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The Scientific Medical Effects of Ionizing Radiation Course, conducted once a year, focuses on the latest research about the medical effects of ionizing radiation to help clinicians, health physicists, and medical planners preserve troop health in the face of radiological/nuclear terrorism or warfare.

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Medical Effects of Ionizing Radiation

Nuclear Weapons Effects

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Objectives

- Describe nuclear weapons effects (NWE) and human response for
  - Radiation
  - Blast
  - Thermal
- Review Hiroshima
- Discuss implications for a nuclear detonation in a modern city center
NUCLEAR DETONATION ENERGY DISTRIBUTION

Low-Yield Airburst
- Blast (50 %)
- Thermal (35 %)
- Radiation (15 %)
- EMP
Thermal & Blast Effects

Nighttime shot, the light is from the detonation

Shadow change indicative of rapid fireball rise

Blast wave destroys wood frame house [16 kT, 1 km away, ~5 psi, ~500 mph]
Blast Effects

Wood House at 4 PSI Overpressure

Wood House at 5 PSI Overpressure

Brick House at 5.5 PSI Overpressure

Reinforced Block House at 5 PSI Overpressure

[Would be destroyed at 8 PSI and would have windows blown out at 0.6 PSI]
Blast Effects: Hiroshima

BEFORE

1000 m radius

AFTER

1000 m radius
Case Study: Hiroshima

25 July 1945

11 August 1945
Case Study: Hiroshima
Case Study: Hiroshima
Case Study: Hiroshima
Case Study: Hiroshima

- **เต็มที่ถูกกลายเป็นวังวน** (Totally collapsed and burned)
- **เต็มที่ถูกถล่ม** (Totally collapsed)
- **ครึ่งที่ถูกถล่มและถูกเผา** (Half collapsed and burned / irreparably damaged)

[Map showing damage zones with concentric circles indicating varying distances from the hypocenter.]

© Hypocenter

- 0.5 km
- 1 km
- 1.5 km
- 2 km
- 2.5 km
- 3 km
- 3.5 km
- 4 km
Blast Overpressure Injuries

Wood Frame House: 5 psi peak overpressure

Brick House: 5.5 psi
Blast Injuries

Direct overpressure
- Collapsed buildings (crush victims)
- Air cavity injuries (e.g., ear, lung, gut)
  - ruptured viscera (organs)
  - alveolar hemorrhage
  - pulmonary edema

Dynamic pressure (nuclear winds)
- Translational effects
  - Decelerative tumbling (fractures, lacerations)
  - Impact with a solid surface (blunt trauma)

Missiling effects (e.g., projectiles, flying shards of glass)
## Translational Injuries

### Translational Injuries

<table>
<thead>
<tr>
<th>Velocity * (m/sec)</th>
<th>Probability of blunt injuries and fractures</th>
<th>Probability of fatal injuries</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.6</td>
<td>&gt; 1%</td>
<td>-</td>
</tr>
<tr>
<td>6.6</td>
<td>~ 50%</td>
<td>&gt; 1%</td>
</tr>
<tr>
<td>17.0</td>
<td>99%</td>
<td>~ 50%</td>
</tr>
<tr>
<td>44.5</td>
<td>-</td>
<td>99%</td>
</tr>
</tbody>
</table>

* Velocities are based on solid impact with a non-yielding surface

### 70 kg Human Body Displaced by Blast Wind Drag Forces

<table>
<thead>
<tr>
<th>Weapon yield (kT)</th>
<th>Velocities * (m/sec)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>2.6</td>
</tr>
<tr>
<td>1</td>
<td>0.38 km</td>
</tr>
<tr>
<td>10</td>
<td>1.0 km</td>
</tr>
<tr>
<td>100</td>
<td>2.5 km</td>
</tr>
<tr>
<td>1000</td>
<td>5.9 km</td>
</tr>
</tbody>
</table>

* Data account for ground friction and consider only prone personnel.
Protection Against Blast Injury

- Avoid areas with a lot of windows.
- Take shelter underground.
- Find a natural shelter such as a ditch.
- Lay down in a field, helmet on, head toward the detonation.
Thermal Injury

- Flame Burns (< 4% of 20-day survivors for N&H)
- Flash (Profile) Burns (> 50% patients)
- Flash blindness & retinal burns
## Flash Burn Injuries

<table>
<thead>
<tr>
<th>Yield of Weapon</th>
<th>1 kT</th>
<th>10 kT</th>
<th>100 kT</th>
<th>1 MT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Range in kilometers for production of 2(^{nd}) degree burns on exposed surfaces (air burst)</td>
<td>0.8</td>
<td>2</td>
<td>5</td>
<td>9</td>
</tr>
<tr>
<td>Duration of thermal pulse (sec)</td>
<td>0.2</td>
<td>0.6</td>
<td>1.6</td>
<td>4.4</td>
</tr>
<tr>
<td>Thermal flux required to produce 2(^{nd}) degree burns on exposed skin (J/cm(^2))[cal/cm(^2)]</td>
<td>14 [3.4]</td>
<td>14 [3.4]</td>
<td>19 [4.5]</td>
<td>24 [5.7]</td>
</tr>
</tbody>
</table>
PROFILE BURN:
30 y/o male with white sleeveless shirt and trousers, 2 months after Nagasaki bombing, 1.49 mi (7800 ft or 2360 m) from GZ in open, corresponds to thermal Q of 3-4 cal/cm².
Flash Burns (Modeling)

Negligible Injury:
<1% BSA 3deg
<5% BSA 2deg
<50% BSA 1deg

Moderate Injury:
1-5% BSA 3deg
5-15% BSA 2deg
50-100% BSA 1deg

Serious Injury:
5-25% BSA 3deg
15-50% BSA 2deg

Fatal Injury:
>25% BSA 3deg
>50% BSA 2deg
>40% BSA 2&3deg (any combo)
Flash Burn Caveats for Hiroshima and Nagasaki Survivors

98% of burns involved head and/or limbs
- Hand burns involved back of hand
- Burns around eyes rare

Majority of burns were 1st or 2nd degree and healed within 4 weeks

Nearly all 2nd and 3rd degree burns became infected

Treatment was limited largely to local applications and dressings

Greatest number and severity of burns occurred in 1500 – 2000 meter range >> Low percentage of survivors within 1500 meters of hypocenter
Ocular Injury

A. Flash Blindness

B. Retinal Burns

<table>
<thead>
<tr>
<th></th>
<th>Clear Day</th>
<th>Night</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flash blindness</td>
<td>1</td>
<td>4</td>
</tr>
<tr>
<td>Retinal Burns</td>
<td>2</td>
<td>3</td>
</tr>
</tbody>
</table>
Protective Actions Against Thermal Injury

• If you know of an impending detonation, seek shelter.

• Don’t look at the fireball for 10 to 20 seconds.

• Remove oneself from direct line of sight from the detonation.

• Use clothed parts of the body to shield other parts of the body.
Radiation Effects

• Initial (prompt) radiation (neutron and gamma)
• Delayed (residual) radiation
  • n-activation near ground zero (mostly gamma)
• Fallout
Radiation Effects

• Fallout
  • fission products (beta and gamma)
  • unused HEU or Pu
  • extends beyond prompt radiation range
  • very hazardous dose rates in 1st 24 hours for distances up to 10 miles downwind
  • In the first few days, the primary health hazard is external gamma radiation from fallout on horizontal surfaces. Breathing in local fallout dust is a minor concern as it is too large to enter the lung
Radiation Injuries

Acute Radiation Syndrome (ARS)
- Classical Subsyndromes: H, GI, CV
- Phases: Prodromal – Latent – Manifest Illness
- New Paradigm: Grading of Multi-Organ Response

Skin injuries
- Erythema/Epilation/Purpura

Other effects
- Gingivitis/Conjunctivitis/Hypotension

Skin injuries

Other effects

Radiation has a delayed effect. Although radiation sickness may occur within a few hours, victims of lethal radiation may not succumb for days or weeks.

Late effects
- Keloids/Cataracts/Cancer

Teratogenic effects

Adequate for MASCAL

Hiroshima ARS Victim (~D +20)
Radiation Injuries - Dose vs Severity and Time of Onset

[Graph showing changes in thrombocytes, hemoglobin, neutrophils, and lymphocytes over time for 1 Gy and 3 Gy doses.]
Skin Erythema

• Depends on total absorbed dose, length of exposure, and energy of radiation
• X-rays ~ 6-8 Gy (2-3 Gy for High LET radiation)
• Erythema within 2-3 h of exposure indicates dose of >20 Gy; within 24 h dose of >6 Gy
• Symptoms may be severe pain, or the sensation of warmth
Beta Burns from Fallout

Beta radiation burns--Marshall Islands

Beta radiation burns--Marshall Islands
Residual Radioactivity

Legend
- **H**: hospital
- Airport Area
- Runways (Regional)
- Major Railroad Lines
- Limited Access
- Highway
- Major Road
- Local Road
- Minor Road
- Other Road
- Ramp
- Ferry
- Pedestrian Way

10 kT 1 hour after explosion

<table>
<thead>
<tr>
<th>Exposure</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.1 cG</td>
<td></td>
</tr>
<tr>
<td>5 cG</td>
<td></td>
</tr>
<tr>
<td>25 cG</td>
<td></td>
</tr>
<tr>
<td>100 cG</td>
<td></td>
</tr>
<tr>
<td>200 cG</td>
<td></td>
</tr>
<tr>
<td>410 cG</td>
<td></td>
</tr>
<tr>
<td>700 cG</td>
<td></td>
</tr>
</tbody>
</table>
Effect of Wind on Fallout Predictions

4 kiloton device detonated @ 300 ft HOB
Acute Lethal Dose – LD50/60

- $\text{LD}_{50/60} = 410 \text{ cGy}$

- 50 percent population dies within 60 days at doses of $\sim 410 \pm 50 \text{ cGy (FIA)}$ or $290 \pm 35 \text{ cGy (MLT)}$. This is based on whole body exposure to young adults without care, or primitive care, for dose rates above 10 cGy/hr. The LD50/60 increases to about 1200 cGy at dose rates down to $\sim 1 \text{ cGy/hr}$
Time after Explosion

Seven/Ten Rule

Gives an indication of intensity of radioactivity at times following the explosion.

<table>
<thead>
<tr>
<th>Time (hr)</th>
<th>Reduction Factor</th>
<th>Example (cGy/hr)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1</td>
<td>500</td>
</tr>
<tr>
<td>7</td>
<td>0.10</td>
<td>50</td>
</tr>
<tr>
<td>49</td>
<td>0.01</td>
<td>5</td>
</tr>
<tr>
<td>343</td>
<td>0.001</td>
<td>0.5</td>
</tr>
</tbody>
</table>
Protection from Fallout Hazards

• Time
• Distance
• Shielding
• Contamination Control
Improvised Nuclear Device
Case Study: Hiroshima

• Little Boy (gun type wpn)
• 0815 a.m., 6 Aug 1945 (Enola Gay)
• 16 kT, 600m HOB (essentially no fallout)
• Clear weather, dense urban flat land
• ~10,000 people/sq km at hypocenter
• 255,000 pop
  • 119,000 okay (47%)
  • 136,000 casualties (53%)
    • 64,000 deaths (25%) @ 4 mo
      ½ to 1/3 in 1st day
      Mostly those close in
    • 72,000 injured (28%)
      Further out w/lower pop density
Medical Statistics: Hiroshima

- Hospitals: 3/45 were functional (6.7%).
- Physicians: 59/298 were functional; only 28 without significant injury (9.4%).
- Nurses: 1654/1780 were casualties (92.9%).
- 10,000 injured patients went on their own or with assistance within 12 hours to the Red Cross Hospital (600 beds).
- In the biggest hospital, the Red Cross Hospital, only 6 out of 30 physicians were able to function. And only 10 out of 200 nurses were able to provide patient care.
- 70% of patients with combined injury.
Hiroshima Casualties at the Red Cross Hospital (D +2, 1.6 km)

(August 8, 1945 - Photo: Yotsugi Kawahara)
Hiroshima Diary (Dr. Michihiko Hachiya) takes You Here During the Period 6Aug—30Sep, 1945

Hiroshima Teishin Hospital and Hiroshima Communications Bureau

Location: Moto-machi (now, Higashi-hakushima-cho)
Distance from hypocenter: approx. 1.4km

Photograph taken toward the west from the vicinity of the Hakushima streetcar stop. The two-story building in the front is the Teishin Hospital, while the four-story building in the rear is the Communications Bureau. Both had window frames and glass blown out by the blast, and at least half of the interior of each was destroyed by fire. Immediately after the bombing, the Communications Bureau building, too, was utilized to accommodate injured people; and even two months afterward, homeless people were living there.
Ponder Some of the Effects from a Low-Yield Nuclear Detonation in a Modern City
Ponder Some of the Effects from a Low-Yield Nuclear Detonation in a Modern City

- Power grid down for days, weeks or months
- Phone communications down for weeks to months
- Fried medical equipment from EMP effects
- Vehicle accidents and subsequent gridlock from the flash and EMP effects
Ponder Some of the Effects from a Low-Yield Nuclear Detonation in a Modern City

- Roads, rails, runways limited/unusable for days
- Fuel distribution limited for days to weeks
- Water pressure gone for days to weeks
- Sanitary water systems down for weeks
Ponder Some of the Effects from a Low-Yield Nuclear Detonation in a Modern City

- Human and animal remains scattered about for days to weeks
- Food may be in short supply for days
- Hospitals overwhelmed and remaining medical staff exhausted within 72 hours
- What about a ground bursts >> Need to mitigate loss of life from fallout.
- Displaced persons and evacuees into the hundreds of thousands.
Scene Commander must set and enforce dose-limits for rescuers.

Rescuers who reach dose-limit are removed from the scene and cannot return.

Trapped victims in high-dose-rate areas cannot be rescued.

Primary rescue effort should be evacuation of uninjured from high-dose areas

Contaminated but not injured >> transfer for decon to some place other than hospitals
On-scene Medical Management

- Arrange for clinical teams from neighboring cities to conduct mass evacuation of casualties via rail heads
- Set up airlift for casualties to distant cities
Military MASCAL Medical Guidance

1. Resources cannot handle patient load
2. Clinical standards of care need not apply

- Provide the maximum care for the maximum number of patients.
- Favor those who are more likely to respond to treatment at the time and place. So the less severely wounded receive a higher priority because their earlier return to duty will be of greatest benefit to the military effort.
- Determine if it may be more effective to move hospitals to the impacted area to free up limited patient evacuation assets.
- Determine methods for rapid evacuation of patients to tertiary care centers that can provide maximal care.
Military MASCAL Medical Guidance

- Conserve/Economize medical resources
  - Limit treatment to those expected to die
  - Avoid procedures which will reduce any patient’s ability to care for himself
  - Do not use trained medical personnel for first aid or rescue operations. Train all personnel and rescue teams in first aid (applying dressings, controlling hemorrhage, field splints, handling the injured)
  - Perform only the most expedient treatments sufficient to meet immediate medical requirements of the patient. Use only simple bandages, splints, etc., for evac prep.

- Sorting is the key to the effective management of a MASCAL event.
  - Initial Triage >> IDME or DIME
### Combined Injury Patient Triage starts with Traditional Triage Methods

<table>
<thead>
<tr>
<th>Physical injury without irradiation</th>
<th>Expected changes in triage categories after whole-body irradiation</th>
</tr>
</thead>
<tbody>
<tr>
<td>uninjured</td>
<td>Expected changes in triage categories after whole-body irradiation</td>
</tr>
<tr>
<td>&lt;2 Gy Vomit &gt;4 hrs</td>
<td>2~6 Gy Vomit 1-4 hrs</td>
</tr>
<tr>
<td>&gt;6 Gy Vomit &lt;1 hr early erythema</td>
<td></td>
</tr>
</tbody>
</table>

- **Uninjured**
  - Ambulatory monitoring
  - Ambulatory monitoring, routine care and delayed hospitalization

- **Minimal**
  - Immediate

- **Delayed**
  - Delayed

- **Immediate**
  - Immediate

- **Expectant**

An obvious technology gap for initial nuclear casualty triage
Ground Burst Nuclear MASCAL Planning Factors

- Assume the following triage categories for planning:
  - Delayed..............................20%
  - Immediate............................20%
  - Minimal..............................40%
  - Expectant............................20%

- Expect flash burns on ½+ patients who were in the open.
- Expect contusions, abrasions, lacerations and penetrating wounds on ¼+ patients.
- Expect symptomatic radiation exposure on ½+ patients.
- Expect combined injury on ¼+ patients.
Early Treatment Fundamentals

• Patient history remains paramount (Where were you?)
• Unlike trauma, symptoms for survivable radiation doses are not immediate and NOT acutely life threatening
• First Actions are Medical not Radiological
• EXCEPTION: If Expectant is ruled in due to radiation dose, limit treatment and redirect resources
• Early wound closure (36-48 hours) is a priority for doses above 1-2 Gy. Else, delay surgery until substantial hematopoietic rebound.
• Never delay critical care because a patient is contaminated
Advising Individuals

1. Leave the immediate area of the blast zone (go upwind or lateral)
2. Locate shelter (preferably reinforced concrete type)
3. Remove outer layer of clothing (place it in a sealed bag and store the bag at least 3 meters away from yourself and others)
4. Take a shower (shampoo twice) – As a minimum try to clean body areas not protected by clothing
5. Watch or listen for emergency personnel and then follow their directions – Also, listen to radio broadcasts

95% EFFECTIVE
Manage Contamination

- Fallout contamination is simply dirt and dust that is radioactive.
- **Decon is easy.** Remove the dirt.
- Decon forward as much as possible (e.g., Locate decon at casualty collection points)
- Identify/tag those who have gone through decon
PATIENT DECON

FIXED SHELTER

PORTABLE

Fire Truck
Decontamination Procedures

- Remove patient’s clothing.
- Wash patient with soap and water.

95% EFFECTIVE
Staff Protection

- Patients are not hazardous to medical providers
- PPE = UNIVERSAL PRECAUTIONS ++
  - Plastic or water repellent gowns
  - Prevent the spread of contamination
  - Surgical mask or N95
  - Gloves (2-5x) … change often and between patients
  - Shoe covers
  - Secure ankles and wrists with tape
- Survey hands and clothing with radiation meter
- Replace gloves or clothing that is contaminated
Summary

• Primary nuclear weapons effects (NWE) – Blast/Radiation/Thermal
• Better understanding of Hiroshima
• Injuries and implications for a nuclear detonation
Questions?

• How can you distinguish erythema from a flash burn or beta burn?

Hiroshima, H +3, 2 km