
- Firemen
- Civil Defense
- Military
- Paramedics
- Trauma hospital
- Severe ARS
- Severe CRS

Integrated and coordinated medical response system

On-the-scene*

RC*

Trauma hospital (the contamination issue)
On-the-scene number one

• If a life-threatening hazard is possible, victim should be removed to a safe area

• Hazards:
  – Fire
  – Smoke
  – Steam
  – Chemicals
  – Electrical
  – **Radioactive contamination**
  – **High air dose rate**

Photo credits: NIRS
On-the-scene actions in a nuclear or radiological emergency

- Hazard identification and assessment
- Victims’ triage
  - Medical (comes first!)
  - Radiological
- Stabilization of life-threatening conditions
- Decontamination procedures
- Notification and information to designated hospitals
- Transport of victims to designated hospitals
- Proper handling of deceased bodies
Medical triage

• **Priority 1 (P1) or Triage 1 (T1): immediate care needed** - requires immediate life-saving intervention

• **P2 or T2: intermediate or urgent care needed** - requires significant intervention within two to four hours

• **P3 or T3: delayed care** - needs medical treatment, but this can safely be delayed

• **Dead** is a fourth classification and is important to prevent the expenditure of limited resources on those who are beyond help
On-the-scene radioactive decontamination

- Removal of clothes
  - Clothes should be placed in bags with a tag identifying their owner
- Protection of possibly contaminated skin areas and wounds

Frame from CDC “Radiological terrorism: just-in-time training for hospitals clinicians”
Transfer of patients to designated hospitals

• As long as possible:
  – Vehicle protection
  – Stretcher covering
  – Contamination protection and monitoring of transfer personnel
Hospital assistance

- Conventional assistance
- External exposure evaluation
- Internal contamination assessment / treatment
- ARS diagnosis / treatment
- CRS diagnosis / treatment
- Referral to tertiary level centers
Needs for the hospital assistance

- Integration into a SYSTEM
- Plans and procedures
- Preparedness
- Facilities for specialized treatment
  - Laminar flow unit + HEPA + reverse isolation
  - HSCT
  - MSC
  - Decorporation drugs
    - KI
    - DTPA
    - Prussian Blue
Notification on patients’ arrival

- *First measure is to get as much information as possible, but without causing unacceptable delay on the activation of the hospital’s response plan*

- Identification (name, position, ID, phones numbers etc.) of person informing the event
- Number of patients
- Relevant information about the radiation source if available
- Kind, time, estimated dimension and place of the event; possibility of contamination with radionuclides (which, if known or suspected); co-existence of other hazards as chemical and biological agents (which, if known or suspected)
- Estimated time of arrival to the hospital
- Clinical and radiological status of each patient; traumatic injuries; any kind of treatment given to the patients
- Decontamination procedures already adopted
Triggering the hospital’s plan

- It is an essential part of planning and preparedness to have a previously designated area in the hospital facilities to receive and evaluate persons not directly affected by the accident but that could be concerned with possible radiation-related manifestations (worried-well)

- Authorities should establish a screening facility in other location, different from the hospital, for possibly affected persons (known as Reception Center, Radiation Monitoring Unit, or Emergency Care Centre, etc.)
Roles in-advance of patients’ arrival
Triage at the hospital

- Triage should be based on the medical condition of patients and NOT initially on their radiological status (like on the existence or not of radiological contamination).
- Stabilization of patients with life threatening conditions, such as airway obstruction, significant hemorrhage, multiple trauma, etc. is the FIRST priority.
## Medical/radiological conditions and treatment areas

<table>
<thead>
<tr>
<th>Condition</th>
<th>Treatment Area</th>
</tr>
</thead>
<tbody>
<tr>
<td>External exposure combined or not with conventional injuries</td>
<td>Regular patient treatment areas</td>
</tr>
<tr>
<td>Any of the above + radiological contamination</td>
<td>Hospital treatment / decontamination area in the emergency department (as the hospital response plan)</td>
</tr>
<tr>
<td></td>
<td>If necessary, regular patient treatment areas in the emergency department or elsewhere in the hospital could be adapted to accommodate patients with radiological contamination, but they should not be assisted in the same local ordinary patients are being cared</td>
</tr>
<tr>
<td>Radiological contamination</td>
<td>Decontamination area (as established in the hospital response plan)</td>
</tr>
</tbody>
</table>
Patients with suspected or confirmed whole-body radiation exposure

- If whole-body exposure to penetrating ionizing radiation is suspected, a concern may be the development of the *Acute Radiation Syndrome (ARS)*

- ARS is a set of clinical and humoral manifestations which medical consequences depend mainly on the radiation dose, its body distribution, and the total exposure time for the dose distribution

- ARS syndrome occurs after acute whole-body or significant partial-body irradiation of greater than 1 Gy (dose threshold)

- ARS includes the hematopoietic, gastrointestinal, and neurovascular (cerebrovascular) syndrome varieties
Patients with suspected or confirmed whole-body radiation exposure

- Time of emesis and dose estimation

<table>
<thead>
<tr>
<th>Time of emesis after exposure</th>
<th>Dose range estimation (Gy)</th>
<th>% incidence of emesis in exposed individuals</th>
<th>Severity of ARS</th>
</tr>
</thead>
<tbody>
<tr>
<td>No vomiting</td>
<td>&lt;1</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>≥ 2 h</td>
<td>1-2</td>
<td>10-50</td>
<td>Mild</td>
</tr>
<tr>
<td>1-2 h</td>
<td>2-4</td>
<td>70-90</td>
<td>Moderate</td>
</tr>
<tr>
<td>&lt;1 h</td>
<td>4-6</td>
<td>100</td>
<td>Severe</td>
</tr>
<tr>
<td>&lt;30 min</td>
<td>6-8</td>
<td>100</td>
<td>Very severe</td>
</tr>
<tr>
<td>&lt;10 min</td>
<td>&gt;8</td>
<td>100</td>
<td>Lethal</td>
</tr>
</tbody>
</table>
Laboratory evaluation of patients with suspected or confirmed whole-body radiation exposure

- **Basic Exam**
  - Complete blood count (CBC), platelets and analysis of reticulocytes by flux cytometry
  - CBC and differential with absolute lymphocyte counts every 6 h for 48 h when history indicates possibility of whole body irradiation

  *To estimate the exposure dose range; initial counts establish a baseline, subsequent counts reflect the degree of injury.*

- **Rationale**
  - The kinetics of neutrophils and platelets in circulating blood are extremely important, for not only prognosis but to indicate the need for specific medical interventions like the administration of cytokines (as G-CSF), platelets infusions, and the use of antibiotics.

- **Biological dosimetry**
  - (chromosomal aberration analysis from cultured circulating lymphocytes)

  *Rings and dicentrics*

- **Serum amylase**

  *Irradiation of the salivary glands produces a rapid increase of salivary amylase in serum, released by the highly radiation sensitive serous cells of the glands. Serial assays of may serve as an indicator of the upper neck region dose and indirectly of the whole-body dose.*

**Plasma Flt-3 ligand concentration**

**Plasma citrulline**
Patients with suspected or confirmed whole-body radiation exposure

Andrews lymphocyte response curve

Patients were exposed to different doses of radiation and their lymphocyte levels were measured over time.

- (1) 3.0 Gy
- (2) 4.5 Gy
- (3) 5.5 Gy
- (4) 7.0 Gy

The lymphocyte levels were categorized as:
- Normal
- Moderate
- Severe
- Very severe
- Lethal

The diagram shows the lymphocyte levels over time for each dose group.
Facilities for in-hospital management of severe cases of ARS

<table>
<thead>
<tr>
<th>Localized at the hospital</th>
<th>Not necessarily localized at the hospital</th>
</tr>
</thead>
<tbody>
<tr>
<td>Specialized care unit for immunosuppressed patients with laminar flow and absolute HEPA filtering system</td>
<td>Cytogenetic dosimetry laboratory</td>
</tr>
<tr>
<td>Intensive care unit</td>
<td>Electron spin resonance laboratory</td>
</tr>
<tr>
<td>Hematology and Hemotherapy (leukoreduced and irradiated blood products, including the availability for platelets infusions)</td>
<td>Bio-assay laboratory</td>
</tr>
<tr>
<td>Hematopoietic Stem Cells (HSC) transplantation center</td>
<td></td>
</tr>
<tr>
<td>Specialized departments (Gastroenterology, Infectious diseases, Pediatrics, Mental Health and Neurology...)</td>
<td></td>
</tr>
<tr>
<td>Advanced medical imaging technologies</td>
<td></td>
</tr>
<tr>
<td>Other advanced laboratory technologies, that could include HLA typing</td>
<td></td>
</tr>
</tbody>
</table>

Credit: REAC/TS
Accidental heterogeneous whole-body exposure
Mol, Belgium, 1965

- Estimated mean dose to bone marrow: 5 Gy
- But 16% of bone marrow received less than 1 Gy

DOSE RECONSTRUCTION

Mixed field irradiation, neutron (10%) and γ (90%)

Severe aplasia from day 4 to day 31 and complete hematopoietic reconstitution within 3 months
Patients with localized radiation exposure
The Cutaneous Radiation Syndrome (CRS)

<table>
<thead>
<tr>
<th>Manifestation</th>
<th>Dose threshold (Gy)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Erythema</td>
<td>3-10</td>
</tr>
<tr>
<td>Temporary epilation</td>
<td>3-7</td>
</tr>
<tr>
<td>Definitive epilation</td>
<td>7-10</td>
</tr>
<tr>
<td>Dry epithelitis</td>
<td>10-15</td>
</tr>
<tr>
<td>Exsudative epithelitis</td>
<td>15-25</td>
</tr>
<tr>
<td>Necrosis</td>
<td>&gt;25</td>
</tr>
</tbody>
</table>
Patients with localized radiation exposure
The Cutaneous Radiation Syndrome (CRS)
Evaluation

Credit: ARN, Argentina  Credit: HNMD, Brazil  Credit: IRSN, France
The Cutaneous Radiation Syndrome (CRS)
Specialized treatment
Dosimetry guided surgery & cell therapy

Credit: IRSN, France
The Cutaneous Radiation Syndrome (CRS)
Specialized treatment
Dosimetry guided surgery & cell therapy
Internal contamination with radionuclides

- Diagnosis and assessment
  - Samples bio-assays
  - Whole-body counting
  - Lung counting
- Treatment decision making
Internal contamination with radionuclides

Treatment

• Conventional general measures
• Blocking agents
  • KI
• Isotopic dilution
  • Hydration
• Displacement therapy
  • Calcium gluconate for radiostrontium
• Ion exchange
  • Prussian Blue
• Chelating agents
  • DTPA
• Lung lavage
The health community must be aware...
Thank you!