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National Nuclear Security Administration

Nuclear Detonation Response Training
Shelter and Evacuation

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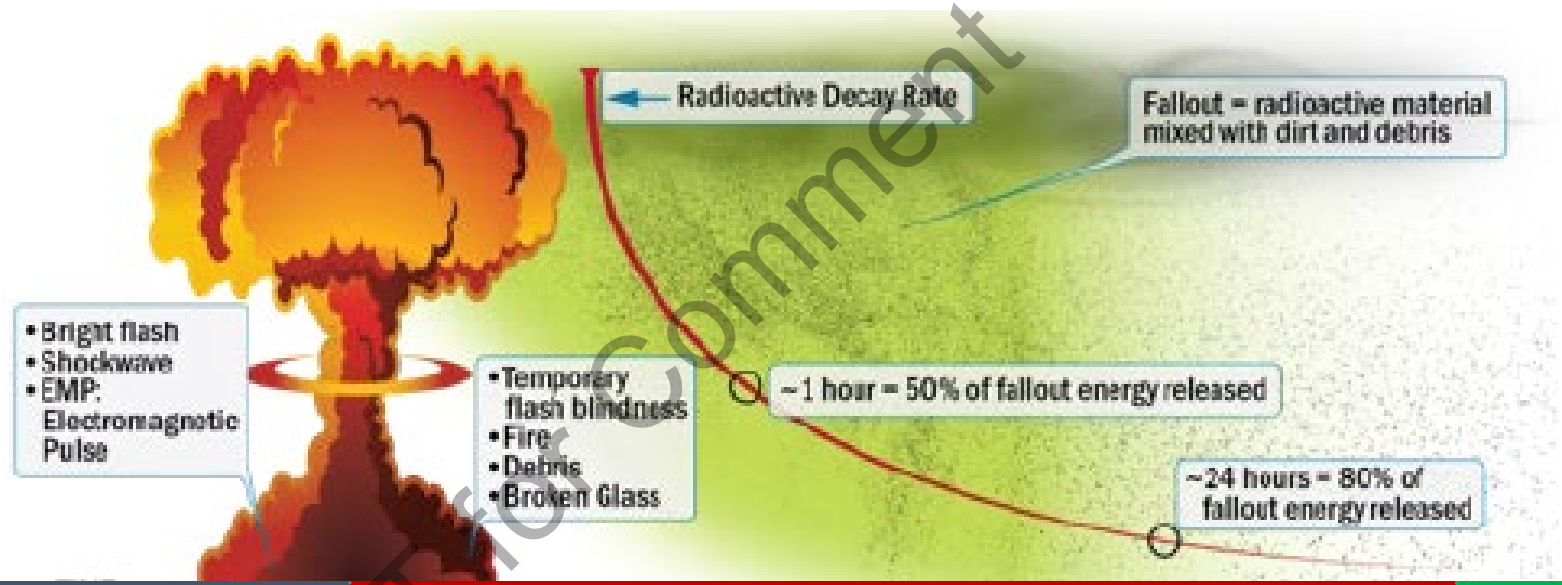
This Module Focuses on the First 24 Hours



Before the Incident		After the Incident				Sustained Operations
		15 min before	15 min after	First day	Days to weeks	Months to years
Preparedness and education	Elevated threat	**Attack warning (if possible)**	**Rapid public messaging**	**Life-saving messaging and activities**	Continued life saving & stabilization	Long-term recovery

Key Response Challenges

- There are multiple, competing hazards
- Actions in the first hours are critical
- Available resources are likely less than required
- A large area is impacted
- Movement in the region is severely limited

Early (<24hr) response actions need to focus on minimizing the number of people in immediately life-threatening situations

US Response Planning Highlights

Step 1: First Go and Stay Inside

- Seek adequate, nearby shelter

Step 2: Develop Situational Awareness

- Identify people in immediately life-threatening situations
- Assess available response capabilities and capacities

Step 3: Address Immediately Life-Threatening Situations

- Control large fires
- Evacuate people if no other option exists

Step 4: End Shelter When the Situation Permits

Steps 2 and 3 may overlap in time

Step 1: First Go and Stay Inside (Seek Adequate, Nearby Shelter)

Why Go and Stay Inside?

- It is fast and requires minimal situational awareness and communication
- Adequate shelter protects against life-threatening radiation exposures
- Being inside protects against both weather and smoke hazards
- Staying inside reduces transportation demand
  - Responders will have better access
  - Easier to evacuate those that need to evacuate

Sheltering is the best default action to take immediately before or following a nuclear explosion

Going Inside Needs to be Quick (First Hours Matter the Most)

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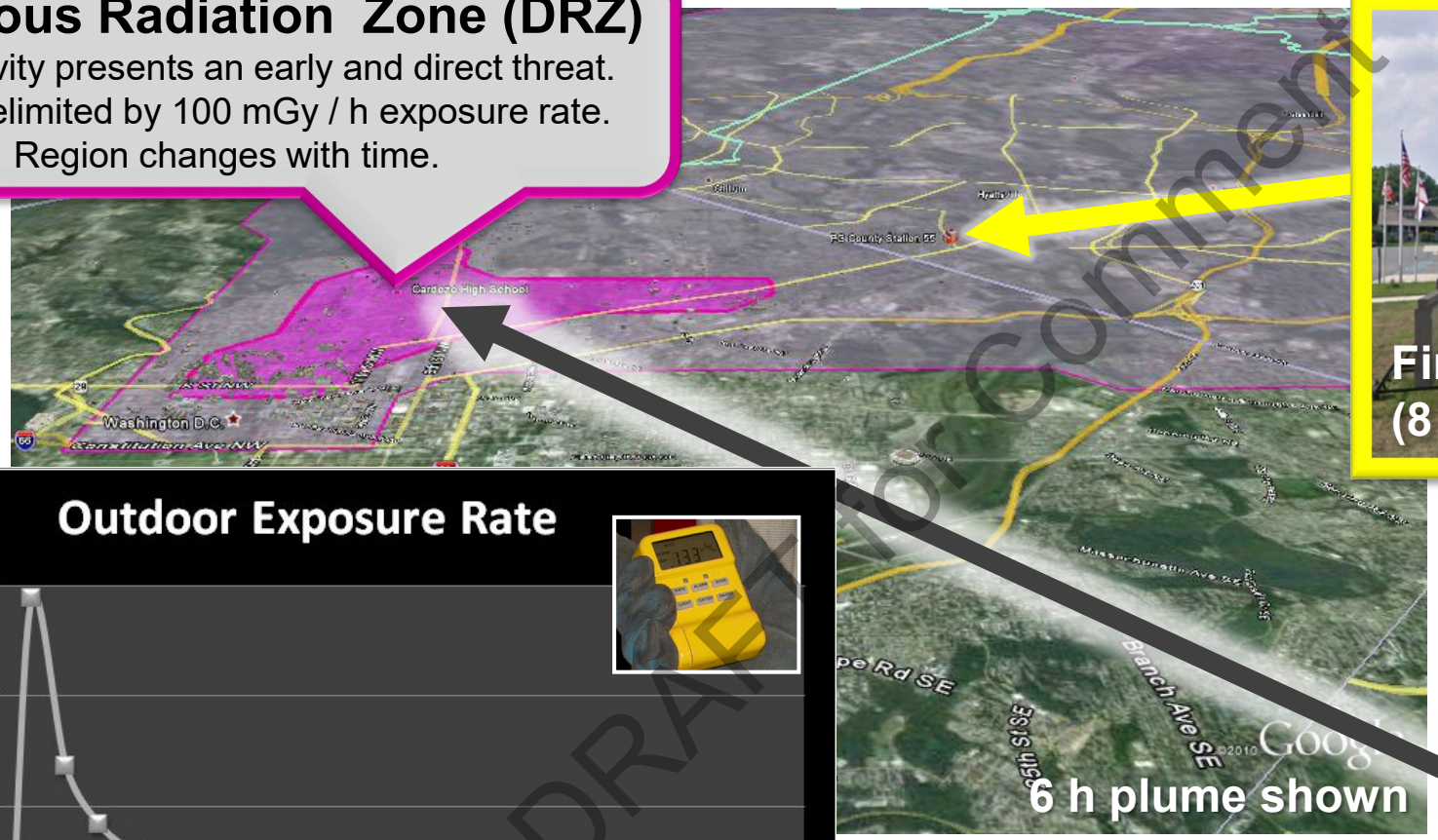
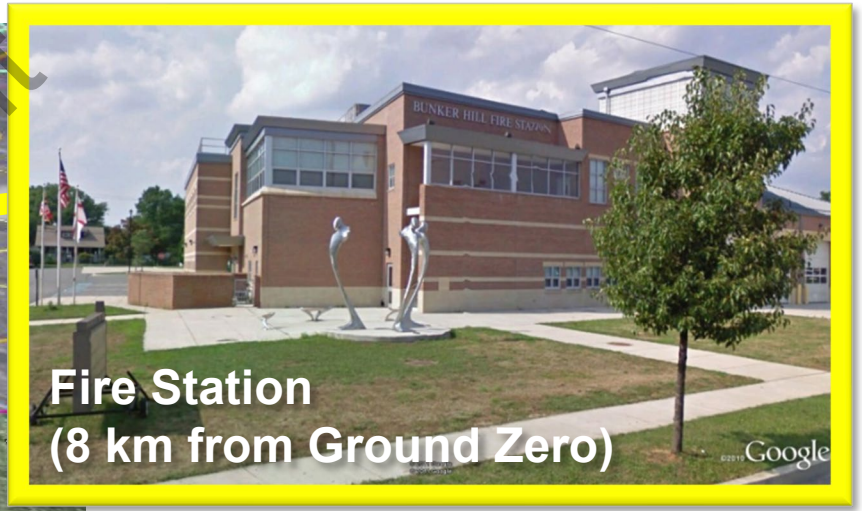
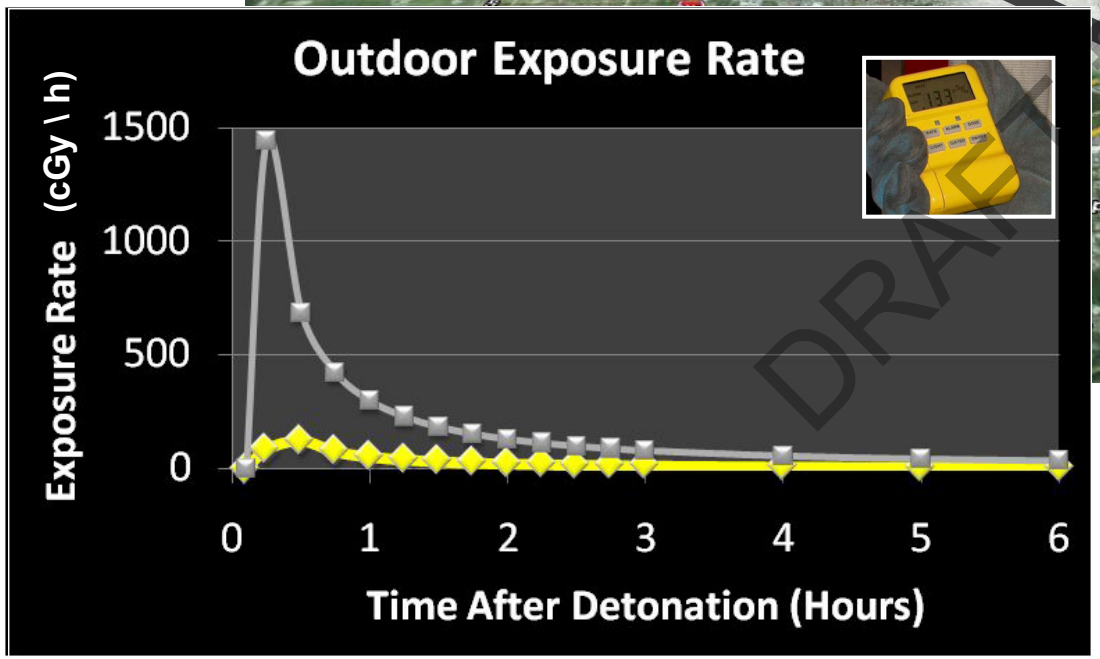
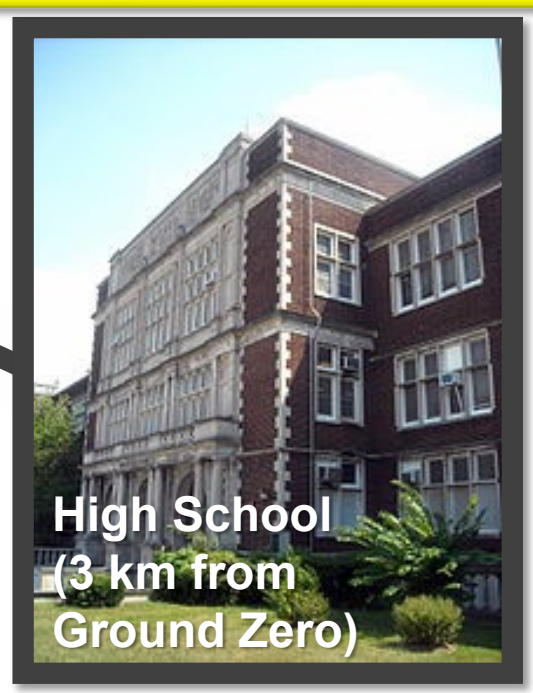
Dangerous Radiation Zone (DRZ)

Radioactivity presents an early and direct threat.
Region delimited by 100 mGy / h exposure rate.
Region changes with time.



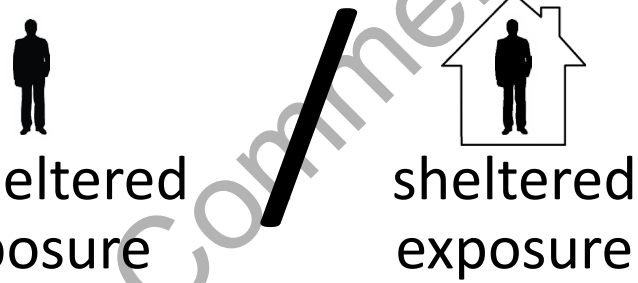






Protection Factor Definition

Shelter quality is measured in units of:

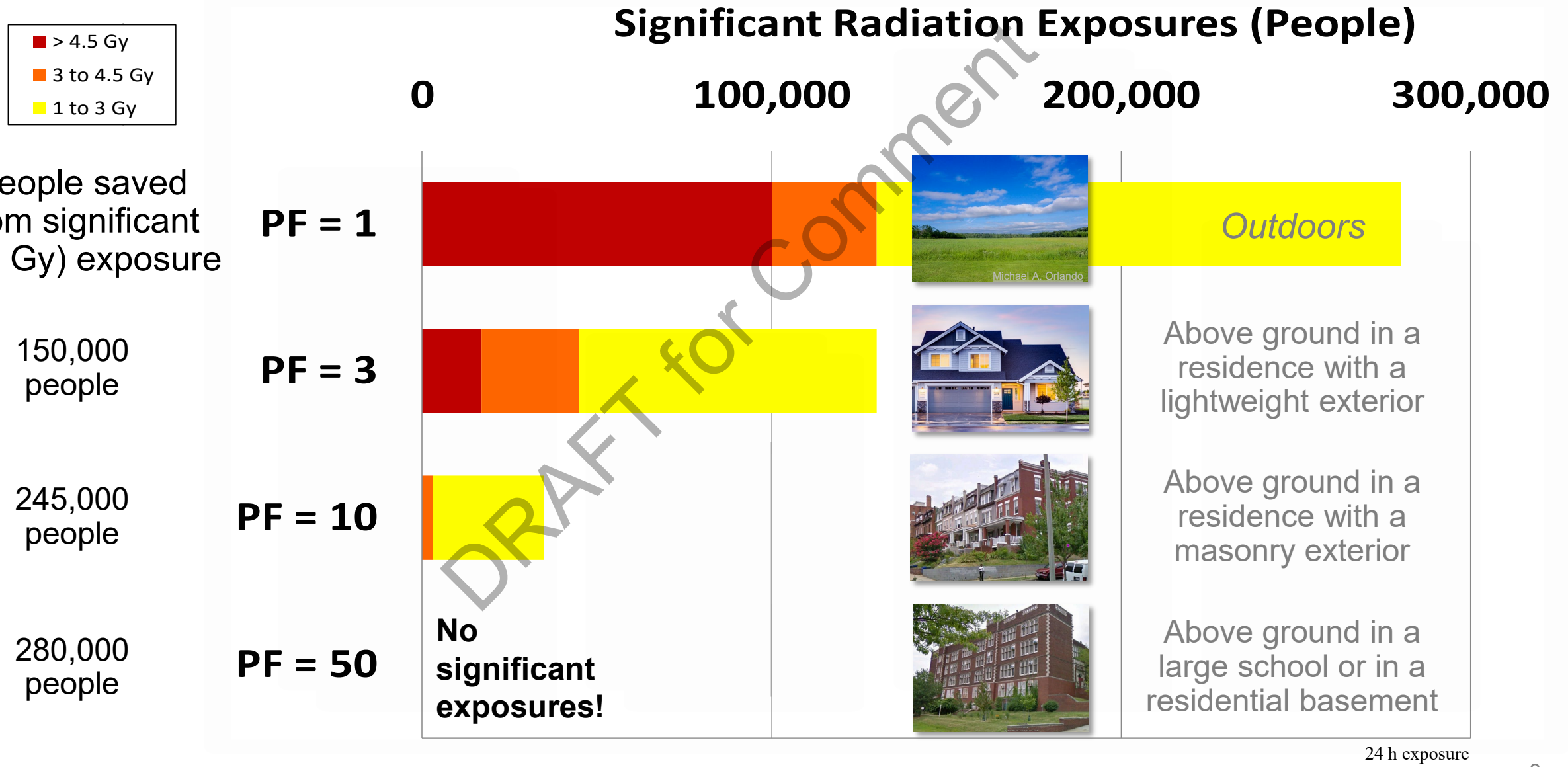
protection factor = 

Larger protection factors indicate more protection

Adequate radiation protection is a protection factor = 10
(indoor dose is 10x less the outdoor dose)

Adequate protection prevents
most severe (acute) fallout radiation injuries

Being Inside Saves Lives (and Building Protection Matters)



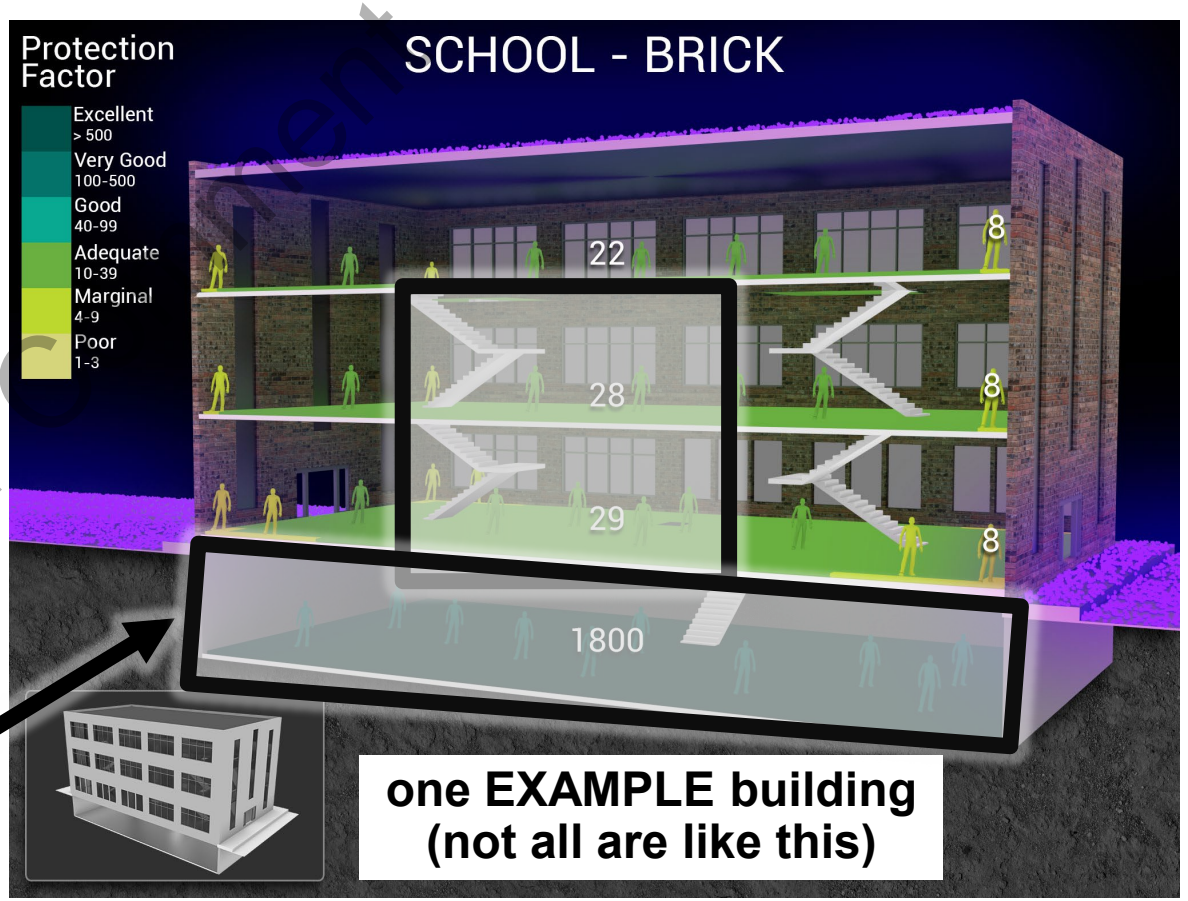
Building Protection Varies Widely

Fallout building protection depends on

- How the building is built (construction details)
- How the building is used (building contents)
- Where people are located in the building

Protection factors can, but not always, vary widely (1 to 1,000+)

- Within a single building
- Among different buildings of same type, such as offices or apartments
- Between different countries



Best protection is in the building center or below ground

For more information:
https://doi.org/10.2172/1358310
https://figshare.com/articles/preprint/US_Fallout_Shelter/20444598

Which US Buildings Have Adequate Protection?

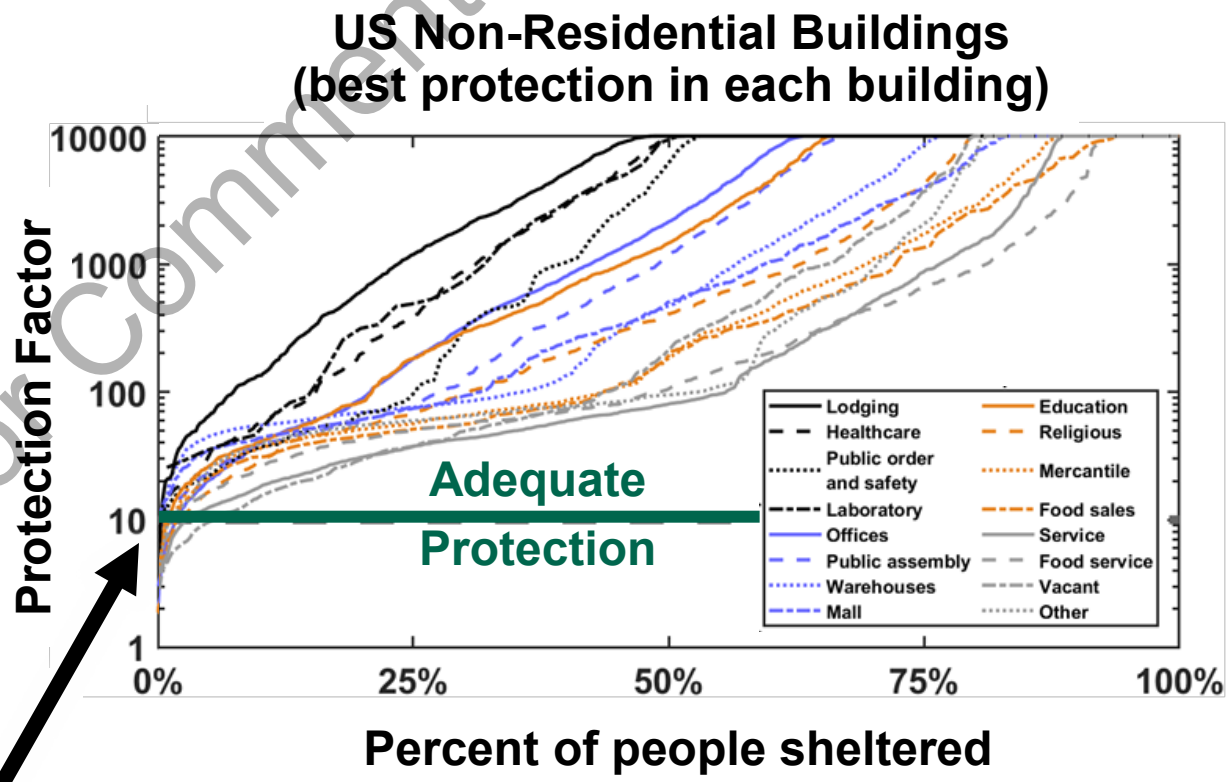
We calculated detailed building protection estimates for >100,000 cases

Basements provide adequate protection

Above ground US residential building protection is sensitive to the exterior wall

- Lightweight exterior (wood or vinyl siding) buildings lack adequate protection
- **Masonry exterior (brick or concrete) buildings provide adequate protection**

Most (> 90%) people in non-residential buildings have adequate protection if they go to the building center or below ground



For more information:
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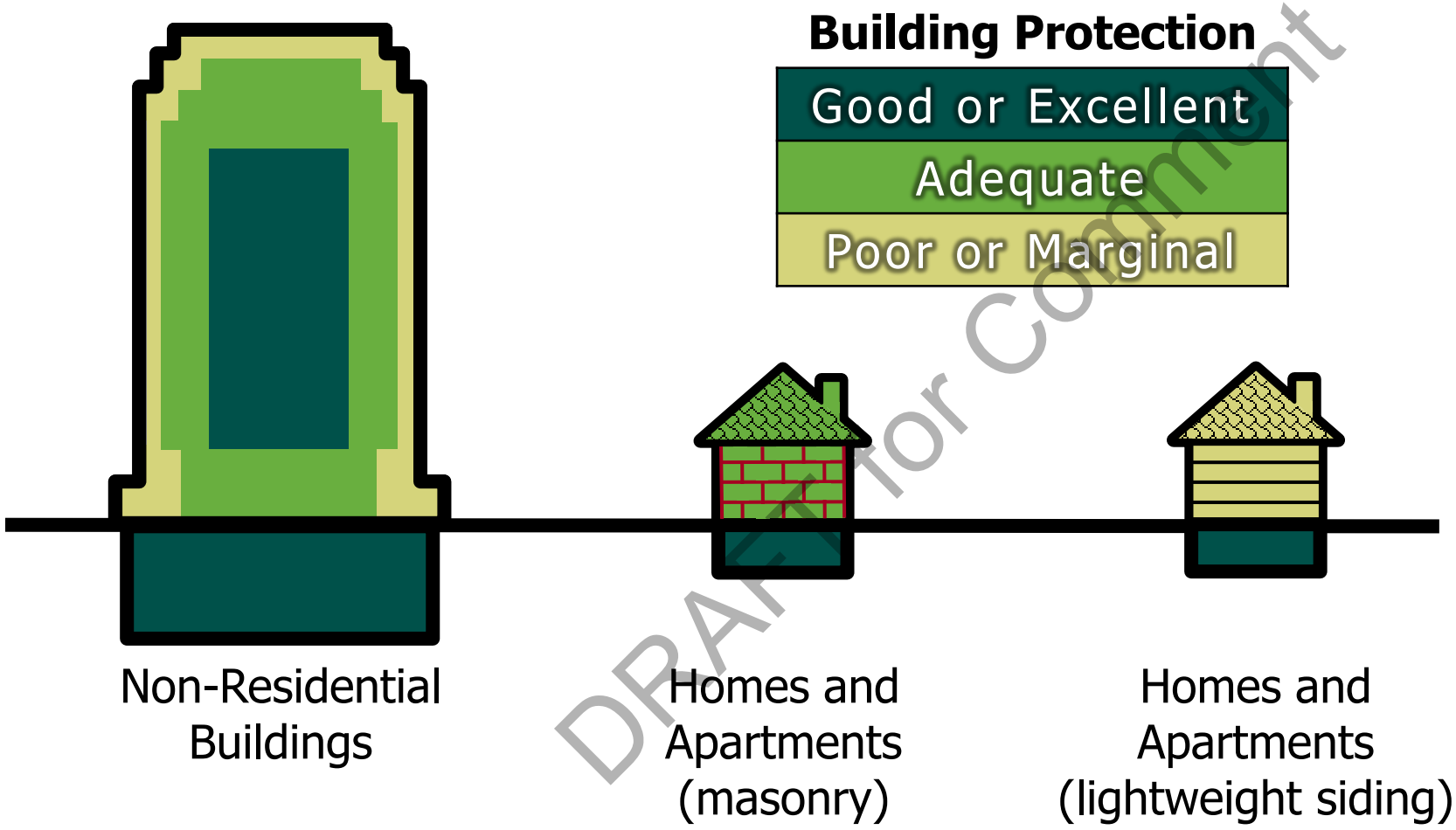
Illustration of US Building Fallout Protection



Adequate or better protection prevents most severe (acute) fallout radiation injuries

Best protection is in the building center or below ground

For more information
https://figshare.com/articles/preprint/US_Fallout_Shelter/20444598

Building Protection Outside the United States

Building construction varies by region

Some countries typically use heavier building materials (concrete and masonry) than most US residences

Limited Ukraine experimental data from Chornobyl accident studies*

Wooden Houses:	**5 to 20 PF**
Brick Houses:	**8 to 100 PF**
Multi-Story Residence or Work Buildings:	**50 to 100+ PF**

Box-Wall Apartment Building

Photo from:
Urban Terrain Building Types, Second Edition (https://apps.dtic.mil/sti/pdfs/ADA586279.pdf)

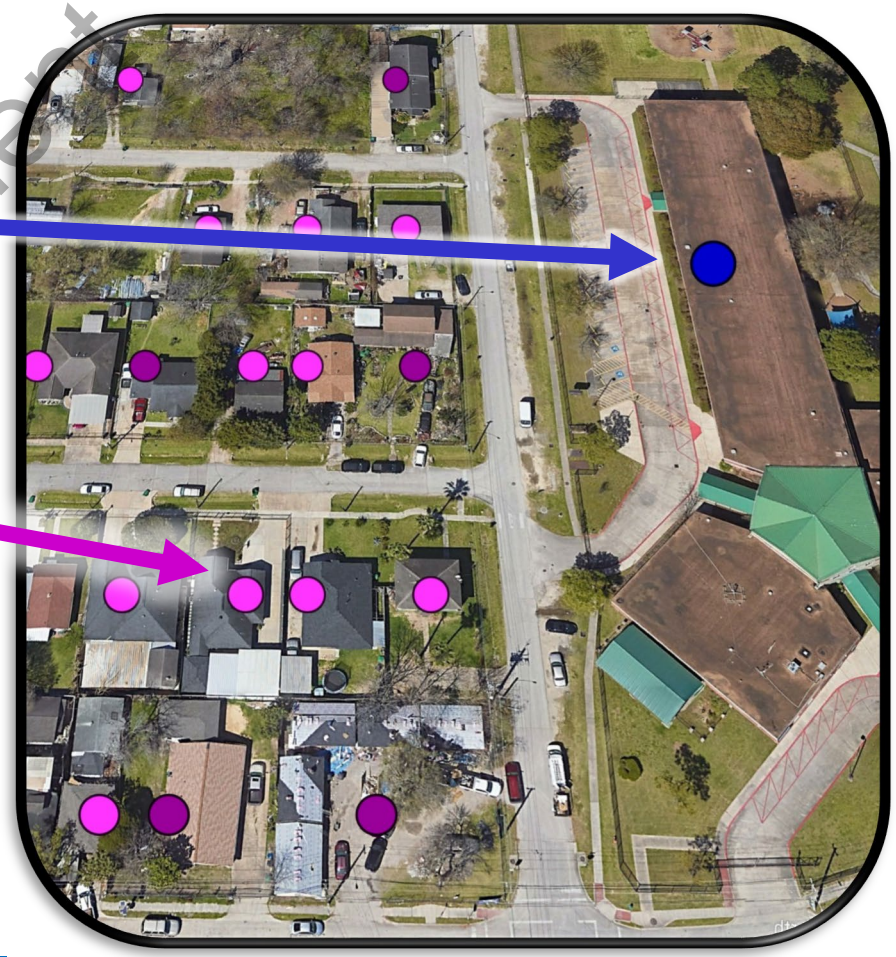
For more information
https://figshare.com/articles/preprint/US_Fallout_Shelter/20444598, Table 2
https://doi.org/10.1007/s00411-002-0167-2, Table 4
https://doi.org/10.1097/00004032-199601000-00013 , Table 4

* Approximate values, fallout protection values will be somewhat smaller

Seek Adequate, Nearby Shelter

There may be buildings with adequate protection nearby

Many US homes lack adequate protection (people are at risk in the Dangerous Radiation Zone)



People should travel to nearby, adequate shelter (within 15 min travel)

For more information
https://doi.org/10.1098/rspa.2013.0693

Review: Building Protection Benefits

Dangerous Radiation Zone (DRZ)

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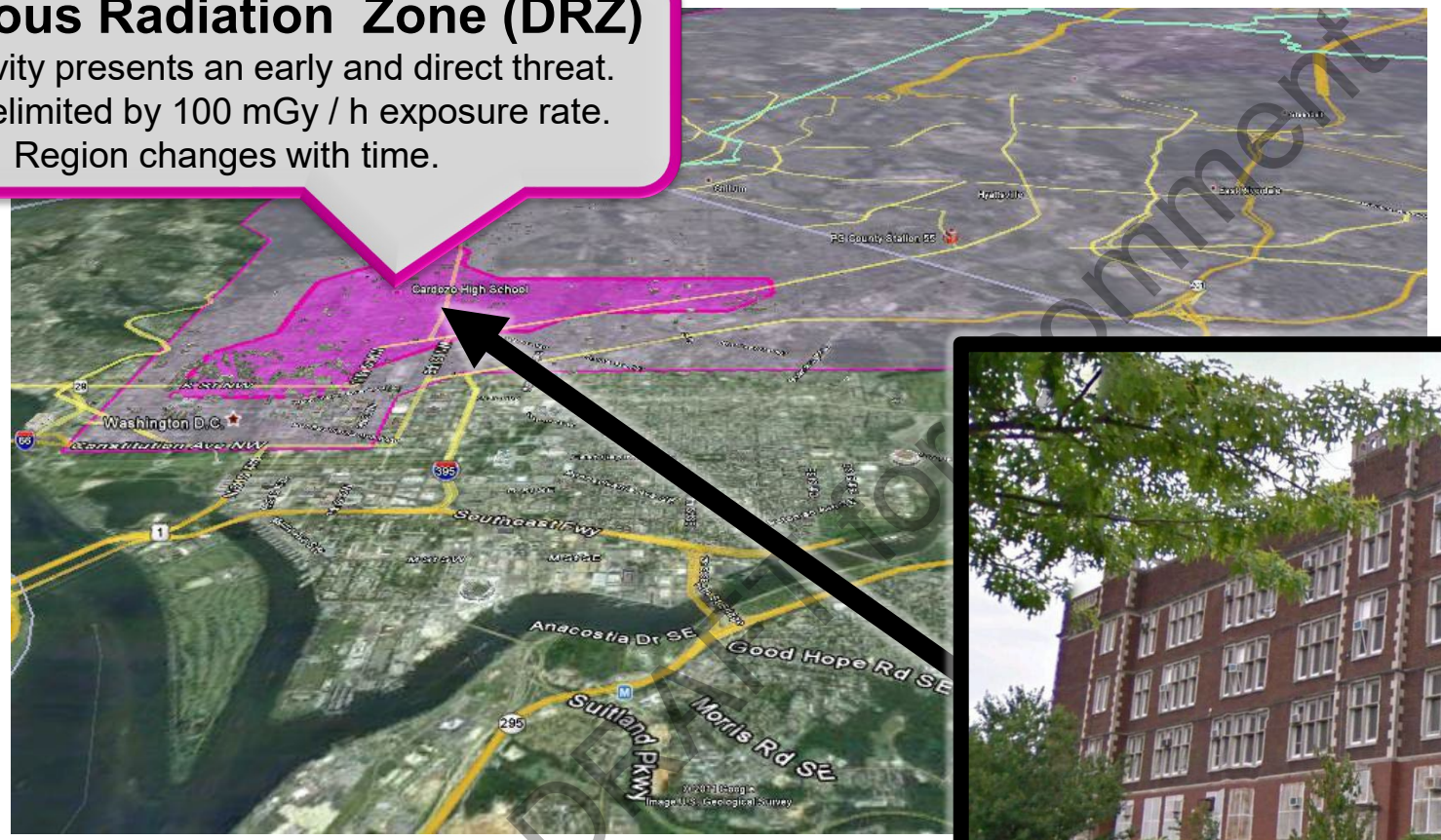
Region delimited by 100 mGy / h exposure rate.
Region changes with time.



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Survival Probable ▸ Increasing Risk of Death ▸ Certain Death

(Gy) 0.1 0.5 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15

Step 2: Develop Situational Awareness

Why Do We Need Situational Awareness?

- Need to make the best use of limited resources (triage)
- Need information to reduce the number of fatalities

Specifically we need to

- Identify people facing immediately life-threatening situations
- Identify available response resources

Early (<24hr) focus on immediately life-threatening situations

Emergency Operations Centers Play a Key Role

Emergency Operations Center
coordinate and prioritize the response

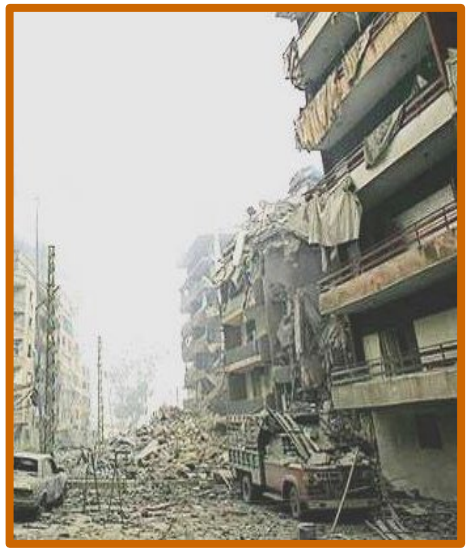
Collect and use key information

- Assess weather hazard (if any)
- Identify hazard zones
- Identify non-nuclear detonation hazards
- Assess regional shelter quality
- Identity population centers
- Assess current capabilities / capacities for
  - Communications and messaging
  - Evacuation
  - Fire fighting

Life-Threatening Weather Exposures

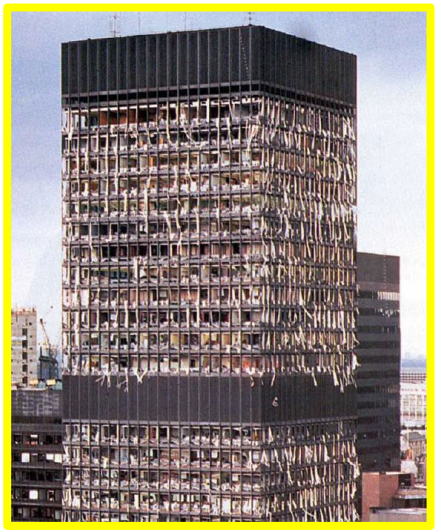
Adverse weather can be life-threatening for unsheltered people

People are most at risk in



Moderate Damage Zone
Light buildings destroyed
Blown out interiors

Light Damage Zone
Buildings still standing
Nearly all windows shattered



Local Reporting Can Identify Hazardous Regions

Short timescale for critical observations to support life-saving decisions (minutes to hours)

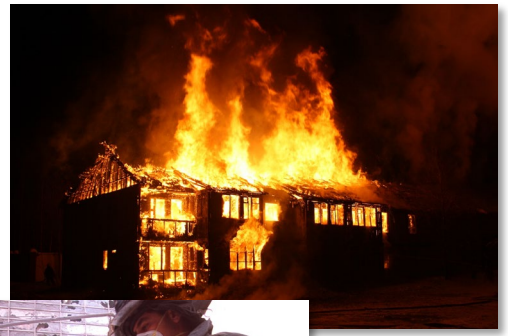
Initial efforts will rely on local personnel

Observations of local conditions will need to be reported to Emergency Operations Center by embedded responders and public

Key information

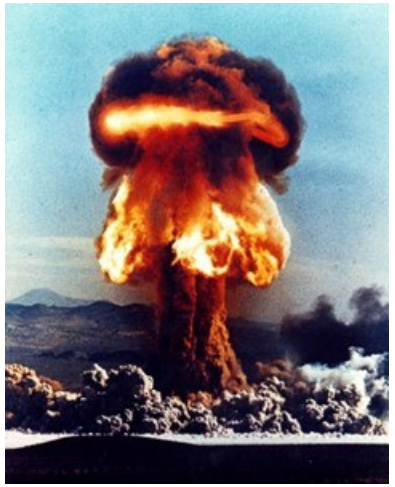
- **Extent of building damage**
- **Life-threatening fires**
- **Outdoor radiation levels (and measurement time)**

Drones may be useful for rapid visual assessments



Building Damage Determines Blast Zones

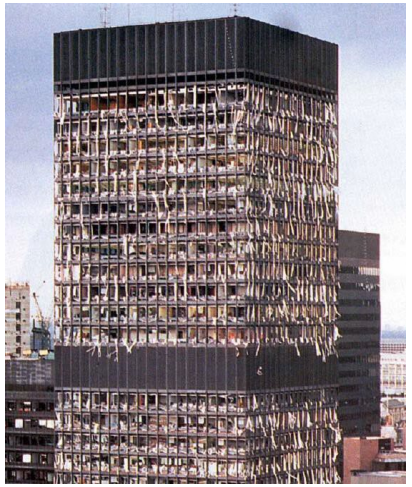
Ground Zero
Fireball
May have crater



Severe Damage Zone
Nearly all buildings destroyed

Moderate Damage Zone
Only light buildings destroyed
Blown out interiors

Light Damage Zone
Light buildings standing
All windows shattered



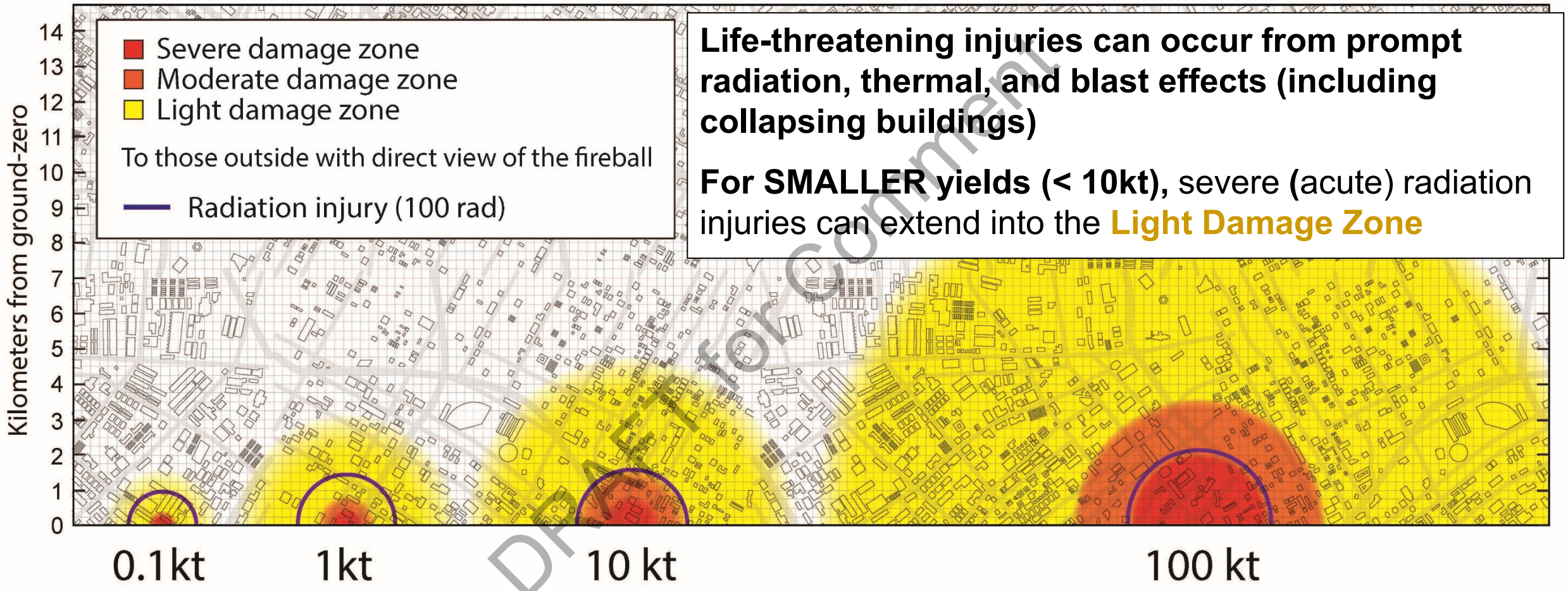
Severe Damage Extent

Moderate Damage Extent

Light Damage Extent

THESE ARE THE THREE KEY VALUES

Review: Life-Threatening Prompt Injuries



Life-threatening injuries can occur from prompt radiation, thermal, and blast effects (including collapsing buildings)

For SMALLER yields (< 10kt), severe (acute) radiation injuries can extend into the **Light Damage Zone**

The most treatable life-threatening injuries will occur in the Moderate Damage Zone

Life-Threatening Fires

The heat from a nuclear detonation, can start fires, particularly in the **Moderate Damage Zone**

Once started, they can spread to the **Light Damage Zone** and beyond

Fires are more likely for air-bursts

Mass fires can cause fatalities in sheltered populations, block evacuation routes, and force relocation of emergency operations

Fallout Exposures

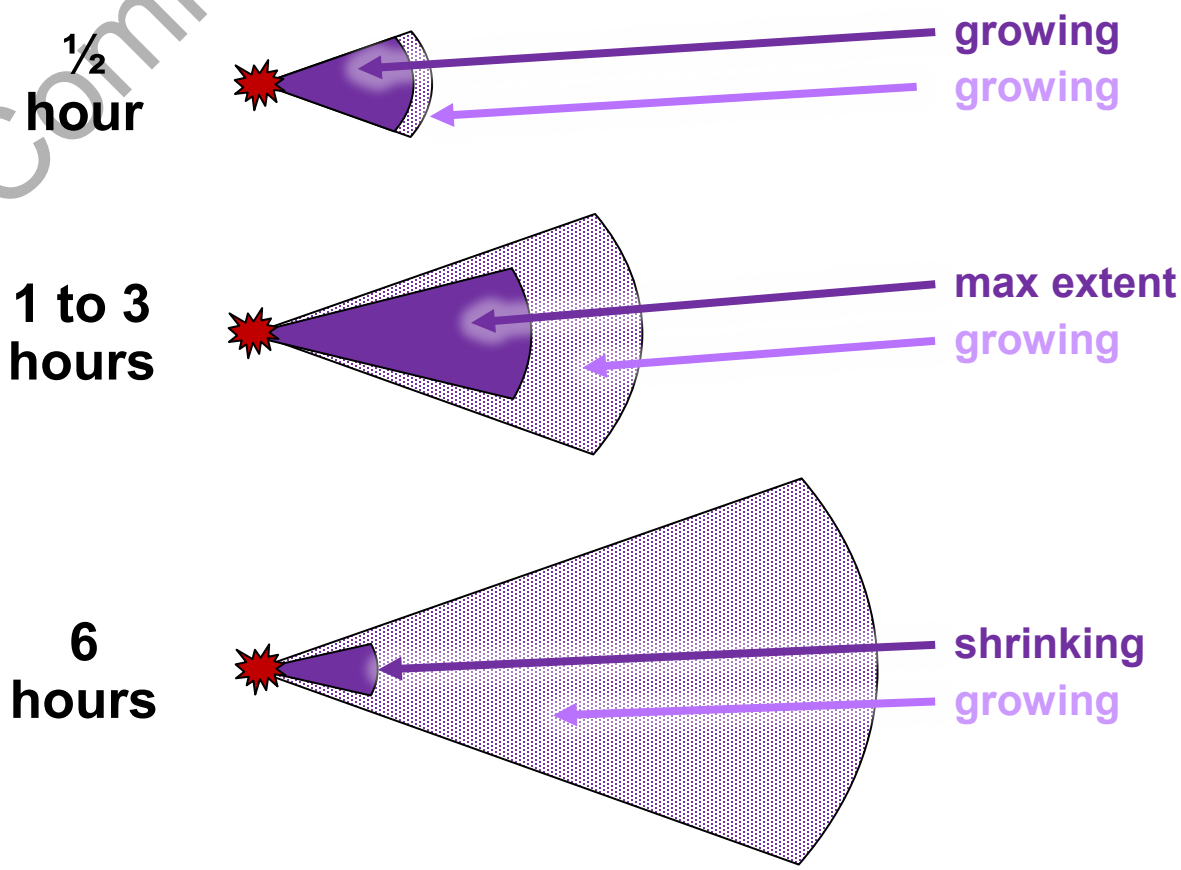
Potentially fatal radiation exposures can occur in the Dangerous Radiation Zone

Adequate building protection greatly reduces the risk of severe (acute) radiation injuries

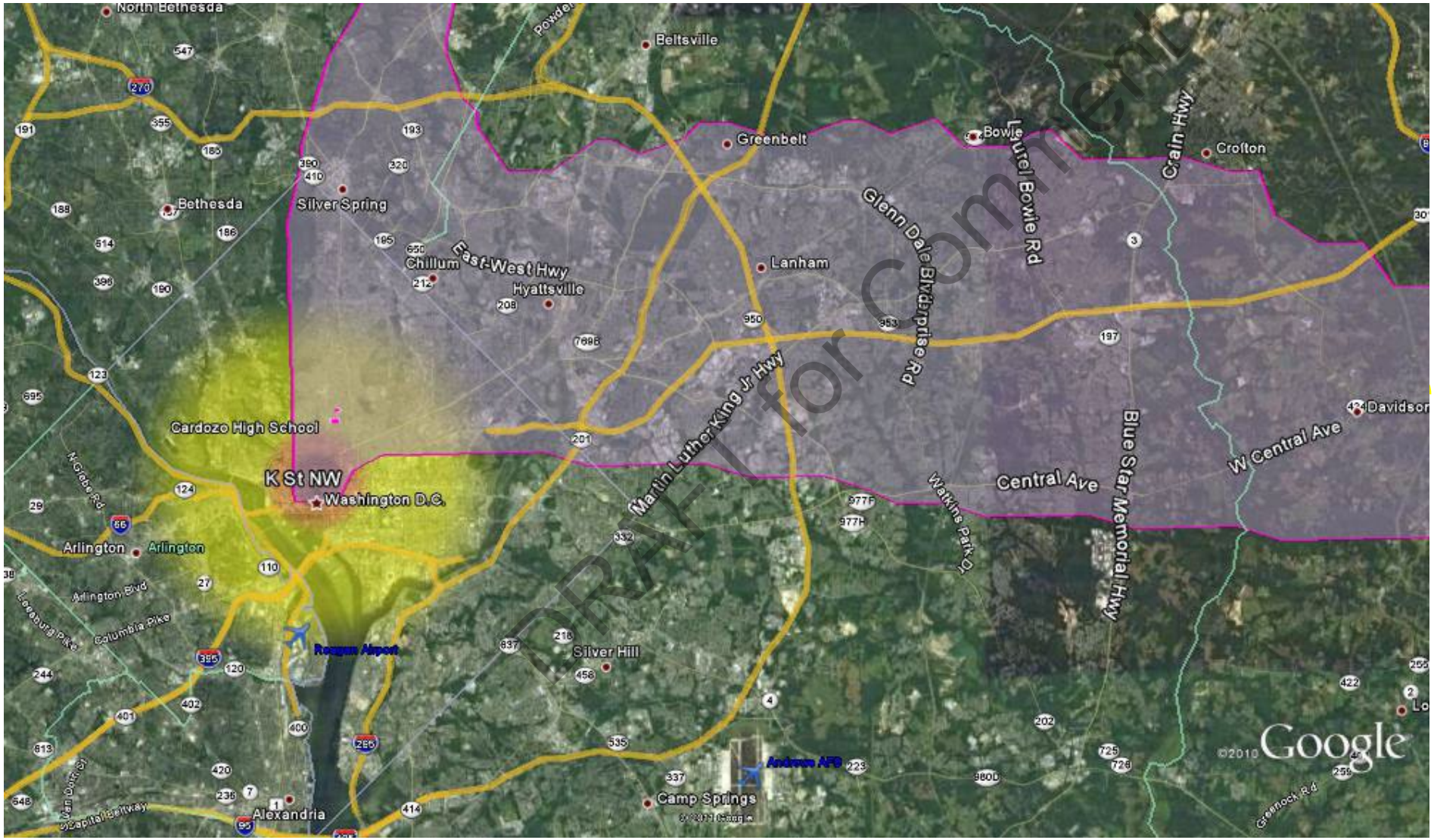
With adequate building protection, elevated cancer risk remains but is reduced relative to being outdoors

Rain and snow can cause dangerous hotspots far downwind

Dangerous Radiation Zone (lethal) and Hot Zone (cancer risk) Change with Time



Review:
Fallout Radiation Exposure Changes with Time



Day 7

The Dangerous Radiation Zone grows over the first hour or so and then shrinks

Emergency Operation Centers Use Local Information To Identify Response Zones

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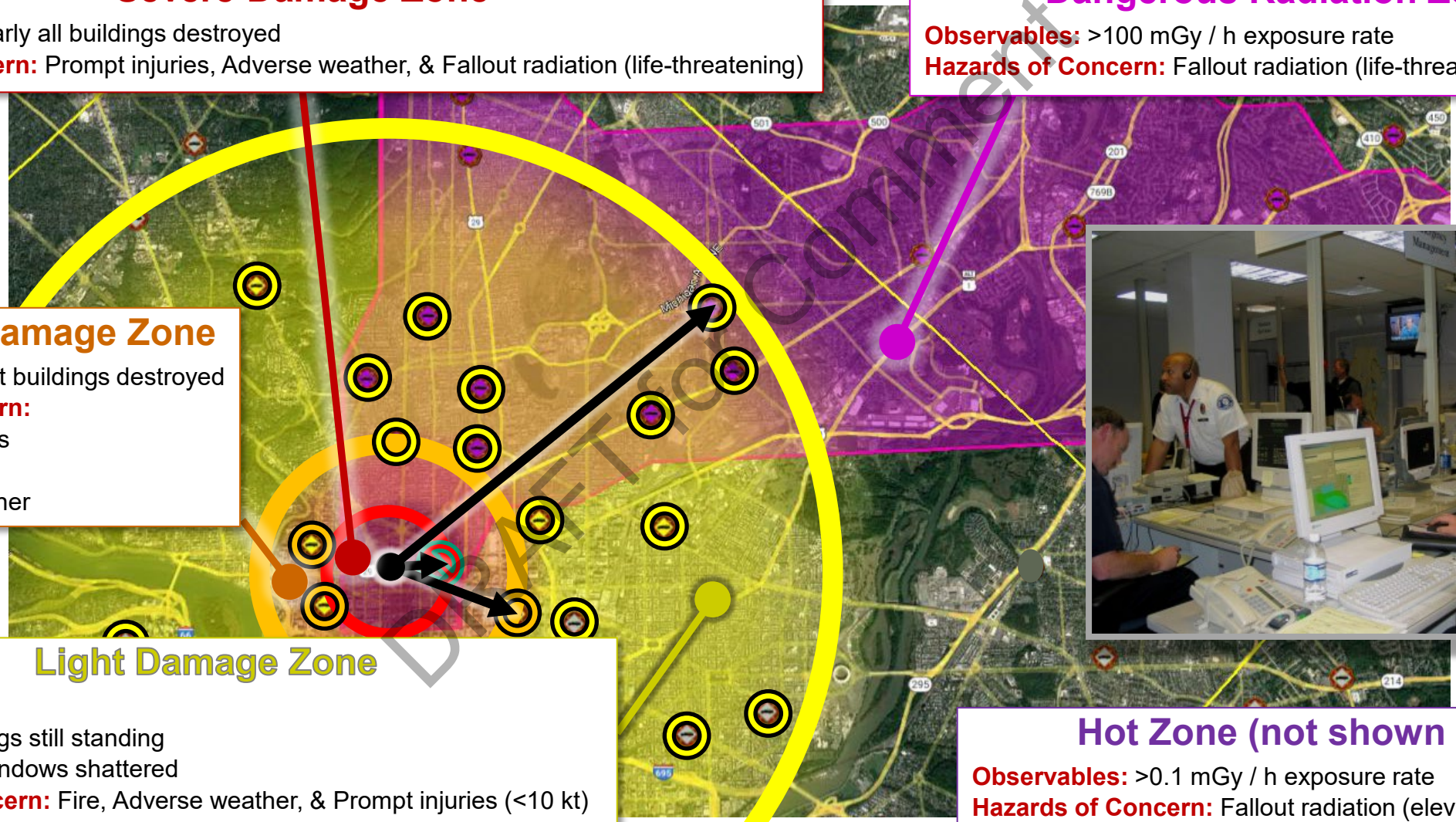
Severe Damage Zone

Observables: Nearly all buildings destroyed
Hazards of Concern: Prompt injuries, Adverse weather, & Fallout radiation (life-threatening)

Dangerous Radiation Zone

Observables: >100 mGy / h exposure rate
Hazards of Concern: Fallout radiation (life-threatening)



Moderate Damage Zone

Observables: Light buildings destroyed
Hazards of Concern:

- Prompt injuries
- Fires
- Adverse weather

Light Damage Zone

Observables:

- Light buildings still standing
- Nearly all windows shattered

Hazards of Concern: Fire, Adverse weather, & Prompt injuries (<10 kt)

Hot Zone (not shown here)

Observables: >0.1 mGy / h exposure rate
Hazards of Concern: Fallout radiation (elevated cancer risk)

Hazard Predictions Based on Physics-Based Models May Assist

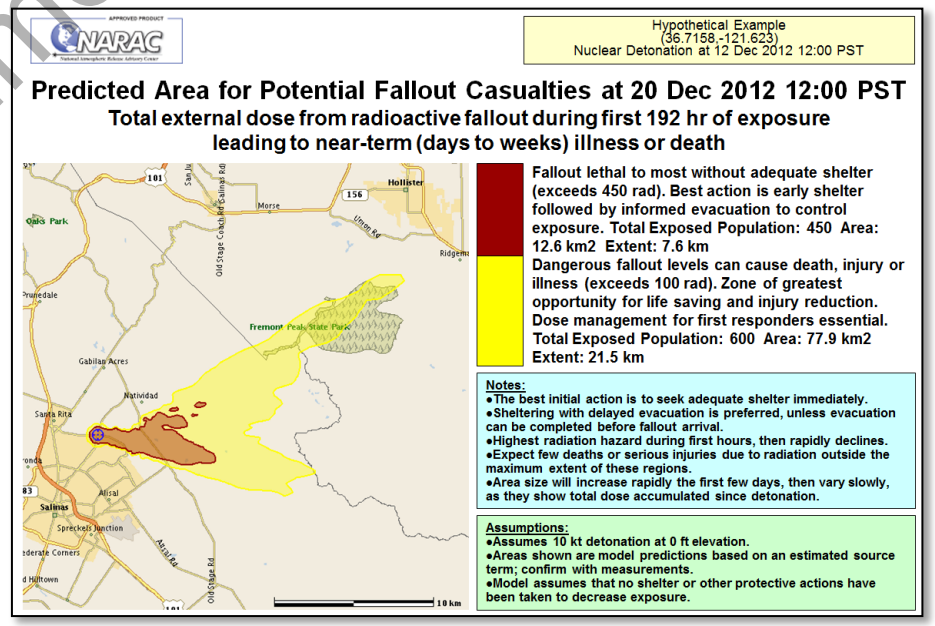
Plume models can predict hazardous areas based on available information

Predictions evolve during the response

- Initial predictions are very uncertain
- Later predictions, which incorporate measurement data, are more accurate

Predictive modeling alone is not sufficient for making US worker protection decisions

Modeling Product Example



Modeling should be performed by subject matter experts

Assess the Regional Shelter Quality

Identify three key regions:

- In *Shelter-In-Place* regions, most buildings have abundant, adequate shelter against fallout radiation
- In *Nearby Shelter* regions, most buildings lack adequate shelter, but it is available nearby
- In *Inadequate Shelter* regions, there is not enough adequate shelter nearby

This can be determined prior to the event

Photos from:
Urban Terrain Building Types, Second Edition (https://apps.dtic.mil/sti/pdfs/ADA586279.pdf)
https://www.flickr.com/photos/wbaiv/44241743650/in/photostream/
https://commons.wikimedia.org/wiki/File:Suburbs,_Virginia_%286045440309%29.jpg

Identify Population Centers

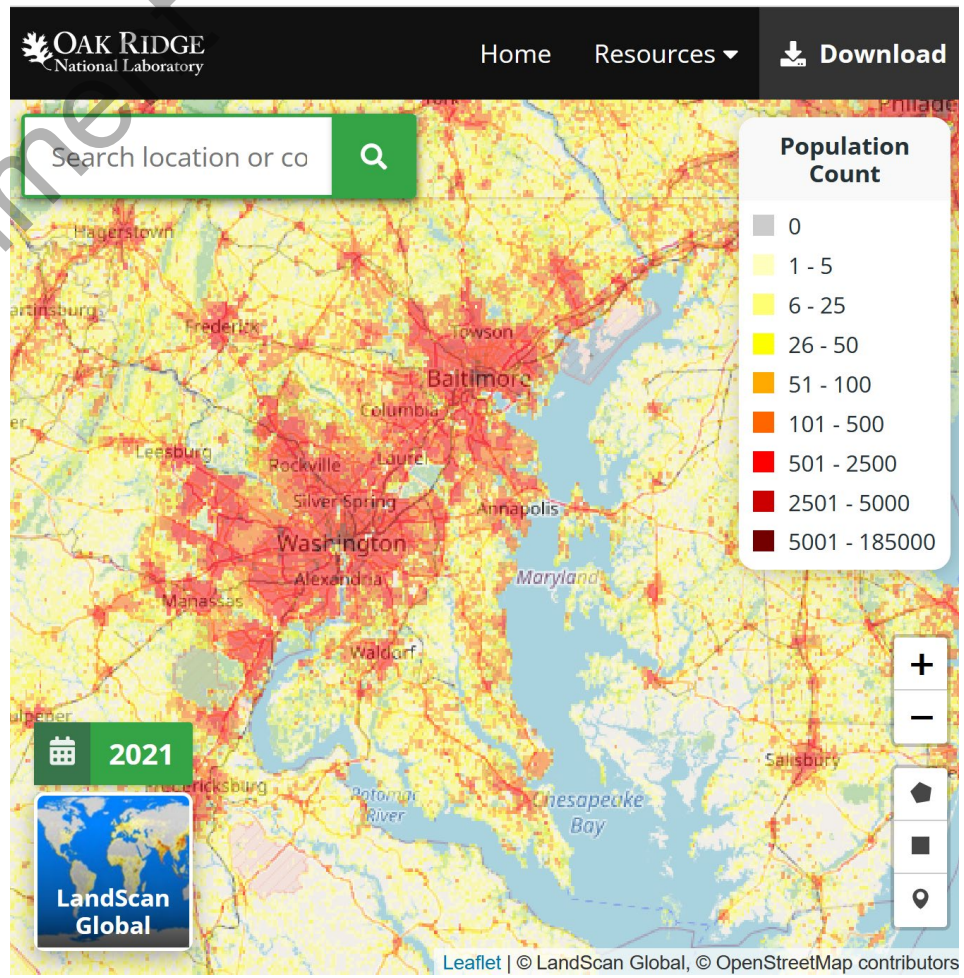
Identify regions with high population

Use this information to

- Guide fire-fighting activities (prevent fires from burning high population areas)
- Plan and prioritize evacuations (for regions with life-threatening hazards)

This can be determined prior to the event

To view and download data:
https://landscan.ornl.gov/



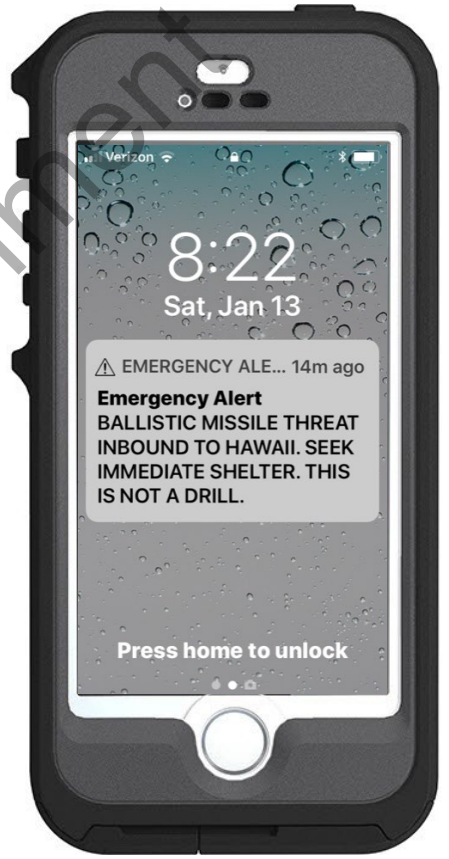
Assess Messaging Status

Rapid guidance is critical to saving lives

- **Advise everyone to Get and Stay Inside**
- Coordinate fire fighting activities
- Evacuate people in immediately life-threatening situations

Identify (or develop) key public messages

- **Ideally this is done before the nuclear detonation**
- If feasible, adapt existing messaging (Get Inside, Stay Inside, Stay Tuned)
- Coordinate messages among different agencies (one message, many voices)



For more information, see the Public Communications module

Assess Current Communication Capabilities and Capacities

Telling the public about the protective actions they can take is critical

- Immediate dissemination of messages
- Redundant dissemination outlets to compensate for damaged infrastructure

Assess communication infrastructure status

- Most electronic equipment operable after reset
- Assess available communication pathways
  - Landlines and cell towers (encourage texting)
  - Satellite connections
  - Point-to-point radios
  - Radio / TV stations
  - Warning sirens, Megaphone, & Loudspeakers
  - Internet (websites, social media)
- Assess regional and out-of-area (reachback) communication status

For more information, see the Public Communications module

Assess Evacuation Capabilities and Capacities

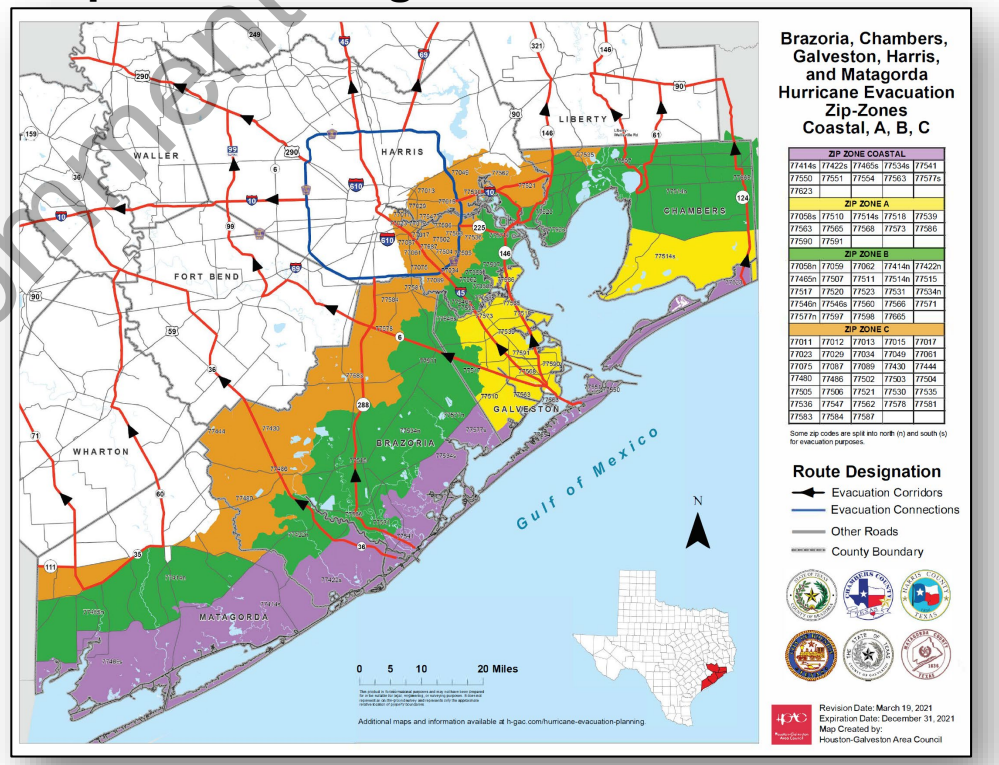
Evacuation will be necessary to save lives, particularly in the Moderate Damage Zone and Dangerous Radiation Zone

Leverage existing evacuation plans

Identify evacuation routes / capabilities

- Identify evacuation routes
- Assess road conditions
- Consider non-road transportation options (trains, boats, etc.)

Example of Existing Hurricane Evacuation Plan



https://h-gac.com/hurricane-evacuation-planning

Ensure routes do not obstruct critical transportation or overall response operations

Step 3: Address Immediate, Life-Threatening Situations

Why?

- Goal is to save as many lives as possible
- Actions in the first few hours will have the greatest impact on lives saved
- "Buy time" for additional resources to become available

Specifically, responders can reduce the number of fatalities by

- Preventing people from facing life-threatening situations
- Removing people from existing life-threatening situations
- Providing timely medical care to people with life-threatening injuries

When faced with competing hazards, prioritize immediate, life-threatening situations

If Feasible, Control Large Fires

Mass fires can cause fatalities in regions people are staying inside

Preventing fires from burning high population areas allows people to stay sheltered longer

Jean Beaufort
https://www.publicdomainpictures.net/en/view-image.php?image=172520&picture=firefighters-live-fire-training

If your building is on fire … LEAVE!
Find a safe building or evacuate

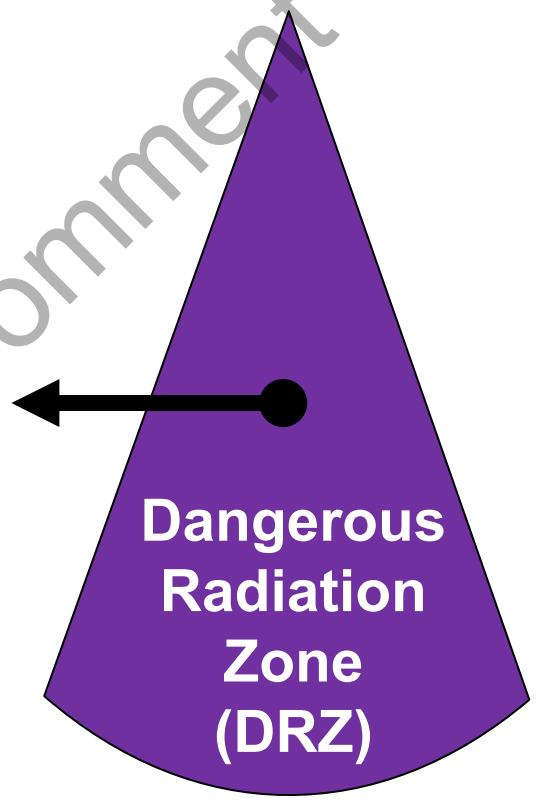
If No Other Option Exists, Responders Can Direct People to Evacuate

When selecting evacuation routes, minimize the overall dose

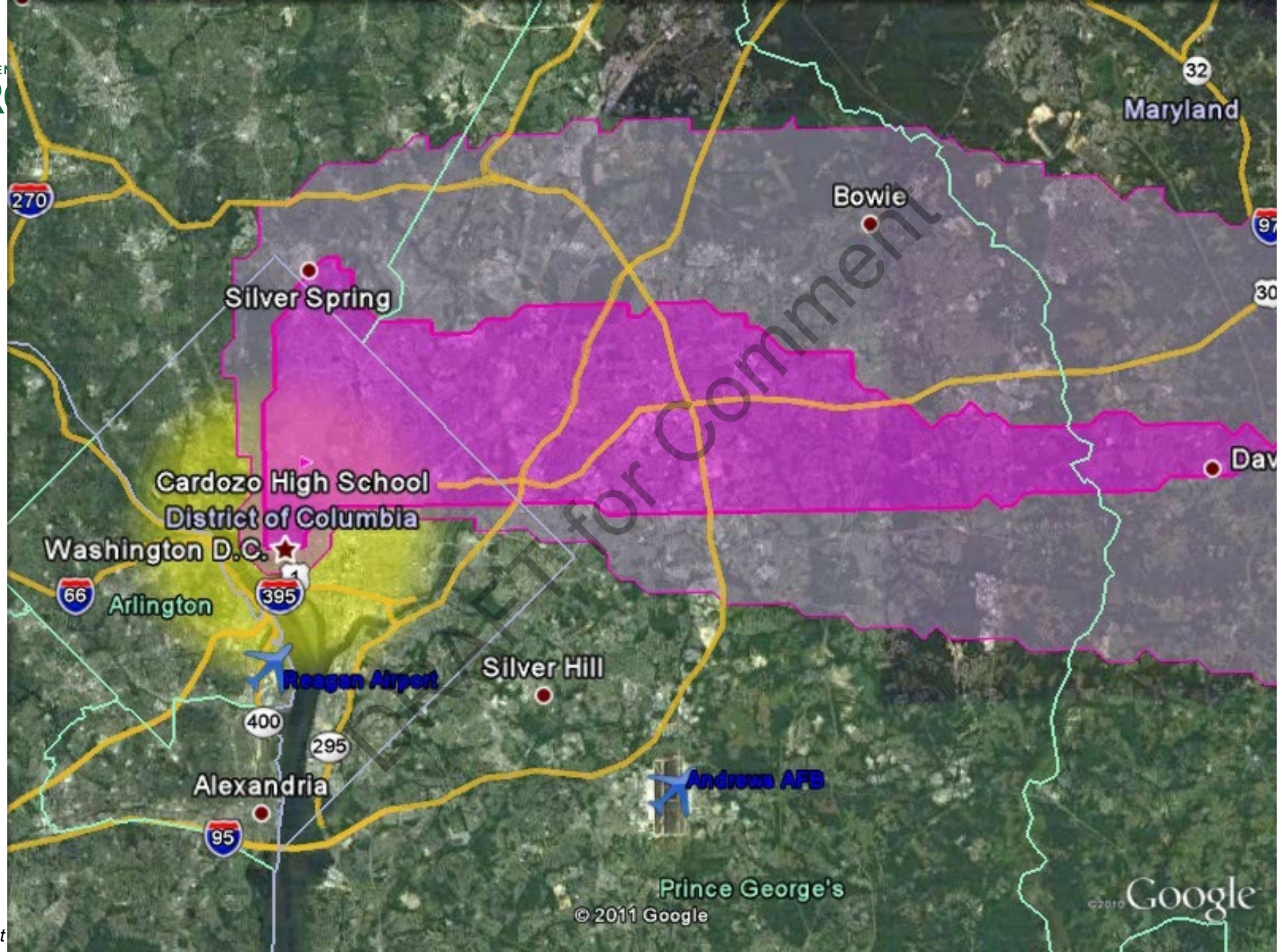
If feasible,
use underground or indoor routes

Consider lateral evacuation,
travel at right angles to the fallout and away from the plume centerline

Direct evacuees to triage centers and provide needed medical care



Anticipate self-evacuations regardless of guidance
Provide guidance specifically for those self-evacuating


Maryland
Bowie
Silver Spring
Cardozo High School
District of Columbia
Washington D.C.
Arlington
Reagan Airport
Silver Hill
Alexandria
Andrews AFB
Prince George's
© 2011 Google
Google
270
32
66
395
400
295
95
DRAFT for Comment

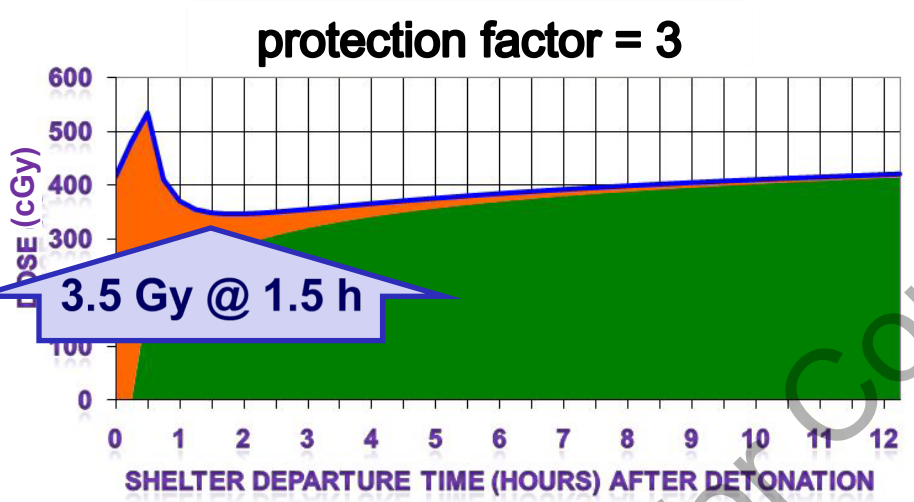
Evacuation Example

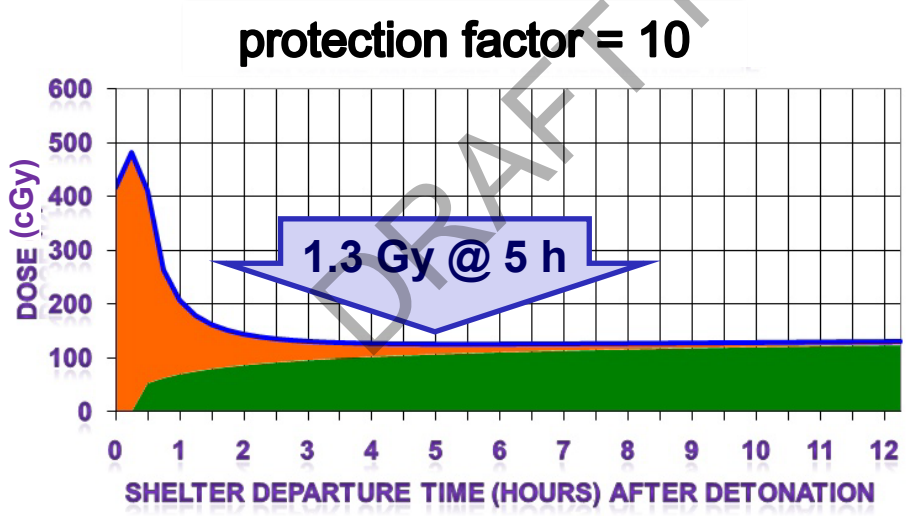
Cardozo High School

Example Protection Factor: 50

(Most of the shelter locations would reduce dose by 98%)

Optimal Shelter Time Depends on Building Protection





Optimal shelter time (radiation dose minimum) depends on both the sheltered (**green**) and evacuation (**orange**) doses

Optimal shelter time increases with shelter quality

With adequate (or better) shelter (PF ≥ 10), err on staying "too" long

For more information
https://doi.org/10.1098/rspa.2013.0693

Review of Steps 1 to 3: Identify and Address Life-Threatening Situations

Responders can reduce the number of fatalities by:

- **Preventing people from facing life-threatening situations**
  - Direct people to get inside to protect them from hazardous radiation and weather
  - Control fire spread to allow people to stay inside longer
- **Remove (evacuate) people from existing life-threatening situations**
  - Have life-threatening injuries
  - Remain in inadequate buildings in the Dangerous Radiation Zone
  - Are threatened by fire
- **Providing timely medical care to people with life-threatening injuries**

When faced with competing hazards, prioritize immediate, rather than longer term, threats

Step 4: End Shelter When the Situation Permits

In damaged or hazardous areas, going and staying inside should be followed by facilitated evacuation

- If feasible, **individuals should stay in an adequate building for 12 h to 24 h**
- Evacuations should occur only after appropriate paths have been identified
- Evacuations should be staged as to not overwhelm transportation and evacuation capacity

For regions clearly outside the Dangerous Radiation Zone and Hot Zone, lift the go and stay inside order (no evacuation needed)

Shelter is inherently a short-term response

Check Your Knowledge

What is the overall response goal for the first 24 hours?

1) Assess the hazards and available resources and then develop a detailed response plan
2) Save as many lives as possible
3) Evacuate everyone from the impacted region
4) Minimize radioactive contamination in the surrounding regions

Answer:
(2) Save as many lives as possible

Check Your Knowledge

Why is the initial response guidance to Go Inside, Stay Inside, and Stay Tuned? (select all that apply)

1) It is fast
2) It requires minimal knowledge and communication capabilities
3) It can protect against life-threatening radiation exposures, weather, and smoke
4) It reduces transportation demand

Answer:
All of the answers!

Check Your Knowledge

Which of the following is critical information that the Emergency Operations Center needs *from the field*?

(select all that apply)

1) Building damage
2) Weather conditions
3) Measured outdoor radiation levels
4) Large fires

Answer:
(1) Building damage
(3) Measured outdoor radiation levels ; (4) Large fires

Check Your Knowledge

When should people with adequate building protection leave? (select all that apply)

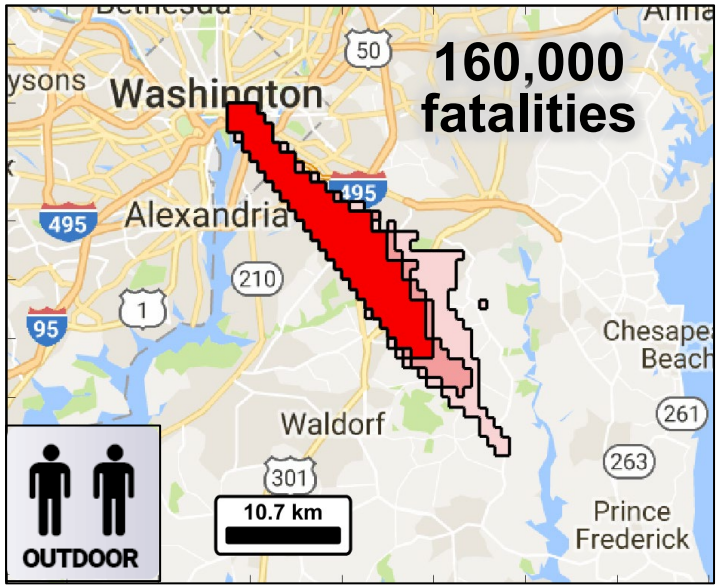
1) Immediately
2) When their building is on fire
3) When they feel ready
4) After 24 hours and safe evacuation routes have been identified

Answer:
(2) When their building is on fire
(4) After 24 hours and evacuation routes have been identified

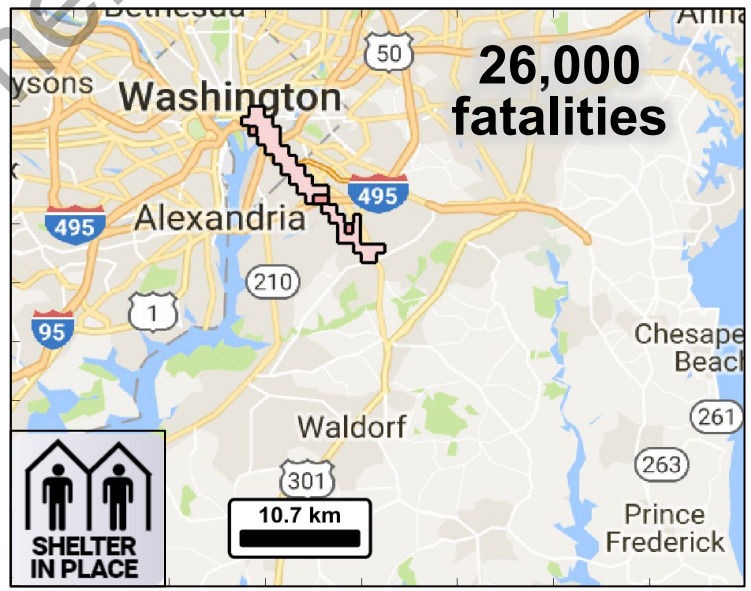
Thank you

Being Inside Matters

Buildings protect against fallout radiation



Risk Level	Probability
Near Certain	90+ %
Likely	50% to 90%
Possible	10% to 50%



Buildings can also protect against:

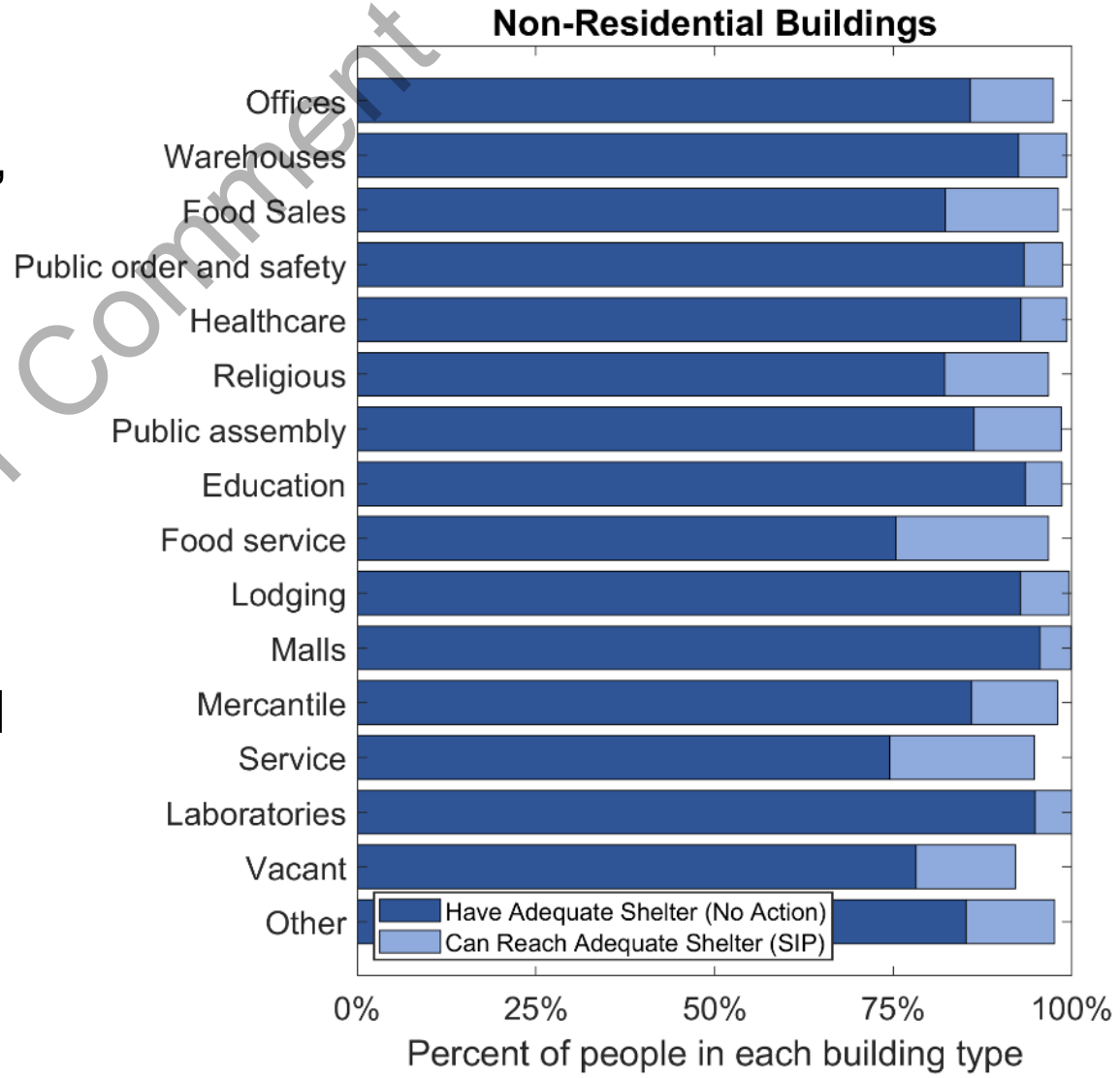
- Outdoor smoke (make sure to close windows and doors)
- Weather exposures including as heat, cold, rain, and snow

US Non-Residential Buildings (Office, Hotels, Hospitals, Stores, etc.)

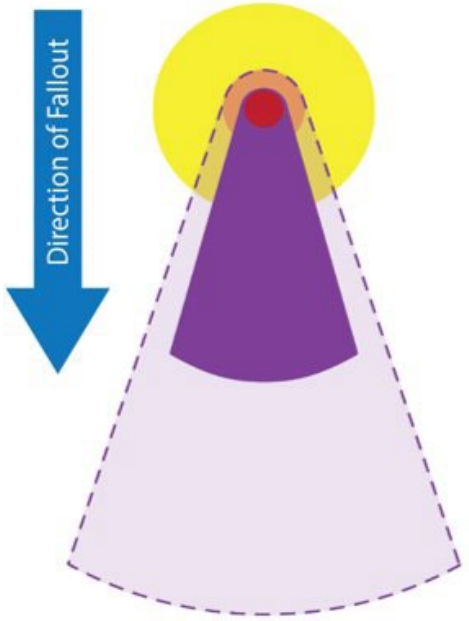
US non-residential buildings typically have significant mass in the exterior walls, interior walls, and the building contents

Most people naturally have adequate protection (no additional action is required)

> 90% of people are adequately protected if they shelter in place (SIP) by going to the building center or below ground



Response Zone determines Early Evacuation Priority (remember the first step is to go and stay inside)



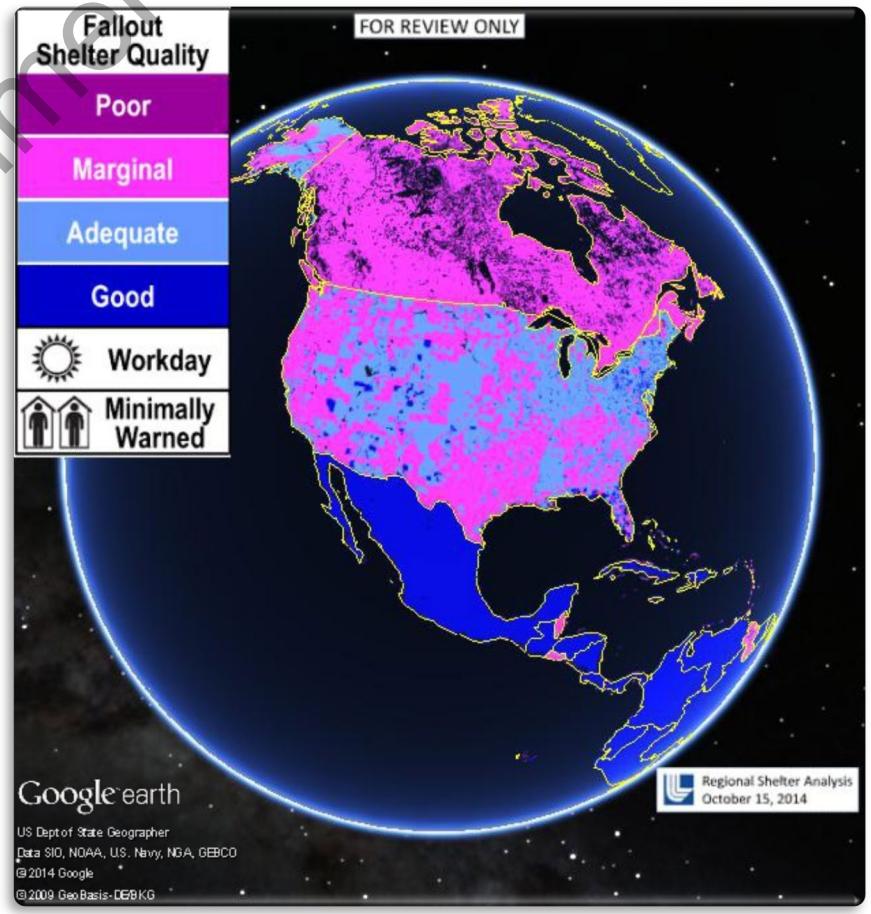
Zone Type	Early Shelter / Evacuation Priority
Light Damage Zone (LDZ)	Encourage public to **go and stay inside**
Moderate Damage Zone (MDZ)	Prioritize and support public **evacuation**
Severe Damage Zone (SDZ)	Public and responder should **go and stay inside**
Dangerous Radiation Zone (DRZ) (use DRZ guidance for regions overlapping the MDZ & LDZ)	Prioritize public and responder to **go and stay inside** Transition to phased evacuation as radiation decays (prioritize MDZ evacuation)
Hot Zone (HZ) (beyond MDZ & LDZ)	Encourage public to **go and stay inside**

Always prioritize people in immediate, life-threatening situations for evacuation

Regional Shelter Analysis

- Incorporates shelter quality into existing assessment methods
- Applicable to
  - Nuclear, radiological, chemical, and biological acute and chronic hazards (e.g., outdoor particle air pollution, wildfire smoke)
  - External radiation and inhalation exposure (rad and non-rad) pathways
  - Spatial scales ranging from individual buildings to census tracts to entire countries
  - Capable of using multiple data sources
- Elements integrated into operational models
  - US Department of Energy, NARAC
  - US Department of Defense, HPAC

Illustrative fallout protection



https://figshare.com/authors/Michael_Dillon/4116202