Environmental Health Issues Associated With Disasters

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Learning Objectives

- At the end of the lecture, participants will be able to:
  - Describe at least two examples of disasters and their environmental health impacts.
  - Describe risk communication challenges and strategies in addressing environmental health impacts following disasters.
  - Define the “Haddon matrix” and describe its utility in understanding contributing factors to disaster environmental health impacts.
Why are disasters so relevant relevant to environmental health?
Burning Questions in Disasters

- What agents were naturally, accidentally, or intentionally released into the environment?
- Where is the agent in the environment, and where will it go?
- Who will be exposed, and to how much?
- What will happen to those who are exposed?
- What can we do to reduce exposure and treat survivors?

Environmental Health Paradigm

1. Contaminant formation & release from source
2. Transport/ transformation in the ambient environment
3. Exposure (individual, community, and population)
   Measurements:
   - Susceptibility Factors
   - Exposure Assessment
4. Toxicokinetics
   Measurements:
   - Susceptibility Factors
   - Biomarkers
5. Toxicodynamics
   Measurements:
   - Susceptibility Factors
   - Biomarkers
6. Adverse health effects
   Measurements:
   - Susceptibility Factors
   - Health outcome indicators
7. Policies & Regulations

Adapted from: http://cfpub.epa.gov/roe/chapter/health/index.cfm
Industrial Disasters & Accidents

**Industrial Disaster – Industrial Accident**

**Accident:**
- Typically localized
- Minimal long term consequences
- Local resources sufficient to respond/control

**Disaster:**
- Local resources insufficient
- Public health consequences. Typically long-term
- Environmental impact. Can be long term
- Economic consequences (often)

- Causes often the same
- # killed/injured not an indicator
### Health Consequences

**Direct human consequences**
- Blast injury,
- Burns, crush injuries
- Inhalation injury, toxic exposure

**Indirect/environmental consequences**
- Chemical or radiological contamination (soil, water, air, plants, animals)
- Infrastructure damage
- Long term health effects (e.g., cancer)

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### Industrial Disasters - Numbers

From 1945 to 1986, the number of major events has more than tripled and mortality from industrial disasters increased 30 fold.

From 1988 to 1992, more than 34,000 chemical accidents occurred in the United States.
Increasing Frequency and Severity

- Industrialization (often unchecked)
- Lack of governmental regulation & oversight
- Population growth and urban density
- Poor urban zoning and urban sprawl
- Proximity of people to industry
- Increasing profitability from industry

Mechanisms

<table>
<thead>
<tr>
<th>Catalyst</th>
<th>Systematic root problems</th>
<th>Active</th>
<th>Passive</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tech failure</td>
<td>Human error</td>
<td>Cost cutting</td>
<td>No culture of safety</td>
</tr>
<tr>
<td>Inadequate response training/equipment</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Inadequate/missing backup/safety systems</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lack of protocol</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>External factors (e.g., Earthquake)</td>
<td>Underestimating impact of external factors (e.g., 18’ tsunami barrier)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Complexity</td>
<td>Poor working relationships</td>
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<td></td>
</tr>
</tbody>
</table>

Some ‘Typical’ Industrial Disasters

Chemical Leaks
Bhopal, 1984

- Isocyanate gas leak from U.S. Union Carbide plant next to city of Bhopal, India
- 3,800 killed, ~200,000 injured
1969 - Union Oil Rig - Platform A leaked 200,000+ gallons crude oil across forty miles of U.S. Pacific coastline.

1976 - Argo Merchant runs aground on the Nantucket Shoals off Cape Cod (Massachusetts USA), spilling 7.6 million gallons of No. 6 fuel oil.

1978 - Amoco Cadiz tanker runs aground off the coast of France, spilling 1.6 million barrels of crude oil.

Map of air plume from Fukushima (Cesium deposition, April 29th)

- 1900-9100 mrem/hr
- 950-1900 mrem/hr
- 380-950 mrem/hr
- 190-380 mrem/hr
- 100-190 mrem/hr
- < 100 mrem/hr

NRC annual public dose limit is 100 mrem

Image credit: IAEA

Source: NRC at http://www.nrc.gov/about-nrc/radiation/around-us/doses-daily-lives.html#1

http://www.youtube.com/watch?v=7eh4nBVJtsw&feature=player_embedded

Image credit: IAEA

Other Industrial Disasters & Accidents

- Coal Mine Explosion…Fire…Collapse…Flood…
- Fertilizer plant explosions
- Fireworks plant explosions
- Oil / Sugar / grain refinery explosions
- Tunnel fires
- Rail accidents
- Bridge collapse
- Smog with temperature inversion

Donora Smog
Oct 1948 Pennsylvania
Factors Affecting Occurrence of Industrial Disasters

- Location of industry and vulnerability to disasters
- Proximity to highly populated areas
- Poor regulation and maintenance
- Limited emergency response resources
- Limitations of infrastructure
- Weather conditions (atmospheric inversion)
- Accessibility to terrorism
- Potential for human error or lack of training

Are industrial disasters all bad?

Yes!!

But there have at least been some constructive outcomes:

- Employers’ Liability Acts (1906 and 1908)
- Clean Air Act (1963/1967)
- Clean Water Act (1972)
- Emergency Planning and Community Right-to-Know Act (1986)
System Factors Impact Safety

"The root causes are systemic and, absent significant reform in both industry practices and government policies, might well recur".

"Obama oil spill commission’s final report blames disaster on cost-cutting by BP and partners”. Telegraph. 5 January 2011.

Lessons Learned

- Situation mirrored in many developing countries
- Need for emergency preparedness and basic industrial safeguards
- Need for strengthening the pre-hospital emergency medical system
- Need for advanced community planning
- Governmental regulation and surveillance helps
Personnel Needed in Industrial Disaster Mitigation

- Safety engineers
- Health systems specialists
- Law enforcement officials
- Pre-hospital care providers
- Epidemiologists and toxicologists
- Health sanitation engineers
- Toxicologists
- Occupational health (surveillance)

What are some risk communication challenges relating to disaster environmental health impacts?
Risk Communication Theory

- Based on four models:
  - Risk perception
  - Mental noise
  - Trust determination
  - Negative dominance

Risk Perception

**Key Principle:**

*Perception* of risk is often very different than *actual* risk.
### Risk Perception

**Risk perception = Actual risk + Outrage (Fear)**

Numbers or statistics are often the least important factor in determining risk.

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Environmental health and disaster risk communication challenges: **Ionizing Radiation Example**
The Psychology of Risk Perception

- Focus on radiation as a prime example
- Two sets (or dimensions or "axes") of "factors" drive risk perception:
  - Threat
  - Observability

Radiation and Risk Perception

- Radiation has virtually all of the characteristics that increase perceived risk
  - Involuntary exposure
  - Exposure not known to us (radiation can’t be sensed)
  - Often no benefit from the activity producing the exposure
  - Usually delayed health consequences
  - Potentially fatal health consequences
### Willingness-to-Respond by Disaster Scenario in Local Health Depts. (n = 71 LHDs)

<table>
<thead>
<tr>
<th></th>
<th>Weather-Related</th>
<th>Pandemic Influenza</th>
<th>Radiological ('dirty') Bomb</th>
<th>Anthrax Bioterrorism</th>
</tr>
</thead>
<tbody>
<tr>
<td>If required</td>
<td>93%</td>
<td>91%</td>
<td>74%</td>
<td>80%</td>
</tr>
<tr>
<td>If asked</td>
<td>83%</td>
<td>80%</td>
<td>62%</td>
<td>69%</td>
</tr>
<tr>
<td>Regardless of Severity</td>
<td>77%</td>
<td>79%</td>
<td>53%</td>
<td>65%</td>
</tr>
</tbody>
</table>

### Radiation and Negative Dominance

- When people process information, negative messages have greater influence.
Ionizing Radiation Effects – Negative Dominance

- **Delayed— stochastic (random) and deterministic effects**
  - Random: cancer, genetic changes
  - Burns, cataract formation: 100 rem threshold
  - Growth and mental retardation: 10 rem threshold

- **No such thing as zero risk** of stochastic health effects (e.g., cancer) from ionizing radiation!

Ionizing Radiation Effects – Negative Dominance

- **Acute—deterministic effects**
  - Prodromal syndrome: 100+ rem
  - Hematopoietic syndrome: 100s of rem
  - Gastrointestinal syndrome: 1,000s of rem
  - Central nervous system syndrome: 10,000s of rem

  ✓ Near 100% fatality: 600 rem
Mental Noise

- When people are upset they have difficulty hearing, understanding, and remembering.
- This is directly relevant to fears about disaster-related health impacts!

The Haddon Matrix and Environmental Health Issues in Disasters
The Haddon Matrix: Development

- William Haddon, Jr., MD, MPH
  - Background in injury epidemiology, specifically traffic-related injuries
- Developed matrix in the 1960’s
  - Targeted automobile traffic-related injuries
- The challenge:
  - Traffic safety education was having the desired impact on reducing traffic-related injuries and outcomes

The Haddon Matrix: Origins

- Haddon’s approach:
  - Understand the factors that contribute to traffic-related injuries before, during, and after the injury-causing event
  - Incorporate epidemiological triad of host, agent, and environment
- Result: The Haddon Matrix (Phase-Factor Matrix)
  - Went through several iterations
  - Final version (in use today) established in early 1980’s
# The Haddon Matrix: Structure

<table>
<thead>
<tr>
<th></th>
<th>HOST</th>
<th>AGENT</th>
<th>PHYSICAL ENVIRONMENT</th>
<th>SOCIO-CULTURAL ENVIRONMENT</th>
</tr>
</thead>
<tbody>
<tr>
<td>PRE-EVENT</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>EVENT</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>POST-EVENT</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

# The Haddon Matrix: Example

**Haddon’s Matrix, Pedestrian Injury Example**

<table>
<thead>
<tr>
<th>Event Dimension</th>
<th>Pre-Event</th>
<th>Event</th>
<th>Post-Event</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Intoxicated pedestrian</td>
<td>Osteoporosis in elderly pedestrians</td>
<td>Elderly pedestrian</td>
</tr>
<tr>
<td></td>
<td>Speeding vehicle</td>
<td>Car front-end profile</td>
<td>Crash investigation with vehicle inspection</td>
</tr>
<tr>
<td></td>
<td>Intersection with poor lighting</td>
<td>Road surface characteristics</td>
<td>Distance to trauma care facility</td>
</tr>
<tr>
<td></td>
<td>Low rate of enforcement of yield laws</td>
<td>Speed limits</td>
<td>Regionalized trauma care</td>
</tr>
</tbody>
</table>

**Epidemiological Dimension**

<table>
<thead>
<tr>
<th>Human Factors</th>
<th>Agent or Vehicle</th>
<th>Physical Environment</th>
<th>Sociocultural Environment</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
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<td></td>
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</tr>
</tbody>
</table>
Haddon Matrix and Injury Prevention Epidemiology

1. Gather info to identify problem and population
2. Identify strategies
3. Choose strategies
4. Develop the plan
5. Implement the plan
6. Evaluate and revise

Summary

- It’s usually the long-term impact
- Highly ‘specialized’ impacts (typically)
  - Requires multidisciplinary approach
  - Disaster-specific planning
- Governmental regulation and surveillance
- Enforcement
- Risk Communication
- Haddon Matrix as analytic tool
Haddon Matrix & Industrial Disasters: Fukushima Case-Based Example

Fukushima Daiichi Nuclear Power Station

Source: TEPCO
• 160 miles (260 km) from Tokyo.
• One of the largest plants in the world.
• Six boiling water reactors (biggest in US has 3)

March 11, 2011, 2:46pm (JST)
Earthquake measuring 9.1 Richter occurred 112 miles from Japan's east coast.
The earthquake was the largest Japan has ever experienced.
Risk Communication
Daniel Barnett, MD, MPH

The Aftermath at Fukushima

• Earthquake exceeds the construction code for 3 of the 6 reactors.

• Loss of all off-site electrical power.

• Emergency generators automatically started and provided power to emergency systems.

• Reactors automatically shut off fission reaction due to seismic activity.

• Japan Meteorological Association issued a tsunami warning: Potential 3 meter (10 feet) tsunami. Station workers evacuate to higher ground.
Not a major disaster…
That was close!!!

Aftershocks!
That was close!!

Tsunami

A series of water waves caused by the displacement of a large volume of a body of water, typically caused by an earthquake, volcanic eruption, landslide or an underwater explosion.
41 minutes after the earthquake the tsunami wave hits.

Plant protected by breakwater!

...6 more waves follow
Highest wave reaches 50 feet in height

Based on 2002 guidelines for NPPs issued by the Tsunami Evaluation Subcommittee of the Japan Society of Civil Engineers.
Impact of Tsunami & Outcomes

- Reactors 5 & 6 maintain backup power and sustain limited damage.
- ~1 hour after earthquake, water floods emergency generators and kills backup power.
- Most battery backups are underwater.
- Some battery power remaining ... in one reactor...
- The seawater intake is severely damaged and rendered nonfunctional → No core cooling to remove reactor heat → heat/pressure buildup.
- Fire engines used to restore water injection to provide cooling water to the reactors.
- Car batteries brought in to restore some instrument power.
- Due to inadequate cooling, fuel damage occurred in 3 reactors: Step #1 of meltdown!
1. Fuel rods and steam are present.

2. Water is removed, leading to water level drops.

3. Fuel rods are exposed, and temperature rises.

Hydrogen explosion shown in image.
• Hydrogen buildup causes explosions in 3 reactor buildings
• The loss of containment integrity resulted in ground-level releases of radioactive material.
Surveys performed over the following weeks discovered localized dose rates greater than 1,000 rem/hr around the facility. (annual dose limit for a nuclear plant worker is 5 rem\(^1\)).

\[\text{Source: NRC at} \, \text{http://www.nrc.gov/about-nrc/radiation/around-us/doses-daily-lives.html#1}\]

**Impact**

The Fukushima event was rated as a level 7 event on the International Nuclear and Radiological Event (INES) scale.

- ~17 million curies of iodine-131 equivalent radioactive material was released into the air
- ~0.127 million curies released into the sea between March 11 and April 5.
- The 1986 accident at Chernobyl was the only other to have a level 7 INES rating.
- According to the IAEA, the Chernobyl accident resulted in ~378.4 million curies of radioactive material being released into the environment\(^2\).

\[\text{1 Institute of Nuclear Power Operations (INPO), Special Report on the Nuclear Accident at the Fukushima Daiichi Nuclear Power Station, November 2011} \]
\[\text{2 The International Nuclear and Radiological Event Scale courtesy of IAEA (IAEA.org)} \]
\[\text{3 Chernobyl's Legacy: Health, Environmental and Socio-Economic Impacts. The Chernobyl Forum 2003-2005 Second Revision} \]
Map of air plume from Fukushima (Cesium deposition, April 29th)

1900-9100 mrem/hr,
950-1900 mrem/hr,
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190-380 mrem/hr,
100-190 mrem/hr,
< 100 mrem/hr

NRC annual public dose limit is 100 mrem

Image credit: IAEA
Leakage of radioactive water to the ocean
April 1 - 6 from the pit of Reactor 2

Image credit: IAEA

http://www.youtube.com/watch?v=7eh4nBVJTsw&feature=player_embedded

Trace amounts of radiation from Japan have been detected across the United States and Europe. But natural background radiation is more than 100,000 times the highest levels detected. 

Holistic
Targets dose exposure of population
Validated effectiveness
Cost effective
Minimizes waste
Key Concluding Points

- The Haddon matrix is a practical tool for analyzing – and identifying practical & feasible strategies to address complex environmental challenges, including industrial accidents and disasters.
- In an industrial disaster, local resources are insufficient for managing the event.
- In an industrial accident local resources are sufficient for event management.
- Health and safety considerations associated with industrial disasters and accidents fall squarely within the environmental health paradigm.

Acknowledgments

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- Gai Cole
Thank You

Questions?

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