Exploring Medical and Public Health Preparedness for a Nuclear Incident: A Workshop

Workshop Briefing Materials
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III. Forum on Medical and Public Health Preparedness for Disasters and Emergencies Background Document (Parent Activity)

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VI. List of Resources on Nuclear Preparedness

VII. Literature Informing the Planning of and Discussions During the Workshop:

COMMUNICATION AND INFORMATION:
2. Individuals’ Decisions Affecting Radiation Exposure After a Nuclear Explosion (Florig and Fischhoff, 2007)
3. Social, Psychological, and Behavioral Responses to a Nuclear Detonation in a US City: Implications for Healthcare Planning and Delivery (Dodgen et al., 2011)
5. Disaster Warnings in Your Pocket: How Audiences Interpret Mobile Alerts for an Unfamiliar Hazard (Bean et al., 2016)
MEDICAL AND PUBLIC HEALTH PREPAREDNESS AND RESPONSE:
1. Vulnerability of Populations and the Urban Health Care Systems to Nuclear Weapon Attack – Examples From Four American Cities (Bell and Dallas, 2007)
2. The ‘RTR’ Medical Response System for Nuclear and Radiological Mass-Casualty Incidents: A Functional Triage-Treatment-Transport Medical Response Model (Hrdina et al., 2009)
3. A Possible Approach to Large-Scale Laboratory Testing for Acute Radiation Sickness After a Nuclear Detonation (Adalja et al., 2011)
4. Scarce Resources For a Nuclear Detonation: Project Overview and Challenges (Coleman et al., 2011)
5. Public Health And Medical Preparedness for a Nuclear Detonation: The Nuclear Incident Medical Enterprise (Coleman et al., 2015)
7. Are We Prepared for Nuclear Terrorism? (Gale and Armitage, 2018)

WORKFORCE READINESS ISSUES:
1. Characterizing Hospital Workers’ Willingness to Respond to a Radiological Event (Balicer et al., 2011)
2. A Sustainable Training Strategy For Improving Health Care Following a Catastrophic Radiological or Nuclear Incident (Blumenthal et al., 2014)
3. Developing a Nuclear Global Health Workforce Amid the Increasing Threat of a Nuclear Crisis (Burkle and Dallas, 2016)
Workshop Information

Dates:
August 22-23, 2018

Time:
Day 1: 8:00am – 6:00pm
Day 2: 8:00am – 1:00pm

Location:
National Academy of Sciences Building
Fred Kavli Auditorium
2101 Constitution Ave NW
Washington, DC 20418

Website:
Exploring Medical and Public Health Preparedness for a Nuclear Incident: A Workshop

STATEMENT OF TASK

Under the auspices of the Forum on Medical and Public Health Preparedness for Disasters and Emergencies, an ad hoc committee will organize and convene a 2-day public workshop in Washington, D.C. Through this workshop, participants from government, NGO and private sector organizations will explore current assumptions behind and the status of medical and public health preparedness for a nuclear incident, examine potential changes in assumptions and approach, and discuss challenges and opportunities for capacity building in the current threat environment.

Specific topics that may be discussed in this workshop include:

- The current state of medical and public health preparedness for a nuclear incident and how these relate to the prior assumptions about the threat environment;
- Possible changes to planning assumptions for nuclear incidents, with particular attention to the (re-)emergence of state-actor threats, and the implications of those changes for nuclear incident prevention, planning and response;
- Implications for capacity building of potential communication, education and information challenges posed by a nuclear incident, and opportunities and approaches for addressing them;
- Challenges, opportunities, and implications for building capabilities to respond to and recover from a nuclear incident, including building capability for assessment, early treatment, monitoring and long-term health surveillance among survivors.

The committee will develop the agenda for the workshop session, select and invite speakers and discussants, and moderate the discussions. Workshop proceedings will be prepared by a designated rapporteur in accordance with institutional guidelines, based on the presentations and discussions held during the workshop. The proceedings will be subject to appropriate review procedures before release.

PLANNING COMMITTEE ROSTER

James Blumenstock (Co-Chair)
Association of State and Territorial Health Officials

Tener Veenema (Co-Chair)
Johns Hopkins Bloomberg School of Public Health

Steven M. Becker
Old Dominion University

John Benitez
Tennessee Department of Health

Stephen Broomell
Carnegie Mellon University

Cham Dallas
University of Georgia

Bruce Evans
Upper Pine River Fire Protection District (CO)

David P. Eisenman
University of California, Los Angeles

Chad Hrdina
Office of the Assistant Secretary for Preparedness and Response, HHS

Ann Knebel
National Center for Advancing Translational Sciences, NIH

John Koerner
Office of the Assistant Secretary for Preparedness and Response, HHS

Roberta Lavin
University of Tennessee

Martha Linet
National Cancer Institute, NIH

Matthew K. Wynia
University of Colorado
WORKSHOP STAFF
Scott Wollek, Senior Program Officer
Lisa Brown, Senior Program Officer
Ben Kahn, Research Associate
Maria Babirye, Senior Program Assistant (Until August 2018)
Rebecca Ray, Senior Program Assistant
Erica McCorkle, Senior Program Assistant
Andrew M. Pope, Director, Board on Health Sciences Policy

WORKSHOP WEBSITE
For additional information and resources, please visit:

CONTACT INFORMATION
Ben Kahn, Research Associate
(202) 334-1811 (Office)
bkahn@nas.edu
Forum on Medical and Public Health Preparedness for Disasters and Emergencies

Background
The Forum on Medical and Public Health Preparedness for Disasters and Emergencies convenes public and private sector leaders to improve the nation’s preparedness for, response to and recovery from disasters, public health emergencies and emerging threats. The Forum fosters in-depth policy discussion and collaboration to identify barriers and explore solutions to ensure and sustain national security, promote recovery and enhance resilience.

The Forum is a self-governing body composed of members and other key stakeholders at the federal, state, and local levels representing government, non-government, and the private sectors. Its membership identifies meeting and workshop topics for exploration and discussion and creates strategic direction to advance the field of medical and public health preparedness.

Over the next year, the Forum membership will be focusing their attention on the following topic areas:

Global Health Security
Global health security focuses on ongoing efforts to accelerate progress toward a world safe and secure from emerging infectious diseases and other threats. The Forum will concentrate its discussion on strengthening the U.S. health care and public health systems capacity to detect, prevent, plan for, respond to, and recover from naturally-occurring outbreaks and intentional or accidental releases of dangerous pathogens.

Communication and Coordination
Ensuring timely communications and effective coordination within all levels of government and between government, the private sector, and the public during large-scale disasters and incidents is critical to ensuring the health and welfare of the nation. The Forum will center its attention on ways to improve situational awareness, threat intelligence sharing, risk communication, and collaboration among multi-sector disaster response networks including public, academic, private, governmental, and non-governmental organizations.

Personal and Community Resilience
Personal and community resilience is the sustained ability of an individual and a community to utilize available resources to respond to, withstand, and recover from adverse situations following a catastrophic event. The Forum will explore opportunities and barriers to enhancing the resilience of individuals and communities through disaster risk reduction; ensuring that health is included in post-disaster recovery planning efforts; work with non-traditional sectors, and exploring special considerations needed to strengthen a community after a mass casualty incident.

Critical Infrastructure
Critical infrastructure protection focuses on ongoing efforts to secure the assets, systems, and networks, whether physical or virtual, vital to the security, public health, and safety of the nation. The Forum centers its discussion on the health care and public health sector and interdependent sector vulnerabilities, consequences of cascading and prolonged failures of infrastructure, threats from chemical, biological, radiological, nuclear, and high yield explosives, and the increasing threat and consequences of cyber-attack.

Project Staff
Scott Wollek, Senior Program Officer
Claire Giammaria, Associate Program Officer
Benjamin Kahn, Research Associate
Rebecca Ray, Senior Program Assistant

500 Fifth Street, NW, Washington, DC 20001
Website: www.nas.edu/MedPrepForum
<table>
<thead>
<tr>
<th>Name</th>
<th>Title and Organization</th>
</tr>
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<tbody>
<tr>
<td>DAN HANFLING (Co-Chair)</td>
<td>Contributing Scholar, Johns Hopkins Center for Health Security</td>
</tr>
<tr>
<td>SUZET MCKINNEY (Co-Chair)</td>
<td>Executive Director and CEO, Illinois Medical District</td>
</tr>
<tr>
<td>STACEY ARNESEN</td>
<td>National Library of Medicine, National Institutes of Health</td>
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<tr>
<td>PHILLIP MAYTUBBY</td>
<td>National Association of County and City Health Officials</td>
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<tr>
<td>ERIC BLANK</td>
<td>Association of Public Health Laboratories</td>
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<tr>
<td>AUBREY MILLER</td>
<td>National Institute of Environmental Health Sciences, National Institutes of Health</td>
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<tr>
<td>MARY CASEY-LOCKYER</td>
<td>American Red Cross</td>
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<tr>
<td>JOHN OSBORN</td>
<td>Mayo Clinic College of Medicine</td>
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<tr>
<td>BROOKE COURTNEY</td>
<td>Office of Counterterrorism and Emerging Threats, U.S. Food and Drug Administration</td>
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<tr>
<td>TARA O'TOOLE</td>
<td>IQT</td>
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<tr>
<td>JOHN DREYZEHNER</td>
<td>Association of State and Territorial Health Officials</td>
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<tr>
<td>ANDREW PAVIA</td>
<td>Infectious Diseases Society of America</td>
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<tr>
<td>DAVID EISENMAN</td>
<td>University of California, Los Angeles</td>
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<td>ALONZO PLOUGH</td>
<td>Robert Wood Johnson Foundation</td>
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<td>BRUCE EVANS</td>
<td>National Association of Emergency Medical Technicians</td>
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<tr>
<td>TERRY RAUCH</td>
<td>Defense Health Agency, Department of Defense</td>
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<tr>
<td>JAMES FICKE</td>
<td>American College of Surgeons Committee on Trauma</td>
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<tr>
<td>STEPHEN REDD</td>
<td>Office of Public Health Preparedness and Response, Centers for Disease Control</td>
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<tr>
<td>LARRY FLUTY</td>
<td>Office of Health Affairs, Department of Homeland Security</td>
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<tr>
<td>SARA ROSZAK</td>
<td>National Association of Chain Drug Stores</td>
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<tr>
<td>CAROLYN MEIER</td>
<td>Administration for Children and Families, Department of Health and Human Services</td>
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<tr>
<td>ROSLYNE SCHULMAN</td>
<td>American Hospital Association</td>
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<tr>
<td>JOHN HICK</td>
<td>Hennepin County Medical Center</td>
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<tr>
<td>RICHARD SERINO</td>
<td>Harvard University School of Public Health</td>
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<tr>
<td>ROBERT KADLEC</td>
<td>Assistant Secretary for Preparedness and Response, Department of Health and Human Services</td>
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<tr>
<td>ALAN SINISCALCHI</td>
<td>Council of State and Territorial Epidemiologists</td>
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<tr>
<td>CLAUDIA KELLY</td>
<td>Seqirus</td>
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<tr>
<td>CRAIG VANDERWAGEN</td>
<td>East West Protection, LLC</td>
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<tr>
<td>THOMAS KIRSCH</td>
<td>Uniformed Services University of the Health Sciences, Department of Defense</td>
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<tr>
<td>JENNIFER WARD</td>
<td>Trauma Center Association of America</td>
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<td>DREW LEWIS</td>
<td>Meridian Medical Technologies</td>
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<tr>
<td>GAMUNU WIJETUNGE</td>
<td>National Highway Traffic Safety Administration, Department of Transportation</td>
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<td>NICOLETTE A. LOUISSAINT</td>
<td>Healthcare Ready</td>
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<tr>
<td>MATTHEW WYNIA</td>
<td>University of Colorado, Denver</td>
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<tr>
<td>FREDA LYON</td>
<td>Emergency Nurses Association</td>
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Exploring Medical and Public Health Preparedness for a Nuclear Incident: A Workshop

August 22-23, 2018
National Academy of Sciences Building – Fred Kavli Auditorium
2101 Constitution Ave. NW, Washington, DC 20418

Meeting Objectives

- Understand the current state of medical and public health preparedness for a nuclear incident and how these relate to the prior assumptions about the threat environment;
- Discuss possible changes to planning assumptions for nuclear incidents, with particular attention to the (re-)emergence of state-actor threats, and the implications of those changes for nuclear incident prevention, planning and response;
- Consider the implications for capacity building of potential communication, education and information challenges posed by a nuclear incident, and opportunities and approaches for addressing them;
- Explore challenges, opportunities, and implications for building capabilities to respond to and recover from a nuclear incident, including building capability for monitoring and long-term health surveillance among survivors.

Day 1 – August 22, 2018

Session I Introduction and Overview of the Workshop

8:00 AM Chairs’ Welcome

Jim Blumenstock
Chief Program Officer, Public Health Practice
Association of State and Territorial Health Officials
Workshop Planning Committee Co-Chair

Tener Veenema
Professor of Nursing and Public Health
Johns Hopkins School of Nursing
Johns Hopkins Bloomberg School of Public Health
Workshop Planning Committee Co-Chair

Session II Briefing: Federal Planning for Nuclear Incidents (Unclassified)

8:15 AM Briefing Panel: Federal Planning for Nuclear Incidents

Brooke Buddemeier
Principal Investigator, Global Security Directorate
Lawrence Livermore National Laboratory
### Session III  
**Current State of Nuclear Preparedness**

<table>
<thead>
<tr>
<th>Time</th>
<th>Event</th>
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<tbody>
<tr>
<td>9:00 AM</td>
<td>Q/A</td>
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<tr>
<td>9:15 AM</td>
<td><strong>Panel Discussion I: Current State of Preparedness</strong></td>
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<tr>
<td></td>
<td><em>Moderator: Roberta Lavin</em></td>
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<tr>
<td></td>
<td>Executive Associate Dean and Professor</td>
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<td></td>
<td>College of Nursing, University of Tennessee</td>
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<td></td>
<td><strong>Regina Hawkins</strong></td>
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<td></td>
<td>Senior Analyst, Preparedness</td>
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<td></td>
<td>Association of State and Territorial Health Officials</td>
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<td></td>
<td>Co-Lead, National Alliance for Radiation Readiness</td>
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<td><strong>Michael “Mac” McClendon</strong></td>
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<td></td>
<td>Director, Office of Public Health Preparedness &amp; Response</td>
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<td></td>
<td>Harris County Public Health</td>
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<td>Chair, Radiation Workgroup</td>
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<td>National Association of County and City Health Officials</td>
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<td></td>
<td><strong>Patrick Lujan</strong></td>
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<td>Preparedness Manager</td>
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<td>Department of Public Health and Social Services, Guam</td>
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<td><strong>Chris Williams</strong></td>
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<td>Deputy Director, Office of Radiation Protection</td>
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<td>Washington State Department of Health</td>
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<tr>
<td>10:15 AM</td>
<td>Q/A</td>
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<td>10:45 AM</td>
<td><strong>Break</strong></td>
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<tr>
<td>11:00 AM</td>
<td><strong>Panel Discussion II: Updating Planning Assumptions</strong></td>
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<td><em>Moderator: Cham Dallas</em></td>
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<td></td>
<td>University Professor of Health Policy &amp; Management</td>
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<td>Director, Institute for Disaster Management</td>
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<td>University of Georgia</td>
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<td><strong>MG Arthur J. Logan</strong></td>
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Adjutant General  
Hawaii State Department of Defense

**Robert Whitcomb**  
Chief, Radiation Studies Section  
National Center for Environmental Health, Centers for Disease Control and Prevention

**James Young**  
Program Manager, Radiological Emergency Preparedness, Emergency Management  
North Carolina Department of Public Safety

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<tr>
<th>12:00 PM</th>
<th>Q/A</th>
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<td>12:30 PM</td>
<td>Lunch</td>
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<tr>
<th><strong>Session IV</strong></th>
<th><strong>Implications of Communication, Education, and Information Challenges</strong></th>
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<tr>
<td>1:30 PM</td>
<td>Keynote: Communication, Education, and Information Challenges of Nuclear Events</td>
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</table>
| **Steven M. Becker** | Professor, Community & Environmental Health  
Old Dominion University |
| 2:00 PM | Q/A |
| 2:15 PM | Presentations: Implications of Communication, Education and Information Challenges for Building Capabilities – Lessons from Research |
| **Hamilton Bean** | Associate Professor of Communication  
Director, International Studies Program  
University of Colorado, Denver |
| **Baruch Fischhoff** | Howard Heinz University Professor  
Institute for Politics and Strategy, and Engineering & Public Policy  
Carnegie Mellon University |
| **Robert Levin** | Public Health Officer  
Ventura County (CA) |
| **Jessica Wieder** | Public Affairs Specialist  
Environmental Protection Agency |
| 3:15 PM | Q/A |

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<tr>
<th><strong>Session V</strong></th>
<th><strong>Challenges for Building Capacity Within the Healthcare System</strong></th>
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<tr>
<td>3:45 PM</td>
<td><em>Break</em></td>
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<tr>
<td>4:00 PM</td>
<td>Panel III: Challenges for Building Capacity – Healthcare Systems Perspectives</td>
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</tbody>
</table>
Moderator: **Bruce Evans**  
Fire Chief  
Upper Pine River Fire Protection District (CO)

**Amanda Bettencourt**  
Research Fellow, Center for Health Outcomes and Policy Research  
University of Pennsylvania School of Nursing

**Cullen Case Jr.**  
Program Manager  
Radiation Injury Treatment Network

**James Jeng**  
Surgeon, Crozer-Chester Medical Center (PA)  
Chairman, Disaster Subcommittee  
Committee on Organization and Delivery of Burn Care  
American Burn Association

**Robert L. Jones**  
Chief, Inorganic and Radiation Analytical Toxicology Branch  
National Center for Environmental Health  
Centers for Disease Control and Prevention

**Ziad Kazzi**  
Associate Professor, Emergency Medicine  
Emory University School of Medicine  
Member, Board of Directors  
American College of Medical Toxicology

**Ian Norton**  
Director, Emergency Medical Teams  
World Health Organization

5:15 PM  
**Q/A**

### Day 1 Wrap Up

5:45 PM  
**Chair’s Reflections and Preview of Day 2**

**Jim Blumenstock**  
Chief Program Officer, Public Health Practice  
Association of State and Territorial Health Officials  
Workshop Planning Committee Co-Chair

**Tener Veenema**  
Professor of Nursing and Public Health  
Johns Hopkins School of Nursing  
Johns Hopkins Bloomberg School of Public Health  
Workshop Planning Committee Co-Chair
### Day 2 – August 23, 2018

<table>
<thead>
<tr>
<th>Time</th>
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<th>Event</th>
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</table>
| 8:00 AM| Welcome   | Welcome and Recap of Day One<br>**Jim Blumenstock**<br>Chief Program Officer, Public Health Practice<br>Association of State and Territorial Health Officials<br>Workshop Planning Committee Co-Chair<at
|        | Recap of Day One | **Tener Veenema**<br>Professor of Nursing and Public Health<br>Johns Hopkins School of Nursing<br>Johns Hopkins Bloomberg School of Public Health<br>Workshop Planning Committee Co-Chair |
|        | Session V    | Capability Building Challenges and Opportunities<br>**Panel Discussion IV: Building Response Capability**
| 8:15 AM|            | Moderator: **John Benitez**<br>Medical Director, Emergency Preparedness<br>Tennessee Department of Health<at
|        |            | **Amesh Adalja**<br>Senior Scholar<br>Johns Hopkins University Center for Health Security<at
|        |            | **Steve Adams**<br>Deputy Director, Division of Strategic National Stockpile<br>Office of Public Health Preparedness and Response<br>Centers for Disease Control and Prevention<at
|        |            | **Mary Casey-Lockyer**<br>Senior Associate, Disaster Health Services<br>American Red Cross<at
|        |            | **Mary Pat Couig**<br>Program Manager, Office of Nursing Services<br>Department of Veterans Affairs<at
|        |            | **James J. James**<br>Executive Director<br>Society for Disaster Medicine and Public Health<br>Editor in Chief, *Disaster Medicine and Public Health Preparedness* |
| 9:15 AM|            | Q/A<at
| 9:30 AM|            | Panel Discussion V: Ensuring Workforce Readiness and Response Capacity<br>**Moderator:** John Koerner<br>Senior Special Advisor, CBRNE Science & Operations<br>Office of the Assistant Secretary for Preparedness and Response<br>Department of Health and Human Services
**Daniel Barnett**  
Associate Professor  
Environmental Health and Engineering  
Johns Hopkins Bloomberg School of Public Health

**Michael Consuelos**  
Senior Vice President, Clinical Integration  
The Hospital and Healthsystem Association of Pennsylvania

**Roberta Lavin**  
Executive Associate Dean and Professor  
College of Nursing, University of Tennessee

**Ron Miller**  
Director (Acting), National Disaster Medical System  
Office of the Assistant Secretary for Preparedness and Response  
Department of Health and Human Services

**RADM Susan Orsega**  
Chief Nursing Officer  
U.S. Public Health Service

**Tener Veenema**  
Professor of Nursing and Public Health  
Johns Hopkins School of Nursing  
Johns Hopkins Bloomberg School of Public Health  
Workshop Planning Committee Co-Chair

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<tr>
<th>Session VII</th>
<th>Workshop Wrap-Up</th>
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<tr>
<td>11:00 AM</td>
<td>Reaction Panel: Building Preparedness and Response Capability – A Way Forward</td>
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Moderator: **Laura Wolf**  
Director, Division of Critical Infrastructure Protection  
Office of the Assistant Secretary for Preparedness and Response  
Department of Health and Human Services

**Steven M. Becker**  
Professor, Community & Environmental Health  
Old Dominion University

**John Benitez**  
Medical Director, Emergency Preparedness  
Tennessee Department of Health

**Cham Dallas**  
University Professor of Health Policy & Management  
Director, Institute for Disaster Management  
University of Georgia
Bruce Evans
Fire Chief
Upper Pine River Fire Protection District (CO)

John Koerner
Senior Special Advisor, CBRNE Science & Operations
Office of the Assistant Secretary for Preparedness and Response
Department of Health and Human Services

Roberta Lavin
Executive Associate Dean and Professor
College of Nursing, University of Tennessee

12:00 PM  Closing Remarks

Robert P. Kadlec
Assistant Secretary for Preparedness and Response
Department of Health and Human Services

12:45 PM  Day Two Wrap-Up

Jim Blumenstock
Chief Program Officer, Public Health Practice
Association of State and Territorial Health Officials
Workshop Planning Committee Co-Chair

Tener Veenema
Professor of Nursing and Public Health
Johns Hopkins School of Nursing
Johns Hopkins Bloomberg School of Public Health
Workshop Planning Committee Co-Chair

1:00 PM  Adjourn Workshop
The National Academies of Sciences, Engineering, and Medicine have previously published on topics related to this workshop. To read our recent publications on medical and public health preparedness for nuclear incidents and learn more, search for the following titles (and see other related titles) on our publisher’s website:

www.nap.edu

Recent publications on this topic include:


* The Medical Implications of Nuclear War: Consensus Study Report (1986) *

Keep an eye out on the website for the published proceedings from this workshop in early 2019.
Online Resources on Medical and Public Health Preparedness for Nuclear Incidents


2. ASPR TRACIE Topic Collection: Radiological and Nuclear

3. Disaster Medicine and Public Health Preparedness Vol. 5 Supplementary Issue 1 (2011; focused on nuclear preparedness)


Emergency Communication and Information Issues in Terrorist Events Involving Radioactive Materials

STEVEN M. BECKER

ABSTRACT

With the threat posed by terrorism involving radioactive materials now high on the nation’s agenda, local, state, and federal agencies are moving to enhance preparedness and response capabilities. Crucial to these efforts is the development of effective risk communication strategies. This article reports findings from an ongoing study of risk communication issues in nuclear/radiological terrorism situations. It is part of a larger CDC-funded effort that aims to better understand communication challenges associated with weapons of mass destruction terrorism incidents. Presented here are formative research findings from 16 focus groups (n = 163) in which a multi-part, hypothetical radioactive materials terrorism situation was discussed. Twelve of the focus groups were carried out with members of the general public (drawn from a variety of ethnic backgrounds and geographic locations), and four groups were composed of first responders, hospital emergency department personnel, and public health professionals. One aim of the focus groups was to elicit detailed information on people’s knowledge, views, perceptions, reactions, and concerns related to a nuclear/radiological terrorism event, and to better understand people’s specific information needs and preferred information sources. A second aim was to pretest draft informational materials prepared by CDC and NIOSH. Key findings for the public and professional groups are presented, and the implications of the research for developing messages in radiological/nuclear terrorism situations are explored.
agents); and the University of Oklahoma (chemical agents).

The project seeks to identify people’s information needs and concerns vis-à-vis various threat agents and then use the results to develop pre-crafted informational messages that are responsive and scientifically accurate and that have been carefully tested. The term “pre-event” is used because the messages are to be prepared in advance and kept for later use. This approach is seen as essential, because in the context of a major unconventional terrorism event, agencies may face unprecedented public demands for information, even as resources are stretched thin attempting to manage the incident. In such a situation, preparing information during the event would not only be difficult, it would likely be too late.

The first phase of the Pre-Event Project, carried out in 2003, involved conducting formative research to better understand communication and information issues associated with WMD agents. A series of focus groups was conducted in several geographic locations with various population segments in order to better understand people’s attitudes and perceptions, concerns, information needs, preferred information sources, and views of existing informational materials. This article presents the findings from the formative research conducted on nuclear/radiological terrorism issues.

THE GROWING THREAT OF TERRORISM INVOLVING RADIOACTIVE MATERIALS

In recent years, concern about nuclear/radiological terrorism has grown substantially, and preparedness for such events has moved high on the nation’s homeland defense agenda. The apprehension stems from a constellation of interrelated developments. Because radioactive sources have numerous beneficial uses and are vital for a wide range of applications, they are now ubiquitous. Around the globe there are literally millions of radiation sources in use in government facilities, military facilities, clinics, hospitals and other medical institutions, research and educational laboratories, power plants, waste facilities, and industrial manufacturing facilities. In the developing world, for example, more than 16,000 sources are used annually for industrial radiography alone. Although security for radioactive sources around the world has improved, serious vulnerabilities remain. According to a 2003 report, although nuclear weapons and nuclear weapons materials are generally well guarded, protection for radiological sources is often minimal: “The world of radiological sources developed prior to recent concerns about terrorism, and many of the sources are either unsecured or provided, at best, with an industrial level of security.”

Every year, numerous radioactive sources are lost or stolen. While many are small and pose relatively little risk, and while some missing sources are eventually recovered, significant numbers of potent radioactive sources have been completely lost from regulatory control. Furthermore, it is clear that there is an active global market involving the trafficking in radioactive materials. According to the International Atomic Energy Agency (IAEA), between 1993 and 2001 there were “175 cases of trafficking in nuclear material and 201 cases of trafficking in other radioactive sources (medical, industrial).” To make matters worse, there is also an active market in technology and weapons information. Equipment and know-how for radiological devices and even for nuclear weapons is available in a way that was never the case before. “There is a sophisticated worldwide network,” IAEA Director General Mohamed El Baradei has warned.

Further adding to concerns are reports of known terrorist organizations attempting to acquire radioactive materials. A Monterey Institute database that tracks such activities includes various examples, including a report of al-Qaeda trying to secure strontium-90 and another report of Islamic Jihad attempting to acquire plutonium and uranium. Beyond that, there is information indicating that radiological weapons have already been assembled and tested. Iraq reportedly exploded a test device in 1987, and al-Qaeda is reported to have tried unsuccessfully to build a radiological device in Sudan in the late 1990s. Perhaps the best-known example took place in 1995, when Chechen rebels reportedly placed a functioning “dirty bomb” using dynamite and cesium 137 in a Moscow park but did not detonate it.

The final factor in the rising concerns about terrorism involving radioactive materials relates to the aims and motivations of terrorist organizations. A wide range of expert assessments, from United Nations panels to think tanks to the intelligence community, have all concluded that terrorists are willing to use such weapons. “We know beyond a shadow of a doubt,” concluded U.S. ambassador-at-large for antiterrorism Cofer Black, “that a number of these groups, if they had it, would use it.” If al-Qaeda “were to put together a radiological device, they’re going to use it. We know they have the determination.”

The actions and the proclamations of terrorist organizations themselves appear to support this conclusion. A statement appearing in December 2002 on one of the main websites frequented by supporters of al-Qaeda warned: “The coming days would prove that Qa’idat al-Jihad is capable, with Allah’s help, of turning the United States into a lake of lethal radiation…” While there is no way of knowing whether this particular posting was propaganda or a specific statement of intent, the cluster
of factors described above has produced a threat picture that is clearly sobering.

The seriousness with which the radioactive materials terrorism threat is taken was evident during the December 2003 holiday season. The Department of Homeland Security raised the threat level to “orange,” and, according to numerous media reports, “one of the U.S. officials’ main fears was of a dirty bomb.” Dozens of specialists “with sophisticated radiation detection equipment hidden in briefcases and golf bags” were reportedly sent to scour five major U.S. cities (Washington, New York, Las Vegas, Los Angeles, and Baltimore), and radiation detectors and monitors were sent out to police in other cities.15

The U.S., the IAEA, and others are currently devoting substantial efforts and resources to preventing terrorists from acquiring and using radioactive materials.16 For example, in November 2003, a joint operation by the IAEA and authorities from France and Côte d’Ivoire succeeded in securing a highly dangerous, disused cesium 137 source that had been abandoned in Abidjan.17 Successful recovery operations and related measures undoubtedly help to reduce the likelihood that powerful radioactive sources will fall into the hands of terrorists. Nevertheless, terrorism involving radioactive materials will remain a serious and continuing threat for the foreseeable future, making it essential for local, state, and federal agencies to be fully prepared should an attack occur.

THE IMPORTANCE OF COMMUNICATION AND INFORMATION ISSUES

One of the most crucial components in radiological/nuclear terrorism preparedness efforts relates to information and risk communication. Even under normal, non-emergency circumstances, effective communication “undergirds almost all of public health practice.”18 During normal operations, state public health agencies spend more time responding to requests for information than on initiating dialogues with interested constituencies or alerting the public to risk.19

In disaster and emergency situations, effective communication is even more critical. The timely and effective flow of information between agencies and the public is vital for facilitating and encouraging appropriate protective actions, reducing rumors and fear, maintaining public trust and confidence, and reducing morbidity and mortality. But as the 2001 anthrax attacks made clear, the communication difficulties posed by a WMD terrorism incident can be enormous. An attack can occur without warning, the threat may be invisible, and the agents may be unfamiliar and especially frightening to people.20-22

Under such circumstances, authorities may face unprecedented public demands for information, even as agency resources are stretched thin attempting to assess and manage the incident.

Research and historical experience suggest that incidents involving radiation can pose especially difficult challenges for information and risk communication,23-25 because situations involving radioactive materials have a remarkable capacity to produce widespread fear, a profound sense of vulnerability, and a continuing sense of alarm and dread. As Flynn and colleagues have noted, “Nuclear science and its technologies are among the great achievements of the 20th century—at once magnificently impressive and greatly feared. The fear emanates from the massive destructive power of nuclear weapons and from the dangers of other sources of man-made radiation.”26

A large body of research carried out over the past several decades by Slovic, Fischhoff, Lichtenstein, and others has demonstrated that nuclear technology, radioactive waste, and the like are perceived by the public as being extremely risky.27,28 Slovic has suggested that people assess the risks of technologies and activities on the basis of two broad dimensions or sets of factors: “dread risks” and “unknown risks.” Among the perceived characteristics of dread risks are catastrophic potential, fatal consequences, uncontrollability, inequitable distribution of risks and benefits, involuntariness, and a high risk to future generations. “Unknown risks” are perceived to be new, unobservable, unknown to those exposed, with delayed effects. Nuclear power, nuclear weapons fallout, and radioactive waste score high on both of these dimensions.29

When various groups of people were asked to rate the risk associated with 30 activities and technologies, and when the overall results were ordered, nuclear power was seen as the most risky.30 When an expanded set of 90 activities, substances, and technologies were assessed, and when perceived risks and benefits were taken into account, “nuclear weapons” topped the list for overall adjusted risk, followed by “warfare,” “terrorism,” and “nuclear power.”31 Finally, when researchers surveyed people to find out what images they connect with a high-level radioactive waste repository, they found overwhelmingly negative associations: “The most arresting and most important finding is the extreme negative quality of those images,” noted the researchers. Frequent associations included danger, death, sickness, pollution, war, and radiation. “Positive images were rare.” Indeed, noted the researchers, the images “demonstrate an aversion so strong that to call it ‘negative’ or a ‘dislike’ hardly does it justice. What these responses reveal are pervasive qualities of dread, revulsion, and anger. . . .”32

Drawing on the work of Slovic and colleagues, Rosa and Freudenburg concluded: “[N]uclear risks are perceived to be the riskiest—and are the most dreaded.”33
“Fear,” as Gray and Ropeik have pointed out, “has powerful public health implications.” Particularly in situations where information is scarce, unavailable, or confusing, fear can translate into responses that put people at risk and make managing the incident even more difficult. As noted in NCRP 138, a comprehensive report on radiological/nuclear terrorism prepared under the auspices of the National Council on Radiation Protection and Measurements, real-world experience with radiation incidents clearly demonstrates the potential for such behavioral reactions as mass flight, psychological stress, the seeking of health care in massive numbers, and powerful social stigma.

The September 1987 accident in Goiania, Brazil, is often cited as the quintessential example of how radiation incidents can produce profound and widespread fear. The accident began when scavengers found a metal container in an abandoned radiotherapy clinic and took it to a junkyard, where it was then broken open. Inside was a metal capsule, which was sawed open, containing 100 grams of luminescent material (later identified as cesium 137). Children played with the glowing substance, workers took samples home to show to friends, and the radioactive substance was spread to buses, homes, animals, and even some currency. Ultimately, the accident resulted in 4 deaths, about 260 people showing some signs of contamination, 49 needing medical treatment, and some 800 acres being contaminated.

“When measured in terms of fatalities and injuries alone,” Petterson observed, the event “hardly seems to be of international significance—certainly no more than any other industrial accident.” But because radiation was involved, ripples of worry and attendant secondary impacts extended far from the epicenter of the event. More than 112,000 people, concerned about potential exposure, voluntarily sought examinations. “The fear was so intense that some people fainted in the queues, as they approached the moment of monitoring,” wrote psychologist Ana Bandeira de Carvalho. Some people exhibited stress-induced symptoms that mimicked radiation exposure: vomiting and diarrhea, blisters, burns, or reddened skin. “Even people who lived far from the affected areas or in other states of Brazil and did not need to be screened, went.”

The event “sparked fears throughout Brazil.” Local agricultural products would not sell, and throughout the country “Goiania was regarded as a place to be avoided.” There were “significant drops in visitation and cancellations of virtually all conventions planned for the city.”

Even two regional medical association conventions were cancelled. Most dramatically, people from Goiania faced far-reaching discrimination: “Hotels in other parts of Brazil refused to allow Goiania residents to register. Some airline pilots refused to fly airplanes that had Goiania residents aboard. Cars with Goias license plates were stoned in other parts of Brazil.” Because discrimination against Goiania residents was so bad in other regions, some 8,000 residents requested and received official certificates saying that they were not contaminated.

Such reactions would not necessarily be outcomes of a radiological/nuclear terrorism situation. But as a recent Department of Homeland Security report concluded, “[P]ublic fear of a terrorist attack involving radioactive materials is likely to be high and could produce responses that endanger physical and mental health as well as the economic viability of affected communities.” In such a setting, information and risk communication will be absolutely central to the success or failure of consequence management. As the National Research Council report titled Improving Risk Communication points out, “[E]ven though good risk communication cannot always be expected to improve a situation, poor risk communication will nearly always make it worse.”

In the domain of nuclear accidents and radioactive materials incidents, historical experience surely bears this out. At the Three Mile Island (TMI) nuclear accident in 1979, for example, risk communication failures greatly exacerbated the human impact of the emergency. Because information needs were not adequately addressed, “residents around TMI were unduly confused and alarmed. . . .” In the words of risk communication specialist Peter Sandman, “. . . what went wrong at TMI—really, really wrong? The communication.”

In a radiological or nuclear terrorism situation, communication and information will have “a profound impact on the public’s reaction to the event and the government response.” A well-planned and well-executed effort could help to provide the public and key responder groups with understandable, scientifically accurate information; positively influence the responses of target populations to terrorist-initiated incidents so that people can take appropriate steps to protect themselves; prevent or reduce psychological effects; enable health authorities to be proactive in their communications; build trust and confidence with the public; and reduce morbidity and mortality. In short, “an effective and consistent communications strategy could reduce the impact” of the event and “also diminish the terrorists’ success.”

THE PRE-EVENT MESSAGE DEVELOPMENT PROJECT

A fundamental part of an effective WMD crisis communications strategy is the development of “pre-event messages.” Developed in advance and kept at the ready, such messages can enable public health authorities to be more proactive in communicating with the public when
METHODS

Eighty-seven percent of participants had a high school education or better, with almost 38% reporting having completed a college or graduate degree; 71% said that English was the language spoken most in their homes; 36% reported being Caucasian, 26% indicated they were African American, 17% of focus group participants reported being African American, 10% reported being Asian, and 8% indicated they were American Indian or Alaskan Native.

Across all 16 radioactive materials focus groups, a total of 163 people participated. Of the 16 focus groups, 12 were carried out with members of the general public and 4 were carried out with professionals groups likely to have a frontline role in managing a WMD incident. The breakdown of the 12 general population groups was as follows: 3 focus groups with African Americans (2 urban groups, 1 rural); 3 focus groups with whites (2 urban groups, 1 rural); 3 focus groups with Hispanics (2 urban groups, 1 rural); 1 focus group with Asians (urban); 1 English as a second language group; and 1 Native American group. In terms of geographic distribution, 3 of the 12 general public focus groups were conducted in the southeastern United States, 4 were carried out in the Midwest, 3 were held in the West, and 2 were conducted in the Southwest.

Focus group participants were recruited through neighborhood and community-based organizations and professional networks. Small cash stipends or gift certificates were given to participants to help defray transportation and other related costs incurred in attending the focus group. All focus group participants read and signed an informed consent document, and all work was conducted in accordance with Institutional Review Board guidelines.

Analysis of the demographic characteristics of participants in the 16 radioactive materials focus groups showed the following: 48% of participants were male, 57% of participants reported that they were married or living with a partner, and 69% of participants reported having children. Participants ranged in age from 18 to 84, with a mean age of 42.6 years. Seventeen percent of focus group participants reported being African American, 36% reported being Caucasian, 26% indicated they were Latino/Hispanic, 10% reported being Asian, and 8% indicated they were American Indian or Alaskan Native.

Eighty-seven percent of participants had a high school education or better, with almost 38% reporting having completed a college or graduate degree; 71% said that English was the language spoken most in their homes; 79% of the participants reported being currently employed; and 43% of the focus group participants reported...
a family income of less than $30,000 for 2002, while 13% reported incomes over $90,000 for the same year.

CDC had earlier carried out 3 exploratory focus groups (in Chicago, Los Angeles, and Philadelphia) involving a hypothetical “dirty bomb,” or radiological dispersal device (RDD), scenario. To effectively follow up and build on this earlier work, CDC, NIOSH, and the Pre-Event Team determined that it would be useful to use a broader hypothetical scenario involving the detonation of a small, improvised nuclear device (IND). The scenario was chosen to build on earlier work and to allow a wider range of issues to be explored (e.g., radiation concerns, protective actions, internal vs. external contamination, radioprotective agents, mass casualty management, etc.).

For the 12 focus groups with members of the public, a three-part discussion guide with a progressively unfolding hypothetical scenario was used. In the first part, participants were told that the Homeland Security Advisory System had been raised to red due to a credible threat that a terrorist group might be planning an attack in this area. Participants were then told that although the threat was not specific, officials suspected it “may involve radiation or nuclear materials.” In the second part, focus group participants were told that when they turned on the radio, they learned that there had been an explosion in the area and that “radiation has been detected by initial emergency responders.” They were told that hundreds of people had been injured and that people were being “advised to ‘shelter in place’ until more is known about whether radiation was involved.” In the third portion of the focus group guide, participants were told that about an hour after hearing the radio report, they see a local government official issue a statement on television. The official confirms “that a small nuclear explosion has gone off and that people in the area may have been exposed to radiation.” The official also reports that health and emergency personnel are working to contain the problem, seriously injured people are being taken to the hospital, and others who believe they might have been exposed are being referred to assessment centers near the hospitals. In addition, the official advises that “residents who were not close to the bomb should listen for information about which way the plume is spreading and evacuate or shelter in place according to emergency officials’ recommendations.”

Following each of the progressively unfolding sections, focus group participants were asked about their emotional reaction to the news, what their immediate concerns were, what they would do, what they would want to know, and where they would turn for information. In addition, following the second and third parts of the unfolding hypothetical scenario, focus group participants were presented draft informational materials that had been prepared by CDC. After reading the materials, the participants were asked how believable they found the information, what if anything might make it more believable, whether they felt that anything was not being disclosed, whether they were confident that following the action recommendations would keep them safe, whether they were confident they could carry out the recommendations, and whether they had any recommendations to make the fact sheets better or more useful. The same progressively unfolding scenario was also used in the 4 focus groups with professionals. However, in those focus groups, no draft CDC informational materials were pretested. Instead, at the end of the three parts, a series of NIOSH draft fact sheets for professionals were presented for feedback.

All 16 radioactive materials focus groups were carried out between May and August 2003. Each session lasted approximately 90 minutes and was led by a trained facilitator. Also present was a notetaker/quality control observer. Discussions were recorded, transcribed, and coded using a unified set of constructs/domains developed by the four Pre-Event teams. The constructs/domains included knowledge and beliefs, perceived risk, emotional response to threat, intended actions, confidence in the government and public health response to a potential attack, information needs, and information-seeking behaviors. For pretesting of materials, domains included comprehension, emotional response, believability, self-efficacy and response-efficacy, intention to follow advice, and recommendations for improvement. Intercoder reliability, which was assessed by the four universities, was considered acceptable when it equaled or exceeded 70%. Code-recode reliability was considered acceptable when it equaled or exceeded 80%.

Transcripts that had been coded using the unified set of constructs/domains were further analyzed using computer-based thematic analysis. Thematic analysis, which is a commonly used strategy in qualitative research, involves making repeated passes through the data in order to categorize them. As the analysis proceeds, a progressive “funneling” of the data takes place. As more and more evidence is classified, categories and subcategories become more clear and refined, and regularities and patterns become evident. Key themes that emerged from the thematic analysis are discussed below.

**FINDINGS: GENERAL PUBLIC**

**Reactions**

Not surprisingly, many people in the general public focus groups used words such as fearful, worried, scared, and upset to describe their likely reactions to the hypothetical scenario. As might be expected, people’s con-
cerns often centered around the safety and well-being of family members. “I would be worried about my family” and “I would start rounding up my family” were typical comments. Particularly within minority communities, it was also common to hear repeated references to prayer. As one person noted in a representative remark, “I would pray for protection, that would be the first thing I would do.”

Another reaction in evidence across various population groups was a sense of helplessness, confusion, fatalism, or futility. While in no sense a majority reaction, it was not uncommon.

“I think as far as a radioactive emergency like that, there’s really not much you can do... .”

“If it’s radiation, if it’s very close to you, you’re not going to have to worry about any of this—you’re going to be dead.”

**Information seeking**

Beyond immediate emotional reactions, one common action response across all population groups was to seek information needed for self-protection and survival.

“I think you’ve got to just stay level-headed and make sure that you can account for everybody that’s in your house or that you care for and start getting the information, and then start making an educated decision on what you need to do... .”

The kinds of information sought by people fell into three broad categories: specifics regarding the incident, facts about the threat agent, and information about health issues. With respect to the incident, people wanted to know who had carried out the attack, why it had happened, and whether it could happen again. In addition, people wanted to know where the terrorist incident had occurred, how big an area was affected, how much devastation had been caused, and how long the emergency would last. With respect to the threat agent, people had many questions: “What is radiation?” “What is the difference between x-rays and radiation?” “What radiation is—how it works,” and the like.

**Health issues**

But people’s primary information concerns centered on health issues, self-protection, and the protection of family members. In the most immediate sense, this translated into wanting to know which direction the wind was blowing and whether it was carrying radioactive contaminants in their direction. More generally, people wanted to know what should be done with pets and whether food and water would be safe to use. People also wanted to know what they should do if they were in a car at the time of the incident, rather than at home or in the office.

Another emphasis was on understanding, detecting, and avoiding potential health effects. People wanted to know how much radiation was involved and how far away was considered safe. Typical questions included, “How much radiation are we talking about?” and “How far away do I need to get?”

A major focus of concern involved knowing how people could tell if they had been exposed, and what the signs or symptoms (if any) would be: “How are we going to know that we are exposed to radiation? Is it a powder?” Linked with this was a desire to know when it was appropriate to seek medical attention.

“I’m just wondering at what point do they tell you to go to the doctor?”

“When do they need to get medical help, or what can they do at home to alleviate these symptoms?”

Likewise, people wanted to know what the potential health implications of the incident could be years later: “You need to know the long-term effects.”

**Problematic terms**

One of the most important findings from the first round of pre-event research is that key terms found in many current radiological/nuclear terrorism emergency information sheets or other materials can be confusing or unclear for some people. One such term is “shelter in place.” Some focus group participants understood the meaning of this often-used phrase, and others were able to derive the meaning from context, but some were unclear or confused as to the term’s meaning.

“Who provides shelter, the Red Cross?”

“Shelter in place. What does it mean? Does it mean stay where you are?”

“I assume shelter in place means to go to the place that affords you the greatest protection.”

“The word shelter sounds a little confusing. I think people hear shelter first thing and think, time to interpret that. If shelter means stay where you are at and stay covered, that would be more clear.”

The word “plume,” which is commonly used in emergency information materials, may have been somewhat less of a problem. Nevertheless, it was still unclear to some individuals: “That word plume, what is that?”
Sheltering versus flight

In discussing their expected reactions to a recommendation to “shelter in place,” people were influenced by how they felt they could best protect their loved ones. For those who believed that the best way to protect family members was to gather them together and perhaps flee, the option of sheltering in place was rejected.

“Well, I don’t shelter in place—I would be gathering my kids and stuff up.”

“I would still go get my children no matter what. Because to me that is everything.”

“I think I’d probably be a little selfish and grab my immediate family and hit the road as fast as I could.”

However, for people who believed that moving around outside would put people at greater risk, shelter in place was seen as the correct strategy.

“This is radiation. This is so completely different from a tornado. And so, your children might be safe if they stay in their place. And if you leave you expose yourself, and if you take them you expose them too.”

“My first reaction would be flight, but I also know that in radiation you need to stay under cover regardless.”

With respect to another protective action—that people remove outer clothes with potentially contaminated dirt or dust—people generally agreed that they would do so if it would help protect them. In a typical comment, one person put it this way: “If I’m contaminated anyway, I’m going to do whatever I can to try to keep myself as safe as I can.” But a few people said they might disregard the recommendation because of modesty concerns: “I’m not going to take my clothes off outside. I’m not going to do that.”

More generally, with respect to all recommended protective actions, there was a sense that if the measures “have been tested” and were “tried and true,” they would be more likely to be seen as something that could really help keep people safe. As one person explained, a recommended protective action would carry far more weight if it were seen to have been “tested or practiced somewhere, where it . . . proved itself to be effective. . . . It is not this theory we have. . . . [I]t was something that showed us that it was actually used and is effective in use.”

Perceptions of government and the color alert system

Some participants expressed confidence that government was trying hard and doing its best to deal with the terrorism threat. Others were still concerned about preparedness and the ability of authorities to act quickly during an event. Critical comments about the Homeland Security color alert system were not uncommon. Some participants indicated that they didn’t know what the various colors stood for or how the system really worked. “I have no clue what those mean,” said one person, while another complained, “You can kind of speculate on your own. Oh, it is orange, well I guess that is one up.” Still other participants suggested that the vagueness of the warnings reduced their value: “I have always thought it was so vague that I didn’t understand what went into them changing the color anyway, so it didn’t have any meaning.” Said one participant, “First of all the color changes, there are so many colors, okay, nobody pays attention anyway.” Said another, “What is the point?”

Some focus group participants also worried that complete information might not be provided during a terrorist incident involving radioactive materials. Here comments such as “I trust the government but I think they’re not going to tell you” or “I doubt I’d get the full story from what’s reported” were heard. Concerns were also expressed about whether information would be available in multiple languages. Overall, people emphasized the importance of being given as much information as possible and without the use of jargon.

“If you start using a lot of jargon that people don’t understand, it’s just going to cause more panic and more hysteria because people don’t understand what’s going on.”

“They’ll ignore it if they don’t understand it.”

Sources of information

In discussing who they viewed as good sources of information about the incident, some focus group participants identified agencies and authorities thought to have an understanding of the local situation. These included the fire chief, the police chief, the sheriff’s department, emergency management and civil defense officials, the military/national guard, and the county health department. Others chose national-level figures or agencies with expertise on health matters, such as the CDC or the Surgeon General of the United States. “That’s who you need because everybody that is going to be affected is going to wonder how this is going to affect my body and my life. . . .”

In terms of where people would go to find information during an event, the results were consistent with recent survey research: The media were mentioned most frequently. This was the case in the focus groups even though concerns about sensationalism were sometimes
expressed: “They can oversimplify things a lot or they can make things way out of proportion. . . .” For people seeking information, television was the clear first option. Radio, however, was seen as useful in an emergency, particularly if the power were knocked out as a result of the incident: “I think radio is ideal. . . . You may have electricity knocked out, so radio is going to be best.” Also mentioned as places to go for information were the emergency broadcast system, computer/internet, cell phones, and word of mouth. With respect to the media, national media outlets were often mentioned because of their extensive resources and because of the national implications of a terrorist attack. However, many people indicated that they would also turn to outlets closer to home because these would have more detailed information about the local situation.

**FINDINGS: PROFESSIONAL GROUPS**

**Newness of the threat**

Some professionals were concerned about what they perceived as the “newness” of the radiological/nuclear terrorism threat and the challenges it poses. A first responder put it this way: “This one is going to involve radiation or nuclear materials, this is a new one.” Likewise, there were concerns about preparedness. Said one professional, “I just wonder if the training and equipment is up to it.” Similarly, a health-care professional commented, “Although we have drilled on this, I would be concerned about how prepared we are to take this on.”

**Protection of family**

Like members of the general public, professionals were concerned about their families. “The first thing that comes to my mind is my family,” said one. Commented another, “I guess right off the bat, you know, if something happens, it would be my family.” Concerns were also expressed about the welfare of fellow professionals who might be in harm’s way: “Was anybody that I work with involved? That would be my biggest concern after my family.” At the same time, first responders and others felt and expressed a clear sense of duty: “Family first, but I know in my capacity, it is time to work.” As one professional put it: “That is what we do, after family, we go to work.”

**Self-protection**

Consistent with other recent research on responder needs (e.g., the RAND “Lessons Learned” Study55), professionals in the focus groups saw it as vital to have appropriate information on self-protection. “How can I do my job and help other people, and protect myself from getting hurt or killed? There is always that safety issue you’ve got in the back of your head.” In addition, there were concerns about becoming a target. For first responders, secondary devices were the focus: “You’re also concerned about . . . one being set somewhere . . . waiting for us to come in and start doing work and detonating it to get us.” For doctors and nurses, the focus was on the hospital: “How do we know, is there somebody detecting a bomb here in our facility?”

**The role of information**

Professionals described information as crucial, both to speaking as professionals but also as members of the community. A number of focus group participants specifically mentioned the local weather person as an excellent source. Local television news meteorologists were seen to be apolitical and without an axe to grind: “Why would he tell us something he didn’t believe in? It’s not like he will be voted out of office.” In addition, news meteorologists were seen as well known, familiar figures that people regularly watched for daily weather information or, more important, for updates on weather emergencies: “Usually, if something bad happens, it is weather. So when you go to the TV, there he is giving us the information.”

**A potential role for local meteorologists**

Speaking as professionals but also as members of the community, a number of focus group participants specifically mentioned the local weather person as an excellent source. Local television news meteorologists were seen to be apolitical and without an axe to grind: “Why would he tell us something he didn’t believe in? It’s not like he will be voted out of office.” In addition, news meteorologists were seen as well known, familiar figures that people regularly watched for daily weather information or, more important, for updates on weather emergencies: “Usually, if something bad happens, it is weather. So when you go to the TV, there he is giving us the information.”

**Concern about 911 breakdown, population flight, being deluged with worried individuals**

Professionals expressed a concern that phone lines and the broader 911 system could rapidly overload. A hospital emergency room professional commented, “I think the phone lines would tie up really fast. If those phone lines do tie up, we’re so dependent on that piece of equipment that we’re going to be stymied.” A first responder put it this way: “People are going to get paranoid and they are going to start calling 911 over everything.” Professionals also saw population flight as a potential problem. “That’s going to be a drain on manpower. We can expect accidents. We can expect road rage out of that kind of thing, because people are going to get cut off as they’re trying to move.” In addition, there was concern that health-care facilities could be flooded with worried
people, walk-ins, people self-reporting, and people fearing that they may have been exposed. “Those that are being brought by ambulance is one thing, but you’re going to have a deluge . . . brought here by private vehicle, or they’re going to walk in here. . . .”

**Concerns about potassium iodide**

Many concerns were expressed regarding potassium iodide. Known as KI, potassium iodide can confer some protection to the thyroid when radioactive iodines are released (e.g., in a nuclear power plant accident). However, many radioactive materials terrorism scenarios are unlikely to involve radio-iodines. Health department and hospital personnel were concerned that they would have to deal with demands for potassium iodide even when its use was not indicated. Said one health professional, “Everybody’s going to want it.” Commented another, “It doesn’t matter that it’s not recommended. They’re not going to care.”

Responders and health personnel also had their own concerns. One such concern was how they would know whether radio-iodines were involved: “How are we going to know whether or not the radioactive cloud contained iodine?” In addition, professionals asked how they would know when to take KI and where they would get it. Said one responder, “Like the KI, where can I get this, because right off the top of my head I wouldn’t have a clue.” Another responder remarked: “. . . should I take potassium iodide? . . . where can I get it? . . .” Finally, other professionals felt it was important to have full information about contraindications. As one public health worker commented, “A list of contraindications would be helpful to people. If you have this, don’t take this.”

**DISCUSSION**

The first phase of the Pre-Event Message Development Project provides a variety of useful insights into the communication issues associated with radioactive materials terrorism events. With respect to the general public, it is clear that health issues are at the very center of people’s expressed concerns and information needs. Questions about potential long-term effects, signs and symptoms of exposure to radiation or radioactive contamination, and when someone should seek medical attention were common. Emergency messages, therefore, need to clearly emphasize very early that authorities’ primary concern is people’s health and safety, and the content of messages needs to anticipate and answer the aforementioned types of health questions. Given the salience of health concerns, consideration should be given to including spokespersons with high credibility on health issues in emergency messages. Message developers also need to remember that people will not always be in their homes or offices when an incident occurs. To be fully effective, messages also need to include content advising people how to protect themselves when they are in a car, outside, or in other places during an incident.

While fatalism was not the majority response to the hypothetical radioactive materials terrorism scenario, it was a common enough response to make it clear that many people are prone to believe that “there is nothing you can do.” It will be crucial for emergency messages to tackle this head-on so that people undertake the protective measures needed to safeguard health. One of the findings from the first round focus groups is especially useful in this regard: People will take messages and protective actions more seriously if they believe the steps being advised are “tried and true” rather than just theoretical. Whenever possible, therefore, it may be beneficial to provide people with information confirming that protective measures work.

A key finding with the general public is that the phrase “shelter in place” is confusing or unclear to some people. It may be advisable to re-think the use of this term, which is currently found in most local, state, and federal emergency messages. Either greater effort needs to be made to ensure that people genuinely understand the phrase, or the term needs to be replaced. More generally, if special terms must be used, they should be simply and clearly explained so as to avoid confusion that impedes protective actions. It is important to ensure that messages are straightforward, use easily understood words, employ pictures and graphics, and are available in multiple languages.

Given the favorable light in which television meteorologists are viewed, their possible role in emergency communications needs to be further explored. In addition, having suitable messages available for radio will be important, since many people view this as an important back-up source. This may not be an easy task given that relatively little radio programming originates locally today in many markets.

With respect to professional groups, it is apparent that communication in a radiological/nuclear terrorism event will need to address a range of issues: the “newness” of the threat, self-protection, the threat of being targeted, and concerns about such problems as 911 system overload and the flooding of health-care facilities by worried individuals. In addition, it will be crucial for messages to take into account the fact that professionals have many concerns related to potassium iodide. Some of those concerns relate to expectations that the public will demand KI regardless of whether it is appropriate, while other concerns center around a need by professionals for more
information on whether, when, and how they should use potassium iodide themselves.

CONCLUSION

A carefully planned, empirically grounded, and well-executed risk communication program is a vital part of any effort to address the threat of terrorism involving radioactive materials. Given the enormous potential of incidents involving radiation to generate fear, effective risk communication may be one of the most important actions that health, safety, and emergency management agencies can take to help people take appropriate self-protection measures, limit adverse social and psychological effects, maintain trust and confidence, and reduce morbidity and mortality.

Results from the Pre-Event Project’s first round of focus groups are already being used to improve message development at CDC and elsewhere. Meanwhile, the next phase of the Pre-Event Project research is underway. For example, an expanded set of focus groups with the public health workforce was recently completed, and additional focus groups with other professional groups are planned. In addition, the Pre-Event Project team is working with CDC to develop improved web content, CDs, fact sheets, and television and radio spots for the general public. These, in turn, will undergo preliminary audience testing in 2004. Results will be released as soon as they are available.

It is hoped the findings presented here, and future Pre-Event findings, will prove useful not only to federal agencies, but also to state and local health departments, emergency management agencies, first responder organizations, hospitals, and other bodies with responsibility for managing a terrorist incident involving radioactive materials.

ACKNOWLEDGMENTS

This research was supported by the U.S. Centers for Disease Control and Prevention (CDC) and the Association of Schools of Public Health (ASPH). Special thanks are due to Betsy Mitchell, CDC’s Pre-Event Project Coordinator, and the following specialists at CDC, NIOSH, and ASPH who provided invaluable assistance: Marsha Vanderford, Charles Miller, Carol McCurley, Robert Whitcomb, John Cardarelli, Greg Lotz, Cheryl Lackey, Rita Kelliher, Stephanie Goad, and Karen Sauers. Thanks also to the members of the UAB Pre-Event Message Development Team. Additional appreciation goes to Angela Becker, who provided helpful feedback on the manuscript. Finally, thank you to the editors and anonymous reviewers at Biosecurity and Bioterrorism for their helpful comments and suggestions.

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INDIVIDUALS’ DECISIONS AFFECTING RADIATION EXPOSURE AFTER A NUCLEAR EXPLOSION

H. Keith Florig* and Baruch Fischhoff*†

Abstract—In the aftermath of a nuclear attack, shelters can offer potentially important protection. How well they fill that role depends on a set of interdependent decisions made by the individuals and organizations that must prepare and use them. We look at three such decisions. For each, we begin with formal analysis of the consequences expected from different possible actions. Those analyses are, then, reviewed in terms of how individuals facing these choices will perceive them, given the information that they are likely to have. The first example suggests that preparing a home shelter according to guidelines from the Department of Homeland Security may not pass a cost-benefit test. The second example explores the use of readily available information about a blast to infer how urgently shelter should be sought. The third example considers when shelters should be left, suggesting that individuals with the best shelters and slowest evacuation speeds should evacuate last, if they have the provisions needed to remain. In each case, helping people to protect themselves requires prior risk analyses and communication development.


Key words: risk communication; weapons; public information; fallout

INTRODUCTION

Perhaps the threat of greatest consequence in terrorists’ arsenal is detonating a stolen or improvised nuclear device in an urban area. Various bodies have issued guidance on how citizens should respond to this threat, typically recommending that they take shelter in order to reduce radiation exposure from fallout (CDC 2005; NAE 2005). Although any shelter is better than none, it is not clear how fully this advice considers the options and consequences facing citizens. For example, sheltering in one’s current location may provide less protection than sheltering in another one, even when considering the additional exposure while in transit between the two. Even when a shelter provides enough additional shielding to justify moving there, reduced radiation exposure will not be the only issue on many citizens’ minds. For example, they might wonder about the risks that they would be taking, by forsaking the best personal shelter, in order to help others. Or, they might wonder whether the resources needed to provision a home shelter might be better invested in other protective actions or other things altogether.

Sound advice regarding sheltering (or any other behavior) should reflect analyses that systematically evaluate the expected utility of alternative actions. Absent such analyses, advice may mislead its recipients. When individuals’ circumstances vary, then any single message will fit some of them better than others. As a result, such advice should reflect a deliberate weighting of those individuals’ welfare—so that it fits best those whom it will bring the greatest benefit. That benefit will depend on recipients’ willingness and ability to follow the advice.

Here, we develop advice regarding three interrelated sheltering decisions. For each, we accommodate the variability in people’s circumstances, at a level of complexity suitable to the conditions under which the decisions will be made. In each case, we show how relatively simple analysis can capture important elements of the decision. The three decisions are:

1. Should one prepare a shelter space in one’s home?
2. Should one risk traveling from one’s location at the time of a blast?
3. How long should one remain in a shelter before evacuating the area?

HOME SHELTER PREPARATION

A number of government and non-government organizations with emergency-management functions recommend that people stock emergency supplies in their homes to sustain and protect them in the event of an emergency requiring people to stay sheltered for an

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extended period. The Department of Homeland Security (DHS), which the National Response Plan names as the primary government organization for mass care (DHS 2004), recommends stocking enough emergency supplies to sustain those in the shelter for three days. Their checklist of recommended emergency supplies (DHS 2006) includes over two dozen items, including water, food, clothing, utensils, medicines, first aid supplies, personal sanitation supplies, radio, flashlight, dust mask, duct tape and plastic sheeting, bedding, pet needs, and entertainment. Other organizations to which the public might turn for advice on radiological emergencies offer similar, but not identical, stockpile recommendations (CDC 2005; American Red Cross 2006). Given that the effort and expense of procuring and organizing these emergency supplies are non-negligible, a reasonable person might ask whether the benefits of securing them outweigh their costs. Tables 1 and 2 address this question.

Some cost estimates

Table 1 details the approximate costs of equipping a home shelter to supply four people for 3 days with the goods on the DHS Emergency Supply List (DHS 2006).

Durable goods are assumed to last 10 years and non-durables are replaced as needed. The initial outlay for the median household is estimated to be about $465, with additional annual costs of roughly $250. Applying a 4% discount rate, the net present value of the 10-y costs of following DHS’s recommendations comes to about $2,400. The initial outlay might be negligible for some families and impossible for others (equaling two weeks’ income for minimum wage workers). Census data on disposable income could be used to assess its affordability across the population. Doing so would be a necessary first step toward estimating compliance rates. It would also allow targeting those for whom the message is meaningful (because they could, conceivably, comply), while avoiding those who might find it offensive (because it asks them to do the impossible if they want to protect their families).

The recurring annual cost of maintaining provisions, which includes rent on the space needed to store them, is roughly half the initial cost. Psychologically, it may seem to be even less for people who substantially discount future costs. Conversely, the initial costs may seem disproportionately large for people who expect to move

Table 1. Estimated 10-y costs of provisioning a home shelter to sustain 4 people with 3 days of supplies, as recommended by the DHS Emergency Supply List. Ranges represent central 95% of households. Costs for items used by only some households (e.g., pet food) are weighted averages across all households.

<table>
<thead>
<tr>
<th>Component</th>
<th>Initial stocking cost, $</th>
<th>Annual replacement cost, $</th>
</tr>
</thead>
<tbody>
<tr>
<td>Potable water in safe container, 1 gallon/person/day</td>
<td>1−30</td>
<td>0−30</td>
</tr>
<tr>
<td>Food with long shelf life</td>
<td>25−70</td>
<td>5−70</td>
</tr>
<tr>
<td>Radio (AM/FM and NOAA weather) with extra batteries</td>
<td>10−20</td>
<td>2−4</td>
</tr>
<tr>
<td>Flashlights and batteries</td>
<td>5−10</td>
<td>2−5</td>
</tr>
<tr>
<td>First aid kit and first aid book</td>
<td>30−50</td>
<td>2</td>
</tr>
<tr>
<td>Whistle</td>
<td>5</td>
<td>0</td>
</tr>
<tr>
<td>Dust mask (one per person)</td>
<td>3</td>
<td>0</td>
</tr>
<tr>
<td>Duct tape and plastic sheeting</td>
<td>10−20</td>
<td>0</td>
</tr>
<tr>
<td>Personal sanitation/hygiene supplies</td>
<td>6</td>
<td>1</td>
</tr>
<tr>
<td>Tools (wrench, pliers)</td>
<td>5</td>
<td>0</td>
</tr>
<tr>
<td>Can opener</td>
<td>4</td>
<td>0</td>
</tr>
<tr>
<td>Road maps</td>
<td>3</td>
<td>0</td>
</tr>
<tr>
<td>Medicines including prescriptions</td>
<td>1−20</td>
<td>1−10</td>
</tr>
<tr>
<td>Eyeglasses or contact lenses and cleaning supplies</td>
<td>3</td>
<td>2</td>
</tr>
<tr>
<td>Infant formula and diapers</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Pet food</td>
<td>5</td>
<td>0</td>
</tr>
<tr>
<td>Copies of important documents</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Cash ($500)$</td>
<td>35</td>
<td>35</td>
</tr>
<tr>
<td>Bedding</td>
<td>10−50</td>
<td>0</td>
</tr>
<tr>
<td>One change of clothes and shoes per person</td>
<td>10−40</td>
<td>5</td>
</tr>
<tr>
<td>Chlorine bleach and medicine dropper</td>
<td>3</td>
<td>2</td>
</tr>
<tr>
<td>Fire extinguisher</td>
<td>10−30</td>
<td>0</td>
</tr>
<tr>
<td>Paper plates, paper towels, and plastic utensils</td>
<td>5</td>
<td>0</td>
</tr>
<tr>
<td>Books, games, and entertainment</td>
<td>5−30</td>
<td>0</td>
</tr>
<tr>
<td>Space to store materials—1 m$^2$ @ $8$−15 m$^{-2}$ mo$^{-1}$</td>
<td>100−180</td>
<td>100−180</td>
</tr>
<tr>
<td>Time valued at S6−20 h$^{-1}$</td>
<td>18−60</td>
<td>9−30</td>
</tr>
</tbody>
</table>

Estimated median across all households: 465, 252

Net present value over 10-y lifetime, 4% discounting, $2,400

*a Assumes existing eyeglasses/contacts are used. Costs are for cleaning supplies only.

*b Assumes opportunity cost of cash stashed away is 7% per year.
soon, given the hassles of arranging for storage space and moving supplies to a new home. Those people might defer action until after they have moved, hoping that nothing happens in the interim. Determining the prevalence of such tendencies would allow further refining estimates of compliance rates.

Each item on the DHS list could be evaluated in terms of its impacts on individuals’ choices. For example, the largest single cost in Table 1 is rent for the floor space needed to store the supplies. Some households will have room to spare and not consider this a cost; others will have no way of securing the space. Shelter preparation would be easier for individuals in the former category, impossible for those in the latter. The prevalence of these “market sectors” might be estimated from census data on housing size or dedicated surveys.

The time needed for stockpiling is another large cost in Table 1. The number of hours is a rough estimate of how long it would take a person to translate DHS’s general list into specific terms, purchase them, prepare the space, and stow them. The value of that time covers a range of wages. Although one might argue that people should not consider the value of the time spent in protecting themselves, economists commonly use time expenditures when placing a value on other human activities. For instance, the “travel cost method” is a standard way for monetizing the value of resources like national parks (Parsons 2003).

The cost estimate for medicine covers routine over-the-counter remedies, which all households are assumed to need, and a weighted average of prescription medications, which some households need more of than do others. It underestimates costs for people who need special drugs, especially if their insurance plan will not cover such advance purchases or they must purchase additional refrigeration. These estimates, too, could be refined with dedicated studies (asking people about their

<table>
<thead>
<tr>
<th>Event</th>
<th>Plausible probability</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. The probability of a nuclear attack anywhere in the U.S. over the physical lifetime of the shelter</td>
<td>0.05</td>
</tr>
<tr>
<td>2. If attack happens in U.S., it will be in their city</td>
<td>0.1</td>
</tr>
<tr>
<td>3. If attack happens in their city, the wind will blow fallout toward their house</td>
<td>0.2</td>
</tr>
<tr>
<td>4. If wind is blowing toward their house, ( n = 1, 2, 3, ) or 4 people will be at home</td>
<td>0.26, 0.13, 0.07, 0.34</td>
</tr>
<tr>
<td>5. If ( n ) people are at home, a timely alert indicating the need to take shelter will be issued</td>
<td>0.5</td>
</tr>
<tr>
<td>6. If timely alert is issued, they will hear it in time to take shelter</td>
<td>0.5</td>
</tr>
<tr>
<td>7. If a timely alert is issued, they will decide to take shelter rather than to flee</td>
<td>0.5</td>
</tr>
<tr>
<td>8. If they decide to shelter, their shelter will provide sufficient protection to save them</td>
<td>0.5</td>
</tr>
</tbody>
</table>

Joint probability that shelter will save the lives of 1, 2, 3, or 4 people: \( 1.6 \times 10^{-5}, 0.8 \times 10^{-5}, 0.4 \times 10^{-5}, 2.1 \times 10^{-5} \)

Expected number of lives saved, \( p_1 + 2p_2 + 3p_3 + 4p_4 \) = \( 1.3 \times 10^{-4} \)

The analysis of the DHS list should begin by assuming wholly rational behavior, in the sense that citizens understand the options perfectly and choose the one with the greatest expected utility. The analysis should then be repeated, making more behaviorally realistic assumptions, such as recognizing that people sometimes forget that they need drugs or that they have extra doses already. The former would be less prepared than they think, while the latter overestimate the costs of stocking their shelter.

The estimates in Table 1 would represent an infeasible expense for some people, a trivial one for others. For the former, ignoring DHS’s advice could reflect a reasoned response. For the latter, though, failure to stock up would require another explanation. The next section considers one possible other reason, seeing little chance of using the shelter—and getting a return on that investment.

Some benefit estimates

Let, \( p_1, \ldots, p_4 \) be the probabilities that using the shelter over its 10-y lifetime will save the lives of exactly 1, . . . , 4 household members, respectively. Using the cost estimates in Table 1, the expected cost per life saved for a household of four would be

\[
\text{Cost per life saved} = \frac{\$2,400}{(p_1 + 2p_2 + 3p_3 + 4p_4)}. \tag{1}
\]

Each \( p_n \) can be estimated as the product of the string of probabilities in Table 2. For illustrative purposes, plausible values have been assigned to each. For example, we assume that all household members are at home during sleeping hours (8 h d\(^{-1}\)), while during non-sleeping hours, each person spends the population average time at home (33%; Klepeis et al. 2001), distributed
uniformly over the non-sleeping period. Under these assumptions, the probabilities of exactly one, two, three, and four household members being at home at a randomly selected time during any 24-h period are 26%, 13%, 7%, and 34%, respectively, for an expected occupancy of 2.1. An attack timed for maximum impact might be detonated during peak business hours, in a central business district. In that case, the expected occupancy of homes outside that area would be smaller.

Each probability in Table 2 could be similarly refined. After computing technically sound estimates of the chances of people benefiting from shelter preparations, one can examine the accuracy of the beliefs that will determine their actual choices. For example, optimism bias (Weinstein 1980) could lead people to underestimate the probability of a nuclear attack being in their city and to overestimate the probability of being near their shelter should it be needed. Lay estimates might be less than expert estimates because citizens believe that terrorist threats are being exaggerated for political purposes. Lay estimates might be greater than expert estimates because citizens do not appreciate just how many targets there are in the U.S. (and the world), relative to the limited number of nuclear weapons that terrorists might conceivably secure. Assessing the magnitude of these possible biases in lay beliefs requires direct empirical study, the results of which can focus risk communications on critical misunderstandings.

Given the values in Table 2, the joint probability of these events occurring (and a shelter saving lives) is very small. Psychological research has identified two processes that could lead people to exaggerate this probability and, with it, the value of a shelter. One such process is not seeing how a set of mostly possible events could add up to a nearly impossible conjunction (Cohen et al. 1956). The second is finding the scenario as a whole so compelling that its number of constituent events is neglected (Tversky and Kahneman 1973). Conversely, some people may view the probability of an attack occurring in their city as so small that they dismiss the entire prospect. Here, too, research is needed to assess the prevalence of such beliefs and the possibilities for changing them (Morgan et al. 2001; Fischhoff 2005).

Applying the probabilities in Table 2 in eqn (1) yields a cost per life saved of roughly $15 million. This value is much greater than the cost-effectiveness of many other household life-saving interventions (e.g., smoke detectors, bicycle helmets) and well above the median $4 million/life-saved guideline for government measures addressing health and safety risks (Morrall 2003). Individuals who see sheltering this way might rationally decide that provisioning one is a poor investment.

Like the estimates in Table 1, those in Table 2 could be refined. Perhaps the most uncertain is the first, the probability of a nuclear attack in the U.S. over the next decade. If shelter decisions are robust across the range of plausible values, then no greater precision is needed. If not, then more precise probability assessments are needed or the value of a shelter is indeterminate. Table 2’s second entry (target city) might be taken from the analyses supporting the Department of Homeland Security’s Urban Areas Safety Initiative, allocating money to cities according to threat levels and protection opportunities, or from external reviews (Willis et al. 2005; GAO 2006). Repeating this analysis at a finer geographic scale could accommodate statistics on the likelihood of living so near the blast that prompt effects are lethal or so far away that sheltering only modestly reduces cancer risk. The third value in Table 2 (wind direction) could be honed with meteorological data. The fourth value (being at home at the time of an attack) was discussed above. The fifth and sixth values depend on emergency authorities’ operational readiness for issuing an alert and getting it heard. The seventh and eighth values partly depend on issues considered below concerning the risk reduction from getting to a shelter and staying there.

The benefits of incurring the costs documented in Table 1 will be greater if the same preparations serve other ends, such as helping households to get through extreme weather events or extended electrical outages. Assessing these benefits requires additional analyses (e.g., preparations that help in an ice storm might be useless in a flood), incorporating factors like those in Fig. 1.

DHS has also issued recommendations for stockpiling emergency supplies at places of work (DHS 2005). Those, too, could be subjected to cost-benefit analyses similar to those presented here.

DHS has also issued recommendations for stockpiling emergency supplies at places of work (DHS 2005). Those, too, could be subjected to cost-benefit analyses similar to those presented here.

![Fig. 1. Factors affecting the utility of sheltering.](image-url)
TRAVELING IMMEDIATELY AFTER THE BLAST

Blast effects, immediate thermal/ionizing radiation, and fire would be lethal to most people within some radius (~2 km for a 10 kT ground burst) of ground zero. Beyond that, the main health concern is radiation exposure from fallout. As noted, unless a blast occurs at night, most people will be away from home. People who have prepared a home shelter will want to know what radiation risk they face in traveling home in order to gain its benefit. They may also want to know the risk from other travel, such as getting to loved ones at day care or a nursing home—or getting provisions that they neglected before (or consumed for routine purposes).

It is not known how quickly official public announcements relevant to travel decisions could be issued after an event as disruptive as a nuclear blast. If experience with Hurricane Katrina is any guide, it may take many hours. News media outside the blast zone, however, will likely continue to operate. As a result, people in fallout-vulnerable zones should be able to learn the blast’s location quickly if their electricity is still working or they have battery-powered radios. If official recommendations were pre-positioned with media sources, along with simple criteria for using them (e.g., bright flash and mushroom cloud), they could be broadcast without post-blast authorization. Such preparation of news outlets could provide life-saving information to many people. However, survivors closest to the blast zone who must secure shelter within minutes, could not wait even that long. They need to receive sound, comprehensible instruction before an emergency, as do people without access to communications. Not everyone needs that information, as long as someone around them has it and shares it. Understanding those advice distribution channels is an essential part of disaster preparation.

Regardless of the information channel (pre-blast education, pre-positioned media messages, or post-blast official announcements), the intense conditions after an attack mean that any advice will have to make minimal cognitive demands on those receiving it. Table 3 shows one possible form of such guidance, calibrated for a 10 kT ground burst. It offers simple recommendations, based on the time until fallout arrives or, if that estimate cannot be computed and conveyed, distance from the blast. Its simple decision rule compares risk from radioactive fallout with possible benefits of travel. For those closest to the blast, it gives orders, not options.

Table 3 advises taking shelter immediately for anyone whom fallout will reach within 15 min. The distance version of this advice applies it to the several-kilometer wide zone subject to local fallout (large particles of radioactive material either impelled directly by the blast or falling soon after being swept aloft by the “upwind” of the blast). Given the very high dose rates within this zone, it is hard to imagine circumstances that would override this advice.

Beyond this zone, the best possible advice would depend on wind speed and direction. The debris cloud from a 10 kT blast would rise to an altitude of perhaps 8 km, where winds might differ substantially from those at ground level. Officials who know these conditions might be able to derive more precise advice and communicate it clearly. Unless they can, distance might be the best basis for decision making. In order to rely on it, people

<table>
<thead>
<tr>
<th>Fallout arrival</th>
<th>Distance from blast</th>
<th>Risk from unsheltered exposure during first hour of fallout</th>
<th>Risk from 90% effective shelter during first hour of fallout</th>
<th>Recommendation</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt; 15 min</td>
<td>&lt; 4 km</td>
<td>Acutely fatal for all</td>
<td>Acutely fatal for most</td>
<td>Shelter in deepest space reachable within minutes</td>
</tr>
<tr>
<td>15–60 min</td>
<td>4–10 km</td>
<td>Acutely fatal for most. Quadruple cancer risk for the few survivors.</td>
<td>Acutely fatal for some. Doubling of cancer risk for survivors.</td>
<td>Travel only if certain that better shelter can be reached before fallout arrives. Use extra time to fortify shelter space.</td>
</tr>
<tr>
<td>30–90 min</td>
<td>10–20 km</td>
<td>Acutely fatal for some. Doubling of cancer risk for survivors.</td>
<td>20% additional cancer risk</td>
<td>Travel if risk of exposure to fallout seems worth the benefit. Use extra time to fortify shelter space.</td>
</tr>
<tr>
<td>1–3 h</td>
<td>20–50 km</td>
<td>20% additional cancer risk</td>
<td>2% additional cancer risk</td>
<td>Travel if risk of exposure to fallout seems worth the benefit. Failure to reach shelter before fallout arrives has health consequences that are significant, but not acutely fatal.</td>
</tr>
<tr>
<td>&gt; 2 h</td>
<td>50–100 km</td>
<td>5% additional cancer risk</td>
<td>&lt; 1% additional cancer risk</td>
<td>Sufficient time exists for travel to get home, collect family members, and/or flee</td>
</tr>
</tbody>
</table>

Table 3. Travel recommendations for the period immediately after detonation of a 10-kiloton fission bomb, before the arrival of fallout. Cancer risks are based on dose estimates from Hotspot 2.05 (Homm 2003) and are expressed as the fractional increase in lifetime cancer risk from non-radiation causes. Distance ranges, risks, and recommendations would differ for a blast of significantly lower or higher yield. © 2021 The Health Physics Society. Unauthorized reproduction of this article is prohibited.
might need to be dissuaded from relying on surface winds to predict the fallout plume.

Although officials should quickly know the blast’s location, they may be uncertain about its magnitude. For an improvised nuclear device, 1–10 kT is the range of most likely yield (Mark et al. 1987; Ferguson and Potter 2006). Smaller yields, including a fizzle, are also possible, as are higher yields, with nuclear weapons diverted from a national arsenal. Because total radioactivity in the debris cloud is roughly proportional to yield, quick estimates of yield would allow refining advice on travel and sheltering. The most expedient method may be relating yield to the altitude and diameter of the debris cloud, several minutes after the blast. Night or overcast skies would require another method. Any method should be simple and robust to variations in conditions after a blast, with predetermined and pretested translation to advice for the public.

People further from the blast will have more opportunities to prepare for fallout. The second category of advice in Table 3 is for those whom fallout will reach in 30–90 min. They might be able to take reasonable gambles to improve their conditions (e.g., reach a home shelter, collect nearby family members, or shore up shielding in an existing space). To that end, they need to know which actions are most worth doing. Prior analysis can inform these choices by assessing the effectiveness of measures and the probability of accomplishing them, given the disruptions likely after a blast (e.g., will traffic lights work? will TV/radio be on the air?). Where the advice is counter-intuitive, messages should include brief explanations, previously tested for effectiveness (e.g., don’t evacuate immediately because outdoor radiation levels are lethal; the water is safe for a while, because the reservoir is covered; don’t drive, because roads are clogged with abandoned vehicles).

When personal radiation exposure is the only consequence that matters, it pays to change shelter locations only if doing so reduces exposure by improving one’s shielding or one’s ability to hold out. That calculation is straightforward and better done by radiation specialists than average citizens. More difficult tradeoffs arise when people decide whether to expose themselves in order to help others. Such valor is the natural tendency in disasters (Wessely 2005). Those who suppress the instinct to help will have to live with the knowledge that they put themselves first. In the unprecedented circumstances of a nuclear attack, people will be unusually attentive to expert advice. It must be formulated in a way that does not leave survivors feeling that they were induced to act against their own moral judgment. Here, as elsewhere, messages must be pretested, so that they are understood as intended.

Compared to the first row of Table 3, the second covers many more people, with more varied circumstances. Analysis is needed to assess how sensitive the advice is to that variation. For example, a sustained wind aloft could mean that some individuals are better served by advice in the third row or even the fourth. Taking advantage of that reality requires determining wind conditions and disseminating clear advice before people have committed to a course of action. It is a sad reality of communication that complicating any message will confuse some individuals. Thus, allowing some people to take advantage of lower fallout in their area will mean exposing others to more fallout—because they are confused about which advice applies to them. Whether that risk is justified requires explicit analysis after research creates the best possible messages.

Analogous integration of risk analysis and risk communication research is needed to evaluate and refine the rest of Table 3’s advice—or any other advice. Risk analyses could incorporate knowledge about traffic patterns, vehicles’ shielding properties, clothing contamination, etc. The communication research would consider lay beliefs about radiation and shielding, citizens’ priorities, etc. That research would also allow refining Table 2’s estimates, by clarifying the chances of using a shelter.

**SHELTERING DURATION**

Those entering a shelter, or contemplating its use, must look ahead to when they will leave it. Fig. 1 shows some factors relevant to that choice. In addition to radiation risk, they include non-radiation health concerns, worry about contamination, physical discomfort, economic loss, and concern about loved ones elsewhere. In order to weigh these concerns, people need to know how evacuation timing affects their radiation risk. Fig. 2 offers a simple calculation of the sheltering period that minimizes the sum of the radiation doses received during sheltering and evacuation. Some people will want to stay longer (e.g., to allow injuries to heal); some will want to leave earlier (e.g., because of hunger). All will want to know what the dose-minimizing moment is—as will individuals wondering whether three days’ provision will suffice.

Dose accumulates during (1) the sheltering period, as a function of the gamma ray shielding that the building provides as well as the building’s air exchange rate, and (2) the evacuation period, as a function of conditions in the fallout-contaminated zone that would be crossed. The ground-level outdoor dose rate, $D_o \tau$, from fission-product fallout decreases with time since the blast as $\tau^{-1.2}$ (Glasstone and Dolan 1977):

$$D_o \propto \tau^{-1.2}.$$ (2)
The dose-reduction factor of a shelter (U.S. EPA 1992) is the ratio of the dose received within the shelter to that received on open ground. If \( f \) is the dose-reduction factor of a shelter, defined to include both gamma penetration and fallout particle infiltration, then the dose rate within the shelter is
\[
\frac{D_s}{H} \propto f^{-1.2}.
\]
(3)

We assume no shielding during the time, \( \tau_e \), spent traversing the contaminated zone when evacuating. Integrating dose rate over the shelter and evacuation periods, the dose-minimizing sheltering duration, \( \tau_s \), is found to be the solution to the transcendental equation:
\[
-1.2 \ln(\tau_s) + \ln(1 - f) = -1.2 \ln(\tau_s + \tau_e).
\]
(4)

Note that, under the assumptions leading to eqn (4), the sheltering duration that minimizes total dose is independent of dose rate. Thus, if radiation risk is the only concern, those closer to the blast point should evacuate no sooner (or later) than those far away—assuming that their evacuation takes equally long. Fig. 2 plots the relationships in eqn (4), showing the dose-minimizing sheltering period as a function of the shelter’s dose-reduction factor and the time needed to cross the fallout-contaminated zone. Dose-reduction factors differ substantially for different prospective shelter locations. A person on the first floor of a wood frame house, in the basement of a brick house, or in the interior of a multistory building would receive roughly 90%, 20%, and 10%, respectively, of the gamma dose of an unshielded person outdoors (Glasstone and Dolan 1977; U.S. EPA 1992). According to Fig. 2, people in weakly protective shelters should evacuate within just a few hours of the arrival of fallout, even if it takes several hours to cross the fallout-contaminated zone. Those in highly protective shelters may be better off staying for several days, especially if the expected egress time is long. Actual dose-reduction factors will be larger than those used in these calculations, as a result of fallout particles infiltrating the shelter. The dose from infiltration is typically estimated to be much smaller than the gamma dose from outdoor particles (Ng et al. 1990). This may not be true for multistory buildings with air intakes that are not shut as the fallout cloud passes (Mead and Gressel 2002).

Given the sensitivity of the optimum sheltering period to shielding effectiveness and egress time, advice must be tailored to individuals’ conditions. If people follow that advice, they will evacuate at different times, reducing congestion, so that everyone can leave more swiftly and, hence, sooner. Holding other things equal, the analysis shows that those with better shelters should wait longer. One possible complicating factor is discomfort from sheltering, for those who prepare only for the 3-d recommended period. For those with a moderately effective shelter and moderately long evacuation time, it would be better to stay longer.

Acting on this advice requires citizens to know the dose-reduction factor and egress speed relevant to their circumstances. That, too, is a matter for prior communication research. It should explore how to explain staged evacuation so that people feel that they are being treated equitably.

The analysis represented in Fig. 2 assumes that people are completely unshielded during evacuation, as would happen if they walked out of the contamination zone. Shielded evacuation vehicles could shorten the optimum sheltering period by getting people out faster and with greater protection during transit. A small number of shielded vehicles might be enough for a staged evacuation.

CONCLUSION

In principle, shelters can provide valuable protection after an event dispersing radioactive fallout. For that to happen, however, those shelters need to be properly prepared and used. We have adopted a behavioral decision research approach to examining three critical decisions: (a) whether to provision a shelter, according to Department of Homeland Security guidelines; (b) whether to travel immediately after an attack; and (c) how long to stay in a shelter. These choices are interdependent. The expected value of preparations depends on the chances of being able to use a shelter and of its...
provisions being sufficient. The acceptability of risks from traveling before fallout arrives depends on the benefits that such travel provides (e.g., getting one to a good shelter).

In keeping with behavioral decision research, each case study begins with a formal analysis of the decision, applying technical knowledge to identifying the action that best achieves individuals’ goals. Each proceeds to ask how individuals perceive the options, given the information that is naturally available to them and that could be made available. These assessments seek behavioral realism in their expectations regarding the information that authorities can generate and disseminate, as well as that which individuals can absorb and apply. Each concludes by considering the opportunities to improve those choices.

Our goal has been to show how such citizen-centered research could proceed, rather than reach definitive recommendations. Nonetheless, these initial analyses suggest some tentative conclusions and directions for future work.

Preparations

The cost of the provisions on DHS’s list (Table 1) would be trivial for many individuals, prohibitive for others. Those who cannot afford it need help if they are to comply (Bellagio Group 2006). Even those who can afford it may not comply if they see too little chance of recouping their investment, perhaps because they see probabilities like those in Table 2, perhaps because they expect to be trapped longer than three days (Fig. 2). If so, then authorities who count on citizen preparedness should reanalyze that expectation and see if they can make things better, with good communication and material support, for those who cannot act on their own.

Immediate response

After an attack, authorities will have limited ability to collect, analyze, and disseminate information. They may only be able to identify the blast location, then communicate simple advice for people in broad areas (Table 3). Investments in finer characterizations (e.g., plume models) may have little practical value, especially compared with investments in helping individuals to grasp and apply these simple rules (e.g., understanding the risks of traveling in fallout to be with loved ones).

Ultimate evacuation

Plausible ranges of shielding effectiveness and egress time lead to a wide range of optimal periods for staying in a shelter, in terms of minimizing radiation exposure. Other considerations (Fig. 1) might justify incurring the extra radiation exposure from evacuating earlier. Those pressures might be reduced by well-guided shelter preparations and plans for meeting the needs that impel people to travel (e.g., assured care for loved ones).

Such life-and-death decisions deserve formal analyses, both to provide citizens with sound advice and to provide authorities with realistic expectations for citizens’ behavior (Dombroski et al. 2006; Fischhoff et al. 2006). Those analyses must reflect all the goals that individuals value—and not just those central to experts (e.g., radiation protection professionals, economists). Empirically evaluated messages are needed to ensure that individuals have the best possible chance of understanding what they are up against, so that they may make sound choices.

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SPECIAL FOCUS

Social, Psychological, and Behavioral Responses to a Nuclear Detonation in a US City: Implications for Health Care Planning and Delivery

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ABSTRACT

A nuclear detonation in a US city would have profound psychological, social, and behavioral effects. This article reviews the scientific literature on human responses to radiation incidents and disasters in general, and examines potential behavioral health care provider (BHCP) contributions in the hours and days after a nuclear detonation. In the area directly affected by the blast, the immediate overarching goal of BHCP interventions is the support of lifesaving activities and the prevention of additional casualties from fallout. These interventions include 6 broad categories: promoting appropriate protective actions, discouraging dangerous behaviors, managing patient/survivor flow to facilitate the best use of scarce resources, supporting first responders, assisting with triage, and delivering palliative care when appropriate. At more distant sites, BHCP should work with medical providers to support hospitalized survivors of the detonation. Recommendations are also made on BHCP interventions later in the response phase and during recovery.

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Key Words: nuclear terrorism, emergency medical response, mass casualty, disaster mental health, behavioral health, posttraumatic stress disorder, nuclear detonation

The detonation of a 10-kiloton (kT) nuclear device in a US city would produce the “light of a thousand suns” and an explosion equivalent to 5000 Oklahoma City truck bombs.1,2 There would be immediate and severe health consequences, and physical damage to the community would be extreme.3 Thousands, perhaps tens of thousands, of people would be killed, and many others would be injured or become ill. In short, a nuclear detonation in a US city would be a watershed event that would pose unprecedented challenges for health care planning and delivery.1

This article examines the social, psychological, and behavioral effects of a nuclear detonation incident. These effects would likely be widespread and profound, with ripple effects touching even those distant from ground zero. Furthermore, key social, psychological, and behavioral issues could affect how the incident unfolds and would affect the extent of its consequences. For example, whether the population in the path of the bomb’s fallout undertakes recommended protective actions and how responders react to the situation could be critical in determining the overall level of morbidity and mortality. Thus, social, psychological, and behavioral issues need to be an integral part of planning, preparedness, and response for a nuclear detonation incident.

This article considers the detonation’s implications for those local systems and the health care receivers and responders caring for the injured and ill during the first 3 to 4 days after a nuclear detonation. Among the key issues considered are the mental health effects experienced by the public (including vulnerable populations), potential effects on emergency responders and other caregivers, and broader effects on communities and society. Because people’s responses and actions can affect health outcomes, issues of public information, communication, and population behavior are also considered. Finally, the article includes a series of general principles and recommended actions, interventions, and other measures to prevent, reduce, and address a nuclear detonation’s social, psychological, and behavioral consequences.

Although the content of this article may be read as a standalone document, it is intended to complement the entire suite of articles in this supplement dealing with the health care implications of a nuclear detonation.3-10 The aim is to help build an integrated approach to preparedness and response for a nuclear detonation.

The threat of radiological/nuclear terrorism has grown significantly recently. One major focus of concern has been on radiological dispersal devices (RDDs), which many experts perceive to be the most likely form of terrorism involving radioactive materials. RDDs, which combine radioactive materials with conventional explosives or other means of dissemination, spread radioactive contamina-
tion but do not involve a nuclear explosion. A “dirty bomb” is an example of an RDD.

Increasingly, however, experts are focusing on a threat that is seen as less likely than a dirty bomb, but orders of magnitude more devastating: the terrorist use of an improvised nuclear device. This crude nuclear weapon produces a yield usually defined as being between 0.01 and 10 k-T. (A kiloton is the amount of energy that is released by an explosion of 1000 tons of dynamite.) Although this type of detonation is considered low in yield when compared with modern military nuclear weapons, the detonation of a 10-kT nuclear device would still have catastrophic consequences in nearby areas, as described in Knebel and colleagues elsewhere in this supplement. Such a device would be only slightly smaller than the 12.5-kT bomb that destroyed Hiroshima in 1945.

The US health care system has been fortunate in that it has never had to manage a mass casualty terrorist incident involving radioactive materials. What this means, however, is that many questions and uncertainties remain regarding how such an incident may unfold, how people may react, how emergency responders would be affected, what the magnitude of mental health effects would be, and what the broader psychosocial implications and consequences may be for society as a whole.

These questions cannot be answered in advance with certainty, particularly when considering as large and calamitous an incident as the explosion of a terrorist nuclear weapon in a US city. Not surprisingly, then, there is discussion and sometimes debate in the academic and practice communities about the ways the public and emergency personnel may be affected and how people would respond. Definitive answers and iron-clad predictions are not possible because of a paucity of direct scientific evidence and experience.

Nevertheless, there is considerable information that can speak to the likely psychosocial effects of a nuclear detonation and inform preparedness and response strategies. Potentially relevant material can be gleaned from real-world experience with large-scale disasters, incidents involving the accidental or intentional release of radioactive materials, the atomic bombings of Hiroshima and Nagasaki, large-scale explosions in urban areas, conventional and unconventional terrorist events, and the extensive body of social, behavioral, and public health research on disasters and emergencies.

What is clear is that nuclear detonation would have immense social, psychological, and behavioral consequences and that authorities need to be ready to do the following:

- Undertake a coordinated series of measures to prevent, reduce, and address those effects
- Help the population take appropriate protective actions
- Provide support to emergency responders and health care providers

Key steps toward these ends are discussed in below. The following section examines what is known from research on and experience with the consequences of a nuclear detonation.

**REACTIONS TO A NUCLEAR DETONATION**

**Radiation Is a Particularly Dreaded Hazard, and the Fear Associated With It Is Powerful**

There are important differences between a nuclear detonation and other kinds of disasters, even most terrorist attacks. The detonation of a nuclear device involves radiation, radioactive contamination, and deadly fallout. A large body of risk perception research has demonstrated that people view radiation as among the most dreaded of all hazards. Reports of the massive destruction of infrastructure and horrific burns, injuries, and long-term illnesses caused by atomic bombs and the specter of nuclear annihilation by thermonuclear missiles during the Cold War have contributed to perceptions of the risks posed by radiation. Radiation is not detectable using our senses. Thus, people are unable to distinguish safe areas from contaminated ones and must rely on special instruments and experts to determine whether danger is present. The increased risk of developing cancer decades after exposure is a source of concern for a period of years, as are the special risks that exposure or contamination may represent to children. Finally, worry that one’s genetic material may have been altered in a way that can harm future generations further compounds the sense of dread.

The powerful fear that radiation incidents generate has been highlighted during several real-world events. It is complicated to assess the degree to which fear of radiation alone has driven behavior because poor risk communication is often an accompanying factor. During the 1979 Three Mile Island nuclear accident, for example, a combination of fear and inadequate, ambiguous, and conflicting information resulted in a large “evacuation shadow.” For every person who had been advised to evacuate, many times that number actually did. Ultimately, about 144,000 people fled. Such data emphasize the critical need to disseminate timely, clear, accurate, and credible information regarding protective actions.

Fear during radiation incidents also has the potential to overwhelm health care or related facilities. The quintessential example is the 1987 radioactive contamination incident in Goiania, Brazil, in which a disused radiotherapy source was found by scavengers and broken open. Sadly, 4 people ultimately died from the incident. As fear associated with the incident rippled outward, more than 112,000 people sought screening for exposure or contamination. Some people even manifested stress-induced physical symptoms that were similar to those from actual exposure to high levels of radiation. These data emphasize the need to communicate effectively with the public and have in place triage and medical surge practices that can address the physical and psychological effects of fear and anxiety, includ-
Responses to Nuclear Detonation in a US City

Although the Bombings of Hiroshima and Nagasaki Were Nuclear Incidents, They Are of Limited Usefulness in Gauging What the Public Reaction Would Be to a Modern Nuclear Detonation

The only actual experience with individual and group behavior after nuclear explosions comes from the World War II bombings of Hiroshima and Nagasaki in 1945; however, there are severe limitations in applying the lessons learned from those events to contemporary times. Although there was recognition early on that the devastation in Hiroshima was caused by a new type of weapon, it was not immediately recognized that the incident involved radiation. Therefore, people’s responses in the early days were not affected by perceptions of the danger of radiation per se, although many people feared some sort of residual hazard. Similarly, the clinical presentations associated with acute radiation syndrome were puzzling and were initially attributed by some to be a consequence of poisoning or secondary infectious diseases.

How might things unfold if there were a nuclear detonation in a US city today? How long would it take people to comprehend what had happened? There would be a blinding flash of light followed by a huge explosion. Intense heat, pressure waves, and wind would herald the detonation. However, a 10-KT nuclear groundburst may not be recognized initially as being nuclear in origin, especially by those closest to the epicenter. Moreover, the characteristic mushroom-shaped cloud may not form due to urban canyon effects. Not long after, however, people would likely begin to speculate that a nuclear blast had occurred, and formal and informal news media around the world would begin around-the-clock coverage. As in past events such as the September 11, 2001, terror attacks, some information initially reported would be speculative or wrong, and that could contribute to public confusion. It is unclear precisely when survivors in areas near the detonation point would learn of the radiation hazard, but it would likely be within the early aftermath of the detonation. While the electromagnetic pulse effect would probably not extend far, there is concern that the nearby electrical grid and nearby communication equipment may be affected. Similarly, it is unclear how quickly emergency management personnel could begin disseminating guidance to people in specific areas to shelter in place or evacuate to minimize exposure to dangerous fallout. Nevertheless, it would certainly not take long for neighboring communities to learn that a nuclear device had been detonated in their region. Information about how people can best protect themselves from fallout would need to be disseminated as quickly as possible.

The world has changed dramatically since 1945. Information about radiation, including some that is inaccurate and some that can best be described as myth, is widespread. An act of terror using a nuclear device would now have manifold levels of meaning and associated fear that would significantly affect the way people and systems respond. Instant national and international communications, Web-based social media, knowledge of previous radiation incidents, and the anticipation that terrorists could detonate additional nuclear devices in other locations are just a few of the variables involved in this new calculus of behavioral response.

Possible Wide Variation in Immediate Behavioral Responses of People In and Around the Impact Zone

Research on disasters in general concludes that people typically rise to the occasion, providing initial lifesaving activities, rescuing survivors, and providing general assistance. Following earthquakes, for example, the first responders who attempt to find and rescue survivors are people who happen to be at the scene of building collapses.

Analyses of terrorist bombings reinforce the view that people react in helpful ways. People’s behavior during the September 11 terrorist attacks demonstrated that even under extreme conditions, people act in a prosocial and adaptive manner. Within the World Trade Center buildings themselves, panic was rare, and people helped one another, even at personal risk. The evacuation was orderly: an estimated 13,000 to 15,000 safely exited the towers before they collapsed. Similarly, examinations of people’s responses to the July 7, 2005, bombing attacks on the London Underground transport system indicate that selfish behaviors were rare and mutual helping was common. Factors that have been shown to correlate with prosocial behaviors include perception of a common fate, social norms, unambiguous need, and knowledge of an appropriate response or action.

At the same time, research also indicates that some survivors can exhibit antisocial behavior or panic, some but not all of which can be directly related to seeking lifesaving protection and resources. For disaster scientists, panic implies much more than terror: It connotes an irrational, unnecessary, or hysteric.
terical flight during which one operates on an “every-man-for-himself” basis. Panic in this sense is uncommon after a disaster. In general, several conditions must exist together to trigger panic:

- There appears to be a narrow window of opportunity to escape
- There is a threat of being trapped
- Flight seems to be the only way to survive
- Help is unavailable

In addition, although we can expect some variable but probably small cohort of “pure” panic, most manifestations of the panic process will occur somewhere less extreme on a prosocial to antisocial continuum and will still affect social responses. Even so, or perhaps especially so, identifying and addressing the critical variables involved with this process and promoting resilient, prosocial responses will be important.

There is debate about the extent to which these conditions may exist in some areas after a nuclear detonation and the degree to which there may be panic or antisocial behavior. Clearly, high levels of fear/terror will be experienced, not only in the stricken area but also throughout the nation and probably the world due to the fear of additional attacks.

Undoubtedly, better and more effective communication and information can reduce the likelihood of panic, foster helping behaviors, and encourage people to take the appropriate protective actions. This makes the development of effective communication strategies and emergency messages 1 of the most crucial components in nuclear detonation preparedness and response efforts. An interagency group of communications and technical experts has recently released messages that can be used in the immediate aftermath of a nuclear detonation. It is for interim use while it undergoes public message testing and review by key stakeholders.

Emergency Responders Typically Are Heroic in Their Efforts to Save Lives, But Require Training and Ongoing Support

As noted by Hick and coauthors,7 the discussion regarding role abandonment by first responders and other critical personnel has been considerable. After the bombings of Hiroshima and Nagasaki, responders who were still alive did their utmost to help those in need. Memoirs and interviews of health care providers reveal heroic efforts to assist patients experiencing trauma, burns, and undiagnosed radiation sickness in a context of widespread devastation and extremely limited supplies.34-36

Research by Becker and others involving numerous types of emergency responders shows a powerful sense of duty and a deep commitment to helping others. This ethos of service undoubtedly comes into play in the context of a nuclear detonation. At the same time, the research also shows that emergency responders of all types have deep concerns about incidents involving radiation. First, there is a sense that situations involving radiation are new and different from other threats and that they represent special risks. Second, responders also often indicate a lower level of familiarity and comfort with responding to a radiological incident than to other kinds of threats. Third, responders have serious concerns about individual and organizational readiness for responding to a radiological/nuclear terrorism event.35,37,38 In addition, survey results suggest that there is a significantly lower level of responder willingness to be involved in dealing with radiological/nuclear incidents than with most, or sometimes even all, other types of threat.39-42 Therefore, at least in terms of what they express in surveys, focus groups, and other research settings, emergency responders are deeply concerned about radiation incidents and are substantially less likely to want to respond than they are for other types of emergencies.

This must be balanced, however, with the findings on the strong commitment to duty and the fact that people’s behavioral intentions are often not good predictors of actual behavior. As much as researchers try to approximate actual conditions, it is virtually impossible to create the context in which the usual rules of social order are quickly shifted to ones that support adaptive functioning in a much-altered environment. This is particularly the case for something as horrific as a nuclear detonation.

Again, no ironclad predictions are possible. Nevertheless, based on experiences with a range of situations, it is likely that responders in large numbers will do their best to do what they have always done: behave heroically and save lives. This response will be facilitated if responders have the radiological/nuclear training and the support and information they need. If, however, responders are forced to face a nuclear detonation without appropriate training and with poor, unclear, or inadequate information, their stress will increase dramatically, it will be markedly harder for them to carry out their missions, and this could have severe negative effects on the effectiveness of the overall response.

Factors that contribute to enhanced professional commitment include repeated training, prebriefing, having a clear plan of action, and familiarity with professional roles and responsibilities. When people recognize the duties they will perform in a disaster context, they are more likely to report to work and function well. The Planning Guidance for Response to a Nuclear Detonation43 was developed to provide practical information to inform emergency responders of roles and responsibilities for all levels of government and to guide local planning efforts. The articles in this supplement10,44 add to this information and in-
Responses to Nuclear Detonation in a US City

include guidance and tools to help in preparedness and planning. Developing plans that address responders’ family-related concerns also is important. For example, responders who have access to information about family, have confidence that schools will take appropriate care of children, have a plan in place for how to reunify, and minimize contamination risks to families (eg, a change of clothes) are likely to be able to function more effectively. Pre-event planning should also address first responders’ and health care providers’ families needs. Family members of emergency responders will require honest and up to date information on dangers, personal protective equipment and other safety measures, the mission assignment for their loved one(s), and any support services that they can access for updates (eg, a dedicated call center).

Another factor in how emergency responders will react is the availability of response resources. Historical experience has shown that when professionals are vastly overwhelmed and severely underresourced, they can become dysfunctional. After the bombing of Hiroshima, 10 physicians began treating injured people in a school gymnasium. They functioned well and improvised successfully in treating up to the first 1000 patients. As they began facing hundreds and hundreds of patients, however, they essentially gave up and left the gymnasium (D. Mileti, personal communication, 2009). This finding underscores the importance of moving patients as quickly as possible to locations that have sufficient resources and the need to prioritize and sequence treatment. Planning, training, and having resource information available is critical for psychologically preparing health care workers to deal with prolonged catastrophic events.

Spontaneous volunteers and citizen preparedness efforts that are supported by federal, state, local (eg, Citizen Corps, Medical Reserve Corps), nongovernmental, and other organizations such as the American Red Cross, will need to be factored into the plans for critical helpers and responders to a nuclear detonation. The preparedness planning and actions of citizen responders is 1 factor that will enhance lifesaving efforts, be protective factors for individuals, and enhance community resilience. Because people take cues from those around them, engaged citizens working toward common goals will promote effective action and reduce a shift toward panic or aggression. In fact, research on spontaneous volunteerism after September 11, 2001, in New York City confirmed that helping yielded long-term positive benefits for the volunteers’ personal healing and community engagement after a disaster.45

Barring active interventions and a coordinated communication strategy, people bringing ill and injured individuals for treatment, people looking for loved ones, and people seeking a safe haven will converge on nearby hospitals. A major task, then, must be to help direct those without immediately life-threatening injuries elsewhere to conserve and better target resources. The functionally organized radiation triage, treatment, and transport (commonly known as RTR) system has factored in these expected behaviors in its designation of medical care sites and assembly centers.8

STRATEGY FOR PREVENTING, REDUCING, AND ADDRESSING NEGATIVE SOCIAL, PSYCHOLOGICAL AND BEHAVIORS IN THE AFTERMATH OF A RADIOLOGICAL INCIDENT

Behavioral Health Care Interventions

Broadly stated, the goal of early behavioral health intervention is to identify and remove impediments to the natural psychological recovery process. These interventions must take into account the differential needs of the entire community, including children, older adults, people with disabilities, and other groups with special needs. At present, scientific evidence is insufficient to determine which interventions are effective in preventing or mitigating adverse psychological outcomes. Absent this information, guidance on early behavioral interventions is based primarily on expert consensus.

Behavioral interventions are, in general, stepwise. Initially, interventions tend to be population based and address ordinary people responding to extraordinary events. Over the course of a few weeks, the behavioral health focus shifts to more individual or small-group interventions targeting psychiatric disorders and monitoring people at high risk for developing psychiatric morbidity, such as those injured by the incident. It is critical that cultural considerations be integrated into all behavioral interventions, because cultural beliefs and values will be central organizing principles for survivors.46

Behavioral principles and practice for intervening in the immediate aftermath of traumatic events may be useful for health care providers. For example, psychological first aid (PFA) was developed to be the psychological analogue of medical first aid. There are versions of PFA designed for the public in addition to those developed for behavioral health care providers (BHCP). PFA offers a quick review of common responses to trauma and practical tips on how to support survivors, which health care providers may find useful to incorporate into their practices.

To maximize effectiveness, standard disaster interventions such as PFA should be modified or augmented to address the unique and potent stressors of a specific incident. A primary focus of such a modification for a radiological/nuclear incident should be on guidance to help reduce the intense fear and apprehension associated with radiation.

Five empirically based principles of behavioral intervention may also be helpful for responders interacting with survivors in the minutes and hours after the detonation.47 Actions by helpers should promote a sense of safety, calm, a sense of individual and group efficacy, connectedness with others, and hope. Health care providers may wish to explore ways in which emergency response plans can build upon and reinforce these principles.
**Acute Response (First 48 Hours)**

The overarching goals of BH interventions in the first 48 hours are to support lifesaving activities for those with immediate injuries and to prevent additional casualties from fallout. To the extent that channels remain functional, communication will provide guidance on protective actions to those in the affected areas. In this initial phase of confusion and limited resources, BHCPs can do the following:

- Provide input on effective communication strategies and approaches
- Promote appropriate protective behaviors (eg, adhering to guidance to shelter) and address psychological barriers to taking protective measures (eg, paralyzing anxiety)
- Discourage dangerous behaviors (eg, entering high radiation areas to search for loved ones)
- Help manage patient/survivor flow in support of crisis standards of care
- Assist with psychological management of patients in all medical care settings
- Support first responders’ and first receivers’ ability to function
- Assist with medical triage
- Aid in caring for patients who are pregnant
- Practice “buddy care,” use “buddy teams”
- Use only the staff, stuff, and space that is absolutely necessary

Communication will be important to diminish surge on hospitals and medical care sites. In the aftermath of a disaster, people converge on hospitals for a number of reasons, such as to look for missing loved ones, to receive treatment for minor injuries, and to seek a safe haven. A major task will be to encourage people without immediately life-threatening injuries to radiation triage, treatment, and transport assembly sites and predetermined assembly centers to more effectively assist people and conserve and better target scarce medical resources. Messaging should inform people who are evacuating about where the assembly sites and centers are located and that information about injured patients will be provided at designated nonhospital settings in outlying areas. (Ideally, emergency plans will have a system for handling missing persons inquiries and prescribed messages explaining how to access it.) Fairness in the allocation of scarce resources is a strong value held by the public. It will be essential to keep people informed about the process for evaluating radiation exposure and to be transparent about why certain groups may be prioritized higher than others. BHCP may be useful in providing information and directing people to established assembly and evacuation sites. They can also help provide assistance to severely distressed or anxious individuals.

As conditions permit, BHCP, especially those with consultation/liaison or emergency department experience, can assist in triage to distinguish symptoms of physical injury from strictly stress-induced reactions and provide appropriate assistance. BHCPs can also help care for patients who are pregnant (those likely to succumb despite every available medical intervention) and support other staff with this responsibility. Health care providers unaccustomed to working with dying people may experience feelings of helplessness and hopelessness associated with not being able to prevent death. Focusing on actions that relieve suffering when unable to save lives may diminish feelings of helplessness. Ideally, this focus would include administering medications to provide symptom relief and give fluids. Even in the worst case, no available resources, patients (and their families) will likely receive some comfort knowing that they did not die alone. Similarly, health care providers may later find meaning and enhanced self-worth knowing that they stayed and did their best rather than abandon patients.

As more information becomes available about the nature of the attack, radiation concerns will become more prominent for both medical personnel and the public. Ideally, BHCPs will have participated in planning for reception centers and the screening process for radiation. Reminding planners that any protocols that rely on separating children from parents will be unsuccessful is an example of the kinds of behavioral advice that can make systems run more smoothly and better meet the needs of survivors.

As soon as resources become available, the initial responders and care providers should be sent off-duty and be provided with rest, food, and safe shelter. It is important to watch for staff resistance to leaving work (overdedication), especially among leaders. Guidance published by the US Department of Health and Human Services incorporates psychological factors into occupational safety for disasters.

Consultation to medical leadership likely will be the most effective way to provide immediate assistance to health care providers. There may be limited opportunities for BHCP to support staff in making the difficult transition from customary practice to crisis standards of care. Preventing unnecessary exposure to dead and dying people diminishes traumatic stressors. Studies have suggested that pairing experienced staff with those in training or new to the field may be useful in minimizing stress in the latter group.

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**Early Response (48 Hours to 1 Month)**

It will be important from this point on to coordinate or integrate medical and behavioral health care. Aside from injuries sustained during the disaster, psychological problems (not disorders) and physical symptoms (not disease) are often seen in survivors. Increasingly, there is recognition that traumatic events are associated with increased physical complaints such as fatigue, musculoskeletal pain, stomachache, and headache. Indeed, physical symptoms may last longer than distress and psychiatric disorders. Primary care providers must be alert not only
to acute stress disorder/posttraumatic stress disorder but also to complicated bereavement, unexplained physical symptoms, sleep disturbance, family conflict and violence, and increased use of tobacco and alcohol. The link between traumatic exposure and these presentations can be overlooked both by the patient and the primary care provider. All providers should also be vigilant for comorbid psychiatric conditions such as major depression and posttraumatic stress disorder.\textsuperscript{53,54}

There is little scientific understanding of how physical and mental illnesses influence one another. What is clear is that medical management of patients postdisaster can be improved by better understanding and recognition of the interplay between mind and body. This is especially true in cases in which there is ambiguity about whether one has been exposed to an invisible agent like radiation or when there is uncertainty about the risk of eventually developing health effects.

Just-in-time training or refresher courses to educate health care professionals at receiving facilities about how to safely care for patients with internal and/or external radioactive contamination will be important. The rapid identification of those who have received significant radiation exposure and who could benefit from medical intervention will be a high medical and behavioral priority. Depending on the characteristics of the nuclear detonation and the success of protective actions, the numbers of people affected could vary tremendously—from thousands to hundreds of thousands. Rapid screening will be enormously important from a psychological and a medical standpoint.

Rapid screening, enrollment in registries, and the provision of appropriate treatments foster trust and confidence in survivors. Understandably, people will want to learn as much as possible about their health status, including potential long-term implications of exposure. Uncertainty and waiting are discomfiting aspects of the human condition; in general, the more quickly people learn about their exposure status, the better they will fare psychologically, even if the news is bad. Because concentration and the ability to retain information decrease under high stress, those screened should be given a record of their results, however primitive the record. Ideally, these results would also be entered into a registry.

BHCPs can support the screening process by assisting in keeping people informed and listening to people’s concerns:

- Assist in keeping the public informed so that they can accurately assess their situation and choose the best course of action
- Listen to people’s concerns and provide feedback to improve the screening process
- Provide support to those who need help in coping
- Provide services and assistance for those with preexisting psychiatric and substance abuse disorders
- Assist with family reunification
- Follow up with individuals at higher risk for psychiatric morbidity

- Assist leadership in quickly setting up routines and organizational supports for the diverse populations and various needs of those directly affected by the event
- Assist in staff assembly, dispensing, screening, triage, and alternate care sites

Feedback from those waiting may be helpful in modifying screening procedures if problems are identified. Having a plan to address the basic needs of those waiting (eg, challenge of standing for long periods, need to save people’s places in line while they use restrooms, provision of water/food) may help queuing go more smoothly.

For those patients who learn that they have acute radiation syndrome, psychological support may help them and their families cope better with treatment. BHCPs familiar with working with patients with cancer and other life-threatening conditions may be especially useful in planning for these patients’ and their families’ needs. Past radiation incidents suggest that active outreach be made to women who become pregnant and those with small children because they have high levels of concern about the potential adverse health effects of radiation on children and developing embryos/fetuses.\textsuperscript{31,54-56}

As in all settings of rapid evacuation, clinicians should be alert for signs and symptoms of substance withdrawal and intervene accordingly. Similarly, efforts should be made to provide missing medications, including psychotropic medications, to evacuees who have left them behind so as to prevent relapse or flare-ups of underlying illness.

Populations at high risk for psychiatric morbidity, particularly ill and injured people, should be monitored closely. Burn patients and those blinded and deafened by the detonation should be evaluated and supported as appropriate. Consultation/liaison psychiatry models for the management of hospitalized patients can inform an integrated care plan for this traumatized group.\textsuperscript{57-59}

Sleep disturbance is common and may be treated by the judicious use of medication once safe lodging is ensured. Outreach and consultation to primary care colleagues can help them recognize and, when possible, treat psychiatric disorders.

There will be a universal wish for information about the incident, loved ones, and ongoing danger(s). The threat of further incidents and hostilities cannot be ruled out and also must be planned for. Realistic information on the status of safety and security must be provided. At the same time, constant media exposure to dramatic and horrific events can traumatize viewers who are “glued to the TV.” Media messaging that provides necessary information and resources rather than sensationalism should be encouraged as much as possible. As quickly as possible, communication should inform people about the process for reunification. As more information is learned about the nuclear detonation, the areas in which people most likely were killed will be delineated, serving essentially as death notices. Traumatic bereavement and grief should be anticipated and plans
made for addressing them. Concurrent with acute interventions, attention must turn to longer-term mental health needs and the recovery process.

Recovery Phase (1 Month Through Years)
Psychiatric disorders associated with terrorist attacks can be expected to develop over time.

The usual trajectory of psychological response is one of resilience in which initial distress responses resolve in days to several weeks from discrete traumatic events. Often, however, stresses persist after the incident has passed. This would certainly be the case for a nuclear detonation in which additional major stressors such as resettlement, contamination, and the delayed onset of illness and death would continue to affect mental and physical health for decades.

The greatest amount of work for BHCPs will occur during the recovery period, when they can play a major role in a number of activities. The recovery environment is an important determinant of people’s psychological outcome, either enhancing resilience or contributing additional stressors. The recovery environment can be designed to bolster resilience. Scientific literature and consultation from disaster social scientists and disaster behavioral health experts can inform recovery activities and programs such as temporary housing and relocation. Lessons gleaned from the Chernobyl accident illustrate the potential medium- and long-term psychosocial consequences. For example, the comprehensive review of lessons learned from Chernobyl found that “any traumatic accident or event can cause the incidence of stress symptoms, depression, anxiety (including posttraumatic stress symptoms), and medically unexplained physical symptoms.” This review also found that “exposed populations had anxiety levels that were twice as high as controls, and they were 3-4 times more likely to report multiple unexplained physical symptoms and subjective poor health than were unaffected control groups.” Finally, the review found that people came to be known as “Chernobyl victims,” and this label “had the effect of encouraging individuals to think of themselves fatalistically as invalids . . . Thus, rather than perceiving themselves as “survivors,” many of those people have come to think of themselves as helpless, weak and lacking control over their future.”

In contrast to prevention and mitigation activities, there are evidence-based interventions to guide treatment of these psychiatric conditions, the risk factors of which are as follows:

- Severity of traumatic exposure (most robust predictor)
- Number of stressors
- Death of loved one
- Injury to self or family member
- Panic during the disaster
- Threat to life
- Financial loss
- Relocation
- Property damage
- Female gender
- Lower socioeconomic status
- Avoidance as coping mechanism
- Assignment of blame
- Parenthood
- Parental distress (predicts child’s distress)
- Ethnic minority
- Predisaster psychological symptoms

Relocation, itself, is associated with a greater risk of psychiatric morbidity. The following summarizes the types of psychiatric disorders associated with disasters:

- Posttraumatic stress disorder
- Depression
- Anxiety
- Dissociative responses
- Acute stress disorder
- Demoralization
- High perceived stress
- Negative affect
- Physical health problems
- Increase in use of alcohol or drugs
- Somatic concerns
- Poor sleep quality
- Physiological arousal

Collaboration between primary care providers and the mental health community optimizes patient care in both the short and long term. Most people with psychiatric disorders will present to primary care providers rather than mental health care providers. For those exposed to lower doses of radiation or for whom the level of exposure is unknown, concerns about developing cancer will likely be present. Strategies for managing this uncertainty and addressing other concerns can be facilitated by strong collaboration among health care providers and a good working relationship between health care provider and patient.

The recovery and identification of human remains will be an emotionally charged process, especially given that many bodies will perish with no trace, similar to what happened in the collapse of the World Trade Center. Rituals and memorials can play an important role in assisting families and communities mourn their losses and rebuild their lives.

A great deal of art and science is involved in developing processes that are healing rather than fracturing. Lessons learned should be incorporated into planning to minimize undue secondary traumatization. Health care providers should be proactive in exploring signs and symptoms of depression and complicated bereavement in patients who have lost loved ones.

CONCLUSIONS
The social, psychological, and behavioral effects of a nuclear detonation would likely be widespread and profound and would affect how the incident unfolds and the severity of its conse-
Responses to Nuclear Detonation in a US City

quences. Among the key issues are the mental health effects on the public, potential effects on emergency responders and other caregivers, and broader effects on communities and society. Although the knowledge base on the immediate social, psychological, and behavioral effects of a nuclear detonation is limited, the present article has used the best available information to outline how people are likely to react and how BHCPs can assist in the response.

Given the existing knowledge, there are some reasonable assumptions that can be made about people’s reactions. First, although many people will likely be to engage in the kinds of altruistic behaviors that occur in most disasters, fear of radiation and contamination or lack of needed information has the potential to produce other kinds of behaviors and responses including some that could complicate response and recovery efforts. Effective communication will be key to fostering prosocial responses and encouraging the taking of appropriate protective actions. Second, emergency responders in large numbers will likely do their best to carry out their missions provided they have the training, information, and support they require. To the degree that these are lacking, stresses will increase, responder confidence will diminish, and risks for ineffective responses will increase.

After exposure to traumatic events (such as the September 11 attacks), people commonly experience a range of distress responses. A nuclear detonation’s psychological impact may be based both on the devastation of the incident and on potentially ongoing traumatizing processes the detonation creates. In fact, it may be better to understand a nuclear detonation less as a discrete incident and more as an ongoing potentially traumatizing process lasting weeks, perhaps years. Thus, interventions would be required for a longer time.

Research on the effect of traumatic events suggests that when the aftermath of the incident is focused on coping, effective help, and healing, the outcomes for survivors are much better. Broadly stated, the goal of early behavioral health intervention is to identify and remove impediments to the natural trajectory of psychological resilience. Initial interventions tend to be population-based and address ordinary people responding to extraordinary events. Actions by helpers should promote a sense of safety, calm, a sense of individual and group efficacy, connectedness with others, and hope.

A few weeks after a detonation, the behavioral health focus shifts to individual or small-group interventions targeting psychiatric disorders and monitoring people at high risk for developing psychiatric morbidity. Early initiation of cognitive-behavioral therapy (at about 3 weeks postevent) with individual survivors of motor vehicle crashes and nonsexual assaults diagnosed with acute stress disorder has been shown to reduce psychological resilience and address ordinary people responding to extraordinary events. Actions by helpers should promote a sense of safety, calm, a sense of individual and group efficacy, connectedness with others, and hope.

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REFERENCES

The Impact of Communication Materials on Public Responses to a Radiological Dispersal Device (RDD) Attack

M. Brooke Rogers, Richard Amlôt, and G. James Rubin

It is a common assumption that, in the event of a chemical, biological, radiological, or nuclear (CBRN) attack, a well-prepared and informed public is more likely to follow official recommendations regarding the appropriate safety measures to take. We present findings from a UK study investigating the ability of crisis communication to influence perceptions of risk and behavioral intentions in the general public in response to CBRN terrorism. We conducted a focus group study involving a scenario presented in mock news broadcasts to explore levels of public knowledge, information needs, and intended behavioral reactions to an attack involving an overt radiological dispersal device (RDD), or dirty bomb. We used the findings from these focus groups to design messages for the public that could be presented in a short leaflet. We then tested the effects of the leaflet on reactions to the same scenario in 8 further focus groups. The impact of the new messages on levels of knowledge, information needs, and intended compliance with official recommendations was assessed. The provision of information increased the perceived credibility of official messages and increased reported levels of intended compliance with advice to return to normal/stop sheltering, attend a facility for assessment and treatment, and return to a previously contaminated area after decontamination of the environment has taken place. Should a real attack with an RDD occur, having pretested messages available to address common concerns and information needs should facilitate the public health response to the attack.
PUBLIC RESPONSES TO A DIRTY BOMB

Such messages should take account of research into how people respond to emergencies. This literature has challenged the concept of a panic-prone public. Instead, goal-directed, rational behaviors in the face of difficult and potentially life-threatening circumstances are more common and have been termed “normative responses” to terrorism. Normative responses can entail the seeking of information, attempts to contact family members and loved ones, undertaking protective steps for self and family, and locating food, water, and shelter during a terrorist incident. This does not mean that individuals avoid changing their behavior, but rather that they find ways to cope with and adapt to the situation without incurring lasting psychological health effects.

This article presents the results of a 2-phase focus group study designed to gain a better understanding of normative responses to radiological terrorism and to assess the impact of terrorism-related messaging on levels of knowledge, understanding, and intended compliance with official advice on the part of the UK public. During this study, members of the public took part in focus groups relating to a hypothetical attack involving a radiological dispersal device (RDD), or dirty bomb. Radiological incidents are of particular interest because they typically score so high on psychometric risk measures of fear and dread, and thus, even without the context of terrorism, it is often assumed that there is the potential for mass flight or overwhelming demands on health services.

We assessed participants’ knowledge about CBRN terrorism, explored what information participants believed should be included in government messages related to CBRN terrorism, identified intended behaviors in response to such an event, and identified the desired sources of official advice. We then developed and tested the impact of communication messages for an incident involving an RDD.

METHODS

Design

Two phases of focus groups were conducted 14 months apart. Phase 1 used 3 2-hour (N=22) focus group sessions during the summer of 2007 to explore the internal logic of public perceptions of risk and behaviors in response to a hypothetical RDD attack. Information gained from the Phase 1 focus groups was then used to develop a leaflet intervention designed to address participants’ information needs. The leaflet intervention was pilot-tested during a read-aloud study (N=5) before being introduced during the Phase 2 focus groups in order to explore its impact on levels of knowledge, understanding, and intended compliance with official recommendations.

The Phase 2 groups were conducted during September and October 2008 and included 8 3-hour sessions (N=64). Phase 2 participants were shown the same hypothetical RDD terrorist attack used in Phase 1. Two Phase 2 groups were designated as baseline groups in order to provide an indication of any general changes in participant responses that could be attributed to the passage of time between Phases 1 and 2. The remaining 6 groups acted as leaflet intervention groups. Intervention group participants were issued the information leaflet during the scenario; Phase 2 baseline group participants were issued the information leaflet after they completed the scenario and were asked to consider how they felt the leaflet might have affected their responses had they received it earlier.

Participants

The 22 participants for the Phase 1 focus groups and 64 participants for the Phase 2 groups were recruited from outer London and the surrounding counties in the UK. Participants were recruited by a market research organization, Research Quorum (RQ). RQ uses a network of professional consumer group recruiters who draw from a comprehensive database of contacts representing a wide range of the public across all demographic categories in order to ensure that respondents fit any quota criteria. The participants were selected and assigned to each focus group in order to obtain a small but representative sample of participants. The sample included a mix of gender, age, ethnicity, and education and included some parents (Table 1).

In line with the King’s College London research ethics procedures (ethics approval code: RESC/06/07-12), the anonymity of each individual participant was maintained. Participants were provided with consent forms describing their right to withdraw from the study and, after the study, with information sheets including additional websites providing useful CBRN-related information and the contact details of the researchers if they had further questions after participating in the focus groups. Participants were provided with small cash stipends to cover the cost of transportation and other related expenses incurred by focus group attendance.

Scenario

The scenario was presented to participants in 4 stages:

Stage 1: A time prior to the incident (morning). Participants were presented with a mock newspaper article describing a series of incidents involving the discovery of radiological materials during a dawn raid by police in a location near their hometown.

Stage 2: A mock television news announcement shortly after the start of the incident (later that morning/early afternoon) included a police announcement informing respondents that an explosion had occurred, that radiation had been detected in the area, and that members of the public were being advised to shelter indoors with doors and windows closed. Additional media reporting described bodies at the
Table 1. Demographic Details of Participants for Phase 1 \((n=22)\) and Phase 2 \((n=64)\) Focus Groups

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PUBLIC RESPONSES TO A DIRTY BOMB

scene of the explosion, police in protective clothing and respirators, and a rising plume of smoke from the area.

Stage 3: A mock television news announcement in the hours/days following the incident encouraged individuals to return to normal and to attend an assessment and treatment center if they believed they had been exposed. Messages were provided by a medical doctor.

Stage 4: A mock television news announcement several weeks after the incident suggested that the government had encouraged evacuated individuals to return to live and work in their newly decontaminated area. However, the news footage also discussed ongoing bans on food and milk within a certain radius of the location of the attack and noted that several tons of topsoil had been removed. Messages were provided by an “independent scientist” who challenged the official advice to return to normal.

The data generated by the Phase 1 focus groups were used to inform the information included in a leaflet intervention designed for the second phase of this study. The Phase 2 focus groups followed the same 4 stages listed above. However, participants were also provided with the leaflet prior to the presentation of Stage 3.

Leaflet Design

The leaflets contained information intended to help members of the public make informed decisions about appropriate protective behaviors for themselves and their families. Some examples of broad issues identified for inclusion in the leaflets included background information concerning the threat (eg, “What Is Radiation?”), how exposure can occur, a description of symptoms of radiation sickness, how to tell if you have been exposed, and whether there is any treatment for exposure. Additionally, information concerning likely emergency responses and the likely actions of the authorities in the event of an RDD was included, along with sources for further information. The leaflets were designed to be generic, as if they had been prepared in advance of our scenario occurring and distributed immediately afterwards. As such, they did not discuss specific events relating to our scenario but gave broader advice about RDDs in general.

The text of the leaflets was reviewed by experts from the Health Protection Agency (HPA) and compared with information from the HPA and CDC websites in order to ensure accuracy of the scientific information. The leaflet intervention was pilot-tested with a read-aloud study (N=5) to test legibility and comprehensibility of the information before being implemented in Phase 2. The leaflet can be viewed at www.liebertpub.com.

Analysis

Using coded, anonymized versions of the transcripts, we used interpretative phenomenological analysis (IPA) to identify key themes related to participants’ understandings of a terrorist attack involving an RDD and their behavioral intentions and information needs. We conducted a subjective assessment of themes attributable to the presence of the leaflet in the Phase 2 focus groups to identify the impact of the leaflets on levels of knowledge, understanding, and intended behaviors in response to an RDD attack. In addition, we analyzed individual responses to the quantitative rating questions to identify any differences between self-rated responses across the baseline and intervention groups.

Results

The leaflet intervention increased the perceived credibility of official messages and tended to increase reported levels of intended compliance with advice to (1) return to normal and stop sheltering, (2) attend a facility for assessment and treatment, and (3) return to a previously contaminated area after decontamination had taken place.

Baseline Knowledge, Perceptions, and Intended Behaviors

The 2 Phase 2 baseline groups that did not receive the leaflet until after the scenario had been completed showed similar responses to the scenario as the Phase 1 groups. This suggested that the passage of time between Phase 1 and Phase 2 had not affected the participants’ reactions to the
scenario. Data from the 2 relevant Phase 2 groups were therefore included with the Phase 1 data for our qualitative analysis.

With respect to level of knowledge and understanding about an RDD incident, the baseline responses were characterized by low levels of knowledge and elevated levels of confusion, concern, and fear. Participants reported vague or inaccurate knowledge of the threat, with particular concerns about the long-term health effects of radiation including cancer, organ damage, and possible adverse effects to future generations, a theme that ran throughout the study. Comments included references to the explosion "going out in the wind" (GP6, R4) and the belief that exposure to an RDD would result in a systems failure in the body:

"It's like close down the system, isn't it? You know ... the organs start packing up. I don't know how it acts on the body, but it can’t feel good, can it? (GP1, R1)

An exploration of baseline information needs indicated that our participants held unexpected and occasionally highly idiosyncratic views about RDDs and the ways in which dirty bombs and radiation exert their negative effects. Participants initially focused on a need to understand the basic properties of radiation. They requested information explaining how the radiation was likely to travel or spread, whether or not drinking water would be contaminated, the length of time any contamination was likely to last, and detailed information about the short-term and, especially, long-term effects and symptoms of exposure to radiation. Respondents expressed concern that the symptoms of exposure are difficult to differentiate from common flu-like symptoms.

A strong desire existed for information that was factual and linked to practical suggestions or advice:

"I don't know what the threat is. I don't understand the chemistry behind it. I'm not sure what the logical response to it is; therefore, I need advice. Shall I go out to work, shall I stay in, shall I close the windows? (GP4, R4)

Participants also suggested that official recommendations must go beyond the simple provision of fact by offering an explanation for the underlying rationale informing public health recommendations:

"I've put down that we still do it, remove clothes, take shower, etc., but I don't see what that is going to do against the fumes of smoke given off by a radioactive explosion. You breathe in bad smoke, and what good is taking off your clothes and having a shower going to do? (GP4, R4)

This also applied to the official advice encouraging members of the public to return to normal after following advice to shelter (eg., "Why is it safe to leave the shelter a few hours after a plume has passed?") as well as the official advice encouraging members of the public in the exposure zone to attend an assessment and treatment center even if they were asymptomatic. In short, official advice had the potential to cause confusion if the underlying rationale for the health advice was not communicated.

The baseline findings for behavioral intentions confirmed the presence of a number of normative responses such as seeking information, contacting family members and loved ones, taking protective steps for self and family, and locating food, water, and shelter. A number of additional behavioral responses were also identified including: collecting children from school in spite of official warnings to shelter in place or continue with normal routines; fleeing the area even if located outside of the affected zone; unwillingness to attend an assessment or treatment center because of fear of contamination from others; and unwillingness to return home or resume normal routines after receiving information that it was safe to do so.

**Impact of the Leaflet**

Phase 2 respondents reported that the leaflet improved their knowledge and understanding of a dirty bomb and addressed their immediate, short-term concerns about radiation and the impact of an RDD incident:

"I think it helps in a certain ... where it kind of paraphrases what a dirty bomb is, because I had in my head ... I imagined huge, big mushroom clouds and, you know, the worst case thing. And, you know, it kinda just says, basically, it’ll just take out a street. So, I think if I’m not in that street, quids in, you know. (GP14 Leaflet, R6)

Other comments included:

"Very informative leaflet—lots of facts and helpful advice. This would help to prevent rumours and myths. (GP8 Leaflet written response, R6)

"I thought it was good. It was very informative. It tells you what a dirty bomb is; it tells you what you should do and it tells you why you should do it. (GP8 Leaflet written response, R3)

Overall, the provision of information lowered levels of anxiety and helped create a sense of control over the situation:

"Having read this, I’m not in control, as I said, but I feel more in control. If this happens and I've read this, I will remember these bullet-points. They're in my mind and I will think, "yes," you know. And I think that's helpful. It stops panic. (GP16 Leaflet, R4).

The leaflet intervention also addressed a number of the information needs identified during the baseline focus groups. Table 2 presents the results of the individual written responses to the questions asked immediately after each mock newspaper or DVD inject in the baseline (Phase 1) and intervention (Phase 2) focus groups.
The majority of Phase 2 participants believed that the leaflet would help them make decisions about the scenario (M=81.8) and that the leaflet would help them understand the advice from the authorities (M=83.4). Overall, participants rated the leaflet as “credible” (M=80.7), and participants reported:

> It made you do things that you probably wouldn’t have, wouldn’t have otherwise done... Having a shower, bagging up your clothes, not rubbing your eyes, and that sort of thing. (GP15 Leaflet, R7)

The information in the leaflet concerning pathways to contamination and symptoms was seen as effective. However, once the basic information needs had been addressed, Phase 2 participants generated unique, additional information needs. These included requests for additional information on water and food contamination; the ease with which radiation is spread from person to person and from pets; and the way in which the experts or authorities are checking, measuring, and monitoring radiation. Others requested information and checklists to help them seal up their houses. This illustrates the changing nature of information needs over the life cycle of an incident once the initial health concerns have been addressed.

Phase 2 participants were clear about the level and type of proof they would require in order to feel convinced that their compliance with the official advice was worthwhile. In the short term, participants requested contamination zone maps that offered specific advice and behavioral recommendations for individuals living in each zone. These detailed area maps were expected to indicate different levels of contamination, as well as safe zones.

Table 2. “First Reaction” Quantitative Questions Asked in Phase 1 and Phase 2, RDD Baseline, and Intervention (leaflet) Focus Groups. Participants responded individually to the questions prior to the start of discussions at each scenario stage. Scores ranged from 0 (not likely/not credible) to 100 (very likely/very credible) for each question (standard deviation in parentheses).

<table>
<thead>
<tr>
<th>RDD Scenario</th>
<th>Phase 1 (n=22)</th>
<th>Baseline (n=16)</th>
<th>Intervention (n=44)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Stage 2:</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>How likely are you to “Go in, stay in, tune in”?</td>
<td>86.0 (17.6)</td>
<td>80.0 (21.7)</td>
<td>73.6 (30.9)</td>
</tr>
<tr>
<td>How likely are you to remove and seal clothes and take a shower, assuming you had been in contact with the smoke given off in the explosion?</td>
<td>94.1 (22.0)</td>
<td>99.3 (2.6)</td>
<td>93.5 (18.0)</td>
</tr>
<tr>
<td><strong>Stage 3:</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>How likely are you to follow the advice that “sheltering is no longer necessary”?</td>
<td>47.0 (28.9)</td>
<td>43.7 (32.6)</td>
<td>68.4 (26.1)*</td>
</tr>
<tr>
<td>How likely are you to “avoid the cordon area”?</td>
<td>98.2 (5.0)</td>
<td>100 (0)</td>
<td>99.6 (3.0)</td>
</tr>
<tr>
<td>How likely are you to “attend sports facility for monitoring if exposed”?</td>
<td>82.5 (23.3)</td>
<td>89.7 (23.8)</td>
<td>91.8 (17.4)</td>
</tr>
<tr>
<td><strong>Stage 4:</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>How likely are you to return home, because levels are safe?</td>
<td>17.1 (26.9)</td>
<td>38.7 (28.3)</td>
<td>54.3 (31.6)</td>
</tr>
<tr>
<td><strong>Final scenario questions:</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>How credible (ie, believable and trustworthy) were the advice messages given by the authorities?</td>
<td>33.2 (20.7)</td>
<td>38.7 (22.2)</td>
<td>65.8 (21.5)**</td>
</tr>
<tr>
<td>How likely are you to return home, because levels are safe?</td>
<td>17.1 (26.9)</td>
<td>38.7 (28.3)</td>
<td>54.3 (31.6)</td>
</tr>
<tr>
<td>For the credibility of the “independent scientist”?</td>
<td>72.5 (24.1)</td>
<td>61.0 (24.2)</td>
<td>51.9 (26.6)</td>
</tr>
<tr>
<td><strong>Leaflet discussion questions:</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>To what extent do you think the leaflet [would have] helped you in making decisions about the scenario?</td>
<td>78.7 (20.2)</td>
<td>81.8 (16.3)</td>
<td></td>
</tr>
<tr>
<td>To what extent do you think the leaflet [would have] helped you understand the advice from the authorities presented in the scenario?</td>
<td>83.3 (11.4)</td>
<td>83.4 (15.8)</td>
<td></td>
</tr>
<tr>
<td>How credible (ie, believable and trustworthy) do you think the advice messages in the leaflet are?</td>
<td>80.7 (16.5)</td>
<td>88.1 (12.6)</td>
<td></td>
</tr>
</tbody>
</table>

Note. Bold text indicates significant difference between Baseline and Intervention group scores (*p<0.01; **p<0.001) using Mann-Whitney U tests.
They should show a map on there, say, "Right, this is where the explosion happened in all this circle, and within that circle down" and then it’s your judgement if you’re just behind it, or whatever, and then everyone else don’t have to worry. (GP10 Leaflet, R4)

These area maps should be linked to detailed, practical information about the steps one should follow if one is in a specific area (eg, if you are in the red zone, please report to the assessment center; if you are in the yellow zone, please shelter; if you are in the green zone, carry on as normal and avoid the cordoned-off area).

In the long term, the Phase 2 participants requested repeated checks on health and levels of contamination in the area, including scales and comparisons that would enable them to put the contamination into a context relative to their everyday lives. Many participants suggested that simple tools, such as radiation badges (if available), would give them a greater sense of control.

In spite of the leaflet’s ability to address a number of information needs, a lack of consistency in messages across the various messengers (eg, police, medical, independent scientist, leaflet) served to increase confusion and anxiety in both the baseline and intervention groups. For example, Phase 1 and Phase 2 participants reported that the Stage 4 discussions about levels of contamination in the surrounding areas (ie, in meat and vegetables) and the description of several tons of top-soil being removed from the immediate area generated high levels of concern and confusion because the official advice in Stage 3 indicated that the radiation levels had decreased to the point that sheltering was no longer necessary.

In spite of increases in confusion and anxiety during Stage 4, Table 2 illustrates that the perceived credibility of the advice and messages given by the authorities almost doubled between the baseline and intervention studies. For example, Phase 1 and Phase 2 participants reported that the Stage 4 discussions about levels of contamination in the surrounding areas (ie, in meat and vegetables) and the description of several tons of top-soil being removed from the immediate area generated high levels of concern and confusion because the official advice in Stage 3 indicated that the radiation levels had decreased to the point that sheltering was no longer necessary.

The provision of appropriate messages increased intended compliance with official advice to engage in a number of protective behaviors. Table 2 also shows the change in behavioral intentions between the baseline and intervention focus groups. However, it should be noted that compliance rates with suggested protective behaviors, such as sheltering, attending a sports center for monitoring if exposed, and showering, were high across both groups. While the leaflet intervention did not change the likelihood of avoiding the cordoned area (Question 4), as compliance rates were already high (Phase 1: M = 98.2, SD = 5.0; Phase 2: M = 99.6, SD = 17.4), the leaflet intervention appeared to increase the likelihood of following the advice that “sheltering is no longer necessary.” However, some respondents indicated that, in spite of their belief that sheltering was no longer necessary, they would take a “better safe than sorry” approach and remain in their homes (shelter) for another day, if not 48 hours.

The leaflet intervention also had a strong influence on reluctance or refusal to return to an area after decontamination had taken place. This behavior had the lowest intended compliance rate during the Phase 1 focus group and appeared to be the most difficult behavior to overcome. Concerns included “… that they don’t know enough and are rushing families back to a possible unsafe area which could have long-term effects on them” (GP4 written response, R1). In spite of this, after receiving the information about radiation and contamination/decontamination in the leaflet, the “timing” of advice to return to normal became less of an issue as long as there was proof of the level of safety:

If everything has been done that’s humanly possible to do to ensure that that area is returned to normal, then … if it takes two weeks then so be it; if it took a month, but if they would say to me, everything has returned to normal, then so be it. (GP10 Leaflet, R8)

Many of the discussions centered on the long-term checks and repeated measurements that were needed in order to certify that an area and homes were safe. Overall, participants in Phase 2 were less likely to leave the area but appeared to be more demanding of the type and levels of ongoing proof they desired to feel certain that the area was safe. The majority of Phase 2 participants expressed an increased willingness to wait for additional information before making their choices.

Several methodological limitations should be kept in mind when reviewing our results. For instance, while the small number of participants in our focus group studies allowed us greater depth of engagement than larger-scale survey studies and enabled us to recognize clear trends and patterns across the qualitative responses, we are unable to comment on the wider significance of the differences in intended behaviors and levels of trust reported in Table 2. It is also possible that the desire to please the experimenter informed some of the responses of our participants when presented with our leaflet, although justifications for the written responses were explored in detail and subject to change through group discussion, and outlying trends were weeded out through the in-depth process of IPA. Additionally, while issues of conformity and group polarization are always a concern in this type of study, the use of experienced facilitators and the format used for capturing participants’ initial responses through writing prior to discussion with the group go some way toward addressing these issues. Finally, although the hypothetical nature of our scenario inevitably prevents us from drawing definitive conclusions about how the public would behave during a real incident, the correspondence between our results and the behaviors seen in genuine incidents involving radiation provides some reassurance.

**Discussion**

Our Phase 1 focus groups identified several behavioral intentions that might have negative impacts for response
organizations following an RDD. These included intended compliance with advice to return to normal (eg, sheltering is no longer necessary), attendance at a facility for treatment and assessment, and the intention to return to a previously contaminated area after decontamination of the environment has taken place. In general, findings from the Phase 1 focus groups were broadly consistent with those of previous studies in this area. For example, several previous studies have noted that members of the public lack knowledge about radiation and tend to show heightened levels of anxiety about radiological terrorism. The behavioral responses identified in this phase also correspond well with the results of previous studies, which have identified a tendency for members of the public to collect children in the immediate aftermath of a terrorist attack, self-evacuate from areas perceived to be at risk from radiation, express unwillingness to attend an assessment center for fear of coming to harm, and be wary about the potential for long-lasting contamination despite attempts to communicate a low level of risk.

The outcomes of the Phase 2 focus groups demonstrated that the provision of appropriate messages increased the perceived credibility of official advice and that such behaviors are amenable to change by the provision of clear, consistent, and trustworthy information. Overall, responses to the information leaflet were positive, and the contents addressed a variety of information needs, including improved knowledge and understanding of the scale, impact, and response to the RDD scenario. Participants who received the leaflet were more likely to believe that the incident was contained to a small area, less likely to leave the area altogether, and more willing to return to a previously decontaminated area. As a result, participants appeared to be more receptive to official advice and rated messages coming from the authorities as more credible. These findings correspond well with previous research suggesting that a key aspect of people’s concerns regarding radiation incidents relates to the inherent difficulty in understanding where risk exists and where it is safe, by providing more information on this issue, our leaflet appeared to effectively reduce levels of worry among our participants.

The leaflet also improved intended compliance with advice to attend an assessment center if exposed, to follow advice that sheltering is no longer necessary, and to follow advice to return home once levels are declared safe. Nevertheless, not all of the participants believed that they would shelter during an incident or remain in a previously contaminated area, especially if they had young children. It is likely that this will be a key communication issue in a CBRN incident, and focus group participants indicated that they would likely comply with the recommendations as long as they could ensure the safety of their immediate family, especially children. In order to address this, response organizations must offer advice and guidance on the emergency plans and procedures schools have in place and openly communicate these plans to parents before, during, and after an incident. To date, the role of information about, and from, schools in guiding behavior during a disaster has been neglected in the literature.

Participants acknowledged that the leaflet intervention successfully addressed the majority of their immediate short-term concerns. However, the leaflet did little to address their long-term health concerns around exposure, contamination, and treatment or management. It is likely that information on long-term consequences will need to be provided separately to the information in the existing leaflets. Participants made a number of useful suggestions regarding how the leaflet could be refined and improved. For example, providing members of the public with a detailed insight into what will occur at an assessment and treatment center when they arrive should be a key feature of any communication targeted at encouraging individuals to report to assessment centers. Emphasizing the expertise of the center’s staff may also be desirable.

Finally, it is important to note that leaflet interventions are designed to accompany, not replace, messaging that addresses the need for real-time information about an ongoing incident. Our study has shown that compliance with recommended behaviors could be improved through effective communication about a CBRN incident, as long as the information presented is consistent and clear, addresses the knowledge gaps and information needs of the intended audience, and is delivered through a variety of sources (eg, leaflet, TV, radio, newspaper, internet).

A word of caution is needed, however, as a few participants believed that the leaflet played down the threat of radiation, which could cause some individuals to hesitate when it came to seeking treatment:

Yeah, it reassures me, but I don’t know if that’s necessarily always a good thing. ‘Cause if I was a little bit more panicked I’d be more inclined to follow the step by step. I mean I would anyway, but I imagine someone might get a bit blasé about it and think, “Oh, I’ll be fine.” (GP16 Leaflet, R1)

This led to the suggestion that:

... they should emphasize the point that you don’t have to have cuts and bruises to be contaminated because it’s what you can’t see that’s the problem, rather than what you can see. (GP16 Leaflet, R2)

In either case, simple reassurance may not be an effective way to increase compliance with behavioral recommendations.

In conclusion, in spite of the concerns about how and when the leaflets would be received, the current study illustrates that effective communication about CBRN threats could improve compliance with preferred behaviors through increasing knowledge, reducing anxiety, managing expectations, building trust, and creating familiarity with organizations and emergency response procedures. Explaining the nature of the threat in practical detail has the potential to decrease some of the anxiety surrounding the agent and provide reassurance, as well as decreasing some of the...
resistance to returning to a previously contaminated area or home. Furthermore, for communication to be effective, decisions must be made about the point (ie, pre-event, incident, postevent) at which the information is delivered.

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Disaster Warnings in Your Pocket: How Audiences Interpret Mobile Alerts for an Unfamiliar Hazard

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This study investigates how people interpret Wireless Emergency Alerts (WEAs) and Twitter-length messages (‘tweets’) delivered over mobile devices for an unfamiliar hazard. Specifically, through four (N=31) focus groups and 31 think-out-loud interviews, participants' understanding of, belief in and personalisation of WEAs and tweets were assessed for a mock improvised nuclear device detonation in a major U.S. metropolitan area. While participants offered a wide variety of interpretations, WEAs and tweets were often deemed confusing, difficult to believe and impersonal. Participants also consistently found WEAs and tweets to be fear inducing and uninformative. The findings compel improvements in the way that WEAs and tweets are currently written, as well as indicate future directions for applied risk and crisis communication theory development.

1. Introduction

In 2011, the U.S. Federal Emergency Management Agency (FEMA) began allowing authorised emergency management officials across the United States to broadcast Wireless Emergency Alerts (WEAs) to mobile devices to help warn people of imminent threats where they live and work (FEMA, 2014). Although mobile alert and warning systems are being deployed in countries including the United Kingdom, Australia and Japan, how 90-character WEAs actually influence public interpretation and response to hazard situations in the United States is unknown. Also unknown is how WEAs influence public responses and behaviours in comparison with other types of terse messages, particularly 140-character Twitter messages (‘tweets’), which some emergency managers have used to distribute alerts and warning since Twit-
Mobile Alerts

In this section, we introduce three areas of research that informed our investigation: social media messaging during disasters, mHealth and public warning. But first, we briefly introduce WEAs and Twitter use in a disaster context.

2.1 WEAs and disaster tweets

A WEA resembles a text message and indicates the hazard, the time and location of the alert, a protective action that recipients should take and the agency issuing the alert in a standard order and format. However, WEAs differ from traditional text messages in that they are geo-targeted and distributed through a wireless channel that remains unaffected during times of network congestion. WEAs also are not counted towards texting limits on a recipient’s wireless plan, are uniquely displayed on a device’s screen, are limited to 90 characters and are accompanied by a distinctive tone and vibration, both repeated twice. Furthermore, WEAs for imminent threats, such as rapid-onset terrorism incidents, are an opt-out only system. WEAs are thus intended as a kind of first alert or warning siren in your pocket (FEMA, 2014).

Twitter can be especially effective for imminent threat alerts because of its short length (140 characters), ability to immediately alert users to new messages and capability to be accessed from mobile devices (Choi, 2012; van der Meer & Verhoeven, 2013). Unlike WEAs, tweets are not geographically targeted. Also, compared to WEAs, imminent threat tweets have several distinct features: (1) tweets allow for interaction with receivers through the ‘@’ replying and direct messaging functions, (2) tweets are opt-in and (3) Twitter allows for user customisation in that audible tones and other functions can be tailored to user preferences. Finally, Twitter is a more familiar alerting platform among U.S. audiences given that Twitter was launched in 2006, six years before the WEA system.

2.2 Disaster mobile media messaging

Investigations of social media use during crises and disasters provide insight into public perceptions of short messaging channels, including their usefulness to relay informative and emotive content (Lachlan, Spence, Lin & Del Greco, 2014) and as a source of credible information in crisis response (Jin, Liu & Austin, 2014; Westerman, Spence & Van Der Heide, 2014). Recent research on the use of Twitter for the dissemination of official messages to populations at risk of disaster impact have revealed that short messages have the potential to deliver instructional content, leading to protective action (Sutton et al., 2014b). However, short messages sent under limited time (such as the time needed to take immediate action) and context (such as not having access to additional sources of information nor the ability to exchange messages) – described as the terse communication ‘regime’ (Sutton et al., 2014a: 766) – direct individuals to take protective action without first seeking additional information. WEAs provide insight into public perceptions of short messaging channels, including their usefulness to relay informative and emotive content (Lachlan, Spence, Lin & Del Greco, 2014) and as a source of credible information in crisis response (Jin, Liu & Austin, 2014; Westerman, Spence & Van Der Heide, 2014). Recent research on the use of Twitter for the dissemination of official messages to populations at risk of disaster impact have revealed that short messages have the potential to deliver instructional content, leading to protective action (Sutton et al., 2014b). However, short messages sent under limited time (such as the time needed to take immediate action) and context (such as not having access to additional sources of information nor the ability to exchange messages) – described as the terse communication ‘regime’ (Sutton et al., 2014a: 766) – direct individuals to take protective action without first seeking additional information.
such as through dialogic engagement with social media users (Latonero & Shklovski, 2011), or access to additional information via web links (Stephens et al., 2013), may increase the likelihood that individuals will act quickly under conditions of threat.

Importantly, research on terse messaging has thus far focused mostly on Twitter messages and predicted rates of public retransmission. Consequently, scholars do not know much about how publics interpret or understand terse warning messages nor how these messages may spur people to interact with others—a behaviour extensively documented within disaster communication research writ large (e.g., Jin et al., 2014; Mileti & Darlington, 1997; Wood et al., 2012). One recent study of Twitter use during a large-scale fire found limited effectiveness in that most government tweets were buried under an avalanche of citizen tweets (Helsloot et al., 2013). The authors warned government authorities to reject the notion that Twitter offered a crisis communication panacea. Along these lines, it is important to examine to what extent the message delivery platform itself influences the motivation of publics to respond to imminent threats. While research on social media use for disaster messaging has yet to adequately consider the mobile element, we can turn to the burgeoning research on mHealth (mobile health communication) for insights about how the mobile aspect of communication might influence public responses to disaster communication.

mHealth is ‘medical and public health practice supported by mobile devices, such as mobile phones, patient monitoring devices, personal digital assistants and other wireless devices’ (World Health Organization, 2011). A strength of mHealth technology is that mobility allows for place-shift, meaning that people can receive risk communication messages where they are and when they are ‘most open to communications about behaviour change’ (Lefebvre, 2009: 493). Specifically, the public that owns mobile devices almost always has these devices with them and typically turned on (Lefebvre, 2009). This allows for ‘time-independent communication’ or communication that can occur independent of regular business hours and independent of message receivers geographic location (Bajwa, 2014). Consequently, disaster communication via mobile devices may have a built-in, engaged audience facilitated by place-shift. Furthermore, by providing protective actions via terse messages when at-risk publics immediately need the information, place-shift may be an important theoretical construct to flesh out the emerging research on terse messaging. Indeed, research reveals that the majority of smartphone owners use their phone to follow and share breaking news, in part because of the convenience of place-shift (Smith, 2015).

Mobile communication can also facilitate meeting individuals’ desired goals (Schuster, Drennan & Lings, 2013), whether these goals are, for example, smoking cessation, disease prevention or weight loss (Abroms, Ahuja, Kodl, Thaweethai, Sims, Winickoff & Windsor, 2012; Fjeldsoe, Marshall & Miller, 2009)—or, we argue, disaster response. Transferring mHealth research findings to mobile disaster communication, WEAs and tweets may be able to help recipients receive convenient and timely information necessary to effectively respond to imminent threats. Conversely, Twitter allows for long-term engagement and two-way communication (although not message tailoring). Given research concerning terse messages and mHealth, we ask:

RQ1: How do message receivers initially characterise and respond to the terse format and mobile delivery of WEAs and tweets?

2.3 Public warning: interpretation and response

Scholarly interest in terse public warning messages has only recently occurred, largely because associated communication channels have been developed and diffused only within the last decade. However, there has been a lack of research on the use and effectiveness of terse messages even as practitioners are driven to adopt associated technologies (Casteel & Downing, 2015; Crowe, 2012; Sutton, Gibson, Phillips, Spiro, League, Johnson, Fitzhughb & Butts, 2015a; Sutton, League, Sellnow & Sellnow, 2015b). Klafft (2014) synthesised current issues in crisis communication and alerting in the European context, noting that emergency managers tend to still rely on a one-message-fits-all strategy despite the customisation capabilities of new technologies. While Klafft’s volume focused mainly on mass media contexts, Reuter, Ludwig, Friberg, Pratzler-Wanczura and Gizikis (2015), Reuter, Ludwig, Kaufhold and Spiehlofer (2016) examined the integration of social media within European emergency management systems. Using qualitative and quantitative research involving emergency management practitioners from many European countries, the authors found that social media activity was more common when authorities were issuing public warnings, but that telling people what to do to protect themselves was still more likely to occur via traditional mass communication channels, a conclusion also reached by those studying social media use in emergency management in the U.S. context (Hughes & Palen, 2014). Our study complements Klafft (2014) and Reuter et al.’s (2015, 2016) European studies in that it focuses on the details of mock WEAs and tweets to pinpoint message-centred concerns—at
both theoretical and practical levels. The U.S. WEA system currently relies on a one-message-fits-all strategy, but there is scant research examining how audiences actually interpret and respond to WEAs or WEA-like tweets. 

Coombs (2009) explained that crises create a demand for knowledge that must be produced within and through communication. Public officials must anticipate, to the extent possible, how stakeholders will perceive crisis communication and act in accordance with those perceptions. Coombs therefore argued that sensitivity to communication must be woven throughout the entire crisis management process: precrisis, crisis response and postcrisis. WEAs and tweets can, in theory, be used for communication during any part of the crisis management process, although WEAs are currently designed only for immediate crisis response communication. These two formats, WEAs and tweets, uniquely shape crisis response communication’s form and content, especially what can be said in terms instructing information, that is, telling people what to do to protect themselves. Coombs noted, ‘Very little research exists that explores ways to improve the development and delivery of instructing information’ (Coombs, 2009: 106), although scholars have theorised links between effective warning message content and instructional design research (Sellnow & Sellnow, 2010; Sellnow, Sellnow, Lane & Littlefield, 2012). In this study, we focus on the use of WEAs and tweets for immediate crisis response communication, specifically, the moment of onset for an imminent and catastrophic disaster (albeit a mock disaster).

Recent investigations by Crowe (2012), Sutton et al. (2015a,b), Klaft (2014), Reuter et al. (2015, 2016) and Coombs (2009) build upon an extensive body of research that identifies five key topics to include in an effective public warning message: source, guidance, hazard, location and time (Mileti & Sorensen, 1990). The style of public warning messages is also important, and research indicates that simply worded, precise, unambiguous, accurate, authoritative, confident and consistent messages encourage people to protect themselves (Mileti & Peek, 2000; Sorensen, 2000). When these content and style elements are present, public response outcomes tend to improve (Dash & Gladwin, 2007). However, whether and how these content and style elements can be included within WEAs or tweets is an open question (Sutton et al., 2014a).

Between warning receipt and initiating (or not) a protective action, interpretation occurs. Interpretation involves hearing, understanding, believing and personalisation (also called situational risk perception), which, in turn, influence decision-making, searching for additional and confirming information (milling) and action (Mileti et al., 1990). Understanding refers to attaching a personal meaning to the received warning message and researchers including Greene, Perry and Lindell (1981) and Quarantelli (1984) have documented the effect of message content and style factors on understanding. Specifically, ambiguous information concerning the hazard, the time and location of impact, and what to do for self-protection significantly influences understanding (Mileti et al., 1990). Therefore, we asked:

RQ2a: How do WEA and tweet content and style characteristics influence receivers’ understanding of the messages?

Believing refers to determining whether message content is accurate, credible and real (Baker, 1979; Rogers, 1985). Mileti et al. (1990) found that ambiguous information concerning the hazard, the time and location of impact, and what to do for self-protection significantly influenced believability. Therefore, we asked:

RQ2b: How do the content and style characteristics of WEAs and tweets influence receivers’ belief in the messages?

Personalising means coming to think that one is no longer safe and that the given warning is, indeed, aimed at oneself. Perry (1979) and Perry, Lindell and Greene (1981) documented the effect of message content and style factors on personalising. Phillips and Morrow (2007) and Sellnow et al. (2012) found that personalisation was particularly salient among female message recipients. Therefore, we asked:

RQ2c: How do the content and style characteristics of WEAs and tweets influence receivers’ personalisation of the messages?

3. Methods

We chose an improvised nuclear device scenario for this study for two reasons. First, a November 2012 workshop that we conducted with 16 experts (citation masked for blind review) allowed us to gain feedback on the study’s design, and the consensus of the group was that research participants should confront an unfamiliar hazard because it would focus attention on the warning message and be more difficult to rely on prior hazard experience for guidance. Second, a nuclear device scenario is complex from a messaging viewpoint, which required careful consideration of what information to include in the mock WEAs and tweets. Detailed federal public protective action guidance also exists for this hazard, which aided message development (National
Security Staff, Interagency Policy Coordination Subcommittee for Preparedness and Response to Radiological and Nuclear Threats, 2010; U.S. Nuclear Regulatory Commission, 2012). It is important to note that current policy allows for only one 90-character WEA to be issued to at-risk publics during an emergency; therefore, our research focused on a single terse message—rather than multiple messages—issued in response to an imminent threat. Our inclusion of 140-character Twitter-length messages in this study arose from both their growing use among emergency management officials and the possibility that WEA character limits might increase in the future; therefore, we deliberately wrote the Twitter-length messages using the current WEA format. The four mock WEAs and Twitter-length messages used in this study are provided in Figure 1. A map that included one’s location relative to the hazard area was also developed and used in one of the WEAs and one of the Twitter-length messages, as indicated in Figure 1.

To investigate these mock WEAs and tweets, the lead qualitative researcher conducted think-out-loud telephone interviews and four focus groups totalling 31 participants for both methods. The focus groups were conducted in a conference room at the lead qualitative researcher’s campus, which is located in an easily accessible, downtown urban setting. While Denver was chosen as the site for the mock disaster scenario for convenience, an act of terrorism like the one imagined for this study could occur in any city, especially those with a large concentration of military and civilian government facilities, an international airport and high-profile landmarks (FEMA, 2013a).

Recruitment of the 31 participants (12 male and 19 female) occurred via Denver’s Craigslist community volunteer page, and the participants reflected the demographic characteristics of the metro Denver area: 70% White, 18% Hispanic, 5% Black, 3% Asian, 1% Native American and 3% multi-racial, with a median age of 32. Prior to the focus groups, participants also undertook a short, telephone-based ‘think-out-loud’ interview at their home or workplace that involved reading a mock 90-character WEA or 140-character tweet for an improvised nuclear device explosion in downtown Denver. One message was emailed to each participant during the think-out-loud interview.

Figure 1. Mock WEAs and Twitter-length messages.
Think-out-loud is a useful method for uncovering participants’ internal states and cognitive processes (Ericsson & Simon, 1993). Each participant was first called on the telephone and presented with a standardised context to imagine, specifically, ‘You are at home in Littleton when you receive the following message on your mobile phone’. Then, each participant was immediately emailed one mock WEA or tweet. Research participants were instructed to read the message out loud and to think out loud, that is, describe their thoughts as they interpreted, re-read, questioned or puzzled over the message. While reading a mock WEA or tweet out loud, participants commented on its contents without direction or elaboration from the researcher. No follow up questions were asked. The think-out-loud interviews ranged from just over one minute to more than 12 minutes, with an average time of close to four minutes.

Subsequently, the same research participants undertook in-person focus groups that probed on the topics featured in the study’s primary research questions. Four focus groups examined four core questions: (1) Do you understand this message? (2) Do you believe this message? (3) Do you think this message impacts you specifically? and (4) What will you decide to do next? For all questions, discussion probes focused on why participants answered each question as they did, focusing on message type and content elements including source, hazard, guidance, location and time. Focus groups ranged from 77 minutes to 106 minutes. Each focus group examined two of the four mock messages, and these two mock messages were presented in a different order during each focus group.

Think-out-loud and focus group sessions were audio recorded and subsequently transcribed, producing 110 pages of single-spaced transcripts. Coding was conducted using NVivo 10, a software package that facilitates systematic thematic analysis. Coding focused on identifying statements that referred to participants’ understanding, belief and personalisation of messages, as well as milling, decision-making and emotions (six codes). These statements were simultaneously associated with one or more of six codes representing the message elements of hazard, guidance, time, location, source or map (Mileti et al., 1990). Additional codes were inductively generated to account for statements that referred to message elements beyond the six codes derived from Mileti et al. (1990). These six message elements included acronyms, technical message terms, URL, lexical issues, order and message length. Collectively, these 18 codes directly corresponded to our research questions concerning how message receivers characterise and respond to the format, delivery, content and style of WEAs and tweets. Using a scissor-and-sort technique (Stewart & Shamdasani, 2015), similarities and differences in participants’ stated responses to the messages were grouped and analysed for recurring themes in order to answer the research questions.

4. Results

This section reports the results of our analysis in relation to our research questions.

4.1 RQ1: initial responses to WEAs and tweets

We found that participants’ think-out-loud and focus group responses tended to characterise both 90 and 140-character messages as fear inducing, uninformative and confusing. There was no perceivable difference in participants’ responses between the two formats. The primary response to the WEAs and tweets was confusion and fear. ‘Before it even opens [the email message], I see ‘radiological hazard,’ and I’m like, holy crap!’ said one participant. Another declared, ‘Okay, my thoughts are: What the f***? That’s my first thought. Because I don’t know what a ‘radiological warning’ is. But that did get my attention, and it was scary’. A third participant noted, ‘To me, it just doesn’t seem complete. It seems like just enough to terrify you, but not to really help you do anything’. ‘I’d be freaked out if I got that message’, said another. ‘My thoughts? [. . . ] fear, panic’, said another.

A lack of information both produced and compounded participants’ confusion and fear. The WEAs and tweets were too uninformative for most participants. ‘Okay, my first thought is just the word “radiological.” Oh my god! You can’t see it, you can’t touch it. How do I protect myself from this? Where do I go?’ said one. ‘I don’t know what a “radiological warning” is. I’ve never seen or heard that before, it’s not been spelled out anywhere, it doesn’t redirect me to a website’, said another. A third declared, ‘I’m thinking, nuclear bomb? A nuclear bomb has gone off somewhere? Great, but because I have nothing kind of leading into this or prepping me for it, I kind of don’t know what to do with it’.

Ambiguity about the nature of the hazard accompanied uncertainty about the appropriate response. ‘When it’s saying “take shelter” – where do I need to take shelter? And how? And how much time do I have?’ ‘Because from what I understand, you only have a short amount of time before it really doesn’t matter’, said one participant. The 90-character WEAs were deemed especially uninformative, ‘I don’t even know where shelter is. I don’t know, in Denver, like, where it would be. That would be horrible. I don’t know what I would do, actually’, said one participant. Or, as another participant stated, ‘I think it’s too vague. It needs to spell [out] stuff more. Some people
don’t know what MDT stands for’. ‘So it’s like, what do you consider sturdy? I may consider the shed in my backyard much sturdier than my house’, said a third.

A lack of information also appeared to produce confusion for many participants. This confusion prompted some participants to question the authenticity of the WEAs and tweets. ‘Who sent me this message...? [... ] But the ‘US DHS’ leads me to question: How legitimate is this message? I don’t think — after the initial few seconds of alarm, I don’t necessarily believe that this is a true message, or a true scenario. Because I just don’t think a United States governmental department would sign it like that’, said one participant of the 90-character WEA. Said another, ‘I’m kind of confused on the radiological hazard warning, and then also with the way they highlight the area [on the map]. I don’t really like that’. 140-character tweets also produced confusion and suspicion. ‘For me, I’m unclear, I guess, on a couple of the acronyms here’, said one. ‘What are the side effects? Should I put something over my head? Should I close the windows? It’s just confusion and fear right now’, said another. ‘I would like it to say there’s been a warning, ‘This is not a test.’ Something like that. [... ] just to verify that no one is playing games’, said a third. One participant declared, ‘My first thought, honestly, would be that it was spam. I don’t like the way that it’s abbreviated. There’s nothing on there that tells me that it’s an official emergency notification’. Based on these initial characterisations of the WEAs and tweets, issues of message content, source and hazard familiarity should concern emergency managers.

However, not all participants reacted negatively to the WEAs and tweets. For example, one participant stated, ‘[...] it’s very short, to the point, and succinct, and good’. Another participant stated, ‘I would take it seriously. I would probably be checking my phone to find out exactly what it is. But in the meantime, [I would be] taking shelter and keeping a close eye until when the hazard has passed and it’s safe to come out’.

‘We further found that only a little more than third of participants (11 total) stated that they would immediately heed the message’s instruction to shelter. Instead, consistent with models of public warning response (Mileti et al., 1990; Perry, 1979), most participants intended to seek additional information before taking any protective action, while a few participants stated that they would ignore the message or try to outrun the radioactive fallout. Some participants indicated that they would attempt to obtain more information while sheltering. ‘I’d go in the basement, get out my radio and my iPad, and start trying to get as much information as possible’, said one. ‘Well, you know, it says take shelter, you know? Probably [I’d] just close all the doors and windows and check TV or wait for other news updates’, said another. For participants who intended to leave the area, fear of radioactivity was a primary concern.

These few positive responses aside, fear, a desire for additional information, and confusion characterised the majority of participants’ initial reactions to the WEAs and tweets.

4.2 RQ2a: understanding

The majority of participants did not understand the WEAs and tweets due to a lack of clarity about the hazard, the protective action guidance, the affected area, the time of the incident, time needed to complete the protective action and the source. Concerning the hazard, one participant acknowledged, ‘I don’t know what a “radiological hazard” is’. Concerning protective action guidance, one participant asked, ‘I would like to know, when they say “shelter,” do they mean shelter-in-place in my home; go to a basement like in a tornado? Or do they mean go to an outside shelter that the city has set up?’ Participants were also uncertain about the affected area. ‘I don’t know what “this area” is’, said one. ‘We don’t know what area it is taking place in’, said another. ‘I wish there [...] was a map, which gave you the area. This one doesn’t [have a map], so I’d be kind of confused getting this. Like, where am I in that area now? Am I not in that area? Is this just based on where I’m at, or based on where my home is?’ asked a third. Regarding time, one participant asked, ‘[...] when did it start? Was it at noon? Was it in the morning?’ Another remarked, ‘We only know when it stops [the alert] but we don’t know when it started’. In terms of the message source, one participant stated, ‘I think it would be helpful to explain what ‘US DHS’ means. It’s Department of Human Services, but that could, most people aren’t going to know, I don’t think, what DHS is’. This participant’s misinterpretation concerning the source acronym was not unique. Another asked, ‘Is that the Dacono High School, or DHS? I’m just not sure who this would be from’.

The terseness of the messages frustrated some participants. One asked, ‘Why is it so limited? I mean, why is it? This is like a pretty serious thing. Why am I getting so little information?’ Another summed up the general consensus of the group, ‘Basically, this tells us nothing’. Not all participants agreed, however. ‘I do [understand the WEA]. I wish there was more information, but it’s straightforward and to the point’.

4.3 RQ2b: belief

The study’s hypothetical scenario complicated assessment of the believability of the WEAs and tweets.
Belief was influenced by a nonmessage factor, specifically, whether or not participants thought that they had opted-in to an alert system for the messages. For example, one participant stated, ‘There needs to be something that verifies that this is indeed coming from Homeland Security, that we can trust’. Another remarked, ‘I would never expect to get a message that I didn’t subscribe to, so I wouldn’t believe it. I would just think it was spam’. The majority of participants indicated that their belief in the message would improve once they confirmed its validity via TV, radio or the Internet, or if they knew that they had opted-in to the service. ‘But if this was something I’d signed up for, this would be totally believable’, said one participant.

The believability of the WEAs and tweets increased for several participants when the message source changed to ‘Denver PD’ and was placed at the beginning of the message (as noted in Figure 1, each of the four WEAs and tweets included either a federal or local source). One participant stated, ‘I also agree that the order is important, and it’s nice to have the source of the message, like, in front so you know, okay, this came from the Denver PD’. Other participants, however, did not find this source believable, mostly due to not understanding why or how they had come to receive the WEA. ‘It’s believable, but if I just got this without knowing I was signed up for anything, it would be questionable’, said one participant. In sum, the issues of opt-in/opt-out and message source influence the believability of WEAs and tweets.

4.4 RQ2c: personalisation

Many participants did not understand whether or not the hazard impacted them specifically, a finding that applied to both WEAs and tweets. As one participant explained, ‘I’d be kind of confused getting this. Like, where am I in that “area” now?’ In almost all cases, the inclusion of a map indicating the participants’ location and relation to the hazard improved participants’ perception of personal risk. For example, when asked by the moderator whether people thought including a map impacted them specifically, one participant replied, ‘Yes, because there is a [map and a] flag that says “You!”’. Another participant explained, ‘[...] it says “Denver” and it shows a map with the blast radius or where the contamination is. If I’m inside that, you know, I’m moving pretty quick. If I’m outside of it, I’m making a lot of phone calls. So I take that seriously’. Another noted, however, ‘Actually, I kind of find the “You” [in the map] a little joking. I think if I saw that, I’d be like, “Are you kidding me? We’re about to die?”’

5. Discussion

The findings reported here lead to five primary insights and needs for additional research concerning the intersection of terse messages, mobile communication and public warning.

5.1 Slight improvement in outcomes as messages move from 90- to 140-characters

First, as noted above, there were no perceivable differences between WEAs and tweets in terms of participants’ understanding, belief or personalisation. Participants deemed both formats problematic for similar reasons. Again, only 11 participants overall – about a third – stated that they would immediately take shelter in response to the WEAs and tweets. However, when carefully analysing the focus group transcripts, we found that 140-character tweets slightly increased participants’ intentions to take shelter. Only three recipients of the 90-character WEAs indicated that they would immediately take shelter as instructed, while eight recipients of the 140-character tweets stated that they would take shelter. Although 140-character tweets appeared to slightly reduce milling when compared to 90-character WEAs, it was unclear exactly what elements of the messages contributed to the difference. Based on several participants’ stated confusion regarding the term ‘radiological hazard’, we speculate that the words ‘nuclear explosion’ in the 140-character tweets were more understandable, and thus perhaps more motivating, than the 90-character WEAs.

5.2 Inadequate information

Second, while we cannot use think-out-loud interviews or focus groups to conclusively predict actual public response to WEAs or tweets during an improvised nuclear device scenario, participants’ interpretations and responses indicate that terse messages for an unfamiliar hazard lack adequate information and are unlikely to spur widespread, immediate protective action taking. Instead, terse messages appear likely to spark information seeking and confirmation (‘milling’). While milling occurs in response to longer public warning messages as well (Mileti et al., 1990; Perry, 1979), terse WEAs and tweets provide so little information that they may also lead to increased fear and misunderstanding, and, consequently, to an even greater need for information to confirm the warning through interacting with other people and/or information sources. Both the 90-character WEAs and 140-character tweets produced misunderstanding among participants.
Returning to theory, WEAs and tweets are a form of terse communication in that they limit the amount of message content, do not provide an opportunity for dialogue and require the message receiver to quickly take protective action. As theorised, terse communication can generate uncertainty, thereby prompting WEA and tweet recipients to ‘mill’ for additional and confirming information. Previous research on Twitter under imminent threat conditions showed that even though officials have the ability to interact and engage with people who receive Twitter messages, they rarely do so, which likely contributes to milling among message receivers (Sutton et al., 2014a,b). In this study, we identified factors that seem to generate milling in response to terse messages: fear, confusion and uninformative message content. At what point a terse message becomes a message that is sufficiently informative is an open question. Nevertheless, WEAs and tweets include information in a way that does not appear to generate high levels of understanding, belief and personalisation in a nuclear device explosion scenario. WEAs and tweets may be more effective for more familiar hazards, but further research in this area is warranted.

The fear, desire for additional information and confusion that characterised participants’ think-out-loud responses to WEAs and tweets could potentially lead to a troubling result: threat denial (Drabek, 1999). A lack of information, combined with suspicion and fear, could lead some message recipients to simply ignore these messages. Ambiguous information concerning the hazard, the time and location of impact, and what to do for self-protection has been shown to significantly influence understanding, belief and personalisation (Mileti et al., 1990). Our focus group findings are consistent with research that demonstrates that such ambiguity sparks intentions to mill for additional and confirming information (Dash et al., 2007), thereby delaying life-saving protective action taking.

5.3 Public information needs regarding the WEA system

Third, there is a need for additional public information about WEAs. The results suggest that WEAs could exacerbate uncertainty in absence of adequate pre-event communication that (a) explains how to decipher a WEA to understand the degree of immediate risk, and (b) explains what publics should do in response to certain hazards. That several participants did not understand the meaning of ‘DHS’, or asserted that a local source was more believable, also indicates a potential problem with source credibility and trust.

Indeed, many participants’ belief in the message hinged on whether or not they thought that they had opted-in to the alerting system. If they had not opted-in, several participants were prone to dismiss the message as ‘spam’ or a ‘hoax’. A few participants could not believe that WEA technology even existed; as one participant declared, ‘And in the case of a national emergency, all of a sudden they’re going to calculate hundreds of thousands of locations to send those of us a personalised message? That’s Santa Claus [make believe]’. Although FEMA partnered with the Ad Council in 2013 to develop a public education campaign about WEAs, this study’s findings suggest that WEAs do not yet seem to be widely known or understood, at least in the Denver area. The need for more public education about the purpose of WEAs, who sends them, how and why, is clear.

5.4 Mobilising disaster communication

Fourth, we found a mixed bag in terms of how well mHealth constructs, combined with public warning constructs, appear to transfer to WEAs and tweets. For example, while we saw evidence of place-shifting, the results regarding understanding and believing the message indicated that place-shifting may not necessarily lead to openness for behaviour change, as found in the mHealth literature (Lefebvre, 2009). One explanation for these findings is that WEAs and tweets, as terse messages, do not allow for message personalisation, and WEAs do not allow for two-way communication. Both WEAs and tweets are limited in their ability to convincingly motivate recipients to take protective action. Indeed, the findings regarding distrust of the message may be related to mHealth research that finds place-shift may raise questions about authenticity and security because some message recipients distrust messages appearing on their mobile devices from unknown and/or unexpected sources (Bajwa, 2014). This distrust may be compounded by the terseness of messages delivered over mobile devices because length constraints may prohibit adequately explaining the message source and why people are receiving the message.

Similarly, while we saw evidence to support the convenience function of WEAs and tweets, again, less than half of our participants indicated they would immediately take shelter after receiving the message. Thus, convenience as facilitated by place-shift may not necessarily translate into a rapid, life-saving response. Instead, some at-risk publics will still opt to search for additional information before deciding whether to take recommended protective action.

Furthermore, given that multimodal health interventions are more effective than unimodal health interventions (i.e., only via mHealth) (Abroms et al., 2012), WEAs and tweets likely need to accompany more types and sources of information. One option could be to include a link to additional information about...
the hazard that allows for content tailoring, such as FEMA’s disaster planning and response smartphone ‘app’ (FEMA, 2013b), which could take advantage of place-shift and convenience while providing access to additional information as needed. In addition, future research should investigate different hazard types to determine if mHealth constructs transfer better to WEAs and tweets for hazards that are more familiar to the public, such as floods or tornados. It is possible that the largely unfamiliar nature of the hazard that we explored – an improvised nuclear device detonation – led to levels of fear and uncertainty that cannot be overcome with WEAs and tweets alone. Future research should also study whether receiving multiple WEAs and tweets about a single imminent threat, rather than one stand-alone WEA or tweet, as studied here in conformity with current WEA policy, impacts at-risk publics’ interpretations and responses. As Klafft (2014) explained, new and evolving technologies offer greater opportunities to customise – and therefore improve – crisis response communication in relation to audience, time, place and frequency.

5.5 Message elements

Fifth, this study’s findings suggest that nearly anything could serve as a potential message or style element that influences WEA and tweet interpretation and response. The size, format and arrangement of text, the type and quality of a map (if included), the audible tone accompanying WEA receipt, the familiarity, intensity and arrangement of the words used in a message and other factors, could all potentially influence people’s understanding, belief and personalisation of messages. WEAs and tweets are part of a raft of alert and warning communication increasingly available to many communities. How WEAs and tweets complement and/or conflict with other types of alert and warning messages is an open question. This study did not explore nonmessage factors that also influence public protective action outcomes, such as recipients’ native language, age, education level, family role or hazard familiarity (Messias, Barrington & Lacy, 2012; Shaw, Kobayashi & Kobayashi, 2004). Nevertheless, this study indicates that increasing the amount of detail about the hazard and guidance, as well as clarifying the location and time elements, might improve compliance with the recommended protective actions included in WEAs and tweets. Localising the message source and placing it at the beginning of the message might also slightly improve believability.

6. Limitations and conclusion

To reiterate, participant intentions to comply with protect-action guidance slightly improved as messages expanded from 90- to 140-characters, yet both message lengths still lacked adequate information and spurred milling for most participants. Public education about the WEA system is needed to capitalise on the benefits of place-shift, and numerous, subtle factors influenced the understanding, believability and personalisation of the mock WEAs and tweets examined. A word of caution about these five conclusions is needed, however, because some participants voiced statements contrary to each of them. We do not know for certain how participants’ interpretations and actions would differ in an actual emergency. Study participants were drawn from only from Denver and surrounding areas, and it is possible that residents of different metro areas would interpret WEAs and tweets differently. We only explored one hazard type in this study, and as already noted, it is unclear whether and how hazard type impacts people’s response to WEAs and tweets. Consistent with studies concerning the ambiguity of warning signal words, such as ‘danger’, ‘warning’, and ‘caution’ (Hellier, Aldrich, Wright, Daunt & Edworthy, 2007), as well as public information issues in terrorist events involving radioactive materials (Becker, 2004), some of the misunderstanding and confusion reported in the focus groups stemmed from a lack of knowledge of the meaning of public warning terminology and what to do in the aftermath of a nuclear device detonation.

Future research should investigate WEAs and tweets in relation to various populations and subgroups, in a variety of geographical locations, and use quantitative, qualitative and experimental approaches with larger sample sizes. Reuter et al. (2016) found a lack of European crisis response communicators skilled in the use of social media, and it is reasonable to suggest that both U.S. and European emergency managers ought to understand more about the benefits and limitations of terse messages in efforts to improve the use of social media and SMS-like tools. As an exploratory study, the findings reported herein are not generalisable; they do, however, provide insights about how people living in a major U.S. metropolitan area might interpret a WEA or tweet issued in response to a nuclear device detonation or another unfamiliar hazard. Finally, qualitative researchers are committed to the premise that investigations of social phenomena should include the voices of affected stakeholders (Lindlof & Taylor, 2010). Despite laudable U.S. and international efforts to develop standardised alert and warning messages that conform to crisis communication best practice (e.g., Niebla, Chaves, Ramirez, Mendes & Ferrer, 2012), the participant voices reported here indicate that no singular WEA or tweet will lead to maximal outcomes for all. Ideally, this study serves as an important step in achieving better outcomes for most.
Acknowledgements

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Vulnerability of populations and the urban health care systems to nuclear weapon attack – examples from four American cities

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Abstract

Background: The threat posed by the use of weapons of mass destruction (WMD) within the United States has grown significantly in recent years, focusing attention on the medical and public health disaster capabilities of the nation in a large scale crisis. While the hundreds of thousands or millions of casualties resulting from a nuclear weapon would, in and of itself, overwhelm our current medical response capabilities, the response dilemma is further exacerbated in that these resources themselves would be significantly at risk. There are many limitations on the resources needed for mass casualty management, such as access to sufficient hospital beds including specialized beds for burn victims, respiration and supportive therapy, pharmaceutical intervention, and mass decontamination.

Results: The effects of 20 kiloton and 550 kiloton nuclear detonations on high priority target cities are presented for New York City, Chicago, Washington D.C. and Atlanta. Thermal, blast and radiation effects are described, and affected populations are calculated using 2000 block level census data. Weapons of 100 Kts and up are primarily incendiary or radiation weapons, able to cause burns and start fires at distances greater than they can significantly damage buildings, and to poison populations through radiation injuries well downwind in the case of surface detonations. With weapons below 100 Kts, blast effects tend to be stronger than primary thermal effects from surface bursts. From the point of view of medical casualty treatment and administrative response, there is an ominous pattern where these fatalities and casualties geographically fall in relation to the location of hospital and administrative facilities. It is demonstrated that a staggering number of the main hospitals, trauma centers, and other medical assets are likely to be in the fatality plume, rendering them essentially inoperable in a crisis.

Conclusion: Among the consequences of this outcome would be the probable loss of command-and-control, mass casualties that will have to be treated in an unorganized response by hospitals on the periphery, as well as other expected chaotic outcomes from inadequate administration in a crisis. Vigorous, creative, and accelerated training and coordination among the federal agencies tasked for WMD response, military resources, academic institutions, and local responders will be critical for large-scale WMD events involving mass casualties.
Background

The increasing likelihood of the use of weapons of mass destruction (WMD) on large civilian populations has been described in international government alerts [1]. U.S. Congressional hearings [2], research studies [3,4], and numerous scientific publications [5-9]. Islamic terrorist attacks on New York and Washington, D.C. have accentuated the reality of this threat, though the magnitude of casualties with WMD would be many times greater in scale. There is continued concern over the security of the enormous arsenal of nuclear, chemical, and biological agents left over in Russia as a result of the Cold War. It is known that Libya, Iran, Syria, Iraq, and North Korea have been actively recruiting the scientists that constructed this massive stockpile, and it is not certain where many of these experts are now [10].

While thousands of deaths occurred in a single day with the World Trade Center attack in New York, the impact on the health care system was not equivalently severe, as relatively few morbidity cases were produced. In most conceivable WMD attacks, however, it is reasonable to expect that the health care system would be overloaded with massive numbers of patients requiring an array of professionals with specialized training. If this already stretched medical community was also severely impacted by the very attack that requires its response, the effects would be even more devastating. In addition to the loss of medical care, among the anticipated outcomes for the general public will be fear of invisible agents and contagion, magical thinking about radiation, anger at perceived inadequacies by government entities, scapegoating, paranoia, social isolation, demoralization, and loss of faith in social institutions [11]. Intervention, guided by the appropriate use of WMD modeling software, would be the fastest and perhaps even the only effective means to effectively respond before loss of the sense of social and group responsibilities occurs, and before sufficient decline in the ideological metaphors which bind the community results in mass chaos and highly negative social sequelae.

Integration of casualty estimates into current WMD response paradigms

Model estimates of casualty distributions could be of great benefit in mass casualty planning when utilized by the existing WMD response systems, though development of these approaches toward the extreme conditions of a nuclear attack are still underway. This process has advanced through a number of stages, with the magnitude of the response necessary for nuclear attack requiring extensive revisions. An early approach to linking first-responder, public health, and health care systems by the U.S. government was the Metropolitan Medical Response System (MMRS, originally known as Strike Teams) [12]. There were over 50 urban areas that developed MMRSs, which focus primarily on the training and coordination of local personnel within target communities.

Another initial approach was the upgrading of civilian first responders in 120 communities by the U.S. Army Soldier and Biological Chemical Command (SBCCOM). The Department of Justice’s National Domestic Preparedness Office (NDPO), now part of the Department of Homeland Security (DHS), is currently processing information pertaining to law enforcement, emergency medical response, medical, and public health issues [13]. While there are various private efforts at planning a mass casualty response, the absence of a large-scale WMD experience has precluded validation of these efforts. Recently, the military has developed field deployable emergency response units, which could prove highly valuable in a WMD crisis if model predictions could target where they should be deployed. Health hazard surveillance, control, and the mitigation of effects in WMD incidents by mobile response units would be significantly enhanced by the availability of accurate mass casualty estimates by these kinds of model efforts. Deployment of these resources in a large scale crisis like nuclear detonation would be significantly enhanced by knowledge of the location of burn, trauma, and other casualties.

Mass casualty estimation on a geographic basis

The Defense Threat Reduction Agency (DTRA) has expended considerable effort to develop models for calculating mass casualties from a nuclear detonation. In order to specifically evaluate urban medical systems vulnerability we are employing the PC based Consequence Assessment Tool Set (CATS) v6, with ESRI’s ArcGIS9 [14], CATS/JACE (Joint Assessment of Catastrophic Events) v5 with ESRI’s ArcView 3.3, Hazard Prediction and Assessment Capability (HPAC) V4.04SP3 [15], as well as custom GIS and database software applications. HPAC does excellent Chemical Biological and Nuclear (CBN) modeling, although output could provide more flexibility. Additionally, results can be exported to CATS for further analysis and display. All three programs can access the current weather data from both classified and unclassified weather servers. Examples of uses of CATS/HPAC are hurricane, tidal surge and earthquake damage, prediction of the results from nuclear, biological and chemical releases, assessment of persons and infrastructure affected and at risk (e.g. which hospitals and pharmacies are under a CBN plume and are thus out of commission), and mobilization of surviving and nearby infrastructure outside the plume that would be needed to address healthcare and other emergency response needs of the community.

These models have been, and continue to be, developed with a view to better estimating the impact of WMD weapons in an offensive setting. However, recent DTRA
enhancements and our modifications have facilitated their use in helping estimate potential casualties from a WMD terrorist incident. One area of intense interest, and somewhat of a vacuum in public health planning, has been the utility of this approach in estimating medical care vulnerabilities in such an attack, and for the calculation of the distribution of surviving medical care resources. While much work has already occurred in estimating the impact of chemical weapons (due to the dual use in chemical spill management from transportation and industrial accidents), or in nuclear power plant accident management, much less research and development has gone into estimating the impact on our civilian population of a nuclear weapon detonation from a terrorist incident in a large urban area. The models already calculate such factors as the impact of blast, thermal effects and fallout, but results are often not available at the detail level needed for civil defense purposes, casualty management, and planning the use of scarce health resources in response to a nuclear weapon detonation. Furthermore, the models do not readily facilitate the calculation of injuries from multiple effects such as burns and blast with fallout or prompt radiation. The complexity of the urban three-dimensional landscape and its local impact on thermal, blast and radiation is also poorly understood. Additionally, given their traditional world-wide focus, and the increased sensitivity to providing information on the U.S.A. of use to terrorists, the models do not provide detailed or current data that exists for the United States that would help provide better casualty estimates and response. The models can be customized locally and data updated if the user has sufficient expertise. However, there is often a significant duplication of effort due to overlapping jurisdictions and the lack of data sharing due to security and other considerations.

CATS and HPAC are also useful for creating realistic scenarios for training and planning before a disaster strikes, thus enabling responders to drill and exercise so they know roughly what to expect and how to react. Contingency plans can be created using comprehensive national and more detailed population and infrastructure data. Should disaster strike, the affected population and the impact on critical facilities can be quickly assessed, although efforts frequently need to be expended to ensure regional and local databases are current and useful.

**Utilization of model casualty estimates in medical planning**

Without the directed use of accurate casualty distribution estimates, it is likely that past failures in mass casualty planning in large-scale medical disasters will be repeated. During the Sarin attack on Tokyo, hospitals became part of the problem when 23% of the healthcare workers became ill by unintentionally spreading the nerve agent to hospital and emergency staff workers. During the SARS epidemic in China, hospitals in Beijing and Hong Kong became "Super Seeders" of the coronavirus and dramatically accelerated contagion up to 250 individuals per day. A study by the American College of Emergency Physicians (ACEP) Task Force found that "little or no WMD-based expertise" existed among medical staff workers in hospitals [16].

Based on information from the National Commission on Terrorist Attacks upon the United States (9–11 Commission)[17], public hearings on the initial response show a terrible confusion among first responders that resulted in the addition of a "Catastrophic Incident Annex" to the second draft version of the National Response Plan (NRP) [18]. First responders during 9/11 suffered from an inability to communicate information concerning the scale and magnitude of the disaster, and thereby released conflicting public service information during the crisis that resulted in additional loss of life. The findings of these hearings show a critical need for a "National Strategy" for medical response to catastrophic incidents. The requirements of the Catastrophic Incident Annex exceed the CDC and HRSA benchmarks of 500 hospital beds for a population of one million needed for natural disasters.

For an effective response, delineating the geographic zones in which different types of injuries are likely to be found, and delineating zones in which victims are likely to sustain multiple injuries, is critical. In the case of a nuclear explosion, thermal effects will produce very large numbers of burn casualties – a dramatic medical and security challenge that differs from routine medical emergencies or non-nuclear WMD events. Multiple trauma injuries will accompany the injuries inflicted by thermal radiation. These will be qualitatively similar to current trauma protocols, with the exception of fallout contamination, but will differ drastically on the quantitative level. Additionally, certain regions will experience the unique casualties from prompt and fallout radiation. Multiple effects make for sicker patients, slower recoveries, and greater danger of severe sickness or death, especially among the old, the young, and the infirm.

A future goal for this work will be to focus on identifying those geographic areas and those combinations of casualties for which scarce medical resources can do the most good in the early stages of a disaster. This will help commanders determine where, among the harder hit areas, they should turn their attention as more resources come to bear. Currently, casualty management modeling and resource estimation support tools such as NBC CREST [19] exist for the military, but much work needs to be done to modify them from a military focus and make them useful in a civil defense environment. Work also
needs to be done on identifying zones of different types of multiple injuries and estimating the impact of a fleeing population on casualties requiring treatment in various zones.

**Use of model estimations to help address limitations in mass casualty resources**

Once accurate model estimations of mass casualty distributions are available, this data could be invaluable in the distribution of limited medical response resources in a WMD crisis in order to minimize mortality and morbidity in mass casualties. Although the National Disaster Medical System has voluntary access to 100,000 hospital beds nationwide, getting patients to these widely dispersed beds in time would be a logistical nightmare in nuclear as well as other WMD scenarios. A particularly dangerous deficiency is the lack of equipment for patient respiration and supportive therapy nationwide [20]. In a crisis in which there are tens of thousands of victims requiring respirators, there is certainly a potential for most of the more critical cases to perish. An ironic feature of the recent terrorist attacks in New York was the lack of impact on the health care system there, since most of the victims in the World Trade Center collapse died, without producing large numbers of ancillary casualties. However, nuclear detonation, as well as most WMD attacks, would be expected to produce the need for large mass casualty resources, including respirators. A national pharmaceutical stockpile has been created by the Centers for Disease Control to provide large supplies of many of the pharmaceutical agents that we would expect to need in likely WMD attack scenarios [21]. Arrangements are in place to use commercial carriers to speed elements of the stockpile to the various locations in which the attacks occur. Selection of the locations to place these critical distribution points would be considerably expedited by accurate predictions of where the casualties that critically need them would most likely be located.

**Data and methods**

**Study area**

Four of the top ten sized cities (New York City, Chicago, Washington, D.C. and Atlanta) were selected for this study of the impact of downtown nuclear detonations on populations and health care systems. All four cities are considered potentially high risk cities for a terrorist event.

**Size of weapon**

Two sizes of nuclear weapon were simulated. The explosion of a tactical nuclear weapon with a predicted yield of 20 kilotons (Kt) and the explosion of the most common size of strategic weapon in the Russian arsenal with a 550 Kt yield. A fission fraction of 1 was assumed for the smaller device and 0.8 was assumed for the 550 Kt device [22]. Both weapons were assumed to explode close to the ground surface, as in a truck or a ship. Bursts at higher levels would cause greater thermal and blast effects which would be somewhat offset by lower downwind radiation amounts.

**Affected population**

Population calculations were based upon block level data from the 2000 census, so calculations are based upon night time population data. In downtown areas, daytime populations, and therefore casualties, would be higher. Secondary deaths from radioactive fallout and other effects of the blasts would greatly increase the immediate deaths. Daytime building population estimates are rarely available but can be very high. Some examples of daytime populations for individual buildings are: Illinois Center in Chicago – 40,000; Empire State Building, New York – 20,000; former World Trade Center Complex – 50,000 employees with up to 100,000 visitors daily. The total nighttime population in Manhattan is roughly 1.5 million rising to 2.1 million with workers during a typical day. To this number must be added visitors for special events and tourists, a number that is highly variable, and for which no official estimates exist [23]. For Washington, D.C. Homeland Security Council (HSC) [24] quotes Oak Ridge National Laboratory’s (ORNL) estimate of the daytime population at 1,066,666 and the nighttime population at 571,476, yielding 495,190 additional people during the day. HSC estimated an additional 701,000 people by day within 11 kilometers (kms) of downtown Washington of which 481,000 were within a 5 km radius of downtown, and an additional 220,000 were distributed in a donut shape with an outer radius of 11 kms and an inner radius of 5 kms. In the absence of building level data, the National Planning Scenarios suggest a better estimate of daytime population for Washington can be obtained by adding an additional 6124 people per square km to the 5 km central part of Washington and 579 people per square km to the 5–11 km ring. [24]. In the case of Manhattan, spreading the additional 600,000 daytime population evenly adds an additional 7,059 per square km during daytime, giving a better approximation of 24,706 per square km for the daytime population without visitors.

**Hospital data**

Data on the number and types of hospital beds were obtained from DTRA’s CATS/JACE database and updated from ESRI’s 2004 Data and Maps [25] and InfoSource’s American Directory of Hospitals 2004 [26]. Psychiatric and other special hospitals were removed from consideration. Some discrepancies were fixed using the American Hospital Directory [27].

**Weather and climate data**

Weather and climate has a significant effect on impacts resulting from a nuclear detonation [28]. Wind is one
major factor, as wind carries the resultant fallout cloud downwind. Atmospheric stability affects the height of the typical mushroom cloud and behavior of the fallout plume, and the amount, thickness and height of clouds impact the scattering, reflection and absorption of radiation. Detonations occurring below clouds have a much greater impact on thermal radiation as radiation is reflected back down to earth, while detonations above cloud reflect radiation out to space and reduce radiation at the surface. Snow also enhances the effect of thermal radiation through its high albedo. Snow and cloud together typically increase the impact of thermal radiation roughly twofold, but in extreme situations, with high visibility beneath dense clouds, there can be up to five times the radiation of a clear day [29].

Average upper air climate for a month or season does not estimate nuclear effects well, as averaging a north and south wind could cancel each other out. What is needed is a synoptic climatology of typical upper air conditions for major cities. These data are currently not available, so for this study we selected a number of case studies from upper-air radiosonde data for particular days, and we have used these weather conditions as model inputs. The data were selected after looking at three years of twice daily skew-T Log P thermodynamic diagrams from the Plymouth State University’s meteorology program WEB site to get a better understanding for the data [30]. The days we have selected are significant days when winds generally ran in a direction with major impact on the health care system. However, these days are not isolated, as similar patterns were seen to repeat on many other days. When analyzing data for civil defense purposes it is critically important not to underestimate the potential impacts of the catastrophe being analyzed. For our selected case studies, data was input on pressure, altitude, temperature, wind speed, wind direction and humidity for several levels up to the 300 millibar level or about 9,000 meters (m).

Model used and sources of uncertainty

We used the DTRA’s CATS-JACE model to simulate the effect of fallout radiation from a nuclear explosion [31], EM-1 to calculate blast effects [32], and Brode’s work [33], as modified by Binninger [34] to calculate thermal fluence, using thermal fractions as discussed in Northrop [35]. With any such models there are many sources of uncertainty in the input parameters which can be expected to impact the accuracy of the predictions.

Atmospheric effects

As noted above, atmospheric conditions affect the quantity of energy absorbed, reflected and scattered, with a highly significant impact on casualty distributions. Near surface bursts create craters and large amounts of dust and solids from the ground, or buildings are thrown into the air. Low cloud above the fireball will cause a considerable degree of reflection back to the surface which will reflect from many different angles and considerably increase the impact of thermal radiation and favor mass fires. Fresh snow on the ground would also reflect the radiation, further increasing the thermal impact.

Wind speed and direction have a tremendous impact on where fallout radiation is deposited. This depends upon many factors, from the overall synoptic situation and topography to local turbulence and surface roughness, land use, and street width and orientation. Models give better results when current three dimensional weather data are utilized as input, along with detailed topography and land use. However, generally speaking, much further work needs to be done before dispersion models can provide detailed, realistic results in complex city centers. Observers have noted large changes in radiation fallout over small distances caused by variations in local atmospheric conditions and topography [36].

Protection offered by buildings and vehicles

Buildings provide various degrees of protection from radiation according to the type of construction and location. The level of protection offered typically varies between 10% and 80%. Some of the factors which affect protection include whether the building is in an urban or rural area, the roof and wall type and thickness, number of floors and location of office or home relative to other floors, e.g., single story, multistory, basement, top floors, middle floors and lower floors and whether glass is shattered by blast [37,38]. Blast damage greatly reduces the protection factors through the blowing in of doors, loss of roof integrity, and breaking of windows. At Hiroshima, windows were broken at a radius of 15 kms by overpressures of only a fraction of a pound per square inch and in exceptional cases were broken up to 27 kms away [38]. Using typical figures from Hiroshima and the cube law for blast extrapolation, one could expect windows to break at up to 17.5 kms for 20 Kt and 53 kms for 550 Kt detonations. Injury thresholds for window glass are considered to be about 0.6 pounds per square inch (psi) [26] or 6 kms for 20 Kt and 18 kms for 550 Kt detonations from fig 2.29 [34]. Recent research [39-41] has shown that buildings, even in their best condition, fail to provide good filtration from radioactive particles in the 1–10 micron range, where the greatest health threat exists.

The highest impacts of radiation generally occur when people are caught in the open, or, are tied up in traffic jams trying to escape in vehicles, which provide little protection against fallout. Based on evidence from recent natural disasters in Louisiana and Florida it is likely that major exit arteries after a nuclear event will be completely...
impassable during the time period when fallout is at a maximum, exposing fleeing population to high levels of fallout. It is also expected that due to lack of information getting to the public, many people will try to flee by car or on foot, often in the wrong direction, again exposing themselves to high levels of radiation, as vehicles provide virtually no protection. Shelter-in-place options are poorly understood, and without effective communications and well thought out and prepared plans by both authorities and potential victims, could prove equally disastrous.

Buildings also protect against thermal effects by blocking a direct line of sight to the detonation. Thermal effects may be affected by such factors as the number, size and orientation of windows; presence or absence of intact windows after the blast; size, number of panes and tinting of glass, presence or absence of bug screens, and height, spacing and orientation of buildings. Window coverings and type of furniture and furnishings will respond differently to the increased thermal surge, with some materials being more susceptible to burning than others.

Discussion and results

Effects of nuclear weapon detonations

Thermal effects – fires and burns

The thermal impacts of a nuclear explosion are always large but scale much faster than blast with larger yield detonations. Thermal radiation decays as the inverse square of the distance from the detonation, while blast decays as the inverse cube of the distance. Figure 1[42] shows the blast and thermal effects from a low free air burst for a 12 Kt (Hiroshima size) and a 500 Kt typical Russian warhead. It shows the much larger rate of increase of the thermal component compared to the blast component in going from the 12 Kt to the 500 Kt devices. A similar effect for 20 and 550 kiloton devices is shown in Figures 2a through 2d, using Atlanta as an illustration. For large weapon sizes (> 100 Kt), significant thermal effects extend to much greater radii than substantial blast effects.

Absorption of thermal energy can cause fires in the vicinity of the detonation point and burns to individuals, either directly from flash burns or indirectly from the mass fires themselves. Binninger et al [34] have conducted work for DTRA on fire prediction modeling. In urban environments, a large number of variables can affect the intensity and impact of the thermal pulse. These include the weapon yield, the fraction of the total yield emitted as thermal radiation, the distance between the weapon and point of interest, and the thermal radiation transmissivity through the immediate atmosphere. EM-1 [32], Brode [33], Binninger [34], Northop [35] and Glasstone [37] have all calculated the thermal fluence for any point at a distance from ground zero, and we have used Brode’s method, as modified in Binninger.

Clouds and the presence of snow have a major impact, and, as noted above, if the fireball occurs below thick continuous cloud, a five-fold increase in reflection may occur. Recent snow cover further increases effects, although the study of cloud and snow interaction is a subject for further research. Cloud height, thickness, type, atmospheric scattering, dust particles in the air, humidity, building orientation and size and location of windows, all have effects, as do type and quantity of flammable materials that will be illuminated within a room. Building construction also plays a major role in room to room and floor to floor spread, as do separation and orientation of neighboring distances [42].

In general, fire effects of nuclear weapons are not as well developed as the modeling of blast and target destruction, yet it is recognized that casualties resulting from fires, and burns in nuclear attack would be of major impact for civil defense [43] and emergency health care. Major fires can occur when thermal fluences exceed 10 calories (cals)/cm² and are very common with fluences over 25 cals/cm², although this varies with the type of construction, building contents, and morphology of the city [34,43]. Fires will start much easier when windows are blown out as glass greatly reduces the thermal fluence inside a room. Skin burns are generally classified into first (like very bad sunburn), second (produce blisters that lead to infection if untreated and permanent scars) and third degree burns (which destroy skin and underlying tissue) and are dependent upon the intensity of the radiant exposure and the size of the explosive device (Table 1 from Fig 12.65 [37]). The entire US has specialized facilities to treat roughly 1,500 burn victims, which is far less than the burn casualties produced by one single small nuclear explosion. Additionally, most of these beds are already occupied.

The thermal effects listed in tables 2 and 3 refer to block level Census 2000 or nighttime affected population that are within the given thermal contour. For populations within the mass fire contour (13 cals/cm²) very few people will escape without some form of significant injury. In the third degree burn zone there will be many burns from resulting fires as well as those directly affected by flash burns from the detonation. For the first and second degree burn zones, the number of people exposed (i.e. in direct line of sight to the fireball) will vary greatly by time of day, time of year, weather, city and building morphology. Weather factors such as cloud above the fireball and snow on the ground will aid in multiple and omni-directional reflection of radiation and greatly increase the numbers and average intensity of burns. Typical exposure propor-

International Journal of Health Geographics 2007, 6:5 http://www.ij-healthgeographics.com/content/6/1/5
Peak blast overpressure and total thermal energy as a function of range from detonation for 12 and 500 Kt weapons. (A) Range dependence of peak overpressure and thermal energy from a 12 kiloton detonation at a height of burst of about 2,000 feet. (B) Similar curves for a 500 kiloton detonation at a height of burst of about 8,000 feet. A comparison of the graphs shows that thermal energy scales much faster than peak overpressure.

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Figure 2
Blast, Thermal and Fallout Effects for 20 Kt and 550 Kt Nuclear Explosions in Atlanta. (a) 20 Kt Blast Intensity. (b) 550 Kt Blast Intensity. (c) 20 Kt Thermal Intensity. (d) 550 Kt Thermal Intensity. (e) 20 Kt Fallout. (f) 550 Kt Fallout.
Table 1: Intensity of thermal fluence by thermal effect type

<table>
<thead>
<tr>
<th>Type of Thermal Effect</th>
<th>20 Kt Device Thermal Fluence Calories/cm²</th>
<th>550 Kt Device Thermal Fluence Calories/cm²</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mass Fires Virtually Certain</td>
<td>25</td>
<td>25</td>
</tr>
<tr>
<td>Mass Fires Likely</td>
<td>13</td>
<td>13</td>
</tr>
<tr>
<td>Mass Fires Possible</td>
<td>10</td>
<td>10</td>
</tr>
<tr>
<td>3rd Degree Burns (50% chance)</td>
<td>7.6</td>
<td>9.4</td>
</tr>
<tr>
<td>2nd Degree Burns (50% chance)</td>
<td>5.0</td>
<td>6.2</td>
</tr>
<tr>
<td>1st Degree Burns (50% chance)</td>
<td>2.5</td>
<td>3.1</td>
</tr>
</tbody>
</table>

The areas of New York, Washington, D.C., Chicago, and Atlanta affected by blast from a 550 Kt nuclear detonation are shown in Figures 3, 4, 5, 6 respectively. The destruction of the major hospitals in the downtown areas is nearly complete in all four cities. Hydrology of the urban areas can be a significant factor with the impact of rivers, lakes, and ocean systems in and adjacent to the urban areas. In New York (Figure 3), with the division of Manhattan from the other city areas by two rivers emptying into the ocean, the loss of the hospital infrastructure is alleviated somewhat by the wider geographic distribution of the health care system (the dense urban packing of hospitals still intensifies the hospital bed loss). In Washington D.C. (Figure 4), hospital distribution occurs primarily north of the Potomac River, further concentrating urban health care systems in the areas significantly impacted by the severe zones of thermal effect. Location next to a large body of water helps to dissipate the effect of the blast damage over water when ground zero is in the downtown area. Inland cities like Atlanta (Figure 6) do not have these mitigating factors, and hospital distribution follows primarily economic factors.

**Blast damage**

Most damage to buildings in cities comes from explosive blast. The blast drives air away from the explosion causing objects to be crushed and high winds that can knock objects down, such as people or trees. Four pounds per square inch (4psi) is usually enough to destroy most residential dwellings. Most blast deaths occur from the collapse of occupied buildings, or from people being blown into objects, or objects impacting people. Typically, about half the people whose low rise buildings collapse on them survive the collapse.

The areas of New York, Washington, D.C., Chicago, and Atlanta affected by blast from a 550 Kt nuclear detonation are shown in Figures 7, 8, 9, 10, respectively. One staggering factor of the blast damage in Washington is the extremely high concentration of government buildings within the blast zones, with higher concentration of buildings corresponding to a higher degree of blast damage (Figure 7). With the overlap of blast damage with thermal effect zones, there is a similar decrease of blast damage coverage in New York due to the presence of river systems as occurred with thermal effects (Figure 8). The lack of hospitals west of the Hudson River, for instance, results in a relatively small impact of blast damage on health care systems in that approximate half of the blast zone (though the relative lack of access to health care in this area will only be exacerbated in this crisis). As noted previously with a 550 Kt detonation in Chicago, location next to a large body of water helps to dissipate the effect of the blast damage over this unpopulated area (as it did for thermal effect). Indeed, for the example of this nuclear attack simulation, ground zero was placed further to the West in anticipation of this factor (Figure 9). If large-scale nuclear devices are detonated immediately adjacent to large water systems in their likely placement in downtown areas, this will consistently lower blast damage and thermal effects. The example of Atlanta, with the widespread distribution of government buildings outside the downtown urban area, demonstrates the disseminated effect in cities located in interior locations away from significant water systems (Figure 10). However, there still is a disproportionate effect on health care systems, though not as distinctive as in the other cities in this study.

**Source Region Electro-magnetic Pulse (SREMP)**

Electrical and electronic equipment, both plugged-in and some unplugged, will be severely impacted in areas affected by Source Region Electro-magnetic Pulse (SREMP). SREMP is produced by low-altitude nuclear bursts and will affect areas from 3–8 km radius from the detonation point depending upon yield [33], with National Planning Scenarios assuming 4 kms for a 10 Kt device. This is roughly the same region likely to be affected by blast and shock. For hospitals this means power and any connected backup power sources will be lost, and...
most equipment connected using a plug to access power will likely have been destroyed by SREMP. Equipment that is unplugged may or may not be affected. SREMP affected areas extend up to the 1psi blast contour for small blasts (< 20 Kt) and up to somewhere between the 1 and 2psi contours for our 550 Kt example.

The combination of SREMP on electronics, and blast effects on antenna integrity and alignment will severely curtail radio, cell phone and satellite communications in a post event environment [46].

**Prompt radiation**

Prompt radiation occurs from fission products in the first second after a nuclear explosion. Significant health effects extend out to roughly 2 kms for a 20 Kt nuclear detonation and to 3–4 kms for a 550 Kt device, depending upon the radiation characteristics of the actual device. In general, radiation doses closer to ground zero are very high with a rapid fall off in dose as one proceeds outward. Within the inner zone near ground zero fatalities are generally 100% for those exposed in the open, and, even for those in buildings, mortality will be high except for those in basements.

**Fallout radiation**

The conical-shaped plumes of casualties generated by radioactive fallout account for the largest geographic distribution of effect from most nuclear weapon detonations. Most of the radioactive particles generated by the blast will fall within 24 hours on areas extending out from ground zero in the direction of prevailing winds and is referred to as early fallout.

From the radioactive fallout, the larger, relatively more radioactive particles fall out closer to the detonation area within hours. Known generally as "early fallout" this constitutes by far the greatest hazard to health. Slightly smaller particles generated by the nuclear blast will behave like aerosols and are dispersed into the troposphere where they could stay suspended for months. The fallout from this portion remains in bands around the earth at the latitude of the detonation. This portion of the fallout is often referred to as "late fallout", and is less hazardous than early fallout [47]. Additional fallout pene-

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**Table 2: Affected populations from 550 Kt surface detonations in 4 downtowns**

<table>
<thead>
<tr>
<th>Effect Type</th>
<th>Washington</th>
<th>New York</th>
<th>Chicago</th>
<th>Atlanta</th>
</tr>
</thead>
<tbody>
<tr>
<td>Combined Fallout and Thermal</td>
<td>2,678,638</td>
<td>6,456,056</td>
<td>3,398,527</td>
<td>1,243,165</td>
</tr>
<tr>
<td>Combined Fallout and Blast</td>
<td>2,541,368</td>
<td>6,001,862</td>
<td>3,167,676</td>
<td>1,178,751</td>
</tr>
<tr>
<td>All Thermal categories</td>
<td>923,401</td>
<td>3,309,930</td>
<td>1,614,371</td>
<td>459,639</td>
</tr>
<tr>
<td>All Fallout categories</td>
<td>2,170,917</td>
<td>5,042,904</td>
<td>2,430,731</td>
<td>1,064,928</td>
</tr>
<tr>
<td>All Blast categories</td>
<td>708,710</td>
<td>2,554,308</td>
<td>1,251,965</td>
<td>353,925</td>
</tr>
<tr>
<td>All Thermal categories &gt; 25 cal cm² Zone</td>
<td>923,401</td>
<td>3,309,930</td>
<td>1,614,371</td>
<td>459,639</td>
</tr>
<tr>
<td>&gt; 13–25 cal cm² Zone</td>
<td>211,206</td>
<td>903,591</td>
<td>316,847</td>
<td>122,572</td>
</tr>
<tr>
<td>3rd Degree Burn Zone</td>
<td>135,752</td>
<td>521,519</td>
<td>305,725</td>
<td>68,720</td>
</tr>
<tr>
<td>2nd Degree Burn Zone</td>
<td>94,202</td>
<td>315,388</td>
<td>190,071</td>
<td>42,141</td>
</tr>
<tr>
<td>1st Degree Burn Zone</td>
<td>165,557</td>
<td>509,926</td>
<td>256,134</td>
<td>71,496</td>
</tr>
<tr>
<td>All Fallout Categories &gt; 25 cal cm² Zone</td>
<td>316,684</td>
<td>1,059,506</td>
<td>545,594</td>
<td>154,710</td>
</tr>
<tr>
<td>Mortality &gt; 0.5%</td>
<td>2,170,917</td>
<td>5,042,904</td>
<td>2,430,731</td>
<td>1,064,928</td>
</tr>
<tr>
<td>Mortality &gt; 50–90%</td>
<td>1,016,206</td>
<td>3,229,502</td>
<td>1,473,337</td>
<td>614,767</td>
</tr>
<tr>
<td>&gt; 10–50%</td>
<td>583,486</td>
<td>493,519</td>
<td>261,381</td>
<td>123,160</td>
</tr>
<tr>
<td>&gt; 0.5–10%</td>
<td>311,292</td>
<td>678,783</td>
<td>180,456</td>
<td>119,567</td>
</tr>
<tr>
<td>All Blast categories &gt; 1psi</td>
<td>708,710</td>
<td>2,554,308</td>
<td>1,251,965</td>
<td>353,925</td>
</tr>
<tr>
<td>&gt; 20psi</td>
<td>20,710</td>
<td>158,889</td>
<td>52,950</td>
<td>19,476</td>
</tr>
<tr>
<td>10–20psi</td>
<td>32,703</td>
<td>155,019</td>
<td>34,704</td>
<td>25,437</td>
</tr>
<tr>
<td>3–10psi</td>
<td>158,287</td>
<td>596,150</td>
<td>231,341</td>
<td>77,985</td>
</tr>
<tr>
<td>2–3psi</td>
<td>138,363</td>
<td>537,279</td>
<td>316,306</td>
<td>71,105</td>
</tr>
<tr>
<td>1–2psi</td>
<td>358,647</td>
<td>1,106,971</td>
<td>616,664</td>
<td>159,922</td>
</tr>
</tbody>
</table>

* Approximately 500,000 additional daytime workers will be affected for Washington and 600,000 for New York for the second degree burn zones or the 2psi zone. No data are available for Atlanta and Chicago.
trates the stratosphere and its particles are deposited worldwide over a period of months to years [28]. Most of the radioactive fallout is downwind from the explosion and up to 70 per cent is in the larger particle portion, or "early fallout" occurring within hours. One principle of note is that the intensity of the radioactivity varies inversely with distance from the site of explosion. With a steady wind, the pattern of accumulated dose of radioactivity assumes the shape of nested cigar-shaped contours, each contour denoting a particular dose [48].

In a nuclear explosion, over 400 radioactive isotopes are released into the biosphere. Among these, about 40 radio nuclides are considered potentially hazardous [49]. Of particular interest are those isotopes whose organ specificity and long half-lives present a danger of irreversible damage or induction of malignant alterations [50,51]. Both early and delayed fallout result in the deposition of radioactive material in the environment [52]. The annual average whole-body fallout rate in the United States at the end of the 20th Century was approximately 45 FsV (4.5 mrem) [53,54].

To consider the relative long-term impact of fallout, a device about twice the size of the 550 Kt weapon analyzed in this study (one MT), detonated at ground level with a steady wind of approximately 15 miles per hour, would produce a fallout radioactivity dose rate of 400 rem in 24 hours in an area of approximately 400 square miles. At a dose rate of 2 rem per year, more than 20 times the maximum recommended by the EPA, an area of 1,200 square miles would remain unfit for use for a year and more than 20,000 square miles would be uninhabitable for a month [55].

Several Federal Web sites offer good discussions of nuclear issues including fallout [56-58]. The Department of Homeland Security has a number of ongoing initiatives such as the Radiological and Nuclear Countermeasures Program to enhance U.S. security against unconventional attacks. Their summary provides an excellent background

Table 3: Affected population from 20 Kt surface detonation in 4 downtowns

<table>
<thead>
<tr>
<th>Effect Type</th>
<th>Washington</th>
<th>City</th>
<th>Chicago</th>
<th>Atlanta</th>
</tr>
</thead>
<tbody>
<tr>
<td>Combined Fallout and Thermal</td>
<td>188,430</td>
<td>1,649,587</td>
<td>614,535</td>
<td>182,717</td>
</tr>
<tr>
<td>Combined Fallout and Blast</td>
<td>233,570</td>
<td>1,733,983</td>
<td>637,033</td>
<td>207,025</td>
</tr>
<tr>
<td>All Thermal categories</td>
<td>39,641</td>
<td>140,701</td>
<td>79,451</td>
<td>36,256</td>
</tr>
<tr>
<td>All Fallout categories</td>
<td>172,819</td>
<td>1,592,968</td>
<td>554,048</td>
<td>160,224</td>
</tr>
<tr>
<td>All Blast categories</td>
<td>92,040</td>
<td>286,587</td>
<td>104,988</td>
<td>63,814</td>
</tr>
<tr>
<td>All Thermal categories</td>
<td>39,641</td>
<td>140,701</td>
<td>79,451</td>
<td>36,256</td>
</tr>
<tr>
<td>&gt; 25 cal cm² Zone</td>
<td>1,024</td>
<td>12,336</td>
<td>11,574</td>
<td>1,431</td>
</tr>
<tr>
<td>&gt; 13–25 cal cm² Zone</td>
<td>963</td>
<td>15,303</td>
<td>14,685</td>
<td>1,810</td>
</tr>
<tr>
<td>3rd Degree Burn Zone*</td>
<td>3,132</td>
<td>20,660</td>
<td>12,456</td>
<td>5,001</td>
</tr>
<tr>
<td>2nd Degree Burn Zone**</td>
<td>9,876</td>
<td>22,993</td>
<td>10,381</td>
<td>8,593</td>
</tr>
<tr>
<td>1st Degree Burn Zone</td>
<td>24,646</td>
<td>69,409</td>
<td>30355</td>
<td>19,421</td>
</tr>
</tbody>
</table>

To take into account daytime populations near central business districts [26]
* Add roughly 32–35,000 additional people within 3rd degree burn isoline
** Add roughly 53–60,000 additional people within 2nd degree burn isoline
*** Add roughly 50,000 additional people within the 3psi isoline and 90,000 within the 2psi isoline.
on where we are today and where we are going, as well as some useful theory [59]. Should a real event occur, federal assistance can be provided by specialized teams, such as the Oak Ridge Institute for Science and Education's (ORISE) Radiation Emergency Assistance Center (REAC/TS) [60]. These teams can also provide pre-event nuclear and radiation training.

The areas of New York, Washington, D.C., Chicago, and Atlanta affected by fallout and thermal from 550 Kt and 20 Kt nuclear detonations are shown in Figures 11, 12, 13, 14 and Figures 15, 16, 17, 18, respectively. In the case of New York, the prevailing West to East weather pattern results in a conical extension of fallout casualties down the length of Long Island following the 550 kt detonation in Manhattan (Figure 11). This scenario carries significant negative impacts on the health care systems distributed consistently along the length of the island, with 51% of hospitals and 53% of the medical staff lost within 20 miles of ground zero (Table 4). This is the highest number of affected hospitals (at 54) in this publication, for all four cities considered. Even for the smaller 20 Kt weapon in New York (Figure 15), wind patterns coming inland off of the ocean result in a devastating loss of the great majority

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**Figure 3**
of health care systems located between the East and Hudson Rivers due to the resulting fallout.

The stunning impact of fallout radiation from the 550 Kt detonation is evident from the loss of the hospital systems from two major metropolitan areas: the loss of Washington D.C. health care systems from the thermal and blast effects and the loss of Baltimore hospitals from the fallout plume 40 miles away (Figure 12). This resulted in a 48% loss of hospitals in the 20 mile buffer around the two cities, a 57% loss of beds, and 67,000 health care workers directly affected for a total loss of 62% of the workers (Table 4). In Figure 16, the mass fire zones in Washington D.C. after a 20 Kt detonation are hardly visible due to the
Figure 5
A large number of government buildings in the burned out areas. Even for this relatively small nuclear device, half of the hospitals in the immediate vicinity of the city will be circumscribed by the fallout plume.

Not all fallout plumes will be symmetrical cones in shape, as demonstrated in Figure 13 in Chicago, with the weather pattern for that day resulting in a broader, heart-shaped plume extending from ground zero into the interior.
beyond Lake Michigan. Such expansions can greatly increase the impact on health care systems, as indicated by the 48% loss of hospital beds within 20 miles of the plume area (Table 4). This is similar to the hospital bed loss rate for both cities affected by the Washington detonation (Washington D.C. and Baltimore), and considerably higher than the hospital loss rates for New York and Atlanta. The actual percentage of hospital bed loss also was higher for Washington D.C. and Chicago than for New York and Atlanta. Unlike Washington D.C. though, the smaller 20 Kt detonation did not have the same inclusive effect on hospital loss, with the narrow radiation
plume in the Chicago example leaving a large number of unaffected suburban hospitals intact. In this case, the significant urban sprawl of America's third largest city has resulted in a sufficiently widespread distribution of suburban hospitals, resulting in a significant number of hospitals escaping deactivation from the relatively narrow fallout plume. A similar situation is seen with Atlanta (Figure 18), where the narrow fallout plume of the smaller 20 Kt device devastates several key urban hospitals, but many more in the suburban sprawl are apparently spared contamination resulting in immediate threat to life.

**Measuring radiation dosage**

Like most drugs or chemicals, there is a relationship between radiation dose and its effect on the body. Radiation dosing can be thought of as an amount of energy absorbed by the body. The rad is a unit of absorbed radiation dose defined in terms of the energy actually deposited in the tissue. One rad is an absorbed dose of 0.01 joules of energy per kilogram of tissue. To accurately assess the risk of radiation, the absorbed dose energy in rad is multiplied by the relative biological effectiveness (RBE) of the radiation to get the biological dose equiva-
lent in rems. The RBE is a "quality factor," often denoted by the letter $Q$, which assesses the damage to tissue caused by a particular type and energy of radiation. For alpha particles, $Q$ may be as high as 20, so that one rad of alpha radiation is equivalent to 20 rem. The $Q$ of neutron radiation depends on their energy. However, for beta particles, x-rays, and gamma rays, $Q$ is taken as one, so that the rad and rem are equivalent for those radiation sources [61,62].

Figure 9
Overall effects

The effects of thermal, blast and radiation for both 20 and 550 Kt events can be readily seen in figures 2a through 2f. Blast and thermal effects can be compared for 20 and 550 Kt detonations in figures 2a and 2b, and 2c and 2d respectively. All four of the figures are on the same scale. The figures readily bring out the relative importance of blast compared to thermal for the smaller 20 Kt event (compare figure 2(a) to 2(c)) and the much larger effects of thermal with the larger 550 Kt event (compare figure 2(d) to 2(b)). The much greater relative size of the fallout plume for a 550 Kt compared to a 20 Kt event is easily seen in figures 2e and 2f, which are at the same scale.

Despite the smaller effect of thermal compared to blast for the 20 Kt detonation, it must be emphasized that hospitals have very few burn beds in the entire U.S.A. (< 1500) and only a few (less than 150) are not occupied at any one time. Even a small nuclear event will totally overwhelm our hospitals' ability to take care of resulting burn casualties.

Figure 10

Figure 11
**Figure 12**


Figure 13
Figure 14
Figure 15
Thermal and Fallout Impacts of a 20 Kt Surface Nuclear Detonation on New York City with Weather as of August 8th, 2003.

Figure 16
Figure 17
Figure 18
Table 4: Effect of 550 Kt detonation on health care in four cities*

<table>
<thead>
<tr>
<th>Affects of 550 Kt Detonation within 0.1% mortality contour and 1 psi</th>
<th>Hospital Beds in Affected Area (in thousands)</th>
<th>Total Beds within 20/40 miles of incident edge (in thousands)</th>
<th>%Beds lost within 20/40 miles of incident edge</th>
<th>Number of Hospitals in Affected Areas</th>
<th>Additional Hospitals within 20/40 miles outside affected area</th>
<th>% Hospitals lost to incident</th>
<th>Number of Health Staff Affected by incident (in thousands)</th>
<th>Additional Health Staff within 20/40 miles (in thousands)</th>
<th>% Health Staff Lost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Washington</td>
<td>9.9</td>
<td>7.3/13.1</td>
<td>57/43</td>
<td>30</td>
<td>33/61</td>
<td>48/33</td>
<td>67.1</td>
<td>41.7/81.0</td>
<td>62/45</td>
</tr>
<tr>
<td>New York</td>
<td>24.5</td>
<td>24.0/33.6</td>
<td>51/42</td>
<td>54</td>
<td>77/107</td>
<td>41/34</td>
<td>145.3</td>
<td>127.4/178.2</td>
<td>53/45</td>
</tr>
<tr>
<td>Chicago</td>
<td>12.1</td>
<td>9.8/17.3</td>
<td>55/41</td>
<td>42</td>
<td>45/72</td>
<td>48/37</td>
<td>75.1</td>
<td>58.0/99.8</td>
<td>56/43</td>
</tr>
<tr>
<td>Atlanta</td>
<td>4.5</td>
<td>4.4/10.3</td>
<td>50/43</td>
<td>14</td>
<td>23/40</td>
<td>38/26</td>
<td>28.8</td>
<td>25.8/35.2</td>
<td>53/45</td>
</tr>
</tbody>
</table>

* Effect contour was considered to be 0.1% mortality for radiation or 1 pound per square inch for blast, which would break windows and also subject staff to some burn effects when exposed to thermal radiation.

**Effects of 20 Kt surface detonation**

In the first 750 m (12psi) virtually all buildings will be destroyed by blast, mass fires are common and prompt radiation doses are fatal except in basements, resulting in very few survivors. Between 750 and 1250 m the peak overpressure decreases from 12 to 5psi with walls blown out of buildings, though building frames may well survive. Debris will be tens of feet thick in most downtown areas with ten-plus story buildings [45]. Roughly half of the population in this area will be fatalities, mainly from collapsing buildings, with the other half injured. Most of those surviving will have been exposed to a fatal dose of prompt radiation, though death will occur first due to mass fires or third degree burns. Between 1250 m and 1750 m peak overpressures will fall from 5psi to near 3psi, and burn thresholds towards the edge of this zone will drop from third degree to second degree levels. Prompt radiation also will typically drop quickly from over 800 rem at 1600 m to over 400 rem at 1700 m. At 1900 m or 3psi, large numbers of trauma injury would ensue from walls blown out of steel framed buildings, severe residential damage and people caught in the open. By 2000 m, burn risk will drop to first degree levels. At up to 3800 m or 1 psi people will be endangered with flying glass and debris from damaged structures and glass will break out to over 6 kms, exposing those houses in the downwind fallout radiation zone to more radiation.

**Effects of 550 Kt surface detonation**

A 550 Kt detonation differs dramatically from a 20 Kt one as the thermal effect increases dramatically in proportion to blast effects. Thermal intensities of 25 cals/cm2 with high mass fire probability reach out 4.7 kms or as far as the 3.8 psi blast contour, while 13 cal/cm2 intensities with many fires or even mass fires in some cities reach out to 6.3 kms, roughly the same as the 2.5 psi blast contour.

In the first 1800 m peak overpressures will exceed 20psi, destroying even the largest and best built structures. At 2200 m overpressures will be above 12 psi, destroying virtually all but a very few specially constructed buildings. The five psi contour extends out to 3,800 m, where the walls of most buildings are blown out. Most or all of this area will have very high prompt radiation values depending upon the bomb design. In addition the area will almost certainly be consumed by fire as thermal fluences exceed 25 cals/cm² out to 4700 m. The high blast, high radiation and high thermal combination means there will be virtually no long-term survivors from these areas. High thermal fluences continue out to beyond 6 kms (13 cal/cm²) with overpressures of 2.5 psi. At 7 kms thermal fluences still exceed 10 cals/cm², associated with 2 psi overpressures. Some of those areas will experience fires, even mass fires in some cities like Atlanta where there are many frame houses within these contours. Secondary fires will also start from damaged gas and power lines. Third degree burns extend out to 7.3 kms with 2 psi overpressure present, and second degree burns occur out to 8.7 kms with overpressures exceeding 1.5 psi. Overpressures of 1 psi with first degree burns extend to almost 12 kms and the 0.5 psi glass breakage extends out to almost 20 kms.

**Populations affected by the detonations**

Tables 2 and 3 show the affected populations in each of the four cities for 550 and 20 Kt detonations. They are broken down into those affected by thermal, fallout radiation, blast hazards and combined effects. The actual percentage of the affected population in each group that becomes a casualty depends on many factors, as well as the interaction of the hazards.

**Casualties from fallout**

In the most extreme example of this effect in these simulations, mortality rates from 90+% in Brooklyn extend continually across the length of Long Island to 1% at the eastern tip, with deaths due solely to radioactive fallout (without thermal or blast injuries) from the 550 Kt detonation in New York [Figure 11]. This could result in over 5,000,000 deaths in the > 90% plume area, which would extend from Brooklyn to almost half the length of Long Island.
Island (the most populous half). As evaluated in the combined injuries section, these numbers inevitably include some thermal and blast initiated deaths.

An interesting pattern in these graduated mortality plumes is that for the smaller 20 Kt detonation, the number of victims in the 50–90% radioactive fallout plumes is considerably less than in the 10–50% mortality range plumes. For example, in the 20 Kt blast for New York (Figure 15 and Table 3), for example, those mortality numbers are 145,123 and 358,922, respectively, or an approximate 1:2 ratio. This was also the case for the 20 Kt Washington D.C. (Figure 16) and Chicago (Figure 17) mortality plumes for radioactive fallout in the 50–90% and 10–50% mortality ranges. For Atlanta (Figure 18), the same pattern was also seen except the difference was even higher at almost 1:4. This higher number of fatalities in the areas with a lower percentage of mortality is due to the smaller area covered by the 50–90% mortality plumes relative to the higher (904%) and lower (10–50%) ranges upwind and downwind. Apparently, the very high deposition rates of radioactive particles that occur in the first kilometers from the detonation rapidly drops off in magnitude with wind dispersion, with the broader areas of dispersion at the lower concentrations of radioactivity sufficient to account for remarkably higher rates of mortality.

**Combined injuries**

The coincidence of the thermal and blast casualty areas emanating from ground zero generates both a zone of dual casualty categories as well as a greatly enhanced mortality and morbidity rate for the geographically impacted areas. Figures 2b and 2d show substantial areas affected by both blast and thermal hazards. The casualty model predicts a zone of mass fires with >25 cals cm\(^2\) for both sizes of nuclear weapons detonations in these simulations. In this area, the fireball generated by the blast, as well as spontaneous incineration of buildings from radiant heat, will generate mass fires that would consume the great majority of the structures above ground. This quantity of thermal energy would be expected to result in virtually complete mortality from thermal injuries alone. For all four cities, for a 550 Kt detonation the model generates a nearly equivalent geographic area for this central >25 cals cm\(^2\) mass fire zone as it does for the blast ring incorporating trauma injuries resulting from up to 3 lbs/in\(^2\) blast pressure. The central blast rings of 20 and 10 lbs/in\(^2\) would be expected to result in primarily complete mortality from the blast effects, like the total mortality resulting from thermal effects in the >25 cals cm\(^2\) thermal zone. However, there would have been significant survival from blast trauma effects in the 3 lbs/in\(^2\) blast ring were it not for its coincidence with the >25 cals cm\(^2\) thermal zone. These people surviving blast trauma injury would succumb instead to death from the mass fires.

Overall, the total number of affected population by thermal injuries is 30% greater than that for blast injuries for all four cities for the 550 Kt detonation predictions (Table 2). Outside the mass fire areas, there will be geographic areas dominated by either first, second, or third degree burns in surviving victims of the nuclear detonation. These three thermal injury category zones coincide approximately with the 1 and 2 lbs/in\(^2\) blast ring areas in all four cities for the 550 Kt detonation simulations (compare Figures 3, 4, 5, 6 for thermal with Figures 7, 8, 9, 10 for blast). The total number of thermal injuries from the 2nd and 3rd degree burn areas is consistently smaller than the trauma injuries in these geographically similar areas for the 1–2 psi blast rings. For Washington, New York, Chicago, and Atlanta (550 Kt simulations in Table 2), these two burn areas together produce 73%, 75%, 72%, and 71%, respectively, of the blast injuries from 1–2 psi that occur in the same approximate area.

A comparison/contrast of blast, thermal and prompt radiation effects is best made with the 20 Kt detonation, as the dominance of thermal effects at the larger nuclear detonations masks their associations. For a 20 Kt detonation mass fires from 13 cals/cm\(^2\) thermal fluences would normally extend out to a location where blast effects at the 7psi level are also present. Blast effects alone at 7psi would account for at least 10% fatalities with virtually all of the rest injured due to catastrophic structural damage and impaction or injuries from flying glass. Just 80 m closer to ground zero, fatalities due to blast at 8psi would leap to 50%. Much of this zone would likely be consumed by mass fires as it is within the 13 calorie/cm\(^2\) contour. It is also well within the area of intense prompt radiation with values well over 1000 rem; only those in well protected basements or in subways would escape this prompt radiation.

The third degree burn zone would extend out to where blast intensities of just over 4psi were experienced, causing major structural damage to frame houses and lighter commercial construction. In addition to burns, many injuries will occur because of movement of interior walls and objects, and impaction of humans, especially those standing, on fixed items. In addition, prompt radiation of over 1000 rem in the open will have affected the entire area, greatly compounding the recovery process for those experiencing good protection by buildings and causing death to those exposed in the open or in many types of buildings [[26], 1–10]. In this third degree burn zone, 15% of the affected population who are outside or near line-of-sight windows will die because of second degree or worse burns to their bodies followed by shock; another
40% will have buildings or walls fall on them and be killed, trapped or injured with trauma events. At least 15% will receive lethal prompt radiation doses and 10% will die in the plume from exposure to very high levels of fallout radiation. Of the 20% left, about a third will have received about 500 rem (assuming an average protection factor of 0.5 for prompt neutrons) which will eventually prove fatal in this environment. Another third will receive about 300 rem, which will prove fatal for 5–10% of them after 60 days. In the end, there may only be a 10% survival rate in the third degree burn zone (1500 m).

As we move from the 1500 meter to the 2000 meter distance from ground zero, conditions for survival improve rapidly. Peak overpressures decrease from 4 psi to just over 2.5 psi and burn injuries decrease to first degree. Two psi is reached at 2300 m and one psi at 3800 m. Prompt radiation falls off precipitously between 1600 (1000+ rem), 1700 (400 rem) and 2000 m (80 rem). Many of those in the open will have been subject to fatal doses, but those inside with reasonable protection factors should be safe from prompt radiation in the outer parts of this zone. Mortality and morbidity will remain high for those in the fallout plume as these people will have been exposed to very high levels of radiation, with some additional blast and burn injury combinations.

Injuries from breaking glass will occur at over 6 kms, where radiation in the fallout plume is 1800 rem. Most injuries beyond 2000 m will occur due to people being caught in the fallout plume where radiation exposures, even with protection, remain in the fatal range (2400 rem in the open at 3800 m).

Due to the combination of injury categories, death rates can be exacerbated far beyond that expected for any one of the injuries taken alone. Victims cannot move and could be consumed by fire or are simply left to die due to lack of resources. Others fall victim to poor sanitation due to failure of the main power, water and waste facilities. Lack of immediate (12 hours) or even intermediate (48 hours) health care often results in the body going into shock or succumbing to infection, which would not have occurred had basic health care been available.

**Immediate deterioration of urban institutional health care resources**

The nationwide trend of locating a majority of the major urban health care institutions in downtown areas would result in a staggering loss of the total institutional health care delivery following nuclear weapon use. Data is shown for the four example cities in Table 4, though we have seen very similar results in the 20 largest U.S. urban areas (data not shown).

The four cities in Table 4 show 50–56% loss of hospital beds within a 20 mile radius of a 550 Kt detonation, and a 41–43% loss of beds at a 40 mile radius from a downtown ground zero. These results are strikingly similar in view of the very different geographic and demographic landscapes of these four cities. When considering the actual number of hospitals lost, Washington D.C., New York, and Chicago are similar in magnitude of the percentage of hospitals lost, between 41–48% within 20 miles, and 33–37% lost within 40 miles of the detonation. Atlanta, which is the smallest city of the test sample, had a smaller percentage of hospitals lost compared to the others. Due to the pattern of having the larger hospitals in the downtown area, Atlanta still had a similar percentage of bed loss, even though the number of hospitals lost overall was smaller.

A closer look at the New York map (Figure 11) shows that the situation is much worse for Long Island residents as half of the hospitals within 20 miles are either west of the Hudson in New Jersey and inaccessible due to high radiation levels and/or fires on Manhattan or only accessible by water across Long Island Sound. The loss of critical tunnels and bridges from Manhattan and contamination of boats along southern Long Island Sound would vastly complicate the relief effort and medical response for Long Island residents.

As emergency planners begin to understand the importance of providing surge capacity some ameliorating events are occurring. In the State of Georgia, the Division of Public Health has purchased 11,000 portable emergency hospital beds which is an impressive increase of almost 70% over existing bed capacity for the State. These resources will be distributed around the State and, in an emergency, could be moved closer to the disaster for greater efficiency in treatment and as a means to increase the capacity of surviving hospitals. This approach is now being pursued by other states.

Obviously, the most important resource in medical response are the trained health care personnel, and it is in this area that the most dramatic impact of a nuclear detonation is seen on overall health care response. Losing at least half of your health care responders in the first minute of the attack is all the more damaging because so many of the thermal and trauma injuries require immediate care and cannot wait for the time-consuming importation of replacement medical workers.

Another issue deals with medical and credentialing records. Currently many records are stored in inner city areas and may be lost in an attack. Many hospital records are not stored off site and patient and staff records could be lost or made inaccessible. Much work needs to be done
on supporting informatics to ensure overall post-event success.

One very important finding in the loss of hospitals and medical resources from urban nuclear attack is the potential for a relatively greater impact of thermal injuries versus blast effects as the magnitude of the nuclear device increases. Comparison of Figures 3 and 7, representing thermal and blast impacts, respectively, for a 550 Kt detonation in New York, demonstrates that overall there is a greater radius of impacted hospitals from thermal effects than blast effects. This pattern is repeated for Washington D.C. (Figures 4 & 8), Chicago (Figures 5 & 9), and Atlanta (Figures 6 & 10). The outer edges of effects for the blast effects, with 1 or 2 psi, could be expected to impact the hospitals in those areas certainly, by blowing out windows, moving equipment around, and, in combination with thermal effects, injuring 25–45% of the population. However, the outer edge of the second degree burn zone burns extends roughly to the 1.5 psi radius (5.4 miles) and would severely impact personnel in any hospital in direct line of sight to the explosion. First degree burn effects extend out further (7 miles), roughly to the 1 psi contour. Even if some attempt to restore the hospital infrastructure was made, combined thermal, EMP and blast injuries would make it unlikely that the personnel would be able to function effectively, especially in a mass casualty crisis.

**Future directions for improvement in casualty models to expedite disaster response**

One of the largest limiting factors of these models is that they require one to model an event of a known size. Initial data will be inadequate to estimate the size of the weapon with any certainty. Is it a 5, 10, 20 Kt or larger event? As more information becomes available, better estimates may be made. The collection of relevant real time data from field sensors would greatly improve early estimates of the event size and event impact, enable the models to be run iteratively, making their output more reliable with time and greatly improve decision-making. To maximize the efficacy of these models and their associated databases, responders, from the emergency medical technician on scene, all the way up to the incident commander, must understand in general terms the capabilities and limitations of our models. Accordingly, it would be necessary to involve them in tabletop and field exercises involving the use of models.

Improved calculation of thermal effects (including burns and mass fires) and fallout estimates for dense multi-storey urban environments in major US cities require more detailed databases. DITRA is already coordinating the creation of building databases for priority U.S. cities. Oak Ridge National Laboratories is preparing a more accurate LandScan USA database on a 90 meter grid with both daytime and nighttime population estimates for future release [63]. Detailed land use and tax parcel data and building information (height, construction date and type, number of stories, etc) are being acquired for several cities and will help to further refine the models and test the sensitivity of the casualty estimates to different variables. The incorporation of numbers of people actually present in downtown and in the suburbs during working hours will improve our predictions immensely. The addition of detailed journey-to-work (origin-destination) data and building-level population data from fire departments and insurance risk assessments to estimate daytime populations in urban centers will make for better casualty planning and management.

These increased capabilities allow detailed Geographic Information Systems analyses of the impact of potential mass fires, and, of first, second and third degree burns, and fallout and blast from nuclear incidents. Analysis of block group data allows the impact of skin color and age to be taken into account for better estimating burn intensity and fallout mortality. More detailed data on buildings allow the use of better radiation protection factors, which improves casualty estimations further. They also improve life and death decision-making processes such as shelter-in-place or flee. These additional data permit the interaction of blast, thermal and fallout effects to be better modeled and thus generate more robust estimates of different types of potential mass casualties which, in turn, help us plan better responses for casualty prioritization and treatment, given the limited medical resources that will be available in the first few days after an incident.

While preparing for the potential use of WMD within areas that have not seen mass casualties previously (such as the United States) is of critical importance, these “upgrades” of emergency response capabilities will also have important “peacetime” benefits. Geographic information systems used in tracking releases of toxic chemical and radioactive agents and mobilizing emergency response resources to targeted areas would also be highly useful in responding to tornado and flood disasters. While we can continue to hope that large-scale mass casualties from WMD attacks will remain high consequence, low probability scenarios, it is mandatory that we invest the appropriate physical and human resources to deal with such a staggering prospect.

**Competing interests**

The author(s) declare that they have no competing interests.
Authors’ contributions
WCB and CED jointly conceived the paper concept, formulated the focus on health care vulnerability, and selected the scenarios from a much larger available set of urban nuclear attack simulations conducted by this group. WCB programmed the thermal and blast effects, built the database and ran the GIS and CATS/HPAC models. CED and WCB jointly analyzed the data outputs and shared in the manuscript composition. Both authors read and approved the final manuscript.

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The “RTR” Medical Response System for Nuclear and Radiological Mass-Casualty Incidents: A Functional TRiage-TReatment-TRTransport Medical Response Model

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Abstract
Developing a mass-casualty medical response to the detonation of an improvised nuclear device (IND) or large radiological dispersal device (RDD) requires unique advanced planning due to the potential magnitude of the event, lack of warning, and radiation hazards. In order for medical care and resources to be collocated and matched to the requirements, a [US] Federal interagency medical response-planning group has developed a conceptual approach for responding to such nuclear and radiological incidents. The “RTR” system (comprising Radiation-specific TRiage, TReatment, TRTransport sites) is designed to support medical care following a nuclear incident. Its purpose is to characterize, organize, and efficiently deploy appropriate material and personnel assets as close as physically possible to various categories of victims while preserving the safety of responders. The RTR system is not a medical triage system for individual patients. After an incident is characterized and safe perimeters are established, RTR sites should be determined in real-time that are based on the extent of destruction, environmental factors, residual radiation, available infrastructure, and transportation routes. Such RTR sites are divided into three types depending on their physical/situational relationship to the incident. The RTR1 sites are near the epicenter with residual radiation and include victims with blast injuries and other major traumatic injuries including radiation exposure; RTR2 sites are situated in relationship to the plume with varying amounts of residual radiation present, with most victims being ambulatory; and RTR3 sites are collection and transport sites with minimal or no radiation present or exposure risk and a victim population with a potential variety of injuries or radiation exposures. Medical Care sites are predetermined sites at which definitive medical care is given to those in immediate need of care. They include local/regional hospitals, medical centers, other sites such as nursing homes and outpatient clinics, nationwide expert medical centers (such as cancer or burn centers), and possible alternate care facilities such as Federal Medical Stations. Assembly Centers for displaced or evacuating persons are predetermined and spontaneous sites safely outside of the perimeter of the incident, for use by those who need no immediate medical attention or only minor assistance. Decontamination requirements are important considerations for all RTR, Medical Care, and Assembly Center sites and transport vehicles. The US Department of Health and Human Services is working on a long-term project to generate a database for potential medical care sites and assembly centers so that information is immediately available should an incident occur.

Background

Preparation for a mass-casualty radiological or nuclear incident in the US requires unprecedented planning, organization, and cooperation among Federal agencies, and state, local, tribal, territorial, regional, and private sector responders. The Office of the Assistant Secretary for Preparedness and Response of the Department of Health and Human Services (HHS) is responsible for all-hazards preparedness. The RTR model is designed specifically for radiation-related mass-casualty events due to the:

1. Threat of potential radiation hazards for responders and victims;
2. Abruptness and potential enormity of a nuclear incident;
3. Need for medical care and resources to be collocated and matched to the requirements;
4. Need to predetermine as much of the detail of the response as possible; and
5. Need for responders to rapidly communicate conditions on the ground.

The “RTR” model was developed for radiation mass-casualty responses. It is in place for both an Improvised Nuclear Device and a Radiological Dispersal Device (RDD). The National Planning Scenarios have been used to conduct detailed planning for a 10-kiloton IND detonation in an urban setting (IND, Scenario #1) and a cesium-137 (Cs137), (cesium chloride) improvised explosive RDD detonation (RDD, Scenario #11). The RTR model and plan are consistent with the designated responsibilities of HHS by the Homeland Security Presidential Directives #18 and #21 and the National Response Framework.

In order to estimate the requirements generated by a domestic IND or RDD detonation, there must be modeling and a planning process that describes both concepts of operations and more detailed, multi-jurisdictional (or joint) response plans. Accurate estimates of the required resources depend upon understanding the predicted consequences that can be obtained by modeling, and the basic response strategies that can and will be employed.

In developing the basic concepts supporting radiation (radiological and/or nuclear) response plans for the US Federal Emergency Support Function #8 (Public Health and Medical Services) of the National Response Framework, it is understood that the initial response to any incident is the jurisdiction of the local and state emergency responders. Due to the magnitude and nature of an IND or RDD incident, a local/state public health emergency likely will be declared followed by a Stafford Act Presidential declaration of emergency or major disaster, thereby involving Federal response. To be effective, all tiers from institutions and local responses, through state and Federal responses, must have cohesive plans based on a common nomenclature and shared priorities. The US National Incident Management System and resource typing glossaries help to facilitate seamless, multi-tiered response to major incidents much like a common nomenclature. The Federal radiological response involves assets from multiple agencies and groups including the HHS, the Department of Homeland Security, the Department of Energy, the Department of Defense, the Department of Veterans Affairs, the Department of Transportation, the Defense Threat Reduction Agency, and others.

Planning the medical response to the detonation of an IND or RDD requires coordination with subject matter experts in nuclear and radiological emergencies who traditionally have not held central roles in emergency management. Specific expertise will be needed to coordinate monitoring and quantification of environmental contamination, to assist in the management of radiation injuries, to establish laboratory capabilities for the measurement of radionuclides (radioisotopy) and assessment of individual exposures (biodosimetry), and to provide flexible protocols for optimal use of resources that are in high demand, but have limited local availability.

To assist in developing concepts for integrated medical response to a mass-casualty IND incident that incorporates these additional considerations, a model system was developed. In this system, three types of RTR sites for out-of-hospital management (Triage, Treatment, and Transportation) are designated based on their proximity to the blast location, the ongoing presence of radioactive groundshine (radiation emitted from the ground that had been made radioactive by the nuclear explosion) and fallout (radioactive material falling following the explosion), their accessibility to transportation, and the types of victims near these sites. It was named the RTR System as the location of usable sites depends on the potential exposure to radiation (“R”) and the site-specific activities and requirements for Triage, Treatment, and Transportation (“TR”) of the associated victim populations. In addition to the three types of RTR sites, the model incorporates definitive medical care sites that include hospitals, medical centers, and other healthcare facilities such as nursing homes and medical clinics, alternate care facilities such as Federal Medical Stations, and distant, even nationwide medical facilities such as cancer centers, burn centers, and trauma centers, that can provide specialty care of patients with burns, bone marrow depletion, or other complications from trauma and radiation. Finally, the model also includes human services sites (Assembly Centers). These sites are established in major facilities (stadiums, schools, convention centers, shopping centers, etc.) along evacuation routes well outside of the areas affected by the blast or plume. Many of the potential Assembly Center sites can be designated in advance of potential incidents. At Assembly Center sites, registries of displaced persons, their initial locations during the event, and planned destinations can be initiated and linked virtually. Those requiring medical attention or biodosimetry studies based on their injuries or location during the event, but who are asymptomatic, will be referred to appropriate sites for follow-up. Assistance with sheltering, transportation, and other human services are facilitated through these sites as well.

The spectrum of the acute medical consequences of an IND or RDD attack include both temporary and permanent blindness (IND), blast injuries, including hearing loss from ear drum perforation, burns injuries, trauma from debris or structure collapse, and the sequela of radiation exposure. Combined injuries that include radiation and physical injuries from trauma have a higher fatality rate than the sum of the individual injuries. It is important to note that traumatic injuries from the blast can occur in the

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absence of radiation, and likewise, radiation exposure can occur without other injuries. Psychological stress\textsuperscript{13,14} and the need to care for extant medical conditions during the loss of the normal medical care infrastructure will add to the demands of the emergency response.

**Effects of Radiation Exposure**

The presence of radiation and the clinical effects it produces will influence triage, treatment, and transport strategies as a result of their impact on the exposed victims as well as the constraints they impose on emergency responders. Medical injury from radiation falls into three broad categories:\textsuperscript{15–18}

1. **Acute Radiation Syndrome** is due to whole or substantial partial body exposure to a dose of radiation above 1 Gy (Gray; 1 Gy = 100 rem) that likely will cause some mild clinical effects such as nausea and vomiting; doses >2 Gy likely will require immediate treatment for potential organ toxicity and other clinical effects. The acute radiation syndrome includes, by increasing dose: hematopoietic syndrome, cutaneous syndrome, gastrointestinal syndrome, and central nervous system effects. The risk and severity of these effects/syndromes increase with increased radiation exposure (often called the “deterministic” effect);

2. **Chronic effects of radiation** include tissue fibrosis and organ dysfunctions that occur months to years after exposure.\textsuperscript{16} The major organ at-risk is the lung, which requires a dose in excess of 8 Gy to cause radiation fibrosis. For other tissues, substantially higher doses are required to cause chronic effects such that the higher dose is lethal and the victim would not likely survive the initial radiation injury; and

3. **Radiation-induced cancer** and other tissue effects may occur years to decades following exposure.\textsuperscript{19–23} The cancer risk (likelihood of developing a cancer) increases with increasing exposure to radiation; however, the severity of the cancer is unrelated to dose (often called “stochastic” effect). Whether the risk increases linearly with increasing dose at the low end of the dose range (<10 cGy or 10 rem), or that these lower doses are less of a risk is a subject of debate.\textsuperscript{24–27} Nonetheless, the linear relationship usually is assumed for radiation protection purposes. Protective Action Guidelines established for industrial or occupational exposures suggest that annual radiation exposure be limited to <5 rem per year, although higher exposures may be considered for persons engaged in life-saving measures/rescue operations.\textsuperscript{28,29}

**Medical Responses and Management**

During most mass-casualty incidents, local emergency medical services providers provide the initial triage, treatment, and transport. It is recognized that during larger events, people likely will self-transport or use non-emergency medical services mechanisms to go to the nearest hospital, so it will take some time before a secure perimeter and casualty collection and triage points are established. Triage determines the order in which patients are treated and transported to the nearest or most appropriate hospital. Prehospital treatment typically occurs at a field station or in an ambulance en route to the hospital. For mass-casualty incidents, medical triage determines victim care requirements: immediate care, delayed care, palliative care, or no treatment, and establishes victim priority for transport to definitive care locations.\textsuperscript{30,31} Due to the large number of patients involved, on-scene treatment areas or casualty collection points (RTTs) will be established to maximize the effective management of a large number of patients awaiting transport to definitive care by the limited field personnel. Concentrating patients at discrete locations in the field also increases the efficiency of the transportation function.

Medical triage following radiation incidents is more complex than in other mass-casualty incidents. Indeed, Cone and Koenig\textsuperscript{31} have noted “Field trauma triage systems currently used by emergency responders at mass-casualty incidents and disasters do not adequately account for the possibility of contamination of patients with chemical, biological, radiological, or nuclear material”. They reviewed a number of medical triage systems,\textsuperscript{31–35} including T1–4 and color coded (green, yellow, red, black) designations.\textsuperscript{34,35} Other radiation-specific triage systems have been proposed as well,\textsuperscript{36–39} but they are better suited for incidents involving a limited number of casualties. Response and triage strategies differ between military\textsuperscript{40} and civilian settings, but both consider how to best use limited resources through establishment of plans and guidelines in advance of an event.\textsuperscript{11} The complexity of a radiation event including multiple types of injuries and the limited outcome data available suggest that a consensus approach to developing a triage approach would be valuable.\textsuperscript{41} This is under consideration by HHS.

Field management and treatment of victims of a nuclear incident also present greater challenges than during other mass-casualty incidents because of the potential scope of a nuclear detonation and the complicated radiation environment that may result. There will be requirements for the initial care of trauma and burn injuries, but there also will be issues related to operations in the radiologically contaminated environment as well as the management of patients with acute radiation sickness and combined injuries requiring treatment or palliative care.

Many victims also will need to undergo decontamination between initial contact and transport to definitive medical care. Gross field decontamination decreases the continued exposure of externally contaminated patients and minimizes the amount of radiological material transferred to the transportation assets and the downstream medical community (subsequent contamination). Removal of outer clothing and washing with water and mild soap removes most of the contamination. Following an IND detonation, self-decontamination is an important part of limiting the dose.\textsuperscript{52,43}

The magnitude of a nuclear incident also will impact transportation plans compared to other mass-casualty incidents. Disruption of normal transportation activities/routes by physical destruction, the influx of response assets along said routes, the inability for response assets to reach the site and set up, and the affected population attempting to self-evacuate will impede victim transport operations and subsequently, the effective delivery of victims to definitive care. Following a mass-casualty incident, it typically is necessary...
to distribute victims to definitive care sites across a broader region because the local trauma centers quickly are overwhelmed. A mass-casualty incident involving radiation will require a wider distribution of patients to find available beds for all of the victims, and obtain the medical specialty services for management of radiation-related injuries. A networked system for locating these assets and transporting patients to the most appropriate definitive care sites must be included in a medical response model to a nuclear incident.

Finally, a robust capability for identifying, tracking, and providing a wide range of human services for those displaced by the detonation and/or plume also will be required. This human services component will involve a small but essential medical element comprising documentation of potential radiation exposures, recommendations or referrals for appropriate follow-up care for those who may have been exposed, and establishment of a registry/tracking system of the displaced persons.

One of the greatest challenges of a radiological incident for the emergency response community will be determining where responders can deploy safely, and the length of time that they can work under ambient conditions. To help address what is an “acceptable” level of radiation exposure for emergency responders, a number of experts in health physics and emergency response fields have developed Protective Action Guidelines (PAGs) through evidence-based development and interagency consensus. The controversy in estimating the risk of radiation-induced cancer has been noted above. These PAGs propose time limits for working in various conditions of radioactivity. The acceptable levels of exposure for personnel should be a command decision, and should follow pre-established PAGs.

This paper outlines a radiation incident-specific Triage, Treatment, and Transport model for effective management of a mass-casualty incident. Rather than a single type of prehospital treatment or casualty collection site, the unique characteristics of the nuclear scenario require three distinct types of field sites to accommodate the victim population types and the environmental conditions in which the responders are working. These are called Radiation Triage, Treatment, and Transport (RTR) sites. In addition, the model includes nationally networked sites for definitive medical care, and assembly centers to address the registration and human services functions.

The Model

In the process of developing the RTR model, current civilian and military medical response plans were inventoried and characterized by interagency working groups. Potential casualty numbers and categories of injury were provided by the Interagency Modeling and Atmospheric Assessment Center under the [US] Department of Homeland Security, the National Atmospheric Release Advisory Center, and the Defense Threat Reduction Agency.

The RTR model was designed to be scalable and enhance the opportunity for efficient collaboration among all tiers of the emergency medical response. Resources can be pre-positioned appropriately, or, if possible, deployed soon after an IND event.

The RTR medical response system in an IND event is diagrammed in Figure 1. The concentric circles denote the IND detonation epicenter as well as the zones with likely lethal prompt radiation, blast overpressure (shockwave), and thermal damage, as well as the radiological plume and fallout. The size and location of these zones relative to one another depend on the size of the IND detonation and meteorological conditions. Near the epicenter, multiple combined injuries will be common, and immediate fatalities are expected, potentially numbering in the many tens of thousands. Planning models to estimate numbers and locations of individuals with different types of injury can be used for any given city, time of day, and meteorological conditions.

The prevailing upper-level atmospheric wind (jet stream) is illustrated with the arrow and label on the left. For an IND, the radiation plume will reach upper-level atmospheric winds within a minute and will begin returning to earth within minutes to hours as fallout. Immediately after an event, the direction and speed of the wind that will carry the plume will be available from the Interagency Modeling and Atmospheric Assessment Center. Surface winds will be influenced greatly by the blast and urban canyon effects; however the atmospheric winds can be tracked and downwind deposition sites will be predicted. Of course, the ability of models to predict detailed exposure rates is limited, and weather conditions change. Actual environmental measurements will determine ambient dose rates, including local hot spots where debris settles. These dynamic considerations serve to emphasize the importance of continuous, on-scene radiation monitoring for environmental conditions and personnel exposure.

Inner and Outer Perimeter lines representing ambient radiation exposure levels per unit time will be established by the incident commander and/or safety officer with advice from health and medical physicists using computer models, area radiation-sampling by on-site response teams, and detailed victim dose information that may be available. Local responders likely will request assistance from the Federal Radiological Monitoring and Assessment Center and other Federal response teams. The estimated dose rates (in rem or Gy per hour) will determine allowable work time for responders in each zone, as indicated by the marked field perimeter lines. They also will be used to estimate potential radiation exposure and the subsequent likelihood of a victim developing acute radiation syndrome. Ambient radiation levels will change rapidly over time as the radioactive plume rises and travels through the upper atmosphere, fallout is deposited, and radioactive decay occurs. Therefore, frequent modeling, measurement, and documentation will be necessary so the safety perimeters/zones can be adjusted accordingly.

RTR Sites

The incident commander will designate the RTR Sites with input from emergency responders. There will be multiple venues for each RTR-site type. Many of these venues will be defined spontaneously in real time as victims collect or are brought to specific areas/sites. These may be areas that are perceived by victims as providing shelter and/or sites of opportunity established by responders. The major functions at RTR sites are identification, triage, medical stabilization (or provision of palliative care), and transport of victims, when possible. Gross decontamination also

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may be performed at these sites as permitted, though stabilizing serious injuries takes precedent over decontamination.

There are three different types of RTR sites based on physical relationship to the epicenter and fallout. The radiation and infrastructure considerations will impact the types of patients encountered in the respective areas as well as the availability of responders, length of time responders can serve in the area, and transportation constraints. The latter will bear on the ability to evacuate patients from the RTR sites and the options for transporting supplies and personnel to the sites. Victim flow will be the result of the destruction of infrastructure, spontaneous aggregation of victims, self-evacuation, ability to communicate information to victims, and ability to provide services or care. The multiple RTR sites will self-assemble. The goal is to get the victims to Medical Care sites and Assembly Centers.

The location of the RTR1 sites will be near the epicenter of the incident, and will be associated with the highest levels of ambient radiation. At the RTR1 sites:

1. Many or most victims are non-ambulatory, or soon will be; victims will have physical trauma, burns, acute radiation syndrome, and combination injuries;
2. Based on both their proximity to the blast and time to onset of symptoms, it will be clear that many of the victims have been lethally irradiated and primarily will require comfort care;
3. Because of ambient radiation levels, emergency medical responders will have limited periods of time to work safely in this environment;
4. Transportation will be delayed after such a large incident and response assets likely will have difficulty reaching these sites, possibly for a few days, due to infrastructure loss and persistent radiation; and
5. The combination of the proximity to the epicenter, paucity of resources, and transportation limitations will render the RTR1 sites the most austere of all of the RTR sites, and will pose the greatest challenges for providing care to victims.

The locations of the RTR2 sites will be in or near the path of the radiation plume/fallout, which will start at the epicenter and could extend for long distances. Similar to RTR1 sites, these sites either may be spontaneous gathering points for victims or aid stations established by emergency medical responders. While identification, triage, treatment, and transport all are the ultimate goals of these sites, patients at RTR2 will be treated for survivability rather than palliation, contingent on the availability of supplies and responders’ time constraints. The sites will have more supplies and responders than will the RTR1 sites. At the RTR2 sites:

1. Most victims will be ambulatory, and fewer victims will have combined injuries. Many victims may have significant radiation exposure from fallout;
2. The time constraints for responders must be monitored carefully due to ambient radiation, but likely will be longer than at the RTR1 sites;
3. If response caches have been mobilized to the appropriate areas, it may be possible to initiate some treat-
ment for mitigation of acute radiation syndrome (e.g., cytokines) and provide symptomatic treatment. Strategies and detailed concepts of operations for forward deployment of medical countermeasures are being developed by HHS and interagency, state, and local partners that might ultimately improve response capabilities at these sites; and

4. Transportation still may be delayed in reaching these sites, and even when transportation routes are intact, they may be choked by evacuees and/or responders.

The locations of RTR3 sites will be away from the immediate blast zone (ambient radiation) and plume. (There may be glass and blast damage miles from the epicenter that is not complicated by radiation, so structural damage to buildings does not necessarily mean radiation is present). At the RTR3 sites:

1. Almost all victims will be ambulatory, and many people may have minor to no injuries and no significant radiation exposure;
2. The time constraints for responders at these sites will reflect regular disaster shift schedules and is not limited by ambient radiation. Local physical dose monitors and radiation safety officers will alert the incident commander and/or safety officer if a RTR3 site becomes contaminated. Should a RTR3 site become contaminated, this may result in movement of the RTR3 site to a clean location, or conversion of the site to RTR2 operations, using the dose-rate information to help determine work/rest cycles;
3. Symptomatic treatment can be administered if appropriate, prior to transportation;

4. Following triage and initiation of minor treatments, available transportation assets will evacuate victims to medical care or assembly center sites as appropriate, some of which may be at a far distance;

5. Radiation monitoring devices and people who know how to calibrate and use them, and decontamination capabilities should be available at the RTR3 sites. Transportation will be available here, and it is important to minimize contamination of health and shelter facilities and transport vehicles.

6. The RTR3-related infrastructure will be relatively intact, so roads and logistics should not impose serious limitations to the capabilities at these sites. Control of the evacuation and transport routes will be vital, and will be facilitated greatly by civilians abiding with public messages.

The RTR model can be used as an information network for the incident commander during the early stages of an event to rapidly convey the local situation and allow the implementation of the response in a way that optimizes distribution of resources while accounting for the limits imposed by radiation. A typical report from a RTR2 site would identify the location and indicate that “there are 78 victims and four responders present with a measured dose rate of 0.5 rem/hr”. The profiles of the triage category distribution likely will be characteristic of the RTR-site types. For example, a RTR1 site may have a majority of black tags (expectant category) and virtually no green designations (“walking wounded” category), while the opposite would be true in the RTR3 site.

As part of the transportation plan, the destination of all victims leaving an organized RTR site, including RTRs 1–3, Medical Care, and Assembly Center sites, will be communicated to a central location for tracking and facilitation of victim distribution to Medical Care sites and regional/national facilities and expert centers with capacity. Once organized, the locations of the sites can be provided by public service announcements and other methods of emergency communication to assist those who are self-evacuating to register and obtain needed aid. The same announcements will provide area-specific advice as to whether to evacuate or shelter-in-place.

Medical Care Sites

Medical Care sites are venues where sophisticated medical care will be administered. These include hospitals, clinics, and medical centers. They are the focal points for the delivery of expert medical personnel and materiel. Some of the facilities nearest to the blast will not be operational due to a loss of infrastructure, and others may not be usable due to their location within the fallout area. Regarding Medical Care sites:

1. Medical Care sites should be identified as thoroughly as possible before an incident. Their Geographic Information System coordinates, addresses, and details on capabilities and capacities such as trauma level and bed counts should be included. A bed-count would be done at the time of an incident and at regular intervals, consistent with National Surge Capability plans. The National Hospital Available Beds for Emergencies and Disasters System (HAvBED) currently provides this capability to some degree, and this system integrates medical facilities with state and Federal governments. Currently, HHS utilizes HAvBED with integrated reporting from multiple jurisdictions;

2. During a large event, some medical care facilities will be unusable due to their location, while other sites such as outpatient clinics and nursing homes not normally used as major medical facilities may become incident-specific hospitals to maintain the local medical care capacity;

3. Disaster Medical Assistance Teams will be deployed immediately to support triage and provide medical care at the austere disaster site, or they can be set-up to augment the emergency departments of receiving Medical Care sites;

4. Alternate care facilities, such as Federal Medical Stations will be set up as rapidly as possible, usually within 24–72 hours, to care for less severely ill medical needs populations;

5. Victims with immediate medical needs will be transported or directed from RTR1, 2, and 3 sites to Medical Care sites. Additionally, people with medical needs, displacement, and socio-behavioral needs to the best of their ability, will likely self-evacuate to the Medical Care sites. Some will require special assistance and guidance to evacuate. Those who do not need immediate medical care will be directed to Assembly Centers or to their homes as appropriate;
6. Many of those in need of medical care may require decontamination. For those who self-evacuate following radioactive contamination, it will be necessary for the Medical Care sites to provide this service;

7. Medical history, including the victim's location during the incident, as well as portal monitoring to detect the presence of radiation contamination, will be important in the medical evaluation process. Information gathered from history or monitoring, if possible, should be captured during triage intake and should stay with the patient;

8. To provide necessary space for severely injured victims, Medical Care facilities nearest the epicenter will discharge or transfer patients to home care, if possible, or other facilities outside of the region.

9. Some Medical Care sites may be long distances from the site of the event and even beyond state boundaries. Transportation of victims to these facilities may require activation of national networks such as National Disaster Medical System35 and the Radiation Injury Treatment Network36 with coordination by state and Federal authorities. The Radiation Injury Treatment Network provides coordinated and integrated medical care capability for victims with radiation injury, and currently includes a number of National Marrow Donor Program Centers and National Cancer Institute Comprehensive Cancer Centers37,38 with future expansion planned;

10. Victim tracking in Medical Care facilities will rely largely on patient records established during the event. They will be integrated with the data collected at the RTR sites and/or patient transport tracking systems, the development of which remains a work in progress;59 and

11. Anticipating that most physicians will not have had experience managing radiation injuries, and will have little time to review, a just-in-time, algorithm-based set of medical guidelines and a comprehensive tool called the Radiation Event Medical Management9,10 system (REMM) has been developed in collaboration with the National Library of Medicine and is available at http://remm.nlm.gov.

Assembly Centers will be evacuee receiving and registry centers as well as temporary shelters where people may receive food and shelter and/or can check in with authorities so that they can be accounted for after the event. These sites are for those with no or minimal requirements for medical care. Some may arrive directly or may have been directed from RTR and Medical Care sites. Regarding Assembly Center sites:

1. They will be predetermined as much as possible, including major public facilities, highway rest stops, schools, auditoria, sports facilities, shopping centers, etc. Some will form spontaneously, especially along evacuation routes. Some predetermined sites likely will be unusable due to the plume;

2. Very limited or no medical care will be available or needed at these sites, although some medical history and blood testing may be done for radiation screening of victims. Many or most people will not have been in the blast or plume;

3. Information as to where persons were at the onset of the event and thereafter should be captured at Assembly Center sites, if possible;

4. Some non-victims may be in close proximity to Medical Care sites, but should be sent to Assembly Center sites or home rather than use Medical Care resources;

5. Some victims who are possibly at risk for acute radiation syndrome but who have few symptoms may enter the response/tracking system at Assembly Center sites because they moved away from the blast and may not encounter assistance until this point. They would need further evaluation and medical care at Medical Care sites at some point in time;

6. Nearly all people will be ambulatory;

7. Preparedness education and public messaging will provide guidance to evacuation and/or sheltering in-place;

8. Staffing may include non-medical personnel or those with limited medical expertise. The focus at Assembly Center sites is providing minimal medical care, housing, and human services, as detailed in Emergency Support Function #6 of the National Response Framework;4 which is coordinated by the Federal Emergency Management Agency; and

9. Complete victim and evacuee tracking will be done but may not be fully accomplished given the large number of victims.

**Evacuation Centers and Drop Zones**

Evacuation centers and drop zones should not be confused with Assembly Center sites, as the former are hubs for major victim and evacuee transport by land, rail, air, and/or water. Some hubs may be designated for incoming supplies and personnel and others for outgoing, while others may transport persons or goods both in and out.

1. Transportation is a major challenge covered by the Emergency Support Function #1 of the National Response Framework.4 This will be accomplished by local/regional assets through ambulance contracts, volunteer allocations, and vehicles. The Department of Transportation will assist “Federal, state, tribal and local governmental entities, voluntary organizations, nongovernmental organizations and the private sector in the management of transportation systems and infrastructure during domestic threats or in response to incidents”.6 Extensive self-evacuation likely will occur. Transport capacity will be severely limited in the early hours after an IND, and control of the evacuation and transport routes will be critical.

2. Medical supplies, including those from the Strategic National Stockpile,62 will be sent to Points of Distribution from which they will be transported to Medical Care sites and, to a lesser extent, Assembly Center sites; again recognizing the challenge due to limited infrastructure.

3. New solutions, including pre-positioning and forward deployment of time-sensitive or anticipated medical countermeasures are being developed by Emergency Support Function #8, and state and local planners, and are a work in progress.
1. Medical transport from the RTR1 sites will be severely limited, especially during the first hours and days.

2. Self-evacuation will likely be a major source of victim movement. Victims likely will go to Medical Care and Assembly Center sites based on knowledge from local preparedness plans and/or directions from responders and the media. Those who do not need immediate medical care will be directed to Assembly Center sites and told specifically to avoid Medical Care sites.

3. Some of those at risk for acute radiation syndrome from fallout may self-evacuate to Medical Care and Assembly Center sites. Depending on medical history and initial evaluation, some may need to be directed to appropriate facilities for further evaluation (e.g., blood tests and/or biodosimetry or bioassay studies), and some may need transport to expert care centers to be monitored and treated as outpatients for the development of acute radiation syndrome.

4. Identification of contaminated victims and the provision of effective decontamination, including self-decontamination, is critical to medical management in radiation events. In addition to decontaminating victims and first responders, protection and decontamination of materiel, facilities, shelters, and transport vehicles is important. A nuclear incident is large, and assistance from all tiers of government and the private sector will be needed for adequate decontamination capacity in the response.

The RTR medical response system for an explosive RDD, which is a much smaller incident than is an IND detonation is in Figure 2. Unlike an IND, in which a large amount of radiation is discharged by the detonation (and immediately dissipates with the blast), and is broadly deposited in the fallout, an RDD is a much smaller device that disperses radioactive material as with a dirty bomb or aerosolization device. (Non-explosive dispersal of radioactive material also is a form of RDD.) Radiation exposure depends on the duration of the proximity to radioactive material. Most of the radiological exposure from a RDD is from external contamination, but some victims may have internalized radiological material from inhalation, ingestion, contaminated shrapnel, or wound contamination. While a large incident is possible, most RDD incidents...
involve a limited section of a city, will likely have a radius of a few hundred meters, and involve fewer victims than from an IND. The RDD plume is short-lived, settling or diffusing within minutes to a half-hour, and is confined largely to surface and urban winds. Distribution of radioactivity would be determined by an urban canyon effect and depending on prevailing winds and city layout, can be limited or broadly contaminating (Figures 3). While some resuspension and spread of radioactive material may occur during response operations and ground movements, the ambient radiation zone is largely determined by the footprint of where the material initially landed.

Thus, for a RDD event, the high-level winds displayed by Interagency Modeling and Atmospheric Assessment Center modeling maps will show the direction and distance that only very small amounts of buoyant radiological particles (likely not enough for health effects) will be carried. While long-range deposition of RDD fallout is worth noting for possible interdiction of food supply and eventual clean-up, radiological material carried beyond the local site is unlikely to cause acute radiation syndrome because it is too limited in quantity.

The functions of RTR1–3, Medical Care, and Assembly Center sites are the same for a RDD as for an IND. The inner and outer perimeters and the blast zone will be nearer to the epicenter and used by the responders and local incident commander to determine the RTR1–3 sites as well as determining if any medical care and assembly center sites are non-functional due to their location or infrastructure damage.

Figure 4 illustrates how the radiation dose rate (rem or Gy per hour) will be used to determine protective action guidance for first responders occupying areas in proximity to the RDD detonation (exclusion zones) and also the risk to victims for developing acute radiation syndrome. While radiation distribution models are vital to shaping the initial response, on-the-ground measurements are critical for determining where responders can or cannot spend time and whether or not a victim is at risk for developing acute radiation syndrome. Figure 4 illustrates that the time permitted within a zone depends on the dose rate. The time limitation for responder occupancy of a zone is based on the risk to a person/responder for developing a radiation-induced cancer (<0.5% per 5 rem), which characteristically does not occur until years or decades later.

Mapping the Doses: Plume versus Footprint
Experience from recent exercises suggests that information on Interagency Modeling and Atmospheric Assessment Center plume/dispersal plots could be confusing to incident commanders and responders. Interagency partners are working on improved nomenclature and data display. When looking at plume and footprint maps, one must distinguish: (1) acute dose rate for the risk for developing acute radiation syndrome; (2) acute dose rate for implementing protective action guidelines for responders and
Health Professionals within HHS—“This system of State based systems will, when complete, form a National system that will allow efficient utilization of health professional volunteers in emergencies by providing verifiable, up-to-date information regarding the volunteer’s identity and credentials to hospitals or other medical facilities in need of the volunteer’s services.”

Specific medical expertise for managing radiation events will come from the Radiation Injury Treatment Network and volunteer help from professional medical societies.

**Discussion**

Readiness for a nuclear or radiological mass-casualty incident requires extensive preparation and planning due to the potential magnitude and consequences. Concern for acute radiation injury and delayed effects of acute radiation exposure (especially radiation-induced cancer) makes responses to an event even more complicated because of the additional pressures to leave the area and reluctance by responders to enter a radiation zone.

The HHS is responsible for coordinating the Federal public health and medical responses to Presidentially-declared disasters and public health emergencies. An effective response plan will require collocating medical personnel and supplies with the victims in need, transporting victims to appropriate aid locations, and protecting responders and victims from radiation exposure as best as possible.

The RTR model has been developed to facilitate planning to meet these needs. The model outlines the major components of a response and configures them in a way upon which a medical and logistics management system can be overlaid for planning purposes. The RTR sites (RTR1—near the blast with persistent radiation, RTR2—

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**Figure 4—Radiation zones**

- **Potential local “hot spots” from debris and fallout**
- **“inner zone”**: 10 rem/hr X 0.5 hr = 5 rem
- **“intermediate zone”**: 1 rem/hr X 5 hr = 5 rem
- **“outer zone”**: 0.1 rem/hr X 50 hr = 5 rem
- **0.01 rem/hr X 500 hr = 5 rem**

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near the plume with some persistent radiation, and RTR3—collection points with minimal to no radiation risk) will be determined in real time while Medical Care and Assembly Center sites will be largely pre-determined with data on these sites available on a detailed map usable by Federal and non-Federal planners and incident commanders. There is an ongoing effort within HHS (MedMap project) to map and store information on Medical Care sites and also on possible Assembly Center sites so that as much information as possible is immediately available in the face of an event.

Nuclear incident response requires extensive medical support so that Medical Center sites well beyond the region will be engaged and include national and international capabilities. Medical care systems include the National Disaster Medical System,53 the growing Radiation Injury Treatment Network,54–58 and other medical centers. Personnel shortages will be filled by volunteers including those in the Medical Reserve Corps and Emergency System for Advance Registration of Volunteer Health Professionals69,70 and just-in-time medical management guidelines are available on REMM.8,9

For all RTR sites, including the RTR1–3, Medical Care, and Assembly Center sites, full victim tracking is required, and developing systems that can perform this function is a high priority.59 For those potentially at risk for internal contamination and the development of acute radiation syndrome based on history and symptoms,8 laboratory determinations for exposure and internal contamination are needed. There also are plans for establishing a radiation laboratory network.12 Transportation will be an enormous challenge and evacuation and supply routes must be controlled with attention to contamination and worker safety issues. Sheltering-in-place, including preparedness education and public messaging will reduce the pressure on the medical response system.

Conclusions

The RTR Medical Response system provides a model for the conduct of triage, transportation, and on-site treatment taking into account the limitation imposed on responders by radiation. Dialogue and planning between Federal and non-Federal partners is needed. The Office of the Assistant Secretary for Preparedness and Response and other HHS and Federal and non-Federal partners are working on the various components of the response to radiation incidents,12 as well as on all-hazards preparedness and responses for the vision of “a Nation Prepared”71

The RTR system is an integral part of the zonal response approach included in the “Planning Guidance for Response to a Nuclear Detonation”, prepared by a subcommittee of the Homeland Security Council, January 2009.

References


May – June 2009 http://pdm.medicine.wisc.edu Prehospital and Disaster Medicine
A Possible Approach to Large-Scale Laboratory Testing for Acute Radiation Sickness after a Nuclear Detonation

Amesh A. Adalja, Matthew Watson, Samuel Wollner, and Eric Toner

After the detonation of an improvised nuclear device, several key actions will be necessary to save the greatest number of lives possible. Among these tasks, the identification of patients with impending acute radiation sickness is a critical problem that so far has lacked a clear solution in national planning. We present one possible solution: the formation of a public-private partnership to augment the capacity to identify those at risk for acute radiation sickness.

If a 10-kiloton nuclear device were to be detonated at ground level in a major U.S. city, U.S. government modeling suggests that tens of thousands of people within a radius of approximately 1 mile would be killed or severely injured. Beyond this radius, the number of serious acute injuries would rapidly decrease, but an even greater number of people would be at risk of exposure to dangerous levels of radioactive fallout. Most of these people would be outside of the immediate blast vicinity and would likely have few if any traumatic injuries, and most will be ambulatory. More important, as prodromal symptoms are likely to be non-specific, these people would probably not have acute symptoms in the first hours or days that could unquestionably be attributed to radiation.

The identification of patients with impending acute radiation sickness from the million or more people who might be in the general vicinity of the fallout plume is a critical problem that so far has lacked a clear solution in national planning, but which, if solved, could lead to more appropriate matching of patient medical needs and available medical capacity and thus potentially save thousands of lives. In this article, we formulate the proposition that a public-private partnership with national commercial clinical laboratory chains may be a key to solving this problem.

Radiation Exposure in the Fallout Zone

Fallout is pulverized material that is forced into the atmosphere as a result of surface level detonation. This fine-grained material becomes infused with radioactive particles from the nuclear detonation as it is carried miles into the air before falling back to earth. The plume of radioactive dust can travel miles downwind as it gradually settles. Modeling indicates that dangerous levels of fallout could extend as far as 20 miles from ground zero. In a densely populated urban environment, this would translate to well over 100,000 people being exposed to levels of radiation from fallout sufficient to cause acute illness.

If people in the area of the fallout know to immediately seek adequate shelter and stay there for several hours, deaths from fallout could be dramatically reduced. It is, however, reasonable to assume that many people would not be willing, able, or aware of the need to shelter. Even in the best case, it is likely that thousands of people would be at risk for radiation sickness from fallout. Some victims in the path of the radioactive fallout would be exposed to supralethal levels of radiation and would not survive regardless of medical intervention, and some would receive lower levels of exposure, which would not require immediate medical attention. But many thousands of people would fall in a...
LARGE-SCALE LABORATORY TESTING FOR ACUTE RADIATION SICKNESS

middle range of radiation exposure, in which medical intervention could make the difference between life and death—if they could be rapidly identified, triaged, and transported to locations where they could receive appropriate medical care. This group could number in the tens of thousands, but possibly a million individuals or more would need to be screened to identify this subgroup.

**Acute Radiation Sickness (ARS)**

Acute radiation sickness, or ARS, is a systemic illness caused by exposure to a level of whole body ionizing radiation sufficient to damage the hematopoietic, gastrointestinal, cardiovascular, or central nervous system.5 The threshold level of whole body radiation needed to develop initial signs and symptoms of ARS is approximately 1 Sievert (Sv) in a healthy adult.* Below this level, radiation exposure can have long-term health effects, such as an increase in the lifetime risk of cancer, but is unlikely to cause serious acute problems. In humans, the dose of radiation expected to kill 50% of those exposed within 60 days, or the LD50/60, is 3.5 Sv. With adequate medical treatment, the LD50/60 may double to about 7 Sv.6

Some bodily tissues are more sensitive to the effects of radiation than others. In general, tissue sensitivity to radiation is proportional to the rate of its cell proliferation and inversely proportional to the degree of cell differentiation. For example, bone marrow, where blood cells are made, is among the most sensitive.5 Relatively low doses of radiation may suppress the bone marrow and yet cause little damage to other organ systems. The effects of bone marrow cell suppression (ie, hematopoietic syndrome), characterized by increased risk of opportunistic infection and uncontrolled hemorrhage due to gradual pancytopenia, may take days or weeks to become clinically manifest. With good medical care, most patients with only bone marrow suppression will probably survive.

In contrast, patients with higher doses of radiation exposure will experience acute gastrointestinal, cardiovascular, and/or neurological effects well before the effects of bone marrow cell suppression are clinically evident. In most cases, patients presenting with these symptoms cannot survive even with good medical care. Therefore, it is the cohort of patients with impending, but not yet fully manifest, hematopoietic syndrome that are most likely to be saved by medical intervention. Table 1 summarizes the various syndromes that comprise ARS and the corresponding radiation doses needed to cause them.

**Table 1. Radiation Dose and ARS Syndrome**

<table>
<thead>
<tr>
<th>Radiation Dose</th>
<th>Syndrome</th>
<th>Prognosis</th>
</tr>
</thead>
<tbody>
<tr>
<td>1-8 Sv</td>
<td>Hematopoietic</td>
<td>Potentially survivable</td>
</tr>
<tr>
<td>8-30 Sv</td>
<td>Gastrointestinal</td>
<td>Fatal</td>
</tr>
<tr>
<td>&gt;30 Sv</td>
<td>Cardiovascular</td>
<td>Fatal</td>
</tr>
<tr>
<td>&gt;30 Sv</td>
<td>Central nervous system</td>
<td>Fatal</td>
</tr>
</tbody>
</table>

*A Sievert is a measure of the biological effect of radiation. By contrast, Grays, another common unit of measure of radiation, measures the energy imparted to a material by radiation. For gamma and beta radiation, 1 Sv equals 1 Gy. Gy and Sv have replaced the old units of radiation measure, rads and rems. 1 Sv equals 100 rems.

**Treatment of ARS Patients**

There is no antidote to the effects of external radiation; however, supportive treatments exist that can partially mitigate the consequences of the hematopoietic effects. These consist primarily of bone marrow stimulating agents (colony-stimulating factors), blood products, and antimicrobial agents.7 Bone marrow stimulants such as filgrastim (G-CSF), pegfilgrastim (pegylated G-CSF), and sargramostim (GM-CSF), which are widely available and commonly used to treat cancer patients, stimulate undamaged bone marrow cells to produce more blood cells in order to compensate for the damaged bone marrow. These medications are more effective the earlier they are administered after radiation exposure—ideally within 1 or 2 days.6

Blood products—especially platelets, which control bleeding—will be needed several weeks into the illness as the patient’s blood counts fall to dangerous levels. During this same time, antimicrobial drugs will be needed to fight infections that are likely to occur due to low white blood cell counts. These patients may need protective isolation to prevent infection during the time that their blood counts are the lowest.6 This kind of care is the same that is used for some cancer patients who develop neutropenic fevers or profound thrombocytopenia while undergoing intense chemotherapy. This kind of care is provided frequently in many U.S. hospitals. Although some of this treatment can be conducted on an outpatient basis, it is likely that most patients with a significant degree of hematopoietic ARS would benefit from hospitalization, if resources are available.

**No Operational Plan Exists**

There are likely to be enough hospital beds in the U.S. to treat all the patients with ARS.8 The Radiation Injury Treatment Network (RITN), a voluntary collaboration of bone marrow transplant centers, has been created to facilitate the hospital care of patients with ARS. The network provides the capacity to treat thousands of ARS patients.9 Furthermore, it provides the backbone of a system in which these specialty centers can help guide care at nearby general hospitals. But because regional medical resources would likely be limited, especially in the first few days following a detonation, and because time is of the essence in initiating
some treatments, and resources for transporting patients to where they can receive adequate care may be limited, it is crucial that those most likely to benefit from treatment be identified as quickly as possible.

In the event of a nuclear detonation, many times more people will likely present for medical triage than actually have early ARS. As always happens in disasters, victims present for medical evaluation for many diverse reasons. Because the transient initial symptoms of radiation sickness are often mild and nonspecific, symptoms alone are not enough to discriminate between those with or without radiation sickness. And geographic information, while useful, is not likely to be a sufficient screening tool. This is because in the early hours and days after the event, it will be very difficult to ascertain where the fallout occurred and what the radiation levels were at a given location at a specific time. Even if this were known, an individual’s exposure will be affected by the adequacy of shelter. Therefore, it will be impossible to know with certainty who has been exposed to significant levels of radiation based solely on where they were after the detonation.

In a major metropolitan area, 1 million or more people might reasonably be concerned about dangerous radiation exposure and may need to be screened for radiation treatment. To date, there has been no operational plan developed to identify ARS victims on this scale.

**Time-to-Vomiting**

Some have advocated the use of the time from the detonation to the onset of vomiting as a crude screening tool with good negative predictive value. Most people exposed to doses of 2 Sv or more would be expected to vomit within 4 hours. Therefore, it has been suggested that this time-to-vomiting criteria could be used to separate those with doses higher or lower than 2 Sv. However, such a methodology, though easy to perform, may not be reliable. The 4-hour rule assumes a point-in-time exposure; it is not clear how time-to-vomiting would be useful if exposure occurs over many hours. Furthermore, vomiting in the midst of such an event may occur for a number of reasons other than ARS, including psychological stress, eardrum rupture, and head injury. Conversely, vomiting may be suppressed in some patients taking certain medications. Of note, a more comprehensive clinical assessment, the Medical Treatment Protocols for Radiation Accident (METREPOL), which assesses the effects of radiation on 4 organ systems and incorporates complete blood count testing (CBCs), has been developed and advocated by the European Group for Blood and Marrow Transplantation (EBMT).

**Chromosomal Dicentrics**

The gold standard for determining radiation exposure is the measurement of chromosomal dicentricism—aberrant chromosomes created by exposure to radiation. This analysis, however, is labor-intensive and time-consuming and requires specially trained technicians. It is not performed in most clinical laboratories outside the Centers for Disease Control and Prevention (CDC). Therefore, its usefulness in screening thousands of people in a short period of time is limited. Newer approaches to cytogenetics are being developed that involve fewer steps and could potentially have a turnaround time of 2 days—the same time frame during which drawing an absolute lymphocyte count would be most useful. The U.S. government’s Biomedical Advanced Research and Development Agency (BARDA) has provided funding for the further development of new tests for chromosomal dicentrics. Additionally, there are efforts to develop capacity in routine laboratories for dicentrics biodosimetry capabilities to be used during a radiation emergency.

**Other Methods of Biodosimetry**

Other types of biodosimetry under development include analysis of tooth enamel using such techniques as electron paramagnetic resonance (EPR), also known as electron spin magnetic resonance (ESR); metabolomics; and stress gene signature analysis. EPR detects the quantity of radiation-induced free radicals in dental enamel, which are then correlated to an absorbed radiation dose. Ideally, EPR is performed on extracted teeth, but modifications have been made in order to perform EPR *in situ*; however, this decreases its reliability due to the presence of confounding substances (eg, dentin). A metabolomics-based biodosimetry would involve performing mass spectroscopic analysis on body fluid (eg, urine) to identify molecules characteristic of radiation exposure (radiation biomarkers). Stress gene signature analysis involves collecting lymphocytes from the blood and analyzing their gene expression profiles with particular attention to genes whose expression is augmented with radiation exposure. These tests are not readily available for use and are not currently scalable for a response to a nuclear detonation.

**Possible Solution: Absolute Lymphocyte Counts**

In contrast, a validated, simple, and inexpensive laboratory measurement that can determine radiation dose—albeit with somewhat less precision—is the absolute lymphocyte count (ALC). An ALC is one of the most common and straightforward clinical tests. Part of a complete blood count with differential white blood cell counts (“CBC with diff”), it is performed in nearly every clinical laboratory every day.

When lymphocytes (a type of white blood cell) are exposed to ionizing radiation, they undergo a predictable rate...
of decline that correlates with the radiation dose. A 50% decline in absolute lymphocyte count in the initial 24 hours following exposure, followed by a further, severe depletion within 48 hours, indicates a potentially lethal dose exposure. Therefore, if the time from radiation exposure to the acquisition of the blood specimen is known, lymphocyte counts can be used to estimate the radiation dose. With this estimated dose, people can be sorted into 3 treatment categories: exposure level too low to require treatment, exposure level too high to benefit from treatment, and exposure level meriting treatment.

For ALCs to be most useful, measurement at 48 hours after exposure is ideal. Serial measurement of lymphocytes may provide a better estimate of radiation dose than a single test but logistically becomes more difficult. It is unclear what the capability is for laboratories to determine the rate of lymphocyte depletion (the rate constant), which may provide the best information about prognosis. Also, if there is a delay in running the test, which is likely during such a chaotic time, it is unclear to what extent lymphocyte numbers continue to fall after the blood sample has been drawn but prior to the sample’s being analyzed—an area in which further research is needed. Blood stored at room temperature for 2 days will yield a reliable result.

But for lymphocyte counts to be useful for screening people for ARS, 2 significant challenges must be addressed:

1. There must be a way to draw the blood and run the tests quickly and on a massive scale. It is possible that a million people could be in the general area of the fallout, and it is likely that they would all have to be screened to identify the 100,000 or so with radiation sickness.
2. There must be a way to get the results to the clinicians who would be treating the patients.

While most hospitals can perform hundreds of lymphocyte counts in a day, it is expected that all hospitals and their respective laboratories within driving distance of the detonation site will be overwhelmed with caring for the tens of thousands of people with acute injuries. Some physician offices and clinics can also perform lymphocyte counts, but the desktop analyzers that they typically use are not capable of performing large volumes of tests.

**Information Needs**

In addition to being able to perform the test, it is just as important that the results of the test be efficiently made available to clinicians who would be treating the patients. After a nuclear detonation, a large portion of the local population, including those with impending ARS, will likely be on the move. Thus, patients in need of screening will probably not be in the stricken city 48 hours after the detonation. In fact, they may not remain in the same place where their blood is drawn long enough to get their results the next day or to receive treatment days later. Furthermore, some patients with borderline results may benefit from serial testing, which may need to be performed in different locations as patients continue to migrate away from the point of detonation. Therefore, an information system must exist to enable the patients’ treating clinicians, wherever they are, to access the results of the test irrespective of where the blood was drawn or the test performed. It is expected that, except in the attacked city, the internet and electrical grid will be functional following a single 10-kt detonation.

Both Quest Diagnostics and LabCorp have existing internet portals that allow physicians as well as patients to view laboratory results. These portals have very large capacity and are routinely accessed millions of times per day by clinicians, patients, and healthcare facilities. Most hospitals, physicians, and clinics are already registered users of one or both of these systems. Both companies indicate that registering new users in a crisis, though daunting, is feasible. The release of laboratory results to exposed individuals has the potential to create confusion among lay persons, especially in a high-anxiety situation. It remains to be determined whether releasing information to the patient directly would be advisable. The fact

**National Laboratory Chain Capacity**

The U.S. is primarily served by 2 large distributed clinical laboratory companies: Quest Diagnostics and LabCorp. Collectively, the firms have dozens of large laboratories located throughout the U.S. that perform routine and specialty laboratory testing for hospitals and physicians. Specifically, Quest Diagnostics has more than 2,000 patient care centers and 37 major laboratory facilities, while LabCorp has more than 1,700 patient care centers with 51 primary laboratories. Additionally, both possess transportation networks consisting of small fleets of aircraft and large fleets of vehicles used to move specimens around the country.

To validate the proposition of incorporating national clinical laboratory chains into the medical response to a nuclear detonation, the authors met with both LabCorp and Quest Diagnostics in order to further explore the problem and potential solutions. While detailed proprietary laboratory capacity figures were shared in strict confidence and cannot be published here, both companies indicated that together they likely have the surge capacity necessary to perform 1 million lymphocyte counts within a 24-hour period. This initial self-assessment of their surge capacity would need to be independently verified before any action is taken on this proposition. The existence of their “stat” labs and blood draw stations nationwide would allow for an organized collection of blood from victims who may have left the metropolitan area in which the detonation occurred.
that a large percentage of the U.S. population is already registered in one or both systems could save time, reduce misidentification, and in some cases give access to baseline lymphocyte counts.

**Radiation Treatment, Triage, and Transport Response System (RTR)**

The U.S. government has developed the concept of multiple treatment, triage, and transportation locations in and around the stricken city to provide initial care to victims of all kinds. These RTR sites would be established at large locations of opportunity such as gymnasiums, auditoriums, and similar locations. These RTR sites could potentially provide phlebotomy, patient registration, and brief clinical assessment 48 hours post-detonation. Because a large segment of the population may have relocated to another city in that 48 hours, blood drawing and patient registration sites would need to be established in nearby cities and towns as well. At these sites, phlebotomy could be performed by laboratory personnel, medical volunteers, and government personnel. Existing national laboratory chain draw stations in these cities could also serve these functions. There is a need to model the most likely relocation sites for major cities to quantify the resources available in the surrounding locales. In addition, the use of point-of-care, battery-operated analyzers, capable of providing the lymphocyte count within minutes (now undergoing FDA evaluation), might augment capacity, especially at RTR sites with limited electricity.

**Many Details Must Be Addressed**

Although the national laboratory chains provide enormous testing capacity and robust information infrastructure, many operational, logistical, and regulatory hurdles must be overcome to fully harness their capability, including, among others: patient identification, physician order requirements, reagent supply bottlenecks, packing of specimens, transportation from draw sites to processing facilities, payment for services, and integration of test results from the multitude of smaller laboratories that would also be testing patients.

**Accurate Patient Identification**

In order for information to be useful, and not potentially harmful, it has to be accurately associated with an individual patient. Following a nuclear detonation, members of the public may have little identification on hand, and some may not know, or have, or be willing to share their social security number. However, the need for a definitive way to match patient and specimen (with draw time clearly indicated) through a unique identifier is essential. An alphanumeric identifier using a combination of birth date, name, and street address—all things expected to be known by patients from memory—is one possibility. There would need to be agreement by all stakeholders on the specifics of the identifier and just-in-time instructions for personnel entering patient and specimen information.

**Physician Order Rules**

Many states regulate laboratory tests by requiring that a physician or other healthcare provider order the test. This will not be possible in the event of a nuclear detonation. In those states in which a healthcare order is needed for laboratory testing, state governments should develop provisions to suspend this need in an emergency situation, perhaps by including a blanket waiver of these requirements in an immediate emergency declaration by the governor or the secretary of health.

**Reagent Availability**

A third obstacle that must be addressed is the availability of reagents. While national laboratory chains have the capacity to do 1 million lymphocyte counts, the instruments on which these tests will be performed have a supply chain of reagents needed for their operation. Currently, the national laboratory chains adhere to “just-in-time” principles that leave them with only a few weeks’ supply of reagents on hand—not enough to accommodate testing for 1 million people. If national laboratory chains are to be employed in the medical response to a nuclear detonation, the suppliers of their reagents will also need to be engaged and the feasibility of reagent stockpiles and the ability to rapidly mobilize reagents evaluated. The cost of keeping large amounts of reagent on-site at all times might be prohibitive in normal circumstances. In addition to reagents, phlebotomy supplies (eg, EDTA tubes, needles, tubing, and tourniquets) may also need to be stockpiled.

**Other Laboratories**

Even if LabCorp and Quest were to provide the bulk of ALC testing after a nuclear detonation, a large number of tests would also be performed in hospitals (eg, on injured patients) and by other smaller laboratories. It would be important to take advantage of this testing capacity and to be able to access the results of these tests.

**An Untapped Resource**

In the event of a detonation of a nuclear weapon, quickly and accurately identifying those most likely to benefit from
LARGE-SCALE LABORATORY TESTING FOR ACUTE RADIATION SICKNESS

medical treatment for radiation sickness would be a daunting task, but one that could save tens of thousands of lives. Engaging the large clinical laboratory chains in national planning to provide access to their capacity in a clinically relevant timeframe could help to solve this tough challenge and strengthen U.S. resilience.

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COMMENTARY

Scarc Resource for Nuclear Detonation: Project Overview and Challenges

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A terrorist nuclear detonation of 10 kilotons would have catastrophic physical, medical, and psychological consequences and could be accomplished with a device in a small truck. Tens of thousands of injured and ill survivors and uninjured, concerned citizens would require medical care or at least an assessment and instructions. In proximity to the incident location, there would be a huge imbalance between the demand for medical resources and their availability. Beyond the immediate blast area, much of the infrastructure would remain intact. Most people would reach medical care by self-referral and require sorting and assessment to determine what medical intervention is necessary, appropriate, and possible.

No society has the resources to deliver the full spectrum of care needed in the timeframe required. Yet, careful planning and a clear understanding of how best to allocate scarce resources, triage and evacuate patients, and implement crisis standards of care have the potential to save thousands of lives and provide comfort to those unlikely to survive. The US government and nongovernment experts continue to develop planning guidance,1,4-8 medical countermeasures,9,10 and medical specialty capacity and capabilities.11-13 This Scarce Resources for a Nuclear Detonation Project provides data, supporting information, and tools for medical planners and responders to address the issues of scarce resources and plan for triage and resource allocation in the first 4 days postdetonation, when there will be severe shortages.

PROJECT ORGANIZATION

Recognizing the imperative to plan for such an incident, the Assistant Secretary for Preparedness and Response (ASPR) in the US Department of Health and Human Services convened a panel of subject matter experts (the participant list and details of the manuscript preparation process are found in the Appendix) to answer the question, “What do I do?” and provide practical tools for individuals involved in planning for and response to this scarce-resource setting. The resulting articles in this special issue of Disaster Medicine and Public Health Preparedness are not intended to be exhaustive reviews, and they reflect the judgment and opinion of the experts, not those of the governmental agencies or academic institutions that employ them.14-22 The recommendations are based on the available data, recognizing that the human and animal data on radiation injury alone and on combined injury are limited.

Model output for casualty types and number are described in a general manner.15 (The Department of Health and Human Services has detailed models from which the data and guidance in these articles are based for the consequences of nuclear detonation in a range of cities, from a variety of heights of burst, and under a range of meteorological conditions, and for scarcity of specific resources for medical management of acute radiation syndrome. The detailed data are for restricted use and not publication.) This work builds on previous contributions that focused on scarce resources in pandemic influenza. These include a series of articles in Chest,23-27 ethical guidance by the Department of Veterans Affairs,28 a letter report on crisis standards of care by the Institute of Medicine;2 monographs on mass medical care with scarce resources, Mass Medical Care With Scarce Resources: A Community Planning Guide2 and Mass Medical Care With Scarce Resources: The Essentials,32 which ASPR developed in collaboration with the Agency for Healthcare Research and Quality and others. Many of the principles in this special issue pertain to scarce resource situations in general, but these articles address issues specific to the unique characteristics of a nuclear detonation.

SUMMARY OF ISSUES AND CHALLENGES

Below are high-level summaries of the issues addressed herein and some of the most important challenges according to the experts. Detailed discussions and references are contained within the individual articles.

Nuclear Detonation Incident

The scope of the damage and spectrum of the injuries in a nuclear detonation incident depend on many factors, including but not limited to yield of device, geography, height of burst, specific location (eg, type of structures), time of day, and meteorological conditions. The physical infrastructure damage will limit transport and access to those in need.15 The detonation will release dangerous levels of radiation immediately and also for hours to days from fallout. Combined injury (defined as physical trauma plus radiation) greatly increases the fatality risk even with maximal medical treatment, which will not be readily available. Many of the trauma casualties from blast, glass breakage, and motor vehicle crashes will have no radiation exposure, and many people in the fallout zone will have radiation exposure but no physical trauma.14,21 Understanding the expected injury types has implications for triage decision making as outlined by Coleman and colleagues.22

Four damage zones are defined in Planning Guidance for Response to a Nuclear Detonation and detailed by Knebel et al: severe dam-
age, moderate damage, light damage, and dangerous fallout. The dangerous fallout zone footprint, in which there is sufficient radiation to produce the acute radiation syndrome, will reach its maximal extent after approximately 1.5 hours and then shrink rapidly as fallout decays. Sheltering in place for the first few hours has the potential to save many lives and reduce the severity of radiation injury in the dangerous fallout zone. Radiation will complicate search and rescue efforts and contribute to resource limitations.

Given the size of the incident in relation to the number of emergency responders, the majority of victims will reach medical care locations without prior sorting or triage. The Radiation TRiage, TReatment, and TRansport system forms the basis for organizing the response, accounting for physical damage and radiation injury.

This conceptual approach to the medical response has the potential to maximize the available resources to save lives.

Initial triage decisions by responders will consider trauma and burns using existing triage schemes with which they are familiar. As presented in the articles by DiCarlo et al.22 and Coleman et al.,23 triage category will need to be modified for the presence of radiation, which will be determined by an individual’s physical location during the incident and his or her signs, symptoms, and laboratory data available over time.

Initially, there will be a profound imbalance between resource supply and demand even if resource-conserving strategies are used aggressively.29 There will be heterogeneity in the availability of resources by distance from and time after the incident. Although approaches to optimizing resources may help provide structure for decisions and delay severe shortages,2,28 close to the incident there will be an immediate shift to crisis standards of care, with modification in triage order and resource allocation. Farther from the incident, resource supply and demand imbalances will be less dramatic, but they may necessitate a stepwise shift in the resource settings from conventional to contingency to crisis with the need to implement crisis standards of care.2 The rapidly changing conditions make apparent the importance of preplanning for crisis standards of care.

Casualty management follows the principles (not specific criteria) of the sort, assess, lifesaving intervention, treatment/transport/triage scheme.31 The emphasis is on iterative assessment, because the victims’ medical conditions and the availability of resources may change rapidly over time, allowing them to move from the expectant (likely to die) category into the immediate or delayed treatment categories. Palliative/comfort care is an important component of the medical response and resources should be allocated for this and for saving lives.

Following initial triage and treatment, some casualties will require expert secondary and tertiary care. The Radiation Injury Treatment Network,11 the National Disaster Medical System,12 and other centers with expertise in trauma and hematology/oncology care will be involved to the extent that their capacity allows and transportation assets are available.

The tracking of displaced people and those in need of medical care is essential, but unfortunately may be incomplete given the numbers of people involved. Individuals requiring screening for long-term radiation effects may be identified in the first days or may not be identified until much later.

Fatality management, as detailed in Planning Guidance for Response to a Nuclear Detonation is a secondary concern in the early hours; however, an organized approach should be implemented as soon as is reasonably possible.

Challenges
The challenges that will be faced in a nuclear detonation incident are the following:

For the initial response—communication and public understanding:

- Understanding of the need for “duck and cover” after the initial flash (to prevent blast-wave injuries from falling glass) and to shelter in place (as one would for a tornado) until further information is received
- Having familiarity with physical damage and radiation zones and the rate of change of radiation exposure
- Ensuring methods to provide timely and credible communication to guide the public on the situation and what to do/not to do to facilitate effective response

For society in general:

- Understanding that an incident of this magnitude will require unprecedented medical triage that will be extraordinarily difficult for responders and victims
- Understanding that care for people with minor injuries and routine medical conditions may be delayed for days; triage categories will need to be modified according to crisis standards; reassessment may lead to a modification of triage category
- Recognizing that providing the greatest good for the greatest number of people includes using resources for palliation and not only for saving lives
- Recognizing the critical need for consistency of public health and medical decisions across the response area; this requires preincident dialogue and preparation

Ethical Considerations
With the magnitude and suddenness of a nuclear incident, responders will be forced to operationalize medical triage that places many people who would normally receive first priority for care (immediate) into a category in which they will not receive “curative” treatment (expectant). Even medicines for symptom relief may not be available, so vast numbers of casualties may receive little or no care. Rationing of medical care will be required in a context of incomplete situational awareness. Providers will make difficult allocation decisions without the benefit of an administrative structure that could address broader optimization of resource use.
Principles of medical ethics hold that fair prioritizing is based on a first-come, first-served approach unless this order is preempted by individuals with much greater needs for which there are available resources. The effectiveness of an intervention must be taken into account. In the scarce-resources setting it is not considered fair to allocate resources to someone who is unlikely to benefit from them. Priority for care and resources distribution will be determined by the need of the patient and the ability to meet that need with the resources available. As detailed by Caro and colleagues, for fair allocation, providers will apply more stringent determinations of whether an intervention will be effective (efficacy of medical intervention modified by the context) and, therefore, whether use of the resource is acceptable for that person. Whenever needs cannot be fully met, patients must still be accorded comfort, assistance, relief of symptoms, and explanations.

**Challenges**
The ethical challenges that will be faced are as follows:

For ethicists:
- Determining how to deal with factors such as age and pre-existing comorbidities in setting priorities; it is proposed that these would be considered only to the extent they affect effectiveness of medical intervention.
- Determining how to help the medical community differentiate between efficacy of an intervention (best possible outcome) under normal circumstances and the effectiveness of an intervention (ability to complete the intervention) in the setting of critically scarce resources.
- Conveying the importance of fairness and that “the greatest good for the greatest number of people” includes using some of the resources that could be used for lifesaving care to provide palliation/comfort for those who are in the expectant or delayed categories.

For society in general:
- Because of unprecedented resource scarcity, there is the need to change priorities from sickest first to those with serious but more effectively managed injury, and that crisis standards will be needed in the setting of severe shortages.
- Patient characteristics such as age and prior comorbid conditions should not be used as primary considerations in triage except to the extent that they alter the effectiveness of treatment.

**Psychological Support**
The national and international psychological and sociological effects of a nuclear detonation would be enormous. In the 4 response zones and the surrounding communities, the overarching immediate goal of behavioral health care provider (BHCP) interventions is to support lifesaving activities and prevent additional casualties from fallout. BHCPs can assist in the following areas:
- Promoting appropriate protective behaviors (eg, adhering to sheltering recommendations) and addressing psychological barriers to implementing them (eg, paralyzing anxiety).
- Discouraging dangerous behaviors (eg, entering dangerous fallout areas to search for loved ones).
- Helping manage patient/survivor flow to facilitate the best use of scarce resources.
- Supporting first responders’ and first receivers’ ability to function.
- Assisting with triage, including psychological triage of victims, and assisting medical triage personnel.
- Delivering palliative care.

At more distant sites, BHCPs should work with other health care providers to support hospitalized survivors, who are at greater risk for psychiatric morbidity and may need assistance in coming to terms with life-altering diseases or injuries (eg, blindness, limb amputations). Wherever people congregate, a BHCP’s calm and empathic presence can foster a supportive environment and help restore a sense of security. BHCPs can play a consultative role to leaders, ensuring responsiveness to the changing needs of survivors. As patients at high risk for radiation sickness are identified, BHCPs can help them and their families navigate treatment decisions and expected outcomes. The month after the detonation should be used to formulate plans for longer-term mental health delivery strategies and surveillance of at-risk populations.

**Challenges**
The challenges faced by BHCPs are as follows:
- Expanding the capacity of the response to meet psychological needs.
- Assisting responders during the incident—supporting them in real time as they make difficult triage decisions and preventing burnout by encouraging them to take periodic breaks.
- Offering direct support to casualties and encouraging effective participation to help casualties and each other.
- Emphasizing resilience over rage/revenge.

**Legal Considerations**
Providers need to be informed in advance about relevant law so that concerns regarding legal liability and other legal requirements do not interfere with the willingness of clinicians to make crisis standards of care decisions to save lives. An understanding of the breadth of these laws at the federal, state, territorial, tribal, and local levels, the application of them, and how each may change in an emergency is critical to an effective response. Laws may vary from one geographic area to the next and may vary in an emergency, affording waivers or other extraordinary actions/protections under federal, state, or local emergency powers.

Legal requirements that are commonly of concern and should be examined for flexibility, reciprocity, and emergency exceptions include liability protections for providers; licensing and credentialing of providers; consent and privacy protections for patients; occupational safety and employment protections for providers; procedures for obtaining and distributing medical countermeasures and supplies; property use, condemnation, and...
Commentary

protection; restrictions on movement of individuals in an emergency area; and reimbursement for care.

Challenges
The following are the legal challenges that will be faced:

- Providing advance guidance to providers about what liability protections are available to them when they respond in their state or move between states
- Providing advance guidance to providers about what licensing requirements apply when they move between states to respond
- Developing crisis standards of care within a medical and legal framework
- Assessing what legal requirements may change or be waived in an emergency
- Assessing what further steps may be needed to ensure legal requirements support a response

Triage
Given the complexity of the immediate medical response, modeling can be used in advance to develop decision-making strategies that support specific approaches to prioritization of victims for treatment. The model of resource and time-based triage was built to test triage methods for prioritizing victims presenting to hospitals, given the likely pattern of casualties after a nuclear detonation.

The model considers the varying severity of traumatic injuries likely to result from a nuclear detonation: crush, blunt, and penetrating. The model also considers a range of resources (space, staff and supplies). Because staff are required to use space and supplies, the model focuses on maximizing the efficiency of critical staff in a hospital by focusing staff on those for whom care will make the greatest difference in survivability.

The model predicts that in a scarce resources setting, the most lives will be saved if those with moderate life-threatening injuries are prioritized before those with the most severe life-threatening injuries and those who are most likely to die. It indicates that people in the moderate category survive at a much greater rate (5% vs 30% mortality) if treated. In a constrained-resources environment, prioritizing injured people in the moderate category over people in the severe life-threatening injured category saves 50% more lives, and this increases in proportion as resources become more constrained. Figure 1 illustrates how this triage categorization may look in a scarce-resources setting; however, it is but one of several charts that planners and responders need to consider together.

Before the establishment of incident command and full situational awareness, decisions will be made by providers. Ideally, medical facilities plan for managing scarce resources and put systems in place to implement those plans. Harmonizing an approach across a region would help ensure fairness. Once situational awareness and resources allow, a proactive approach would include a formal system such as a clinical care committee and a triage team with clearly defined operating and decision-making procedures. The importance of these groups is to make proactive triage decisions and to remove the decisions about resource allocation and triage for individual patients from the hands of their treating physician(s).

Challenges
The challenges faced in triage after a nuclear detonation include the following:

For medical responders:

- Triage categories for nuclear incident are not well understood by providers and require preincident and just-in-time education.
- Medical management and the unfamiliarity with radiation injury and its treatment require preincident and just-in-time education.
- The shift from the usual priorities of sickest first to moderate life-threatening injuries first is difficult for providers and requires a change in thinking.
- Iterative retriage is required because triage into the expected category may not be a final categorization if more resources become available or conditions change.
- Surge capacity will require assistance from many untrained volunteers and the ability to move people to better resource settings. This will require excellent planning and incident management.

For laboratories:

- Laboratory capacity for biodosimetry (used to assess the radiation dose a person received), including hematology surge capacity for lymphocyte counts, must be expanded.
- High throughput technologies for point-of-care diagnostics are needed to cope with demand. Ideally, these would have dual utility beyond a nuclear detonation. (Research and development projects are in progress.)

For modeling and prediction:

- There is a lack of detailed understanding of time to death from various causes for untreated victims. This gap could be filled by primary research using existing data.
- Limited information is available on combined injury outcomes. Laboratory research is not possible for some injury types.
- The lack of understanding of the effects of a nuclear weapon on the medical system itself hampers predictions of response.
- There is a lack of understanding of what medical resources will be truly limited in relation to distance from the incident. This gap could begin to be addressed by a comprehensive modeling program that accounts for resource hierarchies, resource substitution, the cost of shortfalls, predicted evacuation times after the incident, and the ability to re-supply and distribute resources from those already within the region.
FUTURE STEPS
The goals of the Scarce Resources for a Nuclear Detonation Project are to provide useful information for planners and responders in advance of a nuclear detonation, to enhance the public’s knowledge of actions and priorities after a nuclear detonation, and to encourage dialogue and preparation, because most jurisdictions remain unprepared for such an incident. The challenges identified in our deliberations will help define the next steps to be considered.

Updates regarding a nuclear detonation incident can be found in Planning Guidance for Response to a Nuclear Detonation1 and on the Radiation Emergency Medical Management,12 Centers for Disease Control and Prevention,13 Armed Forces Radiobiology Research Institute,11 National Institute for Arthritis and Infectious Diseases,9 and ASPR5 Web sites. Interested readers are encouraged to join the REMM listserv.

It is recognized that there is no single right or perfect solution for responding to a nuclear detonation, yet a well-considered response is possible. Efficiency (maximizing lives saved) is important, but fairness is the ethical principle that considers patients’ needs as well as the effectiveness of the available resources in caring for patients. Although different individuals and communities may weigh the needs of the patients and the effectiveness of resources differently, ensuring fair and consistent treatment and symptom relief may be one of the most important factors in a successful response after a nuclear detonation. We anticipate that this special issue of Disaster Medicine and Public Health Preparedness and other tools will improve the awareness, preparedness, and resilience for response to a nuclear detonation, and will produce further discussion, appropriate adaptation, and ongoing progress. Through planning, preparing, exercising relevant scenarios, and applying these concepts, preparation for mass casualty incidents will continuously improve.

APPENDIX
At the initial Scarce Resources for a Nuclear Detonation Project meeting, experts presented background information on topics of relevance to the scarce resources setting of a nuclear detonation incident. The panel then identified topic areas for inclusion in the manuscripts that would be submitted for possible publication in the peer-reviewed literature. Each topic area had a lead author or authors assigned. The writing team for each manuscript ensured that there was broad representation of relevant expertise. Input was sought from the Radiation Injury Treatment Network at one of their group meetings11 to refine focus areas and create general consensus around strategies of medical response. Where necessary, the leads sought additional expertise such as modeling experts. The writing teams convened subgroup meetings to develop outlines and draft manuscripts. A second smaller meeting of the lead writers was hosted to ensure continuity and conceptual clarity across the manuscripts. The panel of experts provided internal peer review of the manuscripts before submitting them for possible publication. Consensus agreement was reached among the experts, or the areas of disagreement were cited in the manuscripts. In the end, 10 manuscripts were written to address the central topics. The manuscripts were submitted for peer review and potential publication in the scientific literature. An ad-

FIGURE

### Triage category for trauma and combined injury

<table>
<thead>
<tr>
<th>Injury severity</th>
<th>Trauma only</th>
<th>Severe trauma*</th>
<th>Moderate trauma*</th>
<th>Minimal trauma*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Immediate</td>
<td>Immediate</td>
<td>Immediate</td>
<td>Immediate</td>
<td>Minimal</td>
</tr>
<tr>
<td>Delayed</td>
<td>Delayed</td>
<td>Delayed</td>
<td>Delayed</td>
<td>Minimal</td>
</tr>
<tr>
<td>Expectant</td>
<td>Expectant</td>
<td>Expectant</td>
<td>Expectant</td>
<td>Minimal</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Standard of care**</th>
<th>Conventional</th>
<th>Contingency</th>
<th>Crisis</th>
</tr>
</thead>
<tbody>
<tr>
<td>Resource availability</td>
<td>Normal</td>
<td>Good</td>
<td>Fair</td>
</tr>
</tbody>
</table>

**Adding >20% total body surface area burn to trauma worsens triage priority by 1 category (puts them lower on the priority list).**

*Radiation dose received by the whole body of a significant portion of the whole body. At higher radiation doses (>6 Gy), triage category may worsen—as on Combined Injury card.

### Triage category for TRAUMA and COMBINED INJURY affected by injury severity, radiation dose, and resource availability

- **Trauma** + **radiation** = Combined injury
- **Trauma only** BURN >20% BSA worsens triage category (lowers priority) 1–2 levels
- **Severe trauma** Immediate Immediate Immediate Expectant
- **Moderate trauma** Immediate Delayed Delayed Immediate Expectant
- **Minimal trauma** Minimal Minimal Minimal Minimal

<table>
<thead>
<tr>
<th>Legend: Trauma and combined injury</th>
</tr>
</thead>
<tbody>
<tr>
<td>Radiation dose of &gt;2 Gy to whole body or significant portion of whole body plus moderate or severe trauma and/or burn injury.</td>
</tr>
<tr>
<td>Radiation dose of &gt;6 Gy to whole body or significant portion of whole body plus moderate or severe trauma and/or burn injury.</td>
</tr>
<tr>
<td><strong>Radiation dose received by the whole body. At higher radiation doses (&gt;6 Gy), triage category may worsen—as on Combined Injury card.</strong></td>
</tr>
</tbody>
</table>

**This is 1 of a series of “cards” that indicates how triage category changes based on the availability of resources for trauma and combined injury. These are discussed in detail in Coleman et al.22 and PDFs of all cards can be downloaded at http://www.dmphp.org. There are 4 resource settings (adapted and modified from the Institute of Medicine): normal, with conventional standards of care; good, with contingency standards in which substitution of resources allows normal triage order, crisis, which is subdivided into fair, when there are enough resources to treat the moderate life-threatening trauma, and poor, when there are insufficient resources to treat the moderates. The injury severity categories are severe life-threatening, in which likelihood of death is >20% even when aggressive treatment is available; moderate life-threatening, in which the injuries are less severe and mortality is <20% minimally, in which the injuries may require intervention, even substantial intervention, but are not life threatening within the next day or so (eg, certain limb fractures); and combined injury, which is moderate or severe life-threatening injury plus a radiation dose of >2 Gy (lower doses are not considered to be combined injury and are triaged as trauma only). Burns of >80% total body surface area worsen triage category 1 level (eg, delayed to expectant). In the conventional and contingency settings, the usual “sickest first” order is followed by severe receiving immediate care, then moderate, and minimal after that (although in a mass casualty setting, some of the minimal may be given temporary remedies and sent on to splint or bandage for fracture or non-life-threatening wound). In the crisis setting with fair resources, moderates would be treated before severe; with poor resources, moderates would be treated first, recognizing there are not even sufficient resources for them. In general, individuals with combined injury would be treated similarly to the severe, although at the higher radiation doses survival is so limited that they may receive a lower priority (eg, in crisis, fair resources delayed may be changed to expectant). Reevaluation is a key part of triage and management because the initial triage category may change over time (eg, a moderate may become a severe) and as resource setting improves (eg, delayed may become an immediate).**

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**Disaster Medicine and Public Health Preparedness**

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Commentary

Additional background paper was added after the initial review based on feedback from the editors of Disaster Medicine and Public Health Preparedness.

The participants who attended the March 5, 2009 executive steering committee meeting for the Scarce Resources for a Nuclear Detonation Project are listed below.

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Abbreviation key: ASPR = Assistant Secretary for Preparedness and Response; BARDA = Biomedical Advanced Research and Development Authority; CBRN = chemical, biological, radiological, nuclear; CDC = Centers for Disease Control and Prevention; DAIT = Division of Allergy, Immunology, and Transplantation; DHHS = Department of Health and Human Services; NIAID = National Institute of Allergy and Infectious Diseases; NCI = National Cancer Institute; NIH = National Institutes of Health; OPEO = Office of Preparedness and Emergency Operations; SAIC = Science Applications International Corporation; UPMC = University of Pittsburgh Medical Center.

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REFERENCES


PUBLIC HEALTH AND MEDICAL PREPAREDNESS FOR A NUCLEAR DETONATION: THE NUCLEAR INCIDENT MEDICAL ENTERPRISE


Abstract—Resilience and the ability to mitigate the consequences of a nuclear incident are enhanced by (1) effective planning, preparation and training; (2) ongoing interaction, formal exercises, and evaluation among the sectors involved; (3) effective and timely response and communication; and (4) continuous improvements based on new science, technology, experience, and ideas. Public health and medical planning require a complex, multifaceted systematic approach involving federal, state, local, tribal, and territorial governments; private sector organizations; academia; industry; international partners; and individual experts and volunteers. The approach developed by the U.S. Department of Health and Human Services Nuclear Incident Medical Enterprise (NIME) is the result of efforts from government and nongovernment experts. It is a “bottom-up” systematic approach built on the available and emerging science that considers physical infrastructure damage, the spectrum of injuries, a scarce resources setting, the need for decision making in the face of a rapidly evolving situation with limited information early on, timely communication, and the need for tools and just-in-time information for responders who will likely be unfamiliar with radiation medicine.

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INTRODUCTION

Following the 11 September 2001 terrorist attacks, the United States began detailed preparation to address 15 National Planning Scenarios††† (USDHS 2007, 2011). Scenario #1 is a 10 kt improvised nuclear device, also called a nuclear detonation. Scenario #11, a radiological dispersal device, has elements in common with a nuclear detonation but is not the subject of this report. The radiation research and sciences communities began working together to consider the science, tools, and treatments available for acute radiation injury (Coleman et al. 2003), and efforts were initiated at the federal level to improve planning and preparedness for the health and medical response to such incidents, which in the National Response Framework is a responsibility of the U.S. Department of Health and Human Services (DHHS) per Emergency Support Function #8 and the Nuclear/Radiological Incident Annex (FEMA 2008, 2013a).

A 2009 publication presented the systems approach being developed by DHHS and its interagency partners, which emphasized the importance of basing the response on the available and emerging science (Coleman et al. 2009; Dainiak et al. 2011a and b). A number of guidance...
As the individual tools and concepts in NIME were developed, they were published in the peer reviewed scientific literature so that the ideas and products benefit from review, broad discussion, and public dissemination. Most of these tools and capabilities can also be used for mass casualty radiation incidents other than a nuclear detonation.

**Nuclear incident medical enterprise**

Fig. 1 illustrates the interrelated components of NIME. While there are various ways of presenting the content, the authors felt it was important to be able to visualize the components in a single chart in which their relationships could be understood. The enterprise is based on knowledge from science and medicine with the awareness that partnerships and senior leadership coordination will be essential for preparing for and mounting the response. Understanding the "nuclear scenario and its impact" is the basis for planning and response. Public health and medical concepts are the basis for developing resources that facilitate medical management and situational awareness. Built on these resources are response tools and capabilities that are assessed and modified in exercises and used during incidents including minor radiological incidents and the Fukushima Nuclear Power Plant accident. While there is overlap as to which NIME categories in planning and response, resources, and tools are developed, in the NIME chart they are placed into the five columns that occur in sequence following an incident: decision making and communication, organizing response, triage, medical management, and medical care. While “medical” is used in the title for simplicity, the enterprise addresses public health and medical needs. Some of the components have been specifically designed for or adapted to a nuclear incident, while most reflect general all-hazards capabilities available within the Office of the Assistant Secretary for Preparedness and Response (ASPR) with DHHS and the federal government.

NIME recognizes that public health and medical responses begin at the local level and that federal resources are mobilized only when requested. It assumes that an incident of this magnitude will rapidly overwhelm the local, state and regional resources and that federal assistance will be requested. The items in Fig. 1 are next discussed by row from the bottom up.

**SCIENCE BASE**

**Radiation sciences**

The information and resources developed for both planning and response are based on the best available science, including knowledge of research and development in progress, some of which may not yet be publicly available. There are experts in multiple federal agencies who share knowledge through research projects, seminars, and working groups. This includes a periodic informal exchange of

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**Planning Guidance for Response to a Nuclear Detonation** (National Planning Guidance) (HSC 2010) coordinated by the Office of Science and Technology Policy that includes information on potential physical infrastructure damage, guidance for shelter and evacuation, and communication in addition to health and medical issues; and

**Scarce Resources for a Nuclear Detonation Project** coordinated by DHHS (Coleman et al. 2011a; Knebel et al. 2011), which addressed managing radiation casualties under conditions of resource scarcity (Coleman et al. 2011b).

Additionally, the U.S. government is supporting ongoing programs to develop medical countermeasures (MCM), diagnostics, and distribution systems. Formal collaborations with international partners have been established, and valuable experience has been gained from exercises and the response to the nuclear power plant disaster in Japan (Coleman et al. 2013; NA/IOM 2013). Current capabilities and experience have been distilled into the Nuclear Incident Medical Enterprise (NIME), which is described in this paper and addresses public health and medical planning and response.

When developing information, resources, and tools for decision makers as well as public health and medical responders, planners make a number of core assumptions:

- information needs to be in an understandable and usable format, with up-to-date content available just-in-time under a very compressed timeline (minutes) for a variety of audiences;
- detonation of a nuclear device is thought to be such an overwhelming scenario that many localities do not expend scarce preparedness resources planning for it (GAO 2013); when, in fact,
- although there would be catastrophic destruction near the epicenter, much infrastructure in the surrounding areas will remain intact and could provide meaningful support to affected populations; and, therefore,
- while solid science, theory, law and policy underpinnings are critical, what is needed for responders and planners is the answer to the question “What do I DO?!?”

While a consistent effort to share available information and tools has been made, recent workshops focusing on regional preparedness have shown that additional efforts are needed to bring the answers to this question to the public’s attention (NA/IOM 2014).
The nuclear incident medical enterprise (NIME). NIME is a composite of the approach of DHHS and interagency partners, working with state, local, regional, territorial and tribal partners, and academia toward the public health and medical preparedness, planning and response to a nuclear detonation. It is a “bottom up” compilation with current and evolving science and collaboration as the underpinning of the enterprise. On this base are the scenario and models, concepts, resources, and lastly specific tools and capabilities. Working from left to right on the top three rows are how these will be used during the phases of preparedness and response. There are tools and resources that transcend all phases.

Resilience and the ability to mitigate the consequences are key goals. The concepts, resources, tools and capabilities for NIME can be applied to the all-hazards approach used for emergency planning and response. Responses begin at the local level with federal resources provided when requested. Description and essential information are presented in the text with the goal of having a single source that includes the information that is contained in a number of resources. Text in blue represents projects for which substantial development is necessary and in progress.

COORDINATION

ASPR, ASPR working groups, PHEMCE, CDC

The Public Health Emergency Medical Countermeasures Enterprise (PHEMCE) (ASPR 2013a) coordinates federal efforts to enhance the response to chemical, biological, radiological, nuclear, and explosive threats from an MCM perspective. PHEMCE is led by ASPR and includes three primary DHHS internal agency partners: Centers for Disease Control and Prevention (CDC), Food and Drug Administration, and the National Institutes of Health, as well as several interagency partners [the U.S. Departments of Defense, Veterans Affairs, Homeland Security (DHS), and Agriculture]. Working groups operating under the PHEMCE perform the wide range of functions, with integration of efforts across disciplines and departmental boundaries, a major group being the Radiological/Nuclear Integrated Project Team. A key emphasis for all of U.S. government planning and response is working closely with partners, especially nonfederal U.S. partners, but also international partners. Given the magnitude of a nuclear detonation, this cooperation is particularly important.

Nonfederal partners: state/local/tribal/territorial

The ASPR Office of Emergency Management (OEM) works at the state and regional level through exercises and educational programs. There is substantial ongoing scientific participation by nongovernment SMEs, as illustrated in the authorship of the Scarce Resources for a Nuclear...
Of the Detonation Project (Coleman et al. 2011a) and the medical planning guide (Coleman et al. 2012a).

International partnerships

Federal agencies, particularly ASPR, collaborate with international partners for health and medical issues through multilateral forums such as the Global Health Security Initiative (ASPR 2013b) and with partners at the International Atomic Energy Agency and the World Health Organization, including its BioDoseNet (2014) and the Radiation Emergency Medical Preparedness and Assistance Network (WHO 2014) components. Additionally, the NIAID Centers for Medical Countermeasures Against Radiation have established collaborations with international organizations to advance basic research and MCM development.

SCENARIO AND IMPACT

Scenario modeling

A great deal of progress has been made in refining initial National Planning Scenario (USDHS 2007) models. A wide range of robust, detailed computer models have been built to describe many types and locations of nuclear detonations, including air and ground detonations, various sizes of detonations, and both meteorological and topographical factors that could affect ground contamination, fires, the blast, and the trajectory, deposition, and decay characteristics of the fallout cloud. The consequences of a detonation have also been modeled from human fatalities and injuries to impacts on infrastructure and the amount of debris generated. These models have been critical for characterizing a range of incident parameters for which plans have been developed and for which only limited data were available before the modeling.

Table 1. Estimated casualties from nuclear detonation modeling for trauma only, radiation injury only, and combined injury (radiation plus trauma).

<table>
<thead>
<tr>
<th>Injury type</th>
<th>Category</th>
<th>50%</th>
<th>85%</th>
<th>95%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Trauma (injury severity score)</td>
<td>Mild (1–9)</td>
<td>20,000</td>
<td>53,000</td>
<td>80,000</td>
</tr>
<tr>
<td></td>
<td>Moderate (10–14)</td>
<td>34,000</td>
<td>118,000</td>
<td>121,000</td>
</tr>
<tr>
<td></td>
<td>Severe (&gt;15)</td>
<td>14,000</td>
<td>63,000</td>
<td>143,000</td>
</tr>
<tr>
<td>Radiation only injury (radiation dose)</td>
<td>Mild 0.75–1.49 Gy</td>
<td>4,000</td>
<td>23,000</td>
<td>72,000</td>
</tr>
<tr>
<td></td>
<td>Moderate 1.5–5.29 Gy</td>
<td>6,000</td>
<td>25,000</td>
<td>41,000</td>
</tr>
<tr>
<td></td>
<td>Severe 5.3–8.3 Gy</td>
<td>3,000</td>
<td>6,000</td>
<td>12,000</td>
</tr>
<tr>
<td></td>
<td>Expectant &gt;8.3 Gy</td>
<td>5,000</td>
<td>16,000</td>
<td>47,000</td>
</tr>
<tr>
<td>Combined injury (radiation dose &gt;1.5 Gy)</td>
<td>Trauma and/or mild-severe burn</td>
<td>2,000</td>
<td>20,000</td>
<td>45,000</td>
</tr>
</tbody>
</table>

aThe values in this table are estimates used for planning purposes and are derived from 185 different scenarios with various nuclear detonation yields (0.1–10 kT) in various cities under various conditions. Because of the range of possibilities, casualty numbers can vary by factors of 5 to ≥10 among cities and among detonation locations within cities. The percentiles used represent a mid-range (50th percentile), a moderately-high (85th percentile), and an estimate for a high-consequence scenario (95th percentile) (adapted from Knebel et al. 2011).

Interagency partners - planning for the scope of nuclear detonation

The National Planning Guidance (HSC 2010) provides a structure from which the public health and medical response will occur. It describes four physical damage zones (severe, moderate, light damage, and dangerous fallout) and illustrates that there will be a wider area of radioactive fallout where people and responders can remain and work for varying periods of time.

The Interagency Modeling and Atmospheric Assessment Center (IMAAC) (USDHS 2013) led by DHS produces, coordinates, and disseminates dispersion modeling and hazard prediction products. This Center is a partnership among eight federal agencies to specifically address the integration necessary for atmospheric modeling. IMAAC information can be incorporated into MedMap (ASPR 2013c) for planning and situational awareness during a response as described below.

For a sense of scope of a nuclear detonation incident, general estimates of the numbers and types of casualties following an improvised nuclear device detonation are in Table 1 (Knebel et al. 2011; Coleman et al. 2012a).

UNDERLYING CONCEPTS

SME support and availability

Should a nuclear incident occur, it would be essential for decision makers to have readily available expertise in the radiation sciences and in the management of radiological and nuclear emergencies. Public health and medical expertise is available from the Advisory Team for Environment, Food and Health, known as the A-Team (CDC 2014a), and from ASPR subject matter experts (SME). There is a proposed formalization of SMEs into a subject matter advisory resource team that would include government and nongovernment experts. Research scientists,
including clinicians and epidemiologists, are available from federal agencies as noted above in Radiation Bioterrorism Research and Training. The Radiation Injury Treatment Network (RITN) is a nongovernment group that has world renowned oncology and hematology experts and capabilities to assist in planning, treatment-protocol development, and treatment for patients with acute radiation syndrome (Ross et al. 2011; NMDP 2014).

**Risk communication**

Risk communication experts are available during exercises and incidents from federal agencies. The importance of timely and effective communication was seen in the response to the Fukushima Nuclear Power Plant disaster. A set of prescribed messages for preparedness and response to a nuclear incident is available (FEMA 2013b) as noted in Response Tools and Capabilities of Fig. 1.

**Medical-decision management model**

Based on decision managing the Fukushima Nuclear Power Plant disaster in Japan, a medical decision-management model was proposed by a multi-agency group of experts who worked with the U.S. Embassy team in Tokyo during the crisis (Coleman et al. 2013). The underlying principles are that decisions must be made in real-time based on emerging information, as is done in rapidly evolving medical care such as emergency medicine and oncology, and that it is best done with SMEs on site with the senior decision makers. Reach-back expertise and consultation are necessary but should not delay critical decision-making and communication.

**PAGs**

As defined on the EPA website:

“A PAG is defined … as the projected dose to an individual from a release of radioactive material at which a specific protective action to reduce or avoid that dose is recommended. PAGs are guides to help officials’ select protective actions under emergency conditions during which exposures would occur for relatively short time periods. They are not meant to be applied as strict numeric criteria but rather as guidelines to be considered in the context of incident-specific factors. PAGs do not establish an acceptable level of risk for normal, nonemergency conditions, nor do they represent the boundary between safe and unsafe conditions. The PAGs are not legally binding regulations or standards and do not supersede any environmental laws” (USEPA 2013).

For the general public, the Protective Action Guide (PAG) dose, even if it is reached, is very low. It is below 0.05 Gy for radiation workers and lower for members of the public. Anyone receiving a dose below the PAG limit would be far below risk of acute radiation syndrome (USEPA 2013) and would not need any medical intervention for radiation exposure per se. Response worker dose guides are higher (0.05–0.25 Gy or possibly higher) and require prior understanding and/or informed consent. In comparison to the PAG doses, symptoms from acute exposure begin to occur at ~0.75–1 Gy and screening for possible acute radiation syndrome begins at ~2 Gy.

In an evolving nuclear or major radiological incident response, the plume models and measured radiation data would be used to guide decision makers and responders as to where to deploy, who to evacuate and when, who should shelter in place, identify those individuals who are not affected, and for those who have evacuated, when they might return. It is noteworthy that radioactive fallout decays rapidly following a nuclear detonation so that the boundary lines of where responders will be excluded due to the higher radiation exposures will shrink rapidly over the first few hours to days.

**Scarc resources triage**

Perhaps the most significant challenge for emergency responders and triage officers will be the possible need to alter triage assignment for individual victims from the usual “sickest first” model. The Scarce Resources for a Nuclear Detonation Project addressed the issue of scarce resource allocation and the possible need to alter triage (Casagrande et al. 2011; Coleman et al. 2011a and b; Knebel et al. 2011). Performing medical triage in the field will pose a serious challenge to most emergency responders and healthcare facilities due to a lack of familiarity with the medical issues related to radiation exposure and/or contamination. To address this issue, the Radiation Emergency Medical Management (REMM) website (NLM 2014a) was developed for those unfamiliar with radiation exposure and/or contamination. REMM will be useful for symptoms such as time to vomiting, but the algorithms show the importance of laboratory support for biodosimetry, more accurate triage, and medical management (NLM 2014b). A model of resource and time-based triage was developed by Casagrande, Coleman, and colleagues (Casagrande et al. 2011; Coleman et al. 2011b), and an algorithm-based approach for triage (Coleman et al. 2011b) is available as triage cards and a web-based tool on the REMM website.

**Biodosimetry**

The ability to estimate the dose received by individuals will determine resource allocation and will aid in patient triage, emphasizing the importance of taking care of potentially fatal injuries first and considering the effect of radiation second. A diagnostic test that estimates radiation dose is called “biodosimetry.” A number of assays are used, with the blood count (especially lymphocyte depletion kinetics) and cytogenetic changes (dicentric chromsome assay) being the most widely used techniques. As recently reviewed by Sullivan et al. (2013), newer
approaches are being studied, including point-of-care diagnostics that will sort people into broad dose groups (e.g., \(<2, 2–4, 4–6, \text{and } >6 \text{ Gy}\) for initial triage and secondary diagnostics high throughputscreening that can provide a more accurate dose for definitive medical management.

**Radiation medicine**

Depending on the dose and presence of combined injury, people with radiation exposure \(>2 \text{ Gy}\) will require either immediate treatment or referral to a center with expertise in radiation injury. People with low doses (e.g., \(<2 \text{ Gy}\)) and without physical injury will not require immediate care and might be among those monitored in long-term epidemiological studies, such as those conducted by the National Cancer Institute Division of Cancer Epidemiology and Genetics Radiation Epidemiology Branch (NCI 2013b). Determining who requires acute care in the immediate aftermath of the incident will be critical if medical resources are in short supply, as they are likely to be.

**MCM requirements**

The determination of what resources will be required for an incident is essential to effective planning. Resource requirements include the MCMs, clinical diagnostic tools, supporting material needed for a range of emergencies, and the infrastructure for storing, accessing, and dispensing MCMs. Determining what resources are required must take into account the ability to deliver and use them during the crisis. Organized by the ASPR Office of Policy and Planning, Division of Medical Countermeasure Strategy and Requirements (ASPR 2013d), requirements, documents, and processes are built on detailed modeling of:

- the incident;
- medical conditions anticipated;
- patient illness and injury distribution;
- treatments potentially available and their operating characteristics (e.g., intravenous, oral, temperature for storage, single packaging versus multi-dose, shelf-life, etc.);
- whether the MCM is used in routine practice (called “dual-utility”);
- quantity in routine use;
- ease of administration (including self-administration); and
- other factors.

**Product development**

While some aspects of MCM and diagnostic development are classified or confidential (due to business decisions or pending decisions on acquisitions), much is published in the peer review literature. The Biomedical Advanced Research and Development Authority (BARDA), which is a part of ASPR, partners with industry to facilitate advanced product development for MCMs that are guided by federal working groups. The products and concept of operations (CONOPS) for their use are continually evaluated to optimize what is available and also to develop products that could perform under the most likely scenarios.

The NIAID Radiation and Nuclear Countermeasures Program (NIAID 2013) has a research and development program addressing radiation-induced normal tissue injury and biodosimetry, with a focus on post-exposure treatment, mitigation, and public health emergency needs. As part of this program, the NIAID Centers for Medical Countermeasures against Radiation and the Radiation and Nuclear MCM Product Development Support Services engage academic and industrial/biotechnology companies in early stage research and product development that can serve as a source of potential new products for BARDA’s advanced development. Earlier stage research and discovery is supported by the National Institutes of Health basic and translational research grants. The Armed Forces Radiobiology Research Institute (AFRRI) has long-standing research and development programs for radiation MCM and biodosimetry (AFRRI 2014). While NIAID and BARDA focus on post-exposure mitigation, the U.S. Department of Defense supports pre-exposure, prophylactic MCM research at AFRRI and the Defense Advanced Research Projects Agency.

**PLANNING AND RESPONSE RESOURCES**

**REMM**

Development of the Radiation Emergency Medical Management (REMM) website was initiated early on, as the first versions of playbooks were written (NLM 2014a). REMM is a collaboration of ASPR, the National Cancer Institute, the National Library of Medicine (NLM), and SMEs from within and outside the federal government. REMM reflects evidence-based, peer-reviewed literature, and is updated frequently as medical science and official planning documents evolve. REMM uses an algorithm-based approach similar to that used in advanced cardiac life support. It provides guidance for both responders who manage an incident as well as individual health care providers who manage patients. REMM can be used as a just-in-time resource or pre-incident for training and education. “Mobile REMM” is a smart-phone app and can be downloaded for multiple platforms (ASPR 2014a). Both REMM and Mobile REMM have an interactive tool that uses the absolute lymphocyte count from one or more complete blood counts to estimate whole-body dose (NLM 2014c). The algorithm was developed by AFRRI.

**MedMap**

A nuclear scenario will evolve rapidly over time and location. In order to maintain situational awareness and provide a common operating picture for responders, MedMap was developed by ASPR to respond specifically
to a nuclear detonation. However, MedMap is now used for all hazards and continues to grow in capacity and capability. MedMap is a secure, Geographic Information Systems-based application that combines data from multiple federal and public agencies and sources into a single mapping environment, with individual layers reflecting details about the incident as well as many kinds of response resources and analytical tools. With consultation from chemical, biological, radiological, nuclear, or explosive SMEs (ASPR 2013c; CDC 2013a), data can be integrated and interpreted as an incident unfolds. MedMap can be updated iteratively in real-time as new data arrive to provide incident managers with big picture situational awareness. It displays areas with damage and fallout and shows the locations of resources for planning and responses, including medical care sites and mobilization points. Access to MedMap can be shared by request to ASPR when needed.

CONOPS

DHHS and other federal agencies have developed their own specific CONOPS for a nuclear detonation response that describes in detail the agency’s planned overall response. The DHHS CONOPS, prepared by OEM while working with intra- and interagency experts, focuses on the DHHS role and how other agencies and state/local responders will interact with the federal response. What is key in the NIME approach is that MCM use and delivery must be realistically executable within the CONOPS (Sullivan et al. 2013). CONOPS are modified to accommodate the characteristics of the necessary supplies and their distribution. Thus, CONOPS are constantly evolving and are operationalized within playbooks and guidance documents.

RESPONSE TOOLS AND RESOURCES

Decision-makers’ guide

After seeing first-hand the scope of and immediate need for information in the real-time management of the Fukushima Nuclear Power Plant disaster, a decision-makers’ guide was developed to enable better informed decisions by primary decision makers (who may be an elected official without a science or medical background). The decision-makers’ guide contains critical information on aspects of a radiation or nuclear incident that can be used until SME support is available (Coleman et al. 2012a; Koerner et al. 2014; Coleman 2011c). A web-based electronic version is in preparation.

Communication guidance

Effective and timely messaging is critical. Resources have been developed to aid responders in providing information and life-saving instructions to the public (FEMA 2013b; CDC 2014b; Koerner et al. 2014). The resources have been reviewed and tested by state and local responders and communications experts.

Playbooks

Considerable energy is devoted to the development of plans and playbooks that become the basis for training and exercises so that responders can prepare for and respond quickly to events they have never experienced before, except to some extent in exercises. These may be incident-specific documents or an annex to an all-hazards plan. DHHS playbooks and plans are produced by planning and operations SMEs within OEM. Other federal agencies have internal plans that detail their responsibilities and how they will interact with others (FEMA 2008).

There are a number of plans, playbook, and other resources available on the ASPR website [http://www.phe.gov (ASPR 2014b)]. While the federal response has much in common with state/local/tribal/territorial responses, ASPR has worked with state/local/tribal/territorial experts to develop a playbook template for a nuclear detonation and which uses both a time- and sector-oriented response (Murrain-Hill et al. 2011).

The Radiation Triage, Treatment, and Transport System

As described in Planning Guidance for Response to a Nuclear Detonation (HSC 2010), there will be locations after a nuclear detonation where there will be some people with combined injury (e.g., radiation, mechanical trauma, and/or burn) as well as many people with either isolated physical injury or isolated radiation exposure. Triage will be based first on standard triage systems in use by the local/regional responders. Radiation exposure will be assessed based on the person’s location at the time of the detonation and during the period of fallout deposition and by symptoms and laboratory measurement. In that the responders need a system to account for the presence of radiation, the Radiation Triage, Treatment, and Transport System was developed to help manage radiation injury and has been used in a number of exercises and regional planning efforts (Hrdina et al. 2009).

Victim tracking

The ability to reunite displaced people after an incident of this magnitude will present a complex challenge. A common process for tracking patients, fatalities, and responders remains a significant gap. State and local agencies should establish a registry as early as possible that can be used to contact people who require short-term medical follow-up and/or long-term health monitoring; assistance is available from CDC and the Agency for Toxic Substances and Disease Registry (CDC 2014c). The Agency’s Rapid Response Registry is available to assist state and local personnel with epidemiological investigations. Other examples of registry and epidemiological
tracking forms are available from the National Alliance for Radiation Readiness (NY DOH 2014) or as part of the Virtual Community Reception Center training program (CDC 2014d; NLM 2014c).

**Integrated clinical diagnostics system**

For a nuclear detonation, various techniques will be used to estimate an individual’s whole-body radiation dose from external exposure. There may be physical radiation dose levels from monitors in fixed locations (e.g., police and fire stations) and from responders in the field. Computer models (USDHS 2013) will analyze doses reported from various venues and create geographic dose maps that evolve over time. With these maps, responders can “bin” members of the public into groups based on their physical location(s) and estimate likely dose from radiation exposure to prompt radiation and subsequent fallout.

Physical dosimetry (field measurements) and models will be helpful, but for medical management biodosimetry, they will be necessary to estimate doses received by an individual as noted above. SMEs have proposed an architecture that will allow for a massive, immediate national biodosimetry surge (HSC 2010; Grace et al. 2011; Hatchett 2011; NA/IOM 2013), and the concepts for an Integrated Clinical Diagnostics System (ICDS) are under development (Coleman et al. 2009; Sullivan et al. 2013; Blumenthal et al. 2014). The ICDS concept recognizes that the role of clinical diagnostics will change based on the location of testing and over time after the incident. Physical and clinical biodosimetry would be used initially for triage, then to inform medical management, and still later for long-term epidemiology and risk assessment. The establishment of ICDS is a work in progress. This system has a unique focus on radiation and its special requirements and is not a component of the CDC Laboratory Response Network (CDC 2013b), although there are potential processes in common.

**Population monitoring**

CDC prepared *Population Monitoring in Radiation Emergencies: A Guide for State and Local Public Health Planners* (CDC 2014e), which has been used in the design and conduct of drills and exercises at local, state, and federal levels (NLM 2014c). States are beginning to incorporate population monitoring into their radiation emergency response plans. The operational concept of the community reception center is also being incorporated in radiation emergency response plans across the country. To support these efforts, CDC has developed a number of training and planning tools and resources specifically related to population monitoring and community reception center operations.

**MCM**

The effective and efficient use of medical countermeasures (MCM) requires a CONOPS for managing and co-locating the staff and resources with the victims who need assessment and treatment. As a nuclear detonation response will require a national and, indeed, an international response expanding the current planning and use of MedMap for a “national CONOPS” is a work in progress by ASPR. MCM’s include medicines and supplies, which may be common across hazards. Examples for a nuclear detonation include bone marrow cytokines, antibiotics, antiemetics, intravenous fluids, and burn kits. There is a DHHS Blood and Tissue Working Group looking at these products. The special needs for at-risk populations and pediatric patients, such as liquid formulations and alternate dosing schedules, are considered during MCM development and dispensing. Product development of novel radiation countermeasures is supported by NIAID and BARDA.

**Managed inventory approaches for MCMs**

The CDC Division of Strategic National Stockpile ensures the availability of critical MCMs that can be rapidly integrated into a public health response when needed. The Division of Strategic National Stockpile uses multiple managed-inventory systems to ensure inventory of available MCM. A new User-Managed Inventory approach (Coleman et al. 2012b), currently under consideration, could enhance the capability of local responders to have MCMs in the first 24 h before major outside resources can reach the incident. The User-Managed Inventory approach would stockpile and store inventory in local care facilities and is under discussion or development by a few cities and RTIN. Table 2 compares various kinds of actual and potential storage and stockpiling methods.

**Medical care**

The number of individuals seeking medical attention will likely rapidly and significantly overwhelm the local/regional capacity, which will have a substantial ripple effect throughout the region and country. During an emergency, most deployable federal medical resources other than the SNS are coordinated through the OEM, which oversees assets such as the National Disaster Medical System. In a nuclear disaster, these assets will supplement an integrated national medical response capability by assisting state and local authorities (ASPR 2013f). The U.S. Public Health Service and local Medical Reserve Corps teams located across the United States will also support this “whole medical community” response, and these assets are connected at the federal level both to ASPR and the DHHS Office of the Surgeon General and the Assistant Secretary of Health. Very few of these teams, however, are equipped to operate in a contaminated environment or have the ability to treat contaminated patients. Additionally, current local and state efforts supported by the Hospital Preparedness Program (ASPR 2014c) grants for developing hospital
### Table 2. Medical countermeasure storage and stockpiling methods.

<table>
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<th>Emerging Strategy</th>
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<tr>
<td>Forward Deployed Stockpile-Managed Inventory</td>
<td>User-Managed Inventory</td>
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</tbody>
</table>

**Source of additional capacity**
- Manufacturer or vendor maintains guaranteed level of needed supplies or technologies.

**Responsible party**
- Manufacturer or vendor under SNS oversight.

**Vertical inventory**
- DARPA, US Army, US Navy, etc.

**Expected delivery time**
- Varies by item: <1 h, 1-3 h, 3-12 h, 12-24 h.

**Expected use scenarios**
- Medical/surgical supplies for blast and trauma: 24-48 h.
- Anti-emetics: Immediate use in facility where stored.

**Expected time frame**
- Immediate use in facility where stored.

**Expected time to deliver**
- From source to destination in 24 h.

**Expected time to process**
- Varies by item: <1 h, 1-3 h, 3-12 h, 12-24 h.

**Expected time to treat**
- Varies by item: <1 h, 1-3 h, 3-12 h, 12-24 h.

**Expected time to mitigate**
- Varies by item: <1 h, 1-3 h, 3-12 h, 12-24 h.

**Expected time to remove**
- Varies by item: <1 h, 1-3 h, 3-12 h, 12-24 h.

**Expected time to report**
- Varies by item: <1 h, 1-3 h, 3-12 h, 12-24 h.

**Expected time to recover**
- Varies by item: <1 h, 1-3 h, 3-12 h, 12-24 h.

**Expected time to return**
- Varies by item: <1 h, 1-3 h, 3-12 h, 12-24 h.

**Expected time to replace**
- Varies by item: <1 h, 1-3 h, 3-12 h, 12-24 h.

**Expected time to replace inventory**
- Varies by item: <1 h, 1-3 h, 3-12 h, 12-24 h.

**Expected time to validate**
- Varies by item: <1 h, 1-3 h, 3-12 h, 12-24 h.

**Expected time to verify**
- Varies by item: <1 h, 1-3 h, 3-12 h, 12-24 h.

**Expected time to weigh**
- Varies by item: <1 h, 1-3 h, 3-12 h, 12-24 h.

**Expected time to x-ray**
- Varies by item: <1 h, 1-3 h, 3-12 h, 12-24 h.

**Expected time to y-tap**
- Varies by item: <1 h, 1-3 h, 3-12 h, 12-24 h.

**Explain how your research on nuclear incident medical enterprise” (NIME) has impacted or will impact the field of radiological response to nuclear detonations.”**

**SUMMARY AND CONCLUSION**

A nuclear incident would have devastating consequences. If prevention fails, an effective response could save tens to hundreds of thousands of lives. NIME describes a systematic approach with various interrelated and interdependent concepts, resources, tools, and capabilities designed to facilitate such a response.

The critical impact of reducing radiation injury by sheltering in place for the first day or until authorities can provide evacuation guidance is a key primary response that can markedly reduce radiation casualty numbers (HSC 2010).

Medical interventions can be effective if implemented in a timely, strategic way. The science and technology for detection, diagnosis, MCMs, and treatment will continually improve, and CONOPS will be modified to take advantage of advances.

Given the catastrophic nature of a nuclear detonation, the entire country will be impacted and will need to respond. Responding effectively will include transferring patients to centers where expert care can be provided (e.g., RITN), sharing resources, recognizing and treating the intense psychological trauma that such an event will cause, and monitoring and supporting dislocated populations. The NIME systematic approach and enhanced models under development will enhance the effectiveness and capability for planners, responders, and researchers and provide some assurance to members of the public that this complex incident has been considered.

**Acknowledgments**—The authors acknowledge the many individuals who have contributed to the programs that are a part of nuclear and radiological incident emergency management. These include subject matter experts and supporting staff from within and outside government, many of whom are co-authors of the papers describing the components and projects of the Nuclear Incident Medical Enterprise (NIME) that are in the references. The support of sequential Assistant Secretaries of Public Health Emergency Preparedness and Assistant Secretaries for Preparedness and Response has been essential: Stewart Simonson, Rear Admiral Craig Vanderswaan, and Rear Admiral Nicole Lurie. Particular thanks goes to Rear Admiral Ann Knebel, whose leadership, vision, experience, tireless support, direct contributions, and enthusiasm were indispensable to the realization of many facets of NIME. Alicia Livinski from NIH Library for editorial assistance.

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US cities are not medically prepared for a nuclear detonation

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It’s been more than five decades since concern about a nuclear conflagration was as prominent a focus for world leaders as it is again now. In the aftermath of World War II, during the Cold War between Russia and the United States, the fear of nuclear attack was front and center in the minds of US citizens, impacting their daily lives. Fallout shelter signs on office buildings, weekly tests of air raid sirens, and drills by school children were stark reminders that the threat was real. Anxiety peaked during the 1962 Cuban missile crisis, when many Americans believed it was a question of when, not whether, a nuclear confrontation with Russia would occur.

Less than three decades later, though, glasnost had begun and relations had thawed between the two arch-enemies. As this new reality set in, so did complacency about planning for the worst. Barrels of supplies stored in fallout shelters were allowed to rust, and their contents deteriorated to the point of uselessness. The ensuing period of cooperation between the superpowers, for all its benefits, also left us with a form of amnesia. The United States is now completely unprepared to manage the aftermath of a nuclear detonation.

The case for preparedness

Some would argue that the possibility of any type of nuclear attack is so low that expending energy to discuss the threats, much less plan for an attack, is a fool’s errand. It is true that the probability of a nuclear detonation on US soil is low; on the other hand, it could happen. We know that North Korea has constructed and tested nuclear devices, and that its leader, Kim Jong-un, has verbally threatened the United States and US allies. We know that Pakistan’s stockpiles of highly enriched uranium, or HEU – the critical component needed to make an improvised nuclear device or nuclear bomb – are not especially secure, and a change in regime could leave the material in the hands of leaders who support terrorism. We know we lack the ability to prevent HEU from being smuggled into the United States. We know that it is quite possible to obtain 55 kilograms of HEU, the amount required to build a 10-kilotons (kt) nuclear bomb, which is around the size of the “Little Boy” dropped on Hiroshima in 1945. As remote as the possibility may be, the use of a nuclear device in a major city would have long-term catastrophic consequences. It would be irresponsible in every sense, knowing that a nuclear strike by a terrorist group or hostile nation is possible, not to plan for such an event.

What we’re up against

There are four types of potential nuclear incidents that require some level of preparation: an accident or attack at a nuclear power plant, a dirty bomb, terrorist use of an improvised nuclear device, and an attack using a nuclear weapon executed by a foreign nation.

The first two types of events – an incident at a nuclear power plant and a dirty bomb – have received a greater level of planning attention than the others. An attack on a nuclear power plant or a catastrophic accident like the
ones that occurred at Chernobyl in 1986 and Fukushima in 2011 would have devastating short- and long-term effects. With that in mind, the Federal Emergency Management Agency (FEMA) and Department of Energy require that states with nuclear power plants practice notification, response, and evacuation plans. Zones requiring specific actions have been designated depending on communities’ proximity to nuclear power plants. Fortunately, the track record of the US nuclear power industry has been reassuring in terms of planning for accidents.

The possibility of a dirty bomb attack has also received planning attention from US authorities, in part because it is seen as relatively likely on the spectrum of nuclear disasters. A dirty bomb is a rather simple device composed of a conventional explosive – much like the one used to blow up Oklahoma City’s Alfred P. Murrah building in 1995 – laced with radiological materials called isotopes. Gaining access to radioactive isotopes is not as challenging as one might expect. Medical facilities use various types for diagnostic testing, and several industries require them. Certain isotopes, while difficult to come by, have a long half-life, and if used in a dirty bomb would contaminate the blast area and that around it with residual radioactive material for months or years. This would create a “hot zone” too dangerous to enter for any type of firefighting, rescue, or reconstruction activity. Additionally, radioactive particles dispersed in the air can be carried downwind in a “plume” and deposited far from the explosion. Planning for the aftermath of a dirty bomb will vary from city to city. Most cities have some level of preparedness for managing a mass-casualty event, but the problem of radiation contamination adds complexity. The majority of contamination can be handled by removing clothing and washing victims’ skin. Once victims are removed from the area, the residual ground and building contamination is a less urgent problem, and decisions about clearing the area will likely be made by city authorities in conjunction with federal agencies.

The most devastating kind of incident would involve a nuclear weapon: Terrorists could acquire or build and detonate an improvised nuclear device in a major city, or – worse because the bomb would be bigger – a foreign nation could launch a nuclear attack.

In the first scenario, the device would likely be between 5 and 10 kt. A 10-kt bomb would release the same amount of energy as 10,000 tons of TNT. The kind of improvised nuclear device we are most likely to see is a “gun” type of bomb that would use an explosive to fire a mass of HEU through a tube at another mass of HEU, causing fission and the release of energy in an eruption of pressure, light, and heat. A 10-kt improvised nuclear device would destroy or significantly damage everything within a half-mile radius.

An attack by a government with a long-standing nuclear weapons program could be orders of magnitude worse. The strength of the explosion could range from something around 10 kt – the size of a nuclear bomb North Korea tested in 2013 – to measurements in the megatons, or hundreds of times greater. In a nuclear attack, the bomb will be dropped from an aircraft or delivered via missile. Unlike a bomb carried into a city on a truck, a bomb delivered by air can be detonated above a city rather than at ground level, causing a larger area of destruction and loss of life.

In the discussion that follows, I make the assumption – based on information from open-source material – that terrorists are unlikely to construct a device greater than 10 kt, and that a missile launched by North Korea would carry a warhead in the 10–15 kt range. These scenarios are both more likely than a multimegaton nuclear warhead being launched at the United States.

What to expect

For those who must think about planning for the aftermath, one of the starkest facts about a nuclear bomb attack is that on top of killing people on a vast scale, it will thoroughly destroy the capacity to respond.

When a nuclear bomb made with HEU detonates, it releases an enormous amount of energy of four different types. The blast releases 50 percent of its energy in the form of a pressure wave so powerful that it levels buildings. There is little chance for human survival within a quarter mile, and as the wave travels farther out and weakens, it can shatter glass within half to three quarters of a mile. Thirty-five percent of energy from the blast creates the blinding flash, emitting heat that incinerates all but concrete buildings (and melting glass and burning the contents even in those). Fires will be so numerous and radiation levels so high that firefighting will be impossible. Initial (or “prompt”) radiation accounts for 5 percent of the energy. The remaining 10 percent is released in long-term fallout or residual radiation, which can, when carried by wind, travel over long distances.

Should an improvised nuclear device detonate in New York City’s Times Square, the initial blast will kill between 75,000 and 100,000 people in seconds. They will be incinerated so thoroughly that their ashes will be indistinguishable from the ashes of the buildings around them. Others will be crushed by falling buildings, struck by flying debris, or thrown
by the pressure wave against buildings, the ground, or each other.

Another 100,000–200,000 people will be injured, some with burns from the heat of the blast, others by objects hurtling through the air. Many will be exposed to various levels of radiation that will cause suffering or death over weeks and months. The loss of city government, fire and police departments, and other emergency responders, coupled with demolished hospitals and destroyed water, sewage, power, and gas lines, means that repairs will take months or years even outside the contaminated “hot zone” and be impossible within it. The city will become a ghost town. As a result of the plume carrying radioactive particles downwind, hundreds of square miles may be unusable and need decontamination.

People will leave their homes in search of safe havens. With no radios to give them instructions, some will move into the path of the plume and be exposed to a higher dose of radiation than they would have received had they stayed home. Many of these evacuees will die from radiation exposure.

Chaos will prevail as millions of people try to evacuate the city without aid of communications systems, which will have been destroyed. They won’t know where to go or where to receive medical care. Following a hurricane, people can reach shelters, medical teams, and sources of food and water that were deployed in advance. Following a nuclear attack, none of these assets will have been prepositioned prior to the explosion.

In the early 1980s, while living outside of Boston, I received a pamphlet in the mail instructing me to evacuate to a specific town should the worst happen. A reporter following this effort to prepare citizens traveled to several of the “host” towns to determine their readiness to receive all the evacuees. The reporter was startled to find townspeople who said the new arrivals wouldn’t be welcome. Where would city evacuees go if an attack occurred today?

A massive medical challenge

From 2009 to 2010, as part of research I was doing for the Defence Academy of the United Kingdom, I conducted an end-to-end assessment of the medical capabilities of several countries and cities to respond to terrorist use of an improvised nuclear device. (It was similar to one I completed while serving as director of the Mayor’s Office of Emergency Management in New York City, looking at the aftermath of biological and chemical attacks.) No city or country visited during this assessment was prepared to manage the aftermath of a nuclear detonation. Even taking into account just the medical needs of a large city following a nuclear attack, the results clearly showed that current planning efforts were not sufficient to manage the carnage.

Using New York City as a model, it’s anticipated that several hundred thousand people will require some sort of medical evaluation or care. With the loss of hospitals and 35–50 percent of first responders, and health care personnel unable or unwilling to go to work, surviving hospitals will need to use every inch of space to treat only the most critically injured. Makeshift treatment centers or casualty collection points near the blast will be required to triage the injured. Ethical and moral issues will arise as the overwhelmed staff, short on supplies, is forced to decide who should receive treatment and who should be moved to end-of-life care, receiving morphine to ease their pain. The profound psychological impact on these healthcare workers and first responders cannot be overstated. Their task is essential, though: The ability to make some order out of the chaotic wave of people with different levels of injuries, from those with various kinds of physical trauma to those with psychological trauma to the “worried well,” is a key to reducing morbidity and mortality.

Certain characteristics of nuclear attacks make them especially hard to prepare for. A nuclear blast causes an electromagnetic pulse that knocks out communication systems, some irreversibly. Without the ability to communicate, coordination among medical personnel and other first responders will become nearly impossible. Assuming medical staff can get to where they need to be, demand for them will be extraordinary, but managers will have to rotate them to prevent exhaustion and reduce the psychological impact.

There will be an overwhelming number of patients. After triage, some will have to be transported. Hospitals will have to not only care for the injured but also control security and coordinate the flow of information to victims’ families. Local, state, and federal governments will have to rapidly set up alternate-care facilities close to the “hot zone.” They will have to have plans for alternate standards of care, so that, for example, emergency medical technicians are allowed to perform tasks ordinarily reserved for paramedics or nurses, freeing paramedics and nurses to perform more advanced medical treatment than normally permitted. This last issue, the focus of numerous studies and reports, presents both legal and ethical challenges, many of which need to be resolved in state capitals, where the scope of practice for health care professionals is typically controlled. And planners should remember that just because an ethical issue is resolved in advance, doesn’t mean that the decision will be followed in practice in the aftermath of a disaster.
Sending an adult to end-of-life care may pull on the heartstrings, but sending a child to the same fate could prove to be too difficult for many medical personnel.

Beyond the difficult frontlines of triage, survivors of a nuclear explosion will have a variety of injuries, some well known to modern hospitals but others more difficult to diagnose and develop a plan for. Acute radiation syndrome, in particular, results from exposure to radiation and does not have to coincide with any other injury. It may be the only effect a survivor suffers, and it may not manifest soon after exposure. Acute radiation syndrome occurs when a significant portion of the body is exposed to a large dose of penetrating radiation in a short period of time. The nature of acute radiation syndrome depends on the dose. At lower doses, the only effect may be on the gastrointestinal system and bone marrow. At higher doses, bone marrow will stop producing infection-fighting white blood cells, platelets that assist in blood clotting, and red blood cells that carry oxygen. Larger doses also destroy the lining of the gastrointestinal system, causing diarrhea, vomiting, and an inability to swallow or digest food, requiring patients to receive nutrition and fluids intravenously. At the highest levels of exposure, the heart and nervous system are impacted and rapid progress toward death is certain. Some of the most difficult patients to manage are those with combined injuries – say, a penetrating wound from a shard of glass, requiring rapid surgical intervention, and also acute radiation syndrome.

Finally, a great moral and societal challenge will be managing the dead. Many victims will be in the “hot zone,” where responders can’t enter and radiation levels may not be safe for years. Victims’ families, though, will demand recovery of loved ones. Even where identifiable remains exist, the number of dead will be so large that months may pass before a family receives them. At some point in recovering bodies, a decision may have to be made to bury victims in mass graves. The United States has excellent systems in place to manage mass fatality incidents – but they have never been tested with several hundred thousand dead at one time.

**Where do we stand?**

These issues have not received enough attention from FEMA, the US government entity responsible for helping states plan for and respond to disasters. FEMA takes what emergency planners call an “all hazards” approach, meaning it addresses effects common to many different types of disasters. This lack of planning to deal specifically with a nuclear incident is a serious weakness.

That makes it all the more important for states and cities to have their own plans in place for worst-case scenarios. It’s far easier to scale back a response if resources are not needed than to need them but not have them. While serving as Commissioner of Homeland Security and Emergency Services for New York State, I asked each of the 57 counties to plan for what they thought to be a worst-case scenario. (Scenarios varied from county to county.)

Where FEMA has lagged, the US Department of Health and Human Services has aggressively built up its capability to respond to a nuclear incident. It has medical response teams that are staffed and equipped to mobilize in response to an incident, support state and local governments, and, depending on what is needed where, either provide comprehensive health care infrastructure or augment existing hospitals and clinics. In the aftermath of Hurricane Sandy in 2012, these teams provided the only medical care available to some communities on Long Island, just east of New York City. They provided invaluable aid in evacuating Manhattan hospitals.

The Department of Health and Human Services has also committed significant resources to acquiring medical treatments for the survivors of a nuclear detonation. The Strategic National Stockpile, composed of 12 separate units at classified locations around the country, is also under the department’s control, and capable of being dispatched to any city within 12 hours. In it are supplies to treat burns injuries, as well as cutting-edge therapeutics to aid in reversing the effects of radiation by stimulating bone marrow to produce platelets (which help stop bleeding) and white blood cells (which help prevent infection). Should respirators be needed, the Strategic National Stockpile can provide them, along with antibiotics, vaccines, and massive quantities of intravenous solutions. Many units from the stockpile will be needed to support a city in the aftermath of a nuclear detonation.

Cities far from the nuclear blast are also a potential resource. The federal government is sure to ask for help from far afield as soon as demand for medical resources exceeds local supply in a given area. Governors and mayors may be reluctant to release personnel, though, either for political reasons or out of concern that their cities and states may be targeted next. I believe most elected officials will rise to the occasion, and dispatch as much help as they can spare. But no number of simulated incidents can
predict how political dynamics will shift following the real thing.

Over the course of the study I conducted in 2009 and 2010, several government officials said they were unable to take steps forward because the elected officials they reported to were unwilling to discuss the issue. Privately, many politicians used to worry that if they discussed nuclear terrorism, they would likely be ridiculed for fearmongering. In the last seven years, that concern has changed dramatically at the national level, with President Obama and other world leaders convening to address nuclear proliferation and nuclear terrorism. Silence at the local level continues, though. Among city and state governments, the only ones that I’m aware have some level of ongoing planning for nuclear disaster are New York (city and state), Washington state, Los Angeles, Boston, and Chicago. To a much lesser extent, several more cities are engaged as well. The state of Hawaii has asked the federal government for assistance in planning for a nuclear attack.

**A path forward**

In 1965, the folksinger Barry McGuire recorded the powerful lyrics “We’re on the eve of destruction” in the song “Eve of Destruction.” Perhaps that one-time hit should be resurrected to remind US leaders that we are not prepared for nuclear disaster. To those who say that preparing for such an incident makes an enemy more likely to strike sooner, I would argue otherwise. It is highly unlikely that preparedness would factor into any decision to detonate a device on American soil. Plus, a terrorist group would find it challenging to gauge the level of US preparedness.

Realistically, no matter the level of preparedness, detonating a nuclear bomb in an American city would cause immediate and enormous loss of life, vast destruction, and trillions of dollars in damage. It would cripple the US economy and dramatically impact other nations’ financial stability, for years if not decades. That is why it is our responsibility to educate the public. The reinvigoration of US civil defense programs should not be a matter of debate or concern over political impact. It needs to be mandated at every level of government so that the United States is prepared for a nuclear Armageddon.

**Disclosure statement**

No potential conflict of interest was reported by the author.

**Notes on contributor**

Jerome M. Hauer has served in cabinet positions at the local and state level and was an acting assistant secretary for the Office of Public Health Emergency Preparedness at the US Department of Health and Human Services. Hauer is an associate editor of the *Journal of Special Operations Medicine* and president of the Homeland Security Section of the Health Physics Society. He earned his doctorate at Cranfield University, has a master’s degree from the Johns Hopkins School of Public Health, and holds a bachelor’s degree from New York University. He is also an Adjunct Associate Professor at Georgetown University and Visiting Professor at the Cranfield University.
Are We Prepared for Nuclear Terrorism?

Robert P. Gale, M.D., Ph.D., and James O. Armitage, M.D.

No plan ever survives first contact with the enemy.

— General Helmuth von Moltke, Prussian Army Chief of Staff

Was von Moltke right, or was Winston Churchill, who said “He who fails to plan is planning to fail”? Recent events have increased concern about the consequences of nuclear terrorism. Nuclear terrorism can take several forms, such as forceful takeover of a nuclear power facility by terrorists, targeting of a country’s nuclear power facilities by terrorists or rogue states using conventional or nuclear weapons or commercial aircraft, intentional detonation of a nuclear weapon by a terrorist organization or rogue state, or the use of radiologic dispersion or exposure devices (such as radioactive material from a stolen nuclear weapon or a conventional explosive device (“dirty bomb”)) by terrorists. Our focus in this report is on preparedness in the United States, but most concepts apply to other developed and developing nations.

In 1945, the United States detonated two atomic weapons (A-bombs, or fission bombs) over Japan to end World War II. The bombs had an explosive force of approximately 13 kilotons and 22 kilotons of TNT (trinitrotoluene), respectively (approximately 50 to 100 terajoules). It is estimated that 120,000 to 250,000 persons in Hiroshima and Nagasaki died within 4 months, most of them immediately or within a few days after the explosions. Most of these deaths were caused by percussive force, projectiles, and thermal injuries from “superfires” (i.e., fires of approximately 100,000,000°C; for comparison, the surface of the sun is 6000°C), not by radiation. Nuclear fission reactions release approximately 10 million times more energy than equivalent-mass chemical explosions. However, less than 10% of the energy released by a nuclear weapon is in the form of ionizing radiation (mostly neutron and gamma [photon] radiation). Consequently, only a small fraction of the deaths after the detonation of a nuclear weapon are radiation-related. In addition, although there is concern about the long-term carcinogenic effects of radiation exposure, only approximately 5% of deaths from cancer among A-bomb survivors have been attributed to radiation exposure.

Since the atomic bombings in Japan, and especially during the Cold War, people have been concerned about the threat of nuclear terrorism and nuclear war. However, beginning about 40 years ago, accidents at the Three Mile Island, Chernobyl, and Fukushima nuclear power facilities heightened this fear; the fear has been compounded by several recent events, including the acquisition of nuclear weapons capability (a thermonuclear weapon [H-bomb, or fusion bomb]) by North Korea and the seeming ability of that country to target the United States with an intercontinental ballistic missile, threats to dismantle the U.S.–Iran nuclear deal (Joint Comprehensive Plan of Action), the deterioration of U.S.–Russian nuclear arms–limitation agreements, and the recent decisions by the United States and Russia to upgrade their nuclear arsenals. In this report, we consider whether it is necessary to plan for nuclear terrorism and whether such plans will be effective. We conclude that although planning is potentially useful for a small-scale nuclear terrorist event, responses to large-scale events are difficult to plan effectively. We should not expect these events to play out as planned for, and prevention is key. Because the effectiveness of any nuclear terrorism emergency plan relates predominantly to exposure circumstances, we consider several scenarios below.
NUCLEAR POWER FACILITIES

Exposure of fewer than 100 facility personnel to ionizing radiation from an incident or accident at a U.S. nuclear power facility is planned and trained for, as are measures to protect the surrounding population, including sheltering in place, evacuation (if appropriate), and distribution of iodine tablets to block uptake of radioactive iodine (reviewed by Christodouleas et al.1). The extent to which this is the case in all other nations with nuclear power facilities is uncertain and is affected by the level of societal development and political stability.

However, the above scenario is a rather different from one in which terrorists commandeer a nuclear power facility or when a nuclear power facility is targeted with a hijacked commercial airplane or a conventional or nuclear weapon. Are these scenarios hypothetical? Unfortunately, no. In 1972, hijackers took control of a U.S. airliner and threatened to crash into the Oak Ridge nuclear weapons facility. In 1981, Iran and then Israel attacked and destroyed Iraq’s Osirak nuclear power facility before it could be fueled with enriched uranium. Iraq bombed Iran’s Bushehr nuclear plant six times between 1984 and 1987. The United States bombed a nuclear fuel enrichment facility and three nuclear reactors in Iraq in 1991. Also in 1991, Iraq used Scud missiles to target the Dimona nuclear power facility in Israel. In 2014, Hamas targeted the Dimona facility from Gaza. Several of these attacks were thwarted by Patriot missile defenses. Some threats to nuclear facilities have fortunately not been realized; for example, in the 1990s during the Balkan Wars, Slovenia shut down its Krško nuclear power plant, fearing a Serbian air force attack.4 In 2007, Israel launched an attack on a Syrian reactor that was under construction and not yet fueled. Beginning in about 2009, the Iran Natanz nuclear power facility was targeted by a cyberattack with the Stuxnet virus, presumably by Israel and the United States. And very recently, Yemeni rebels claimed to have targeted the Barakah nuclear power facility that is under construction near Abu Dhabi in the United Arab Emirates.

Terrorist takeover of a nuclear facility can be prevented by counterintelligence, intervention, and adequate on-site security measures. Force-to-force exercises are performed at U.S. nuclear power facilities every 3 years. However, these measures are not foolproof. Recently, antinuclear activists entered nuclear power facilities in France and Belgium and set off fireworks to show the vulnerability of the facilities. The U.S. 9/11 Commission reported that the 9/11 terrorists initially considered targeting U.S. nuclear power facilities. The bottom line is that nuclear power facilities are no longer merely theoretical targets of terrorism or military targets. Furthermore, when we consider the possible consequences of terrorism against a nuclear power facility, radiation exposure is only part of the equation: infrastructure damage, mass evacuations, and public fear may be of a much greater magnitude than radiation-induced injuries. This is an example of potential terrorist gains from “mass distraction” and mass disruption rather than mass destruction.

The concept of nuclear power facilities as military targets has been reviewed elsewhere.4 The International Atomic Energy Agency (IAEA) has an International Nuclear and Radiological Event Scale (INES), shown in Figure 1. The accidents at the Chernobyl and Fukushima nuclear power facilities were a 7 on this scale, whereas the event in Goiânia, Brazil (discussed below), was a 5 (www-ns.iaea.org/tech-areas/emergency/ines.asp).

RADIOLOGIC EXPOSURE DEVICES

Another scenario is one in which terrorists use a radiologic exposure device. In this scenario, terrorists steal a radioactive source — for example, material from a radiation therapy department, an inadequately secured nuclear weapons site, a nuclear power facility, or a politically unstable state — and place it in a public space. There are several reports of such thefts, including thefts of nuclear fuel rods from U.S. and U.K. nuclear power facilities. Some nations, fearing an invasion, have dispersed their nuclear weapons to many sites, which makes security more difficult. When terrorists use a radiologic exposure device, the radiation doses to the public are likely to be relatively low; few people are likely to be exposed to high doses. The most important issue is detection, which is easier if the device is stationary and more difficult if it is on a bus or train, where exposed persons enter and exit at different points.
Physicians need to be alert to the signs and symptoms of radiation exposure, and coordination by an agency such as the Centers for Disease Control and Prevention might be needed to synthesize a cogent picture. The complexity of detecting such an event was evident to us in dealing with a stolen cesium-137 radiotherapy unit in Goiânia, Brazil, in 1987, a situation in which it took more than 2 weeks from the first exposure to detection.5 Paradoxically, delayed detection makes this strategy less useful to terrorists who rely on responses of the government and the public rather than radiation-induced casualties to achieve their political aims. Physicians should consider possible radiation exposure in persons who have a constellation of nonspecific signs and symptoms, including epilation and gastrointestinal symptoms. Low counts of blood granulocytes, lymphocytes, and platelets should increase suspicion. Guidance on how to detect radiation exposure is available from the IAEA, the World Health Organization (WHO) (www.who.int/ionizing_radiation/a_e/IAEA-WHO-Leaflet-Eng%20blue.pdf), and elsewhere.

Radiologic Dispersion Devices

A third nuclear terrorist scenario involves radiologic dispersion devices. Such an attack can involve stealing radionuclides from a university laboratory or a nuclear medicine department and spreading them over a large area with a small plane, introducing radiation into a municipal water reservoir, or covering a conventional explosive device (e.g., one made with dynamite or TNT) with radioactive materials — a so-called dirty bomb. Thefts of radioactive materials are common. The IAEA has records of more than 2000 such incidents, including more than 100 in 2016. It is unlikely that intensive radiologically oriented medical interventions would be required for most victims of a radiologic dispersion device such as a dirty bomb, because percussion and projectile injuries will probably account for more injuries than radiation exposure. There may be a risk of unacceptable long-term radiation exposure at the detonation site, but this is unlikely and can be mitigated by decontamination, shielding, and, if needed, short-term or long-term evacuations. Radiologic dispersion devices are, again, more a matter of mass distraction and mass disruption than mass destruction. Terrorists’ goals for deploying such devices are predominantly political and psychological. Although few people will be harmed in terms of their health, there is likely to be widespread confusion and hysteria. This may result in possibly inappropriate government actions that could

![Figure 1. International Nuclear and Radiological Event Scale (INES) from the International Atomic Energy Agency.](image-url)
complicate or even worsen the situation, such as a conventional or nuclear attack against a foreign state that is perceived as encouraging or harboring the terrorists. U.S. actions against Afghanistan immediately after the 9/11 World Trade Center attacks is an example of potential cascading events. The most effective countermeasure to radiologic dispersion devices is, again, prevention. However, education of government officials, policymakers, and the public about securing radioactive sources, early detection of radiation exposures, and, perhaps most importantly, the potential risks associated with radiation exposure is an important measure. A guide to early response to radiologic dispersion devices is available at www.crcpd.org/mpage/RDD.

**Improvised Nuclear Device**

Things can get considerably worse. The U.S. Department of Homeland Security and the Federal Emergency Management Agency (FEMA) developed 15 Disaster Planning Scenarios to deal with potential terrorist attacks and natural disasters. Scenario 1 is entitled “Nuclear Detonation — 10 Kiloton Improvised Nuclear Device.” In this scenario, planners consider a situation in which terrorists from a “Universal Adversary” assemble a 10-kiloton nuclear device stolen from a nuclear facility in the former Soviet Union, smuggle the components into the United States, assemble it in a van, and detonate it in the center of Washington, D.C. What would happen? First, the percussive force, projectiles, and superfires would cause complete destruction or severe damage to buildings within 1 km of the epicenter and extending out to approximately 6 km. (A nuclear weapon is most effective when detonated approximately 1 km above the hypocenter rather than at ground level.) Communications would be disrupted by electromagnetic forces from the detonation. Many people within the immediate vicinity would be killed immediately, as would emergency and medical personnel, including many physicians and health care providers. Persons at greater distances, including first responders, would be exposed to high doses of neutron and gamma radiation from the initial blast and from radioactive fallout, which typically occurs after a ground detonation (Fig. 2). Figure 3 compares the relative effects of a nuclear weapon, an improvised nuclear device, a radiologic dispersion device, and a radiologic exposure device. In the scenario of an attack with an

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**Figure 2.** Severity of Damage Associated with Nuclear Devices. Relative areas of severe damage (dark red), intermediate damage (lighter red), and light damage (pink) associated with different sizes of nuclear devices are shown. The shaded blue area represents the zone of dangerous fallout. The figure was adapted from the Federal Emergency Management Agency.6
improvised nuclear device, there would be approximately 100,000 immediate deaths and another 100,000 casualties requiring medical intervention. Guidelines for triaging these huge numbers of casualties have been published.\(^7\) Approximately half a million people would need to shelter in place for hours or days, after which they would leave the area in a planned and, hopefully, orderly evacuation. Although there are, of course, huge political, economic, social, psychological, and societal consequences associated with this scenario, our focus here is on medical preparedness and especially on dealing with radiation-induced bone marrow failure.

If you think the notion of commandeering a nuclear weapon is far-fetched, consider this: during the recent attempted military coup in Turkey, dozens of U.S. nuclear weapons were at risk for takeover at the Incirlik Air Base, which is close to the border with Syria, where a civil war has been raging for 7 years. And although some argue that these weapons would be inoperable because of electronic safeguards (permissive action links), we and others are not convinced.

The ultimate nuclear terrorism scenario is a nuclear war, which could be one weapon launched by a rogue state, an accidental or intentional strike with one or a few nuclear weapons by an adversary (real or perceived) or even an ally, or a full-scale nuclear war. The United States and Russia together have approximately 8500 stockpiled nuclear weapons, 3000 of which are operationally deployed. An attack or counterattack with even a fraction of these weapons is not properly defined as terrorism, and we do not discuss this scenario further. It is estimated that there are 1100 nuclear weapons in seven other countries, including the United Kingdom, France, India, Pakistan, Israel, and North Korea. The average destructive force of modern nuclear weapons is equal to approximately 1 megaton of TNT, but some weapons, such as the Soviet RDS-220 hydrogen bomb, is equivalent to 50 megatons of TNT or approximately 5000 times more powerful than “Little Boy,” the bomb that was dropped on Hiroshima. Planning an effective medical response to an attack with weapons like these is futile. Areas of fireball, percussive, and thermal damage for different targets of one or more nuclear weapons of sizes ranging from 100 tons to 100 megatons for an airburst at 3 km can be modeled at http://nuclearsecrecy.com/nukemap/.

Exposure to high doses of ionizing radiation in one or more of the terrorist scenarios we describe has adverse biologic effects. Tissues such as the skin, lung, gastrointestinal tract, and bone marrow are the most severely immediately affected targets within a survival dose range. Persons exposed to less than 2 Gy of uniform whole-body ionizing radiation, equivalent to approximately 200,000 chest radiographs, generally do not require immediate medical intervention and will probably recover without medical intervention. At the other extreme, persons exposed to more than 12 to 15 Gy will probably die despite medical intervention. Consequently, the focus of medical preparedness for nuclear terrorism is on persons exposed to 2 to 10 Gy, in whom the most immediate problems are bone marrow failure and gastrointestinal damage. However, in
many of the radiation-exposure scenarios we describe, victims will have concurrent injuries from percussive forces, projectiles, thermal burns, and chemicals. Interventions that might save some patients from death from bone marrow failure will be only partially effective because of these competing causes of death. In addition, trauma, especially burns, often increases mortality due to any level of radiation exposure in experimental models. This was seen among victims of the Chernobyl accident. There are also long-term consequences of radiation exposure, including diverse cancers (e.g., thyroid cancers and other thyroid disorders, leukemias, and solid cancers), infertility, and an increased risk of cardiovascular disease, all of which were seen among the A-bomb survivors.

**Radiation Dose**

Effective therapy for persons exposed to ionizing radiation requires an accurate dose estimate. Exposed persons will almost certainly not have radiation-monitoring devices. However, because many survivors have smartphones, it is possible to perform electron paramagnetic resonance spectroscopy on the display glass of smartphones and to perform optically stimulated luminescence analysis of smartphone resistors in order to estimate the dose of radiation. Other physical measurements include electron spin resonance measurements of dental enamel and some clothes (such as clothing made of cotton but not synthetic fibers) and neutron capture of urine samples. These physical measurements are technically demanding and not readily available, especially not quickly or on a large scale. Biologic dosimetry can be performed on blood or bone marrow samples, including analyses of dicentric chromosomes, micronuclei, premature chromosome condensation, gamma H2AX foci, and chromosome painting — but only if health care facilities are intact and trained technical personnel are available. Computer-based dose reconstruction with the use of source–dispersion models requires time and is rarely victim-specific. Even when a combination of these approaches is used, point estimates of dose are often inaccurate and have wide confidence intervals or credibility limits.

These data may be sufficiently accurate for triage but not for some therapy decisions, such as the decision about whether to perform transplantation. After the Chernobyl accident, we used a combination of clinical variables, including the kinetics of decline of blood lymphocytes and granulocytes. This approach, of course, is possible only if there are surviving medical personnel nearby to obtain serial blood samples, surviving machines to analyze the blood samples, and surviving experts to analyze the data. One or more of these conditions may not be met in the context of a major nuclear event. There is also confounding in the interpretation of these data when other injuries are present, as is likely to be the case. One simple way to triage large numbers of potentially exposed persons is to exclude those who have not had nausea and emesis within 4 hours. Not everyone with these symptoms has a radiation dose of more 2 Gy, but patients without such symptoms can be reasonably excluded.

The consequences of inaccuracies in dose estimates vary. For some interventions, such as oral antibiotic or antiviral drugs, an inaccurate estimate may be inconsequential. This is less true for parenteral drugs, such as intravenous antibiotics, red-cell and platelet transfusions, and hematopoietic growth factors (e.g., filgrastim and sargramostim [granulocyte and granulocyte–macrophage colony-stimulating factors]), which use more health care resources and personnel and have greater associated risks of adverse events. There is far less tolerance for an inaccurate dose estimate in the context of contemplated hematopoietic-cell transplantation.

Another issue is dose uniformity. Even if the estimated midline dose is accurate, there is no guarantee of uniform exposure. If a person’s arm or leg is shielded by an automobile or concrete, some of the bone marrow may be unexposed or less exposed, and hematopoietic-cell transplantation may not be required. Unfortunately, it is unlikely that physicians will be able to make correct informed decisions regarding the benefits and risks of diverse medical interventions, especially ones with substantial potential adverse effects, in many of the terrorist scenarios we describe (as discussed below).

**Medical Preparedness**

How do we best prepare for nuclear terrorism? Our focus is on major events, such as an attack with an improvised nuclear device or a limited nuclear strike, accidental or intentional. Although...
stockpiling drugs such as antibiotics, antivirals, and hematopoietic growth factors seems wise, deciding who needs these interventions and determining who is alive to estimate the radiation doses or to give parenteral drugs will be complicated if many or most health care and technical personnel are casualties and if a substantial part of the infrastructure, including hospitals, clinics, transportation facilities, and communications, is destroyed.\textsuperscript{13,14} (The Nagasaki A-bomb hypocenter, for example, was directly over the Nagasaki University School of Medicine.) Details of the U.S. Strategic National Stockpile (SNS) are reviewed elsewhere.\textsuperscript{15} Storing hematopoietic cells — for example, in a bank of umbilical cord blood cells — seems sensible, but not if the cells are exposed to the same high-dose ionizing radiation as the victims who might benefit from receiving them. It can be argued that cells could be transported from unexposed sites; this may be difficult in some instances and almost certainly would be impossible in the context of a multisite nuclear attack. Two other sources of hematopoietic cells for transplantation are HLA-haplotype-mismatched relatives and HLA-matched unrelated volunteers. However, there is a high likelihood that in a large-scale event, relatives of a radiation victim will also be exposed or injured. Identifying potential unrelated donors elsewhere in the United States or overseas is time consuming and requires intact telecommunications and computer networks, resources that are unlikely to be available soon after a major nuclear event.

There are nation-specific and international plans and organizations for responding to radiation and nuclear incidents, including transporting patients with severe radiation exposure across state, provincial, or even international borders. The IAEA hosts an Incident and Emergency Centre (IEC) that coordinates international responses to nuclear or radiologic incidents, including transport of patients from unexposed sites; this may be difficult in some instances and almost certainly would be impossible in the context of a multisite nuclear attack. Two other sources of hematopoietic cells for transplantation are HLA-haplotype-mismatched relatives and HLA-matched unrelated volunteers. However, there is a high likelihood that in a large-scale event, relatives of a radiation victim will also be exposed or injured. Identifying potential unrelated donors elsewhere in the United States or overseas is time consuming and requires intact telecommunications and computer networks, resources that are unlikely to be available soon after a major nuclear event.

Several recent trends and events beyond those already mentioned are disturbing. One is that the U.S. government considers Russia to be in violation of the 1987 Intermediate-Range Nuclear Forces Treaty, and Congress has approved measures to expand and increase the capability of nuclear weapons in the U.S. arsenal. The Trump administration recently gave the Air Force permission to develop a stealth nuclear cruise missile and approved funds to begin replacing the aging Minuteman missiles in silos across the United States. The United States recently decided to develop smaller nuclear weapons that could be used in tactical settings; the smaller size of the weapons increases the likelihood that they would be used and increases the number of weapons that could be stolen by terrorists and transported into the United States. Our treaties, such as the Strategic Arms Limitation Treaty (SALT), to limit, reduce, and eventually eliminate nuclear weapons are in disarray. We are not alone. Russia is taking parallel steps to increase its nuclear attack capabilities.

Contrary to what one might have hoped for 25 years after the end of the Cold War, the Bulletin of the Atomic Scientists Doomsday Clock has been set 3 minutes closer to midnight than in 2014, reflecting global nuclear weapons mod-
ernization, outsized nuclear-weapons arsenals, and collapsing nuclear-weapons treaties, which pose extraordinary and undeniable threats to the continued existence of humankind. These scenarios, whether they result from an accident or from an intentional detonation of a nuclear weapon or a terrorist action, require diverse strategies that include policy decisions, public education, medical preparedness, and, as a last resort, medical interventions for an effective response. However, as in all of medicine, prevention is better than cure.

**Policy Implications**

Educating government officials, policymakers, and the public about the risk of nuclear terrorism is essential. Understanding what we can achieve — and especially what we cannot realistically achieve — with medical preparedness is also essential. Preventing nuclear terrorism is key but is unlikely to be universally successful. Several of the scenarios we describe can be dealt with by careful planning. At the other extreme are scenarios involving hundreds, thousands, or even millions of casualties, for which medical preparedness is likely to be ineffective and possibly dangerous in fostering the impression that we can respond successfully to these events. We believe the best approach is a carefully conceived, long-term plan within the public education system to provide lessons on radiation biology. Because this subject is usually not well taught in medical schools, health care providers, including physicians, also should be required to take an informational course, much as several of the states require for responses to child abuse, therapy options for breast and prostate cancer, and management of Alzheimer’s disease. Unfortunately, many medical schools lack appropriate educators to accomplish this task. Also needed after such an event are a well-informed command and control structure and credible, independent medical experts working in concert to provide instructions and information to the public when government credibility is compromised, as was the case after the Chernobyl and Fukushima accidents. We and others have published nontechnical books, directed toward people with a high school–level education, that may help.

**Conclusions**

There is increasing public concern over nuclear terrorism, an accident or attack against a nuclear power facility, intentional or unintentional use of a nuclear weapon, or the use of radiologic dispersion or exposure devices, such as a dirty bomb. Dealing effectively with these events requires diverse strategies, including policy decisions, public education, prevention, and, as a last resort, medical preparedness. Prevention is the most effective strategy. Planning for these events is important, but we should realize the limitations and not be misled into thinking that preparedness trumps prevention.

Disclosure forms provided by the authors are available with the full text of this article at NEJM.org.

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Characterizing Hospital Workers’ Willingness to Respond to a Radiological Event

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Abstract

Introduction: Terrorist use of a radiological dispersal device (RDD, or “dirty bomb”), which combines a conventional explosive device with radiological materials, is among the National Planning Scenarios of the United States government. Understanding employee willingness to respond is critical for planning experts. Previous research has demonstrated that perception of threat and efficacy is key in the assessing willingness to respond to a RDD event.

Methods: An anonymous online survey was used to evaluate the willingness of hospital employees to respond to a RDD event. Agreement with a series of belief statements was assessed, following a methodology validated in previous work. The survey was available online to all 18,612 employees of the Johns Hopkins Hospital from January to March 2009.

Results: Surveys were completed by 3426 employees (18.4%), whose demographic distribution was similar to overall hospital staff. 39% of hospital workers were not willing to respond to a RDD scenario if asked but not required to do so. Only 11% more were willing if required. Workers who were hesitant to agree to work additional hours when required were 20 times less likely to report during a RDD emergency. Respondents who perceived their peers as likely to report to work in a RDD emergency were 17 times more likely to respond during a RDD event if asked. Only 27.9% of the hospital employees with a perception of low efficacy declared willingness to respond to a severe RDD event. Perception of threat had little impact on willingness to respond among hospital workers.

Conclusions: Radiological scenarios such as RDDs are among the most dreaded emergency events yet studied. Several attitudinal indicators can help to identify hospital employees unlikely to respond. These risk-perception modifiers must then be addressed through training to enable effective hospital response to a RDD event.

Introduction

The number of terrorist bombings in the world has risen in the last 10 years [1,2]. Examples such as the bombings in Bali (2002, 2005), Istanbul (2003), Madrid (2004), Egypt (2005), London (2005), and Mumbai (2006, 2009) have demonstrated the need for effective and rapid response in order to minimize casualties. A radiological dispersal device (RDD, or “dirty bomb”) combines a conventional explosive device with radiological materials. This type of device has the potential to generate greater effects on the targeted population than a conventional explosive device - due not only to radiological injury, but perhaps more importantly due to the profound economic and psychological impact of such an attack [3–5]. Although yet to be deployed successfully, the potential use of a RDD as a terrorist weapon is of significant concern to the United States government; deployment of a RDD is one of the fifteen Department of Homeland Security National Planning Scenarios [6]. Response to a dirty bomb detonation was exercised...
on the national level in TOPOFF 2, in which simulated use of a RDD in Seattle was one of the simultaneous modes of attacks used by hypothetical international terrorists [7].

In addition to psychological trauma to affected populations, RDD events may result in physical injuries and variable levels of radiation contamination. Severity of physical injuries depends on the nature of the explosive used, and extent of contamination is based on the degree of dispersal of the associated radiation. The physical health consequences from the RDD blast and its dispersed radiation would likely be limited to a maximum area of a few city blocks; further, the most significant contributor to injury and mortality from a RDD would be from the blast rather than the radiation [8]. Indeed, any victim close enough to receive an acute lethal radiation dose would likely have been killed by the blast itself [9]. For most people directly involved in a RDD scenario, it has been estimated that the exposure would carry a lifetime health risk comparable to that from smoking five packages of cigarettes or the accident risk of taking a hike [10]. Thus, from a public health perspective, a RDD is much more of a psychological weapon than a physical one [11].

Experts agree that while a dirty bomb is unlikely to sicken or kill many people from a public health perspective, it is very likely to cause fear and panic in the general population [12,13] and is likely to result in disaster activation at local hospitals. The potential panic engendered by such an attack may overwhelm local health care facilities with individuals experiencing psychological rather than physical effects from the hazard itself [14]. The Centers for Disease Control and Prevention (CDC) estimates that 50–80% of victims of an explosive event arrive at medical facilities within the first 90 minutes [15] which illustrates the importance of hospitals being prepared to rely on their own staff for an initial rapid response to a radiological event, rather than relying heavily on external response assets. A growing body of emergency preparedness literature among a variety of care providers—including emergency medical technicians (EMTs) [16], local public health department workers [17,18], and urban healthcare workers [19–22]—indicates that willingness to respond during a disaster is a scenario-specific phenomenon. Furthermore, research suggests that response willingness is multidimensional and influenced by a variety of risk perception modifiers peripheral to the actual event, such as perception of the importance of one’s role in the agency’s overall response [23] and concerns about personal and family safety [10]. Personal safety concerns may play an even larger role for healthcare responders in the dirty bomb scenario than in many other types of disaster scenarios, given factors such as the risk of exposure to the radiological contaminant, potential lack of adequate protective equipment, and the unusual nature of this type of attack [23–25].

The willingness of hospital-wide staff to respond to a RDD has not yet been assessed. One framework that has proved applicable in assessing root causes of willingness to respond to duty during emergencies has been Witte’s Extended Parallel Process Model (EPPM). This framework allows for examining the interplay and influence of perceptions of “threat” and “efficacy” on adaptive or maladaptive behavior of healthcare workers in deciding whether to report to duty in the face of risk [26].

We have set out to assess the willingness of employees at a large, urban, tertiary-care medical center to respond during a RDD event. Accordingly, we aim to gauge whether a clinically significant proportion of the workforce may be unwilling to respond to duty during an RDD event, and whether specific personal characteristics and beliefs are independently associated with willingness to respond in this event. We further analyze the influences of perceived threat and perceived efficacy among hospital employees utilizing Witte’s EPPM and attempt to identify factors potentially influencing willingness and ability to respond.

Methods
Study Setting
The survey was administered at the Johns Hopkins Hospital (JHH) in metropolitan Baltimore, Maryland. JHH is a Level 1 Trauma Center with 982 beds. It is the major teaching center for the Johns Hopkins School of Medicine and School of Nursing.

Ethics Statement
Research ethics approval for the survey and its administration was received from The Johns Hopkins Medicine Institutional Review Board (JHM IRB) with a waiver of written consent. Study materials included an electronic disclosure describing the study and emphasizing voluntary participation; verbal consent was not requested or required by JHM IRB.

Study tool
The survey tool, entitled “Disaster Preparedness and Emergency Response Survey”, was an anonymous online instrument (SurveyMonkey.com, Portland, OR) consisting of two main sections: a demographic section and an attitude/belief section that focused on hospital workers’ attitudes and beliefs toward emergency response. The demographic and professional information included are listed in Table S1.

For the RDD scenario, a series of attitude and belief statements were presented for level of agreement along with two open-ended questions. Responses to the attitude and belief statements were based on a 9-point Likert scale with a response of ‘1’ indicating strong agreement with the statement, a response of ‘5’ indicating neutrality, and a response of ‘9’ indicating strong disagreement with the statement. Respondents could also indicate “don’t know”.

These attitudes and beliefs are detailed in the Results section. Two main contexts for willingness to respond (“WTR”) to a RDD were also assessed—WTR if asked but not required to respond (hereafter referred to as “WTR if asked”), and WTR if required, were presented using the 9-point Likert scale.

In accordance with the EPPM-based threat and efficacy methodology validated by multiple studies and explained in previous work [17,18,27,28], levels of perceived threat and perceived efficacy (both with regards to the individual respondent) were determined, and four profiles were constructed.

Study participants
All employees of the Johns Hopkins Hospital (N = 18,612) were designated as eligible for participation in the survey, which was conducted from January 2, 2009 to March 9, 2009. Study notification and requests for voluntary participation were distributed via department manager announcements, hospital-wide emails, posters, and informational plasma screens throughout the hospital.

Statistical Analysis
Prior to analysis, responses to the attitude and belief statements were dichotomized into categories of ≤4 (“positive response”) versus ≥5 (“negative response”). One of the four EPPM profiles was assigned to each respondent using the low and high perceived threat and efficacy categories calculated as described in previous EPPM survey-based research [17,18,27,28].

Distributions of demographic/professional factors and agreement with attitude/belief statements were obtained with respect to the two main WTR contexts noted above. Univariate logistic
regression analyses were performed to determine key demographic factors most predictive of a positive response to the main WTR contexts. Multivariate logistic regression analyses, adjusting for the key demographic factors, were then performed to evaluate the attitude/belief statements, EPPM profiles, and training scenarios predictive of a positive response for each of the main WTR contexts. Missing and "don’t know" responses were excluded from the analyses. All analyses were performed using STATA version 11.1 (STATACORP, College Station, Texas).

Results

Responses to the online survey were received from 3426 JHH employees. This sample constitutes 18.4% of JHH staff. An accurate estimate for response rate is difficult to assess, as it was not possible to ascertain what proportion of JHH staff have indeed been exposed to the email invitation to participate in the survey. Key characteristics of the respondents are detailed in Table S1; JHH staff data on age, gender and professional category show that this sample is representative of the overall JHH staff characteristics.

Among the respondents, 27.3% were male, and 72.7% were female; 16.5% were younger than 30 years, 47.5% were aged 30–49 years, and 36% were aged 50 and older. Thirty-four percent of the respondents were clinical staff, and 66% were non-clinical (the latter including food service/linens, IT, legal, executive officers, nursing administration, parking, pharmacy, safety, social workers, supply chain, telecommunications, etc). Of the 1170 clinical respondents, 42.7% were physicians, 49.2% were nurses, and 8.1% were “other” (physician extenders and medical/nursing students). The majority of respondents (60.7%) had worked in the hospital for 10 or fewer years.

Table S2 details the percent agreement with key attitudes and belief statements. Of note is the fact that 88% of the respondents considered a RDD event likely to be of severe health consequences, that only 41.9% felt they were knowledgeable about this threat, that only 35.8% felt they were able to address public questions on this threat, and only 31.9% were aware of their job-specific responsibilities in such an event. The average “don’t know” response proportion was generally stable across strata (7–13%). One single stratum, the lowest education level, had a higher proportion of “don’t know” responses (16%).

Overall willingness to respond to a RDD scenario was 61% if asked, and 72% if required. Table S1 shows that higher levels of WTR if required and of WTR if asked, as compared to the odds for the reference low-threat/low-efficacy profile [OR(95%CI): 7.12 (4.91, 10.32), and 7.16 (5.12, 10.00), respectively]. The threat component of the profiles had no independent significant impact on WTR if required, and the high-threat/low-efficacy profile had no advantage over the low-threat/low-efficacy profile in either WTR if asked or WTR if required. This similarly applies to the RDD “regardless of its severity”.

In accordance with the EPPM, measures for threat and efficacy perception were calculated. When adjusting for the key demographic factors, higher perceived threat [OR(95%CI): 1.26 (1.03, 1.54)] and higher perceived efficacy [OR(95%CI): 6.89 (5.43, 8.75)] were associated with a higher WTR if asked (Table S2). When the threat and efficacy factors were combined into the four EPPM profiles, the High-Threat/High-Efficacy profile was associated with at least seven times higher odds of WTR if required and of WTR if asked, as compared to the odds for the reference low-threat/low-efficacy profile [OR(95%CI): 7.12 (4.91, 10.32), and 7.16 (5.12, 10.00), respectively]. The threat component of the profiles had no independent significant impact on WTR if required, and the high-threat/low-efficacy profile had no advantage over the low-threat/low-efficacy profile in either WTR if asked or WTR if required. This similarly applies to the high-efficacy comparison between threat levels.

Table 1 lists associations between self-reported willingness to respond to a RDD emergency and respondents’ training and disaster experiences. Only 50% of the respondents had received some form of training, and less than 14% had undergone an RDD drill. Those respondents that had no RDD training were almost 1.5 times more likely not to be willing to respond to duty even if required, compared to those with at least some training. Participants that had both disaster management training and disaster experience were 6 times more likely to respond to a RDD event, adjusted for the four key demographic factors associated with WTR.

Discussion

Our study suggests that during a RDD or “dirty bomb” event, a high proportion (39%) of the medical center staff may opt out from
responding to duty, and that several attributes, most importantly willingness to work extra hours (associated with having dependent family members and pets at home) are very strongly associated with willingness to respond in such an emergency.

The use of a RDD or “dirty bomb” as a terrorist weapon is a concern, as reflected by its inclusion among the U.S. National Planning Scenarios. Psychological models suggest that risk perception is an interplay between affective (risk as feeling) and analytic (risk as analysis) processes [29]. According to these models, peripheral factors independent of the actual risk have a major effect on the perceived dread of an event. Factors that render a perceived risk as more dreadful include events that are involuntary, manmade, exotic, catastrophic, and with potential to affect the next generation with little or no individual control. Virtually each and every one of these risk perception modifiers is present in a RDD scenario, rendering this event to be highly dreadful to some, well beyond the actual (analytic) risks it bears.

During critical events, healthcare workers are expected to work additional hours under significant stress, potentially at risk of personal safety. When faced with the need to respond to duty during a terrorist event, health professionals are subject to the psychological impact of dread and outrage, caused by the perception-modifying characteristics of a RDD event. This may explain, at least in part, why such a large proportion of hospital workers, almost 39%, report they would not be willing to report to duty if asked during a RDD event. When further probed if they would respond to a RDD event “regardless of severity”, almost half (51%) of surveyed staff indicated they are unlikely to do so. This is a very high proportion when considering the first receiver role of these personnel, ostensibly accustomed to responding to emergencies and disasters.

These outcomes are in accordance with the limited but expanding evidence-based literature on the perceptions of the hospital-based workforce toward their emergency response duties in a post-9/11 world. In two surveys performed in 2005 of NYC healthcare workers (n = 6,428), and hospital employees in 5 states (n = 1711), workers were far more willing to respond to natural disasters than to a radiological event or an infectious disease

| Table 1. Associations between self-reported willingness to respond (WTR) to a radiological dispersal device emergency and respondents’ training and disaster experiences. |
|----------------------------------|------------------|------------------|
| Training/Disaster Experience     | WTR if required  | WTR if asked but not required |
|                                  | %a  | % Agreeb | OR (95% CI)d   | % Agree | OR (95% CI)d   |
| Any training                     | Some | 50.6    | 75.5 | Reference | 64.5 | Reference |
|                                  | None  | 49.4    | 69.1 | 0.69 (0.57–0.84) | 58.2 | 0.74 (0.62–0.891) |
| Tabletop exercise(s)             | No   | 84.0    | 71.2 | Reference | 60.0 | Reference |
|                                  | Yes  | 16.0    | 78.1 | 1.38 (1.03–1.82) | 68.7 | 1.40 (1.09–1.81) |
| Full-scale drills(exercise(s)     | No   | 85.9    | 71.3 | Reference | 60.3 | Reference |
|                                  | Yes  | 14.1    | 78.7 | 1.53 (1.13–2.07) | 68.0 | 1.36 (1.03–1.78) |
| Academic coursework              | No   | 85.5    | 71.0 | Reference | 59.3 | Reference |
|                                  | Yes  | 14.5    | 79.8 | 1.46 (1.08–1.97) | 73.0 | 1.66 (1.25–2.20) |
| Face-to-face training(lecture(s)/presentation(s) | No   | 80.0    | 70.5 | Reference | 59.2 | Reference |
|                                  | Yes  | 20.0    | 79.6 | 1.63 (1.25–2.18) | 70.0 | 1.58 (1.25–2.00) |
| Online training module(s)        | No   | 89.0    | 71.7 | Reference | 60.2 | Reference |
|                                  | Yes  | 20.0    | 75.0 | 1.26 (0.98–1.61) | 66.1 | 1.40 (1.11–1.77) |
| Writing emergency/disaster management (EM) plans | No | 91.9 | 71.5 | Reference | 60.2 | Reference |
|                                  | Yes  | 8.1     | 81.7 | 1.96 (1.31–2.95) | 74.3 | 2.11 (1.48–3.03) |
| Real-life disaster experience     | No   | 93.6    | 71.5 | Reference | 60.5 | Reference |
|                                  | Yes  | 6.4     | 84.9 | 2.02 (1.24–3.27) | 74.5 | 1.64 (1.09–2.46) |
| Disaster experience or training   | No   | 51.4    | 68.8 | Reference | 57.9 | Reference |
|                                  | Yes  | 48.6    | 75.9 | 1.50 (1.23–1.83) | 64.9 | 1.39 (1.16–1.68) |
| No training or disaster experience| 51.4 | 68.8 | Reference | 57.9 | Reference |
| Disaster experience only         | 1.4  | 80.0    | 1.72 (0.69–4.30) | 69.0 | 1.41 (0.62–3.21) |
| Any training only                | 42.2 | 74.6    | 1.42 (1.12–1.74) | 63.5 | 1.34 (1.10–1.62) |
| Any training and disaster experience | 5.0  | 86.2    | 2.62 (1.48–4.62) | 75.9 | 2.03 (1.27–3.25) |
| No EM training or disaster experience | 87.2 | 71.0    | Reference | 59.7 | Reference |
| Disaster experience only         | 4.7  | 81.4    | 1.65 (0.98–2.76) | 69.0 | 1.31 (0.85–2.05) |
| EM training only                 | 6.4  | 78.0    | 1.70 (1.11–2.61) | 70.4 | 1.86 (1.26–2.74) |
| EM training and disaster experience | 1.7  | 94.6    | 6.19 (1.43–26.79) | 89.2 | 4.70 (1.63–13.58) |

*aPercent of respondents included in category. 
*bPercent agreeing with WTR statement (positive response). 
*cOR is the odds ratio provided in the logistic regression which compares the odds between a positive WTR response and a negative WTR response with respect to the type of training compared to its Reference category, adjusted for key demographic characteristics: gender, age, children/marital status, and type of professional category. 
*d95%CI is the 95% confidence interval for the odds ratio.

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outbreak [19]. Yet the results of our study regarding WTR in a RDD event are markedly worse than the 28% who were unwilling to respond to a pandemic influenza event, measured in the same setting and population (just prior to the 2009 H1N1 pandemic) [27,28].

Having a workforce that is willing to respond is a critical component of mitigating the effects of any disaster, and our study results are a clear call for action. While work is being done by disaster planners to improve “readiness” or “ability” to respond during disasters, such as encouraging personal preparedness planning, more needs to be done to address beliefs and attitudes that may hinder “willingness” to respond. It is thus critically important for us to understand why some healthcare workers are unwilling to perform their duties during a radiological emergency in order to implement changes in disaster training, education and messaging.

Survey responses suggest that more attention is needed to address healthcare workers’ basic knowledge level with regard to radiation events. In fact, 58% of respondents disagreed with the statement “I am knowledgeable about the potential medical impacts of a dirty bomb emergency.” Two thirds of the staff surveyed did not feel educated enough to address public questions, and less than one third of the staff knew their role-specific responsibilities. Indeed, in a recent study of 668 emergency nurses in New York, the existing knowledge in regards to radiological emergencies was determined to be poor [19]. In that study, knowledge level and clinical ability had a positive association with nurses’ level of willingness to respond to a radiological terrorism event.

Quantitative results from our hospital-based study also echo a qualitative study that assessed the views and perspectives of emergency department clinicians in regard to radiologic terrorism [30]. Researchers found through a series of ten focus groups that study participants clearly and consistently felt that their facilities were not adequately prepared for such an event, due to inadequacy of response protocols, potential for staffing shortages, and concerns about contamination and self-protection. When considering the fear of potential staffing shortages indeed, in our study, staff who felt that their peers are unlikely to respond to duty, were 17 times more likely to refrain from reporting to duty themselves in our study. This finding lends us a potentially powerful tool to impact willingness to respond, by targeted education campaigns to change subjective norms regarding response to such an emergency.

One construct that was strongly and independently associated with WTR was belief that the workplace will be safe. Perception of personal safety was identified as a primary determinant of willingness to respond in a radiological disaster in other previous work as well [23]. This concern about personal protection is not unique among responders to the potential scenario of radiological terrorism events; in one study the question of “Will the hospital protect me?” was the most important factor in determining the workers willingness to respond [31]. First responders must be educated as to the minimal risk of contamination from radiologic materials in such an attack if universal precautions are used [32], as well as in specific strategies of mitigating and minimizing personal risk in such events. Thus, it is not surprising that requiring the staff to report will not be enough to address the worker shortage. Unwillingness of hospital staff to respond to a RDD event remained as high as 27.6% if the workers were required (and not just asked) to report to duty. Thus, even the potential threat of loss of compensation or job is of limited influence, as still over one of every four employees from a large urban tertiary care hospital indicated they would not report for work even if required – at a time they would be most needed in their respective work roles.

Of all attitudes and beliefs, the attitude statements most strongly associated with high WTR was willingness to work extra hours if required. Those able and willing to work extra hours were 20 times more likely to be willing to respond during this event, after controlling for demographic factors. These results may be interpreted in view of the strong association identified between lower ‘if asked’ WTR and having dependents at home – either elderly (OR = 0.81), children (OR = 0.69) or even pets (OR = 0.79). Single parents with children had the lowest estimated likelihood to respond to this event (OR = 0.56). One reasonable explanation may be that some of the hesitance to report to duty among those unable to work long hours is associated with the need to continuously take care of dependents during such an event. Indeed, 88% of those unwilling to work extra hours had a family member or a pet dependent solely on them.

Witte’s EPPM offers a framework for examining the interplay and influence of perceptions of “threat” and “efficacy” on adaptive or maladaptive behavior in the face of risk [26]. It has shown its utility in previous work assessing WTR in pandemic influenza and other catastrophic event scenarios [18,27,28]. Our study is the first to analyze hospital employees’ perceived threat, efficacy, and WTR during a RDD event through the lens of the EPPM. This model potentially allows us to see how hospital workers’ individual degrees of perceived threat (“concern”) and perceived efficacy (“confidence”) influence their willingness to respond to this type of event. In accordance with EPPM theory, our survey results show that those who have a perception of high threat and high efficacy – i.e., those who fit a “concerned and confident” profile in the EPPM framework—had a high rate of declared self-reported willingness to respond (if required) to a dirty bomb event, which was about seven times [OR(95%CI): 7.16 (5.12–10)] higher than those fitting a “low threat/low efficacy” profile.

In contrast with the classic EPPM theory, perception of threat had little impact on willingness to respond among hospital workers in our study (Table S2). This could either imply that the perception of threat in motivating response behavior in hospital employees is not as important as the perception of one’s efficacy in response, or that our threat assessment questions assessed the ‘analytic’ aspect of RDD risk perception, and could not assess the ‘affective’ effect of the additional dread associated with this event, which is the effect that may impact WTR more significantly. One other potential explanation is that the level of dread from such a scenario is such that only minor variability exists between individuals, in a level that bears little impact on decision making.

Our survey indicates that hospital employees are receptive to more training in response to a radiation disaster. In fact, 87% of respondents agreed that the hospital should provide pre-event preparation and training for dirty bomb emergencies. Only 50% of the respondents had received some form of training. Those who had were almost 1.5 times more likely to be willing to respond to duty even if not required than those with no training. Participants that had both disaster management training and disaster experience were 6 times more likely to respond to a RDD event, adjusted for four demographic characteristics associated with WTR. Most preparedness training for hospital workers presents factual information on threats and response roles. Classroom and web-based educational interventions are generally awareness-level courses that focus on knowledge objectives, such as the nature of disasters or terrorist events, medical effects, treatment modalities, personal protective equipment, and immuno- or chemo-prophylaxis if available [33,34]. Some practicum courses have added skills.
objectives through hands-on workshops [35]. Additional strategies to mitigate such concerns include the application of internet-based learning courses on aspects of radiation emergency management and hazard mitigation [36], as well as conferences or medical symposia to educate medical professionals on the aspects of patient management in radiation injury scenarios [57], and extensive preparatory planning [38].

Our study had several key limitations that must be considered when interpreting its results. We have used an online survey, and thus some members of hospital staff may have had unequal opportunity to respond to it, despite the availability of computers all around the hospital accessible to all employees. However, the large number of respondents, representative of the entire hospital staff, may point to its internal validity. This study was limited to one institution, thus limiting its external validity. Despite this, the study allows us to consider these results a high-level estimate for other non-tertiary centers around the country. It is theoretically possible that an individual could have responded more than once to the survey, although the authors believe this is very unlikely given the length of time required to fill out the survey. Finally, there is always a concern about the difference between the declared responses and actual conduct when facing the actual risk. Again, one can assume that these results are thus conservative, and actual willingness to respond may be lower but is unlikely to be higher in a real-life event.

Conclusions

Our study demonstrates a significant gap that exists in hospital preparedness for a 'dirty bomb' radiological terrorism event, with nearly 40% of the workers unwilling to respond to duty during the event. The subjective norm (perceived willingness of peers to respond), personal safety issues, and perceived efficacy in one's role in response were found to be important parameters associated with willingness to respond, while the level of perceived threat had only minor impact. These data, in view of the considerable gaps in perceived knowledge and training identified, lay the evidence needed to guide future preparedness and curriculum planning for hospital employees and to identify critical incentives for the hospital workforce response during this type of disaster.

Supporting Information

Table S1 Associations between demographic characteristics and self-reported WTR to a radiological dispersal device emergency.

Table S2 Associations between attitudes/beliefs and self-reported WTR to a radiological dispersal device emergency.

Table S3 Associations between attitudes/beliefs and self-reported WTR to a radiological dispersal device emergency compared to those not willing to respond.

Author Contributions

Conceived and designed the experiments: RDB CLC DJB. Performed the experiments: CLC. EBH HSG JML. Analyzed the data: CBT. Contributed reagents/materials/analysis tools: RDB DJB CBT NLS MJM CMW HSG JML. Wrote the paper: RDB MJM. Editing and reviewing for critical content: CLC DJB EBH MJM NLS CMW HSG JML.

References


A Sustainable Training Strategy for Improving Health Care Following a Catastrophic Radiological or Nuclear Incident

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Abstract
The detonation of a nuclear device in a US city would be catastrophic. Enormous loss of life and injuries would characterize an incident with profound human, political, social, and economic implications. Nevertheless, most responders have not received sufficient training about ionizing radiation, principles of radiation safety, or managing, diagnosing, and treating radiation-related injuries and illnesses. Members throughout the health care delivery system, including medical first responders, hospital first receivers, and health care institution support personnel such as janitors, hospital administrators, and security personnel, lack radiation-related training. This lack of knowledge can lead to failure of these groups to respond appropriately after a nuclear detonation or other major radiation incident and limit the effectiveness of the medical response and recovery effort. Efficacy of the response can be improved by getting each group the information it needs to do its job. This paper proposes a sustainable training strategy for spreading curricula throughout the necessary communities. It classifies the members of the health care delivery system into four tiers and identifies tasks for each tier and the radiation-relevant knowledge needed to perform these tasks. By providing education through additional modules to existing training structures, connecting radioactive contamination control to daily professional practices, and augmenting these systems with just-in-time training, the strategy creates a sustainable mechanism for giving members of the health care community improved ability to respond during a radiological or nuclear crisis, reducing fatalities, mitigating injuries, and improving the resiliency of the community.


Introduction
Headlines regularly remind medical communities about the possibility of catastrophic events; consider the 9/11 terrorist attacks and more recent Boston bombings. The detonation of a nuclear device in a US city would be a catastrophic event unlike any other.
It would result in enormous numbers of casualties, thousands of fatalities, and profound psychological, political, social, and economic implications.1 Health care systems would face an overwhelming surge of activity in the days following such a disaster as people seek treatment for physical trauma, thermal burns, acute radiation exposure, and radioactive contamination. A localized radiological incident would also require substantial medical resources. As the Fukushima accident demonstrated, fear of radiation, even absent actual risk of radioactive contamination, may tax the health care system.2 In this range of scenarios, the medical community must be able to meet public health needs, including the medical management of radiation injuries. Unfortunately, most members of the US public health and medical communities are insufficiently prepared for responding to a significant radiological or nuclear incident.3-6 These professionals lack basic knowledge for diagnosing and managing acute exposure to ionizing radiation, identifying the type of radiation emitted from radiological or nuclear devices, or treating combined injuries featuring physical trauma or thermal burns alongside radiation exposure.7,8

If a radiological or nuclear incident were to occur, individuals throughout the health care delivery system would need some understanding of radiation both to do their jobs properly and to assist the general public. Emergency department physicians, Emergency Medical Services system medics and paramedics, hospital security, and janitorial staff would all be involved if such incidents transpired. All need some level of training to prepare for their roles, though amounts and content should differ. This paper proposes a sustainable, four-tiered training strategy for propagating radiation emergency medicine information by identifying the content needed for the encounters each group of workers can expect to have with casualties and others seeking assistance. This approach is consistent with the US National Health Security Strategy, which defines national health security as when “the Nation and its people are prepared for, protected from, respond effectively to, and able to recover from incidents with potentially negative health consequences”.9 The recommendations discussed below are informed by medical specialists at the US Department of Energy’s Radiation Emergency Assistance Center/Training Site (REAC/TS) and the US Department of Defense’s Armed Forces Radiobiology Research Institute (AFRRI) who routinely educate and advise health care providers and support staff.

Report
Given limited and diminishing resources, conventional wisdom might suggest focusing the health care community on the most common or life-threatening health threats. Admittedly, detonation of a nuclear device or dispersal of radioactive material in an American city is a low-probability health risk. Communities may be reluctant to expend funds for low-probability scenarios and hazards even though they may represent high-consequence risks. However, the justification is simple: the costs of unpreparedness are unacceptable while the costs of preparing are relatively low. Misinformation surrounds radiation, fear of radiation is especially high, and radiation injuries can be life threatening. Indeed, according to the Institute for Medicine, the costs of inadequate training could increase the risks of morbidity and mortality following a nuclear incident.10 Conventional injuries may also remain untreated or treatment may be delayed by fear of radiation in the medical community after an incident. In combination, this creates a daunting problem for unprepared medical professionals, emergency response workers, and hospital staff that, left unresolved, could lead to unnecessary deaths and illnesses.

Additional time-consuming training is not needed to prepare members of the American health care delivery system to treat radiation injuries and illness; instead, an elegant, tiered training system built into and from existing education programs, expanded to new platforms, and with a just-in-time training capability can serve this purpose. For example, an Emergency Medical Technician (EMT) does not need knowledge about treatment of internal radioactive contamination. These first responders need to understand the difference between radiation exposure and radioactive contamination, that internal contamination is manageable, and how to employ methods for protecting themselves and their patients. Meanwhile, emergency physicians, emergency nurses, public health practitioners, and poison control center personnel need training that includes details on internal contamination diagnosis and treatments. A core principle of the proposed training strategy is connecting radiation training to concepts people already know and use, rather than introducing novel concepts. Rather than lengthy new courses, building just a few hours or days over the span of many years into existing educational programs would help realize significant preparedness gains. For example, health care professionals already learn how to prevent the spread of infection and contagious diseases, and those same practices and personal protective equipment can be used to prevent the spread of radioactive contamination and reduce radiation exposure.

Figure 1 shows the proposed tiered approach for determining the types of personnel who require radiation injury-specific training targeted to their individual response functions. Customized, role-specific training curricula should be required for each of these groups, and a cost effective, efficient system for implementing such training should be established, integrating radiation modules into preexisting mass-casualty baseline and refresher training. Table 1 explains the components of each tier in greater detail.

Tier 1 consists of subject matter experts (SMEs). They could be drawn from radiation oncologists, nuclear medicine specialists, and other medical professionals who are knowledgeable about and regularly deal with ionizing radiation. Professionals in this tier will serve as a force multiplier, making real time

![Figure 1. Tiers of Responders Categorized by Training Needs](Image)
Meanwhile, personnel in Tiers 2 through 4 should be located at highest risk to best match the scarce resource with known threats. Surging in that direction. Training Tier 1 personnel in UASI cities not among these ten requires SME support, those trained could be most likely to target these cities. Should another city or location to bolster local training and response capabilities, since threats are available within the top UASI cities around the United States. The UASI identified 64 major metropolitan areas at risk, 54 areas as a lesser, but still high, risk. Optimally, SMEs should be classified ten as highest risk, and considered the remaining classification. The UASI developed a model that characterizes the major metropolitan areas in the country that are at the highest risk of terrorist activities, including an improvised nuclear device (IND) detonation. The UASI identified 64 major metropolitan areas at risk, classified ten as highest risk, and considered the remaining 54 areas as a lesser, but still high, risk. Optimally, SMEs should be available within the top UASI cities around the United States to bolster local training and response capabilities, since threats are most likely to target these cities. Should another city or location not among these ten require SME support, those trained could be surged in that direction. Training Tier 1 personnel in UASI cities at highest risk best matches a scarce resource with known threats. Meanwhile, personnel in Tiers 2 through 4 should be located in cities throughout the country, and their training should be designed to reach broadly dispersed groups.

Health care delivery and radiation safety personnel make up Tier 2 and are broken into three subgroups: health care providers, EMTs and paramedics, and radiation safety professionals. Members of Tier 2 are most likely to be the people who make first contact with both casualties and those who fear they were exposed to radiation or those who are contaminated. While each group in Tier 2 requires different types of specific training, they need comparable levels of expertise and should be prepared to work in concert with one another after a major radiological or nuclear incident.

Health care providers in Tier 2 include doctors, nurses, and other medical practitioners who directly treat victims of an incident. They should be able to perform initial diagnoses and management of radiation injuries or illnesses in the immediate post incident period up to 72 hours, after which those with more specialized training are expected to be available. These personnel may be called on to establish medical and surgical priorities for patients with radiation exposure or radioactive contamination. Operating within traditional care facilities and community reception centers, they need to know how to implement radiation protection procedures for staff and patients. Available evidence suggests radiation medicine training improves a physician's comfort level with relevant competencies, such as chelating agent administration and use of radiation detectors.11

The second subgroup within Tier 2 consists of EMTs and paramedics who work in potentially hazardous environments. These personnel triage and stabilize patients and transport them to health care centers. They need to know how to protect themselves and their patients from the spread of contamination and how to recognize the signs and symptoms of radiation exposure. This group should also have a basic, working knowledge of the medical consequences from radiation exposure and radioactive contamination so that they can assist with planning, preparations, and possible responses.

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<th>Tier</th>
<th>Health Care Institution Support Workers:</th>
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<td>1</td>
<td>Subject Matter Experts:</td>
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<td>Medical personnel who would be activated following a radiological or nuclear incident. Their training background should be extensive and complex, allowing them to address the most challenging issues demanding the greatest expertise. Ideally, their expertise would include knowledge of medical countermeasures, medical management of internal and external contamination, detection of exposure and contamination, and any special considerations needed for at-risk populations. As needed, SMEs could cross train one another on specialized topics to ensure wide distribution of key knowledge across Tier 1. An integral component of this proposed training strategy is ensuring that the right people have the right knowledge. Tier 1 is a small group with substantial expertise. They need to be strategically located. Under the Urban Area Security Initiative (UASI), the Federal Emergency Management Agency (FEMA) developed a model that characterizes the major metropolitan areas in the country that are at the highest risk of terrorist activities, including an improvised nuclear device (IND) detonation. The UASI identified 64 major metropolitan areas at risk, classified ten as highest risk, and considered the remaining 54 areas as a lesser, but still high, risk. Optimally, SMEs should be available within the top UASI cities around the United States to bolster local training and response capabilities, since threats are most likely to target these cities. Should another city or location not among these ten require SME support, those trained could be surged in that direction. Training Tier 1 personnel in UASI cities at highest risk best matches a scarce resource with known threats. Meanwhile, personnel in Tiers 2 through 4 should be located in cities throughout the country, and their training should be designed to reach broadly dispersed groups.</td>
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Radiation safety professionals, including health and medical physicists, industrial hygienists, and nuclear medicine technologists, make up the last subgroup in Tier 2. They are accustomed to dealing with radiation safety and protection issues. After a radiological or nuclear incident, they would play an essential support role to the medical providers by determining levels of radiation exposure and radioactive contamination in casualties. In particular, these professionals need to understand radioactive contamination control procedures, dose assessment techniques, instrumentation, personal protective equipment requirements, radioactive waste management practices, decontamination techniques, and basic radiation biology. If possible, radiation safety professionals should have knowledge of bioassays and appropriate countermeasures. In a catastrophic situation, it is also important that radiation safety professionals understand how to interact with a fearful public and are prepared to communicate that medical treatment takes precedence over radiological decontamination. These professionals may be more accustomed to working in a regulatory environment, so training directed at them should stress the importance of staying focused on health and safety, rather than regulatory compliance, during an incident.

The health care providers and EMTs are the medical front line and should have sufficient knowledge to comfortably deal with ionizing radiation while providing medical treatment, rather than avoiding or delaying treatment. For radiation safety personnel, the educational need is to provide familiarity with medical casualties, including those related to radiation exposure. Doing so would enable these responders to be comfortable with individuals who have experienced physical trauma while screening them for radioactive contamination and providing additional support to the medical teams. All Tier 2 personnel, regardless of the role they fill, should know how to protect themselves and their patients from radiation hazards and be prepared to work in an environment with a highly disrupted, and potentially contaminated, public infrastructure.

Tier 3 contains public safety personnel who are responsible for fire suppression, crowd control, traffic control, and communication with the general public and other workers during an emergency with public health considerations. It also contains emergency management planners, who work directly with public safety personnel after the incident to establish community reception centers and command posts, and address other operational needs. Tier 3 personnel should understand the basics of radiological and nuclear hazards and the principles of radiation protection and radioactive contamination control. They do not treat casualties, but they do operate in the same hazardous environment and need to be comfortable performing their lifesaving functions, such as putting out fires and directing crowds. These public safety personnel may be required to explain hazards to the general public and suggest ways to stay safe. Consequently, those in this tier should have instruction in risk communication and the Incident Command System, a well-established structure used at the federal, state, and local level for coordinating personnel during an emergency. Tier 3 training must teach these professionals that radiological issues should never delay immediate life safety operations; any delay could cause inadvertent harm to the public or slow recovery. Providing each tier with the appropriate knowledge builds responder confidence, resilience, and comfort, all of which help them appropriately respond to the challenges of a catastrophe.

Tier 4 consists of health care institution support personnel responsible for facility operations in health care institutions of all kinds (eg, hospitals, nursing homes, ambulatory care facilities). These include food service, sanitation, laundry, and security personnel, hospital administrators, emergency department administrative staff, and many others. Without their efforts, vital health care organizations could not function during a crisis. In particular, personnel in Tier 1 and Tier 2 would be unable to deliver care or manage the potentially large number of casualties. Tier 4 personnel should have a basic understanding about the nature of radiological and nuclear hazards and know how to protect themselves, including distinguishing between radioactive contamination and radiation exposure. The goal is to enable them to effectively perform their jobs in the midst of potentially contaminated or exposed people without endangering their own well-being or being scared to come to work.

Table 2 suggests the type of radiation-related information that would be appropriate for the four tiers of responders. The detail

<table>
<thead>
<tr>
<th>Knowledge Area</th>
<th>Tier 1</th>
<th>Tier 2</th>
<th>Tier 3</th>
<th>Tier 4</th>
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<tr>
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<td>Biological effects of radiation</td>
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<tr>
<td>Basics of ionizing radiation</td>
<td>X</td>
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<tr>
<td>Medical management of external contamination</td>
<td>X</td>
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<tr>
<td>Medical management of internal contamination</td>
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<tr>
<td>Diagnosis of exposure and contamination</td>
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<tr>
<td>Radiation detection instrumentation</td>
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<tr>
<td>Treatment of radiation injury</td>
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<tr>
<td>Detailed principles of ionizing radiation</td>
<td></td>
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Table 2. Knowledge Areas That Form the Basis of Tier-Specific Curricula
and depth of the information would vary by subgroups within the tier, and the creation of curriculum specifics requires further study.

While creating new education modules will be important for building the initial radiation knowledge base in each tier of the health care community, just-in-time education targeted to the individual tiers will also be needed during an actual incident, when a protracted response necessitates surge capacity. This approach provides initial training to additional personnel in the health care delivery system and serves as a refresher for responders for whom prior training occurred years before. Some just-in-time information currently is available on the internet. For example, the Radiation Emergency Medical Management (REMM) website funded by the US Department of Health and Human Services (HHS) is a valuable resource. For an actual incident, however, traditional news media and social media will assist in providing specific messages needed by the general public and responders. The content of the just-in-time education should be congruent with the steady state curriculum used by each tier.

Discussion
Regardless of scale, an adequate reaction to a radiologic or nuclear emergency will require responders with specific knowledge and competencies. At least one of the major educational agencies, REAC/TS in Oak Ridge, Tennessee (USA), provides educational activities for just over 2,000 participants per year out of millions of physicians, nurses, nurse practitioners, physician assistants, medics and paramedics who might be called to respond in case of a significant radiologic or nuclear incident. Many explanations for lack of training exist for each part of the response community, including competing priorities, absence of any mandate, and uncertainty and fear.

Since nuclear or radiological incidents are thought to be unlikely in the United States, many health care providers and senior leaders managing health care support personnel select other areas for spending their limited resources. Thus, medical professionals are prepared for the most common incidents, but defer training to address injuries resulting from uncommon radiologic or nuclear incidents.

Personal fear of radiation exposure also appears to contribute to minimal demand for specific radiation emergency medicine education and training. Health care providers appear to believe that if trained, they would be responsible for responding to future radiation emergencies, and they have concerns about filling that role. Studies suggest that health care providers of several disciplines are less likely to volunteer or report to work if they know they may be exposed to radiation or will need to interact with patients who may be radiation victims. Mandated training and preparedness may improve this problem.

Currently, professional emergency response curricula for most health care providers include very little radiation content. Most existing lesson plans for mass casualty management focus on all-hazard emergency responses and provide little specialized information about the nature of radiation hazards and personal safety. Together, training inadequacies and fear may result in a vicious cycle: fear of radiation leads to little demand for response training, which results in poor preparedness, leading to more fear.

In addition, several misperceptions undermine radiation emergency medicine training. First is a common, albeit erroneous, perception that clinical radiation injury is always very severe, usually irreversible, and that treatment is usually futile. Lack of knowledge about gradations of radiation injury and the existence and availability of potentially effective medical countermeasures contributes to these false beliefs, which create additional disincentives to select radiation training and incentives to select training for trauma or other diseases that are considered more "treatable." Second, among medical providers and research professionals, radiation biology and physics are both considered complex topics. This contributes to the under selection of radiation specialties for careers, other than diagnostic radiology. The same perception of radiation as a complex concept may affect the training choices of other health care and public safety personnel. Well crafted and well targeted training materials can overcome this issue.

The radiation science community has its own difficulties; namely, it is shrinking in size and limited funding sources are not dependable or plentiful. Reports indicate a major shortfall in the number of radiation research scientists needed to address research demands relating to cancer as well as radiological or nuclear terrorism. Recent surveys also suggest that as the population of academics with extensive radiation biology training grows older, there are few properly trained replacements. As a result, those less familiar with radiation sciences are now teaching radiation biology to future scientists and medical practitioners. Meanwhile, fewer new health physicists are currently being trained than in the past, and in a dwindling number of health physics academic programs. Indeed, so few health physicists are being trained that there is more than one job available per health physics graduate. With these human resources challenges in the radiation science community, gaps in preparedness are increasingly apparent.

Finally, physicians tend to focus on mandates when selecting continuing medical education and training. Currently, no mandate for radiation injury training exists, either for initial licensing or continuing certification. Establishment of a mandate either through professional society licensure, recertification, or Joint Commission on Accreditation of Health care Organizations rules would help encourage training throughout the medical community, but can be a difficult and time-consuming process. With other members of the health care delivery system, a more pervasive problem is the lack of recognition that personnel in Tiers 3 and 4 need radiation related awareness training.

Challenges associated with adequately training medical communities are not simply addressed. However these challenges are also not insurmountable. The tiered approach offers a starting point for a sustainable training strategy for improving health care following a catastrophic radiological or nuclear incident. Importantly, it identifies key public health and medical response stakeholders and provides initial suggestions about the types of activities in which they will engage during an incident. It also identifies the types of knowledge needed to prepare them for those activities. Research shows that radiation medicine education improves provider comfort level with various skills needed during responses, which in turn helps save lives. Broader application of this finding to personnel throughout the health care delivery system and public safety community can, likewise, save lives, improving resiliency in the event of a radiological or nuclear catastrophe. Getting the necessary education to the right people throughout the community is the aim of the tiered training system, as shown in Table 2.
To begin developing the system, SMEs from various disciplines should conduct a systematic study of what specific radiation details each tier of responders must know to carry out its roles during a response. Table 2 provides a useful starting point for this effort and is derived from the diverse experiences of this paper’s authors; however, a full study should ultimately guide development of a detailed curriculum for each tier. Coordinating this effort with appropriate professional societies and institutional partners will be necessary to facilitate future dissemination of radiation education curricula.

Once curricula are developed, a well crafted, tiered radiation training system with classroom and online modules customized for responder roles could be easily incorporated into existing all-hazard emergency education programs, new hire training, and other existing educational opportunities. This concept addresses several of the barriers to entry that hamper current radiation emergency medicine training. First, it eases the burden on obtaining the education. Indeed, formal distance learning modules with multimedia elements to teach complex content is one way to enhance student understanding, increase the numbers who have access to vetted materials, and to minimize cost. Other uses of technology also could be explored for sharing training materials, including use of existing internet resources like HHS’s REMM website, which would help make the program even more efficient. Second, by plugging into existing all-hazard programs, this system mitigates issues surrounding training levels, mandates, and licensure. In the proposed format, completion of preapproved modules might easily be applied toward continuing medical education (CME) requirements or other certifications. It also eliminates the need for a standalone training series or separate courses, and reduces the time it takes to spread the curriculum to the appropriate audiences. Third, this system provides an opportunity to tie radiation-related medical training back to daily professional practices, which will help give the training relevance. Finally, in this conception, elements of the training could be used for multiple tiers, which would reduce costs and increase efficiency even while the breadth and depth of training would still reflect specific responder categories and roles as shown in Table 1 and Figure 1.

As the program develops, the “tiers of training” strategy could be expanded to include the need-to-know information necessary for addressing a wider range of potential mass casualty incidents, including chemical and biological threats. The same tiers useful for educating the health care community about radiation emergency medicine may also prove useful to those designing training programs focused on special types of chemical and biological hazards that the community often does not see. Efforts to adapt the tiered training concept for major chemical and biological incidents would go a long way in helping solidify this type of training practice by reinforcing many of the common medical techniques useful during each incident.

Radiological and nuclear incidents may be low likelihood, but they may also be extremely high consequence. Detailed federal requirements mandating federal planning for such events and considerable sophisticated national and some local medical response planning for these types of incidents have been developed and implemented since September 11, 2001.42-44 With thoughtful planning and prior training of responders, thousands of lives could be saved, injuries treated, and illness mitigated.45 This is precisely the goal of the proposed training system. The potential human cost of failing to prepare for a radiological or nuclear incident is unacceptably high, but the financial and organizational costs of preparing are relatively low.

Conclusion

Community resilience after a catastrophe is correlated, in part, with the knowledge, expertise, and judgment of medical responders. This would be especially true following an incident like an IND detonation or other mass casualty radiological incident. This report recommends implementing a four-tiered approach for training specific groups of responders based on their likely roles in an incident involving potential radioactive contamination or radiation exposure. Additional work is needed to further define the educational elements appropriate for the needs of each tier, and the most efficient and effective methods of delivering this educational material before and during an incident. While the proposals suggested in this paper are geared toward the American medical community, they may also provide a useful starting point for other countries considering how to improve their own capabilities. Moreover, employing the proposed training system would also yield lessons learned that are applicable to other mass casualty incidents, including those associated with chemicals or biological agents. This is all the more reason for it to be implemented without delay.

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References


ABSTRACT

This study argues that any nuclear weapon exchange or major nuclear plant meltdown, in the categories of human systems failure and conflict-based crises, will immediately provoke an unprecedented public health emergency of international concern. Notwithstanding nuclear triage and management plans and technical monitoring standards within the International Atomic Energy Agency and the World Health Organization (WHO), the capacity to rapidly deploy a robust professional workforce with the internal coordination and collaboration capabilities required for large-scale nuclear crises is profoundly lacking. A similar dilemma, evident in the early stages of the Ebola epidemic, was eventually managed by using worldwide infectious disease experts from the Global Outbreak Alert and Response Network and multiple multidisciplinary WHO-supported foreign medical teams. This success has led the WHO to propose the development of a Global Health Workforce. A strategic format is proposed for nuclear preparedness and response that builds and expands on the current model for infectious disease outbreak currently under consideration. This study proposes the inclusion of a nuclear global health workforce under the technical expertise of the International Atomic Energy Agency and WHO’s Radiation Emergency Medical Preparedness and Assistance Network leadership and supported by the International Health Regulations Treaty. Rationales are set forth for the development, structure, and function of a nuclear workforce based on health outcomes research that define the unique health, health systems, and public health challenges of a nuclear crisis. Recent research supports that life-saving opportunities are possible, but only if a rapidly deployed and robust multidisciplinary response component exists. (Disaster Med Public Health Preparedness. 2016;10:129-144)

Key Words: public health, nuclear weapons, international agencies, nuclear disasters, foreign medical teams

If the larger, more threatening issue is not to be openly acknowledged and confronted, why worry about lesser problems?
– Rita R. Rogers, MD, on denial of the nuclear threat, Psychosocial Aspects of Nuclear Development

The Ebola crisis in West Africa is a wake-up call for how the world defines global health and global health security. Despite a 2005 post-SARS robust International Health Regulations Treaty (IHR) that gave unprecedented authority to the World Health Organization (WHO) to rapidly deal with any future epidemics or pandemics, the subsequent resulting preparedness capability quickly diminished before the Ebola tragedy because of major cuts in funding, staffing, and resources. A saving grace in this tragedy was the manner in which the Global Outbreak Alert and Response Network (GOARN), foreign medical teams (FMTs), and international nongovernmental organizations (INGOs) coordinated with available WHO resources for the common good to address what was declared a public health emergency of international concern (PHEIC). The WHO, under the IHR, recognizes that PHEICs require “maximum measures…tailored to the actual threat faced” internationally to control the crisis. Unfortunately, the Ebola crisis experience underscored many unresolved challenges facing the global community in how they will address PHEICs in the future. Of the many proposals placed before the WHO to be discussed and debated include one for the development of a Global Health Emergency Workforce.

During the Ebola tragedy, an unprecedented global workforce was mobilized to provide dire health solutions while foreign-led governmental and military resources restored the public health infrastructure and protections that were equally necessary to counter the epidemic spread. Understandably, there is significant concern over the capacity and capability of global resources to duplicate the efforts seen in West Africa let alone organize, resource, and sustain these resources to thwart any future global PHEICs, one of the foremost being the egregious prospect of a major nuclear catastrophe.

This study dissects what is known of the changing face of credible nuclear threats and argues for the immediate formation of a nuclear global health
workforce in support of the technical expertise of the International Atomic Energy Agency (IAEA) and WHO’s Radiation Emergency Medical Preparedness and Assistance Network (REMPAN) leadership in utilizing frameworks like GOARN and the expanding network of FMTs to pattern competency-based professionalization, education, training, and response criteria for all PHEICs. None of these challenges can afford a weak IHR, WHO, or international organizations that deal specifically with nuclear agendas.

THE PROBLEM

Crisis on a world scale can be defined as natural, human systems failure, or conflict-based.7 Operationally, what defines the criticality and the need for external and often global response is the recognition that many crises adversely impact the public health system, its protective infrastructure (ie, water, sanitation, shelter, food, fuel and energy-yielding infrastructures, and health care access and availability), and prevention programs (eg, vaccinations, maternal and child health, mental health).6,8 Characteristically, crises result in massive direct mortality and morbidity rates but over time even more indirect consequences are seen as the preventable public health infrastructure breaks down, human insecurity becomes more prevalent, and large numbers of the at-risk populations flee.6,10 Indeed, indirect consequences often represent 60% to 90% of the total mortality and morbidity, especially in large-scale and protracted conflicts and wars.7,11 Once the catastrophic event occurs, goals must shift to ensure optimal mitigation of a rise in indirect mortality and morbidity through provisions of directed prevention and preparedness actions and resources.

Historically, since the end of World War II and the passage of the United Nations (UN) charter, about every 2 decades the reasons leading up to declared humanitarian crises and how the world responds to them have dramatically changed.12 The Marshall Plan and similar infrastructure efforts helped to restore the public health protections immediately after World War II as did aid organizations guided by the newly minted 4th Geneva Convention and its subsequent protocols that codified civilian and humanitarian protections. However, over the decades of the Cold War in many countries, especially under the Soviet Block, restoration remained slow with painful public health consequences for their populations. The end of the Cold War in the 1990s ushered in an era where nation-states, many formerly under the Soviet Union, suffered internal public health and humanitarian crises resulting in wanton violations of international humanitarian law, massive corruption, and suspension of the rule of law resulting in massacres and genocide. So-called “unconventional” warfare followed, characterized by large numbers of internally displaced populations fleeing prolonged intrastate conflicts where the Laws of War and IHL struggled to be relevant. By the turn of this century, non-declared unconventional warfare—like social media-driven nation-state revolts and the rise of nonstate actors personified by ISIS, al-Qaida, their affiliates, and small group jihadists—have become the new norm where prolonged conflict, infrastructure destruction, and chronic insecurity have left major areas of the world with few viable health systems and public health protections.

As we enter the 21st century, the term mega-catastrophe is now being used to describe extreme events that are global in scale with outcomes that are difficult or even impossible to reverse.12 Such events are distinguished from previous disaster taxonomy by increasing frequency and severity of devastating effects on large human populations and the environment, including rapid unsustainable urbanization, emerging biodiversity crises, issues regarding climate extremes, and the impending realities of major resource scarcities.12 These have the sobering prospect of being played out in a desperate competition for water, energy, land, and food. Infectious disease pandemics, epidemics, and increasing outbreaks are often rekindled and hastened by increasingly dense populations and scarce or collapsed basic public health protections. Regrettably, they also represent tragedies in which the WHO Regional Offices and the international community face inadequate funding, staffing, and resources, risking a weakened or delayed response capacity making the original intent of the IHR in doubt.

We emphasize that any nuclear weapon exchange or major nuclear plant meltdown, in the categories of human systems failure and conflict-based crises, will immediately provoke an unprecedented PHEIC. Nuclear detonations in urban areas in particular will not only destroy the existing public health protections but will, most likely, make it extremely difficult to respond, recover, and rehabilitate them. Massive evacuations of survivors will be necessary, leaving large swaths of territory uninhabitable for decades, with catastrophic impacts on humans, the economy, and the environment. Mental health and societal chaos would rapidly ensue and result in highly destabilizing ripple effects throughout both the region and globally. The nascent nuclear response organizations will find themselves beset with a similar, but even more grievous, dilemma than that which confronted responders during the rapidly spreading Ebola epidemic.

NUCLEAR PROLIFERATION

Nuclear Weaponry

At the end of the Cold War there were over 52,000 nuclear warheads, 97% belonging to the United States and the dissolving Soviet Union.13 Today, there are 9 nations (Table 1) that are known to possess approximately 16,350 nuclear weapons. Fortunately, the United States and the Soviet Union (now Russia) have dramatically decreased the number of active nuclear weapons, with far fewer weapons on “standby” to be used on rapid notice. It must be noted, however, that many warhead “cores” are kept in the United States and Russia in stockpiles, ready to be reactivated onto missile warheads or
The recent addition of 40 new intercontinental ballistic missiles by Russia illustrates this danger, as they are taking scores of nuclear warheads out of storage and putting them back on new missiles. Although the total number of warheads, the “size” of their nuclear arsenal, stays the same, the relative danger of their use has increased dramatically. This also reflects a disturbing reversal of the trend between the United States and Russia that had existed of the gradual decrease in both the number of warheads in the arsenal (Figure 1) and the number of “active” warheads on missiles and in devices ready for detonation (Figure 2). The United States is now the only nation that is no longer “modernizing” its nuclear arsenal, by either increasing weapon numbers or their deployment capability.

China, France, Russia, the United Kingdom, and the United States are officially recognized as possessing nuclear weapons by the Nonproliferation Treaty (NPT). The NPT, which entered into force as a Treaty in 1970, grew to 190 members including 5 nuclear-weapon nations. India, Israel, and Pakistan are nuclear powers that never joined the NPT. North Korea, which has the material to produce a relatively small nuclear weapon arsenal, announced its withdrawal from the NPT in 2003 and tested nuclear devices. Uncertainty persists about how many additional nuclear devices North Korea has assembled beyond those it has tested, possibly up to 20. Several more carry out secret programs or aspire to create nuclear weapons. There are nations hosting nuclear weapons on their soil and also nations that rely on a nuclear alliance with the United States for their security (Table 1). The Federation of American Scientists in 2014 reported that at least 40 nations possess nuclear power or research reactors capable of being diverted for weapons production, several with the ability to make a weapon in a matter of months. Of concern for the near future, several other nations are believed to possess significant nuclear munitions and the capability to manufacture significant numbers of nuclear warheads relatively quickly once they choose to do so, such as Iran and Japan (Table 1).

Regional nuclear arms races are very worrisome between antagonistic neighbors with whom previous and repeated nonnuclear conflicts are now capable of being fought with nuclear weapons. Claiming its nuclear program was for peaceful purposes, India first tested a nuclear explosive device in 1974. That test spurred Pakistan to ramp up work on its secret nuclear weapons program. India and Pakistan both publicly demonstrated their nuclear weapon capabilities with a round of tit-for-tat nuclear tests in May 1998. The West fears politically unstable Pakistan and its ability to secure its nuclear weapons in war at the end of World War II, the development of the established pattern of mutual assured destruction between powerful nuclear weapon states is shown, along with the relative decline over time in the massive nuclear arsenals.

On the “positive” side, there has been some progress on the reduction of the number of nations possessing nuclear weapons. Belarus, Kazakhstan, and Ukraine inherited nuclear weapons following the Soviet Union’s 1991 Cold War collapse but returned them to Russia and joined the NPT as non-nuclear-weapon nations. In the 1970s and 1980s, South Africa secretly developed 7 nuclear warheads. At the end of the Cold War, the weapons were dismantled and South

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**TABLE 1**

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<td>Russia</td>
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**FIGURE 1**

Path to Nuclear War.

The historical progression of the likelihood of the medical and public health consequences of nuclear war. Starting with the only use of nuclear weapons in war at the end of World War II, the development of the established pattern of mutual assured destruction between powerful nuclear weapon states is shown, along with the relative decline over time in the massive nuclear arsenals.
Africa joined the NPT in 1991. Iraq had an active nuclear weapons program prior to the 1991 Persian Gulf War but was forced to verifiably dismantle it under the supervision of UN inspectors. Libya voluntarily renounced its secret nuclear weapon development efforts in December 2003 under pressure from the United States. Argentina, Brazil, South Korea, and Taiwan have also shelved their nuclear weapons programs for the present.

Arguably, the Middle East is a cauldron of potential nuclear threats as the distances between antagonistic nations is a matter of minutes by ballistic missile. Iran, Libya, and Syria pursued secret nuclear activities in violation of the treaty’s terms. Syria, with the help of North Korea, secretly began to develop a weapons reactor but Israel’s military bombed it in 2007. Iran has been steadily increasing its significant stockpiles of enriched uranium to the 20% level, with the capability to increase this large stockpile to weapons grade material (>90%) in a relatively short time frame. The IAEA, the institution charged with verifying that states are not illicitly building nuclear weapons, concluded since 2003 that Iran has undertaken covert nuclear activities to establish the capacity to independently produce fissile material. Secret facilities for these activities have been repeatedly discovered in Iran, and the IAEA is continuing its investigation and monitoring of Tehran’s nuclear program.

Other significant concerns are the threats of a dirty bomb (explosive device encased in radioactive materials), crude radioactive dispersal devices, and “lost” former Soviet nuclear materials from the infamous “suitcase nukes.” Although dirty bombs are not immediately lethal (other than the conventional explosives) and generally are not expected to result in significant radiation-induced casualties, it is likely that the use of a dirty bomb or some other dispersal of radioactive materials will result in immediate and significant disruption from mass panic and terror. The IAEA reports that “about 140 cases of missing or unauthorized use of nuclear and radioactive material” were reported to the UN atomic agency in 2013, adding that “any loss or theft of highly enriched uranium, plutonium or different types of radioactive sources is potentially serious” and “can be used in radioactive dispersal devices.” This includes sources “found in hospitals, factories or other places that may not be very well protected.” While it is assumed that nonstate terrorists lack capacity to develop a nuclear weapon, they have shown both the capacity and considerable interest in developing a dirty bomb from radioactive materials. Whether that capacity and capability is increasing or not is unknown.

The authors conclude that the increasing spread of nuclear weapons to more nations, the increased volatility of international relations, the developing technological sophistication among terrorist groups, the increasing global availability and distribution of radioactive materials, and the increasingly hostile accompanying rhetoric has significantly escalated the risk for a nuclear exchange and its devastating impact on medicine and public health worldwide.
Nuclear Power Plants
Nuclear energy facilities are expanding worldwide. At the moment, there are 388 operating reactors in operation in 31 countries; however, this represents 50 fewer than at the peak in 2002. Belgium, Germany, Switzerland, and Taiwan are phasing out nuclear power and Egypt, Italy, Jordan, Kuwait, and Thailand have decided not to engage or re-engage in nuclear power programs. Construction costs are rapidly rising.22 Most of the world’s power reactors are edging toward old age, so even if modest short-term growth is achieved, significant new reactor construction will be required in coming decades just to replace permanent reactor shut downs. The average age of the world’s operating nuclear reactor fleet continues to increase and by mid-2014 stood at 28.5 years. Over 170 units (44%) have operated for 30 years or more; of those units, 39 have run for over 40 years.22

Following the earthquake and tsunami in Japan in 2011 and the ongoing problems at the Fukushima nuclear power complex, the level of preparation and readiness for impact from natural disasters is a rising global concern. Seismologists predict that another major earthquake in Japan, this time in Tokyo, is likely in the next 10 years.23 Despite grievous failures in the management of the immediate Fukushima crisis and in its recovery process, Japan is still significantly dependent on nuclear power owing to its enormous previous investment in this infrastructure and otherwise complete dependence on imported fossil fuels.24 Additional costs arising from upgrading and back-fitting measures in many countries following the lessons of the Fukushima crisis remain uncertain and vary widely according to the requirements of the safety authorities in various countries.

However, there is continued (and even renewed) interest in nuclear reactor power production in the United States and elsewhere as coal-generated electricity is now increasingly losing momentum in the wake of climate concerns.25 It cannot be denied that much of the avowed interest in nuclear reactors for power generation has been in the past and is also today tied to the secret desire to also develop nuclear weapons. A number of countries are actively constructing power plants for the first time (Belarus, United Arab Emirates, Lithuania, Turkey, Bangladesh, Jordan, Poland, and Vietnam). However, many countries have rolled back “previously ambitious plans primarily due to finances and/or concerns over political support,” especially in Europe.22

FACTORS INFLUENCING NUCLEAR RISK
Several significant nuclear plant and radiation-related device accidents have demonstrated the potential hazards of the release of large amounts of radioactive materials into the environment, for example, the huge radioactive material and chemical explosion and large-scale radiation dispersion at Chelyabinsk Mayak in 1957; the nonnuclear explosion and fire at the large Chernobyl nuclear reactor complex in the Soviet Union that resulted in the very large airborne dispersion of radiation in 1986; the Goiania, Brazil, high-dose radioactive source release of 1987; and the Fukushima reactor core and spent fuel rod meltdown and large-scale radiation dispersion in contaminated water in 2011. Additional factors unique to concerns over nuclear risk fall into 3 categories: (1) deceptive governmental and military practices, (2) religious and culturally driven motivations, and (3) collective denial.

Deceptive Governmental and Military Practices
A major reason for risk expansion lies in the disturbing pattern that began immediately after World War II where, despite robust assurances to the contrary, nuclear “secrets” have always rapidly spread. Cold War tensions and paranoia were largely driven by the fear of nuclear war, yet the strategic doctrine called mutually assured destruction (MAD) was dependent on mutual knowledge that the nuclear arsenals of the United States and the Soviet Union were sufficiently capable of destroying the other side.26 Proponents argued that since launching a nuclear attack was akin to signing your own country’s death warrant, this fear ultimately served as a deterrent to nuclear aggression. In retrospect, while apparently successful, this Cold War deterrent was an extremely risky policy.27,28 For instance, during the Cold War both American and British military field commanders had authorization to use tactical nuclear weapons (smaller warheads for use on the battlefield). Since Soviet orders determined that any nuclear attack on its forces legitimized a full-scale nuclear response, MAD could have been easily triggered in this and a variety of other events. During the 1962 Cuban missile crisis, the United States was surprised that the Soviets had already deployed nuclear weapons to Cuba and that local commanders had authority to use them.29 The 1967 JASON Committee report contemplated the “appeal” of using tactical nuclear weapons in Vietnam.30 A report that supported the premise that the post–World War II use of nuclear weapons was slowly becoming “normalized” in military and political culture.31 While fears dramatically subsided in the 1990s, similar rhetoric escalating between Russia and the West recently has again fueled fears and paranoia.

Regional hatreds generated and sustained over a thousand years, like that between the Hindus of India and the Muslims of Pakistan, led locally to a “series of nuclear threats” in South Asia in the late 1990s, and then dramatically accelerated global nuclear proliferation when a noted Pakistan nuclear scientist sold centrifuge technology to North Korea, Iran, and Libya.32 Sagan33 argues persuasively with these incidents and an increasing number of others that the danger of the actual use of nuclear weapons somewhere in the world is mounting. Governments with nuclear weapon capability believe that shielding themselves with their nuclear arsenals will allow them to engage more safely in other nonnuclear aggressive actions and deter others from competing with them.
due to their nuclear “strength.” Burké argues that traditional diplomatic negotiations are becoming useless with many despots suffering severe narcissistic sociopathy as they fill the power void left from the dissolution of the Cold War. They continue to thrive on prolonged intrastate conflicts, some supporting major terrorist cell leaders. Nothing is more dangerous than an ego-wounded narcissist when his or her power is challenged, as we have recently witnessed in Syria and North Korea, than perhaps a nuclear-armed narcissist.

Religious and Culturally Driven Motivations

Scientists in the Armed Forces Countermeasures Programs attribute increased probability for acute radiation exposures a “rising concern" based on changing social and political climates. They see a greater threat to “detonation of nuclear weapons by terrorists, sabotage of nuclear facilities, dispersal and exposure to radioactive materials and accidents.”

Today, the capabilities of suicide bombers has increased, especially since 9/11. Motives for suicide attacks include “religious beliefs, nationalistic ideologies, obedience to charismatic and authoritarian leaders, or desire for political change.” In a 2013 “Victory Day” parade, North Korea displayed a truckload of soldiers “each strapped into a chest pack festooned with black and yellow radiation symbol.”

North Korea has amply demonstrated that a nation that cannot feed its own people can still acquire nuclear weapons, using threats of a nuclear attack as their only negotiating leverage.

Perry reminds us that “some of the most appalling atrocities in history have not been rooted in religion per se but rather in racial or class hatred.” In modern times, however, humanitarian efforts are more commonly tied to patterns and consequences of religious-based violence of “intense and ruthless character.” Wars in the name of religion have dominated the last 3 decades with possession and use of advanced weaponry now advancing to nuclear weapon arsenals. This ominous combination is profound between Pakistan and India, Israel and its Islamic neighbors, the new nuclear arms race between the Sunni and Shi’a branches of Islam, and other ethnic populations who, except for religious beliefs, share strong undeniable cultural identity and similar genetic heritage.

Collective Denial

Denial is one of our most powerful defense mechanisms designed to protect the ego (and collectively shared mankind) from uncomfortable but real issues or events that we cannot cope with. Despite overwhelming evidence that something is true, denial will reject its existence. There is a blockage of awareness and the potential emotional impact of what we don’t want to know, think about, or feel. Frank emphasizes that humans respond to events as they perceive them, not necessarily as events occur in reality. The human race has always “conferred weapon’s strength upon their possessors, both in appearance and in fact.”

Despite this widespread denial, the perfect storm of total health management inadequacy will occur even for small nuclear weapon attacks. It is even more difficult to imagine (and for most it is difficult to face) what will occur if sizable nuclear weapon exchange took place. Yet, there has been for years, largely among diplomats and health care professionals, a poorly understood huge and collective atmosphere of denial surrounding the consequences of nuclear war. This occurs at the population level as massive denial. The predominance of technical jargon that exists among professionals and intellectualizing the consequences beyond the realm of popular understanding. Without clear answers or rebuttal, denial will, over time, become incorporated into religious and fantasy beliefs that provide and interpret meaning and reason to what are seen as inevitable catastrophic outcomes, especially to those perceived as being backed into a corner. Decision to use nuclear weapons by Iran remains the authority of the Ayatollah, the religious Supreme Leader of the Islamic Revolution. One is reminded of Fein, a physicist, who in 1981 gave little hope for nuclear reduction, making the case that the weapons hold society in thrall, having attained a sacred aura by their mystery and awesome capabilities, and as a sacred object were being developed with a kind of “religious fervor, in which the weapons were being worshipped,” a view that might have applicability to the current Middle East arms race.

It is curious that among global health care providers there are not more references to the health catastrophe that would occur; this lack is symptomatic we believe of our own, and too often, pattern of denial. A consummate failure in diplomacy may occur if medicine and public health hesitates to inform the otherwise sacrosanct and impervious realm of politically focused conventional dialogue. Effective diplomacy surrounding nuclear deterrence is an exception to conventional dialogue; it must first reveal and stress, with transparency, the uncomfortable but accurate information of the consequences of such an event. With uncompromised cross-cultural, religious, and spiritually sensitive skill, efforts must be made to work toward replacing “extremism fantasy” with unvarnished truth and reason.
HEALTH OUTCOMES

The most commonly recognized thread of illness, injury, and death seen in nuclear crises is acute radiation syndrome (ARS). Radiation overexposure induces ARS characterized by 3 consecutive subsyndromes: hematopoietic/bone marrow (30-70 rads, or 0.3-0.7 Gray), gastrointestinal (600-1000 rads, or 6-10 Grays), and cardiovascular/neurovascular (2000-5000 rads, or 20-50 Gray). ARS occurs from irradiation of the entire body, or most of it, by a high dose of penetrating radiation in a short period of time. The survival rate decreases with increasing dose. The 3 ARS subsyndromes have in common 4 clinical phases:

1. Prodromal: anorexia, nausea, vomiting, diarrhea;
2. Latent: asymptomatic recovery from phase 1;
3. Manifest illness: return of phase 1, infection, hemorrhage;
4. Recovery or death.

The higher the dose, the shorter the phases. The speed of onset of these phases can serve as an indicator of exposure dose. ARS with a good prognosis is characterized by vomiting that starts more than 4 hours after the incident, no significant changes in serial lymphocyte counts within 48 hours after the incident, and no other significant injuries. ARS with a bad prognosis is characterized by coma, seizures, vomiting more than 4 hours after the incident, a drop in serial lymphocyte count of greater than 50% within 48 hours, bloody vomitus or stool, and other serious injuries. Indeed, observation of the highly exposed Chernobyl workers revealed that those who had nausea and vomiting beginning in less than 30 minutes after the initiation of radiation exposure were unlikely to survive, whereas those who had prodromal symptoms that did not ensue until after 3.5 hours were more likely to be survivors.

Radiation Overexposure Accidents

Relatively, the least damaging of events and health outcomes occur from radiation overexposure accidents. A 2015 study of 634 victims over a 33-year period confirmed that most accidents occurred in the industrial sector and in medical practice and radiation specialists, and radiation safety of 634 victims over a 33-year period. The types of major radiation incidents, contamination, detection, and ARS recognition and treatment options.

Nuclear Plant Accidents and Meltdowns

In the Chernobyl nuclear catastrophe, the badly designed and managed nuclear reactor led to a complete meltdown of the reactor core, resulting in 10-day-long emission of radionuclides into the atmosphere that migrated throughout the entire Northern Hemisphere and penetrated the equator down to the South Pole. Luckily, the catastrophe led to relatively low radiation doses overall for the global civilian population, but higher doses occurred with the over 240,000 terribly managed liquidators (cleanup workers), with 134 diagnosed with ARS resulting in 28 deaths. To date, a large increase (thousands) in the incidence of thyroid cancer has occurred among survivors who were young children and adolescents at the time of the accident and lived in the most contaminated areas. Since the Soviet government did not inform the population for three days after the accident, these exposed young people did not receive iodine protective pharmaceuticals until they were no longer useful. Secondary thyroid cancers, leukemia, and cataracts are still being monitored.

Coming out of this catastrophe, mental health impacts are regarded as the largest public health problem. The most severe acute and long-term health consequences in the civilian population are psychological with widespread high levels of stress, anxiety, overuse of alcohol, unexplained physical symptoms, and violent behaviors and suicides. Fighting the panic and mass hysteria could be regarded as the most important countermeasure to protect the public should a similar accident occur.

This study pulls from the work of the IAEA Response and Assistance Network (RANET) Field Assistance Teams, which represent “technically qualified and equipped personnel that may be called upon to provide in situ assistance in a requesting nation-state.” Personnel must have competence and experience in radiation medicine, emergency medicine, disaster medicine (eg, mass casualties), and other related areas (eg, hematology, burn treatment, physical and biological dosimetry, bioassay). Additionally, the External Base Support assets are not deployed but may be called upon to provide advice on monitoring and recording of prodromal signs and symptoms, consultation in relevant medical specialties (eg, hematology, burn treatment, surgery, nuclear medicine, radiotherapy, and psychology), and advice on sampling procedures (eg, repeated blood cell counts, biodosimetry, bioassay). Moreover, based on common lessons learned from responses to previous nuclear or radiation events and the Fukushima
TABLE 2
Major Public Health Challenges in Responding to Nuclear Events

- Limited capacity and availability of radiation health experts for monitoring potentially exposed people for radioactive contamination.
- Limited mobilization, recruitment, training, and valid exercises of the very large numbers of medical and public health personnel required for nuclear event response, especially for nuclear weapon use.
- Lack of the utility, training, and understanding of the feasibility of radiation decontamination among health care facilities and health responders.
- No public health authority to detain people contaminated with radioactive materials.
- Limited public health and medical capacities for a coordinated response to nuclear weapon medical response.
- Need to improve public health communications and response for the unique aspects of radiation-related mass events.
- Lack of uniformity in national and international exposure standards for radiation measurements (and units) and protective action guidelines.
- Limited access to timely radiation emergency monitoring data.
- Current distribution potential for potassium iodide (KI) in response to airborne radiiodine not likely to meet narrow window of effective distribution (no later than 4 hours after exposure).
- Lack of timely access (or knowledge) concerning highly effective approved and experimental radioprotectant drugs.
- Lack of knowledge and training with approved and stockpiled thermal burn treatments ideal for mass casualty burn applications.
- Lack of knowledge of rapid questionnaire for radiation exposure triage generated from Chernobyl highly exposed worker experience.
- Lack of knowledge of health care workers for environmental radiation effects versus medical radiation use, myths and realities of radiation exposure, and likely outcomes of a health care response, as judged by recent surveys.

experience, Table 2 lists the major public health challenges identified that may not be adequate at the time of a large-scale radiological incident.

Nuclear War
In 1984, at the height of the Cold War, WHO’s study on the global health repercussions of nuclear war concluded that the immediate and delayed loss of human and animal life would be enormous and “the plight of survivors would be physically and psychologically appalling.”55 Subsequently, the International Committee of the Red Cross and UN agencies asserted “that a nuclear attack anywhere in the world would overwhelm the health infrastructure, making an effective humanitarian response impossible. Those attempting to provide relief to the sick or wounded would be exposed to high levels of radioactivity, risking their own lives. Nowhere in the world would it be possible to render an effective humanitarian response, underscoring the absolute imperative of nuclear abolition.” WHO concluded that “the only approach to the treatment of the health effects of nuclear explosions is primary prevention of such explosions.”55 In 2011, Coleman et al56 asserted that “thoughtful planning is not futile and can substantially mitigate health consequences of a nuclear attack,” citing “never ending new technologies, diagnostics, medical countermeasures, resource-sharing models” and a myriad of advanced knowledge and tools from the medical and physical sciences.

For the production of trauma injuries, a shock wave accompanies the pressure change that results in the destruction of buildings, causes damage to eardrums and other structures in humans, and results in the intense movement of massive amounts of debris.58 The destruction of buildings and the movement of materials within the shock wave can be expected to generate very large numbers of trauma injuries, amounting to hundreds of thousands of trauma patients in a densely populated urban area for a large nuclear weapon, although much smaller numbers would result from a 10-15 kT device expected to be used by the newer nuclear powers.59

Owing to the intense demand on medical personnel in treatment, the large number of thermal burn injuries will be daunting to address in mass casualty response to a nuclear detonation. Thermal burn injuries, which would occur immediately after the detonation (resulting in both fatalities and survivors), should be distinguished from radiation burns, which will not appear until hours and days after the event.60 The large release of radiant heat as well as the generation of many fires in the blast area will cause a large number of thermal burn victims, which will create one of the most perplexing logistical medical issues in a nuclear weapon response.61 With the detonation of a large nuclear weapon in a major urban area, more than 100,00 serious but survivable burn victims could need to be managed by the medical response community.62 Fortunately, the number of thermal burn victims is dramatically less for the smaller nuclear devices (10-15 kT), which are generally expected to be the more likely weapons to be initially used (according to US Department of Health and Human Services planners).57

Radiation injuries in nuclear detonations result from both immediate and delayed radiation exposure. Gamma
irradiation is released in a single massive burst by the detonation, affecting those in close proximity. Exposures to delayed radioactivity can occur over wide areas secondary to the airborne dispersion of fission products, which condense and return to the ground as what is known commonly as “fallout.” The dispersion of fallout is dictated primarily by the prevailing winds in the first days following the detonation. Most of the very high mortality and morbidity results in concentrated areas where the fallout lands in the first 24 hours (early fallout), whereas much lower levels of radioactivity (and much lower risk) will exist over very wide areas.\textsuperscript{53}

In considering a planned medical and public health response to nuclear weapon use, it is feasible to predict the likely distribution of the different categories, including degree of severity, of casualties in order to enable rational planning of the response needed and possible with existing resources.\textsuperscript{59} In a timely comparison with the current diplomatic effort relative to the acquisition of nuclear weapons by Iran, Dallas and colleagues\textsuperscript{64} calculated deaths and injuries for various possible plume-based scenarios in a feasible nuclear war between Israel and Iran over the next decade. The 26 devastating scenarios in this study detailed the impact of targeting of compact urban areas in these Middle Eastern nations. It was shown that a devastating loss of critical public health infrastructure and enormous social chaos, rapid eradication of communications, transportation, security, fire-fighting, ambulances, hospital systems, and personnel would kill more people directly and indirectly in a matter of hours in both nations than occurred in the entire Holocaust.\textsuperscript{64}

The consideration of a rational approach to health management of a nuclear war would involve planning for treating casualties with ARS, trauma injuries, thermal burns, and combined injuries and patients with radionuclide contamination.\textsuperscript{65} Depending on the territory and landscape, any major nuclear crisis would probably see all degrees of ARS health consequences and outcomes. While massive numbers would die from burns and traumatic injuries in these “death zones,” many of those in the “injury zones” would survive the initial blast with grievous traumatic wounds, lacerations, orthopedic injuries, and second- and third-degree thermal burns. Without immediate expert treatment, the injury zones would also become death zones with death from overwhelming infections and shock resulting from lack of treatment.\textsuperscript{64}

One key conclusion in nuclear war health management is that owing to the high degree of effort currently necessary in emergency thermal burn care (eg, the high ratio of medical personnel to burn patients, and the need for sterile conditions), it is highly unlikely that these thousands of burn victims will receive any meaningful medical treatment. Even with the unlikely scenario that health facilities remain intact and all health care workers survive and respond, existing health care systems will not have the capacity to deal with the catastrophic number of victims. At best, there will be over 1000 critical victims for each surviving physician. Unless a dramatic change is made in the organization of the medical and public health response to nuclear war, the thousands of thermal burn victims will receive little to no care, as the very limited surviving medical resources are most likely to be devoted to the trauma casualties, which are more familiar to medical personnel, require relatively less effort per patient, and achieve more robust outcomes for each patient relative to available resources.

It is known that as nuclear powers expand their nuclear capability over time, they gradually develop higher yields in their weapons. Evidence from nuclear weapon casualty predictions show that the larger weapons play a dramatic role in casualty propagation. Fortunately, it is generally considered that the most likely initial use of nuclear weapons will involve the smaller weapons, for example, a 10–15-kT weapon (Hiroshima-sized), which is the domain of the relatively younger nuclear powers (North Korea, Pakistan, Iran) that might be considered more likely to use these weapons in the near future (Figure 3). In US emergency planning, the planning scenario (one of 15) that deals with a nuclear detonation assumes a 10-kT detonation as the most likely to occur.\textsuperscript{57} Therefore, emergency planning for a nuclear global health workforce could reasonably adopt this as a planning goal as well, in order to provide a reasonable hope of accommodating a response. Once initial planning and response for this smaller weapon size has progressed, an expansion to larger weapon responses could be envisioned. Planning for the smaller weapon use would also help significantly in dealing with the denial issue, as progressing toward what is considered an “achievable” goal would enable the effort to at least begin in earnest.

**POPULATION EVACUATION**

Distinct to nuclear reactor and nuclear war scenarios are the massive number of evacuees and the major and often unexpected demands produced. Timely evacuation decisions are essential to all health and logistics outcome parameters but also bring new health challenges. Decisions to evacuate at-risk populations must be made within hours, but plans for and criteria to evacuate are lacking. Within a few weeks after the Chernobyl accident, more than 116,000 persons were evacuated from the most contaminated areas of Ukraine and Belarus. Another 230,000 people were relocated in subsequent years. Thousands continue to live in areas classified by Ukrainian and Belarusian authorities as strictly controlled zones, where chronic radioactive cesium contamination remains a problem.\textsuperscript{52} The day after the Fukushima earthquake and tsunami, over 210,000 people were evacuated from areas surrounding the nuclear plant due to release of radioactive elements into the environment. On day 3, an additional 180,000 people living within 20 km of the plant were evacuated and those living beyond the 20 km and up to
30 km were advised to remain indoors. The government’s worst-case scenario called for the evacuation of over 500,000. The evacuation process was severely plagued by misinformation, inadequate and confusing evacuation orders, delay in releasing information, stranded elderly and infirm being left in areas near the plant, poor treatment and placement of hospitalized patients, and some evacuees being sent to higher dosed areas, all leading to loss of public trust in the government and poor compliance. Wilson argues that the reaction was incorrect and detrimental to public health, citing that the risks of unnecessary evacuation exceeded the risk of radiation cancers hypothetically produced by staying in place. This was not realized by those who had to make a decision within hours; arguing strongly for immediate international guidelines for both evacuation criteria and "important changes in radiation protection." A high-yield nuclear war would bring evacuation numbers to incomprehensible levels. However, new evidence has altered previous dire predictions in low-yield nuclear blasts. The United States has limited evacuation in their planning after a low-yield (10 kiloton) nuclear bomb, emphasizing in a Washington, DC, scenario that despite 100,000 fatalities and about 150,000 casualties, the blast plume would be confined to a relatively small area. People upwind would not need to take any action and those sufficiently downwind would not move other than to seek "moderate shelter." These considerations point to a continued reasonable expectation that a viable response could be envisioned for the nuclear global health workforce to respond to nuclear weapon attack, starting initially with the most likely scenario of a relatively small weapon in the Hiroshima-size range.

**Is a Nuclear Global Health Workforce a Viable Option?**

Despite the gloomy prospects of the health outcomes of any large-scale nuclear event common in the minds of many, it is both mankind’s nature and moral and ethical obligation to respond to any and all PHEICs. Cutting through the global denial that can exist in many humanitarian crises, humanitarian providers have taken the painful incremental steps, often brought about by awareness that most health and other providers do see themselves as global citizens, to accept increasing global health and security obligations (eg, SARS, Ebola, Chernobyl). The case is made here that the consequences of the most likely initial nuclear event (ie, a smaller Hiroshima-sized device) will enable the formation of a nuclear global health workforce for initial planning and organization.
One can draw historical analogies to the state of the UN humanitarian agencies during the Cold War and that of UN nuclear agencies today. From 1945 to 1990 was a period during which US and Soviet representatives to the UN’s Security Council “would frequently veto aid missions to areas on either side of the capitalism/communism divide” leading to indefensible UN noninterventions. However, during those years, UN agencies (eg, UNHCR, UNICEF) designed plans and developed standards for humanitarian response (eg, refugee camp design, legal protocols, staffing requirements) but these talents were rarely put to use. In 1991 and the end of the Cold War, the Security Council voted to provide humanitarian aid for the Kurdish Crisis in northern Iraq. Because the UN agencies had no operational capacity, the UN asked member states to assist the Kurds. Within 48 hours, the United States, the United Kingdom, and militaries from several Gulf War allies defended the fleeing Kurds and furnished “direct assistance” (protection/security, logistical transport, communications, and some emergency health care) until it was safe for the humanitarian community to take over. A similar Security Council debate and action would occur with any nuclear exchange. The IAEA and WHO’s REMAP, with experiences in radiation overexposure and nuclear plant accidents, are prepared to provide the legal framework, requisite concept of operations, functional area detailed protocols and worksheets, a compatible and integrated system for the provision of international assistance, and standards for any technical and health response and resources required. While many of these products serve as models adapted to a larger-scale PHEIC resulting from a nuclear exchange, these agencies lack the coordinated and collaborative response capabilities and the variety of operational professional staffing elements.

For example, GOARN serves as a technical collaboration of existing institutions and networks that pool human and technical resources for rapid identification and confirmation for outbreaks of international importance. Recognized now as an independent body under the WHO, it provides an operational framework to link this expertise and skill sets to keep the international community constantly alert to the threat of outbreaks. GOARN does not claim extensive nuclear expertise; however, in any nuclear crisis, life-saving infectious disease, immunology, and sterile environment skill sets that are essential to GOARN will also be crucial in providing care to burned and trauma survivors who will be at greater risk of secondary infections and radiation-induced immunity problems. This will only be realized with a formal, well-coordinated and collaborative professional relationship with a similar global workforce from the nascent nuclear community. Similarly, advances in the Global FMTs Registry sets minimum standards for international health workers ready for deployment that clearly outline their services and skills for a bevy of humanitarian crises. The FMT initiative coordinated over 60 governmental and INGO FMTs deployed during the Ebola epidemic, and 132 FMTs, an additional 15 military teams, and 75 local and international urban search and rescue teams responded to the 2015 Nepal earthquake tragedy, a capability and capacity not previously seen in PHEICs.

In calling for an authority for crisis coordination and accountability for humanitarian crises in 2011, Burkle and colleagues cited the potential of the 2005 IHR that obliges the WHO to obtain expert advice on any declared PHEIC, emphasizing that the success of the IHR, and its language, opens the door for potential international cooperation wider where similar models of response can be introduced. While the Ebola tragedy exposed the subsequent weaknesses of the WHO response capacity, it is encouraging that today fertile discussions are taking place that would strengthen WHO staffing and resources as well as the properties and resources of GOARN, FMTs, and urban search and rescue assets. In calling for a global health emergency workforce, it is timely that equal emphasis be brought to bear on the formation of a nuclear global health workforce, one that would provide an operational framework worthy of the technical expertise of the IAEA and the WHO. Experiences with radiation overexposure and nuclear plant accidents reveal the critical concept of operations and potential national assistance and response capabilities within IAEA and WHO leadership. Extensively detailed protocols and worksheets serve as models for what could be adapted to larger-scale PHEIC-coordinated responses. Admittedly, there remain major gaps in coordination, collaboration, resource sustainability, and the education and training of available global health professionals.

Looking at this question from a health outcomes perspective, the very high casualty outcomes in nuclear war pose an extreme dilemma for those planning and executing any medical response, which understandably, often results in despair and denial. The first response would be to assume that any efforts at planning and response would not be productive. However, as predictive studies of nuclear war medical casualties have shown, the many variations in nuclear war (as in all warfare) shows sufficient heterogeneity that allows for potentially effective changes in the strategy of the utilization of resources based on variations such as the approximate geographic distribution of casualties and the mobilization of specific medical professionals to meet these needs. These are particularly achievable goals in responding to the relatively smaller nuclear weapons as illustrated in the simulation study. Knowledge of the location of trauma victims is highly useful in planning of patient transport, especially in an effective emergency response system. For both large and relatively smaller nuclear weapons, predictions of the distribution of radiation casualties is essential to planning and response for the decontamination of these patients before transport and for the prevention of contamination of rescue teams and planning of where to send the limited number of teams to both protect them and use them most efficiently.
The location of accessible numbers of trauma victims from broken glass on the periphery of the blast zone is another example of a casualty distribution that is a favorable prediction for productive action for both smaller and larger nuclear weapons. In this manner, it can be a source of hope to be able to plan and respond in selected areas identified by predicted casualty distributions. Also, trauma injuries are familiar to all emergency medical professionals, and therefore provide a focal point to beginning a rational response to expanding that response to the scale envisioned for a relatively smaller nuclear weapon. To enable this expansion of scale to the very large medical response demands of nuclear war, the mutual aid of other countries would be enlisted, specifically among worldwide medical and surgical assets, and existing FMT and urban search and rescue assets, to allow productive, strategic planning and proper resource distribution. The extensive use of ship and aeromedical transport would be greatly expedited with prior planning and mutual aid staffing and funding agreements with the WHO and their operational components. Admittedly, while FMTs do have skills in trauma and basic burn care, with the current limited knowledge base of radiation risk it is understandable there would be concerns about the short- and long-term risks and similar hesitancies would exist, many seen with the Ebola epidemic, that would understandably be present with a radiation tragedy limiting FMT deployment. However with extensive preparedness education and training, and guided by estimates (verified over time) of casualty distributions and locations at the time of a nuclear blast, it could be made sufficiently safe for the dispatch of rescue teams and the air transport itself (by avoiding radiation zones, traffic barriers, and security issues), and provide a better chance for getting certain patient categories to the air transport in time to actually save lives. A lower-tech approach involving training armies of nonspecialists in surgical debridement from heavily sedated patients and administration of burn medicines would provide many of those in the “injury” zones the best opportunity for survival.64

A most convincing argument comes from both recent and archival studies on definitive survivability of medical casualties that make the same point over time. Given advances in standards of care, mass casualty burn victim strategies, and triage approaches, the central theme and common assumption of all is that many measures leading to survivability can be approached, if not solved.56,74-85

It must be emphasized that no one country has the medical and organizational assets to manage a nuclear tragedy alone. A PHEIC by definition will always require a robust international response. It is proposed that a nuclear global health workforce be developed from a similar hybrid of untapped professional nuclear technical and health assets incorporated in partnership with future WHO-supported preparedness training of potential deployable teams. This initiative would be supported by a large network of INGOs, the Global Health Security Agenda, and other UN bodies covered under existing WHO and IHR mandates and the appropriate political and diplomatic mutual aid arrangements in advance of nuclear war and mass casualty surge planning. Because of the nature of the crisis and where expertise currently lies, expertise will come from a myriad of civil, military, and private assets. However, while conventional wisdom may suggest that the military have robust operational capability, especially in those countries that deploy nuclear weapons, in fact this capability is relatively minor and less than the public may believe. Overall civil and military willingness to be deployed will depend on evidence-based residual risk and safety data. Lastly, a workforce-directed and WHO-supported robust education and training program is vital and constructed on global consensus of scenario-based scientific evidence, best clinical and public health practices, and sound professional and policy principles.

PROPOSED NUCLEAR WORKFORCE FRAMEWORK

The workforce framework would include medical support to triage, care to those with the opportunity to survive, and palliative care to the expectant population as well as the less-affected populations and those evacuated to safer ground. Ongoing support for scarce resource allocation and ethical decision-making to best mitigate both direct and indirect mortality and morbidity is vital.74-77 This would require capability and capacity for the following.

Nuclear Triage Centers

The requirements would be for centrally coordinated mobile and fixed initial triage and dose-monitoring facilities designed to identify, assess, transfer, decontaminate, and move casualties efficiently to survivor or palliative care facilities. Patients will have various degrees of ARS, combined injuries, local radiation injuries, and radionuclide contamination. Early research suggests that clinical symptoms and hematological indicators alone fall short for initial critical triage decisions. While admittedly clinical presentation should determine the “priority and nature of treatment,”78 first-line triage in nuclear triage centers would be best supported by additional and “fast biological dosimetry” designed for the purpose of triage.86 Biodosimetry has been considered most accurate in determining “probability of fatality” and less so on “severity of injury.”78 Serial secondary triage in reentrant treatment facilities would focus on clinical, serial hematological and other advanced biological parameters (eg, protein biomarkers for better triage accuracy than one biomarker alone).78,87

Triage decisions will optimize opportunities for both direct casualty care and mitigation of indirect or preventable mortality and morbidity. Well researched triage tools and cards leading to treatment guidance are readily available. Triage is an ongoing process, never a onetime event. Primary and secondary triage decisions will normally fluctuate as assessments and system-wide resources become available. Professional staffing recommendations (Table 3) derived
from IAEA/RANET and REMPAN recommendations include both primary and supporting elements.

**Nuclear Survival Centers**
The requirements would be for fixed/hospital-based facilities to optimize survival opportunities and mitigate secondary indirect mortality and morbidity. Professional staffing (Table 3) would include both primary and supporting elements.

**Nuclear Palliative Care Centers**
The requirements would be for both fixed and mobile facilities to provide palliative care including pain relief/management,

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<th>TABLE 3</th>
<th>Field-Based Centers Under the Nuclear Global Health Workforce$^a$</th>
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<td><strong>Nuclear Triage Centers</strong></td>
<td>RANET’s mission assets: triage, biodosimetry/bioassay teams</td>
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<td></td>
<td>Multidisciplinary specialists to advise and provide triage consultation</td>
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<td>Radiation safety officers</td>
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<td></td>
<td>Civil-military coordinators: logisticians, security, transportation, communications, resource managers</td>
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<td>Coordinators for casualty referrals</td>
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| **Nuclear Survival Centers** | Entry-Level secondary triage team: emergency physicians, nurse practitioners, triage resource managers | Secondary biodosimetry/bioassay teams |
| | General, burn, trauma, ophthalmologic, and orthopedic surgeons | Radiologists, radiation oncologists, nuclear medicine, and radiation safety officers |
| | Hematologists, gastroenterologists, clinical toxicologists, pediatricians | Infectious disease/immunology/sterile environment assets |
| | Psychiatrists/psychologists | Anesthesia/critical care/pain management |
| | Radiation safety officers | Rehabilitation medicine: crisis-trained debridement professionals |
| | Primary health care specialists: internal medicine, pediatrics, family medicine | Acute and chronic care nurses and nurse practitioners: surgery, burn, critical care |
| | Preventive medicine and public health experts: surveillance and data gathering | Hospital-level ward and isolation nurse staffing; general nursing and paramedics, unit administrators |
| | Mental health professionals and family counselors | Pharmacists |
| | Cross-trained optometrists, veterinarians, dentists | Primary health care specialists: internal medicine, pediatrics, family medicine |
| | Religious/cultural/legal experts/information management professionals/anthropologists | Preventive medicine and public health experts: surveillance and data gathering |
| | Medical staff | Mental health and social work professionals and services, anthropologists |
| | Hospital and clinic-based primary health care physicians and nurses | Essential public health infrastructure monitoring teams: water, sanitation, food, health access and availability, shelter and energy |
| | Hospital-based subspecialists | Radiation monitoring team surveillance and education teams |
| | Essential public health experts: surveillance and data gathering | Coordinators for deployable FMTs |
| | Mental health and social work professionals and services, anthropologists | Coordinators for deployable FMTs |
| | Hospital and clinic-based primary health care physicians and nurses | Prevention of health effects of radiation and other hazards |
| | Hospital-based subspecialists | Religious/cultural/legal experts/information management professionals/anthropologists |
| | Essential public health infrastructure monitoring teams: water, sanitation, food, health access and availability, shelter and energy | Coordinators for deployable FMTs |

$^a$Abbreviations: EMS, emergency medical services; FMT, foreign medical team; RANET, Response and Assistance Network.
social, psychological, family, and burial support services. Professional staffing (Table 3) would include both primary and supporting elements, including trained volunteer staff and support services from the surrounding communities and national governments.

Health System Support Centers
The requirements for populations in unaffected zones and evacuees are to recover, restore, rehabilitate, and sustain essential public health infrastructure and health systems and to ensure both availability and access to health care in mitigating indirect mortality and morbidity. This includes the monitoring of vulnerable population indicators, including noncommunicable diseases. The health system support centers would be the primary area for FMTs and other health- and non-health-related INGOs and IOM. The global health workforce would provide supplemental care through pre-crisis-identified NGOs, FMTs, and indigenous health care volunteers, who have experience in refugee and internally displaced population care. Staffing (Table 3) in both fixed and mobile facilities would supplement indigenous health system personnel as well as staff new facilities for the evacuated populations.

Estimations would be made of the likely professional group categories and their respective numbers and ratios that would be needed. Crossover applications of capabilities that also apply to nuclear global response efforts, such as surge capacity in beds and nurse-to-bed ratios and the transfer of previously existing patients out of the nuclear/radiation areas to increase surge capacity without increasing the morbidity or mortality of either the previous or the new patients. For example, these disasters require ophthalmologists and cross-trained optometrists for similar debridement and wound closure following mass casualties. Existing hospital integrated community services would apply to nuclear global response efforts, such as surge capacity without increasing the morbidity or mortality of existing patients or_nums to increase the number of beds and nurse-to-bed ratios and the transfer of previously existing patients out of the nuclear/radiation areas to increase surge capacity without increasing the morbidity or mortality of either the previous or the new patients. For example, these disasters require ophthalmologists and cross-trained optometrists for similar debridement and wound closure following mass casualties. Information technology technicians to rig emergency medical communication between the various care centers, evacuation camps, and other field applications, to name but a few.

CONCLUSIONS
Many factors have contributed to the escalating threat of a major nuclear crisis, which would immediately result in an unprecedented PHEIC, leading to massive numbers of direct and indirect morbidity and mortality. However, health outcomes research supports that life-saving opportunities are possible, even after a major nuclear war, but only if a robust multidisciplinary response capability and capacity was developed. Whereas the IAEA and WHO assets currently provide field-level guidelines, nuclear triage and management plans, workshops and technical (eg, bioassay and biodosimetry) monitoring standards required for radiation overexposures and nuclear plant accidents, it lacks the operational leadership for a coordinated and collaborative effort demanded of a large-scale nuclear crisis such as a nuclear weapon exchange. This study argues for the development of a nuclear global health workforce: one that brings together nuclear and nonnuclear technical and health professionals to educate and train in partnership with an IHR mandate and the WHO to meet the preparedness, coordination, collaboration, and staffing requirements necessary for a large-scale nuclear crisis response.

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