Population-Based Triage, Treatment, and Evacuation Functions Following a Nuclear Detonation

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Introduction

A nuclear detonation in a major U.S. city has the potential to dwarf prior terrorist and natural disasters in terms of mortality, early and late health effects (both physical and mental), and infrastructure damage. Ground-level detonations are expected to produce a smaller damage zone but more fallout debris compared to a tactical nuclear high yield air-burst detonation. Air burst detonations tend to produce more burns and traumatic injury over a wider area. The discussion in this paper pertains to a terrorist release of a device with a yield of approximately 10 kT.

The "footprint" of a nuclear detonation includes three "prompt" physical damage zones and a dangerous fallout zone (Figure 1):¹

- Severe Damage Zone. Structures are essentially destroyed due to blast effects and the high levels of prompt (blast related) and residual radiation result in minimal survival in this area.
- **Moderate Damage Zone**. Structures are damaged with a range of severity from the part of the zone close to the blast to the outside perimeter of the zone. Prompt radiation levels are variable and may reduce rapidly over time. There may be little or no radiation exposure in part of this zone.
- Light Damage Zone. Glass breakage and light structural damage is prevalent in this area. Prompt radiation levels are none to limited. Glass breakage may extend miles from the blast origin.
- **Dangerous Fallout Zone**. Dust, soil, and debris mobilized by the blast is carried by prevailing winds (with some ground level wind effects) and may expose large numbers of unsheltered persons to very high levels of radiation. The border of this zone is defined as 10 rad/h.^a
- This zone will shrink rapidly over time as the radioactive materials decay. It will overlie only a portion of the Moderate and Light Damage zones.

A recent analysis conducted by the U.S. Department of Homeland Security (DHS) of a 10 kT nuclear detonation in New York City's Times Square predicts over a *million* acute injuries from the blast and

^a Rad=radiation absorbed dose, or the amount of energy from any type of ionizing radiation deposited in any medium (e.g., water, tissue, air). Rem = an adjusted absorbed dose that accounts for biologic damage potential. For emergency response purposes Rad and Rem may be considered equivalent.

radiation injury of the detonation. Outside of the 3 Prompt Damage Zones, the Dangerous Fallout Zone in the area has ~ 1,500,000 daytime population at its maximum extent and could result in over 350,000 radiation injuries. Early shelter would significantly reduce the overall number of fallout radiation casualties.

Though the challenges of a nuclear detonation response are multiple, planners must address three key and unique activities apart from usual EMS/hospital/trauma care response:

 Immediately issue shelter-in-place orders to the population in the Dangerous Fallout Zone to minimize exposure—generally for 24 hours though more precision is possible with modeling data.² Broader sheltering orders may have to be issued initially until weather data at multiple altitudes can be obtained. Fallout clouds may be visible on Following a nuclear detonation, planners must:

- 1. Immediately issue shelter-inplace orders to the population in the Dangerous Fallout Zone to minimize exposure-generally for 24 hours.
- Establish Assembly Centers (ACs) within 24 hours for rapid screening of the affected population.
- Screen survivors to prioritize those with "moderate dose" radiation exposure that can most benefit from medical countermeasures.

Doppler radar and monitoring of upper level winds can provide valuable information about where fallout will be deposited. The first formal radiation dose and dose rate modeling is not expected until hours after a detonation. As information becomes more exact, sheltering orders can be modified accordingly.

- 2. Establish Assembly Centers (ACs) within 24 hours for rapid screening of the affected population. This should include those exposed to prompt and/or fallout radiation though the number of survivors affected by fallout will be much higher. These assembly centers must be capable of processing thousands of persons each day. The details of these centers are described below.
- 3. Screen survivors to prioritize those with "moderate dose" radiation exposure that can most benefit from administration of medical countermeasures such as myeloid cytokines and evacuation to geographic areas with more intact healthcare infrastructure for definitive, specialized care.

This discussion paper describes the functions of an AC and the <u>Exposure and Symptom Triage</u> (EAST) protocol for the screening function that will primarily be conducted at ACs. This paper summarizes work of a subject matter expert working group supported by the U.S. Health and Human Services Office of the Assistant Secretary for Preparedness and Response (HHS/ASPR), and the Federal Emergency Management Agency (FEMA). The workgroup was comprised of subject matter experts from the private and public sector (including those from FEMA, HHS, the Centers for Disease Control and Prevention [CDC], and the Radiation Emergency Assistance Center Training Site [REAC/TS]) representing emergency medicine, emergency medical services (EMS), and other response disciplines.

This material is designed for jurisdictional emergency planners and responders as a planning reference. It contains response tools and strategies that will assist them in planning for Assembly Centers and mass screening functions. The local medical response to a nuclear detonation is not the focus of this paper and has been detailed in other publications.³

Initial Challenges and Response

A nuclear detonation creates two disasters with very different profiles—the initial blast and radiation exposure to those in the immediate area of the detonation (prompt effects) and the fallout radiation exposure that results when the highly radioactive debris particles (building materials, dirt, etc.) from the blast drift with prevailing winds and settle in downwind areas, creating a significant and dynamic radiation exposure pattern that changes rapidly over time. Those in the Dangerous Fallout Zone (DFZ) are at high risk for severe radiation illness unless they are adequately sheltered, ideally in the interior of a concrete building. Figure 1 highlights how small the boundaries of the DFZ are compared to the area of lower level contamination that still must be regarded as being "Hot."



Figure 1. Damage Zones and Illustration of Fallout Zones. Source: Buddemeier, B.R. and Suski, N. <u>Preparing for the Aftermath of Nuclear Detonation: An Analytical Framework for Disaster</u> <u>Management</u>. Nuclear Safety and Security Challenges. Lawrence Livermore National Laboratory. November 17, 2014. Los Angeles, CA.

EMS and medical response should assume that most casualties in the Severe Damage Zone will die either immediately from trauma or extremely high prompt radiation exposure. No early entry into this zone is possible for responders to facilitate rescue of salvageable casualties that were sheltered at the time of the blast. As radiation levels decrease, the potential to search the area improves. However, relatively few survivors are likely in the Severe Damage Zone compared to the Moderate Damage Zone, in which responders can operate for longer times without exceeding radiation safety thresholds (usually 5 rad for routine operations and up to 25 rad for life-saving operations).⁴ The Moderate Damage Zone will have a large number of victims with both physical and radiation injury that require treatment, but will likely survive. In many areas of the Light Damage Zone, no radiation will be present as it is not in the downwind area affected by fallout. The Light Damage Zone will therefore contain large numbers of casualties with less severe physical injuries, many of whom will have little to no radiation injury.

RTR (Radiation TRiage, **TR**reatment, **and TR**ansport) is a well-described geographic/functional framework for response after a nuclear incident.⁵ The RTR sites are event-driven (i.e., spontaneous) sites for patient collection, either self-selected by victims (i.e., places where victims took refuge) or selected by responders (e.g., school, fire station). Ambulatory victims can be directed for care at these sites, where immediate triage and basic treatments in the first 24h are performed. Patients from the RTRs may be released, referred/transported to functioning medical care facilities (MCs), referred to an Assembly Center (AC) for further evaluation, or to an Evacuation Center (EC) for forward movement (Figure 2). Note that the ECs support moving patients to areas where they can receive medical services or other specialized assistance. ECs do *not* serve the large numbers of persons that are self-evacuating to neighboring areas in an uncontrolled manner. If the number of survivors is significant, a priority system is necessary to avoid overwhelming the EC. The primary means of evacuation for radiation injury patients is likely to be commercial aircraft, since many survivors by the time of evacuation will be in the latent (relatively asymptomatic) phase of Acute Radiation Syndrome. Rail and road transport are also possible, but more limited in capacity and distance. Trauma and combined injury patients will require dedicated medical transport.



Figure 2. Community Response Constructs and Location after Nuclear Detonation. *Note: Not to scale. Multiples of each site may exist and will be initiated at different times. RTR = Radiation Triage, Treatment, and Transport, AC = Assembly Center, MC= Medical Care facility, EC = Evacuation Center, CRC = Community Reception Center*. Modified from Hrdina, C.M., Coleman, C.N., Bogucki, S., et al. (2009). <u>The "RTR" Medical Response System for Nuclear and Radiological Mass-Casualty Incidents: A</u> <u>Functional Triage-Treatment-Transport Medical Response Model</u>. Prehospital Disaster Medicine. 24(3):167-178.

The RTR system is primarily designed to funnel triage of trauma and radiation injuries for victims leaving the moderate damage zone and within the light damage zone as they encounter the emergency medical care system. Supporting the RTR sites and providing general trauma care is the focus of response activities in the first 24 hours.

The importance of sheltering-in-place to reduce the number of fallout casualties is crucial. For the New York Scenario, sheltering has the potential to prevent *over 300,000 radiation illness deaths*¹ and has direct impact on the throughput requirements for the assembly centers (fewer exposed = less injured = less screening and treatment). Without proper sheltering orders and actions, it may be extremely difficult to manage the overwhelming numbers of victims who will require screening, triage, transport and treatment.

Sheltering orders generally recommend that citizens immediately seek shelter—ideally in a concrete/steel structure, toward the interior, and below ground when possible—and stay there for 24 hours. During the end of the first 24-hour period as rescue operations and treatment of the injured victims begins to decline, the focus must shift to assessment of those potentially exposed to significant radiation. Even with the best sheltering compliance, this could require the assessment of hundreds of thousands of victims.

Assembly Center Function

The AC is designed to screen those patients *without* significant traumatic injury but who have been exposed to significant levels of radiation that have already caused invisible but substantial injury to their bone marrow and body organs as well as provide an opportunity for external decontamination. Most will experience some initial symptoms of acute radiation syndrome. Victims that have had very severe radiation injury will develop progressive symptoms and are generally not salvageable.

The goal of the AC is to identify victims with moderate radiation exposures who will have transient, mild symptoms initially and can be supported and evacuated to areas with more intact infrastructure to continue their medical care during the later phase of illness when they become susceptible to infections due to their bone marrow injury.

These patients can benefit from early injections of myeloid cytokines—medications that stimulate white blood cell production to help prevent infections that would otherwise cause illness and death when white blood cell counts fall (neutropenia) in the weeks after the radiation exposure.^b These cytokines are usually available at cancer treatment centers, and are also stockpiled in the Strategic National Stockpile (SNS) by the federal government. Some myeloid cytokines must be given daily, and others weekly. They are most effective when given within a few days of radiation exposure.⁶ Therefore, rapid screening should be coupled with rapid access to cytokine injections whenever possible. This requires coordination and pre-planning so that cytokine assets (local, regional, federal) arrive in a timely manner to the right location for distribution and administration. Using these drugs for those who do not need them can cost lives, so indiscriminate use is not appropriate.

The AC prioritizes victims that would most benefit from medical countermeasures and transport to areas with adequate resources for ongoing medical care. This function may also occur at other sites, though on a smaller scale. Sorting can be done through an Exposure and Symptom Triage (EAST) process described below. Key concepts of the ACs include:

- ACs are **only** established in areas of scarce resources in the region of the detonation where normal screening of victims of radiation exposure is impossible (see additional details below).
- ACs are *not* designed for acute medical care or ongoing sheltering activities. Though they may be co-located, the functions are distinct. Some medical support should be available on site for

^b The white blood cells already present in the patient's body at the time of exposure survive as usual for a few weeks, but the injured bone marrow is unable to make more to replace them

emergency conditions. On-site or electronic medical consultation to support screening and answer questions that may arise regarding radiation injury and care should be available.

- ACs are *not* Community Reception Centers (CRC) as described by the CDC for detailed radiation exposure assessment, as the CRC process is more resource-intensive and focused on radiation exposure quantification and bioassay sample collection to quantify internal contamination as required, rather than rapid screening based on location at time of detonation and symptoms.
- ACs sort patients into high, moderate, and low priority for cytokine administration and evacuation to definitive medical care resources. This insures that only those who need resources get them.

	Assembly Center (AC)	Community Reception Center (CRC)	
Location	Close to detonation	Far from detonation	
Resources in community	Scarce	Adequate	
Goal	Rapid assessment for total body radiation exposure	Detailed assessment for external and internal residual radiation	
Resources required	Minimal	Extensive	
Decontamination	Gross/Containment	Technical	
Registration / interview	Minimal	Detailed	
Other functions on site?	Likely – some medical care, cytokine administration, possible shelter/support operations	Unlikely	
Time to initial operation	18-24 hours	48-96 hours or more	

Table 1. Differences Between CRC and AC

The community goal for ACs should be to begin their operation by 24 hours after the detonation, with expanding and continuing operations for at least 96 hours. This will allow the sheltered population to have a defined destination and plan for what to do and where to go when they leave their shelter. Jurisdictions should plan to further expand screening operations and integrate arriving resources as they become available in the days following the detonation.

Assembly Center Location

AC sites should be located outside of, but accessible from, the Dangerous Fallout Zones and Moderate Damage Zones. These sites should not be located in a "Hot Zone" but some ambient (background) radiation can be expected at these locations and volunteers and staff should understand this fact. Background radiation will need to be continuously monitored and likely will decrease over time near

the damage zones; it will increase over the downrange fallout zones. Note that the goal of the AC is to focus on the *irradiation injury (acute radiation syndrome)* that occurred and not on external contamination. However, most patients will have some external contamination, and entry screening and clothing control/gross decontamination should be performed to keep the levels of radiation in the AC as low as is reasonably achievable.

Some of these AC sites may be spontaneous, with the AC function carried out in locations where people have gathered. However, communities should identify larger sites where thousands of patients can be rapidly screened. These sites may have already been identified for other community-based public health interventions, such as mass vaccination. Some of the structures (incident management, flow, information management, registration) and queuing functions from these public health processes can be applied to AC operations. Co-location with temporary shelter, medical care, or cytokine administration operations is possible and may help leverage available structural and personnel assets. Locations in reasonable proximity to the 'Hot Zone' are optimal to reduce transportation needs.

Screening Limitations

The optimal form of screening at the Assembly Center would be based on pre-existing personal dosimetry such as radiosensitive materials embedded in driver's licenses, cell phones, or other commonly carried objects that could be interpreted on-site. Unfortunately, this type of technology is not currently available in a widespread, useful, or cost-effective format. Other models of exposure screening are in the research phase, but are not yet ready for market.

Determining a person's Absolute Lymphocyte Count (ALC) from a complete blood count is likely the next best predictor that could be made available on a large scale. Though single values of the ALC are not as accurate as serial values, they are still far more helpful than symptom-based screening alone. ALC does require blood drawing and sample processing on laboratory equipment. Though studies have estimated that national laboratories have the capacity to run the samples, the logistics of transportation, tracking, and providing results in a timely manner are very problematic in a scarce resource environment. Portable technologies are available though none are currently stockpiled. This may be an option in the future, although the logistics of the number of blood draws and tests required is still daunting and would require significant planning and implementation investment by the jurisdiction, as well as trained providers to obtain the samples and operate the instruments. Focusing this capability at the evacuation centers (EC) as well as the receiving communities for arriving patients should be the first priority as it allows for more accurate triage of those persons being transferred.

Since ACs are intended to operate in an area of significant resource shortage, it should be assumed that assessment and screening will usually be based on the victim's location at the time of the detonation, what shelter actions they took, and any signs or symptoms they have. There are several critical limitations that planners *must* understand:

- Individuals have unique responses to radiation thus, there are *no* symptoms that offer precision about a specific radiation exposure dose.
- Symptoms of anxiety can be extremely similar to acute radiation illness symptoms e.g., nausea, dizziness, headache and these symptoms may be "contagious" within a congregate population that is worried about exposure.

• Even some asymptomatic victims may have still had significant radiation exposure. The EAST screen is *not* a definitive evaluation, and *all* victims should have more formal assessment and be entered into a registry as resources allow.

The EAST method is helpful to perform an initial, but not definitive evaluation. All victims should have a more formal assessment as resources allow.

Assembly Center Framework

The overall Assembly Center functional sequence is:

- Contamination Containment minimize radioactive materials brought into the center
- Queuing-may complete a self-assessment during this waiting time
- Assessment (Acute symptoms/At-Risk)—does the victim have acute illness/injury (refer to medical care if yes), and was he or she in an at-risk area (if no, refer to shelter/other resources)? (Note that medical care resources may be co-located or at a separate site depending on the situation and community plans.)
- Screening (Shelter/Symptoms/Signs)—what shelter did the victim take and what symptoms/signs of illness is he or she exhibiting?
- Triage (for Treatment and Transport)—categorize the victim as high, medium, or low priority for cytokines and evacuation using the EAST tool (below) with or without an initial ALC, or other strategies.
- Disposition—referral to local shelters, resources, medical care, evacuation point.

The summary of the process is captured in Figure 3, and additional details of each step are described below.



Assembly Center: Outcomes from Screening / Assessment Process

Figure 3. Summary of Assembly Center Functional Sequence.

Contamination Containment

Upon arrival to the AC, it is optimal to have a station for contamination *containment* to prevent significant amounts of radioactive debris from being tracked into the Center. Individuals should be instructed to perform self-decontamination at home, which is critical for limiting exposure. Foot covers, wiping, and clothing control or removal of significant dust and debris on clothing will help to limit this importation. Rapid screening with hand-held counters may expedite this process. Note that the goal is *not* formal assessment and technical decontamination as would be implemented at a CRC where the resource situation is better⁷, but is simply a means of limiting radioactive materials entering the facility. The focus of the AC is screening for whole body radiation effects, with much less concern at this point for any small amount of residual external or internal radioactive materials that may be present. Personal dosimetry and other radiation detection equipment can assist with monitoring background levels of radiation and providing gross assessment of contamination. Background levels of radiation in the center may vary over time.

Queuing

Queuing is an integral part of many disaster-related public health processes such as mass vaccination and CRC activities. Jurisdictions should use existing plans to model the incident management and setup of the physical site for the AC to ensure orderly flow through the step-wise process. Ideally, the jurisdiction should develop a registry form that victims can fill out while waiting in line, including selfassessment symptom-based questions. Some of these may be modified from forms used for CRCs^{8,9} though the level of detail may not be appropriate for the venue, and transferring this amount of information rapidly to electronic form may be problematic. The jurisdiction should also consider whether a portion of this form is retained by the victim with their triage category and recording of any administered countermeasures.

Assessment – Acute Injury/Illness and Risk Assessment

The primary focus of the ACs is to identify individuals exposed to fallout radiation. While prompt radiation remains an important potential source of radiation exposure for victims, many of these patients will have traumatic injuries, and thus their screening for radiation exposure will be addressed in the medical care system.

During the Assessment process, medical care personnel should first determine if a victim has acute physical injuries or is significantly ill, and refer him or her to medical care as needed. The AC process is not designed for those with significant acute medical care needs. In fact, the EAST tool should not be applied to severely ill patients, particularly those with combined trauma and radiation injury.

In some cases, very basic treatment (e.g., anti-emetics) for mild symptoms may be given and then it may be appropriate to continue screening. In addition, individuals exposed in the MDZ or LDZ with minor traumatic injuries may present at an AC. Thus, the availability of at least some degree of on-site medical support for usual symptoms should be considered.

Victims should then be interviewed to determine if their initial location or travel path put them at risk for radiation exposure (as the victim may have passed through the Dangerous Fallout Zone (DFZ) on their way out of their shelter area). This assessment should be based on the best information available at the time for potential exposure areas. Atmospheric dispersion models, like those produced by the

Interagency Modeling and Atmospheric Assessment Center (IMAAC),¹⁰ provide a first estimate of the DFZ within hours. More accurate potential exposure area maps will come from measurements data. These include maps generated by the Federal Radiological Monitoring and Assessment Center (FRMAC)¹¹ after measurement overflights but these will take time to develop and circulate. The jurisdiction should assure that there is a mechanism to share the most current maps and information with AC site leaders. It is important to note that some of the population presenting to the ACs may have had prompt radiation exposure without injury, and maps of the MDZ radiation areas should be available for reference as well.

Location history is helpful to determine relative risk of exposure but unfortunately is a very *poor* method to estimate dose. The rapidly changing radiation levels due to fallout arrival and decay in the first few hours means that slight differences in understanding when and where the exposure occurred could result in order of magnitude differences in exposure. In a NYC example, a difference of 15 minutes between the time an individual entered the DFZ while transiting across it resulted in an exposure difference of 3.5 Gy vs. 5 Gy.^c

Once it has been determined that the victim was exposed, the victim proceeds to screening for specific signs and symptoms. The location information should be noted and coupled with sheltering information on the screening tool.

Screening

The screening staff then uses the screening tool (see below) to determine the symptoms or signs of potential ARS that the victim has experienced or is experiencing. The screening may be conducted by the same person that conducts the assessment, or this responsibility may be split. Ideally, medical personnel should be available for consultation should questions arise during the screening process. The appropriate category should be circled or checked for each of the variables.

Triage

The screening tool is not precise. The screening process starts with the *most predictive* information and ends with the *least predictive* information. The screener asks the victim for the presence and severity of symptoms in each category. The victim should ideally not see the triage table, to avoid bias. Because no one indicator is definitive and answers may fall into more than one column, the screener must balance the answers if they fall into different columns and weigh those with more predictive value when assigning the triage category. The column with the most predictive/dominant symptoms correlates with the triage category in the same column at the bottom of the table.

The triage category at the bottom of the column that contains the dominant number of responses assigns a priority of high/medium/low for victim evacuation and cytokine access. Children and pregnant women may be given higher priority due to their relative susceptibility and vulnerability. Further, those with medical conditions that would pose a life-threat if not treated in the next few days (e.g. insulin-dependent diabetes off usual medications, dialysis) may be prioritized to a higher category for evacuation. In some cases, victims with severe medical conditions and likely high levels of radiation exposure may be de-prioritized for transfer and triaged to local palliative care, but this should be

^c For response purposes, 1 Gy = 1 Sv = 100 rad.

conducted in conjunction with clear communication with incident management and in the context of available resources.

At this point, the triage personnel should provide documentation (colored or bar-coded wristband, card, etc.) of the triage category and any other information to the victim that will accompany them onward. Victims may know the association of usual red/yellow/green colors, therefore choices of other colors or numbers that designate the priority of the groups may be preferred.

Disposition/Support Desk

Once the triage process is completed, next steps and options should be presented and explained to victims. If transfer can be arranged from the AC, the victims at highest priority may be able to be directly transferred to a higher level of medical care. More likely, those in the high and medium priorities should be referred to a staging area or evacuation center (bus, train, other). If cytokine administration can be offered it should be provided on-site, nearby, or at the staging/evacuation center (i.e. the victim should not be referred to a separate site for cytokine treatment and then to another for transportation if possible). If the victim has shelter, food, or other needs, they should be able to be provided with information on how and where to access those resources (note that some ACs may be established near or within large shelters).

The EAST Screening Tool

Predictive tools for radiation exposure are usually tied to results of ALC and other formal testing that will not be available in a scarce resource environment. Using current literature and subject matter expertise as a basis, the working group did its best to create a screening tool based on environmental exposure and current symptoms to expeditiously sort the fallout victim population (Figure 2) without benefit of other resources. The goal was to create a one-page tool that could be used by minimally trained personnel to rapidly assign priority. These limitations come with constraints. As mentioned above, correlation of the degree of radiation exposure with symptoms is poor. Further, few medical providers have experience with ARS and may be subject to many misconceptions. They may also fail to recognize the overlap between anxiety-related symptoms and symptoms of ARS. However, when presented with tens or hundreds of thousands of victims that cannot all be offered priority for cytokines and evacuation, a system of triage with significant limitations is still preferable to none.

As soon as resources allow, serial absolute lymphocyte counts (ALC) should be obtained for all victims. Triage based on these data should then be implemented, as they are far more predictive of radiation dose, and require only common clinical laboratory testing available at most hospitals and some clinics. Single values of ALC are not as accurate as serial values, but have better predictive value than symptoms, thus we included this in the screening data in case blood counts can be performed on site. Single-value ALC is less accurate due to both host response variability as well as difficulty defining the exact time the exposure began, as well as the actual dose rate during fallout exposure—both of which are best addressed by serial values. ¹² Nonetheless, very abnormal or completely normal values are useful in decision-making.

A fairly rapid increase in mortality is seen in whole body radiation exposures between 2 Gy and 3 Gy (from < 5% to between 15 - 30% with standard medical care not typically including cytokine treatment). ¹ The threshold of 3 Gy whole body irradiation (as usually seen with fallout) has been established by some expert working groups as an appropriate level at which to institute bone marrow

stimulant cytokine therapy after a nuclear detonation¹³ and standard practice in hematology is to initiate after a > 2 Gy exposure. Coleman et al defined priority groups for treatment after a nuclear detonation event with thresholds of 2-6 Gy for moderate and > 6 Gy severe, with priority for care falling to delayed for a > 6 Gy exposure in a scarce resource environment¹⁴ (Figure 4).



Figure 4. Triage category affected by radiation dose and resource availability. Source: Radiation Emergency Medical Management. (2016). <u>Online triage tool for use during scarce resources</u>. (Note that green group A should receive confirmatory laboratory testing. Those in Category B should not, but should still be entered into a registry.)

Therefore our group chose to develop a screening tool that would attempt to identify victims in the 2-6 Gy range, i.e., those that would be most likely to benefit from cytokines **and** would benefit from medical support, but would not be likely to require intensive amounts of healthcare resources. This is consistent with the investment of the most resources toward the moderately irradiated group as described by DiCarlo as being the preferred strategy in a scarce resource environment.¹⁵ In a normal healthcare environment, **all** patients should receive appropriate available resources.

Patients will be re-triaged as the resource setting changes so that an 'Expectant' in poor availability will become 'Immediate' in normal or good resource settings. Consequently, patients with estimated > 6 Gy exposure should receive resources as they become available later in the event. Many in this group should be salvageable with appropriate interventions.

As with all triage tools, the goal is to avoid over-triage (categorizing patients to a higher than appropriate priority) and under-triage (categorizing patients to a lower than appropriate priority).

Under-triage of a small number of victims that will have > 2 Gy exposure and be asymptomatic is unavoidable. Therefore, when resources allow, **all** victims (even those whose initial estimate is < 2 Gy exposure) should have further assessment. Very few victims who received < 2 Gy exposure would be expected to have severe complications. Lower level exposures are of more concern in patients with combined traumatic and radiation injuries that need to be cared for in the Medical Care facilities (MC as defined in the RTR structure in Figure 1), as the combination of mild radiation injury and moderate trauma can be lethal. This type of assessment should be conducted in Medical Care facilities and is not further addressed here.

In contrast, over-triage is a major potential problem as many symptoms consistent with early acute radiation syndrome (e.g., vomiting, headache, confusion) are commonly associated with acute emotional stress, which is anticipated to be a common denominator for all persons affected by a nuclear detonation. Thus, appropriate secondary screening of patients once resources allow (e.g. in the receiving community after evacuation) must be conducted to assess actual exposure and define the need for further treatment.

The EAST tool^d,^e sorts victims into three general groups:

- Category 1 most likely to benefit from cytokines and require moderate medical care interventions (moderate exposure 2-6 Gy = highest priority)
- 2. Category 2 some benefit from cytokines and likely intensive medical support needs (severe exposure >6 Gy= **moderate** priority)
- 3. Category 3 -unlikely to benefit (mild/minimal exposure <2 Gy = lower priority)

Common and easily assessable symptoms from standard ARS categorization and triage tools were included in the EAST tool. Some of the thresholds from these common sources were combined so that they resulted in three groups or were otherwise modified in order to properly fit the patients into a corresponding group. Fatigue and abdominal pain, included in many ARS assessments were not included due to the wide variety in subjective perception of intensity of these symptoms and numerous potential confounders.^{16,17,18,19,20,21}

A brief overview of the dose estimate methodology, in order of **most predictive** to **least predictive** are:

- 1. **Point of Care Biodosimetry.** Development efforts by BARDA and other agencies for field radiation diagnostics are demonstrating potential viability. Generally, these use small blood samples or pre-event radiation sensitive biofilms to look for exposure related protein expression. Although not currently available, these tools would provide the greatest accuracy for early exposure estimates. These are not included in the current version of the tool, but should be incorporated as these technologies advance.
- 2. **Absolute Lymphocyte Count (ALC).** Easily available in most clinical environments and with good predictive accuracy (particularly in series and optimally 24 hours apart), the ALC at present requires clinical laboratory equipment, time, and expertise. Though likely to be available in areas of intact medical infrastructure, it is unlikely to be available at the ACs, particularly in the

^d <u>https://www.remm.nlm.gov/EAST_Tool_and_Notes_2017.pdf</u>

^e https://www.scribd.com/document/51555334/DMPHP-Scarce-Resources-Paper-2011

first hours to days of operation. Standard reference tables are available at: https://www.remm.nlm.gov/aboutlymphocytedepletion.htm

- 3. Vomiting onset. Vomiting is frequently mentioned in radiation triage strategies. In fact, some triage tools recommend expectant management for victims with vomiting onset within the first hour. Exact time to onset of vomiting as examined by Demidenko was not a precise predictor of dose with a 190% degree of error overall for time of onset vs. predicted dose.²² Parker et al also found poor correlation between vomiting at 1 hour with dose, though Sandgren and others developing the BAT tool found better correlation at 1 hour with doses of at least 4 Gy.²³ Further, the absence of vomiting does not equate with absence of risk. In general, about 60% of victims with 2 Gy exposures and 75% with 3 Gy exposures will exhibit some vomiting by 4 hours after exposure, so that by the time an AC opens, those that will vomit should have experienced it.¹ Based on available data, it is clear that time to vomiting cannot be used as a firm triage criterion. Accurate timing of the onset of vomiting relative to the fallout exposure can also be difficult since the exposure itself may occur over hours. Time to onset of vomiting is still relatively helpful in context with other symptoms and is included in the table but with understood limitations. Vomiting also has many causes apart from ARS-trauma, anxiety, fear, and the sights and smells of the disaster's aftermath may cause or potentiate vomiting unrelated to radiation exposure. Vomiting that develops more than a day after the event may also be due to food poisoning or infectious sources (e.g., norovirus infection in a shelter).
- 4. **Vomiting (persistent).** Continuing nausea and vomiting persisting into the period that an AC is in operation (12-96hours) may be of significant prognostic value, though this is tempered by the potential that gastritis and ketosis (presence of ketones in the blood from breakdown of fats when the body is depleted of glucose due to inadequate oral intake) can potentiate vomiting and may be unrelated to the degree of ARS. Vomiting in the days following the detonation may also be due to infectious and other causes, as mentioned.
- 5. **Skin burns.** Must be distinguished by history. Thermal burns from a fire or other source would not be considered related to risk. Flash burns from the initial detonation would be an indicator of potential significant prompt (immediate) radiation exposure. Particulate fallout exposure landing on an exposed person can lead to skin burns (so-called beta burns) which are a good indicator of significant radiation exposure but are rarely present. Burns around the collar or scalp where fallout particles may have remained for long periods are highly suggestive.
- 6. Interview for time motion analysis. Will be most helpful to rule out a significant exposure if the evacuee was not in the Moderate Damage Zone or did not cross through the Dangerous Fallout Zone (DFZ). The IMAAC can provide predictive models to estimate the location of the DFZ. These should be developed within hours after an incident and will improve with time as measurements are made to determine the ground truth. For those that shelter for at least the first 12-24 hours and then evacuate when the decay rate is not as dynamic, the estimate of evacuation dose will become more accurate. However, access to the most up to date contamination information at the AC sites may represent a significant challenge. Local and postal code maps should be available for victim reference.
- 7. Diarrhea. Occurs with less predictability in the early phase of ARS but is associated with higher doses, with < 10% incidence in exposures under 4 Gy and a rapid increase in incidence and severity at higher doses. Diarrhea is less likely due to psychogenic factors. It may be due to infection and food-related issues. However, this is less likely in the first day or two after a</p>

detonation, but may be more common after several days when access to safe food and water, lack of good hygiene, and exposure to infectious agents may be contributing issues.

- 8. **Headache**. May be related to numerous other causes, including lack of sleep, anxiety, and injury. However, the development of a significant, otherwise unexplained (e.g. no trauma) headache, particularly in combination with other symptoms, may be a significant contributing feature in ARS, particularly if it interferes with normal activities.
- 9. **Fever.** Not caused by anxiety and therefore may be helpful in association with other variables. Infection can cause fever, but would be unlikely in the first few days after a detonation.

Predictors 2-9 are thus included in the final EAST screening tool (Figure 5 [on pages 18-20]), which provides an imperfect sorting structure for use in a *crisis environment* and is not to be used when resources allow more expert clinical or laboratory assessment.

Figure 5. The Exposure and Symptom Triage (EAST) Tool

Nuclear Detonation Survivor Prioritization for Evacuation / Bone Marrow Cytokines



Assess symptoms/data - major predictors listed first (e.g. ALC is best predictor, skin changes unlikely) - base cytokine and evacuation priority on column with majority or strongest predictive variables (2)

ARS Severity Prediction	Severe ARS Predicted (>6 Gy)	Moderate ARS Predicted	Mild ARS Predicted (<2 Gy)	
ALC/lymphocyte single value estimate (x10 ⁹) (3)	< 0.7 at 24h < 0.4 at 48h	0.7 – 1.1 at 24h 0.4 – 0.9 at 48h	> 1.1 at 24h > 0.9 at 48h	
Vomiting onset (4)	Rapid (within 1h) after exposure	Intermediate (1-4h)	Delayed > 4h	
Vomiting (per day) (5)	>6 or worsening with time	Moderate 3-6	1-2 or resolved	
IMAAC /official 12-24h estimated dose map (6)	>6 Gy (modify to 2-6 Gy if good shelter for 24h)	2-6 Gy (modify to < 2 Gy if good shelter for 24h)	<2 Gy	
Location in damage or fallout zone (non- IMAAC map) first 12- 24h	In damage or fallout zone with minimal / no sheltering	In damage/fallout zone with good sheltering (e.g. concrete)	Not in damage/fallout zone according to map	
Diarrhea (stools / day)	Severe (>6)	Mild / moderate (<6)	None	
Headache (7)	Severe, interferes with activities	Mild/moderate	None/minimal	
Fever (unexplained)	High/sustained	Low (< 101F) or resolved	None	
Skin (beta) burns (8)	Burns / blisters > 3% BSA	Burns/blisters < 3% BSA	None	
Match dominant signs/symptoms in column above to suggested triage category in same column below				
GCSF/myeloid cytokine priority (9)	2 – Possible benefit	1 – Most benefit	3 – Unlikely benefit	
Evacuation group (10)	2 – Second evacuated	1 – First evacuated	3 - Third evacuated	
Complicating Medical Conditions / Vulnerability (see note 10)				

Complicating Medical Conditions / Vulnerability

Adjust evacuation priority to a higher color (e.g. yellow up to red) if patient has a condition for which local care is not available and that could deteriorate within 48h putting the patient at risk including but not limited to:

Diabetes

- Dialysis / End Stage Renal Disease
- CHF (Congestive Heart Failure)
- Pregnancy
- Immunosuppression (e.g. AIDS, taking steroids/transplant meds, recent chemo)

Severe Respiratory Disease (e.g. Asthma, COPD with disability, requiring oxygen, or daily symptoms)

Vulnerable / at risk in current environment (e.g. pediatric, disability)

Myeloid cytokine (GCSF/other) administration (record dose/time) according to priority/availability (11)

Support – referral to resources for evacuation and basic needs coordination (12)

End notes - turn over

Notes on tool (to be printed on back of screening sheet):

Goal: Initial rapid triage of persons with radiation exposure (no/limited injury) to prioritize them for evacuation/myeloid cytokine administration when not enough capacity in system to provide for all survivors.

Setting: Assembly Center or other screening location in resource-poor environment after a nuclear detonation. Process: Screen patients from highest to lowest precision predictors of ARS and assign priority. This tool is an imprecise guide and should not substitute for expert clinical and radiologic opinion when available. Use of serial ALC values for screening is optimal and should be instituted as soon as blood counts can be performed.

Outcome: One or combination of:

- Triage to acute medical care (depending on situation/severity of condition may have on-site resources to provide care • or have to refer to another facility/location).
- Refer to myeloid cytokine administration/other medical support (may be co-located or separate).
- Assign priority for evacuation to area with adequate medical resources. •
- Refer to shelter/basic needs support.

Endnotes

- 1. Medical/trauma symptoms that preclude completion of assessment process. Consider oral anti-nausea/anti-diarrhea medications as needed without medical care (MC) referral during and post-assessment. Persons referred to MC may be treated and referred back for assessment or assessed in medical care area/hospital. Combined trauma/radiation injuries should be assessed by physician as worse prognosis when significant combined injury.
- 2. This tool is ONLY for use in severely resource-constrained environments. In areas with appropriate resources standard assessment tools (BAT, etc.) should be used. (see https://www.remm.nlm.gov/newptinteract.htm#skip)
- Single values of ALC to predict dose are not precise. Obtain serial values as soon as possible. Use formulas and 3. nomograms even for single values as accuracy is best when the time is precise (see link). Time is start of exposure began (e.g. fallout) NOT detonation (https://www.remm.nlm.gov/ars_wbd.htm#ldk_section)
- 4. Vomiting may be due to psychogenic or traumatic effects and time to onset may depend on fallout variables and NOT detonation time. Thus, caution is required when interpreting time to onset.
- Vomiting can cause irritation of the stomach and other factors that can make the vomiting continue despite a 5. relatively low radiation exposure. Thus, vomiting should be assessed in light of other signs and response to any medical treatment already provided.
- In damage or dangerous fallout zone during first 12-24 h per IMAAC or other official mapping. Exposure likely 6. significantly less than IMAAC predicted values if good quality (concrete / steel) sheltering for 24h
- 7. Headaches (HA) can be due to many things including lack of sleep, stress, trauma, and other factors. However, a severe HA in conjunction with other symptoms is likely radiation-related.
- 8. Radiation related burns occur from direct contact with highly radioactive fallout particles or flash burns from the initial explosion. Absence of skin changes does not have predictive value but the presence of skin burns, sloughing, or blistering that is **not** due to thermal burns is a poor prognostic indicator. Estimate 1% body area as the size of the patient's palm.
- 9. Myeloid cytokines (e.g. GCSF) may not be available in a quantity sufficient for treating all candidates. Priority reflects degree of benefit based on prognosis. Refer to scarce resource triage tool for further information (see http://www.remm.nlm.gov/triagetool intro.htm)
- 10. Evacuation priority is based on prognosis as well as resource demands and assumes that medical care in the area is inadequate. Higher priority for evacuation (e.g. yellow patient moves up to red group) may be assigned if underlying medical conditions could be potentially life-threatening if untreated for > 2d. Vulnerable adults, pregnant women, or children at risk in current environment may also receive higher priority for evacuation. In some cases, experienced providers may lower the evacuation priority based on low chance of survival in which case palliative care and scheduled re-evaluation and re-triage should be provided
- 11. Myeloid cytokine administration may be co-located with other assembly center functions or located at another site. Administration should be tracked – both on a card that remains with the victim and in a retainable/sharable database.
- 12. Support functions should include re-unification/communication support, shelter and basic needs facilitation, facilitation of evacuation, and provision/referral for mental health and medical services. Some of these may be colocated at the assembly center and others at separate sites.

Notably, though this screening tool is the product of an expert working group, it has not been tested in exercises (to the degree that they can replicate the disorder and chaos of a nuclear detonation). The tool should be assessed further and modifications may need to be made. The tool will be updated as required on the REMM website where it is available for download at

<u>https://www.remm.nlm.gov/EAST_Tool_and_Notes_2017.pdf</u>.²⁷ Even with appropriate implementation of all strategies discussed here, thousands of people will still die from the effects of radiation illness, many of them salvageable if the appropriate resources were available. It is the goal of planning and response tools such as these to try to minimize the number of deaths by attempting to fairly allocate the resources available at the time.

Additional Planning Considerations

Cytokines

Receipt, distribution, administration, and tracking of cytokines is a key planning element that must be incorporated into the AC system planning. Will the cytokines be given at the AC? If not, how will transportation be assured? How will a record of administration be maintained? Without a specific plan, delays are likely and will result in deaths.

Bone marrow cytokines are often available in metropolitan areas in limited quantities for oncology use. Some major medical centers have attempted to increase the quantities available in case of a radiation event, though the amount of product that can be kept current through the supply chain is quite small compared to the demand that will occur after a nuclear detonation.

The SNS contains significant quantities of these medications. Each state has a plan for receiving and distributing SNS materials, however, plans may not reflect the level of detail required to assure that cytokine medications are rapidly requested, received, distributed, and administered. The responsibilities for planning for these functions are local, and beyond the scope of this document, but local jurisdictions should ensure that response plans address the following:

- Protocols for ensuring SNS assets are requested as rapidly as possible.
- Medication allocation—where medications will be sent and default quantities (by percentage) of medications for each location to assure a balance between reaching the exposed population most likely to benefit, and delivering medication to surrounding communities where self-evacuating people will go and where more resources exist for treatment/administration.
- Decisions about whether cytokine administration for 'at-risk' victims will be co-located with ACs, MC, and/or staging functions for transport to MC (or a combination thereof).
- Balancing the number of cytokine doses delivered to hospitals vs. delivered to other administration locations (e.g., AC).
- Assuring adequate and appropriate staff to administer injections at community-based locations (including legal and regulatory considerations).
- Tracking system(s) for the administration of cytokines (consider paper and electronic systems).
- Assuring adequate security for the medications, staff, and individuals receiving medication.

Public health mass vaccination plans may provide a good template for cytokine administration as similar functions are required—documentation, queuing, administration, supply management, and other planning have direct applicability. As with vaccines, cytokines must be refrigerated. Unlike most vaccines, cytokines are administered via subcutaneous injection, as opposed to intramuscular injection.

Side effects are common, and drug information should be provided to the patient at the time of injection. If daily dosing is required, the patient should understand options and locations for repeat dosing.

Tracking

Jurisdictions should have a system in place to track victims via paper, and, optimally, via electronic means. Though tracking through the AC process is not critical, the victim must carry some record of the triage category/encounter with them. This may take the form of a small card, bracelet, or other mechanism that records lab values and administered medications. Tracking becomes critical when the patient is evacuated to a different location for continued care and support.

Note that all victims must be entered into a registry regardless of symptoms as even low levels of radiation exposure can lead to long-term risks for malignancy years later (stochastic effects). All victims in the area, even with nominal levels of exposure, should be registered when resources allow and entered into long-term monitoring programs.

The absence of a national database/registry is concerning, as victims will wind up scattered across the nation and will require lifetime surveillance. In the immediate post-incident phase less formal data sharing will likely predominate with the balance toward more open access. As formal registries are created over time the balance will shift toward formal systems and more privacy for the patients.

Mental Health

The mental health effects of a nuclear detonation on victims, and responders, will be unparalleled. Every effort should be made to reunite families; provide access to communications (internet, phone, etc.); and provide basic shelter, food, and comfort needs to all affected, as quickly as possible following the incident. Providers should be monitored closely by supervisors for signs of overt stress and for job performance issues. Tasks should be kept as scripted as possible, as cognitive abilities will be impaired by the stressors of the event. As noted in preceding sections, REMM provides algorithms to aid in decision-making. Assuring clear documentation of the ambient radiation levels at the AC, as well as the threshold levels for safe operation, will go a long way to helping providers feel safe. Principles of psychological first aid should be applied to providers and victims, and mental health professionals should ideally be part of the AC staff. Support for providers' families, and provider contact with their families, should be assured whenever possible. Duty cycles should be monitored and adequate rest/sleep time incorporated into staffing plans. Providers will require ongoing monitoring, and perhaps, interventions, for years after the event.

Referral and Transfer

One of the key distinctions between patient movement during a conventional disaster, and movement of survivors with acute radiation sickness is that those with ARS in the 2-6 Gy exposure range should enter their latent phase of illness at about the time evacuation can be organized. Therefore, large numbers of relatively well survivors may be sent via conventional transport (i.e., planes, trains, or buses) to receiving centers in areas of the nation that have the resources to further evaluate and treat them before they become much sicker in the subsequent days to weeks.

Usual patient movement after a disaster focuses on non-ambulatory movement via specialized airlift or ground ambulances with a hospital as a destination. Following a nuclear detonation, the incoming

victims will require a community-based receiving process that can reassess the degree of radiation illness and treatment needs, and then match the victim to appropriate medical and social support. It should be remembered that patients are not radioactive and do not pose a threat at receiving sites.

The receiving community may need to continue cytokine treatments, perform sequential laboratory testing, administer antibiotics and other medications to outpatients, provide shelter, and have capacity for hospital admission for a smaller percentage of patients that require intensive support.

The Radiation Injury Treatment Network²⁸ is a voluntary commitment of major oncology/bone marrow transplant centers to serve as receiving facilities for patients with severe radiation illness. Most of these are in major metropolitan areas that should be the destinations of choice for evacuated high-priority victims. These centers must be prepared for large numbers of hospitalized patients with severe complications of radiation injury and should also assure that their community is prepared to manage the larger number of referred victims that will need outpatient care only or lower levels of inpatient care that can be provided at community hospitals. This is a significant resource and planning commitment for the receiving community. At present, this remains a major gap that needs to be addressed by potential receiving communities to maintain continuity of care for evacuated victims.

Conclusion

One of the biggest challenges after a nuclear detonation is to triage tens to hundreds of thousands of potential fallout and prompt radiation casualties for evacuation and cytokine administration while in a setting of damaged local infrastructure and scarce medical resources. Inadequate access to cytokines, medical care and transport resources are anticipated based on the expected numbers of survivors and the damage to infrastructure. The EAST process and screening tool may be helpful in crisis conditions to prioritize survivors based on their exposure history and symptoms to appropriate resources, and contribute to saving the most lives possible during a catastrophic event.

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