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# Preparing for the Aftermath of a Nuclear Detonation; an Analytic Framework for Disaster Management

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# Preparing for the Aftermath of a Nuclear Detonation; an Analytic Framework for Disaster Management

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**Preparedness activities for complex, technical hazards require a sound scientific basis integrated into appropriate guidelines and preparedness activities. The Federal *Planning Guidance for Response to a Nuclear Detonation* provides the strategy for response to an improvised nuclear device detonation and was built on an analytical framework of supporting science developed by national laboratories and other technical organizations. Recent advances in our understanding of the hazards posed by such an event includes detailed fallout predictions from the advanced suite of three-dimensional meteorology and plume/fallout models developed at Lawrence Livermore National Laboratory, including extensive global geographical and real-time meteorological databases to support model calculations.**

**This is an updated case study of the analytic framework for disaster management being applied to response preparedness. The methodology and results, including visualization aids developed for response organizations, have greatly enhanced the community planning process through first-person points of view and description of the dynamic nature of the event.**

***Keywords-improvised nuclear device; disaster management; emergency response; radiological hazard; blast analysis***

## I. INTRODUCTION

The Federal Emergency Management Agency (FEMA) provides technical guidance for regional, state and local responders who have responsibility for developing local Improvised Nuclear Device (IND) response plans. In support of these preparedness activities, Lawrence Livermore National Laboratory (LLNL) provides advanced modeling; technical assessments; briefings; and reports to inform Federal, state, and local response and recovery planning activities. This technical work provide the analytic framework for sound Federal, state, local, and private sector nuclear terrorism response planning.

This document provides an overview of the potential impacts of a nuclear detonation, and the planning considerations that could dramatically reduce the number of casualties by helping the public and responders avoid exposure and support rapid response.

Extensive review of nuclear weapon effects studies and discussions with nuclear weapon effects experts from various federal agencies, national laboratories, and technical organizations have identified key issues and bounded many of the unknowns required to support response planning for a low-yield, ground-level nuclear detonation in a modern U.S. city.

The scale and severity of disasters are growing and will likely pose systemic threats that require an engaged and resilient community to address [1]. Disaster-management strategies will be affected by many factors, including global interdependencies, technical innovation and dependency, the evolving terrorist threat, and the changing role of the individual. Meeting these challenges requires much more sophisticated methodologies and innovative approaches to predicting, understanding, and mitigating potential hazards through the development of effective response plans to improve resiliency.

Preparing for a catastrophic event is quantitatively different in terms of mass casualties and fatalities, infrastructure damage, and disruption of life-sustaining services. For complex technical threats involving weapons of mass destruction (WMD), actions taken now to understand and plan for the immediate aftermath of such an event will be critical to saving lives and rebuilding communities. The Disaster Management Analytic Framework (DMAF) [2] enables emergency planners to quantify and visualize the impact of a significant WMD incident. DMAF provides insights that can lead to more effective preparedness for response and recovery operations and can be applied to other catastrophic planning activities.

Scenario #1 of the 15 Department of Homeland Security (DHS) national planning scenarios is a 10kT improvised nuclear device (IND) detonation. An effective response involves managing a large-scale incident, including mass casualty, mass evacuation, and mass decontamination issues. Preparedness planning activities based on the nuclear terrorism scenario present difficult challenges in time-critical decision making; the need to coordinate large-scale response operations across multiple jurisdictions; and the need to effectively respond with limited infrastructure and resources. A DMAF for scenario #1 was utilized to define key characteristics of the event and aid response planning.

In 2007, the U. S. Congress expressed concern that cities have little guidance to help them prepare their populations for the critical moments shortly after a nuclear terrorism event. They directed the DHS, Office of Health Affairs (OHA) to work with the National Academies Institute of Medicine, the Homeland Security Institute, the national laboratories, and state and local response organizations to address this issue [3]. The OHA initiative is currently managed by FEMA as part of a

coordinated federal effort to improve response planning for a nuclear detonation.

## II. NEED FOR PLANNING GUIDANCE

Federal protective action guidance for radiation exposure has existed for decades; however, the focus has been concentrated on avoiding relatively low-level exposures to decrease the risk of cancer from an accidental transportation or nuclear power plant release. The 2008 Federal Register Notice published by DHS [4], which clarified how existing protective action guidance can be applied for radiological and nuclear terrorism, did not specifically address guidance for the acute effects of a domestic nuclear explosion. This was a recognized deficiency and the analytical framework approach was used provide supporting science to inform a development effort by the Office of Science and Technology Policy to provide guidance for responding to the aftermath of a nuclear detonation in a modern city [5]. A 2013 update of the protective action guides [6] reaffirmed that “PAGs were inadequate for early response planning needs specific to an IND” and the OSTP guidance is the appropriate document for this information.

The Cold War civil defense program can help with some insights and advice, but many of the paradigms no longer apply. For example, the concept of a fallout shelter worked well with a few minutes warning of incoming missiles, but its applicability is less clear for an attack that occurs without any notice. There also appeared to be a lack of scientific consensus on the appropriate actions to take after a nuclear detonation. For example, the recommendations of DHS’s *Ready.gov*, which are consistent with the recommendations of the National Academy of Sciences [7], were recently criticized by the Federation of American Scientists [8] because of conflicting recommendations with a RAND study [9].

The work presented here demonstrates how the DMAF principle was used to update the Cold War guidance to address the asymmetric threat we now face. Both society and urban environments have changed significantly over the last half-century, and new preparedness guidance is required.

## III. METHODOLOGY

This DMAF methodology provided key planning considerations and response strategies associated with response to a nuclear detonation. These strategies are designed to protect response personnel, provide regional situational assessment, and support public health and safety. A capabilities-based planning approach utilized extensive modeling and technical analysis and discussions with almost 500 emergency responders from across the nation to develop key response planning factors. The DMAF provides a common foundation that facilitates the development of strategic response priorities and enables a more collaborative, transparent, and responsive analysis for planning scenarios<sup>1</sup>. Every community has unique requirements and may reasonably adopt different response strategies based on the same analysis. For example, the

importance of early, adequate shelter followed by informed evacuation as a key public protection strategy will be applied differently in a community that lacks an abundance of adequate shelters or effective evacuation routes.

To resolve conflicts in the technical community and create a coordination point for research, DHS formed the IND Modeling and Analysis Coordination Working Group (MACWG). Membership includes national laboratories, technical organizations, and federal agencies. The purpose of the MACWG is to establish scientific consensus (where possible) on nuclear weapons effects; bound uncertainties and identify unknowns; and resolve conflicts with respect to recommended response actions. The MACWG brought together the collective capabilities in nuclear-weapon effects modeling, atmospheric transport and dispersion, radiation health physics, and blast and shelter analyses to create a scientific basis for IND response planning. The MACWG has enabled better coordination within the federal, state, and local community and has provided a venue in which to discuss critical scientific and technical issues that must be resolved to save lives and ensure resilience to disasters.

## IV. NUCLEAR DETONATION EFFECTS

The basic anatomy of a nuclear explosion is well known and documented in literature such as Glasstone’s *The Effects of Nuclear Weapons* [10] and NATO documents [11]. Mitigating the impact of a domestic nuclear explosion requires a basic understanding of key effects. These effects can be broken into two main components: prompt and delayed. As an example, the effects identified below are approximate for a ten kiloton (10kt) nuclear explosion in a generic large city. This is consistent with the national planning scenario #1 and with early nuclear weapons such as those used on Hiroshima and Nagasaki.

Primary among prompt effects is blast (Figure 1). A 10kt explosion is equivalent to 5,000 truck bombs like the one used to destroy the Murrah building in the 1995 Oklahoma City bombing [12]. Blast will damage or destroy most buildings within a half-mile of the detonation location, and it is unlikely that the population in this area would survive. From a half-mile to about a mile out, survival will mostly likely depend on the type of structure a person was in when the blast occurred. Even at a mile, the blast wave will have enough energy to overturn some cars and severely damage some light structures.

A mile from the detonation is also the approximate distance at which a person outdoors could receive a significant exposure of initial ionizing radiation. The closer to the detonation point, the higher the exposure. The same is also true for an outdoor individual’s exposure to the thermal pulse from the detonation, which may also cause burns to exposed skin out to this range, and possibly further on a day with good visibility. Both of these effects are reduced for people inside buildings or in the shadow of buildings in the urban area.

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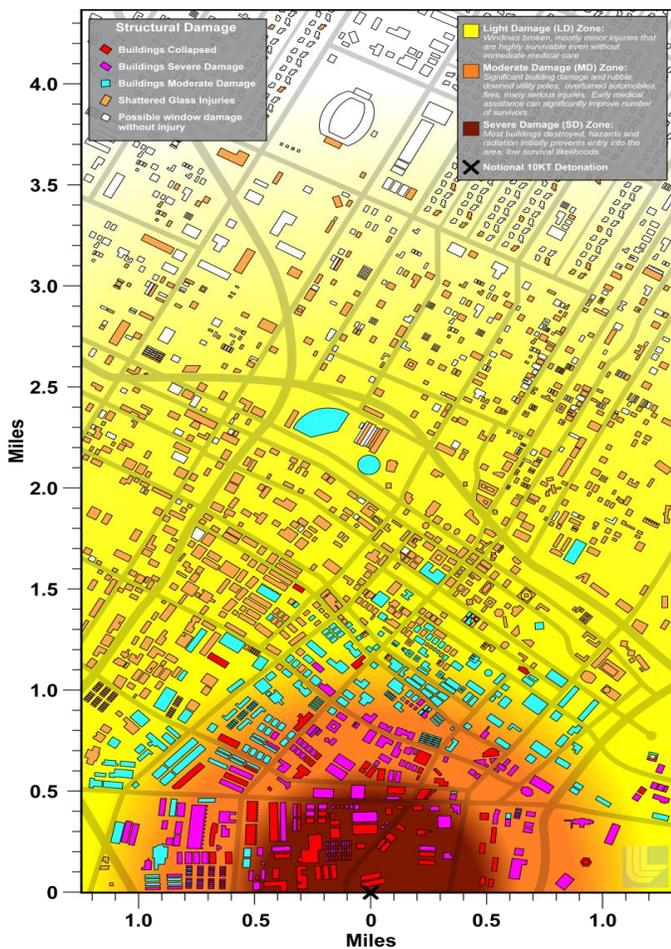


Figure 1. Damage zones resulting from a domestic nuclear detonation.  
Figure Credit: Lawrence Livermore National Laboratory.

In addition to ionizing and thermal radiation, the detonation creates a brilliant flash of light that can cause temporary blindness to those outdoors over 5 miles away. This effect could go further if there is good visibility or clouds to reflect the light, or if the event occurs at night. “Flash blindness” can even occur if the victim is not looking in the direction of the detonation. It can last several seconds to minutes. Although this effect does not cause permanent damage, the sudden loss of vision to drivers and pilots could cause a large number of traffic casualties and make many roads impassable.

Another long-range prompt effect, which is poorly understood, is glass breakage. Most of the injuries outside of the Murrah building in the 1995 Oklahoma City bombing were caused by this phenomenon [13]. Extrapolating from more recent work on conventional explosives [14], a 10kt explosion could break certain types of windows (e.g., large monolithic annealed) over 8 miles away. Also noted in this same study was the tendency for glass to fail catastrophically even at extreme ranges, causing severe injury to those behind it. NATO medical-response planning documents [11] for nuclear deto-

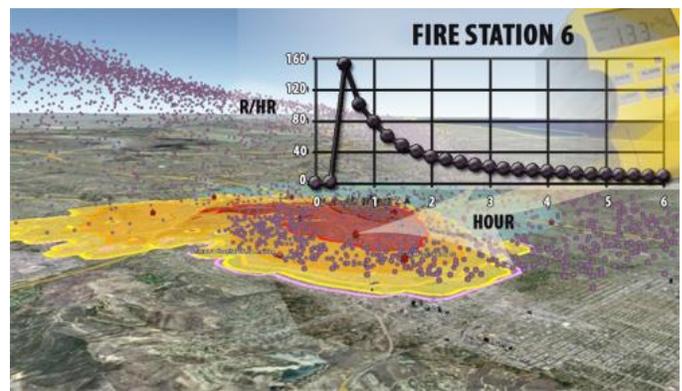


Figure 2. Example of fallout pattern from a 10kt ground-level detonation.  
Figure Credit: Lawrence Livermore National Laboratory.

nations state that “...missile injuries will predominate. About half of the patients seen will have wounds of their extremities. The thorax, abdomen, and head will be involved about equally.” A significant number of victims from Nagasaki arriving at field hospitals exhibited glass-breakage injuries.

The primary delayed effect from a ground-level nuclear detonation is from ‘fallout’ (Figure 2). Fallout is generated when the dust and debris excavated by the explosion combine with radioactive fission products and are drawn upward by the heat of the event. This cloud rapidly climbs through the atmosphere, up to 5 miles high for a 10kt, and highly radioactive particles coalesce and drop back down to earth as it cools. It is important to note that Hiroshima and Nagasaki did not have significant fallout because their detonations occurred at altitude.

The hazard from fallout comes not from breathing the particles, but from being exposed to the ionizing radiation they give off after they have settled on the ground and building roofs. Radiation levels from these particles will drop off quickly: most (55%) of the potential exposure occurs in the first hour, and 80% occurs within the first day. Although they are highly dependent on weather conditions, the most dangerous concentrations of fallout particles (i.e., potentially fatal to those outside) occur within 10 miles downwind of the event and are clearly visible as they fall, often the size of fine sand or table salt [15].

## V. RECENT RESEARCH

The results of recent modeling [16] indicate that a modern urban environment can greatly mitigate some of the effects of a low-yield nuclear detonation. For example, thermal burns from the heat of the initial explosion, primarily a line-of-sight phenomenon, can be greatly reduced in an urban environment where structures can block the thermal radiation. Fig. 3 shows how building shadows can protect the outdoor population from significant thermal exposure by modeling conducted at Lawrence Livermore National Laboratory [17].

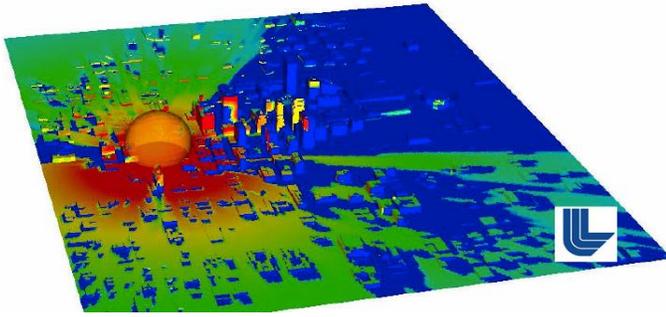


Figure 3. Integrated thermal flux from a 10kt ground-level nuclear detonation in a small U.S. city. Figure Credit: Lawrence Livermore National Laboratory.

Detailed MCNP Models developed at Applied Research Associates (ARA) [18] and Los Alamos National Laboratory have shown similar reductions in injuries from the initial radiation produced in the first minute of a nuclear explosion. Figure 4 demonstrates the nonsymmetrical reduction in radiation exposure by the urban environment. The right side of the image represents an unobstructed exposure from a 10kT surface detonation as compared to the reduction of outdoor radiation levels indicated in the left side of the image. Like the thermal analysis, these studies indicate that the ambient, outdoor radiation levels from a low-yield, ground-level nuclear detonation in an urban environment could be significantly reduced.

Unlike prompt effects, which occur too rapidly to avoid, health effects from fallout can be mitigated by leaving the area before the fallout arrives or by taking shelter from it. Although some fraction of ionizing radiation can penetrate buildings, shielding offered by walls and distance from outdoor fallout particles can easily reduce exposures by a factor of 10 or more, even in common urban buildings.

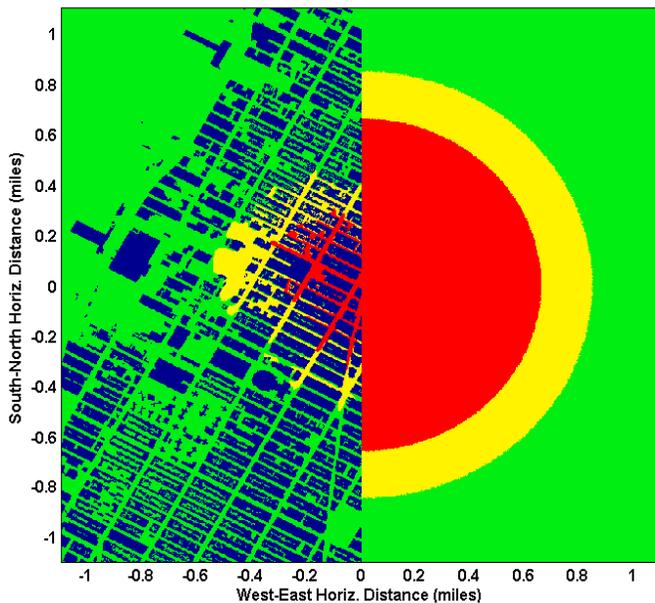


Figure 4. Outdoor casualty areas for high rise urban area (left) and for an open field (right) from a 10-kT IND; red >800 rads (lethal), yellow 100-

800rads (injurious to lethal), green < 100 rad (non injurious). Figure Credit: Applied Research Associated, LLC.

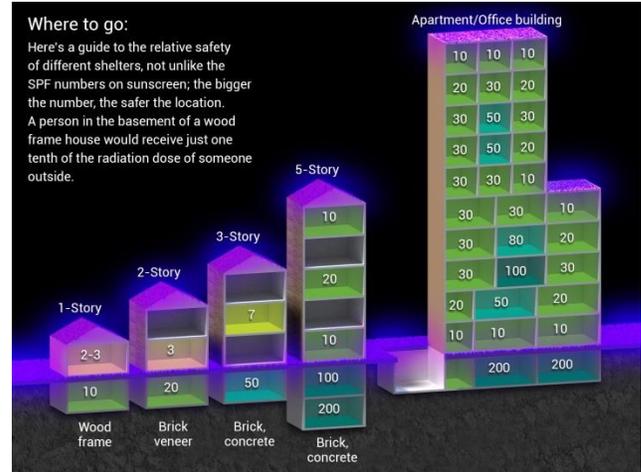


Figure 5. PF by building and by location within building. Figure Credit: Lawrence Livermore National Laboratory.

The quality of shelter is defined by a protection factor (PF), which is equal to the ratio of outside dose rate divided by inside dose rate. Like sunscreen's SPF, the higher the PF value, the lower the exposure compared to the exposure of an unsheltered person in the same area. Figure 5 above shows sample PF estimates based on evaluations conducted in 1973 [19] for typical structures during that era.

Efforts are under way to update the analysis of the level of protection that modern buildings could provide from fallout radiation. Figures 6 shows an analysis of more detailed urban structures completed at Lawrence Livermore National Laboratory, in which most areas (shown in green or blue) had PFs greater than 10; which is considered adequate by the Federal Planning Guidance.

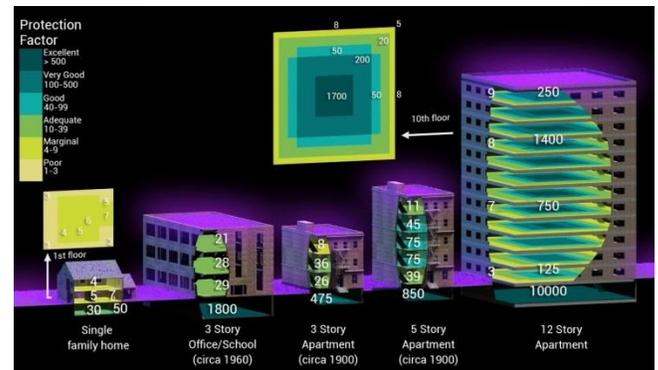


Figure 6. Protection provided by typical urban buildings. Figure Credit: Lawrence Livermore National Laboratory.

Scientists at Lawrence Livermore National Laboratory are developing the capability to assess the quality of urban shelter with respect to nuclear fallout on a regional level [20]. With the results of this assessment (see Figure 7), planners and responders can estimate: (a) the protection provided by existing buildings to fallout radiation, (b) the effectiveness of shelter strategies using existing buildings, and (c) approximate radiation exposures if these shelter strategies were to be used.

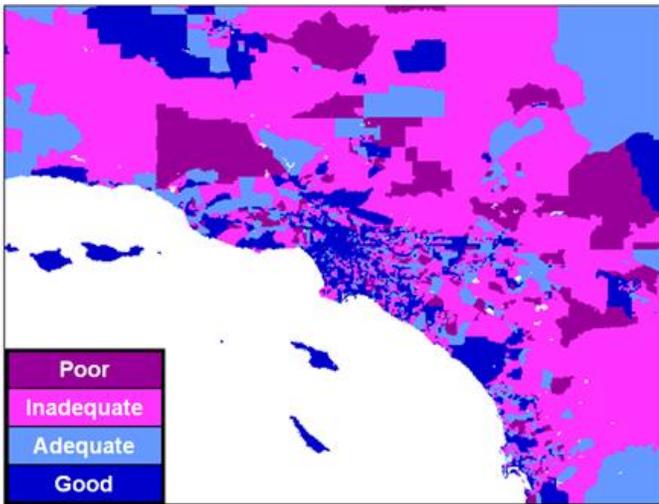


Figure 7. Illustrative evaluation of the protection offered by local (nearby) shelter in the Los Angeles Basin. Figure Credit: Lawrence Livermore National Laboratory.

Other effects, such as the electromagnetic pulse (EMP) and fires, also need to be considered in response planning and are areas of ongoing research. For a ground-level detonation, most EMP effects will be limited to the blast-damage zones, with a few, random, longer-range disruptions occurring a few miles beyond. Although the possibility of a ‘firestorm’ is unlikely given modern construction, there will be a large number of small, disparate fires started by thermal and blast effects (generally around the 1-mile perimeter), which could spread and coalesce if not mitigated. [24]

## VI. KEY RESPONSE PLANNING FACTORS

As stated in the outset of this paper, the end goal of this activity is to build the scientific foundation for responding to

large-scale disasters utilizing a nuclear detonation as a case study. *Planning Guidance for Response to a Nuclear Detonation*, 2<sup>nd</sup> Edition, produced by a Federal interagency committee led by the Executive Office of the President, Office of Science and Technology Policy [16], is the result of a collaborative effort across many federal departments and agencies. It utilized some of the latest research discussed in this paper and identifies key recommendations in order to respond to and recover from an IND incident. The document identified a zoned approach to facilitate response planning, with the key zones defined as:

- **Light Damage Zone:** Windows mostly broken; injuries requiring self- or outpatient-care.
- **Moderate Damage Zone:** Significant building damage and rubble, downed utility poles, overturned automobiles, fires, many serious injuries; greatest life-saving opportunities.
- **Severe Damage Zone:** Most buildings destroyed; radiation prevents entry into the area; lifesaving not likely.
- **Dangerous Fallout Zone:** Area where large doses could be delivered to the unsheltered public and emergency responders in a short period of time. This is the dark purple area in Fig. 8.
- **Hot Zone or 0.01 R/h Boundary:** Areas where emergency operations can be safely performed provided that responders take appropriate planning and dose monitoring and control measures. This is the light purple area in Figure 8.

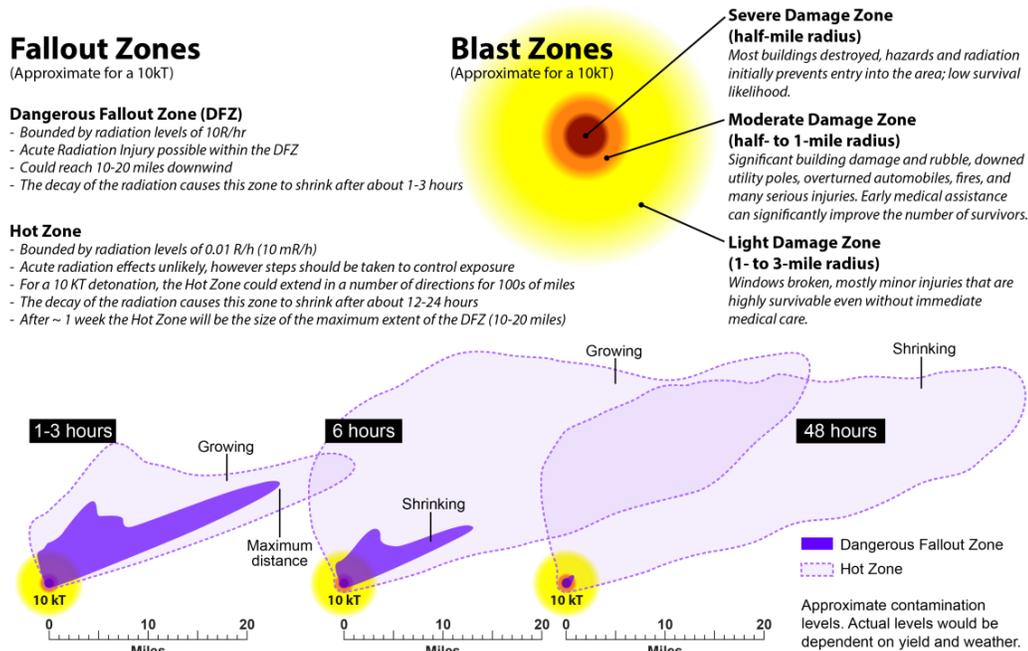


Figure 8. Description of Key Response Planning Zones. Figure Credit: Lawrence Livermore National Laboratory.

The *Key Response Planning Factors for the Aftermath of Nuclear Terrorism* report [21] provided the scientific basis necessary to identify the following response objectives:

- Seek adequate shelter—the most critical lifesaving action for the public and responders is to seek adequate shelter (PF of 10 or more) for at least the first hour.
- Protect response personnel—initial responder efforts should be spent on making high-range dose-rate measurements within their shelter.
- Support regional situation assessment.
- Develop an informed evacuation strategy.

The National Council of Radiation Protection and Measurement Report Number 165; *Responding to Radiological and Nuclear Terrorism: A Guide for Decision Makers* [22] provides additional scientific backing for the response strategies discussed above. This report is a comprehensive analysis of key decision points and information needed by decision makers at the local, regional, state, and federal levels to help them respond to radiological or nuclear terrorism incidents.

DHS has continued to develop and use the supporting science for response planning activities. Several FEMA regions have developed IND regional joint planning guides and response playbooks to supplement their All Hazards Plans using community specific impact assessments. With every community assessment, new discoveries are made to inform and improve the planning process. FEMA continues to work with responders, emergency managers, and regional planners to better understand how to apply the supporting science and identify community needs.

FEMA continues to facilitate federal, state, and local agency working groups that develop improved guidance and information such as the *Improved Nuclear Device Response and Recovery; Communicating in the Immediate Aftermath* [23]. The updated analysis and resulting guidance has been integrated into the training curriculum of FEMA's Incident Management Assistance Teams and mainstream education programs such as Harvard's "Radiological Emergency Planning: Terrorism, Security, and Communication" [24] and Georgetown University's Emergency and Disaster Management Master's Program [25].

## VII. CONCLUSION

Recent advances in analyzing the effects of a nuclear detonation in an urban area have addressed a number of difficult issues and greatly improved our ability to reduce the consequences of such a horrific event. However, considerable research challenges remain. It is important to note that although sound science is the cornerstone of good response planning, it must be tempered with the unique issues, operational realities, and constraints of emergency-response capabilities in each community. As such, each community may reasonably adopt different response strategies based on the same technical analysis.

This is the cornerstone of the Disaster Management Analytic Framework (DMAF) which provides a flexible process for (1) developing and using sound science to (2) inform community specific assessments that will (3) support the development of guidance that (4) drives regional and national preparedness. The DMAF can be applied to a variety of natural and manmade catastrophic events involving large-scale incident response, and is especially useful for technical hazards that often confound traditional response planning efforts. DMAF facilitates scientific consensus and the development of comprehensive planning guidance in support of emergency managers and response operations.

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