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# Assessing Surge Capacity for Radiation Victims with Marrow Toxicity

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Hematologists/oncologists would provide essential care for victims of a catastrophic radiation incident, such as the detonation of an improvised nuclear device (IND). The US Radiation Injury Treatment Network (RITN) is a voluntary consortium of 37 academic medical centers, 8 blood donor centers, and 7 umbilical cord banks focused on preparedness for radiation incidents. The RITN conducted 2 tabletop exercises to evaluate response capability after a hypothetical IND detonation in a U.S. city. In the 2008 exercise, medical centers voluntarily accepted 1757 victims at their institutions, a small fraction of the number in need. In the 2009 exercise, each center was required to accept 300 victims. In response, the centers outlined multiple strategies to increase bed availability, extend staff and resources, and support family and friends accompanying transferred victims. The exercises highlighted shortcomings in current planning and future steps for improving surge capacity that are applicable to various mass casualty scenarios.

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## INTRODUCTION

"In a strange turn of history, the threat of global nuclear war has gone down, but the risk of a nuclear attack has gone up…Black market trade in nuclear secrets and nuclear materials abound. The technology to build a bomb has spread." President Barack Obama, April 6, 2009.

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### The Event

Detonation of an improvised nuclear device (IND) within a U.S. city could be the greatest disaster in the country's history, resulting in hundreds of thousands of victims with traumatic injury, radiation exposure, or both [1,2]. Current planning by the U.S. Government focuses on the response to a 10-kiloton nuclear explosion, a scenario considered feasible based on current intelligence [1,3-5]. A 10-kiloton explosion, similar in magnitude to the detonation over Hiroshima [6-8], would cause massive infrastructure damage within a radius of 1-2 miles (Figure 1). Many persons within this radius would sustain both traumatic and radiation injuries, the combination of which portends a particularly poor prognosis [9].

Less severe damage, including glass breakage, would extend 5 or more miles from the detonation (Figure 1). Car accidents would be very common as drivers within eyesight of the explosion experienced "flash" blindness. Importantly, many victims with traumatic injury farther away from the detonation would have no radiation exposure [4].

Finally, a ground-level detonation would create a large mushroom cloud that would shower radioactive fallout along the direction of upper-level winds. The highest levels of radioactivity would fall within 10-20 miles of the explosion (Figure 1). Victims in this

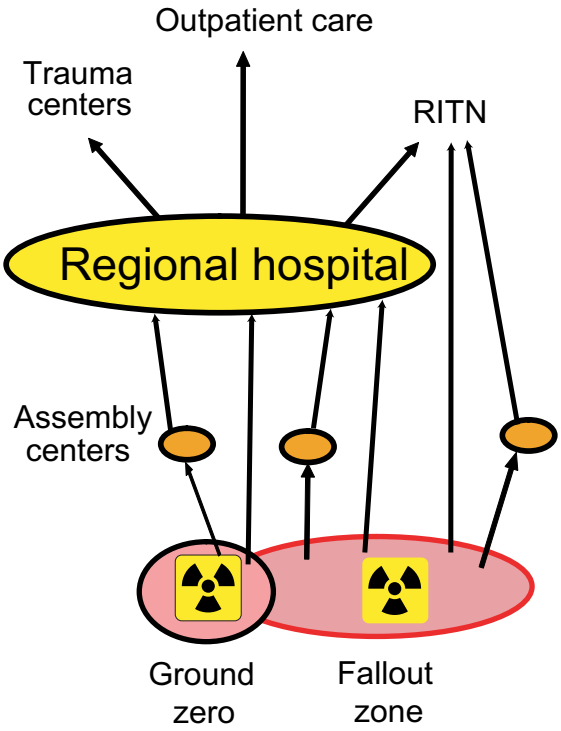


**Figure 1.** Triage after detonation of an improvised nuclear device. Extensive infrastructure damage would be confined to the region immediately surrounding ground zero. The fallout zone would be defined by upper-level winds that direct the mushroom cloud. Patient movement is indicated by arrows. Victims would be evacuated to assembly centers and regional medical centers, where they would undergo initial assessment and decontamination. Those who had sustained significant radiation exposure and required specialized care for marrow toxicity would be prioritized for transfer to RITN centers across the country.

"fallout zone" would have radiation exposure, but most would lack traumatic injury. Infrastructure within this zone would remain essentially intact. The U.S. Strategic National Stockpile Working Group estimated that the number of victims with radiation exposure within the fallout zone could exceed 250,000 [1].

Moderate doses of radiation (ie, 2-6 Gy) can induce a prodrome of symptoms, including nausea, vomiting, and fatigue, within minutes to hours after exposure. However, life-threatening manifestations of acute radiation syndrome, such as leukopenia and profuse diarrhea, would not develop for several days. Thus, radiation-exposed victims would have a window of opportunity to evacuate and then obtain medical care in regions outside the disaster zone. Presumably, many victims would simply drive themselves away from the area. Others would be subject to government-organized evacuation from local assembly centers and medical centers (Figure 1).

Decontamination of radioactive fallout (which looks like grains of sand) can be achieved simply by showering and changing clothes. Thus, it seems

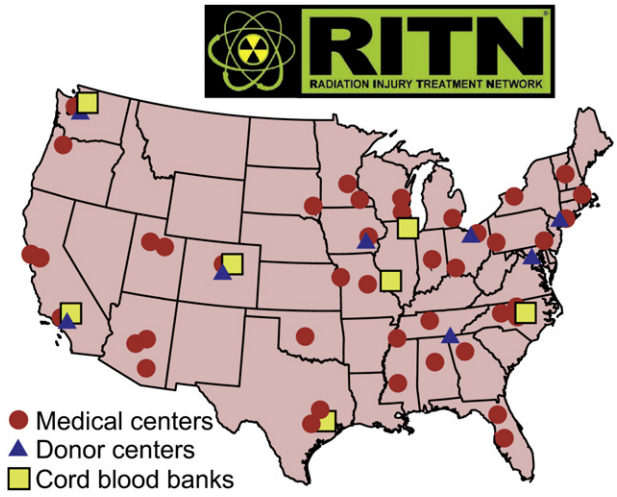


**Figure 2.** Medical centers, donor centers, and umbilical cord blood banks participating in the RITN.

wholly realistic and quite likely that there would be a large number of victims who lacked traumatic and burn injuries, were not contaminated with radioactivity, and sustained clinically meaningful, but potentially survivable, radiation exposure. These victims would experience varying degrees of bone marrow toxicity, and thus would be best served by care involving specialists in hematology/oncology [5,10,11].

## RITN

The US Radiation Injury Treatment Network (RITN) [5] was formed in 2006 through collaboration between the National Marrow Donor Program and the American Society for Blood and Marrow Transplantation, in partnership with the Assistant Secretary for Preparedness and Response of the Department of Health and Human Services (DHHS) [3]. The goals of the RITN are to heighten preparedness and provide surge capacity after a radiation incident, with a specific focus on the victims who were exposed to radiation but lack extensive traumatic and burn injuries. The RITN is intended not to assist first responders in the first 24-48 hours after an IND detonation, but rather to support the management of irradiated victims seeking care across the country days to weeks later.

The RITN is a voluntary consortium comprising 37 adult and pediatric medical centers with expertise in hematology/oncology and hematopoietic stem cell transplantation (HSCT), 8 blood donor centers, and 7 umbilical cord blood banks (Figure 2; additional information available at www.RITN.net) [5,12]. All of the 37 RITN medicals centers are academic institutions with extensive medical/surgical, hematology/oncology, and critical care capacity. RITN centers also include 817 of the 2193 total HSCT beds (37.3%) available at the 127 medical centers in the US National Marrow Donor Program.

### Current Planning

Detonation of an IND within the United States would initiate a broad civilian and military response [2]. The DHHS has primary responsibility for the medical component of this response [7]. Federal assets, including the Public Health Service, Centers for Disease Control and Prevention, and Strategic National Stockpile, would be mobilized to support state and local resources. U.S. military and National Guard units would assist with triage, evacuation, and security, and the Veterans Administration would provide additional surge capacity.

DHHS planners expect that approximately 30,000 victims would be triaged to the RITN (ie, 800 per center), either for management at the 37 RITN centers or for transfer to secondary facilities proximal to RITN centers (Figure 1). According to current plans, victims with a high likelihood of radiation exposure (based on geographic location and/or prodromal symptoms) who lacked traumatic and burn injuries would be prioritized for triage to the RITN [3,12]. These victims would require supportive measures (eg, antibiotics, growth factors, blood products, nutritional support) [1,10,11,13], which could necessitate hospitalization or might be manageable in outpatient clinics.

The RITN conducted tabletop exercises in 2008 and 2009 to define the preparedness, capacity, and willingness of centers to participate in the care of radiation victims. The victims in these exercises were primarily those with radiation injury only. The tabletop exercises also were used to elicit innovative approaches for responding to large numbers of victim transfers.

## MATERIALS AND METHODS

In April 2008 and March 2009, the tabletop exercises were distributed to the RITN centers. The full exercises and additional response data are provided in the Supplemental Information, and also are available at http://www.nmdp.org/RITN/REFERENCE/index.html. For both exercises, each RITN center organized a meeting of clinicians and hospital administrators to address the fictional scenario and answer a series of detailed questions. Centers were allowed approximately 3 months from receipt of the scenario to organize and hold their meeting and then enter their responses online through www.surveymonkey.com.

Both scenarios involved a 10-kiloton IND detonation in a U.S. city. In 2008, centers were asked to estimate the number of victims that they could voluntarily accept as transfers. In contrast, the 2009 exercise mandated that each center accept 300 fictional victims within 2 days. In both scenarios, victims had either self-evacuated or undergone government-organized evacuation to triage centers, where they underwent any necessary decontamination before transfer.

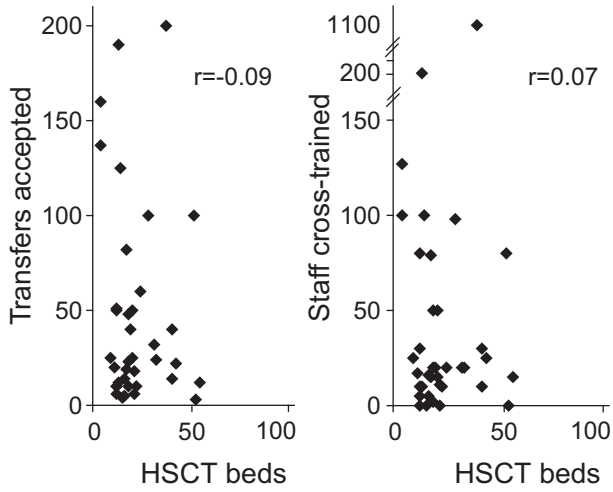


**Figure 3.** Voluntary participation in the 2008 exercise. There was no correlation between the number of HSCT beds at a center and either the number of victims that could be accepted at that center within 48 hours or the number of staff who could be cross-trained to care for victims.

## RESULTS

### 2008 Exercise

All 37 RITN centers participated in the 2008 exercise, with 426 staff members involved (median, 9.5 staff per center). The exercise called for the RITN to collectively accept 5000 victim transfers. In total, the 37 RITN centers voluntarily accepted only 1757 victims within 48 hours. Sixteen centers (43.2%) accepted 20 or fewer victims. The number of victims accepted by the centers varied widely (range, 3-200) and did not correlate with each center's HSCT capacity (Figure 3).

The number of staff members available to care for radiation victims differed markedly among centers (median, 31 per center; range, 1-282). Rapid cross-training of staff who lack expertise in the management of cytopenias could increase surge capacity. The number of staff that could be cross-trained varied widely among the centers (median, 20; range, 0-1100). The number of staff that could be cross-trained also did not correlate with HSCT capacity (Figure 3).

### 2009 Exercise

All 37 RITN centers again participated, and the total number of staff involved increased to 601 (median, 11.5 per center). The exercise focused on approaches to coping with the mandatory acceptance of 300 victims at each center. Plans to increase bed availability included off-loading of existing inpatients to other medical centers (83.8%), off-loading of some victim transfers to other medical centers (78.4% of centers), rapid discharge of existing inpatients (43.2%), and cancellation of elective admissions and procedures (18.9%) (Table 1). Approximately one-half of the centers

**Table 1. Selected Answers to the 2009 Exercise and Future Steps to Improve Response**

**Plans to increase bed availability**

Activate additional space designated for surge:
- Chemotherapy suite
- Simulation lab
- Emergency department
- Procedure areas
- Closed medicine ward

Treat neutropenic patients as outpatients
Rapid discharge of existing patients
Cancel elective admissions and surgeries
Transfer existing patients to other wards in hospital
Cancel outpatient visits and utilize outpatient space
Change private rooms to semiprivate rooms
Place Emergency Department on diversion

**Plans for managing family needs**

Involve American Red Cross
Utilize local hotel(s)
Elicit assistance from hospital departments:
- Social work
- Pastoral care
- Patient/guest services
- Volunteer services

Shelter family members in:
- Preexisting local shelters
- ACS Hope Lodge, Hospitality Houses
- Sports venues, convention centers, gymnasiums, schools, churches
- Dormitories
- State Fair grounds

Establish family assistance center
Crisis counseling and behavioral health support plan
Utilize local disaster psychiatry resource
Website for family member communication
Involve local police

**Authority who designates altered standards**

Chief Cooperating Officer
Chief Executive Officer
Chief Medical Officer
Chief Nursing Officer
Chief of Medical Staff
Chief of Professional Services
Chief of Staff
Clinical Director
Corporate Emergency Operations Center team
Director of Emergency Preparedness
Director of Environmental Health and Safety
Disaster Planning Officer
Emergency Operations Commander
Executive Medical Director
Hospital President
House Coordinator
Incident Commander
Medical Director
Medical Director of the Command Center
Senior Medical Leadership
System Director
Vice Chancellor for Health Affairs
Vice President for Patient Care
No formal policy

**Future steps to improve response**

Formalize plans for patient off-loading
Standardize approaches for staff cross-training
Develop standardized pocket guide
Formalize plans for crisis standards of care
Clarify reimbursement process
Establish formal contacts with local disaster response agencies

Full exercises and additional response data are available in the Supplementary Information and at http://www.nmdp.org/RITN/REFERENCE/index.html.

(51.4%) had a preexisting plan to transfer patients to affiliated hospitals. Various other creative responses were elicited, and multiple strategies for supporting friends and family who traveled with victims to RITN centers were reported as well (Table 1).

The management of 300 victims likely would require implementation of alternate standards of care. Twenty centers (54.1%) had a preexisting written plan for implementing alternate standards. In response to the question "what position at your hospital authorizes altered standards of care?," 24 different positions were mentioned by the 37 centers (Table 1). Of these, Chief Medical Officer (16.2%) was the most common. When asked what constitutes an acceptable patient-to-nurse ratio for neutropenic patients in stable condition during a national emergency of this nature, all but 2 responses were between 3:1 and 8:1.

## DISCUSSION

In the aftermath of a massive disaster like a nuclear detonation, there would be a national call for surge capacity. An optimal response to this call would involve large and small centers, both civilian and military, across the country. The results from our tabletop exercises highlight both the difficulties of accepting large numbers of victim transfers and the innovative planning underway at individual RITN centers. It is worth noting that many victims would simply self-evacuate, using whatever means available. As was observed after Hurricane Katrina, these victims would create a nationwide diaspora independent of the orchestrated government response. Thus, centers should expect to encounter victims whether or not they participate in the RITN [14].

Many of the logistic, financial, and ethical concerns related to the management of radiation victims have not yet been fully addressed. For example, victims who receive moderate doses of radiation are optimal candidates for triage to RITN centers, yet existing technologies for determining an individual victim's absorbed dose are highly limited. Counting the number of dicentric chromosomes in metaphase spreads of peripheral blood lymphocytes can accurately estimate radiation dose [15]. However, this assay is time-consuming, requires multiple days for turnaround, and is performed in only a few specialized laboratories.

New technologies for rapidly estimating radiation dose are currently under development [16,17]. For now, the goal of radiation triage would be to "bin" victims into groups that were exposed to little or no

radiation, absorbed invariably lethal doses, or were in a middle group [3,4]. This binning could be performed using a combination of geographic dosimetry, symptomatology (especially time from possible exposure to vomiting) and, if available, lymphocyte counts [1]. Online algorithms for estimating dose based on these factors are available on the Radiation Event Medical Management web site (http://www.remm.nlm.gov/ars_wbd.htm) [4], as are treatment algorithms, decorporation protocols, template admission orders, and information on a range of radiation events.

In the 2008 exercise, the acceptance of victim transfers was voluntary, and centers tended to be conservative, with fewer than 2000 victims accepted by the full network. This relatively low number may reflect a general nihilism in terms of response to an IND among some practitioners and administrators. In our experience, this nihilism frequently derives from 2 misguided notions: that the chaos erupting after the event would be so widespread as to preclude the evacuation of essentially any victims, and that all irradiated victims would also have severe burns, traumatic injury, and/or radioactive contamination. Dispelling these notions is a primary goal of the RITN.

Of more practical concern, financial reimbursement for victim care is not guaranteed by the federal government. In the current health care economic environment, the risk that victim care might not be reimbursed may have adversely affected the willingness of some centers to accept victim transfers.

Most health care institutions are already at or near patient capacity, suggesting that an influx of victim transfers would rapidly limit their ability to provide routine care to all patients. Very difficult decisions would be required as centers shifted from routine care to alternate standards of care [2,18-20]. Only one-half of centers have formal plans for implementing altered standards of care, and the institutional hierarchies for decision-making vary widely. This variation would be a potential source of confusion in the aftermath of a mass casualty event.

Although multiple governmental and nongovernmental groups have recently proposed altered standards for the aftermath of mass casualty incidents [2,18,20], a legal framework for implementing these guidelines is lacking. The 2008 exercise required each center to balance the needs of distant radiation victims with those of its institution and local patient population. Thus, it was not surprising that voluntary acceptance of transfers and cross-training of staff differed markedly between centers and did not correlate with the number of HSCT beds (Figure 3), which we used as a surrogate for overall capacity. It is noteworthy that some centers addressed the task vigorously, using stretch goals and creativity to accept more transfers.

Simple approaches to increase resources, staff, and bed capacity can markedly improve crisis response [21-23]. In the 2009 exercise, centers offered multiple strategies to cope with 300 mandatory transfers; however, very few centers were willing to accept a patient:nurse ratio >8:1 for hospitalized neutropenic patients. If hundreds of victims were transferred to each RITN center, maintaining ratios <8:1 would require effective strategies, such as cross-training of staff and expanded outpatient care to reduce hospitalizations.

Most centers are also planning to transfer some victims and/or existing in-patients to other regional hospitals (ie, secondary transfer). The secondary transfer of large numbers of patients indicates that an IND detonation would affect both large academic and smaller community hospitals. As such, community and regional hospitals should be involved in the planning, with the understanding that national shortages might simultaneously compromise the availability of myeloid growth factors, medical supplies, and blood products. Although predicting the extent of these shortages is difficult, one potentially mitigating factor is that undirected donation of blood products would likely increase substantially because of a swelling of public support, as occurred after the attacks of September 11, 2001 [24].

There are several limitations to our study. Among these, the wide variability in responses to the 2008 exercise might reflect differences among centers in terms of how seriously they approached the questions. Alternatively, centers might have very different attitudes regarding their role after a disaster of this magnitude. Centers that offered to accept large numbers of victims might have taken a more utilitarian approach, considering that the prognosis for otherwise healthy victims who received moderate doses of radiation is likely superior to the prognosis for many patients with relapsed or refractory malignancies.

Another study limitation is that we focused only on the scenario deemed as the greatest threat by the U.S. government—detonation of a 10-kiloton nuclear device. The response to other scenarios, such as contamination of food or water with a radioactive isotope, would necessitate major changes from the IND response. Even an IND detonation within an airplane would dramatically alter the spectrum of victim injuries compared with a ground-level detonation.

Finally, our scenarios are limited to a very small component of the overall IND response. The exercises ignore the many complications in victim sorting, management, and evacuation that would certainly develop in the aftermath of an IND detonation. Unpredictable factors, such as inclement weather, crime, and infectious disease, can become important during a mass casualty incident, as observed after Hurricane Katrina and the earthquake in Haiti. Future exercises will

address additional factors germane to RITN efforts (Table 1), including the collection, processing, and distribution of blood products, and the relationships between RITN centers and local health, police, and emergency response agencies.

In conclusion, the tabletop exercises performed by the RITN in 2008 and 2009 highlight many of the concerns and limitations inherent to accepting victim transfers after a mass casualty incident. When required to accept 300 victims each, the RITN centers outlined several strategies for enhancing surge capacity. These strategies should be incorporated more broadly into emergency response plans.

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## AUTHORSHIP STATEMENT

Matthew Davids analyzed data and wrote and revised the manuscript. Cullen Case and Raymond Hornung III drafted the surveys and collected data. Cullen Case, Raymond Hornung III, Nelson Chao, John Chute, C. Norman Coleman, Daniel Weisdorf, and Dennis Confer provided critical analysis of the surveys and the manuscript. David Weinstock analyzed data and revised the manuscript. Cullen Case, Nelson Chao, John Chute, Daniel Weisdorf, Dennis Confer, and David Weinstock are members of the RITN Executive Committee.

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