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National Capital Region
Key Response Planning Factors
for the Aftermath of Nuclear Terrorism

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Acronyms

3D	three dimensional
AC	assembly center
AHA	American Hospital Association
ARA	Applied Research Associates
ARS	acute radiation syndrome
BARDA	Biomedical Advanced Research and Development Authority
DCPA	Defense Civil Preparedness Agency
DHHS	Department of Health and Human Services
DHS	Department of Homeland Security
DOD	Department of Defense
DOE	Department of Energy
DFZ	dangerous fallout zone
EAS	Emergency Alert System
EC	evacuation center
EMP	electromagnetic pulse
EMPC	Electromagnetic Pulse Commission
EOC	Emergency Operations Center
EOP	Executive Office of the President
FEMA	Federal Emergency Management Agency
FRMAC	Federal Radiological Monitoring and Assessment Center
Gy	gray
HSEMA	Homeland Security and Emergency Management Agency (DC)
ICRP	International Council on Radiation Protection
IE	informed evacuation
IMAAC	Interagency Modeling and Atmospheric Assessment Center
IND	improvised nuclear device
IPAWS	Integrated Public Alert and Warning System
kT	kiloton
LDZ	light damage zone
LLNL	Lawrence Livermore National Laboratory
MACWG	Modeling and Analysis Coordination Working Group
MC	medical care
MDZ	moderate damage zone
MT	megaton
NARAC	National Atmospheric Release Advisory Center
NCR	National Capital Region
NCRP	National Council on Radiation Protection and Measurement
NUEVAC	Nuclear Evacuation Analysis Code
NNSA	National Nuclear Security Administration
NTS	Nevada Test Site
OHA	Office of Health Affairs
ORNL	Oak Ridge National Laboratory
PAG	protective action guide
PERD	personal emergency radiation detector
PPE	personal protective equipment
PRD	personnel radiation detector
PRND	preventive radiological nuclear detection
R	Roentgen
RDD	radiological dispersal device
REMM	Radiation Emergency Medical Management
RTR	radiation triage, transport, and treatment
R&R	response and recovery
SAVER	System Assessment and Validation for Emergency Responders
SCBA	self-contained breathing apparatus
SDZ	severe damage zone
SNL	Sandia National Laboratories
Sv	Sievert
SVALIN	regional database on shelter distribution
S&T	Science and Technology
UPMC	University of Pittsburg Medical Center

Contents

(Appendices available from responder.llnl.gov)

1. Overview

Background

The National Capital Region (NCR) has an established Federal, state, and local emergency response infrastructure. For a nuclear detonation, efforts are underway to further refine roles and expected activities as part of a regional improvised nuclear device (IND) response planning process. The planning process has involved several workshops through the summer and fall of 2011, and is led by a subcommittee from the Council of Governments and supported by the Federal Emergency Management Agency's (FEMA) Office of National Capital Region, The Department of Defense's (DoD) Office of Secretary of Defense, and FEMA Response Planning Division who sponsored the development of this report.

In support of such preparedness activities, FEMA has engaged Lawrence Livermore National Laboratory (LLNL), Sandia National Laboratories (SNL), and Applied Research Associates (ARA) to provide advanced modeling; technical assessments; briefings; and reports to inform Federal, state, and local response and recovery planning activities. This report, along with the response capability requirements and gaps collected during the workshops, provide the analytic framework for sound Federal, state, local, and private sector nuclear terrorism response planning.

IND response planning activity stems from the U.S. Troop Readiness, Veterans' Care, Katrina Recovery, and Iraq Accountability Act, 2007, (Public Law 110-28), which expressed concern that cities have little available guidance to better prepare their populations for the critical moments shortly after a nuclear terrorism incident. In May 2008, the Department of Homeland Security (DHS), Office of Health Affairs (OHA), launched a program to address this issue by engaging the National Academies' Institute of Medicine, the Homeland Security Institute, and the Department of Energy's National Nuclear Security Administration (DOE/NNSA) national laboratories. This activity was taken over by the DHS FEMA Response, CBRNE branch, which established the DHS Strategy for Improving the National Response and Recovery from an IND Attack (DHS, 2010). As part of its strategy, DHS has supported the improvement of response guidance and has engaged in community-specific assessments to be used in IND response and recovery planning activities.

Longstanding Federal protective action guidance (FR 73-149) exists for accidental radiation exposure to the public; however, the focus has been on avoiding relatively low-level exposures to decrease the risk of cancer from accidental transportation or nuclear power plant release. The Cold War civil defense program provides some insights and advice, but many of its paradigms no longer apply. For example, the concept of a fallout shelter worked well with the likelihood of advanced warning of incoming missiles, but its applicability is less clear for an attack that occurs without notice. Recent research[1] and updated Federal guidance (EOP, 2010) have identified key actions that can be taken to save and sustain life after a nuclear detonation. This report explores the application of recent research and guidance for use by National Capital Region (NCR) decision-makers and responders in assessing community-specific implementation.

An example of the difference between improvised devices and strategic nuclear weapons is clear in Figure 1, which shows the extent of prompt effects from the detonation point for nuclear

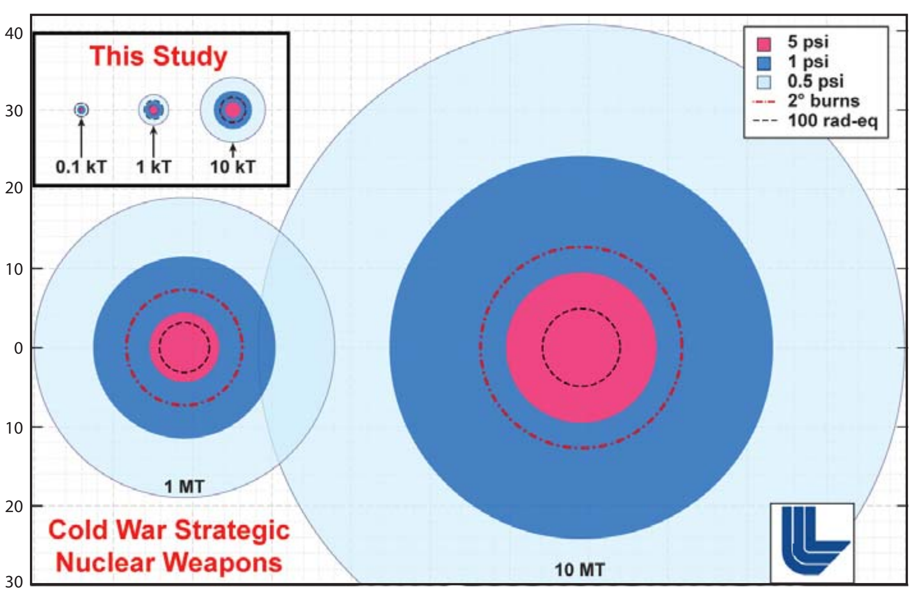


Figure 1. The different colors and lines identify damaging pressures, burns, and doses associated with detonations of various size. The present report is concerned with low-yield nuclear weapons that are far smaller in scale that those associated with the Cold War.

[1] Examples of recent research can be found in (Buddemeier, 2010), (Brandt, 2009a, 2009b, 2009c, 2011a, 2011b), (Nasstrom, 2011), (Johnson, 2010), and (Bergman, 2011b).

terrorism devices (0.1, 1, and 10 kT) compared to those associated with military strategic nuclear weapons (1 and 10 MT).

Methodology

A low-yield explosion from an IND is quite different from Cold War strategic thermonuclear detonation scenarios upon which much of our current understanding and civil defense planning are based. Cold War recommendations provide some insights and advice; however, many of the former paradigms are no longer applicable and must be updated for modern cities and the nature of current threats. This report describes some common misconceptions about a low-yield nuclear detonation and explains important planning considerations.

The basic anatomy of a nuclear explosion is well known and documented in the literature[2]. Mitigating the impacts of a domestic nuclear explosion requires a basic understanding of several key effects. Effects can be categorized as prompt and delayed, or fallout in the latter case. Prompt effects are those that radiate outward from the detonation location within the first minute. Fallout is generated when dust and debris excavated by the explosion are combined with radioactive fission products produced in the nuclear chain reaction. The radioactive material is drawn upward by the heat of the event, often forming a "mushroom cloud" for the first few minutes after detonation. Later as it cools, highly radioactive particles drop back down to earth. Unlike prompt effects, which can occur too rapidly to be easily avoided, exposure to fallout radiation can be minimized by appropriate shelter and evacuation strategies.

This report identifies key planning strategies and important considerations associated with response to a nuclear detonation. The strategies—designed to (a) protect response personnel, (b) perform regional situational assessment, and (c) support public safety—were developed for emergency response planners. This work is the culmination of extensive modeling and technical analysis together with interactions among several hundred emergency response personnel in the NCR. 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. Every community has unique issues, and each may reasonably adopt different response strategies based on the same technical 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 develop the planning factors recommended in the following sections, detailed and state-of-the-art modeling was performed to illustrate and describe potential effects from the hypothetical impact of a 10-kT IND detonation in downtown Washington, DC at the intersection of K Street NW and 16th Street NW using actual weather observed near the detonation site on February 14, 2009. The underlying science used to develop this hypothetical scenario originated from the DHS Science and Technology Integrated Terrorism Risk Assessment (ITRA) required by Homeland Security Presidential Directive 18 (EOP, 2007). Interagency Modeling and Atmospheric Assessment Center (IMAAC) operations at LLNL provided a hypothetical analysis of 0.01-, 0.1-, 1- and 10-kT detonations in downtown Washington, DC and many other locations as well.

The data provided detailed and location-specific information using two grids centered on the hypothetical point of detonation. At the finer scale, a 10- × 10-km grid was used to show grid cells with dimensions of 100 × 100 m; whereas at the larger scale, a 400- × 400-km grid contained grid cells with dimensions of 500 × 500 m. The finer-scale grid included 10,000 grid cells, and the larger-scale (wider-area) grid included a total of 640,000 grid cells. The population contained in each grid cell was representative of typical work day and was obtained from the Oak Ridge National Laboratory (ORNL) Landscan USA Population Database (Bhaduri, 2007). The effects of a nuclear detonation, including fallout, were then calculated for each of the grid cells. Prompt effects were calculated with the SNL NUKE Version 2 model, and fallout effects were calculated with LLNL's LODI model using spatial and time-varying weather data. An example of the grid structure illustrating population density is shown in Figure 2.

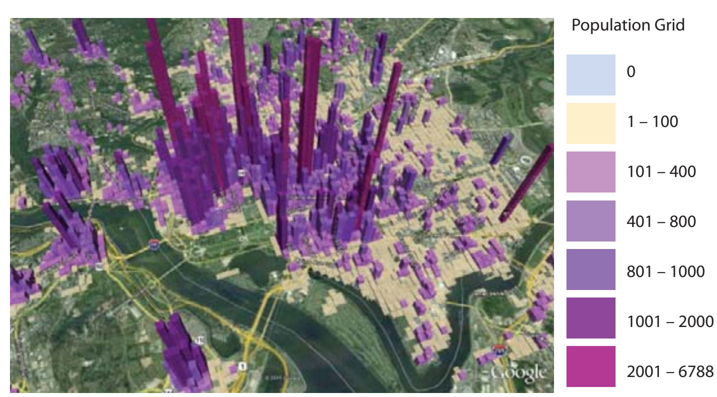


Figure 2. The finer of two modeling scales (100- by 100-m cells) is shown here for downtown Washington, DC to illustrate typical daytime population density. By incorporating other modeled information, each cell can also be used to display overpressures from a nuclear blast, thermal effects, prompt radiation, and fallout doses among other information.

[2]See Glasstone's The Effects of Nuclear Weapons (Glasstone, 1977) and NATO (NATO, 1996) documents as examples.

Researchers at SNL have examined unique, regional factors that affect planning and evacuation options to address a 10-kT nuclear detonation in downtown Washington, DC. The principal analysis tool was the Nuclear Evacuation Analysis Code (NUEVAC) (Brandt, 2009c), developed to calculate integrated doses resulting from exposure to fallout radiation during shelter and evacuation. The calculations drew on high-resolution assessments performed by IMAAC operations at LLNL. The results of these analyses are documented in a separate, more detailed, technical report (Brandt, 2011b).

To illustrate the variability in potential impacts, 12 hypothetical fallout patterns were calculated using recorded mid-day weather data for the location of interest on the 14th of each month in 2009. Figure 3 shows hypothetical results for the 12 fallout patterns associated with a 10-kT detonation in Washington, DC for 12 different days in 2009.

The baseline suite of hypothetical LLNL analyses, which includes prompt radiation exposure, thermal fluences, and peak overpressures, provides estimates for unobstructed effects. Such prompt effects would be appropriate for a ground-level detonation in an open field under ideal circumstances; however, an urban environment offers substantial protection due to geography and buildings. To address this issue, DHS formed the IND Modeling and Analysis Coordination Working Group (MACWG), consisting of national laboratories, technical organizations, and Federal agencies, to coordinate research on the effects of an IND and develop response strategies. The purpose of the MACWG is: (a) to establish scientific consensus (where possible) on the effects of, and issues related to, INDs; (b) to determine uncertainties and identify unknowns; and (c) to resolve conflicts about recommended response actions. Results of the recent research, much of which is used in this report, indicate that many of the potentially lethal effects of a nuclear detonation would be significantly mitigated by an urban environment. Buildings provide shielding and greatly reduce the propagation of thermal and ionizing radiation, and, although fallout will still pose a major hazard, adequate shelter is likely available in the NCR. Advances in scientific understanding, Federal guidance, and preparedness tools have provided a foundation for improved Federal, state, and local planning.

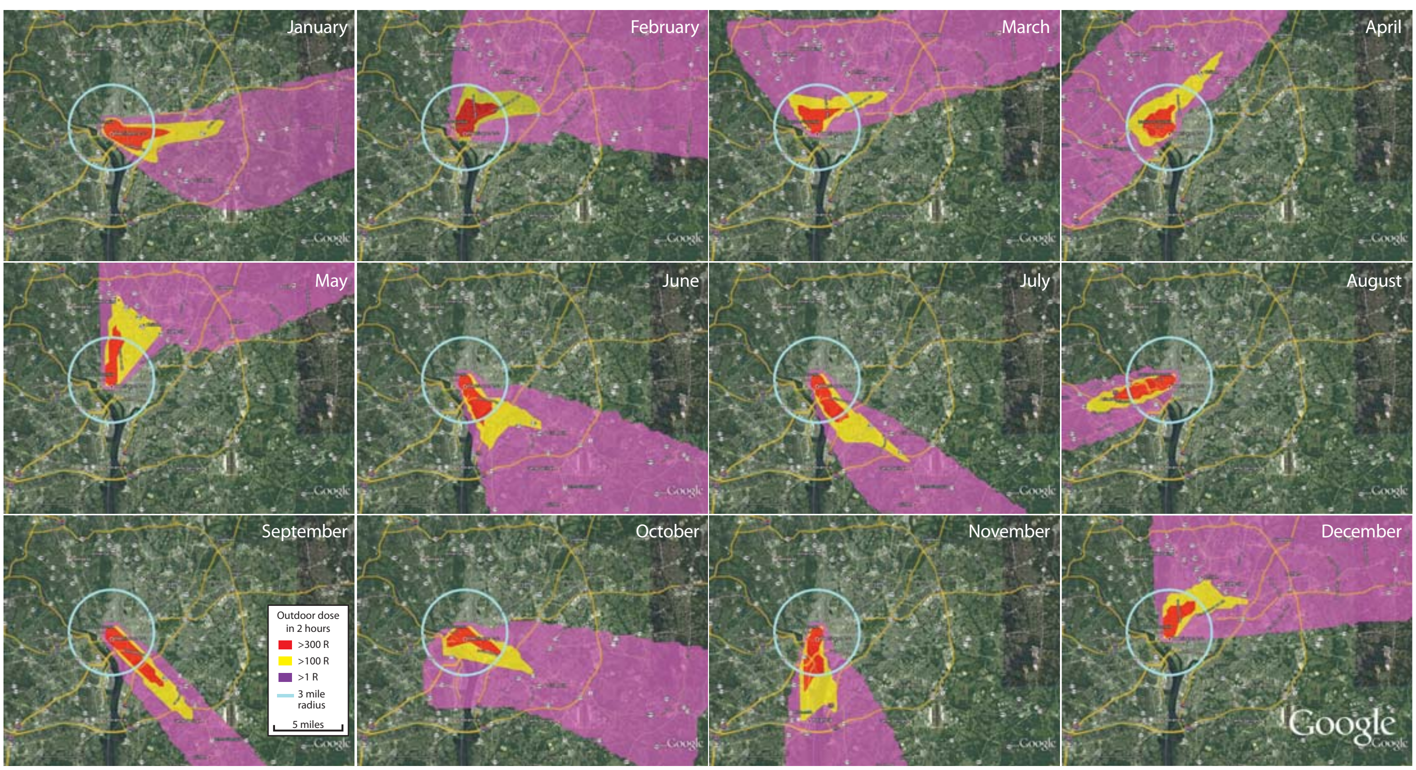


Figure 3. Examples of 12 different hypothetical fallout patterns for the NCR generated using observed conditions from the 14th of each month in 2009.

Contamination vs. Exposure

Fallout contamination is salt- and sand-sized particles that contain unstable (radioactive) atoms that give off energy in the form of ***penetrating radiation***. Although contamination particles can be stopped by clothing and other barriers, the gamma radiation emitted by the unstable atoms penetrates through clothing, roofs, and walls and can deposit energy in living tissue. It is the ***exposure*** and ***absorption*** of this energy that is the primary concern and is measured as described below.

Roentgens, rads, and rems: Units of Radiation Exposure

This document uses units familiar to American audiences and American emergency responders. For those unfamiliar with these units, a brief description follows.

- Roentgen (R): A unit of gamma or x-ray exposure in air. It is the primary standard of measurement used in the emergency-responder community in the US. 1,000 milli-roentgen (mR) = 1 Roentgen (R).
- Roentgen per hour (R/h): A unit used to express gamma or x-ray exposure in air per unit of time (exposure rate) and the unit most commonly seen on radiation-detection equipment used by responders.
- rad: A unit expressing the absorbed dose of ionizing radiation. Absorbed dose is the energy deposited per unit mass of matter. The units of rad and gray are the units in two different systems for expressing absorbed dose. (International unit conversion: 1 rad = 0.01 gray [Gy]; 1 Gy = 100 rad.)
- rem: A unit of absorbed dose that accounts for the relative biological effectiveness (RBE) of ionizing radiations in tissue (Also called equivalent dose). Not all radiation produces the same biological effect, even for the same amount of absorbed dose; rem relates the absorbed dose in human tissue to the effective biological damage of the radiation. (International unit conversion: 1 rem = 0.01 Sieverts [Sv]; 1 Sv = 100 rem.)

For the purpose of this guidance, 1 R (exposure in air) = 1 rad (absorbed dose = 1 rem (whole-body dose). Whole-body doses are calculated for the middle of the body (1.5 m off the ground and 70% of the body-surface exposure), also referred to as the “midline deep dose.”

Health Effects of Radiation Exposure

One of the largest preventable causes of casualties from a nuclear detonation is radiation exposure. Although this report does not go into detail on injury mechanisms associated with ionizing radiation, it is important to establish a general understanding of the health effects of ionizing radiation exposure.

Table 1, taken from the *Federal Planning Guidance for Response to a Nuclear Detonation* (EOP, 2010), shows the potential for injury or death from rapid exposure. Fallout exposure, protracted over hours or days, has a lower potential for injury and fatality. Remember that health effects from radiation exposure may not occur until weeks or months after exposure.

In this document the term casualties is used for both injuries and fatalities. For example, an event that caused 10 fatalities and 90 injuries would result in 100 casualties.

Table 1. Estimated fatalities and symptoms associated with acute whole body absorbed doses.

Short-term whole-body dose (rad[a])	Acute death[b] from radiation without medical treatment	Acute death[c] from radiation with medical treatment (%)	Acute symptoms[d] (nausea and vomiting within 4 hours (%)
1	0	0	0
10	0	0	0
50	0	0	0
100	< 5	0	5–30
150	< 5	< 5	40
200	5	< 5	60
300	30–50	15–30	75
600	95–100	50	100
1,000	100	≥ 90	100

[a] “Short-term” refers to the radiation exposure during the initial response to the incident. The acute effects listed are likely to be reduced by about one-half if radiation exposure occurs over weeks.
[b] Acute deaths are likely to occur from 7 to 180 days after exposure. Individuals with other injuries, significant co-morbidities, children, and elderly would be at greatest risk.
[c] Most cancers are not likely to occur until several decades after exposure; although leukemia has a shorter latency period (< 5 years).
[d] Applies to those individuals that survive Acute Radiation Syndrome (ARS).

Recommended Public Actions

> ***The best initial action immediately following a nuclear explosion is to take shelter in the nearest and most protective building or structure and listen for instructions from authorities.***
>
> ***(EOP, 2010)***

The following is based on recent analysis and recent Federal Guidance, and applies to an IND detonation in any location. Subsequent sections describe specific regional response actions to support the implementation of the guidance based on analysis of the hypothetical 10-kT IND detonation in the NCR. Considerable guidance and information on response to an IND have been recently published by the Federal government, national scientific councils, and other organizations as detailed in the following paragraphs.

Recent research over the last few years has helped to greatly improve our understanding of appropriate actions for the public and responder community to take after a nuclear detonation. Much of this research was recently highlighted in a National Academies Bridge Journal on Nuclear Dangers, the content of which is used extensively in the present document.

The Federal Planning Guidance for Response to a Nuclear Detonation was developed by an interagency Federal committee led by the Office of Science and Technology Policy, 2nd Ed, June 2010 (EOP, 2010). This interagency consensus document provides excellent background information on the effects of a nuclear detonation and key response recommendations. Its definition of zones (damage and fallout) is the standard for response planning and should be integrated into any planning process.

The National Council on Radiation Protection and Measurement (NCRP) Report No. 165, Responding to a Radiological or Nuclear Terrorism Incident: A Guide for Decision Makers, was released in February 2011 and is a national standard that supplies the science and builds on many of the concepts of the Planning Guidance.

For public health information, an entire edition of the journal for Disaster Medicine and Public Health Preparedness was dedicated to public health issues associated with the aftermath of nuclear terrorism. All articles are available for free download.

Key Response Planning Factors for the Aftermath of Nuclear Terrorism developed by Lawrence Livermore National Laboratory in support of the DHS preparedness activity was released in August 2009.

DHS Strategy for Improving the National Response and Recovery from an IND Attack, April 2010, breaks the initially overwhelming IND response planning activity down into 7 capability categories with supporting objectives. This can be a valuable document to guide a state and regional planning process as a lot of work has already gone into time phased capability requirements for Doctrine/Plans, Organization, Training, Materiel, Leadership, Personnel, Facilities, and Regulations/Authorities/Grants/Standards. "This document is for official use only and can be found on the Improvised Nuclear Devices Channel of the Lessons Learned Information System (*www.LLIS.dhs.gov*).

Public Response Priorities

The brilliant flash that can be seen for hundreds of miles can temporarily blind many of those who are outdoors even miles from a nuclear explosion. The explosion can turn several city blocks into rubble and may break glass over 10 miles away. Dust and debris may cloud the air for miles, and fallout that produces potentially lethal levels of radiation to those outdoors falls in the immediate area and up to 20 miles downwind.

It will be initially difficult for those directly affected to assess the scale of devastation. On a clear day, a mushroom cloud might be visible from a distance, but the cloud is unlikely to keep a characteristic shape more than a few minutes and will be blown out of the area in one or more directions in the first few hours (Figure 4). The most critical life-saving action for the public and responders is to seek adequate shelter for at least the first hour.

The scenario discussed in this document is just one of a broad range of possible fallout patterns, yields, and detonation locations. It is important not to plan to a particular scenario, but rather to plan to accomplish key objectives regardless of specifics.

Figure 4. The cloud created by an IND might not take or retain a characteristic "mushroom" shape.

Unfortunately, our instincts can be our own worst enemy. The bright flash of detonation would be seen instantaneously throughout the region and may cause people to approach windows to see what is happening just as a blast wave breaks the window. For a 10-kT detonation, glass can be broken with enough force to cause injury out to 3 miles and can take more than 10 seconds to reach this range.

DUCK and COVER: After an unexplained dazzling flash of light, do not approach windows, and stay behind cover for at least a minute to prevent injuries from flying and falling debris, such as broken glass.

Another urge to overcome is the desire to flee the area (or worse, run into fallout areas to reunite with family members), which can place people outdoors in the first few minutes and hours when fallout exposures are the greatest. Those outside or in vehicles will have little protection from the penetrating radiation coming off fallout particles as they accumulate on roofs and the ground.

Sheltering is an early imperative for the public within the broken glass and blast damage area, which could extend for several miles in all directions from a blast. There is a chance that many parts of the area may not be affected by fallout; however, it will be virtually impossible to distinguish between radioactive and non-radioactive smoke, dust, and debris that will be generated by the event (see Figure 5). Potentially dangerous levels of fallout could begin falling within a few minutes.

Those outdoors should seek shelter in the nearest solid structure. Provided the structure is not in danger of collapse or fire, those indoors should stay inside and move either below ground (e.g., into a basement or subterranean parking garage) or to the middle floors of a multi story concrete or brick building.

Figure 5. Smoke, dust, and debris can obscure the magnitude of the situation for those close to the event.

Those individuals in structures threatened by collapse or fire, or those in light structures (e.g., single story buildings without basements) should consider moving to an adjacent solid structure or subway. Glass, displaced objects, and rubble in walkways and streets will make movement difficult. Leaving the area should only be considered if the area becomes unsafe because of fire or other hazards, or if local officials state that it is safe to move

GO IN, TUNE IN: The best initial action immediately following a nuclear explosion is to take shelter in the nearest and most protective building or structure and listen for instructions from authorities. (EOP, 2010)

Efforts should be made to stabilize the injured through first aid and comfort while sheltered. Even waiting a few hours before seeking treatment can significantly reduce potential exposures.

Fallout is driven by upper-atmospheric winds that can travel much faster than surface winds, often at more than 100 miles per hour. Outside the area of broken windows, people should have at least 10 minutes before fallout arrives for the larger multi-kiloton yields. If the detonation were to happen during daylight hours on a day without cloud cover, the fallout cloud might be visible at this distance, although accurately gauging direction could be difficult as the expanding cloud continues to climb and possibly move in more than one direction. Provided atmospheric conditions do not obscure visibility, dangerous levels of fallout would be easily visible as particles fall. People should proceed indoors immediately if sand, ash, or colored rain begins to fall in their area.

At 20 miles away, the observed delay between the flash of an explosion and "sonic boom" of the air blast would be more than 1.5 minutes. At this range, it is unlikely that fallout could cause radiation sickness, although outdoor exposure should still be avoided to reduce potential long-term cancer risk. The public at this distance should have some time, perhaps 20 minutes or more, to prepare. The first priority should be to find adequate shelter. Individuals should identify the best shelter location in their present building, or if the building offers inadequate shelter, consider moving to better shelter if there is a large, solid multistory building nearby. After the shelter itself is secured, attention can be given to acquiring shelter supplies such as batteries, radio, food, water, medicine, bedding, and toiletries.

Although roads could be initially unobstructed at this range (~20 miles), the possibility of moving the numerous people at risk before fallout arrives is highly unlikely, and those in traffic jams on the road would receive little protection from fallout.

DON'T DRIVE: If in a car, try to find shelter immediately until given official information. A car does not offer protection.

At long distances (more than 100 miles), the additional time before fallout arrival might tempt people to evacuate. However, cloud spread (see Figure 6) and difficulties associated with predicting possible fallout locations will make avoiding the hazard difficult, even when driving. Although people at this distance will not experience life-threatening levels of fallout, using the extra time to seek the best-quality shelter in the area can help reduce exposures and the long-term risk of cancer.

STAY INDOORS: People should expect to remain sheltered for at least 12 to 24 hours. During that time, the intensity of fallout radiation will decrease greatly, allowing for less hazardous egress from dangerous fallout areas. (EOP, 2010)

Unless a given shelter location is considered unsafe due to fire or structural damage, the length of time individuals should remain sheltered depends on instructions from regional emergency management agencies. For those in good shelters, such as a large concrete, brick, or underground structure, optimal shelter times will likely be in terms of days. In the absence of specific guidance from authorities and adequate supplies of food and water, or for those who are in smaller 2- to 3-story structures or shallow basements, evacuation should be considered after 12 hours. Upon leaving shelter, the best course is to follow routes that take advantage of sheltered passages (subways, underground connectors, or through building lobbies) that lead away from damage and heavy fallout areas. Once clear of potential fallout areas, evacuees should seek a change of clothes (including shoes) and wipe or wash exposed skin surfaces.

GET CLEAN: Radioactive fallout particles can spread quickly and remain on the body and clothes until removed. Those in potentially fallout contaminated areas should take off the outer layer of clothing (including shoes) and wipe or wash exposed skin and hair upon leaving a contaminated area.

Tests conducted at the Nevada Test Site (NTS) after above-ground nuclear detonations demonstrated that simple brushing and wiping can be effective at removing fallout particles (Figure 7). Fallout consists of large particles that can be easily brushed off clothing and shoes. The radiation energy given off by fallout particles decays rapidly with time. For this reason early gross decontamination (brushing for example) is better than delayed thorough decontamination (such as a shower).

An event of this magnitude will vastly overwhelm available response resources. The response will depend on a "whole community" approach that requires responding in nontraditional ways. Individuals and communities will be the most critical response and recovery assets present during initial hours and days following a detonation. Radiation sickness is not contagious, and experience has shown that contamination on people does not represent an immediate threat to others. Do not allow the radiological nature of an IND incident to prevent people from providing assistance and aid to those that need help.

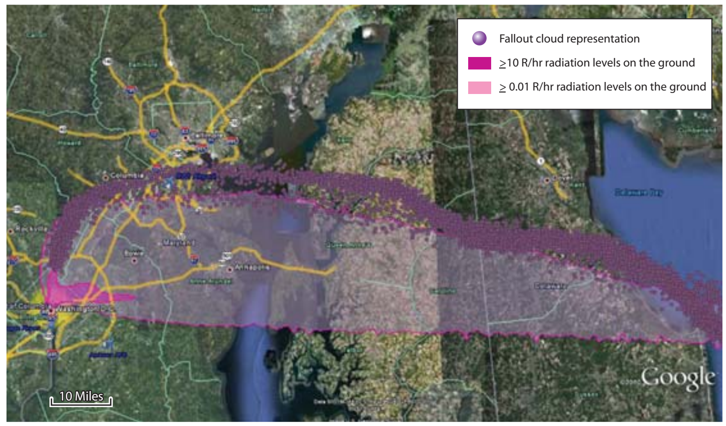


Figure 6. At 2 hours, the top of the cloud has moved over the Atlantic Ocean and the lower portion moves over Baltimore.

Figure 7. Nevada Test Site photo of post-shot decontamination procedures.

HELP OTHERS: Radiation injuries and fallout contamination on people do not represent a threat to others. People should allow others to enter their building, help decontaminate, render first aid, and share information.

A Note About the Illustrative Scenario

The intent of this report is to summarize historical and current efforts to provide a realistic description of what could happen and how to respond to an IND detonation in the NCR. To provide needed context to a broad and complex discussion, this report relates key planning and response considerations to an illustrative (hypothetical) 10-kT IND detonation in downtown Washington, DC at the intersection of 16th and K Street NW using observed weather from noon on February 14, 2009.

Considerable modeling and analysis have been performed to develop this scenario and support IND response planning workshops in the NCR community. Details of the analysis are located in this document's appendices, whereas summary information is provided in the body of this report.

Actual impacts of an IND will vary widely as a function of with yield, location, and weather. Because no single scenario can cover the range of possible impacts, efforts have been made throughout this document to describe the effects and planning considerations in a general way so that hazard zones can be defined by observables. Observables will include visual descriptions that a responder could identify by sight or, in the example of radiation levels, a responder could identify with appropriate detection equipment. Planning according to one specific scenario, as opposed to a general understanding of priorities and potential effects, can lead to dire consequences. Statistician George Edward Pelham Box said: "Essentially, all models are wrong, but some are useful." This report should be used to gain insight into trends and issues based on the best available data and modeling without presuming that a single scenario can predict what will actually happen should an IND incident occur.

To evaluate various shelter and evacuation strategies, this report performed two separate assessments. One assessment evaluates a specific location in the Cardozo/Shaw/U Street Corridor neighborhood for the types of shelter available and the actions that would save the most lives at that location. The second assessment uses a regional view that evaluates the impact to everyone in the dangerous fallout area by placing them into different regions and evaluating various shelter and evacuation strategies. For example, one strategy evaluated was the use the pre-planned "snow emergency" evacuation routes (See Figure 8) where every regional group had a different evacuation route.

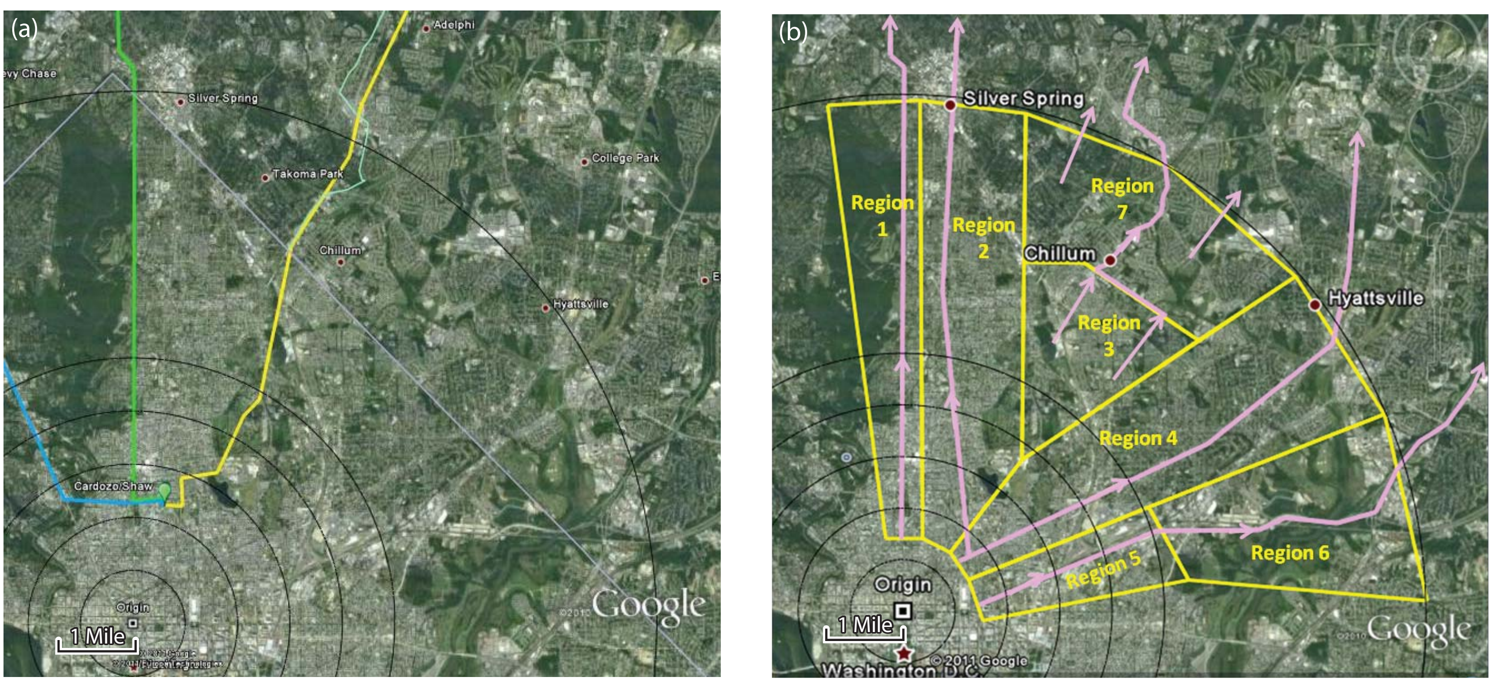


Figure 8. Analysis methods used in this report includes (a) a specific location assessment and (b) a regional assessment which models behavior of the entire population.

2. Prompt Effects

"Prompt" effects—those that radiate outward from a detonation location (ground zero) usually in the first minute—are explained in detail in Appendix A. Such effects include the intense flash of light, blast shockwave, heat, and prompt radiation. With a state-of-the-art assessment of such effects, we find that not only our instincts but also our traditional modeling predictions are incorrect. For example, Figure 9 compares prompt open-field radiation exposure (right side) to that of the Washington, DC environment (left side), demonstrating that Washington, DC, with its built-up areas, would protect the outdoor population and reduce outdoor exposure by more than 75% compared with the predicted open-field exposure traditionally reported in models.

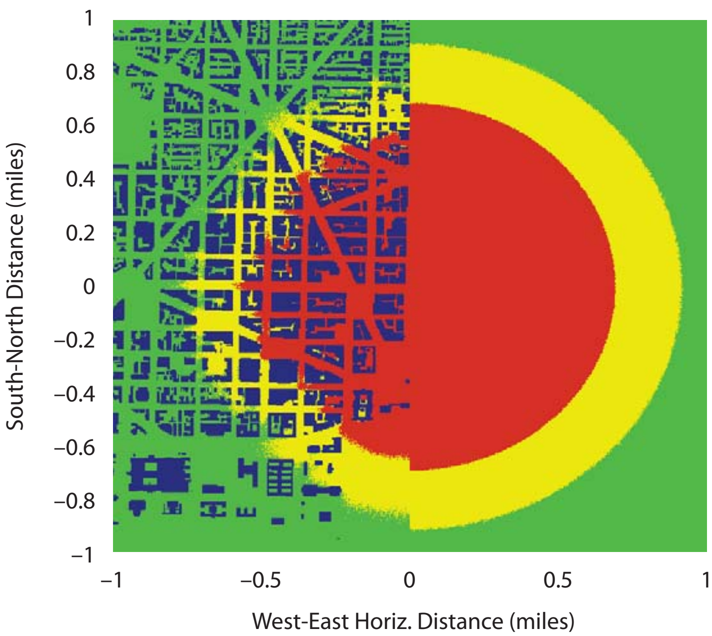


Figure 9. Outdoor casualty areas for the illustrative scenario (left) and for an open field (right) from a 10-kT Hiroshima type device; red >800, yellow 100-800, green < 100 rad..

Damage Zones (Blast Effects)

When assessing the best course of action to take following a nuclear detonation, decision-makers should consider using the three major blast-damage zones recommended by the Federal document, Planning Guidance for Response to a Nuclear Detonation (EOP, 2010). The three zones are:

- Severe damage zone.
- Moderate damage zone.
- Light damage zone.

These three damage zones are determined by the amounts of observable damage from blast effects and inform the most appropriate actions for both responder safety and mission support.

Severe Damage Zone

The Severe Damage Zone (SDZ) is the area that immediately surrounds a detonation site and extends to ~0.5 mile radius for a 10-kT explosion, as shown in Figure 10. In the SDZ, few, if any, above-ground buildings are expected to remain structurally sound or even standing, and few people would survive; however, some people protected within stable structures (e.g., subterranean parking garages or subway tunnels) at the time of the explosion could survive the initial blast. Very high radiation levels and other hazards are expected to persist in the SDZ making the zone gravely dangerous to survivors and responders. The SDZ should be considered a no-go zone during the early days following an explosion.

Figure 10. The SDZ estimated for the illustrative scenario.

As part of the NCR illustrative analysis, ARA used the NucFast model to assess more detailed effects of a 10-kT ground detonation in downtown Washington, DC. Figure 11 shows the predicted structural damage for the illustrative scenario. Figure 11(a) is the model output for direct structural damage (color coded for % of damage) while Figure 11(b) shows additional buildings that might be subject to collapse due to lateral positive and negative dynamic pressures (side sway). Figure 11(c) shows an overlay of damage on the presumed SDZ range (0.5 mile for a 10-kT detonation) to demonstrate that most, but not all, of the expected heavily damaged and collapsed structures would be within the SDZ.

Notice that most of the structural damage in Figure 11(c) is located within an area less than 1/3 mile from the point of detonation. In this downtown location, many commercial and government, steel-framed structures are extremely strong compared to other types of urban buildings. The number of collapsed buildings progresses slightly further to the north where many unreinforced brick residential structures are more easily damaged at longer ranges.

The shockwave movement underground also damages tunnels, such as subway systems, and underground infrastructure, such as water mains, power, telecommunications, and gas conduits. This underground damage area is limited to within a few blocks of the detonation site, well within the SDZ, but the impact to the infrastructure could have repercussions outside of the SDZ.

Moderate Damage Zone

The Moderate Damage Zone (MDZ) is the area adjacent to the SDZ that extends to a distance of about 1 mile from ground zero. Visual indicators describing the MDZ include:

- Significant structural damage.
- Blown out building interiors.
- Blown down utility poles.
- Overturned automobiles.
- Some collapsed buildings.
- Fires.

Sturdier buildings (e.g., those with reinforced concrete) will remain standing, lighter commercial and multi-unit residential buildings may have fallen or been rendered structurally unstable, and most single-family houses would be destroyed. Visibility in much of the MDZ could be limited for an hour or more from disruptive effects of the blast wave and building damage. Dust generated by blast-related damage might not be radioactive; however, parts of the MDZ will be contaminated by fallout. As a result, some of the dust will be radioactive and the dust can also contain other hazardous

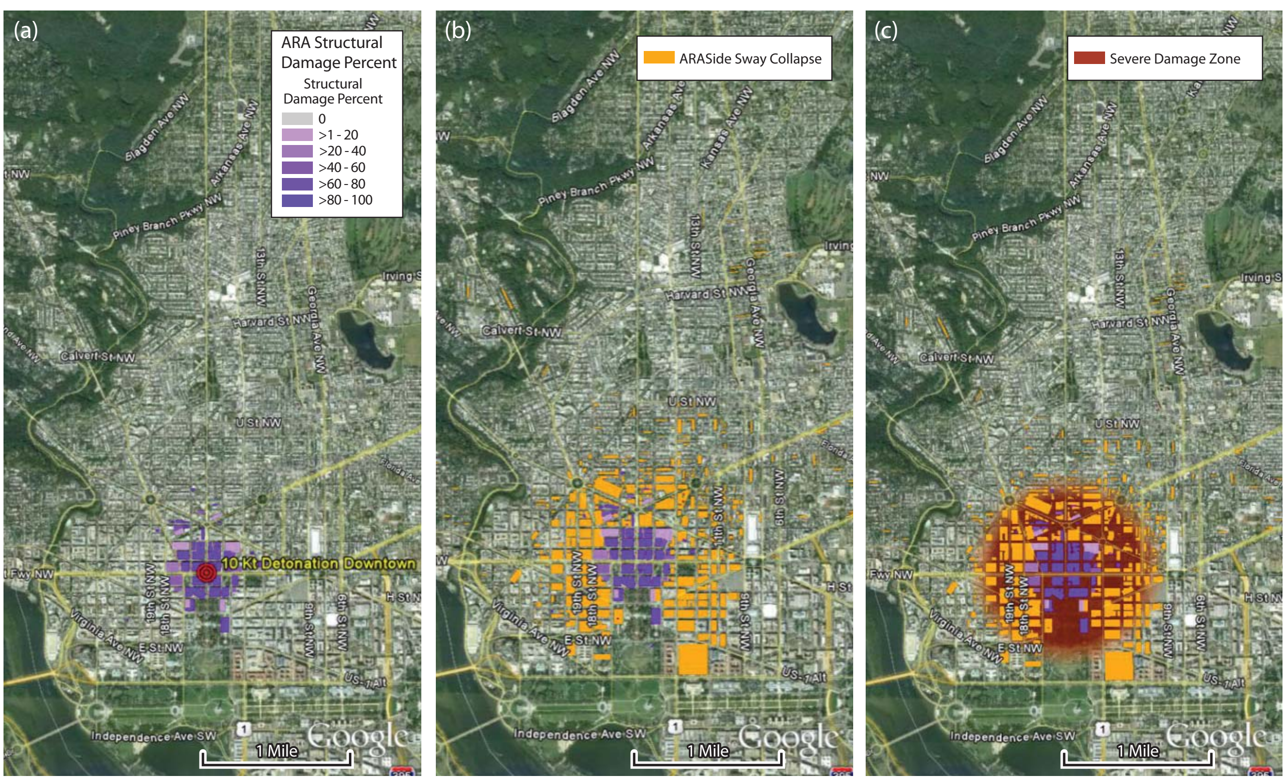


Figure 11.
(a) Structural damage,
(b) potential side sway collapse buildings,
(c) severe damage zone for the illustrative scenario.

contaminants associated with building material, such as heavy metals and asbestos.

Figure 12 shows that external wall damage extends over a much greater distance than does structural damage. Buildings near the detonation point that have not structurally failed are left as hollow, framed structures with exterior walls missing and likely all lightweight interior construction severely damaged. Some exterior wall damage occurs at more than a mile away, but most is contained within the MDZ.

Although the urban environment will create considerable variation of damage, the general extent (range) of the average blast damage estimate is generally the same as that for the ideal open field predictions.

ARA also assessed failures to structural components and external walls to estimate how much rubble would accumulate on the ground. Figure 13 shows that rubble generated from the blast would extend into the MDZ for the hypothetical scenario. Piles could reach 30 ft (10 m) near taller buildings.

Emergency response and access to the MDZ will be greatly affected by the substantial rubble as well as crashed or overturned vehicles that will completely block streets and require heavy

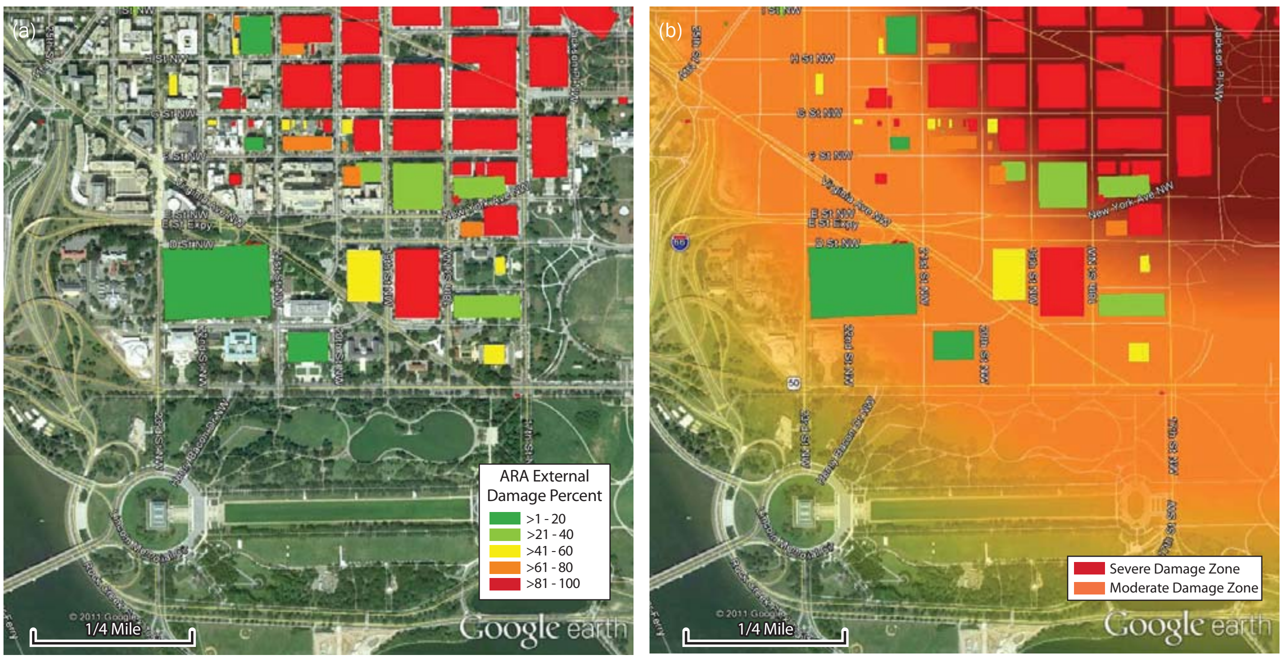


Figure 12. (a) Predicted area of external wall damage and the (b) MDZ for the illustrative scenario.

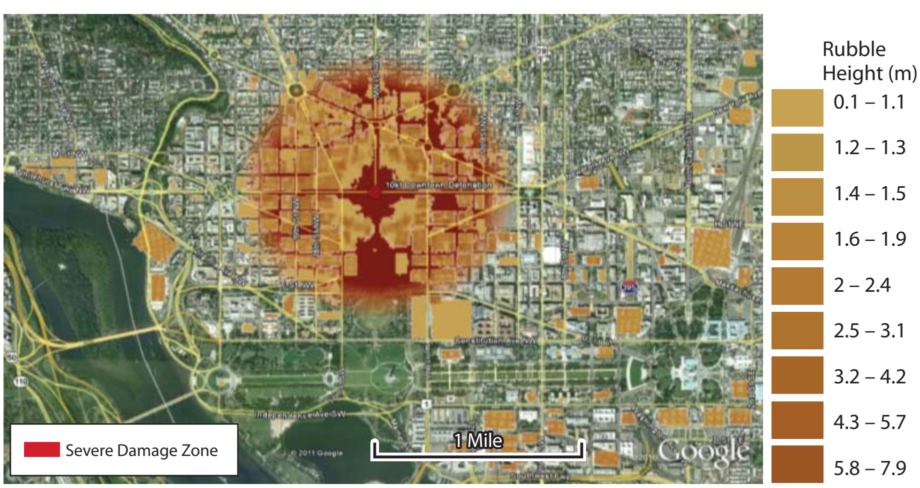


Figure 13. Height of predicted rubble piles in the streets for the illustrative scenario.

equipment to clear. Broken water and utility lines are expected, and fires will be encountered. However, many casualties in the MDZ will survive and will benefit most (compared to casualties in other prompt effect damage zones) from urgent medical care (AMA, 2011). Responders approaching from the blast-area periphery should be cognizant that when they begin observing that most buildings are either severely damaged or have collapsed, they are entering the SDZ.

Light Damage Zone

The Light Damage Zone (LDZ) is the area that starts just outside of the MDZ and can extend to a distance of about 3 miles at the outer boundary. Damage in this zone is caused by shocks, similar to those produced by a thunderclap or sonic boom, but with much more force. Although some windows may be broken over 10 miles (16 km) away, injuries associated with flying glass will generally occur within about 3 miles (4.8 km) from ground zero for a 10-kT nuclear explosion and would be associated with overpressures greater than 0.5 psi. Damage in the LDZ will be highly variable as shock waves rebound multiple times off buildings, the terrain, and even the atmosphere.

As responders move toward the detonation site from outside the LDZ, windows and doors will be blown in, gutters, window shutters, roofs, and lightly constructed buildings will show increasing damage; litter and rubble will increase and there will be increasing numbers of stalled and crashed automobiles that will make emergency vehicle movement difficult.

More significant structural damage to buildings will indicate to responders that they have entered the MDZ. Much of the LDZ may be nonradioactive; however, responders should be prepared to encounter elevated and potentially hazardous radiation. The injuries responders will encounter in the LDZ should be relatively minor, consisting of mostly superficial wounds with the occasional minor crush injuries. Glass and other projectile penetrations are expected to be superficial (i.e., about ¼ inch in depth) in the torso, limbs, and face. Eyes are particularly vulnerable. As responders proceed inward, they will begin to observe an increasing frequency and severity of injuries from flying glass and debris along with crush, translation, and tumbling injuries.

Glass breakage can be an important long-range, prompt effect. Most injuries outside the Murrah building during the 1995 Oklahoma City bombing were caused by this phenomenon. Extrapolating from more recent work on conventional explosives, a 10-kT explosion could break certain types of windows (e.g., large, monolithic annealed) located more than 8 miles away (ARA, 2004). NATO medical response planning documents for nuclear detonations state that "… missile injuries will predominate. About half the patients seen will have wounds of their extremities. The thorax, abdomen, and head will be involved about equally." This expectation is consistent with the historical observation that many victims from Nagasaki arriving at field hospitals exhibited

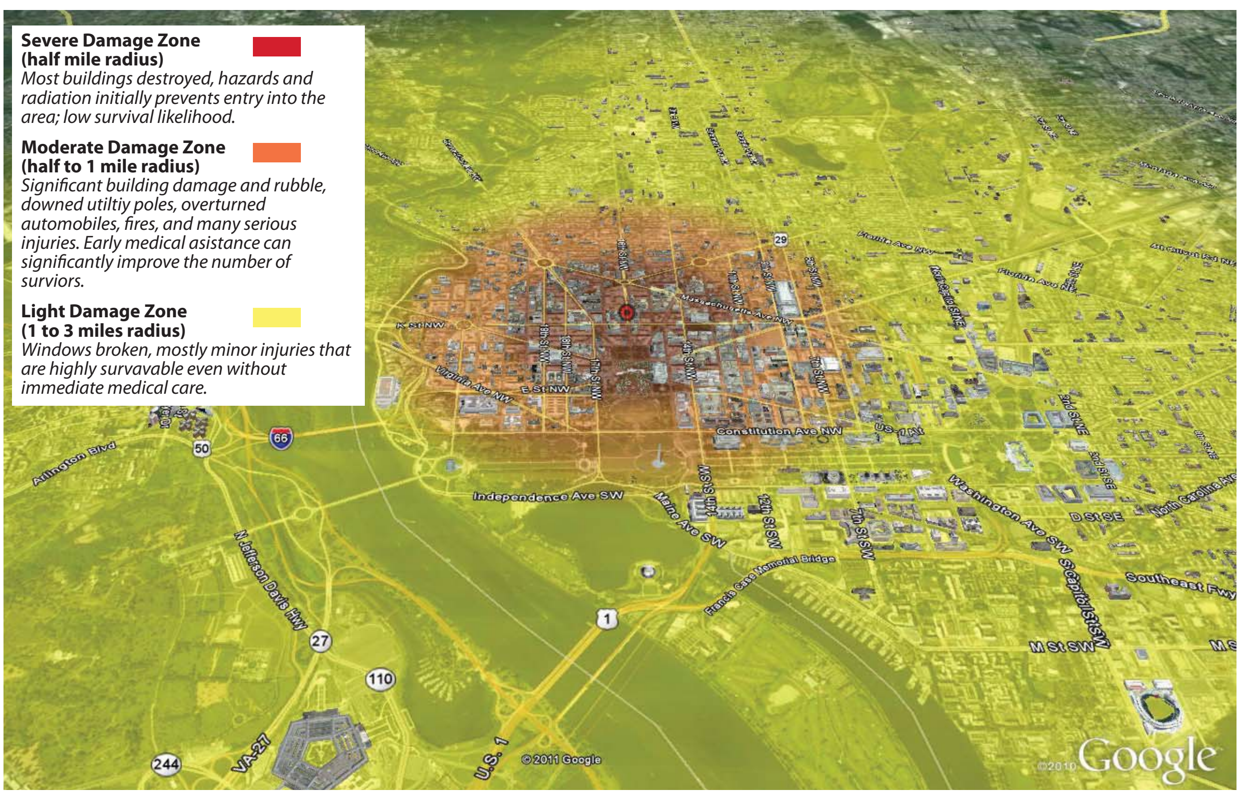


Figure 14. Summary of severe, moderate, and light damage zones and types of damage or injuries likely to be encountered by responders for the illustrative scenario.

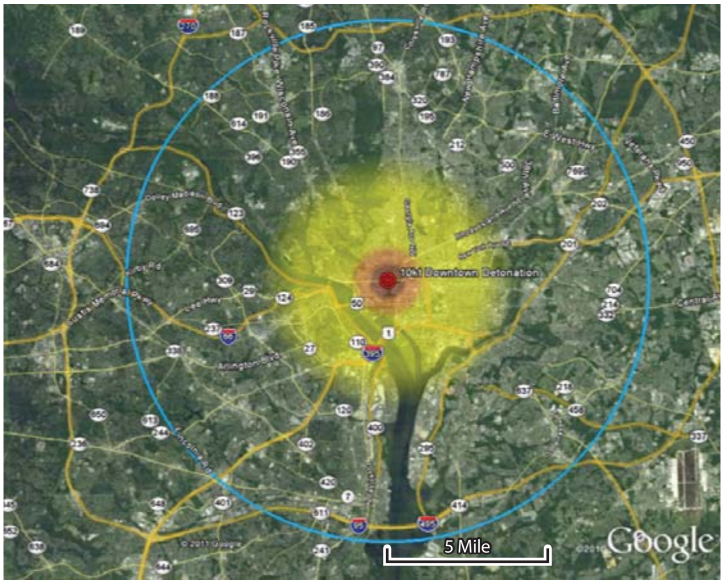


Figure 15. Predicted range of flash blindness for the illustrative scenario.

glass breakage injuries. The shockwave that breaks windows travels much more slowly than the bright flash of light. This phenomenon may cause an increased number of injuries if unwarned populations approach windows to investigate the bright flash prior to the shockwave arrival. Figure 14 summarizes some of the principal features of the SDZ, MDZ, and LDZ.

Flash Blindness

In addition to ionizing and thermal radiation, a nuclear detonation creates a brilliant flash of light that can cause temporary blindness called flash blindness (or dazzling). Flash blindness can last several seconds to minutes during which useful vision is lost. In an open-field setting, flash blindness can occur up 12 miles away on a clear day with direct line of sight of the fireball. The effect could extend much farther if low clouds were present to reflect light or a detonation were to occur at night.

As with ionizing and thermal radiation mentioned above, the bright flash of light will be partially blocked by the urban environment and poor atmospheric visibility. Although flash blindness is not expected to cause permanent damage, a sudden loss of vision for drivers could cause numerous traffic accidents and render many roads impassable. MACWG discussions estimated that the range of concern for daytime drivers would be ~8 miles (Figure 15).

Electromagnetic Pulse

A nuclear explosion also generates a phenomenon known as Electromagnetic Pulse (EMP) that can negatively impact electronic equipment. However, this issue is primarily a concern for a high-altitude, thermonuclear (high-yield) detonation. For a low-yield, 10-kT, ground-level detonation, the most damaging consequences associated with the pulse are not expected to travel beyond about 2 miles (3.2 km) to 5 miles (8 km) (EOP, 2010), with some longer-range disruptions of some sensitive equipment occurring out a few miles more. An excellent reference for EMP effects is the 2008 report of the Electromagnetic Pulse Commission.

EMP consequences can be categorized into two types of effect, direct damage and system upset. Direct damage to electronic equipment from EMP is expected to be limited to the SDZ and MDZ. Sporadic "upset" or "latch-up" of equipment may occur in the LDZ and several miles beyond, though this temporary condition can be cleared by turning a unit off and then on again (or removing and replacing the battery of portable equipment). Not all equipment within the EMP-effects area will fail, and the frequency of failure will increase the closer to the detonation point the equipment is located.

Because of EMP and effects of a blast wave on critical infrastructure (e.g., power and communication substations), for planning purposes it should be expected that electricity and land line communication would not be functional in the SDZ, MDZ, and LDZ. The disrupting nature of the detonation, including a sudden loss of electrical load on the power grid and the possibility of cascading infrastructure issues may affect the electrical and communication infrastructure of surrounding counties.

Fortunately it is likely that most battery (or hand crank) radios in the LDZ will still function. Moreover, emergency radio broadcasts from surrounding areas will be received and instructions provided (EMPC, 2008). Modern vehicles would also likely be unaffected outside of the SDZ and MDZ; however, debris on roadways, traffic accidents caused by flash blindness, and the loss of traffic control systems (one of the more sensitive electronic systems with respect to EMP effect) will make vehicular travel challenging in the LDZ.

Fires

During the Cold War, fires and firestorms were a major concern because the thermal pulse given off by the detonation can start fires. This effect is diminished for a low-yield detonation, especially at ground level in an urban environment because of (a) considerable urban shielding of thermal radiation and (b) a cooler fireball temperature (relative to an elevated burst). Although a "firestorm" is uncertain given modern construction techniques, numerous small fires will likely start from thermal and blast effects in areas of major building damage. Fires could spread and coalesce if not mitigated.

3. Fallout

In addition to prompt effects that radiate outward from a detonation site, a nuclear blast can produce nuclear fallout, which is generated when dust and debris excavated by the explosion are combined with radioactive fission products produced in the nuclear explosion and drawn upward by the heat produced. The cloud rapidly climbs through the atmosphere, potentially up to 5 miles (8 km) high for a 10-kT explosion, forming a mushroom cloud (under ideal weather conditions) from which highly radioactive particles drop back down to earth as the cloud cools. Hiroshima and Nagasaki did not experience substantive fallout because the detonations occurred well above ground at altitudes of 1,900 ft (579.12 m) and 1,500 ft (457.2 m), respectively. At such altitudes, fission products do not have the opportunity to mix with excavated earth.

Exposure to ionizing radiation from particles that settle on the ground and building roofs is the most significant delayed hazard. Radiation levels from the particles drop off quickly, with most (~55%) of the potential radiation exposure occurring within the first hour after detonation and ~80% occurring within the first day. Although a fallout pattern is highly dependent on weather conditions, the most dangerous concentrations of fallout particles (i.e., potentially fatal to those outdoors) occur within 20 miles (32 km) downwind of ground zero. Particles are expected to be clearly visible as they fall, often the size of sand, table salt, ash, or rain. Because of the large particle size, inhalation is not a major concern when compared to the penetrating gamma radiation given off by the particles. Appendix B contains a more detailed analysis of fallout cloud properties, behavior, and details of the NCR illustrative scenario that are summarized in this section.

Close-in Exposure Concerns

Within 10 to 20 miles of the detonation, exposures from fallout would be great enough to cause near-term (within hours) symptoms such as nausea and vomiting. The exposures people would likely receive, presuming that individuals stood outside in the fallout for 2 hours, are shown in Figure 16. This calculation was not chosen because it is expected that people will remain outside and stationary for 2 hours, but rather for use as a consistent benchmark from which to make relevant comparisons. The circular yellow area under the fallout pattern is the LDZ. The yellow fallout area (spreading to the north and 6 miles to the northeast of the detonation location) in Figure 16 represents an outdoor 2-hour integrated exposure of 100 to 300 R. Since the exposure happens early, within the first minutes and hours of fallout arrival, an early evacuation would not be practical in this region.

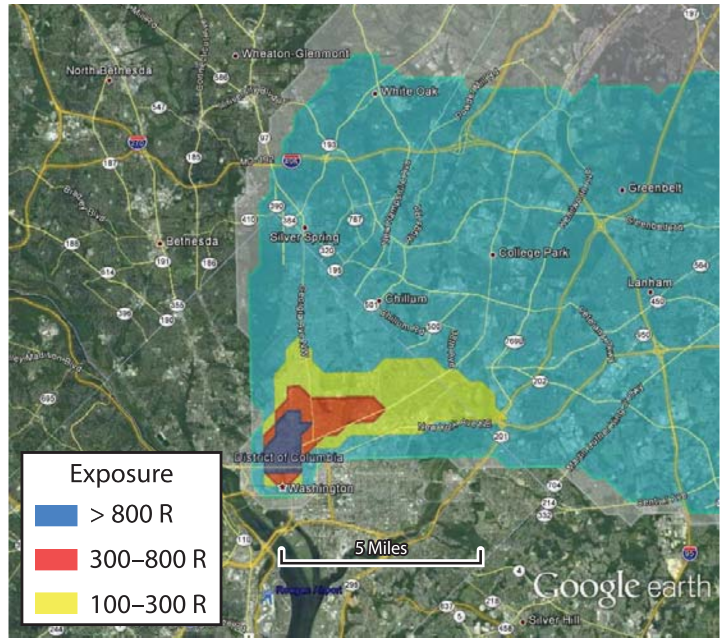


Figure 16. Integrated 2-hr outdoor exposure for the illustrative scenario.

The orange area depicts exposures of 300 to 800 R for those who do not shelter soon enough. Most would experience immediate health effects (e.g., nausea and vomiting within 4 hours), and some fatalities would be likely without medical treatment For those in the dark blue area who do not take immediate shelter, outdoor exposures (>800 R) would be great enough that fatalities are likely with or without medical treatment. **Evacuation is not an option in this area because fallout would arrive too quickly (within 10 minutes) to evacuate.**

Long-Range Exposure Concerns

The white area in Figure 17 represents radiation levels that are above the EPA and DHS (FR 73-149) recommendation for shelter or evacuation (1 to 5 rem in 4 days). This exposure is low enough that no immediate health effects are expected and the probability of long term effects (e.g., cancer) is small (< 0.1%). Even so, protective measures to reduce exposure will likely be performed as good protective practice. The light blue area defines the region where no immediate health effects would be expected; however, exposure is high enough (5 to 100 rem) that the probability of long-term effects (e.g., cancer) warrants protective actions according to the DHS and EPA Protective Action Guidance.

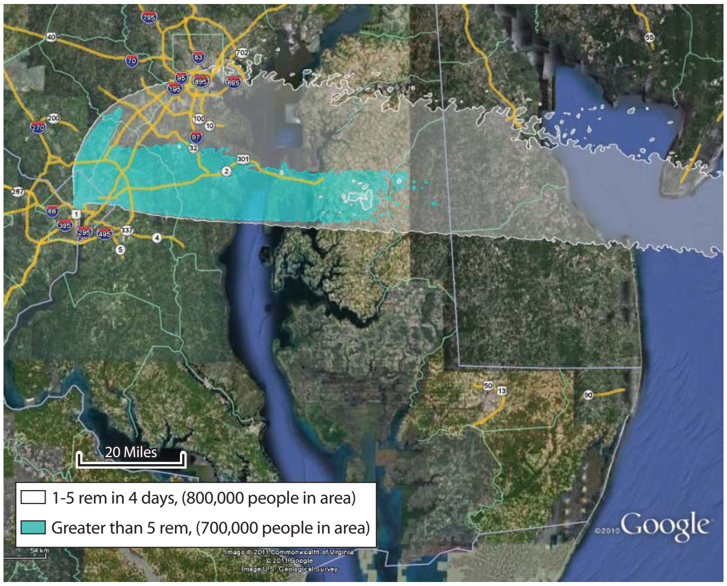


Figure 17. Long-range integrated dose for 4 day outdoor exposure.

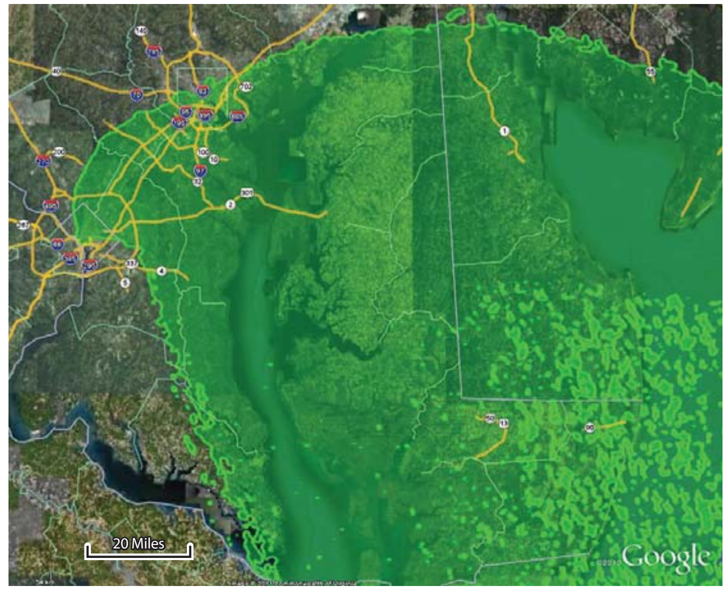


Figure 18. Initial agricultural embargo area from the illustrative scenario.

Agricultural Embargo Areas

Although it is more of an economic impact than direct or long-term injury issue, an agricultural embargo is an example of more far reaching effects of an IND detonation and also represents areas in which fallout contamination would be readily detectable with hand-held survey equipment in the first few days following the detonation. Figure 18 shows an agricultural embargo area associated with the NCR scenario that Chesapeake Bay, all of Delaware and parts of New Jersey, Maryland and Virginia. Although the embargo would be lifted after a few weeks when radiation levels subside, public confidence in the products produced in the region would likely have a longer-term impact.

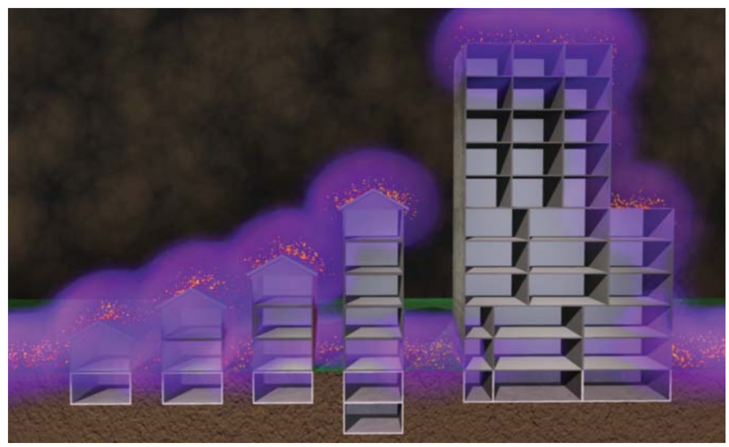


Figure 19. Artist's illustration of locations that fallout will accumulate and the hazard it creates (shown in purple).

Fallout Properties

Although only a small physical quantity of radioactive material is produced in a nuclear detonation, about 20 ounces for a 10-kT device, this material is highly radioactive creating almost 300 billion Curies at a minute after the explosion (Glasstone, 1977). As the fireball cools, highly radioactive fission products coalesce on the thousands of tons of dirt and debris pulled up by the heat of the fireball.

Once fallout particles reach the ground, the primary hazard is due to penetrating gamma rays from the particles, rather than from breathing or ingesting particles. Gamma rays are photons, like x rays, that can "shine" through clothing, walls, and even protective suits. Although gamma and beta radiation are not visible to the naked eye, Figure 19 illustrates (through an artist's suggestion of a purple glow) the most hazardous areas where fallout particles would likely land on rooftops and the ground.

After deposition, the radioactivity emitted by fallout particles decreases rapidly with time similar to how hot metal radiates energy

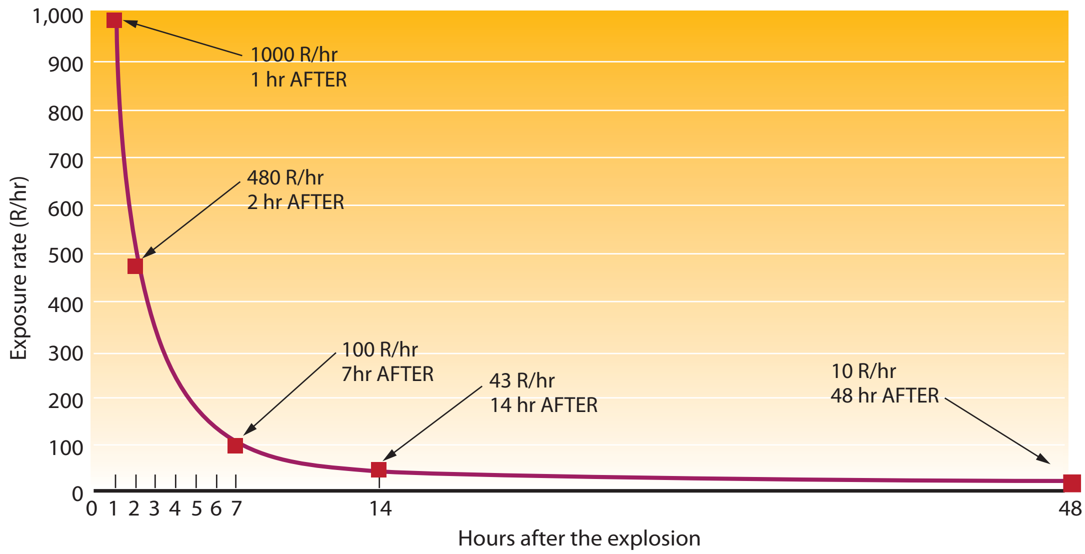


Figure 20. Radiation levels from fallout decrease rapidly over time, emitting more than half of their radiation in the first hour.

(heat) and cools over time (decreasing the amount of energy given off). Fallout gives off more than 50% of its energy in the first hour, and continues to decay rapidly afterward. Figure 20 shows how the radiation levels from fallout continue to decrease with time. For this example an arbitrary starting value of 1,000 R/hr was used starting at one hour after the detonation.

A fallout cloud disperses as it moves downwind, reducing the overall concentration within the cloud and the amount of particles that fall from the cloud to accumulate on the ground. After the cloud passes a given point, fallout particles deposited on the ground continue to give off radiation.

Because the generation of radioactive material occurs all at once, after the fallout cloud passes and has deposited fallout particles on a given area, **there will never be an increase** in fallout radiation levels[3].

To illustrate what the decrease in energy means for populations that find themselves in the fallout region of the illustrative scenario, theoretical outdoor fallout exposure rates in the Cardozo/Shaw/U Street corridor area was calculated. This location is in the LDZ (1.5 miles from the detonation point) but is directly downwind. Figure 21 is an eastward-facing view of the area of interest. Surface winds move the lower portion of the fallout cloud to the north (over the area of interest) and the upper-atmospheric winds move the upper part of the fallout cloud to the east.

The first image in Figure 21, which models the fallout cloud 15 minutes after detonation, indicates that most of the cloud has already passed over Cardozo High School, and fallout has been deposited on the ground. It takes a few minutes for the fallout to reach Cardozo, but as fallout rains down in the area, outdoor radiation levels increase rapidly. Fifteen minutes after the detonation, outdoor radiation levels are slightly below 1,500 R/hr. Although this radiation level is extremely high, it drops off rapidly, and just 15 minutes later (at 30 minutes after detonation) it is ~700 R/hr (less than half the 15-minute value). Two hours after detonation, the exposure rate is less than 150 R/hr, which is less than 10% of the 15-minute value.

Table 2. Modeled dose rates for the illustrative scenario at the point specified in Figure 21.

Time after detonation (hr:min)	Exposure rate (R/hr)
00:15	1,444
00:30	686
01:00	299
02:00	130
04:00	57
08:00	35
12:00	15
24:00	7
48:00	3
96:00	1

[3]Rain or washing of fallout areas might concentrate fallout in sewers and storm drains, but such action would be accompanied by a reduction of fallout concentration elsewhere.

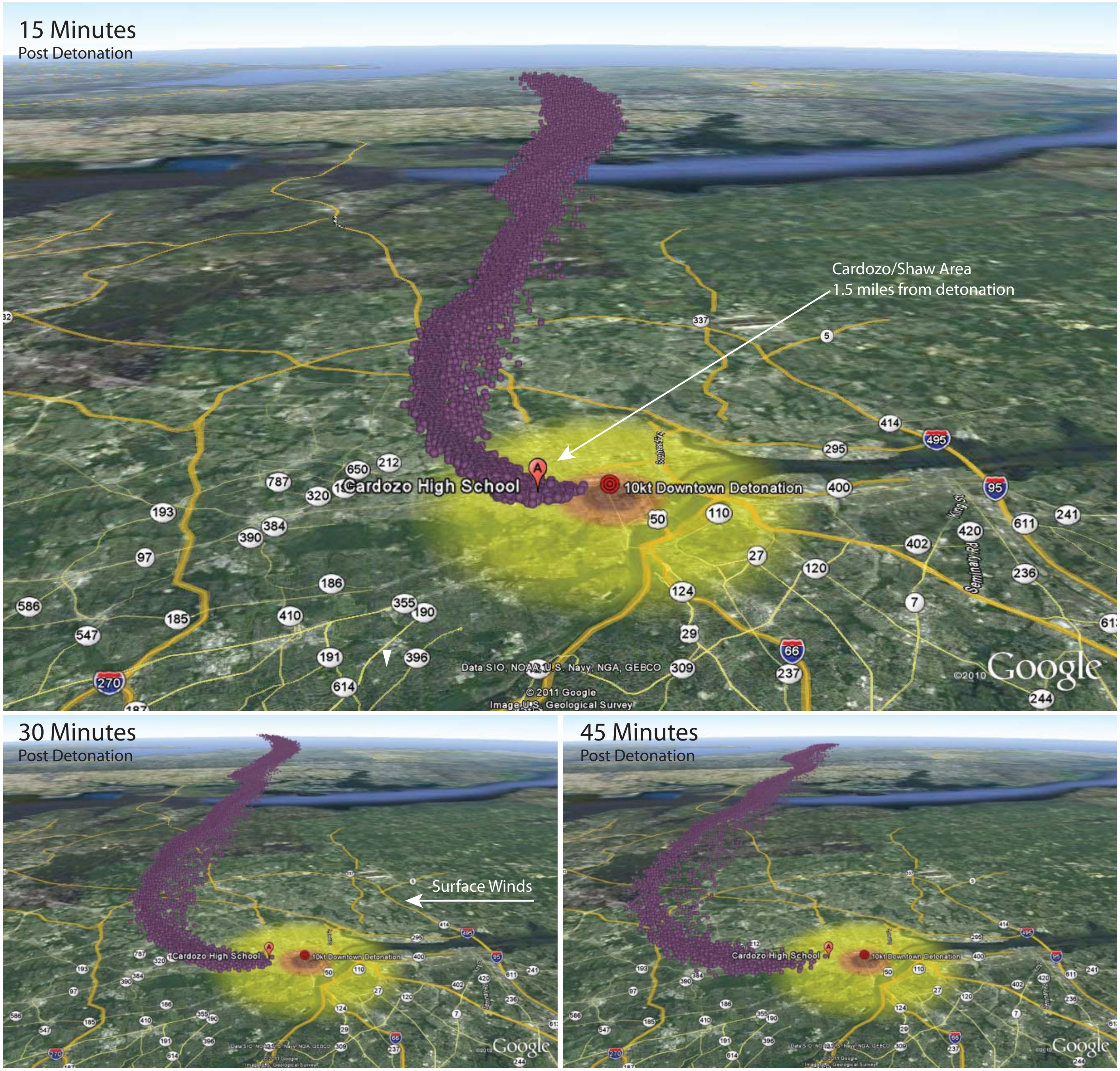


Figure 21. View facing east showing the relative location of Cardozo High School and the fallout cloud at various times for the illustrative scenario.

Radiation levels continue to fall, although less dramatically, after the first few hours. Table 2 summarizes outdoor dose rates for times up to four days after detonation.

Fallout Zones

Similar to the three blast damage zones (severe, moderate, and light), two different fallout hazard zones have been defined; the Dangerous Fallout Zone (DFZ) (EOP, 2010) and the Hot Zone (NCRP, 2011).

Dangerous Fallout Zone

The DFZ is defined by radiation levels of 10 R/hr or greater. For a 10-kT detonation this zone could reach 10 to 20 miles downwind before decay of radiation causes the DFZ to shrink after ~1 hour.

The DFZ has the following characteristics:

- Radiation levels of 10 R/hr and above.
- Acute radiation Injury is possible within the DFZ.
- Could reach 10 to 20 miles downwind.
- Decay of radiation causes this zone to shrink after about 1 hr.

To demonstrate how the DFZ changes over time, Figure 22 shows several time-stamped images that identify the DFZ as the dark purple area. A dashed yellow line is drawn around the DFZ at 1 hour to provide a comparison in subsequent images.

> ***"The area covered by fallout that impacts responder life-saving operations and/or has acute radiation injury potential to the population is known as the dangerous fallout zone (DFZ). Unlike the LDZ, MDZ, and SDZ, the DFZ is distinguished not by structural damage, but by radiation levels. A radiation exposure rate of 10 R/h is used to bound this zone, and the DFZ may span across both the LDZ and MDZ."***
>
> ***Planning Guidance for Response to a Nuclear Detonation (EOP, 2010)***

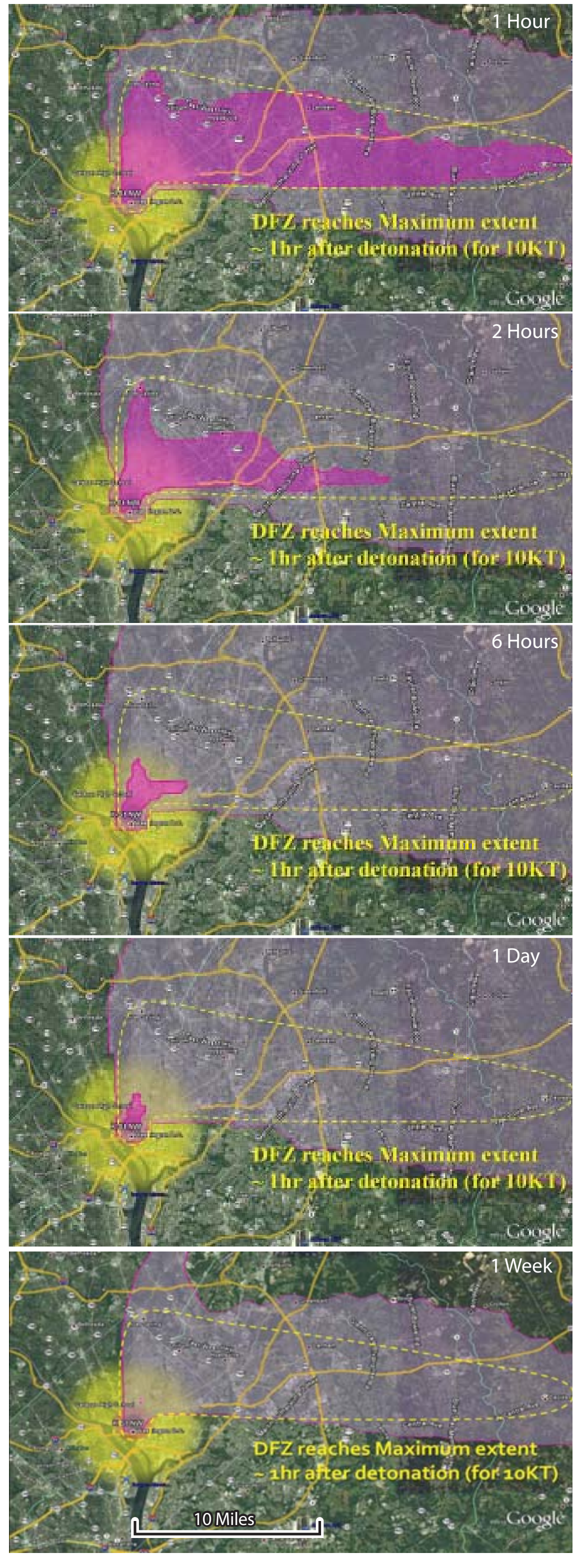


Figure 22. The DFZ (dark purple area) shrinks rapidly in the illustrative scenario.

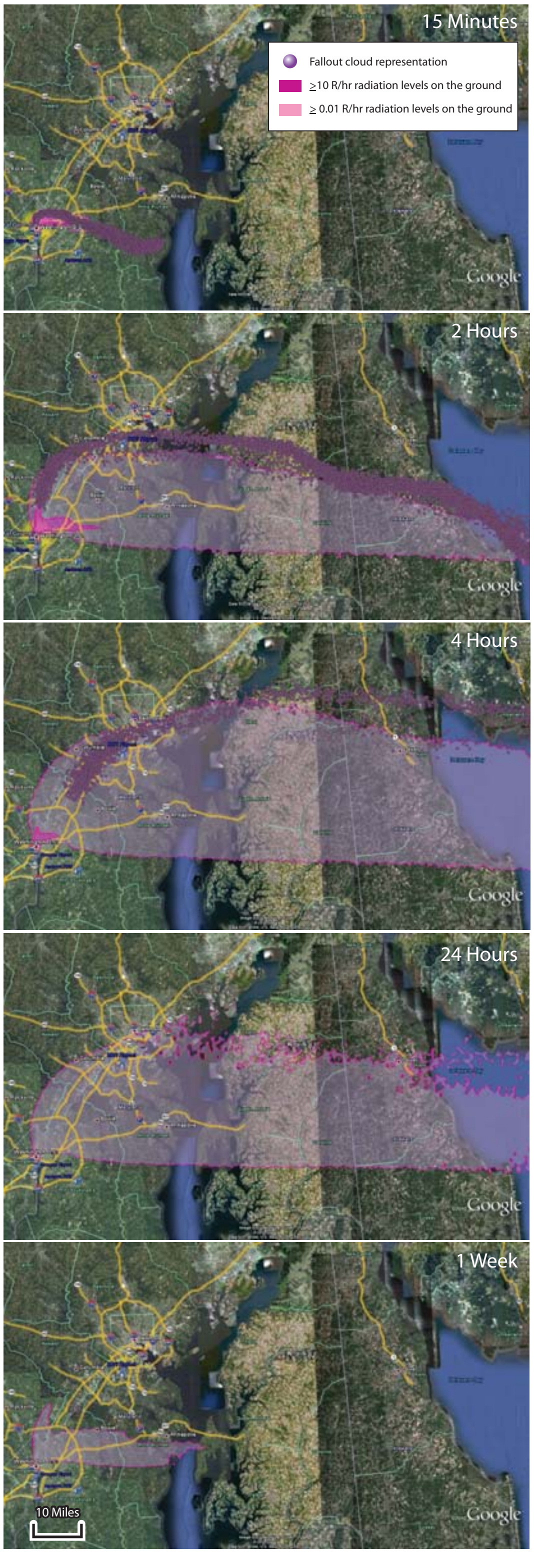


Figure 23. Extent of the Hot Zone (light purple) at 15 minutes through 1 week for the illustrative scenario.

Hot Zone

In addition to the DFZ, designated as the dark purple color, the light purple color in Figure 22 denotes the Hot Zone defined by a dose rate of 0.01 R/hr (1/1000th that of the DFZ) to 10 R/hr. Although this region is outside the area in which acute radiation effects (such as radiation sickness or burns) might be expected, consistent with Federal Planning Guidance it is still an area in which controls to mitigate exposures should be considered.

The Hot Zone has the following characteristics for a 10-kT detonation:

- Radiation levels of 0.01 R/hr (10 mR/hr) to 10 R/hr.
- Extended stays within the Hot Zone are unlikely to cause any acute radiation effects; however, steps should be taken to control exposure.
- Could extend in numerous directions for 100's of miles.
- Decay of radiation causes this zone to shrink after about 12 to 24 hours.
- After about a week the Hot Zone will be about the size of the maximum extent of the DFZ (10 to 20 miles).

To demonstrate how the Hot Zone changes over time, the time-stamped images in Figure 23 show the potential fallout cloud movement (represented as purple balls) and identify the Hot Zone using light purple shading. In this assessment, some parts of the Hot Zone start receding after about 12 hr. After a week, the Hot Zone contracts to an area similar in size to the area occupied by the DFZ when it was at its maximum.

In summary, Figure 24 shows the five zones defined in this document. It is important to recognize that the zones are defined by observable features (blast) or radiation (fallout) readings so that modeling or calculations need not be performed to determine which zone a responder has entered. The five zones represent areas where different priorities and protective measures should be considered.

The zones also represent simplifications of a highly complex and rapidly changing environment. Large variations within a given zone should be anticipated. To demonstrate this variation, Figure 25 shows the different outdoor radiation levels within the DFZ at one hour after detonation. The height (and color) of the bar on each cell represents the relative dose rate to an individual standing outside one hour after detonation.

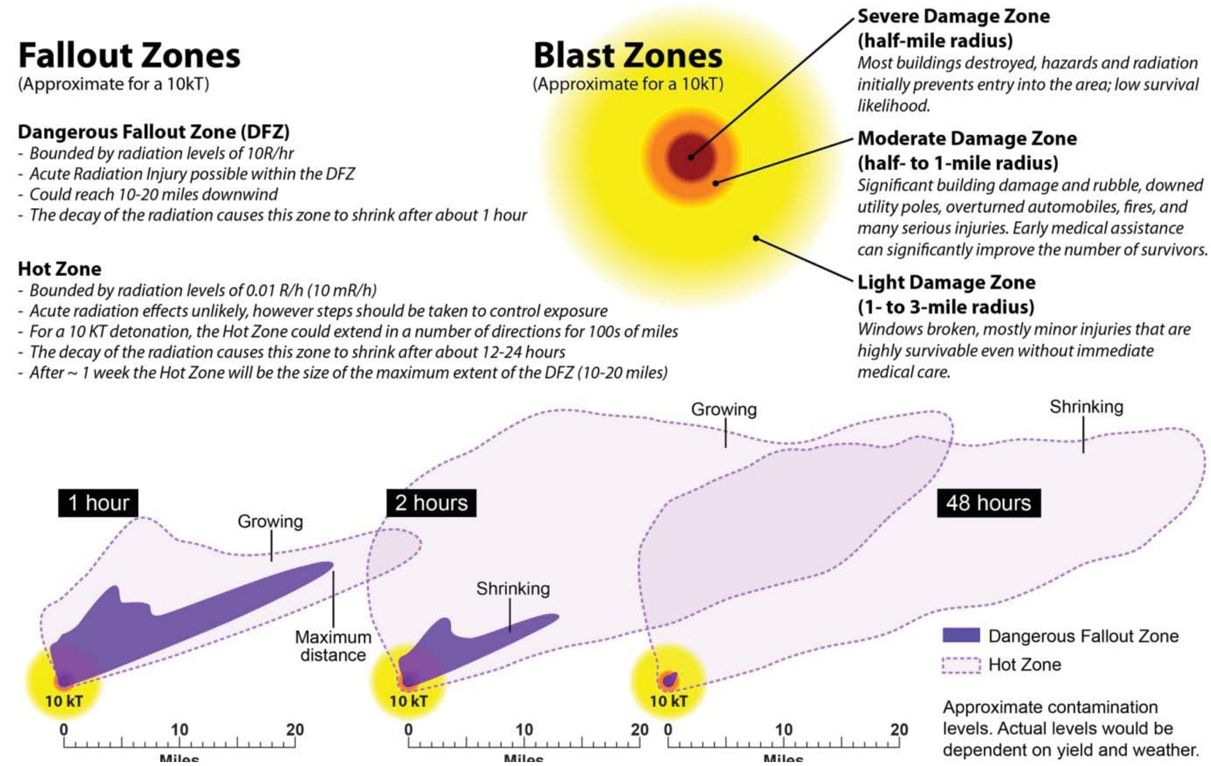


Figure 24. Definitions of five zones and examples of extent at various times following a 10-kT detonation.

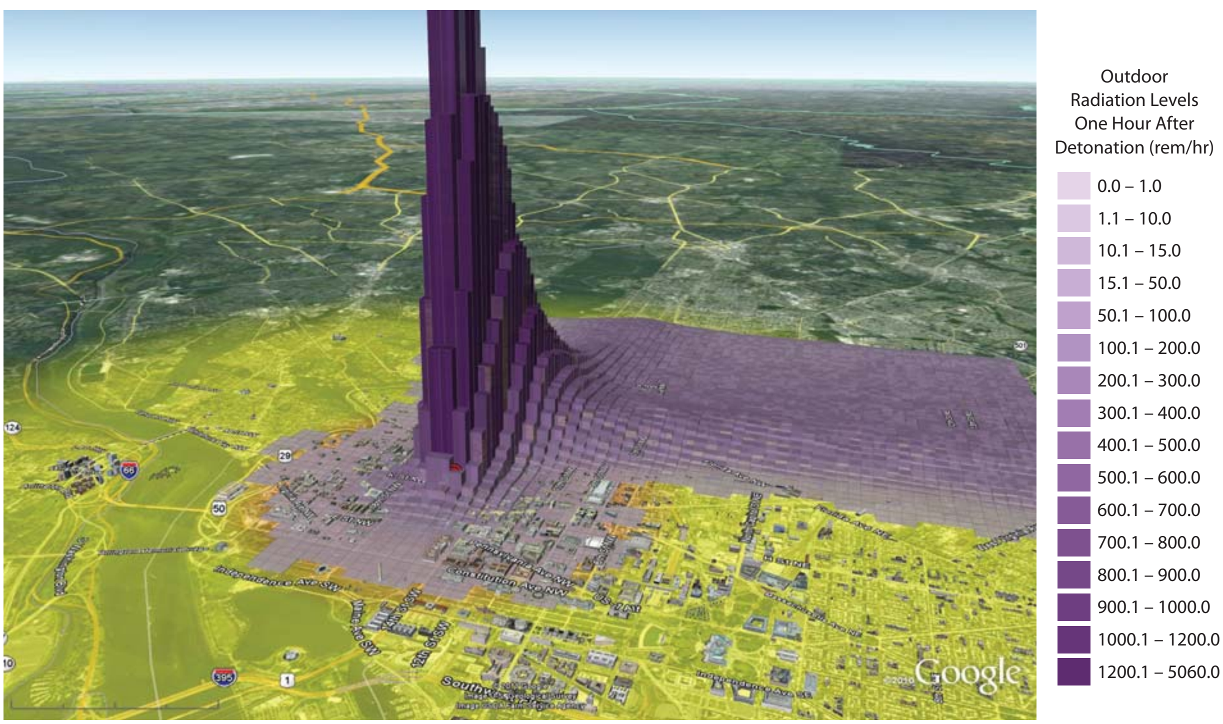


Figure 25. Modeled radiation dose rates in the NCR area using 100- by 100-m grid cells, as explained in Figure 2. The height of a given cell represents the relative dose rate to an individual standing outside one hour after detonation.

4. Shelter

Fallout health impacts can be mitigated by leaving an area before fallout arrives or by sheltering from it because, unlike prompt effects, there is a time after detonation (several minutes or more) to take protective actions. Fallout exposure can be minimized by taking shelter in a sufficiently protective building. Appendix C provides recent analysis of modern structures and detailed assessment of the protection offered by the type of buildings found in the NCR.

The term "Shelter" is ambiguous, as many emergency managers use the term to describe a mass care facility where displaced population go (e.g., "a Red Cross Shelter"); however, for the purpose of this document, shelter refers to an immediately available location that provide protection from fallout radiation. Shelter-in-Place (S-i-P) is the term used to describe a mitigation strategy where people obtain the best protection available in their present building at the time of detonation (e.g., everyone shelters in the basement).

Buildings provide protection to their occupants by (a) increasing the distance between fallout particles and those at risk and (b) blocking fallout radiation as it travels through a building.

A building's protection is described by its protection factor (PF), which is equal to the ratio of the outside radiation exposure to the inside radiation exposure. As with the SPF of sunscreen, the higher the PF, the more protection from radiation a sheltered person receives compared to an unsheltered person in the same area. Adequate protection, which protects occupants against acute radiation sickness, is defined as a PF of 10 or greater. (EOP, 2010)

Figure 26 shows example PF values associated with several building types according to calculations performed during the Cold War. Small, lightly constructed buildings such as wood or vinyl-sided frame houses and offices offer limited protection (PF ≈ 3), whereas inner portions of large, multi-story concrete or masonry office buildings can offer excellent protection (PF > 100). Basements, in general, offer adequate or better protection (PF ≥ 10). Variations in protection can be considerable within a building. For example, a person on the top floor or an outer, ground-level room in the multi-story office building shown in Figure 26 would have a PF of 10 and would receive 1/10 (or 10%) of the exposure that someone standing outside would receive. Someone in the core of the same building above ground level in the room designated with PF 100 would receive only 1/100 (or 1%) of the outdoor exposure. In fallout areas, knowing locations with adequate protection factors could prevent a potentially lethal exposure.

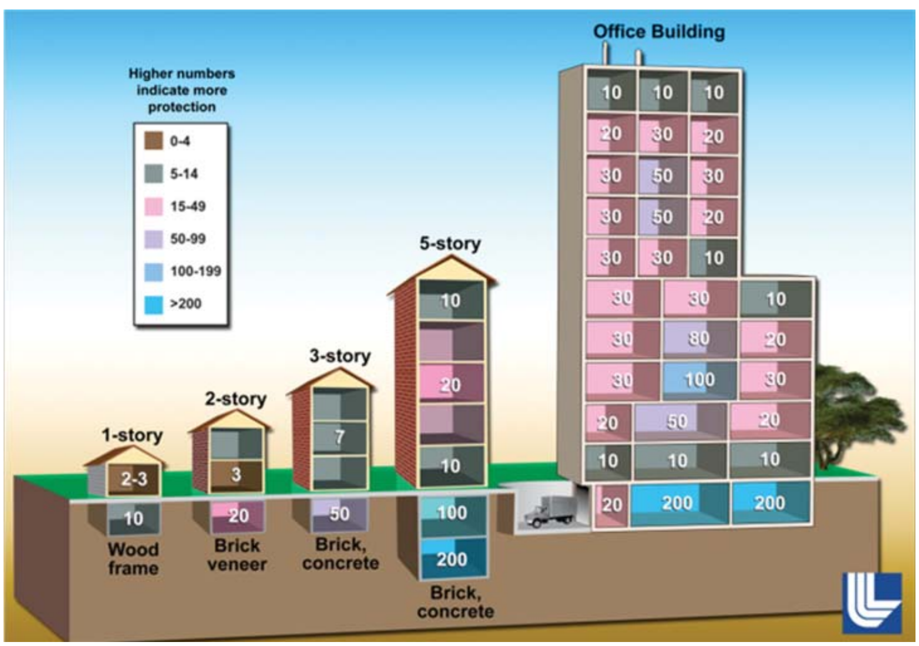


Figure 26. Example protection factors (PFs) for a variety of building types and locations. Adapted from (Ferlic, 1983) and (DCPA, 1973).

Table 3. The color code associated with shelter quality as used in this document.

Shelter quality category (PF)	Illustrative buildings
Poor (< 4)	Vehicles and wood or brick-sided single-story structures without basements, including homes and strip malls
Inadequate (≥ 4 to ≤ 10)	Stand-alone small-footprint, 2- to 4-story, lightly constructed homes and apartment buildings without basements
Adequate (≥ 10 to ≤ 40)	Residential basements, best location in 3-story brick apartments or row homes, or the OUTER areas of high-rise buildings or mid-rise buildings with brick or concrete walls
Good (≥ 40)	Large basements or underground areas and the INNER areas of high-rise buildings or mid-rise buildings with brick or concrete walls

Assessment of Modern Buildings

Efforts are underway at LLNL, ORNL (Johnson, 2011) and ARA (Bergman, 2011a) to use advanced modeling to improve our understanding of the level of protection modern buildings could provide from fallout radiation.

Updated analyses indicate that the PFs generated during the civil defense program may underestimate the protection of modern buildings and many existing structures. Table 4 is a summary of the protection factors assessed and the ranges of protection offered in different locations within buildings.

Here are general principles about how to locate the best shelter location in a building or area:

- The larger the building and heavier the material used in its construction (or contents), the better protection it provides.
- Inner portions of buildings are better protected than outer edges to maximize the distance from fallout particles.
- Middle floors are more protective than top or bottom floors, except in large footprint 3 story buildings.

Table 4. Summary of recent protection factor analysis.

Structure	Basement (PF)	1st Floor (PF)	2nd Floor (PF)	3rd Floor (PF)
Vinyl-sided 2-story home	22 - 46	2-4	2-3	N/A
Brick-sided 2-story home	31 - 62	3-8	3-5	N/A
Brick-walled urban row home	N/A	12-70	12-70	5-30
Vinyl-sided 3-story apt building	N/A	3-7	2-6	3-5
Brick-sided 3-story apt building	N/A	4-11	4-9	4-8
3-story office (brick-sided concrete walls)	N/A	8-126	4-43	3-7

Basements are worthy of special note in that people sheltering in them have either an entire building (distance + mass) or large amounts of earth (mass) between them and fallout particles. As a result, fully below-ground basements generally provide excellent protection against fallout radiation and are often the best-protected areas of a building. Even typical residential basements that are only 75% submerged below grade can still offer good protection for occupants positioned against an earthen wall (see Figure 27).

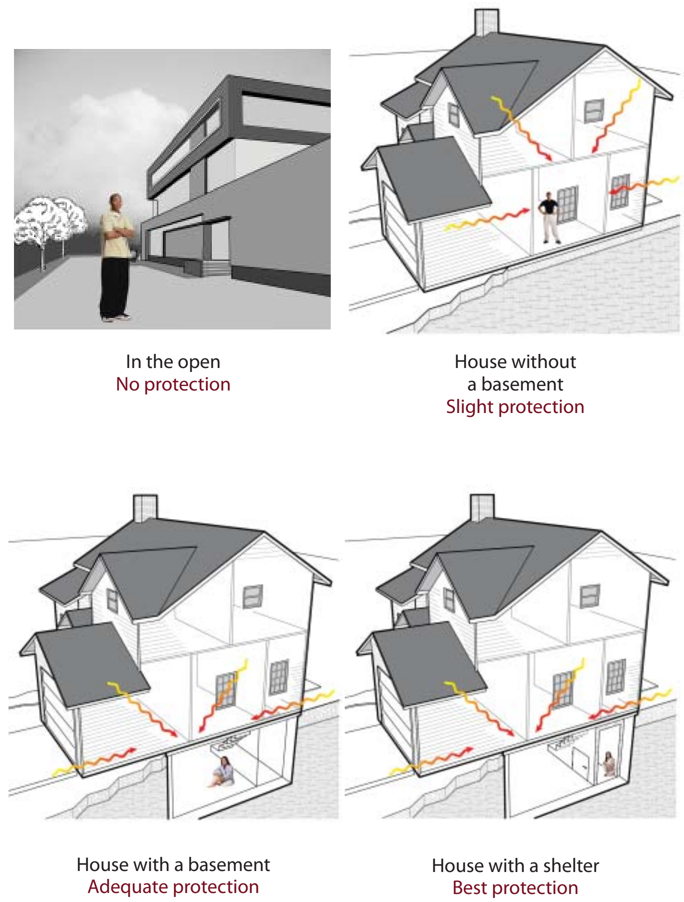


Figure 27. Protection can vary depending on location in a building. In this illustration, the best protected location is in the basement against an earthen wall.

Cardozo/Shaw/U Street Corridor Shelter Quality

Block-by-block modeling allows for an assessment of prompt and delayed effects at every location in a city, including an analysis of radiation levels along potential exit routes. This type of illustrative assessment can be useful from a planning perspective to highlight the potential tradeoffs arising from different response strategies.

For our illustrative scenario, the Cardozo/Shaw/U Street corridor of Washington, DC is in an area in which actions taken can mean the difference between life and death. The area is in the LDZ (1.3 to 1.5 miles from the hypothetical detonation location), and it is also near the center of the DFZ as shown Figure 28.

A 12 hour outdoor exposure in this area would be approximately 1,500 R, which is a fatal exposure. However in this typical urban residential neighborhood, there are many shelter opportunities. The predominant building types are 2- to 3-story, adjacent, brick row homes equipped with English basements. Also present are larger residential, commercial, and public buildings such as Cardozo High School. Figure 29 shows a typical neighborhood, the 3-story brick building on the left would provide good protection, especially on 1st and 2nd floor inner corridors. Basement areas would have protection > 200. On the right of the image, the 3-story row homes would likely have adequate protection (greater than PF 10) in above-ground rooms. Although rare, there are a few smaller brick 1- and 2-story, stand-alone buildings in the area. If such structures do not have a basement, then the protection offered could little as PF = 4 (inadequate).

Figure 30 summarizes how the various classes of buildings protect occupants from dangerous fallout radiation and the exposure inhabitants would receive over time. For the exposure potential of the Cardozo/Shaw/U Street corridor area, people sheltered in buildings with inadequate protection (PF = 4), such as in small,

Figure 28. The Cardozo/Shaw/U Street corridor area.

Figure 29. Typical neighborhood building types for the Cardozo/Shaw/ U Street corridor area.

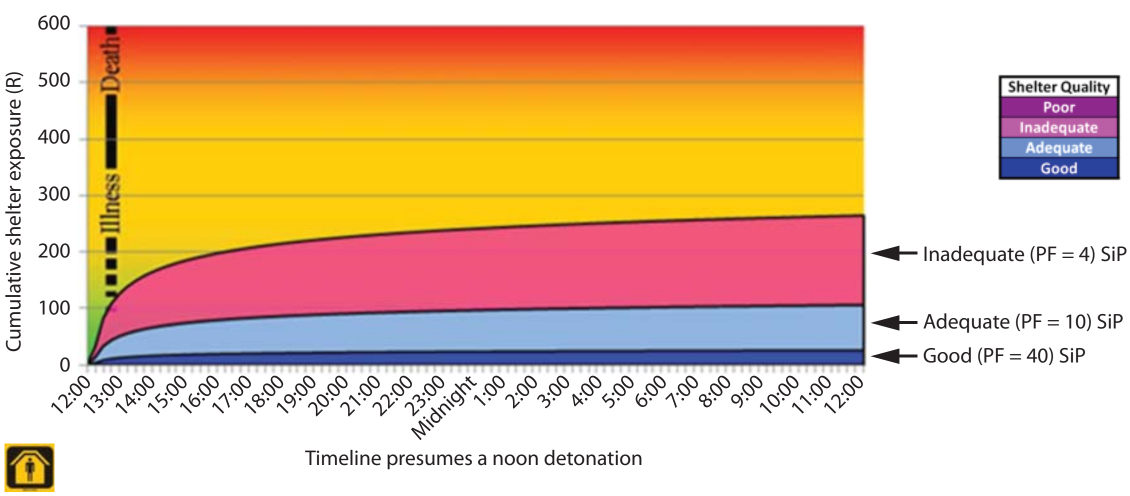


Figure 30. Summary of potential radiation exposures for individuals sheltering in locations with inadequate (PF = 4), adequate (PF = 10), and good (PF = 50) protection.

brick, stand-alone residential houses, would receive exposures that would likely make them ill (280 R in 24 hours). People sheltered in buildings with adequate protection (PF = 10), such as a 3-story row home, would receive exposures that are unlikely to cause illness (~100 R in 24 hours). People sheltered in buildings with good protection (PF = 40), such as larger concrete or brick public, commercial, or apartment buildings, would receive exposures that would not be expected to result in any acute radiation effects and minimal long-term risk (< 30 R in 24 hours).

Regional Shelter Quality in the NCR

Insight about protection provided by individual buildings, while useful, offers an incomplete picture of shelter quality within the NCR because it does not account for people's locations or their actions. In addition to the Cardozo/Shaw/U Street Corridor specific location assessment above, a broader regional assessment of shelters is required to understand the overall regional potential impact. To address this gap, LLNL developed the Svalin model and database to assess the efficacy of various shelter strategies using existing building stock. The results can be combined with fallout estimates to estimate indoor radiation exposures.

The regional map shown in Figure 31, is a result of census track level analysis of the types of buildings in the area and the level of protection from fallout they provide. The image demonstrates, for a census track average, that adequate shelters are ubiquitous in the area and many built-up areas have good shelters readily available.

For a low-yield nuclear detonation, special "fallout shelters" are not needed to keep populations safe. Instead, awareness of the types of buildings that offer adequate protection can keep affected populations safe.

Figure 32 demonstrates this principle. The region highlighted in red shown in Figure 32(a) is the area in our illustrative scenario where an unprotected population would get a 10 R exposure if they were outside for the first 24 hours. If the population in the area were to quickly go into the best nearby building to S-i-P, as shown in Figure 32(b), then the area in which the protected population would receive more than 10R in 24 hours would shrink to a small fraction of the original area, see Figure 32(c), preventing significant casualties.

Sheltering to Prevent Casualties

The term casualties refers to near term radiation related injuries and fatalities and depends on the exposure received. Research at SNL has evaluated several shelter strategies and analyzed the number of fallout casualties that may occur for each strategy.

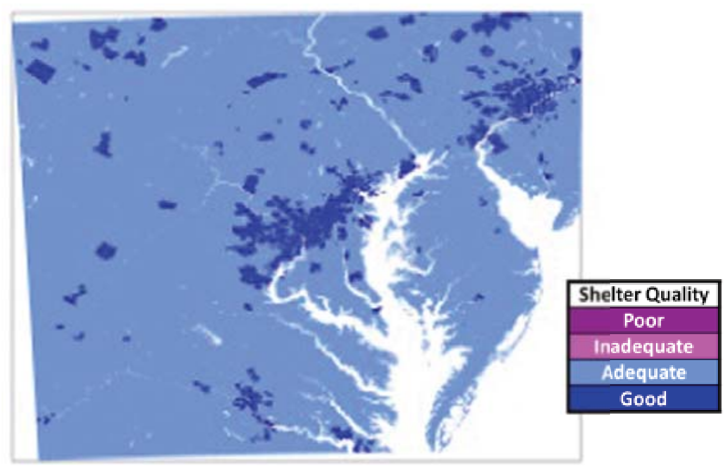


Figure 31. LLNL assessment of the best local shelter quality.

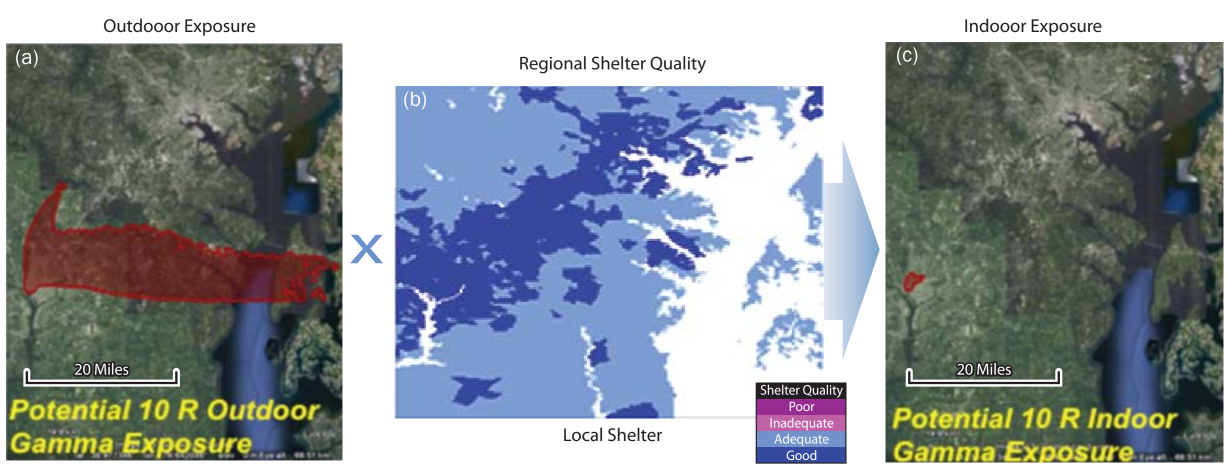


Figure 32. (a) Potential 10-R exposure area, shown in red.
(b) Available shelter quality in the area, shown in blue.
(c) Reduced area (in red) if the population were to shelter in the best nearby building.

The number of preventable fallout casualties in the NCR is 130,000 (82,000 fatalities and 48,000 injuries from radiation exposure). This presumes the unlikely assumption that everyone in the NCR stands outside for the first 4 days after the detonation. This value should not be used as an estimate of likely casualties, but rather the absolute worse case as basis of comparison for the various strategies explored. For example, if everyone in the region were to find a good shelter (PF = 40), approximately 100% of the 130,000 casualties would have been prevented. This assessment only evaluates fallout casualties and excludes the population in the SDZ and MDZ who may have been injured by other mechanisms.

Buildings with adequate protection (PF 10 or greater) are ubiquitous in the NCR area due to the preferred construction methods and building types in the region. If the entire population sheltered for the first few days in a PF = 10 structure (adequate protection), the number of fallout radiation casualties would be reduced by more than 93%, preventing 122,000 casualties. Figure 33 represents this information graphically, showing the number of prevented casualties (lives saved and injuries prevented) for each shelter type. The following results presume that all people in the region occupy the same type of shelter with the prescribed protection factor.

The white bar on the graphic represents the distribution of protection factors from immediately available (nearby) buildings in the neighborhood. This was calculated using the Svalin system (see Appendix C) and the results indicate that adequate and good shelters are generally available in the area and that quickly sheltering in the best nearby building would reduce the number of casualties by 98%.

Figure 33 demonstrates that sheltering, especially when a good shelter location is readily available, can be an effective method of reducing casualties from fallout radiation.

Unfortunately it must be assumed that not everyone will know to, or have the time to, get to an adequate or good shelter. For this reason additional analysis is required to evaluate additional measure to reduce casualties through alternate strategies.

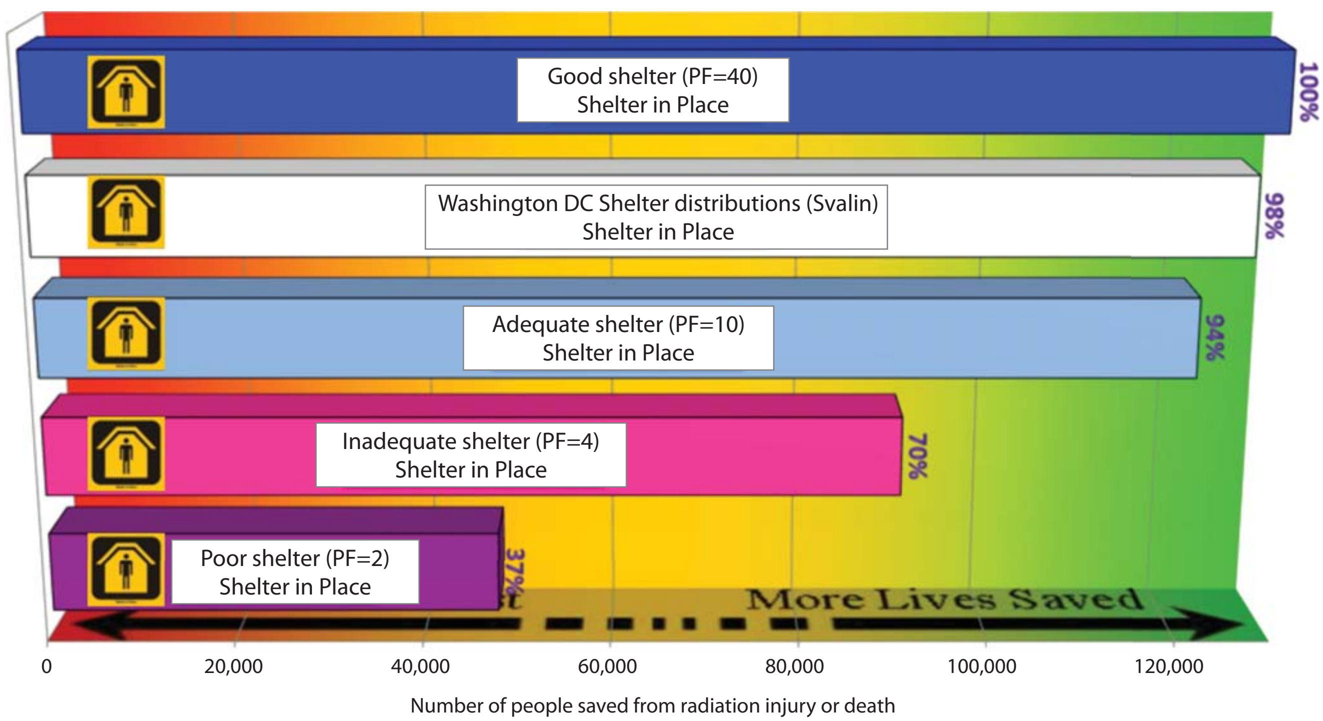


Figure 33. Casualties prevented for various shelter types. The percent of casualties prevented as compared to the 130,000 outdoor exposure casualties is noted as well.

5. Evacuation

As part of the NCR modeling and analysis support, research at SNL examined the unique, local and regional factors that affect planning and evacuation options for the hypothetical scenario. NUEVAC (Brandt, 2009c) was used to calculate exposures from fallout radiation during shelter and evacuation activities. The calculations drew on high-resolution scenario data developed by LLNL.

Two types of assessments were done for the illustrative scenario. First, a specific location Cardozo/Shaw/U Street corridor area was used to asses various shelter and evacuation strategies. Second, a regional assessment specified sheltering characteristics and movement within a hazardous fallout region for every individual initially in the DFZ. The regional assessment divided the fallout area into zones and then assigned shelter and evacuation tactics to each zone.

The alternative strategies were compared by analyzing the reduction of expected number of casualties from acute radiation sickness, in other words, lives saved. The assessment focused on actions taken within the first four days because that is the time when the most severe impacts of fallout radiation would occur.

The following assumptions were made:

- The various shelter–evacuate strategies presumed different levels of knowledge regarding the hazardous fallout area. In some cases, excellent knowledge is assumed to determine the best possible evacuation outcomes. In other cases, action without full information regarding the fallout plume is assumed.
- All individuals comply with the shelter–evacuation policy under consideration.
- Movement is on foot at a nominal speed of 3 km/hr because evacuation areas relatively near the detonation are likely to be filled with obstructions.

Cardozo/Shaw/U Street Corridor Evacuation Assessment

Figure 34 shows three evacuation routes analyzed for Cardozo / Shaw/U Street Corridor neighborhood, all of which start around the vicinity of Cardozo High School.

Route 1 (blue) is the shortest route out of the DFZ and proceeds west across Calvert Street Bridge to Connecticut Ave; Route 2 (green) is the official evacuation route for Cardozo High School as determined by the District of Columbia's Homeland Security and Emergency Management Agency Evacuation Route Lookup website (*http://dcatlas.dcgis.dc.gov/evac/*); Route 3 (yellow) is the Informed Evacuation (IE) route which proceeds through areas of decreasing fallout concentration to the northeast;

As illustrated in Figure 35, radiation levels can vary significantly within the DFZ, and both routes 1 (blue) and 2 (green) lead into very high dose rate areas and would result in higher evacuation exposures despite route 1 being the shortest path out of the area. This example provides a compelling illustration of the effect of evacuation route choice. Despite the fact that these appear to be the preferred routes out of the DFZ, they may actually lead to higher exposures. Figure 35 demonstrates the various exposure rates along the pathway using the height and color of the bar on the image. Evacuation timing and routes from this location illustrate several challenging problems with movements near the highest-dose-rate portions of the fallout area.

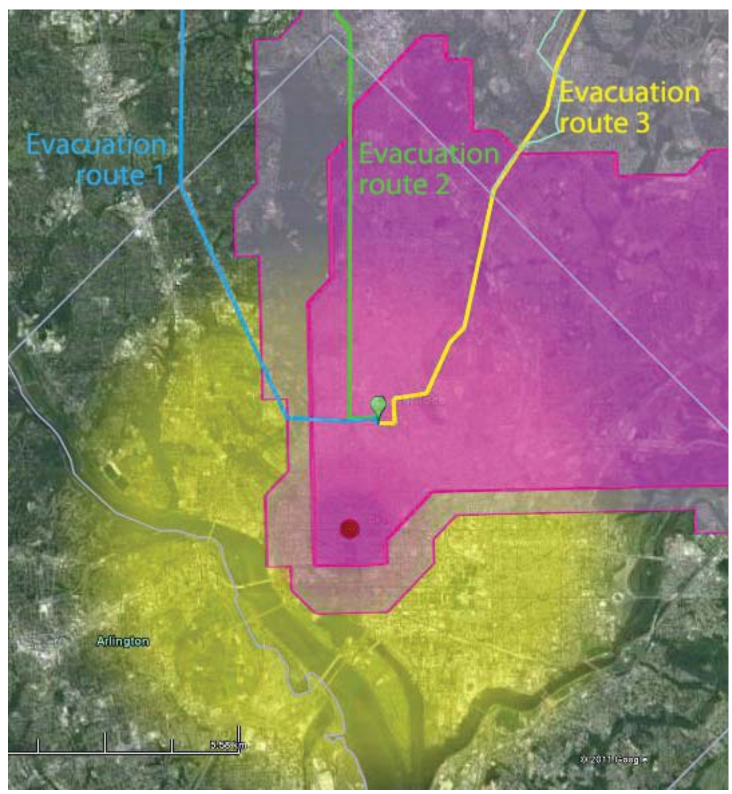


Figure 34. Evacuation routes analyzed for the example location.

Total integrated evacuation exposure was estimated by adding up the exposure received from each block. Depending on how quickly evacuation would be initiated after detonation, dust and debris could cloud the air, limiting visibility. Roads would also be impassible to vehicles so close to the detonation location. For these and other reasons, an evacuation at 3 km/hr was chosen to represent a reasonable "on-foot" evacuation speed.

Figure 36 summarizes the exposures that would be received during evacuation for eight possible departure times (every 15 minutes for the first 2 hours after detonation) and the three different routes assessed. As illustrated, early evacuation can result in fairly substantial exposures, especially if an uninformed route (such as route 2) were taken. In fact, early evacuation (< 30 minutes) along the city's default evacuation route (route 2 in green) would lead to potentially lethal exposures.

Figure 35. Three evacuation routes analyzed. Route #3 affords the lowest exposure to radiation 3 hours after detonation.

The analysis indicates that potential exposures arising from evacuation are greatest if evacuation is attempted in the first hour after detonation. Waiting 2 hours lowers the average potential evacuation dose by 85%, and waiting 24 hours can reduce the evacuation exposure substantially. As an example of the exposures that might be received during evacuation, using the pre-defined DC evacuation route (route 2) 15 minutes after a detonation would result in a 530 R exposure. However, waiting 1 hour before evacuating along the same route would result in an evacuation exposure of 185 R, and waiting 2 hours before evacuation would yield an evacuation exposure of less than 100 R.

Although the lowest possible evacuation exposure can be achieved through delayed departure, the delay also means that individuals receive exposure from fallout while waiting in their shelter. Evaluation of the total exposure for different lengths of sheltering was performed by summing the cumulative exposure received while sheltered (see previous section) with the exposure received during evacuation to determine the total exposure received by an individual for a particular evacuation strategy. Figure 37 adds the potential baseline evacuation exposures

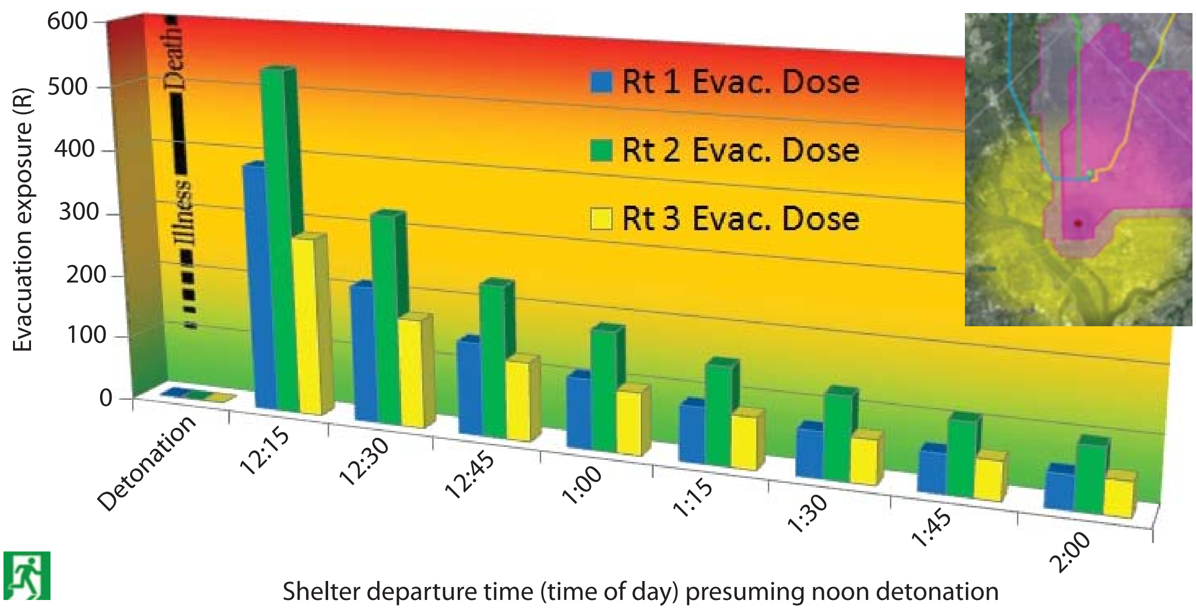


Figure 36. Departure time from a shelter is a key determinant of likely exposure.

(represented by bars) to exposure received in a shelter with an adequate protection factor of 10 (represented by the light blue shaded area in the illustration).

It is the total exposure, including exposure received in a shelter up to the evacuation time and exposure received during evacuation that determines the possibility negative health impact. As an example, if individuals at the Cardozo High School sheltered in an adequate (PF = 10) location for 1 hour after the detonation (until 13:00) and then evacuated along the default "snow emergency" preplanned evacuation route, they would receive 50 R during shelter and 185 R during evacuation. The total exposure would be ~235 R. Notice that waiting 2 hours (until 14:00) would result in only 170 R total exposure.

Figures 38-40 review a variety of shelter and evacuation options.

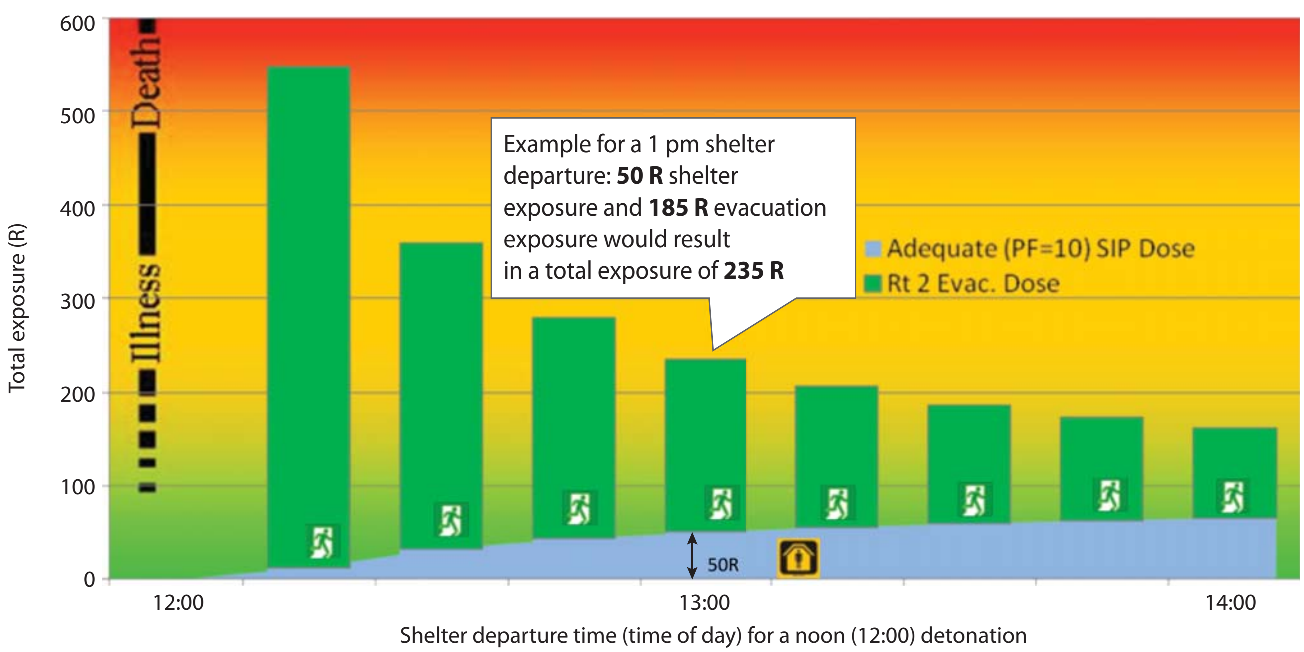
Figure 38 expands the analysis to cover the first 24 hours to demonstrate that the total exposure does not change dramatically after the first 12 hours for this particular example of an adequate shelter and a poor evacuation route (route 2). Note that a 14-hour (2 AM) departure results in the lowest total exposure, 110 R, before the continued shelter exposure brings the total dose up slightly.

Figure 39 illustrates the effect of an inadequate shelter and evacuation along route 2. Pictured is one of the few single story, wood frame, brick veneer structures in the neighborhood. This is the "worse case" scenario in that the shelter is inadequate and the uninformed (city pre-planned) evacuation route provides the highest exposure of the 3 routes studied. Because of this, the optimal evacuation time is closer to 5 hours, as the continued shelter does not provide much long term protection. Even at that optimal shelter departure, the exposure of 240 R will cause radiation sickness. Alternate strategies for those that find themselves in poor or inadequate shelters will be discussed below.

Figure 40 illustrates the effects of a good shelter, which can be commonly found in urban environments, and an informed evacuation route. In this case Cardozo High School would likely have protection factors greater than 50 in many parts of the building, especially underground areas. For the purpose of comparison, a PF = 40 was used and the best (route 3) evacuation route was analyzed.

Although there are significant differences in the total exposure for early evacuation, after 12 hours these differences are minor. In fact, optimal departure times for good shelters are greater than 24 hours because nearly all of the exposure comes during evacuation so waiting for the radiation levels to decrease is advantageous.

Figure 37. Cumulative exposures received while sheltering (light blue) and during evacuation (green) for various departure times.



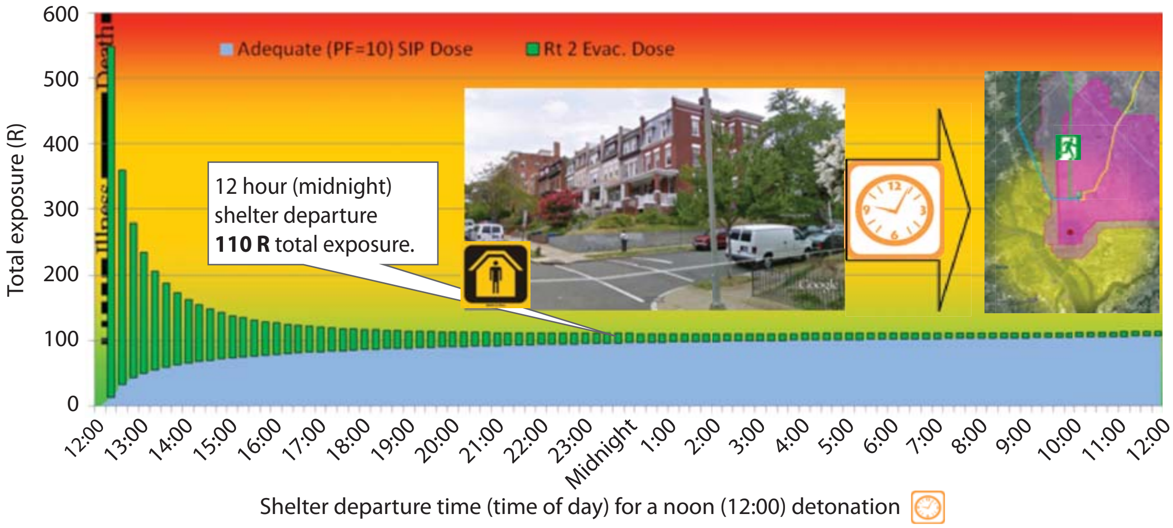


Figure 38. Comparison of total exposure from various shelter departure times from Adequate Shelters (PF=10) like the row homes pictured using the default city evacuation route (green) is selected for evacuation.

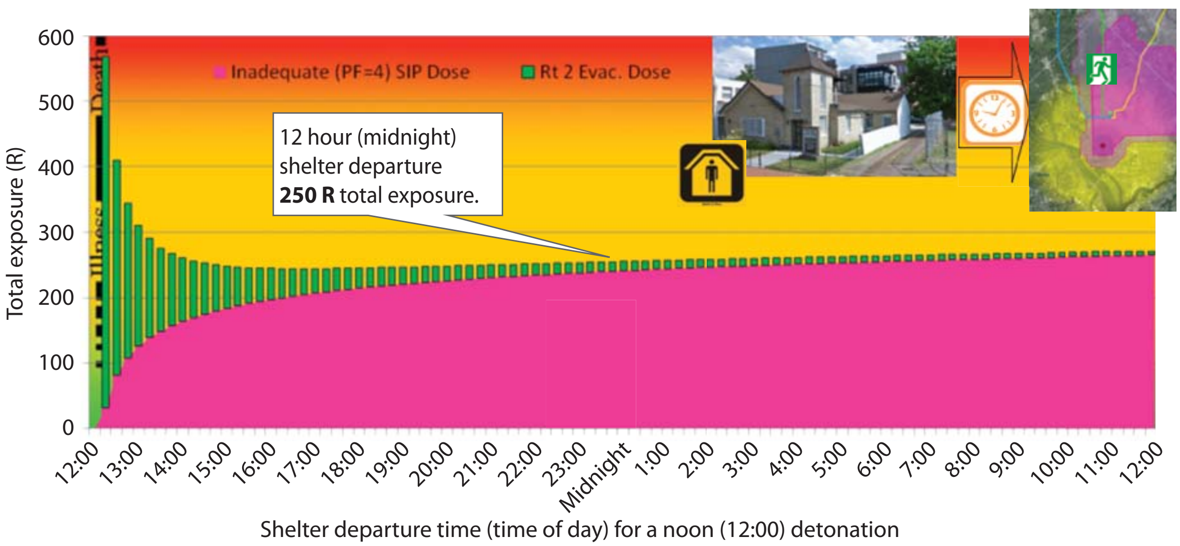


Figure 39. Total exposure from various shelter departure times from a Poor Shelter (PF=4) like the single story brick veneer structure pictured using the default city evacuation route (green).

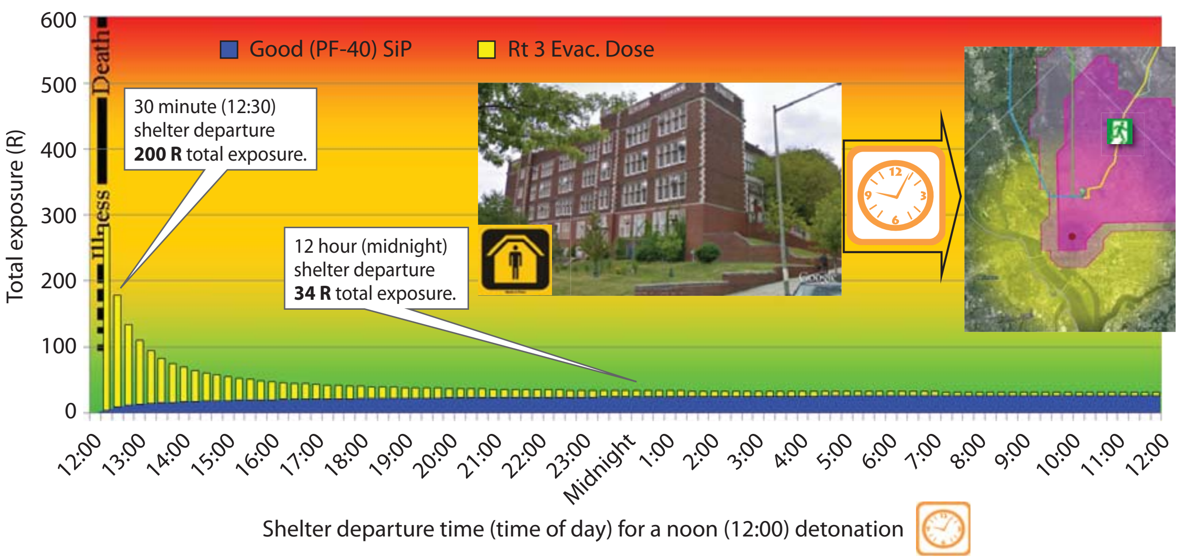


Figure 40. Total exposure from various shelter departure times from a Good Shelter (PF=40) like the school pictured using the Informed evacuation route (yellow).

The Cardozo/Shaw neighborhood assessment is just an example, and specific evacuation times should not be applied literally to other Washington, DC areas. Rather, it is important to note the trends:

- The fastest way out of DFZ is not necessarily the best way out.
- "Snow emergency" and other preplanned evacuation routes may not be the best evacuation routes because they might follow the contamination centerline.
- Early evacuation provides the highest potential exposures.
- Informed (lowest exposure) evacuation routes can provide significantly lower exposures and allow for earlier evacuation, especially for those in inadequate protection structures.
- The current Federal guidance of sheltering for 12–24 hours in adequate (or better) shelters is consistent with the results of this example location.

A key consideration for evacuees is the possibility that there will be no "straight-line" path out of the area and that natural features (such as rivers and cliffs) and man-made obstacles (such as security fences, freeways, culverts, and railroads) might block the best potential routes out of an area. In addition, the lateral evacuation strategy (moving away from the centerline of a cigar shaped fallout pattern) will not be feasible for the complex fallout patterns often observed. The SNL NEUAC assessment applies the same block-by-block analysis to determine the evacuation dose, but uses a more sophisticated regional route analysis to investigate alternative evacuation **strategies for the entire region**. Essentially, it performs the analysis above for everyone in the region at the neighborhood level.

Regional Evacuation Assessment

Washington, DC has predefined evacuation routes (see Figure 8 of the overview) for each DC neighborhood. These routes were developed to aid the public in evacuation of the city during emergencies, although the HSEMA notes that these are "... known evacuation routes for residents. It does not account for real-time disaster updates to evacuation routes."

Figure 41 illustrates the optimal "informed evacuation routes" for the scenario. This is the level of detailed information the emergency management community should be striving to acquire early to facilitate an informed evacuation process in the NCR.

Figure 41 also displays the relative exposure rates in the area. As noted in the previous example, some of the city default evacuation paths take evacuees along the centerline causing higher exposures (see region 1, 2 and 4 of Figure 8).

The pink colored lines in Figure 41 illustrate the lowest exposure evacuation direction for each zone. For example, occupants of the zones west of the centerline of the plume travel westward away from the highest dose rate zones. Individuals northeast of the detonation must proceed through extended Hot Zone areas in order to avoid the highest radiation levels.

Outside of the MDZ, there are potentially 130,000 people that could be injured or killed by fallout exposure alone. The following strategies will assess how many lives can be saved and injuries prevented through various shelter and evacuation strategies.

Sheltering and Evacuation Strategies

Appropriate sheltering and evacuation strategies following detonation of a nuclear device in NCR can save thousands of lives. Researchers at Sandia have examined factors unique to the NCR to evaluate various sheltering and evacuation options (Brandt, 2011b). This work was coordinated by the MACWG group that includes national laboratory and private sector participants with support from the DHS and Department of Defense. The analysis of the NCR scenario considers the following shelter–evacuate protocols:

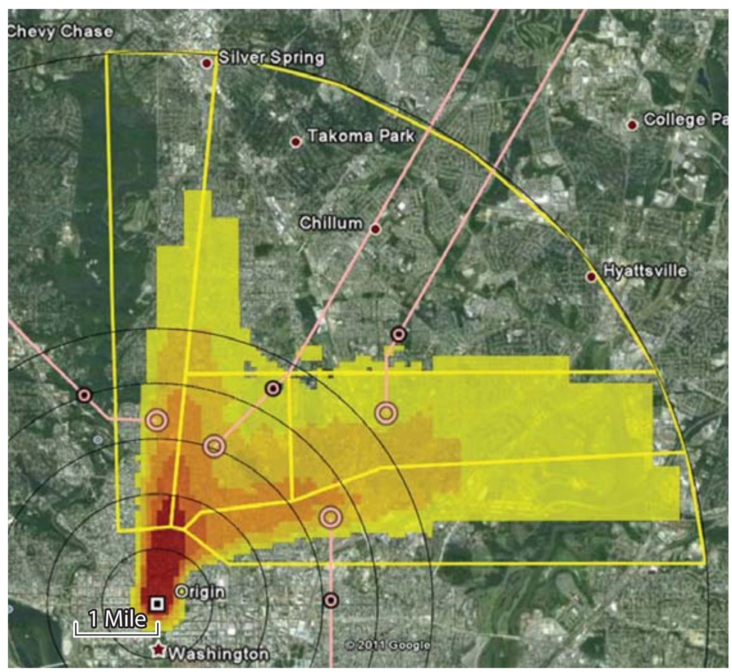


Figure 41. Informed evacuation routes for a given zone shown by pink lines for the illustrative scenario.

- **Extended Shelter-in-Place:** One frequently recommended strategy[4] is to shelter-in-place for an extended period (1–3 days) following a detonation to allow deposited radioactive material to decay to a safer level, hence reducing the dangers of potentially leaving through high level contamination.

- **Shelter-in-Place Followed by Informed Evacuation:** Individuals immediately shelter-in-place to minimize exposure to falling radioactive particulate, then evacuate when better situational assessment indicates the hazard zones and safest evacuation directions (Figure 41). Determinants of the optimal initial shelter interval and regrets associated with ill-timed evacuations are key issues.

- **Shelter-in-Place with Early Move to Better Shelter:** Individuals immediately shelter-in-place to avoid direct contamination during fallout deposition, but soon after the detonation they transit to more effective, nearby shelters (e.g., subway stations or building basements).

- **Uninformed Evacuation Away from Detonation Location:** This will use the city's existing evacuation routes which are generally radial (away from detonation). Radial evacuation has also been used as a surrogate for uninformed evacuation in past assessments.

Some of the best strategies can be used even in the confusion that would likely occur; however, planning and education are necessary, and requirements differ for each strategy. The best strategy for any individual depends on the fallout plume, quality of available shelter, and ability to evacuate from the most hazardous zones. Physical constraints to evacuation—which depend on location of the detonation—together with weather conditions are also important determinants of casualties. For these and other reasons, it is essential to examine regional data specific to the National Capital Region when assessing possible strategies.

Adequate Shelters

Buildings with adequate protection (PF = 10) are ubiquitous in the NCR urban environments. The previous section (shelter) presumes the entire population shelters in the same type of shelter. The assessment below builds on this with several different delayed evacuation assessments.

Example: If the entire population sheltered for the first few days in a PF = 10 structure; the number of fallout radiation casualties would be reduced by more than 94%, preventing 122,000 out of 130,000 casualties (middle bar of Figure 42). If everyone in each region used their best informed evacuation (Figure 41) and departed 3 hours after

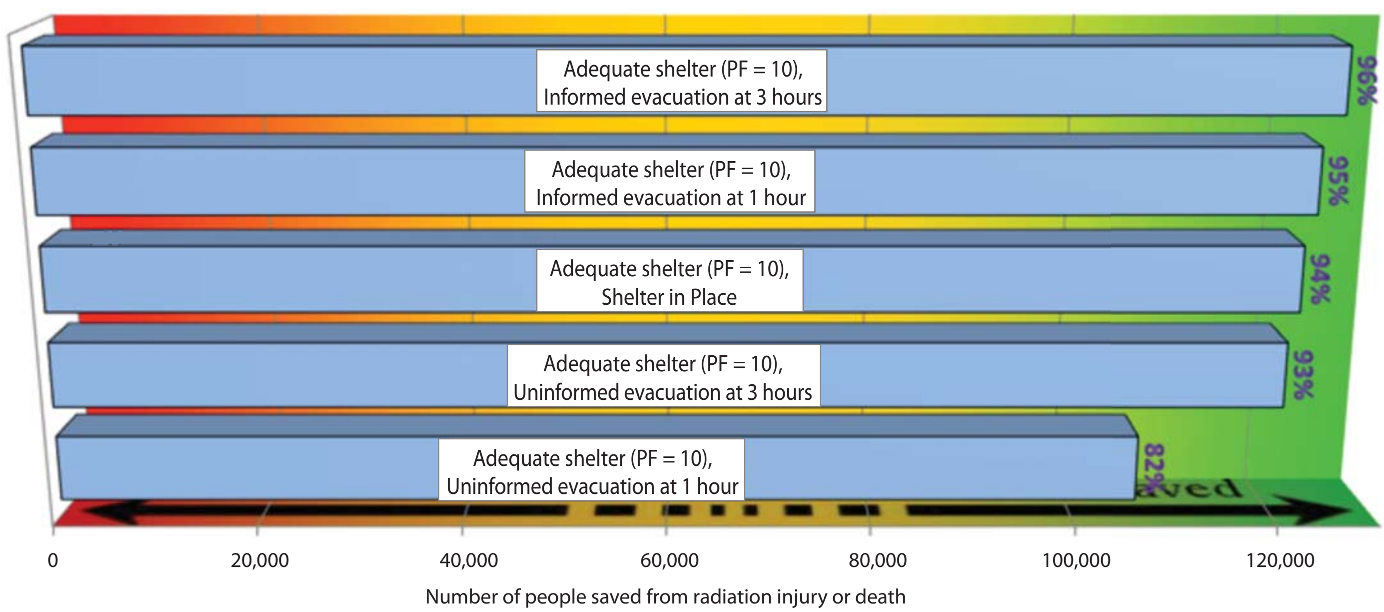


Figure 42. Fallout radiation casualties prevented by shelter-in-place versus various evacuation strategies from Shelter locations offering protection factors of 10 (Adequate Shelter).

[4]See, for example, Carter, A., May, M., and Perry, W. (2007). "The Day After: Action Following a Nuclear Blast in a U.S. City," The Washington Quarterly **30**:4, 19–32. Similar extended-shelter strategies are derived for certain scenarios in Florig, H. K. and B. Fischhoff (2007). "Individuals' Decisions Affecting Radiation Exposure After a Nuclear Explosion," Health Physics **92**(5), 475–483.

detonation, then an additional 3,000 casualties would be prevented bringing casualties prevented to 96% (124,000 out of 130,000).

This illustrates how, for the average population in an adequate (PF = 10) shelter, uninformed evacuations at one and three hours (bottom 2 bars) lead to additional casualties and the earlier the departure, the larger the number of additional casualties. However an informed evacuation strategy (top 2 bars) can further reduce the casualties, but only by a small amount.

This demonstrates that evacuations from adequate shelters should not be undertaken in the first few hours unless an informed evacuation route is known.

Poor Shelters

Figure 43 illustrates a theoretical example that presumes all buildings in the NCR are single-story, wood-frame houses without basements (poor shelters with PF = 2). In this case, a shelter-in-place strategy would still reduce the number of casualties by 48,000 (bottom bar). However because of the poor level of protection offered by a single-story wood-frame house, the analysis indicates that even an uninformed evacuation (3rd and 4th bars) can reduce the number of fallout casualties by an additional 15%, saving 67,000 people from injury or death. A one hour informed evacuation route would result in preventing 85,000 casualties. In the case of a poor shelter, delaying departure times can result in additional casualties.

Strategies for those in Inadequate Shelters

Rather than attempting early, uninformed evacuation from the area, individuals in poor shelters should consider moving to better shelter in the immediate area. Analysis shows (Brandt, 2011) that moving from a poor shelter (PF = 2) to an adequate shelter will save more lives than an uninformed evacuation. A one hour transit to an adequate shelter (PF = 10) will result in ~ 20% fewer casualties than the S-i-P strategy if the entire population was in a poor shelter. These calculations assume that the destination shelter is PF = 10 and that the transit takes 12 minutes. Other sensitivities have been calculated to show that even earlier departure from the poorest shelters may be useful, but are not recommended for those in even slightly better shelter (e.g., PF = 4). Only those in the poorest shelters (PF ≈ 2 or less) with access to nearby adequate shelters should contemplate early transit (less than one hour after detonation) to a better shelter.

Summary of All Strategies

Figure 44 summarizes the regional sheltering and evacuation results for the baseline NCR scenario. Note that the casualty estimates for shelter-in-place using the Svalin regional shelter quality data predict that approximately 98% of potential casualties might be avoided if individuals took refuge in the best sheltering locations of the buildings in which they find themselves at the time of the detonation. This is the result in Figure 44 that best incorporates current understanding of regional shelter quality as embodied in the Svalin data.

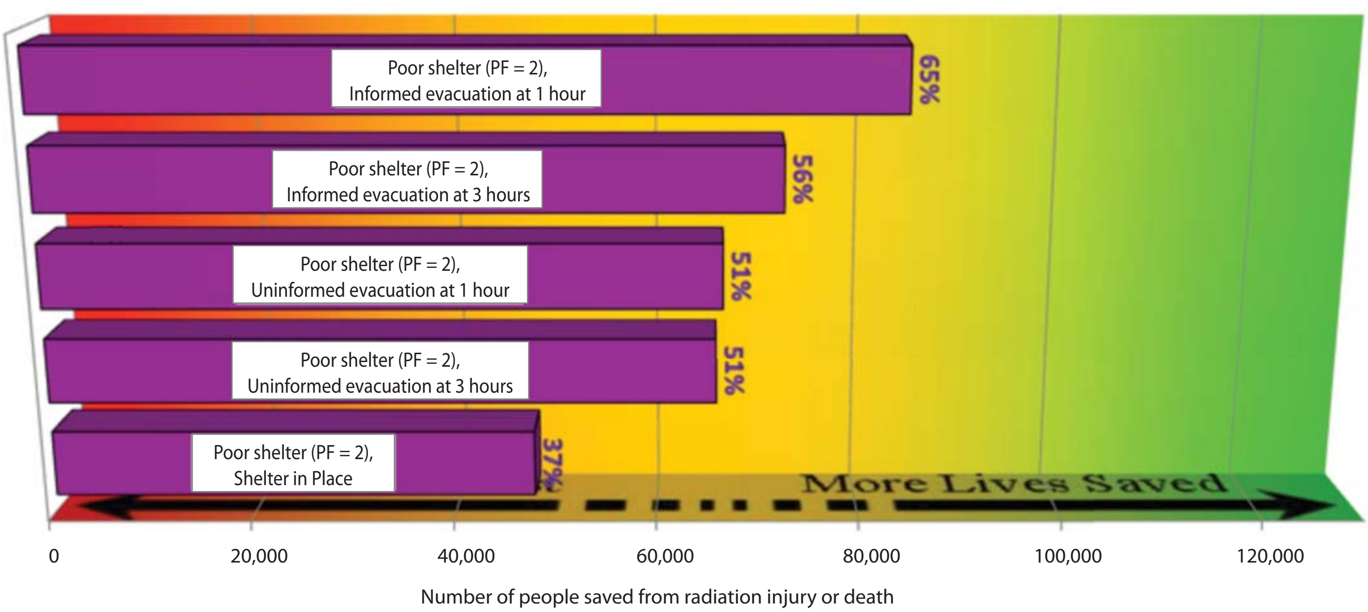


Figure 43. Fallout radiation casualties prevented by shelter-in-place versus various evacuation strategies from shelter locations offering a protection factor of 2 (Poor shelter).

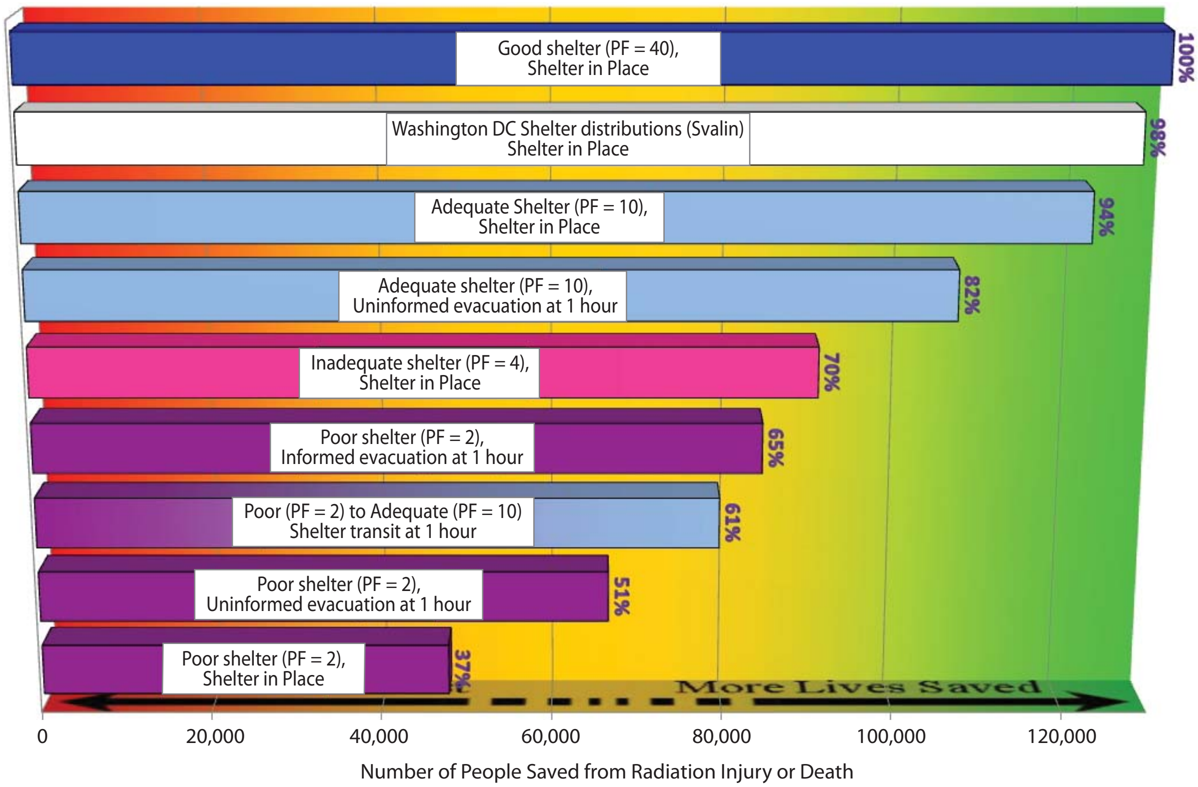


Figure 44. Fallout radiation casualties prevented by shelter-in-place versus various evacuation strategies from shelter locations.

Summary of Findings for the Shelter and Evacuation Analysis

- **Routes make a difference for early evacuees.** The exposure impact of route choice is more significant in the first few hours.
- **Shelter quality determines decision time.** The better the shelter, the longer the time before action is required. For poor shelters, actions should be taken in the first few hours; inadequate shelter, 4–12 hours; for adequate shelters, avoid action before 12 hours unless instructed otherwise.
- **Adequate shelter (PF > 10), stay in place.** Extended shelter-in-place inside an adequate (or better) shelter (PF > 10) is almost always preferred over an uninformed evacuation in the first 12 hours. The gains from an informed evacuation before 12 hours are marginal, while the penalty for an uninformed evacuation can be significant.
- **Poor shelter (PF = 2), move or evacuate.** Early evacuation (at 1 hour) from lower-quality shelters in the DFZ can be life-saving.
  - **Best Strategy For Poor Shelter:** Informed evacuation after approximately an hour. However, without an informed route use next strategy.
  - **Good Strategy for Poor Shelter:** Move to a better shelter. Analysis indicates that this can result in a significant reduction of casualties even as early as 20 minutes after detonation.
  - **Marginal Strategy for Poor Shelter:** Uninformed evacuation after approximately an hour and then leave the area, do not move toward the detonation site or directly downwind.
  - **Bad Strategy for Poor Shelter** Extended Shelter in Place.

- In aggregate, the **existing Washington, DC structures offered better than adequate protection**. If all residents adopted a shelter-in-place strategy, it would reduce the number of potential acute radiation casualties by 98% (there would be ~3,000 fallout casualties out of the ~130,000 potential casualties of an unsheltered population).
- For Regional evacuation planning, errors in identifying the centerline and boundaries of high-dose-rate regions can result in poor evacuation routes that eliminate the benefits of evacuation.
- Preplanned evacuation routes may not be the best evacuation route as they may follow the contamination centerline.
- The current federal guidance of sheltering for 12-24 hours in adequate (or better) shelters was consistent with the results of this report.

6. Discussion and Recommendations

Emergency Management Priorities

> ***"It's like surfing a big wave: you are either in front of it or under it."***
> *Batt. Chief Donnelly, DC Fire and EMS, at the June 14, 2011, National Capital Region IND Response Planning Workshop*

Early actions taken by regional emergency management agencies can potentially save hundreds of thousands of lives and reduce the enormous national impact of a nuclear attack. Although an IND detonation will overwhelm response resources in the area, regional emergency management agencies can take many actions to save and sustain lives. Knowing how to focus on priorities, given initially limited response capabilities, and getting in front of the situation rather than being crushed by it will be critical.

Public Messaging

> ***After a nuclear detonation, use all information outlets when conveying messages including, but not limited to, television, radio, e-mail alerts, text messaging, and social media outlets.***
> ***(EOP, 2010)***

Expect to be able to communicate to the public. The existing Emergency Alert System (EAS) was evaluated as being fairly robust against an EMP attack[5], and updates to the Integrated Public Alert and Warning System (IPAWS) will soon expand this capability to include alternate information channels, such as cellular voice, text messaging, and social networking capabilities. Although blast and EMP effects will damage some parts of the public communications infrastructure, expect enough capability will exist to send public information. Expect that enough of the public will be able to receive information to ensure that messages will be broadly disseminated even in heavily impacted areas. Battery (and hand-crank) radios and most cars[6] (and their radios) will function outside the SDZ (EMPC, 2004).

Radio and television broadcast capability outside of the District of Columbia should continue to function in some capacity to provide messages to those with radios in the affected area.

What to Say

> ***The most effective life-saving opportunities for response officials in the first 60 minutes following a nuclear explosion will be the decision to safely shelter people in possible fallout areas.***
> ***(EOP, 2010)***

As confirmed by the technical assessment described in this document, avoid immediate evacuation because that action will result in the highest exposures from even a poor shelter. The best public protection strategy after a suspected nuclear detonation is to have everyone shelter in the best, immediately available structure or location.

The 2010 revision of the Planning Guidance document (EOP, 2010) included recommended messaging (Figure 45). Additional message testing and development have been drafted and are undergoing testing as of the writing of this document.

Messaging should continue to evolve over time as more information is known; however, initial messages must be performed in the first few minutes following a detonation when little more is known than that a suspected nuclear detonation occurred.

Reducing immediate injuries and long-term risks from radiation exposure requires a "shelter first, analyze later" policy. Uncertainties in the yield and weather will make accurate predictions of affected areas in the critical moments after a terrorist attack difficult. It is far better to shelter those in a large area initially and then release parts of the area that are unaffected when additional information is available through observations or radiation measurements.

The Federal Register Notice, "Protective Action Guides for Radiological Dispersion Device (RDD) and Improvised Nuclear Device (IND) Incidents" (Vol. 73, No. 149, August 1, 2008),

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[5] Electromagnetic Pulse Commission (EMPC, 2008). "... we expect that the EAS will be able to function in near-normal fashion following an EMP attack. The major impact that might occur is a delay in initiation and receipt of an alert message because of (1) the dependency on the commercial telecommunications system, (2) the loss of some receiver channels for the EAS equipment, (3) the potential loss of some radio and television stations from power loss or damage to transmitter components, and (4) the loss of some AM radio receivers."

[6] EMPC (2008). "No effects were subsequently observed in those automobiles that were not turned on during EMP exposure. The most serious effect observed on running automobiles was that the motors in three cars [out of 37 cars] stopped at field strengths of approximately 30 kV/m or above." [Author's note: this would be well within the MDZ for a 10-kT device.]

Sample Key Message from Federal Government IND Messaging Effort

Impacted Community: Immediate Action Message

Suggested for local or state spokesperson: Fire Chief, Mayor, Governor

- We believe a nuclear explosion has occurred at [Location] here in [City].
- If you live anywhere in the metropolitan area, get inside a stable building immediately.
- You can greatly increase your chance of survival if you take the following steps.
  - **Go deep inside:**
    - Find the nearest and strongest building you can and go inside to avoid radioactive dust outside.
    - If better shelter, such as a multi-story building or basement can be reached within a few minutes, go there immediately.
    - If you are in a car, find a building for shelter immediately. Cars do not provide adequate protection from radioactive material.
    - Go to the basement or the center of the middle floor of a multi-story building (for example the center floors (e.g., 3 – 8) of a 10-story building).
    - These instructions may feel like they go against your natural instinct to evacuate from a dangerous area; however, health risks from radiation exposure can be greatly reduced by:
      - Putting building walls, brick, concrete or soil between you and the radioactive material outside, and
      - Increasing the distance between you and the exterior walls, roofs, and ground, where radioactive material is settling.
  - **Stay inside:**
    - Do not come out until you are instructed to do so by authorities or emergency responders.
    - All schools and daycare facilities are now in lockdown. Adults and children in those facilities are taking the same protective actions you are taking and they will not be released to go outside for any reason until they are instructed to do so by emergency responders.
  - **Stay tuned to television and radio broadcasts for important updates**
    - If your facility has a National Oceanic and Atmospheric Administration (NOAA) Weather Radio, this is a good source of information.
    - If you have been instructed to stay inside, stay tuned because these instructions will change.
      - Radiation levels are extremely dangerous after a nuclear detonation, but the levels reduce rapidly in just hours to a few days.
      - During the time when radiation levels are the highest, it is safest to stay inside, sheltered away from the material outside.
    - When evacuating is in your best interest, you will be instructed to do so.
    - People in the path of the radioactive plume – downwind from the detonation - may also be asked to take protective measures.

Figure 45. Sample message. For more information, see Chapter 6 of (EOP, 2010).

Table 5. Example of protective action specified by radiation dose averted.

Protective Action	Projected Dose Averted	Comments
Sheltering-in-place or evacuation of the public. Whichever results in lowest exposure.	1–5 rem (outdoor, 96-hr exposure)	Should normally begin at 1 rem (0.01 Sv); take whichever action (or combination of actions) that results in the lowest exposure for the majority of the population. Sheltering may begin at lower levels if advantageous.

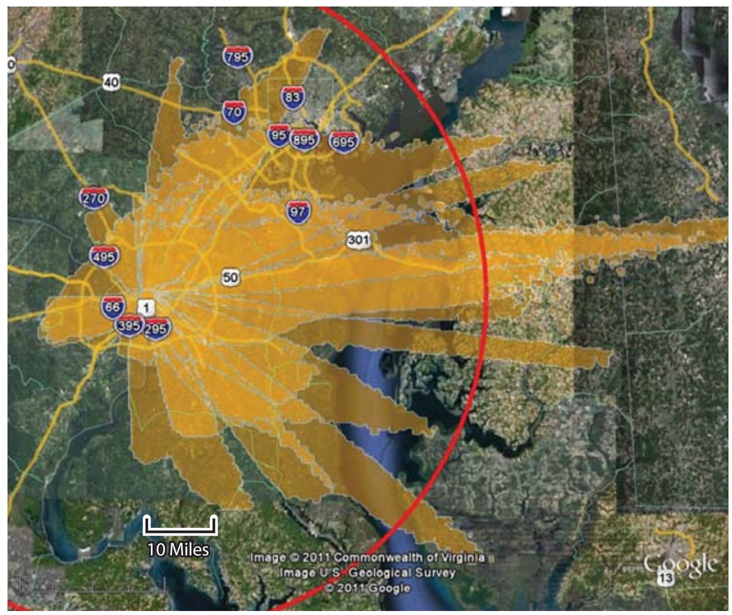


Figure 46. Integrated outdoor exposure for the first 4 days after detonation.

provides initial guidance for exposure levels that warrant protective measures. The guidance was developed primarily to help balance the risk of exposure to low levels of radiation (and the associated slight increase in cancer risk) with the hazards of actions, such as shelter or evacuation. This report focuses on actions that will avoid immediate injuries and fatalities; however, the Protective Action Guidance (PAG) can help bound the extent of potential areas where shelter is warranted due to long term (e.g., cancer) risk. See Table 5 for the Emergency phase shelter / evacuation guidance.

Figure 46 overlays the 12 fallout patterns discussed in the overview and plots the contour for a 5 rem integrated outdoor exposure for the first 4 days after detonation.

The red circle represents a 50-mile radius and contains the majority of the 5-rem (in 4 days) potential outdoor exposure area.

50 MILES: This distance should be used as the initial S-i-P area around a nuclear detonation until more information becomes available.

The 10-kT scenario is a good, worst-case estimate of the kinds of effects that might occur in that the yield is consistent with the approximate size of the first nuclear detonations (Trinity, Hiroshima, and Nagasaki) and National Planning Scenario 1. In addition, upper-atmospheric winds move at high speeds that account for some of the long-distance effects.

For an unknown incident, a 50-mile radius from the detonation site should be used for an initial shelter recommendation. Do not wait for predictive modeling or field measurements. As more information becomes available (from observations, modeling, or measurements) to indicate magnitude and direction of fallout, this

S-i-P recommendation can be extended to 100 miles downwind, which would mostly likely be in easterly direction from the NCR.

REGIONAL COORDINATION: Sharing information across affected counties and states is an early priority. The magnitude of the incident will make it difficult for any single jurisdiction to understand the scope and develop a coordinated response.

Figure 47. The Los Angeles County EOC was activated for Operation Golden Phoenix. (Photo, Paul Williams).

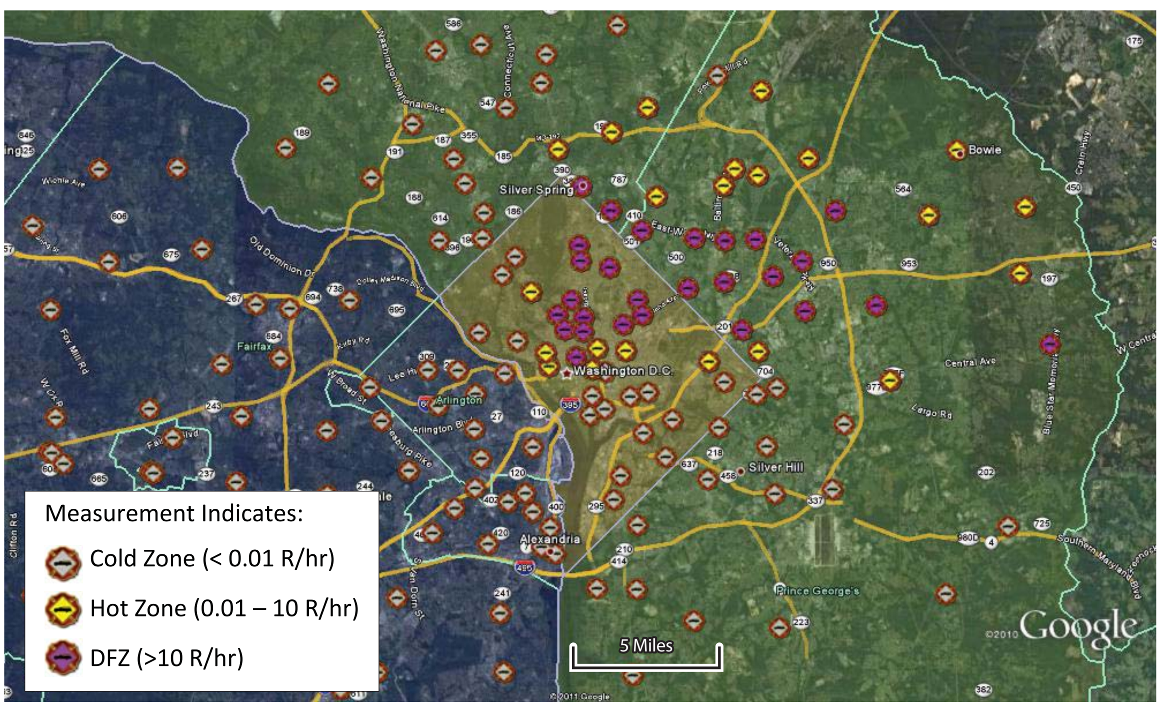
Although individual jurisdictions will need to manage response priorities for their own constituents, broader coordination is necessary to inform resource management and to ensure that each jurisdiction is aware of the magnitude of current and future hazards in a given area. Key steps to ensure regional coordination are:

- Activate local, county, and state Emergency Operations Centers (EOCs) and incident management systems.
- Designate a regional data-collection, weather, and modeling element.
- Define the hazard zones.

Because responders rarely deal with the unique aspects of radiation hazards and the fact that, in this situation, radiation levels will change rapidly in both time and location, it is important to designate a technical, regional situational assessment center outside of the DFZ and away from other hazardous conditions (see for example, Figure 47). The location should have health physics (radiation safety) support and be integrated with Federal and state modeling and monitoring assets.

A regional technical assessment center should work to establish communication with response organizations in the affected area. Functions include providing and collecting local hazard information and conditions for responders in all affected areas. As an example of how critical information can inform an initial response, Figure 48 shows how the radiation zone can be

Figure 48. Determination of radiation zones by reports from NCR fire stations.



determined from fire station locations in the NCR. Notice that the readings are not exact radiation levels (which can be difficult to measure, record, and transmit without error), but rather, simply reports about whether or not a given firehouse is in the DFZ (dark purple, >10 R/hr), Hot Zone (yellow, 0.01 to 10 R/hr), or cold zone (white, <0.01 R/hr).

Such information is extremely important in the initial hours after detonation because it:

- Releases responders from their S-i-P order and allows them to commence response operations in areas south and west of the detonation (areas safe from fallout in the illustrative scenario).
- Establishes response staging areas and evacuation routes.
- Establishes (or confirms) the direction of fallout travel to inform long-range S-i-P protective actions.

As can be seen in Figure 49, firehouse assessments can also be used to define the DFZ and Hot Zone.

Another important role for a regional technical assessment center is to interface with key Federal assets (Table 6). Although such assets are available to all jurisdictions, they represent limited resources and greatly benefit from a coordinated regional interface. For example, the IMAAC and Federal Radiological Monitoring and Assessment Center (FRMAC) can provide invaluable data as well as support for information collection, coordination, and dissemination.

> ***The goal of a zoned approach to nuclear detonation response is to save lives while managing risks to emergency response worker life and health.***
>
> ***(EOP, 2010)***

Defining Zones

Defining zones can be a useful approach to planning because it allows emergency management agencies to:

- Identify priority zones.
- Prioritize actions within each zone.
- Identify responder protection in each zone.
- Determine where to locate staging areas.

Figure 50 identifies the key issues and zone priorities identified in the national Planning Guidance document (EOP, 2010):

- Most of the injuries incurred within the LDZ are not expected to be life threatening and would be associated with flying glass and debris from the blast wave and traffic accidents.

Table 6. Example of key Federal assests.

Asset	Activation Process
Interagency Modeling and Atmospheric Assessment Center (IMAAC).	IMAAC can be activated by calling IMAAC Operations at (925) 424-6465 or the DHS National Operation Center (NOC) Watch at 202-282-8101
Federal Radiological Monitoring and Assessment Center (FRMAC) and DOE Assets	Coordinating agencies and State, tribal, and local governments may request a FRMAC or other support from DOE or DHS. The FRMAC and all other DOE National Nuclear Security Administration (NNSA) assets may be requested through the DOE 24-hour Watch Office at 202-586-8100. Requests for RAP teams may also be directed to the appropriate Regional DOE Office
Advisory Team	DHS, coordinating agencies, and State, tribal, and local governments may request support from the Advisory Team by contacting the CDC Director's Emergency Operations Center (EOC) at 770-488-7100.

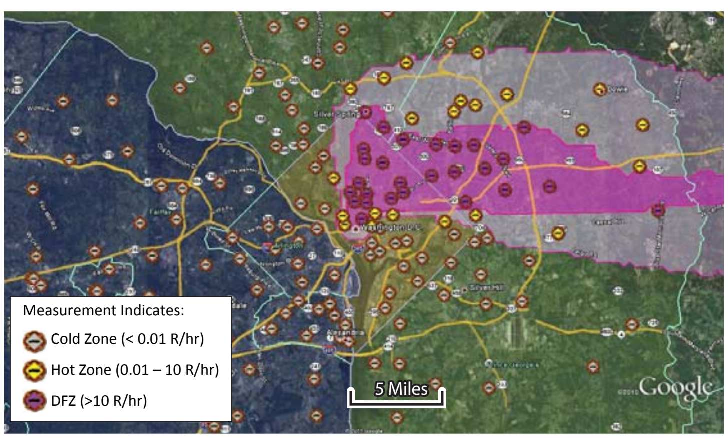


Figure 49. Preliminary estimates of the DFZ and Hot Zones can be determined using fire station reports.

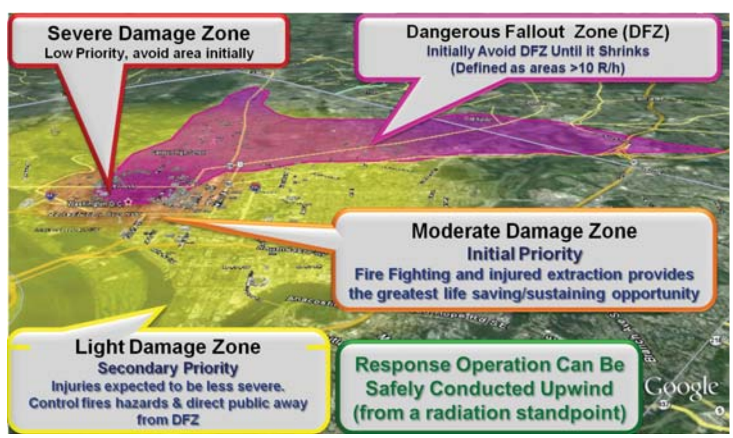


Figure 50. Review of zones association with an IND incident.

- If injured survivors are able to move on their own, they should be directed to medical care or assembly shelters.
- The MDZ should be the focus of early life-saving operations. Focus on medical triage with constant consideration of radiation dose minimization.
- Response within the SDZ should not be attempted until radiation dose rates have dropped and the MDZ response is well advanced.
- All response missions must be justified to minimize responder risks in accordance with risk–benefit considerations built into worker safety plans.

Evacuation Considerations

As established in the previous section, informed (lowest exposure) evacuation routes can provide significantly lower exposures and allow for earlier evacuation, especially for those in less protective structures who should evacuate early to reduce casualties.

Those in shelters threatened by fire, building collapse, or other life-endangering hazards should evacuate or relocate immediately. Figure 41 on p. 30, demonstrates how evacuation route planning can be done once enough information about the DFZ has been collected.

Although radial evacuations from the detonation location will generally keep people from moving into higher contamination levels, a planned, lateral evacuation will result in the lowest exposures. Evacuations should be phased and supported to ensure timely and safe exit of the population from the DFZ and Hot Zone. The NCR's pre-planned evacuation routes should not be used until it is verified that evacuees do not travel near the centerline of the contamination footprint(s).

Figure 51. Manage fires according to priorities.[7]

Glass, building facades, and rooftop mechanical equipment will create several meters of debris in urban street canyons in built-up areas within a few kilometers of the detonation site. Obstructions and debris will force evacuees to walk out rather than drive; thus, volunteers should be used to identify and create safe passages when it is safe to do so. Possible alternate evacuation routes can include subway tunnels or travel through large, intact structures.

Once the DFZ and Hot Zone are established:

- Evacuation planning should begin to move sheltered populations out of harm's way.
- Evacuation routes should be cleared, if possible.
- Routes should take advantage of sheltered passages, such as:
  - Subways.
  - Underground connectors.
  - Building lobbies.
- Execution should be phased to reduce crowding and the time spent moving through fallout areas.
- All other considerations being equal, early candidates for evacuation are those:
  - In the poorest quality shelters.
  - Close to the edge of the fallout zone.
  - Threatened by fire or hazardous materials.

Monitoring and Controlling Fires

Fire control will be important for the safety of those currently sheltered in hazardous areas. Several hundred fires can be expected within a few a kilometers of the detonation site. Extinguishing fires near the detonation site may be difficult because of lack of water pressure and the inability to move heavy equipment and personnel to the area. However several steps can be taken to reduce loss of life from fires.

- Watch for firestorm warning signs, such as fires coalescing and smoke plumes that begin to lean in toward the fire. Rapidly evacuate areas (even in the DFZ) near developing firestorms.
- Prioritize facilitated evacuation (especially non-ambulatory populations) near large fires that have the potential to rapidly spread or turn into firestorms.

Managing fires that are not in danger of spreading, such as those caused by traffic accidents (Figure 51), can be delayed to allow response units to focus on immediate life-safety issues in the MDZ or on evacuation support.

[7] AP Image: Fire engulfs the wreckage of several cars on the Abu Dhabi to Dubai highway, Ghantoot, United Arab Emirates

Responder Priorities

Initially, fire and police personnel in the area of blast damage should also shelter to protect themselves from fallout. If personnel are away from their station at the time of an incident, they should take any radiation-detection equipment that they have in their vehicles with them into the nearest robust building or shelter location. If the responder's structure offers inadequate shelter, consider relocating before fallout arrives if a better shelter is immediately available.

> **PROTECT RESPONSE FORCE:** Response personnel should also shelter initially. Responders with radiation-detection instruments can take further actions; however, those without instruments should follow the same guidance as members of the public.

Appendix D provides detailed information on critical types of personal protective equipment and their appropriate settings for responding to the aftermath of nuclear terrorism. **NOTE: Inclusion of specific equipment in this report does not represent an endorsement; rather such equipment is currently in use in the NCR and the applicability for certain missions is discussed. There is a wide range of equipment that can be used for these missions, for more information see U.S. Department of Homeland Security, System Assessment and Validation for Emergency Responders (SAVER)**, *https://www.rkb.us/saver/*.

Although any type of radiation detector can provide some information, critical equipment for initial responder protection includes **Alarming Dosimeters** and **Personal Emergency Radiation Detectors (PERDs)**. Initial responder efforts should be spent on making **high-range dose-rate measurements** inside the shelter (see figure 52). Older Civil Defense instruments function for this purpose, as do the newer Canberra Ultra or Mini Radiac and the RADOS RAD-60, both of which are used by responders in the NCR area.

Personal Radiation Detector (PRD) equipment used by law enforcement, also known as "Radiation Pagers," are similar in appearance to the electronic dosimeters. Although good for finding contraband radioactive material, these units do not (typically) have the range necessary for personnel protection (i.e., high dose rates) and cannot be used in the Hot Zone or DFZ.

Recently PRD manufacturers have begun offering dual detector systems that allow the PRD to have an extended (high) dose rate range without sacrificing the lower dose rate sensitivity. The NCR recently purchased the Polimaster PM1703-MO1 which has an additional high-range detector capable of measuring up to 1000 R/hr making it useful for both prevention and response missions. Warning: Alarm set points must be changed to match mission needs.

Instrument alarms should be set to alert the wearer when a decision or action should be taken. Table 7 identifies the set points recommended by Federal Guidance and the NCRP.

If radiation levels are present in the responder's shelter location, use the instruments to locate the best shelter location in the structure (area of lowest radiation levels). Provided that radiation levels are less than 10 R/hr at the occupant's shelter location, surveys should be conducted near doors and windows. Radiation levels near doors and windows greater than 10 R/hr indicate that the shelter location is within the DFZ. If readings at a building perimeter are between 0.01 R/hr (10 mR/hr) and 10 R/hr, then the shelter is within the Hot Zone. Readings less than 0.01 R/hr (10 mR/hr) indicate the Cold Zone. Those individuals in the LDZ should allow 20 minutes for any possible fallout to arrive before declaring a location safe from fallout contamination.

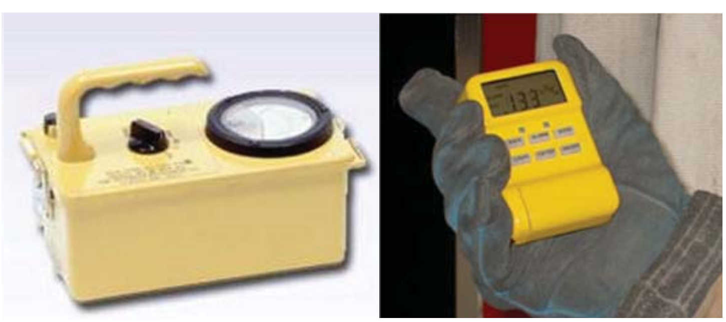


Figure 52. Examples of high-range instruments.

Figure 53. The extended-range Polimaster PM1703-MO1[8] can measure both low and high radiation levels.

[8] Most PRDs used for the interdiction of contraband radioactive material do not have the capability of measuring dose rates above ~0.01 R/hr; however, the Polimaster PM1703-MO1 has an additional high-range detector capable of measuring up to 1000 R/hr.

Table 7. Recommended settings for alarming dosimeters and personal emergency radiation detectors (PERDs).

Alarm Point[1]	Alarm Type[2]	Usage
10 mR/hr	Silenceable Intermittent	Alerts responder to the presence of radiation above a level that could reasonably be expected from natural or legitimate causes. Identifies the hot Zone Boundary.
10 R/hr	Nonsilencing, Nonlatching, Intermittent	Alerts user to an area where responder action should be restricted to only the most-critical, time-sensitive activities, such as the preservation of life. Identifies the DFZ Boundary.
5 R or rem	Silenceable Continuous	Administrative limit: Responder should request authorization from IC to continue activities. IC should consider changing out responder if replacements are available. Other methods should be considered to reduce responder dose (e.g., different approach vector, reduction of stay times, etc.). This administrative limit will help ensure that responders do not exceed Occupational Safety and Health Administration (OSHA) regulatory limit without considered action.
50 R or rem	Nonsilencing Continuous	Responder should leave the area. In extreme life-saving situations, responder can continue if aware of the radiation risks and no alternative rescue method exists.

[1]A dose or dose-rate-level alarm point of 80% can be used as an administrative level to notify the user that a predetermined set point is about to be reached.

[2]Alarm Type: Silenceable indicates that users can acknowledge (silence) the alarm even if they remain in the area. Nonsilencing, nonlatching indicates that the alarm will continue to sound while the user is in the specified dose rate.

COMMUNICATE STATUS: The distributed nature of responders in the community provides an excellent source for regional situational awareness to help establish affected areas and priority actions.

Telephones and cellular systems may not work (or may be overloaded) in the LDZ and MDZ; however, 2-way radio systems should work[9], although they may only function in point-to-point (sometimes referred to as "line-of-sight") mode if repeater towers have been damaged. Point-to-point cellular phones might also function in this capacity. If radios appear to be nonfunctional, power cycling (removing and replacing the battery) might restore the unit.

Radiation Levels will change rapidly; therefore, it is not necessary to report exact measurements. Instead, report the physical location and whether a reading indicates that the present location is in a DFZ, Hot Zone, or Cold Zone (Table 8). Measurements should be updated regularly (every 30 minutes) and recorded (even if readings indicate a low level of radiation). If a data coordination center has not been identified beforehand, report readings to dispatchers or other central repositories if communications can be established.

Table 8. Identification of zones by radiation level.

Radiation Level	Zone Identification
Greater than 10 R/hr	Dangerous Fallout Zone
Between 10 R/hr and 0.01 R/hr (10 mR/hr)	Hot Zone
Less than 0.01 R/hr (10 mR/hr)	Cold Zone

Responders within the DFZ with Radiation Measurement Capabilities

The ability of equipment to measure high-range radiation exposure rates is an important advantage because such instruments can be used both to determine the PF of a building and to establish safe evacuation routes out of an area. A rough estimate of a building's PF can be made by dividing radiation readings at the perimeter by readings at the best shelter location in the building. A recent report by LLNL investigators (Archibald and Buddemeier, 2010), Nuclear Fallout Decision Aid for First Responders, established:

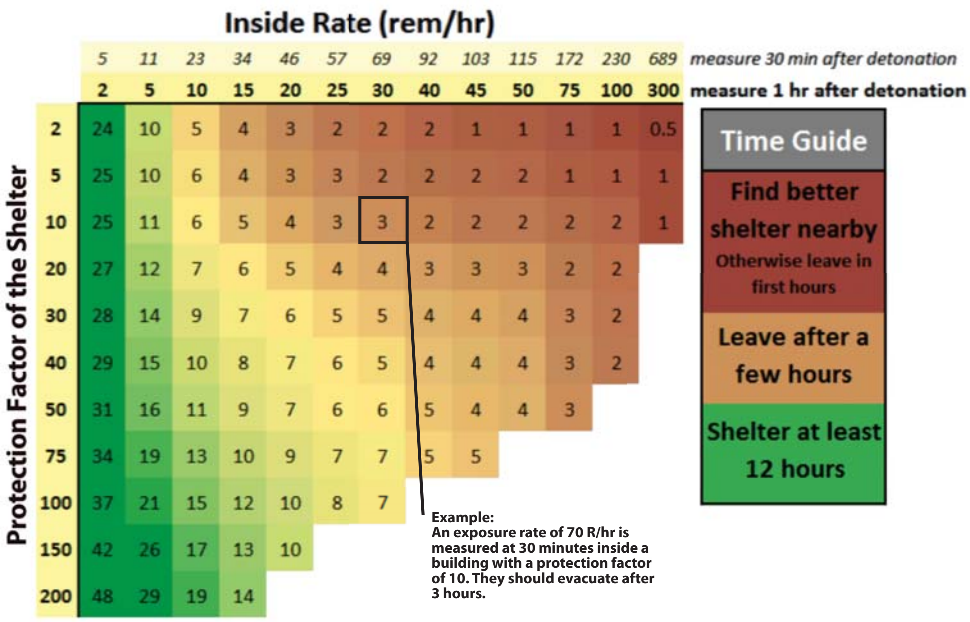
- Guidance for responders as to when they should evacuate according to knowledge of inside dose rate and shelter PF.
- A better understanding of how responders can choose a good evacuation path relying on only information they can visually observe or measure.

When Responders Should Depart a Shelter

Determining when to evacuate depends on shelter quality, measured radiation rates, and the ability to choose a good path. Having a high dose-rate instrument is a major advantage in determining all of these factors.

Provided a good path out of the area is available, optimal departure times can be estimated using Figure 54. Use of this tool requires knowing (or determining) the shelter's PF and the radiation rate **at the best shelter location in the building.**

[9](EMPC 2008). "A variety of mobile radios were tested in the stored, dormant, and operating states, in both hand-held and vehicle-mounted configurations. Consistent with older test data, none of the radios showed any damage with EMP fields up to 50 kV/m." [Author's note: this would likely be within the MDZ for a 10-kT device.]



Protection Factor of the Shelter \ Inside Rate (rem/hr), measure 30 min after detonation	5	11	23	34	46	57	69	92	103	115	172	230	689
measure 1 hr after detonation	2	5	10	15	20	25	30	40	45	50	75	100	300
2	24	10	5	4	3	2	2	2	1	1	1	1	0.5
5	25	10	6	4	3	3	2	2	2	2	1	1	1
10	25	11	6	5	4	3	3	2	2	2	2	2	1
20	27	12	7	6	5	4	4	3	3	3	2	2	
30	28	14	9	7	6	5	5	4	4	4	3	2	
40	29	15	10	8	7	6	5	4	4	4	3	2	
50	31	16	11	9	7	6	6	5	4	4	3		
75	34	19	13	10	9	7	7	5	5				
100	37	21	15	12	10	8	7						
150	42	26	17	13	10								
200	48	29	19	14									

Figure 54 Tool to estimate optimal evacuation time (Archibald and Buddemeier 2010).

Using Radiation Instruments to Find the Best Evacuation Path

The evacuation times noted above depend on an informed evacuation path. The study by Archibald and Buddemeier (2010) found, as others have suggested, that a path perpendicular to movement of the fallout cloud is usually the better course. However, movement of a fallout cloud is not always visible to an observer on the ground, especially in an urban area. For this reason, it is suggested that:

- Responders should test to see which perpendicular path is better by sending scouts ahead. If scouts measure a significant decrease in radiation, the rest of the team should follow.
- If the rate is continuously increasing, however, responders should head in a different direction or seek shelter in a nearby building that offers good protection.
- Fluctuations in dose rates will occur during evacuation. Walking close to buildings will probably result in a different exposure than walking in the middle of the street. Intersections will likely have higher dose rates. Try to walk through areas with lower dose rates.
- Moving through areas without fallout will reduce exposure. If possible, cut through buildings, underground parking garages, tunnels, or subways.

Example Application for the Cardozo/Shaw area

If a responder were sheltered in Cardozo/Shaw area, an outdoor radiation reading at 30 minutes after the detonation would have shown radiation levels to be ~700 R/hr. If the responder found that the lowest radiation level in their shelter was ~70 R/hr, this would indicate a PF = 10.

Given this information, Figure 54 recommends a departure time of 3 hours after detonation. After 3 hours a responder departs the building, using the radiation instrument to make measurements while traveling. The initial evacuation strategy is the default DC evacuation path; however, steadily increasing radiation exposure rate readings indicate that this direction of travel is the wrong evacuation route. Reversing direction and heading northeast resulted in the lowest evacuation dose.

In this example, the high-level dose-rate instrument:

1) Determined the shelter's protection factor and best shelter location within the building.
2) Provided the inside radiation reading, which the responder used the decision aid to find the optimum shelter departure time.
3) Helped the responder avoid a poor evacuation route.

Responders Outside the DFZ

If dose rates are less than 10 R/hr and enough time has passed that all of the fallout has deposited (20 minutes if in the LDZ), then outdoor activities can be conducted. There will be low levels of detectable contamination throughout the area, but such levels will not be life endangering and not a significant respirable hazard.

Working in the Hot Zone

PPE DOES NOT STOP RADIATION: Reducing time spent in high-dose-rate areas is the greatest protective measure. Bulky isolation suits and elaborate respiratory protection methods can actually increase exposure because they reduce speed, the ability to communicate, and worker efficiency.

Self-contained breathing apparatus (SCBAs); respirators; firefighter "turnouts" or "bunker gear;" and Level A, B, or C Hazmat suits do not protect against the primary hazard, which is the penetrating gamma radiation given off by fallout. Inhalation and ingestion of fallout are secondary concerns compared to external exposure.

> ***At the scene of an incident, standard protective clothing (i.e., bunker gear) and respiratory protection devices are sufficient to protect emergency responders against personal contamination by radioactive materials when conducting life-saving and other critical missions.***
>
> ***NCRP, Commentary #19.***

Firefighter turnouts and anti-contamination clothing can help ease decontamination after entries, but time-critical, life-saving activities should not be delayed if such items are not immediately available, provided other hazards at the scene do not dictate specific PPE. After the disruption of a nuclear detonation, many hazards will be present that are not radiation related. Fires, toxic industrial chemicals, and sharp debris are just a few examples of hazards that should be considered when working in the SDZ, MDZ, and LDZ.

The best personal protective equipment for responders working in the Hot Zone or DFZ is a radiation detector that alerts workers to exposure and radiation levels of concern.

> ***Radiation monitoring equipment is necessary for emergency responder dose control and safety while they are in their facilities and on emergency calls.***
>
> ***NCRP Report #165***

Recognize the Features of Each Zone

KNOW YOUR ZONE: Knowing what zone you are in (LDZ, MDZ, SDZ, DFZ, or Hot Zone) will help responders identify priorities and protective measures.

Recognizing the Severe Damage Zone

- Few, if any, buildings are expected to be structurally sound or even standing.
- Very few people would survive; however, some people protected within stable structures (e.g., subterranean parking garages or subway tunnels) at the time of the explosion may survive the initial blast.
- Very high radiation levels and other hazards are expected in the SDZ, greatly increasing risks to survivors and responders. Responders should enter this zone with great caution and only to rescue known survivors.
- Rubble in downtown streets is estimated to be impassable in the SDZ making timely response impracticable.

The SDZ is not an initial priority for response activities because the possibilities of viable survivors are low and risks to responders are high.

Recognizing the Moderate Damage Zone

- Responders can anticipate that they are entering the MDZ when building damage becomes substantial, such as blown-out building interiors, blown-down utility lines, overturned automobiles, caved roofs, some collapsed buildings, and fires.
- In the MDZ, sturdier buildings (e.g., those with reinforced concrete) will remain standing, lighter commercial and multi-unit residential buildings may have fallen or be rendered structurally unstable, and many wood-frame houses will be destroyed.
- The MDZ is expected to have the highest proportion of survivable victims who require medical treatment.
- The MDZ presents major hazards to response workers, including elevated radiation levels; unstable buildings and other

structures; downed power lines; ruptured gas lines; hazardous chemicals, asbestos, and other particulates released from damaged buildings; and sharp metal objects and broken glass, for which consideration and planning are needed.

The MDZ (outside of the DFZ) is an early priority area for response operations. This area will offer the greatest life-saving potential for the response community; however, there are risks to responders, and proper dose-rate monitoring and hazard awareness are key.

Recognizing the Light Damage Zone

- Nearly all windows will be broken, and there will be external panel damage on most structures.
- Damage in the LDZ will be highly variable after shock waves rebound multiple times off buildings, the terrain, and even the atmosphere.
- As a responder moves inward though the LDZ, windows and doors will be blown in, and gutters, window shutters, roofs, and lightly constructed buildings will have increasing damage.

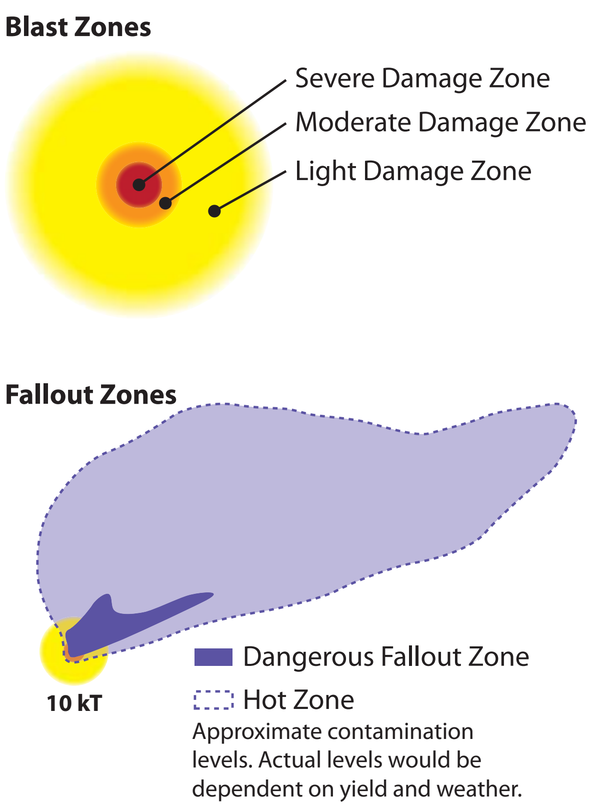


Figure 55. Summary of the zone types associated with an IND detonation. Recognizing the features of each zone is essential.

- The severity of injuries responders will encounter in the LDZ should be relatively light, consisting of mostly superficial wounds and occasional flash burns.

There will be numerous injured in the LDZ; however, the response force should focus its resources on genuine life-safety issues and delay treatment of minor lacerations or crush injuries to better concentrate on supporting operations in the MDZ.

Recognizing the Dangerous Fallout Zone

- Radiation levels of 10 R/hr and above.
- This zone will extend up to ~20 miles downwind from ground zero for a 10-kT.
- The DFZ reaches its maximum extent at 1 hour after detonation.

The DFZ represents a direct and immediate threat to the public and responders. Actions in this zone should be restricted to efforts that are required for the life safety of large populations, and only on an informed, voluntary basis.

Recognizing the Hot Zone

- Radiation levels from 0.01 R/hr (10 mR/hr) to 10 R/hr.
- This zone could extend 150 miles or more for a 10-kT.
- The Hot Zone reaches its maximum extent 12-24 hours after detonation.
- Extended response actions will not result in life-threatening exposures (>100 rem).

Routine emergency response operations can and should be performed in the Hot Zone. Protective measures, such as exposure-rate monitoring equipment should be employed to track responder exposure and ensure responders do not inadvertently cross into the DFZ.

In routine radiation emergency response, entering the zone bounded by 0.01 R/hr entails donning appropriate personal protective equipment (PPE) and being properly monitored for radiation. For a nuclear detonation, the 0.01 R/hr line can reach a maximum extent of several hundred miles within hours of the incident.

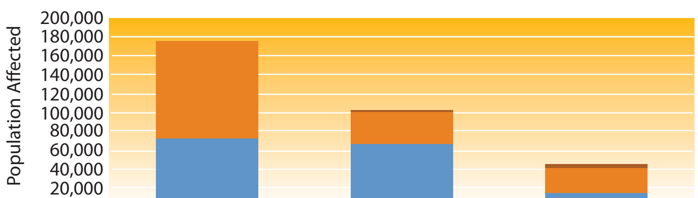
(EOP, 2010)

NO VICTIMS: An incident the scale of an IND detonation does not allow for the luxury of narrowly defined responders who rescue victims. Rather, everyone alive is a survivor who must support other survivors and the nation in response. The public, private sector, and even the injured can play important roles in reducing the burden on traditional response organizations by using actionable information to guide behavior while supporting a whole community response.

The magnitude of a terrorist attack involving an IND will overwhelm all response resources. Make use of citizen volunteers. Life safety will depend on citizen-run triage sites, litter bearers, and evacuation route clearing.

Public Health and Medical Priorities

As discussed in Appendix E which provides a detailed assessment of injury types and distributions, most injuries outside of the Murrah building in the 1995 Oklahoma City bombing were caused by glass breakage. For a 10-kT IND, this phenomenon can be seen at more than 3 miles away. NATO medical response planning documents for nuclear detonations state that "… missile injuries will predominate. About half the patients seen will have wounds of their extremities. The thorax, abdomen, and head will be involved about equally." This assessment is consistent with the historical observation that many victims from Nagasaki arriving at field hospitals exhibited glass breakage injuries. Such effects had not been previously modeled. Depending on how effective sheltering is, there can also be several hundred thousand radiation exposures that could result in acute radiation syndrome (ARS) illness or death.



	Recover	At Risk	Expectant
Major Trauma		1,013	4,428
Mild Trauma	103,858	34,720	25,459
Radiation Only	71,412	66,956	15,160

Figure 56. Number of injured in the Recover, At Risk, and Expectant categories.

Summary of Injury Categories

To visualize the summary analysis discussed in Appendix E, the casualty categories were grouped according to the probability of a treated fatality. Three injury classifications were used: Recover for injuries with a mortality rate of less than 5 percent, At Risk for injuries with a mortality rate between 5 and 95 percent, and Expectant for injuries with a mortality rate of greater than 95 percent. Figure 56 shows the number of injuries in each of the categories.

Overall there are more than 300,000 injuries, not including the prompt fatalities. Figure 56 also illustrates the ratio of trauma (orange and brown) to radiation only injuries (blue), demonstrating that trauma is not necessarily a good indicator of radiation exposure. This model indicates there would be ~ 150,000 radiation only injuries.

Injury Breakdown for the Severe, Moderate and Light Damage Zones

The location specific injury analysis created by DHS S&T allows for zone-specific injury distributions to be assessed. The Federal Planning Guidance document (EOP, 2010) emphasizes the importance of providing early response support to the MDZ. To better understand the number and nature of injuries in the MDZ and LDZ, the relative ratio of injury classifications was evaluated along with an assessment of the population in each zone. (Figure 57.)

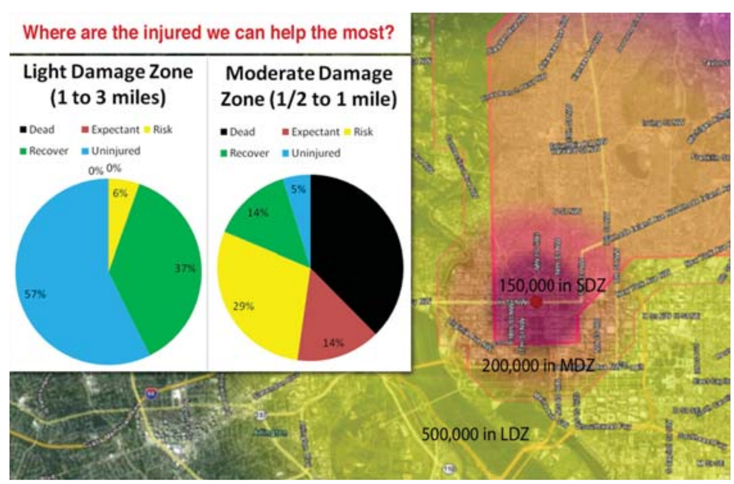


Figure 57. Population and injury breakdown for th SDZ, MDZ, and LDZ.

Although there are likely to be some survivors in the SDZ (those in underground areas or the center of very robust buildings), such specialized locations were beyond the injury modeling effort. Figure 58 shows the relative ratios of injuries and the total population in each of the blast damage zones.

When the injury categories were examined in the MDZ, and LDZ, the MDZ had the greatest number of injured in the "At Risk" group, ~ 58,000. Nearly all "At Risk" injuries in the LDZ are in the overlapping DFZ, which is also not an early response priority because of the radiological hazard to the response force.

Injury Categories That Could Most Benefit From Medical Assistance

Because the purpose of this document is to help planners save and sustain lives, a more in depth analysis of the "At Risk" category is required to help identify the types of injuries of interest and their location. The following two exposure groups containing the largest number of victims who represent the greatest life saving opportunities.

The ***moderate exposure (125 to 300 R) group***, with and without mild trauma, contains 60,000 people. Of the ~15,000 potential untreated fatalities in this category, ~10,000 can be saved with medical care. This category represents the greatest life saving potential. Radiation levels are high enough to complicate an injury or recovery, but not so high as to be acutely life threatening. Since the primary mortality mechanism is complications (i.e. immune-suppression) from ARS, medical care can be applied throughout the acute ARS stages to improve prognosis (even as late as weeks later), however early intervention, especially with anti-neutropenics, can greatly improve outcomes.

The ***significant exposure (300 to 530 R) group***, with and without mild trauma, contains 33,000 people. Of the ~25,000 potential fatalities, ~10,000 can be saved with medical care. Although a considerable life saving potential exists, these individuals will require more intensive care, sooner (<3 days) than those with less severe exposures. Even with advanced medical care ~50% will perish.

Figure 58 shows where moderate (blue) and significant (purple) exposure injury groups would be located in the NCR scenario after 2 hours of outdoor exposure (note: all these radiation injuries which could be prevented through early, adequate shelter).

The height of each bar represents the number of injured at the given location. Such analysis reinforces the importance of conducting priority rescue operations in the MDZ.

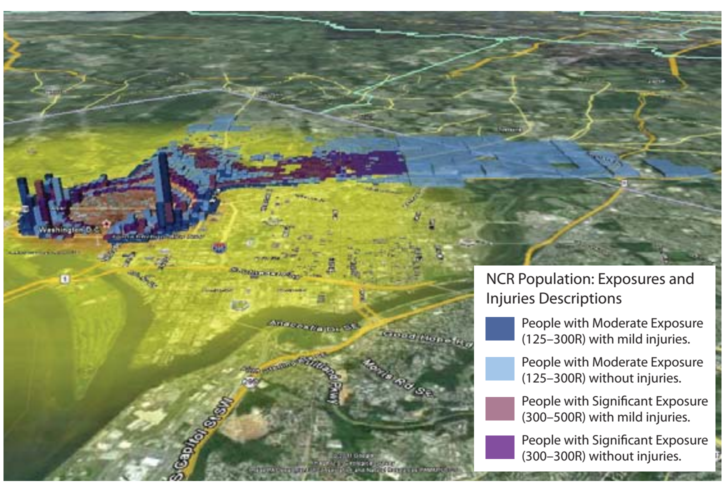


Figure 58. Location of moderately and significantly exposed injured.

Medical Resources in the National Capital Region

Many different factors will determine the impact of an IND on the area's public health and medical resources. Impacts of an IND detonation on public health and medical infrastructures will be directly related to proximity to ground zero. Hospitals in the LDZ are anticipated to be functional except for those in areas that received high levels of fallout.

Numerous casualties can be expected surrounding an IND detonation. Knowing what resources are available will be essential to saving lives. Table 9 identifies selected medical resources in the NCR according to the American Hospital Association (AHA) Database 2006. The areas included in the NCR are the District of Columbia, Montgomery, Prince George, Arlington, Fairfax, Loudoun, and Prince William Counties. When eliminating from consideration those hospitals that are critically affected, identified in Appendix E, the number of available resources is reduced to the values shown in Table 10.

Table 9. Medical resources for the NCR (AHA 2006).

	Total Resources		Available resources	
	DC	NCR	DC	NCR
Beds	5,433	10,798	1,232	2,745
ICU Beds	227	592	52	150
Ventillators	386	1,006	88	256
Staff	1,721	2,284	–	–

Table 10. Estimate of NCR medical resources remaining post-event for the illustrative scenario.

	Total Resources		Available resources	
	DC	NCR	DC	NCR
Beds	2,528	8,537	668	2,177
ICU Beds	148	439	37	118
Ventillators	252	746	63	200
Staff	1,274	2,134	–	–

With greater than 100 times more injured persons than local hospital beds (300,000 injured vs. 2,177 beds), managing the injured will require innovative and unconventional strategies. A well designed, rapidly executed medical surge plan will help deliver medical care to as many people as possible and thereby minimize the impact of the incident.

Situational Awareness and Triage

The public health and medical response community will need to obtain from emergency response personnel initial insight on critical locations and estimated numbers of injured persons in the communities. Once communication channels have been established, hospitals need to relay operating status, including patient loads, onsite injuries, and patient influx to regional coordinators.

Initial triage for critical injuries, especially for immobilized persons, will likely be performed by local EMS personnel. Persons with differing levels of injuries who are still mobile are likely to create spontaneous triage sites at local public health and medical facilities. A structure for such spontaneous "radiation triage, transport, and treatment" (RTR) sites is discussed in the Planning Guidance for Response to a Nuclear Detonation (EOP, 2010). The RTR concept categorizes treatment sites into three levels for medical response, as discussed below.

Radiation Triage, Transport, and Treatment (RTR) Sites

Spontaneous patient collection sites are likely to develop after the blast. A strategy for utilizing these sites and other coordinated treatment sites is shown in Figure 59. The RTR1 through RTR3 sites are described below where MC, AC, and EC refer to medical care, assembly center, and evacuation center, respectively.

For a more detailed discussion on the RTR concept, see The "RTR" Medical Response System for Nuclear and Radiological Mass-Casualty Incidents: A Functional TRiage-TReatment-TRansport Medical Response Model (Hrdina, 2009) and Appendix E of this document.

Initial Hospital Actions

Provided a hospital building is not in danger of collapse or fire, hospitals that are affected by fallout should move patients and personnel towards the interiors, when possible, until peak radiation levels subside. Stable patients should be moved to the basement or underground parking facilities to minimize radiation exposures.

Local hospitals should plan for a massive influx of self-referral patients after the blast. Hospitals can prepare for the influx of patients by taking any usual measures possible for accommodating a surge in patients. For this type of unique incident, numerous additional preparations can aid in management. For example, security personnel can help control the influx and sequester highly radioactively contaminated persons in a predetermined area close to an entranceway. Radiation monitors found in most hospitals can be used to help screen incoming patients. Rudimentary decontamination of incoming patients can be performed to minimize contamination throughout a medical facility. **Decontamination should never take precedence over life-saving medical actions.**

> ***"Life saving tasks takes precedence over external radiation decontamination from fallout or visible debris."***
>
> ***(EOP, 2010)***

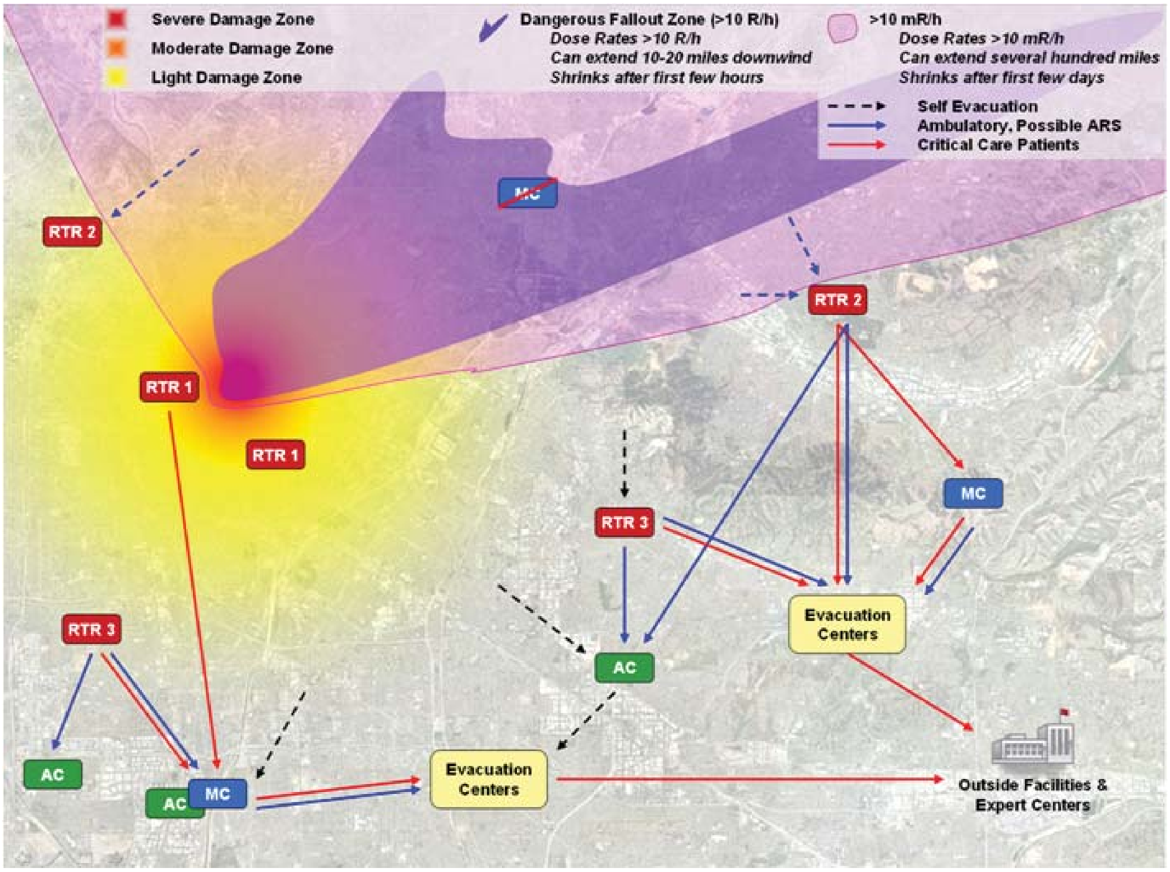


Figure 59. RTR concept according to Planning Guidance for Response to a Nuclear Detonation (EOP, 2010). The RTR 1–3 sites are characterized as offering medical care (MC), serving as an assembly center (AC), or functioning as an evacuation center (EC).

Long-Term Issues

This document focuses on short-term issues associated with immediate life-saving activities. Although the high radiation levels that represent an immediate danger to life and health will rapidly diminish in the initial days after an attack, a long-term (albeit lower-level) radiation component will persist in the area for years. After a week, the Hot Zone will have shrunk considerably, but it will still be more than 20 miles long and similar in size to the maximum extent of the DFZ (Figure 60). The Hot Zone will continue to shrink, although the rate at which it does so will slow over time. If not mitigated by cleanup activities, there would be enough residual contamination to cause radiation exposures to the population in subsequent years that would far exceed natural background radiation levels.

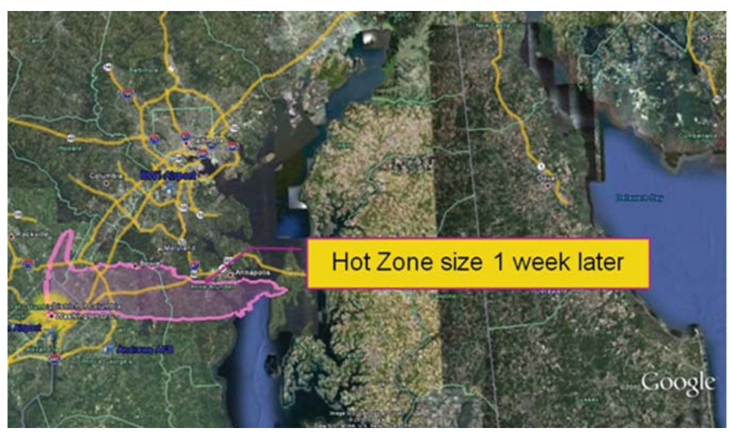


Figure 60. Hot Zone after 1 week.

Table 11. Intermediate phase Federal Protective Action Guidance.

Protective Action	Protective Action Guidance
Relocation of the Public	2 rem (0.02 Sv) projected dose first year. Subsequent years, 0.5 rem/y (0.005 Sv/y) projected dose[a]
Food Interdiction	0.5 rem (0.005 Sv) projected dose, or 5 rem (0.05 Sv) to any individual organ or tissue in the first year, whichever is limiting[b]
Drinking Water Interdiction	0.5 rem (0.005 Sv) projected dose in the first year

[a]Persons previously evacuated from areas outside the relocation zone defined by this PAG may return to occupy their residences. Cases involving relocation of persons at high risk from such action [relocation] (e.g., patients under intensive care) should be evaluated individually.
[b]Accidental Radioactive Contamination of Human Food and Animal Feeds: Recommendations for State and Local Agencies," August 13, 1998, Office of Health and Industry Programs, Center for Devices and Radiological Health, FDA, HHS (http://www.fda.gov/cdhr/dmqrp/84.html).

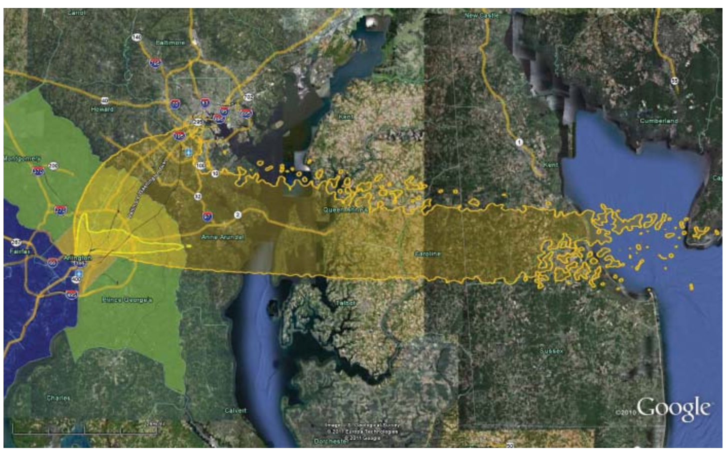


Figure 61. Relocation areas for the first year (orange), and second year (yellow).

"Evacuation is a dangerous default. Whatever happens, most folks are predisposed to evacuate. Shelter in place is often the better choice, but that is not what we have chosen to emphasize in our preparedness thinking and training."

P. J. Palin, Associate Director, Center for Homeland Defense & Security at the Naval Postgraduate School, Howard County Community Emergency Response Network meeting on September 8, 2011.

The Federal Register Notice, "Protective Action Guides for Radiological Dispersion Device (RDD) and Improvised Nuclear Device (IND) Incidents," also provides guidance for when population must be relocated (moved to an alternate location). The relocation PAGs listed in Table 11 below are based on a projected continuous exposure for one year. Note that relocation is not the same as early phase evacuation, and normally there will be time for careful and deliberate decisions about the need for relocation.

Figure 61 shows the first year relocation area (in orange) that includes 1.5 million residents. After the first few months many residents can return, although extensive clean up may be required to restore public confidence and reduce long term exposures in the area.

The area that would still require relocation after the first year (shown in yellow) is almost entirely contained by the District of Columbia and Prince George's County (shown in green). The second year relocation area has 360,000 residents.

Preparedness

Pre-incident preparedness is essential to saving lives. After a nuclear detonation, public safety will depend on the ability to quickly make appropriate safety decisions. Empowering people with knowledge can save thousands of lives.

Message Development

Messages prepared and practiced in advance are fundamental to conveying clear, consistent information and instructions during an emergency incident. Planners should select individuals with the highest public trust and confidence to deliver messages. Such individuals should be prepared to deliver key information almost immediately to the public in affected areas about protection to maximize the number of lives saved.

Use the Zones

Elements critical to all planning and execution are the use of common definitions and zone terminology. Common definitions should be agreed upon and adopted by all regional agencies in advance of an incident to ensure consistency. Such consensus will also allow radiation detection equipment to be preset so that wearers are uniformly alerted when they enter a Hot Zone or DFZ.

Regional Data Coordination

Planners should identify likely locations for the collection and coordination of technical data. Key sites should feature access to health physics support and have existing relationships with IMAAC and FRMAC to ensure a smooth exchange of data. Personnel at candidate locations should develop and practice procedures for collecting and then disseminating information to affected jurisdictions.

Community Preparedness

Several U.S. communities have engaged members of the public to prepare for a response to nuclear terrorism. It is broadly recognized that the largest potential preparedness impact can be achieved through informed citizens. The most recent effort of note is the preparedness checklist developed by the The Rad Resilient Cities Project. Published by the Center for Biosecurity of the University of Pittsburg Medical Center (UPMC), this effort provides cities and their neighbors with a checklist of preparedness actions that could save tens of thousands of lives, or more, following a nuclear terrorist attack. The checklist converts the latest Federal guidance and technical reports into seven clear and actionable steps that all communities can take now to protect residents from radioactive fallout.

Summary and Conclusion

If a nuclear detonation were to occur in the NCR, the greatest reduction of casualties can be achieved through rapid citizen action supported by information and prompt actions by state and local officials. This report provides the analytic foundation necessary to develop and implement response actions and effectively communicate risks to the general public. It is not intended to be prescriptive, but rather to provide a scenario-based approach for the development local and regional planning guidance. Pre-planning is essential because of the short time available for critical decisions and the extensive area impacted. Given the daytime population density of the NCR, those hurt by prompt effects or threatened by fallout could easily be in the hundreds of thousands. Many lives can be saved through appropriate shelter and evacuation strategies and sharing information across affected counties early following a detonation. The largest potential for reduction in casualties comes from reducing exposure to fallout radiation, which is accomplished through early, adequate sheltering followed by informed, delayed evacuation.

In general, all those within 50 miles of a nuclear detonation should shelter until further information becomes available though local emergency management. Provided plans are in place and personnel trained to act quickly, regional response organizations can significantly reduce the number of causalities. Response personnel should also shelter initially for protection; however those with radiation detection instruments can take early action to support the overall response. The distributed nature of response assets maintains a functional capability and provides an excellent source for regional situational awareness. It is important to remember the PPE does not stop radiation and reducing the time spent in high-dose-rate areas is the greatest protective measure for responders operating outdoors.

Finally, an incident the scale of an IND requires a "Whole Community" response where everyone must take an active role in their own safety as well as the recovery of the NCR and the nation. The public and private sectors, and even the injured can play important roles in reducing the burden on traditional response organizations by using the information provided in this document. A prepared emergency management agency and an informed citizenry can prevent hundreds of thousands of casualties in the NCR.

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National Capital Region
Key Response Planning Factors
for the Aftermath of Nuclear Terrorism

Appendices and Supplemental Information

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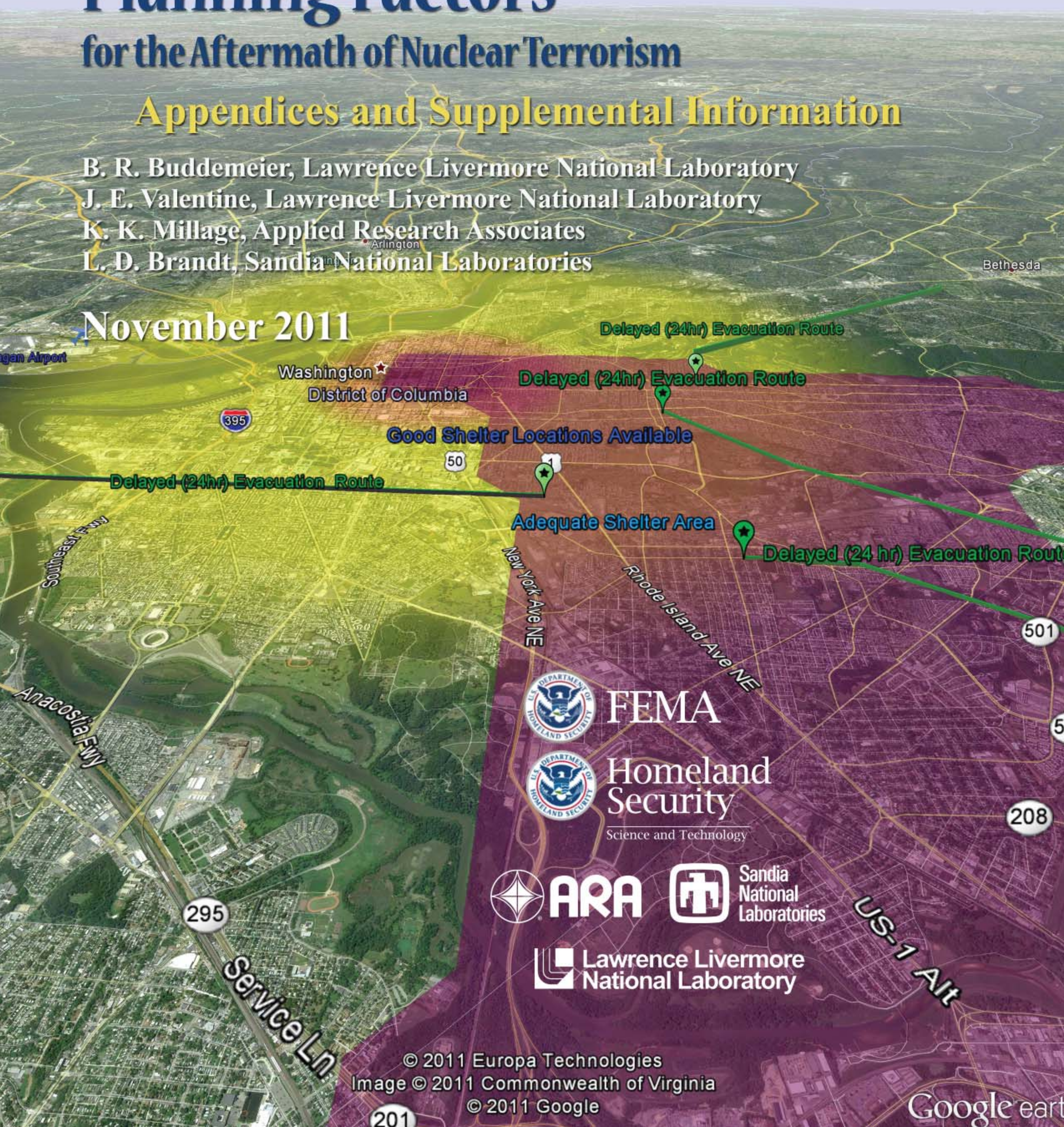

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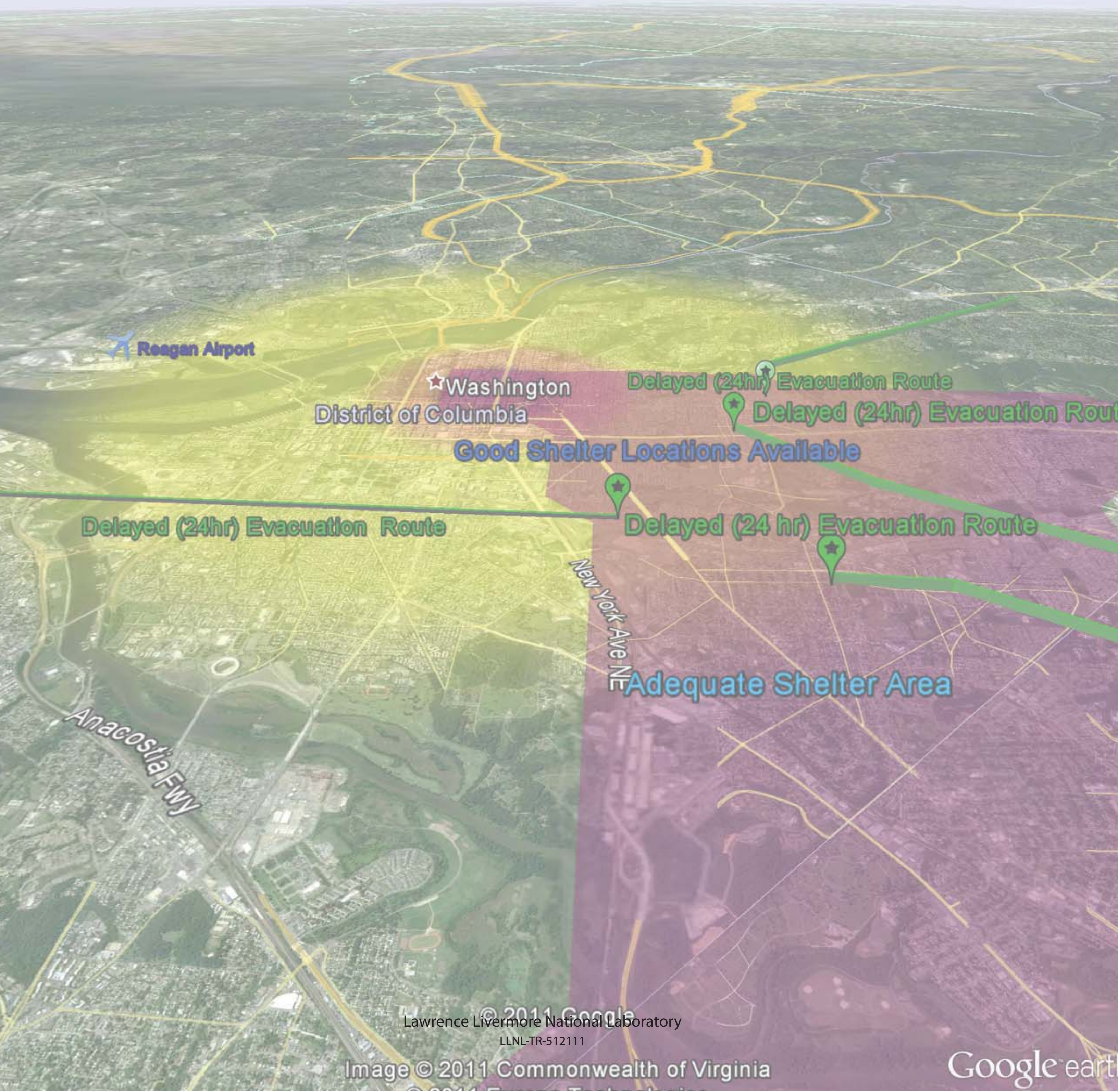
Acronyms

3D	three dimensional
AC	assembly center
AHA	American Hospital Association
ARA	Applied Research Associates
ARS	acute radiation syndrome
BARDA	Biomedical Advanced Research and Development Authority
DCPA	Defense Civil Preparedness Agency
DHHS	Department of Health and Human Services
DHS	Department of Homeland Security
DOD	Department of Defense
DOE	Department of Energy
DFZ	dangerous fallout zone
EAS	Emergency Alert System
EC	evacuation center
EMP	electromagnetic pulse
EMPC	Electromagnetic Pulse Commission
EOC	Emergency Operations Center
EOP	Executive Office of the President
FEMA	Federal Emergency Management Agency
FRMAC	Federal Radiological Monitoring and Assessment Center
Gy	gray
HSEMA	Homeland Security and Emergency Management Agency (DC)
ICRP	International Council on Radiation Protection
IE	informed evacuation
IMAAC	Interagency Modeling and Atmospheric Assessment Center
IND	improvised nuclear device
IPAWS	Integrated Public Alert and Warning System
kT	kiloton
LDZ	light damage zone
LLNL	Lawrence Livermore National Laboratory
MACWG	Modeling and Analysis Coordination Working Group
MC	medical care
MDZ	moderate damage zone
MT	megaton
NARAC	National Atmospheric Release Advisory Center
NCR	National Capital Region
NCRP	National Council on Radiation Protection and Measurement
NUEVAC	Nuclear Evacuation Analysis Code
NNSA	National Nuclear Security Administration
NTS	Nevada Test Site
OHA	Office of Health Affairs
ORNL	Oak Ridge National Laboratory
PAG	protective action guide
PERD	personal emergency radiation detector
PPE	personal protective equipment
PRD	personnel radiation detector
PRND	preventive radiological nuclear detection
R	Roentgen
RDD	radiological dispersal device
REMM	Radiation Emergency Medical Management
RTR	radiation triage, transport, and treatment
R&R	response and recovery
SAVER	System Assessment and Validation for Emergency Responders
SCBA	self-contained breathing apparatus
SDZ	severe damage zone
SNL	Sandia National Laboratories
Sv	Sievert
SVALIN	regional database on shelter distribution
S&T	Science and Technology
UPMC	University of Pittsburg Medical Center

Contents

Appendix A: Prompt Effects



Appendix A: Prompt Effects

Prompt effects are those that radiate outward from a nuclear detonation (from ground zero) usually within the first minute after detonation. Prompt effects include an intense flash of light, a blast wave, heat, and radiation. For illustration purposes, this report focuses on a low-yield device, such as the 10-kT blast similar to that used in National Planning Scenario #1 (DHS, 2005). The total yield of such a blast is approximately 5,000 times the energy of the truck bomb used to destroy the Murrah building in the 1995 Oklahoma City bombing.

Damage Zones (Blast Effects)

When assessing the best course of action following a nuclear detonation, decision-makers should consider using the three major blast-damage zones recommended by the Federal document, Planning Guidance for Response to a Nuclear Detonation (EOP, 2010). The three zones are:

- Severe damage zone.
- Moderate damage zone.
- Light damage zone.

The three zones are defined by amounts of observable damage that are primarily a result of blast effects. Blast effects are the damage or injuries done to structures or people following a detonation caused by direct overpressure and dynamic (wind) pressure. The size of the three zones would change depending on yield and structures in the area. Figure A-1 shows general ranges of the three zones for various yields, but the demarcation between zones is intentionally left ambiguous because there is not expected to be clearly defined differences in visual cues.

Severe Damage Zone

The Severe Damage Zone (SDZ) is the area that immediately surrounds a detonation site, as shown in Figure A-2. In the SDZ, few, if any, above-ground buildings are expected to remain structurally sound or even standing, and few people would survive; however, some people protected within stable structures (e.g., subterranean parking garages or subway tunnels) at the time of the explosion could survive the initial blast. Very high radiation levels and other hazards are expected to persist in the SDZ, making the zone gravely dangerous to survivors and responders; therefore, the SDZ should be considered a no-go zone during the early days following an explosion. For responders approaching ground zero, nearly all buildings would be collapsed or destroyed, and the resultant rubble in regions with high building density could be 30 ft deep or more making movement and timely response impossible. The outer edge of the SDZ is expected to be 5 between 8 psi overpressure, which would extend ~0.5 mile radius for a 10-kT explosion.

As part of the NCR analysis, ARA used the NucFast model to assess more detailed effects of a 10-kT ground detonation in downtown Washington, DC. For the analysis, computer modelers used location features, such as buildings that serve as input to building-response models. NucFast predicts damage to buildings along with the resulting rubble from damaged and collapsed structures by modeling the blast environment that a nuclear device causes. The blast originates from a rapidly expanding fireball from the explosion, which generates a pressure wave front moving rapidly outward from the point of detonation.

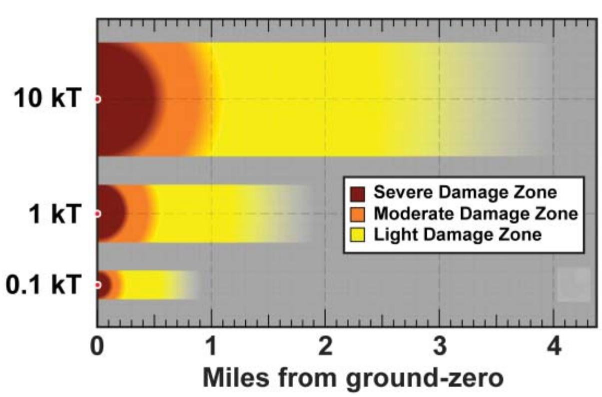


Figure A-1. Approximate radial extent of three damage zones estimated following 0.1-, 1.0-, and 10-kT nuclear detonations.

Figure A-2. The SDZ estimated for the downtown Washington, DC scenario.

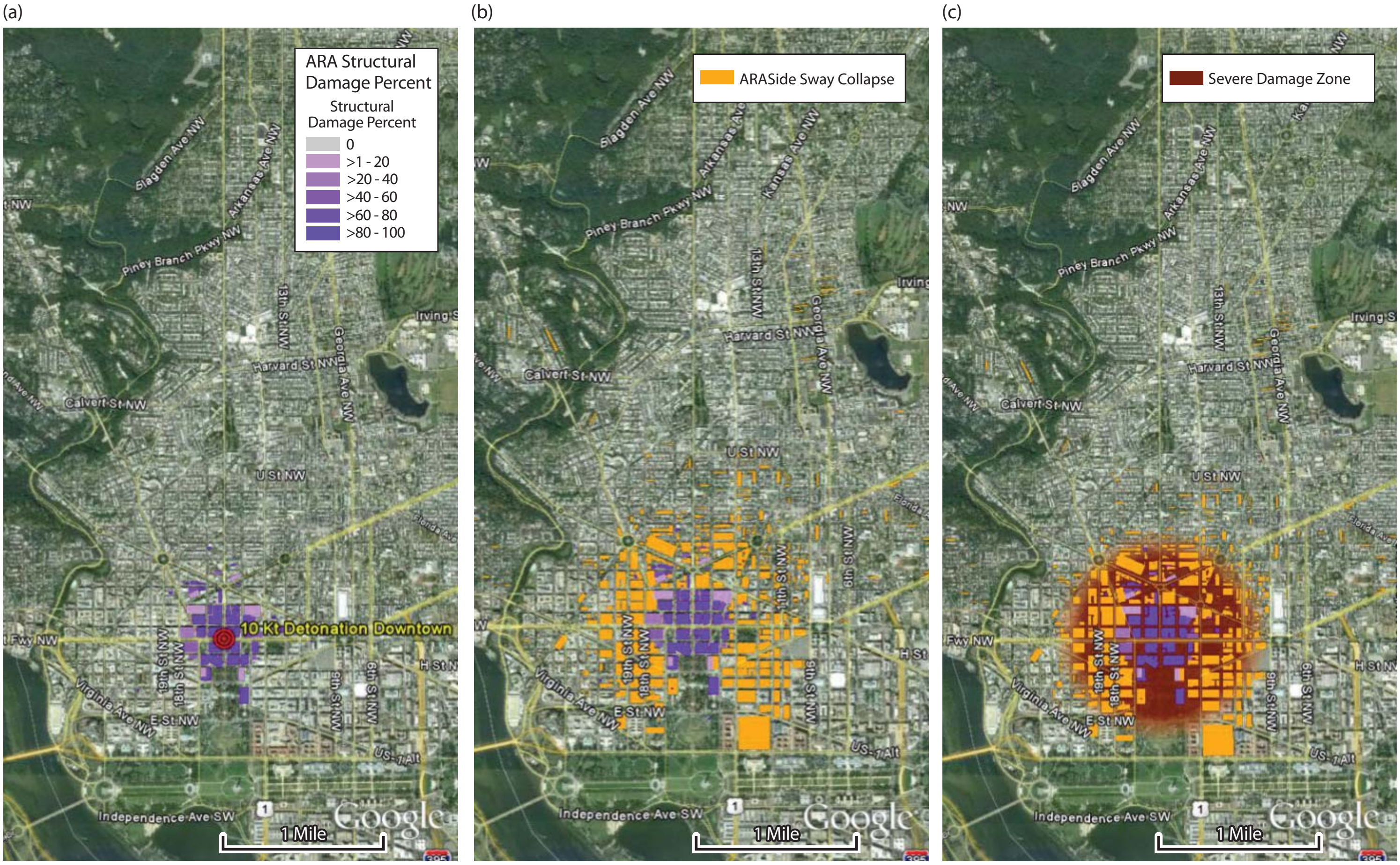


Figure A-3. (a) Structural damage, (b) potential side-sway collapse buildings, and (c) extent of the SDZ for the downtown Washington, DC scenario.

Computer software calculates the overpressure and dynamic pressure that the explosion produces, applies blast loads to each of the modeled buildings, assesses failures to critical components and external walls, and determines whether a given building will collapse. Figure A-3 shows the predicted structural damage for the illustrative scenario. Figure A-3(a) is the model output for direct structural damage while Figure A-3(b) shows additional buildings that may be subject to collapse due to lateral positive and negative dynamic pressures (side sway). Figure A-3(c) shows an overlay of this damage on the presumed SDZ range (0.5 mile for a 10-kT blast) to demonstrate that most, but not all, of the expected heavily damaged and collapsed structures would be within the SDZ.

Notice that most of the structural damage in Figure A-3 is located within an area less than 1/3 mile from the point of detonation. In this downtown location, many commercial, steel-framed structures are extremely strong compared to other types of urban buildings.

Figure A-4. These photos show some of the effects of earthquakes on buried pipelines. (left) Ductile iron pipes with seismic joints can survive large ground deformations. (right) Cast iron pipes can undergo brittle failure.

Figure A-5. Collapsed tunnel at the Nevada Test Site.

The shockwave movement underground would also damage tunnels, such as those associated with subway systems, and underground infrastructure, such as water mains, power, telecommunications, and gas conduits, as shown in Figures A-4 and A-5.

Analysis by Los Alamos National Laboratory researchers (Dey, 2011) using data from nuclear tests at the Nevada Test Site and extrapolation from earthquake damage effects on these systems indicates that:

- Water, power, and telecommunication conduits might be damaged out to 120 m from a 10-kT surface detonation.
- Larger tunnels, such as subway systems might be damaged out to 250 m (~2 city blocks) from a 10-kT surface detonation.

Because the SDZ extends ~0.5 mile (~800 m) from ground zero, this means that the greatest underground infrastructure damage will likely be contained in the SDZ. Figure A-6 shows the regions of predicted damage to underground pipes and utilities in NCR together with the slightly larger region in which underground tunnels and subways would likely be damaged. Note that for the illustrative scenario, two subway lines could be impacted. Although the direct damage to these underground systems will be localized within the SDZ, the resultant damage could cause cascading effects well beyond the SDZ.

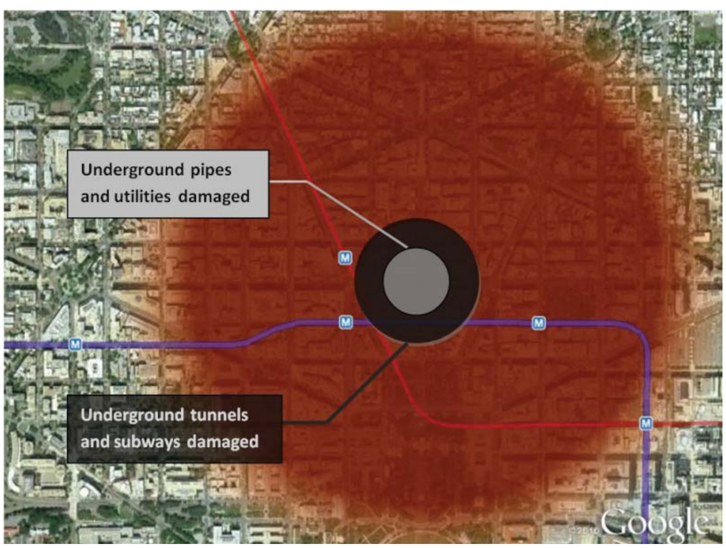


Figure A-6. Underground damage areas (dark and light grey) within the SDZ (red) for the downtown Washington, DC scenario.

Figure A-7. The MDZ for the downtown Washington, DC scenario is represented by the orange area (some buildings are removed in the image to highlight the area of collapse).

Moderate Damage Zone

The Moderate Damage Zone (MDZ) is the area shown in Figure A-7 that is adjacent to the SDZ and that extends to a distance of about 1 mile from ground zero for a 10-kT device. Visual indicators describing the MDZ include:

- Significant structural damage.
- Blown-out building interiors.
- Blown-down utility poles.
- Overturned automobiles.
- Some collapsed buildings.
- Fires.

Sturdier buildings (e.g., those with reinforced concrete) will remain standing, lighter commercial and multi-unit residential buildings may have fallen or rendered structurally unstable, and most single-family houses would be destroyed. Visibility in much of the MDZ could be limited for an hour or more from disruptive effects of the blast wave and building damage. Dust generated by blast-related damage might not be radioactive; however, parts of the MDZ will be contaminated by fallout. As a result, some of the dust will be radioactive, and the dust can also contain other hazardous contaminants associated with building material, such as heavy metals and asbestos.

Figure A-8 shows that external wall damage extends over a much greater distance than does structural damage. Buildings near the detonation point that have not structurally failed are left as hollow, framed structures with exterior or walls missing and likely all lightweight interior construction severely damaged. Some exterior wall damage occurs over a mile away, but most is contained within the MDZ. Damage is not completely symmetrical because of geometry, layout, and types of buildings in the area; and type of construction makes a substantial difference in response to the blast. Heavy, steel-framed buildings tend to be the strongest, whereas small, residential wooden homes tend to be the weakest of building types.

Although there will be considerable variation and non-uniformity of damage to an urban environment, the extent (range) of the average overpressure (and therefore blast damage)

Figure A-8. Figure A-8. (a) Predicted area of external wall damage and the (b) MDZ for the illustrative scenario.

is generally the same as the ideal "open field" predictions. This concept is illustrated in Figure A-9, which shows the predicted peak overpressures from a 10-kT blast. Increased pressures along K Street NW and 16th Street NW occur because the detonation is located at the intersection of those streets (uninterrupted streets tend to channel the blast, with increased pressures observed in selected areas for the first kilometer or more arising in part from reflection off buildings). Peak pressures on the ground are ~5 psi at 0.5 mile from the detonation, although reflected pressures on building surfaces at the same distance can be greater by a factor of 2 to 3.

NucFast also assessed failures to structural components and external walls to estimate how much rubble would accumulate on the ground. Figure A-10 shows that rubble generated from the blast would extend into the MDZ for the hypothetical scenario. Piles could reach 30 ft near taller buildings.

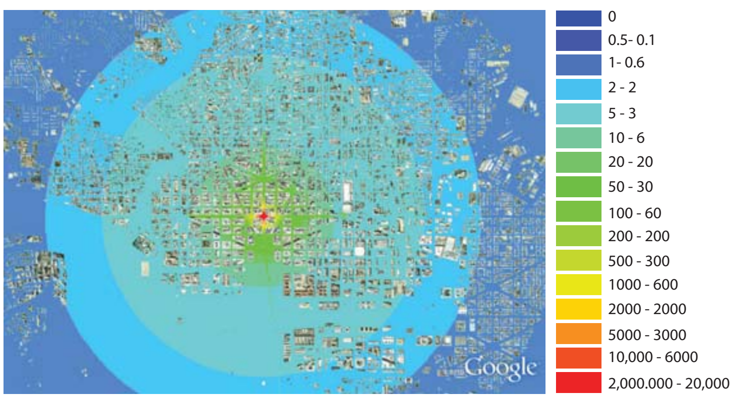


Figure A-9. Ground overpressures in psi modeled by NucFast for the illustrative Washington, DC scenario.

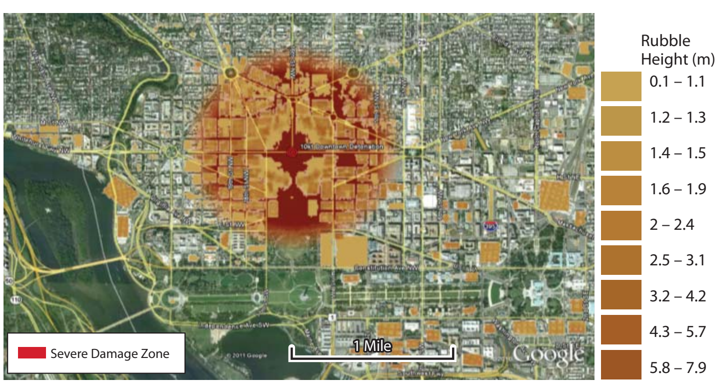


Figure A-10. Height of predicted rubble piles from a hypothetical illustrative detonation in the downtown Washington, DC.

Emergency response and access to the MDZ will be greatly impacted by the substantial rubble as well as crashed or overturned vehicles, which will completely block streets and require heavy equipment to clear. Broken water and utility lines are expected, and fires will be encountered. However, many casualties in the MDZ will survive and will benefit most (compared to casualties in other prompt-effect damage zones) from urgent medical care (AMA, 2011). Responders approaching from the blast-area periphery should be cognizant that when they begin observing that most buildings are either severely damaged or have collapsed, they are entering the SDZ.

Light Damage Zone

The Light Damage Zone (LDZ) is the area that starts just outside of the MDZ and can extend to a distance of about 3 miles at the outer boundary for a 10-kT device. Damage in this zone is caused by shock waves, similar to those produced by a thunderclap or sonic boom, but with much more force. Although some windows may be broken over 10 miles (16 km) away, injuries associated with flying glass will generally occur within about 3 miles (4.8 km) from ground zero for a 10-kT nuclear explosion and are associated with overpressures greater than 0.5 psi. Damage in the LDZ will be highly variable as shock waves rebound multiple times off buildings, the terrain, and even the atmosphere.

As responders move inward from outside the LDZ, windows and doors will be blown in; gutters, window shutters, roofs, and lightly constructed buildings will show increasing damage; litter and rubble will increase; and there will be increasing numbers of stalled and crashed automobiles that will make emergency vehicle movement difficult.

The images in Figure A-11 illustrate the types of damage expected at the outer edge of the LDZ. These pictures were taken ~1.5 miles from an accidental explosion at a booster rocket manufacturing facility in Henderson, Nevada (Reed, 1992). The

Figure A-11. Images of blast damage at Henderson, NV, courtesy of the City of Henderson, NV, similar to that expected at the outer edge of the LDZ.

explosion was estimated to be the equivalent of a 1-kT explosion. In the left image, office glass was blown into the building, and ceiling tiles were caved in. In the right image, the large, lightly constructed flat roof of the warehouse collapsed.

Blast overpressures that characterize the LDZ are calculated to be about 0.5 psi at the outer boundary and 2 to 3 psi at the inner boundary. More significant structural damage to buildings will indicate to responders that they have entered the MDZ. Much of the LDZ may be nonradioactive; however, responders should be prepared to encounter elevated and potentially hazardous radiation. The injuries responders will encounter in the LDZ should be relatively minor, consisting of mostly superficial wounds with occasional flash burns. Glass and other projectile penetrations are expected to be superficial (i.e., about ¼ inch in depth) in the torso, limbs, and face. Eyes are particularly vulnerable. As responders proceed inward, they will begin to observe an increasing frequency and severity of injuries from flying glass and debris along with crush, translation, and tumbling injuries.

Glass breakage can be an important long-range, prompt effect. Most injuries outside of the Murrah building in the 1995 Oklahoma City bombing were caused by this phenomenon. Extrapolating from more recent work on conventional explosives, a 10-kT explosion could break certain types of windows (e.g., large, monolithic annealed) located more than 8 miles away (ARA, 2004). NATO medical response planning documents for nuclear detonations state that "… missile injuries will predominate. About half the patients seen will have wounds of their extremities. The thorax, abdomen, and head will be involved about equally." The NATO prediction is consistent with the historical observation that many victims from Nagasaki arriving at field hospitals exhibited glass breakage injuries. The shock wave that breaks windows travels much more slowly than the bright flash of light. The delay may cause an increased number of injuries if unwarned populations approach windows to investigate the bright flash prior to the shock wave arrival. Figure A-12 summarizes some of the principal features associated with the SDZ, MDZ, and LDZ.

Prompt Radiation

Detonation of a nuclear weapon causes a pulse of ionizing radiation, referred to as prompt radiation. This can be one of the most far-reaching hazardous effects for a low-yield, open-field

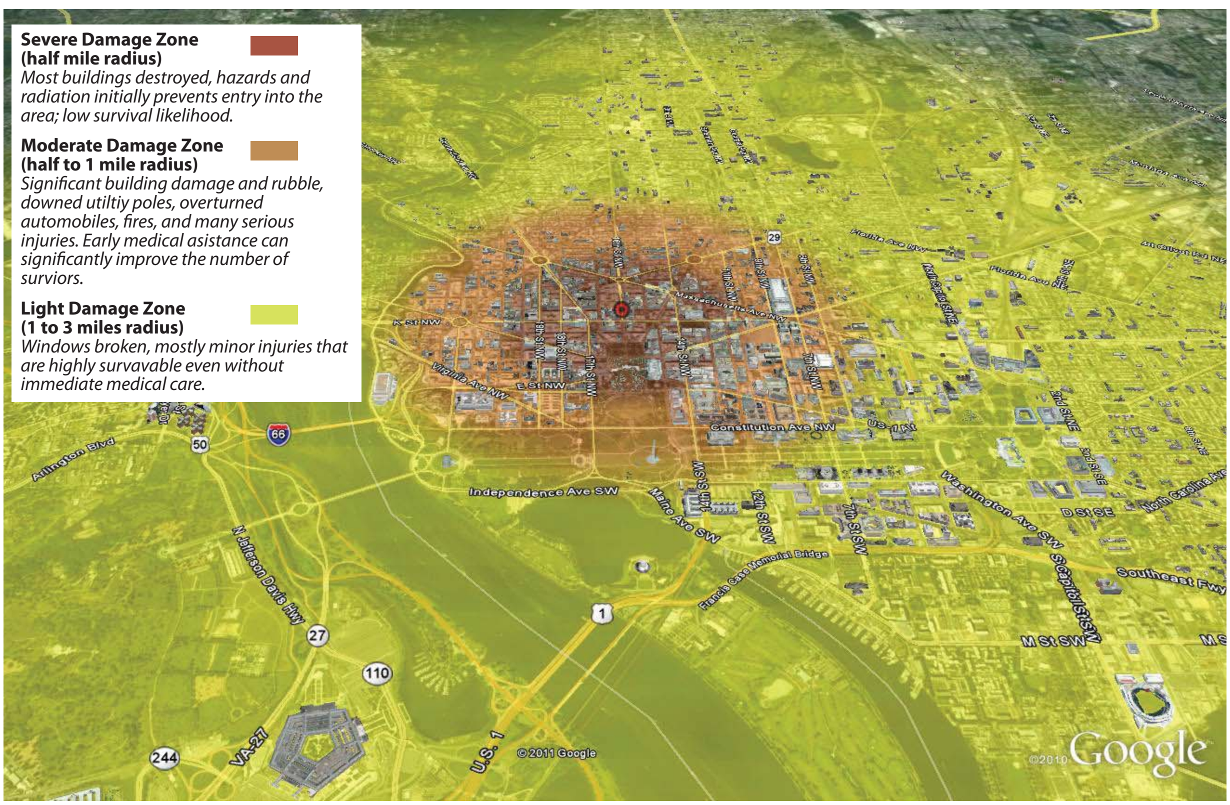


Figure A-12. Summary of severe, moderate and light damage zones and types of damage or injuries likely to be encountered by responders after a hypothetical 10-kT explosion.

nuclear explosion of less than 10-kT. Figure A-13 shows these effects by visually comparing the range of outdoor injury from radiation (dark blue line) to the blast zones previously described.

The distance prompt photon and neutron radiation can travel is greatly reduced in an urban setting because of absorption and scattering of the radiation by urban structures. To evaluate the

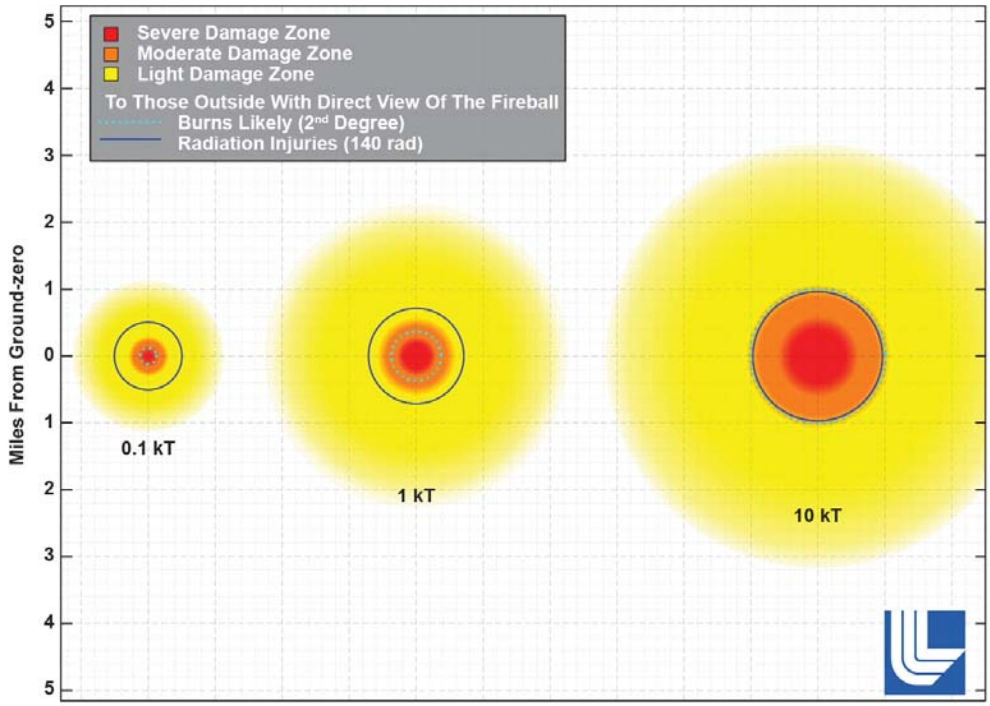


Figure A-13. Approximate ideal (open-field) ranges of prompt effects from three low-yield (0.1-, 1- and 10-kT) nuclear detonations.

Figure A-14. Radiation will propagate differently depending on specific building geometries; the city is divided into quadrants to examine some of these differences. The color of buildings reflects approximate height in meters.

mitigating effects an urban environment might have, researchers at ARA modeled structures in the Washington, DC environment and calculated the effect on prompt radiation fields. Figure A-14 is an image of the "virtual city" that was modeled to calculate how the prompt radiation field might be affected by an urban environment.

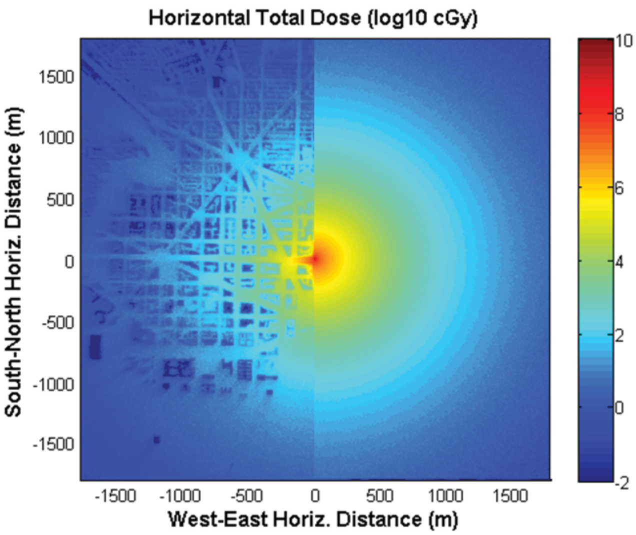


Figure A-15. Total dose prediction for downtown Washington, DC, where red represents the greatest and dark blue represents the lowest estimated doses to people. Dose values shown in this simulation represent outdoor doses in an urban setting; dose values inside buildings were not calculated.

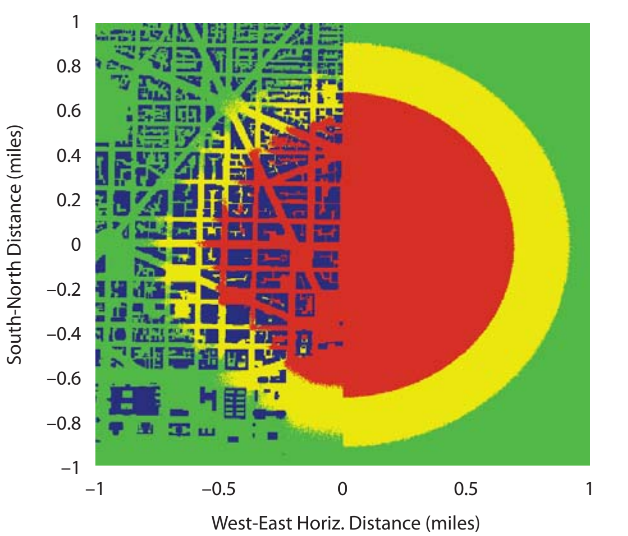


Figure A-16. Outdoor casualty areas for downtown Washington, DC and for an open field from a 10-kT Hiroshima type device; red >800, yellow 100-800, green < 100 rad-eq. Washington buildings are shown in blue.

The detonation location of the illustrative scenario is near the population center of the city where the urban landscape includes a local, densely packed cluster of buildings surrounded by structures that gradually decrease in size and density with increasing distance. Neutron and photon spectra used in this analysis were based on the 10-kT equivalent of "Little Boy," the device detonated over Hiroshima, Japan.

Figure A-15 is a color-coded representation of the total dose calculated at ground level (horizontal dose) over an area of about 4 square miles. The right half of the image shows dose estimates for detonations over an open field (or a concrete slab with no buildings); the left half of the image shows the dose reduction when Washington, DC buildings are taken into account. Because the detonation location is proximal to large downtown buildings, substantial attenuation of radiation is observed. However, the detonation is also located at an intersection so that considerable streaming occurs down streets that have a clear line of sight to create a "starburst "effect when seen from above.

The reduction in prompt radiation levels caused by shielding from an urban environment can substantially reduce the number of expected radiation-related casualties in the MDZ. Figure A-16 shows the areas where someone outdoors would experience a lethal exposure (red) of more than 800 rad (midline dose to the body) or injurious exposure (yellow) of 100 to 800 rad. Persons in the green regions are unlikely to experience any acute radiation effects. As before, the right half of the image shows a potential injury area for a detonation over an open field (or a concrete slab with no buildings); the left half of the image shows the potential outdoor injury area when Washington, DC buildings (shown in blue) are taken into account for a ground-level detonation.

Thermal Radiation

Updated models of line-of-sight exposures in an urban environment demonstrate a similar reduction in the number of previously calculated burns that have been cited in many older studies. A ground-level detonation would reduce the range of both ionizing radiation (noted above) as well as thermal radiation, resulting in fewer thermal burns.

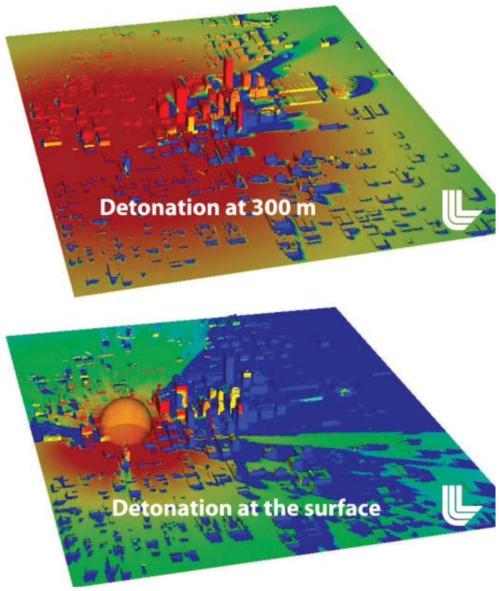


Figure A-17. Thermal radiation in an urban environment for detonations 300 m (top) and 1 m (bottom) above the Oklahoma City bombing site.

Figure A-17 shows how much of the thermal energy from a fireball is blocked by an urban environment. The top image represents a 10-kT detonation 300 m above the original Oklahoma City bombing site; the bottom image represents the same yield, but with a detonation only 1 m above the ground. Areas of green and blue on the maps represent regions of little thermal injury. It is logical to conclude that a built-up urban area such as downtown Washington, DC would provide some protection from line-of-sight concerns, even from an elevated detonation.

Flash Blindness

In addition to ionizing and thermal radiation, a nuclear detonation creates a brilliant flash of light that can cause temporary blindness called flash blindness (or dazzling). Flash blindness can last several seconds to minutes during which useful vision is lost.

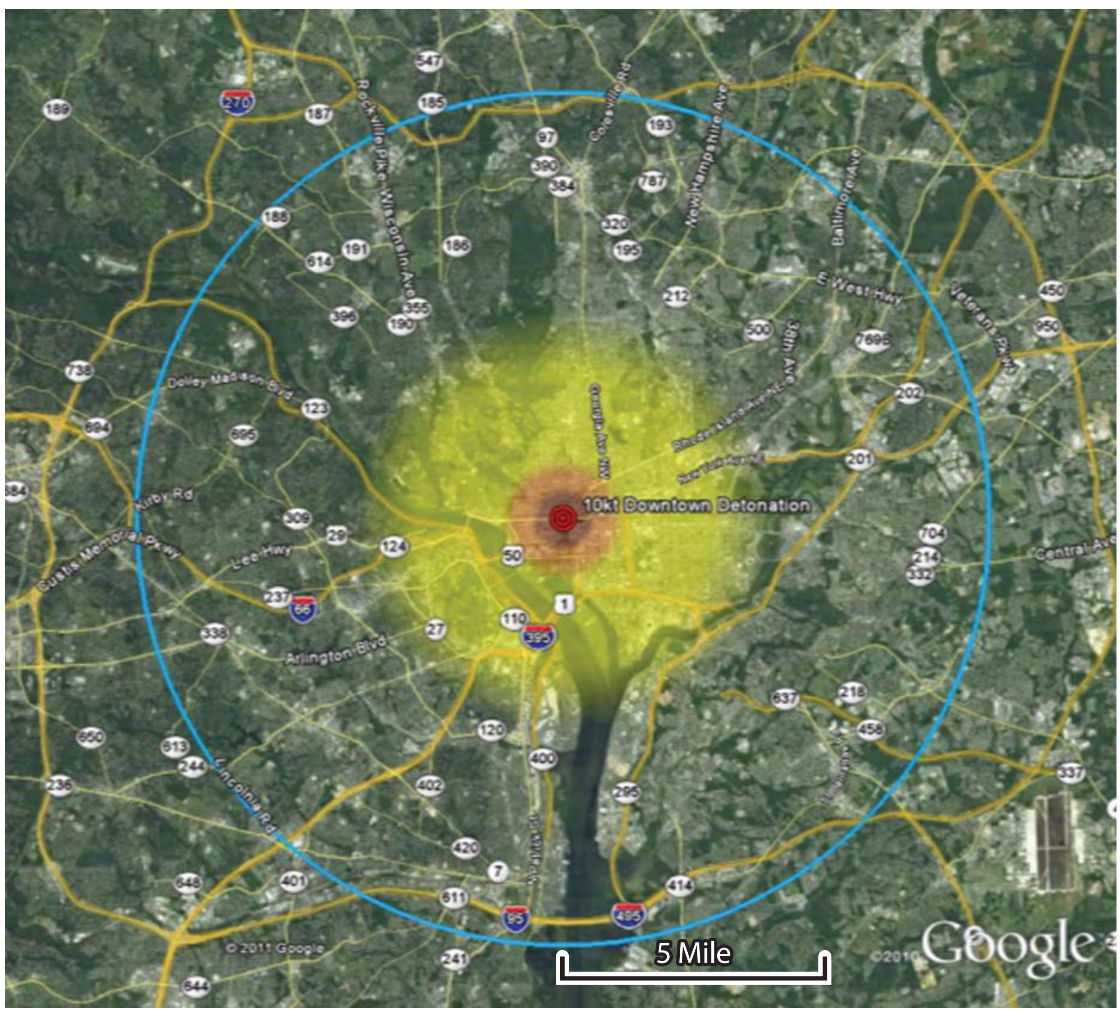


Figure A-18. Predicted range of flash blindness for the illustrative scenario.

For an open-field condition, flash blindness can occur up to 12 miles away on a clear day given direct line of sight of the fireball. This effect could extend much farther if low clouds were present to reflect the light or for a detonation that occurs at night.

As with ionizing and thermal radiation, the bright flash of light will be partially blocked by an urban environment and poor atmospheric visibility. Although flash blindness is not expected to cause permanent damage, a sudden loss of vision for drivers could cause numerous traffic accidents and render many roads impassable. MACWG discussions estimated that the range of concern for daytime drivers would be ~8 miles (see Figure A-18). For the illustrative scenario, this would affect drivers out to the beltway.

Electromagnetic Pulse

A nuclear explosion also generates a phenomenon known as electromagnetic pulse (EMP) that can negatively impact electronic equipment. However, this issue is primarily a concern for a high-altitude, thermonuclear (high-yield) detonation. For a low-yield, 10-kT, ground-level detonation, the most disruptive consequences of the pulse are not expected to travel beyond about 2 miles (3.2 km) to 5 miles (8 km) (EOP, 2010), with some longer-range disruptions of some sensitive equipment occurring out a few miles more. An excellent reference for EMP effects can be found in the 2008 report of the Electromagnetic Pulse Commission (EMPC).

EMP consequences can be categorized into two types of effects, direct damage and system upset. The direct damage to electronic equipment from EMP is expected to be limited to the Severe and Moderate Damage Zones. Sporadic “upset” or “latch-up” of equipment may occur in the light damage zone and several miles beyond, though this is a temporary condition that can be cleared by turning the unit off and then on again (or removing and replacing the battery of portable equipment). Not all equipment within the EMP-effects area will fail and the frequency of failure will increase the closer to the detonation point the equipment is located.

As a result of both the EMP and effects of the blast wave on critical infrastructure (e.g., power and communications substations), for planning purposes it should be expected that electricity and land-line communication would not be functional in the SDZ, MDZ, and LDZ. The disruptive nature of the detonation, including the sudden loss of electrical load on the power grid and the possibility of cascading infrastructure issues, could also affect the electrical and communications infrastructures of surrounding counties.

Fortunately, it is likely that many, if not most, of the battery (or hand-crank) powered radios in the LDZ will still function, and emergency radio broadcasts from surrounding areas can be received and instructions provided (EMPC, 2008). Modern vehicles would also likely be unaffected outside the SDZ and MDZ; however, debris on roadways, traffic accidents caused by flash blindness, and the loss of traffic control systems (one of the more sensitive electronic systems with respect to the EMP effect) will make vehicular travel challenging in the LDZ.

Fires

During the Cold War, fires and “firestorms” were major concerns because the thermal pulse given off by a thermonuclear detonation can start fires at long ranges. However, this effect is diminished for a low-yield detonation, especially at ground level in an urban environment because of (a) significant urban shielding of thermal radiation and (b) a cooler fireball temperature (relative to an elevated burst). Although a firestorm is uncertain given modern construction techniques, numerous small fires will likely start from thermal and blast effects in areas of major building damage. Fires could spread and coalesce if not mitigated.

Conclusion

Many existing models will over-predict thermal and prompt radiation effect ranges in the urban environment. Response plans should be developed using more “building aware” modeling so that areas of potential survivors are not inappropriately dismissed.

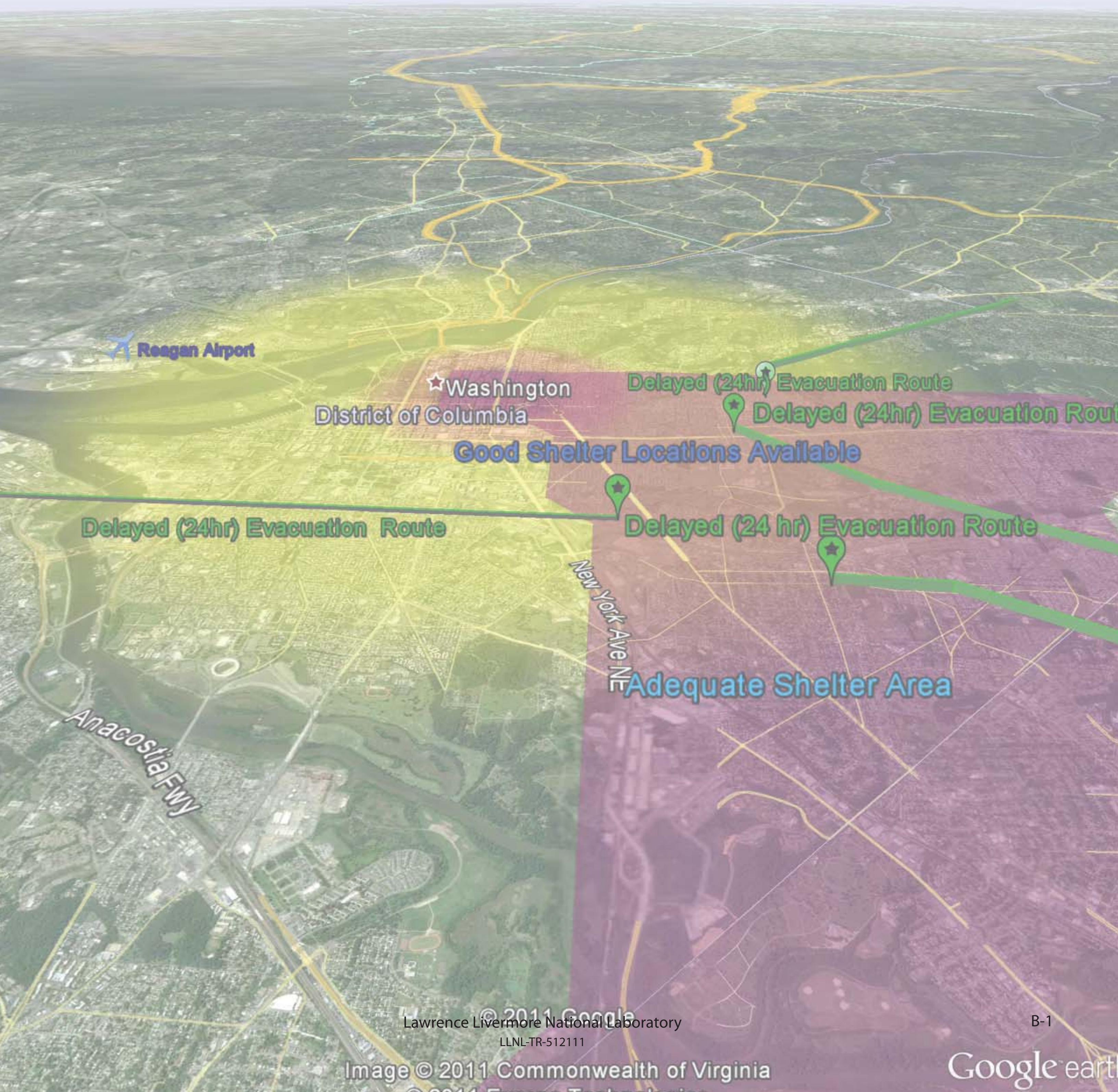
Blast will be a primary injury mechanism and can cause damage and injury several miles from the detonation site and limit vehicle movement from debris and flash blindness induced accidents.

Federal planning guidance has defined several damage zones based on observable effects.

- Severe Damage – responders should not focus on this area, as radiation levels will be too high and survival is unlikely.
- Moderate Damage – This should take highest priority as there is the highest potential to save lives.
- Light Damage – This is a lower initial priority, as most injuries can be treated with minimal or no medical care.

Additional effects such as fire and EMP can complicate the response, and contingency plans should be developed in case these effects are larger than expected.

Appendix B: Fallout



Appendix B. Fallout

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In addition to prompt effects that radiate outward from the detonation site, a nuclear blast can produce nuclear fallout, which is generated when dust and debris excavated by the explosion are combined with radioactive fission products and drawn upward by the heat produced. The cloud rapidly climbs through the atmosphere, potentially up to 5 miles (8 km) high for a 10-kT explosion, forming a mushroom cloud (under ideal weather conditions) from which highly radioactive particles drop back down to earth as the cloud cools. Hiroshima and Nagasaki did not experience substantive fallout because the detonations occurred well above ground at altitudes of 1,900 ft (579 m) and 1,500 ft (457 m), respectively. At such altitudes, fission products do not have the opportunity to mix with excavated earth.

Exposure to ionizing radiation from particles that settle on the ground and building roofs is the most dangerous delayed hazard. Radiation levels from the particles drop off quickly, with most (~55%) of the potential radiation exposure occurring within the first hour after detonation and ~80% occurring within the first day. Although a fallout pattern is highly dependent on weather conditions, the most dangerous concentrations of fallout particles (i.e., potentially fatal to those outdoors) occur within 20 miles (32 km) downwind of ground zero. Particles are expected to be clearly visible as they fall when immediately hazardous levels are present. The gamma radiation emitted from fallout particles can penetrate large distances and being outside, either during the fallout or after the fallout has deposited can result in a high dose. In fact, fallout particles near the detonation are relatively large and although these particles can be inhaled, the inhalation hazard is relatively small when compared to the dose received by penetrating gamma radiation given off by particles that are on the ground or in the air (Millage, 2009).

Fallout Patterns

Gaining a better understanding of fallout patterns requires more accurately accounting for both real weather and urban environments with which the fallout will interact. Weather, specifically wind direction and speed at different altitudes, is one of the most complicated and influential factors in estimating the effects of fallout. Cold War response planning often used simple Gaussian distributions to describe areas affected by fallout, an idealized example of which is shown in Figure B-1.

The dashed line along the middle of the fallout pattern is the "centerline," which is defined by the highest dose rate at any given distance. Moving perpendicularly away from the centerline when evacuating an area is assumed to provide the lowest possible exposure for a Gaussian fallout pattern. This concept is the origin of the simplified "lateral evacuation" guidance that is often reported in the literature.

Although a Gaussian fallout pattern can occur, it is not a good planning assumption, because more complex fallout patterns frequently occur and are more challenging to predict. For example, non-Gaussian distributions can be produced by wind shear (change in wind direction with height above ground). Figure B-2 shows the fallout cloud from a low-yield British nuclear test conducted off the western coast of Australia on October 3, 1952. The effects of wind shear on cloud direction can clearly be seen in the image, which was taken 7.5 minutes after the detonation.

Realistic and complex weather patterns can also result in irregularly shaped areas of ground contamination. Even nuclear tests performed at the Nevada Test Site (NTS), when shot times could be

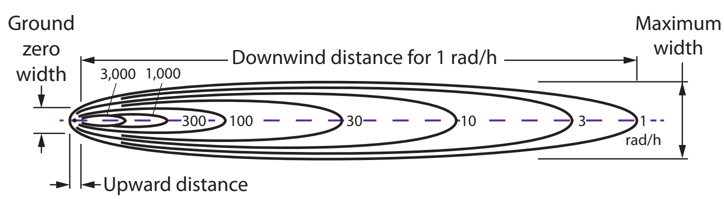


Figure B-1. Idealized Gaussian fallout pattern, (Glasstone, 1977).

Figure B-2. Fallout cloud 7.5 minutes after detonation, with the effects of inversion and shear layers clearly visible.

selected for favorable weather conditions, often resulted in fallout patterns that were unlike the cigar-shaped Gaussian plots that have commonly been used for response planning (see Figure B-3).

Fortunately, higher-fidelity atmospheric dispersion models are now available that take into account the complex wind profiles typically found in the atmosphere and that provide much more realistic examples of how hazardous material from a nuclear detonation move in time and space. The fallout distributions used in this report were generated by LLNL, which serves as the operations hub for the Interagency Modeling and Atmospheric Assessment Center (IMAAC). The analyses were performed using an advanced suite of 3D meteorology and plume/fallout models that account for complex meteorology and terrain effects.

To illustrate the variability in potential impacts, twelve hypothetical fallout patterns were calculated using recorded mid-day weather data for the location of interest on the 14th of each month in 2009. The weather data were derived from detailed atmospheric soundings at nearby airports and weather stations.

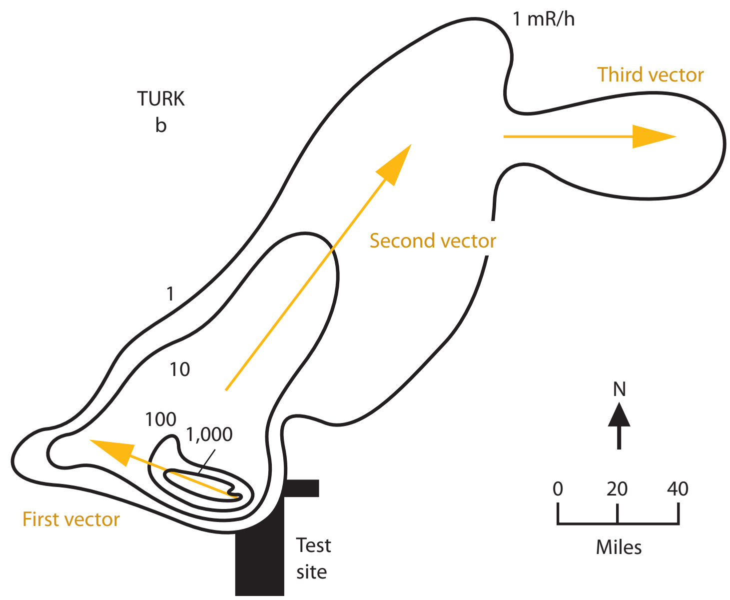


Figure B-3. Early fallout dose-rate contours from the TURK test at the NTS (Figure 9.58b from Glasstone and Dolan, op. cit.).

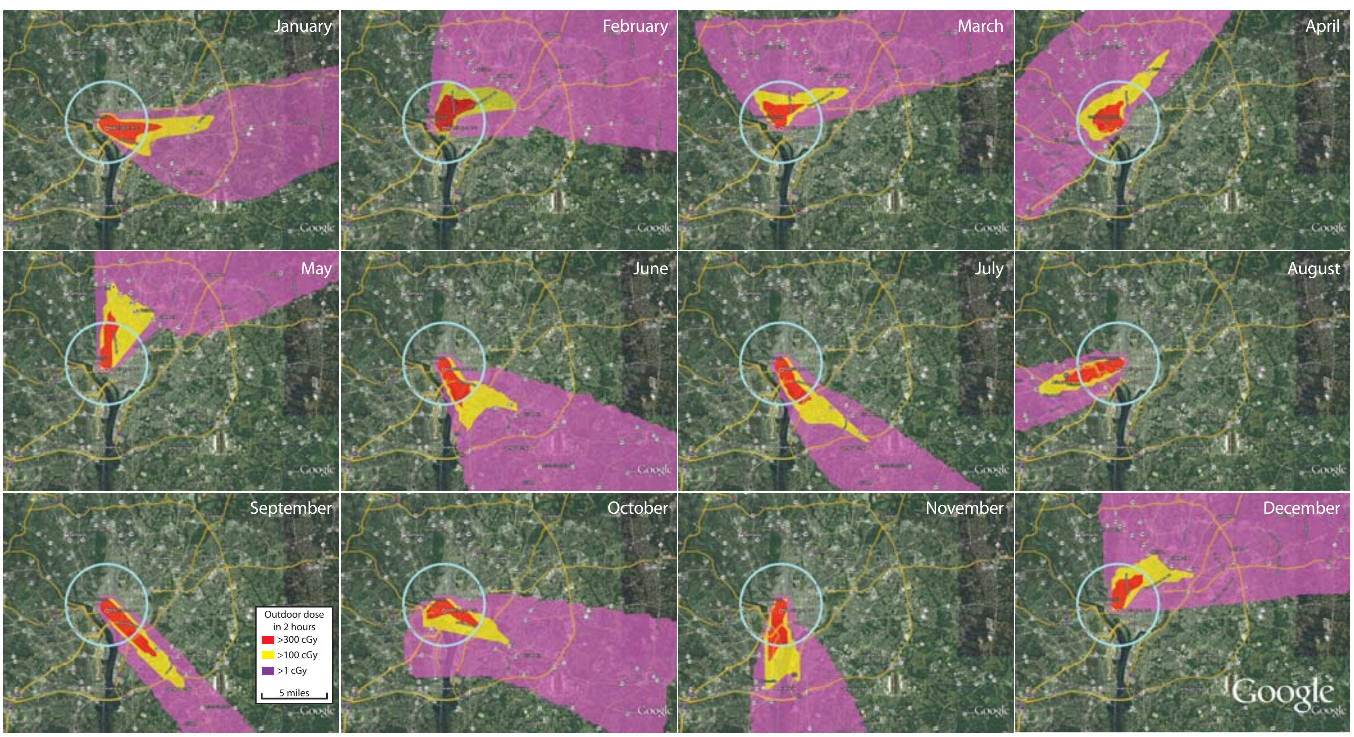


Figure B-4.The hypothetical 12 fallout patterns associated with a 10-kT detonation in Washington, DC for the 12 different days in 2009.

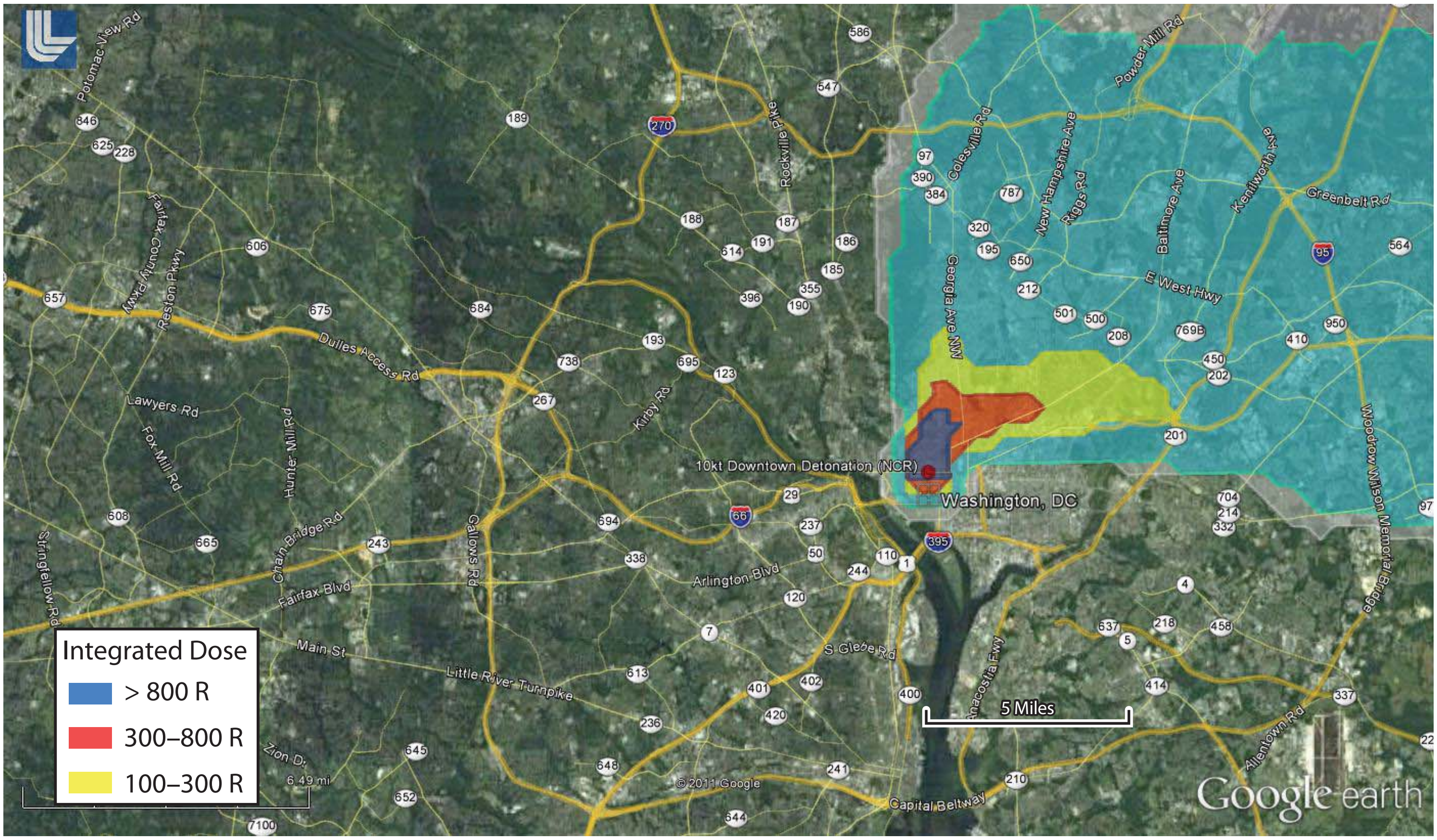


Figure B-5. Close-in view of integrated doses for 2-hr outdoor exposure.

Figure B-4 shows the approximate exposure on the ground from the fallout contamination “footprint” that was left behind after the cloud passed by. This assessment was performed by LLNL and then exported to GoogleEarth™ to allow viewing from several aspects. The light blue ring in the images represents the 3-mile radius from the detonation location (the outer edge of the light damage zone) and the colors indicate an outdoor 2 hour exposure of greater than 300 R (red), 100 R (yellow), or 0.1 R (purple).

The February 2009 weather is used extensively as an illustrative scenario in this report. For this particular example of weather, surface winds are generally from the south, causing the “stem” of the cloud to extend north from the detonation point in Washington, DC. However, some wind shear is present as upper atmospheric winds move the top of the cloud to the east towards Delaware.

Close-In Exposure Concerns

Within 10 to 20 miles of the detonation, exposures from fallout would be great enough to cause near-term (within hours) symptoms such as nausea and vomiting. The exposures people would likely receive, presuming that individuals stood outside in the fallout for 2 hr, are shown in Figure B-5. This calculation was not chosen because it is expected that people will remain outside and stationary for 2 hr, but rather for use as a consistent benchmark from which to make relevant comparisons. The circular yellow area under the fallout pattern is the LDZ. The yellow fallout area (spreading to the north and 6 miles to the northeast of the detonation location) in Figure B-5 represents an outdoor 2-hr integrated exposure of 100 to 300 R. Since the exposure happens early, within the first minutes to hours of fallout arrival, an early evacuation would not be practical in this region.

The orange area depicts exposures of 300 – 800 R for those who do not shelter soon enough. Most would experience early onset of

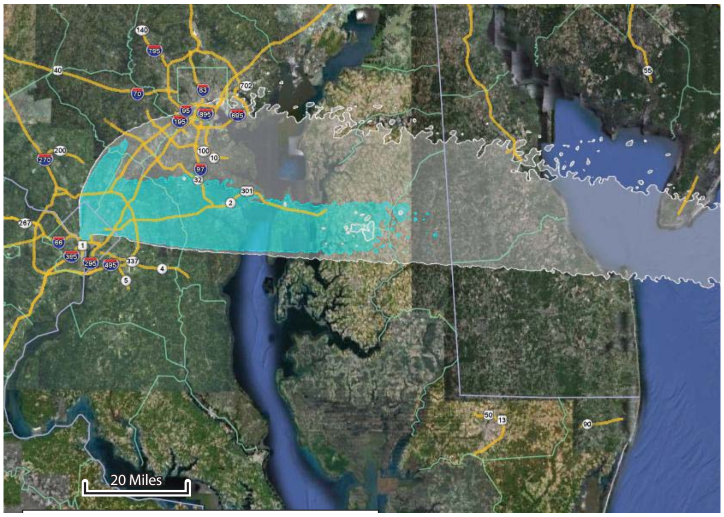


Figure B-6. Long-range integrated dose for 4-day outdoor exposure.

Figure B-7. Area of an initial agricultural embargo following a 10-kT detonation in the illustrative scenario.

health effects (e.g., nausea and vomiting within 4 hr), and some fatalities would be likely without medical treatment.

For those in the dark blue area who do not take immediate shelter, outdoor exposures (>800 R) would be great enough that fatalities are likely with or without medical treatment. Evacuation is not an option in this area because fallout would arrive too quickly (within 10 minutes) to evacuate.

Long-Range Exposure Concerns

The white area in Figure B-6 represents radiation levels that are above the EPA and DHS (FR73-149) recommendation for shelter or evacuation (1 to 5 rem in 4 days). This exposure is low enough that no immediate health effects are expected, and the probability of long-term effects (e.g., cancer) is small (<0.1%). Even so, protective measures to reduce exposure will likely be performed as good protective practice. The light-blue area defines the region where no immediate health effects are expected; however, exposure is great enough (5 to 100 rem) that the probability of long-term effects (e.g., cancer) warrants protective actions according to the DHS and EPA Protective Action Guidance.

Agricultural Embargo Areas

Although an agricultural embargo represents more of an economic issue than a direct or long-term injury issue, it is an example of some of the more far-reaching effects of a hypothetical IND detonation in the Washington, DC area. Likely embargo areas also encompass the regions in which fallout contamination will be readily detectable with hand-held survey equipment in the first few days following a detonation. Figure B-7 shows that the anticipated embargo area would include the Chesapeake Bay, all of Delaware, and parts of New Jersey, Maryland, and Virginia. Although an agricultural embargo would probably be lifted after a few weeks when radiation levels subside, public confidence in the products produced in the region would likely constitute a longer-term concern.

Figure B-8. The 1-kT Teapot Ess test, conducted on March 23, 1955.

The Fallout Cloud

Beyond weather-induced patterns already discussed, the lower yields of INDs may not have the classic mushroom-cloud shape at all, particularly when detonated in contact with the earth's surface. In addition to wind shear, yield, overburden (material above the detonation location), and an urban environment can distort the classic mushroom cloud shape. An example can be found in the NTS test, called Teapot Ess (see Figure B-8). This 1-kT device was detonated 67 ft underground on March 23, 1955. The irregularly shaped cloud climbed to more than 2 miles in about five minutes but maintained a wide, irregular pattern as it traveled downwind, leaving behind fallout contamination that produced dose rates 1 hour after detonation (see Figure B-9) of more than 1,000 Roentgens per hour (R/hr) 1,000 yards (~0.5 mile) away. In an urban setting, the cloud will be disturbed by interactions with the ground and with buildings, and it will be influenced by asymmetric airflow through "urban canyons."

Recent modeling on how a fireball can rise, conducted by researchers at ARA (Crepeau, 2011), indicates that building interactions and the perturbed airflow in an urban environment can reduce the height and temperature of a cloud. Figure B-10 shows the model output at 20 seconds after a simulated detonation, indicating that fallout clouds can have reduced height compared to cloud height from a ground-level detonation over an ideal (flat and open) surface. This type of result is important because atmospheric winds often vary with altitude above the surface, and predictions made after a detonation, including results presented in this report, are typically based on an ideal surface. If fallout travels to a different level in the atmosphere than expected, the result could be a different fallout pattern than current models might predict. In addition, much lower temperatures can occur within the rising cloud, and cooler temperatures can change the characteristics of fallout particulates.

To visualize the possible shapes of fallout clouds in the illustrative scenario more clearly, the images in Figure B-11 were generated by exporting the advanced 3D modeling done at LLNL to a GoogleEarth™ format. Marker particles, which are represented by purple ball shapes, illustrate cloud shapes and locations over the first hour after the explosion. This assessment is based on extrapolation from empirical data from nuclear tests conducted at the NTS. The images in Figure B-11 illustrate cloud location and shape at 15, 30, and 60 minutes after detonation. Dark and light purple contours on the ground represent fallout accumulation on the surface of the earth, the darker the color, the greater the radiation level.

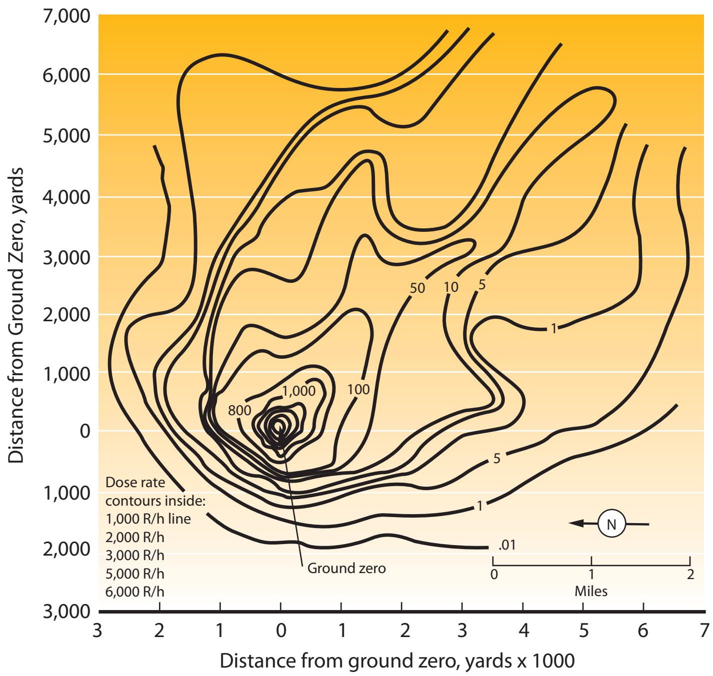


Figure B-9. Topographical fallout dose rates recorded 1 hr after Teapot Ess.

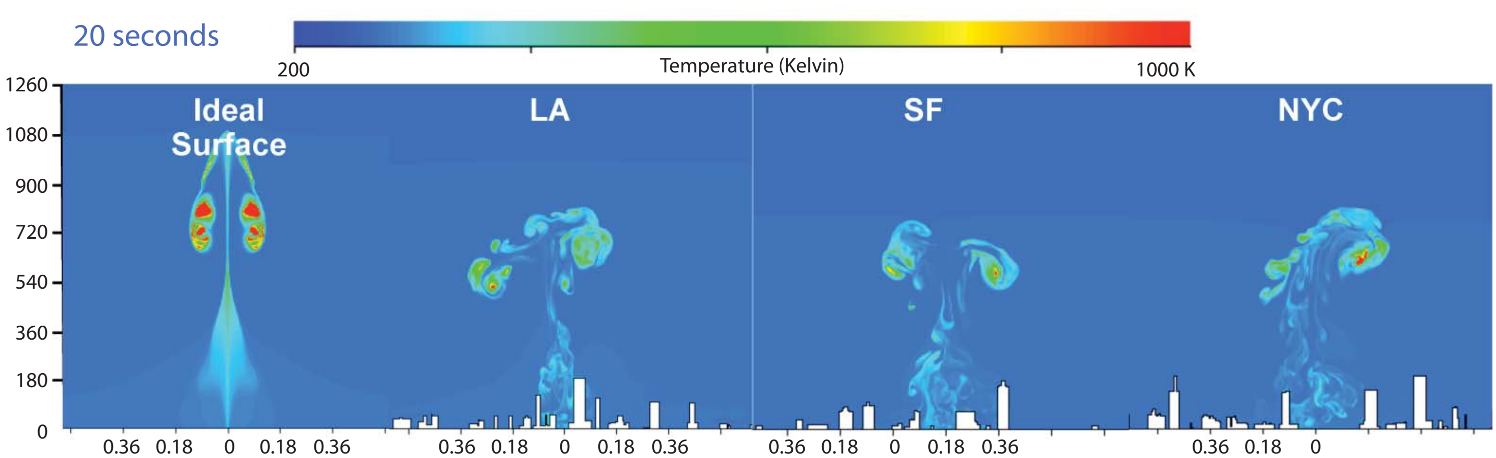


Figure B-10. Cloud rise and deformation in three urban environments (Los Angeles, San Francisco, and New York City) compared to an ideal surface (left). The color indicates cloud temperature at 20 seconds after the detonation.

At 15 minutes after detonation, for this particular weather pattern, the top of the cloud is already over Annapolis, however the ground level contamination lags behind as it takes time for the fallout particles to reach and accumulate on the ground.

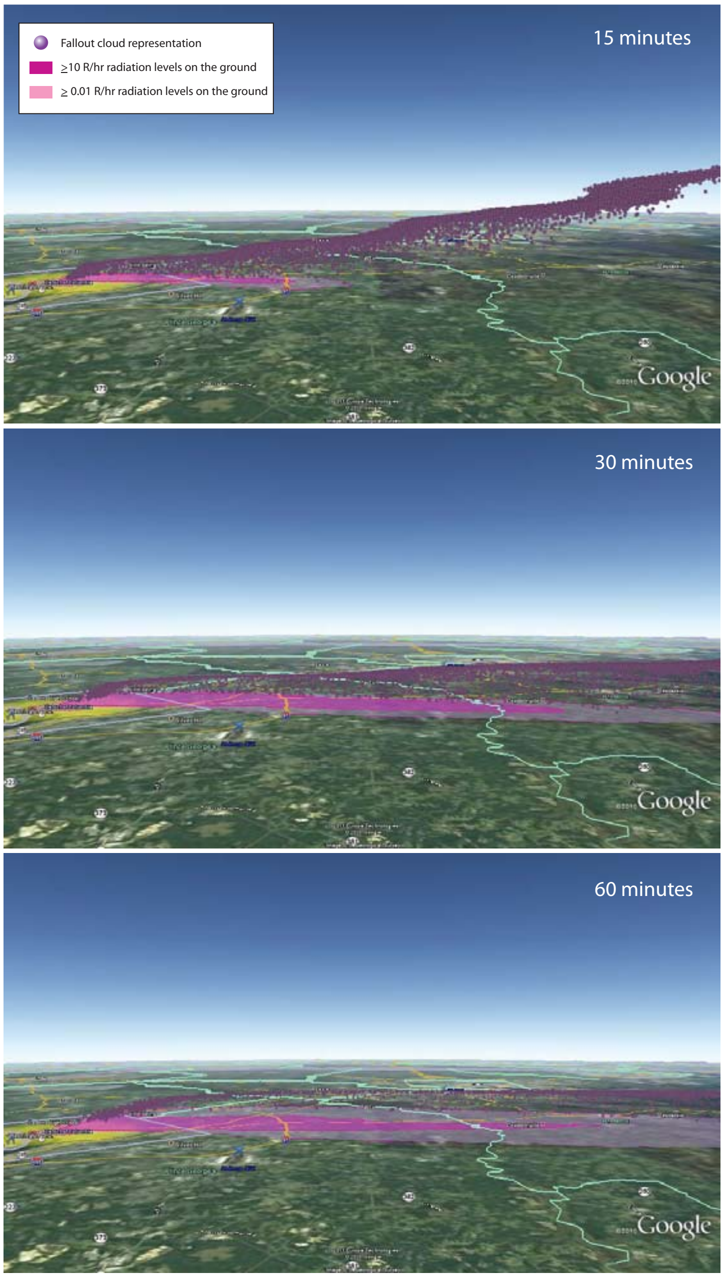


Figure B-11. Modeled fallout cloud patterns (represented as purple balls above the earth) 15, 30, and 60 minutes after detonation. The yellow contour indicates the LDZ.

At 30 and 60 minutes the movement of the lower portions of the cloud, and subsequent contamination, progress to the north.

It is important to remember that even though a person might not be able to see any type of cloud after the first hour, dangerous radiation levels will remain. Understanding how radiation stays behind after a detonation is a key response issue.

Fallout Particles

Despite more than 200 atmospheric tests conducted by the United States government, very few were "ground-level" detonations in which the fireball touched the earth. The information on fallout in this section is derived from extrapolation of empirical data obtained from the few such tests performed at the NTS.

> ***"Nuclear tests in the atmosphere in Nevada have been confined to weapons having yields below 100 kilotons and most of the detonations were from the tops of steel towers 100 to 700 feet. None of these could be described as a true surface burst and, in any event, in the tower shots there is evidence that the fallout was affected by the tower."***
>
> ***Glasstone and Dolan (1977)***

Although only a small physical quantity of radioactive material is produced in a nuclear detonation, about 20 ounces for a 10-kT device, this material is highly radioactive (a minute after the explosion, almost 300 billion Curies are present) (Glasstone, 1977). As the fireball cools, highly radioactive fission products coalesce on the thousands of tons of dirt and debris pulled up by the heat of the fireball. Figure B-12 shows fallout particles from nuclear tests at NTS, illustrating some of the diverse particles that can be formed, depending on the types of materials that are vaporized and pulled up by the explosion (Crocker, 1966). Cooler temperatures within a fireball created in an urban detonation,

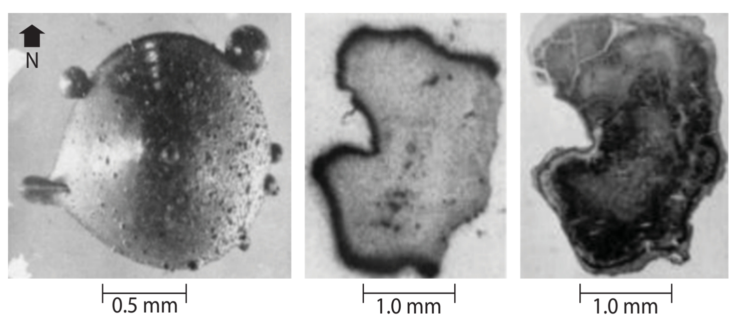


Figure B-12. Fallout particles encompass a diverse range of shapes and sizes.

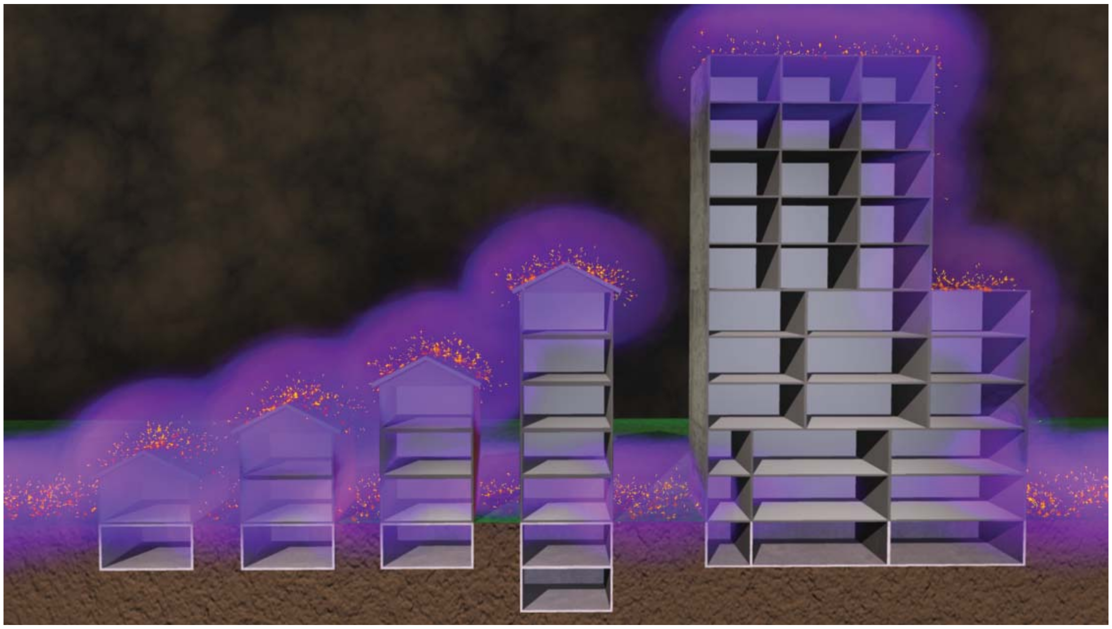


Figure B-13. Artist's illustration of locations that fallout will accumulate and the hazard it creates (shown in purple).

differences in surrounding materials, and the presence of overburden can alter particle formation and physical properties.

Larger particles tend to fall closer to the detonation site, whereas small particles, such as those that might pose an inhalation hazard, tend to stay in the upper atmosphere much longer, perhaps for days or weeks. Although details are highly dependent on weather conditions, the most dangerous concentrations of fallout particles (i.e., potentially fatal to those outdoors) occur within 10 to 20 miles downwind of the explosion and are clearly visible as they fall, often the size of fine sand or table salt (NCRP, 1982). Weather, rain or washing of fallout areas might concentrate fallout in pockets, sewers, and storm drains, but such action would be accompanied by a reduction of fallout concentration elsewhere.

Dangerous levels of fallout can create visible dust and debris, so visible fallout can be used as an indicator of a direct radiation hazard (however, fallout might not be readily noticeable on rough or dirty surfaces after it has fallen). The particles emit penetrating radiation that can injure people (even in cars or within inadequate shelters). However, fallout decays rapidly with time and is most dangerous in the first few hours after a detonation.

Once fallout particles reach the ground, the primary hazard arises from penetrating gamma rays from the particles, rather than from breathing or ingesting particles. Gamma rays are photons, like x rays, that can "shine" through clothing, walls, and even protective suits. Although gamma and beta radiation are not

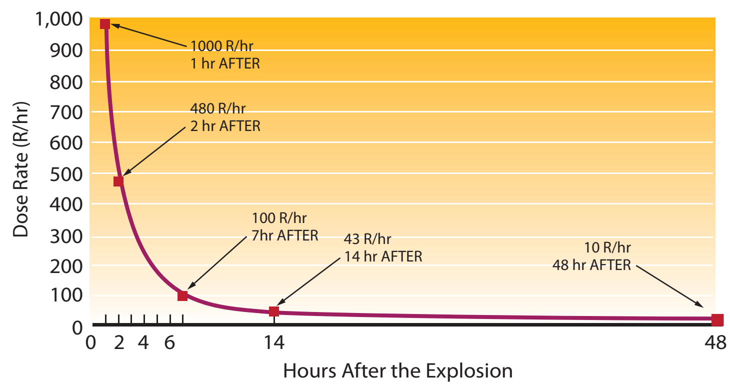


Figure B-14. Radiation levels from fallout decrease rapidly over time, emitting more than half of their radiation in the first hour.

visible to the naked eye, Figure B-13 illustrates (through an artist's suggestion of a purple glow) the most hazardous areas where fallout particles would likely land on rooftops and the ground.

After particle deposition, the radiation emitted by fallout particles decreases rapidly with time similar to how hot metal radiates energy (heat) and cools over time (decreasing the amount of energy given off). Fallout gives off more than 50% of its energy in the first hour, and continues to decay rapidly even after that initial hour. Figure B-14 shows how radiation levels from fallout continue to decrease with time. For this example, an arbitrary 1-hr starting value of 1,000 R/hr was used.

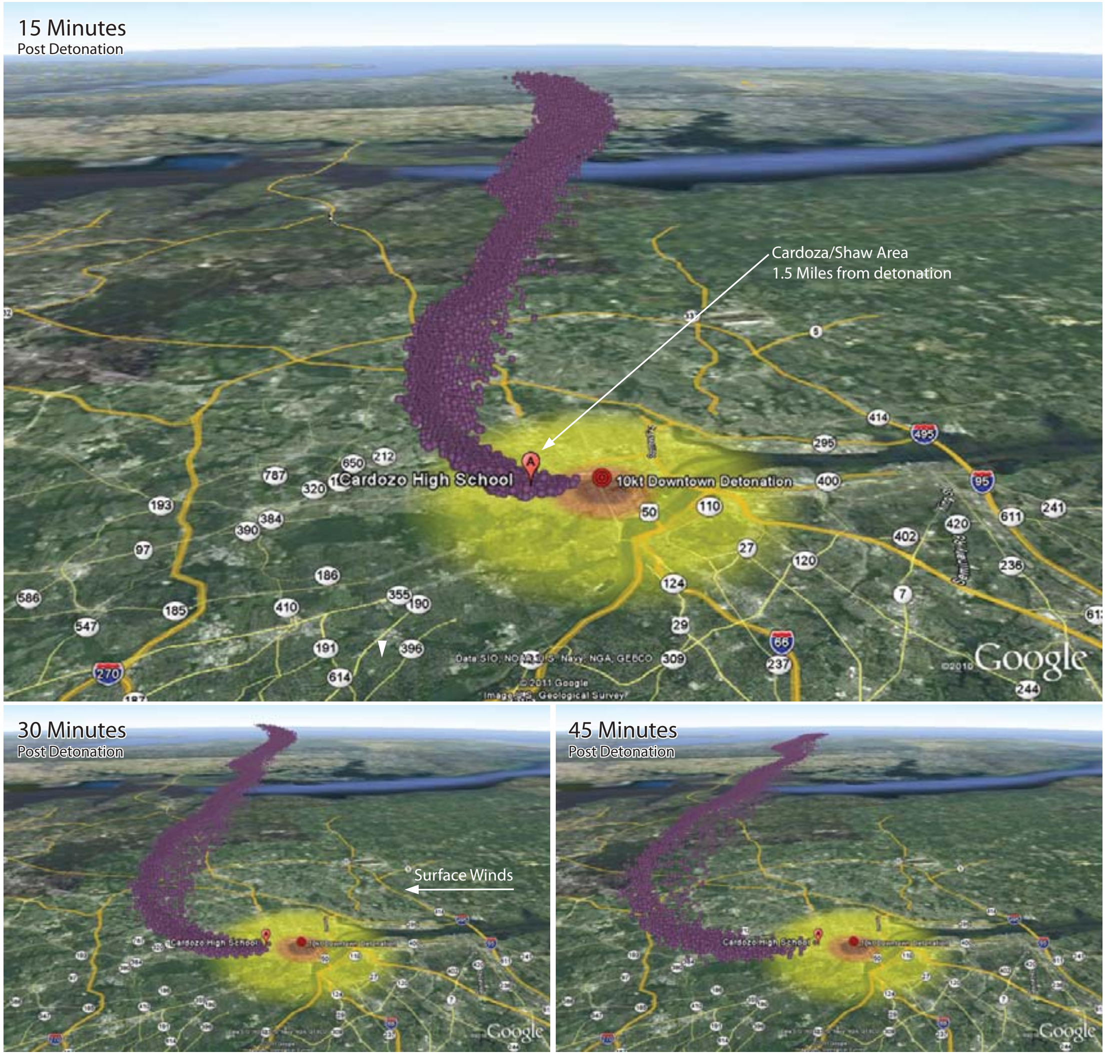


Figure B-15. View facing northeast showing the relative location of Cardozo High School and the fallout cloud at various times for the illustrative scenario.

A fallout cloud disperses as it moves downwind, reducing the overall concentration within the cloud and the amount of particles that fall from the cloud to accumulate on the ground. After the cloud passes a given point, fallout particles deposited on the ground continue to give off radiation. Because of these factors and the fact that the generation of radioactive material occurs all at once, after a fallout cloud passes and has deposited fallout particles on a given area, there will never be an increase in fallout radiation levels.

To illustrate what the decrease in energy means for populations that find themselves in the fallout region of the Washington, DC scenario, theoretical outdoor dose rates at Cardozo High School (Clifton Street Northwest) were calculated. This location is in the LDZ (1.5 miles from the detonation point) and is downwind. Figure B-15 is an eastward-facing view of the area of interest. As noted before, surface winds move the lower portion of the fallout cloud to the north (over Cardozo High School) and upper-atmospheric winds move the upper part of the fallout cloud to the east.

The first image in Figure B-15, which models the fallout cloud 15 minutes after detonation, indicates that most of the cloud has already passed over Cardozo High School, and fallout has been deposited on the ground. It takes a few minutes for fallout to reach Cardozo, but as fallout deposits in the area, outdoor radiation levels increase rapidly. Fifteen minutes after the detonation, outdoor radiation levels are slightly below 1,500 R/hr. Although this radiation level is extremely high, it drops off rapidly, and just 15 minutes later (at 30 minutes after detonation) it is ~700 R/hr (less than half the 15-minute value). Two hours after detonation, the exposure rate is less than 150 R/hr, which is less than 10%

of the 15-minute value. Figure B-16 is a plot of the theoretical outdoor radiation levels at the modeled location.

Radiation levels continue to fall, although less dramatically, after the first few hours. Table B-1 summarizes outdoor dose rates up to four days after detonation.

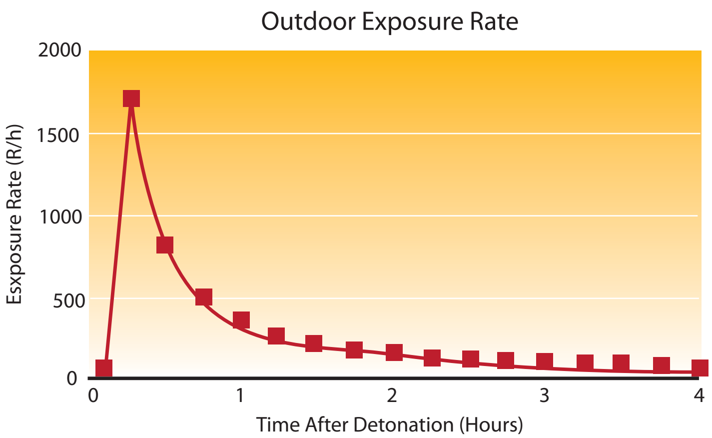


Figure B-16. Modeled outdoor exposure rates for the illustrative scenario for the first 4 hr after detonation.

Table B-1. Modeled dose rates at Cardozo High School for the illustrative scenario.

Time after detonation (hr:min)	Exposure rate (R/hr)
00:15	1,444
00:30	686
01:00	299
02:00	130
04:00	57
08:00	35
12:00	15
24:00	7
48:00	3
96:00	1

Fallout Zones

Federal and national guidance has been developed to help define the relative hazards associated with various dose rates. Similar to prompt-effects areas that have been defined by three blast damage zones (severe, moderate, and light), fallout hazard areas have been defined by two different zones.

Dangerous Fallout Zone

The Dangerous Fallout Zone (DFZ) is radiation levels of 10 R/hr and above. The Federal guidance document, Planning Guidance for Response to a Nuclear Detonation (EOP, 2010) indicates that, for a 10-kT detonation this zone could reach 10 to 20 miles downwind before decay of radiation causes the DFZ to shrink after ~1 hr.

The DFZ is equivalent to the Dangerous Radiation Zone, as defined by the National Council on Radiation Protection and Measurement, Report #165, as follows:

> ***"The area covered by fallout that impacts responder life-saving operations and/or has acute radiation injury potential to the population is known as the dangerous fallout zone (DFZ). Unlike the LDZ, MDZ, and SDZ, the DFZ is distinguished not by structural damage, but by radiation levels. A radiation exposure rate of 10 R/h is used to bound this zone, and the DFZ may span across both the LDZ and MDZ."***
>
> *Planning Guidance for Response to a Nuclear Detonation (EOP, 2010)*

For the purpose of the present document, the term Dangerous Fallout Zone (DFZ) is used to designate this zone. The DFZ has the following characteristics for a 10-kT:

- Radiation levels of 10 R/hr and above.
- Acute radiation Injury is possible within the DFZ.
- Could reach 10 to 20 miles downwind.
- Decay of radiation causes this zone to shrink after about 1 hr.

To demonstrate how the DFZ changes over time, Figure B-17 shows several time-stamped images that identify the DFZ as the dark purple area. A dashed yellow line is drawn around the DFZ at 1 hr to provide a comparison in subsequent images.

Hot Zone

In addition to the DFZ, designated as the dark purple area, the light purple area in Figure B-17 denotes the area bounded by a dose rate 1/1000th that of the DFZ, or 0.01 R/hr. Although this region is outside the area in which acute radiation effects (such as radiation sickness or burns) might be expected, consistent with the Federal Planning Guidance document, it is still an area in which controls to mitigate exposures should be considered:

> ***"A number of authoritative guidance documents have been produced that cite a zone bounded by a radiation dose rate of 0.01 R/h (10 mR/h) and characterize the area as the 'hot zone.' The area bounded by 0.01 R/h may be depicted as an area where radioactivity is found, and the radiation hazard is lower closest to the 0.01 R/h boundary while and the radiation hazard increases approaching the 10 R/h boundary. In routine radiation emergency response entering the zone bounded by 0.01 R/h entails donning appropriate personal protective equipment (PPE) and being properly monitored for radiation. For a nuclear detonation, the 0.01 R/h line can reach a maximum extent of several hundred miles within hours of the incident. Like the DF zone, this zone will shrink in size due to decay after it reaches a maximum size. Provided responders take appropriate planning and dose monitoring measures, emergency operations can be safely performed within the area bounded by 0.01 R/h. The area bounded by 0.01 R/h should raise awareness of all responders operating in the zone and result in establishing staging, triage, and reception centers outside of this area whenever possible."***
>
> ***Planning Guidance for Response to a Nuclear Detonation (EOP, 2010)***

For purposes of the present document, the term Hot Zone is used to designate this zone. The Hot Zone has the following characteristics for a 10-kT detonation:

- Radiation levels of 0.01 R/hr (10 mR/hr) to 10 R/hr.
- Extended stays within the Hot Zone are unlikely to cause any acute radiation effects; however, steps should be taken to control exposure.
- Could extend in numerous directions for 100's of miles.
- Decay of radiation causes this zone to shrink after about 12 to 24 hr.
- After ~1 week the Hot Zone will be about the size of the maximum extent of the DFZ (10 to 20 miles).

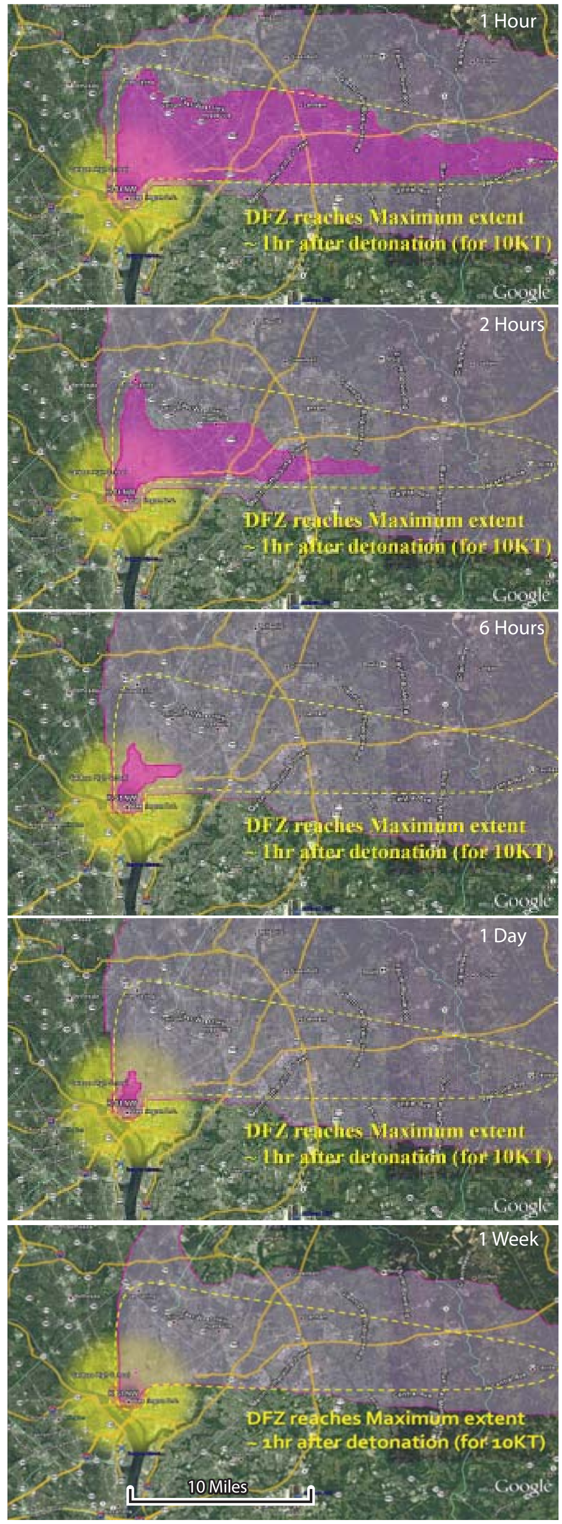


Figure B-17. The DFZ (dark purple area) shrinks rapidly over time following a 10-kT detonation.

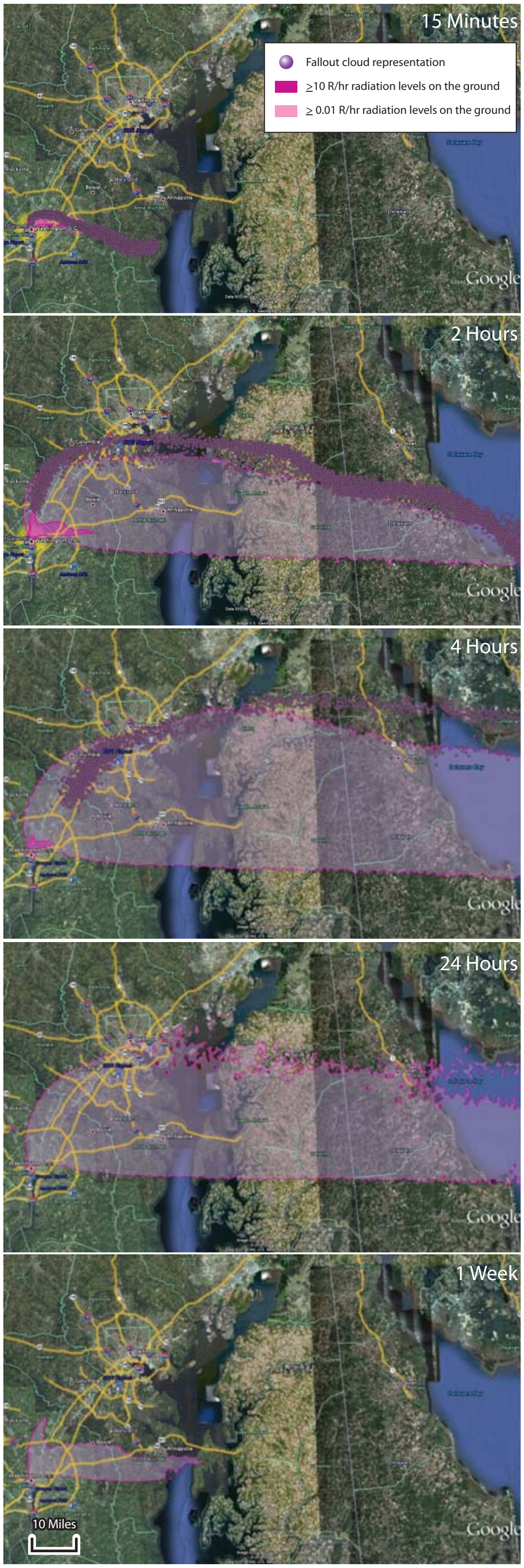


Figure B-18. Extent of the Hot Zone (light purple) after 15 minutes to 1 week following a 10-kT detonation.

To demonstrate how the Hot Zone changes over time, the time-stamped images in Figure B-18 show the potential fallout cloud movement (represented as purple balls) and identify the Hot Zone using light purple shading. At 30 minutes, the top of the cloud has moved over the Atlantic Ocean but the ground contamination lags behind as it takes time for the particles to fall down from the upper atmosphere and accumulate on the ground. At 2 hours, the lower portion moves over Baltimore and then an afternoon lower atmosphere wind shift halts the northward progression.

In this assessment, some parts of the Hot Zone start receding after about 12 hr. After a week, the Hot Zone contracts to an area similar in size to the area occupied by the DFZ when it was at its maximum.

In summary, Figure B-19 shows the five zones defined in this document. It is important to recognize that the zones are defined by observable features (blast) or radiation (fallout) readings so that modeling or calculations need not be performed to determine which zone a responder has entered. The five zones represent areas where different priorities and protective measures should be considered.

The zones also represent simplifications of a highly complex and rapidly changing environment; responders should anticipate observing substantial variation should be expected in each zone. To demonstrate the variation, Figure B-20 illustrates the different outdoor radiation levels within the DFZ at 1 hr after detonation. The darker and higher the bar, the greater the radiation dose rates associated with each 100- 5 100-m block.

Summary

Fallout decays rapidly. The radiation levels are very high initially, but over 50% of the energy is given off in the first hour and over 80% in the first day.

The primary hazard from fallout is being exposed to penetrating radiation from the particles. Getting as much distance and mass between you and the particles is the best protection. By remaining indoors and seeking the best possible shelter in their structure, people can dramatically cut down the radiation dose they are exposed to.

Dangerous levels of fallout are readily visible as they fall. Fallout is not like a toxic gas, rather it is thousands of tons of dirt and debris that is lofted miles into the air. Dangerous levels of fallout are not invisible; there will be visible quantities of material raining down, often the size of salt or sand.

Fallout is not a significant inhalation hazard. Because they are so large and external exposure is much more of a dominant hazard, internal exposures by breathing in the particles is a much lower concern than the external exposure from the particles on the ground.

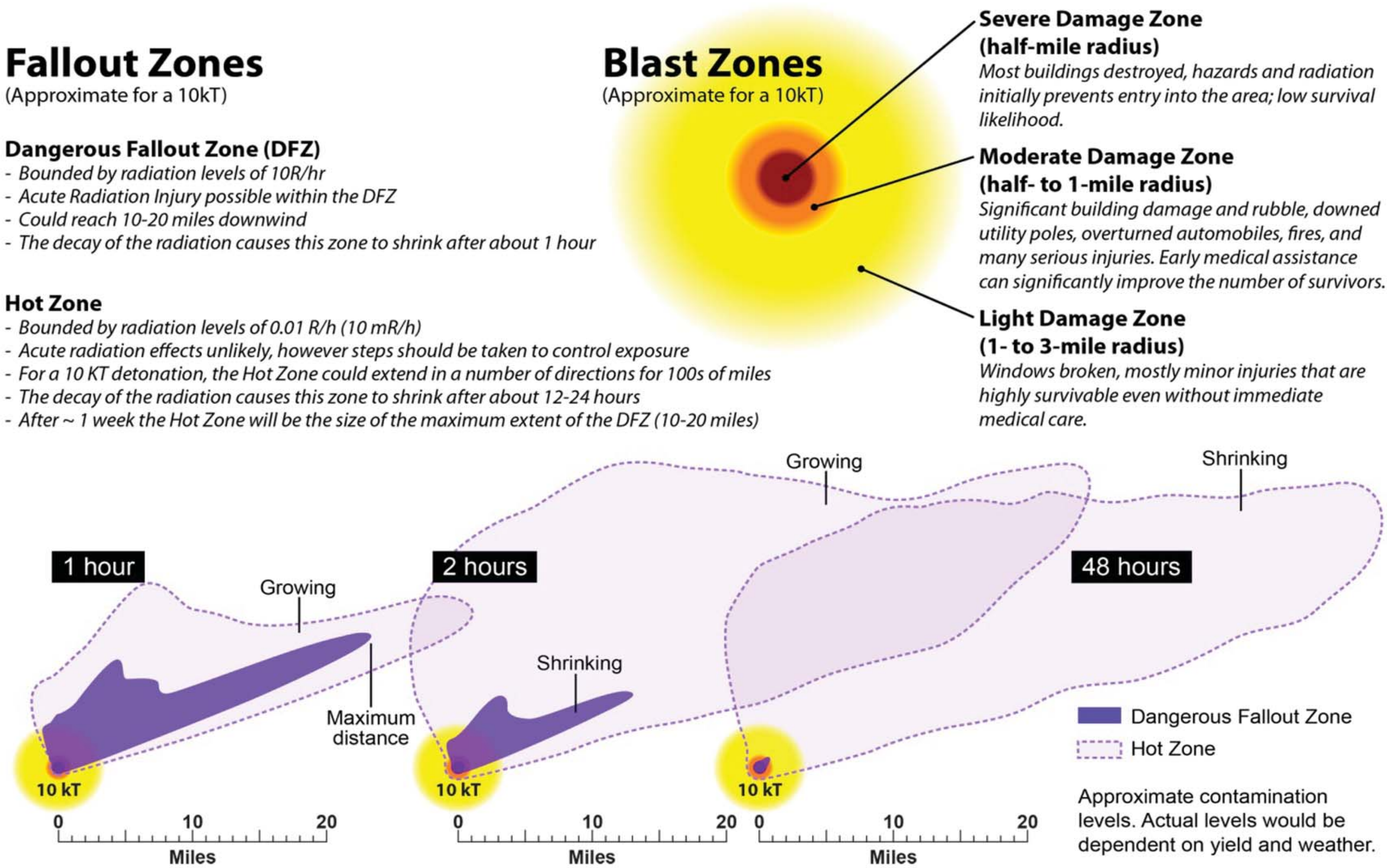


Figure B-19. Definitions of five zones and examples of areal extent at various times following detonation.

Fallout Zones have been defined by the Federal planning guidance and the NCRP, to help identify appropriate protective actions for responders working in each zone, as well as priority zones for response efforts.

- Dangerous Fallout Zone. Radiation levels of 10 R/hr and above and could reach 10–20 miles downwind before the decay of the radiation causes this zone to shrink after about 1 hour. After establishing the perimeter of the DFZ, everyone should be aware that entering that area can cause acute radiation injuries or death. Responders should enter this area only voluntarily, and only after being fully informed of the risks.
- Hot Zone. Radiation levels from 0.01 R/hr (10 mR/hr) to 10 R/hr, this could extend for hundreds of miles before shrinking after the first day. Response actions in Hot Zones will NOT result in a significant exposure that could cause an acute effect to the responder. Caution should still be taken along the edges of the Hot Zone closest to the DFZ to avoid higher exposures.

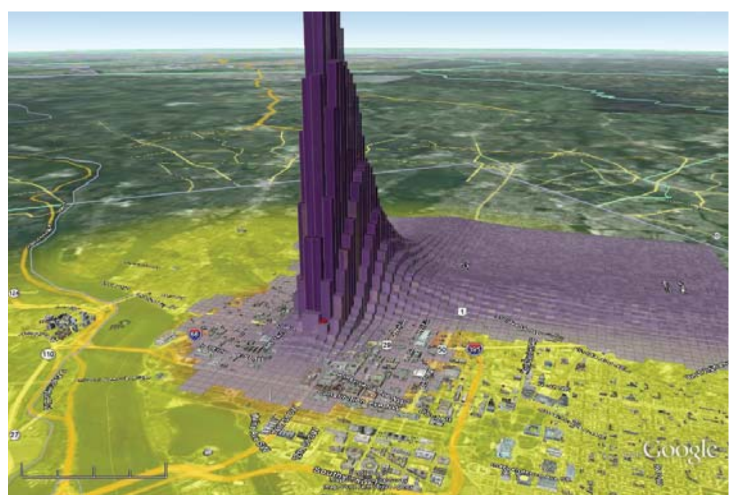
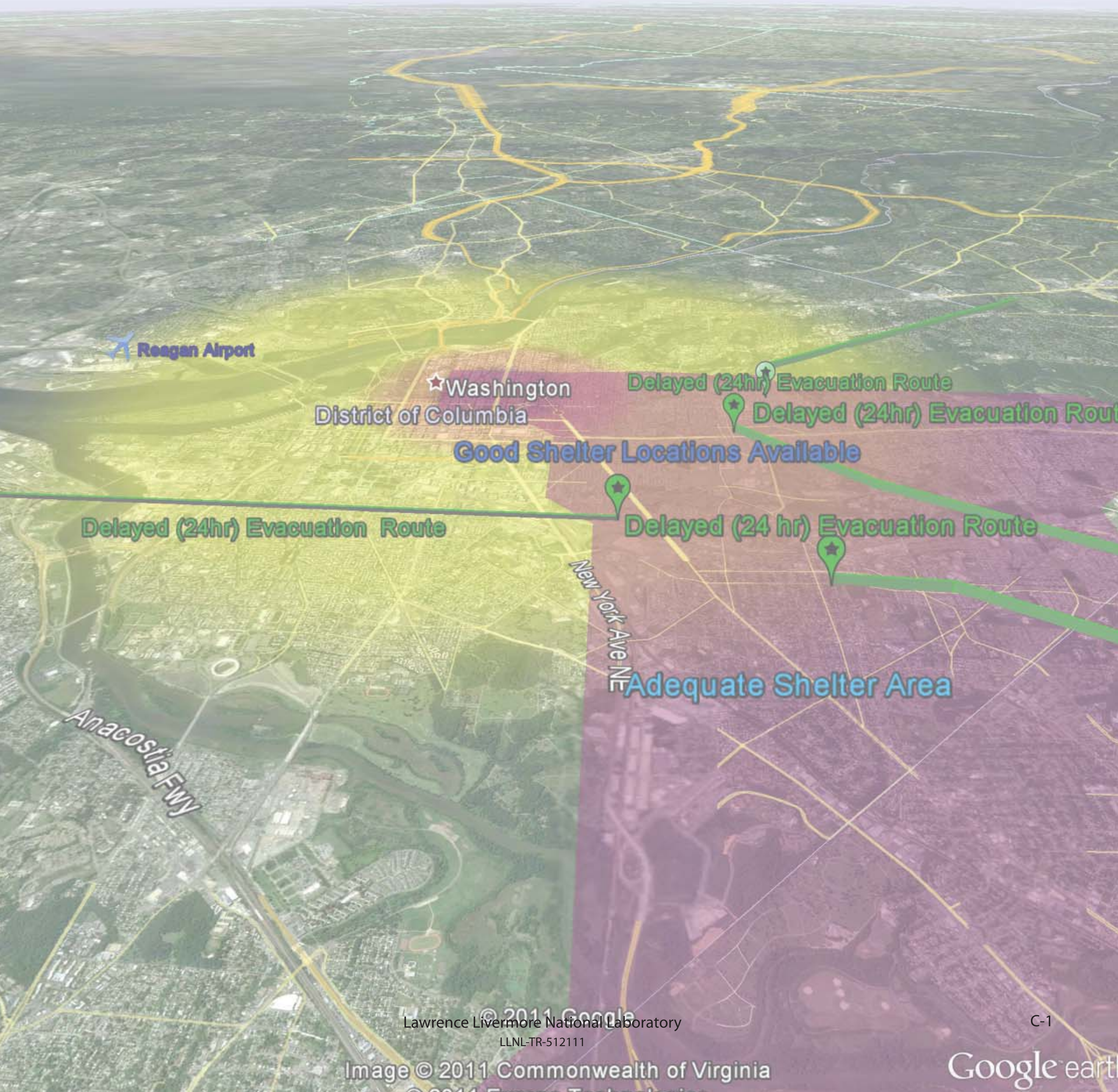


Figure B-20. Modeled radiation dose rates in the NCR using 100-by 100-m grid cells. The height of a given cell represents the relative dose rate to an individual standing outside 1 hr after detonation.

Appendix C: Shelter



Appendix C. Shelter

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The health impacts of fallout can be mitigated by leaving an area before fallout arrives or by sheltering from it because, unlike prompt effects, a time delay occurs before the exposure. Fallout exposure can be minimized by taking shelter in a sufficiently protective building. Buildings provide protection to occupants by (a) increasing the distance between fallout particles and those at risk and (b) blocking (scattering) fallout radiation as it travels through a building. A building's protection is determined by its protection factor (PF), which is equal to the ratio of outside radiation exposure to inside radiation exposure. As with the SPF of sunscreen, the higher the PF, the more protection from radiation a sheltered person receives compared to an unsheltered person in the same area. Adequate protection, which protects occupants against acute radiation sickness, is defined as a PF of 10 or greater (EOP, 2010).

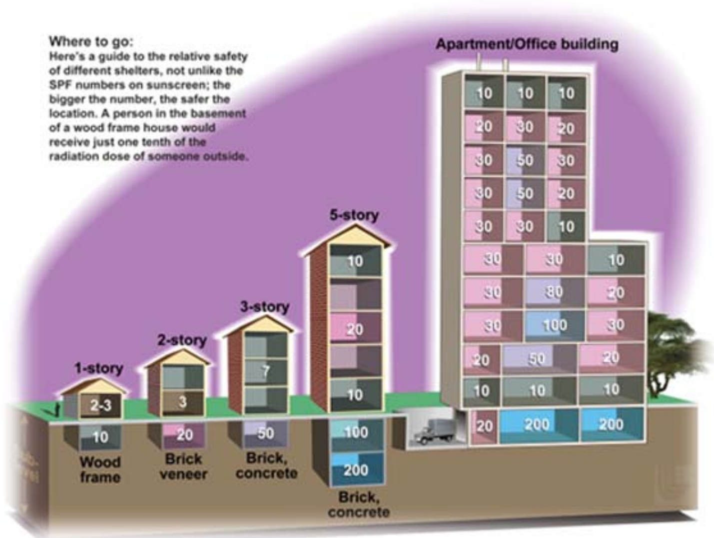


Figure C-1. Example PFs for a variety of building types and locations. Adapted from Ferlic (1983) and DCPA (1973).

Figure C-1 shows the PF values associated with several urban building types from calculations done by the Defense Civil Preparedness Agency (DCPA, 1973) and similar references. Single story, lightly constructed buildings such as wood, vinyl, or thin brick-veneer-sided frame homes and offices offer limited protection (PF ≈ 3), whereas inner portions of large, multi-story concrete or masonry office buildings can offer excellent protection (PF > 100). Basements, in general, offer adequate or better protection (PF ≥ 10). Variations in protection can be considerable within a building. For example, a person on the top floor or an outer, ground-level room in the office building pictured would have a PF of 10 and would receive 1/10 (or 10%) of the exposure that someone outside would receive. A person in the core of the same building could be shielded by a PF of 100 and receive only 1/100 (or 1%) of the outdoor exposure. In fallout areas, knowing locations with adequate PFs could prevent a potentially lethal exposure.

Table C-1 defines the shelter categories developed for this report and provides some example buildings.

Recent Research on Building Protection Factors

Extensive Cold-War-era civil defense work provides an excellent baseline understanding of key factors that are important in assessing building protection (Spencer, 1962; Eisenhauer, 1964; and Bursen and Profio 1977). However, building construction methods have evolved since that work was performed, and it is

Table C-1. Shelter quality definitions and example building types.

Shelter quality category (PF)	Illustrative buildings
Poor (< 4)	Vehicles and wood or brick-sided, single-story structures without basements, including homes and strip malls.
Indadequate (≥ 4 to < 10)	Stand-alone, small footprint, 2- to 4-story, lightly-constructed homes and apartment buildings without basements.
Adequate (≥ 10 to < 40)	Residential basements, best location in 3-story brick apartments or row homes, or the outer areas of high-rise buildings or mid-rise buildings with brick or concrete walls.
Good (≥ 40)	Large basements or underground areas and the inner areas of high-rise buildings or mid-rise buildings with brick or concrete walls.

not obvious how the previously developed rules of thumb should be applied to newer building types, such as glass-walled office buildings. Efforts are underway at LLNL, ORNL (Johnson, 2011), and ARA (Bergman, 2011a) to use advanced modeling to understand the level of protection modern buildings could provide against fallout radiation. This appendix summarizes key considerations for assessing building protection, provides the results of high-fidelity modeling of modern buildings, and describes new models used to assess the quality of fallout shelters in the NCR.

Key Considerations

Protection factors increase with (a) distance from fallout radiation and (b) scattering and absorbing of radiation as it travels between the deposited fallout and an exposed individual. This means that PFs depend on the location of fallout radiation (ground or roof), location within the building, and building construction.

Distance from Fallout Radiation

Protection factors increase with height above flat ground evenly contaminated with fallout, such that adequate (PF ≥ 10) protection is reached at 500 ft above ground (see Figure C-2). For context, this corresponds to 40 stories above the ground.

The PF can also increase with building footprint because of the increased distance between the center portion of the building and the fallout on the surrounding ground. However, without building materials blocking fallout radiation, this increase occurs relatively slowly. Figure C-3 shows the PFs an individual achieves by standing in the center of a fallout-free area in an otherwise contaminated region. Even for a 100-ft clearing (50-ft radius), the PF is only 2 (poor). For comparison, results are also provided for more elevated locations (at 100 and 330 ft).

In contrast to ground contamination, fallout exposure from a contaminated roof can be significantly reduced by increasing an individual's distance from the roof (or other isolated accumulation of fallout) as shown in Figure C-4. In smaller buildings, such as single-family residences, going down even one floor can greatly

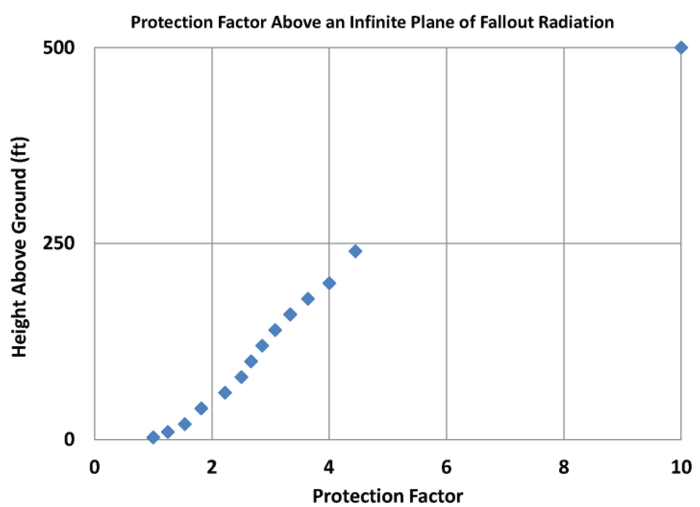


Figure C-2. Increase of PF with height over ground uniformly contaminated with fallout. Data do not include added protection provided by building materials.

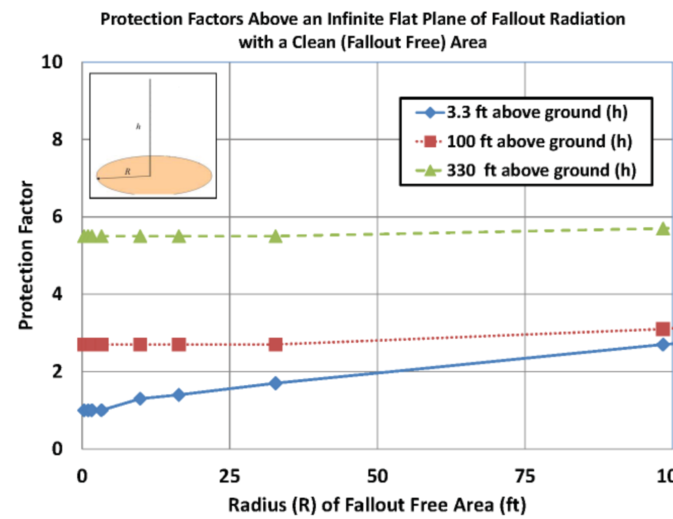


Figure C-3. PFs slowly increase with the size of a fallout-free area.

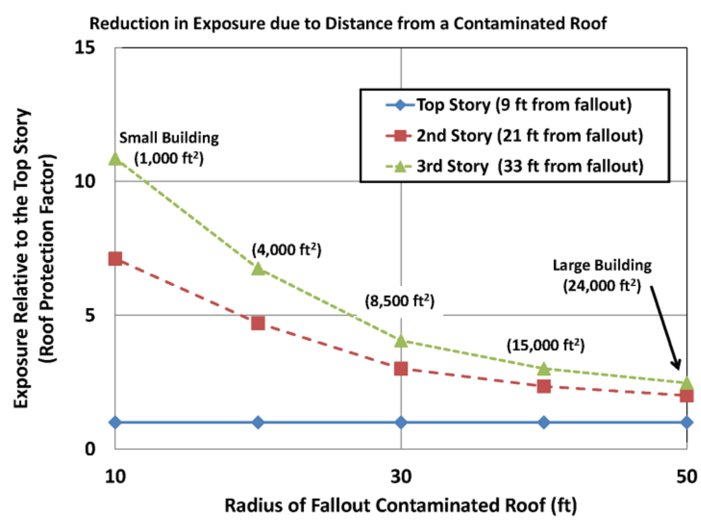


Figure C-4. PFs increase with distance from a contaminated roof.

reduce exposure to fallout radiation. For very large buildings, the roof fallout source is so large that only limited protection can be obtained from distance alone.

Building Materials

Fallout radiation can be shielded by placing as much mass of material between the location of the fallout and the person as possible. Heavier materials, such as concrete, shield more effectively than lighter materials, such as wood. As an example, 3 feet of dirt provides a PF of 1000. Buildings are constructed with a wide variety of materials and it is important to understand how buildings in a particular region are constructed to assess their ability to provide adequate fallout shelter. Table C-2 summarizes a range of common exterior wall, roof, and floor types and their associated mass. Larger numbers imply more material and higher protection. The values provided are approximate.

In many residences, the type of exterior wall (specifically, the amount of its mass) can greatly affect the PF. Figure C-5 was generated to demonstrate the influence of wall composition and uses the same building model as that assessed in Figure C-3 but adds a 1-story exterior wall of varying mass.[1] For such buildings, 8 in. of concrete, approximately 90 pounds per square foot (psf) of dead weight, is sufficient to provide adequate (PF ≥ 10) protection. Comparing Figures C-3 and C-5 illustrates the importance of blocking direct lines of sight to the horizon while sheltering (without the exterior wall, the PF is less than 2). At a practical level, this finding implies that better protection can often be found closer to the floor, particularly below the height of a window sill.

Table C-2. Dead-weight (mass) associated with common building construction materials.

Material Mass (Dead Load in psf)	Exterior Wall	Roof	Floor
10	Wood or vinyl siding with a frame wall	Elastomeric (rubber)	Resilient (linoleum) with wood subfloor
15			Hardwood
20	Stucco exterior with a frame wall	Composition (asphalt) shingle	
35		Concrete or clay tile	Terrazzo
50	Thick brick veneer with a frame wall	4-in. concrete with steel joists and beams	4-in. concrete with steel joists and beams
60	8-in. concrete block wall		
90	8-in. solid concrete wall		
175	1-ft stone wall		

Basements

Below-ground residential basements also provide adequate protection against fallout radiation for two reasons. First, being below ground eliminates direct lines of sight with large regions

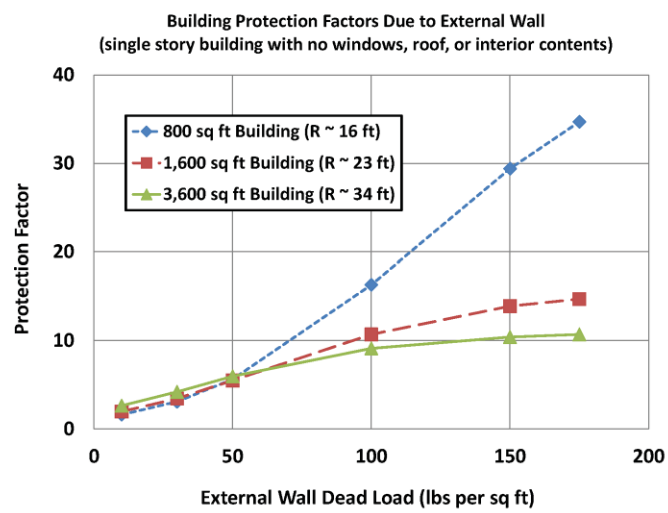


Figure C-5. PFs increase with the exterior wall mass (dead load).

Table C-3. Rules of thumb for estimating basement PFs (Bursen and Profio, 1977).

Basement Type	PF	
	Center of Basement	Basement Corner
1 or 2 walls exposed above ground	7	10
One-story building, top 3 ft exposed	11	20
Two-story building, top 3 ft exposed	17	25
One-story building, <2 ft exposed	17	25
Two-story building, <2 ft exposed	25	40

[1]Consistent with Figure C-3, there is no roof or fallout on the roof.

contaminated by fallout.[2] Second, a basement is located at least two stories below a contaminated roof.[3]

However, many basements are not completely below ground. The top of some basements can be above the ground level, and in sloping terrain, one or more walls of a basement can be above the ground. Table C-3 provides rules of thumb (from both theoretical and experimental considerations) for basement shelter quality. Such rules assume that basement walls are concrete block. Lower PFs should be expected if exposed walls are constructed of lighter materials.

Analyses of Specific Structures

Detailed computer simulations have long been used to provide high-fidelity assessments of building protection for individual structures. As part of the IND response and recovery program, FEMA sponsored ORNL and ARA to analyze several modern buildings using state-of-the-art computer simulations.

Table C-4. PF predictions for a brick-sided house.

Location	2nd floor	1st floor	Basement
A – Front left corner	3	3	
B – Front right corner	3.1	3.4	
C – In front of glass doors	3.1	2.5	
D – Stairwell	4.5	5	
E – Center of livingroom/master bedroom	3.9	4.2	
F – Interior bathroom	4.8	6.6	
G – Against garage wall	5.2	7.5	
H – Rear right corner by garage	3.6	5.7	
I – Rear left corner	3.6	5.7	
J – Back window near garage roof	2.9	4.2	
A – Basement front left corner			*62.4*
B – Basement center			*30.6*

Single-Family Residence

Figure C-6 shows the structure used for a detailed analysis done by ORNL of a modern 2-story, 2,500-ft^2, wood-frame house with an asphalt shingle roof, wood floors, and drywall interior walls. PFs were calculated for both vinyl and brick exterior siding. Figure C-7 shows the results of the calculation using a top down view of the 1st floor. The PF predictions for various locations in the brick-sided house are summarized in Table C-4.

Figure C-6. Structure used for PF analysis of a residential home.

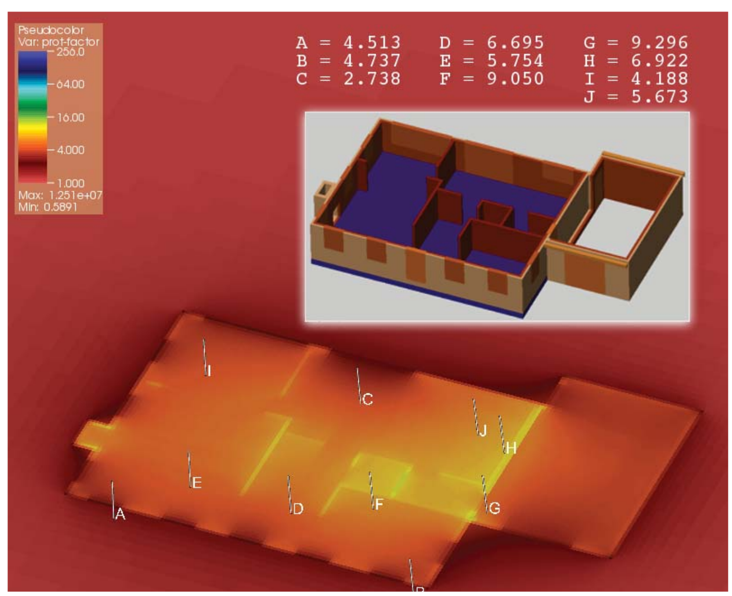


Figure C-7. PF calculation results for the first floor of a 2 story, brick sided home.

[2]Depending on building construction, basement PFs may be lower than shown in Figure C-5 due to radiation reaching the basement after being scattered from above-ground walls, roof, and floors.
[3]Building materials, such as the roof and floors, provide additional protection beyond that shown in Figure C-4.

As expected, above-ground spaces offer less than adequate protection. Peak PFs reach ~8 on the ground floor, consistent with Figure C-5, but with less protection in the upper floor just below the contaminated roof. Adequate protection is predicted in the below-ground basement (with higher protection in the corner). The analysis of a similar vinyl sided structure confirmed the expected lower PF (PFs were 2 to 3 above ground, and 20 to 50 below ground).

Brick Row Home

Figure C-8 shows a single unit of a 3-story, attached, brick row home model that was analyzed by ARA (6 units were attached for a total of 16,500 ft^2). Results of the ARA analysis (Bergman, 2010) are shown in Figure C-9.

The modeled PFs were best inside the well-shielded stairwell region, but were still adequate to good (PF ≥ 10) in the back room with no windows and thick walls between occupants and the outside. In the front room, where windows were present and much of the exterior wall area is similar to that assumed for the single-family residence, PFs were lower and inadequate, PF ≈ 5 to 8, on the first and third floor, and adequate, PF ≈ 10 to 20, on the second floor where a concrete floor provided additional shielding from ground and roof radiation. Units on the row-house end have lower protection relative to those in the center of the row.

Low-Rise (3-Story) Concrete Office Building

Figure C-10 shows a detailed analysis by ORNL of a modern, 3-story, steel frame, tilt up, pre-cast concrete construction office

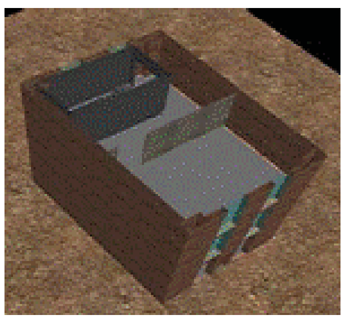


Figure C-8. Model of a single row home unit. Five such units were joined together for the analysis.

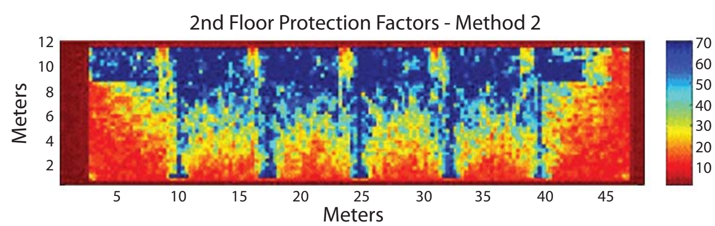
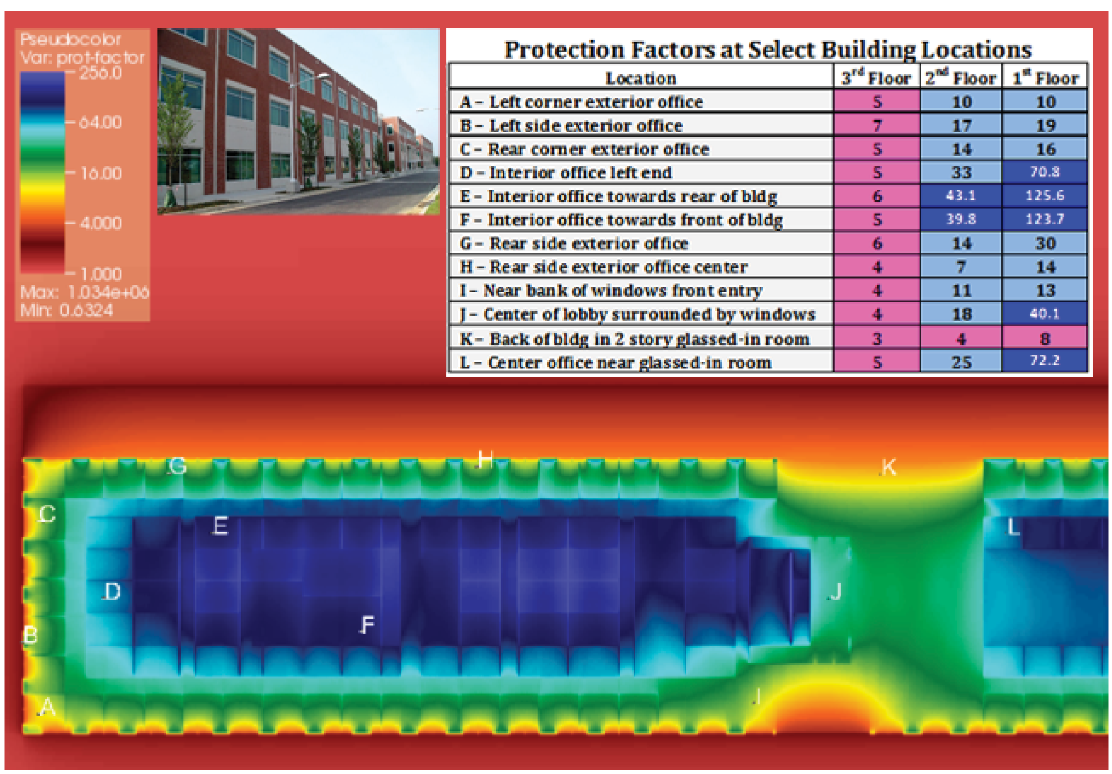


Figure C-9. Results of ARA modeling of a 5-unit brick row house. Blue indicates good protection; light red, yellow, and green indicate adequate protection' and dark red indicates inadequate protection.



Protection Factors at Select Building Locations

Location	3rd Floor	2nd Floor	1st Floor
A – Left corner exterior office	5	10	10
B – Left side exterior office	7	17	19
C – Rear corner exterior office	5	14	16
D – Interior office left end	5	33	70.8
E – Interior office towards rear of bldg	6	43.1	125.6
F – Interior office towards front of bldg	5	39.8	123.7
G – Rear side exterior office	6	14	30
H – Rear side exterior office center	4	7	14
I – Near bank of windows front entry	4	11	13
J – Center of lobby surrounded by windows	4	18	40.1
K – Back of bldg in 2 story glassed-in room	3	4	8
L – Center office near glassed-in room	5	25	72.2

Figure C-10. Top view of a three-story, concrete-walled commercial building. First floor PFs are shown. The color coding in the bottom image is unique, where red = PF 2, yellow/green = PF 10, light blue = PF 50, and dark blue = PF 100+.

building with a flat asphalt roof and brick façade. The interior of this building is filled with drywall partitions that individually provide little protection (~10 psf each).

PFs on the third floor, next to roof fallout, are inadequate. In the first and second floors, where distance and concrete floors reduce exposure to roof fallout, adequate (yellow and green) protection is found along the building periphery, and good (dark blue) protection is found in the building center. The additional protection in the building core is provided by the many drywall partitions between the building center and exterior wall.

Finally, ORNL also performed an analysis on a common 3 story "garden apartment" building pictured in Figure 11. Both vinyl and brick exteriors were assessed (specific location results are not shown).

The results of these studies confirm that the rule-of-thumb guidance for PFs generated during the civil defense program (e.g., Figure C-1) offers an approximation at best. These estimates can underestimate the protection actually provided by many structures. To illustrate this point, Table C-5 provides a summary of the ranges of protection factors found in the buildings discussed above. The protection factors in low-rise (2 to 3 story), brick-sided buildings range from poor (PF = 3) to good (PF > 40).

Figure C-11. 3-story apartment building with 6 units per floor.

Table C-5. Summary of recent protection factor analysis.

Structure	Basement (PF)	1st Floor (PF)	2nd Floor (PF)	3rd Floor (PF)
Vinyl-sided 2-story home	22 - 46	2-4	2-3	N/A
Brick-sided 2-story home	31 - 62	3-8	3-5	N/A
Brick-walled urban row home	N/A	12-70	12-70	5-30
Vinyl-sided 3-story apt building	N/A	3-7	2-6	3-5
Brick-sided 3-story apt building	N/A	4-11	4-9	4-8
3-story office (brick-sided concrete walls)	N/A	8-126	4-43	3-7

PFscreen: A Fallout Protection Screening Tool

As discussed above, fallout protection depends on building construction details and varies considerably with location within a building, even within relatively simple structures, such as residences. Thus, local planning and response efforts require a building-by-building analysis to identify inadequately sheltered populations. High-fidelity models are impractical because they require considerable technical expertise and substantial computing power. Moreover, a modern U.S. city typically has 100,000 to 1,000,000 buildings.

To address this need, LLNL recently developed a prototype fallout-shelter screening tool (PFscreen) that rapidly estimates the range of building protection in a given structure. This section is an overview of building protection calculations and comparison with experimental results. In a following section, the full PFscreen (and related Svalin) capability is discussed, which considers where people are located, both within a building and among buildings in a given neighborhood.

Key building parameters and radiation exposure pathways were identified from a review of Cold-War research, comparison with modeled and experimental estimates of building protection, a review of modern building data, and according to construction and subject-matter expertise. The parameters are:

- Building length and width.
- Number of stories above ground.
- Story height.
- Presence of a basement.
- Exterior wall construction.
- Roof construction.
- Floor construction.
- Interior mass (including live and dead loads).
- Window area and sill height.

A fast-running model was developed to assess the PF for each location within a rectangular building using the above building parameters. Model predictions at individual locations compared well against experiments for above-ground buildings—both a 3-story test building and 12 different low-rise, real-world buildings—and suggest that PFscreen can estimate building PFs within a factor 2. Validation efforts are ongoing for below-ground locations and mid- and high-rise buildings.

Finding the Best Shelter Location

The protection offered by any particular building requires an assessment either with a screening tool such as PFscreen for simple buildings or a more detailed analysis for complex buildings. An example of such an assessment is presented in the following sections; however, to provide context, here are some general considerations about how to locate the best shelter location in a building or neighborhood:

- For smaller, multi-story residential and office structures, exterior wall construction provides a good indication of the overall shelter quality. Walls heavier than brick siding often provide adequate protection. Even in buildings with overall poor protection, select areas, such as a concrete-lined stairwell, might offer adequate protection.
- For larger residential and office structures, interior walls can play an important role in providing adequate shelter. Much better protection is expected in office buildings with closed floor plans (interior walls) relative to those with open floor plans (no interior walls). For certain nonresidential buildings, such as libraries and warehouses, the shielding provided by internal contents can exceed that provided by the exterior wall.
- Unless a roof is heavy, PFs on the floor below a fallout-contaminated roof are much less than PFs for lower floors. For smaller buildings, even a single story can make a large difference. Characterizing roof construction is particularly important for single-story and large buildings with heavy exterior walls.
- Tall (40+ story) buildings can provide adequate protection arising from distance considerations alone.

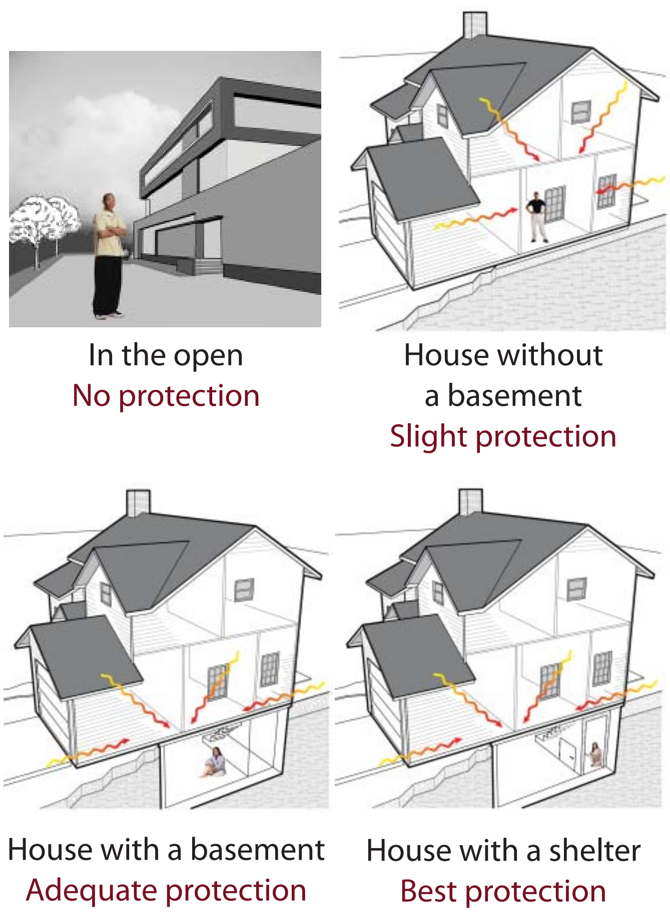


Figure C-12. Protection can vary depending on location in a building. In this illustration, the best protection is in the basement against an earthen wall.

Basements are worthy of special note in that people sheltering in them have either an entire building (distance + mass) or large amounts of earth (mass) between them and fallout particles. As a result, fully below-ground basements generally provide excellent protection against fallout radiation and are often the best-protected areas of a building. Even typical residential basements that are only 75% submerged below grade can still offer adequate protection for occupants positioned on the floor against an earthen wall (see Figure C-12).

Shelter Quality at the Neighborhood to Regional Level

Insight about the protection provided by individual buildings, while useful, offers an incomplete picture of shelter quality within the NCR because it does not account for people's locations or their actions. To address this gap, LLNL has developed the PFscreen and Svalin capabilities to assess the efficacy of various shelter strategies using existing building stock. PFscreen and Svalin are closely related capabilities, but they assess fallout protection at different spatial scales: PFscreen at the individual building to neighborhood scale, and Svalin at the city scale. The results of either capability can be combined with fallout estimates to estimate indoor radiation exposures.

As shown in Figure C-13, Svalin estimates city-scale regional shelter quality for a variety of different shelter strategies using existing buildings. The three steps of the process are:

1. Sort regional buildings into one of 36 building types (categorized by construction, basements, and building height).
2. Determine the protection associated with each building type.

3. Combine building protection estimates with estimates of usable building floor area and total number of individuals (workday and nighttime) in each of the 36 different building types.

Svalin uses the following data:

- DHS (FEMA) HAZUS building datasets.[5]
- Building geometry information available from the National Geospatial-Intelligence Agency (data used under the auspices of the DHS IMAAC program).
- Workday and nighttime population estimates provided by the ORNL LandScan.
- Building protection estimates based on Cold War estimates (Glasstone, 1977).

The Svalin model then provides protection estimates for the following shelter strategies:

- No response: people do not move from their present location in a building at the time of detonation (e.g., everyone in an office building remains seated at their desks).
- Shelter-in-Place (S-i-P): people obtain the best protection available in their present building at the time of detonation (e.g., everyone shelters in the basement).
- Local shelter: people obtain the best protection in the local area (e.g., in a nearby concrete hospital).

Results of the Svalin analysis for the Washington, DC region are summarized in Figures C-14 and C-15.[6]

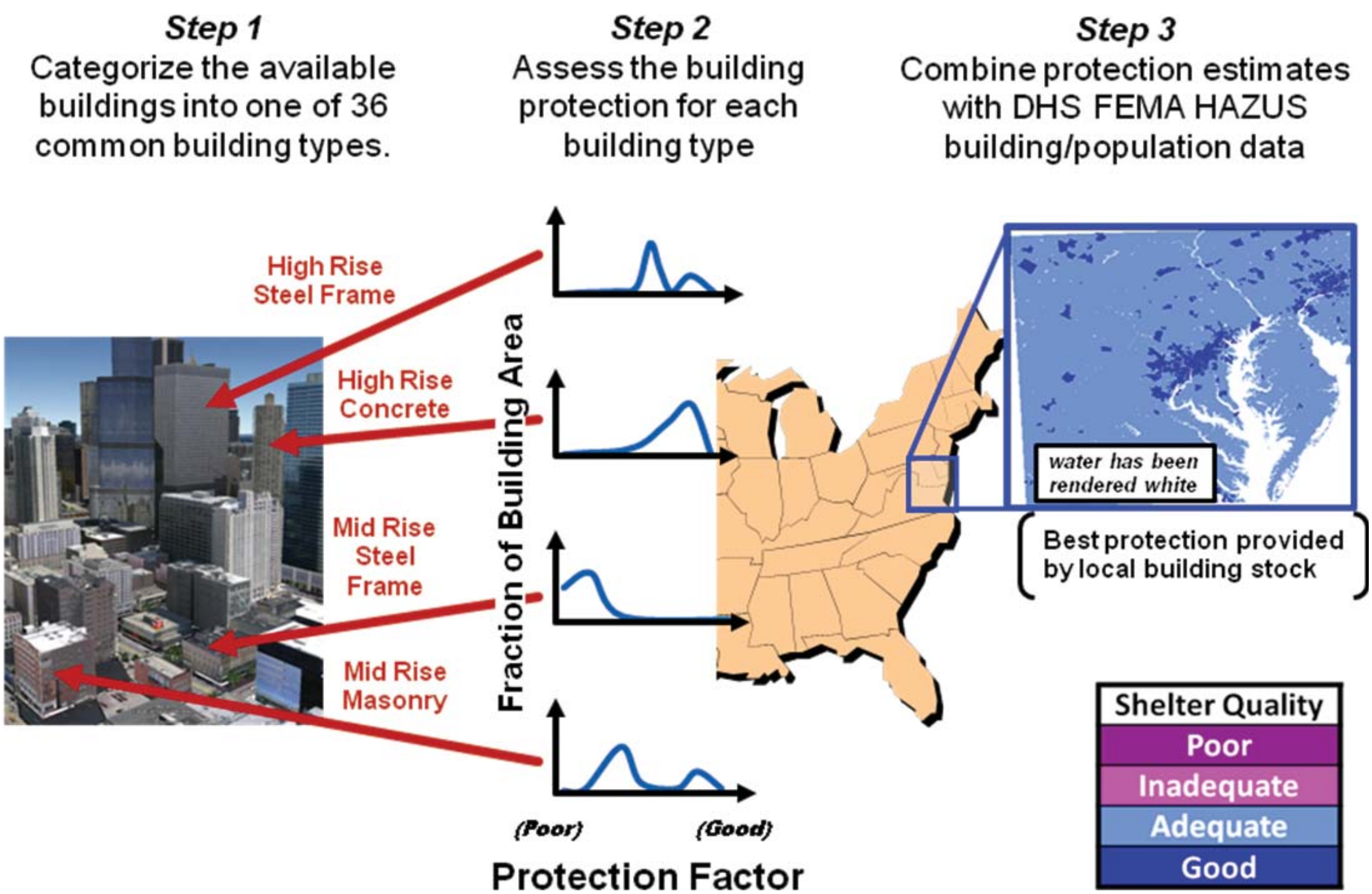


Figure C-13. Three-step process by which Svalin estimates regional shelter quality.

[5]For more information on HAZUS, visit: http://www.fema.gov/plan/prevent/hazus/index.shtm.

[6]When this assessment was performed, the PFscreen model was being upgraded and these results should be considered preliminary. As with all screening tools, follow-up assessment is recommended if a given building or a specific location within a building needs to be precisely characterized.

Because basements are common in single-family homes in this region, the Svalin analysis suggests that adequate shelter is likely in the structure people are already occupying or immediately nearby. Commercial and office building construction, which often provides adequate or good protection, appears as the good shelter regions (dark blue) in Figures C-14 and C-15.

Example of a Washington, DC Neighborhood

Block-by-block modeling allows for an assessment of prompt and delayed effects at every location in a city, including an analysis of radiation levels along potential exit routes. An illustrative assessment of a single neighborhood is useful from a planning

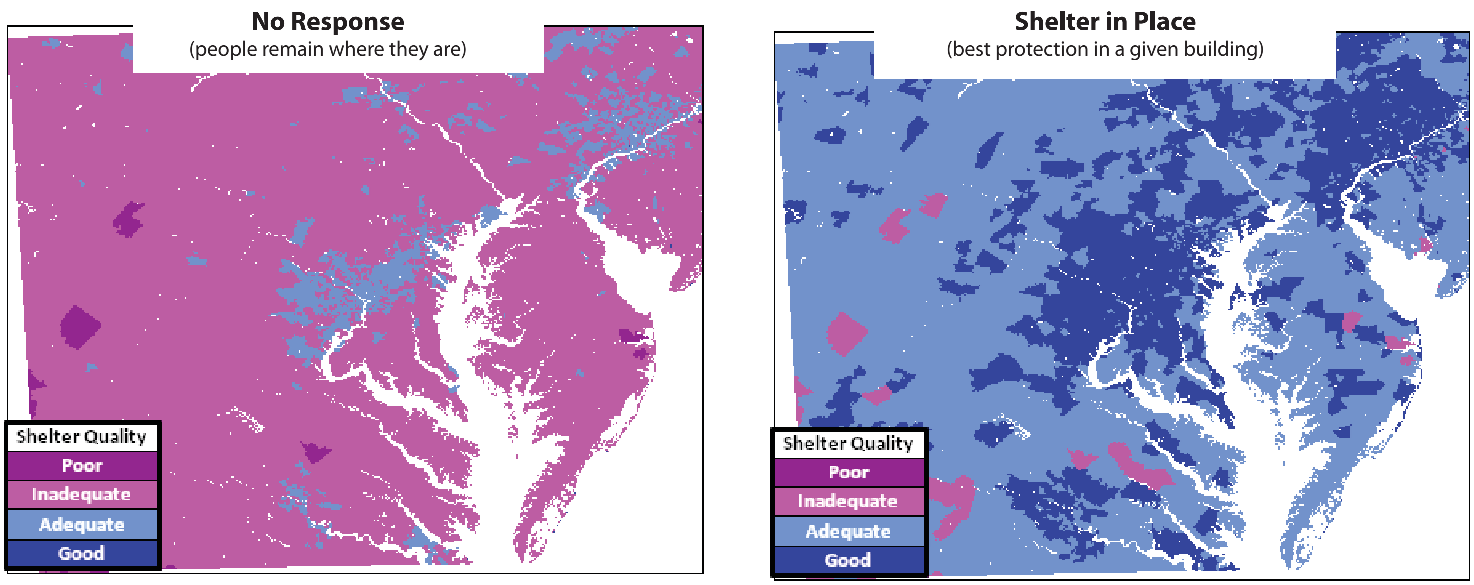


Figure C-14. Maps of Svalin shelter quality for the greater Washington, DC region for a workday. (Left) No response. (Right) Shelter-in-place moving to the best-protected area in a building. Water regions are rendered white.

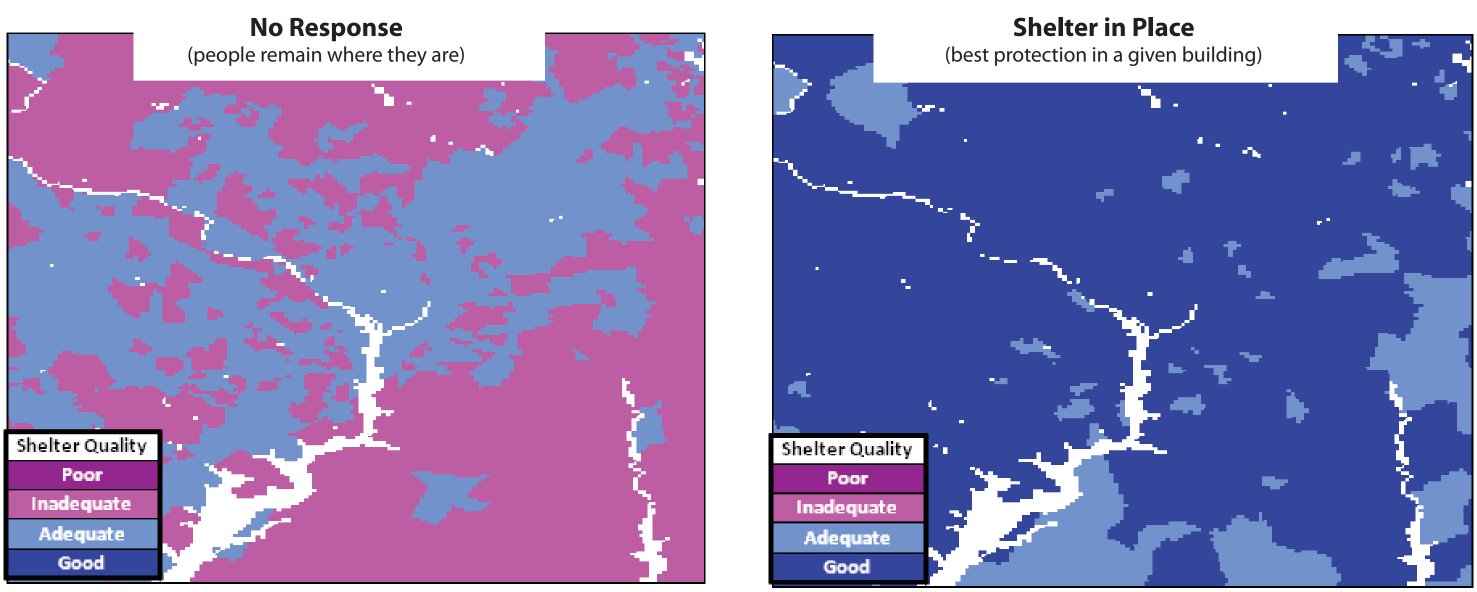


Figure C-15. Svalin shelter-quality maps for Washington, DC proper on a workday. Water regions are rendered white.

perspective to highlight the potential tradeoffs arising from different response strategies.

The Cardozo/Shaw/U Street corridor of Washington, DC is a good example of an area in which actions taken can mean the difference between life and death. The area is in the LDZ (1.3 to 1.5 miles from the hypothetical detonation location) and is also near the center of the DFZ, as shown in Figure C-16.

A 12-hr outdoor exposure in this area would result in 1,500 R, which is fatal. To illustrate the importance of accurately characterizing the shelter in this neighborhood, Figure C-17 summarizes how the various classes of buildings protect their occupants from dangerous fallout radiation. For the exposure potential of the Cardozo/Shaw/U Street corridor area, people sheltered in buildings with inadequate protection (PF = 4) would receive exposures that would likely make them ill (240 R in 12 hr). People sheltered in buildings with adequate protection (PF = 10) would receive exposures that may cause illness in sensitive populations (100 R for a 12-hr exposure). People sheltered in buildings with good protection (PF = 40) would receive exposures that would not be expected to result in any acute radiation effects and would minimize long-term risk (24 R over a 12-hr exposure).

Figure C-16. The Cardozo/Shaw/U Street corridor area.

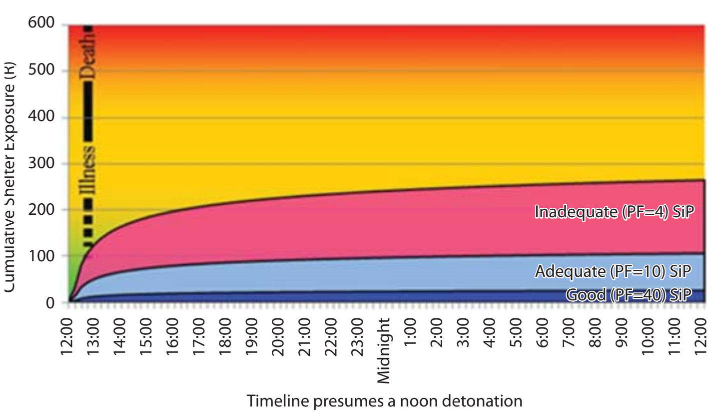


Figure C-17. Summary of potential radiation exposures for individuals sheltering in locations with inadequate (PF = 4), adequate (PF = 10), and good (PF = 40) protection.

This urban residential neighborhood offers many shelter opportunities. Figure C-18 shows a typical street. Predominant residential buildings are 2- to 3-story brick row homes, or brownstones, equipped with English basements. Because the wall area of many English basements are partially above ground and exposed, the basement shelter quality may be adequate. From tax assessor data, row house roofs and floors are typically constructed of lightweight materials. In the absence of a well-protected area, the protection these houses offer is likely close to the brick apartment building assessed by ORNL. Although rare in the neighborhood, there are a few smaller brick and wood-sided, 1- and 2-story, stand-alone buildings. If such structures do not have a basement, then the protection offered is likely poor to inadequate. There are also several larger residential, commercial, and public buildings in the neighborhood that likely offer adequate to good protection.

Figure C-18. Typical neighborhood building types for the Cardozo/Shaw/U Street corridor.

Figure C-19 shows the results of a demonstration PFscreen analysis for this neighborhood using Washington, DC tax assessor data to provide building-specific information.[7] Similar to the city-scale SVALIN model, PFscreen estimates the efficacy of local shelter, S-i-P, and no response strategies for individual buildings as well as the neighborhood as a whole. Whereas most people in the neighborhood have adequate to good protection (blue dots and blue shaded neighborhood outline), numerous people are expected to be inadequately sheltered (magenta dots) under theS-i-P and no-response strategies. Fortunately, the local shelter strategy analysis suggests that good shelter is available in nearby buildings (dark blue dots).

Figure C-19: The dot color represents the S-i-P (best location in building) shelter PF. The shaded blue outline shows the neighborhood analyzed and indicates that most people in this neighborhood would be in good shelter during the workday.

Sheltering to Prevent Fallout Casualties

Research at SNL (Brandt, 2011b) has evaluated several shelter strategies in terms of the number of fallout casualties that may occur for each strategy. The term “casualties,” refers to near term radiation related injuries and fatalities. In general, the radiation level and sensitivity of the particular individual determines if an exposed individual becomes a casuality.

For the baseline planning scenario considered, the number of preventable fallout casualties in the NCR is 130,000 (82,000 fatalities and 48,000 injuries from radiation exposure). Preventable casualities is defined as the reduction in casualities when the potentially exposued population follows a given shelter strategy compared to the entire population standing outside for the first 4 days after the detonation. Since it is unlikely that people would stand outside for 4 days,[8] the preventable casuality metric is most appropriate to compare various strategies in a relative sense. For example, if everyone in the region found a good shelter (PF=40), 99.8% of the 130,000 fallout radiation casualties would have been prevented.[9]

Buildings with adequate protection (PF 10 or greater) are expected to be ubiquitous in the NCR because of building types in the region. If the entire population is sheltered for the first few days in a PF = 10 structure (adequate protection), the number of fallout radiation casualties would be reduced by 94%, preventing 122,000 casualties. Figure C-20 represents this information graphically, showing the number of prevented casualties (lives saved and injuries prevented) for each shelter type.

[7]When this assessment was performed, the PFscreen model was being upgraded and these results should be considered preliminary. As with all screening tools, follow-up assessment is recommended if a given building or a specific location within a building needs to be precisely characterized.

[8]Due to the rapid decay of nuclear fallout, about half of the 4-day dose would be received in the first 12 hours.

[9]This assessment only evaluates fallout casualties and excludes the population in the SDZ and MDZ who may have been injured by other mechnisms.

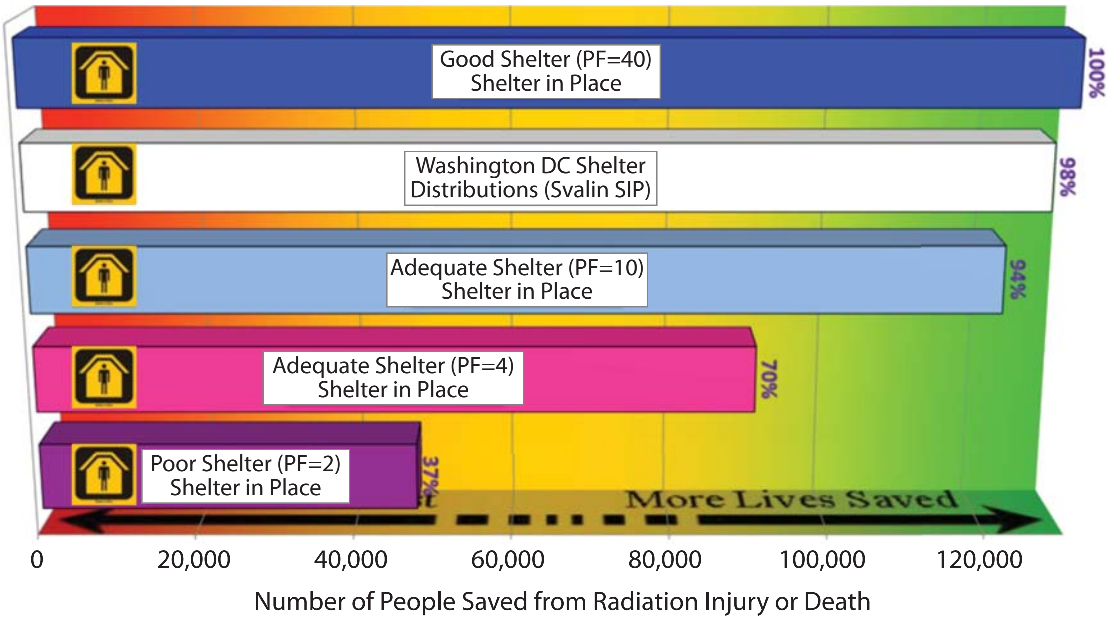


Figure C-20. Casualties prevented for various shelter types for the illustrative scenario. The percent of casualties prevented is also noted.

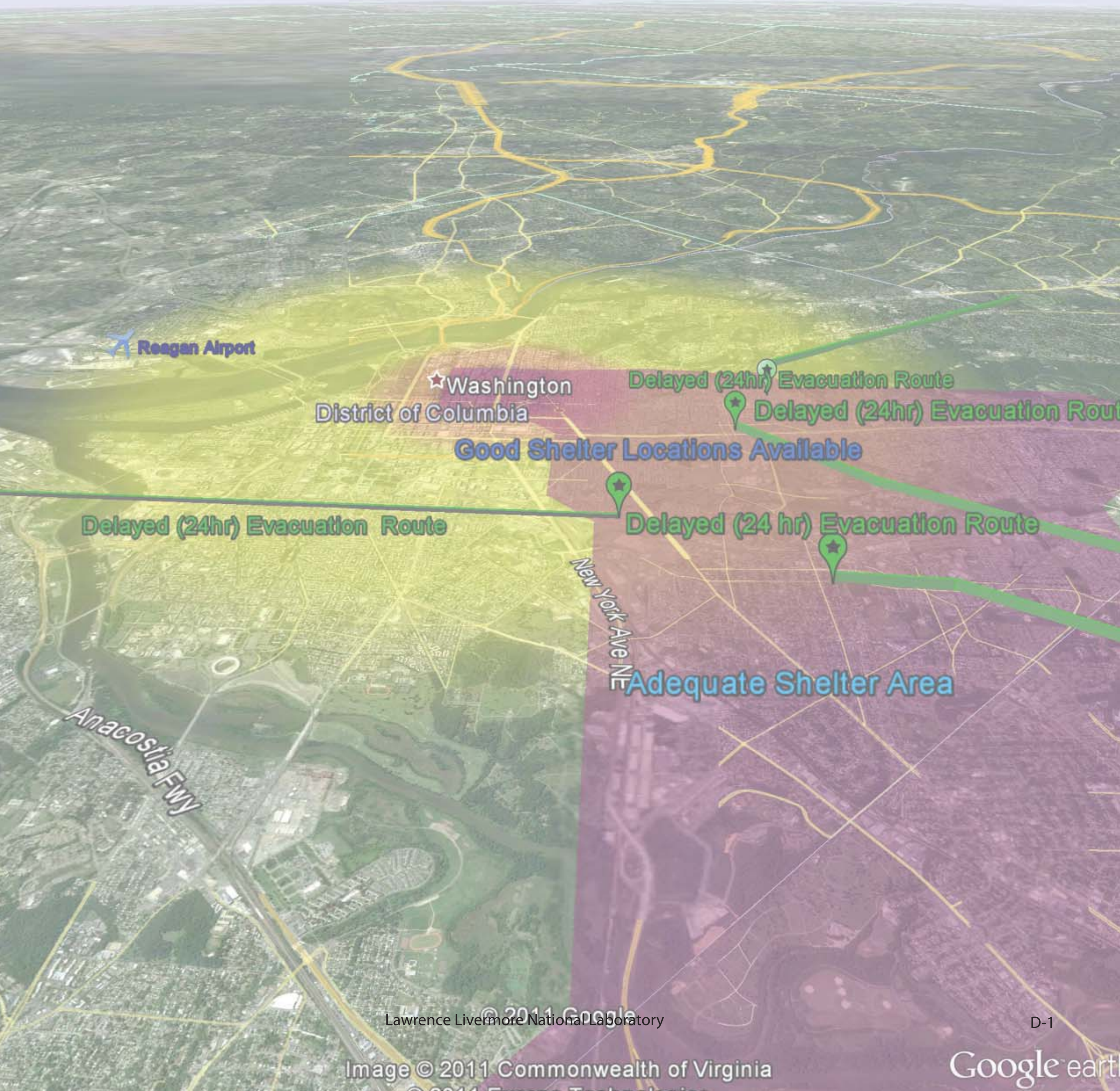
If individuals shelter in the best location in their building (as calculated by the Svalin model) 98% of casualties could be prevented (white bar in Figure C-20). This analysis suggests that (1) adequate and good shelters are generally available in dangerous fallout zone and (2) quickly sheltering in the best nearby location could significantly reduce the number of casualties.

Unfortunately it must be assumed that not everyone will know to, or have the time to, get to an adequate or good shelter and the actual number of preventable causalities is likely less than that shown. For this reason, a more detailed analysis is required to evaluate additional measures to reduce casualties through alternate strategies.

Summary of All Shelter Strategies

The casualty estimates for S-i-P using the Svalin regional shelter quality data predict that approximately 98% of potential casualties in the NCR might be avoided if individuals took refuge in the best sheltering locations of the buildings in which they find themselves at the time of the detonation. This is the result in Figure C-20 that best incorporates current understanding of regional shelter quality as embodied in the Svalin data.

Appendix D: Responder Protective Equipment and Equipment Settings



Appendix D. Responder Protective Equipment and Equipment Settings

Radiation emergencies represent a unique HAZMAT challenge as the normal methods of responder protection, isolation suits and respiratory protection, do not work for the primary hazard of exposure to penetrating gamma radiation. Wearing bulky personal protective equipment (PPE) can actually increase radiation exposures as it increases the time needed to accomplish the mission in the radiation area. Radiation cannot be detected with the five senses, which is why radiation detection equipment is an essential piece of PPE. There is a large variety of radiation detection equipment used in the NCR and many types of equipment can only be used for missions outside the Hot Zone.

Protective Clothing

Self-contained breathing apparatus (SCBAs); respirators; firefighter “turnouts” or “bunker gear;” and Level A, B, or C HAZMAT suits do not protect against the primary hazard from an IND detonation, which is the penetrating gamma radiation given off by fallout. Inhalation and ingestion of fallout are secondary concerns compared to external exposure.

> ***At the scene of an incident, standard protective clothing (i.e., bunker gear) and respiratory protection devices are sufficient to protect emergency responders against personal contamination by radioactive materials when conducting life-saving and other critical missions.***
>
> ***NCRP, Commentary #19.***

Firefighter turnouts and anti-contamination clothing can help ease decontamination after entries, but time-critical, life-saving activities should not be delayed if such items are not immediately available, provided other hazards at the scene do not dictate specific PPE.

After the disruption of a nuclear detonation, many hazards will be present that are not radiation related. Fires, toxic industrial chemicals, and sharp debris are just a few examples of hazards that should be considered when working in the Severe Damage Zone (SDZ), Moderate Damage Zone (MDZ), and Light Damage Zone (LDZ). The best PPE for responders working in the Hot Zone or Dangerous Fallout Zone (DFZ) is a radiation detector that alerts workers to exposure and radiation levels of concern. Table D-1 identifies other PPE recommendations when responders move between zones.

> ***Radiation monitoring equipemtn is necessary for emergency responder dose control and safety while they are in their facilities and on emergency calls.***
>
> ***NCRP Report #165***

Instrumentation

Table D-2 is an expanded version of the instrumentation information provided in the Federal Planning Guidance document (EOP, 2010). Examples are provided relevant to the types of instruments currently in use in the NCR. Inclusion of examples in this document does not represent an endorsement. For information and assessments of radiation instrumentation, refer to the DHS System Assessment and Validation for Emergency Responders (SAVER) program (available at https://www.rkb.us/saver/). An example report can be found at Radiation Detectors – Radiation Survey Meters TechNote, available at https://www.rkb.us/saver/download.cfm?id=3225.

Figure D-1. Appropriate PPE depends on the mission. Images courtesy of the DOE Transportation Emergency Preparedness Program and DHS Personal Radiation Detector (PRD) Training.

Table D-1. PPE recommendations when transitioning between zones.

Dose Rate	Locations	Protective Equipment	Restrictions/Precautions
0.002 R/hr[1]	Outer exclusion zone	Work uniform	Outer boundary for small incidents. No legal restrictions outside this area. Command centers, staging areas, etc., that need to be set up close to the incident can be within this boundary.
0.01 R/hr	Outer boundary of Hot Zone	Minimum: Work uniform and radiation-monitoring equipment. Preferred: Respiratory protection and clothing that can be decontaminated. Active, alarming dose-monitoring equipment.	Proceed for emergency operations (life saving, fire fighting, etc.). Shelter/isolate area, and minimize responder time spent in the area. If possible, monitor and record response-force exposures. If possible, rotate responder workforce to avoid exceeding cumulative dose limits.
10 R/hr	Outer boundary of DFZ	Minimum: Work uniform and active, alarming dose-monitoring equipment. Preferred: Respiratory protection and clothing that can be decontaminated	Proceed for time-sensitive, mission-critical emergency operations such as life saving. Use active, alarming dose- and dose-rate monitoring equipment to ensure predefined exposure levels are not exceeded. Isolate area, and minimize responder time spent in the area.
200 R/hr[2]	"Turn back" level (even for life-saving actions)	Same as above: Proceed only for short period (<15 min), planned rescue attempts	At this dose rate, the likelihood of successful rescue of victims is outweighed by dose effects to responders. Represents the level at which rescue operations may not be justified. Enter such areas only after it has been determined that the likelihood of success outweighs potential harm to rescuers. Survival of non-ambulatory victims who have been in the area for more that 60 minutes is questionable.

[1]A dose of 0.002 R/hr is significantly higher than natural background.
[2]COG Hazardous Materials Subcommittee, Radiological Dispersal Device (RDD) Response Guidelines SOG 1, COG Fire Chiefs, approved on July 20, 2006.

Many types of modern radiation detection equipment, such as PRD, Type I Survey equipment, and contamination monitors, are made to detect very low levels of radiation and may not operate at levels appropriate for Hot Zone or DFZ activities.

For use within the Hot Zone, instruments should be capable of measuring up to 10 R/h so that workers do not inadvertently stray into the DFZ. If entries in the DFZ are required, instruments should measure both exposure rates up to 1000 R/h as well as track exposures. Alarming Dosimeters and Personal Emergency Radiation Detectors (PERDs) are particularly well suited for supporting response activities in the Hot Zone and DFZ, although their alarm set points should be enabled to alert the user when additional protective measures or withdrawal from the area should be considered. Table D-3 identifies recommended settings for these instruments. Table D-4 provides additional assessments of various instruments and systems.

Table D-2. Radiation equipment types and mission applications.

Equipment	Description	Mission Applicability	Example
Alarming Dosimeters & Personal Emergency Radiation Detectors (PERDs)	Designed to be worn on the responder and to measure radiation dose absorbed by the individual. The dosimeter displays the dose and dose rate, and will alarm if pre-set thresholds for either are exceeded.	Used when significant exposure rates may be encountered and provide an alarm when preset administrative and safety levels have been reached or exceeded. PERD ranges allow use in the Hot Zone and DFZ, making them the preferred tool for ensure safety of responders.	
Non-alarming PERDs	Non-alarming PERDs provide a visual indication of exposure to the user and are designed to be worn or carried on the body of the user. These detectors do not have an audible or visual alarm.	Used when significant exposure rates may be encountered. These tools provide a visual indication when safety levels have been reached or exceeded, making them an excellent backup system for the DFZ.	
Personal Radiation Detectors (PRDs)	Also known as "Radiation pagers," similar in appearance to electronic dosimeters; used to detect low levels of radiation using very sensitive crystal or plastic scintillators. Although good for finding contraband radioactive material, these units do not (typically) have the range necessary for personnel protection (i.e., high dose rates) or distant detection.	Primary screening tool for Patrol and Event monitoring. Well suited for law enforcement or inspectors, these devices can alert the wearer to any unusual proximal radiation; however, their sensitivity also means that they often "saturate" at relatively low radiation levels and cannot be used in the Hot Zone or DFZ.	
Special note: Hybrid PRD / PERD	Recently, PRD manufacturers have begun offering dual detector systems that allow the PRD to have an extended (high) dose rate range without sacrificing the lower dose rate sensitivity.	Note: the NCR recently purchased the Polimaster PM1703-MO1 has an additional high-range detector capable of measuring up to 1000 R/hr, making it useful for both prevention and response missions. Warning: Alarm set points must be changed to match mission needs.	
Survey Meter (Type I)	Hand-held devices that detect low levels of radiation or contamination at and above background. Designed to operate in the 0 to 1 mR/hr range. Most common Type 1 meters use G-M tubes or scintillation detectors. Typical survey meters may consist of a base meter with power source and readout in conjunction with one or more interchangeable probes for detecting different types of radiation (alpha, beta, gamma, and/or neutron).	Used during initial detection to localize a radioactive source or detect the presence of contamination. Type 1 survey meters may saturate or give false readings at levels that emergency responders may experience in the aftermath of radiological or nuclear terrorism, significant radiological contamination, or exposure incidents.	
Contamination Meter	A special class of Survey Meters (Type I) that have a thin window detector capable of measuring contamination levels of alpha, beta, gamma or X-ray contamination. Typically reads out in "counts per minute" rather than a dose rate.	Measures surface contamination on people or objects. Measuring alpha contamination requires close proximity (< 1 inch) to the surface. Can be used outside of Hot Zone to check population for contamination or identify Hot Zone boundary	
Survey Meter (Type 2)	Hand-held devices used to quantify high radiation exposure rates. Detectors have a wide dynamic range for measuring gamma radiation, designed to operate in the range of 0.1 to 1,000 R/hr.	Primary detection device used by emergency responders for performing radiation hazard assessment and monitoring within the Hot Zone.	

Instruments are provided as examples only. Inclusion in this report should not be considered an endorsement.

Table D-3. Recommended settings for alarming dosimeters and PERDs.

Alarm Point[1]	Alarm Type[2]	Usage	
0.01 R/hr (10 mR/hr)	Silenceable Intermittent	Alerts responder to the presence of radiation above a level that could reasonably be expected from natural or legitimate causes. Identifies the Hot Zone boundary.	Dose Rate
10 R/hr (10,000 mR/hr)	Nonsilencing Nonlatching Intermittent	Alerts user to an area where responder action should be restricted to only the most-critical, time-sensitive activities, such as the preservation of life. Identifies the DFZ boundary.	Dose Rate
5 R or rem	Silenceable Continuous	Administrative limit: Responder should request authorization from Incident Command (IC) to continue activities. IC should consider changing out responder if replacements are available. Other methods should be considered to reduce responder dose (e.g., different approach vector, reduction of stay times, etc.). This administrative limit will help ensure that responders do not exceed Occupational Safety and Health Administration (OSHA) regulatory limit without considered action.	Total Dose
50 R or rem	Nonsilencing Continuous	Responder should leave the area. In extreme life-saving situations, responder can continue if aware of the radiation risks and no alternative rescue method exists.	Total Dose

[1]A dose or dose-rate-level alarm point of 80% can be used as an administrative level to notify a user that a predetermined set point is about to be reached.
[2]Alarm type: Silenceable indicates that users can acknowledge (silence) the alarm even if they remain in the area. Nonsilencing, nonlatching indicates that the alarm will continue to sound while the user is in the specified dose rate.

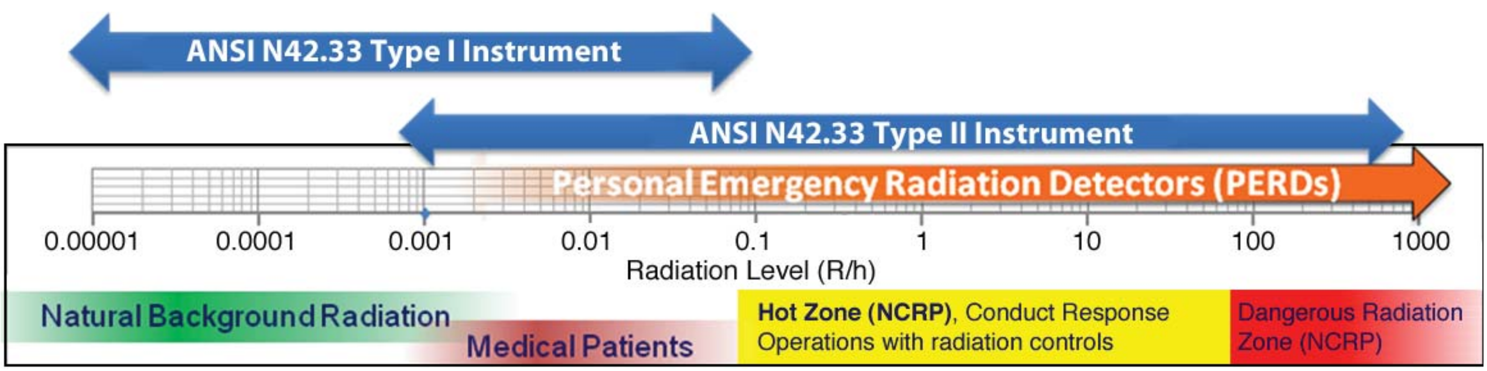


Figure D-2. Applicable exposure rate ranges for selected instrument types.

Table D-4. Instruments for IND response mission applications, an expanded list can be found in Table 2.2 of the federal planning guidance (EOP, 2010).

Mission	Alarming Dosimeters & PERDs[1]	Non-alarming PERDs[1]	Survey Meter[2]	PRD detection[3]	Contamination monitors[4]	Dosimeters	Aerial system
Confirmation of nuclear yield	l	m	l	m	—	—	l
Yield estimation	—	m	l	—	—	m	l
Dangerous Fallout Zone activities[5] (use instruments that can function in exposure rates up to 1,000 R/hr)							
Location of ground zero	—	—	—	—	—	—	l
Worker dose assessment	m	m	—	—	—	l	—
Worker safety for DFZ missions	l	m	m Type II Only	—	—	—	l
Survey of DFZ	l	—	l Type II Only	—	—	—	l
Establishing evacuation routes	l	—	l Type II Only	—	—		l
Hot Zone activities[6] (use instruments that can function in exposure rates up to 10 R/hr)							
Worker dose assessment	m	m	—	—	—	l	—
Worker safety for Hot Zone missions[7]	l	m	m Type II Only	—	—	—	—
Survey of Hot Zone	l	—	l Type II Only	—	—	—	l
Establishing evacuation routes	l	—	l Type II Only	—	—	—	l
Activities outside of Hot Zone (use instruments that can function in exposure rates up to 0.01 R/hr)							
Worker dose assessment	m	m	—	—	—	l	—
Worker safety outside Hot Zone	l	m	m	m	m	—	—
Locating Hot Zone boundary	l	—	l	m	m	—	l
Monitoring medical care locations	l	—	l	m	l	—	—
Monitoring at shelters (radiation levels)	m	—	l	m	l	—	—
External contamination detection (personnel)	m	—	m	m	l	—	—
Internal contamination detection (personnel)	—	—	m	m	m	—	—
Equipment[7] and facility[8] contamination monitoring	m		m	m	l		m

Legend:[9] l Useful m Marginal — Not Useful

[1]The American National Standards Institute is developing performance criteria for PERDs. There are two standards, ANSI N42.49A and ANSI N42.49B, which are in final review:

- Alarming PERDs for Exposure Control (ANSI N42.49A) are alarming electronic radiation measurement instruments used to manage exposure by alerting emergency responders when they are exposed to photon radiation. The instruments provide rapid and clear indication of the level of radiation exposure and/or exposure rate and readily recognizable alarms. The alarms are both audible and visual, and distinguishable between exposure rate and exposure.
- Non-alarming PERDs for Exposure Control (ANSI N42.49B) are ionizing photon radiation measuring detectors that provide a visual indication of exposure to the user, and are designed to be worn or carried on the body of the user. These detectors do not have an audible or visual alarm. These detectors provide indications that decision levels based on recommended DHS Protective Action Guides have been reached or exceeded. These detectors include carbon fiber detectors (a.k.a., pocket ionization chambers or direct reading pocket dosimeters), electronic exposure-indicating detectors, and self-developing photochemical detectors (i.e., color changing cards).

[2]ANSI N42.33 and ANSI N323 describe performance criteria for instruments used for detection and measurement of photon-emitting radioactive substances for the purposes of detection, interdiction, and hazard assessment. A survey meter is generally considered an ANSI N42.33 Type II instrument. Figure D-2 provides information on the applicable exposure rate ranges for these instruments.

[3]Radiation detection systems deployed in support of law enforcement radiological / nuclear terrorism prevention missions are generally too sensitive to be used within the DFZ or Hot Zone; however, they can be of use outside the Hot Zone for the activities noted above. This includes instruments such as the Personal Radiation Detectors (defined by ANSI N42.32), survey equipment (defined by ANSI N42.33 Type I instruments noted above), Radioisotope Identification Devices (defined by ANSI N42.34), Backpack, and Mobile systems.
[4]Contamination monitors are count-rate meters designed to measure activity (alpha, beta, photon, or alpha-beta) per unit surface area or activity of a localized source associated with the contamination of an examined object. These detectors include thin-window detectors such a thin-window Geiger-Mueller (GM) (either "pancake," or end-window) hand-held survey meter and would be acceptable to monitor for either area or personal contamination. Performance criteria are described in ANSI N323, American National Standard Radiation Protection Instrumentation Test and Calibration, Portable Survey Instruments.
[5]Missions within the DFZ should be restricted to time-sensitive, mission-critical activities justified under the worker safety section of this document. Examples include investigation of underground evacuation routes, fire control, supporting a controlled evacuation, and restoration of critical infrastructures required for life-saving activities.
[6]Common missions within the Hot Zone include; fire fighting, direct public notification of protective recommendations, USAR activities, life-saving or sustaining activities, supporting a controlled evacuation, road clearing, and restoration of critical infrastructures. Worker exposures should be justified per the worker safety section of this document.
[7]Includes monitoring of vehicles and materiel being evacuated from the contaminated region.
[8]Facilities include infrastructure and open-air structures.
[9]Definitions of the legend categories:

- Useful – This is a device that can effectively perform the designated mission or task without modification of the device or of its normal mode of employment. In a sense, the device was designed or intended for that mission or task.
- Marginal – The device can provide useful and relevant data in support of the designated mission or task, but with modification to the normal mode of employment. In addition, its use may create a potentially unsafe condition to the user of the device. This implies a need for care in the interpretation of the data produced by such a device under the circumstances.
- Not Useful – Although the device is capable of detecting nuclear radiation, its technical performance characteristics or conditions of use are such that it is unlikely to be able to provide useful information in support of the designated mission or task. In addition, its use may create a grossly unsafe condition to the user of the device.

References of Interest for Equipment Selection)

ANSI N13.11 (2001) "Criteria for Testing Personnel Dosimetry Performance."

ANSI N323A (1997) "Radiation Protection Instrumentation: Test and Calibration, Portable Survey Instruments."

ANSI N42.17A (1989) "Performance Specifications for Health Physics Instrumentation- Portable Instrumentation for Use in Normal Environmental Conditions."

ANSI N42.17C (1989) "Performance Specifications for Health Physics Instrumentation-Portable Instrumentation for Use in Extreme Environmental Conditions."

ANSI N42.20 (2003) "Radiation Protection Instrumentation: Performance Criteria for Active Personnel Radiation Monitors."

ANSI N42.32 (2006), "American National Standard for Performance Criteria for Alarming Personal Radiation Detectors for Homeland Security."

ANSI N42.33 (2006), "American National Standard for Portable Radiation Detection Instrumentation for Homeland Security."

ANSI N42.37 (2006), "American National Standard for Training Requirements for Homeland Security Purposes Using Radiation Detection Instrumentation for Interdiction and Prevention."

ANSI N42.42 (2007) "American National Standard Data Format Standard for Radiation Detectors Used for Homeland Security."

DHS 2006 Preparedness Directorate; Protective Action Guides for Radiological Dispersal Device (RDD) and Improvised Nuclear Device (IND) Incidents; Notice 71FR174.

IAEA EPR - First Responders 2006 "Manual for First Responders to a Radiological Emergency."

IAEA-TECDOC-1432 (2005) "Development of an Extended Framework for Emergency Response Criteria."

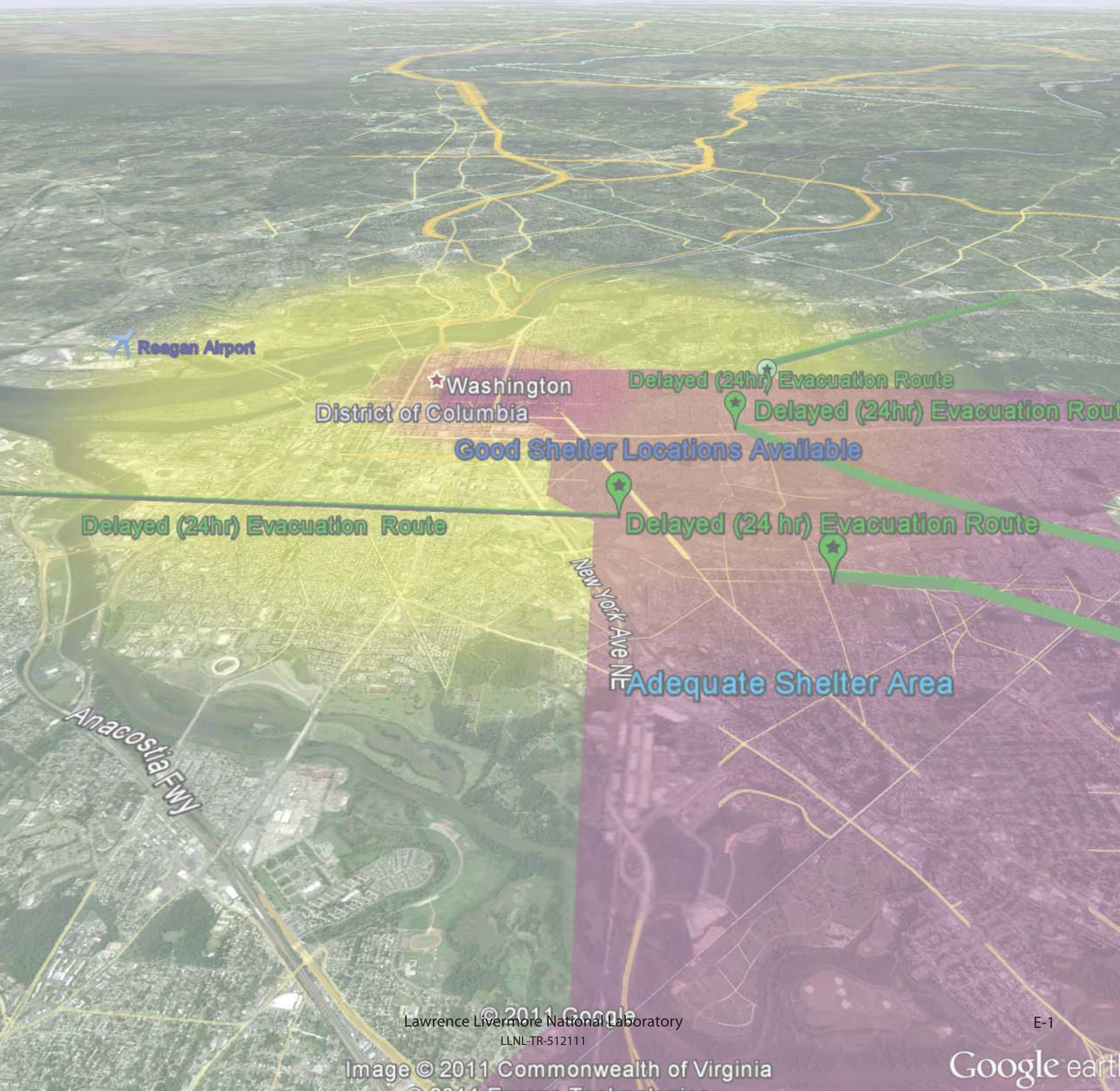
ICRP Publication 96 (2006) "Protecting People Against Radiation Exposure in the Event of a Radiological Attack."

NCRP Commentary No. 19 (2005) "Key Elements of Preparing Emergency Responders for Nuclear and Radiological Terrorism."

NCRP Report No. 138 (2001) "Management of Terrorist Events Involving Radioactive Material."

NFPA 472 (2008) "Standard for Competence of Responders to Hazardous Materials/Weapons of Mass Destruction Incidents."

Appendix E: Injury Analysis and Medical Facility Impacts



Appendix E: Injury Analysis and Medical Facility Impacts

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DHS Science and Technology Advanced Casualty Determination

To effectively model medical countermeasures, the nature and type of injuries must be known for the affected population. DHS Science and Technology (S&T) undertook a detailed, block by block, injury analysis in the Radiological/Nuclear Terrorism Risk Assessment (RNTRA) which is a key component of the ITRA. In this analysis, the impacts of an IND detonation were evaluated for the affected population by distributing people into likely structures for a detonation occurring during a typical workday. The effects of blast, thermal, and ionizing radiation were then calculated for each structure and the population within the structure. Details on the types of injuries are sorted into 97 different casualty codes, which were summed across all buildings in all locations in the venue. A representation of the process is shown in Figure E-1 and details of the assessment methodology can be found in (Buddemeier, 2011b). Key features of the assessment and results are reproduced here to support medical response planning.

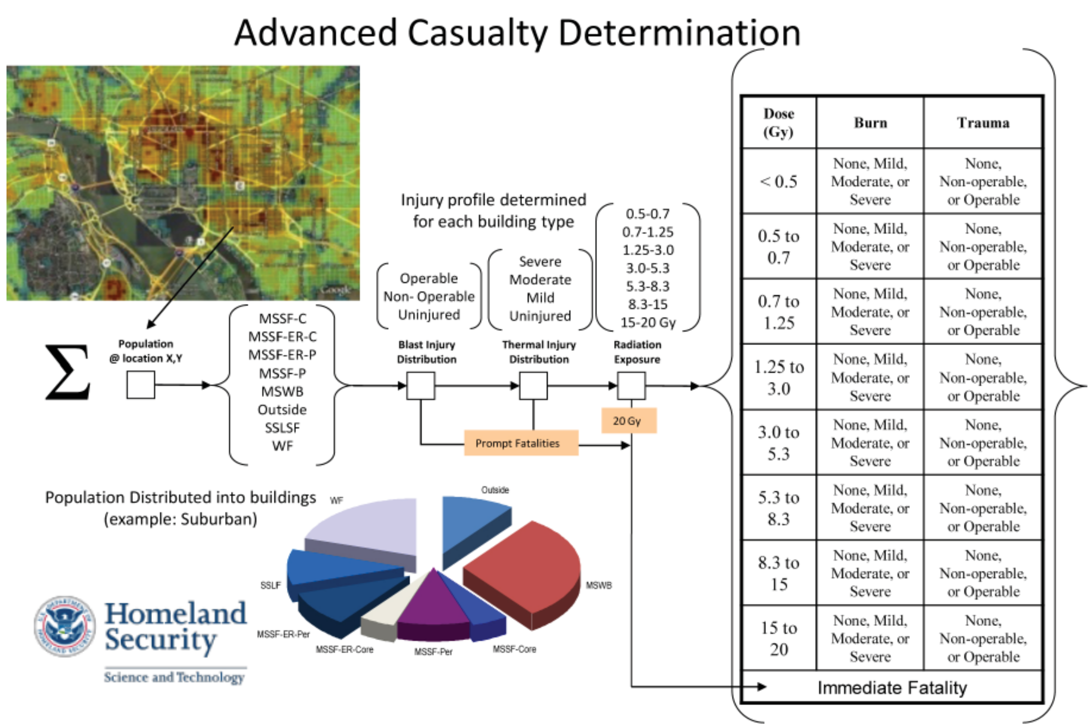
Blast Effects and Injury

As discussed earlier, most injuries outside of the Murrah building in the 1995 Oklahoma City bombing were caused by glass breakage. For a 10-kT IND, this phenomenon would be observed at more than 8 miles away. NATO medical response planning documents for nuclear detonations state that "… missile injuries will predominate. About half the patients seen will have wounds of their extremities. The thorax, abdomen, and head will be involved about equally." This statement is consistent with the historical observation that many victims from Nagasaki arriving at field hospitals exhibited glass breakage injuries. Such effects had not been previously modeled.

The relationship between people and an urban environment is now better understood as a result of recent analyses. Previous

Figure E-1. Summary of the DHS process used for advanced casualty determination.

Structure Type	Fraction of Population
Outside	0.13
Wood frame building	0.03
Multistory wall-bearing building	0.30
Single story light steel-frame building	0
Multistory steel-frame building	0.01
Core	0.0033
Periphery	0.0067
Multistory steel-frame earthquake-resistant building	0.53
Core	0.1749
Periphery	0.3551



Accounting for Glass and Blast Injuries

Typical Overpressure Damage	
Psi	**Damage**
50	LD_{50} from Lung Damage
15	**Lung Damage**
5	**Eardrum Rupture** Brick houses destroyed; trucks overturned; telephone poles collapsed
3	Wall of 12-inch concrete shattered; parked aircraft destroyed
2	Aluminum panels ripped off
0.5	**Windows shattered**

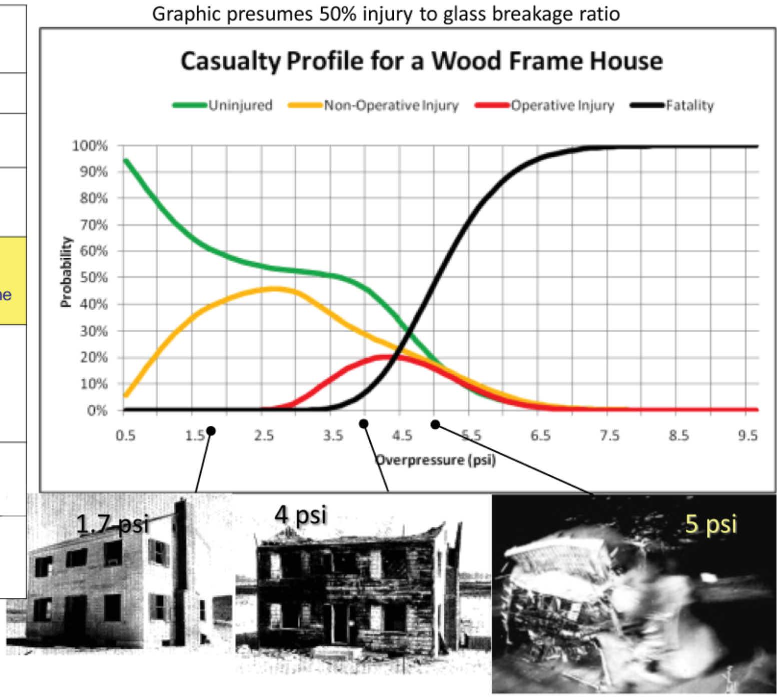


Figure E-2. Blast effects and injury.

models for human effects only went down to the threshold for eardrum rupture which is approximately 5 pounds per square inch (psi), yet at 5 psi, the house shown in Figure E-2 is easily destroyed. Occupants of the house pictured would certainly suffer injuries other than eardrum rupture. Advanced modeling now accounts for collapse, severe damage, or glass breakage to structures and subsequent effects on occupants. Figure E-2 also shows the relationship between prompt overpressure and the types of injuries incurred in a wood frame house. Different curves were used for each of the structure types in the DHS S&T injury analysis.

According to NATO definitions, operative injuries (or major trauma) are more severe trauma injuries defined as those requiring significant medical care, such as major or minor surgery to correct deep penetrating injuries, severe blunt-force trauma resulting in internal organ hemorrhage or other injury, and open fractures. Non-operative injuries (or minor trauma) are defined as injuries such as concussion, simple lacerations, closed fractures, ligamental injuries, and the like. For the present assessment, injuries associated with glass breakage were presumed to be minor and to affect 50% of the population in the vicinity of a broken window.

Although most injuries from flying glass are not expected to be immediately life threatening (Casagrande, 2011), numerous eye injuries can require specialized care. “Most injuries among survivors of bombings have been shown to result from secondary effects of the blast by flying and falling glass, building material, and other debris. Despite the relative small surface area exposed, ocular injury is a frequent cause of morbidity in terrorist blast victims.” (Mines, 2000.)

Burn Injury

As noted in Section 2 on prompt effects, a modern urban environment will greatly reduce the number of flash burns from a ground-level detonation. Accordingly, the S&T injury assessment also found that those with flash burns would perish from other effects. However, there still may be numerous burns from secondary fires, such as those associated with burning buildings or vehicle accidents following an IND detonation. Data from earthquakes are used to analyze burns from secondary fires. From burns caused by building collapse during earthquakes, an estimated 1,700 burn patients can be expected after the NCR illustrative scenario. Of those 1,700 patients, 200 will have mild burns, 650 will have moderate burns and 900 will have severe burns. These data are not represented in the following injury statistics but should be considered for medical planning purposes. (Casagrande, 2011)

Radiation Injury

Immediate injuries are those that occur from thermal burns, trauma, or enough radiation exposure to cause acute radiation syndrome (sickness) or complicate other injuries. Table E-1 shows approximated injuries from short-term radiation exposures and is useful when discussing the following exposure scenarios. Figure E-3, which is taken from the U.S. Department of Health and Human Services (DHHS) Radiation Emergency Medical Management (REMM) website (www.remm.nlm.gov), shows the time delay between exposure and the onset of symptoms. Charts such as this are available on the REMM website for all the exposure categories discussed in this report.

The most important feature from the figure is the delayed appearance of radiation injury, with some potentially lethal effects not occurring until days or weeks later. Such delay can create some confusion because those with significant exposures might initially recover, only later to present with more severe symptoms. Fortunately, several treatment options for radiation injuries can be used throughout the progression of symptoms.

In addition to prompt radiation exposure, the S&T injury analysis presumed that the population also received the equivalent of a 2 hour outdoor fallout exposure.

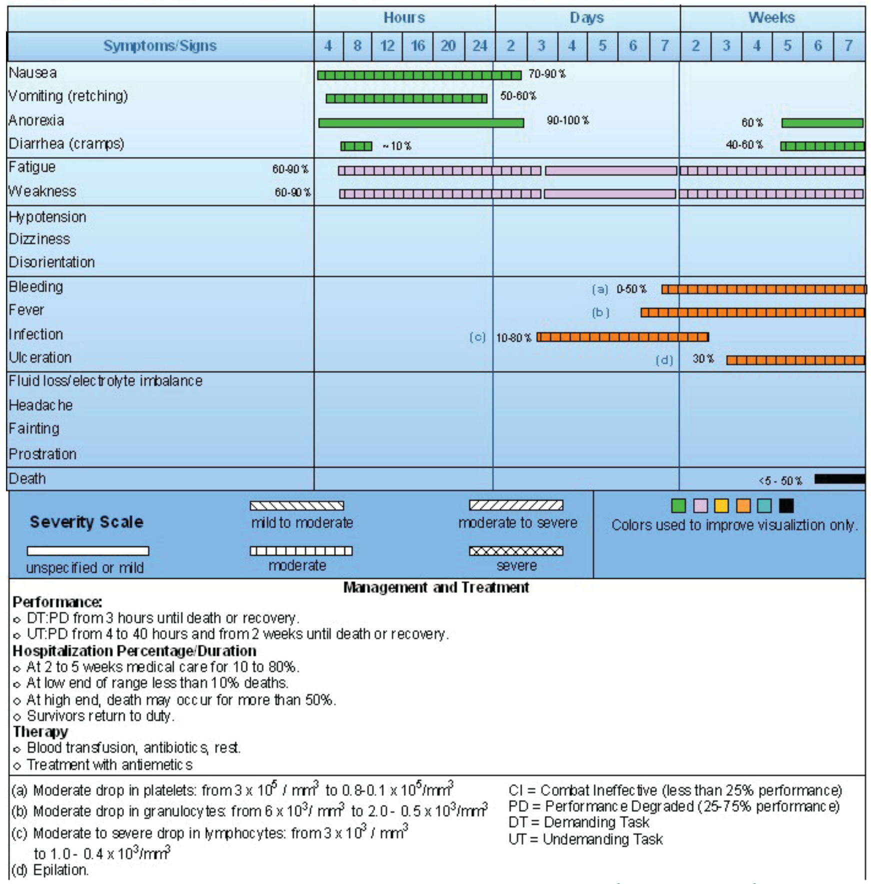


Figure E-3. Symptoms for exposures of 300 – 530 R.

Table E-1. Estimated fatalities and symptoms associated with acute whole-body absorbed doses.

Short-Term Whole-Body Dose [rad[a] (Gy)]	Acute Death[b] from Radiation without Medical Treatment (%)	Acute Death from Radiation with Medical Treatment (%)	Acute Symptoms (Nausea and Vomiting within 4 hours) (%)	Lifetime Risk of Fatal Cancer without Radiation Exposure (%)	Excess Lifetime Risk of Fatal Cancer Due to Short-Term Radiation Exposure[c] (%)
1 (0.01)	0	0	0	24	0.08
10 (0.1)	0	0	0	24	0.8
50 (0.5)	0	0	0	24	4
100 (1)	< 5	0	5–30	24	8
150 (1.5)	< 5	< 5	40	24	12
200 (2)	5	< 5	60	24	16
300 (3)	30–50	15–30	75	24	24[d]
600 (6)	95–100	50	100	24	> 40[d]
1,000 (10)	100	> 90	100	24	> 50[d]

[a]"Short-term" refers to the radiation exposure during the initial response to the incident. The acute effects listed are likely to be reduced by about one-half if radiation exposure occurs over weeks.
[b]Acute deaths are likely to occur from 7 to 180 days after exposure. Individual with other injuries, significant co-morbidities, children, and elderly would be at greatest risk.
[c]Most cancers are not likely to occur until several decades after exposure; although leukemia has a shorter latency period (< 5 years).
[d]Applies to those individuals that survive ARS.

Summary of Injury Categories

Table E-2 summarizes the number of injuries in the exposure and trauma categories discussed above. Burn injuries are not included because the number of flash burns was negligible for the urban 10-kT scenario and the number of burns from secondary fires cannot be easily modeled. Also listed is the presumed prognosis with and without treatments obtained from subject matter discussions within the joint DHS and HHS BARDA Rad/Nuc Consequence Management working group. The prognosis should only be considered as a rough estimate since an actual mortality rates for injuries would depend on the quality and timeliness of care in a post IND environment.

To visualize the results of the analyses, the casualty categories were grouped according to the probability of a treated fatality. Three injury classifications were used; Recover for injuries with a mortality rate of less than 5 percent, At Risk for injuries with a mortality rate between 5 and 95 percent, and Expectant for injuries with a mortality rate of greater than 95 percent. Table E-2 is color coded with the three categories described above.

Table E-2. Number of injuries and presumed prognosis with and without treatment for each category.

Injury Category	10-kT in Washington, DC	Assigned mean mortality with care	Assigned mean mortality without care
< 50R + mild trauma	87,018	1%	5%
< 50R + Major trauma	1	8%	40%
50-70R	31,875	0%	0%
50-70R + mild trauma	6,208	1%	5%
50-70R + major trauma	2	8%	40%
70 – 125R	39,538	0%	0%
70 – 125R + mild trauma	10,633	1%	5%
70 – 125R + major trauma	18	8%	40%
125 – 300R	39,374	8%	25%
125 – 300R + mild trauma	19,995	8%	25%
125 – 300R + major trauma	315	25%	100%
300 – 530R	18,538	45%	73%
300 – 530R + mild trauma	14,725	45%	73%
300 – 530R + major trauma	676	73%	100%
530 – 830R	9,044	87%	98%
530 – 830R + mild trauma	8,656	87%	98%
530 – 830R + major trauma	806	100%	100%
830 – 1,500R	10,580	100%	100%
830 – 1,500R + mild trauma	11,930	100%	100%
830 – 1,500R + major trauma	2,272	100%	100%
> 1,500R	4,580	100%	100%
> 1,500R + mild trauma	4,873	100%	100%
> 1,500R + major trauma	1,350	100%	100%
Injured Total:	323,006		

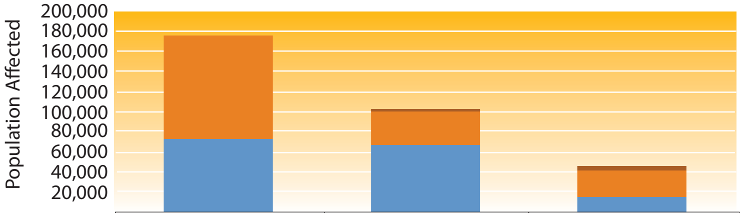
Recover (<5% fatalities)
Likely to survive, minimal immediate care requirements

Risk (5% to 95% fatality)
Acute radiation syndrome and other injuries requires advanced medical care

Expectant (>95% fatality)
Unlikely to survive even with advanced medical care

Injuries represent both prompt and 2hr fallout effects. Exposures are free air (R), multiply by 0.7 to get midline deep dose (rad/rem). Estimated injuries are from using weather from Feb. 14, 2009. Does not include prompt fatalities from trauma or burns.

Figure E-4 shows the information graphically and also illustrates the ratio of trauma (orange and brown) to radiation only injuries (blue), demonstrating that trauma is not necessarily a good indicator of radiation exposure. This model indicates there would be ~ 150,000 radiation only injuries for the illustrative scenario.



	Recover	At Risk	Expectant
Major Trauma		1,013	4,428
Mild Trauma	103,858	34,720	25,459
Radiation Only	71,412	66,956	15,160

Figure E-4. Number of injured in the Recover, At Risk, and Expectant categories.

Injury Breakdown for the Severe, Moderate and Light Damage Zones

The location specific injury analysis created by DHS S&T allows for zone specific injury distributions to be assessed. The Federal Planning Guidance (EOP, 2010) emphasizes the importance of providing early response support to the MDZ. To better understand the number and nature of injuries in the MDZ and LDZ, the relative ratio of injury classifications was evaluated along with an assessment of the population in each zone.

Although there are likely to be a some survivors in the SDZ (those in underground areas or the center of very robust buildings), such specialized locations were beyond the injury modeling effort Figure E-5 demonstrate the relative ratios of injuries and the total population in each of the blast damage zones.

When the injury categories were examined in the MDZ, and LDZ, the MDZ had the greatest number of injured in the "At Risk" group, ~ 58,000. It should be noted that nearly all of "At Risk" injuries in the LDZ are in the overlapping DFZ, which is also not an early response priority due to the radiological hazard to the response force.

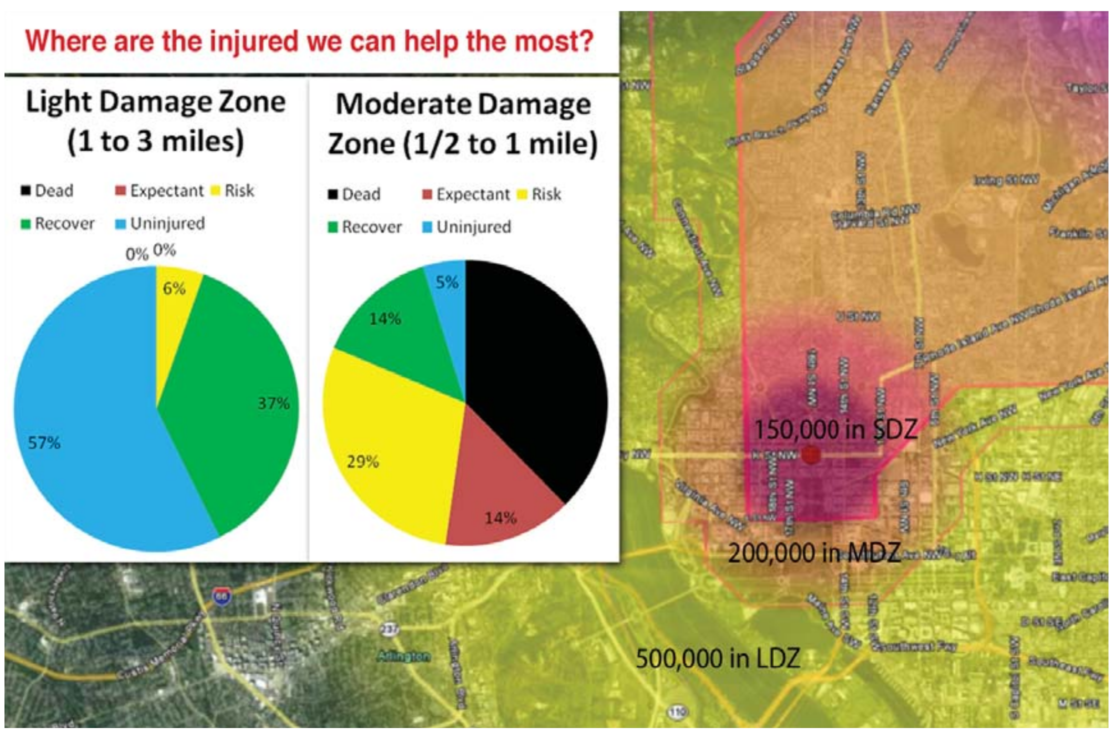


Figure E-5. Population and injury breakdown for the severe, moderate and light damage zones.

Injury Categories That Could Most Benefit From Medical Assistance

Because the purpose of this document is to help planners save and sustain lives, a more in depth analysis of the "At Risk" category is required to help identify the types of injuries of interest and their location. Table E-2 identifies two exposure groups containing the largest number of victims who represent the greatest life saving opportunities.

The moderate exposure (125 – 300R) group, with and without mild trauma, contains 60,000 people. Of the ~15,000 potential untreated fatalities in this category, ~10,000 can be saved with medical care. This category represents the greatest life saving potential. Radiation levels are high enough to complicate an injury or recovery, but not so high as to be acutely life threatening. Since the primary mortality mechanism is complications (i.e. immune-suppression) from Acute Radiation Syndrome (ARS), medical care can be applied throughout the ARS stages to improve prognosis (even as late as weeks later), however early intervention, especially with anti-neutropenics, can greatly improve outcomes.

The significant exposure (300 to 530R) group, with and without mild trauma, contains 33,000 people. Of the ~25,000 potential fatalities, ~10,000 can be saved with medical care. Although a considerable life saving potential exists, these individuals will require more intensive care, sooner (<3 days) than those with less severe exposures. Even with advanced medical care ~50% will perish.

Figure E-6 shows where Moderate (blue) and Significant (purple) exposure injury groups would be located in the NCR scenario. The assessment in this illustration assumes 2 hours of outdoor fallout exposure which could be prevented through early, adequate shelter. The height of each bar represents the number of injured at the given location. Such analysis reinforces the importance of conducting priority rescue operations in the MDZ.

General Considerations for Impact to Medical Facilities

Many different factors will determine the impact of an IND on the area's public health and medical resources. The most immediate resource impact will be the effects on the medical infrastructure that depend on:

- Blast effects to a particular building (related to distance from detonation and cityscape shielding).
- Prompt radiation received at the location (also related to distance from detonation and cityscape shielding).
- Level of local radioactive fallout.
- Availability of electricity and water.
- Accessibility of a facility as a result of debris or other hazards.
- Magnitude of population in the vicinity that will autonomously seek care.

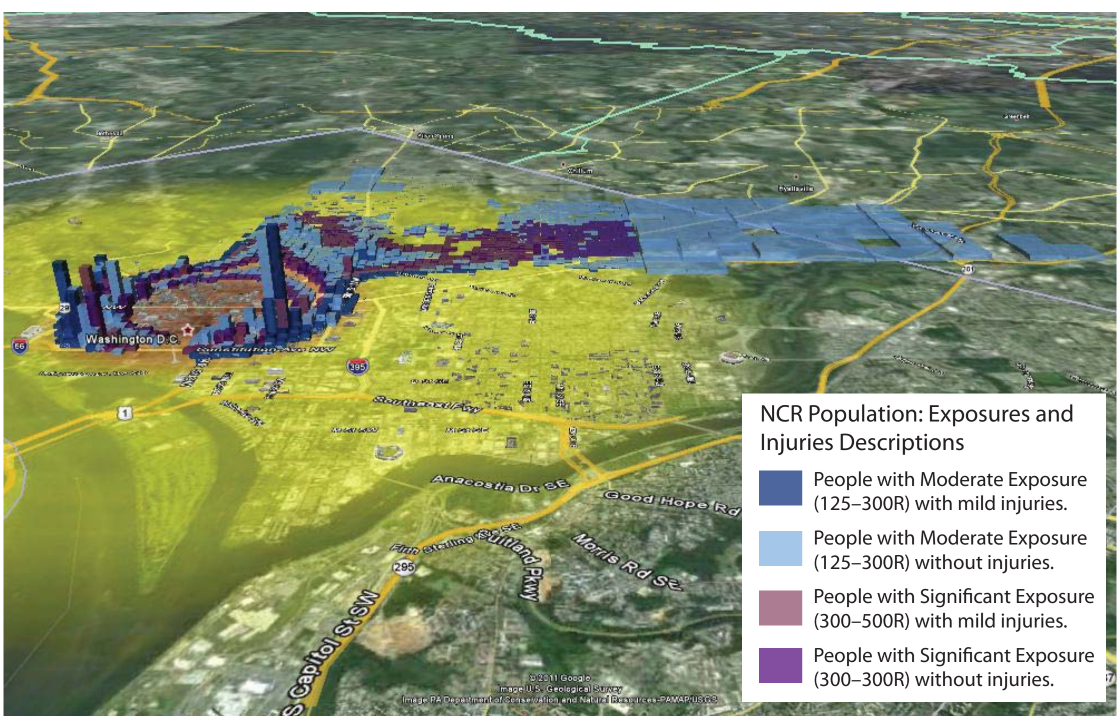


Figure E-6. Location of moderately and significantly exposed injured.

Direct Effects

Impacts of an IND detonation on public health and medical infrastructures will be directly related to proximity to ground zero. The extent of damage and the level of prompt radiation received at health care facilities will vary according to proximity to the detonation and the shielding provided by the urban environment. For example, hospitals within the SDZ will sustain major building damage with collapse likely. Such facilities will be nonfunctional and have numerous casualties from either building collapse, translocation (persons being blown down or into other structures from the blast wave), or shattering glass. Electricity and water may not be available, and backup generators may not be functional. The environment around facilities in the SDZ will likely be heavily contaminated with radioactive material.

Direct impacts on infrastructure of public health and medical facilities in the MDZ will be much more variable. Some facilities may have significant onsite injuries but may be able to sustain basic operations for short times. Hospitals in the LDZ are anticipated to be functional except for those in areas that received high levels of radiation fallout.

Hospitals and other health care facilities can be categorized into one of four categories:

- Red – Significant structural damage sustained, all functions critically impaired, many on-site casualties, has immediate rescue and evacuation needs for survivors.
- Orange – Few on-site casualties, functions moderately impaired due to glass breakage, radiation hazard, and power outage. These facilities will need eventual evacuation but may be able to sustain primary operations for a short time.
- Yellow – Minor damage and minimal radiation fallout, functionally impaired from power outage. These facilities could serve as initial triage sites and provide preliminary sorting.
- Green – No major impairment and highly functional. Facilities in this category could serve as secondary triage and treatment sites; however, these sites are likely to be quickly overwhelmed beyond surge capacity.

For the illustrative scenario, the status of local area hospitals is summarized in Table E-3. In addition to the hospitals listed in Table E-3, the following five hospitals will remain in the Hot Zone at 24 hr after detonation: Greater Laurel Beltsville, Washington Adventist, Prince George's, Doctors Community, Anne Arundel Medical Center, and Baltimore Washington Medical.

Table E-3. Impact to hospitals in the immediate area for the illustrative scenario.

Hospitals	Power	Blast Damage	Fallout zone @ 1hr	Operating Status
George Washington University Hospital	No	High	Hot zone	🔴
Howard University Hospital	No	Moderate	DFZ	🔴
Children's National Medical Center	No	Light-Moderate	DFZ	🟠
Washington Hospital Center	No	Light	DFZ	🟠
Georgetown University Hospital	No	Light -Moderate	Cold zone	🟡
Veterans Affairs Medical Center	No	Light	DFZ	🟡
National Rehabilitation Hospital	No	Light	DFZ	🟡
Providence Hospital	No	Light	Hot Zone	🟡
HSC Pediatric Center	No	Light	Hot/DFZ	🟡
Walter Reed Army Medical	Yes	None	Cold zone	🟡
The Specialty Hospital of Washington	No	Light	Cold zone	🟡
Psychiatric Institute of Washington	No	Light	Cold zone	🟡
Sibley Memorial Hospital	Yes	Minimal	Cold zone	🟢
Saint Elizabeth's Hospital	Yes	Minimal	Cold zone	🟢
United Medical Center	Yes	None	Cold zone	🟢
Hadley Memorial Hospital	Yes	None	Cold zone	🟢

DFZ, dangerous fallout zone with >10 R/hr; Hot zone with 0.01 to 10 R/hr; Cold zone with <0.01 R/hr.

Medical Resources in the National Capital Region

Numerous casualties can be expected surrounding an IND detonation. Knowing what resources are available will be essential to saving lives. Table E-4 identifies selected medical resources in the NCR according to the American Hospital Association (AHA) Database 2006. The areas included in the NCR are the District of Columbia, Montgomery, Prince George, Arlington, Fairfax, Loudoun, and Prince William Counties. When eliminating from consideration those hospitals that are critically affected (identified in Table E-3) the number of available resources is reduced to the values shown in Table E-5.

With greater than 100 times more injured persons than local hospital beds (300,000 injured vs. 2,177 beds), managing the injured will require innovative and unconventional strategies. A well designed, rapidly executed medical surge plan will help deliver medical care to as many people as possible and thereby minimize the impact of the incident.

Situational Awareness and Triage

The public health and medical response community will need to obtain from emergency response personnel initial insight on critical locations and estimated numbers of injured persons in the communities. Once communication channels have been established, hospitals need to relay operating status, including patient loads, onsite injuries, and patient influx to regional coordinators.

Table E-4. Medical resources for the NCR (AHA 2006).

	Total Resources		Available resources	
	DC	NCR	DC	NCR
Beds	5,433	10,798	1,232	2,745
ICU Beds	227	592	52	150
Ventillators	386	1,006	88	256
Staff	1,721	2,284	–	–

Table E-5. Estimate NCR resources remaining post-event.

	Total Resources		Available resources	
	DC	NCR	DC	NCR
Beds	2,528	8,537	668	2,177
ICU Beds	148	439	37	118
Ventillators	252	746	63	200
Staff	1,274	2,134	–	–

Initial triage for critical injuries, especially for immobilized persons, will likely be performed by local EMS personnel. Persons with differing levels of injuries that are still mobile are likely to create spontaneous triage sites at local public health and medical facilities. A structure for such spontaneous “radiation triage, transport, and treatment” (RTR) sites is discussed in the Planning Guidance for Response to a Nuclear Detonation (EOP, 2010). The RTR concept categorizes treatment sites into three levels for medical response, as discussed below.

Radiation Triage, Transport, and Treatment (RTR) Sites

As mentioned above, spontaneous patient collection sites are likely to develop after the event. A strategy based on utilizing these sites and other coordinated treatment sites is shown in Figure E-7. The RTR1-3 sites are described below where MC, AC, and EC refer to medical care, assembly center, and evacuation center, respectively. For a more detailed discussion on the RTR concept, see The “RTR” Medical Response System for Nuclear and Radiological Mass-Casualty Incidents: A Functional TRiage-TReatment-TRansport Medical Response Model (Hrdina, 2009).

Initial triage sites (RTR1) are ad hoc and will be closest to the affected area, often at the head of evacuation routes. They are neighborhood collection points for evacuees and the injured. Such triage sites are inherently temporary and should be located in convenient, safe staging areas. Setting up near hospitals, pharmacies, grocery stores, or clothing stores will help provide bandages, water, and replacement clothing for staff and evacuees.

Persons able to walk, with or without significant injuries, will likely seek medical care at the first available resource they can access. Such sites are anticipated to have incurred physical damage as well as radioactive hazards. Given the circumstances, RTR1 sites can serve as points of triage for stabilizing critical injuries and possibly sorting persons according to injury severity. The sites will quickly be overwhelmed by the massive number of persons seeking care. Circumstances at RTR1 sites will be tenuous until transportation to other sites becomes available.

Reception centers and Tier 2 triage sites (RTR2) are located several kilometers away from the detonation site, often along evacuation routes at the point at which roads are clear enough to allow for vehicular traffic. Large facilities of opportunity (e.g., hospitals, shopping malls, schools, and universities) should be used, especially those with good roadway access and large parking lots or structures that can be used for Federal resource staging and aviation support. RTR 2 sites would have greater functionality and could provide some definitive care in the short term. More detailed diagnostics and sorting of patients will be possible at RTR 2, compared to RTR 1, sites to provide a more streamlined patient stream to definitive care sites.

RTR3 sites will be those facilities in outlying areas with no physical damage or radiation hazard. Because of the absence of a radiological hazard and possible evacuation concerns, RTR 3 sites can serve as definitive and advance care facilities. Again, such resources will also quickly be overwhelmed by the numerous injuries expected.

> ***"Life saving tasks takes precedence over external radiation decontamination from fallout or visible debris."***
>
> ***(EOP, 2010)***

Monitoring and decontamination sites can be stand-alone or co-located with reception centers. Decontamination of nuclear fallout should be focused on those leaving (or traveling through) the DFZ, preferably close to the outer boundary of the Hot Zone. Low levels of contamination will be present throughout the region outside of the Hot Zone, but such contamination rapidly decays and does not represent a hazard to the public or responders. Decontamination efforts should focus on removing or replacing shoes and outer clothing and washing or wiping exposed skin and hair (which is why access to quantities of clothing is an important location consideration, especially in winter).

Initial Hospital Actions

Provided a hospital building is not in danger of collapse or fire, hospitals that are affected by fallout should move patients and personnel towards the interiors, when possible, until peak radiation levels subside. Stable patients should be moved to the basement or underground parking facilities to minimize radiation exposures.

Local hospitals should plan for a massive influx of self-referral patients after the blast. It is estimated that 75% of persons in

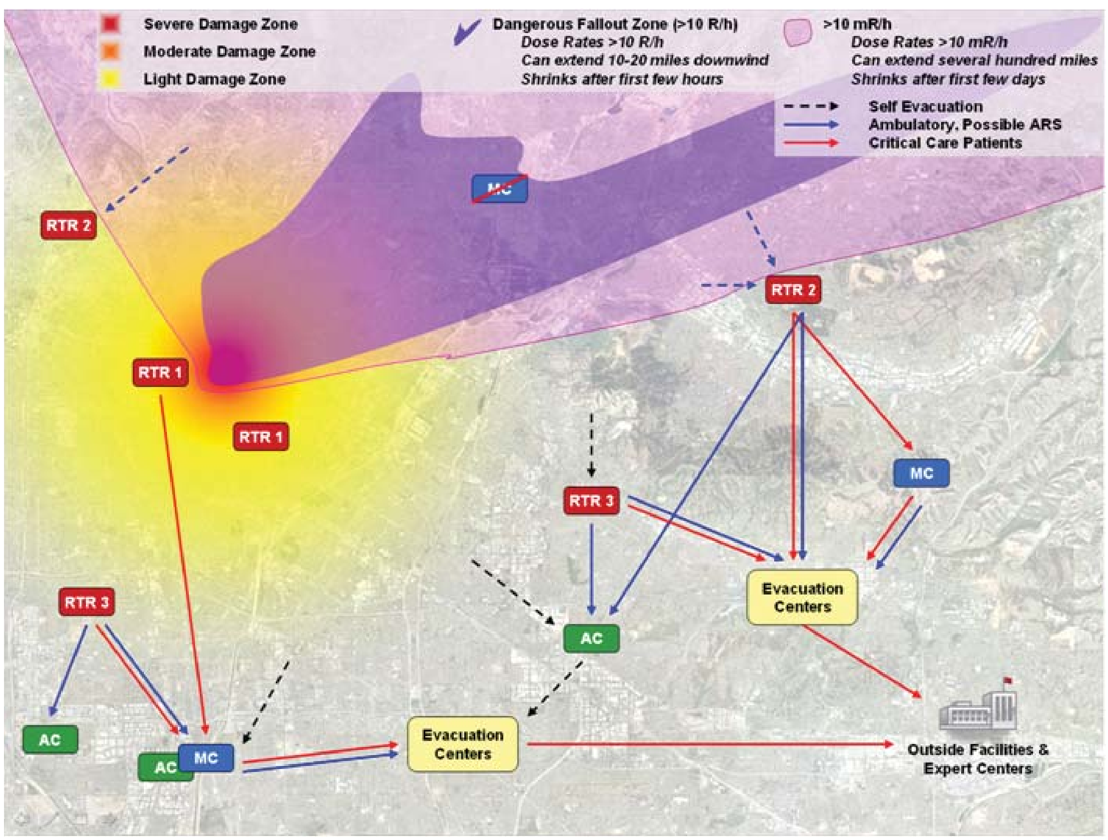


Figure E-7. RTR concept according to Planning Guidance for Response to a Nuclear Detonation (EOP, 2010). The RTR 1–3 sites are characterized as offering medical care (MC), serving as an assembly center (AC), or functioning as an evacuation center (EC).

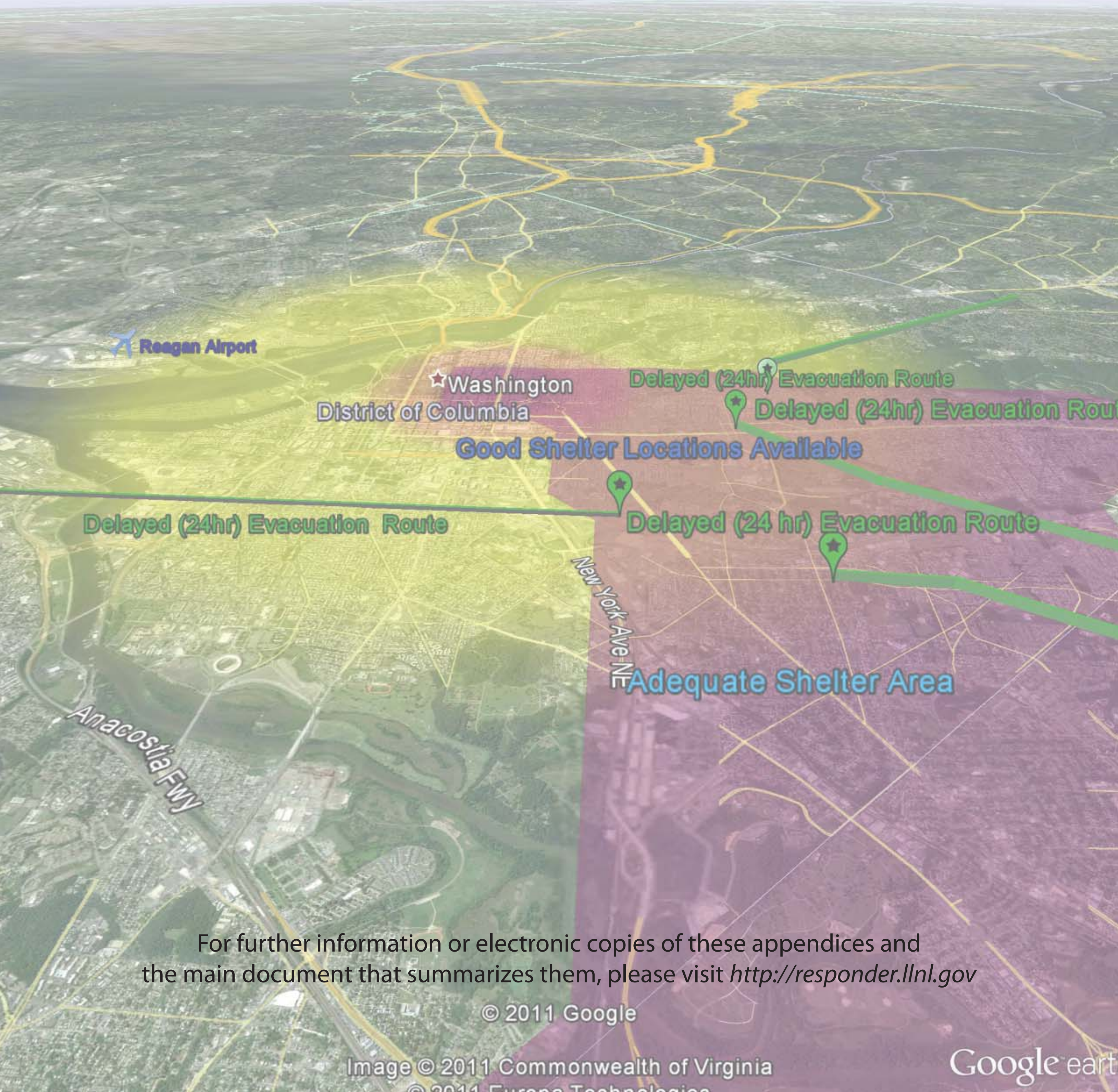
Washington, DC (approximately 1 million persons) will seek medical care after an IND whether they are injured or not. Roughly 25% of persons in the affected areas of Virginia and Maryland will also seek medical care (500,000 and 2 million persons, respectively).

Hospitals can prepare for the influx of patients by taking any usual measures possible for accommodating a surge in patients. For this type of unique incident, numerous additional preparations can aid in management. For example, security personnel can help control the influx and sequester highly radioactively contaminated persons in a predetermined area close to an entranceway. Radiation monitors found in most hospitals can be used to help screen incoming patients. Rudimentary decontamination of incoming patients can be performed to minimize contamination throughout a medical facility. Decontamination should never take precedence over life-saving medical actions.

Conclusions

For the illustrative scenario, modeling results estimate that over 300,000 injuries can result from an IND detonation. The treatment of moderate and significant radiation exposures with or without mild trauma represents the injuries with the greatest life-saving potential. The majority of potentially treatable but "At-Risk" injuries will be located in the MDZ and in the area where the LDZ intersects with the DFZ. The vast majority of people with injuries and many without will seek medical care. The number of injured persons will greatly outweigh existing medical resources. RTR sites will quickly become overwhelmed with patient overflow. Communication of operating status, facility damage, patient numbers, etc. with regional coordinators as soon as possible after the detonation will help identify additional medical resources and enable responders to organize logistics.

Most importantly, preparedness planning can greatly improve the management of such catastrophic events. Pre-identification of public health and medical coordination centers, potential RTR, AC, MC, and EC's, and alternative communication and transportation means can help minimize the impact of an IND.



For further information or electronic copies of these appendices and the main document that summarizes them, please visit *http://responder.llnl.gov*