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Nuclear Detonation Fallout: Key Considerations for Internal Exposure and Population Monitoring

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Introduction

Context

The potential for detonation of a low-yield Improvised Nuclear Device (IND) in a major U.S. urban area is a significant national concern. The Department of Homeland Security Federal Emergency Management Agency (FEMA) is providing technical guidance for regional, state and local responders who have responsibility for developing local IND response plans. Fallout exposure represents the greatest preventable injury after a nuclear detonation.

Fallout Composition

A nuclear explosion can produce fallout, which is generated when dust and debris created by the explosion are combined with radioactive fission products and drawn upward into the cloud produced by the detonation. Due to the heat of the explosion, the cloud rapidly climbs through the atmosphere, potentially reaching heights of 5 miles (8 km) for a 10-kt explosion, and forming a mushroom cloud under ideal conditions. Highly radioactive particles drop back down to earth as the cloud cools.

Although only a small physical quantity of radioactive material is produced in a nuclear detonation by the nuclear fission process, about 20 ounces (1¼ lb) for a 10-kt device, this material is ***highly*** radioactive. One minute after the explosion, there are almost 300 billion Curies present (Glasstone, 1977). This is more than 1,000 times the activity of material released from the Fukushima or Chernobyl accidents. However, unlike nuclear power plant accidents, the majority of fission products released from a nuclear detonation tend to be short lived. **Figure 1** and **Table 1** provides an example of just a ***few*** of the hundreds of radionuclides produced in the explosion and how their relative exposure contribution changes over time.[1] Radionuclides with short half-lives will dominate the exposure in the first few seconds, but then decay away.

[1] Produced by Livermore's Weapon Activation Code (LWAC).

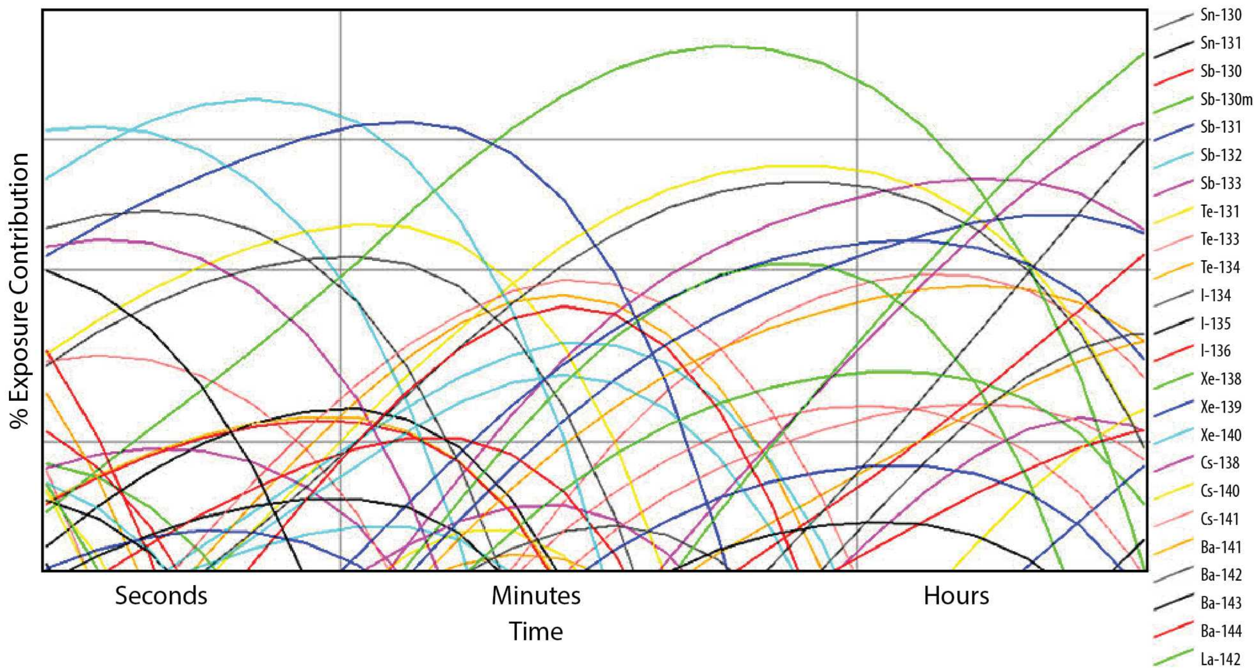


Figure 1. Examples of how nuclear fission product radionuclides change over time. Each line represents the growth and decay of a different radionuclide, a few of which are displayed in the legend.

Table 1 below provides some examples at specific times of the primary fallout activity contributors. Radionuclides that contribute less than 1% were not included.

Table 1: Primary Fallout Activity Contribution at 3 different times

Isotope	Half Life	Activity % @ 100 days	Activity % @ 1 year	Activity % @ 10 years
Sr-89	50 d	11%	3%	
Sr-90	29 y	0.2%	3%	**36%**
Y-91	59 d	**22%**	7%	
Zr-95	66 d	**19%**	2%	
Ru-103	40 d	**19%**	2%	
Ru-106	369 d	3%	**24%**	0.5%
Cs-137	30 y	0.3%	3%	**46%**
Ce-141	33 d	14%	0.7%	
Ce-144	284 d	8%	**34%**	0.2%
Pm-147	2.6 y	1.4%	13%	14%

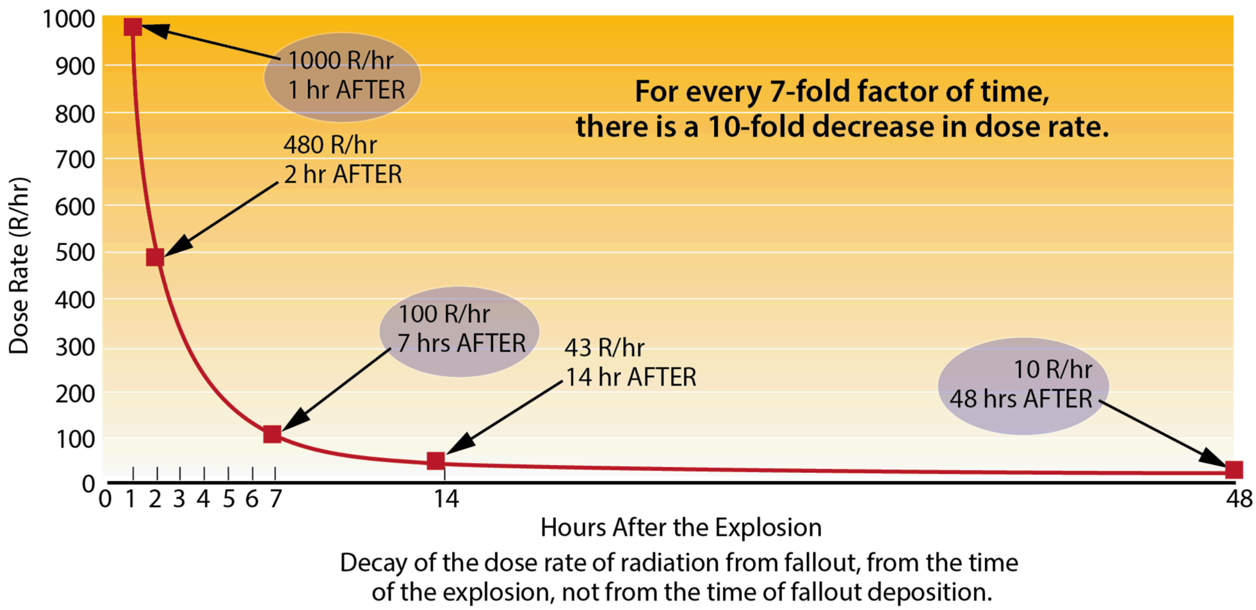


Figure 2. Decay of the dose rate of radiation from fallout (from the time of the explosion, not from the time of fallout deposition).

Because of the large amount of short-lived fission products, the activity (and the radiation) levels decrease rapidly with time. Fallout gives off more than 50% of its energy in the first hour and continues to decay rapidly even after that initial hour. **Figure 2** shows how radiation levels from fallout continue to decrease with time. For this example, an arbitrary 1-hour starting value of 1,000 R/hr was used.

Although the dangerous radiation levels will subside rapidly over the first few days, residual radiation from the long half-life fission products (such as ^{90}Sr, ^{106}Ru, ^{137}Cs, ^{147}Pm, and ^{155}Eu) will become the main contribution to exposure (after about 10 years).

As the fireball cools, the highly radioactive fission products coalesce on the thousands of tons of dirt and debris pulled up by the heat of the fireball. **Figure 3** shows fallout particles from nuclear tests.

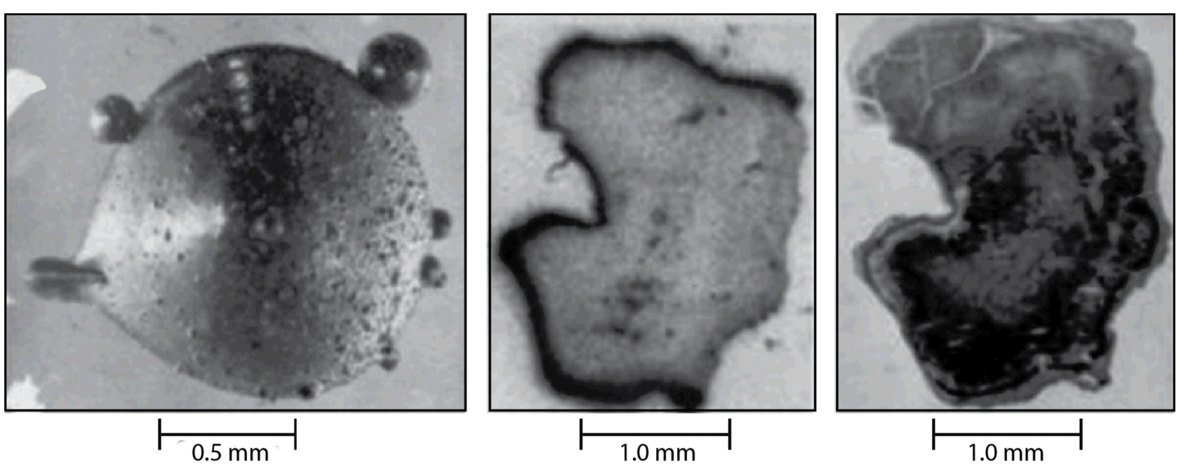


Figure 3. Fallout particles encompass a diverse range of shapes and sizes. The radioactive material coats the outside of the particle as seen by the dark edges of the rightmost image when the particle was left on unexposed film.

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

Dangerous levels of fallout can create visible dust and debris, so visible fallout can be used as an indicator of a direct radiation hazard (however, fallout might **not** be readily noticeable on rough or dirty surfaces after it has accumulated on the ground). The particles emit penetrating radiation that can injure people (even in cars or within poor shelters).

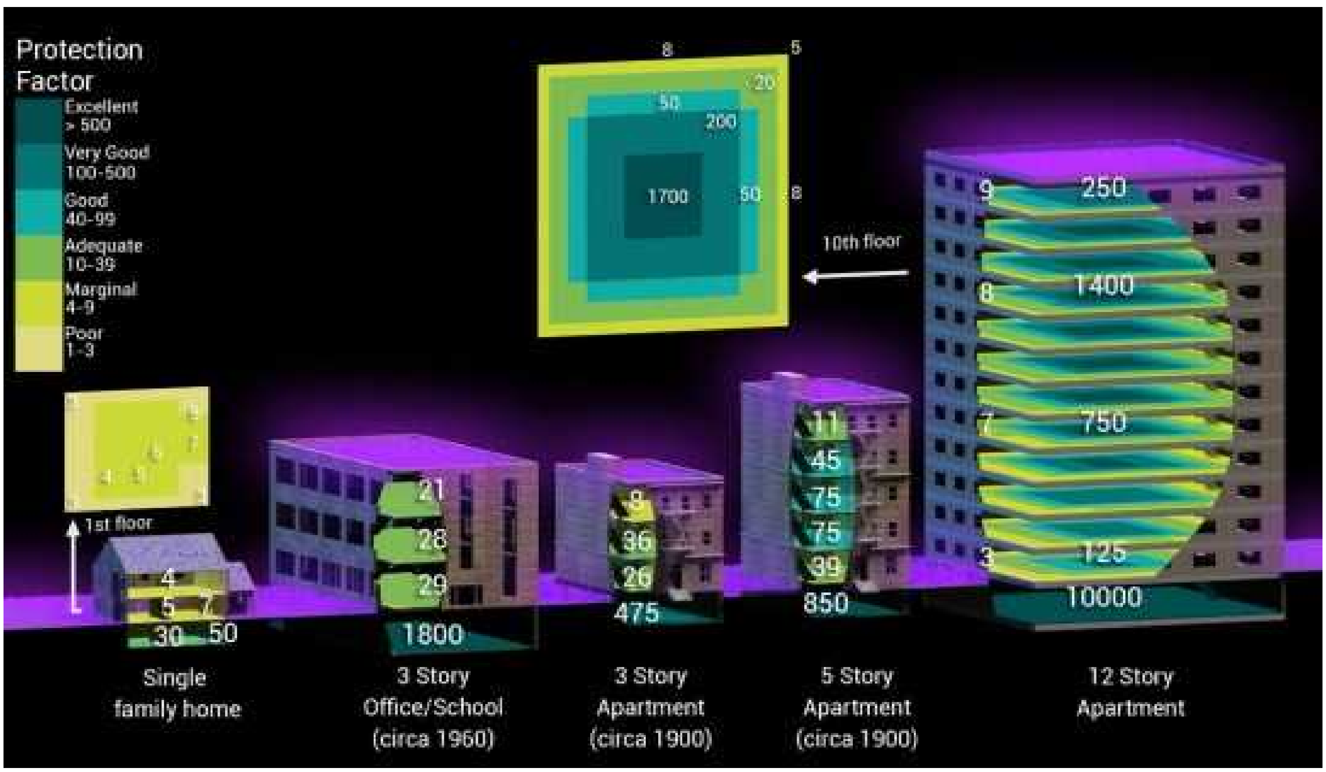
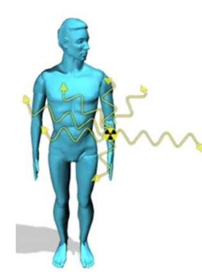


Figure 4: An artist's illustration of locations where fallout will accumulate and the resulting hazard (shown as a purple glow).

External vs. Internal Exposure

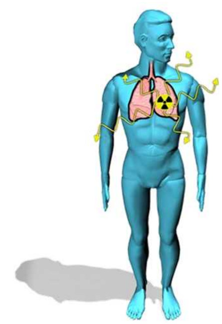
External exposure occurs when the source of the radiation is outside the body. This can include exposure from a point source, ground contamination, a passing cloud of radioactive material, or even contamination on the outside of the body. Removing the person from the radioactive environment (or the contamination from the clothing or skin) will stop the exposure.



The dose is determined by the amount of radiation energy absorbed by the body.

Once fallout particles reach the ground, the primary hazard arises from external exposure to penetrating gamma rays released from the decaying particles, rather than from breathing or ingestion. Gamma rays are photons, like x-rays, that can "shine" through clothing, walls, protective suits, cars, and inadequate shelters. Error! Reference source not found. illustrates the most hazardous areas due to fallout particles landing on rooftops and the ground.

Internal exposures occur when radioactive material gets into the body from either inhalation, ingestions, absorption through the skin, or injection at the site of a wound. Internal exposure from nuclear detonation fallout is not a primary concern during the emergency phase of the response. This is due to several important factors:



1) Early fallout particles tends to be large particles (salt and sand sized) and not easily inhaled
2) The rapid, early decay of fallout means that any particles taking into the body do not generate long term exposures.
3) As a ***relative*** hazard, internal exposures are generally orders of magnitude below external exposures.

The 1988 Health Physics Society Journal Article by I. Levanon and A. Pernick evaluated the inhalation hazard of fallout particles from a nuclear ground burst using ICRP Lung Model and the DELFlC fallout model for the 0.5-kt to 10-Mt yield range. It was found that inhalation of fallout particles does not present a significant radiological hazard. Figure 6 from their paper demonstrates this by comparing the 3 different doses (external from deposited fallout, external from passing cloud, and internal from inhalation during cloud passage) for several yields. The dose from inhalation was generally orders of magnitude smaller than the external exposures and even at their highest (within a few km of a 1MT detonation) was 0.01 Sv (1 rem).

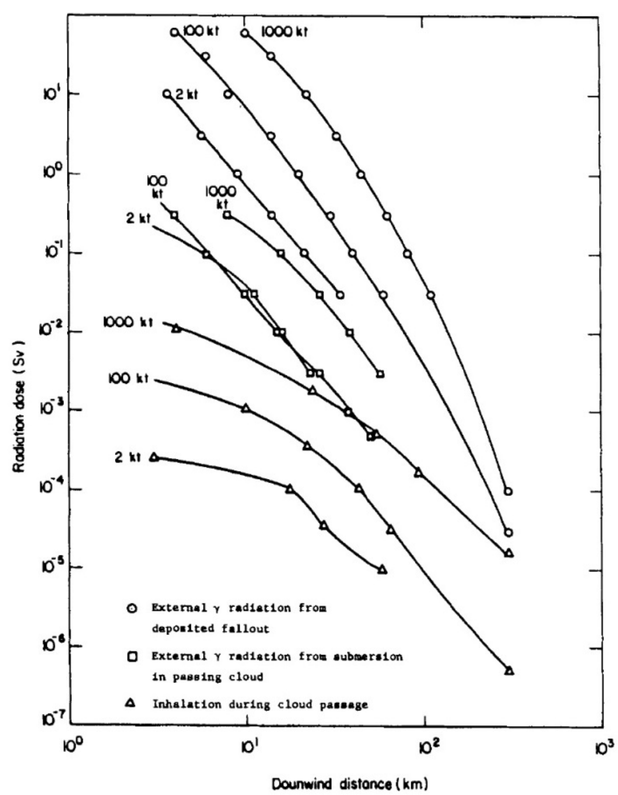


Figure 5: Contributions of different radiation exposure mechanisms as a function of downwind distance from ground (Levanon, 1988)

The conclusions of their analysis are as follows: "***The inhalation hazard of fallout particles reaching ground level by gravitational and diffusive deposition was evaluated by means of the ICRP Task Force Lung Model (ICRP79; TGLD66) and the DELFIC fallout model (To68; No71; No79a). The results establish that the inhalation of fallout particles from a ground***

burst in the 0.5-kt to 10-Mt yield range does not constitute a radiological hazard, even under the conservative meterological conditions used in this study. The results are consistent with experimental evidence."

A follow up 1992 Health Physics Society Journal Article by Kendall R. Peterson and Charles S. Shapiro built on this analysis by comparing external fallout doses to internal doses from ingestion of contaminated food and water consumed in the years following a nuclear war (where it was assumed alternate food was not available). Even with these conservative assumptions their conclusion was ***"the average American family that survived a large-scale nuclear war, using its own home or workplace as a refuge, could receive a total internal dose from ingestion of the four most important radioisotopes that was less than 1 % of the total external dose. Those who stayed where shelter protection factors and contaminated foraged food consumption rates were large could receive internal doses that are typically from 2% to 20% of the external dose. Even with the considerable uncertainties in these dose estimates, the total dose from early fallout is dominated by the external dose in almost all cases of interest."*** The table below was taken from their report:

Table 3. Internal and external whole-body equivalent dose for 10 locations in the United States.

Location	Shelter factor	External dose (Sv)	Internal dose (Sv)	Total dose (Sv)	Ratio of internal to external dose
1. St. Louis, MO	7	3.7	0.066	3.8	0.02
2. Cincinnati, OH	4	0.87	0.0054	0.88	0.006
3. Buffalo, NY	3	1.9	0.010	1.9	0.005
4. International Falls, MN	2.5	2.6	0.0	2.6	0
5. Sidney, MT	5	5.6	0.17	5.8	0.03
6. Memphis, TN	200	0.15	0.033	0.18	0.2
7. Phoenix, AZ	2	2.3	0.033	2.3	0.01
8. Washington, DC	2	0.39	0.0033	0.39	0.008
9. Milwaukee, WI	100	0.28	0.027	0.31	0.1
10. Des Moines, IA	1.5	1.9	0.0013	1.9	0.0007

More recent work by Applied Research Associates (Dudley A. Raine, III, Kyle Millage, & Gene E. McClellan; ARA-TR-09-SEASSP-17176-010) demonstrated that even with conservative assumptions that all fallout was respirable, the internal dose was negligible compared to external exposures. Here is the report's conclusion:

"***This analysis provides guidance on the relative importance of internal doses from the inhalation and ingestion of fallout compared to external doses and blast and prompt radiation effects from a 10-kT nuclear detonation. Based on a scenario that assumes a person remains in the path of the descending fallout until it ends and using a mean particle size distribution that individually maximizes the dose from each radionuclide species, the total 50-year CEDEs from the inhalation of fallout are all less than 2.0 rem."***

The report also looked at ingestion concerns with the conservative assumption that a plate of food was consumed after being left outside during fallout accumulation and found similar results. These results were presented at the 2009 Health Physics Society Meeting and the following assessment of doses from 3 different locations (denoted by their peak intensity dose rate) downwind from a 10kT nuclear detonation was provided:

Dose Type	1000 R/hr	100 R/hr	10 R/hr
External (R) (to H+48)	1900	480	100
Descending Internal CEDE (rem)*	0.14	0.15	0.09
Resuspended Internal CEDE to H+48 (rem)*	1.1	0.39	0.12
Ingested Internal CEDE (rem)	46	13	3

* Worst case fission type assumed

As a more practical example, tests conducted at the Nevada Test Site where troops were deployed into the fallout for troop readiness drills had the following exposure calculations:

Residual radiation doses ranged from 0.04 rem (Shot Grable, BCT-A) to 3.1 rem (Shot Simon, BCT-A). Doses of about 2 rem were accrued by BCT-8, Shot Simon, elements of BCT-B, Shot Gable, and lead elements of BCT-B, Shot Nancy. In the latter instance, the 2.5 R/hr limit on gamma intensity was inadvertently exceeded (to 14 R/hr), but withdrawal to permissible levels was achieved quickly enough that a substantial dose was avoided. The Grable elements, for whom there were no intensity restrictions, were also exposed to 14 R/hr, at an equipment display line briefly visited.

The 50-year dose commitment to the whole body or bone from inhaled radionuclides was derived from Reference 22 to be less than 0.001 rem, except for BCT-8 at Shot Gable. Calculated commitments are 0.01 and 0.05 rem for elements of this BCT.

In other words, troops marching in fresh (hours old) fallout, in dry dessert conditions (in some cases with dust storms that limited visibility) in radiation fields up to 14 R/hr had ***external*** dose calculations of 0.04 rem to 3.1 rem, while ***internal*** doses were only 0.001 rem to 0.05 rem. More information can be found in DNA-TR-84-303 "ANALVSIS OF RADIATION EXPOSURE FOR MANEUVER UNITS: Exercise Desert Rock V, Operation Upshot-Knothole"

The First Few Days

A hypothetical 10kt detonation in New York City with fallout being driven by observed weather from noon (EST) on August 14, 2009 was used to generate Error! Reference source not found. Handheld survey equipment has the ability to measure radiation at very low levels, far below any immediate health threat. Unfortunately, there is a perception that all of the radioactive material is contained within the Hot Zone, which may be the case for a small HAZMAT spill on the roadway but is not true for an event of the magnitude of a nuclear detonation. Rather, the NCRP Hot Zone simply defines an area in the continuum of contamination where controls to reduce responder (and public) exposure are warranted. Figure 6 depicts the area of detectable contamination (0.0001 R/hr, which is 2–4 times background levels) in the region 24 hours after the event.

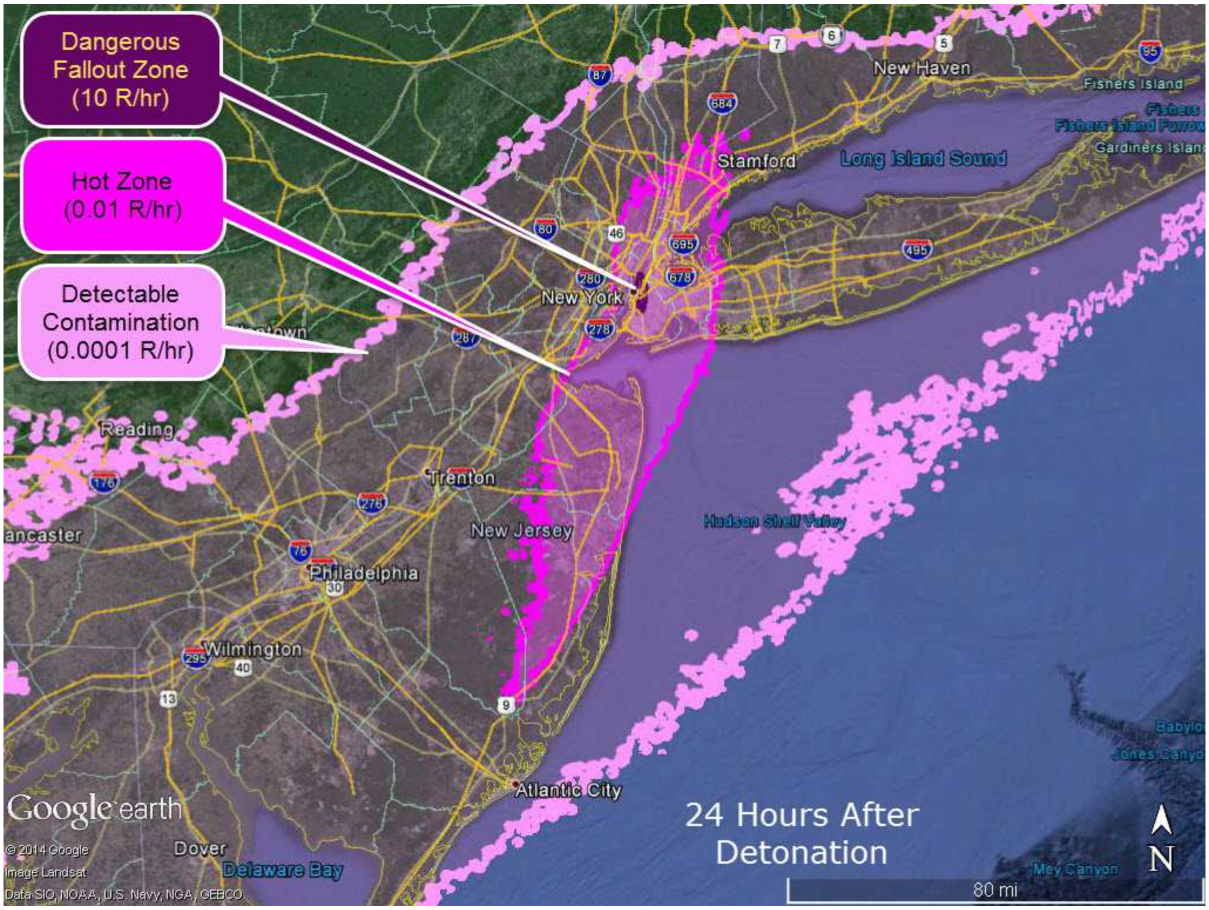


Figure 6: Areas of detectable contamination 24 hours after the detonation.

Nuclear Detonation Fallout Decontamination

Military operations conducted at the Nevada Test Site (NTS) 30 minutes after above-ground nuclear detonations demonstrated that simple brushing and wiping can be effective at removing fallout particles (Figure 7). Fallout consists of large particles that can be easily brushed off clothing and shoes. The radiation energy given off by fallout particles decays rapidly with time, for this reason early gross decontaminated (brushing for example) is better than delayed thorough decontamination (such as a shower).

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

Self-Decontamination instruction can be found in FEMA's Improvised Nuclear Device Response and Recovery; Communicating in the Immediate Aftermath (FEMA, 2013). Limited response resources should not be used on extensive population monitoring and decontamination operations in the first few days. **Decontamination sites** can be stand-alone or co-located with reception centers or transportation hubs and should focused on those left (or traveled through) the DFZ. Consider placement near sources of replacement footwear and clothing.

As demonstrated by Figure 6, **low levels of contamination will be present throughout the region** outside of the Hot Zone. For fallout contamination from nuclear test performed in the Nevada Desert, simply brushing off clothing and exposed skin was sufficient (figure 7). If additional decontamination is required, efforts should focus on removing or replacing shoes and outer clothing and washing or wiping exposed skin and hair (which is why access to quantities of clothing is an important location consideration, especially in winter).

Monitoring is not required, but if it is performed then rapidly (< 30 seconds per person) scan for any immediately evident increased radiation. For very large numbers of evacuees, scan just hands and feet.

Intermediate Phase

As the event progresses past the first few days, the fallout decay rate will slow and there may be more resources and time for monitoring and decontamination.

General observations:

- Unlike many chemical and biological events, being contaminated with fallout is not immediately life threatening to the population or the responders who assist them.
- There will be large numbers (perhaps over a million) of people from fallout contaminated areas who may have some level of detectable contamination.
- Fallout contamination decays rapidly (giving off > 80% of its energy in the first day) so early, gross decontamination (such as removing/changing outer layer of clothing) is far more effective than a delayed, if more thorough, wash down.
- Fallout is likely to be salt and sand sized particles, like dirt, that can be easily removed with brushing and gentle wiping.
- Monitoring equipment and response resources will be critically limited in the initial days after a detonation, for this reason self-decontamination methods are preferred.
- Mass decontamination (i.e. fire hose wash down) techniques used in colder climates can result in more casualties from hypothermia than would have occurred from contamination.

Key Recommendations:

- Primary population decontamination after a nuclear detonation should focus on self-decontamination. Appropriate messaging can be found in "Improvised Nuclear Device Response and Recovery Communicating in the Immediate Aftermath"
- Initially, monitoring equipment/personnel should be used for responder safety, hazard mapping, and search and rescue activities. Mass population monitoring stations should be considered a secondary priority.
- Medical treatment should never be delayed due to contamination concerns. Contamination should be considered the lowest medical priority.
- Shelter should never be denied due to contamination concerns.
- As resources become available and delayed, deliberate evacuations are initiated; monitoring and decontamination sites can be established, preferably close to the outer boundary of the Hot Zone and at locations with replacement clothing and shoes.
- As monitoring resources become available, initial efforts should focus on rapid screening for contamination levels which represent a priority for decontamination. The references below provide a wide variety of potential screening values (from 0.1 mR/h to 10 mR/hr), but the key issue is the speed at which people can be screened. Frisking times for screening levels should be < 30 seconds to ensure adequate throughput. Generally this would be 1mR/h or 10 mR/hr, See Contamination Monitoring Guidance for Portable Instruments Used for Radiological Emergency Response to Nuclear Power Plant Accidents, Federal Emergency Management Agency, FEMA-REP-22, October 2002 for more information.

Overview of Population Monitoring Concepts

In the aftermath of a large-scale radiological release, there will be a need to assess large groups of individuals and prioritize their care from immediate medical needs to potential long-term effects resulting from the radiological incident. Population monitoring is defined by the CDC as the tasks required to "identify, screen, measure and monitor populations (people and their pets) for exposure to radiation or contamination from radioactive materials". As always, life threatening medical issues take priority of contamination issues. With the needs of large groups to be addressed, it is recognized that self-decontamination can provide many benefits (CRCPD, NCRP 165, NCRP 166, CDC). The criteria used to assess the remaining population may vary but requires that the technique specified incorporate the instrument detectability and survey technique into the assessment. Regardless of the approach utilized to manage large groups, it will be important to pair it with public messaging that provides clear instructions and helps to reduce the stress that comes with incidents. For incident specific Recommendations, contact the Advisory Team for Environment, Food and Health (A-Team).

Contamination Detection Methods

Although most of the population monitoring focus is devoted to the level of the contamination on people as determined by the decision levels noted on the next few pages, the biggest influence on the level of contamination detected is mostly dependent on the instrument and method used for primary detection.

Rapid Contamination Detection Method for nuclear detonation fallout, if potentially contaminated with fallout from a nuclear detonation, early gross decontamination is more important than radiation screening. If trying to identify significantly contaminated individuals in a resource constrained environment, use the IAEA Criteria for screening of groups and locations [10 mR/hr (100 μSv/h) at 1 m].

When more resources are available for screening, use the IAEA general monitoring criteria of 0.1 mR/hr (1 μSv/h) at 10 cm.

Key Quotes:

"Skin or wound contamination is never immediately life threatening to affected people or medical personnel"
~ International Commission on Radiological Protection, report # 96

"rescue and medical emergencies take precedence over radiological concerns"

"..radioactive material contamination rarely represents an immediate danger to the health of the victim or the responder. This reduces the immediacy of the need for decontamination and allows the emergency response community greater flexibility in selecting decontamination options"
~ National Council on Radiation Protection and Measurements, Commentary # 19

"The initial screening criteria must focus on preventing acute health effects and must take into account the magnitude of the incident and availability of resources."
~ CDC's 2014 document "Population Monitoring in Radiation Emergencies: A Guide for State and Local Public Health Planners;"

Key References

Centers for Disease Control and Prevention (CDC), ***Population Monitoring in Radiation Emergencies: A Guide for State and Local Public Health Planners***, 2014, 75 pages:

1. **The first priority is to save lives: respond to and treat the injured first.** Treatment of life- or limb-threatening medical conditions should take precedence over decontamination. Standard Precautions are generally adequate to provide protection for first responders, emergency medical personnel, and clinicians.

2. **Contamination with radioactive materials is not immediately life-threatening**. Decontamination procedures are straightforward; removing clothing and washing the body thoroughly with mild soap and water will eliminate most external contamination.

3. **Initial population monitoring activities should focus on preventing acute radiation health effects.** Cross-contamination issues are a secondary concern, especially when the contaminated area or the affected population is large.

4. **Scalability and flexibility are important parts of the planning process**. The criteria used for contamination screening and the radiation survey methods may have to be adjusted to accommodate the magnitude of the incident and availability of resources.

5. **Fear of radiation is high, perhaps higher than with other agents of terrorism.** Providing information and clear communication prior to and during an incident will help allay fears and allow people to make appropriate response decisions.

6. **A key resource for implementing activities described in this guide is a state's lead agency for radiation control**. Additional expertise and resources to plan for and respond to a radiation incident can be obtained from radiation protection professionals in each community. Local emergency response plans should identify experts such as health physicists or radiation safety officers in area health departments, environmental agencies, hospitals, and universities. Relationships with these experts should be established in the planning stages.

7. **First responders and local officials may not be aware initially that a radiation incident has occurred**. Public health and emergency personnel's initial response to an incident may be an all-hazards approach. However, once these personnel have determined that radiation or radioactive material is involved, they must begin addressing the issues related to this type of incident.

8. **Radiological decontamination recommendations differ from those for chemical or biological agents**. Decontamination for chemical or biological agents must be performed immediately. In a radiation emergency, people may be advised to self-decontaminate at home or at a community

reception center. Decontamination should be done as soon as possible, but it usually does not require the same immediacy as chemical or biological contamination does.

9. **Law enforcement agencies will be involved in response to a radiological terrorism incident.** If a radiation incident is the result of a terrorist attack, the site will be considered a crime scene. Close coordination with local, state, tribal, and federal law enforcement agencies will be required to manage the public health response, because both public health and law enforcement personnel will need to conduct operations in the same area.

From the 2010 (2nd Edition) ***National Planning Guidance for Response to a Nuclear Detonation***:

Radioactive contamination is not immediately life threatening.

1. **Identification of individuals whose health is in immediate danger and require urgent care is the immediate priority of any population monitoring activity**. Near the incident scene, this monitoring need is accomplished as part of the medical triage already described in Chapter 4. Management of serious injury takes precedence over radiological decontamination.

2. **The primary purpose of population monitoring, following a nuclear detonation, is detection and removal of external contamination.** In most cases external decontamination can be self-performed, if straightforward instructions are provided. There are two types of decontamination. External decontamination removes *fallout* particles and other radioactive debris from clothes and external surface of the body. Internal decontamination, if needed, requires medical treatment to reduce the amount of radioactivity in the body.

3. **Prevention of acute radiation health effects should be the primary concern when monitoring for radioactive contamination**. Population monitoring personnel should offer or recommend gross external decontamination such as brushing away dust or removal of outer clothing. Cross-contamination issues (e.g., from transport vehicles) are of secondary concern, especially in a nuclear emergency where the contaminated area and the potentially impacted population are large.

4. **Population monitoring and decontamination activities should remain flexible and scalable to reflect the available resources and competing priorities**. For example, if water is a scarce commodity or is needed to fight fires, dry methods can be used for decontamination. Moist wipes can be used to wipe the face and hands in addition to a change of outer clothing. Instead of pouring water as in a shower, small amounts of water can be used to wet paper towels and clean the skin.

5. **Radioactive contamination is not *immediately* life threatening**. Individuals who are self-evacuating may be advised to self-decontaminate. Suggestions for monitoring and decontamination in this chapter assume radioactivity is the only contaminant and that there are no chemical or contagious biological agents present.

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