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Key Response Planning Factors

for the Aftermath of Nuclear Terrorism

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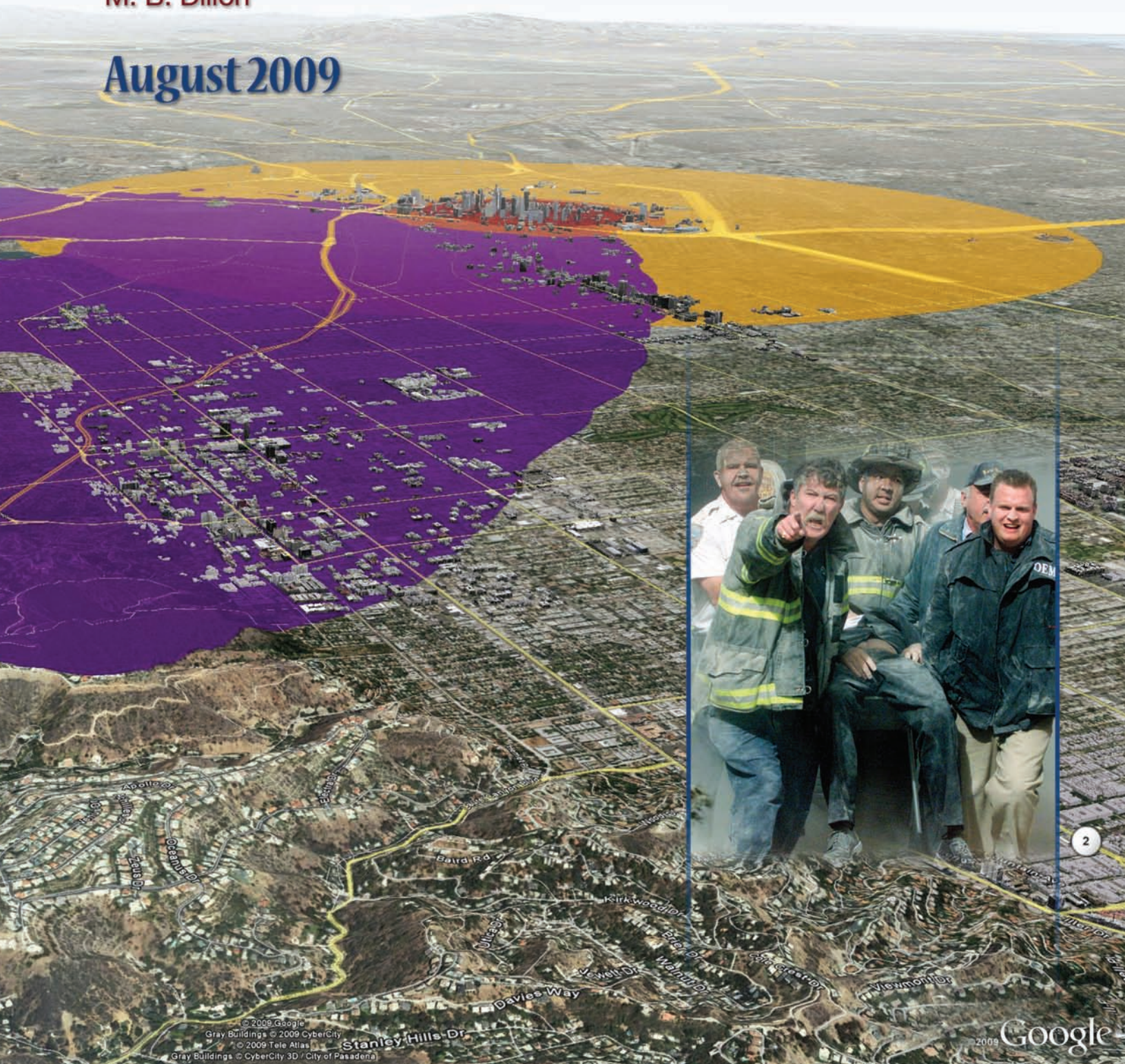

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Key Response Planning Factors for the Aftermath of Nuclear Terrorism

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Executive Summary

Despite hundreds of above-ground nuclear tests and data gathered from Hiroshima and Nagasaki, the effects of a ground-level, low-yield nuclear detonation in a modern urban environment are still the subject of considerable scientific debate. Extensive review of nuclear weapon effects studies and discussions with nuclear weapon effects experts from various federal agencies, national laboratories, and technical organizations have identified key issues and bounded some of the unknowns required to support response planning for a low-yield, ground-level nuclear detonation in a modern U.S. city.

This study, which is focused primarily upon the hazards posed by radioactive fallout, used detailed fallout predictions from the advanced suite of three-dimensional (3-D) meteorology and plume/fallout models developed at Lawrence Livermore National Laboratory (LLNL), including extensive global geographical and real-time meteorological databases to support model calculations. This 3-D modeling system provides detailed simulations that account for complex meteorology and terrain effects.

The results of initial modeling and analysis were presented to federal, state, and local working groups to obtain critical, broad-based review and feedback on strategy and messaging. This effort involved a diverse set of communities, including New York City, National Capitol Regions, Charlotte, Houston, Portland, and Los Angeles.

The largest potential for reducing casualties[A] during the post-detonation response phase comes from reducing exposure to fallout radiation. This can be accomplished through early, adequate sheltering followed by informed, delayed evacuation.[B] The response challenges to a nuclear detonation must be solved through multiple approaches of public education, planning, and rapid response actions. Because the successful response will require extensive coordination of a large number of organizations, supplemented by appropriate responses by local responders and the general population within the hazard zones, regional planning is essential to success.

The remainder of this Executive Summary provides summary guidance for response planning in three areas:

1. *Public Protection Strategy* details the importance of early, adequate shelter followed by informed evacuation.

2. *Responder Priorities* identify how to protect response personnel, perform regional situational assessment, and support public safety.

3. *Key Planning Considerations* refute common myths and provide important information on planning how to respond in the aftermath of nuclear terrorism.

[A] Casualties are defined in this document as both injuries and fatalities.
[B] This report focuses primarily on protection from fallout. Other issues, including planning for actions that would reduce injuries/fatalities arising from the prompt effects of a nuclear explosion (e.g., "duck and cover" to reduce injuries from broken glass), are only briefly discussed.

Public Protection Strategy

Find early, adequate shelter followed by an informed evacuation, and control contamination

1. Find early, adequate shelter

- It is important *to be in the shelter when the fallout arrives*. Fallout arrival times vary with yield and weather. If you are outside of the building-collapse area immediately surrounding the detonation, you should have ***several minutes*** before fallout arrives.
- If you are outside or in a car, seek the nearest adequate shelter. Even an inadequate shelter is better than no shelter.

Adequate shelters are locations that have as much earth, building materials, or distance between the occupants and exposed horizontal surfaces as possible. Exposed horizontal surfaces accumulate fallout. Buildings do not have to be air-tight. Broken windows do not greatly reduce the protection offered by a shelter.

Examples of adequate shelter:
— Basements, usually against a basement wall (in the corner).
— Multistory brick or concrete structures.
— Office buildings (central core or underground sections).
— Multistory shopping malls (away from roof or exterior walls).
— Tunnels, subways, and other underground areas.

Inadequate shelters include:
— Cars, buses, and aboveground rail systems.
— Light residential structures, such as mobile homes.
— Single-story wood-frame houses without basements.
— Single-story commercial structures without basements (e.g., strip malls, retail stores, and light industry).

If you are already in an adequate shelter, stay there (shelter in place).

Exception—Consider immediate evacuation when all three of these factors are present:

1. No available adequate shelter AND
2. Good view of a well-behaved fallout cloud (i.e., view is not obstructed and cloud is not moving in multiple directions) AND
3. Clear, rapid exit route perpendicular to the direction of cloud travel is available.

2. Perform an informed evacuation of that shelter based on three key factors:

- The quality of the shelter.
- Radiation levels at the shelter site.
- Radiation levels and travel time along the evacuation route.

Shelter for *at least* the first hour unless threatened by fire, building collapse, medical necessity, or other immediate threats.

Once you have decided to evacuate:

- Seek instructions and information on the location of dangerous fallout areas.
- Identify the shortest possible evacuation route that avoids high levels of contamination. Consider tunnels, building lobbies, or other evacuation routes protected by earth, heavy building materials, and/or distance from fallout.
- Seek local collection points (with adequate shelter) for evacuation by mass transit.
- Consider evacuating by car if the roads have been cleared.

3. Control contamination

- Avoid outdoor exposure during the first few minutes and hours after the fallout arrives—this is the highest priority. Exposure due to contamination depositing on clothing and skin, inhalation, and ingestion are secondary concerns. Simple respiratory protection, such as a layer of cloth over nose and mouth, can mitigate contamination.
- Remove outer clothing and shoes upon entry to shelter. Alternatively (and less preferably), brush off contamination. If possible, wipe or wash hair and exposed skin to remove fallout particles.

Local Responder Priorities

Protect response personnel, support regional situational assessment, and support public safety

1. Protect response personnel

- Responders without radiation-detection instruments: Follow the general public protection strategy.
- Responders with radiation instruments: Shelter using radiation-detection equipment to monitor shelter conditions.

— Do not exit shelter or enter areas where radiation levels exceed 10R/h unless there is an urgent life-safety issue (e.g., avoiding fire or building collapse).
— When outdoor radiation levels are below 10R/h, perform scene assessment of the immediate area for hazards. Make sure to stay close to adequate shelter locations, closely monitor radiation levels, and *shelter immediately if radiation levels increase rapidly*.

- Reducing the time spent in high-dose-rate areas is the greatest protective measure.
  — SCBAs, respirators, firefighter "turnouts," Level A, B, or C HAZMAT suits do not protect against the primary hazard, i.e., the penetrating gamma radiation given off by fallout.
  — Bulky isolation suits and elaborate respiratory protection methods may actually increase exposure as they reduce worker speed and efficiency, and the ability to communicate.
  — Inhalation and ingestion are a secondary concern compared to the external exposure (penetrating radiation coming off the fallout particles on the ground).

2. Support regional situational assessment

- Designate a regional situational assessment center that will collect information from observations, instrument readings, and weather. Identifying areas that have received or are likely to receive hazardous fallout is a high priority.
- Establish communication with responders in the affected area. Radios outside of the major building-damage area should still function, although repeater towers may have been affected. Use alternate communication methods, if needed.
- Report approximate radiation levels in the area. Radiation readings will change rapidly with time—use the NCRP recommended[1] boundaries of 10mR/h (low) and 10R/h (high) to determine low- and high-hazard zones.
  — Local responders should record and report radiation levels and *the times they were taken* at regular intervals.
  — Identifying high-hazard zones (reading greater than 10R/h) is a priority. Reporting safe areas (reading less than 10mR/h) is also important for the determination of safe evacuation routes and response staging areas.

3. Support public safety

- For a suspected nuclear detonation, use all available communication and emergency alert systems to immediately broadcast shelter instructions.
- Establish safe evacuation routes out of high-hazard zones and identify evacuation priorities. Prioritize your evacuation.
  — Early evacuation: Within the first few hours, plan to evacuate populations who are:

Figure 1. Nevada Test Site post-shot decontamination procedure used in the 1950s.

  – Threatened by fire or toxic materials.
  – In danger of building collapse.
  – In need of medical attention.
  – Without adequate shelter.
  — Secondary evacuation: Within the first day after detonation, plan to evacuate populations who are:
  – In danger from hot or cold weather.
  – Not in fallout areas, provided their evacuation does not hamper emergency response operations or take them through fallout areas.
  – In need of access to constant or consistent medical care (requiring dialysis, oxygen, prescription medication, etc.).
  – Without drinking water.
- Provide local public-safety support, including setting up and directing the general public to adequately sheltered triage sites.
- Establish triage, decontamination, and casualty collection points outside of hazardous fallout zones.
- Fight fires. The detonation will cause fires in the area where populations are sheltered. Take action to slow the spread of fire

Key Planning Considerations

Extensive publication of nuclear-test images and popular fiction may have created several false assumptions and stereotypes about the likely appearance of a low-yield nuclear detonation from an improvised nuclear device. For example, many people assume that it will be easy to tell if a large explosion is nuclear. However, for a low-yield, ground-level detonation, people who are too close to the event to view its totality, may not be able to distinguish a nuclear explosion from a large conventional one.

Below are some guidelines to help responders and the general public to distinguish a low-yield nuclear detonation from a large conventional explosion and some key issues to consider when planning for the response to a low-yield nuclear detonation in an urban location.

Identifying features of a nuclear detonation (not all features may be present)

- An abrupt blinding flash that is visible over a large area (particularly at night).
- The widespread disruption of unprotected electronic devices (EMP).
- Thermal damage and burn victims well away from the blast location.
- Widespread high-level radiation readings.

A "mushroom shaped cloud" may not be generated or visible

- Low-yield, ground detonations in an urban environment may generate a non-uniform, chaotic cloud shape.
- High wind shear may quickly move the cloud in several different directions.
- Blast effects can cloud the air and limit visibility within a few miles of the detonation point.
- Nighttime or overcast skies can obscure the view of the cloud formation and movement.

Predicting or avoiding unsafe fallout areas may be difficult

- The fallout cloud may climb several miles into the atmosphere and be carried in several different directions simultaneously by winds aloft.
- Fallout particles can change directions as they fall to the earth, resulting in contamination in areas other than the cloud top would indicate.
- Upper atmospheric winds often travel at high speeds (>50 mph), making it difficult to "outrun" the fallout cloud.

Take shelter before fallout arrives

- The most significant exposures from fallout occur in the first hour after fallout arrives.
- Seek shelter immediately if sand, ash, or rain starts to fall.
- Except in areas of major building damage closest to the detonation, fallout should take at least several minutes to arrive.

Avoid the primary radiation hazard—external exposure to fallout

- Fallout particles on the ground and other horizontal surfaces give off penetrating radiation; inhalation is only a minor concern.
- Shelter provided by heavy materials (concrete walls, earth, etc.) and distance from the particles on the ground are the primary sources of protection.
- The best place to find protection is in the middle or basement of a building.
- Even with broken windows, buildings can provide adequate shelter.

Areas of blast damage might NOT be contaminated with fallout

- Blast damage extends outward from the detonation in all directions, perhaps for several miles
- Fallout proceeds downwind, contaminating only a fraction of the blast-damaged area.

Hazardous levels of fallout will extend into undamaged downwind areas

- Levels of fallout that can induce sickness from an outdoor exposure may extend 20 miles or more downwind.
- Protective actions against fallout are warranted even if you are not in blast-damaged areas.

Considerations for long-distance, downwind populations

- Immediate evacuation should only be attempted if the population can be out of the area ***before*** the fallout arrives.
- Fallout-modeling projections are only estimates, and protective actions should still be taken in areas adjacent to the predicted path.
- The width of the contamination area will increase with distance from ground zero, requiring increased evacuation travel distance.
- Beyond 20 miles, overall exposures will be much lower and acute affects (i.e., radiation sickness) are not expected. However, take action to reduce exposure of the public to ionizing radiation.

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1.0 Introduction

1.1 Background—Why this Study

The improvised nuclear device (IND) response communications project stems from the U.S. Troop Readiness, Veterans' Care, Katrina Recovery, and Iraq Accountability Act (P.L. 110-28), which expressed concern that cities have little guidance available to them to better prepare their populations for the critical moments shortly after a nuclear terrorism event. 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.

Federal protective action guidance[2] currently exists for radiation exposure; however, the focus has been on avoiding relatively low-level exposures to decrease the risk of cancer from an 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 likelihood of advanced warning of incoming missiles, but its applicability is less clear for an attack that occurs without any notice. There also appeared to be a lack of scientific consensus on the appropriate actions to take after a nuclear detonation. For example, the recommendations of the DHS's ***Ready.gov***, which are consistent with the recommendations of the National Academy of Sciences,[3] were recently criticized by the Federation of American Scientists[4] because the DHS recommendations conflicted with those of a RAND study.[5,6]

In addition, observations from state and local stakeholder workshops indicate that no communities have a coordinated regional plan for responding to the aftermath of a low-yield (<10-kiloton) nuclear detonation. There is a general lack of understanding of the response needs and uncertainty of the federal, state, and local roles and responsibilities. As stated by Chicago responder Joseph Newton on responding to an IND,[7] ***"We don't know what perfect looks like."***

To address these issues, the OHA has coordinated an extensive study involving the effects modeling of 0.1-, 1.0-, and 10-kiloton (kT) nuclear yields in New York City, Washington D.C., Chicago, Houston, San Francisco Bay Area, and Los Angeles; workshops in state and local communities across the nation, as well as the National Academies; focus-group testing of public messaging; and coordination with key federal agencies, national laboratories, and technical organizations who have unique capabilities and knowledge regarding nuclear effects and emergency response. The OHA has engaged Lawrence Livermore National Laboratory (LLNL) to provide support in the areas of modeling; technical assessment; and federal, state, and local stakeholder engagement.

In addition to reports such as this, the DHS, in its lead role, has provided information to, and directly supported the development of, National Planning Guidance for Response to a Nuclear Detonation,[8] Nuclear Incident Public Communication Planning,[9] and work by the National Council on Radiation Protection and Measurement on the development of the "Key Decision Points and Information Needed by Decision Makers in the Aftermath of a Nuclear or Radiological Terrorism Incident" report.[10]

1.2 What this Study Does

The low-yield explosion from an IND is significantly different from the Cold War strategic thermonuclear detonation scenarios upon which much of our current understanding and civil defense planning is based. This implies that while the Cold War recommendations can help with some insights and advice, many of the paradigms are no longer applicable and must be updated for modern cities and the nature of the current threat. This report identifies potential erroneous assumptions about a low-yield nuclear detonation and provides important planning considerations.

The basic anatomy of a nuclear explosion is well-known and documented in literature such as Glasstone's *The Effects of Nuclear Weapons*[11] and NATO documents.[12] Mitigating the impact of a domestic nuclear explosion requires a basic understanding of key effects. These effects can be broken into two main components: prompt effects and delayed effects, or fallout. Prompt effects are those that radiate outward from the detonation location, referred to as ground zero, usually in the first minute. Fallout is generated when the dust and debris excavated by the explosion are combined with radioactive fission products produced in the nuclear explosion and drawn upward by the heat of the event, often forming a "mushroom cloud" from which highly radioactive particles drop back down to earth as they cool. Unlike prompt effects, which can occur too rapidly to be easily avoided,[C] fallout health impacts can be mitigated by leaving the area before fallout arrives or by sheltering from it.

This study identifies key planning considerations and response strategies

[C] Note that the Civil Defense program advice of "duck and cover" can provide protection from prompt effects of flying glass and the thermal pulse, but only if one reacts properly to the bright flash within the first few seconds.

associated with response to a nuclear detonation. These strategies—designed to (1) protect response personnel, (2) perform regional situational assessment, and (3) support public safety—were developed for emergency response planners and the scientific community that serves them. This work is the culmination of extensive modeling and technical analysis in conjunction with interactions with almost 500 emergency responders from across the nation. Although sound science is the cornerstone of good response planning, it must be tempered with the unique issues, operational realities, and constraints of the emergency-response capabilities in each community. Every community has unique issues and 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.

Roentgens, rads, and rem: 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."

1.2.1 Prompt Effects

Prompt effects are those that radiate outward from the detonation location, i.e., ground zero, usually within the first minute after detonation. These effects, depicted by the concentric circles in Figure 2, include an intense flash of light, the blast shock wave, heat, and radiation. For illustration purposes, this study focuses on a low-yield device, such as the 10-kT event,[D] similar to that used in National Planning Scenario #1. This explosive yield is approximately 5,000 times the explosive power of the truck bomb used to destroy the Murrah building in the 1995 Oklahoma City bombing.[13]

The blast from an explosion of this size significantly damages or destroys most buildings within a ½-mile (0.8-km) radius of the detonation, and most of the population in this area would not survive. From a half-mile (0.8 km) to about a mile (1.6 km) from the explosion, survival mostly likely depends on the type of shelter a person is in when the blast occurs. Even at a mile, the blast wave has enough energy to overturn cars and severely damage light structures.

A mile (1.6 km) is also the approximate distance that a person outdoors could still receive enough ionizing radiation exposure in the first few seconds after detonation to cause illness. The closer to the detonation point, the higher the exposure. The same is also true for an unprotected individual's exposure to the thermal pulse from the detonation, which may cause burns on exposed skin out to this range and possibly further, depending on the height of detonation and line of sight. Both of these effects are reduced for people who are inside buildings or not in direct line of sight of the detonation point.

In addition to ionizing and thermal radiation, the detonation creates a brilliant flash of light that can cause temporary blindness to those outdoors up to 5 miles (8 km) away. This effect could extend much further if there is a direct line of sight, low clouds to reflect the light, or the event occurs at night. "Flash-blindness" can even occur if an individual is not looking in the direction of the detonation and may last several seconds to minutes. Although this effect does not cause permanent damage, the sudden loss of vision to drivers and pilots could cause a large number of traffic accidents and make many roads impassable.

Another, poorly understood, long-range prompt effect is glass breakage—falling glass and flying glass shards. Most of the injuries outside of the Murrah building in the 1995 Oklahoma City bombing were caused by this phenomenon[14] and occurred as far as several blocks away. Indeed, an article from the American Academy of Ophthalmology noted that *"[m]ost injuries among survivors of bombings have been shown to result from*

[D] A kiloton (kT) yield is equivalent to the yield from 1,000 tons of TNT.

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."[15]

The shockwave that breaks windows travels much more slowly than the bright flash of light. This delay, up to 30 seconds or more, can increase injuries if people approach windows to investigate the bright flash. NATO medical-response planning documents for nuclear detonations state that "… missile injuries will predominate. About half of the patients seen will have wounds of their extremities. The thorax, abdomen, and head will be involved about equally."[16] A significant number of victims from Nagasaki arriving at field hospitals exhibited injuries due to glass breakage.[17]

Other effects, such as electromagnetic pulse (EMP) and fires, also need to be considered in response planning. For a ground-level detonation, the most damaging EMP effects will be limited to about a mile, with some longer-range disruptions occurring out to a few miles. Although the possibility of a "firestorm" is uncertain given modern construction, a large number of small fires will likely start from thermal and blast effects in the major building damage area (shown as a white dashed line in Figure 2). These fires could spread and coalesce if not mitigated.[18]

1.2.2 Fallout Effects

In addition to prompt effects, which radiate outward from the detonation site, a nuclear detonation can also produce nuclear fallout, which is generated when the dust and debris excavated by the explosion are combined with radioactive fission products produced in the nuclear explosion and drawn upward by the heat of the event. This 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. It is important to note that Hiroshima and Nagasaki did not have significant fallout because the detonations occurred at an altitude of 1,900 ft (579.12 m) and 1,500 ft (457.2 m), respectively, at which altitude the fission products did not have the opportunity to mix with the excavated earth.

Figure 2 depicts areas of potential exposure from fallout contamination in the shaded areas to northeast and east of ground zero. Actual exposures will depend on the length of time spent in the fallout area and the quality of the shelter.

The hazard from fallout is not from breathing the particles, but from exposure to the ionizing radiation given off after the fallout particles have settled on the ground and building roofs. Radiation levels from these 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 the fallout pattern is highly dependent on weather conditions, the most dangerous concentrations of fallout

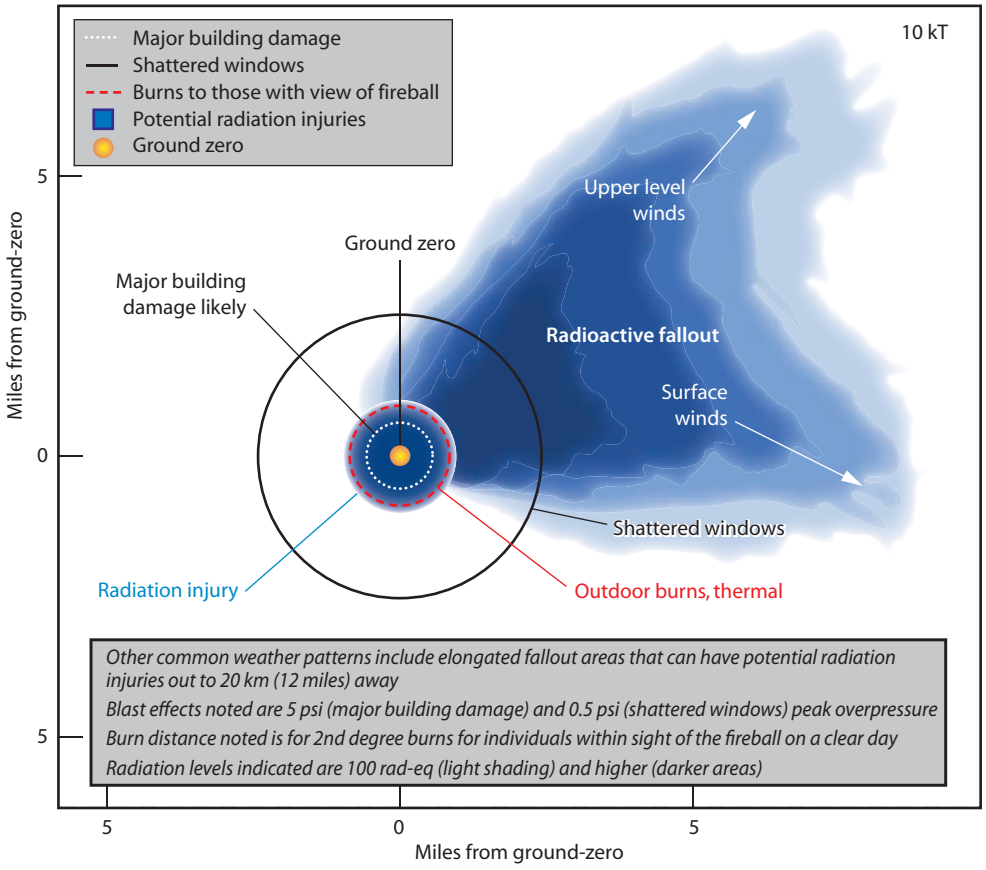


Figure 2. Approximate prompt and delayed (fallout) effects from a 10-kT detonation. (Based on ground-level detonation using HotSpot Health Physics Codes, v2.07, and artist's rendition of outdoor fallout exposure for a commonly occurring weather pattern.)

particles (i.e., potentially fatal to those outside) occur within 20 miles (32 km) downwind of the event and are expected to be clearly visible as they fall, often the size of sand, table salt,[19] ash,[20] or rain.

Unlike prompt effects, which occur too rapidly to easily avoid,[E] fallout health impacts can be mitigated by leaving the area before fallout arrives or by sheltering from it. Although some fraction of ionizing radiation can penetrate buildings, the shielding offered by walls and distance from outdoor fallout particles can easily reduce exposures by a factor of ten or more for many common urban buildings (see Table 1). Figure 3 shows how locations within a shelter offer different levels of protection.

The quality of shelter is described by the protection factor (PF), which is equal to the ratio of outside dose rate divided by inside dose rate. As with the SPF of sunscreen, the higher the PF, the lower the exposure that a sheltered person receives compared to an unsheltered person in the same area. Figure 4 demonstrates a PF evaluation done on a Washington State residence where the basement of the house provided a PF between 15 and 25.

Table 2, adapted from NCRP, AFRRI,[21] Goans,[22] IAEA,[23] ICRP,[24] and Mettler,[25] depicts the potential for injury or death from rapid exposure. Fallout exposure, protracted over hours or days, has a lower potential for injury and fatality. Health effects from radiation exposure may not occur until weeks or months after the exposure.

Inhalation and ingestion of fallout is a minor, secondary concern compared to the penetrating prompt and fallout radiation exposure. This is due to the chemical and physical composition of the fallout particles as well as its rapid radioactive decay.[26–30]

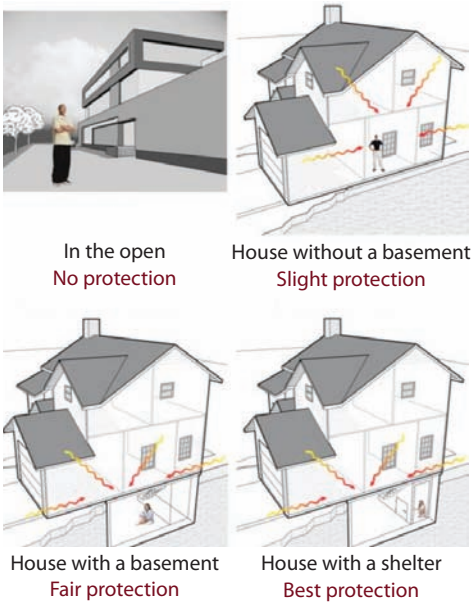
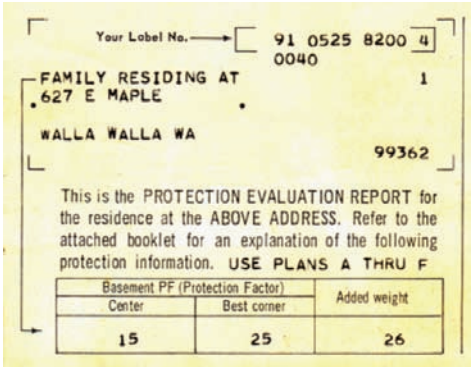


Figure 3. Protection can vary depending on its location in the building.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99362

This is the PROTECTION EVALUATION REPORT for the residence at the ABOVE ADDRESS. Refer to the attached booklet for an explanation of the following protection information. USE PLANS A THRU F

Basement PF (Protection Factor)		Added weight
Center	Best corner	
15	25	26

Figure 4. Example of civil defense shelter factor evaluation for a residence.

Table 1. Protection factors for various shelter locations.[11]

Shelter Location	Protection Factor (PF)
Underground 3 feet	5,000
Wood Frame House	2–3
Basement	10–20
Vehicle	1.7–2
Apartment (upper stories)	100
Apartment (lower stories)	10
Concrete Blockhouse	
9-inch walls	10–150
12-inch walls	30–1,000

Table 2. Approximate acute-death and acute-symptom estimates as a function of whole-body absorbed doses (for adults), for use in decision making after short-term radiation exposure.

Short-Term Whole-Body Dose [rad[a]]	Acute Death[b] from Radiation Without Medical Treatment (%)	Acute Death from Radiation with Medical Treatment (%)	Acute Symptoms (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 30 to 180 days after exposure, and few if any after that time. Estimates are for healthy adults. Individuals with other injuries and children will be at greater risk.

[E] Note that the Civil Defense program advice of "Duck and Cover" can provide protection from prompt effects of flying glass and the thermal pulse; however, it requires reacting properly to the bright flash within the first few seconds.

2.0 Methodology

The methodology used in this study was to involve a more realistic model for fallout patterns than what has been traditionally used (Section 2.1); to create two detailed scenarios using this improved model (Section 2.2); to generate detailed data files capturing the relevant results of the scenarios (Section 2.3); and to evaluate the exposures described by the data as a means to formulate the best possible shelter-evacuation strategies (Section 2.4). Section 2.5 describes the inherent limitations in this study.

2.1 Fallout Patterns

Building a better understanding of fallout patterns requires more accurately accounting for both real weather (Section 2.1.1) and urban environments with which the fallout will interact (Section 2.1.2).

A key methodological issue in this study is how to represent the effects of complex meteorology. Weather, specifically wind direction and speed at different altitudes, is one of the most complicated and influential components in estimating the effects of fallout. Cold War response planning often used simple Gaussian distribution to describe areas affected by fallout, an idealized example of which can be seen in Figure 5.

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 away from the centerline when evacuating the area provides the lowest possible exposure, thus the simplified "lateral evacuation" guidance that is often reported in literature.[32,33]

Although the Gaussian fallout pattern can occur, it is not a good planning assumption as more complex fallout patterns are more challenging and also frequently occur, particularly in coastal areas. This was recognized by FEMA in the 1982 NCRP symposium on The Control of Exposure of the Public to Ionizing Radiation in the Event of Accident or Attack; *"Uncertainties in fallout modeling, coupled with uncertainties about weather, wind shear, and attack patterns make fallout prediction almost useless."* [F]

Fortunately, higher-fidelity atmospheric dispersion models are now available that take into account the complex wind profiles typically found in our atmosphere and that provide a significantly more realistic evaluation of how hazardous material will move in time and space.

The fallout distribution used in this analysis was generated by the National Atmospheric Release Advisory Center (NARAC) at LLNL, which is currently the primary operations center for the Interagency Modeling and Atmospheric Assessment Center (IMAAC). This analysis used an advanced suite of 3-D meteorology and plume/fallout models. The 3-D NARAC modeling system provides detailed simulations that account for complex meteorology and terrain effects.

Non-Gaussian distributions caused by wind shear are very likely. Viewed from the ground, the wind shear may distort or eliminate the classic "mushroom cloud" shape. The image in Figure 6 is from a low-yield British nuclear test 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 only seven and a half minutes after the detonation.

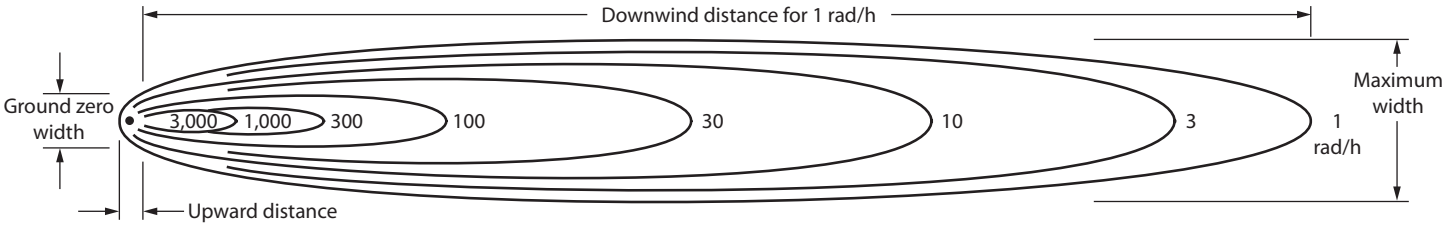


Figure 5. Idealized Gaussian fallout pattern (Figure 9.93 from Glasstone and Dolan, 1977).[31]

Figure 6. Cloud seven and a half minutes after detonation with the effect of the inversion and shear layers clearly visible.

[F] Siebentritt, Carl R. Jr., Federal Emergency Management Agency. Topic 2, Session C; "Radiological Instrumentation Requirements for a National Emergency Such as Nuclear Attack."

Realistic, complex weather patterns result in irregular shaped areas of ground contamination. Even nuclear tests performed at the Nevada Test Site, when shot times could be selected for favorable weather conditions, often resulted in fallout patterns that were unlike the "cigar" shaped Gaussian plots that are commonly used for response planning (Figure 7).

The 12 fallout patterns in Table 3 below represent a sample of how weather affects fallout patterns over the Washington, DC area. The weather data was based on detailed atmospheric soundings at nearby airports and weather stations. An analysis was performed to determine potential fallout patterns using the weather from the 15th of each month in 2006. A noon detonation time was arbitrarily selected.

In the images above, the inner, magenta circle is the range where major building damage would be expected, and the outer, blue circle is the range where glass is being broken with enough force to cause injury. The color coding of the fallout areas are 300 rem (red), 100 rem (yellow), and 1 rem (light magenta) for a two-hour outdoor exposure. These figures are not meant to portray all possible fallout patterns or the full statistical variance for the possible fallout in the Washington, DC area. They do, however, illustrate how complex and variable fallout patterns can be.

In addition to the weather-induced patterns discussed above, the lower yields of improvised nuclear devices may not have the classic mushroom-cloud shape, particularly when detonated in contact with the earth's surface. In addition to the wind shear observed in Figure 6 (p. 5) from the British test, yield and overburden (material above the detonation location) can distort the classic cloud shape. An example of this

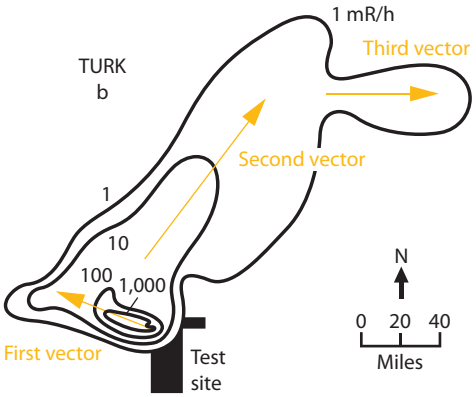
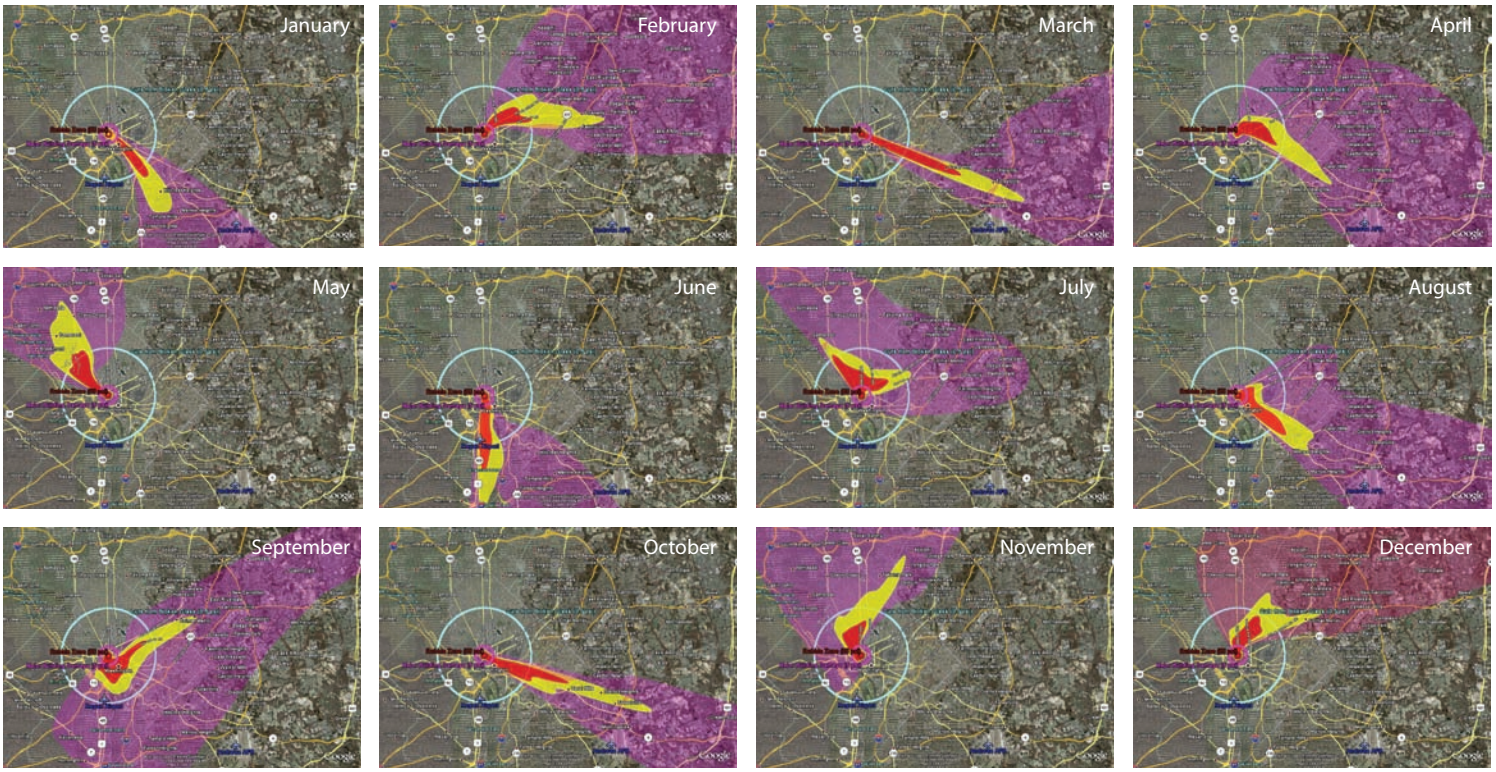


Figure 7. Early fallout dose-rate contours from the TURK test at the Nevada Test Site (Ref. 31, Figure 9.58b).

Table 3. Example of 12 different fallout patterns for Washington, DC.



Buildings © District of Columbia (GS GIC), © 2008 Europa Technologies, Image © 2008 Sanborn, © 2008 Tele Atlas

can be found in the NTS test, Teapot Ess (Figure 8). This 1-kT device was detonated at 67 ft underground on March 23, 1955. The irregular shaped cloud climbed to over two miles in about five minutes but maintained a wide, irregular pattern as it traveled downwind, leaving behind fallout contamination that produced dose rates an hour after detonation (Figure 9) of over 1,000 R/h at 1,000 yards (~half-mile) away.[34] Deep urban canyons and a variety of detonation conditions could produce similar results.

Figure 8. Teapot Ess, March 23, 1955.

Basing response plans on the expectation of a mushroom cloud and a Gaussian fallout pattern creates the false impression that fallout is constrained to a symmetric, easily delineated area. This provides an unrealistic expectation that the fallout area will be quickly and easily traversed and that the impacted population in the fallout area will have perfect situational awareness of what areas have been contaminated by fallout. This has presumably contributed to the "evacuate immediately" guidance[32,33] that can result in higher exposures when used on common, non-Gaussian fallout patterns, as it often places people outdoors and in harm's way when the radiation levels are highest. The difficulty and hazard of implementing an immediate, lateral evacuation tactic is readily apparent for someone north of the detonation location on July 15, 2006 (in Table 3 above) trying to evacuate "perpendicular" to the bifurcated plume.

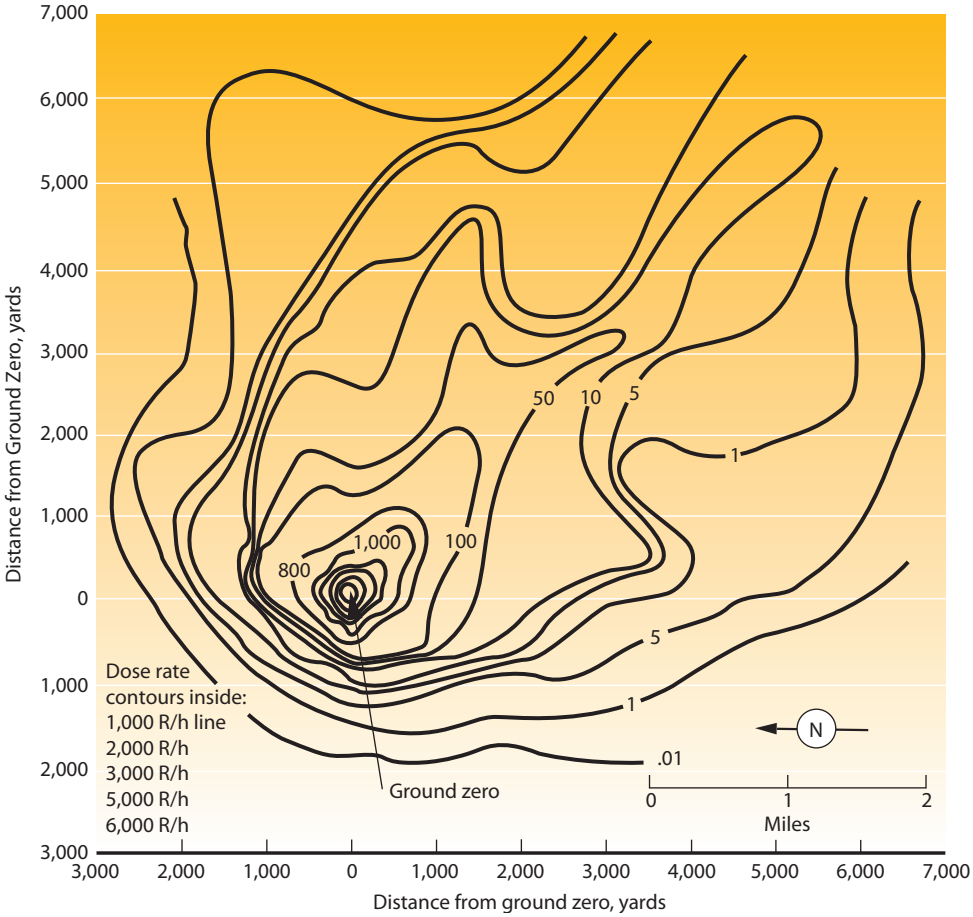


Figure 9. Topographical fallout dose rates 1 hour after Teapot Ess.

2.2 Study Scenarios

This study evaluated the hypothetical impacts of two 10-kT IND detonations with diverse locations and weather patterns incorporating the more realistic fallout patterns describe above. As such, the results of this study, while helpful, are not definitive. The first analysis was modeled using a downtown Washington, DC location and a weather profile from May 23rd 2005.[G] This is similar to National Planning Scenario #1.

This weather pattern is similar to the Gaussian fallout pattern discussed above. Most of the fallout is driven by winds aloft that move the fallout ESE. It should be noted, however, that there was also a light surface wind moving toward the SW that carried the fallout in the SW direction as it came down from the upper atmosphere.

The second scenario utilized was a downtown Los Angeles, CA detonation using weather from July 15, 2006, which had light winds (18 mph) to the NNE near the top of the fallout cloud and light winds (5 mph) near the surface to the NW.[H]

Figures 10 and 11 represent prompt and fallout effects calculations performed by NARAC[I] and then exported to GoogleEarth.™ In both figures, the inner, magenta ring denotes the 5-psi (pound

[G] For the purposes of this illustration, a single-location, non-time-varying meteorological profile was used to generate the hypothetical fallout pattern.
[H] For this scenario, time-and-space-varying meteorology was used to generate the hypothetical fallout pattern.
[I] The prompt effects were calculated using the Sandia National Laboratories (SNL) NUKE model.

per square inch) peak blast-overpressure range within which most buildings will be significantly damaged or destroyed. The outer, blue ring represents the range at which glass will be broken with enough energy to cause injuries to those nearby (0.6 psi peak blast overpressure). Glass will be broken at distances farther than the ring shown above, but it will likely be without the forces needed to cause such injuries.

The fallout contamination shown depicts the areas where impacted population outdoors for the first day after the detonation might receive an exposure that would make cause illness (yellow area, 100 rem) or fatalities (red area, 300 rem).

2.3 Detailed Data Files

The effects of the nuclear detonation, including fallout, were then calculated in the entire region for every block (100-x-100-meter block size was used for Washington and 250-x-250-meter for Los Angeles), resulting in calculating the effects for more than 500,000 cells. The data for each cell includes:

- The distance from the cell to the detonation location.
- Location of cell relative to the detonation location.
- The total population within each grid cell (100-m or 250-m), as provided by the Oak Ridge National Laboratory (ORNL) Landscan[35] Day/Night population database for a weekday daytime period.
- The body-midline gamma dose rate at 15, 30, and 45 minutes, and 1, 2, 4, 12, and 24 hours after the detonation by fallout.
- The time-integrated body-midline gamma-radiation dose from fallout to unprotected individuals who remain in the area for the first 2, 4, 6, 12, and 24 hours following the detonation.
- The prompt gamma and neutron radiation dose (RBE-weighted rad[J]).
- The prompt thermal fluence (cal/cm^2).
- The prompt peak overpressure (psi).

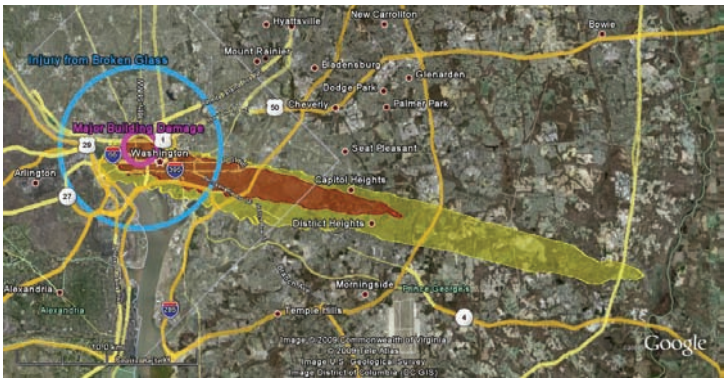


Figure 10.
The Washington, DC scenario.

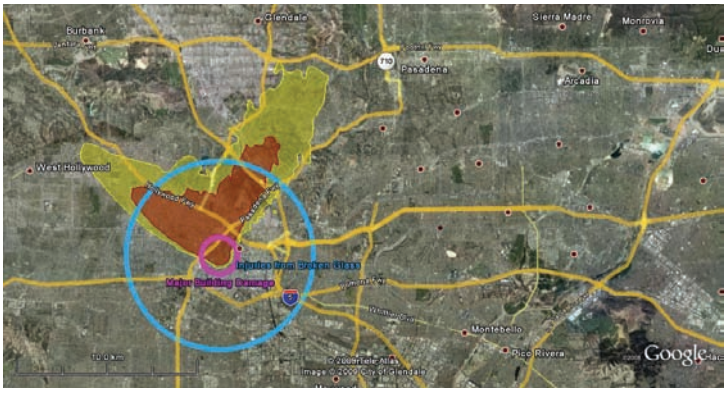


Figure 11.
The Los Angeles, CA scenario.

Table 4. Representative shelter Types used in this study.

Shelter Type	Representative Protection	Examples
Good	PF = 100	Core of large office building, basement of multistory building.
Adequate	PF = 10	Periphery or top floor of office buildings, shallow basements, multi-story brick or concrete buildings.
Inadequate	PF = 3	Cars and light, single-story residential or commercial structures without basements.

2.4 Evaluating Exposures

The detailed data files described above allowed us to evaluate exposures both within shelter (Section 2.4.1) and during evacuation (Section 2.4.2), as well as evaluating total exposures (i.e., combination of exposure both while sheltered and while evacuating) (Section 2.4.3).

2.4.1 Exposure while Sheltered

The reduction in exposure to ionizing radiation due to sheltering within buildings commonly available in the urban environment is considerable.[36] Figure 12 demonstrates presumed protection factors for a variety of buildings and locations within the different building types.[K] For

[J] The prompt radiation dose used a Relative Biological Effectiveness (RBE) of three for high-energy neutrons, and the prompt radiation dose units are therefore in RBE-weighted rad. [See the Units of Radiation Exposure sidebar on p. 2]
[K] Graphic adapted from Armed Forces Radiobiology Research Institute Training and Reports.

example, a person on the top floor or an outer room on the ground level of the office building pictured would have a PF of 10 and would receive only 1/10 (or 10%) of the exposure that someone outside would receive. Whereas someone in the core of the building halfway up, however, would have a PF of 100 and 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.

For purposes of optimizing analysis, the methodology used in this report simplifies all available shelter into three basic types, as described in Table 4.

Although this study addresses conditions at all three PF types, the most variation and thus the most detailed discussion occurs regarding shelters assigned a PF of approximately 10, as this was the minimum protection factor that was considered for "adequate" protection. However, many of the shelter locations discussed would afford the occupants a much higher PF. For example, in the Washington, DC scenario, the Capitol building's construction of marble, sandstone, and cast iron would afford it a PF much higher than 100, especially in the core of the building or on the lower floors.

Figure 13 shows an analysis of the integrated exposure near the Capitol building location in the Washington, DC scenario for the standard shelter types used in this report. The rapid initial increase in exposure is due to the extremely high initial dose rates of the fallout, which were predicted to be over 1,700 rem/h in the first few minutes after arrival. Notice that the time scale on the bottom axis is only for the first four hours, and that the outdoor dose quickly exceeds the threshold for a potentially lethal exposure (300 rem) in less than 15 minutes. The modeled arrival time for the majority of the fallout at the Capitol is approximately 10 minutes, and this analysis uses the simplifying assumption that the fallout arrives all at once.[L] The potential exposure decreases with increasing building protection.

For example, the cumulated exposure inside the PF 100 shelter is barely visible at the bottom of the graph. For an individual within such a building, the

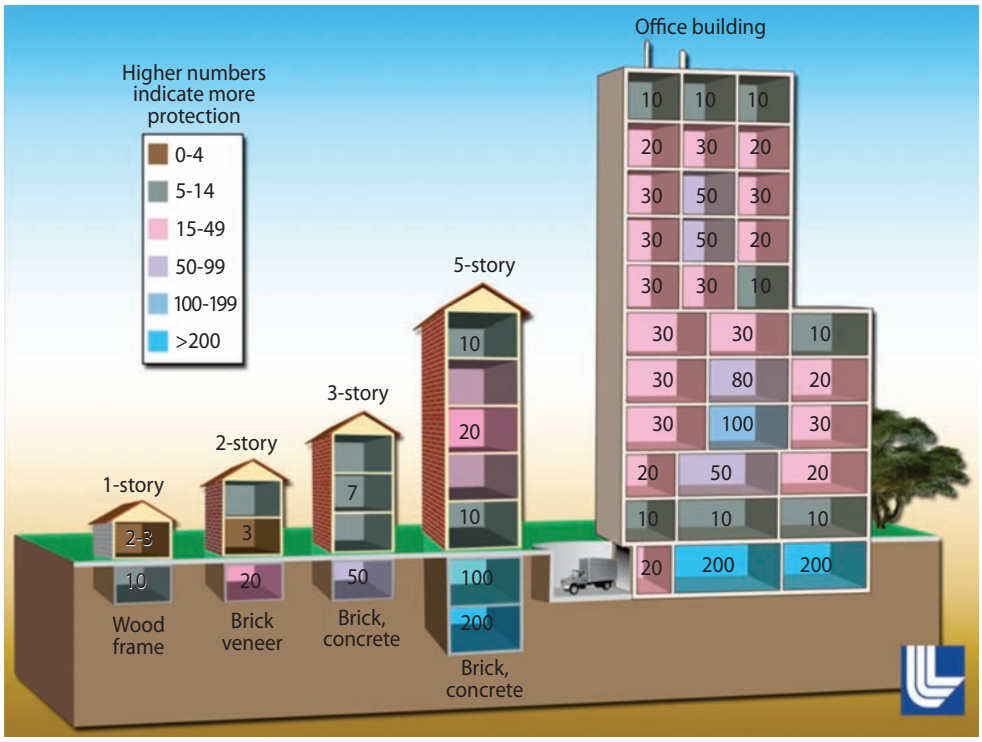


Figure 12. Example protection factors (PFs) for a variety of building types and locations.

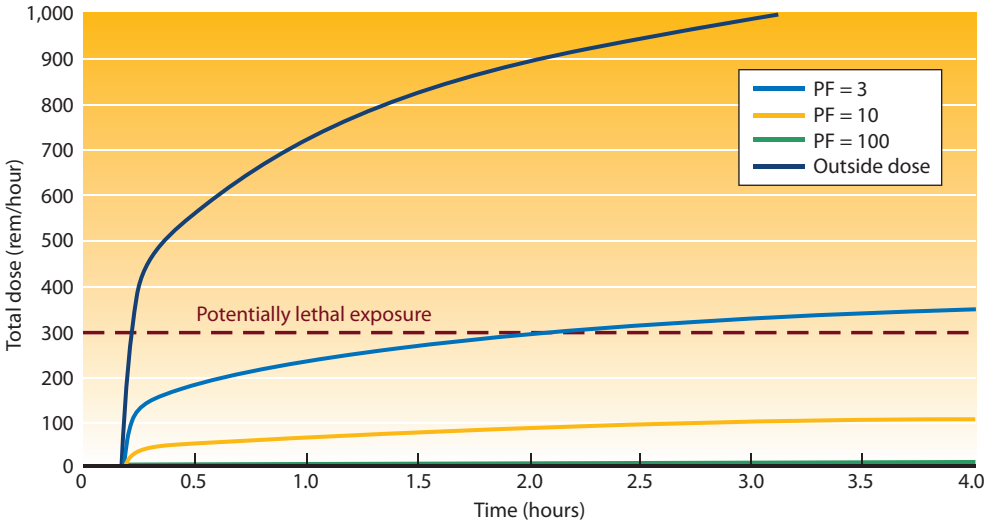


Figure 13. Cumulative exposure with time at the Capitol building.

[L] In reality, some of the fallout would be expected to arrive before 10 minutes and fallout would be expected to continue to accumulate for several minutes.

exposure has only reached 16 rem after 100 hours (~4 days), which is well below the threshold for any acute health effects. In contrast, an inadequate shelter (PF 3) at the same location would result in sheltered individuals receiving a potentially lethal exposure after a few hours.

2.4.2 Evacuation Exposures

The detailed modeling results produced at LLNL allowed for assessment of prompt and delayed effects at every location in the city, including a block-by-block analysis of radiation levels along potential exit routes. The methodology is demonstrated for an evacuation route from the Capitol building.

The majority of fallout is driven by the upper atmosphere winds at the top of the fallout cloud, which (in the Washington, DC scenario) moved perpendicular to surface winds and carried the fallout to the ESE at ~75 mph. These winds (from three to five miles high) are potentially above cloud layers, so the particulate cloud might not be visible during overcast conditions (or at night).

If the fallout cloud were visible (i.e., daytime event with no cloud cover or obscured visibility) from the Capitol, 15 minutes after the detonation, the cloud would appear to pass several miles overhead. This can be seen in Figure 14, in which the NARAC modeling results, as exported to GoogleEarth,™ provide an overhead view of how the cloud might appear 15 minutes after the detonation. The outer, blue circle represents the boundary of the area in which glass is being broken with enough force to cause injury; the inner, magenta circle is an estimate of the range of major building damage.

If the residents of the Capitol building somehow knew that they were on the centerline and followed the lateral evacuation guidance of moving away from the centerline, the most expedient exits away from the centerline are along N. and S. Capitol Streets (for the northerly and southerly evacuation routes, respectively). Northward leads into areas of significant blast damage as the path actually takes the evacuee slightly closer to the point of detonation.

Figure 15 is an example of the Capitol area for the Washington, DC scenario. The colored areas on the map represent various levels of fallout concentration. The callout boxes in Figure 15 display the average outdoor exposure rate for that block at one hour after detonation; this reveals how quickly the dose rate changes with location as the evacuee moves close to the boundary of the fallout area. The dose identified in the each callout box represents the dose received by the evacuee as they traversed the block.

A total integrated evacuation dose estimate was made based on a summation of the dose received from each block. If exiting to the North (roughly perpendicular to the plume), evacuees had to travel about 0.6 miles (1 km) before they leave the area of most significant fallout contamination. This distance corresponds to approximately 15 minutes of travel where the speed of travel, 1.9 mph (3 km/h), was chosen to best represent the potential speed of evacuees traversing through the blast-generated rubble. Depending on how quickly evacuation is initiated after detonation, dust and debris may also cloud the air, limiting visibility. Roads will be impassible to vehicles this close to the detonation location. The exposure received by the evacuee as they cross each block can be seen in the image. As an example of the methodology, if the evacuee departed the Capitol building one hour after the detonation, **the total exposure they would receive during evacuation as they exit the area toward the North would be ~45 rem**.

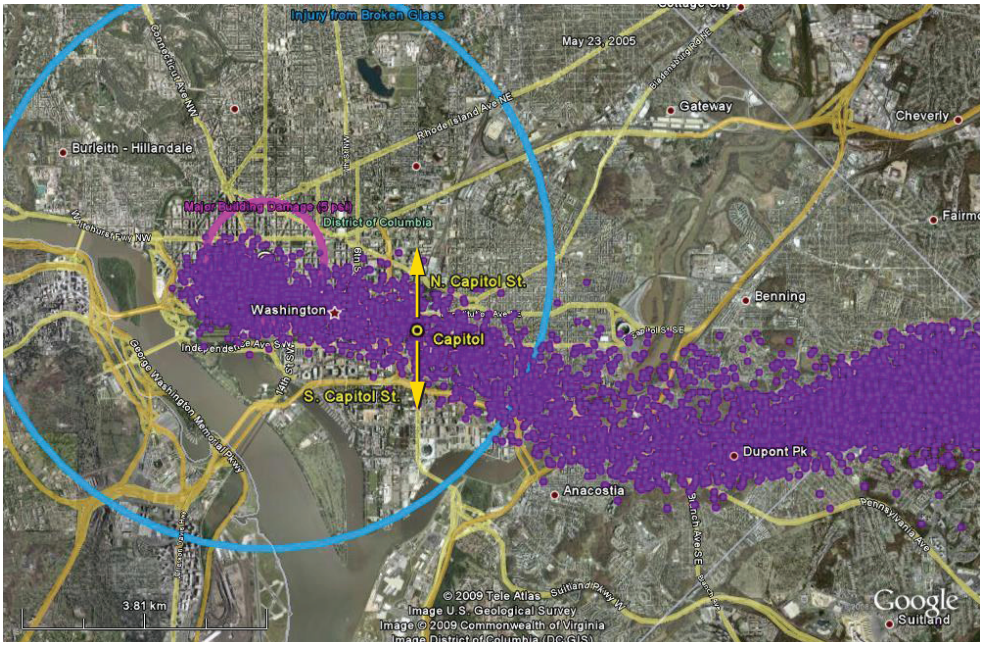


Figure 14. Top view of fallout cloud 15 minutes after detonation.

Due to the position of ground zero relative to the Capitol building, a southward exit will move the evacuees towards areas of lesser damage. However, what may not be as apparent to the evacuees is that on this particular day, like many days, the wind speed and direction changes with altitude and a significant wind shear means that the fallout contamination extends further to the South than the North. Despite the appearance that the top of fallout cloud had moved directly overhead and that dose rates decline in either direction, evacuees would have to travel about twice the distance before leaving the area of most significant contamination.

As can be seen in Figure 16, the longer time spent in the fallout on the **Southern evacuation route results in exposure of ~78 rem**, almost doubling the Northern route dose.

The ***average*** evacuation exposure (62 rem for this example) is reported in the rest of this document. It is recognized that this value ***does not*** represent an actual evacuation exposure received for any given route, but rather provides an average potential exposure for individuals following a lateral evacuation strategy (i.e., evacuation perpendicular to the plume) from a centerline location.

Figure 17 plots the results of the above analysis for a variety of possible departure times. For this case, the analysis indicates that potential exposures from evacuation are highest if evacuation is attempted in the first hour after. Waiting two hours lowered the average potential evacuation dose by an order of magnitude (from 250 rem to 28 rem), and waiting 24 hours brought the evacuation exposure down to 1.5 rem.

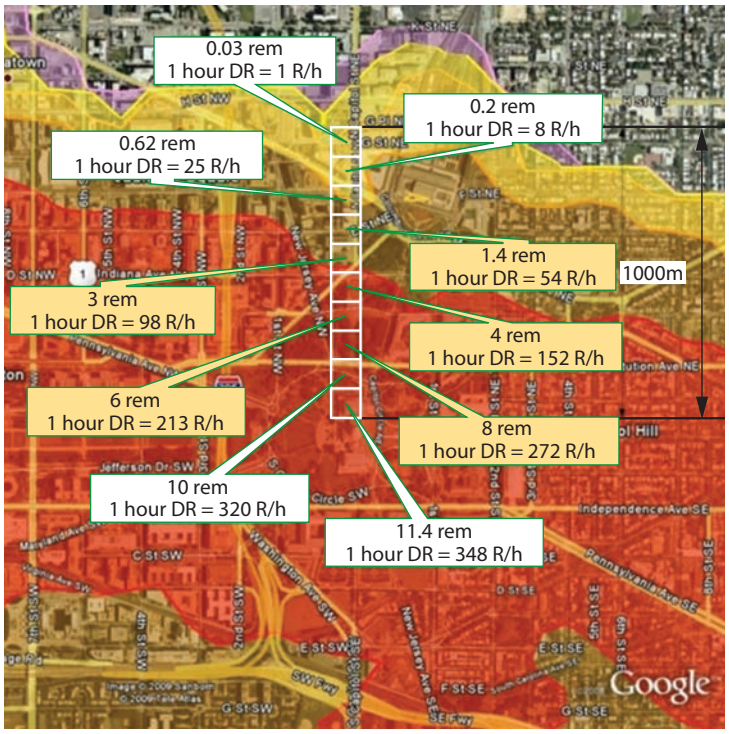


Figure 15. Exit route exposure leaving the Capitol to the North. (DR = dose rate.)

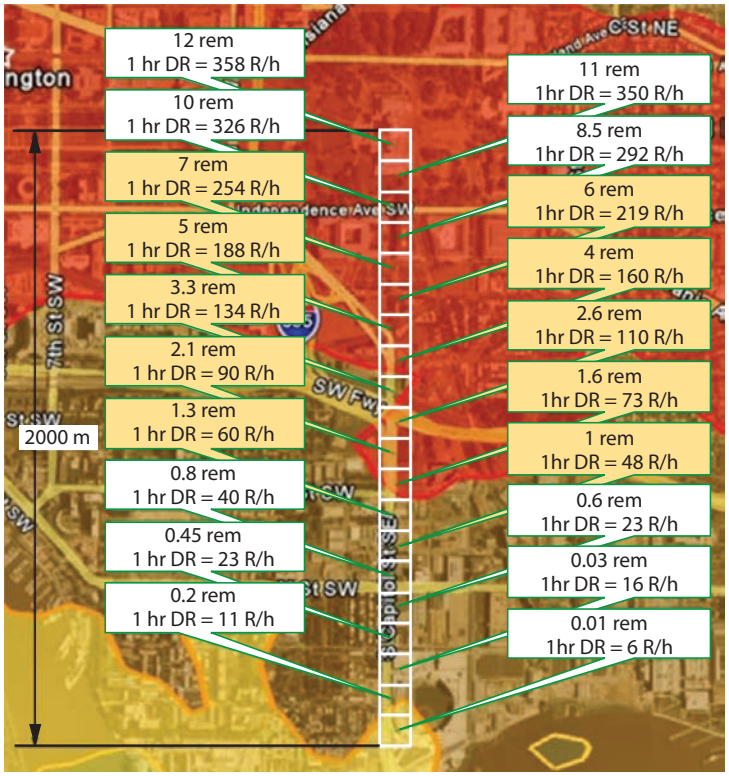


Figure16. Exit route exposure leaving the Capitol to the South. (DR = dose rate.)

2.4.3 Total Exposures

Although the lowest possible evacuation exposure can be achieved through delayed departure, that delay also means that individuals are also receiving exposure from fallout while waiting in their shelter. Evaluation of the total exposure for different lengths of sheltering periods was performed by summing the cumulative exposure received while sheltered (calculated in Section 2.4.1 above) with the exposure received during evacuation (calculated in Section 2.4.2 above) to determine the total dose received by an individual for a particular evacuation strategy (see Figure 18).

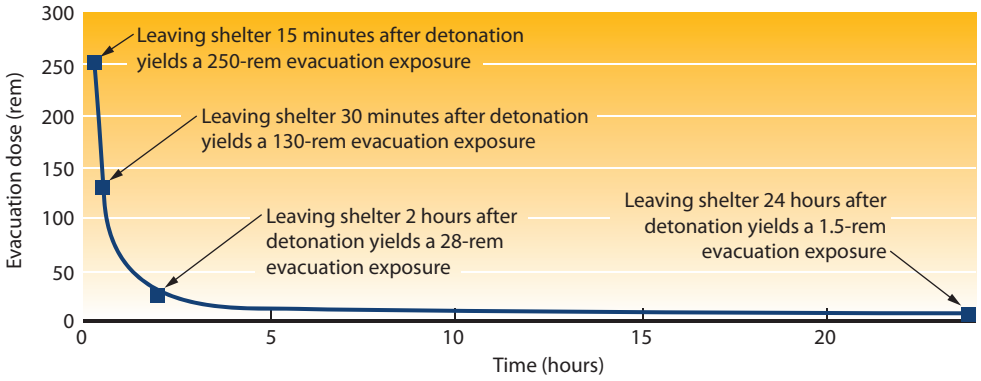


Figure 17. Evacuee dose with various departure times.

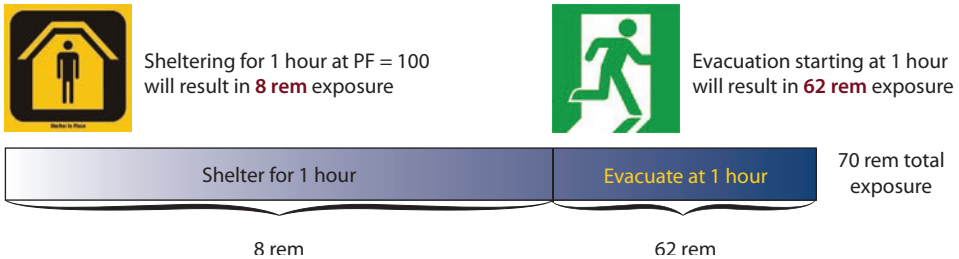


Figure 18. Illustration of cumulated shelter and evacuation dose.

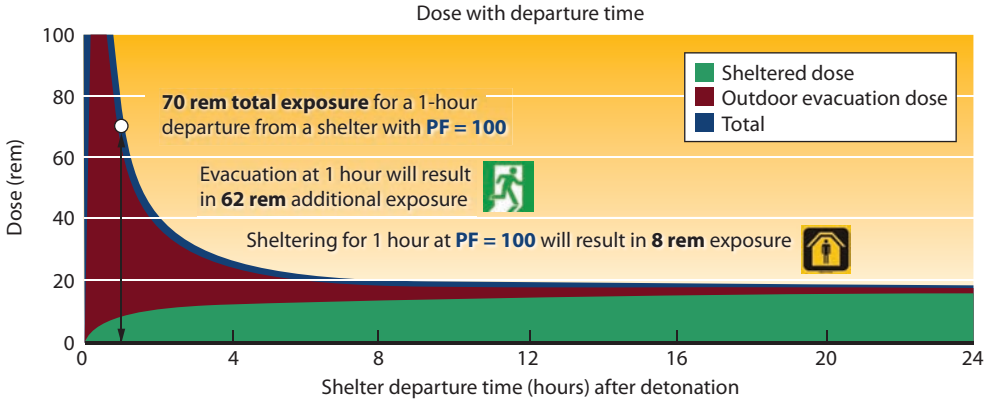


Figure 19. Total dose calculation with various departure times for PF 100 shelter.

Using the average potential dose from the lateral evacuation strategy discussed above for the Capitol, evacuating 1 hour after detonation would result in an 8-rem shelter exposure (for the 1 hour that the person was sheltered presuming a PF = 100) and a 62-rem evacuation exposure, giving a total exposure of 70 rem.

Another way to display this information is in a cumulative dose graph shown in Figure 19, which demonstrates the total exposure (shelter dose + evacuation dose) with various departure times. Again, the one-hour departure will result in cumulated shelter dose of 8 rem and an evacuation dose of 62 rem (average of north and south routes), yielding a total exposure of 70 rem for an evacuation at 1 hour. Notice that the longer sheltering results in a lower total dose, and that a 24-hour departure can result in a total dose of 17 rem, significantly less than the one-hour departure dose of 70 rem. Through the use of this graph, the total (shelter + evacuation) dose can be determined for any of the shelter departure times noted on the X-axis.

Cumulated dose graphs like the one in Figure 19 will be used throughout this report to demonstrate the potential effects of various departure times.

A key consideration for evacuees is the possibility that there will not be a "straight line" path out of the area and that natural (rivers and cliffs) and man-made obstacles (security fences, freeways, culverts, railroads, etc.) may block the best potential routes out of an area. Additionally, the centerline evacuation-strategy calculation described above will not be feasible with the complex fallout

pattern used in the Los Angeles scenario. A method developed by SNL[37] uses the same block-by-block analysis to determine the evacuation dose, but uses a more sophisticated route analysis to investigate alternative evacuation strategies and explore an individual's potential evacuation dose. Data from this analysis is included in this report for the Los Angeles evaluation.

Figure 20 is an example of the SNL evacuation analysis for a route that crosses over higher-dose-rate areas before exiting the contamination area. The dose rate on each block is represented by the height of the bar in the image.

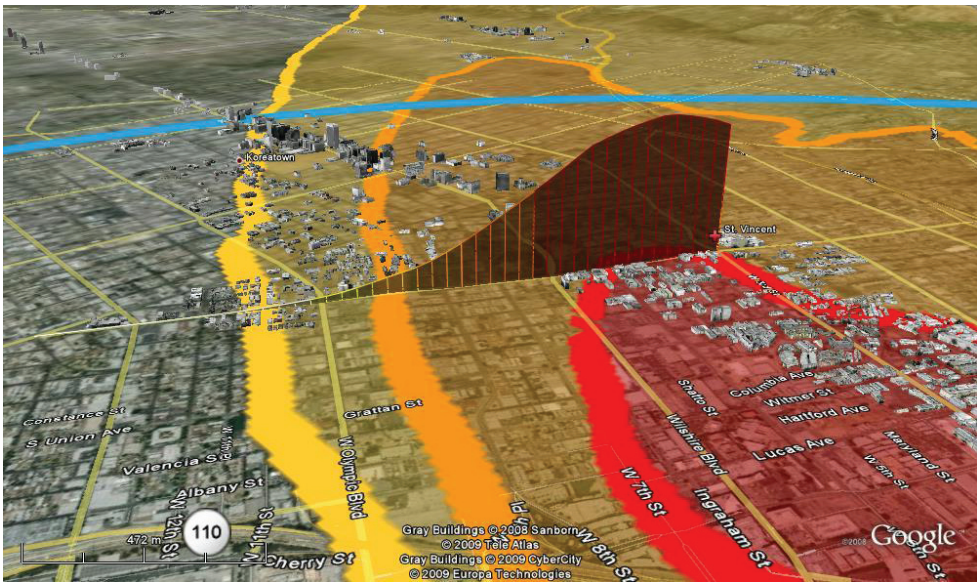


Figure 20. Example of evacuation analysis produced by SNL; superimposed bar chart shows dose rates along the path. (KML file courtesy of SNL.)

2.5 Study Limitations

This study involved the examination of two discrete scenarios to extrapolate trends and issues for general consideration. As such, the results of this study, while informative, are not definitive. The fallout patterns depicted here are based on particular detonation locations, yield, and weather patterns. **Do not presume that any actual fallout pattern will necessarily look like the model results depicted here, as actual results will depend on actual weather, yield, location, and many other variables that are difficult to predict in advance**.

Actual nuclear test data for low-yield, ground-level detonations is limited. Example areas of high uncertainty or lacking scientific-community consensus (especially for a ground-level detonation) include the following:

- Glass missiling range and impact.
- Urban line-of-sight, radiation transport, and flash-blindness effects.
- Blast-wave mitigation and rubble generation in the urban environment.
- Combined injury generation and prognosis.
- Infrastructure issues like power, communication, water, and EMP effects.
- Physical and chemical composition of fallout.
- Sheltering/evacuation and transportation modeling.
- Fire initiation and propagation.
- Activation contribution to local radiation levels.

This analysis focuses primarily on protection from fallout. Other issues, such as fire, EMP, medical surge, and treatment are only briefly discussed.

3.0 Results

Section 2.0 describes the methodology behind the two scenarios. Results are presented here first for the Washington, DC scenario (Section 3.1), then for the Los Angeles scenario (Section 3.2). An integrated analysis of results from both locations follows (Section 3.3).

3.1 Washington, DC Results

In this scenario, the Capitol building is about 1.6 miles (2.6 km) from the detonation location and directly in the fallout path. Although outside of the area of major building damage,[M] some damage (broken windows, overturned equipment) is likely at this range. An increased dose rate from fallout will be seen as early as six minutes after the detonation but will peak about ten minutes after detonation, producing dose rates over 1600 rem/h outside of the Capitol building. Fortunately, fallout decays rapidly; just two hours after the detonation, this dose rate will have fallen off to 130 rem/h, and at two days it will be down to just 3 rem/h.

The time-dependant nature of the radiation levels given off by fallout can be seen in Figure 21, where the calculated dose rate is highest in the first few minutes after the majority of fallout arrives and then rapidly declines.

The average-potential centerline-lateral evacuation dose incurred during evacuation from the Capitol building has already been discussed in Section 2, Methodology. The results are presented in Figure 22, which displays the total dose (shelter exposure + evacuation dose) for various evacuation start times from a building that provides good shelter (PF 100).

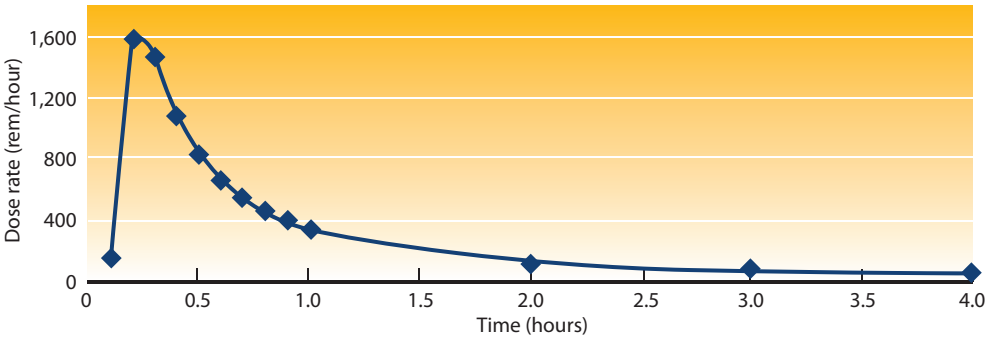


Figure 21. Calculated fallout dose rates outside the Capitol.

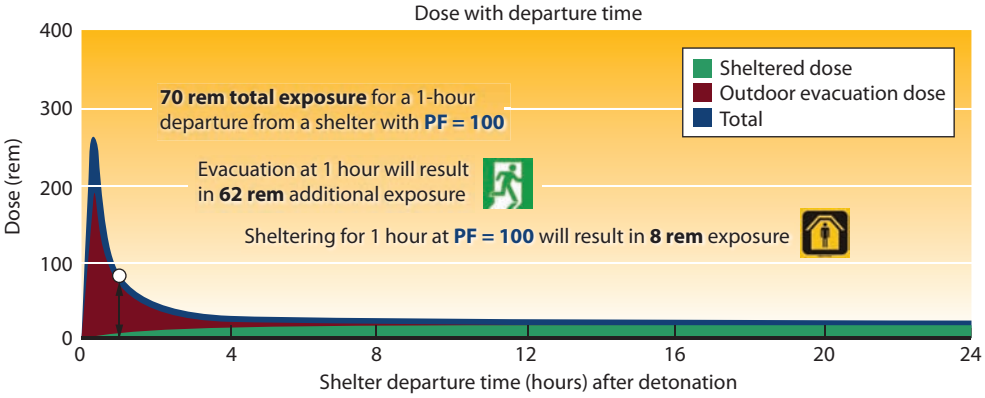


Figure 22. Total Dose (Shelter + Evacuation) for various departure times from a PF 100 shelter.

As an example, a one-hour departure from the PF 100 shelter results in a 70-rem exposure. Earlier departures result in higher exposures. Delayed departures result in lower exposures. For example, leaving the PF 100 shelter after five hours would result in a total exposure of 20 rem.

As indicated by the shape of the curve in the first few minutes, a low exposure can also be achieved if the evacuee leaves immediately. Unfortunately, immediate evacuation is not feasible in this case as it would require knowledge of where the fallout would be going even while the fireball is still rising; even waiting five minutes before departing would result in an evacuation exposure that would exceed 200 rem. Early, adequate shelter followed by informed evacuation is the safest option for this set of circumstances.

3.1.1 Effects of Shelter Adequacy

To provide more detail on how an evacuation strategy might change depending on shelter type, the same average-potential centerline-lateral evacuation dose analysis was performed presuming the same evacuation route as in Figure 22 above, but a PF 10 shelter. This is the adequate shelter defined in the methodology section and would include locations such as the lower floors of an apartment building or the shallow basement of a single-story, wood-frame house. Figure 23 illustrates the total dose for various departure times for the PF 10 shelter.

The evacuation dose for a departure one hour after the detonation remains the same (62 rem), but the cumulated shelter dose is a much higher 80 rem, yielding a

[M] The building-damage region is strongly dependent upon yield—a 10-kT detonation is assumed for this illustrative example.

total dose of 142 rem. Although the sheltering initially for at least an hour does avoid the highest exposures, the figure also reveals that staying sheltered for more than a few hours results in slightly higher exposures. To achieve the lowest possible exposure for the adequate (PF 10) shelter, the optimum shelter-departure window occurs from one-and-a-half to three hours after the detonation. Departures after three hours result in a slightly higher exposure, but only increasing slowly up to an additional 25% at 24 hours after detonation.

Continuing the analysis with an inadequate or poor shelter, such as a car or wood-frame house without a basement that only has a PF = 3, Figure 24 illustrates the total dose with various shelter-departure times. Again, the evacuation dose for a departure one hour after the detonation remains the same (62 rem), but the cumulated shelter dose is much higher (268 rem), yielding a total dose of 330 rem. Although initial shelter can reduce the high evacuation doses observed in the first 30 minutes, it is apparent that staying within the inadequate shelter beyond three hours negates any dose reduction afforded by sheltering. Even with optimum evacuation time, the dose received would be 330 rem and would require advanced medical care.

Even in the case of a relatively poor shelter location, ***almost any shelter plus a delayed evacuation*** strategy will substantially reduce exposures compared to the cumulative outside dose. Figure 25 illustrates that even for the case of *inadequate shelter* (PF 3) explored above, the strategy of shelter followed by delayed (30 minutes or more) departure will always result in a lower exposure than an unmitigated outdoor exposure if no shelter or evacuation is performed. Note that the vertical scale (dose) had to be increased to accommodate the high outdoor exposure range.

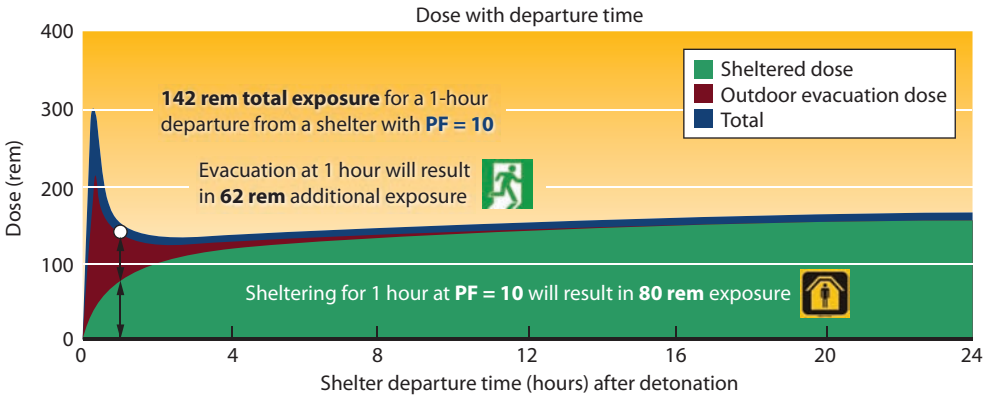


Figure 23. Total dose calculation with various departure times for PF 10 shelter.

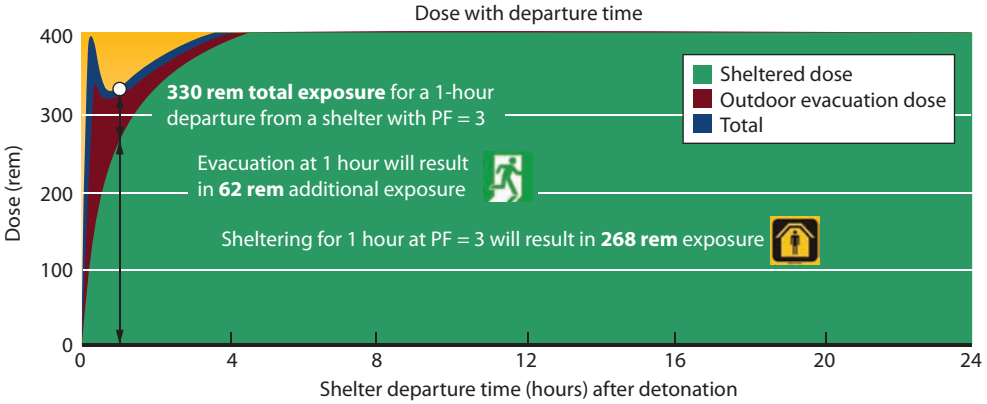


Figure 24. Analysis of evacuation times in the first 24 hours from a PF 3 shelter.

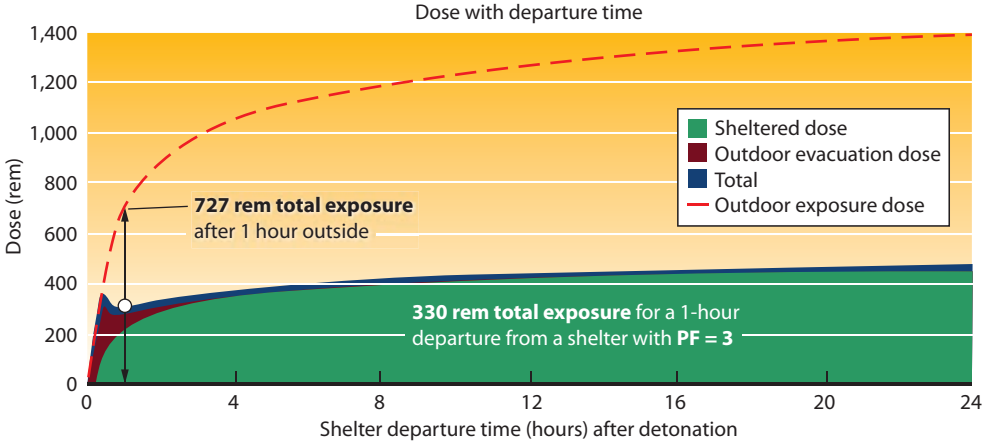


Figure 25. Comparing delayed evacuation with outside exposure.

In summary, the Washington, DC scenario illustrates that:

1. There is likely a minimum dose that could be achieved, which implies an "optimum" shelter period defined as the amount of time in the shelter that will lead to the lowest possible total dose. For a shelter location near the Capitol building in the Washington, DC scenario, the optimum time spent in a shelter is:
   a. One day or more in a good shelter (PF 100 or more).
   b. A few hours in the minimally adequate shelter (PF 10).
   c. Shortly after the fallout cloud passes for inadequate shelters (PF 3).
2. For adequate shelters (PF 10 or greater):
   a. Evacuating early (particularly less than 1 hour after detonation) often results in the highest (potentially lethal) exposures.
   b. Evacuating late may slightly increase the total dose, but this effect is minor compared to the dose increase due to early departure.

This analysis provides insight into an overall response strategy, but additional analysis for a variety of conditions is needed to extrapolate this information to broader response guidance.

3.1.2 Effects of Shelter Distance from Detonation

There has been discussion in the emergency-responder community that the optimal shelter time might change with distance from the detonation location. To evaluate this possibility, a second average-potential centerline-lateral evacuation dose location was evaluated that was ~10 miles (16.6 km) from the detonation site. Figure 26 shows the locations evaluated in this analysis. To evaluate the effect that distance from detonation will have on the optimum shelter time, the following assumptions were made:

1. The same shelter type at each location (PF 10).
2. That a north-and-south evacuation route was available from the centerline.

As the distance increases from the detonation point, the fallout arrival time increases, and the overall dose rates in the area will be smaller. The reduction of the evacuation exposure is the result of these key components. As can be seen by the yellow arrows in Figure 26, the path required to exit the area increases with distance from the detonation, but it is also expected that evacuation will be more quickly carried out as the amount of disruption and blast debris lessens with distance from detonation. As noted above, evacuation from the Capitol was calculated at 3 km/h. For the Beltway location, a fast walk of 6 km/h[N] was used because accidents caused by flash-blindness are expected to limit vehicle traffic.

The total exposure for various shelter occupancy times is plotted below near the Capitol (Figure 27) and in the DC Beltway (Figure 28). All of the plots assume an adequate (PF 10) shelter.

Not surprisingly, this scenario demonstrates that fallout takes longer to reach shelter locations that are further away from the detonation site and will result in lower overall doses. In addition, this scenario also demonstrates that the optimum length of time spent in the shelter after detonation **does not** necessarily change along the plume centerline with distance or peak dose rate. See Table 5. For both examples where a PF 10 shelter and the average of both north and south evacuation routes was used, the optimum shelter-stay time remains two hours and 15 minutes after detonation regardless of downwind distance. The authors note that this analysis does *not* suggest that there is a single optimal stay time for the entire plume, but rather

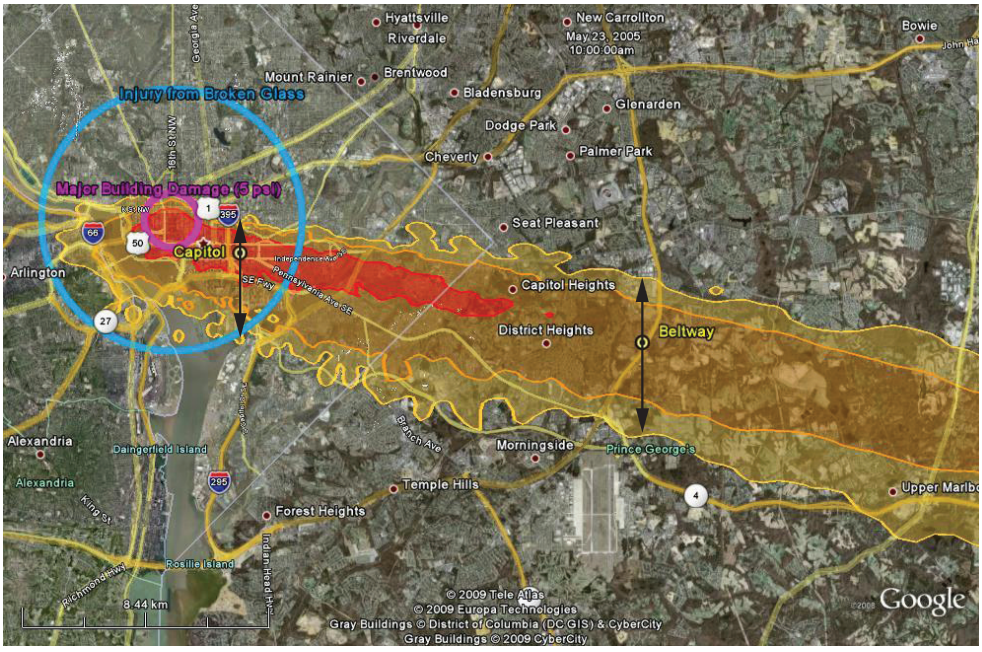


Figure 26. Different downwind locations used in distance study.

[N] 6 km/h is approximately a football field every minute.

illustrates that the optimal stay time depends on relative contributions in the sheltered dose rate and evacuation dose, and does not explicitly depend on the distance from the detonation site.

The "DC Beltway" location, the furthest from our detonation site, identified the possibility of lower exposure due to immediate evacuation. At this location, the fallout arrives about 30 minutes after detonation, and evacuees who started their evacuation within 15 minutes of the detonation could safely leave the area before the fallout arrives. Unfortunately executing this is operationally difficult, if not impossible, because it requires timely knowledge of where the fallout is going to be and how to avoid it. In the first few minutes of an event, the fallout cloud may still be forming, and even if the evacuee could see the cloud, gauging the speed and direction (especially if it is moving toward or away from the evacuee) would be difficult.

Another factor that would make early evacuation difficult is the longer travel times needed to avoid fallout areas. For the sensitivity analysis above, it was presumed that the evacuation speed would increase with distance from the detonation location. In the DC Beltway example, the distance required for the evacuation path (as far as the 1-R/h line) is 2 km to the north and 3 km to the south.

Table 5. Fallout exposure trends with distance.

Distance	Location	Fallout Arrival (minutes)	1-hour Dose Rate (rem/h)	24-hour Outdoor Dose (rem)	Optimum Shelter (PF 10) Stay	Dose if Depart at Optimum Time
1.6 miles (2.6 km)	Near Capitol	10	300	1,400	2 hours, 15 minutes	142 rem
10 miles (16.6 km)	DC Beltway	34	64	190	2 hours, 15 minutes	13.6 rem

Location	Near Capitol
Distance from Ground Zero	**1.6 miles (2.6 km)**
Dose Rate @ 1 hour	360 rem/hour
24-hour Outdoor Dose	1,600 rem
Fallout Arrival	10 minutes
Protection Factor	10
Optimum Departure Time	2 hours, 15 minutes
Minimum Dose	142 rem

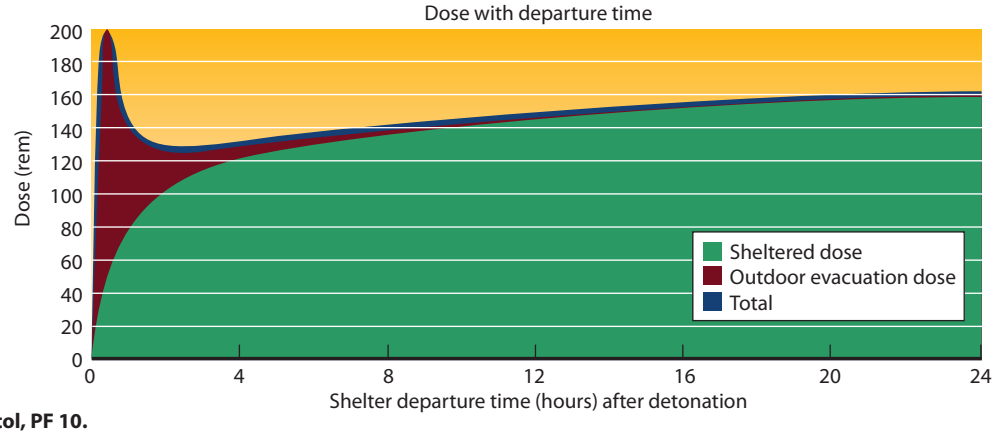


Figure 27. Total exposure occupancy times near Capitol, PF 10.

Location	DC Beltway
Distance from Ground Zero	**10 miles (16.6 km)**
Dose Rate @ 1 hour	64 rem/hour
24-hour Outdoor Dose	190 rem
Fallout Arrival	34 minutes
Protection Factor	10
Optimum Departure Time	2 hours, 15 minutes
Minimum Dose	13.6 rem

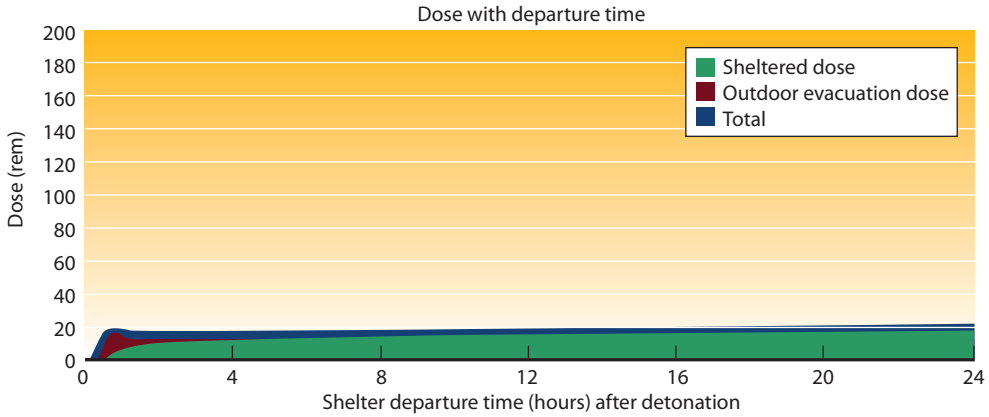


Figure 28. Total exposure occupancy times in DC Beltway, PF 10.

Table 6. Areas above 10 R/h. (Base image from Google Earth[O])

Orange > 10 R/h, Blue = Blast Injury Range

Time after Detonation: 15 minutes

Maximum Distance from Detonation: 7.5 miles (12.1 km)

Time after Detonation: 30 minutes

Maximum Distance from Detonation: 15 miles (23.9 km)

Time after Detonation: 45 minutes

Maximum Distance from Detonation: 18 miles (29.1 km)

Time after Detonation: 1 hour

Maximum Distance from Detonation: 22 miles (35.6 km)

Time after Detonation: 1 hour, 15 minutes

Maximum Distance from Detonation: 22.6 miles (36.4 km)

Orange > 10 R/h, Blue = Blast Injury Range

Time after Detonation: 2 hours

Maximum Distance from Detonation: 22 miles (34.7 km)

Time after Detonation: 3 hours

Maximum Distance from Detonation: 16 miles (23.9 km)

Time after Detonation: 4 hours

Maximum Distance from Detonation: 13 miles (21.0 km)

Time after Detonation: 5 hours

Maximum Distance from Detonation: 10 miles (15.9 km)

Time after Detonation: 6 hours

Maximum Distance from Detonation: 10 miles (15.9 km)

[O] GoogleEarth © 2009 Tele Atlas, Image District of Columbia (DC GIS), Image © 2009 Commonwealth of Virginia, Image U.S. Geological Survey

3.1.3 Area Access

Emergency support to the impacted populations can be performed with appropriate precautions. Activities such as fire suppression; evacuation route charting/clearing; and time-sensitive, mission-critical activities such as life saving are legitimate fallout area access reasons. To perform this access, the 10-R/h inner perimeter guidance of NCRP can be used to define the ***high-hazard zone***.

The 10-R/h high-hazard zone boundary will change rapidly during the first few hours and days. Responders who may enter fallout contaminated areas should be equipped with dose and dose-rate monitoring equipment. Staying below the 10-R/h dose rate will allow for time-sensitive, critical emergency-response activities to be conducted without unnecessary risk to the responder.

Table 6 illustrates how, for the DC scenario, the high-hazard zone grows quickly over the first hour and reaches its maximum range of just over 20 miles (35 km) about an hour after detonation. Analyzing the fallout modeling results indicates that the high-hazard zone maintained its approximate maximum size from one to two hours after detonation, and then contracted significantly. The contraction of the high-hazard zone resulted in halving its extent three hours later (five hours after detonation).

Table 7 provides the time required until a series of centerline points fall below 10 R/h (the "Near Capitol" and "DC Beltway" locations are identified in Figure 26 above). If the 10-R/h dose rate is used as a "turn-back" level for emergency responders, this is the amount of time after detonation that is required before responders can enter the area.

Table 7. Time until areas are below 10 R/h in the Washington DC scenario.

Distance	Location	Time until Area is < 10 R/h
1.6 miles (2.6 km)	Near Capitol	17 hours, 45 minutes
2.8 miles (4.5 km)	Capitol Hill	14 hours, 30 minutes
3.4 miles (5.5 km)	General Hospital	13 hours
5.9 miles (9.5 km)	DC Border	8 hours, 30 minutes
10 miles (16.6 km)	DC Beltway	4 hours, 45 minutes

The radiation levels will continue to decay, even after the area falls below 10 R/h. The potential exposure to a responder who enters the area immediately after dose rates fall below 10 R/h and works outside for 2 or 4 hours is approximately 17 and 32 rem, respectively.[P] Neither of these potential exposures would result in any observable acute health effects.

3.2 Los Angeles Results

As seen in the 12 examples of Washington, DC fallout patterns in Table 3, the cigar-shaped Gaussian distribution is not the typical fallout pattern in many areas. To evaluate the complications of wind shear on a shelter-and-evacuation strategy, a more sophisticated evacuation-dose analysis is required. Wind shear can create the situation in Figure 29, where the impacted population between the two major contamination areas may have to traverse higher levels of fallout contamination to reach safety.

The following analysis uses an example of a 10-kT detonation in downtown Los Angeles and a weather profile from 10:00 a.m. on July 15, 2006. Winds near the top of the fallout cloud are moving to the NNE at approximately 18 mph, and surface winds are moving to the NW at 5 mph. The inner, magenta ring denotes the 5-psi peak blast-overpressure range and within which most buildings are significantly damaged or destroyed. The outer, blue ring represents the range at which glass is likely to be broken with enough energy to cause injuries to those nearby. The fallout contours depict the area where an individual might receive an exposure that would cause illness (yellow area, 100 rem) or fatalities (orange area, 300 rem) if they remain outside for the first 24 hours.

One of the neighborhoods evaluated for the Los Angeles scenario is the area around St. Vincent hospital near the intersection of S. Alvarado St. and W. 3rd St., which can be seen in Figure 30. Approximately 1.4 miles (2.3 km) from the detonation point, this area contains a mixture of large multi-story buildings, strip mall shops, churches, restaurants, and wood-frame homes. At this range, the blast forcibly breaks all of the windows, but does not cause major building damage. Although this area is not in the highest levels of contamination, the best evacuation route takes the evacuees SE down S. Alvarado St. through higher contamination. All other evacuation routes result in higher exposures due to longer travel times.[37] In Figure 30 (previous page), the magenta circle is the major building damage area, and the contamination contours represent the approximate dose rates from the fallout contamination contours five hours after the event. The dose rates in the designated areas are at least 100 rem/h (red), 10 rem/h (dark orange), 1 rem/h (light orange), 100 m rem/h (yellow), and 10 mrem/h (pink).

[P] Note that this calculation does not include the exposure cumulated reaching or leaving the work area.

The model predicts that most of the fallout arrives at the study area ~15 minutes after detonation (see Figure 31). At 15 minutes after detonation, the outside dose rates are almost 1,200 rem/h. As with the Washington, DC scenario, the fallout radiation levels decay rapidly and fall below 400 rem/h at 1 hour after detonation.

The results of an SNL analysis discussed in Section 2, Methodology, can be seen below for the optimal shelter-stay times.

3.2.1 Effects of Shelter Adequacy

This section develops a comparison between the exposures that individuals would receive within typical buildings in the vicinity of St. Vincent's Medical Center and illustrates the dependence of the optimal shelter time upon the shelter quality. The Hospital itself and associated office building (Figure 32) would likely be able to provide a PF of 100 or more to the building occupants. Underground areas, such as basement, parking garages, and subways also often have PFs greater than 100.

Relatively shallow basement or inner areas of smaller commercial cement, brick structures, or apartment buildings; floors adjacent to the roof of a large multi-story building; and the outer rooms on the ground floor can often provide a PF of 10 (Figure 33), which is the minimum adequate shelter recommended by this study.

Simple wood-frame buildings (Figure 34) provide a modest protection factor (PF 3) and are considered to be inadequate shelter for the purpose of this analysis.

As with the Washington, DC scenario results, the optimum shelter-departure time is dependent on shelter quality. Good shelters (PF ≥ 100), like the core of an office building or commercial underground areas, can be occupied for more than a day to achieve lowest possible exposure. Inadequate shelters, like the PF 3 of a single-story, wood-frame house, offer little long-term benefit; evacuation (or relocation) should be considered 30 minutes after the fallout first arrives.

3.2.2 Effects of Evacuation Path Length

Another group to consider is populations near the fallout boundary. For the Los Angeles analysis, the neighborhood of LAFD Station 11 is only about 1 km from the boundary of the fallout area, and there are no higher-dose-rate areas to traverse (see Figures 29 and 30). Like the previous area, this area has large multi-story buildings, short commercial structures, and a few wood-frame structures.

PF 100 would be characteristic of the core of large buildings like office buildings having five or more stories (Figure 35).

PF 10, which is the minimum adequate shelter recommended by this study, results in some dose reduction, but the advantages are lost if the sheltered population stays longer than 90 minutes (Figure 36).

PF 3 is considered an inadequate shelter under this guidance (Figure 37). Often, as illustrated above, even an inadequate shelter can still afford the occupants some protection, but in the case below, there is no dose saving associated with delaying evacuation unless evacuation routes are

Figure 29. Areas of acute effects from blast (blue) and fallout (yellow, orange) for Los Angeles Scenario.

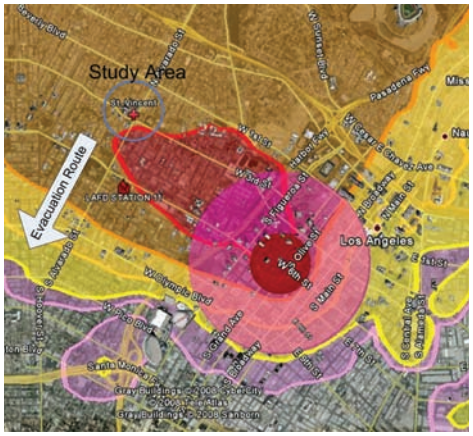


Figure 30. Los Angeles scenario locations.

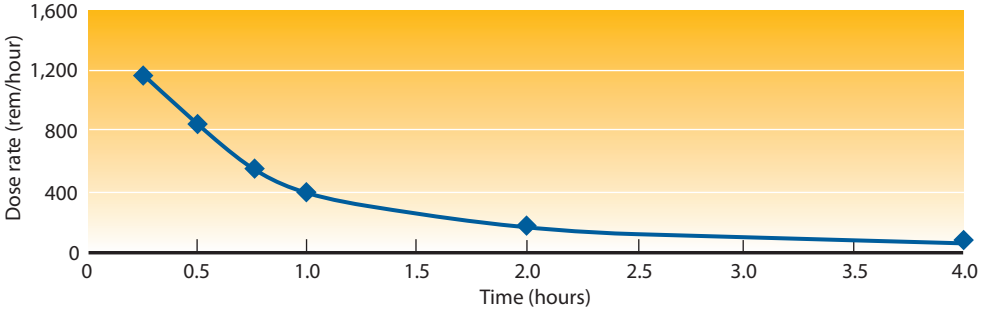


Figure 31. Outside dose rates in the area of St. Vincent's Medical Center.

Location	St. Vincent's Medical Center
Evacuation Distance	~1 mile
Dose Rate @ 1 hour	400 rem/hour
24-hour Outdoor Dose	1,600
Fallout Arrival	14 minutes
Protection Factor	**100**
Optimum Departure Time	~4 days
Minimum Dose	20 rem

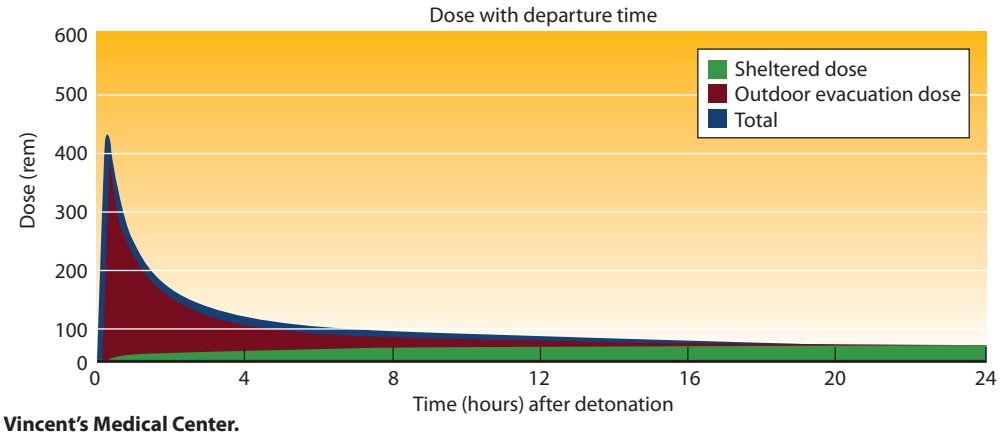


Figure 32. Exposures in good-quality shelter near St. Vincent's Medical Center.

Location	St. Vincent's Medical Center
Evacuation Distance	~1 mile
Dose Rate @ 1 hour	400 rem/hour
24-hour Outdoor Dose	1,600
Fallout Arrival	14 minutes
Protection Factor	**10**
Optimum Departure Time	5 hours, 15 minutes
Minimum Dose	215 rem

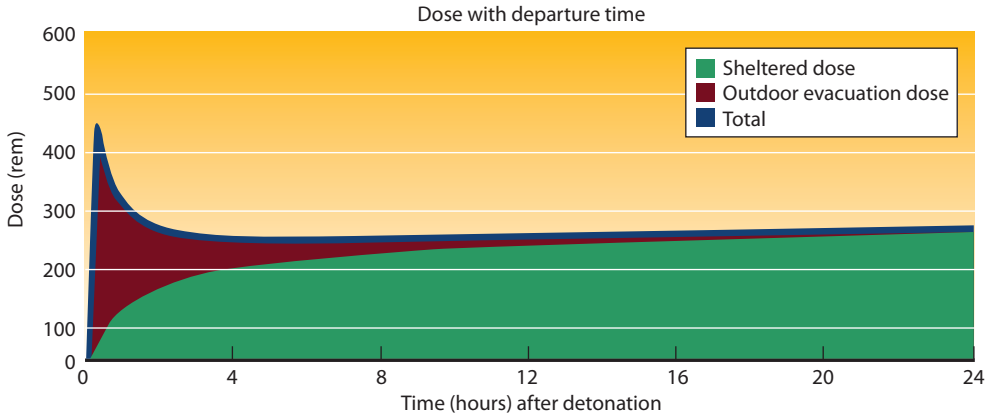


Figure 33. Exposures in adequate-quality shelter near St. Vincent's Medical Center.

Location	St. Vincent's Medical Center
Evacuation Distance	~1 mile
Dose Rate @ 1 hour	400 rem/hour
24-hour Outdoor Dose	1,600
Fallout Arrival	14 minutes
Protection Factor	**3**
Optimum Departure Time	30 minutes
Minimum Dose	460 rem

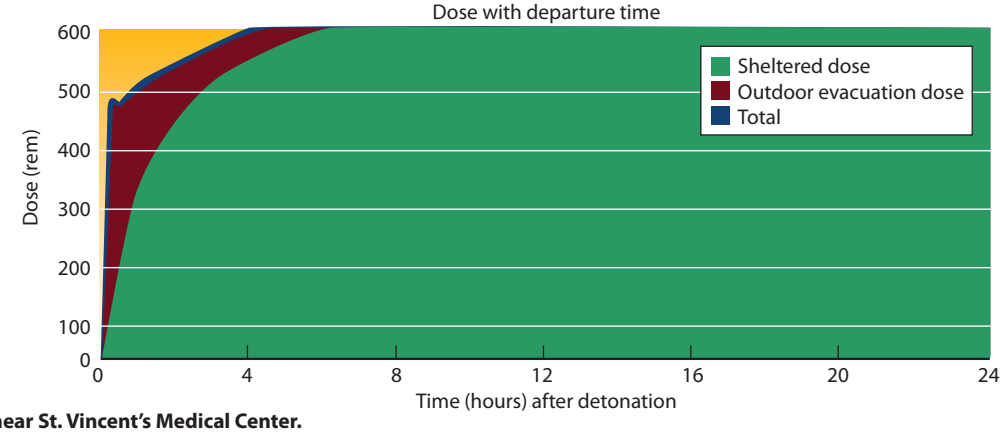


Figure 34. Exposures in inadequate-quality shelter near St. Vincent's Medical Center.

not clear. This result is driven by short evacuation distances, which minimizes the evacuation dose.

Unfortunately, it is unlikely that victims of an event in the most hazardous areas would be able to gather enough situational awareness in the first few minutes of an event to make an informed decision about proximity to future fallout boundaries. Compounding the problem is the issue that the most significant exposure occurs in the minutes following the arrival of the fallout, and a decision to evacuate immediately could result in significantly higher exposures than shelter options if the estimates of contamination boundaries or evacuation routes are incorrect.

Location	LAFD Station #11
Evacuation Distance	~0.5 mile
Dose Rate @ 1 hour	450 rem/hour
24-hour Outdoor Dose	1,800
Fallout Arrival	14 minutes
Protection Factor	**100**
Optimum Departure Time	11 hours, 15 minutes
Minimum Dose	16 rem

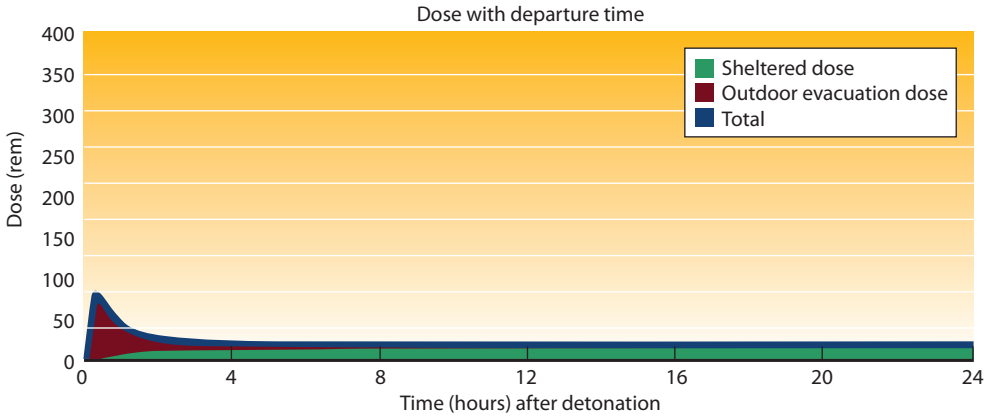


Figure 35. Exposures in good-quality shelter near LAFD Station #11.

Location	LAFD Station #11
Evacuation Distance	~0.5 mile
Dose Rate @ 1 hour	450 rem/hour
24-hour Outdoor Dose	1,800
Fallout Arrival	14 minutes
Protection Factor	**10**
Optimum Departure Time	1 hour
Minimum Dose	95 rem

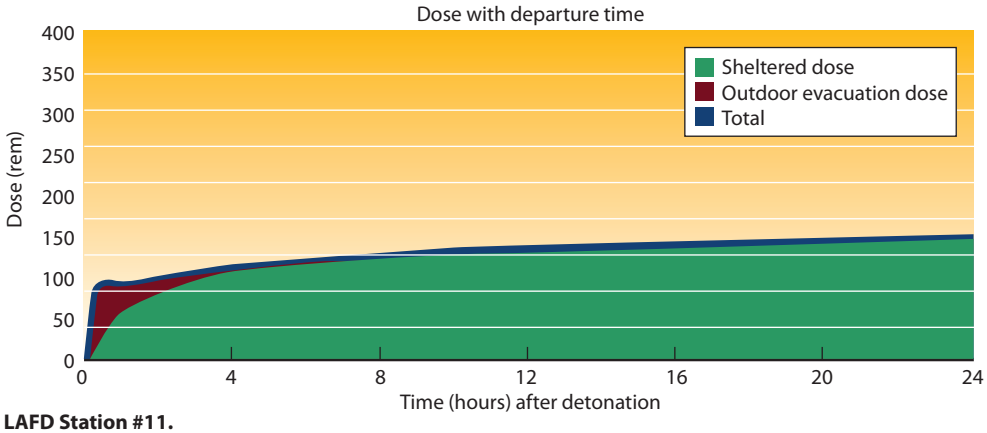


Figure 36. Exposures in adequate-quality shelter near LAFD Station #11.

Location	LAFD Station #11
Evacuation Distance	~0.5 mile
Dose Rate @ 1 hour	450 rem/hour
24-hour Outdoor Dose	1,800
Fallout Arrival	14 minutes
Protection Factor	**3**
Optimum Departure Time	immediate
Minimum Dose	none

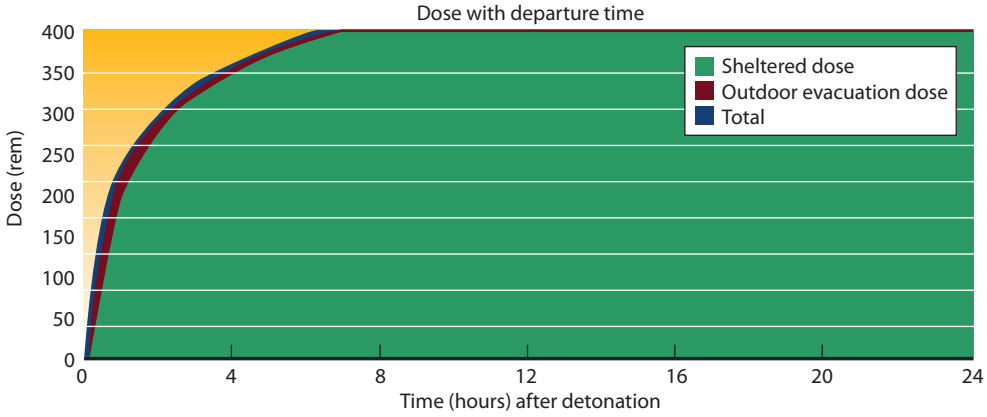


Figure 37. Exposures in inadequate-quality shelter near LAFD Station #11.

3.2.3 *Area Access*

An evaluation of the extent and movement of the 10-R/h high-hazard zone perimeter for the 10-kT Los Angeles scenario revealed similar features identified in the Washington, DC scenario despite the significantly different weather profile. The extent of the 10-R/h high-hazard zone perimeter grew rapidly over the first hour and reached its apex approximately an hour after detonation, having an extent of approximately 10 miles (15 km) and an area of 86 km^2. The high-hazard zone remained approximately the same size from one to two hours after detonation before beginning to shrink. The figures in Table 8 demonstrate the areas on the map that would be greater than 10 R/h (orange) overlaid on the blue circle, which shows the area in which windows are broken with enough force to cause injury.

Table 8. Areas with dose rates greater than 10 R/h over time.

Orange > 10 R/h, Light Blue = Blast Injury

Time after Detonation: 2 hours
Maximum Distance from Detonation: 9.8 miles (15.7 km)
Area with Contamination: 73.3 km^2
Original Daytime Population in Area: 500,000

Time after Detonation: 6 hours
Maximum Distance from Detonation: 4.8 miles (7.8 km)
Area with Contamination: 24.2 km^2
Original Daytime Population in Area: 250,000

Time after Detonation: 24 hours
Maximum Distance from Detonation: 1.7 miles (2.8 km)
Area with Contamination: 3.4 km^2
Original Daytime Population in Area: 100,000

Time after Detonation: 48 hours
Maximum Distance from Detonation: 1.1 miles (1.8 km)
Area with Contamination: 1.2 km^2
Original Daytime Population in Area: 50,000

GoogleEarth Data SIO, NOAA, U.S. Navy, NGA, GEBCO © 2009 Gray Buildings © 2009 CyberCity Image © City of Glendale

At two hours after detonation, the high-hazard zone has a workday population of approximately 500,000 people. This high-hazard zone will shrink rapidly over the coming hours and days, and by six hours after detonation it will only occupy a third of the area observed at two hours. After 24 hours, the impacted area will be down to 1/20 (5%) of the area, and after 48 hours, almost all areas outside of the major building damage zone will be below 10 R/h.

3.3 Summation of Results from Both Locations

A key issue for both scenarios is that the prompt-effect areas and fallout areas are not congruent (see Figure 38). Although they overlap, most of the area in which windows are shattered (creating blast injuries) will **not** be in fallout areas. Using the workday population data for Washington, DC, the area in which glass is broken with enough force to cause injury extends approximately three miles and could have as many as 750,000 people in it. Although it is likely that most of this population would not be harmed by flying missiles, it still represents a large area where significant blast injuries (trauma) could be generated. By contrast, the fallout area, in which there could be acute effects from radiation exposure (such as nausea and vomiting), extends past the Beltway about 10 miles downwind, but only overlaps a small fraction of the blast-injury area. Even in the bifurcated fallout pattern of the Los Angeles scenario, the majority of the potential blast injuries occur outside of

the hazardous fallout areas. The figure above depicts these separate but overlapping areas. The likely existence of these disjoint areas leads the authors to recommend that *after responders are assured of their own safety*, they should support regional situational assessment and provide local public safety support, including setting up, managing, and directing the general public to triage sites when safe evacuation routes and times are established.

Figure 38. Blast-effect and fallout areas overlap but are not congruent.

3.3.1 Optimum Shelter-Stay Time

The optimal evacuation plan for any location is event-specific (i.e., it cannot be formulated in advance) and would need to consider factors beyond those discussed in this document. However, the concept of minimizing the total dose exposure provides some useful planning guidance. The results for the study of specific locations in Los Angeles and Washington, DC scenarios are presented in Table 9.

Table 9. Optimum shelter-stay times for a variety of conditions and shelters.

Shelter Type	Washington, DC Centerline	Los Angeles St. Vincent Area	Los Angeles Near Boundary
PF 100	Shelter for 1 day	Shelter for 4 days	Shelter for 11 hours
PF 10	Shelter for 2 hours	Shelter for 5 hours	Shelter for 1 hour
PF 3	Shelter for 45 minutes	Shelter for 30 minutes	No Shelter

These results suggest the following considerations regarding sheltering versus evacuating:

- Except when victims *know* that they are near (or will be on) the border of the fallout area, they have a clear evacuation route, *and* there is no adequate shelter is available, sheltering should always be considered the first priority.
- Victims should seek the best possible shelter that can be reached *before fallout arrives*. Within a few miles of the detonation this may occur within 10 minutes, though further from the detonation location, there will be more time to obtain an adequate shelter.
- Optimum length of shelter stay depends on shelter quality, radiation dose rates outside the shelter, and the dose received during evacuation. For the specific cases examined in this document, optimal shelter stay times were:
  - One day or more in a good shelter (PF 100 or more).
  - A few hours in the minimally adequate shelter (PF 10).
  - Shortly after the fallout cloud passes for inadequate shelters (PF 3).
- Evacuating early (before 1 hour after detonation) can result in the highest (potentially lethal) exposures.
- For adequate shelters (PF 10 or greater), evacuating late may slightly increase the total dose, but this effect is often minor compared to the higher dose due to early departure. Thus, with respect to fallout hazards, individuals should err on the side of evacuating late.

3.3.2 Extent of High-Hazard Zone

Using the NCRP 10-R/h inner perimeter to define the high-hazard zone, the two scenarios revealed that for a 10-kT detonation:

- **In the first hour:** high-hazard zone rapidly expands.
- **Between the first and second hour:** high-hazard zone maintains approximate maximum extent.
- **Beyond the second hour:** contraction of high-hazard zone, resulting in halving the extent of the maximum size 5 or 6 hours after the detonation and allowing access to almost all areas outside the major building-damage area after a day.
- Responders who work for several hours in an area immediately after the radiation levels fall below 10 R/h would receive doses below the emergency working guidance for lifesaving (25 rem).

4.0 Discussion and Recommendations

The brilliant flash can be seen for hundreds of miles, and can temporarily blind individuals who are outdoors even miles from the explosion. The explosion turns several city blocks into rubble and breaks windows over 10 miles away. Dust and debris cloud the air within a mile of the detonation, and fallout that produces potentially lethal levels of radiation to those outdoors falls in the immediate area and up to 20 miles downwind.

Sections 4.1 and 4.2 describe response priorities for the public and responders, respectively. Note that the Executive Summary presents these same priorities in the form of lists addressed directly to the appropriate audience (the public and responders, respectively).

4.1 Public Response Priorities

It will be initially difficult for those directly impacted to assess the amount or 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 39).

The most critical lifesaving action for the public and responders is to seek adequate shelter (PF of 10 or more) for at least the first hour.

Individuals must be educated to resist the desire to immediately flee the area or attempt to reunite with family members as this can place people outside when the fallout exposures are the highest. Those outside or in vehicles have little protection from the penetrating radiation coming off the fallout particles as it accumulates on rooftops and the ground.

Sheltering is an early imperative for the public within the blast-damage area, which could extend for several miles in all directions from the detonation site. There is a chance that many parts of this area may not be impacted by the fallout, but it will be very difficult to distinguish fallout from the smoke, dust, and debris in the air caused by the blast wave. Figure 40, taken after the collapse of the World Trade Towers, shows how dust and debris can cloud the air and limit visibility after a large destructive event. Potentially dangerous levels of fallout could begin falling within 10 minutes.

Those outdoors should seek shelter in the nearest solid structure. Provided their structure is not in danger of collapse or fire, **those indoors should stay in** and move either below ground (e.g., subterranean parking garage) or to the middle floors of a multi-story building. Those in structures threatened by collapse or fire or in light structures (e.g., single-story buildings without basements) may consider moving to an adjacent solid structure or subway. Glass, displaced objects, and rubble in the walkways and streets will make movement difficult. Leaving the area should only be considered if required by medical necessity, the area becomes unsafe due to fire or other hazard, or if informed by local officials that it is safe to move.

Fallout is driven by upper atmosphere winds, which can travel much faster than surface winds. Outside the area of broken windows, people should have at least

Figure 39. Characteristic fallout-cloud shapes may only last a few minutes.

Figure 40. Dust and debris from the blast may cloud the air, limiting the ability to see and avoid fallout.

10 minutes before fallout arrives. If the detonation happens during daylight hours on a day without cloud cover, the fallout cloud may be visible at this distance, although accurately gauging direction may be difficult as the expanding cloud rises and may move in more than one direction (Figure 41).

Figure 41. Fallout clouds travel in multiple directions.

Provided that dust and debris does not obscure visibility, **dangerous levels of fallout are easily visible as it falls**, and people should proceed indoors immediately if sand, ash, or rain begins to fall in their area.

At 20 miles away, the delay between the flash of the explosion and the sonic boom of the air blast is more than 90 seconds. At this range it is unlikely that the fallout could cause radiation sickness, although outdoor exposure should still be avoided to reduce potential long-term cancer risk. The public at this distance may have some time, perhaps 20 minutes or more, to prepare. Short-term preparation can involve gathering batteries/radio, food, water, medicine, bedding, and toiletries. Individuals should identify the best shelter location in their building, or if the building they are in is an inadequate shelter, they may even have time to consider moving to better shelter if there is an underground area or large, multi-story building nearby.

Although the roads may not be obstructed at this range, attempts to evacuate a large population before the fallout arrives will likely result in traffic jams. As vehicles are inadequate shelters, this would result in a significant number of avoidable exposures.

4.2 Responder Priorities

The largest number of preventable casualties (injuries + fatalities) after the detonation comes from reducing the fallout exposure to the responders and the public, which can be accomplished through an informed shelter-and-evacuation strategy. Situational assessment is a key enabling element of this strategy, and activities such as identifying and communicating hazard zones must initially take precedence over fire fighting and first aid. Responders must balance the need to provide medical care to the individuals injured during initial nuclear explosion with the need to reduce the dose that the general public receives from fallout radiation.

4.2.1 Protect Response Personnel

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

Figure 42. Example high-range instruments for dose-rate assessment. (These are pictures of common radiation detection instruments as examples. The use of these images does not represent an endorsement by the authors.)

Responders should begin using their radiation-detection equipment and trying to establish communication with their dispatcher or other responders. Although any type of detector can provide some information, initial efforts should be spent on **making high-range dose-rate measurements** within their shelter (Figure 42). Provided exposure levels do

not exceed 10 R/h, surveys should be conducted near doors and windows. There will be low levels of contamination throughout the region, but the focus should be on measuring and reporting any doses above 10 R/h which requires the use of high range equipment or electronic dosimeters.

If dosimetry or self reading dosimeters are available, they should be prepared for use and distributed. Figure 43 provides an example of a pocket ionization chamber.

Radios outside of the major building-damage area should still function, although repeater towers may be affected. Efforts should be made to establish communication with other responders and with the area command centers to report local radiation levels. Responders should make sure to report the time at which the radiation reading was made, as radiation levels will change rapidly with time. With the situational assessment, responders should consider reporting the zone as a category, such as *cold* (outdoor exposure rates less then 10 mR/h), *hot* (greater than 10 mR/h), or *high hazard* (greater than 10 R/h), rather than the zone's exact readings. Identification of high-hazard zones (reading greater than 10 R/h) is a priority, but also important is reporting cold areas (reading less than 10 mR/h) for the determination of safe evacuation routes and response staging areas.

One of the first priorities is reconnaissance of the immediate area, including the following steps:

1. Identify and record location of local radiation levels. Turn back if exposure rates exceed 10 R/h.
2. Establish the detonation location. Limited visibility, the effects of the positive and negative pressure blast waves,[38] and blast-wave reflection may create a confusing environment where areas of potential higher hazards may not be readily apparent to those closest to the event (Figure 44).
3. Identify location of fires and other hazards (chemical leaks, downed live high voltage, natural gas leaks, etc.).
4. Identify location of impacted populations and anticipated assistance requirements.

Compile and report status and reconnaissance information. If communication is limited, consider sending a volunteer to the nearest station in the opposite direction of the detonation location. This information will be critical to enable zone definition and response strategy.

4.2.2 Support Regional Situational Assessment

After the first few hours, the fallout cloud has likely left the area and the high-hazard fallout area can be defined. During this period, models, visual observations, and a few measurements can be used to define the high-hazard fallout, severe, moderate, and light damage areas. Uncontrolled fires will burn in some of the buildings surrounding the site.

Priorities include:

- Regional situational-awareness hazard-zone identified.
- Area Command established and coordinated regional response.
- Zone- and situation-specific guidance developed for population.

The high-hazard zone is unlikely to expand significantly beyond the first hour. Once the general direction(s) and magnitude of fallout have been determined, responders that are not in harm's way should perform time-sensitive, critical missions.

4.2.2.1 Defining Zones

As past of situation assessment, responders should define the three different zones associated with the detonation. Figure 45

Figure 43. Self reading dosimeters.

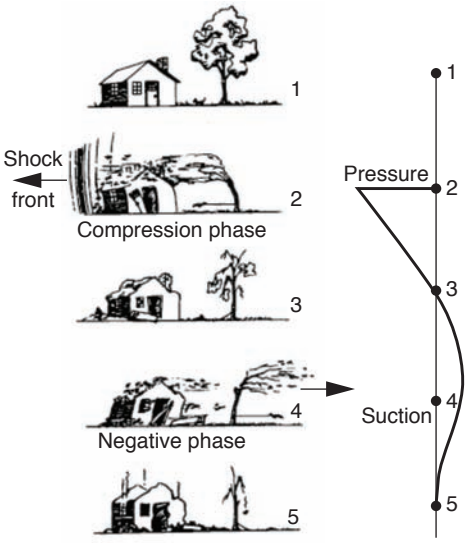


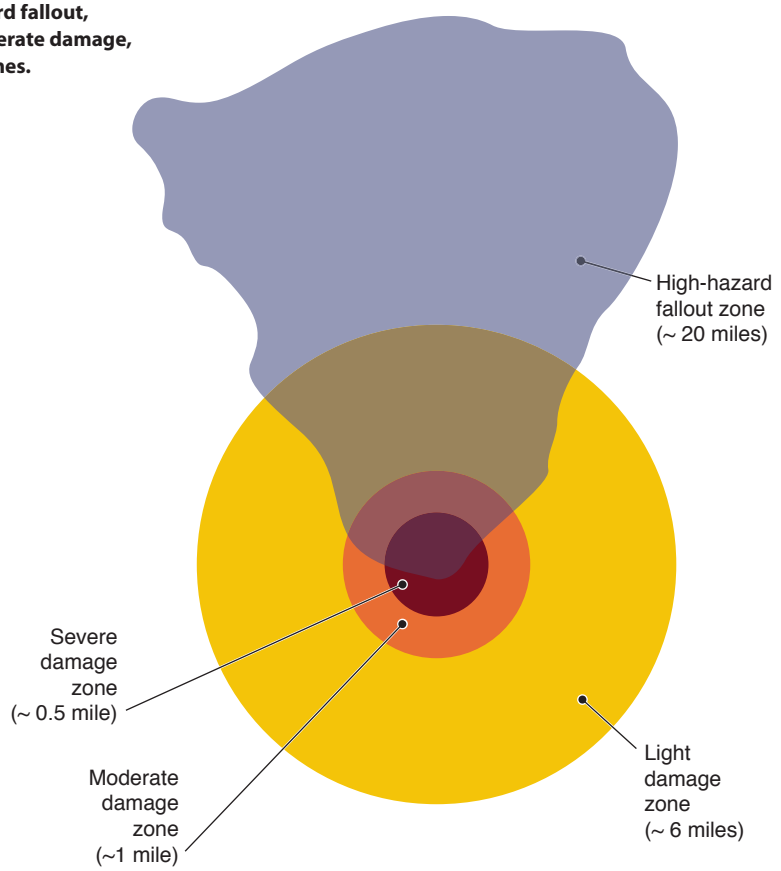
Figure 44. Positive and negative pressure waves can create a confusing debris pattern.

shows how the three damage zones fit together around the central detonation point. The zones described in this document are similar to the definitions described in the recently published *Planning Guidance for Response to a Nuclear Detonation*, which was produced in collaboration with this effort.[39]

Defining the *High-Hazard Fallout Zone.* This area is defined by the potential for fallout contamination levels that might represent an immediate hazard to those outside. Initial observations will have large uncertainty, but there should be enough information to define a downwind area of concern. Until detailed measurements can be made, this area can be conservatively defined as extending 20 miles downwind in a "keyhole" pattern (Figure 45). This zone is characterized by:

- Potentially dangerous levels of fallout on the ground, including outdoor exposure rates that will exceed 10 R/h.
- A recommended initial overestimate of the hazard area, which can be reduced with time as more information becomes available and fallout radiation levels decrease.
- Some blast/burn injuries near the detonation site.
- Areas far from the detonation site with no apparent damage.

Figure 45. High-hazard fallout, severe damage, moderate damage, and light damage zones.



Defining the *Severe Damage Zone*. This is the area immediately around the detonation site that has suffered severe building damage and may also have significant local fallout. It may extend a half-mile from the detonation in the example of a 10-kT ground detonation and is defined by a high level of destruction and large amounts of rubble. Even at the edge of this area, cars will be overturned, and about half the light structures will have been destroyed. There may be survivors who were in the center of very robust buildings at the time of detonation, but most people in this area will likely receive fatal injuries from blast effects or prompt radiation.

Defining the *Moderate Damage Zone.* This area is ***outside*** of the severe damage zone, but still significantly affected by the blast (Figure 46). This area is close enough that there may also be crush trauma for building collapse, flying debris, and tumbling. Many who were outdoors within a mile of the detonation could have also received a significant radiation exposure or may have radiation burns. There may also be a significant number of the buildings on fire within this zone. This zone is characterized by:

- Breakage of almost all windows and significant blast and missiling injury.
- Some collapsed buildings (particularly light buildings).
- Possible burn and radiation injuries.

Defining the *Light Damage Zone.* This area is outside of the medium damage zone but is still affected by the blast and close enough that more than 25% of the windows are broken. For a 10-kT detonation, this may extend beyond six miles, and is characterized mostly by glass injuries and possibly by traffic accidents.

Most of the medium and light damage zones are not in a fallout hazard. They can safely evacuate after it is determined that they are not in the high-hazard fallout zone, but it should not be a priority for evacuation support except for areas threatened by fire or other hazards or for those needing immediate medical assistance. Medical assistance can be provided to those outside of the high-hazard fallout zone, and efforts should be prioritized to the moderate damage zones that have the greatest number of significant injuries.

4.2.3 Support Public Safety

Establishment of triage and casualty reception sites is particularly important to injured populations in the moderate damage zone. Initial mass-casualty triage sites are ad hoc and will be closest to the affected area, often at the head of evacuation routes. These sites may be established by local residents or responders based on convenient, safe, and adequately sheltered staging areas. Setting up near hospitals, pharmacies, grocery, or clothing stores will help provide bandages, water, clothing, and shoes for staff and evacuees.

Reception centers should be located several miles 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, and schools/universities) should be used, especially those with good roadway access and large parking lots/structures that can be used for federal resource staging and aviation support.

4.2.4 Execute an Informed Evacuation Strategy

Developing an informed evacuation strategy is an early priority for local emergency management. The overall evacuation strategy is to keep radiation exposures as low as possible and prioritize evacuation for impacted populations who are in unsafe shelter locations, either due to inadequate shelter or other life-safety issues. Those within the high-hazard fallout zone should plan on evacuations using the shortest possible path out of the zone after having sheltered for at least the first hour.

Evacuation support may be required as glass, building facades, and rooftop mechanical equipment can create significant obstructions on roads within a few miles of the detonation site, forcing evacuees to walk out and creating hazardous walking conditions. Volunteers should be used to identify and create safe passages when it is safe to do so. Possible alternate evacuation routes can include subterranean areas or through large intact structures.

Once the zones above have been identified, an early priority for evacuation is those who are threatened by non-fallout hazards (fire, toxic materials, building collapse) or are in the high-hazard fallout area in inadequate shelters.

Monitoring and decontamination sites can be stand-alone or collocated with reception centers. Decontamination of nuclear fallout should be focused on those leaving (or traveling through) the **high-hazard fallout zone**. It is expected that the fallout particles will be relatively easy to brush off or be removed by changing shoes and clothing. Those outside while the fallout was accumulating should also consider washing hair and exposed skin. Because fallout contamination decays rapidly, it is most hazardous in the first few minutes and hours after contamination. Given this time constraint, the large number of potential victims, and resources required to support a formal decontamination process, simple self-decontamination techniques (such as removing outer clothing, showering, and brushing away fallout material) should be utilized as the impacted population leaves the high-hazard zone or enters a shelter.

4.2.5 Control Fires

Controlling fires will be important for the safety of those currently sheltered in the hazardous areas. Several hundred fires can be expected within a few a miles of the detonation site. Although modern building materials and construction codes may reduce the possibility of a firestorm,[40] spot fires caused by disruptions of the blast may spread or combine to cause conflagrations that can be hazardous to those sheltered in the area. Extinguishing fires near the detonation site may be difficult due to lack of water pressure (water mains may be broken during the initial blast) 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:

1. Watch for firestorm warning signs, such as fires coalescing and smoke plumes that begin to lean over toward the fire. Rapidly evacuate areas (even in the high-hazard fallout region) near developing firestorms.
2. Prioritize facilitated evacuation (especially non-ambulatory populations) near large fires that have the potential to rapidly spread or turn into firestorms.
3. Use airborne fire-control methods to reduce the spread of fires, especially in high-hazard fallout zones, where evacuation may be unsafe.

5.0 Conclusion

If a nuclear detonation were to occur in a modern US city, the greatest reduction of casualties could be achieved through rapid actions taken by citizens supported by information and prompt actions by their state and local officials. Unfortunately, most response organizations (and the general public) currently lack fundamental awareness and planning to make informed decisions following a nuclear event. This planning is needed due to both the short time available for critical decisions and the extensive area impacted. Given the daytime population density of a large modern city, the number that would be hurt by prompt effects or threatened by fallout could easily be in the hundreds of thousands. However, the number of casualties can be significantly reduced by taking appropriate response actions and community pre-event planning at the local level. The largest potential for reduction in casualties comes from reducing exposure fallout radiation which is accomplished through early, adequate sheltering followed by informed, delayed evacuation. A well organized response will allow for timely medical intervention which would greatly improve the prognosis of the injured.[41–49]

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