U.S. DEPARTMENT OF ENERGY

National Nuclear Security Administration

Nuclear Detonation Response Training
Module 1: Nuclear Effects

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Certified Health Physicist

LLNL

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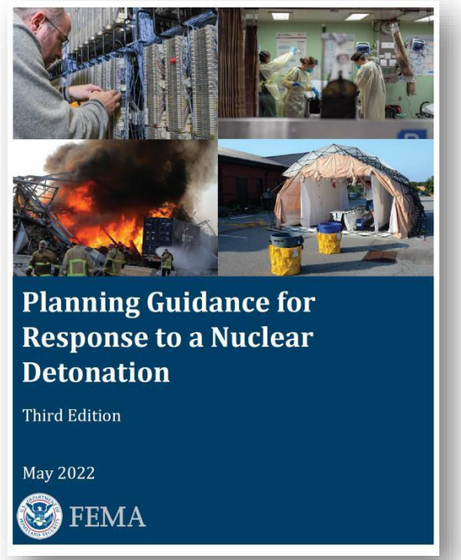
Chapter 1: Nuclear Detonation Impacts

Chapter 1 provides a high-level description of the features that make a nuclear incident **unique**.

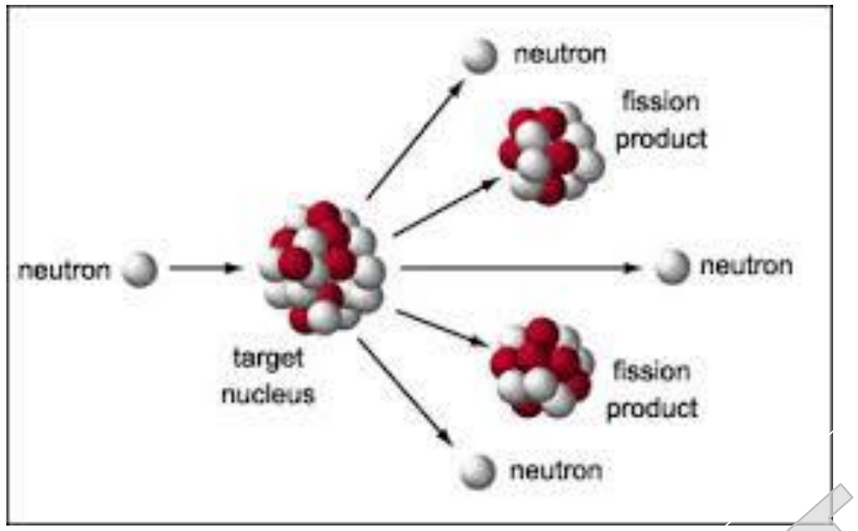
While these subjects are technical, descriptions are tailored for a non-technical audience.

- Blast Effects
- Prompt Thermal Effects and Fire
- Eye Injuries
- Initial and Residual Radiation
- Height of Burst (HOB) Considerations
- Radiation Zones
- Radiation Injuries and Fallout Health Impacts
- Electromagnetic Pulse (EMP) affects

Chapter 1



Nuclear Fission and Chain Reactions
In Fissile Materials (like U-235)

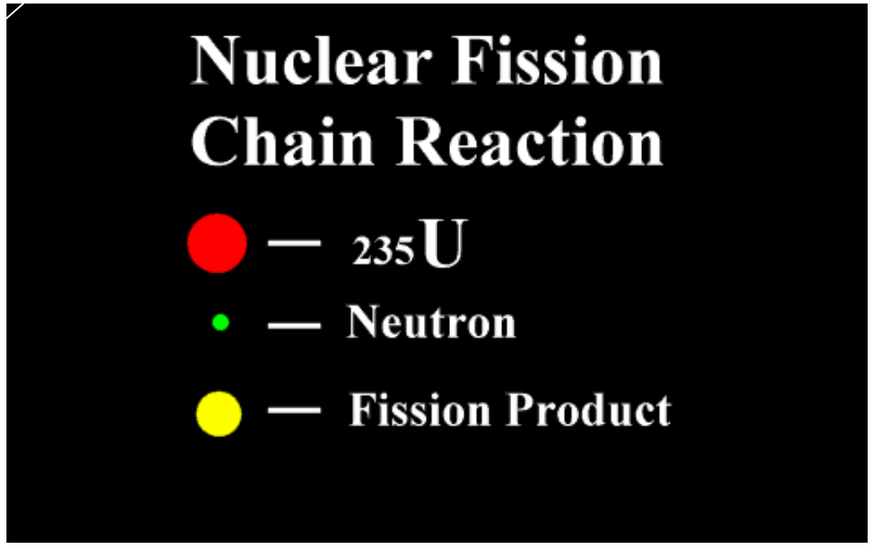


What do the 2-3 Neutron do?

- These neutrons cause additional fissions in a **"chain of reactions"**
- Each fission releasing more energy…

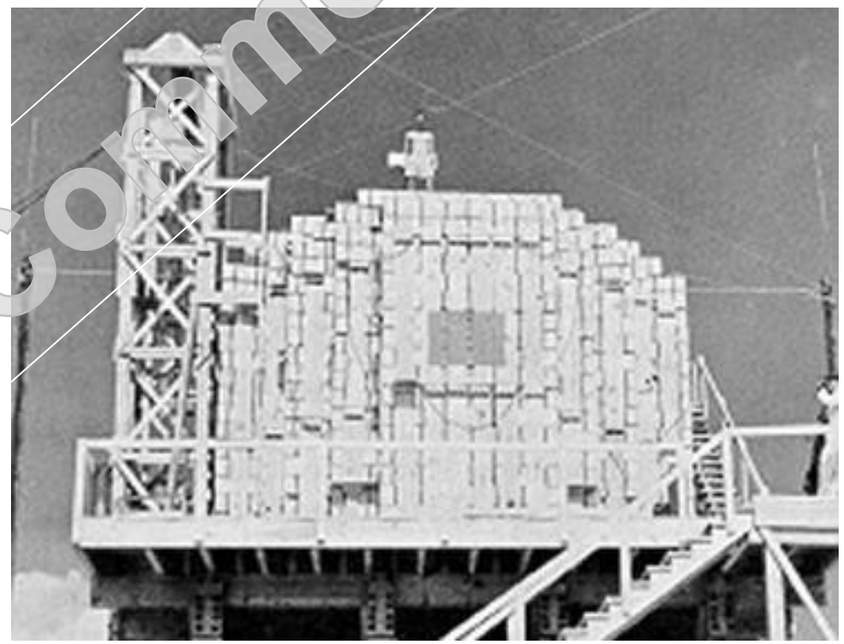
Nuclear Fission Produces:

- 2 or 3 neutrons,
- Energy, and
- Nuclear Fission Products



How Much Energy?

- If all of the atoms in a **coin-sized** piece of uranium fissioned…



- It would release the same amount of energy as **100 tons** of TNT
- Explosive energy is measured in tons of TNT Equivalent Weight
- Image is of 100 tons TNT test before the Trinity Shot.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Nuclear Weapons

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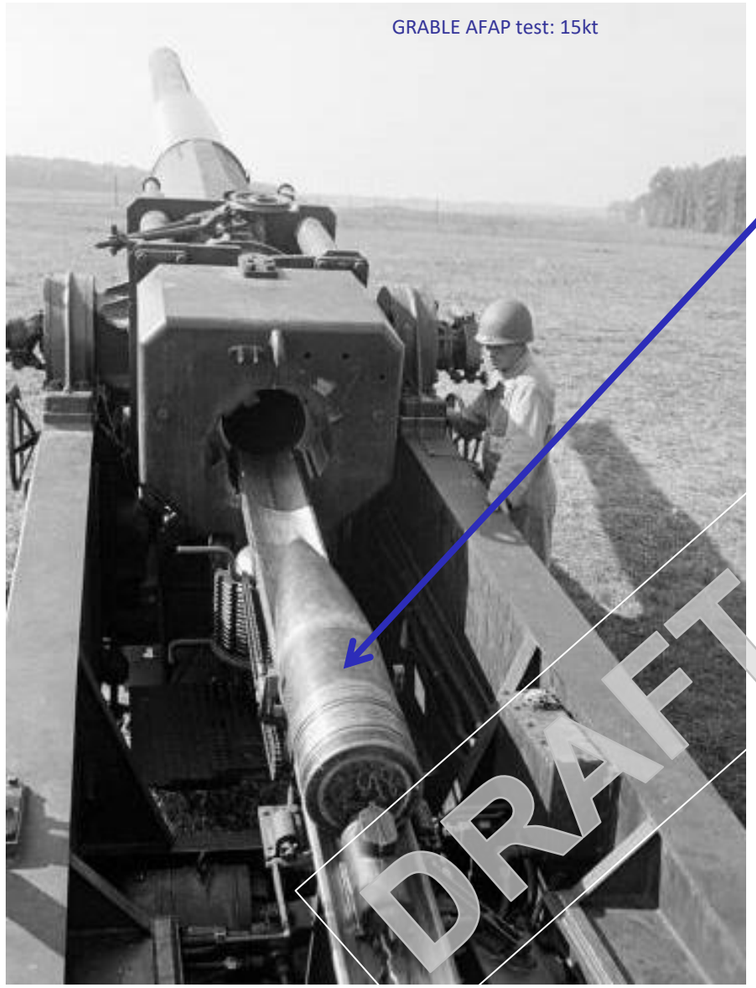


Thermonuclear weapons can be 10,000 of these piles!

Milliseconds

- Intense flash of light
- Initial ionizing radiation
- Electromagnetic Pulse

Seconds

- Thermal pulse
- Blast wave @ kms

Tens of Seconds

- Shock wave @ 10s km
- Fireball rises Rapidly

Minutes

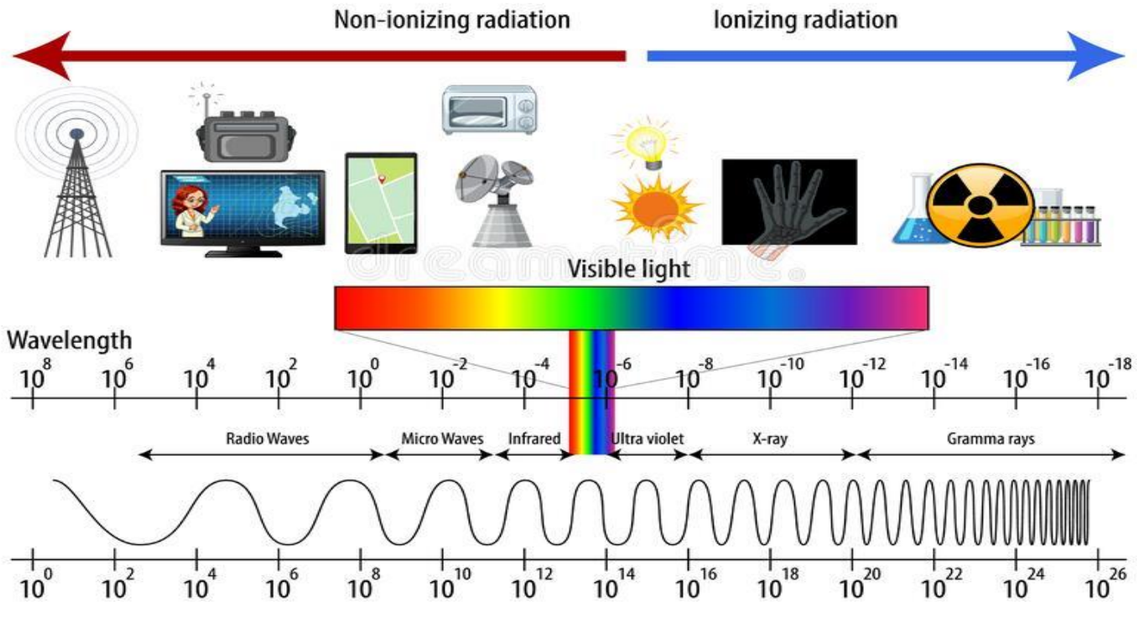
- Fallout cloud several km up
- Particles start "falling out"
- Dangerous deposition levels

Hours

- Dangerous fallout zones shrink
- Fallout hot zone expands downwind

Days

- Fallout hot zone shrinks
- Low levels of global fallout



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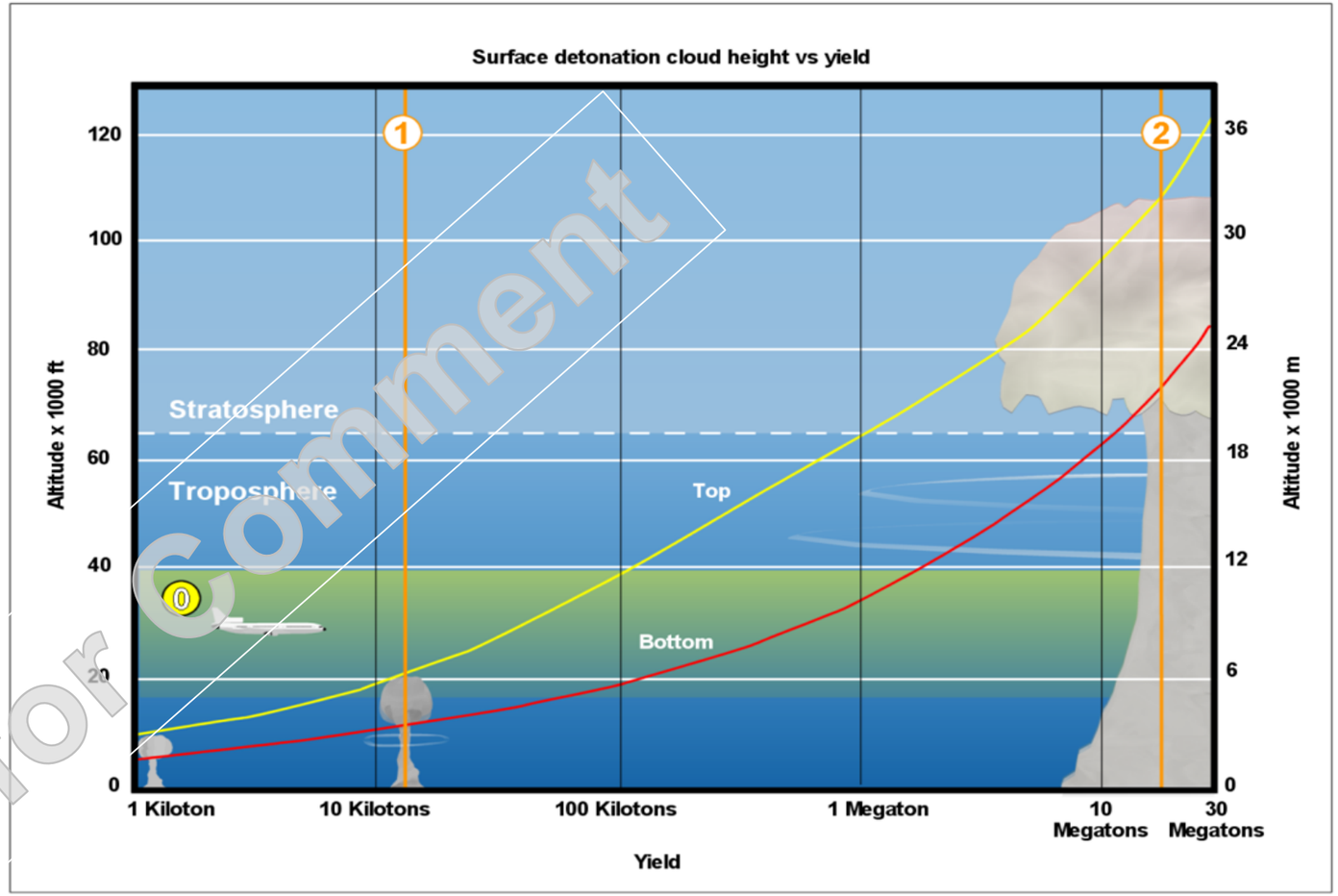
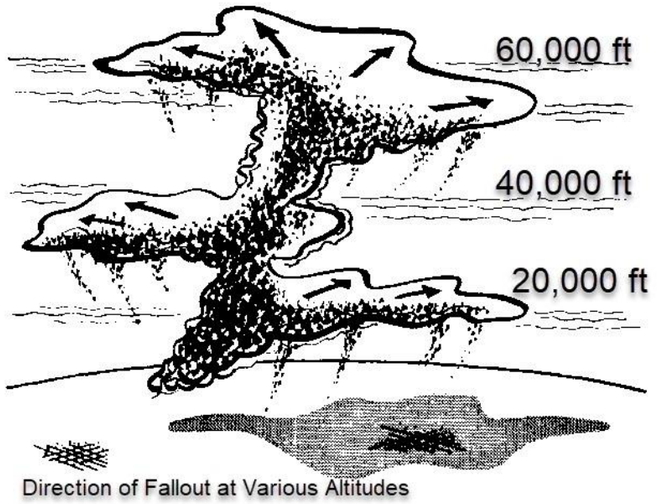
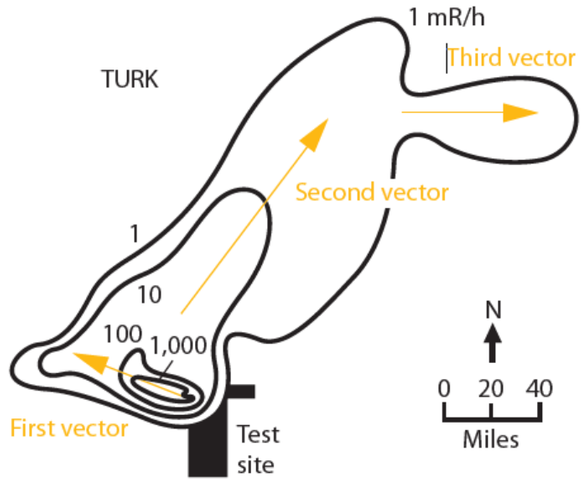




Direction of Fallout at Various Altitudes



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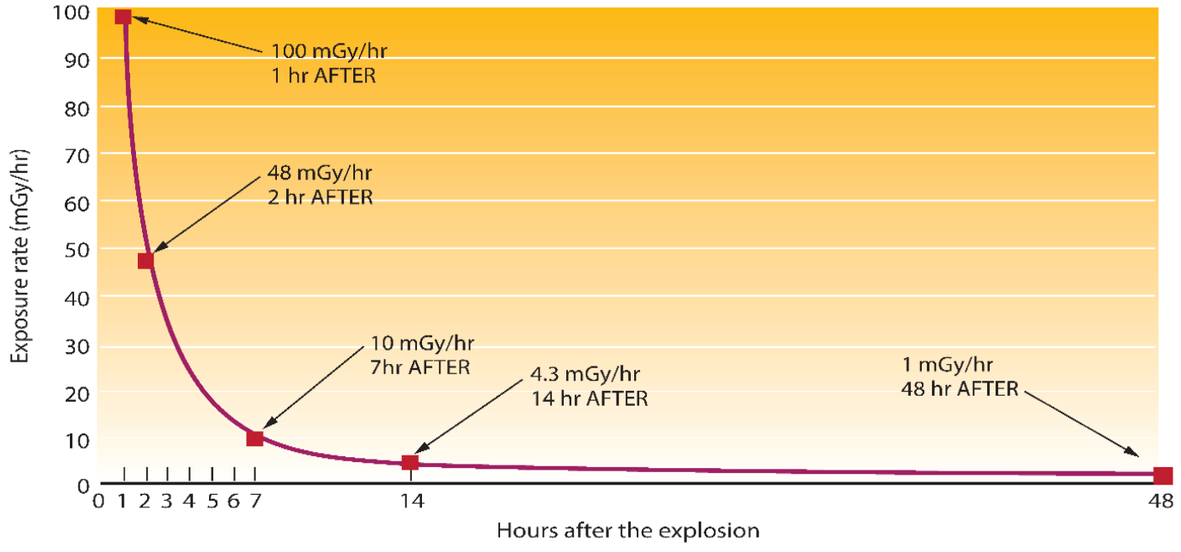

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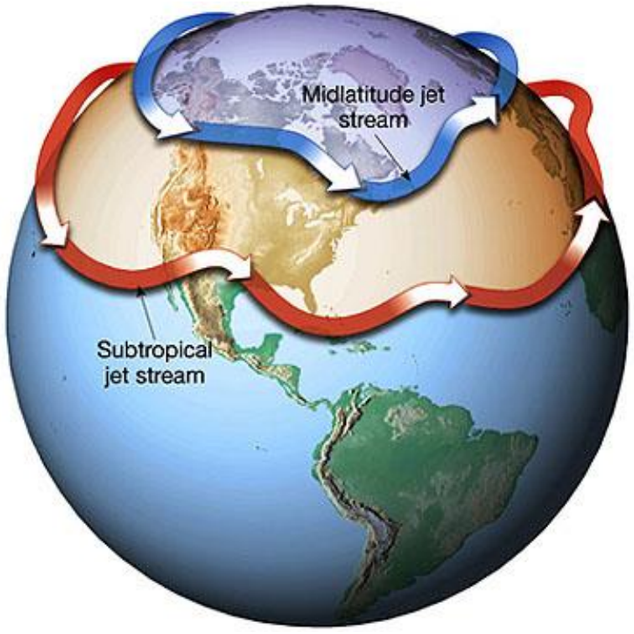

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The Light of a Thousand Suns

As seen at 1 mile for those with line of sight

- Scenario Presumptions:
  - 10kt Yield
  - Ground Level detonation downtown Washington DC, USA
  - Fallout Predicted using Weather from noon on Feb 14, 2009
  - Casualty Numbers Using Daytime Population Estimates

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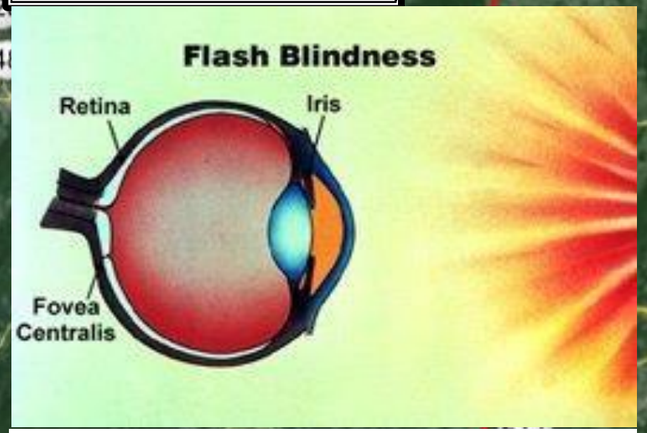
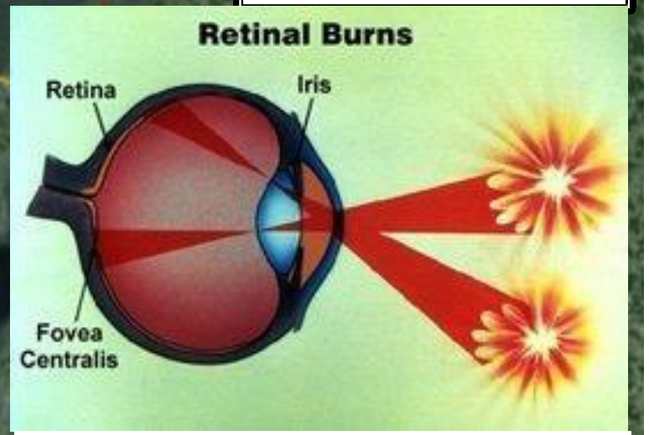
Eye Injury / Long Distance Effects (10kt)

~22 km (13 miles)



Flash Blindness, also referred to as "dazzle," is a temporary (usually less than a minute) impairment of vision. Victim does not have to be looking directly at the source for this to occur.

~23 km (14 miles)



Retinal burn: visual capacity is permanently lost in the burned area (but remainder of vision will still work)

22 km (day)

73 km (night)

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Visual 1.21

40 mi

Image Landsat

Blast Effects


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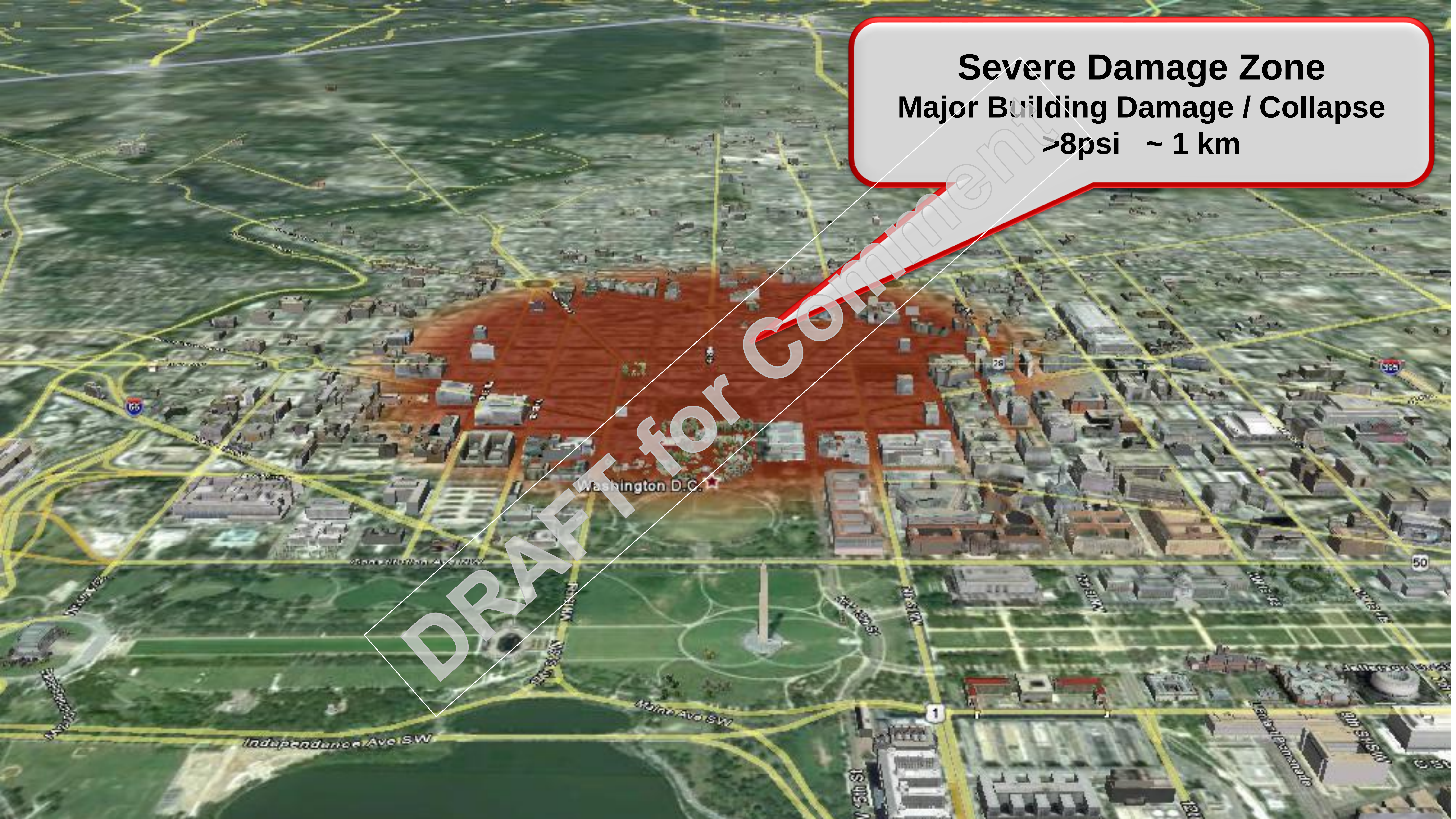
Severe Damage Zone
Major Building Damage / Collapse
>8psi ~ 1 km
Washington D.C.
Independence Ave SW
Maine Ave SW
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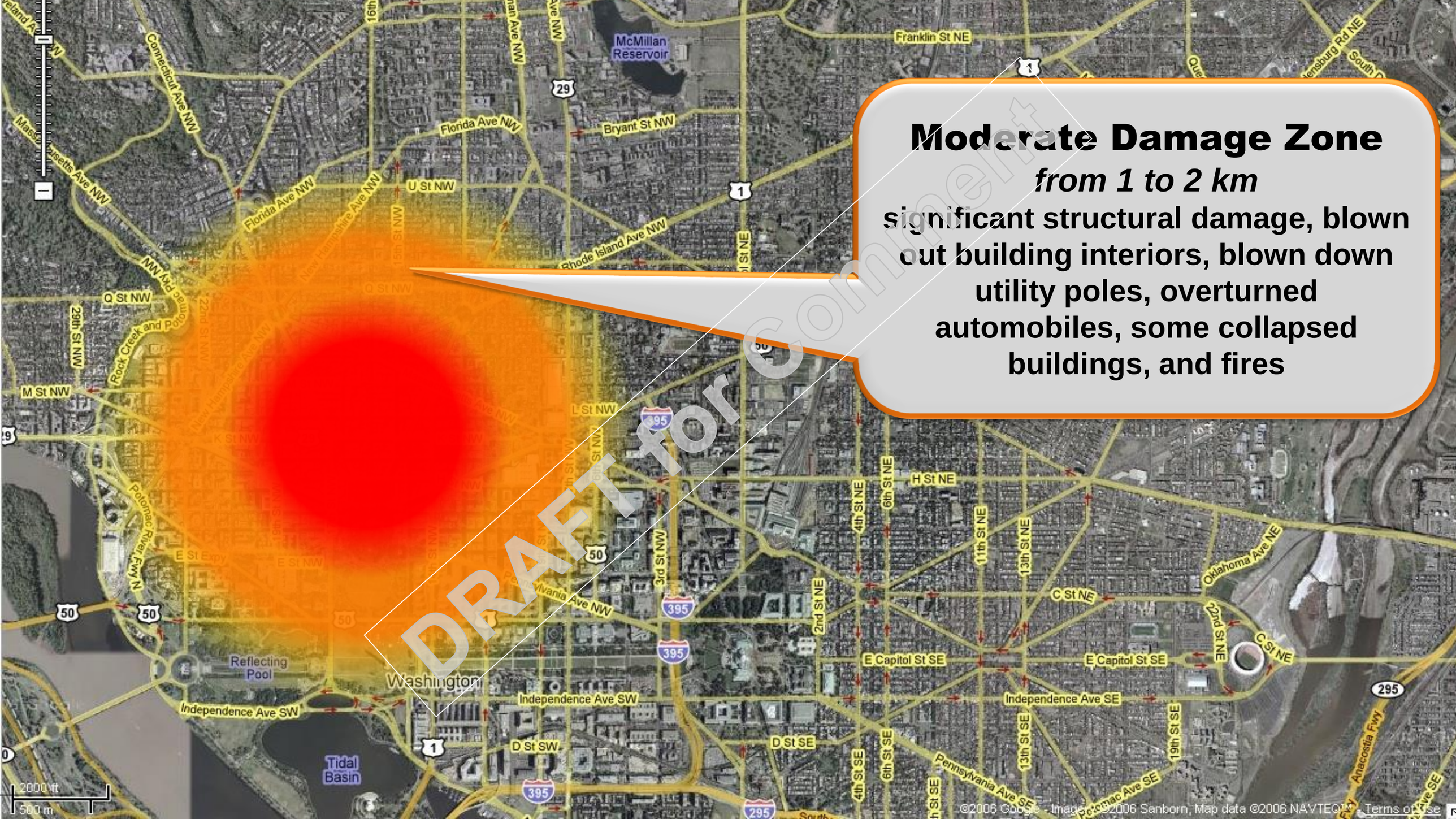
Severe Damage Zone Definition

- In the Severe Damage Zone (SDZ), few buildings will be structurally sound or standing.
- Rubble in streets will be impassable.
- Potentially dangerous radiation levels outdoors during the first day.
- Few survivors expected, except for those in the center of large structures or underground (e.g., subterranean parking garages or subway tunnels) when the detonation occurred.
- Survivors should continue to shelter unless threatened by a more immediate hazard such as fire or building collapse.


Moderate Damage Zone
from 1 to 2 km
significant structural damage, blown out building interiors, blown down utility poles, overturned automobiles, some collapsed buildings, and fires
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McMillan Reservoir
Franklin St NE
Connecticut Ave NW
Florida Ave NW
Bryant St NW
U St NW
Rhode Island Ave NW
Q St NW
M St NW
L St NW
H St NE
C St NE
E Capitol St SE
Independence Ave SW
Independence Ave SE
D St SW
D St SE
Pennsylvania Ave NW
Pennsylvania Ave SE
Oklahoma Ave NE
Reflecting Pool
Washington
Tidal Basin
Potomac River Fwy
E St Expy
Rock Creek and Potomac Pkwy NW
Anacostia Fwy
2000 ft
500 m
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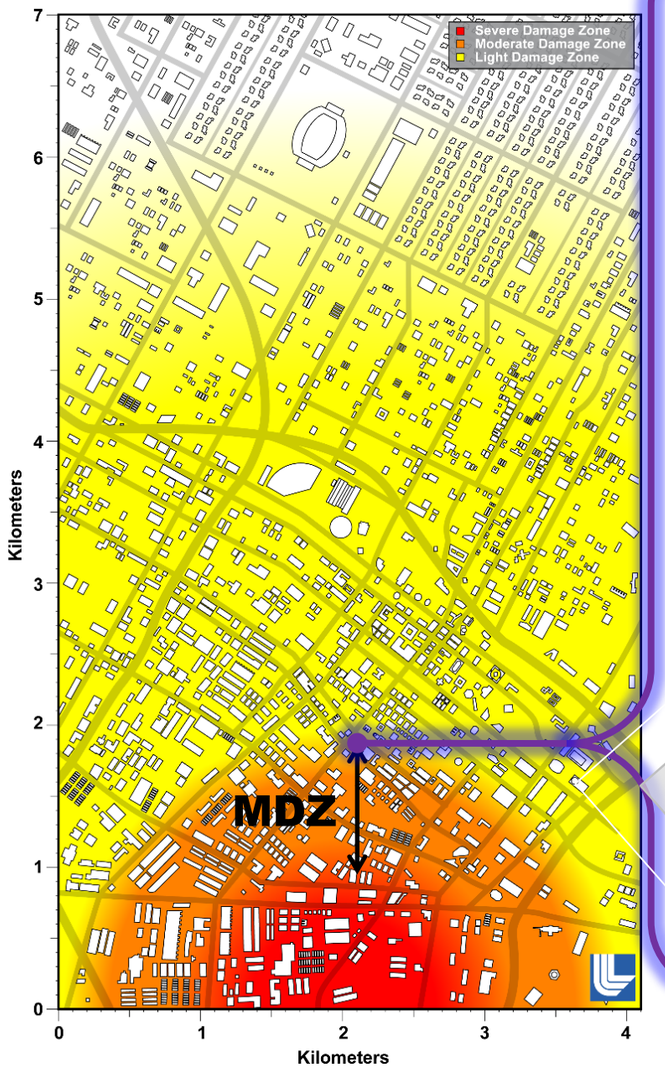
Examples of Damage in the Moderate Damage Zone

Moderate Damage Zone

Outer Edge of Moderate Damage Zone

~ 2 km from 10 kt



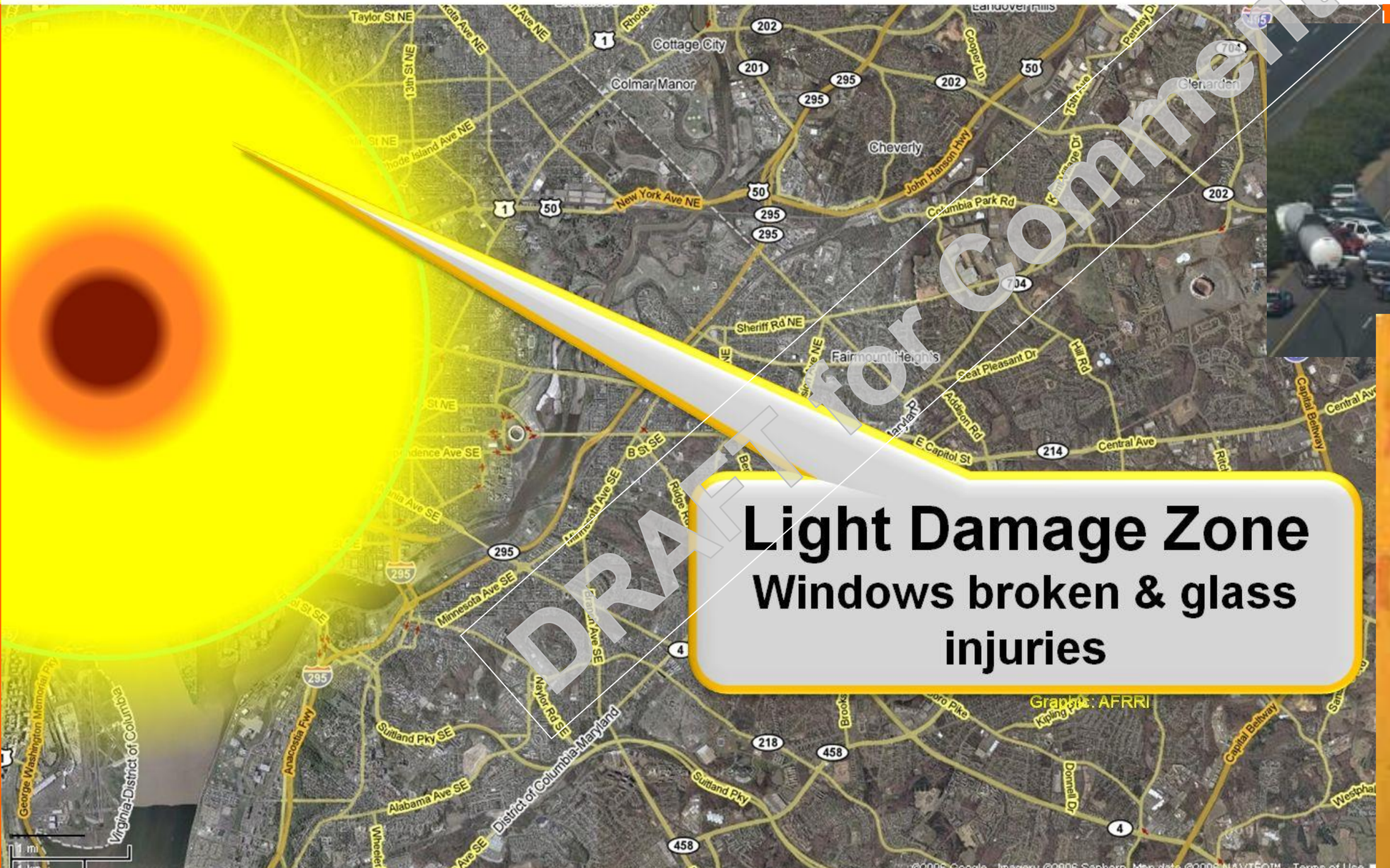
Animation depicts timing and damage from the outer edge of MDZ
(~ 2 km from a 10 kt explosion)

Moderate Damage Zone Definition

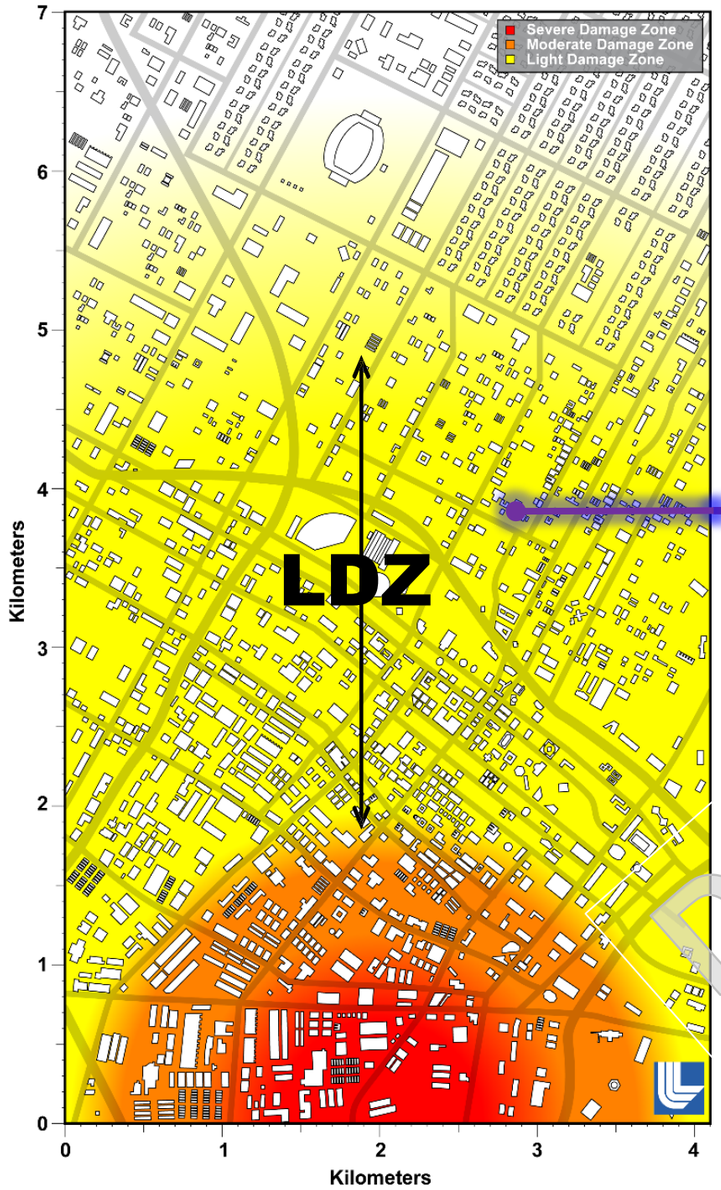
- In the Moderate Damage Zone (MDZ), building damage is substantial.
- The blast wave briefly creates winds greater than 100 mph,
- Sturdier buildings (e.g., reinforced concrete) will remain standing, but lighter commercial and residential buildings may fall be destroyed.
- Expect blown down utility lines, overturned automobiles, collapsed roofs, and fires.

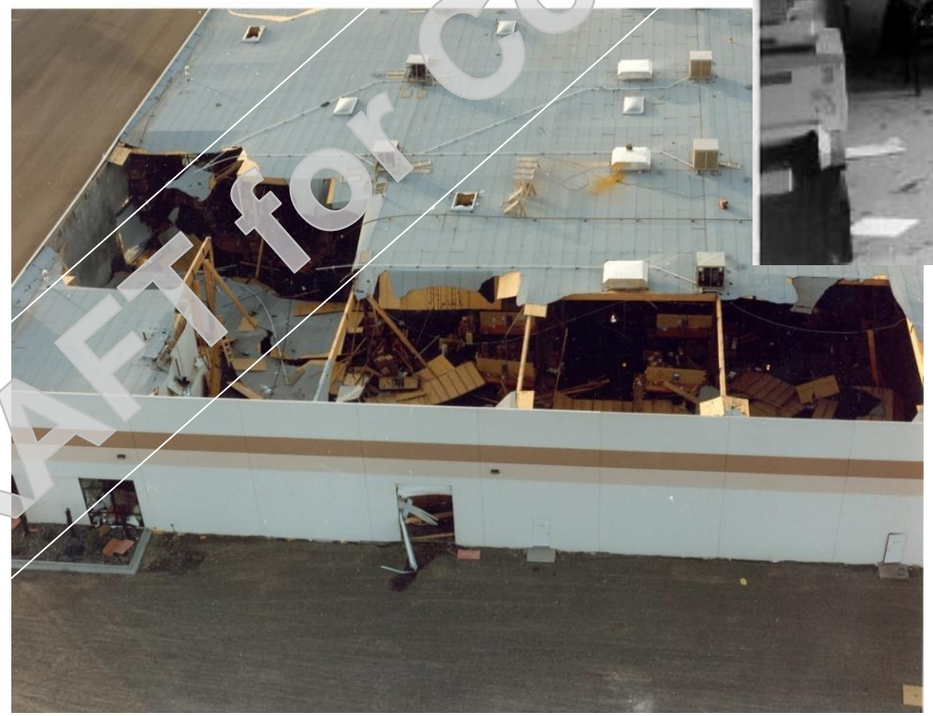
Light Damage Zone

Temporary Blindness up to 22 km



Light Damage Zone (2 to 5 km)





Damage to windows and other large area, weak building features

Images taken at 2.6km (1.5 miles) away from PEPCON (conventional accidental explosion estimated to be equivalent to a 1 kt free air burst), estimated overpressure shock was ~ 0.9 psi

Examples of Damage in the Light Damage Zone

Light Damage Zone Definition

- Damage is caused by the powerful shockwave, like that of a thunderclap or sonic boom but with substantially more force.
- Most windows in the LDZ will break, many with enough force to cause injuries from flying glass and debris, though most people in this are would be uninjured.
- Damage in this area will vary as shockwaves rebound off buildings, terrain, and the atmosphere.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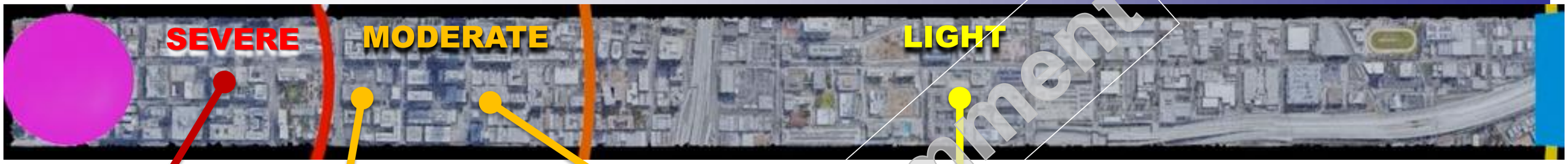
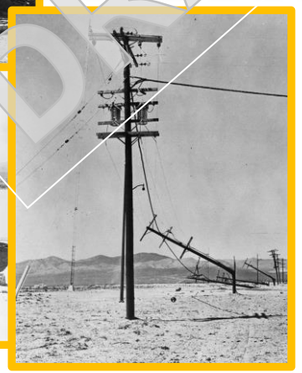
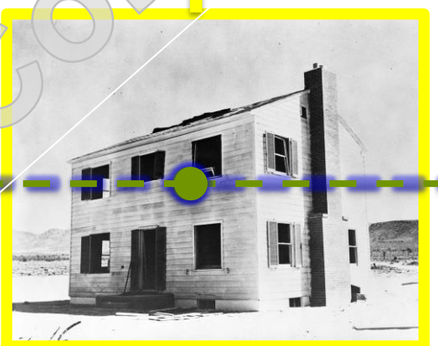
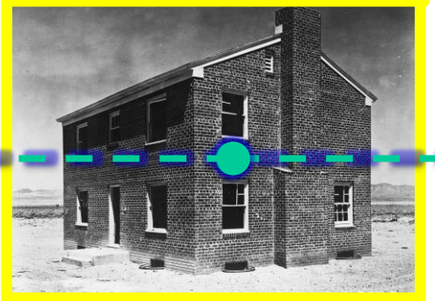
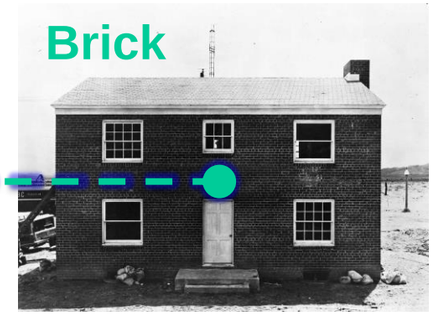








Windows and doors blown in

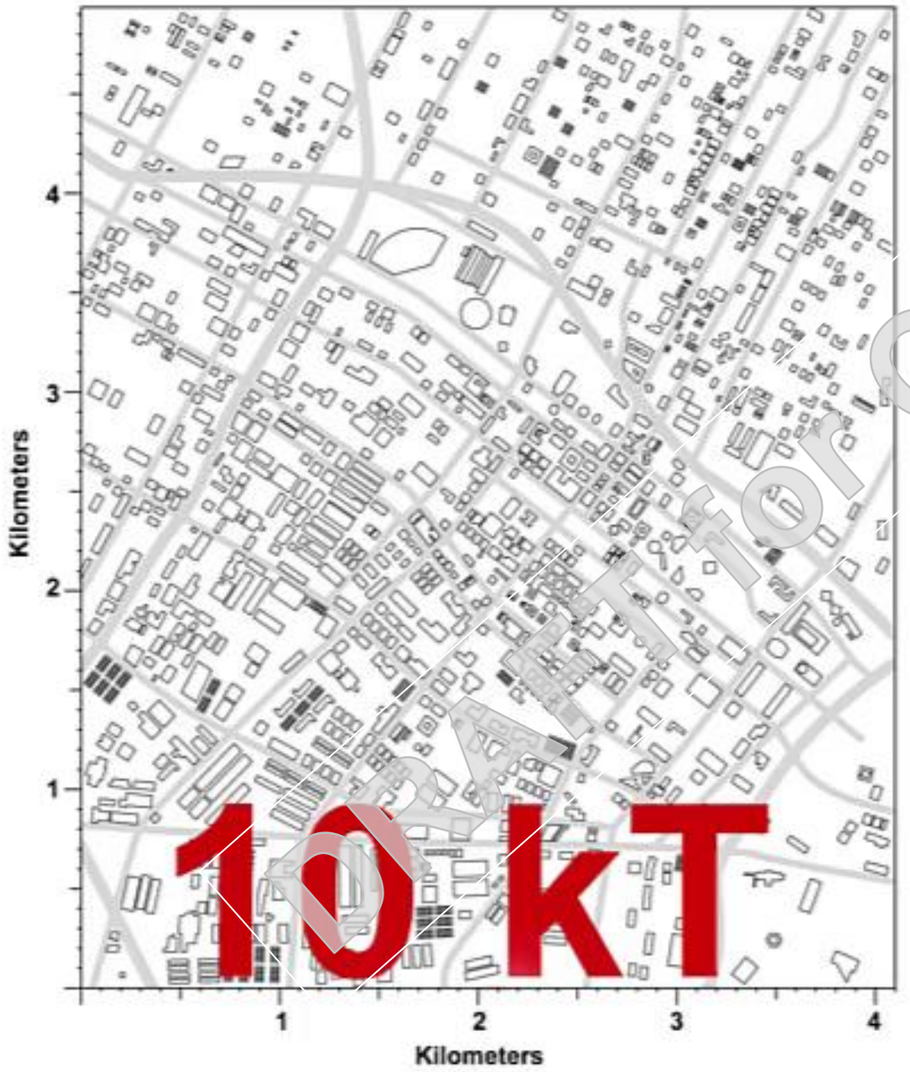


Light Structures Pre-Detonation

Moving through the Damage Zones

Expect movement to be difficult in the blast damage zones because of piles of debris in the street

Comparing Ranges



Thermal Effects

Thermal Impacts

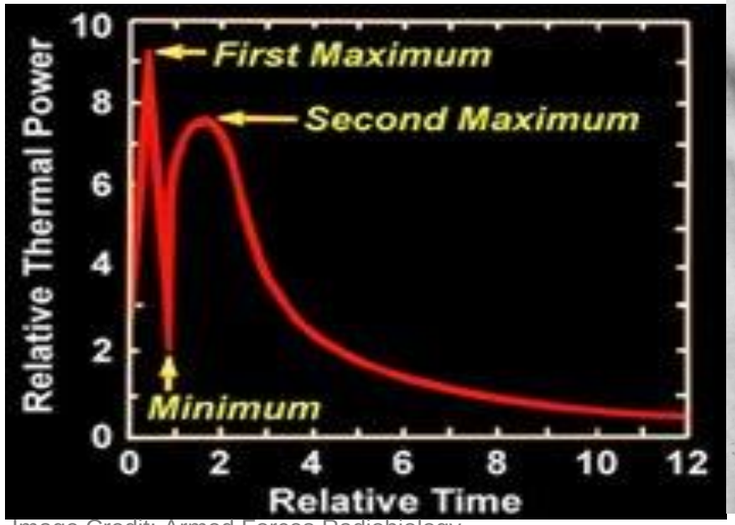
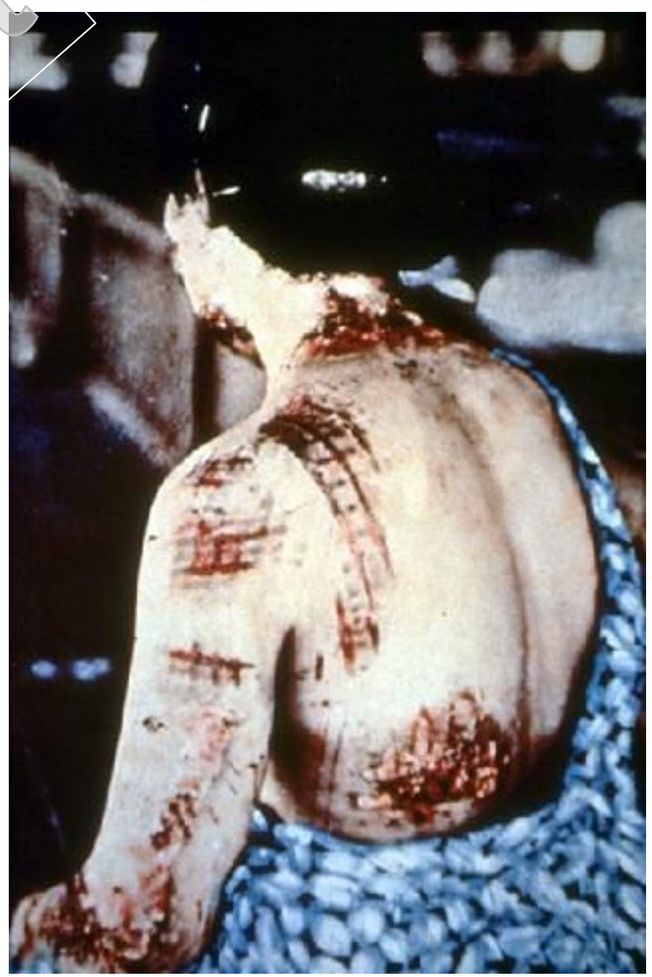


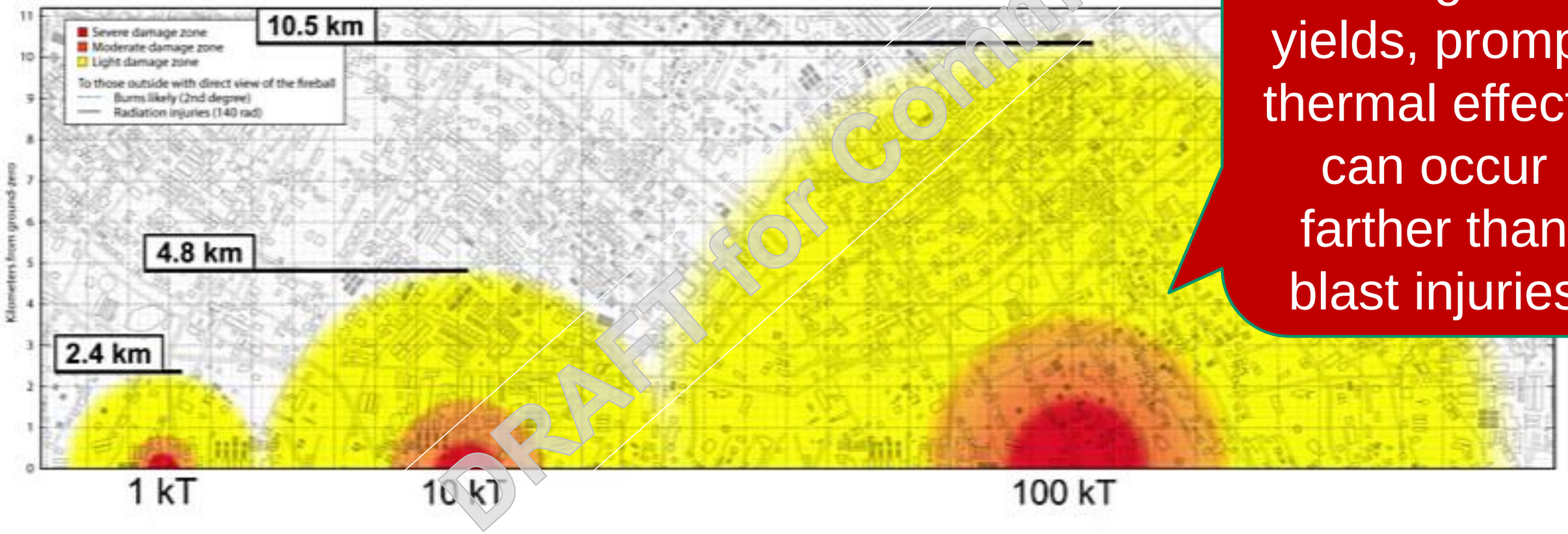
Image Credit: Armed Forces Radiobiology Research Institute

- Initial Heat Pulse (1% of energy) occurs within a fraction of a second, too fast to avoid or even blink!
- The second, slower heat pulse occurs over several seconds and deposits 99% of the heat energy
- This accounted for most of the skin burns in Japan



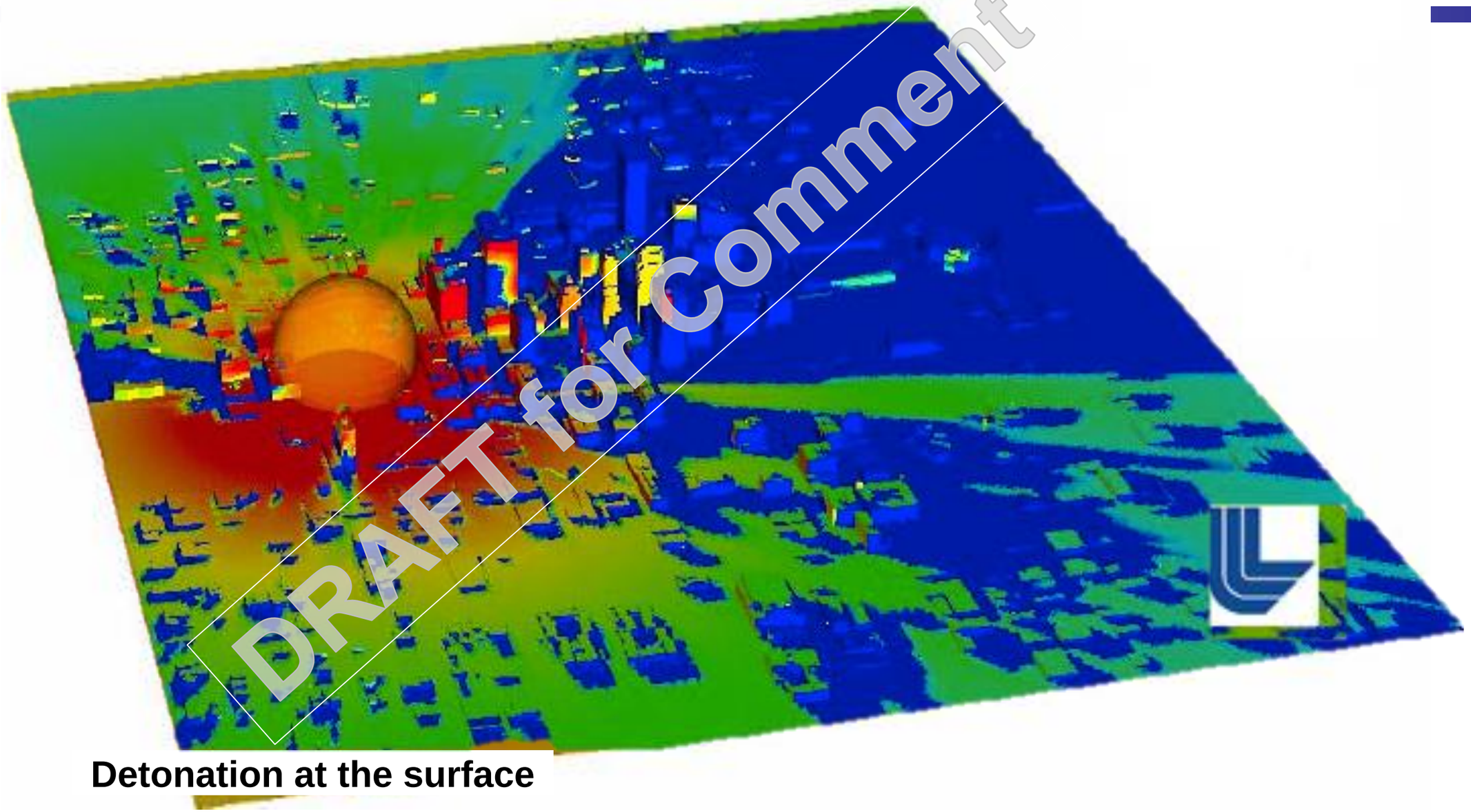
The pattern is from the dark colored areas on her kimono

Prompt thermal range not proportional to blast effects



At higher yields, prompt thermal effects can occur farther than blast injuries

Accuracy of Thermal Ranges

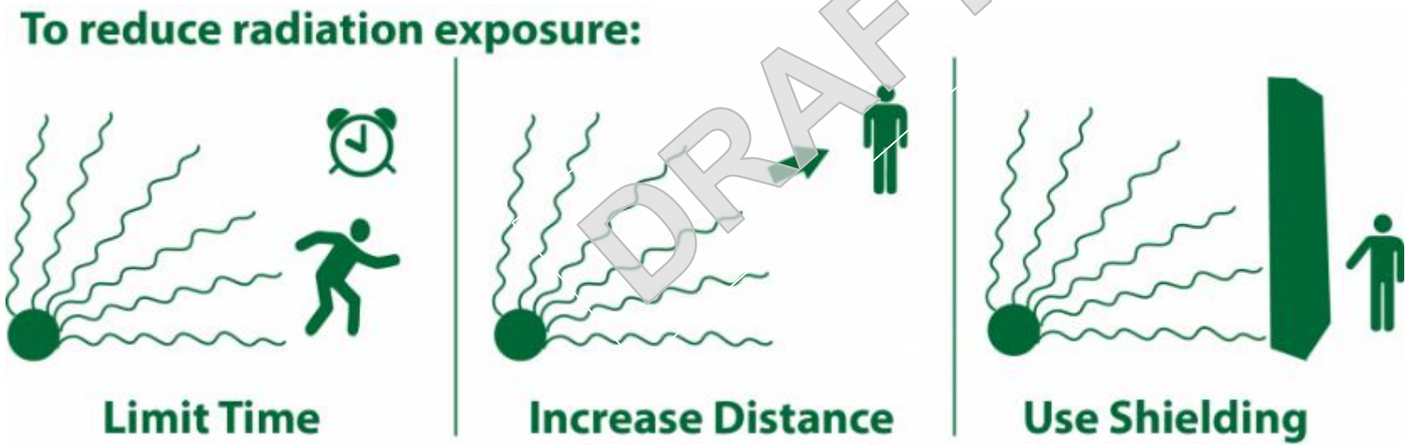


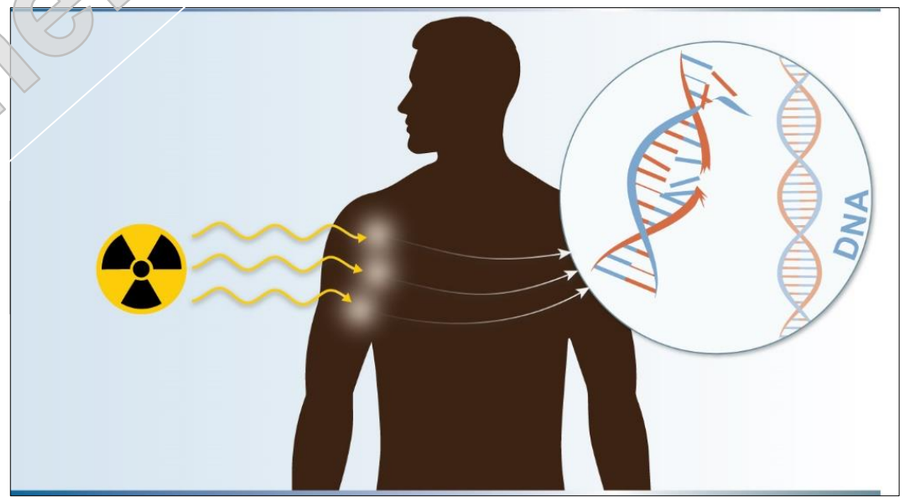
Detonation at the surface

Ionizing Radiation Effects

What is Radiation

- **What is radiation?**
  - Heat, light, any movement of energy through space
- **What is Ionizing radiation?**
  - Radiation that can break chemical bonds, damaging DNA causing cell damage and mutations
- **How do we detect radiation?**
  - Detection and monitoring equipment
- **How do we protect ourselves from radiation?**





Dose Rate vs. Dose

- **<u>Dose</u> describes the amount of radiation energy deposited in the body**

  Measured in:

  Sieverts (Sv) or Gray (Gy)

  For fallout: 1 Sv ~ 1 Gy

  1 Sv = 1000 mSv

  1 Sv = 100 cSv

- **The <u>Dose Rate</u> describes how quickly the energy is being deposited**

  Measured in:

  mSv/h

  mGy/h

Radiation Doses Millisieverts (mSv)	
3,000	Survival rate approximately 50%
1,000	Causes radiation sickness and nausea, but not death.
500	Allowable dose for emergency workers performing life-saving
100	Lowest level linked to increased cancer risk
10	Full body CT Scan
0.01	Dental X-ray

Nuclear Detonation: Ionizing Radiation

Radiation has serious effects on response and is the defining feature of nuclear incidents.

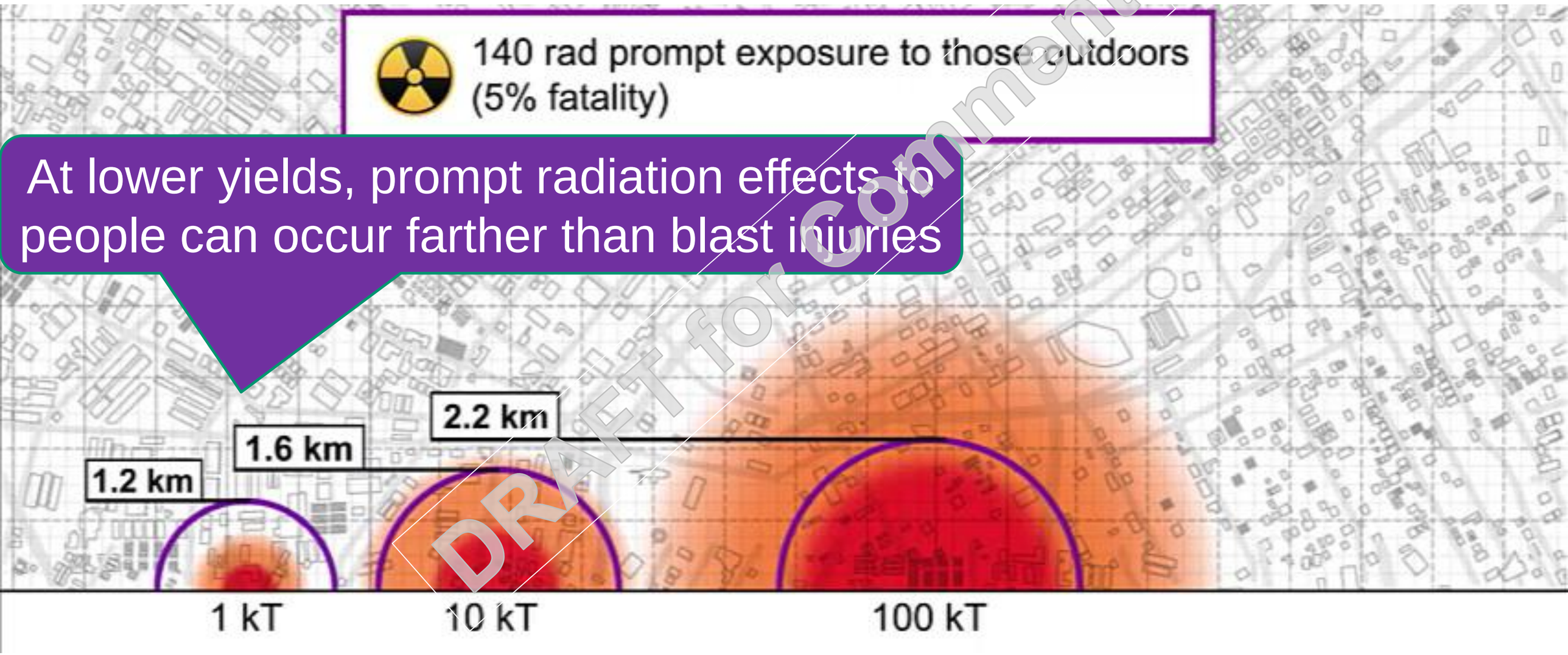
Prompt (Initial) Radiation

- Occurs in the first minute of a nuclear detonation.
- Contributes to casualties within a couple kilometers of ground zero.
- Intensity decreases with distance from ground zero.
- Some initial radiation risks can be mitigated by protective measures taken before the detonation.

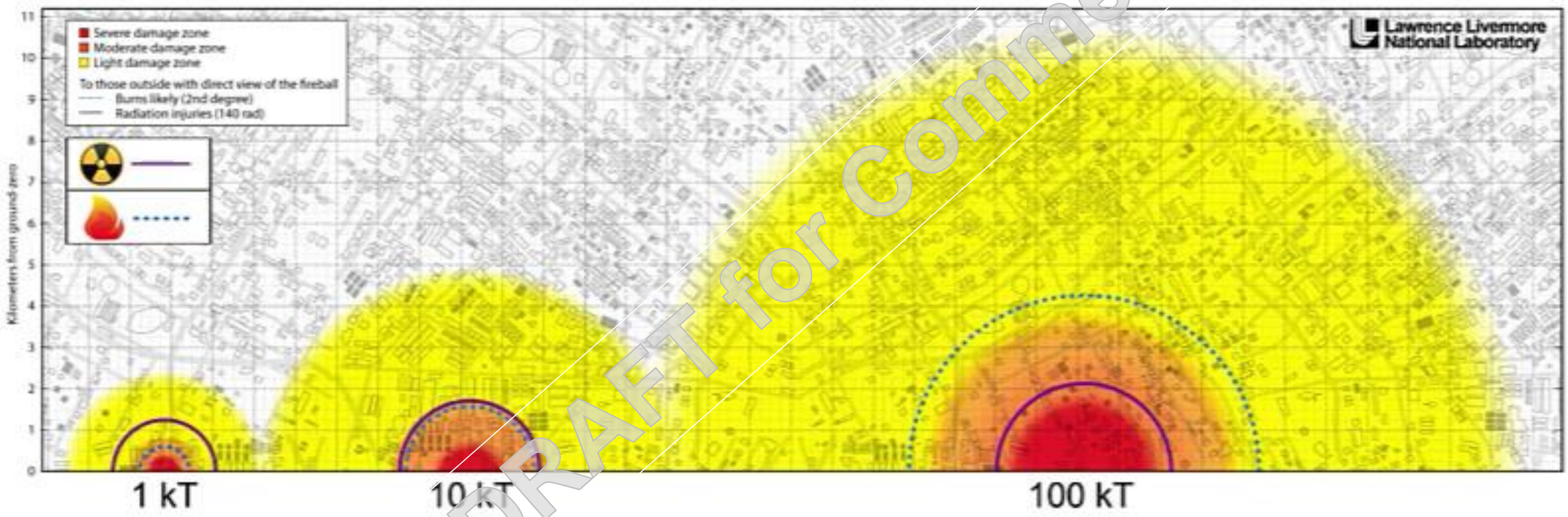
Residual Radiation

- Radiation given off **after** the first minute.
- Produced by fission products and activated material that continue to give off radiation.
- Most dangerous in the first few hours; decays over time.
- Can mix with dirt lofted by the explosion to create ***fallout*** locally and downwind.

Prompt radiation range not proportional to blast effects

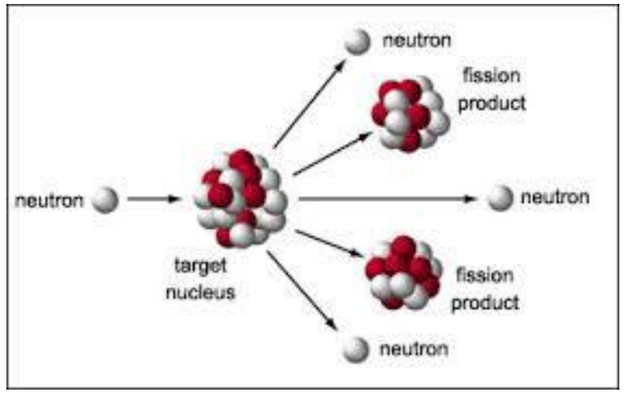


Range of Prompt Thermal and Radiation



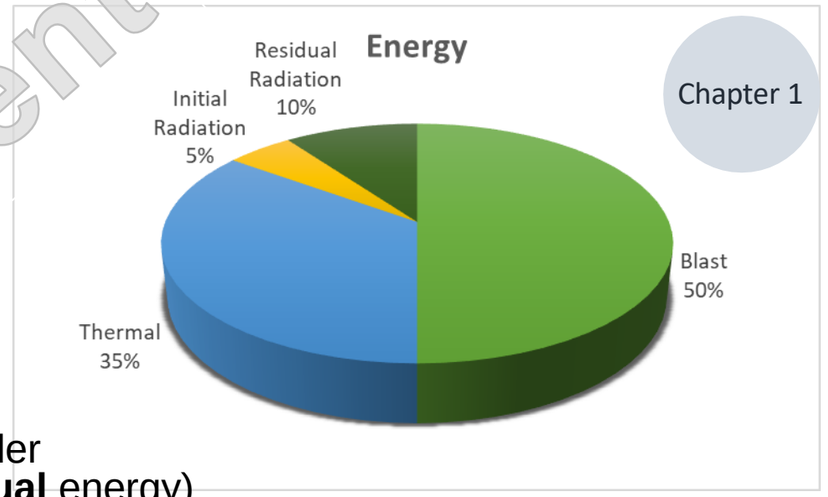
Residual Radiation (Fallout)

Residual Radiation (Fallout)



Nuclear Fission Produces:

- 2 or 3 neutrons,
- Energy, and
- Nuclear Fission Products
  (Fissile atoms, like uranium, split into 2 (or more) smaller **radioactive** elements which continue to give off **residual** energy)

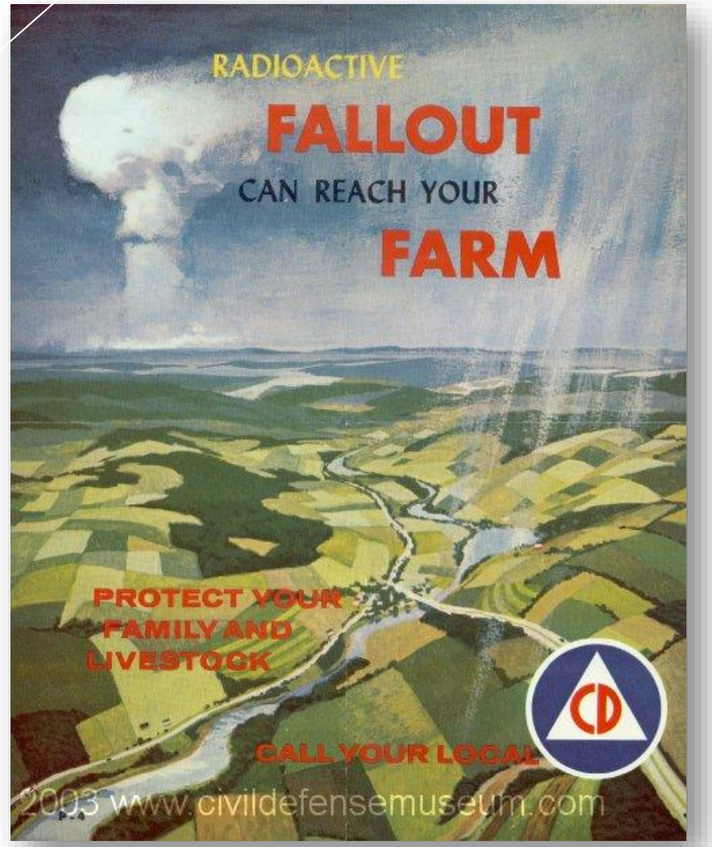


- The burned nuclear fuel (Uranium or Plutonium) from a 10kt nuclear explosion will produce about 500 grams (20 oz) of fission products.
- 1 minute after detonation there would be ~ 1 x 10^{22} Bq [10,000,000,000,000,000,000,000 Bq] (disintegrations per second).
- This is more than 1,000 times the radioactivity of the material released from Fukushima or Chornobyl.

Estimated radioactivity release from : Fukushima ~ 0.024 Billion Ci, Chornobyl ~ 0.1 Billion Ci (IEEE)

Fallout

- The nuclear detonation creates a large cloud of radioactive dust & water vapor which fall **back to earth contaminating surfaces**
- **IF** the detonation occurs near the Earth, dangerous levels of fallout creates visible dust and debris. These particles give off **penetrating radiation** that can injure people (even in cars or inadequate shelter)
- **Fallout decays rapidly away with time**, and is most dangerous in the first few hours after the detonation



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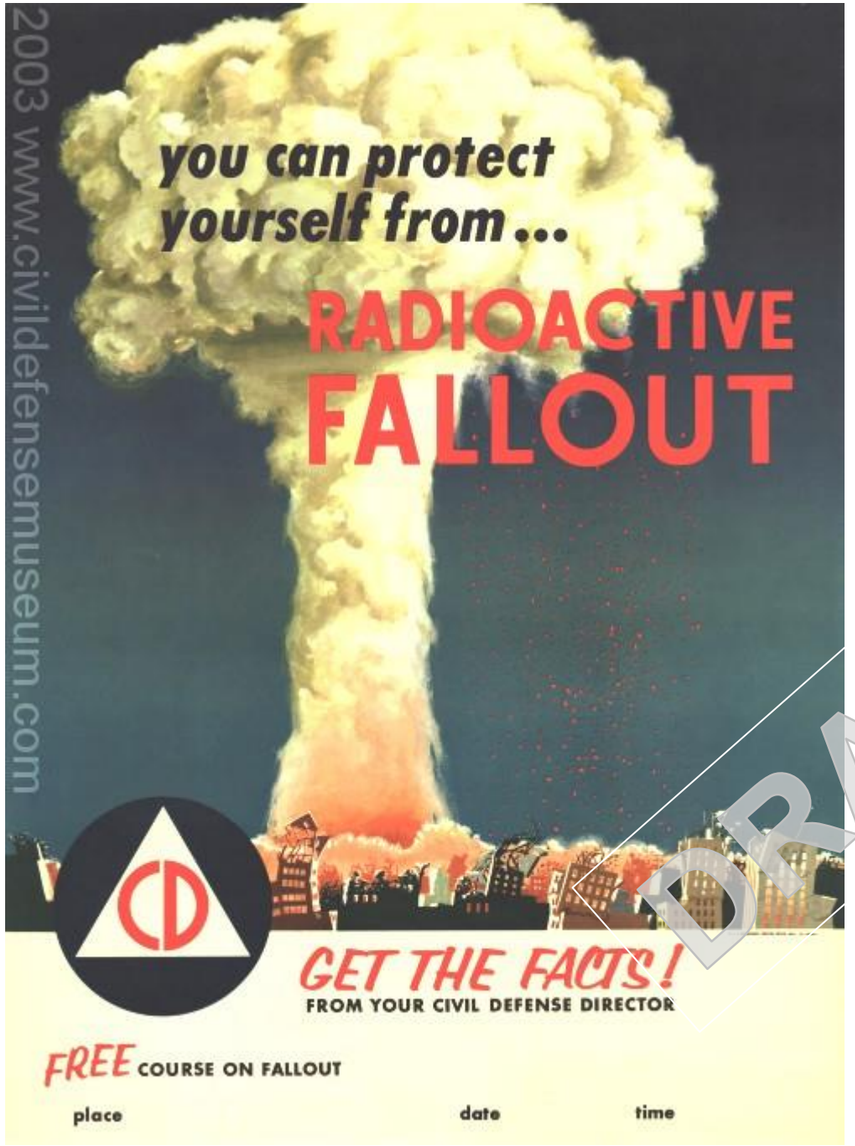
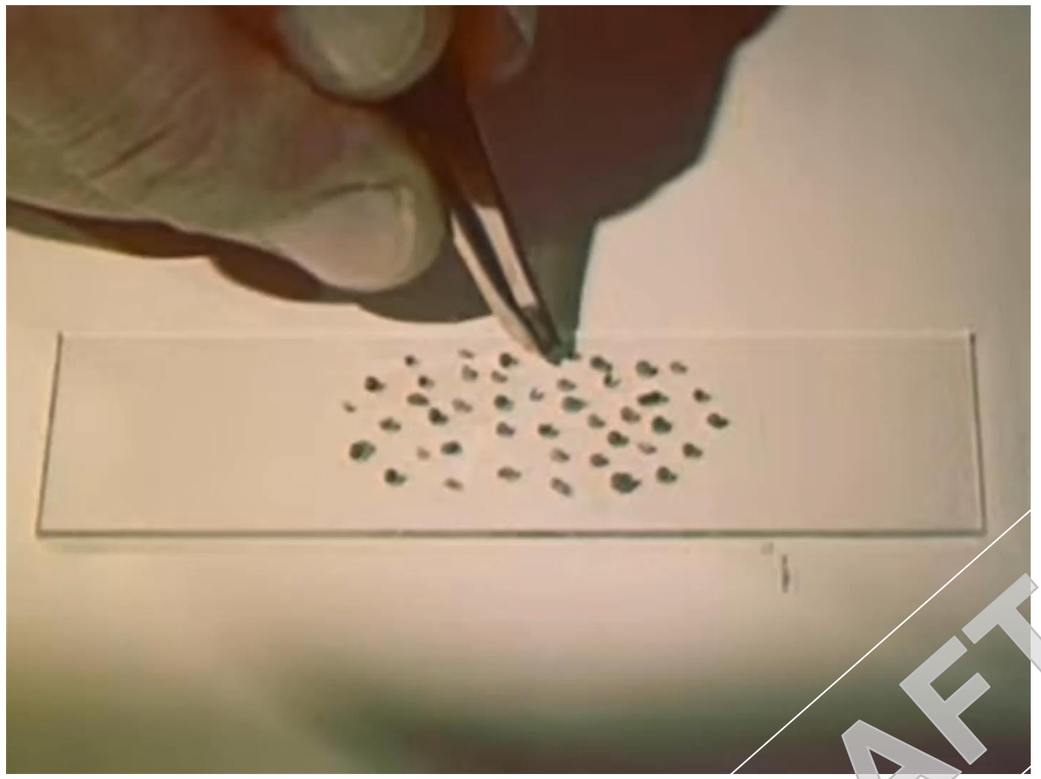
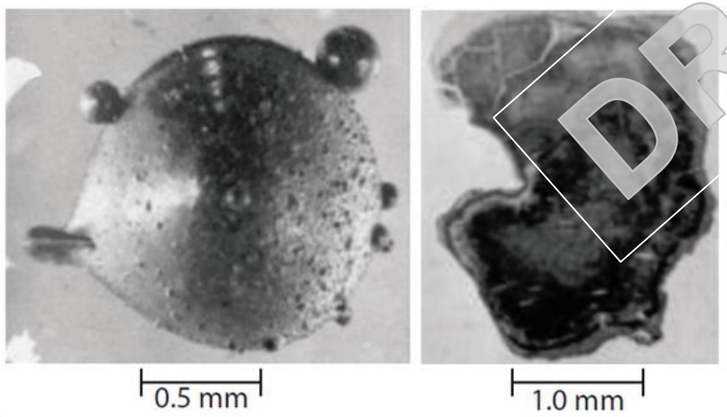


What is Fallout?





- A fireball is hotter than the sun is comprised of a plasma that contains all the fission products produced in the explosion.
- The fireball can interact with the ground.
- The rapid rise of the fireball (> 100s kph) creates a vacuum that pulls up thousands of tons of dirt and debris.
- If the dirt mixes into the fireball, the plasma can melt it and condense onto the dirt
- As they cool, the larger particles “fall out” of the cloud.

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NNSA Nuclear Security Administration

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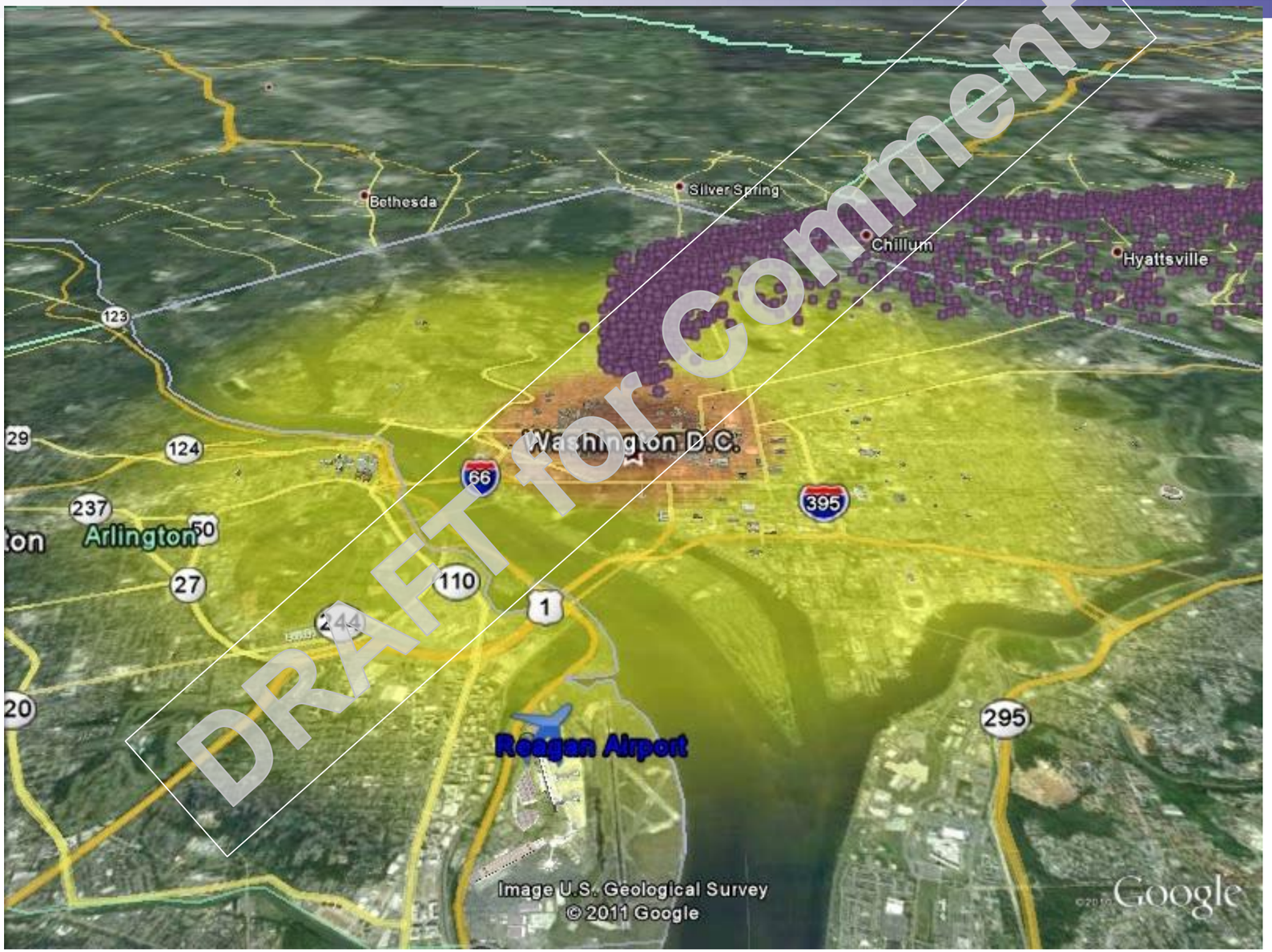
National Nuclear Security Administration

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District of Columbia
Washington D.C.
Silver Hill
495
Radiation from Fallout on the Ground
© 2011 Europa Technologies
© 2011 Google
Image PA Department of Conservation and Natural Resources-PAMAP/USGS
Google

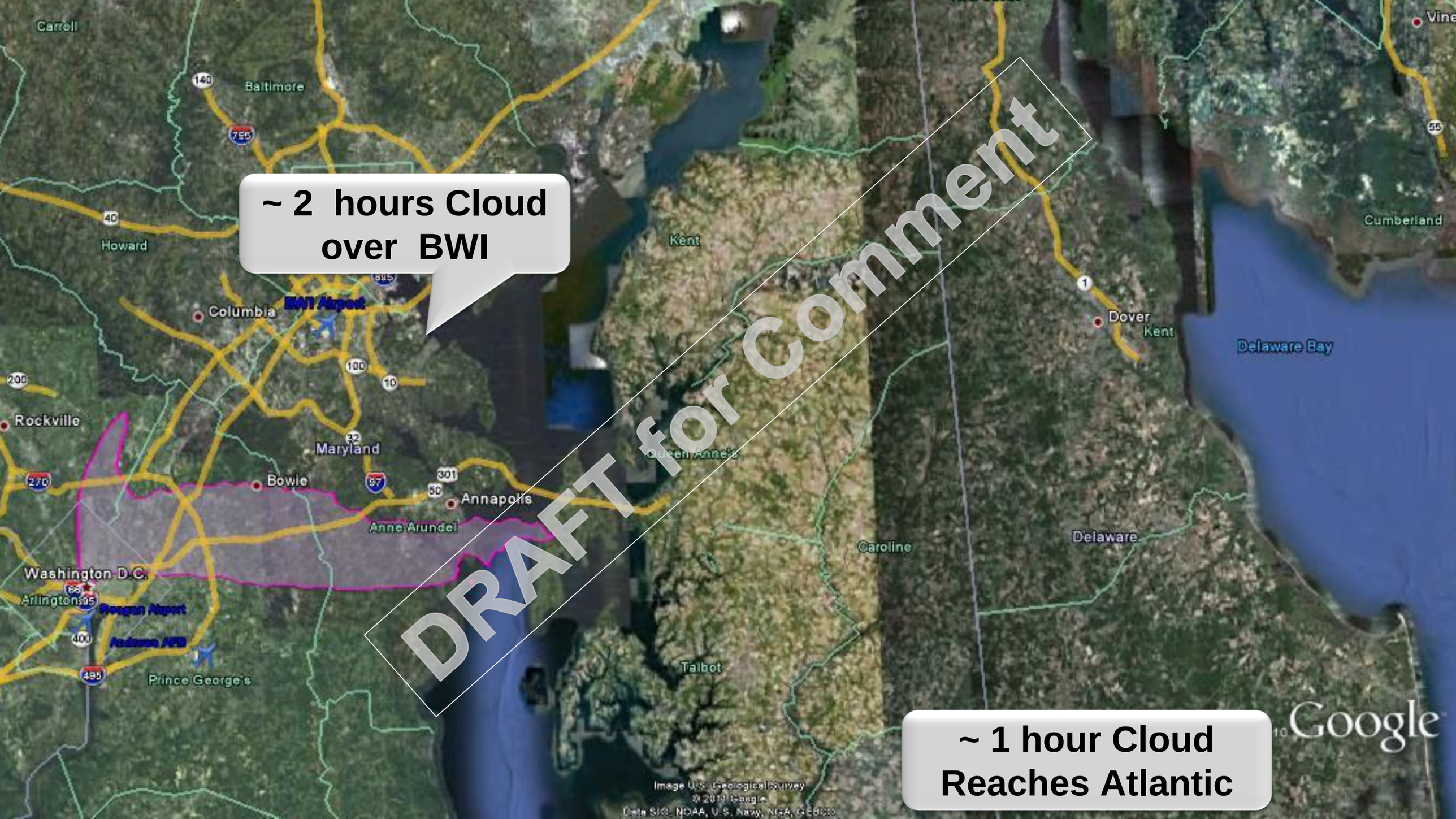
~ 2 hours Cloud over BWI
DRAFT for Comment
~ 1 hour Cloud Reaches Atlantic
Carroll
Baltimore
Howard
Columbia
BWI Airport
Kent
Cumberland
Dover
Kent
Delaware Bay
Rockville
Maryland
Queen Anne's
Bowie
Annapolis
Anne Arundel
Caroline
Delaware
Washington D.C.
Arlington
Reagan Airport
Andrews AFB
Prince George's
Talbot
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Image U.S. Geological Survey
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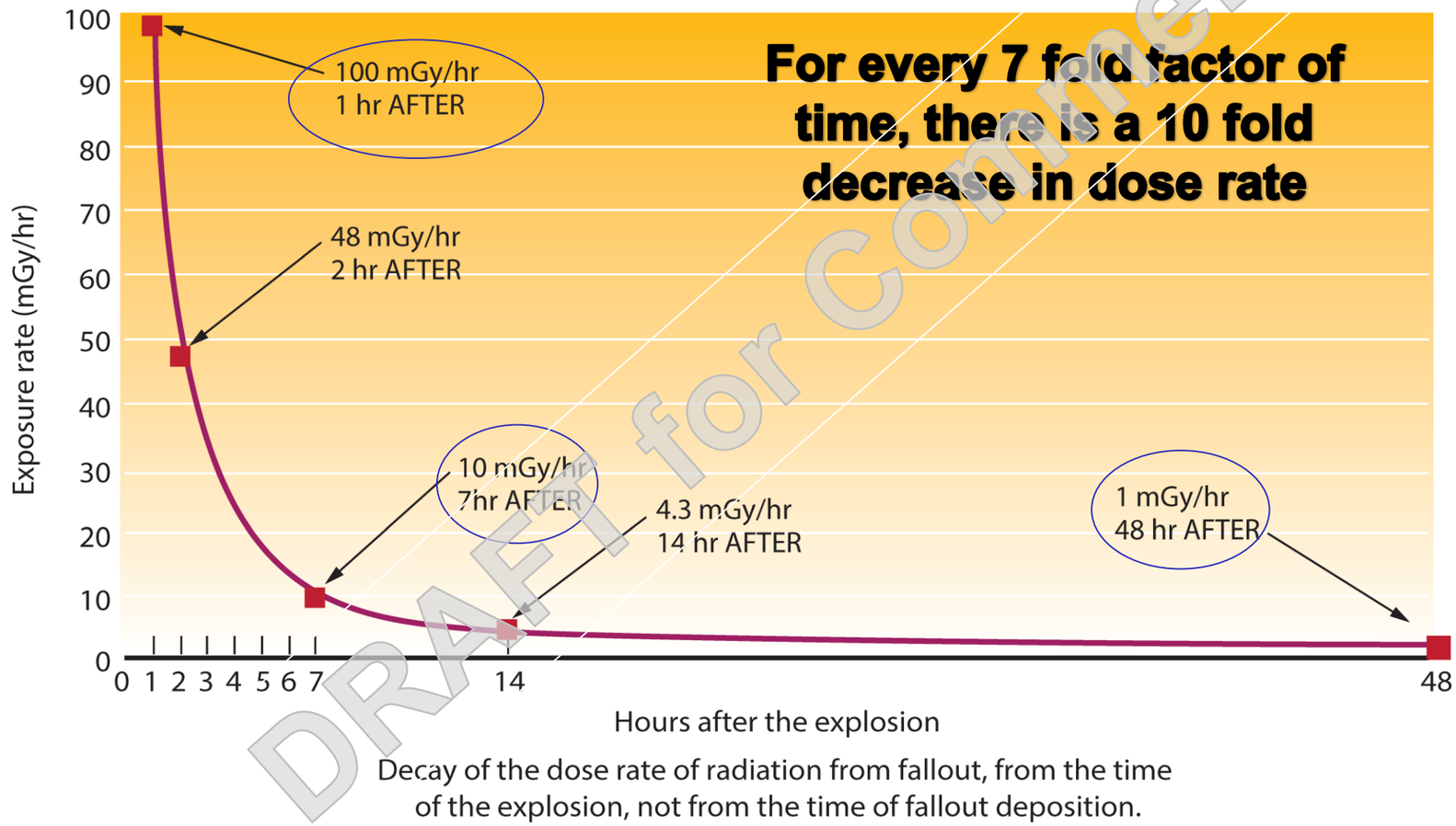
Data SIO, NOAA, U.S. Navy, NGA, GEBCO

Fallout Radiation Levels with Time

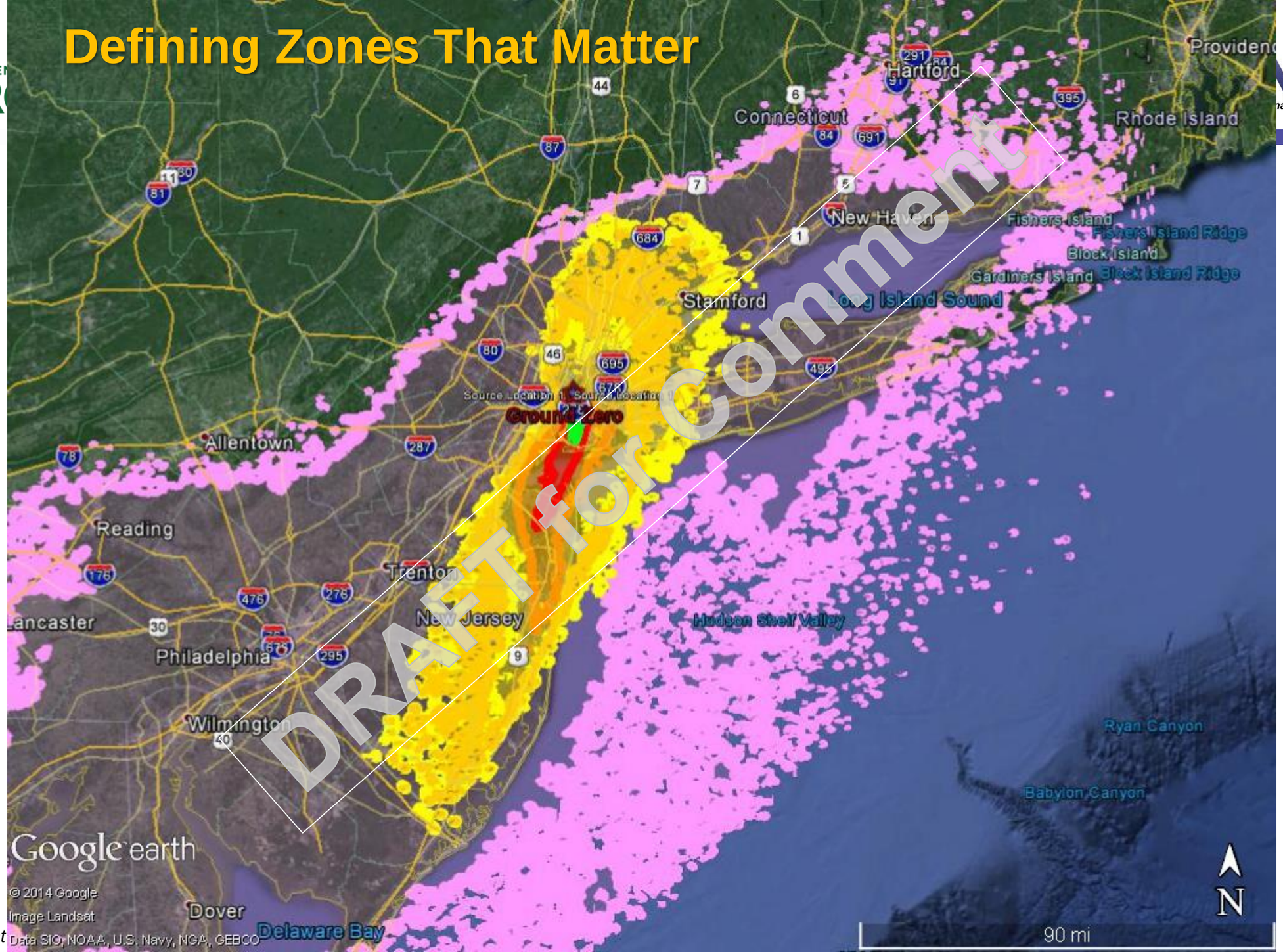


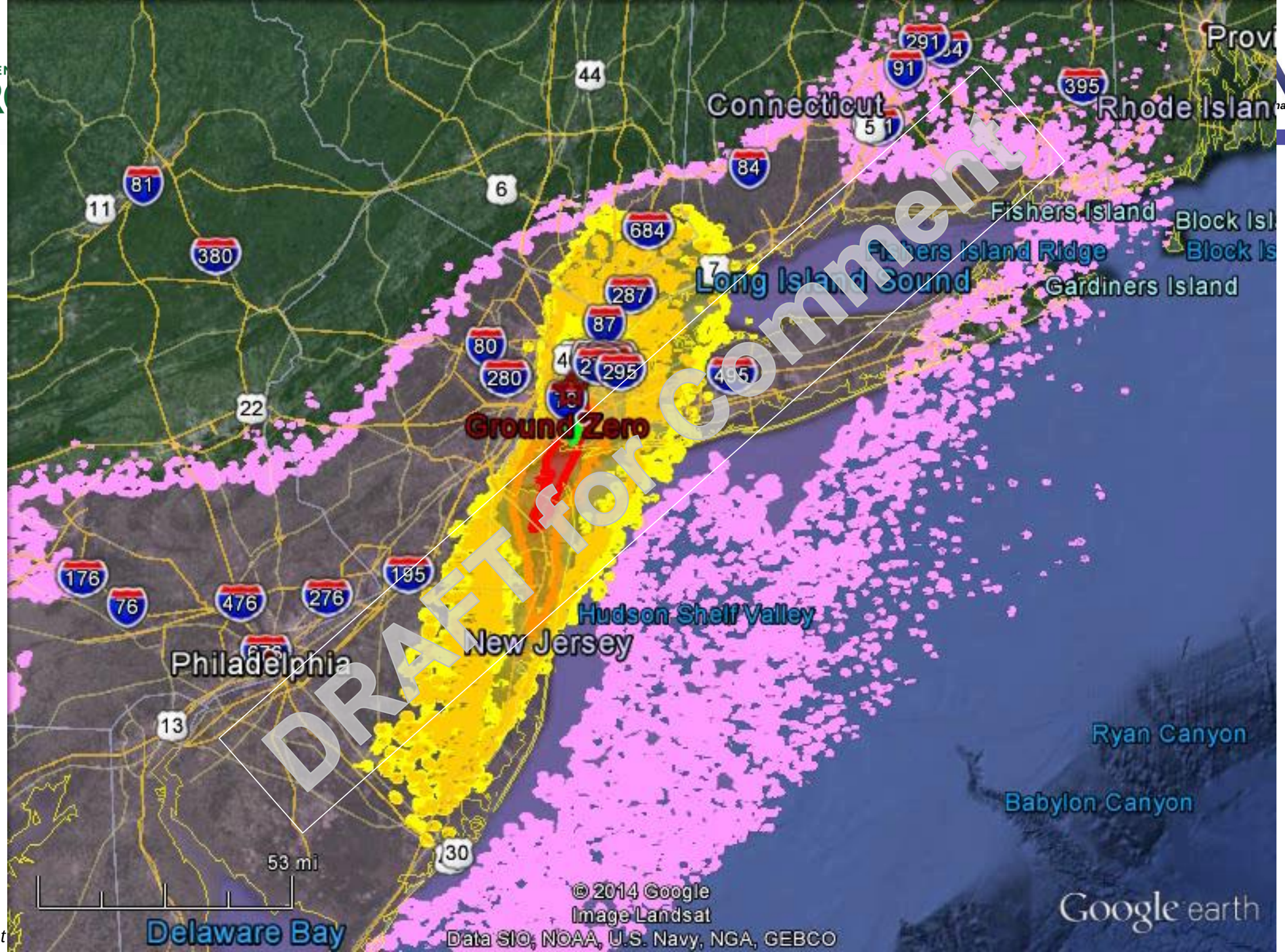
Decay of the dose rate of radiation from fallout, from the time of the explosion, not from the time of fallout deposition.

Dose Rate at 1 hr

Cell Height represents magnitude

Defining Zones That Matter




Connecticut
Rhode Island
Fishers Island
Fishers Island Ridge
Gardiners Island
Long Island Sound
Ground Zero
Hudson Shelf Valley
New Jersey
Philadelphia
Ryan Canyon
Babylon Canyon
Delaware Bay
53 mi
© 2014 Google
Image Landsat
Data SIO, NOAA, U.S. Navy, NGA, GEBCO
Google earth
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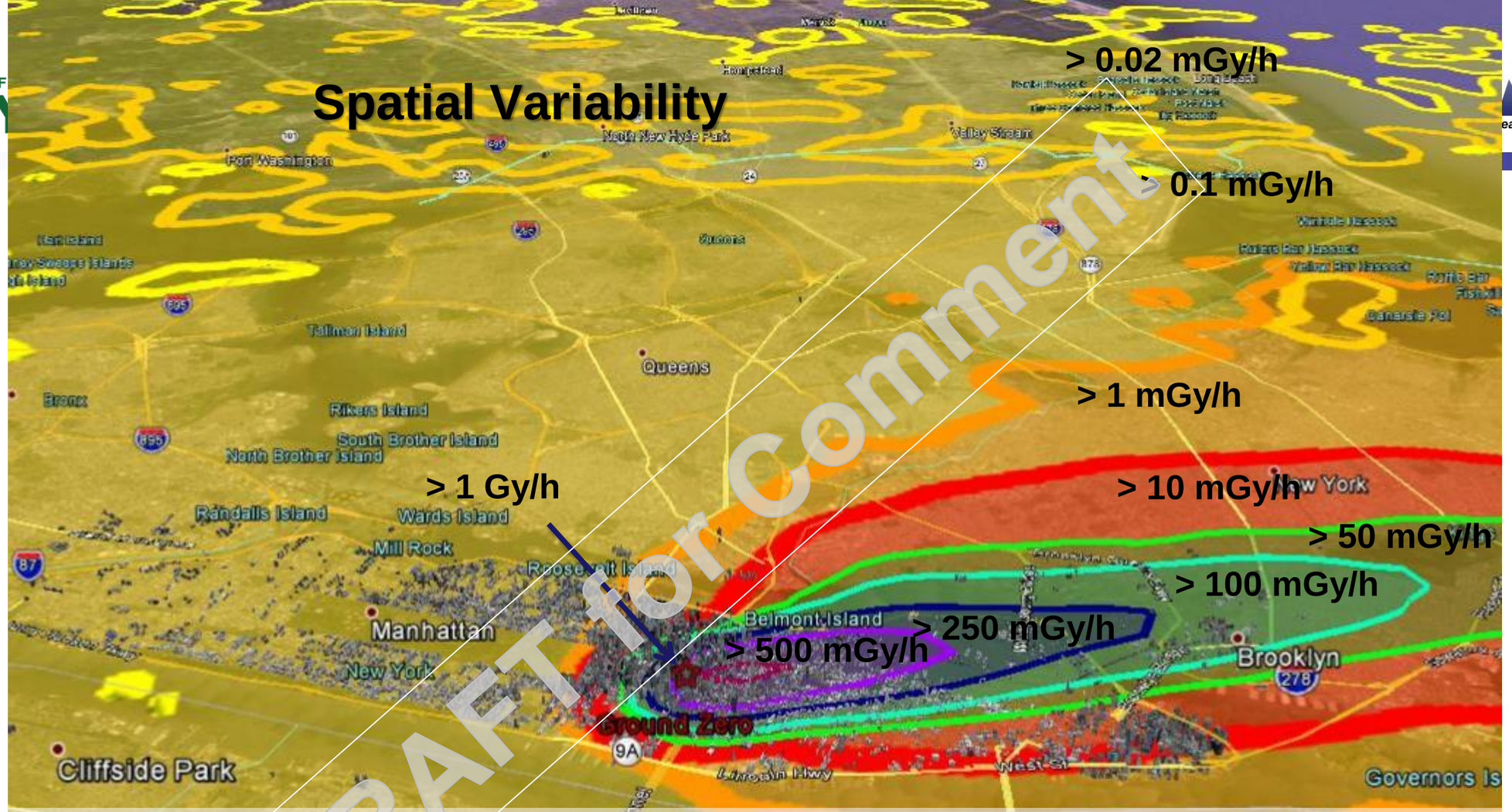
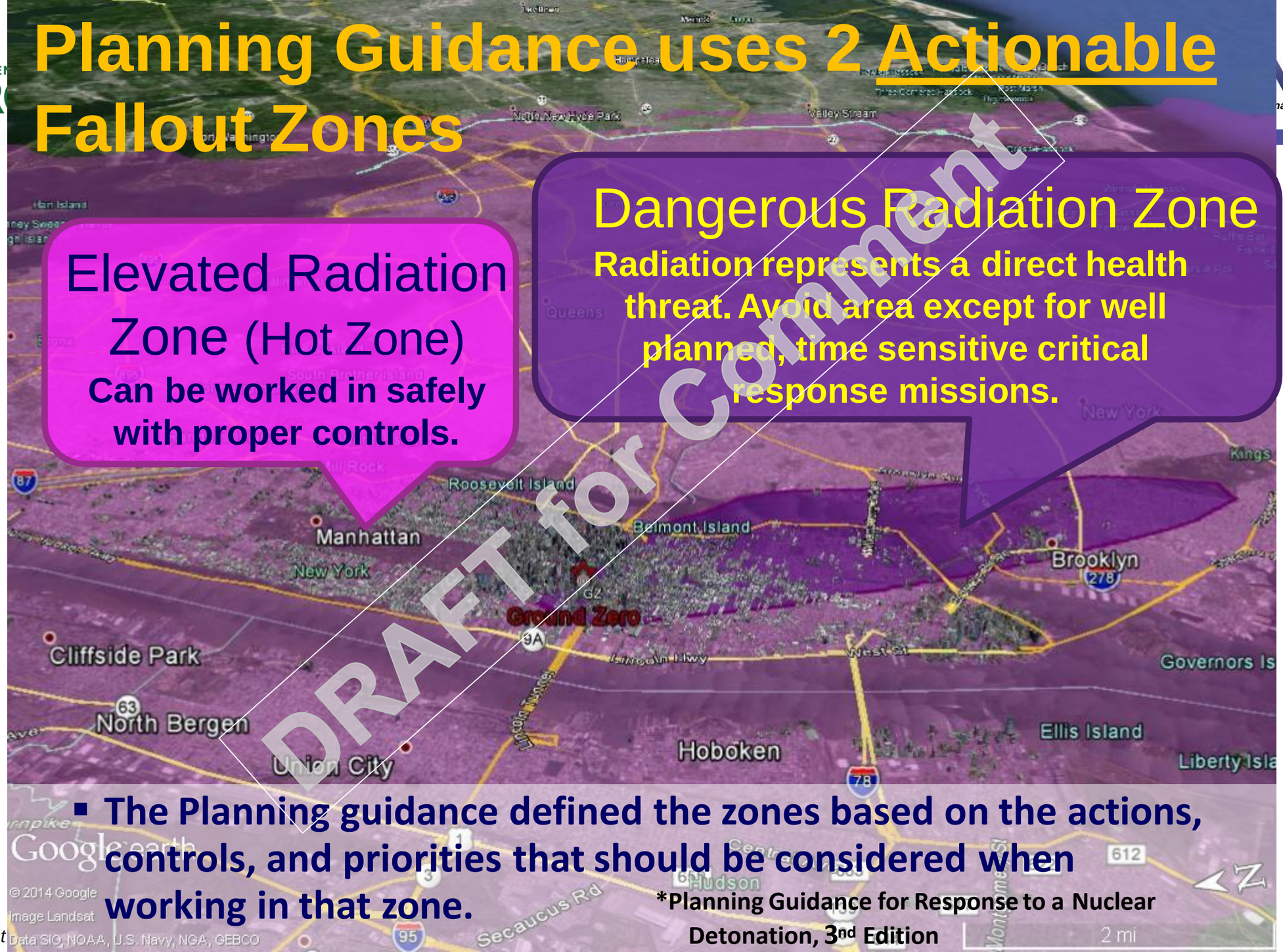
Spatial Variability



- Contours are just reference points in a continuum for exposure rates and demonstrating spatial variation.
- They often fail to provide the answer to the "So what?" question.

Planning Guidance uses 2 Actionable Fallout Zones



- **The Planning guidance defined the zones based on the actions, controls, and priorities that should be considered when working in that zone.**

***Planning Guidance for Response to a Nuclear Detonation, 3nd Edition**

Dangerous Radiation Zone Characteristics

Day 7

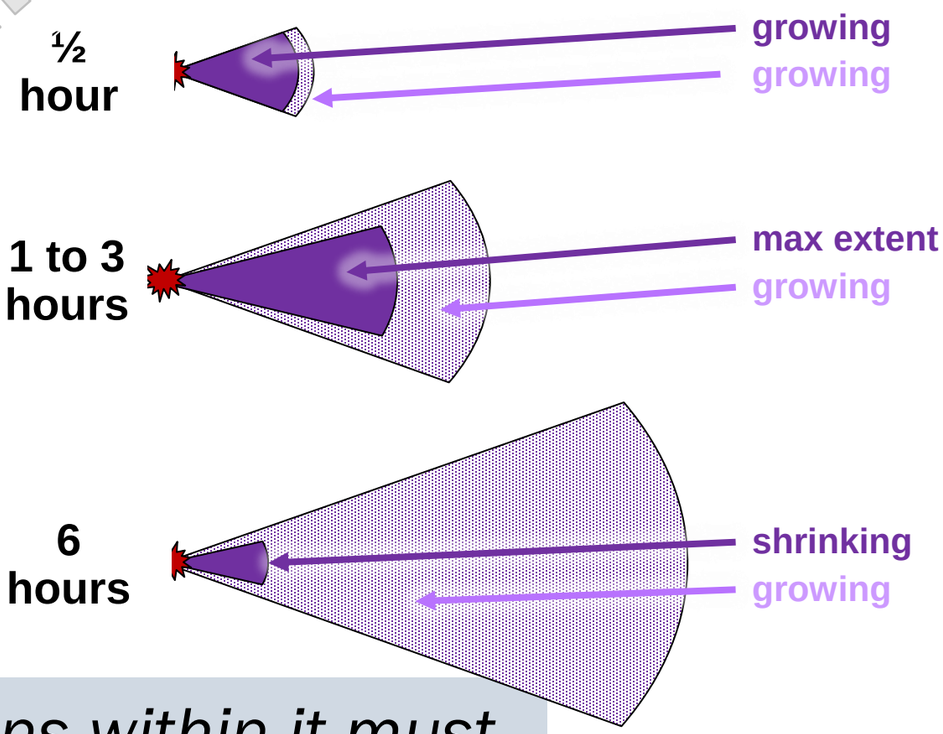
The Dangerous Radiation Zone grows over the first hour or so and then shrinks

Dangerous Radiation Zone (DRZ)

*The Dangerous Radiation Zone (DRZ) **was** formerly the Dangerous **Fallout** (DF) **zone***

- Radiation levels of 100 mGy/h (10 R/h) and above
- Potential for acute radiation injury
- Potentially **tens of kilometers** downwind
- Will begin to shrink within a **few hours** due to radiation decay

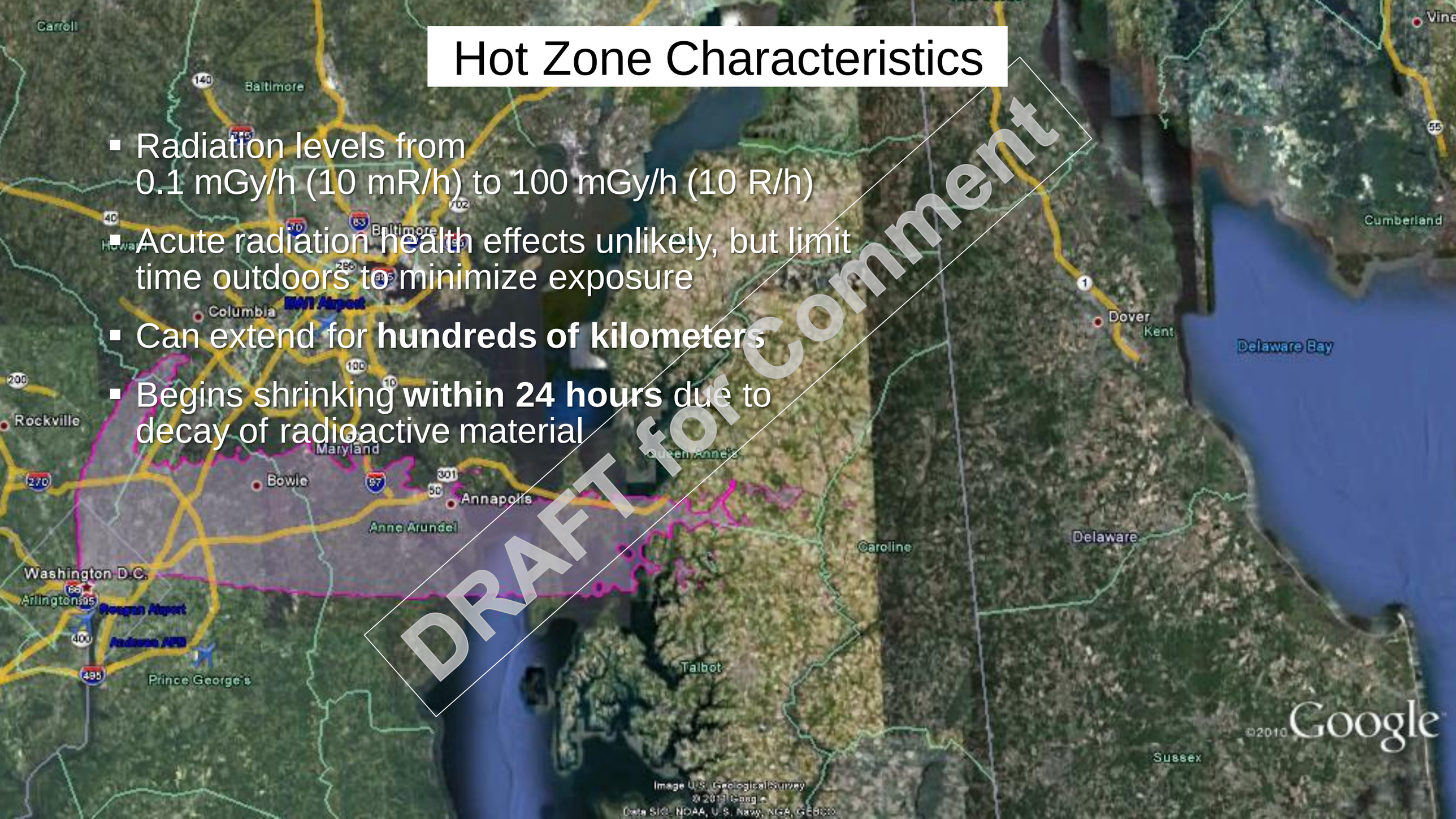
Dangerous Radiation Zone (lethal) and Hot Zone (cancer risk) change with Time



The DRZ is very hazardous, so response operations within it must be justified, planned, and optimized to minimize radiation exposure. Everyone inside the DRZ should seek immediate shelter.

Hot Zone Characteristics

- Radiation levels from 0.1 mGy/h (10 mR/h) to 100 mGy/h (10 R/h)
- Acute radiation health effects unlikely, but limit time outdoors to minimize exposure
- Can extend for **hundreds of kilometers**
- Begins shrinking **within 24 hours** due to decay of radioactive material

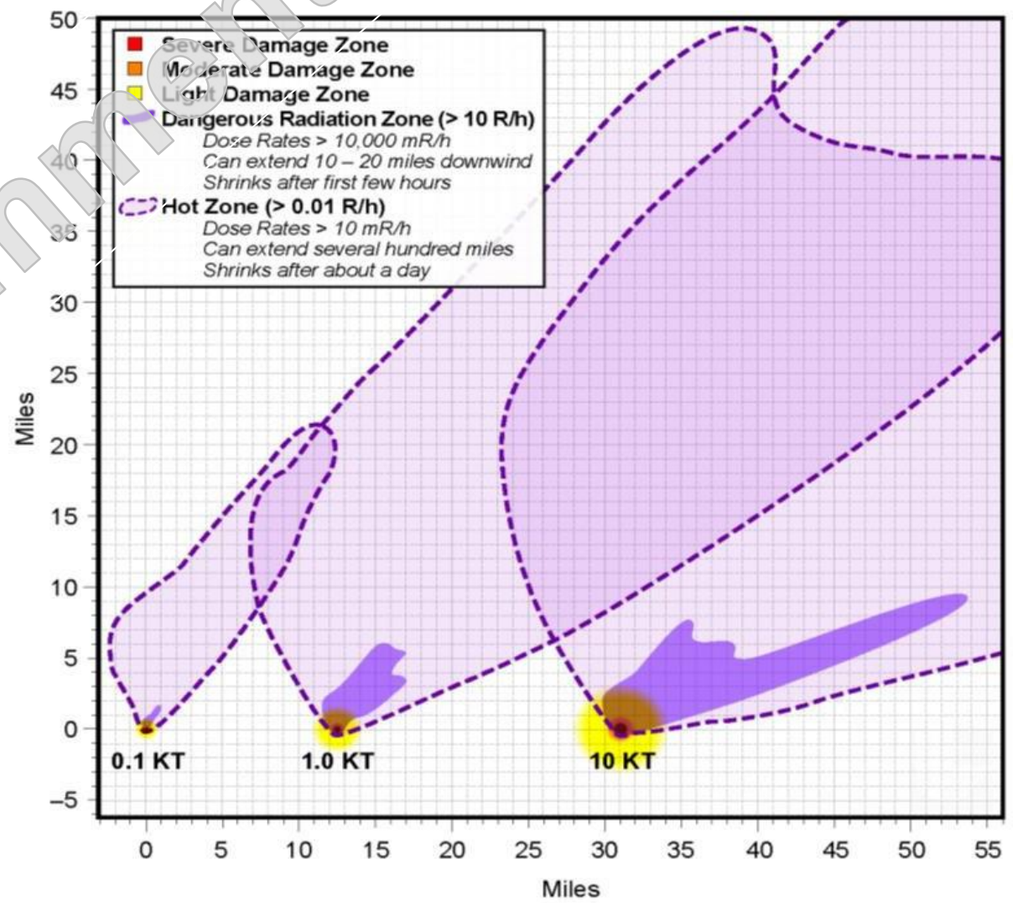


Elevated Radiation Zone (Hot Zone)

Zone Characteristics:

- Radiation levels from 0.1 mGy/h (10 mR/h) to 100 mGy/h (10 R/h)
- Acute radiation health effects unlikely, but limit time outdoors to minimize exposure
- Can extend for **hundreds of kilometers**
- Begins shrinking **within 24 hours** due to decay of radioactive material

Emergency activities can be performed in the HZ without exceeding dose guidelines for emergency response operations, provided appropriate dose monitoring is performed.

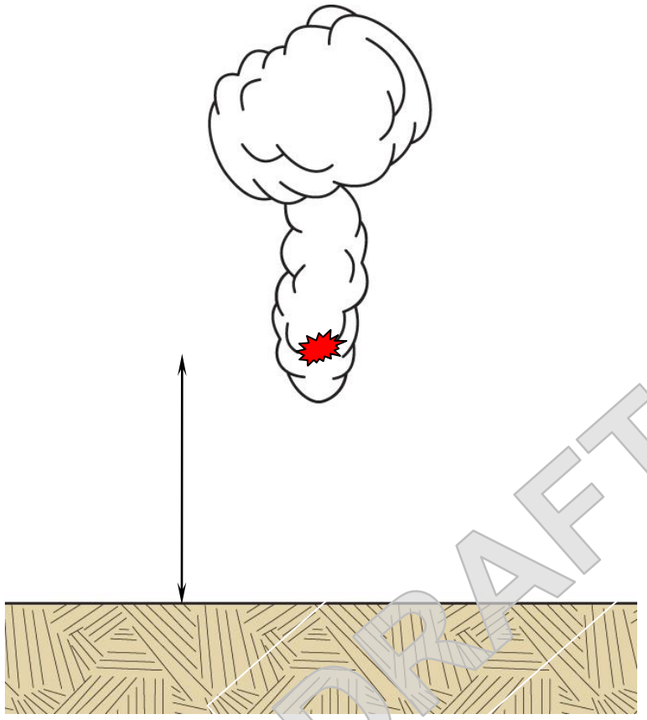


Hot Zone size will be yield dependent

Airburst Considerations

What if it is Detonation in the Air?

- If detonated in the air the residual radiation is on very small particles that tend to stay suspended in the upper atmosphere

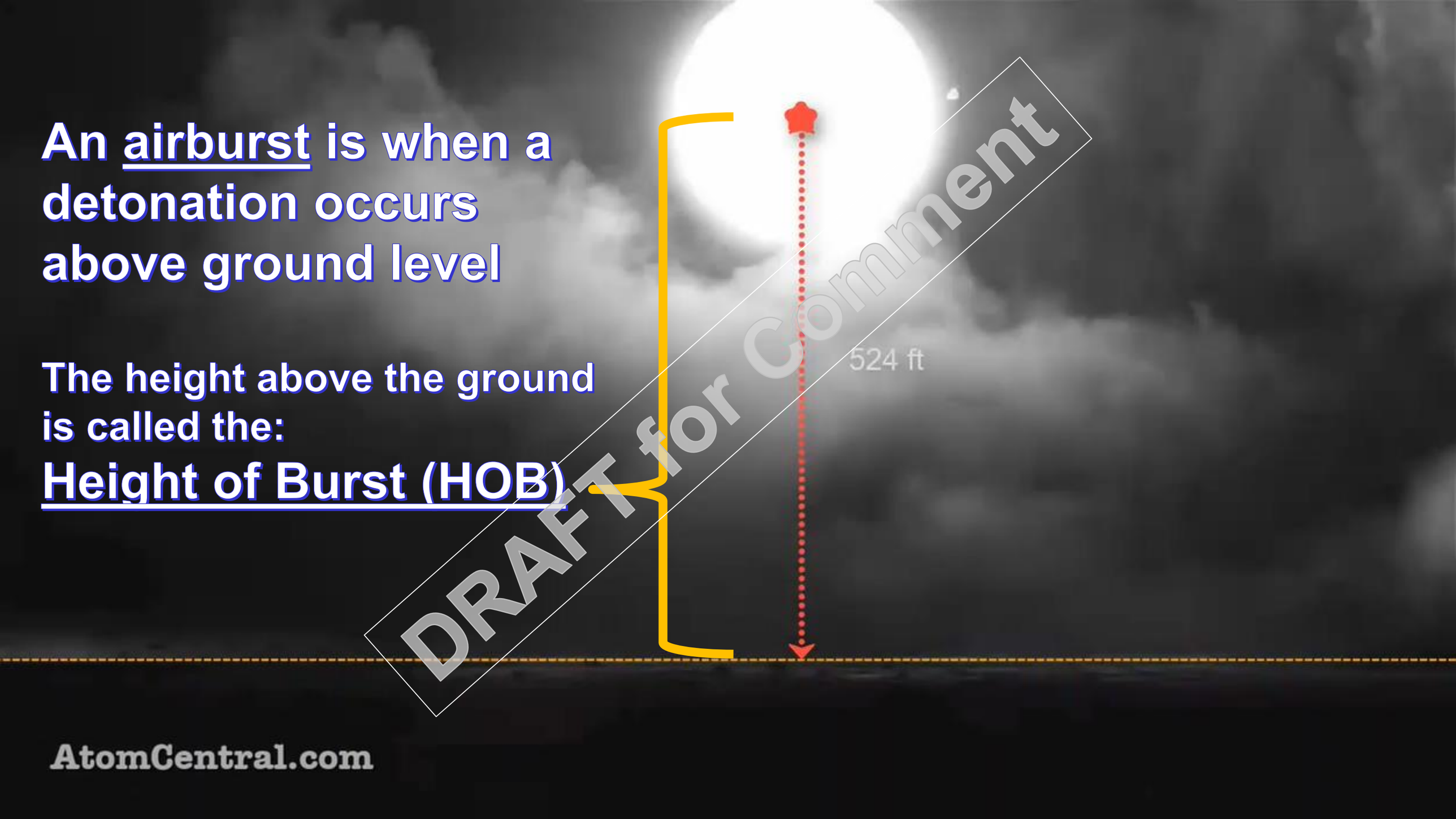


Dixie
(Upshot-Knothole)
11 kt @ 6022 ft

An airburst is when a detonation occurs above ground level

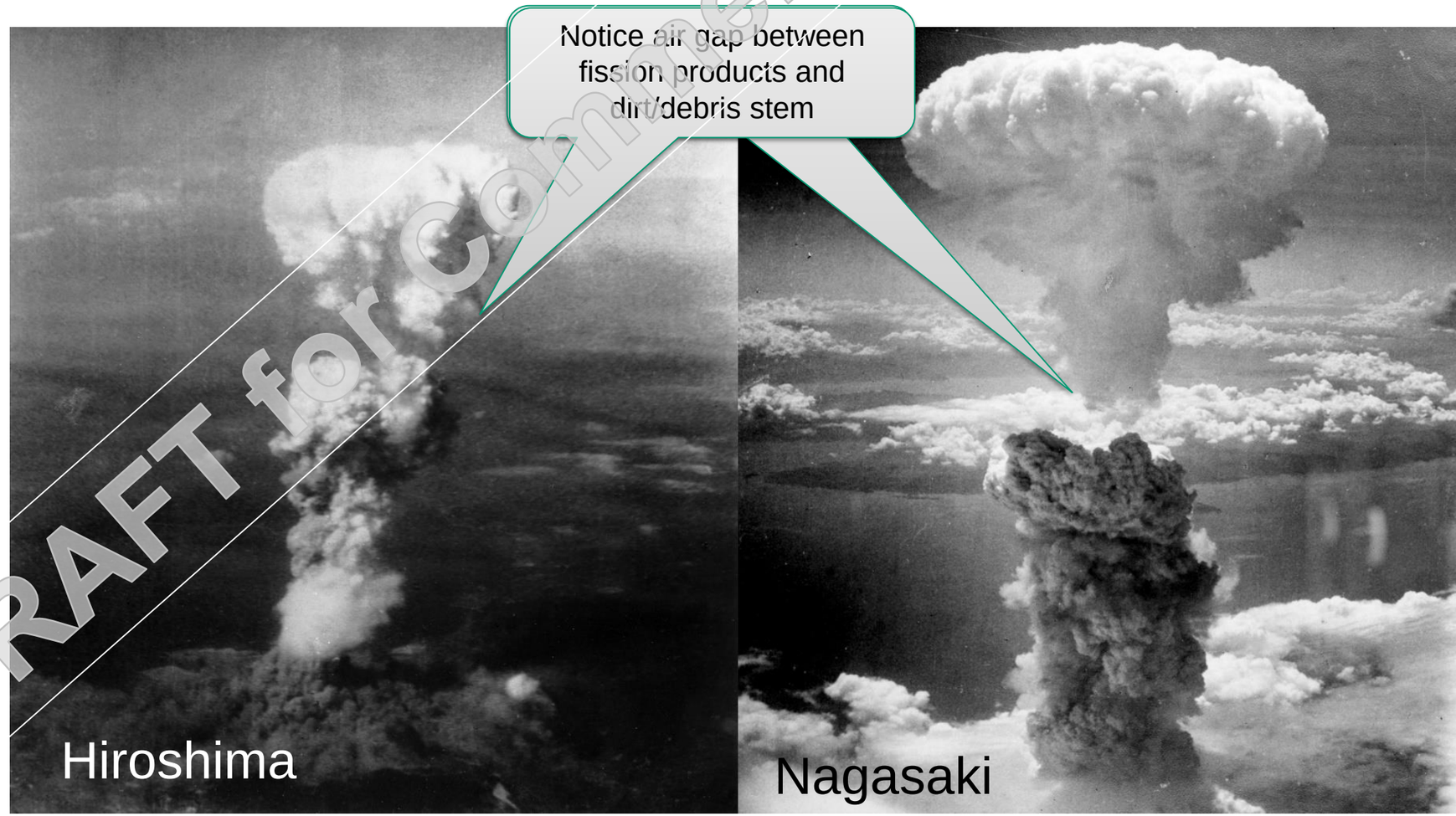
The height above the ground is called the:

Height of Burst (HOB)



HOB Impacts on Fallout

- Hiroshima & Nagasaki were detonated at ~ 500m
- The radioactive material created in the explosion are in the white “cap”
- These small particles tend to stay trapped in the upper atmosphere
- Notice the air gap between the white “cap” and the brown “stem” of the mushroom cloud.
- Because of this, there was no mixing with the dirt and no significant local fallout.



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Height of Burst and Fallout Generation

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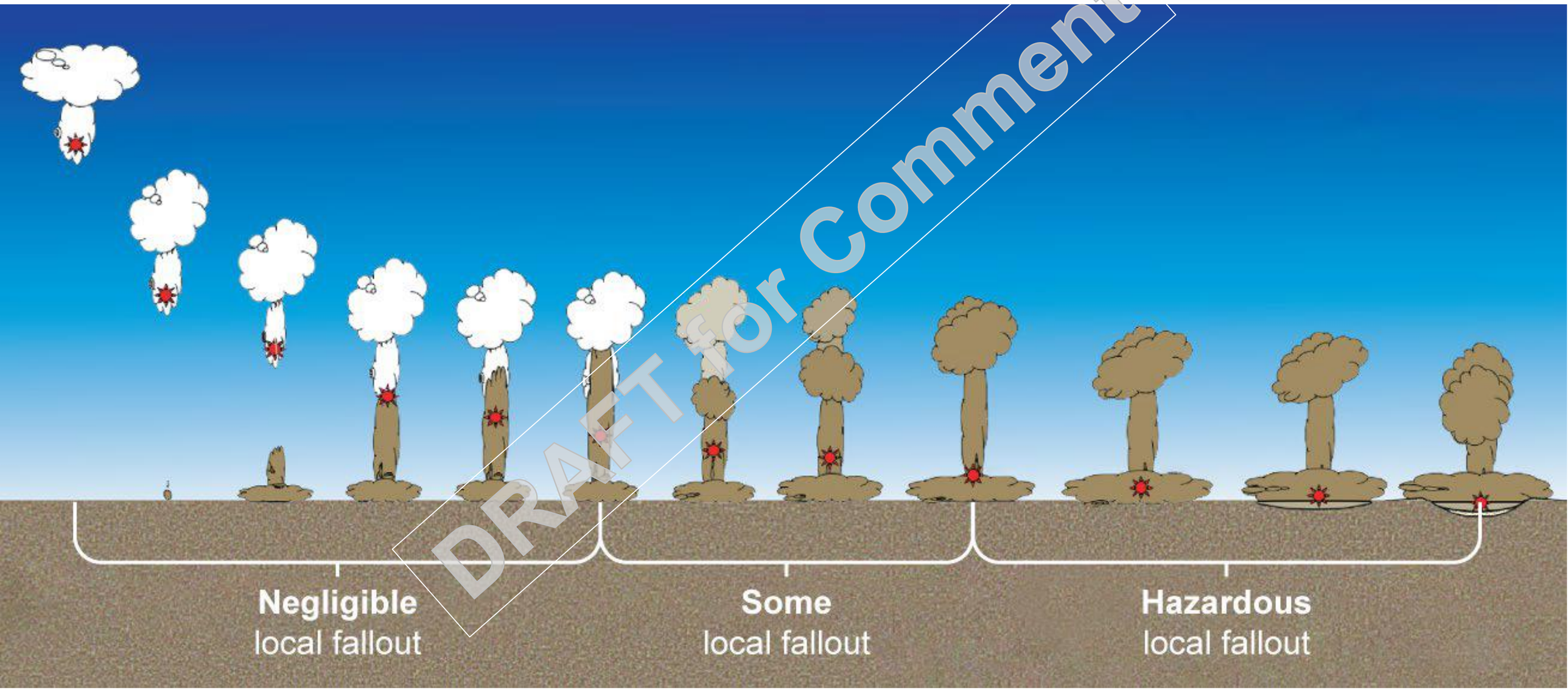


Upshot-Knothole Encore

27 kt, Airburst 2423', 8 May 1953

Negligible Local Fallout

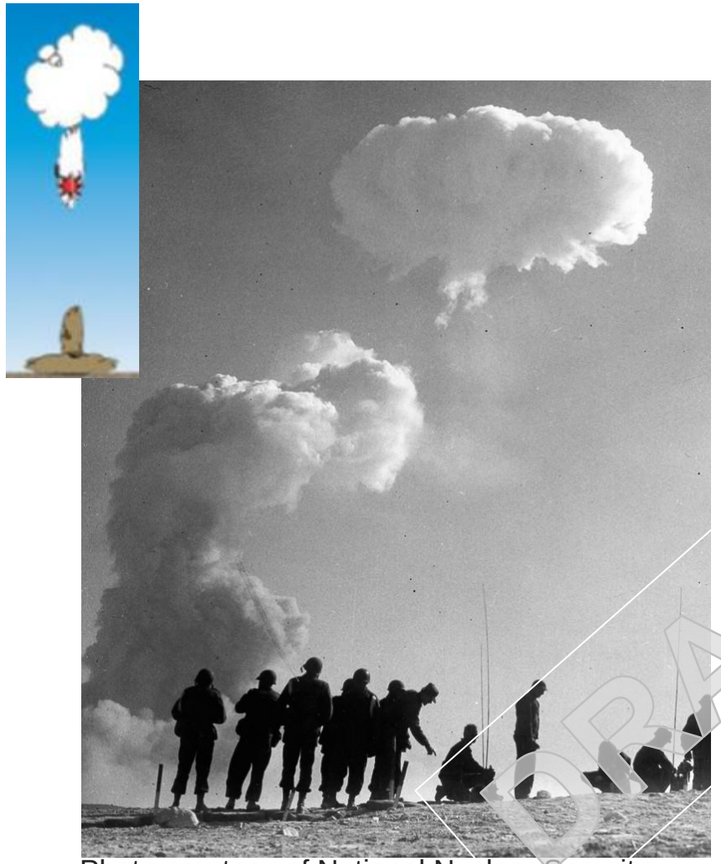


Photo courtesy of National Nuclear Security Administration / Nevada Field Office.
Photo Library under number UK-53-105.

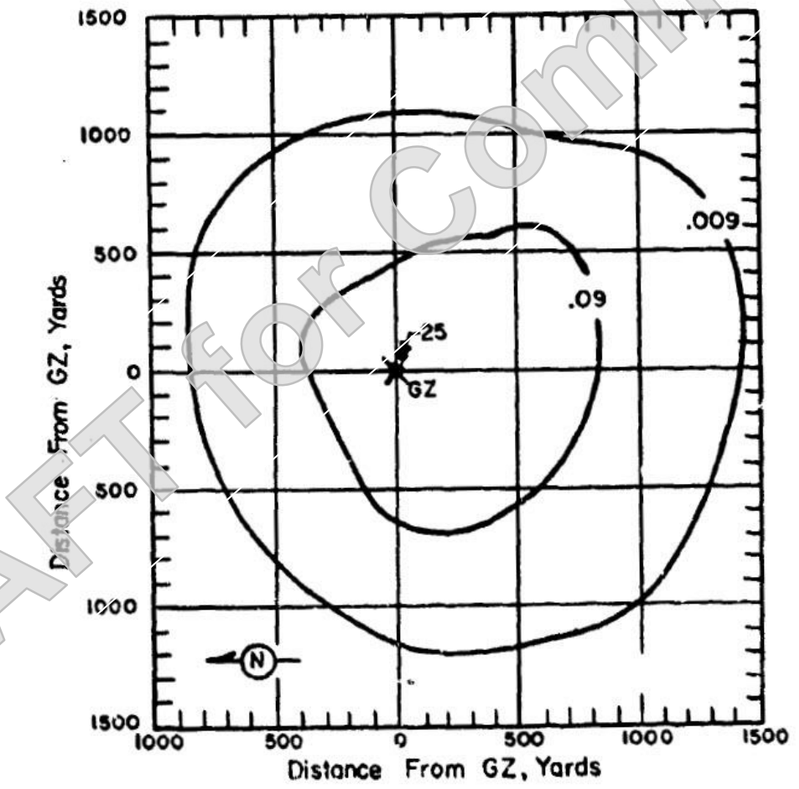
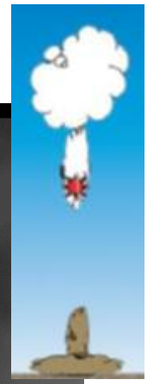


Figure 96. Operation UPSHOT-KNOTHOLE - Encore.
On-site dose rate contours in r/hr at H+1 hour.

- Good example of: **Negligible Local Fallout**
- Air gap between the
  - White "cap" and the
  - Brown stem of dirt

Residual Radiation: Neutron Activation



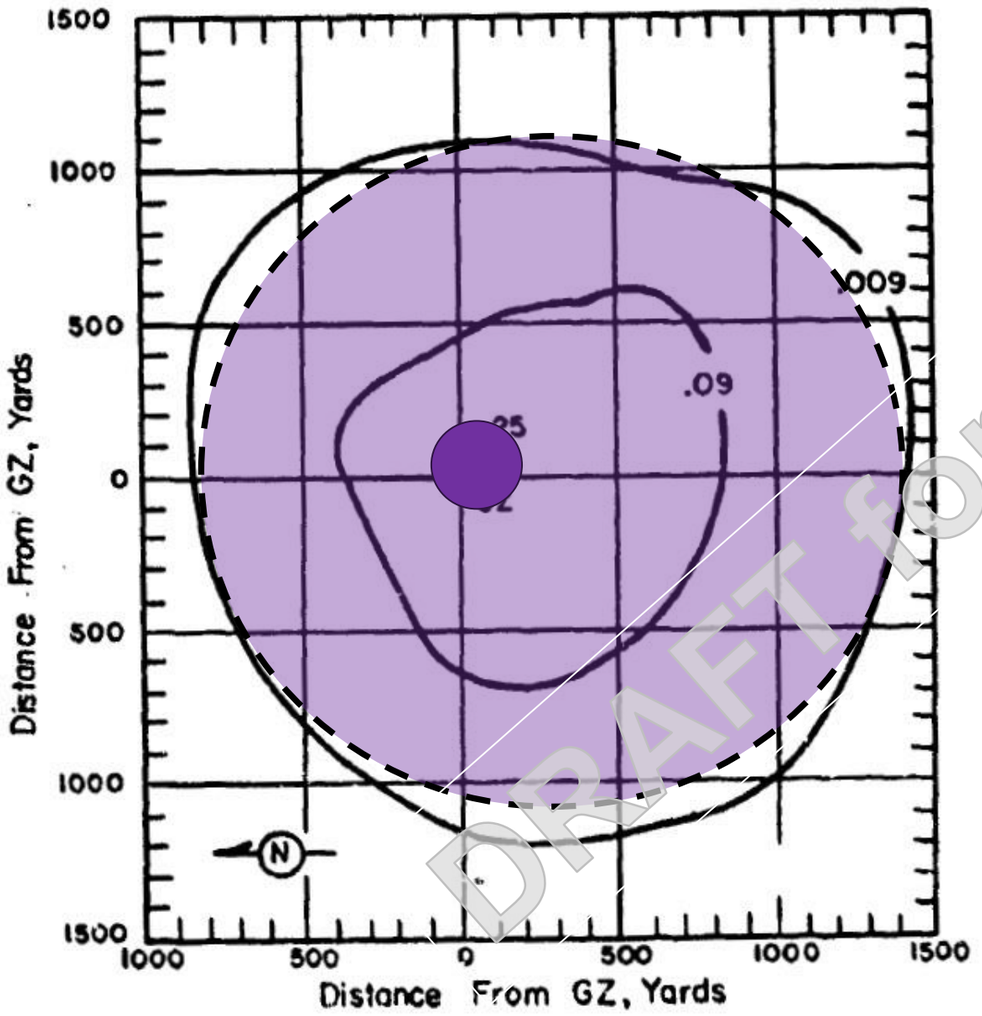
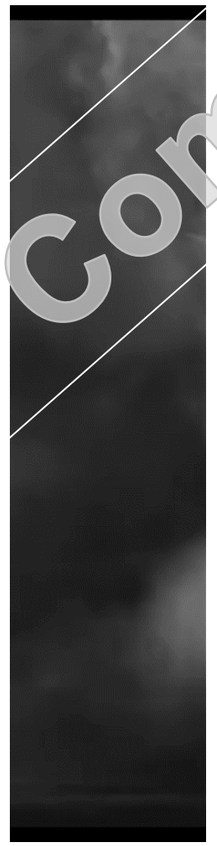


Figure 96. Operation UPSHOT-KNOTHOLE - Encore.
On-site dose rate contours in r/hr at H+1 hour.



H+1 data from DASA-1251

- No appreciable fallout from fission products
- Neutron Activated material directly under the detonation
  - 100 mGy/h (from activation) limited to small area directly under detonation.
  - 0.1mGy/h (from activation) limited to within 1.5 km of GZ
- Some of the material is lofted into the stem and dropped a short distance away (elongated zone to the right)

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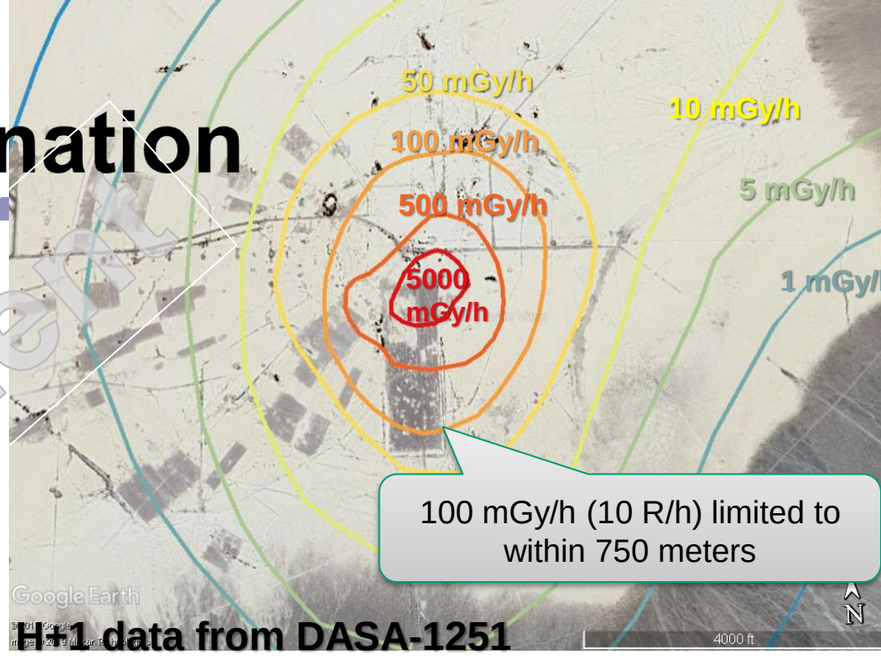
Priscilla "Partial Mixing" Detonation

Some Local Fallout

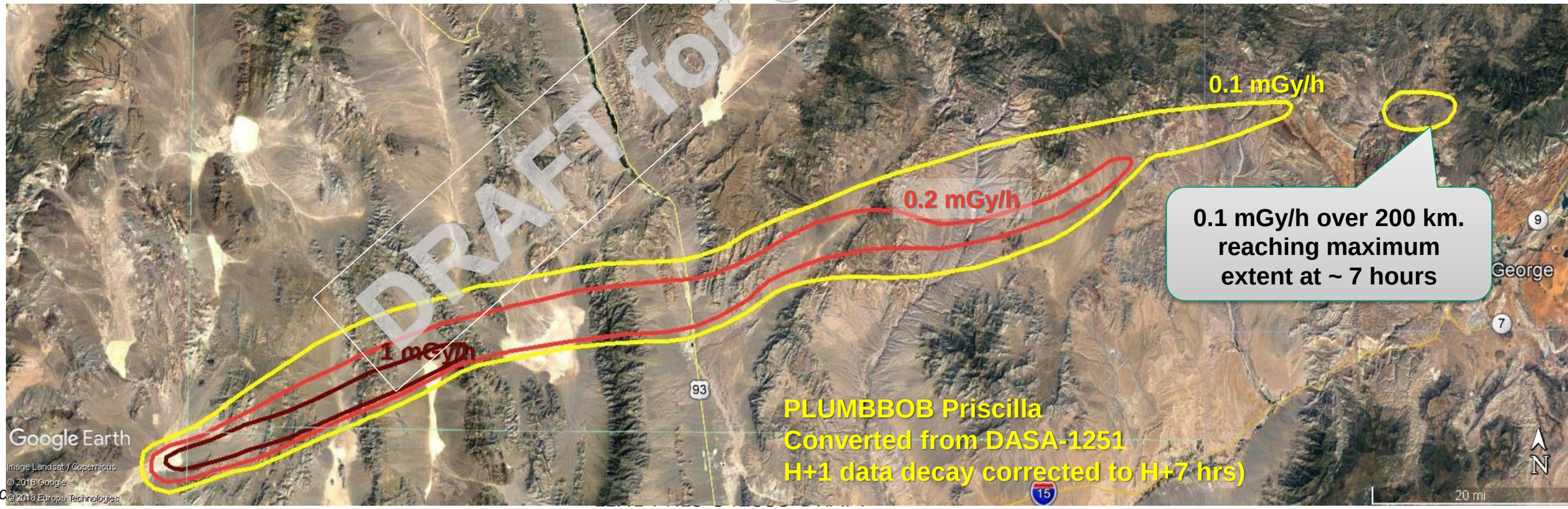
Plumbbob Priscilla Test

37kt detonated at 700 ft

(fallout free height is 760 ft for 37kt)

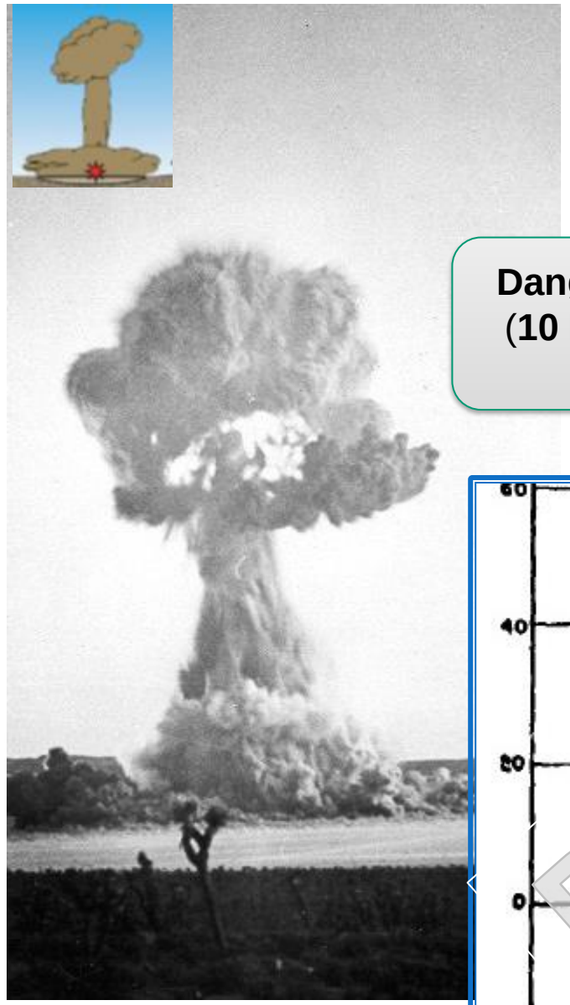


H+1 data from DASA-1251



Simon "Significant Mixing" Detonation

Hazardous Local Fallout

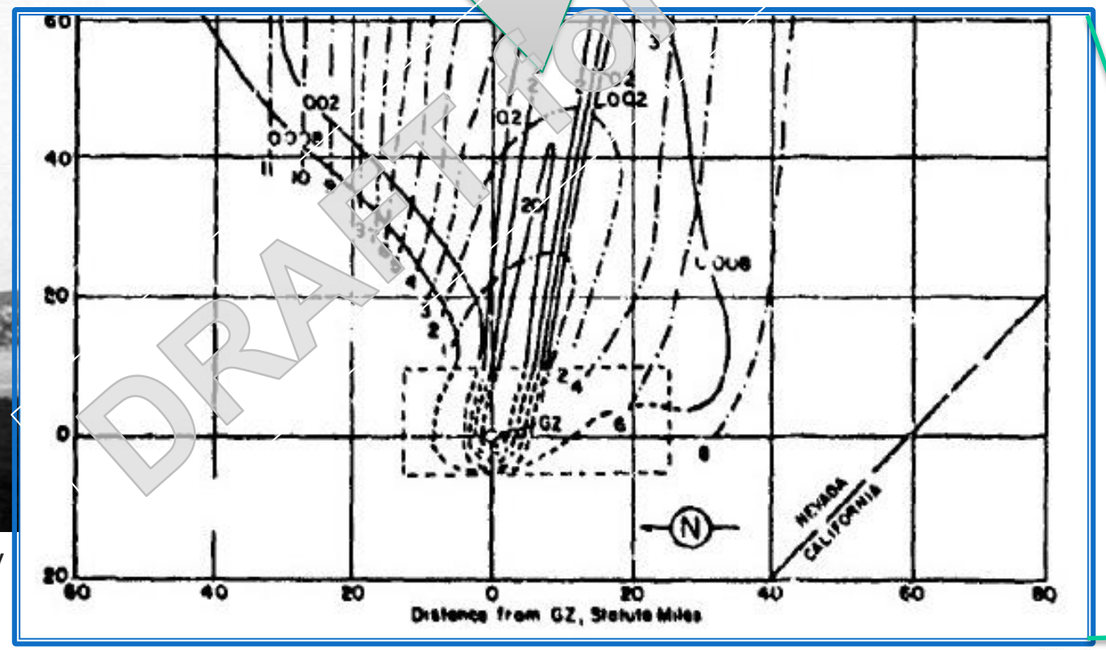


Nevada Site Office Photo Library under number UK-53-102

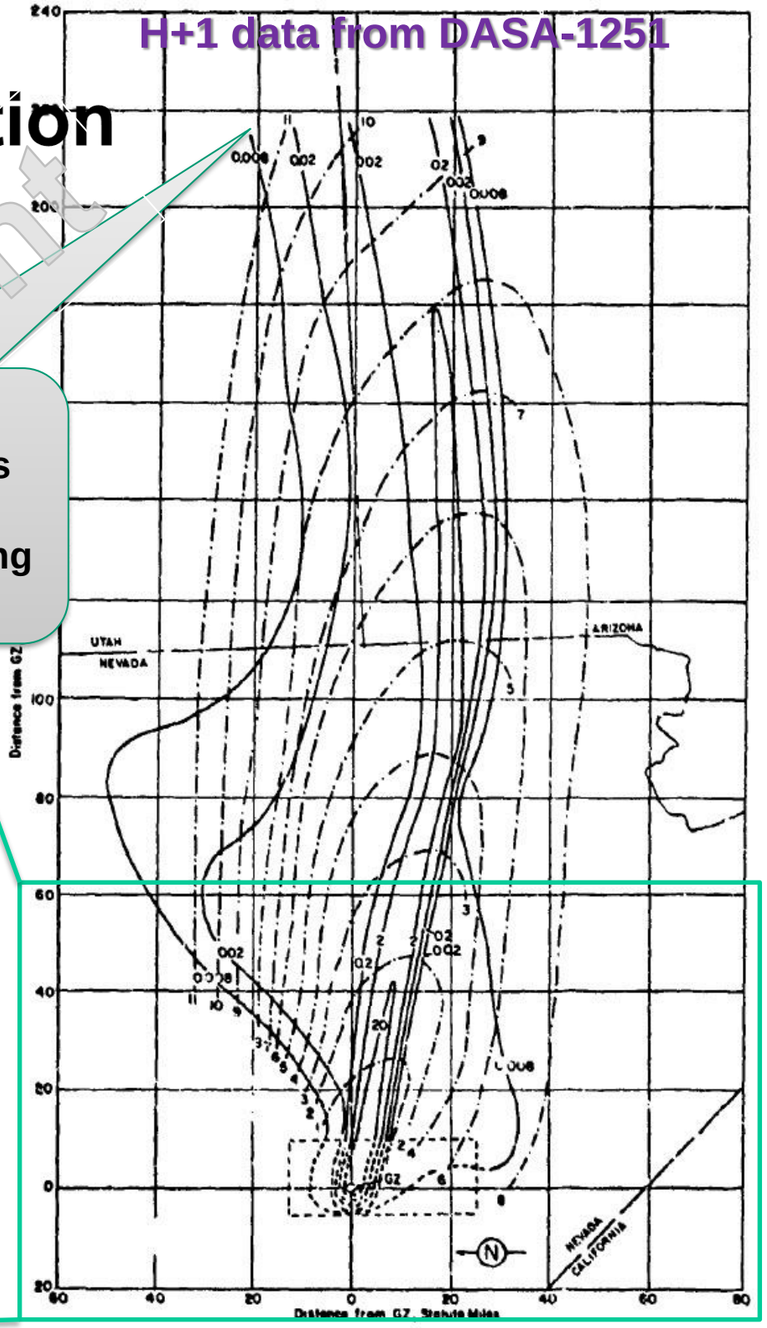
Upshot-Knothole Simon
43 kt, Tower 300', 25 Apr 1953

Dangerous Fallout Zone 100 mGy/h (10 R/h) reaches max extent ~ 1.75 hrs and goes past 65 km.

At 10 hours 0.1 mGy/h contours exceeded offsite monitoring, extending beyond 350 km



H+1 data from DASA-1251



igure 93. Operation UPSHOT-KNOTHOLE - Simon
Off-site dose rate contours in r/hr at H+1 hour.

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Upshot-Knothole Simon; 43 kt, 300’ HOB, 25 Apr 1953

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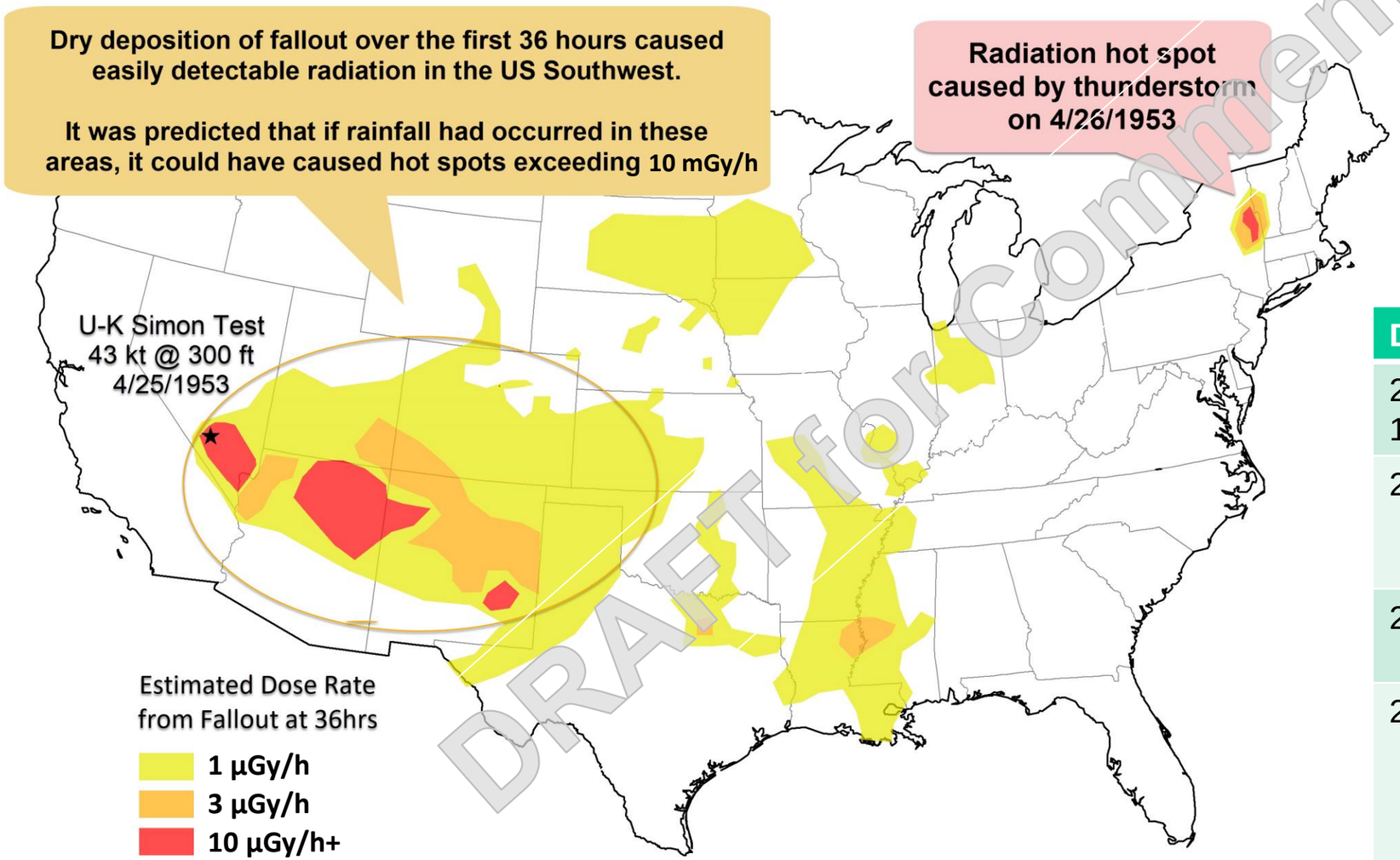
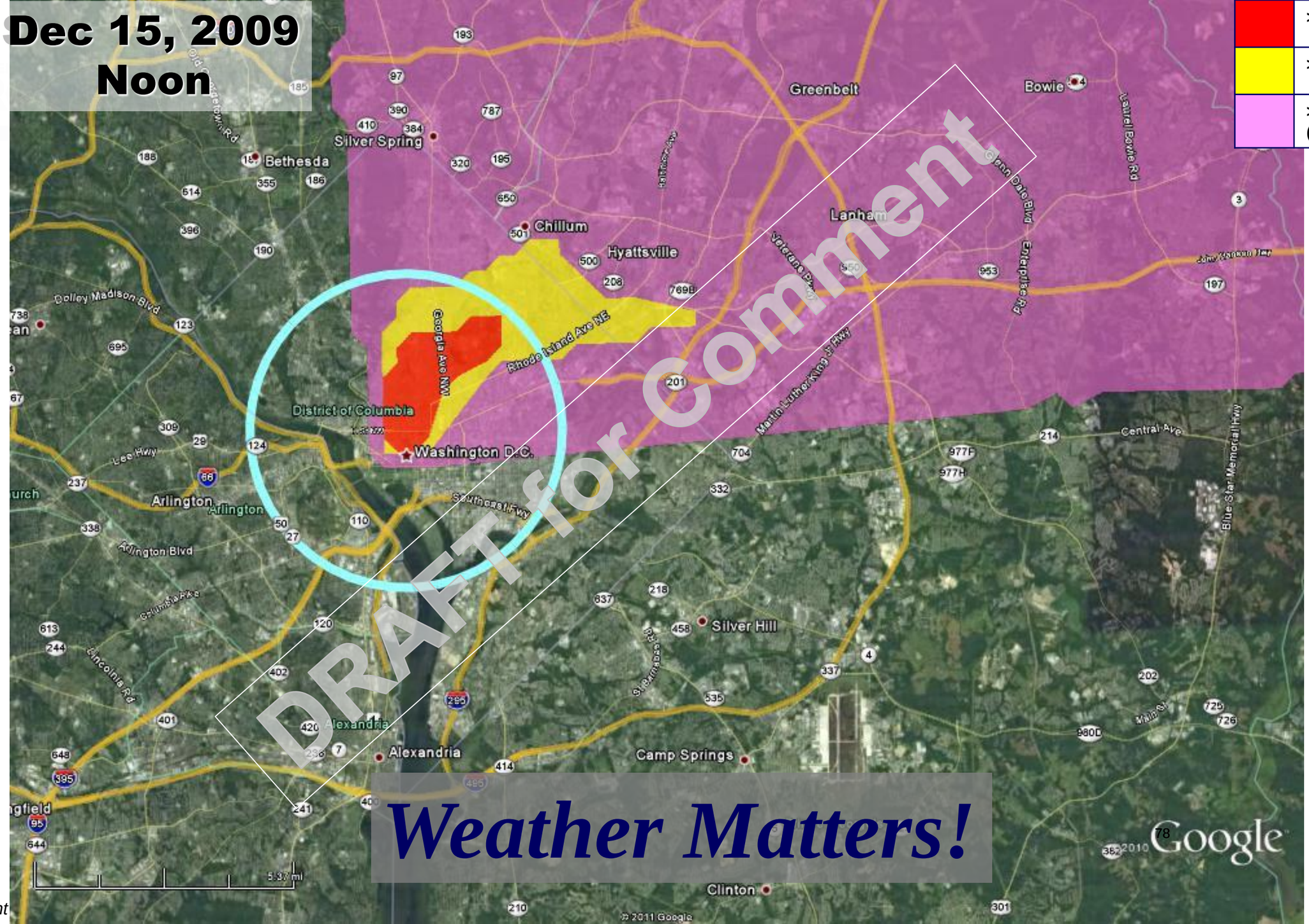
Long Range Concerns



Date	Fallout Location and Type
25 Apr 1953	Nevada Test Site: 43 kt detonated at 300 ft HOB at 0430 AM PST
25 Apr	Dangerous Radiation Zone (> 100 mGy/h) reaches maximum extent of 65 km at 0615 AM PST
25 Apr	Significant dry deposition in NV, UT, and AZ
26 Apr	Significant dry deposition in UT, NM, and TX **Extreme *rainout*** event in Albany, NY (Highest deposition of Upshot-Knothole tests outside the Nevada Test Site)



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Weather Matters!

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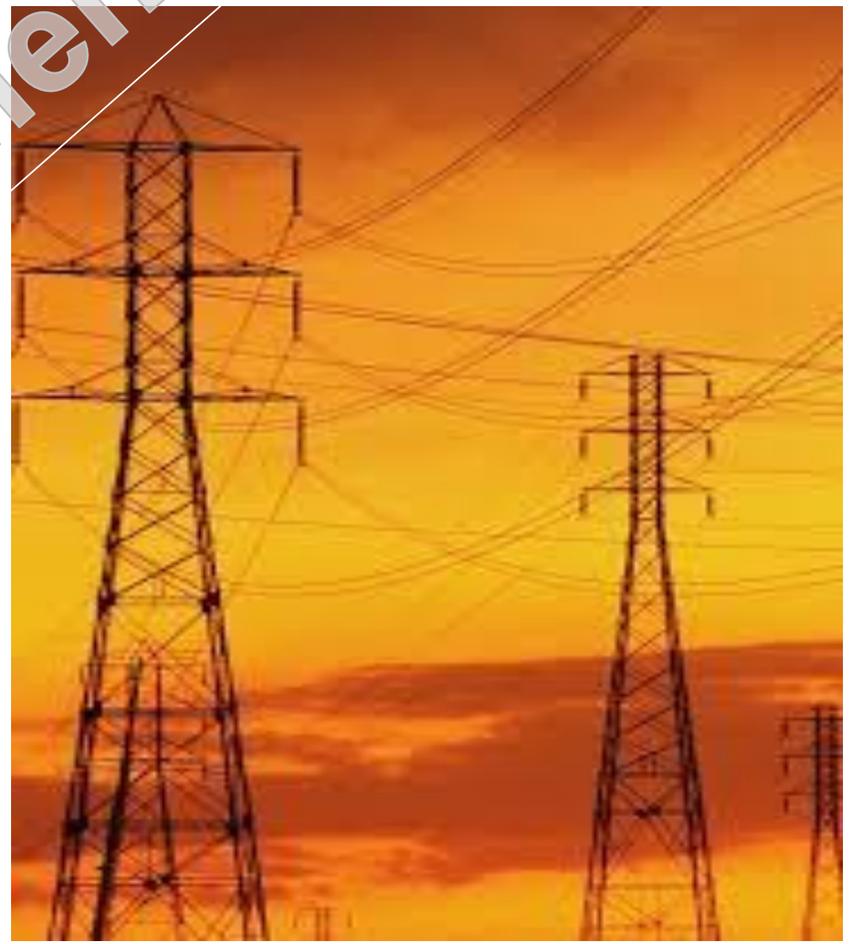
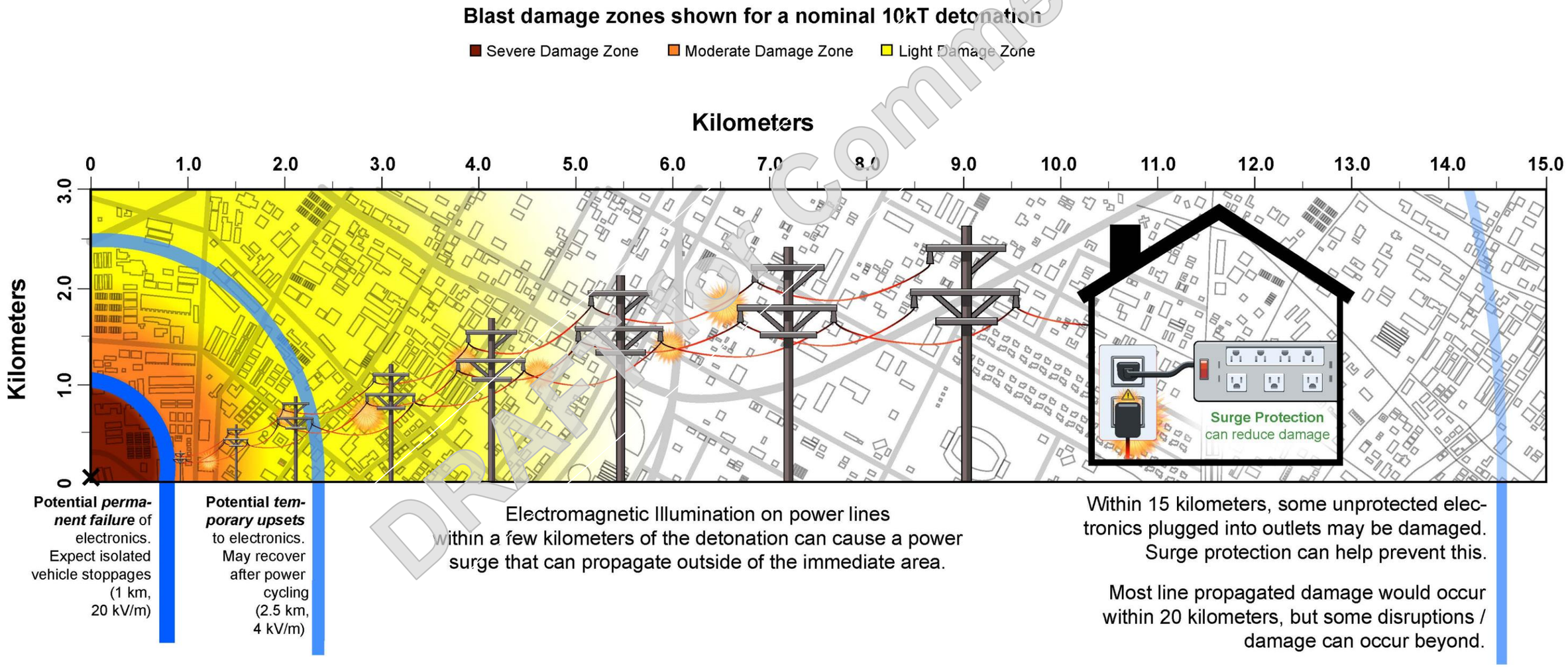
Electromagnetic Pulse

Electromagnetic Pulses (EMPs)

- The initial nuclear radiation from nuclear detonations generates an electromagnetic pulse (EMP).
- Not a hazard to people, the EMP can disrupt or damage electronic equipment.
- For near earth detonations (< 5 km HOB), the EMP:
  - Can damage or disrupt electronics within a few kilometers of the detonation.
  - Can cause disruptive power surges on power lines that can damage equipment without surge protection within tens of kilometers of the detonation.
- High-altitude nuclear detonations (those above 30 km) can produce high-altitude EMP (HEMP) which can disrupt electronics for 100s of kilometers.



Electromagnetic Pulse from Near Earth Detonations (< 5 km Height of Burst)



Test your Knowledge

Knowledge Check | Quiz—Damage Zones

- You are standing in an area where:
  - All windows are broken.
  - Most unreinforced brick and wood frame buildings are severely damaged or completely collapsed.
  - Cement and steel-frame, earthquake-resistant buildings are standing, but much of the building interior is damaged and possibly pushed out the back of the building.
  - Nearly half the population is dead, and the majority of survivors are significantly injured.
- **Which damage zone are you in?**
  A. The Severe Damage Zone
  B. The Moderate Damage Zone
  C. The Light Damage Zone
  D. Beyond the Light Damage Zone (you are not in a zone)

Recognizing the Moderate Damage Zone

- Substantial building damage, such as blown-out interiors, caved roofs, and fires
- Sturdier buildings (e.g., reinforced concrete) remain standing, lighter commercial and multi-unit residential buildings may be fallen or structurally unstable, and many wood frame houses will be destroyed
- Highest percentage of “survivable victims” who require medical treatment
- Significant hazards to response workers, such as elevated radiation levels, ruptured gas lines, broken glass, and hazardous chemicals

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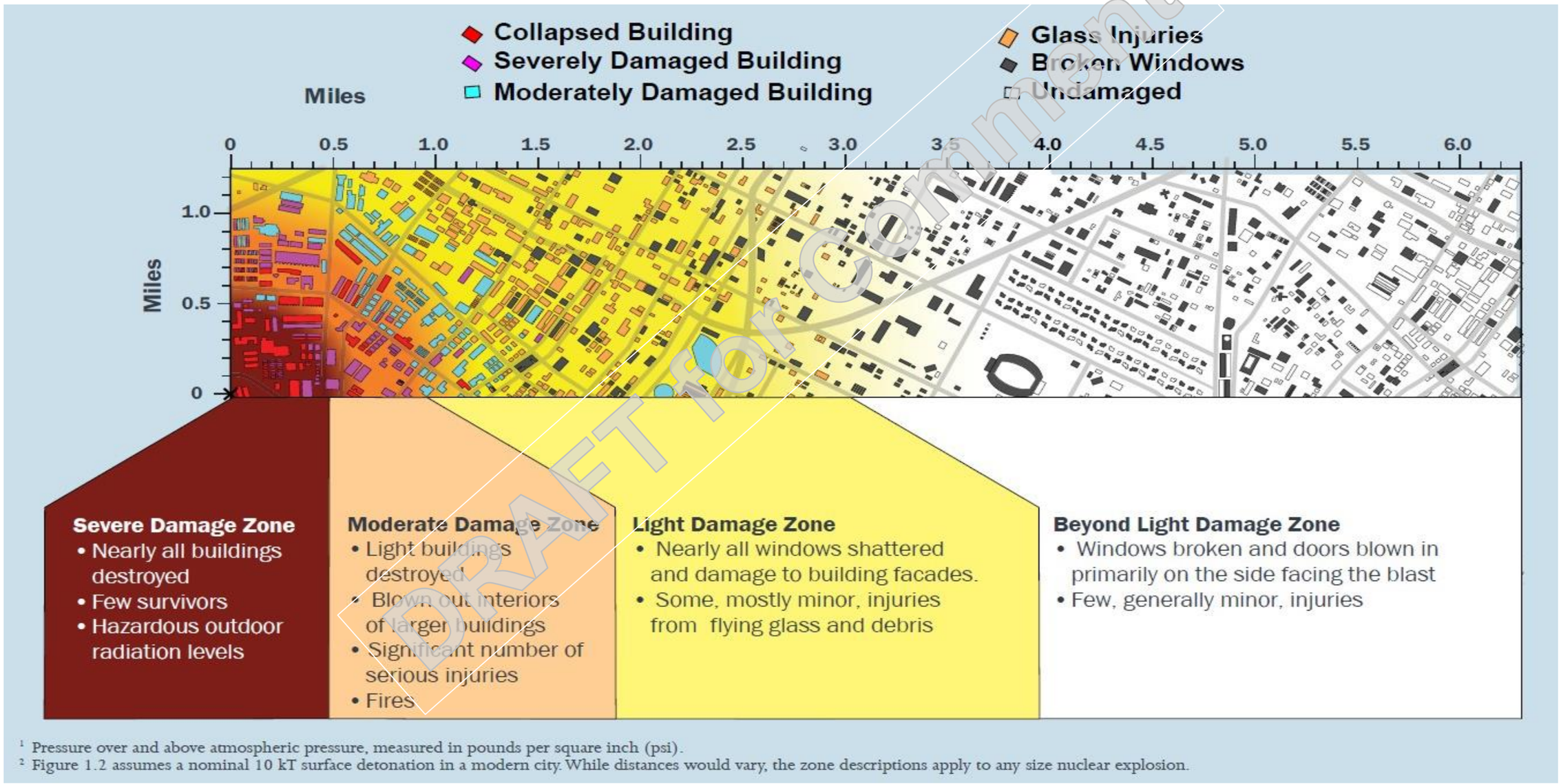
Knowledge Check | Quiz—Damage Zones

National Nuclear Security Administration

- **You are in an area where about 25% of building windows are broken, primarily on the building walls facing the direction of the detonation. There do not appear to be any injuries. Which damage zone are you in?**

A. The Severe Damage Zone
B. The Moderate Damage Zone
C. The Light Damage Zone
D. Beyond the Light Damage Zone (you are not in a zone)

Variability of Effect on Structures



[1] Pressure over and above atmospheric pressure, measured in pounds per square inch (psi).
[2] Figure 1.2 assumes a nominal 10 kT surface detonation in a modern city. While distances would vary, the zone descriptions apply to any size nuclear explosion.

Light Damage Zone:

- Nearly all windows broken; external panel damage on most structures
- Highly variable damage due to shock waves rebounding repeatedly from buildings, terrain, and the atmosphere
- Closer to ground zero within the LDZ:
  - Windows and doors blown in
  - Gutters, window shutters, roofs, and lightly constructed buildings have increasing damage
- Light injuries; mostly superficial wounds with occasional flash burns

Recognizing the Severe Damage Zone

Severe Damage Zone:

- Few, if any, buildings are structurally sound or standing
- Few survivors, but some in stable structures (e.g., subterranean parking garages or subway tunnels) may survive initial blast
- Very high radiation levels; responders should enter cautiously only to rescue known survivors
- Impassable rubble in streets hinders response speed

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Knowledge Check | Quiz—Fallout

National Nuclear Security Administration

- **Will there always be dangerous levels of fallout on the ground?**

A. Yes, there will always be hazardous levels of fallout on the ground
B. No, it depends on the height of burst and surface conditions.

Answer: No

- Although the nuclear detonation will always produce fission products, the amount that will fall to the ground depends on how much dirt is drawn up into the fireball.
- A white cap disconnected from the dirt stem is a good indication there **NOT** be hazardous levels of local fallout.

Conclusions

- At lower yields (< 10 kt), prompt radiation can cause injuries beyond the moderate damage zone.
- A higher yields (> 10 kt), prompt thermal effects become more dominant at longer ranges, causing burns and starting fires.
- Nuclear detonations are variable and dynamic. The yield and HOB drive level and type of key impacts and residual radiation levels on the ground.
- If you can see the fallout cloud a few minutes after the detonation (or know if it was a surface or airburst), this can inform the likelihood of dangerous local fallout.
- Radiation levels from fallout and activation will change rapidly. The first few hours are when it is most dangerous to be outside.

Thank you

Supplemental Slides

Important Links (Ukrainian Language)

TED-Ed video:
https://www.ted.com/talks/brooke_buddemeier_and_jessica_s_wieder_can_you_survive_nuclear_fallout?utm_campaign=tedspread&utm_medium=referral&utm_source=tedcomshare

ICRP Advice for the Public on Protection in Case of a Nuclear Detonation / Рекомендації для населення щодо захисту у випадку ядерного вибуху: https://www.icrp.org/page.asp?id=610

ORISE Medical Factsheets (Ukraine)
https://orise.orau.gov/resources/reacts/translations/ukrainian.html

Self Decontamination Infographic:
https://www.cdc.gov/nceh/radiation/emergencies/pdf/Decontamination-2-25-emb_UKRAINIAN.pdf

New WHO online training course on Mental Health and Psychosocial Support in Emergencies:
https://openwho.org/courses/mental-health-and-psychosocial-support-in-emergencies-UK

Additional Resources (English)

FEMA PrepTalk Video: https://www.fema.gov/blog/preptalks-brooke-buddemeier-saving-lives-after-nuclear-detonation

Planning Guidance For response to a Nuclear Detonation: https://www.fema.gov/sites/default/files/documents/fema_nuc-detonation-planning-guide.pdf

Here more communication resources that are used in the United States: https://www.cbrnresponder.net/app/index#resources/library?rltf=104

Health & Human Services https://www.remm.nlm.gov/nuclearexplosion.htm

- **FEMA Nuclear Explosion Factsheet:** https://www.ready.gov/nuclear-explosion

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- 100 kt Air burst, 5000 ft
- 100 kt Air burst, 1000 ft
- 100 kt Ground burst
- 10 kt Ground burst
- 1.0 kt Ground burst
- 0.1 kt Ground burst

Expanded number of Yields and HOBs