Proposed "Exposure And Symptom Triage" (EAST) Tool to Assess Radiation Exposure After a Nuclear Detonation

John L. Hick, MD; Judith L. Bader, MD; C. Norman Coleman, MD; Armin J. Ansari, PhD, CHP; Arthur Chang, MD, MS; Adela Salame-Alfie, PhD; Dan Hanfling, MD; and John F. Koerner

ABSTRACT

One of the biggest medical challenges after the detonation of a nuclear device will be implementing a strategy to assess the severity of radiation exposure among survivors and to triage them appropriately. Those found to be at significant risk for radiation injury can be prioritized to receive potentially lifesaving myeloid cytokines and to be evacuated to other communities with intact health care infrastructure prior to the onset of severe complications of bone marrow suppression. Currently, the most efficient and accessible triage method is the use of sequential complete blood counts to assess lymphocyte depletion kinetics that correlate with estimated whole-body dose radiation exposure. However, even this simple test will likely not be available initially on the scale required to assess the at-risk population. Additional variables such as geographic location of exposure, sheltering, and signs and symptoms may be useful for initial sorting. An interdisciplinary working group composed of federal, state, and local public health experts proposes an Exposure And Symptom Triage (EAST) tool combining estimates of exposure from maps with clinical assessments and single lymphocyte counts if available. The proposed tool may help sort survivors efficiently at assembly centers near the damage and fallout zones and enable rapid prioritization for appropriate treatment and transport. (*Disaster Med Public Health Preparedness*. 2018;12:386-395)

Key Words: nuclear weapons, triage, radiation injuries

Detonation of a nuclear device in a major city would eclipse any prior terrorist and natural disaster in terms of infrastructure damage, mortality, and morbidity (both physical and mental, acute and chronic).[1-5] In addition, the potential for unprecedented widespread social disruption compounded by fear of exposure is a unique after-effect that may complicate disaster response and recovery efforts.

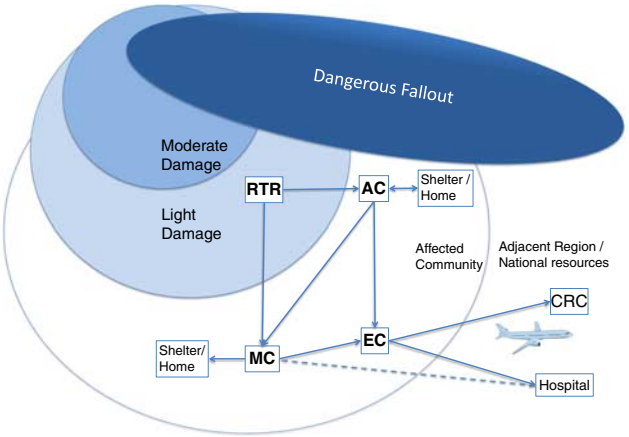
Computer modeling of the number and type of casualties for various scenarios of nuclear detonation has been performed by several federal and nongovernmental agencies.[1-5] The Planning Guidance for Response to a Nuclear Detonation[1] names and describes various zones resulting from the nuclear detonations, including the severe, moderate, and light damage zones, and the dangerous fallout zone. The severe damage zone contains few salvageable survivors. The other zones are represented in Figure 1 along with the health and medical components described below. These zones correlate with the numbers and types of injuries expected.[1] Some areas receive *prompt* radiation via the initial blast and other areas *delayed* radiation via fallout. Survivors who receive delayed radiation exposure in the dangerous fallout zone are the primary subject of this report, but we do refer to generic damage and fallout zones to incorporate the other areas of potential exposure.

Ground-level detonations are expected to produce more fallout debris compared to air-burst detonations, which tend to produce more burns and traumatic injury over a wider area. Various factors influence the number of expected casualties and injury types in the modeled metropolitan areas. These factors include but are not limited to: location, detonation yield (kiloton or kT), topography, weather, population size, time of day, ground or air burst, dose rate, radiation quality (neutrons, x-rays, beta radiation), and infrastructure elements at risk.[2-5] Some detonation scenarios yield potential casualty numbers in the hundreds of thousands or millions.[2-6] For example, a 10-kT Los Angeles, CA, detonation model estimated that over 500,000 persons would be located in the dangerous fallout zone 2 hours after the detonation.[2] Planning an appropriate medical response of this magnitude is very complex and requires thoughtful and detailed advance planning in order to maximize the number of survivors, efficiently use scarce resources, and rapidly establish a coordinated approach to victim identification, triage, treatment, and transfer.

Currently, most state and local plans for radiation incident response focus on much smaller events

FIGURE 1

Functional Illustration of Survivor Care Operations at 48 h After Detonation.



Notes: this is a simplified version of the more detailed RTR system.[12] Figure 1 is not to scale and does not represent the full spectrum of activities. Abbreviations: RTR, Radiation Triage, Treatment, Transport (initial triage and treatment of traumatic injuries and transport to medical care or assembly center [spontaneous sites]); MC, medical care facility (eg, hospital, field hospital); EC, evacuation center (at airport, railhead, bus staging area, etc); AC, assembly center (may be spontaneous or planned; note that this function may occur at other locations as well); CRC, community reception center (formal screening for radiation contamination where resources are adequate; can be established closer to the point of detonation later as resources improve and infrastructure is reconstituted); shelter/home, general shelter or housing in nondamaged/ nonradiation areas (*not* shelter-in-place activity during fallout during first 24 h) as available pending later evaluation and evacuation (survivor can later go to a CRC when it opens near them).

including nuclear power plant failures, industrial accidents, and use of radiation dispersion devices (RDDs, often referred to as "dirty bombs," although nonexplosive dispersal methods can also be used).[7] Compared to nuclear detonations, these scenarios involve a much smaller number of persons, with typically less serious effects. The acute medical care system would seldom be overwhelmed, and concentrated efforts could be applied to detailed screening of those involved with the support of intact community infrastructure. In contrast, a nuclear event creates massive casualty and community demands in the setting of severely damaged infrastructure. Although some states have conducted RDD and even improvised nuclear device (IND) exercises, none have operationalized survivor prioritization for receipt of myeloid cytokines and evacuation.

In the aftermath of a radiation event that mainly results in *contamination*, such as the use of an RDD that may be constructed by using a variety of potential isotopes, well-described models such as the Centers for Disease Control and Prevention's Community Reception Center (CRC) are valuable for careful assessment of external or internal radiation exposure.[8-10] The CRC is intended for asymptomatic ambulatory population screening and is a public health asset. The CRC process is thorough and requires significant resources.

In the aftermath of a nuclear detonation, the major radiation exposure risk is high-intensity gamma *irradiation*, and the relative risk from remaining external or internal contamination is low. Therefore, the priority is not on carefully documenting remaining contamination but on rapid assessment of potential exposure and clinical symptoms to prioritize early treatment and evacuation. Many of the survivors with significant acute radiation syndrome (ARS) will be ambulatory and have minimal or no symptoms as they enter the latent phase of their disease. By the time they develop later complications it will be too late to easily move them and likely too late to save their lives.

To minimize mortality and morbidity, public health and medical response leaders are expected to implement 4 life-saving strategies during the first 96 hours after a nuclear detonation:

1. **Issue "shelter-in-place" orders** immediately for the population in the fallout areas to minimize exposure. Generally, these orders would be for at least 24 hours and would minimize or eliminate significant radiation exposure for potentially hundreds of thousands in the affected area.[2,11]
2. **Organize and provide trauma care** to the overwhelming number of patients with acute injuries. The medical care system and facilities will be focused on trauma care and referral throughout the first several days.
3. **Establish screening** of survivors to establish risk for radiation-related illness and assign priority for treatment and evacuation to adjacent regions or areas of the nation where the medical care system is intact. Assembly centers (ACs) should be stood up adjacent the dangerous fallout and damage zones to provide this population-based function. AC sites may be based on spontaneous congregation of survivors or established at preplanned centers. The screening function may also be carried out in general shelters, at evacuation points, or other locations as required.
4. **Identify survivors with significant but not fatal radiation exposure** who are most likely to benefit from myeloid cytokines in conjunction with supportive care. These survivors should receive cytokine injections as soon as possible and be expeditiously evacuated to intact health care infrastructure outside of the attacked region for continued evaluation and care. Those at lower risk or with extremely severe radiation injury will receive cytokines and evacuation as resources permit.

The screening function must be integrated into an overall nuclear detonation response plan. Prior planning has defined the role of sites in the community for rapid triage, medical

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care, and evacuation centers to meet a host of coincident demands on a damaged and overwhelmed public health and medical system.[12,13] The AC was described as part of that framework but its functions were not well defined until now (Figure 1). Although these screening functions have received little planning priority, they likely have an impact on mortality greatly exceeding the initial trauma care. A nuclear detonation response will require a balance of multiple sites and systems with complementary functions to ensure the greatest good for the greatest number of survivors is provided.

Considerable human and animal data show that supportive care and myeloid cytokines can significantly mitigate the effects of ARS and save lives if cytokines are administered early enough (within 24 to 48 hours after exposure).[14-17] Myeloid cytokines are available in the US Strategic National Stockpile[18,19] and are widely available clinically, as they are used to mitigate effects of cancer chemotherapy.[20,21]

Although lymphocyte depletion kinetics are a well-described marker for dose estimation and the hematologic subsyndrome of ARS[22-25] and could identify candidates for treatment, large-scale ability to perform serial tests will be lacking in the affected area in the early aftermath of a detonation. Dicentric chromosome analysis[26,27] is a very accurate estimate of dose, but this test currently takes over 72 hours to complete and is difficult to scale up for a mass casualty situation. Additional clinical screening tools require training and experience and are not well suited for field use. New point-of-care diagnostics are being developed that may provide future assistance but are not yet ready for implementation (personal communication, JB and NC, 2017).

Given the austere conditions in the immediate post-detonation environment, the expected limited initial local supply of myeloid cytokines, and the absence of readily available diagnostics, a simple screening tool is needed to support initial assessment and triage after a nuclear detonation to help fairly allocate scarce resources.

METHODS

The authors, a federally convened group of government and civilian medical planners of various disciplines from multiple agencies with experience in radiation incident planning and response, developed this proposed triage tool to help medical providers and public health staff assess survivors for radiation injury in ACs and at other sites where screening is required. This tool is for population-based screening and not on-scene first responder use. First responders should use usual trauma and medical triage criteria and refrain from radiation triage owing to the wide variability in symptoms and onset. Current literature was reviewed and assessed for value by the work-group members. Multiple virtual and in-person meetings were held over time to develop and refine the proposed tool.

Data

The EAST tool (Exposure And Symptom Triage) is shown in Figure 2A with important "endnote" clarifications in Figure 2B. The tool is printed on a single page (front and back side), facilitating rapid categorization of survivors on the basis of a brief interview by a medical provider (nurse, advanced practice provider, physician, or other personnel). It uses a single value for the ALC (absolute lymphocyte count) when available along with exposure and sheltering information and selected clinical signs and symptoms known to be associated with radiation injury and ARS to prioritize patients. Although rough cutoffs are listed on the table for the ALC value, for expediency accuracy is sacrificed, and proper interpretation should use available nomograms and interactive tools[28] if available.

The tool is designed for use only in a resource-poor screening environment. The tool output establishes priority for myeloid cytokines and transport to definitive medical care for ongoing assessment and management of ARS. More detailed triage tools have been developed for use in medical care facilities that can be adjusted to the resources available.[29]

DISCUSSION

As the whole-body dose from acute exposure to radiation exceeds 2 Gy, the risk of clinically significant ARS increases, especially among those with special vulnerabilities, eg, immunosuppression, young age, old age, chronic illness, concurrent physical trauma, burns. The estimated LD 50/60 for an untreated adult (an estimate of lethal dose in 50% of the population at 60 days) after rapid whole-body exposure is about 4 Gy.[30] With appropriate care, the curve is shifted to the right and the LD 50/60 is higher. Standard current clinical practice for ARS includes providing myeloid cytokines and supportive care as soon as possible after significant whole-body exposure in excess of 2 Gy.[14,17] Waselenko's expert working group established a threshold of 3 Gy of whole-body irradiation as an appropriate level at which to institute cytokine therapy after a nuclear detonation with a 2-Gy threshold for pediatric and elderly patients or those with combined traumatic and radiation injury.[31]

Recognizing the uncertainty in estimating dose, the need for easy-to-use categories, and also to be somewhat conservative in providing medical treatment to persons on the border of benefitting from it, Coleman et al. defined 2 priority groups for treatment after a nuclear detonation event: a *moderate* exposure group between 2 and 6 Gy and a *severe* exposure group of ≥6 Gy.[29] In a scarce resource environment, treatment of victims with moderate exposures takes precedence over those with severe exposures, who will require significantly more resources and have a much worse prognosis even with maximal support.[32] Our group similarly prioritized the moderate dose range survivors, 2-6 Gy, who would be most likely to benefit from myeloid cytokines and specialized

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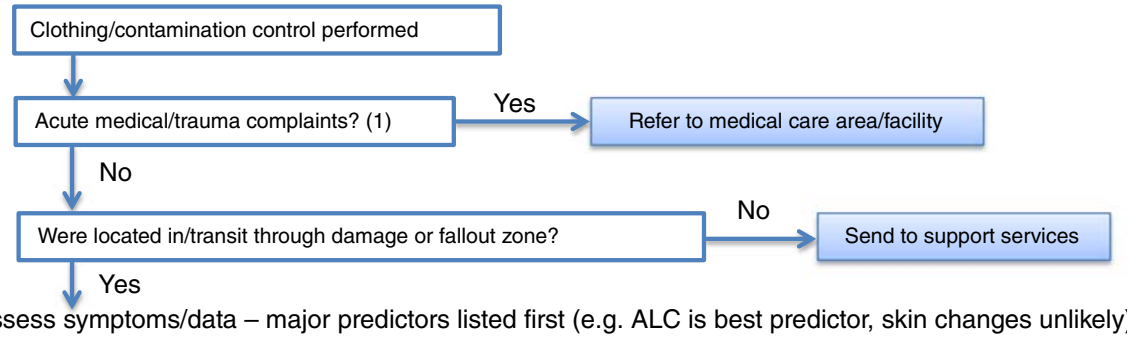
FIGURE 2

Nuclear Detonation Survivor Prioritization Tool. (A) Front of 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)

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)

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FIGURE 2 (Continued)

(B) This table material is printed as endnotes on the back side of the tool for rapid reference.

Goal: Initial rapid triage of persons with radiation exposure (no/limited injury) to prioritize them for evacuation/myeloid cytokine administration as not enough capacity in system to provide for all survivors
Setting: Assembly center or 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)
3. Single values of ALC to predict dose are not precise. Obtain serial values as soon as possible. Use formulas and 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.
5. Vomiting can cause irritation of the stomach and other factors that can make the vomiting continue despite a relatively low radiation exposure. Thus, vomiting should be assessed in light of other signs and response to any medical treatment already provided.
6. In damage or dangerous fallout zone during first 12-24 h per IMAAC or other official mapping. Exposure likely 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 co-located at the assembly center and others at separate sites.

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medical support, but not likely to require intensive medical support in a scarce resource environment.

As with all triage tools, the goal is to avoid both over-triage (ie, assigning a higher than appropriate priority and providing treatment that was not necessary) and under-triage (ie, categorizing patients to a lower than appropriate priority and failing to provide beneficial treatments).

Under-triage of a small number of survivors who have exposure >2 Gy and are asymptomatic may be unavoidable. When resources allow, *all* survivors (even those whose initial dose estimate is ~1-2 Gy) should undergo repeat assessment so that their exposure and risk can be more clearly defined.

Over-triage (categorizing patients to a higher than appropriate priority) is also a potential problem. Many observable symptoms consistent with ARS (vomiting, headache, confusion) are commonly associated with acute emotional stress as well as physical trauma, which is expected after a nuclear detonation. This may result in large numbers of unexposed persons falling into a high priority category for immediate treatment, thus burdening and diluting the resources. Therefore, re-triage based on ALC should be performed when resources allow.

The EAST tool sorts survivors into 3 groups—note that the colors reflect priority, and not severity—similar to Coleman's[29] work: the highest priority in this scarce resource environment goes to the moderately affected group with a high likelihood of benefit for a low resource investment. The sickest individuals are a secondary priority as resources allow:

1. Priority 1 – Red/Highest. Most likely to benefit from myeloid cytokines and priority evacuation and require moderate medical care interventions (moderate exposure of 2-6 Gy predicted).
2. Priority 2 – Yellow/Intermediate. Possible benefit from cytokines but likely to need intensive medical support after evacuation (severe exposure >6 Gy predicted).
3. Priority 3 – Green/Lowest Priority. Unlikely to benefit from cytokines or require medical care interventions (mild exposure/ARS not predicted < 2 Gy).

Exposure

Although survivors arriving at an AC may receive routine decontamination including clothing control or rapid screening for gross radiologic contamination, quantifying external radiation contamination is *not* included in the EAST assessment. Presence or absence of residual radiation is helpful information and if resources are available should be included in the screening process. However, this introduces personnel, training, equipment, and time issues that could inappropriately delay the initial sorting function. Formal CRC functions for mass community population monitoring should be established for this purpose in areas when adequate resources exist.[9,10] In general, self-decontamination is effective after chemical events and more rapid than traditional decontamination and would likely be the most efficient strategy in this setting.[33]

Survivors presenting to an AC with acute medical or trauma needs must be referred to appropriate medical care locations as expeditiously as possible. Depending on the situation, some medical care may be co-located or transport to a medical care site may be required. Usual medical care facilities are likely to be overwhelmed, and alternate systems of care will be needed. The AC should understand the range of options available to survivors in their area. This tool is not designed for use in a medical care facility where combined traumatic and radiation injuries can have much worse prognosis than either injury alone and where the focus should be on serial ALCs.[28,34]

Survivors should first be asked about their potential exposure (ie, is there a reason to believe based on location at the time of the blast that the individual was in or near areas where there was prompt radiation and/or fallout radiation). This assessment should be based on the best dose maps available at the time, optimally those generated by the Department of Homeland Security's Interagency Modeling and Atmospheric Assessment Center (IMAAC)[35] although early maps may be rougher predictive models based on weather conditions. Because the IMAAC maps generally contain the most reliable information linking geography and doses, they are listed first of the maps on the tool. The patient should be asked for an address or indicate on a map where they were, and that location should compared to the dose maps. Maps will be refined as field monitoring data is incorporated.

Access to these maps is critical to screening success. Public health, emergency management, and the medical care sector should already be engaged in a local health care coalition, which can serve as a vital link to disseminate mapping information to key stakeholders in the health and medical community. Printing and distributing current maps to the AC and medical care locations is a high priority that should be understood and planned for by the jurisdictions in advance of an event.

Type and duration of sheltering should be considered. Optimal shelter is generally defined as being in the center or basement of buildings with thick concrete walls. Persons sheltering within a wood frame building still have considerable protection compared with those outside without shelter. Several hours in a dangerous fallout zone with inadequate shelter is a reliable predictor for significant radiation exposure.[1-4,6]

Persons presenting to the AC found *not* to be at risk for prompt radiation or exposure from fallout on the basis of their

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location should be released without further evaluation needed. Those determined to be at risk should proceed to the symptom screening process to further inform their triage category.

Acute Radiation Syndrome

Developing a valid assessment tool for ARS by using signs and symptoms is fraught with difficulty, because the typical signs and symptoms of ARS are not unique to radiation injury, the symptoms are often subjective, and the time course is variable. However, clinical assessment is likely to be the only tool available early on after a nuclear detonation as field laboratory capacity is unlikely. As soon as resources allow, complete blood counts (CBCs) with serial ALCs should be obtained and patients re-assessed and re-triaged, because ARS progresses over time.[28,34]

The CBC is a common test available at hospitals and some clinics and national capacity for CBCs performed in reference laboratories is robust.[36] However, difficulties coordinating sample acquisition, transport, and test result communication in the local damaged and chaotic environment will preclude most field-based sampling. Single-value ALCs are less accurate than serial values, owing to several factors including host variability, partial body exposure, and difficulty defining the exact time the exposure began. The uncertainty about dose rate, especially during exposure to fallout, is additionally problematic because the variable intensity of exposure over time can affect the lymphocyte depletion rate. Nevertheless, even a single ALC is likely better at estimating dose than observable symptoms and is included on the template to encourage planners to integrate access to blood counts as soon as possible (eg, flow cytometer access, large-scale management of clinical samples), particularly at evacuation points and myeloid cytokine administration sites.

Common and easily observable symptoms were taken from standard ARS categorization and other triage tools.[37-40] Some of the thresholds from these common sources were combined to yield 3 groups to be consistent with usual triage constructs (red/yellow/green) or were otherwise modified to properly fit survivors into 1 of the 3 groups. Note that fatigue, anorexia, cognitive impairment and abdominal pain, often a component of the tools, were not included owing to the high potential for subjective variability as well as numerous potential confounders such as lack of sleep and severe psychological stress.

In the tool, the higher the row, the more characteristic and determinative the symptom parameter. Figure 2B includes notes on the symptoms and signs and should be printed on the back of the tool for reference. The screener asks the survivor about the presence and severity of specific symptoms in each row of the table without sharing the triage table itself to avoid self-reporting bias.

Vomiting is the most familiar and prevalent symptom associated with ARS, and some triage tools use time to onset of vomiting as a key factor.[41] Unfortunately, several authors offer strong caveats about the validity of time to vomiting as a clinical parameter for assessing the severity of radiation injury (see Table 1).[42-45]

The tool's other clinical parameters (diarrhea, headache, fever, and skin burns) are well known side effects of whole-body or localized radiation. The manifestations of these will vary significantly from victim to victim depending on the details of exposure, but are useful clinical benchmarks that require assessment and management, sometimes urgently. See Table 1 for additional information.

Contributing factors such as pregnancy, age (eg, childhood), and underlying medical conditions such as immunodeficiency may prompt assignment to a higher priority for evacuation due to higher risk, higher benefit, or vulnerability in their current situation.[31]

After the provider assesses all the rows of the tool, the column with the most predictive information/dominant symptoms drives the assigned triage category (Priority 1, 2, or 3). No single symptom or indicator is definitive, and answers may fall into more than one column (Severe, Moderate, Mild). Therefore, the screener must assess the totality of answers by the survivor and assign the survivor to the column that has the predominance of matching factors, understanding that the first rows are generally more predictive. A tag or wrist band or card system should be developed by the jurisdiction to be worn or carried by each survivor. The jurisdiction may choose to use a lettering or numbering system to avoid visual association of the red/yellow/green colors with the survivor's category.

Limitations and Caveats

The predictive value of a symptom-based screening tool for ARS is limited. None of the individual factors are sufficiently predictive to allow for clear-cut assignment of patients into groups based on individual factors, precluding a simple and binary triage tool. Because of this, multiple factors are included for consideration that may complicate the screening process by introducing complexity and a degree of subjectivity. However, we feel that having some structure and guidance to follow is superior to a first-come, first-served approach that could result in an unjustifiable allocation of scarce resources. A large number of people will be expected to converge on ACs seeking assessment, information, and available treatments, and the ability to implement a first-order triage tool may make a big difference in preserving limited medical countermeasures and other resources for those who can most benefit.

The EAST tool should also help focus planning efforts on the screening process, evacuation process, and the ability to

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TABLE 1

Symptoms Included in the Tool With Comments and Limitations[a]

- **Vomiting – onset:** Time to onset of vomiting is frequently mentioned in radiation triage and some prehospital recommendations include "expectant" triage for those with vomiting within the first hour.[41] However, the absence of vomiting does not equate with absence of risk nor does vomiting within the first hour equate with severe ARS. 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 who will develop vomiting should have had at least some gastrointestinal symptoms (Planning Guide V2 Table 1.5). Exact time to onset of vomiting as examined by Demidenko et al[42] was not a precise predictor of dose with a 190% degree of error overall for time of onset vs predicted dose. Dose rate was not considered. Parker and Parker[43] also found poor correlation at 1 hour with dose, although Sandgren et al[34] developing the BAT tool found better correlation at 1 hour with doses of at least 4 Gy. Although the reference data are not optimal, it is clear that time to vomiting cannot be used as a highly predictive triage criterion. Furthermore, accurate timing of the onset of vomiting relative to the beginning of exposure can also be difficult since the exposure itself may have started minutes to hours after detonation. Time to onset of vomiting is still relatively helpful in context with other symptoms and exposure and is included in the screening tool but with clear limitations. Vomiting has many causes apart from ARS: trauma, anxiety, fear, and the sights and smells of the detonation itself may cause or potentiate vomiting unrelated to radiation exposure. Vomiting that develops more than 1 or 2 days after detonation may also be due to food poisoning or other infectious sources (eg, shelter-based norovirus infection).
- **Vomiting – current severity:** Continuing or worsening nausea and vomiting at 12-96 hours after exposure may be associated with more severe ARS, although tempered by the potential that gastrointestinal symptoms can be caused by physical and emotional stress, ketosis, and other factors.
- **Diarrhea:** Occurs with less predictability in the early phase of ARS but is associated with higher doses especially severe or bloody diarrhea (>10 Gy). Diarrhea is a symptom in a minority of survivors exposed to less than 3-4 Gy and therefore may be helpful, as it has less nonradiation causes than vomiting early after a detonation. However, infection and food-related causes must be considered especially later than 72 hours after detonation when difficulty accessing safe food and water, hygiene, and exposure to infectious agents may be contributing causes.
- **Headache:** may be related to numerous causes other than radiation exposure including lack of sleep, anxiety, physical and emotional stress, and head injury. However, the development of a persisting moderate to severe headache particularly with other neurologic signs such as confusion or obtundation that are otherwise unexplained (eg, no trauma) in combination with other symptoms, may represent severe ARS and be a helpful predictor.
- **Fever:** Fever is unlikely related to anxiety or stress than many other symptoms and therefore may be helpful as a predictive indicator in association with other symptoms/factors. Usual community infections should also be considered as potential causes. ARS-related infections are uncommon in the first few days, but are a major contributor to deaths in the following weeks as leukocyte counts fall.
- **Skin burns:** "Beta-burns" can occur in persons directly exposed to particulate fallout and are in a pattern of deposition on the skin, which is often moist and sloughs. When radiation burns are present, they are generally a sign of severe exposure and would be unusual in the population presenting for screening due to their association with more severe symptoms. Flash burns occur on exposed skin that was facing the detonation, and severity of both burn and accompanying gamma radiation exposure is dependent on distance. Thermal burns can occur from secondary fires or scalds. Both of these types of burns are considered proportionally less likely with a ground-level detonation as compared to an air-burst nuclear detonation where a much larger population is exposed to the flash and heat. Many survivors with flash burns will have associated injuries from the blast.

[a]Note: The table is not included in the triage tool. It provides additional background information on the specifics of the clinical categories. Abbreviations: AC, assembly center; ARS, acute radiation syndrome; BAT, Biodosimetry Assessment Tool.

expediently administer myeloid cytokines because benefit declines rapidly over time.[46] These efforts are critical in the days following the detonation and have the potential to save thousands of lives if executed properly and efficiently. Although the EAST tool helps with prioritization, determining how and where the cytokine administration will be performed and tracked is an under-appreciated aspect of planning that we hope can be emphasized in future exercises. Evacuation center functions have generally not included laboratory screening nor countermeasure administration, but the availability of both of these prior to transport could preserve transport resources for those survivors with suggestive ALC values and provide at least some bone marrow support prior to evacuation.

There is a risk that once categorized, patients may not receive further screening as additional resources become available. This is not acceptable, as signs and symptoms of ARS and the ALC values change over time. The AC function is for areas that lack sufficient resources for usual diagnostics and routine care. When adequate resources become available, all survivors from the affected area should receive serial ALC, evaluation at a CRC, and registry into a long-term monitoring database.

Regional and national receiving communities also need to plan for laboratory screening, CRCs, and medical countermeasure administration functions to support the survivors arriving in their area. This is particularly important for those communities that have commitments through the Radiation Injury Treatment Network[47] and are likely to receive a large number of survivors. Most of these survivors will not require immediate hospitalization, but all will require initial evaluation, ALC monitoring, and potentially ongoing provision of myeloid cytokine and other medical interventions. Many of these functions can occur in a shelter or other processing or screening site for efficiency and to relieve the burden on the health care system, but these strategies must be planned before an event in order to be successful.

Future validation of the EAST tool is recommended by the authors. Public health and medical community testing is vital to be sure providers (1) understand the issues being assessed, (2) understand the limits of the tool, and (3) feel comfortable using the tool. Creating an app to automate the tool and integrating the data into an electronic database would also be helpful, although wireless and other data systems should not be relied on to work after a nuclear detonation.

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CONCLUSION

One of the biggest challenges after a nuclear detonation will be sorting the hundreds of thousands of survivors to identify the presence or degree of radiation injury, prioritize the survivors for myeloid cytokine administration, and evacuate those with severe but survivable exposure and injuries to an area with more intact health care resources in a timely fashion. This requires an easy-to-use tool for a complex function.

Unfortunately, this sorting must occur in the setting of damaged local infrastructure and very limited availability of medical resources, likely including inadequate medical countermeasures, diagnostics, supplies, and transport resources. AC planning is critical to rapid screening of large numbers of persons. The EAST tool could be helpful for prioritizing survivors into groups based on their exposure history and signs and symptoms of ARS. Assignment to the appropriate triage groups will help to ensure that resources are used appropriately to save the most lives possible. Further validation, evaluation, and exercises involving AC functions are critical to furthering nuclear detonation preparedness activities.

About the Authors

Hennepin County Medical Center and Department of Emergency Medicine, University of Minnesota, Minneapolis, Minnesota (Dr Hick); REMM (Radiation Emergency Medical Management) website and US Department of Health and Human Services, Office of the Assistant Secretary for Preparedness and Response, Washington, DC (Dr Bader); CBRNE Science and Operations, US Department of Health and Human Services, Office of the Assistant Secretary for Preparedness and Response, Office of Emergency Management, Washington, DC (Dr Coleman and Mr Koerner); Radiation Studies Branch, Division of Environmental Hazards and Health Effects, National Center for Environmental Health, Centers for Disease Control and Prevention, Atlanta, Georgia (Drs Ansari, Chang, and Salame-Alfie); Hospital Preparedness Program, US Department of Health and Human Services, Office of the Assistant Secretary for Preparedness and Response, Office of Emergency Management (Dr Hanfling).

Correspondence and reprint requests to John L. Hick, MD, Hennepin County Medical Center, Emergency Medicine, 701 Park Ave. S, Minneapolis, MN 55415 (e-mail: John.hick@hcmed.org).

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Disclaimer

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REFERENCES

1. National Security Staff Interagency Policy Coordination Subcommittee for Preparedness and Response to Radiological and Nuclear Threats. Planning Guidance For Response to a Nuclear Detonation. 2nd ed. https://www.remm.nlm.gov/PlanningGuidanceNuclearDetonation.pdf. Published June 2010. Accessed October 24, 2016.
2. Buddemeier BR, Dillon MB. Key Response Planning Factors for the Aftermath of Nuclear Terrorism. https://www.remm.nlm.gov/IND_ResponsePlanning_LLNL-TR-410067.pdf. Published August 2009. Accessed February 4, 2017.
3. Buddemeier BR, Suski N. Preparing for the Aftermath of Nuclear Detonation: An Analytical Framework for Disaster Management. Nuclear Safety and Security Challenges. https://e-reports-ext.llnl.gov/pdf/785616.pdf. Published November 17, 2014. Accessed February 13, 2017.
4. Buddemeier BR. Reducing the consequences of nuclear detonation: recent research. *The Bridge*. 2010 Summer;40(2):28-38. https://www.nae.edu/Publications/Bridge/19804/19920.aspx. Accessed February 13, 2017.
5. DiCarlo AL, Maher C, Hick JL, et al. Radiation injury after a nuclear detonation: medical consequences and the need for scarce resources allocation. *Disaster Med Public Health Prep*. 2011;5(suppl 1):S32-S44. https://doi.org/10.1001/dmp.2011.17.
6. Knebel AR, Coleman CN, Cliffer KD, et al. Allocation of scarce resources after a nuclear detonation: setting the context. *Disaster Med Public Health Prep*. 2011;5(suppl 1):S20-S31. https://doi.org/10.1001/dmp.2011.25.
7. Radiological Dispersion Devices (RDDs). Radiation Emergency Medical Management. US Department of Health and Human Services website. https://www.remm.nlm.gov/rdd.htm. Accessed February 4, 2017.
8. Miller CW, Ansari A, Martin C, et al. Use of epidemiological data and direct bioassay for prioritization of affected populations in a large-scale radiation emergency. *Health Phys*. 2011;101(2):209-215. https://doi.org/10.1097/HP.0b013e31821dd9a2.
9. Community Reception Center (CRC) Drill Toolkit. Emergency Preparedness and Response. Centers for Disease Control and Prevention website. https://emergency.cdc.gov/radiation/crc/crctoolkit.asp. Accessed October 24, 2016.
10. Virtual Community Reception Center (vCRC). Emergency Preparedness and Response. Centers for Disease Control and Prevention website. https://emergency.cdc.gov/radiation/crc/vcrc.asp. Accessed June 27, 2017.
11. Brandt LD, Yoshimura AS. Analysis of Sheltering and Evacuation Strategies for an Urban Nuclear Detonation Scenario. SANDIA REPORT. SAND2009-3299. http://prod.sandia.gov/techlib/access-control.cgi/2009/093299.pdf. Published May 2009. Accessed October 24, 2016.
12. Hrdina CM, Coleman CN, Bogucki S, et al. The "RTR" medical response system for nuclear and radiological mass-casualty incidents: a functional triage-treatment-transport medical response model. *Prehosp Disaster Med*. 2009;24(3):167-178. https://doi.org/10.1017/S1049023X00006774.
13. Hick JL, Weinstock DM, Coleman CN, et al. Health care system planning for and response to a nuclear detonation. *Disaster Med Public Health Prep*. 2011;5(suppl 1):S73-S88. https://doi.org/10.1001/dmp.2011.28.
14. Reeves G. Overview of use of G-CSF and GM-CSF in the treatment of acute radiation injury. *Health Phys*. 2014;106(6):699-703. https://doi.org/10.1097/HP.0000000000000090.
15. Singh VK, Newman VL, Seed TM. Colony-stimulating factors for the treatment of the hematopoietic component of the acute radiation syndrome (H-ARS): a review. *Cytokine*. 2015;71(1):22-37. https://doi.org/10.1016/j.cyto.2014.08.003.
16. Myeloid Cytokines for Acute Myelosuppressive Doses of Radiation (Hematopoietic Subsyndrome of ARS). Radiation Emergency Medical Management. US Dept. of Health and Human Services website. https://www.remm.nlm.gov/cytokines.htm. Accessed February 4, 2017.
17. Dainiak N, Gent RN, Carr Z, et al. First global consensus for evidence-based management of the hematopoietic syndrome resulting from exposure to ionizing radiation. *Disaster Med Public Health Prep*. 2011;5(3):202-212. https://doi.org/10.1001/dmp.2011.68.
18. Strategic National Stockpile. Office of Public Health Preparedness and Response. Centers for Disease Control and Prevention website. http://www.cdc.gov/phpr/stockpile/stockpile.htm. Accessed October 24, 2016.
19. Strategic National Stockpile. Radiation Emergency Medical Management. US Department of Health and Human Services website. https://www.remm.nlm.gov/sns.htm. Accessed February 4, 2017.

20. Smith TJ, Bohlke K, Lyman GH, et al. Recommendations for the use of WBC growth factors: American Society of Clinical Oncology Clinical Practice Guideline update. *J Clin Oncol*. 2015;33(28):3199-3212. https://doi.org/10.1200/JCO.2015.62.3488.
21. Herbst C, Naumann F, Kruse EB, et al. Prophylactic antibiotics or G-CSF for the prevention of infections and improvement of survival in cancer patients undergoing chemotherapy. *Cochrane Database Syst Rev*. 2009;(1):CD007107.
22. About Lymphocyte Depletion Kinetics. Radiation Emergency Medical Management. US Department of Health and Human Services website. https://www.remm.nlm.gov/aboutlymphocytedepletion.htm. Accessed October 24, 2016.
23. Goans RE, Holloway EC, Berger ME, et al. Early dose assessment following severe radiation accidents. *Health Phys*. 1997;72(4):513-518. https://doi.org/10.1097/00004032-199704000-00001.
24. Goans RE, Holloway EC, Berger ME, Ricks RC. Early dose assessment in criticality accidents. *Health Phys*. 2001;81(4):446-449. https://doi.org/10.1097/00004032-200110000-00009.
25. Andrews GA, Auxier JA, Lushbaugh CC. The importance of dosimetry to the medical management of persons exposed to high levels of radiation. In: *Personal Dosimetry for Radiation Accidents*. Vienna: International Atomic Energy Agency; 1965. https://doi.org/10.2172/4606717.
26. Wilkins RC, Romm H, Kao TC, et al. Interlaboratory comparison of the dicentric chromosome assay for radiation biodosimetry in mass casualty events. *Radiat Res*. 2008;169(5):551-560. https://doi.org/10.1667/RR1272.1.
27. Prasanna PG, Moroni M, Pellmar TC. Triage dose assessment for partial-body exposure: dicentric analysis. *Health Phys*. 2010;98(2):244-251. https://doi.org/10.1097/01.HP.0000348020.14969.4.
28. Exposure: Diagnose and Manage Acute Radiation Syndrome (including integrated calculators). Radiation Emergency Medical Management. US Department of Health and Human Services website. https://www.remm.nlm.gov/exposureonly.htm. Accessed February 4, 2017.
29. Coleman CN, Weinstock DM, Casagrande R, et al. Triage and treatment tools for use in a scarce resources-crisis standards of care setting after a nuclear detonation. *Disaster Med Public Health Prep*. 2011;5(suppl 1):S111-S121. https://doi.org/10.1001/dmp.2011.22.
30. Lethality as a Function of Dose and LD 50/60 - Illustration. Radiation Emergency Medical Management. US Department of Health and Human Services website. https://www.remm.nlm.gov/LD50-60.htm. Accessed February 4, 2017.
31. Waselenko JK, MacVittie TJ, Blakely WF, et al. Medical management of the acute radiation syndrome: recommendations of the Strategic National Stockpile Radiation Working Group. *Ann Intern Med*. 2004;140(12):1037-1051. https://doi.org/10.7326/0003-4819-140-12-200406150-00015.
32. Casagrande R, Wills N, Kramer E, et al. Using the model of resource and time-based triage (MORTT) to guide scarce resource allocation in the aftermath of a nuclear detonation. *Disaster Med Public Health Prep*. 2011;5(S1):S98-S110. https://doi.org/10.1001/dmp.2011.16.
33. Chilcott RP, Amlot R, eds. Decontamination Guidance for Chemical Incidents. Primary Response Incident Scene Management (PRISM). Biomedical Advanced Research and Development Authority (BARDA). US Department of Health and Human Services website. https://www.medicalcountermeasures.gov/barda/cbrn/decontamination-guidance-for-chemical-incidents/. Accessed February 4, 2017.
34. Sandgren DJ, Salter CA, Levine IH, et al. Biodosimetry Assessment Tool (BAT) software-dose prediction algorithms. *Health Phys*. 2010;99(suppl 5):S171-S183. https://doi.org/10.1097/HP.0b013e3181f0fe6c.
35. Interagency Modeling and Atmospheric Assessment Center (IMAAC). US Department of Homeland Security website. https://www.dhs.gov/imaac. Accessed February 4, 2017.
36. Adalja AA, Watson M, Wollner S, Toner E. A possible approach to large-scale laboratory testing for acute radiation sickness after a nuclear detonation. *Biosecur Bioterror*. 2011;9(4):345-350. https://doi.org/10.1089/bsp.2011.0042.
37. Mettler FA Jr, Voelz GL. Major radiation exposure—what to expect and how to respond. *N Engl J Med*. 2002;346(20):1554-1561. https://doi.org/10.1056/NEJMra000365.
38. Mettler FA Jr, Upton AC. *Medical Effects of Ionizing Radiation*. 3rd ed. Philadelphia: Saunders Elsevier; 2008:353-359.
39. Fliedner TM, Friesecke I, Beyrer K. *Medical Management of Radiation Accidents: Manual on the Acute Radiation Syndrome*. Oxford, United Kingdom: British Institute of Radiology; 2001.
40. Gorin NC, Fliedner TM, Gourmelon P, et al. Consensus conference on European preparedness for haematological and other medical management of mass radiation accidents. *Ann Hematol*. 2006;85(10):671-679. https://doi.org/10.1007/s00277-006-0153-x.
41. Lerner EB, McKee CH, Cady CE, et al. A consensus-based gold standard for the evaluation of mass casualty triage systems. *Prehosp Emerg Care*. 2015;19(2):267-271. https://doi.org/10.3109/10903127.2014.959222.
42. Demidenko E, Williams BB, Swartz HM. Radiation dose prediction using data on time to emesis in the case of nuclear terrorism. *Radiat Res*. 2009;171(3):310-319. https://doi.org/10.1667/RR1552.1.
43. Parker DD, Parker JC. Estimating radiation dose from time to emesis and lymphocyte depletion. *Health Phys*. 2007;93(6):701-704. https://doi.org/10.1097/01.HP.0000275289.45882.29.
44. Camarata AS, Switchenko JM, Demidenko E, Flood AB, Swartz HM, Ali AN. Emesis as a screening diagnostic for low dose rate (LDR) total body radiation exposure. *Health Phys*. 2016;110(4):391-394. https://doi.org/10.1097/HP.0000000000000476.
45. About Time to Onset of Vomiting. Radiation Emergency Medical Management. US Department of Health and Human Services website. https://www.remm.nlm.gov/aboutvomiting.htm#references. Accessed February 4, 2017.
46. Farese AM, Brown CR, Smith CP, et al. The ability of filgrastim to mitigate mortality following LD50/60 total-body irradiation is administration time-dependent. *Health Phys*. 2014;106(1):39-47. https://doi.org/10.1097/HP.0b013e3182a4dd2c.
47. Radiation Injury Treatment Network. National Marrow Donor Program. http://www.ritn.net/. Accessed October 24, 2016.

https://doi.org/10.1017/dmp.2017.86 Published online by Cambridge University Press