Nuclear Detonation Response Training

Nuclear Detonation Effects

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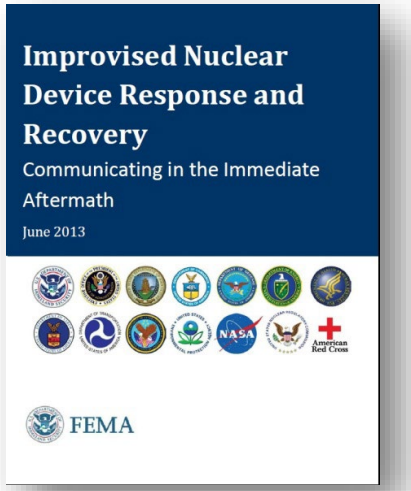
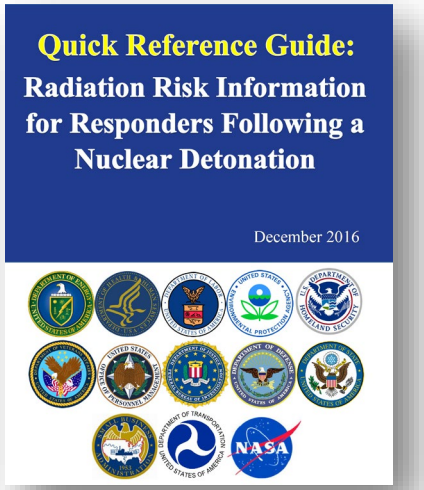
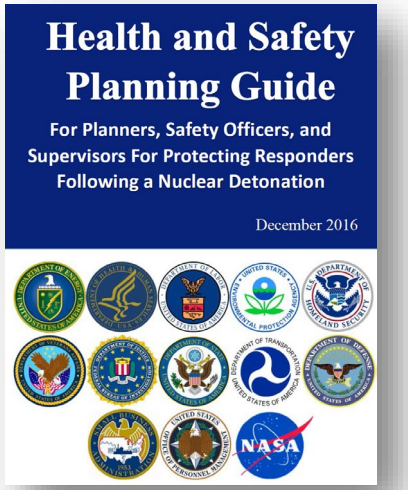
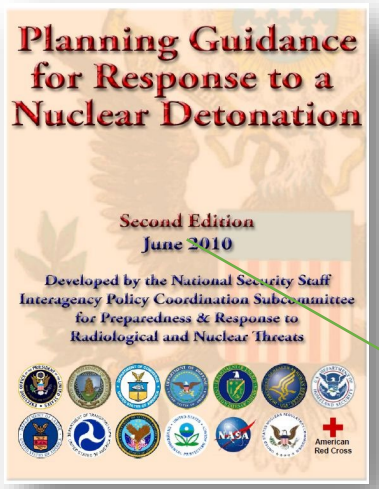
Prepared by LLNL under Contract DE-AC52-07NA27344.

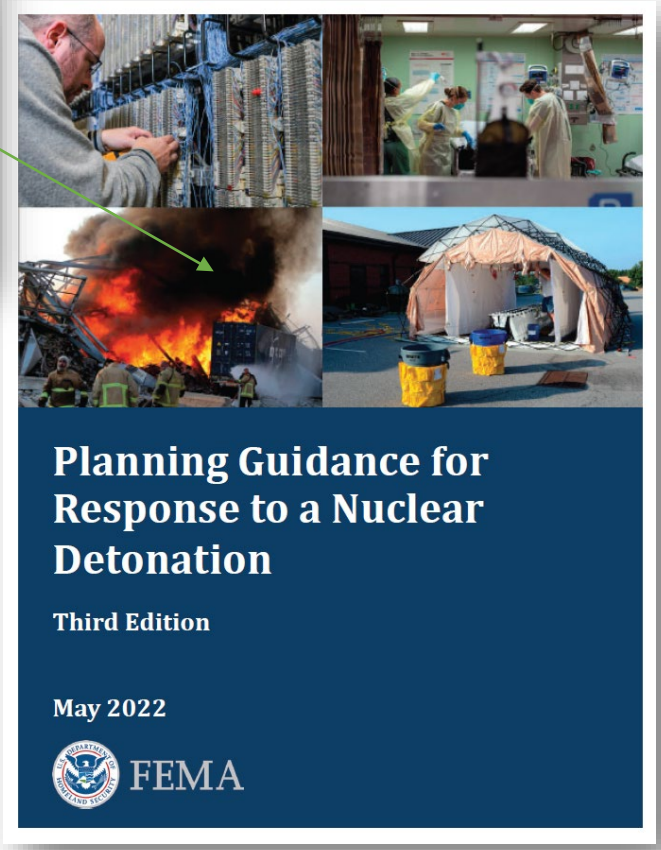
Guidance for Response to a Nuclear Detonation

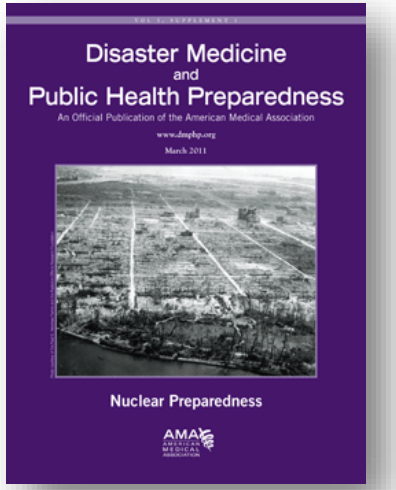


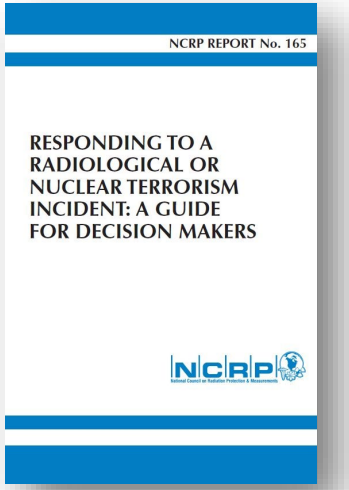












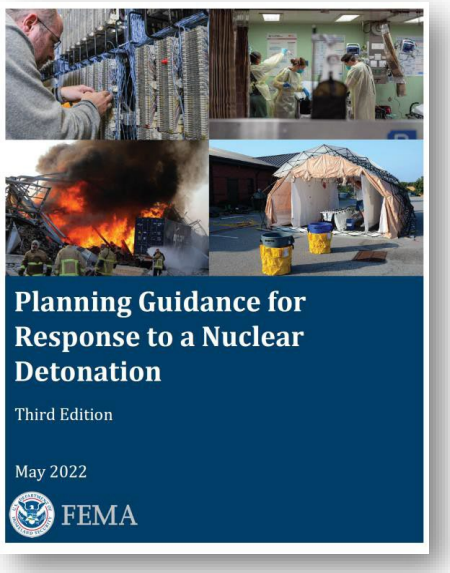
Chapter 1: Nuclear Detonation Impacts

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

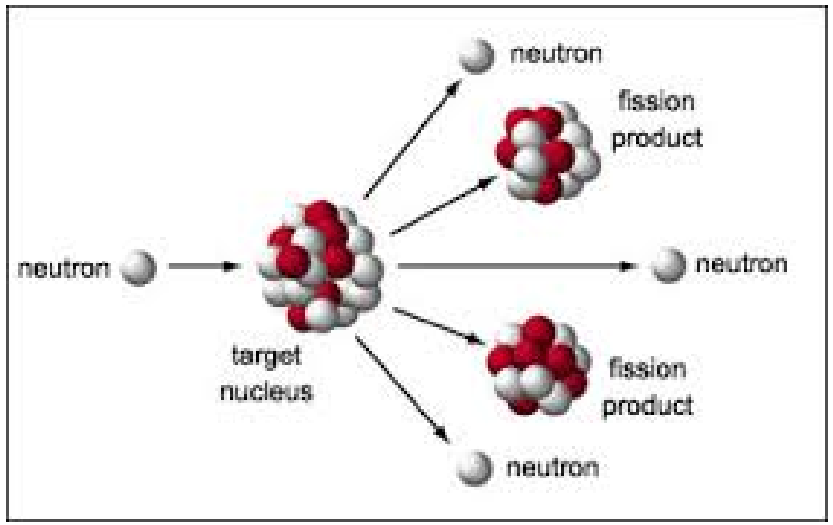
While these subjects are technical, descriptions are tailored for a non-technical audience.

- 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)

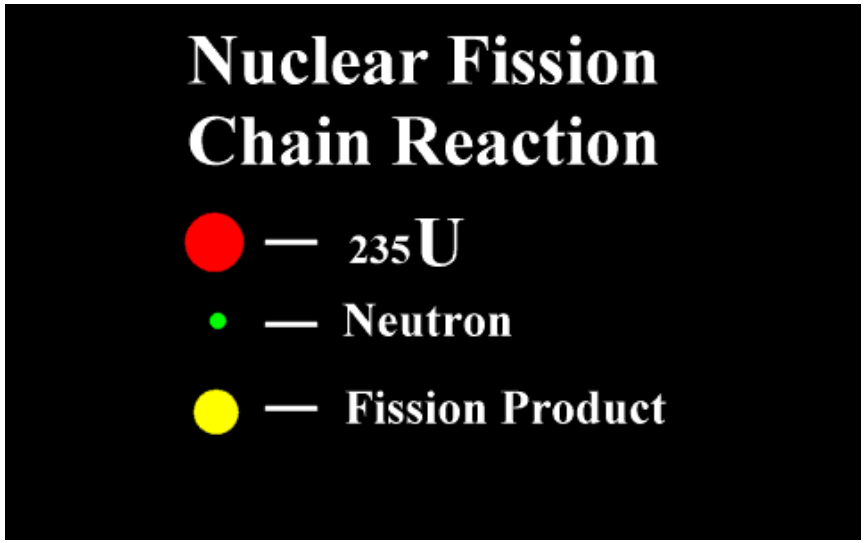


What do the 2-3 Neutron do?

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

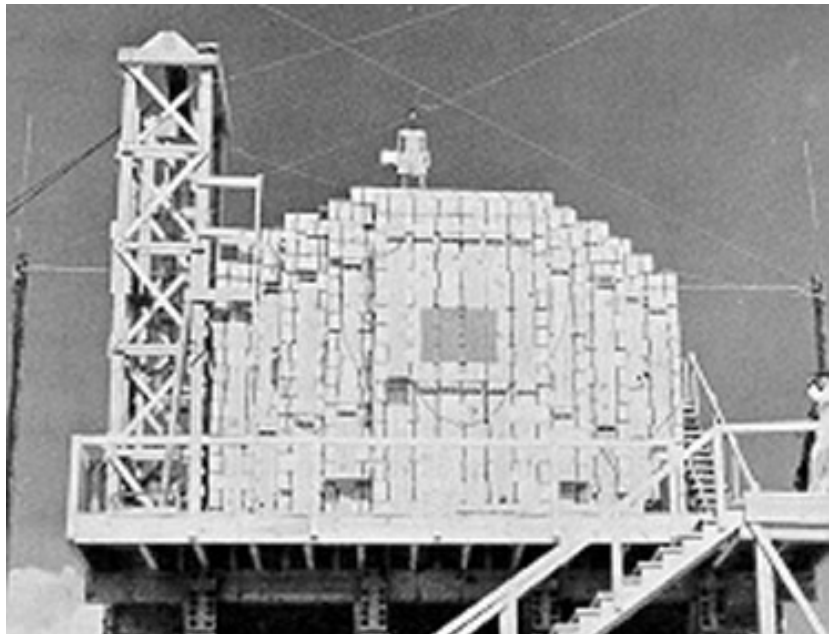
Nuclear Fission Produces:

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



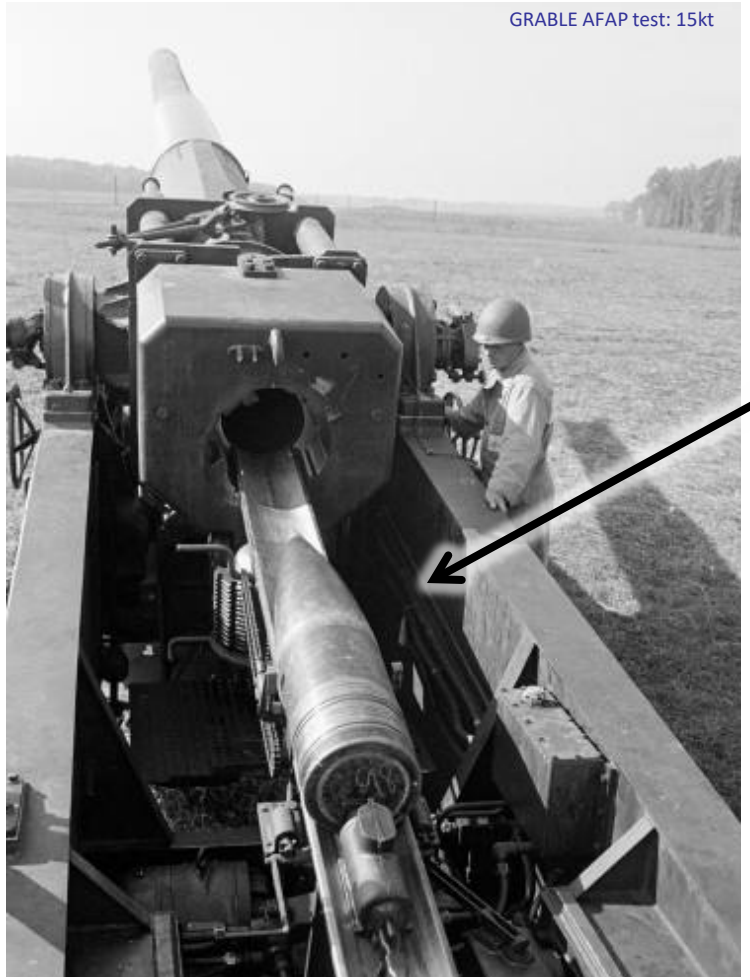
How Much Energy?

- 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.

Comparing Nuclear vs. Chemical Energy



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

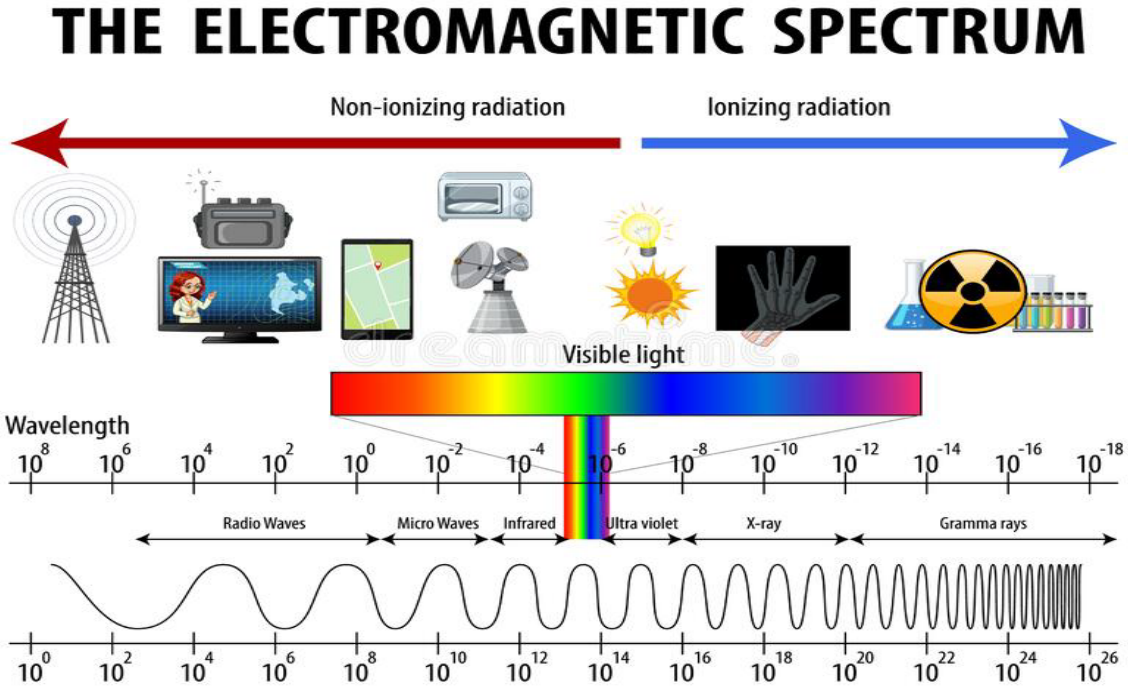
- Fallout cloud several km up
- Particles start "falling out"
- Dangerous deposition levels

Hours

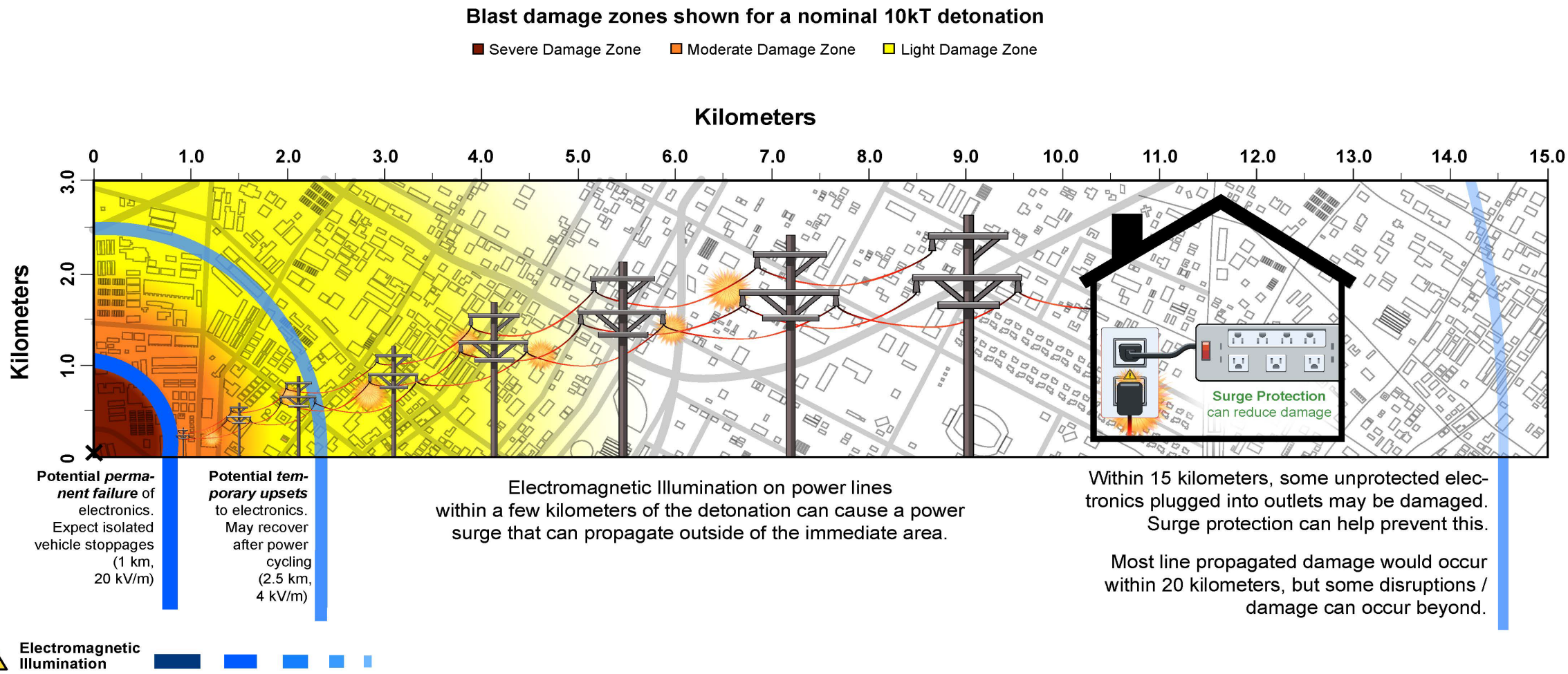
- Dangerous fallout zones shrink
- Fallout hot zone expands downwind

Days

- Fallout hot zone shrinks
- Low levels of global fallout



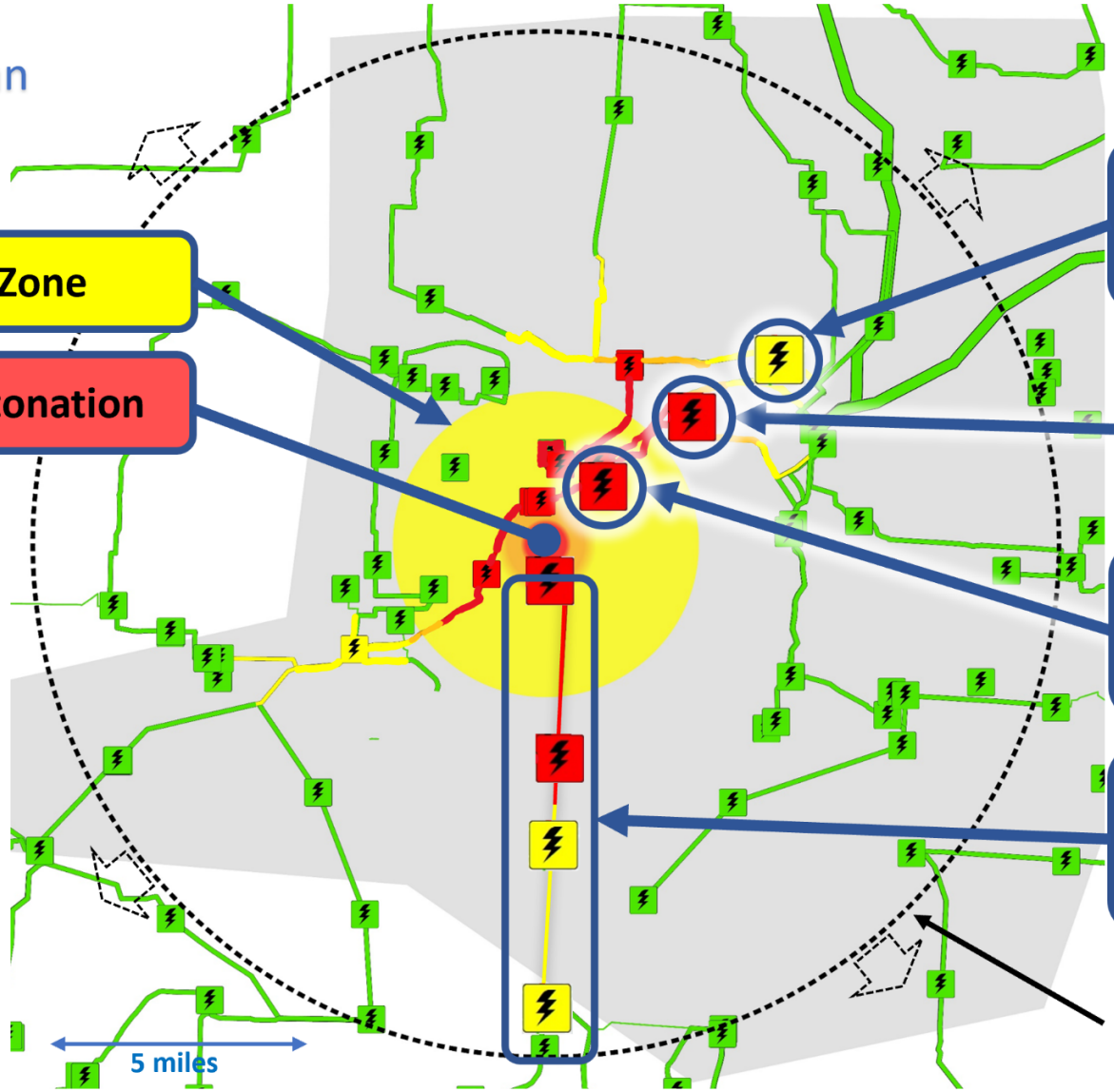
Electromagnetic Pulse from Near Earth Detonations (< 5 km Height of Burst)



Transmission line resistance and junctions reduce the distance at which surge impacts are expected

Notional Urban Power Grid

Artist's interpretation of Source Region Electromagnetic Pulse (SREMP) impacts



Blast Damage Zone

Notional 10kt Detonation

Substations

- Damaged
- Upset
- Not Affected

Transmission Lines

- Significant Surge
- Moderate Surge
- No or Minimal Surge

Circuit Breaker / Protective Equipment trip (temporary upset)

EMP line coupling causes relay burnout (permanent failure until repaired)

Blast Effects causes Substation Damage (permanent failure until repaired)

Long running, non-branching transmission lines can create some impacts at long distances

Most line propagated damage would occur within 12 miles, but some disruptions/damage can occur beyond

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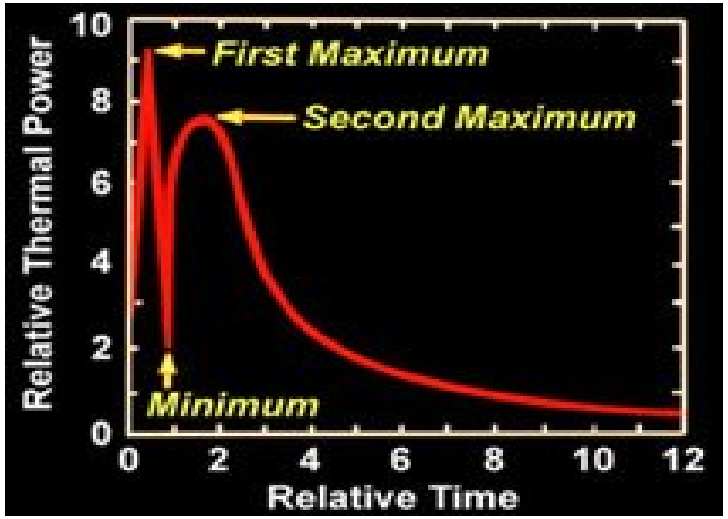

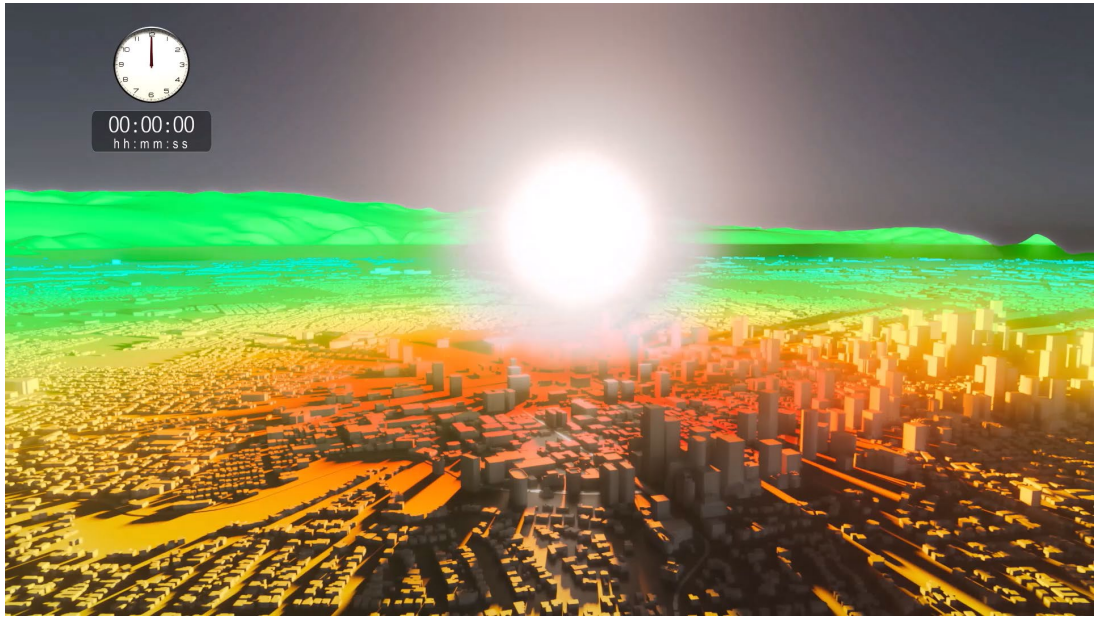

- Initial heat pulse (1% of energy) occurs within a fraction of a second, too fast to avoid or even blink!
- The second, slower heat pulse occurs over a second or more and deposits 99% of the heat energy

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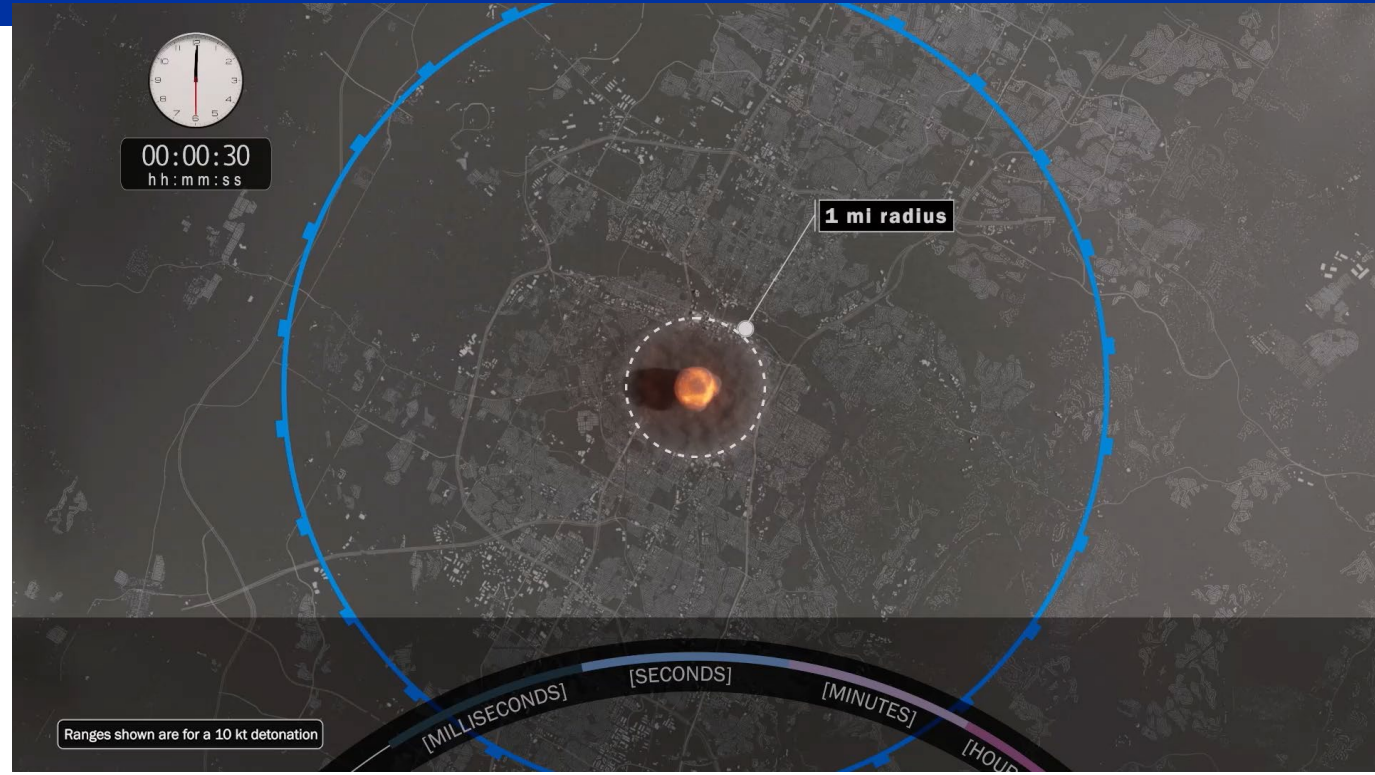

- Initial shockwave moves faster than speed of sound until about 2 km (1 mile).
- Most significant damage done within this area.
- Windows will still be broken with enough force to cause injure out to 5 km (3 miles)

*example distances for a 10 kt

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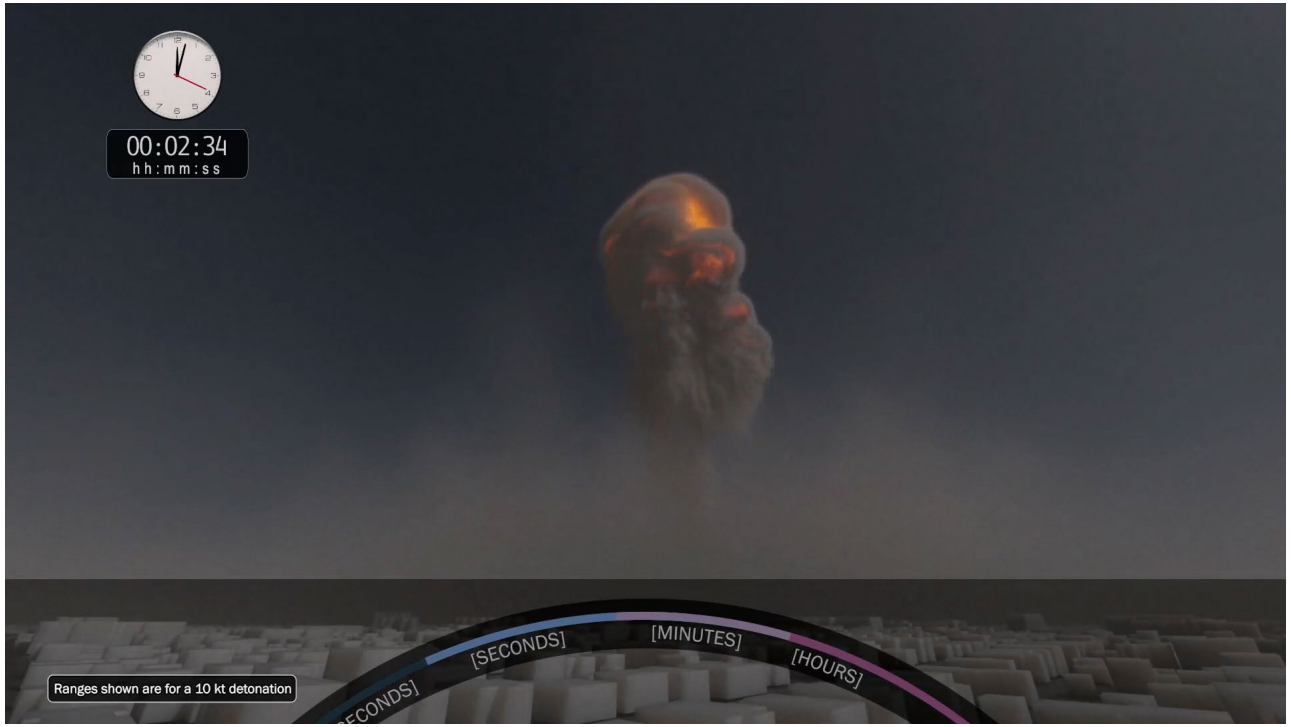

- The shockwave will continue to move outward at the speed of sound for several minutes.
- The Fireball will shoot up at over 100 mph.
- If detonated near the surface this can pull up 1,000s of tons of dirt and debris.
- The cloud will stabilize high in the atmosphere after about 10 minutes

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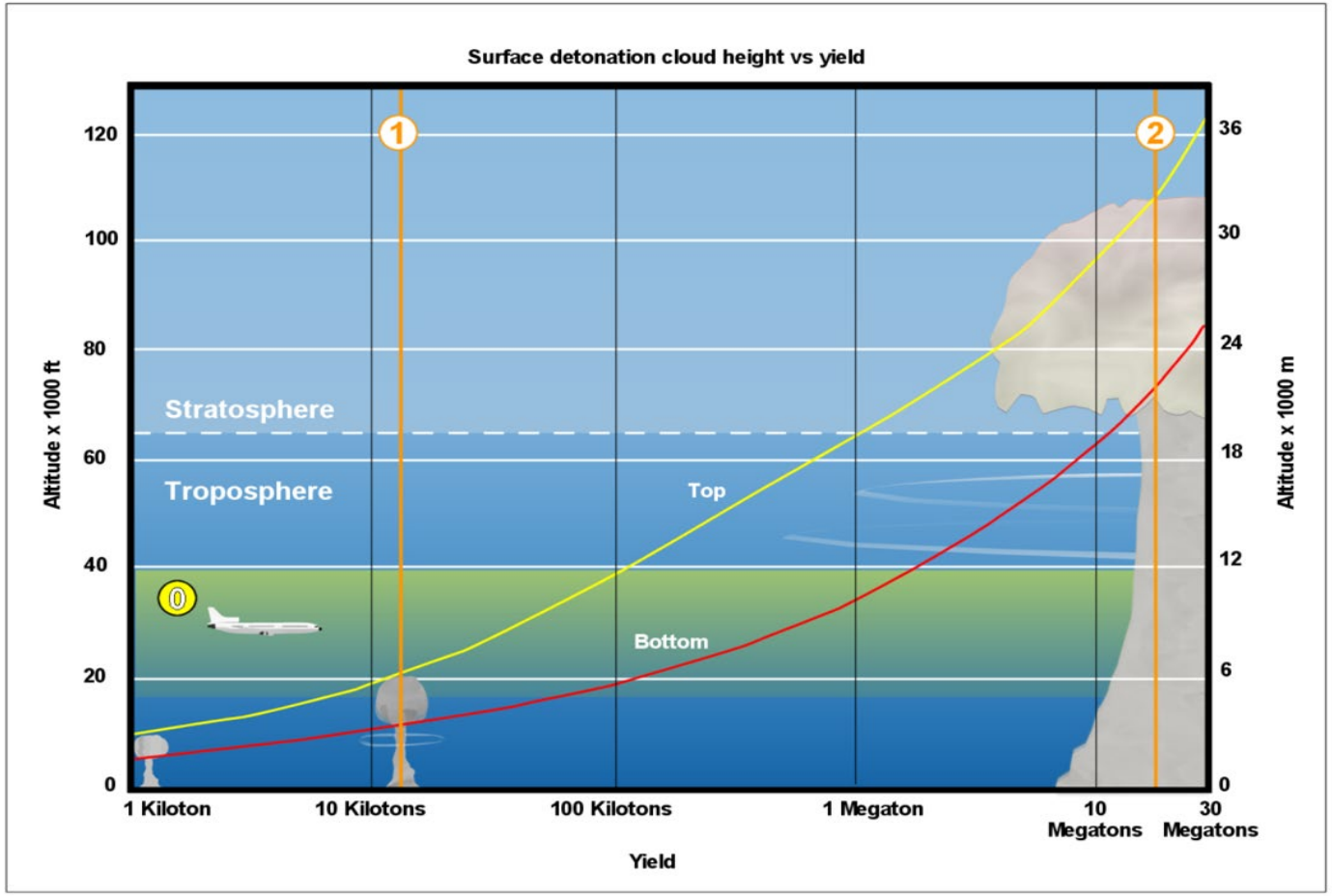
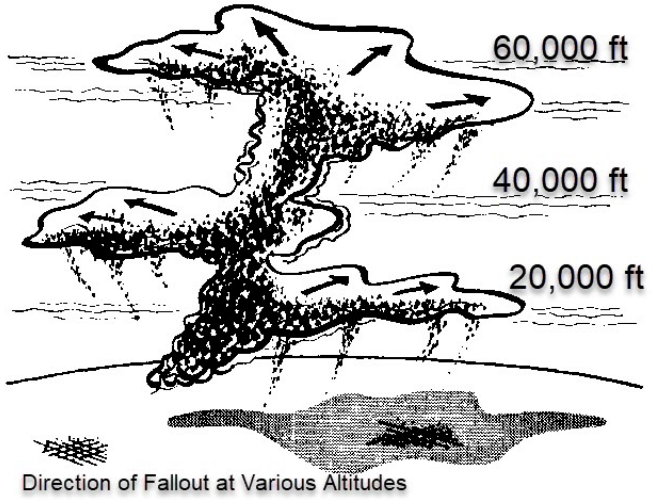
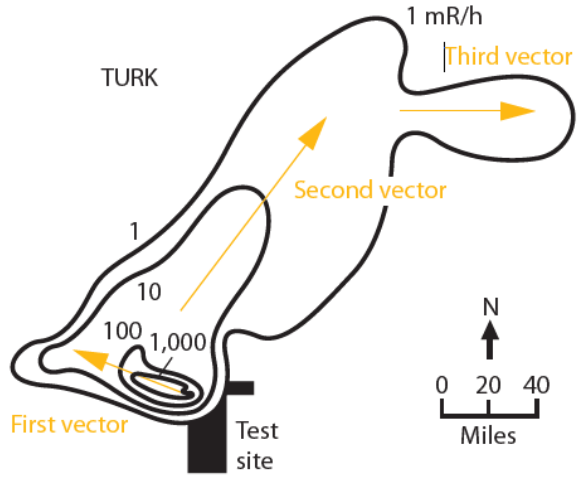
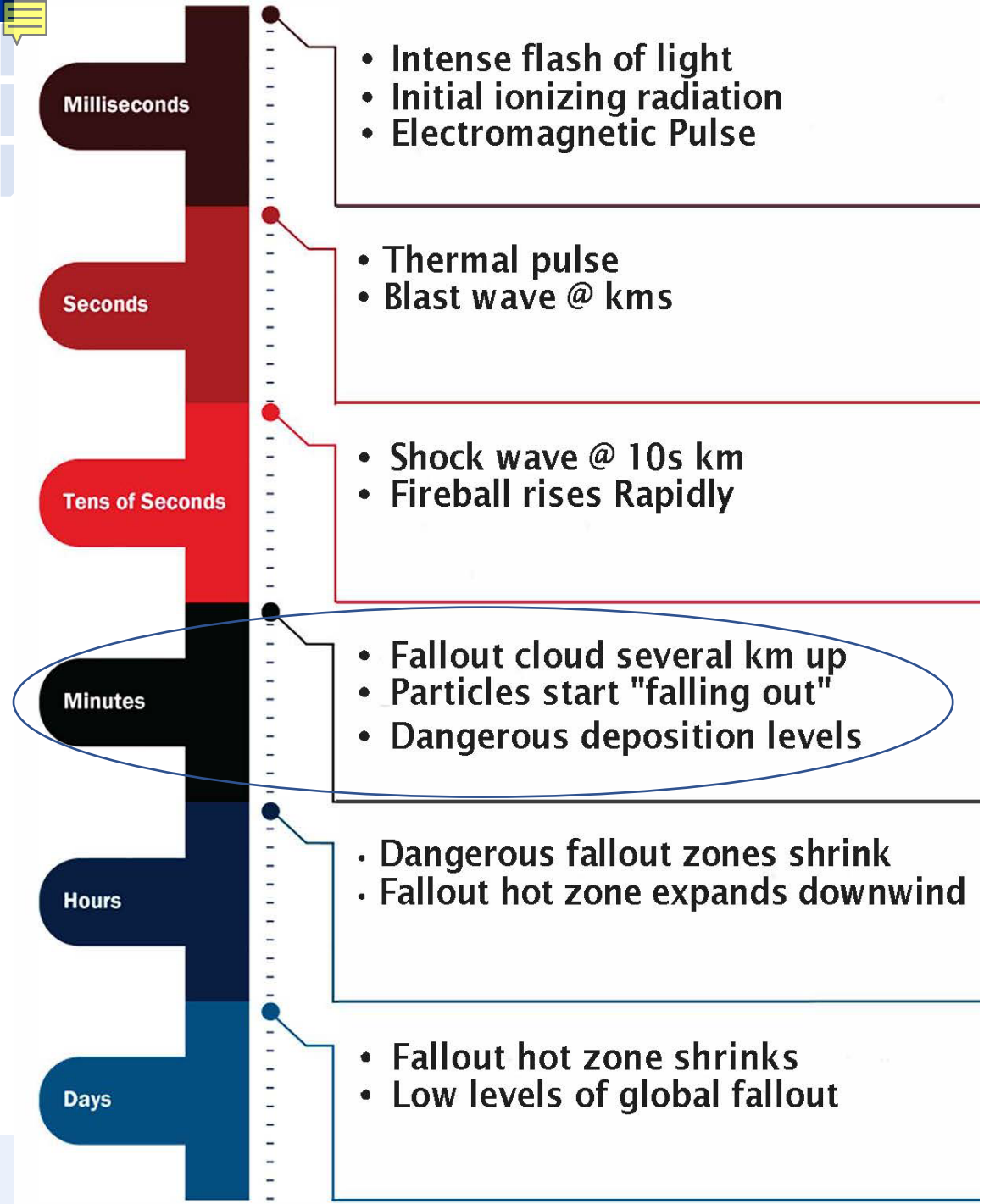
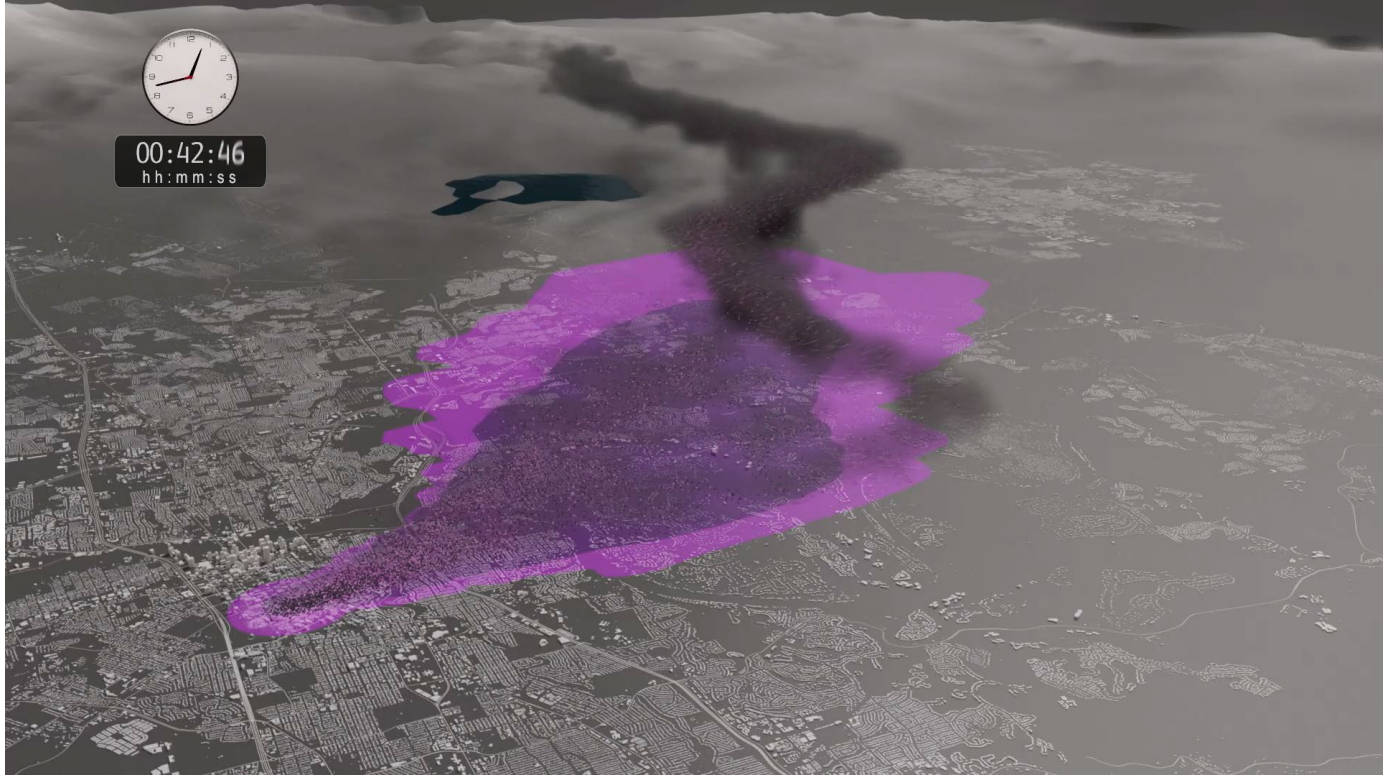




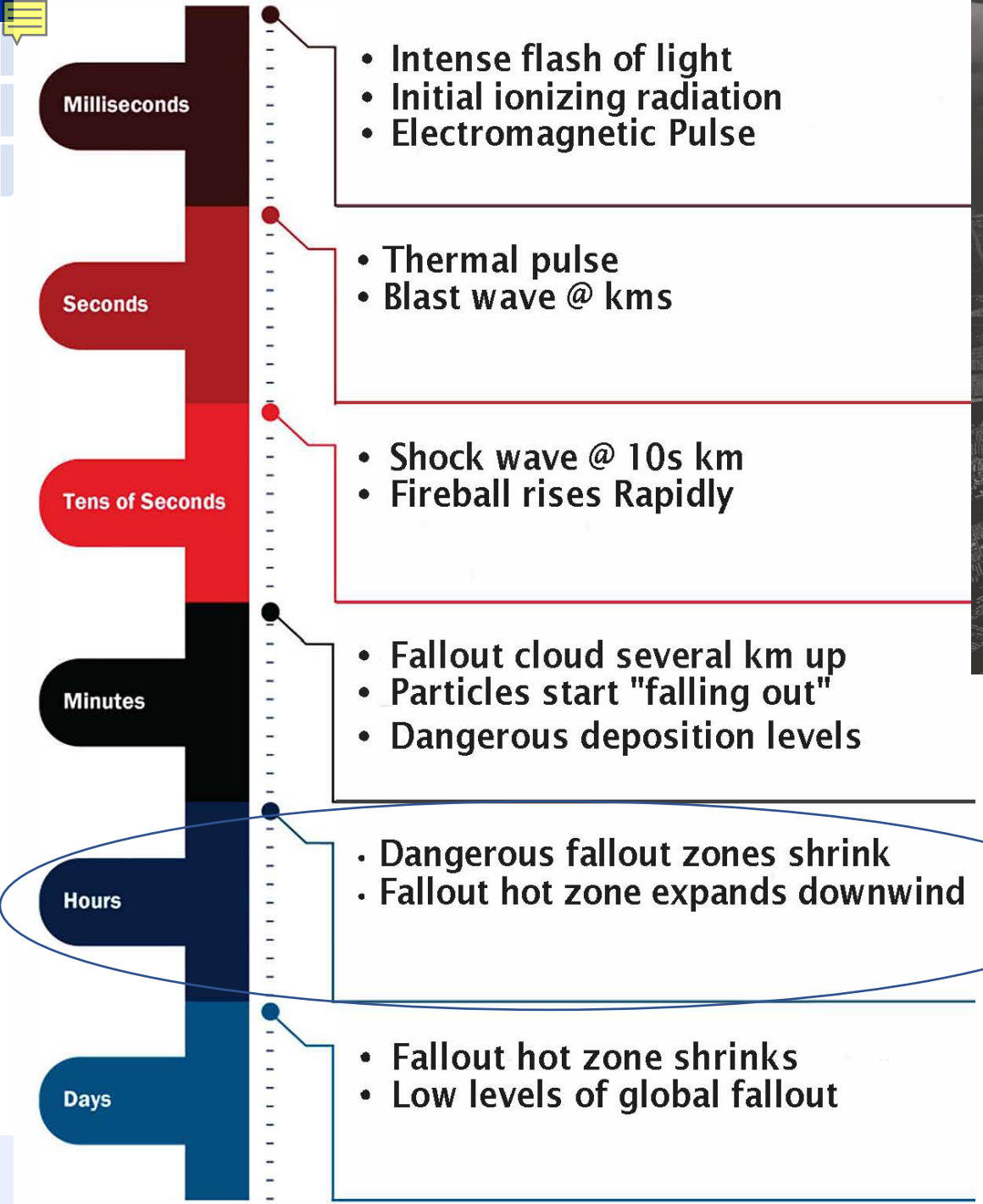
Direction of Fallout at Various Altitudes

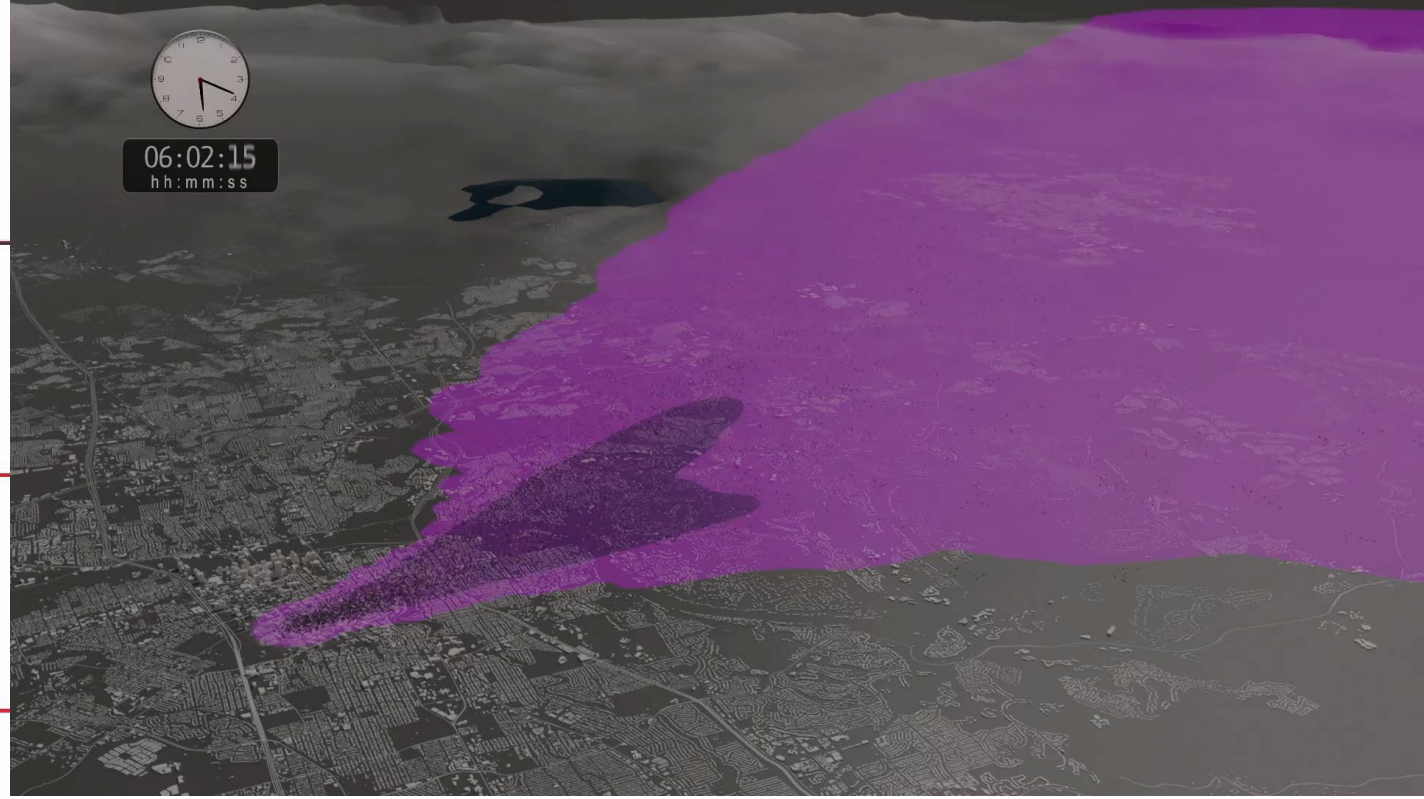






- After 10 minutes or more, the fallout cools and drops back to earth
- The particles are large, sand sized or larger, and give off radiation.
- This creates dangerous outdoor radiation levels, potentially for 10s of kilometers downwind.
- For a 10 kt, this dangerous area would reach it's maximum extent after an hour or two.





- As the fallout cloud moves downwind, it will continue to deposit lower levels of contamination.
- The area with the most dangerous levels of outdoor radiation will begin to shrink after ~ 1 hour due to radioactive decay.
- Initial fallout decay rate is very rapid, dropping by a factor of 10 for every factor of 7 in time.

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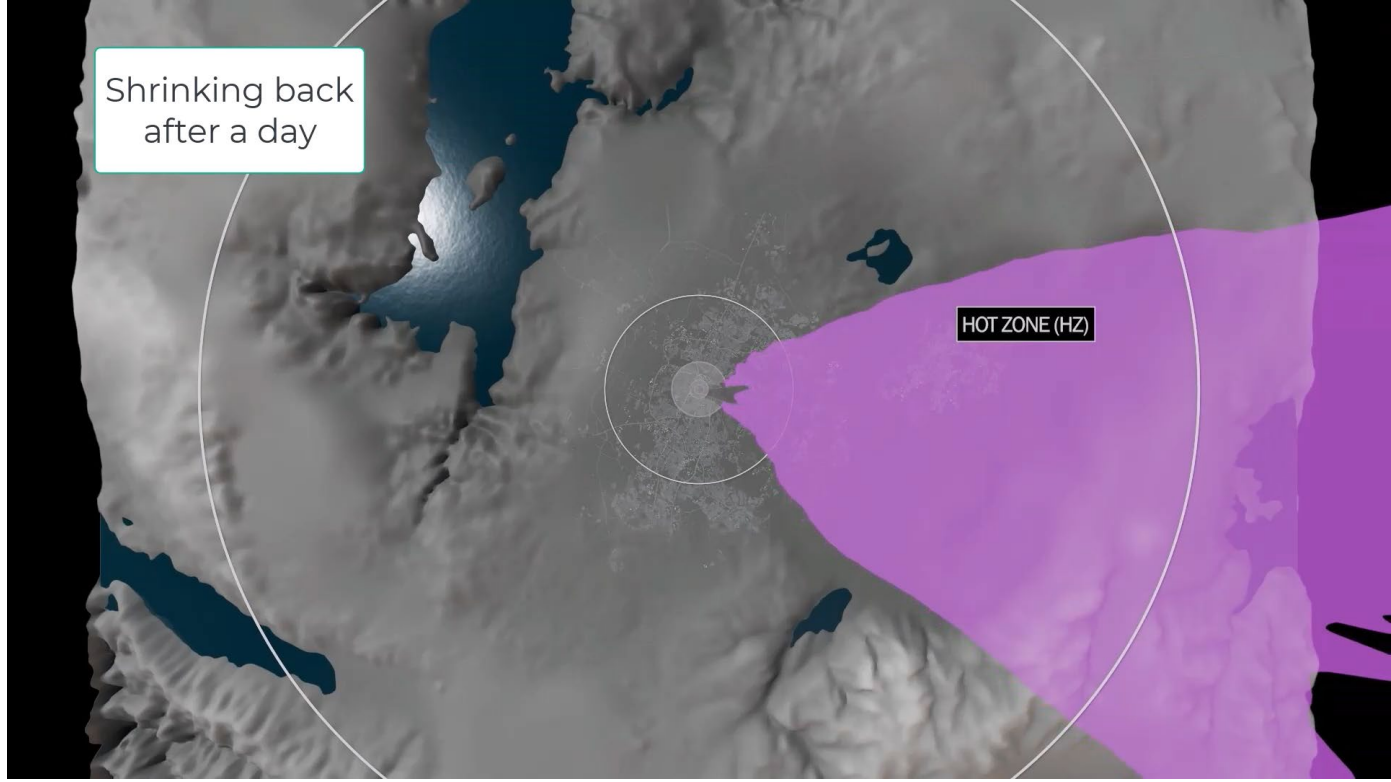
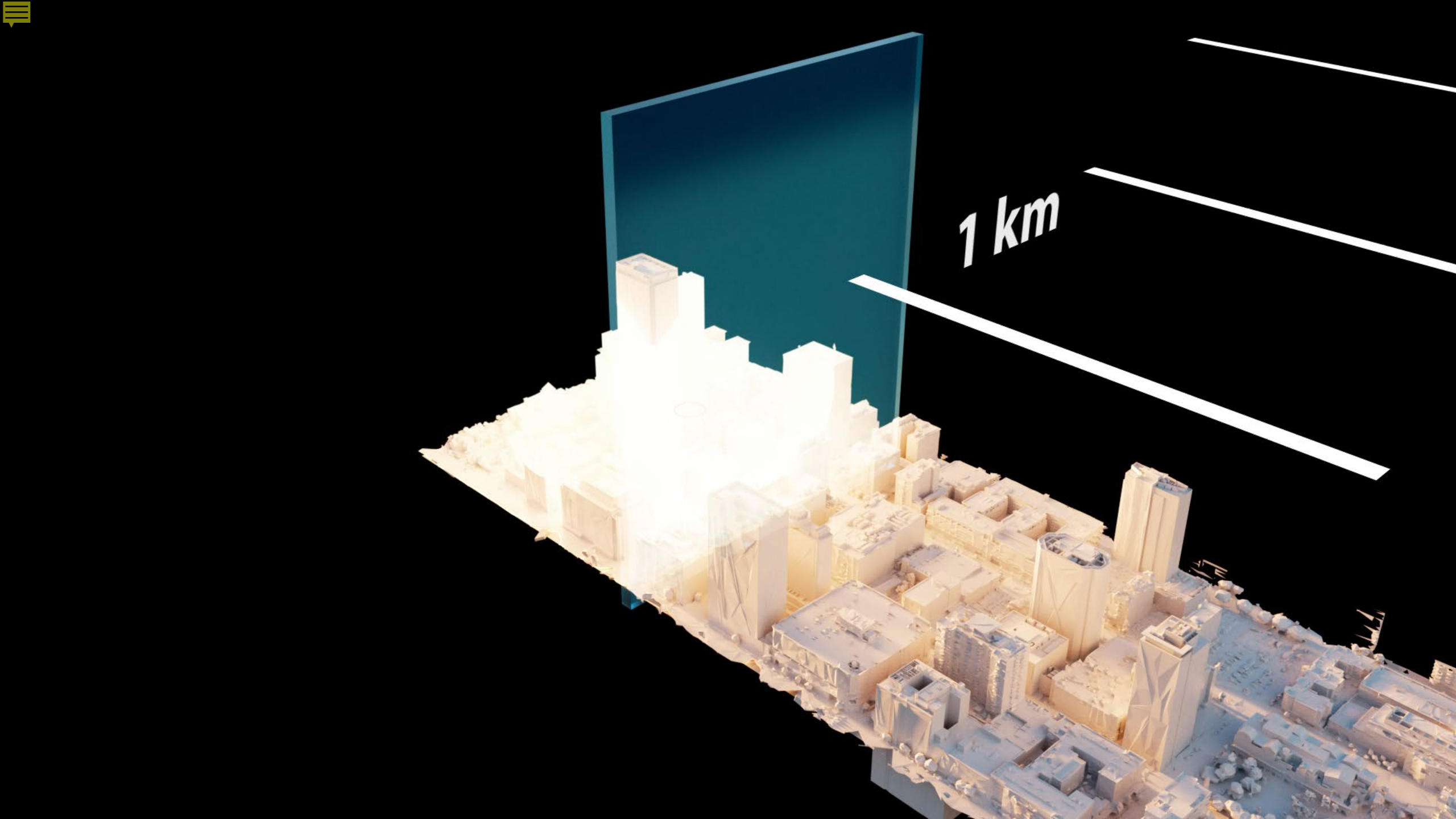
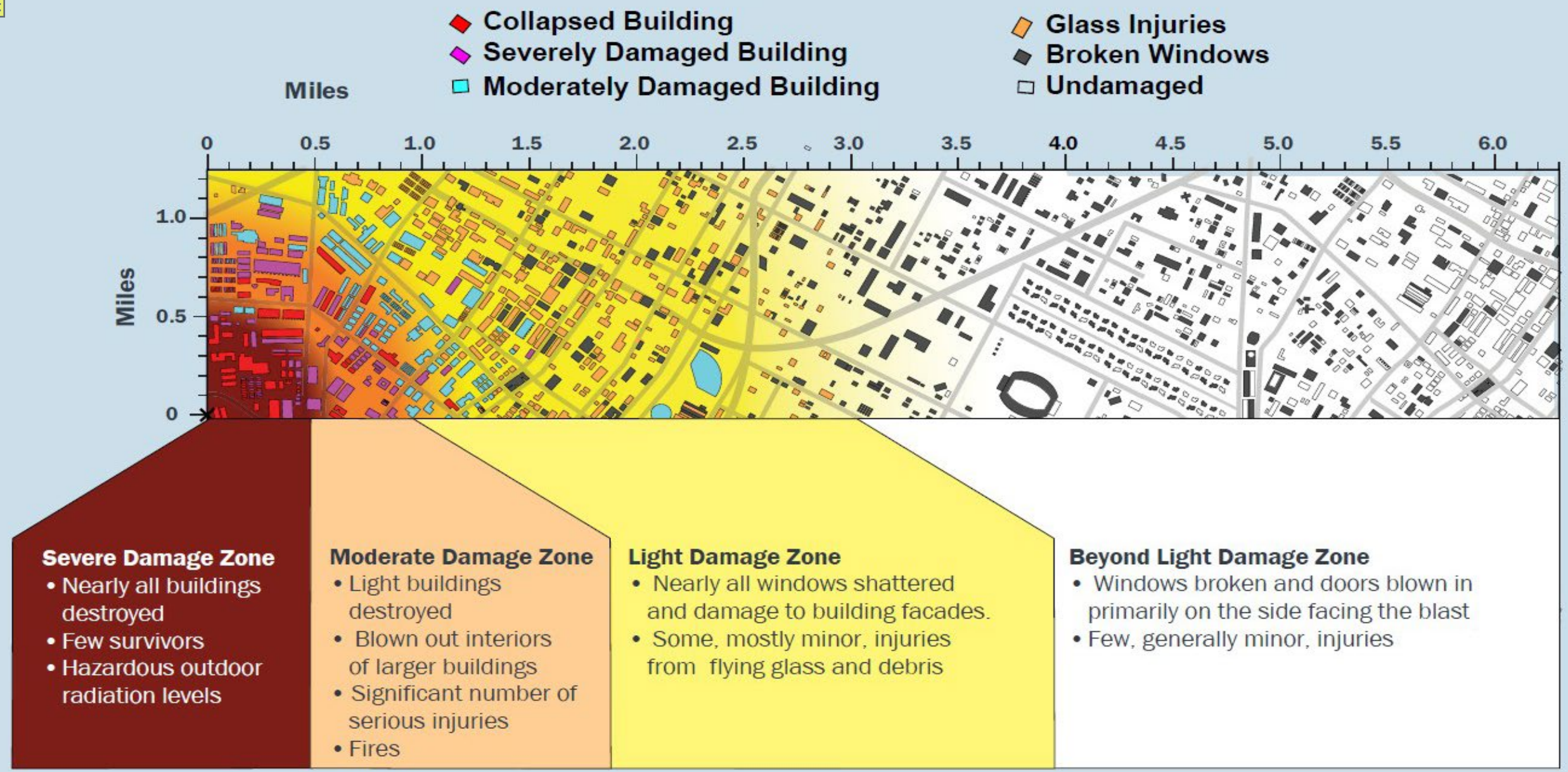


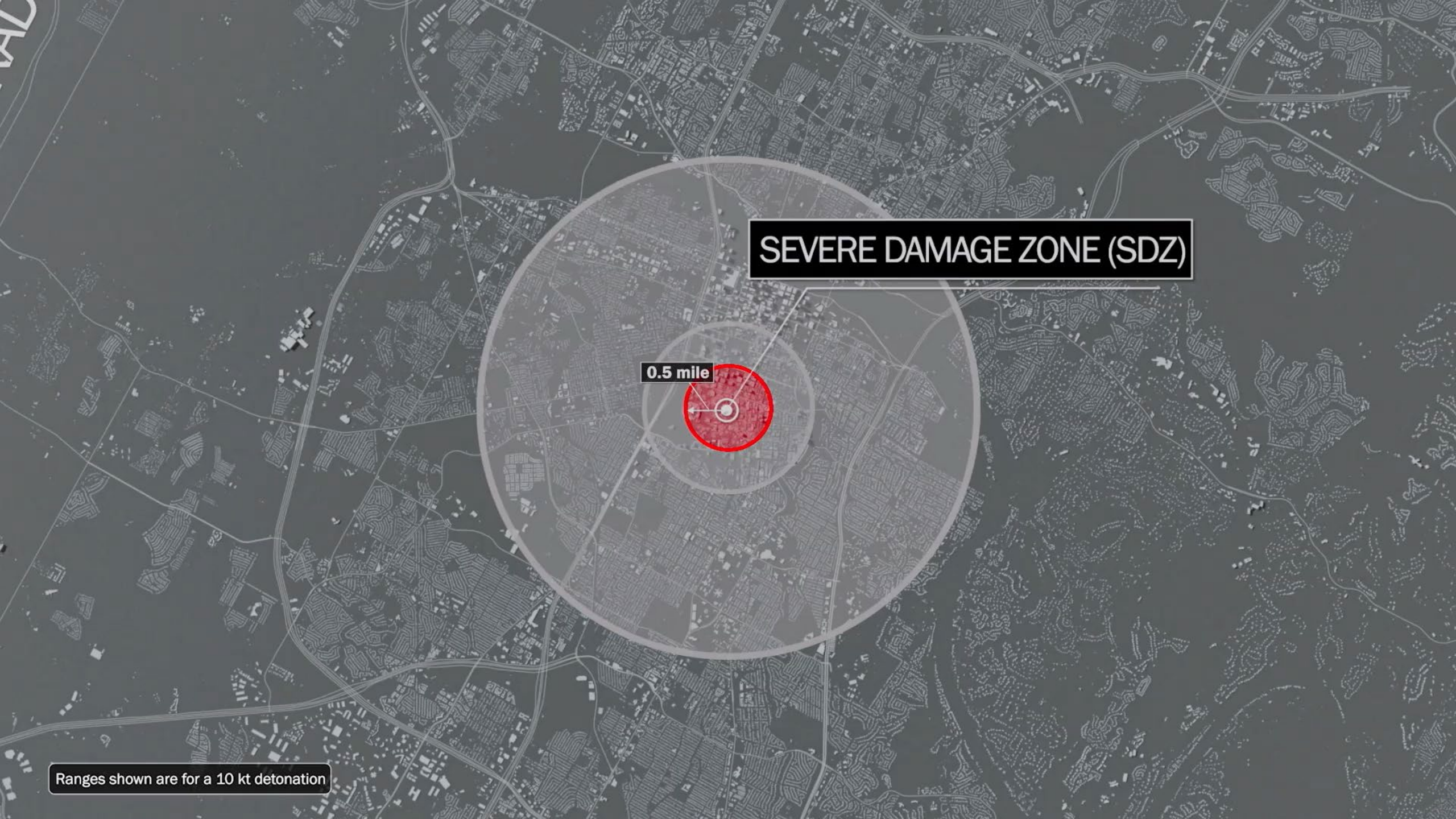
- The Hot Zone, which has levels that still require public protective measures, will continue to expand for 100s of kilometers
- After 12-24 hours (for a 10kt), the Hot Zone will begin to shrink due to decay.
- The smallest fallout particles will mostly remain aloft, circumnavigating the globe.

Blast Damage


1 km

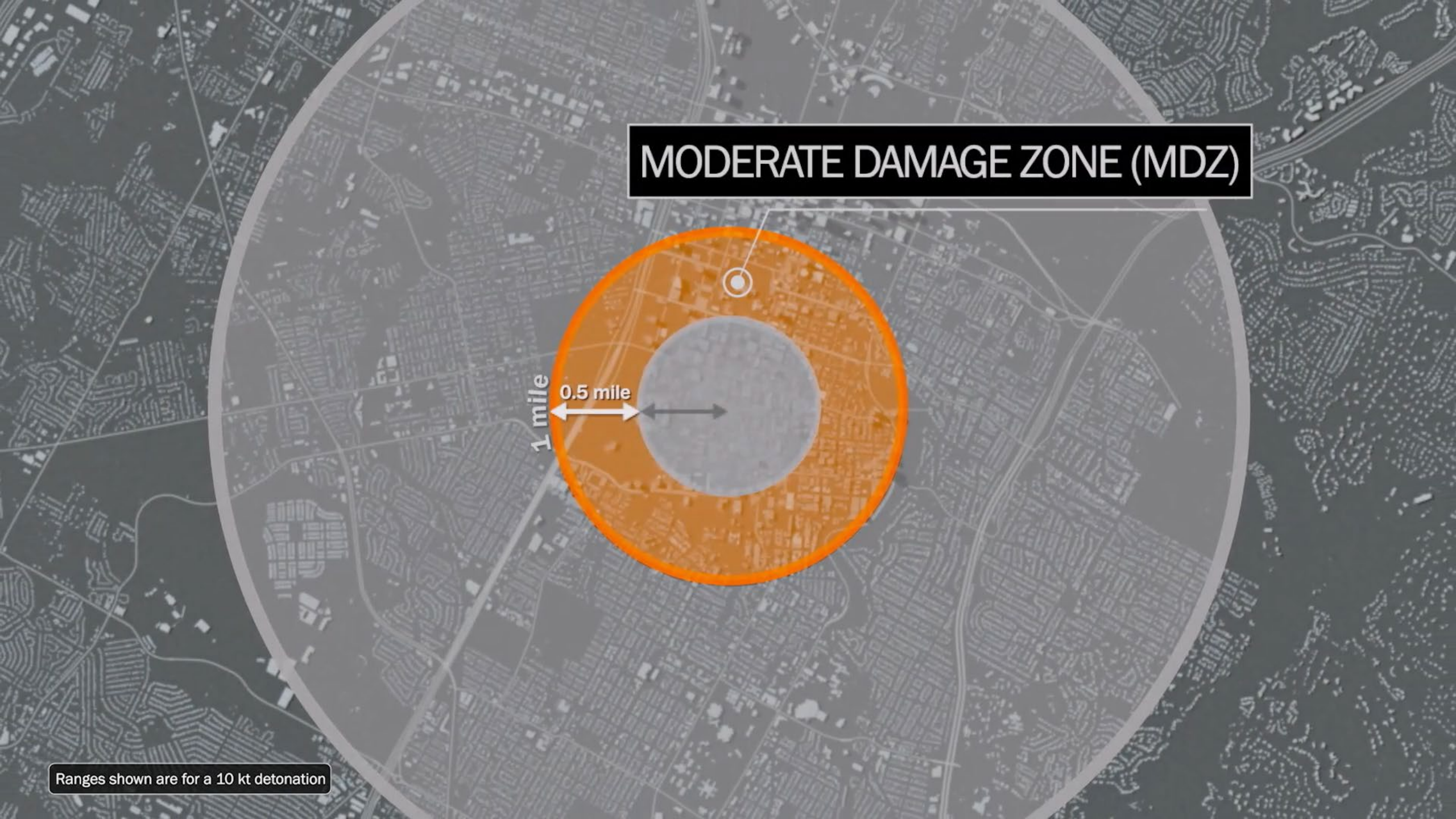


[1] Pressure over and above atmospheric pressure, measured in pounds per square inch (psi).
[2] Figure 1.2 assumes a nominal 10 kT surface detonation in a modern city. While distances would vary, the zone descriptions apply to any size nuclear explosion.


SEVERE DAMAGE ZONE (SDZ)
0.5 mile
Ranges shown are for a 10 kt detonation

Severe Damage Zone Definition

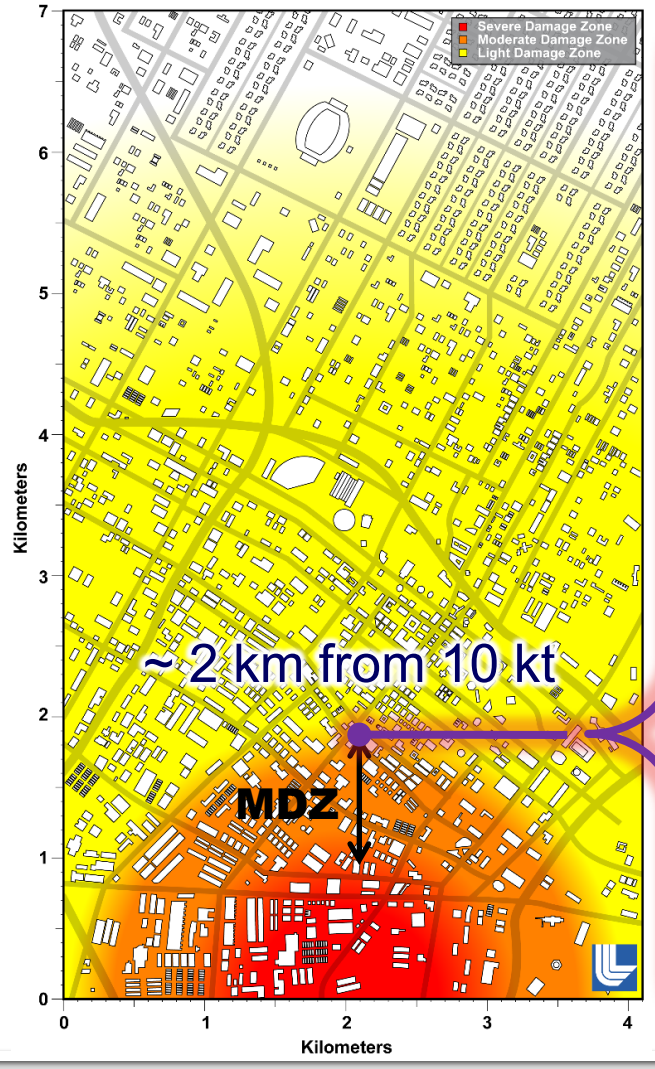
- In the Severe Damage Zone (SDZ), few buildings will be structurally sound or standing.
- Rubble in streets will be impassable.
- Potentially dangerous radiation levels outdoors during the first day.
- Few survivors expected, except for those in the center of large structures or underground (e.g., subterranean 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 (MDZ)
1 mile
0.5 mile
Ranges shown are for a 10 kt detonation

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.

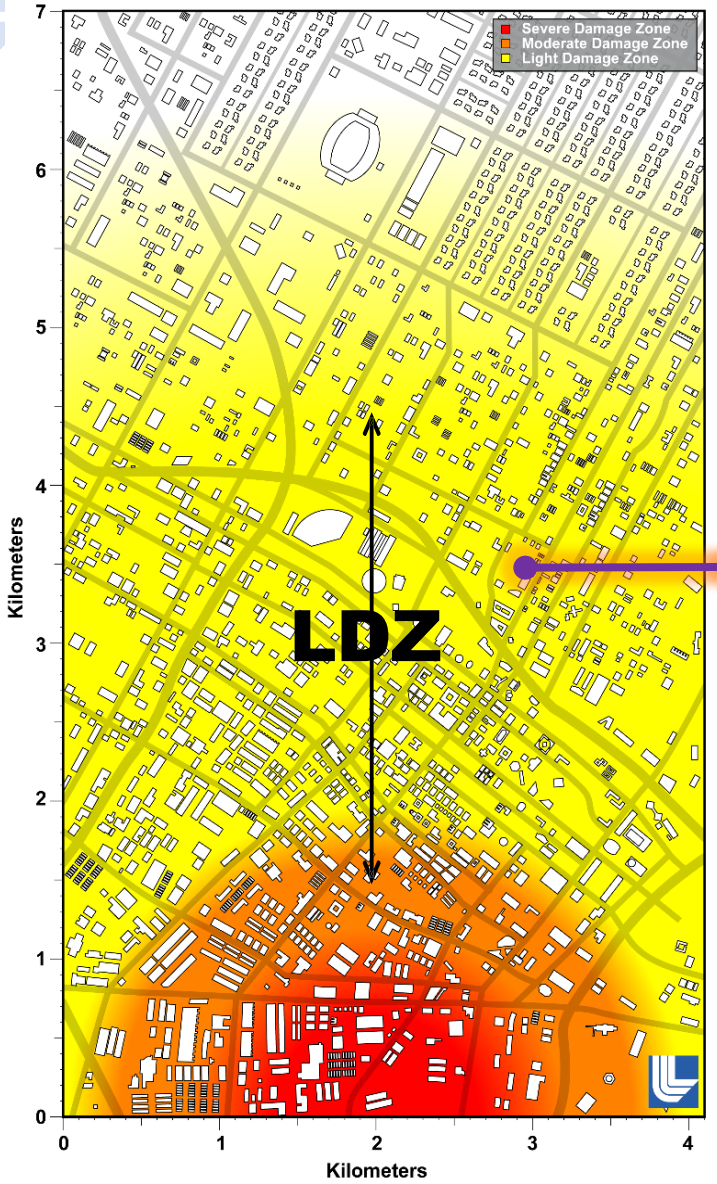
Outer Edge of Moderate Damage Zone

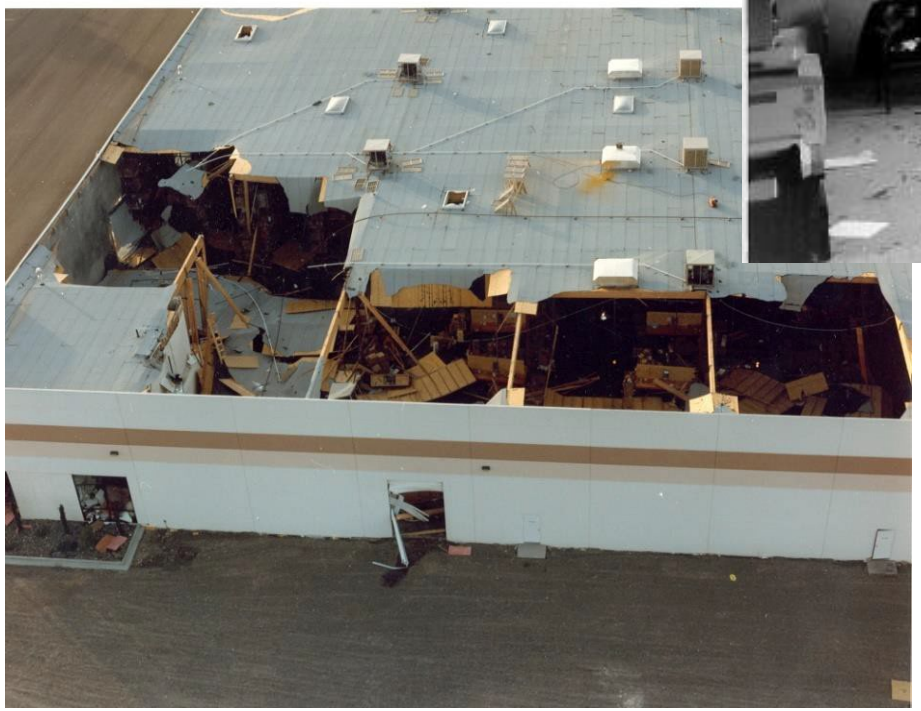


Animation depicts timing and damage from the outer edge of MDZ

Examples of Damage in the Moderate Damage Zone

Light Damage Zone (2 to 5 km)





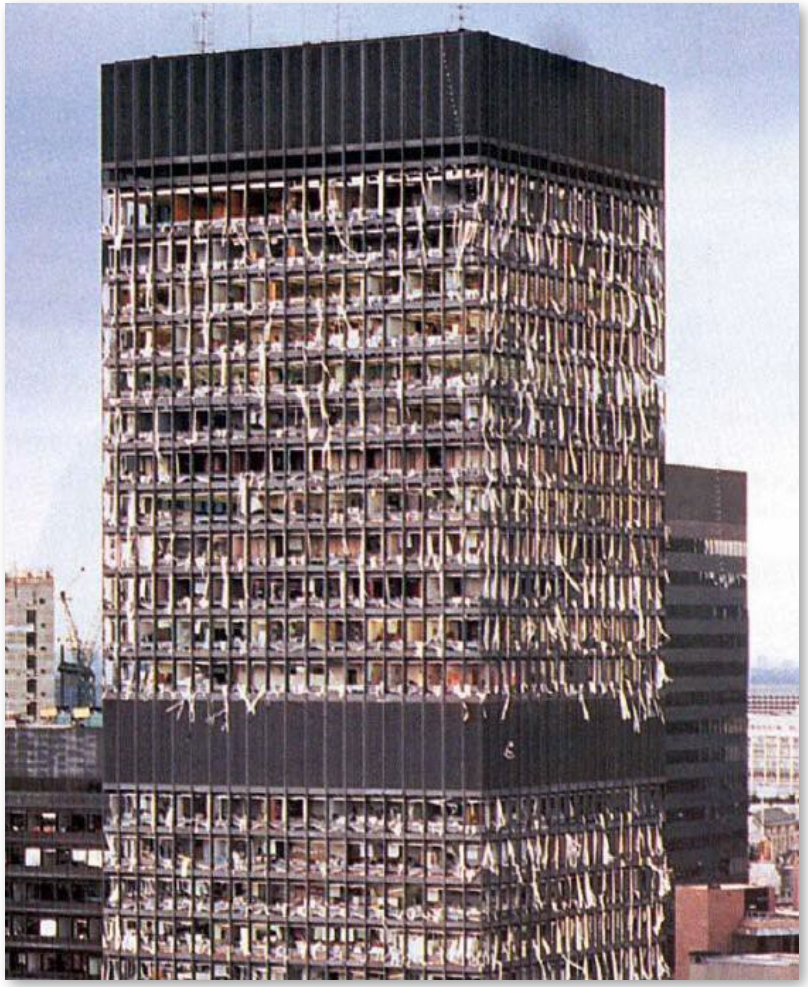
Damage to windows and other large area, weak building features

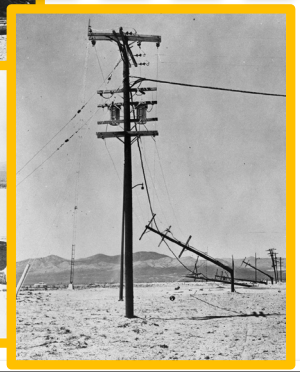
Images taken at 2.6 km (1.5 miles) away from PEPCON (conventional accidental explosion estimated to be equivalent to a 1 kt free air burst), estimated overpressure shock was ~ 0.9 psi

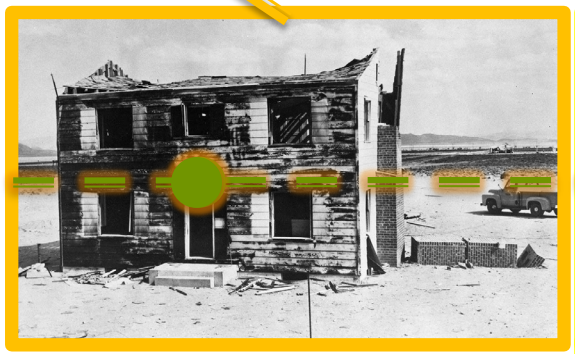
Examples of Damage in the Light Damage Zone

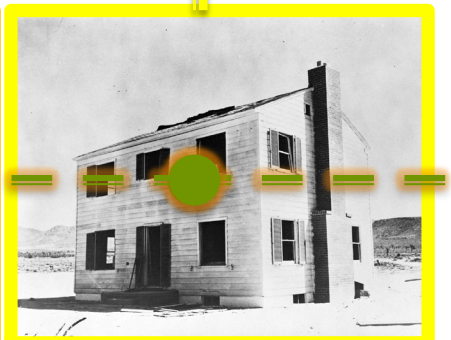
Light Damage Zone Definition

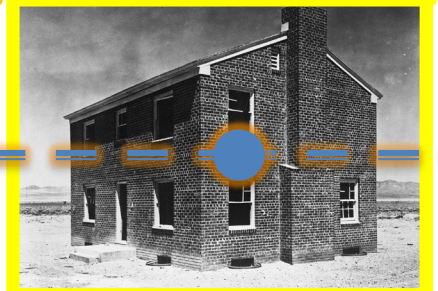
- Damage is caused by the powerful shockwave, like that of a thunderclap or sonic boom but with substantially more force.
- Most windows in the LDZ will break, many with enough force to cause injuries from flying glass and debris, though most people in this are would be uninjured.
- Damage in this area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





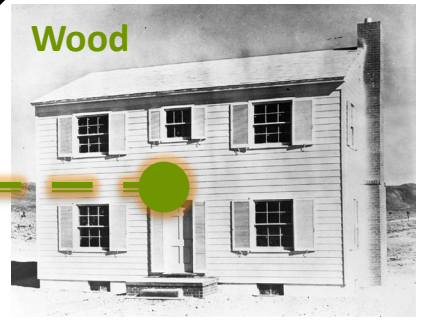




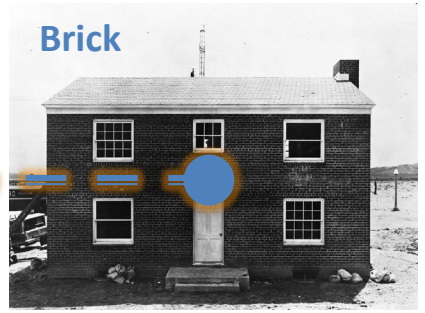


Windows and doors blown in

Wood



Brick

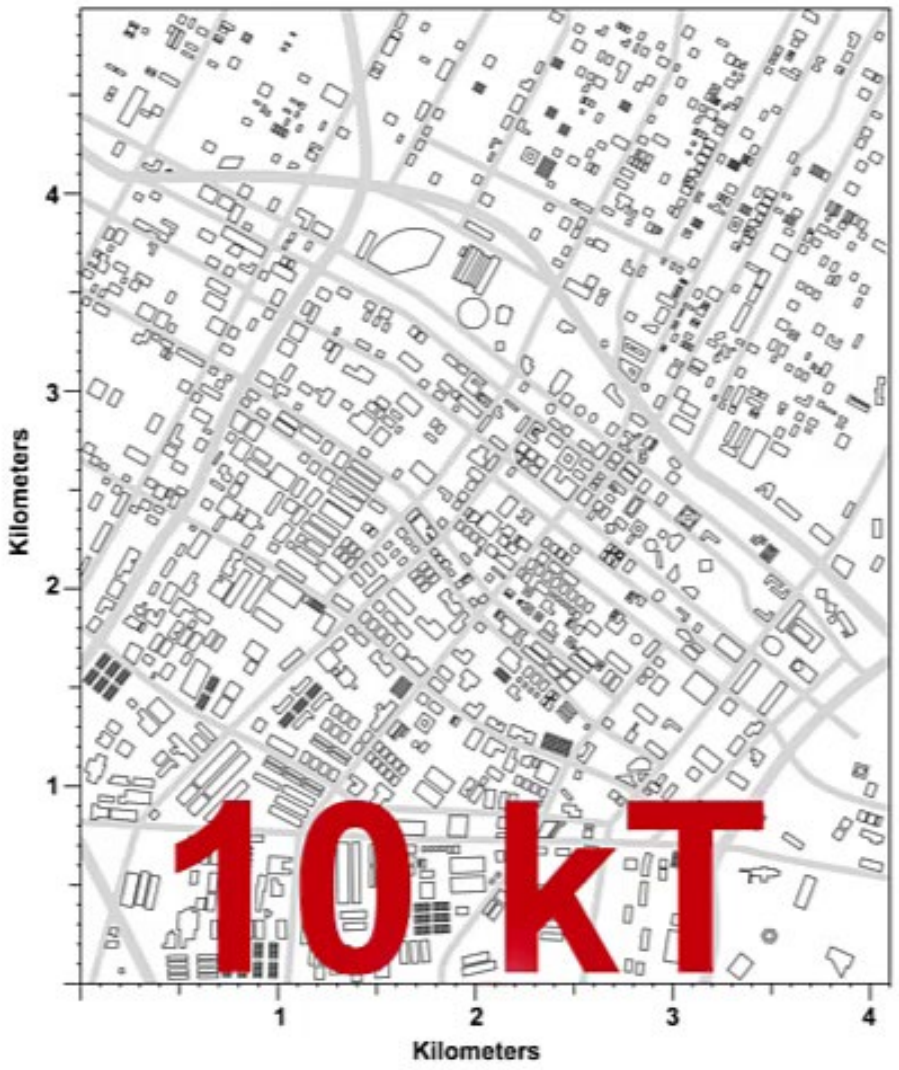


Light Structures Pre-Detonation

Moving through the Damage Zones

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

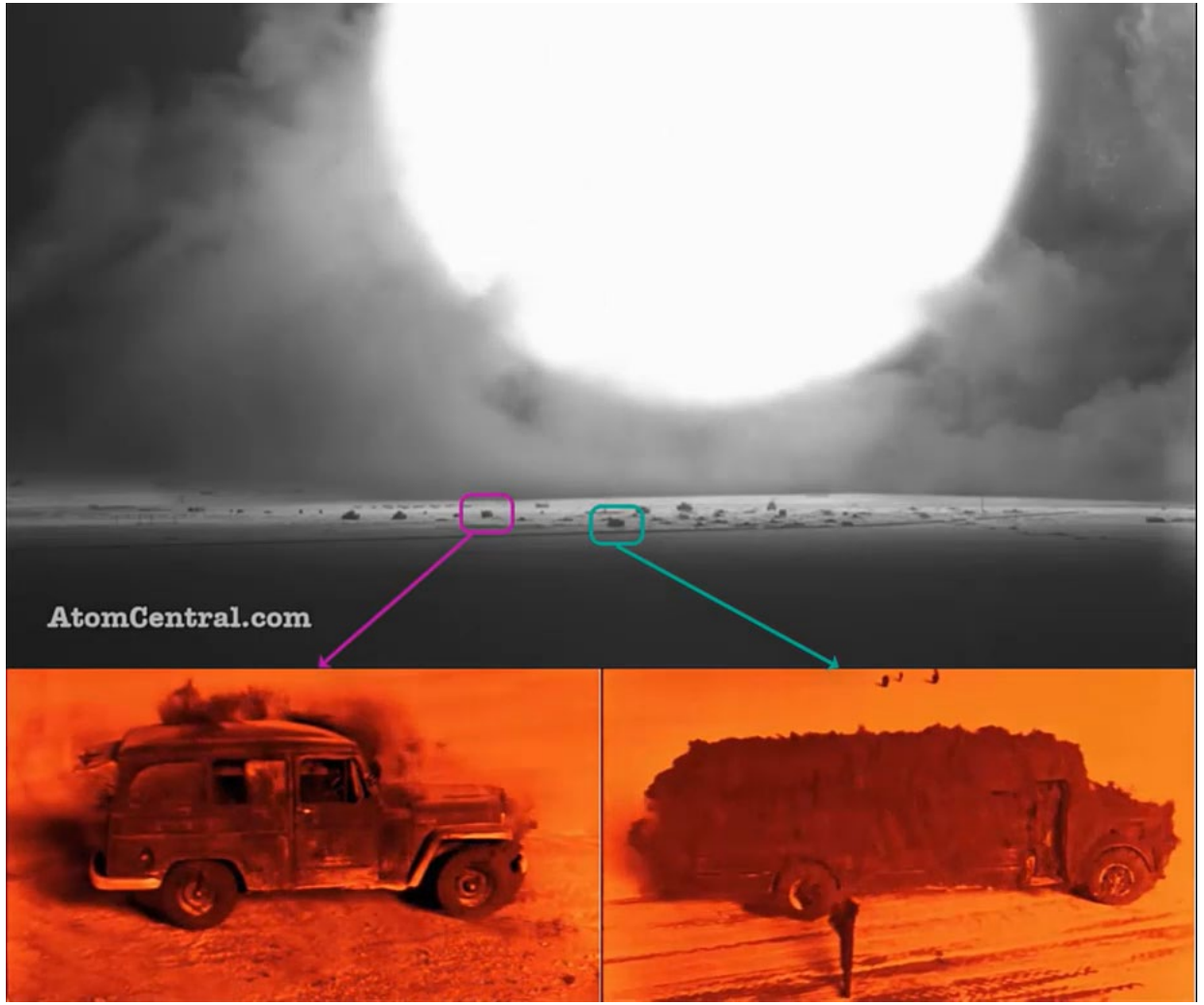
Damage Zone Size Changes with Yield



Thermal Effects

Example of Thermal Effects

- Upshot-Knothole-Grable (Artillery Fired Atomic Projectile)
  - 15 kt
  - 524 ft Height of Burst
  - 558 ft Fireball Radius
  - 25 May 1953



Reference: DASA 1251

Thermal Impacts

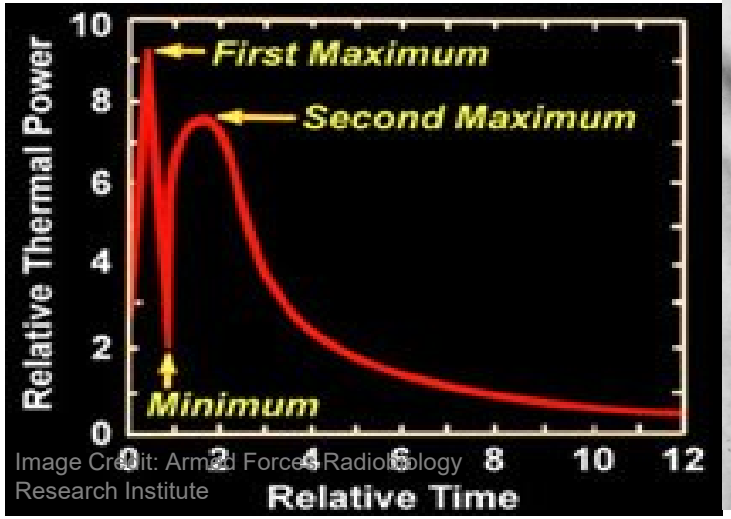
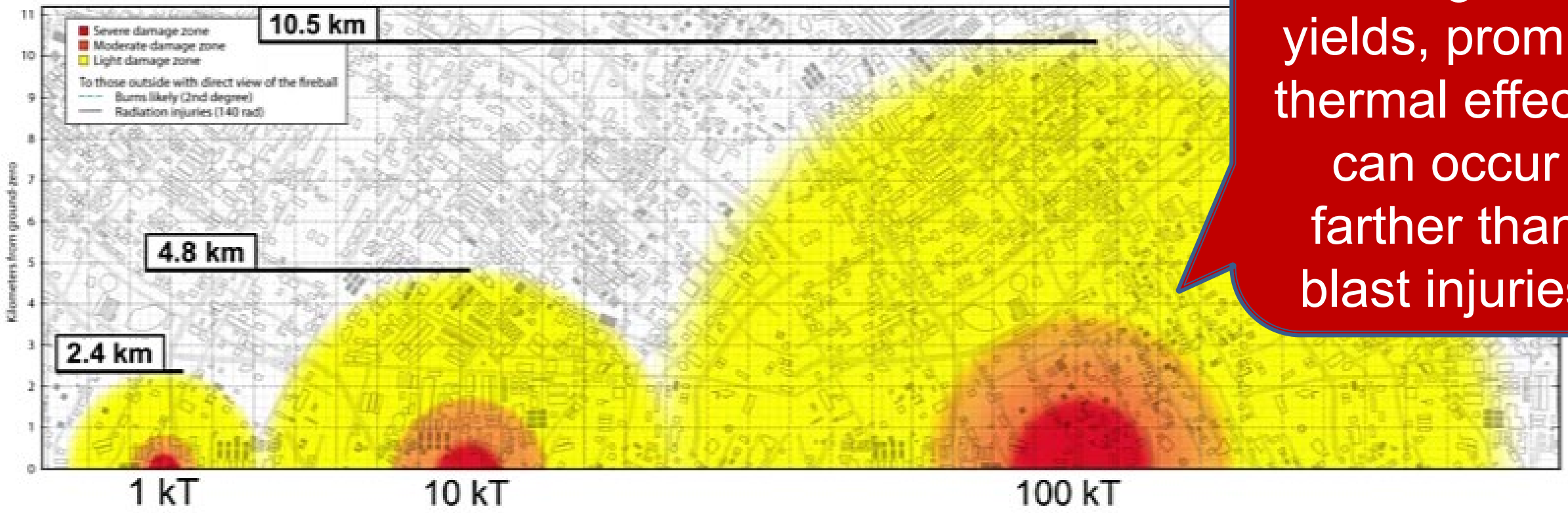


Image Credit: Armed Forces Radiobiology Research Institute

- 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

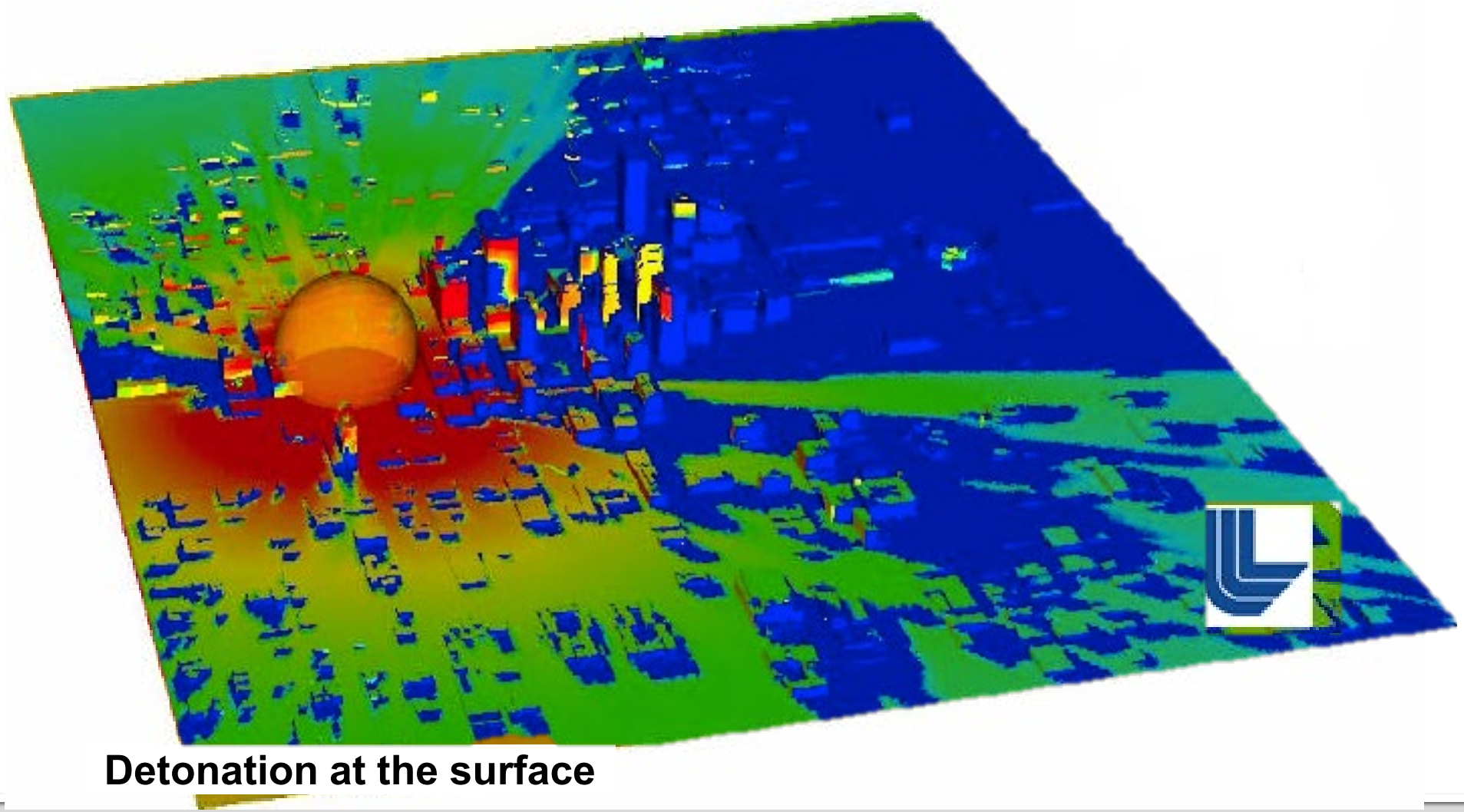
The pattern is from the dark colored areas on her kimono

Prompt thermal range not proportional to blast effects



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

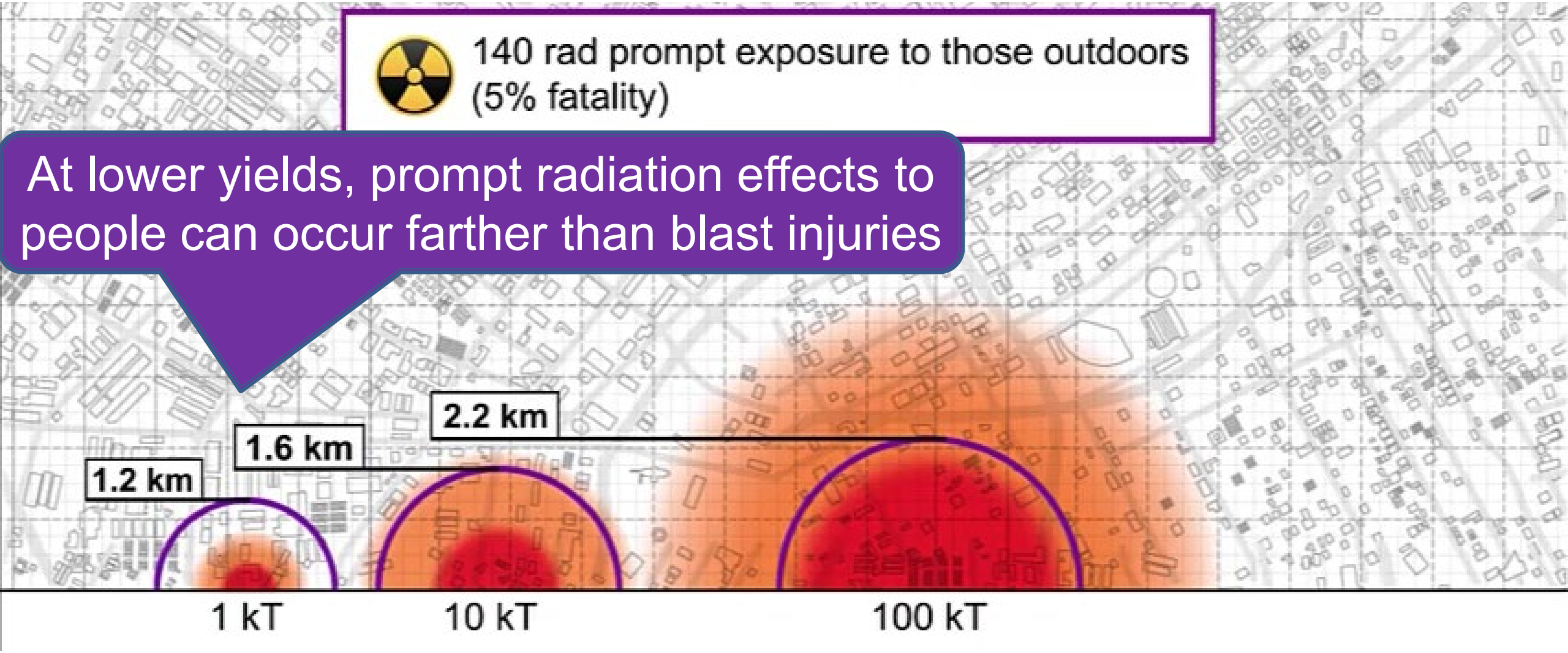
Accuracy of Thermal Ranges



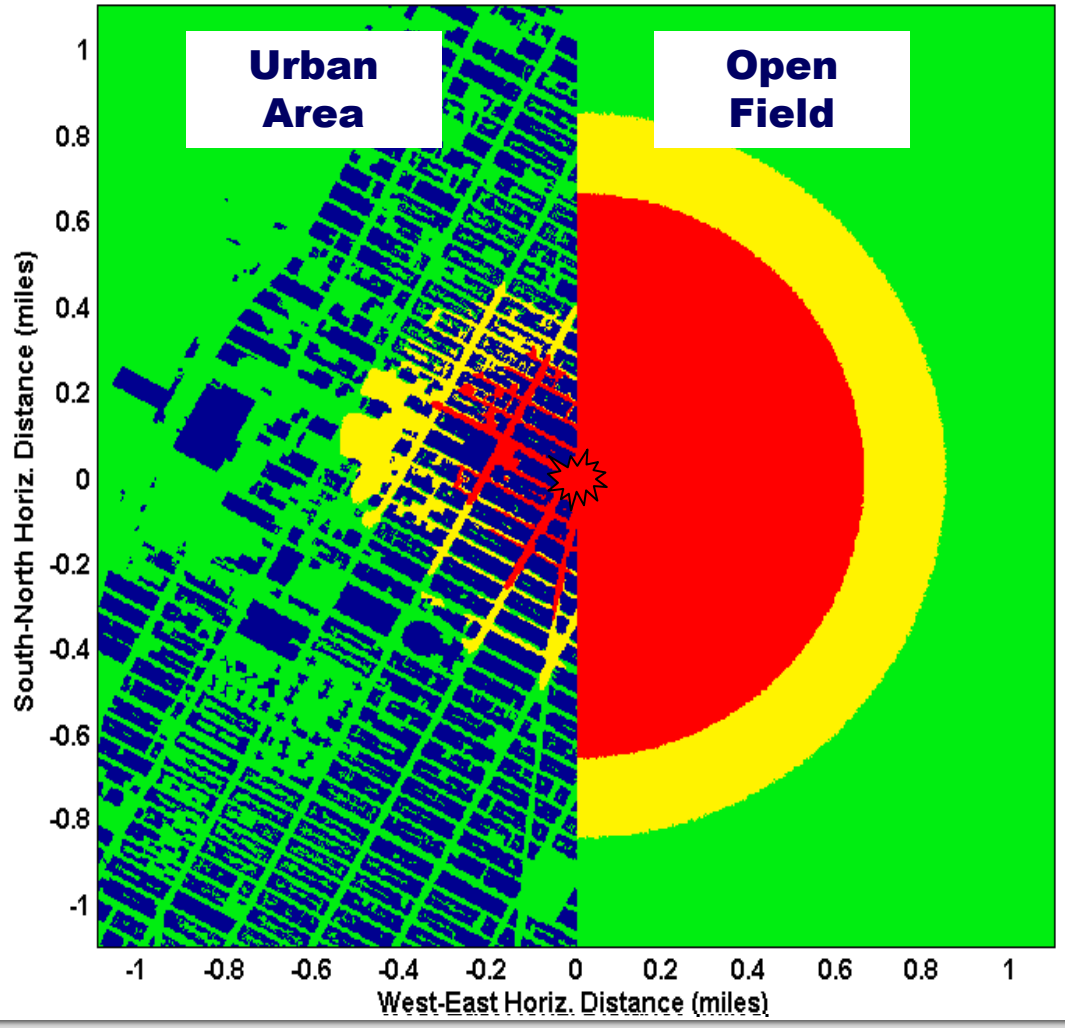
Detonation at the surface

Ionizing Radiation Effects

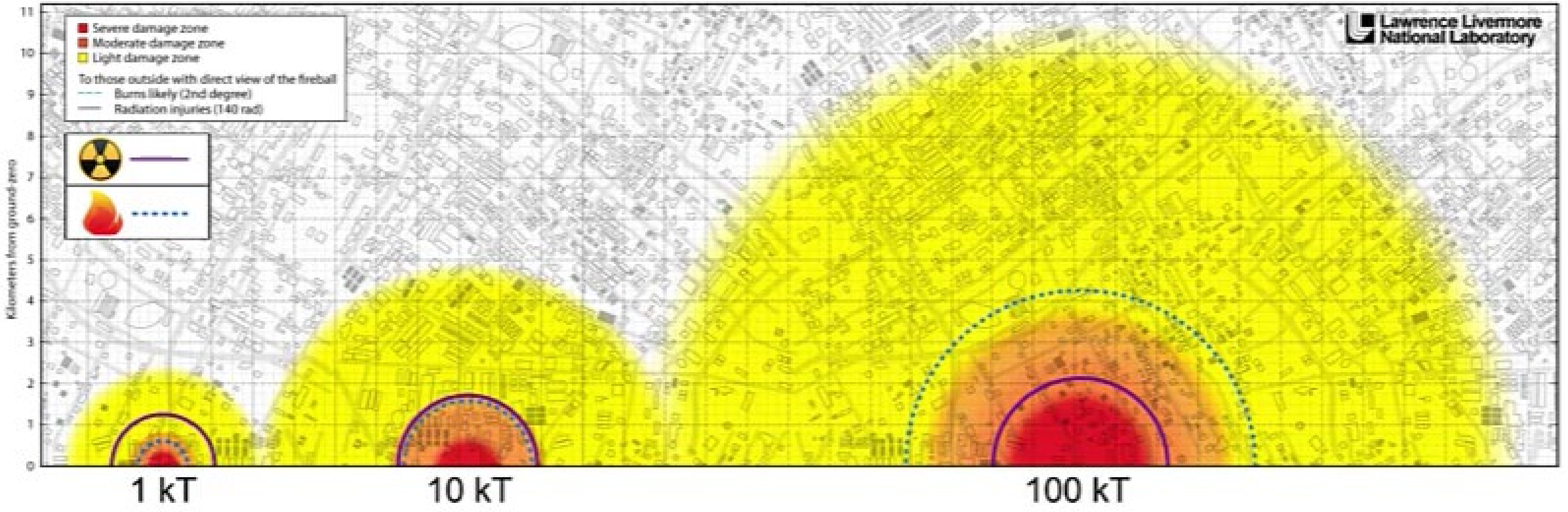
Prompt radiation range not proportional to blast effects



Accuracy of Prompt Radiation Ranges

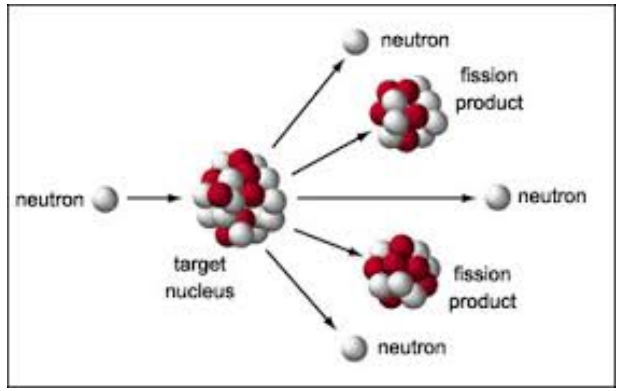


Range of Prompt Thermal and Radiation Compared to Blast



Fallout

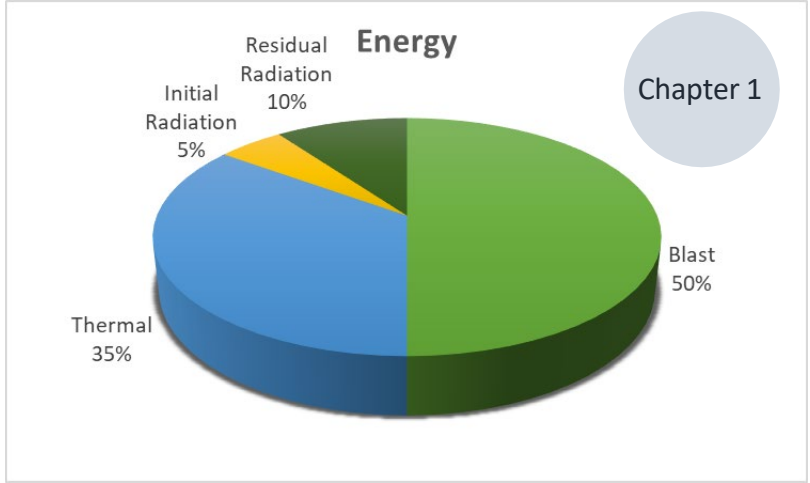
Residual Radiation (Fallout)



Nuclear Fission Produces:

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

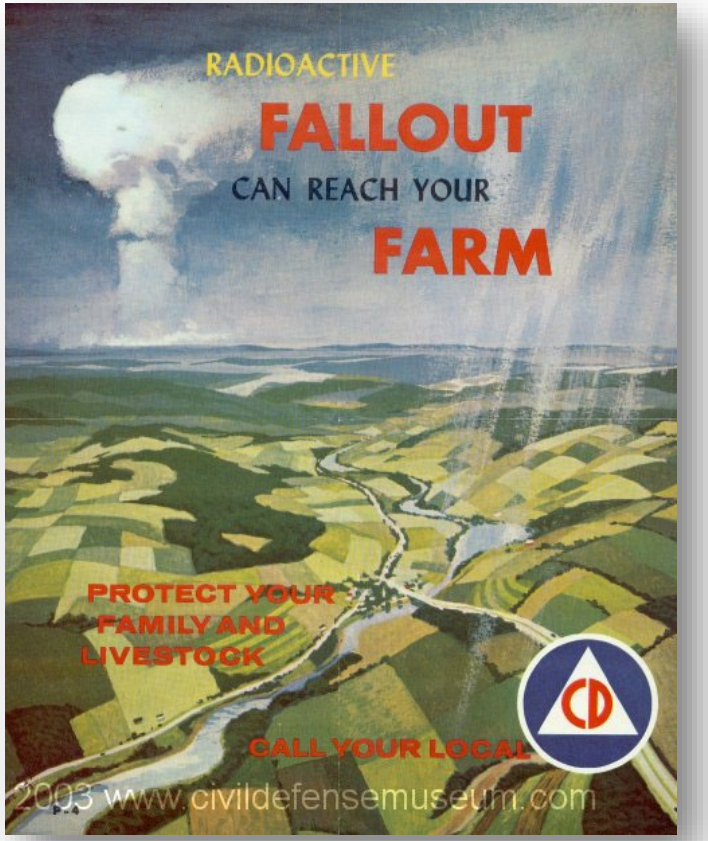
Fissile atoms, like uranium, split into 2 (or more) smaller **radioactive** elements which continue to give off **residual** energy



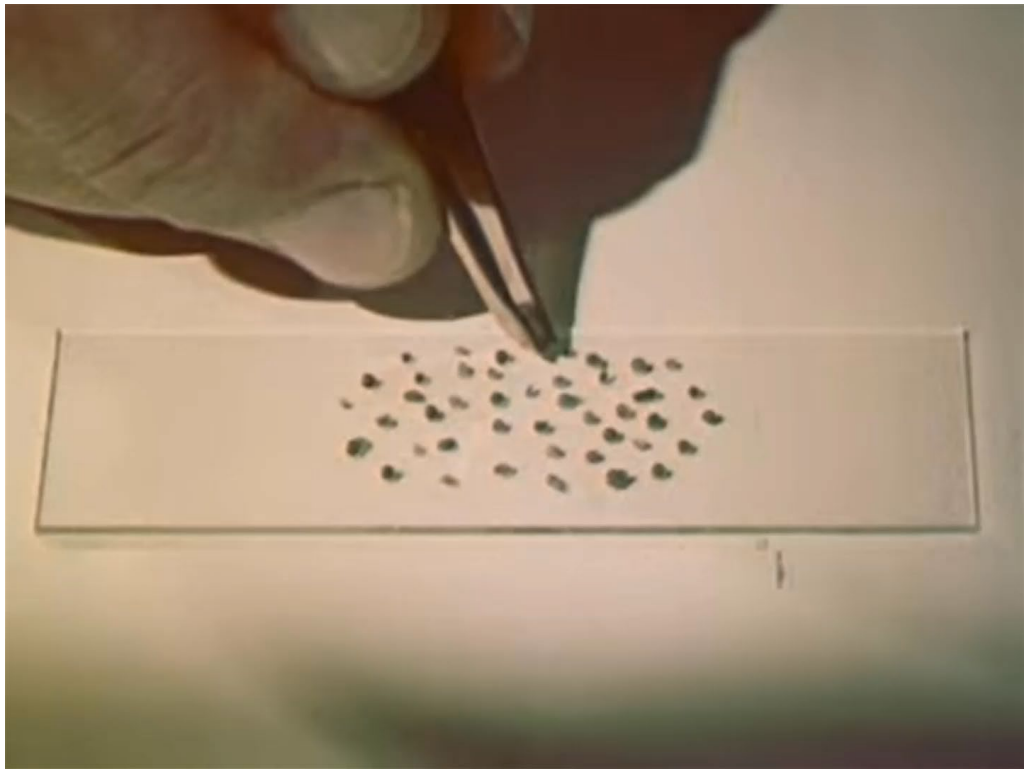
- The burned nuclear fuel (Uranium or Plutonium) from a 10kt nuclear explosion will produce about 500 grams (20 oz) of fission products.
- 1 minute after detonation there would be ~ 1 x 10^{22} Bq [10,000,000,000,000,000,000,000 Bq] (disintegrations per second).
- This is more than 1,000 times the radioactivity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

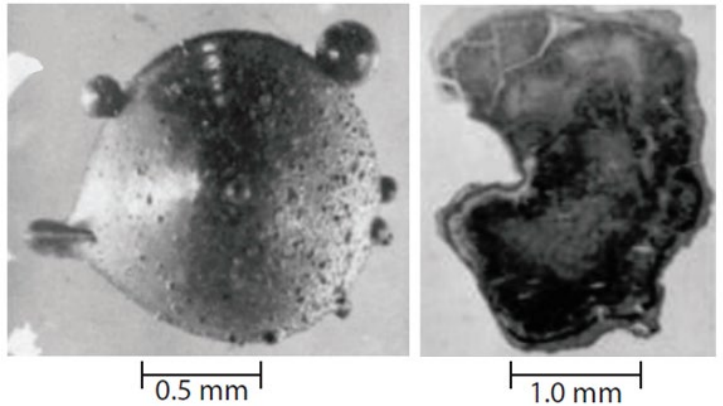
Fallout

- 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



What is Fallout?





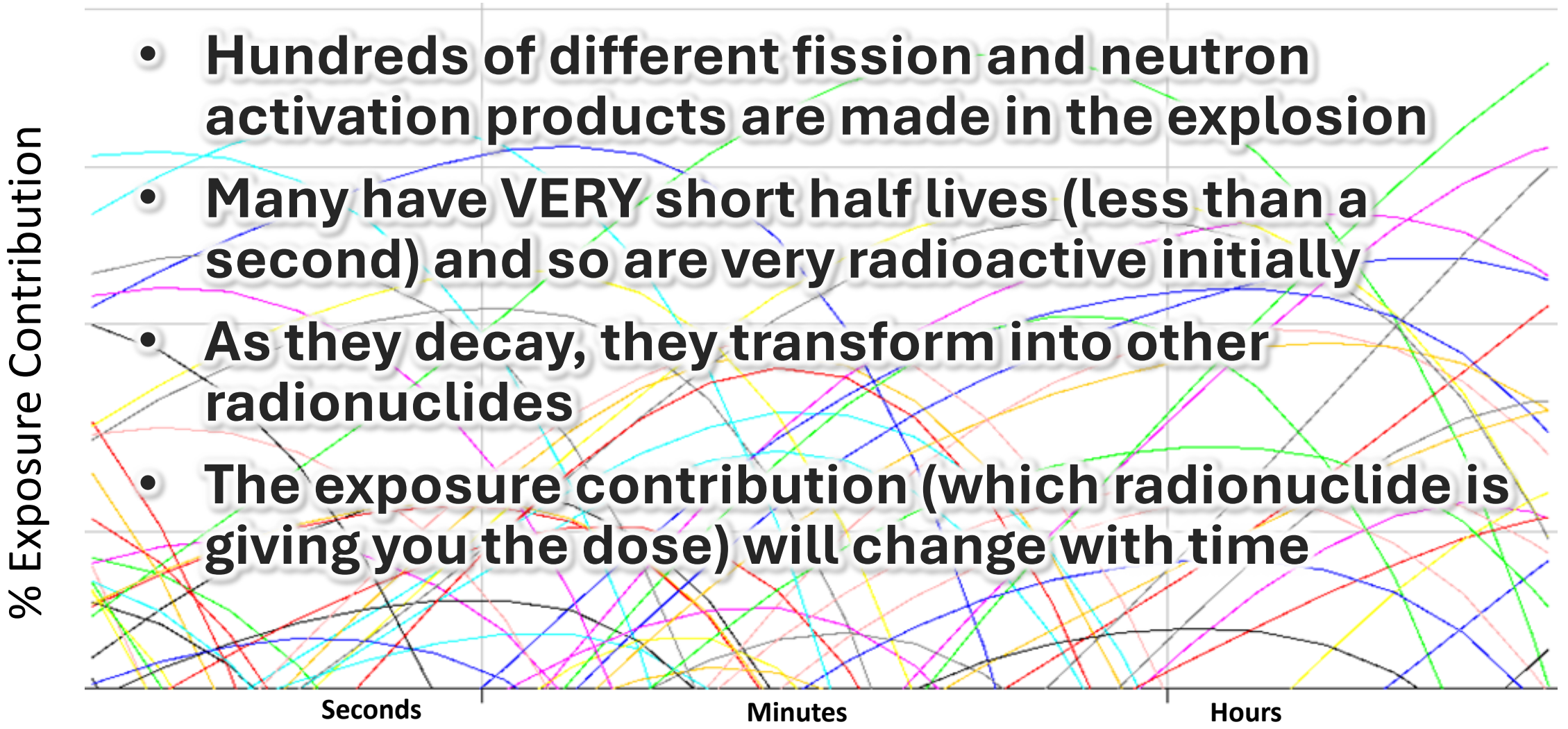
- A fireball is hotter than the sun is comprised of a plasma that contains all the fission products produced in the explosion.
- The fireball can interact with the ground.
- The rapid rise of the fireball (> 100s kph) creates a vacuum that pulls up thousands of tons of dirt and debris.
- If the dirt 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.

Pop Quiz!

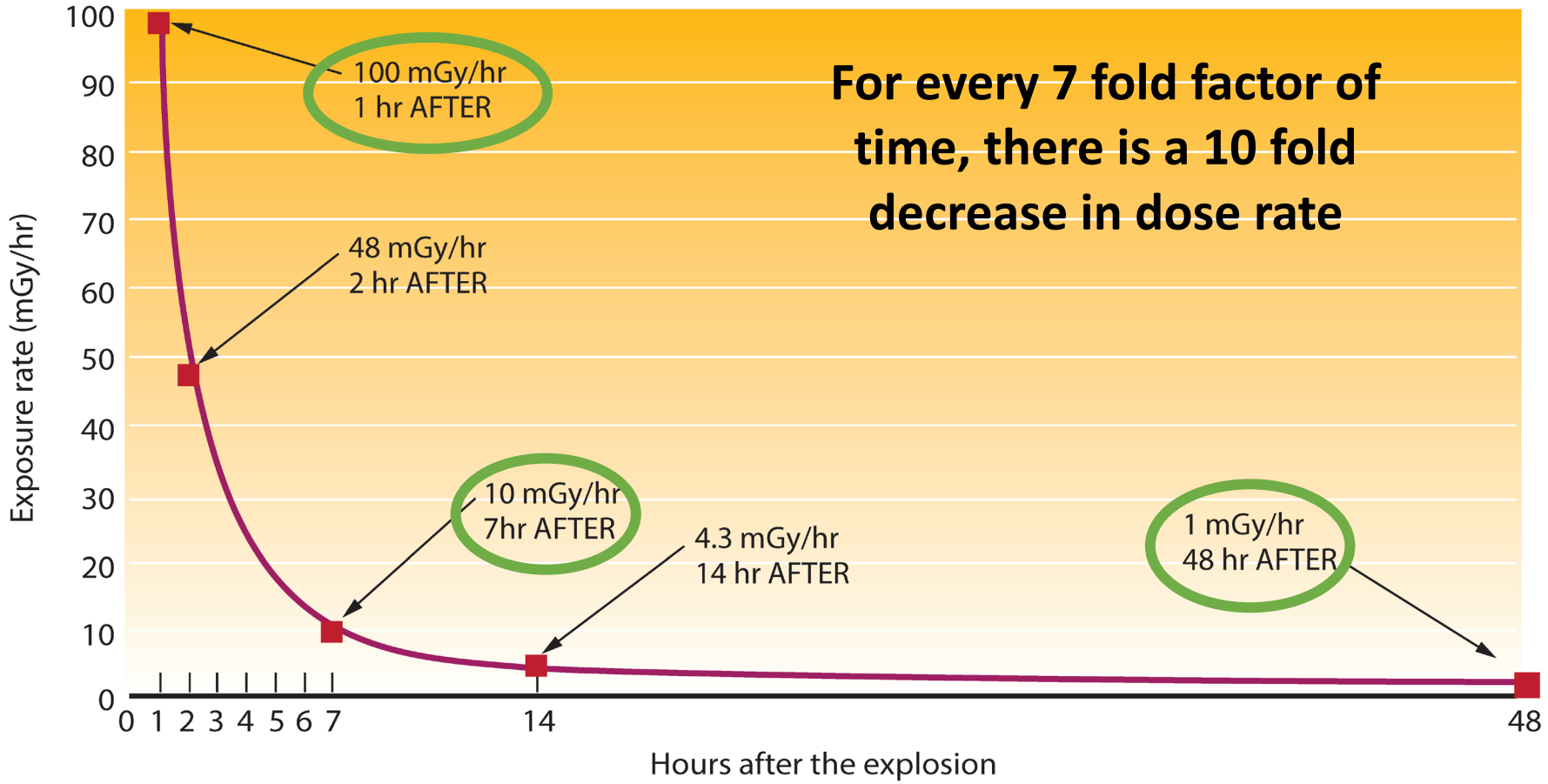
What is main radionuclide in fallout?

What is Fallout?

- Hundreds of different fission and neutron activation products are made in the explosion
- Many have VERY short half lives (less than a second) and so are very radioactive initially
- As they decay, they transform into other radionuclides
- The exposure contribution (which radionuclide is giving you the dose) will change with time



Fallout Radiation Levels with Time



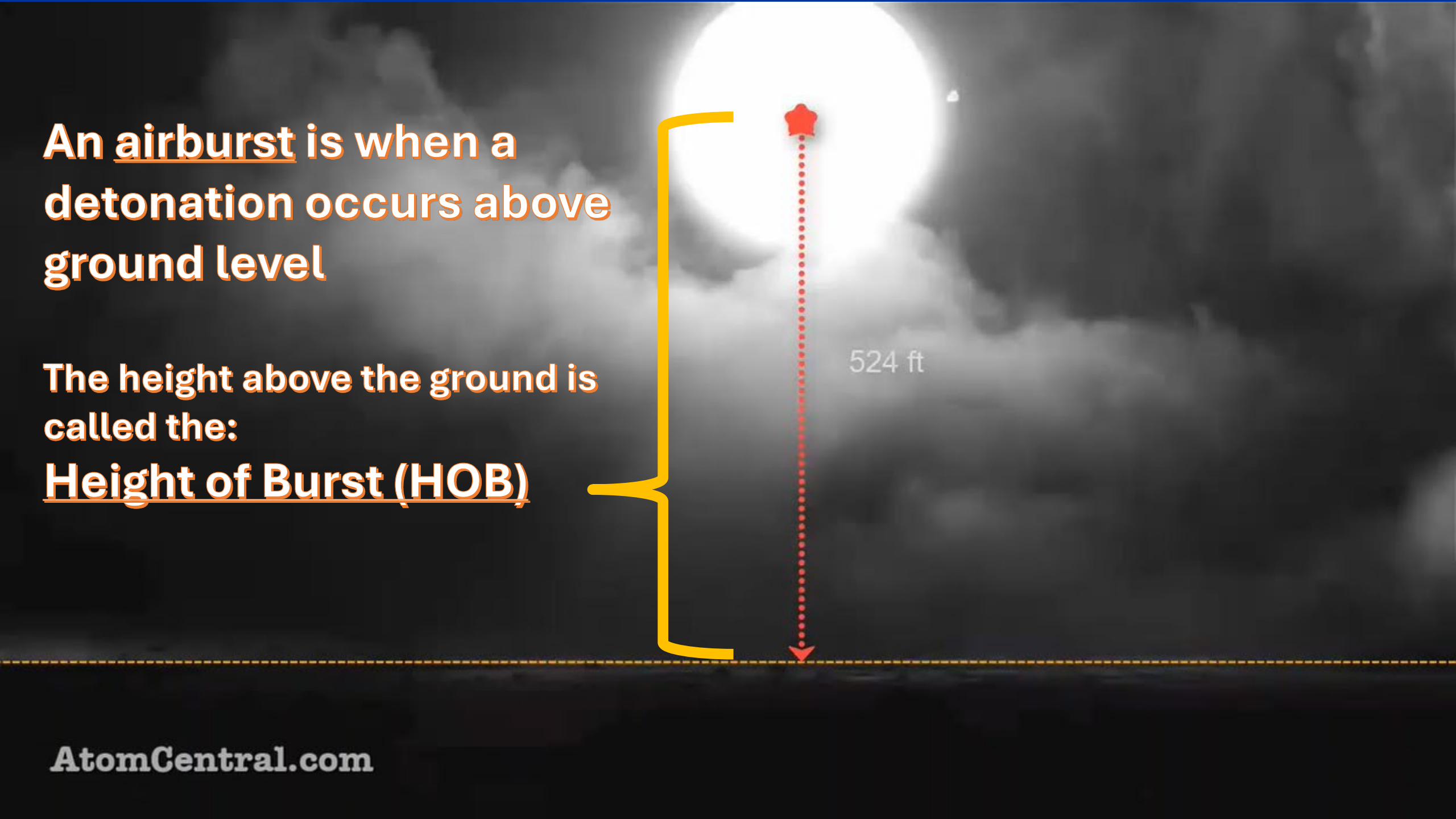
Decay of the dose rate of radiation from fallout, from the time of the explosion, not from the time of fallout deposition.

Height of Burst

An airburst is when a detonation occurs above ground level

The height above the ground is called the:

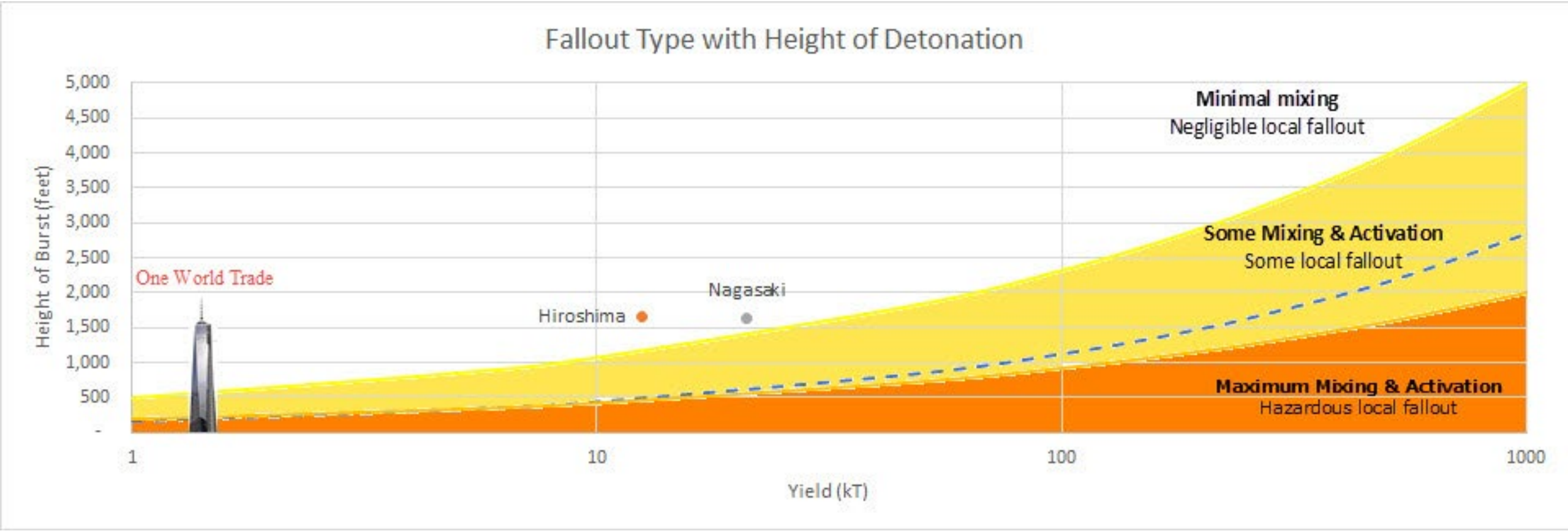
Height of Burst (HOB)



Pop Quiz!

What is the definition of “Fallout Free Height of Burst”?

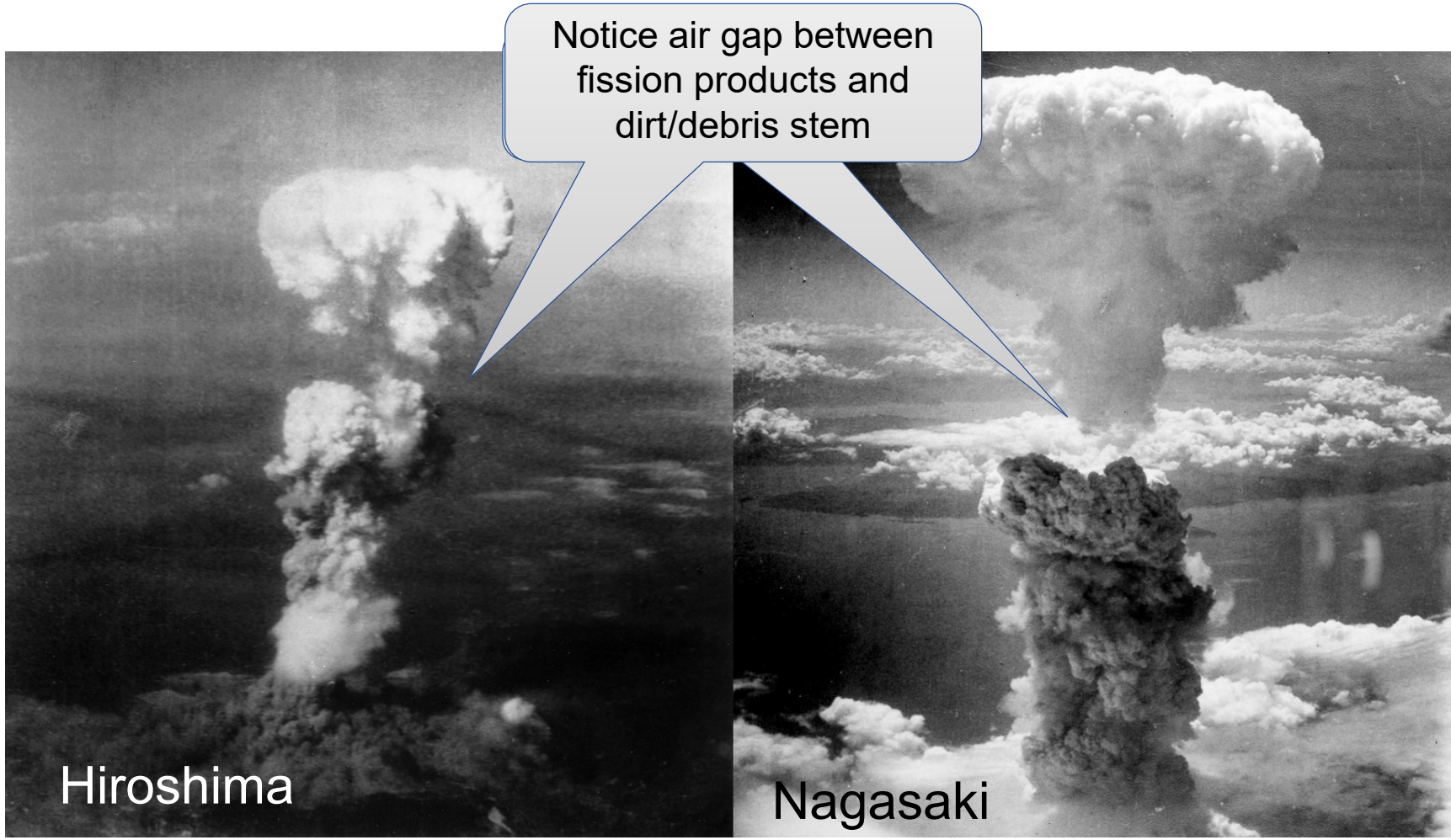
Fallout Type with HOB & Yield



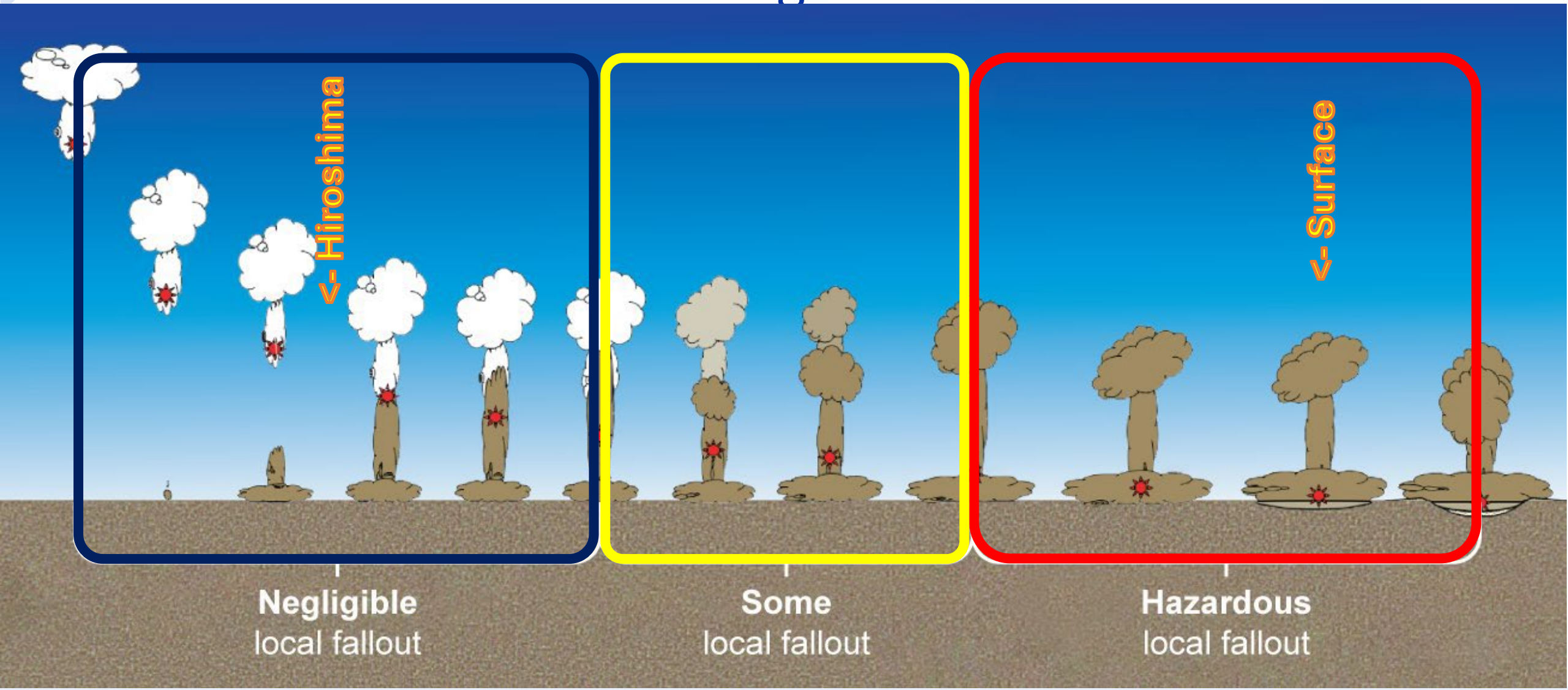
- - - - - Glasstone & Dolan Fallout Free HOB ($H=Y^{0.4}$), when local fallout "ceases to be a serious problem."

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.



How Fallout Relates to Height of Burst



Upshot-Knothole Encore

27 kt, Airburst 2423', 8 May 1953

Negligible Local Fallout

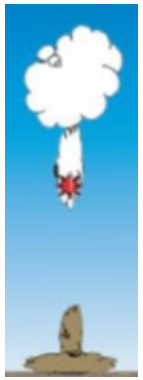


Photo courtesy of National Nuclear Security Administration / Nevada Field Office.
Photo Library under number UK-53-105.

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

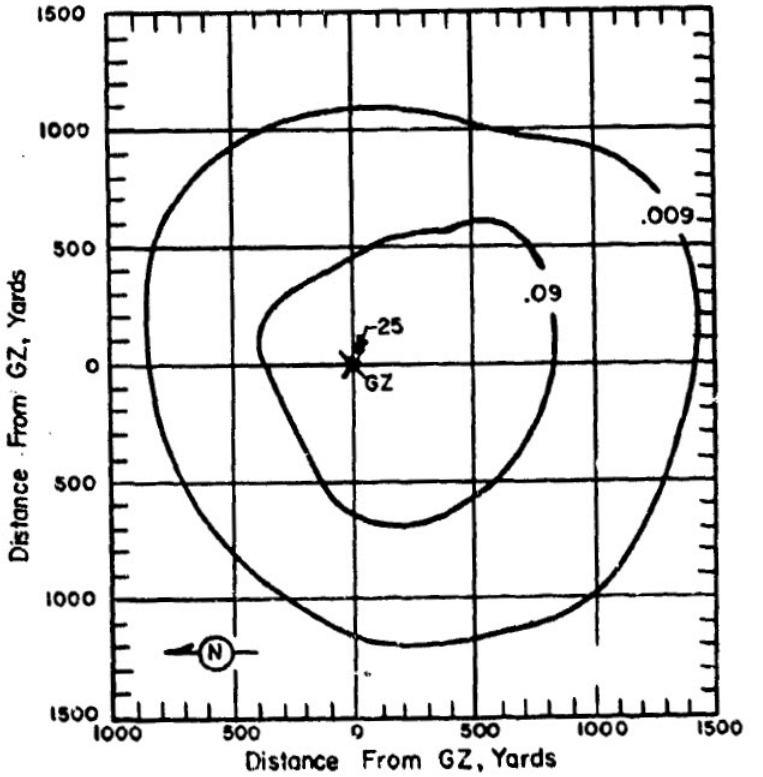


Figure 96. Operation UPSHOT-KNOTHOLE - Encore.
On-site dose rate contours in r/hr at H+1 hour.

Residual Radiation: Neutron Activation

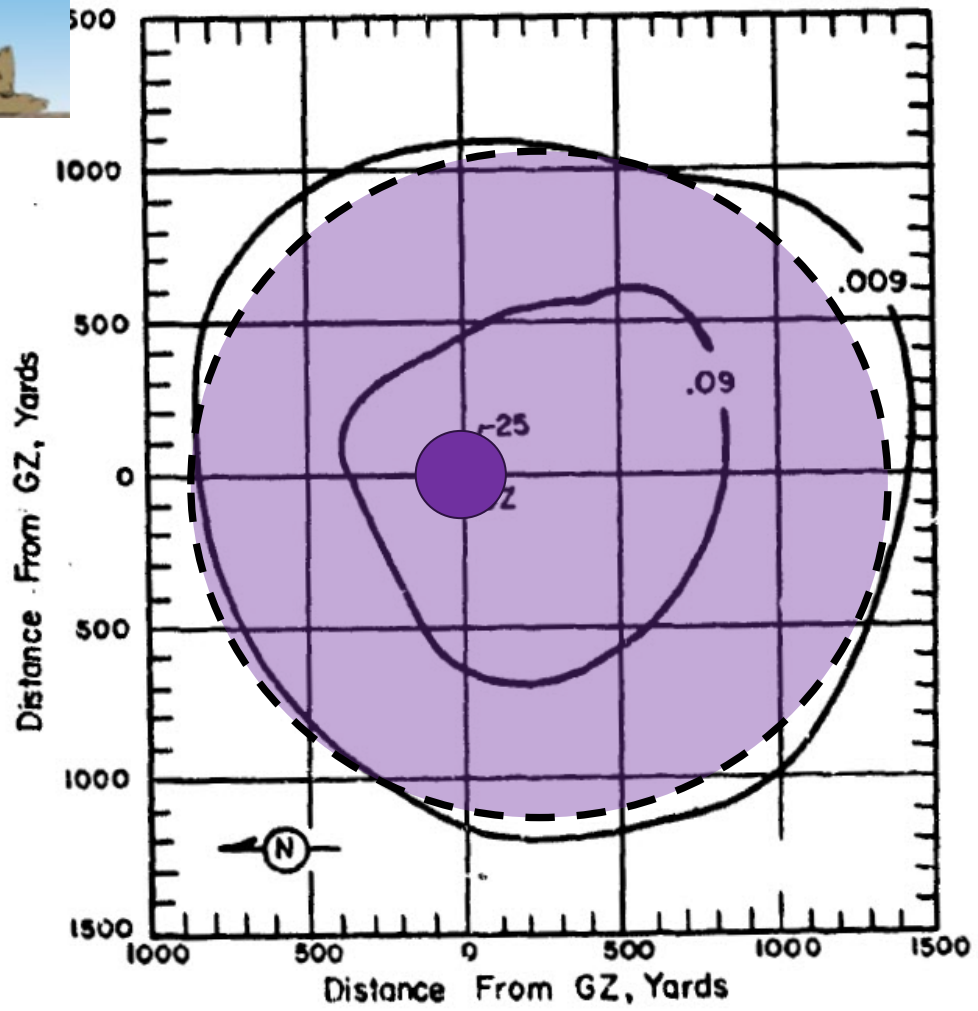


Figure 96. Operation UPSHOT-KNOTHOLE - Encore. On-site dose rate contours in r/hr at H+1 hour.

- 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)

data from DASA-1251

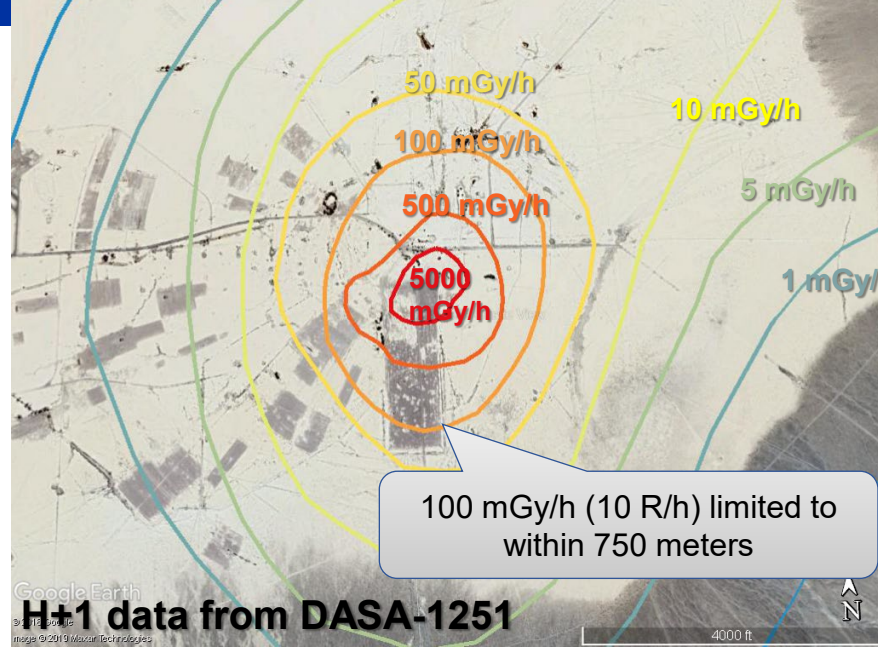
Priscilla “Partial Mixing” Detonation

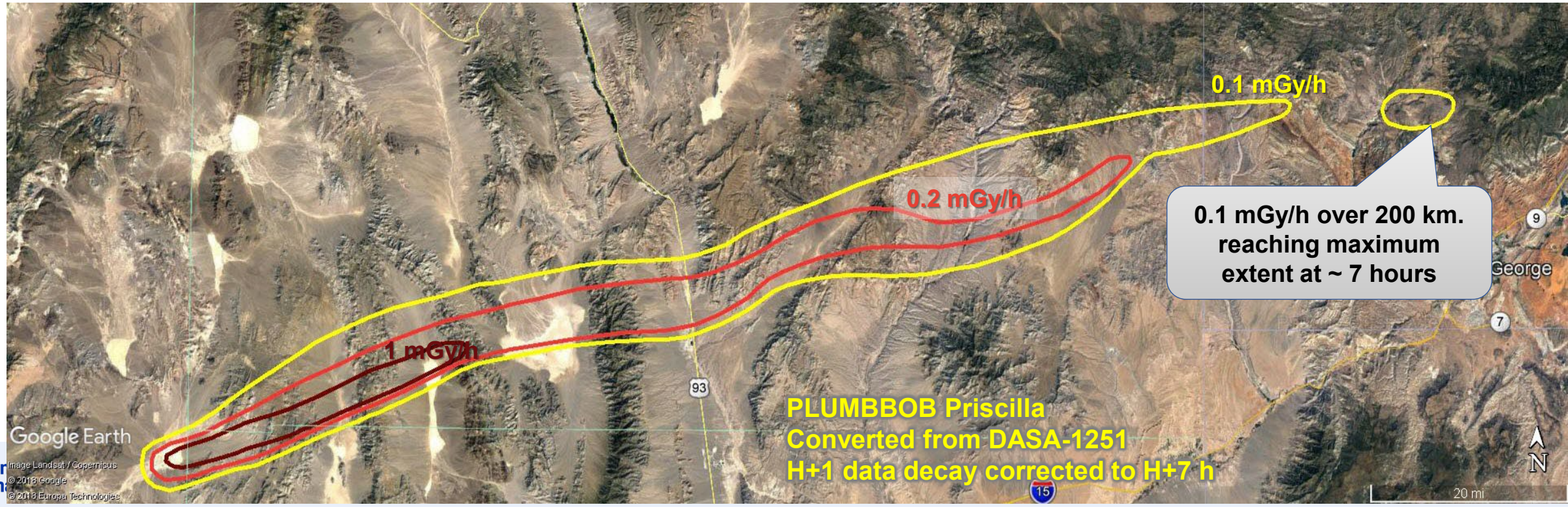
Some Local Fallout

Plumbbob Priscilla Test

37kt detonated at 700 ft

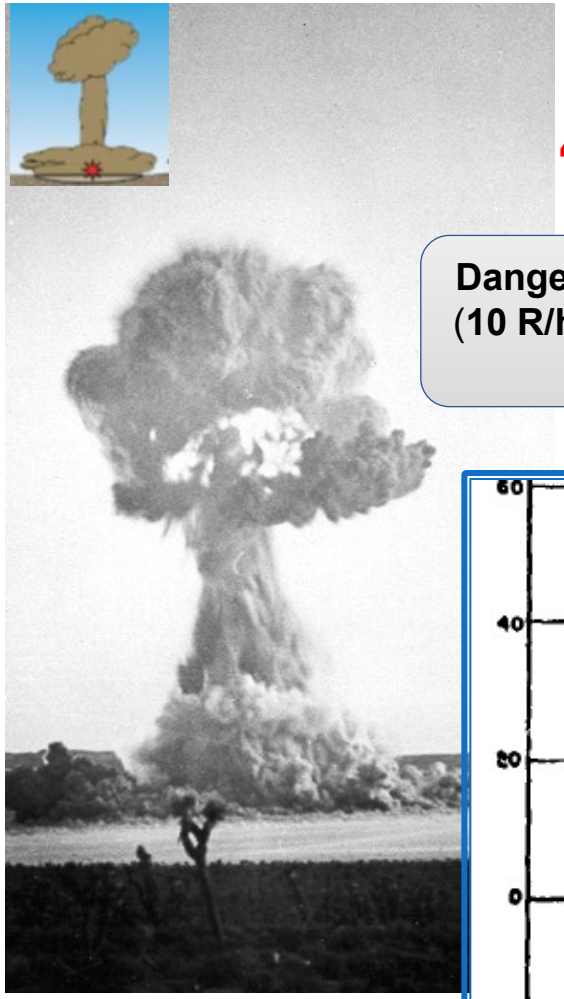
(fallout free height is 760 ft for 37kt)





Simon “Significant Mixing” Detonation

Hazardous Local Fallout

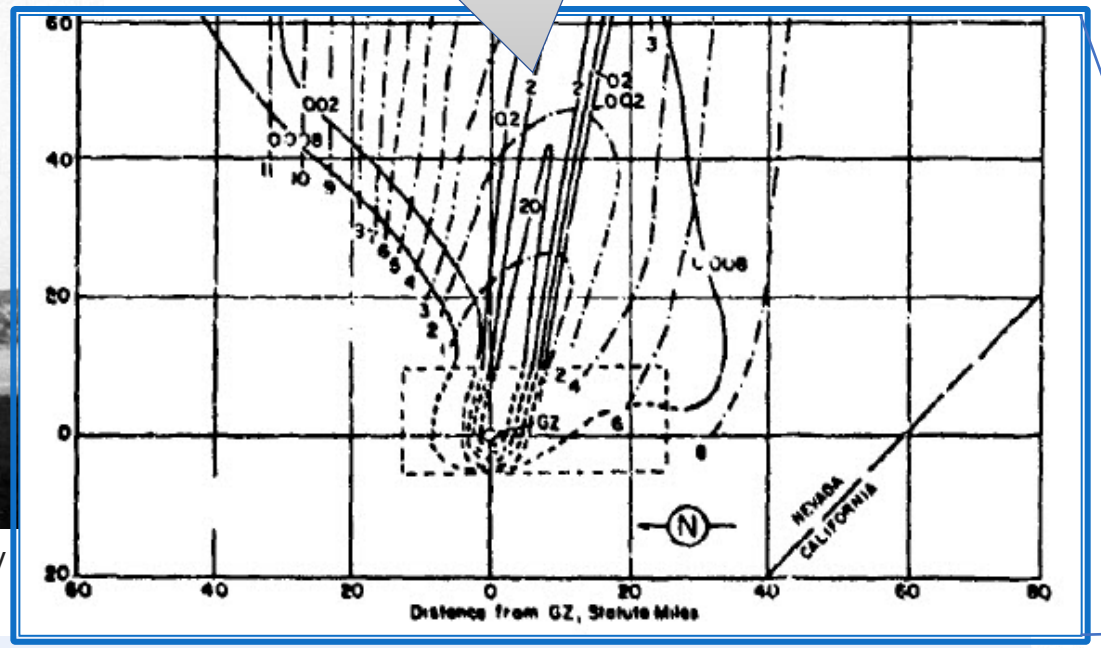


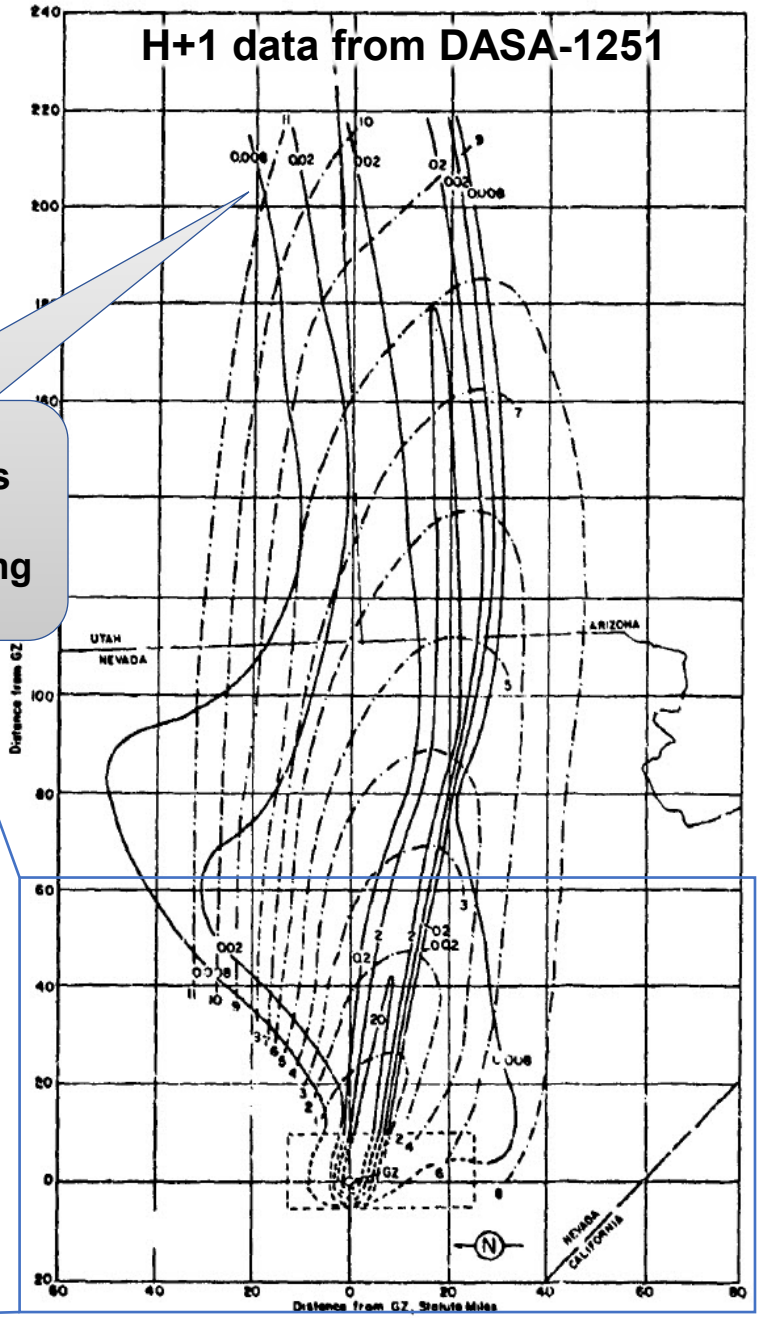
Nevada Site Office Photo Library under number UK-53-102

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

Dangerous Radiation 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

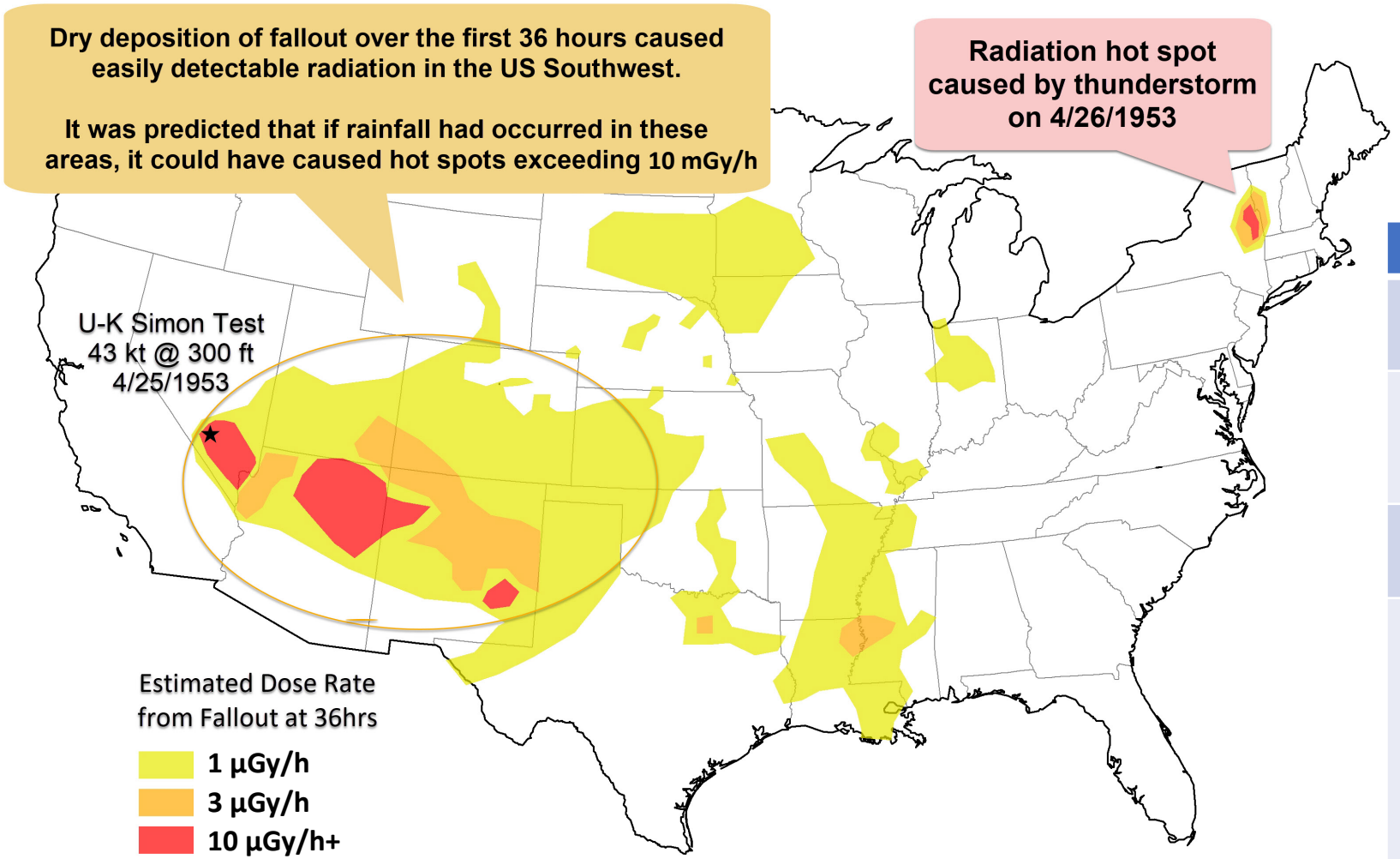




igure 93. Operation UPSHOT-KNOTHOLE - Simon
Off-site dose rate contours in r/hr at H+1 hour.

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

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)

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.

Key Findings

- 100,000s of casualties can be significantly reduced through proper action (both individual action and leadership)
- First hour most critical, a prepared response community is needed (a prepared public would also be helpful)
- Public Protection Strategy: Early, adequate shelter followed by delayed, deliberate evacuation

Questions?

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

Knowledge Check | Quiz—Damage Zones

You are in an area where

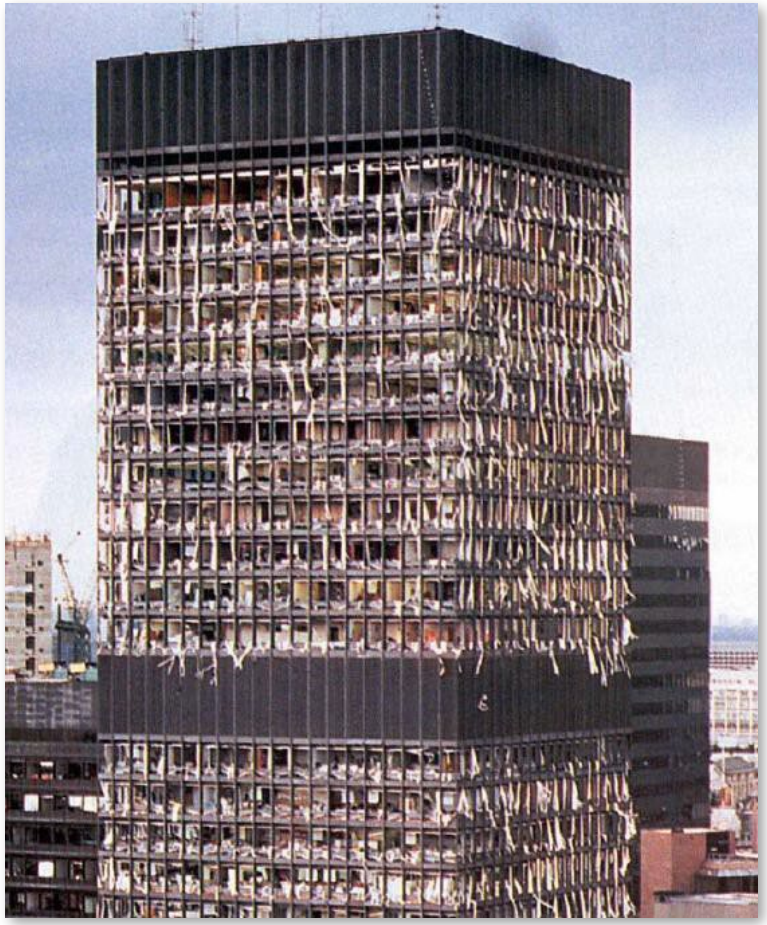
- about 25% of building windows are broken, primarily on the building walls facing the direction of the detonation.
- There do not appear to be any injuries.

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)

Recognizing the Light Damage Zone (LDZ)

- 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 (SDZ)

- 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

Knowledge Check | Quiz—Fallout

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

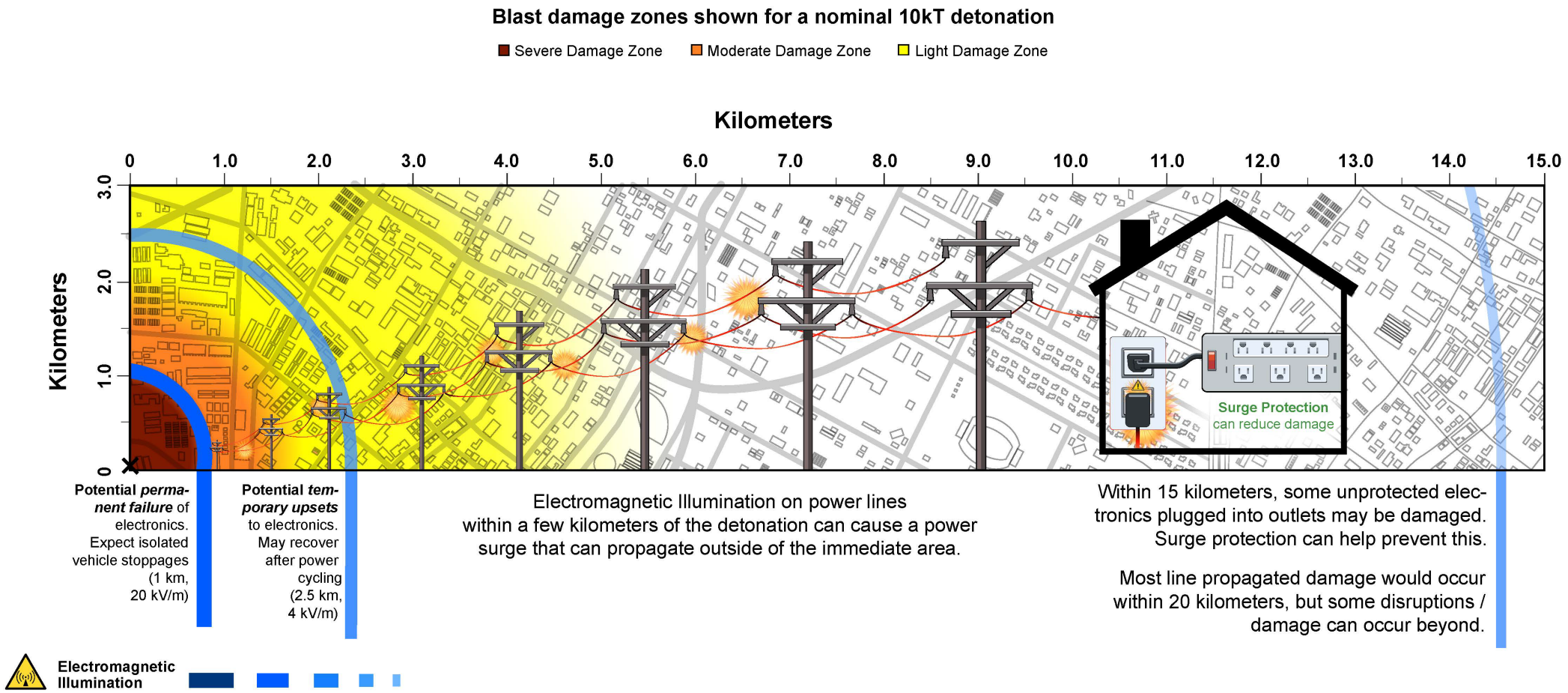
- Although the nuclear detonation will always produce fission products, the amount that will fall to the ground depends on how much dirt is drawn up into the fireball.
- A white cap disconnected from the dirt stem is a good indication there **NOT** be hazardous levels of local fallout.

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.

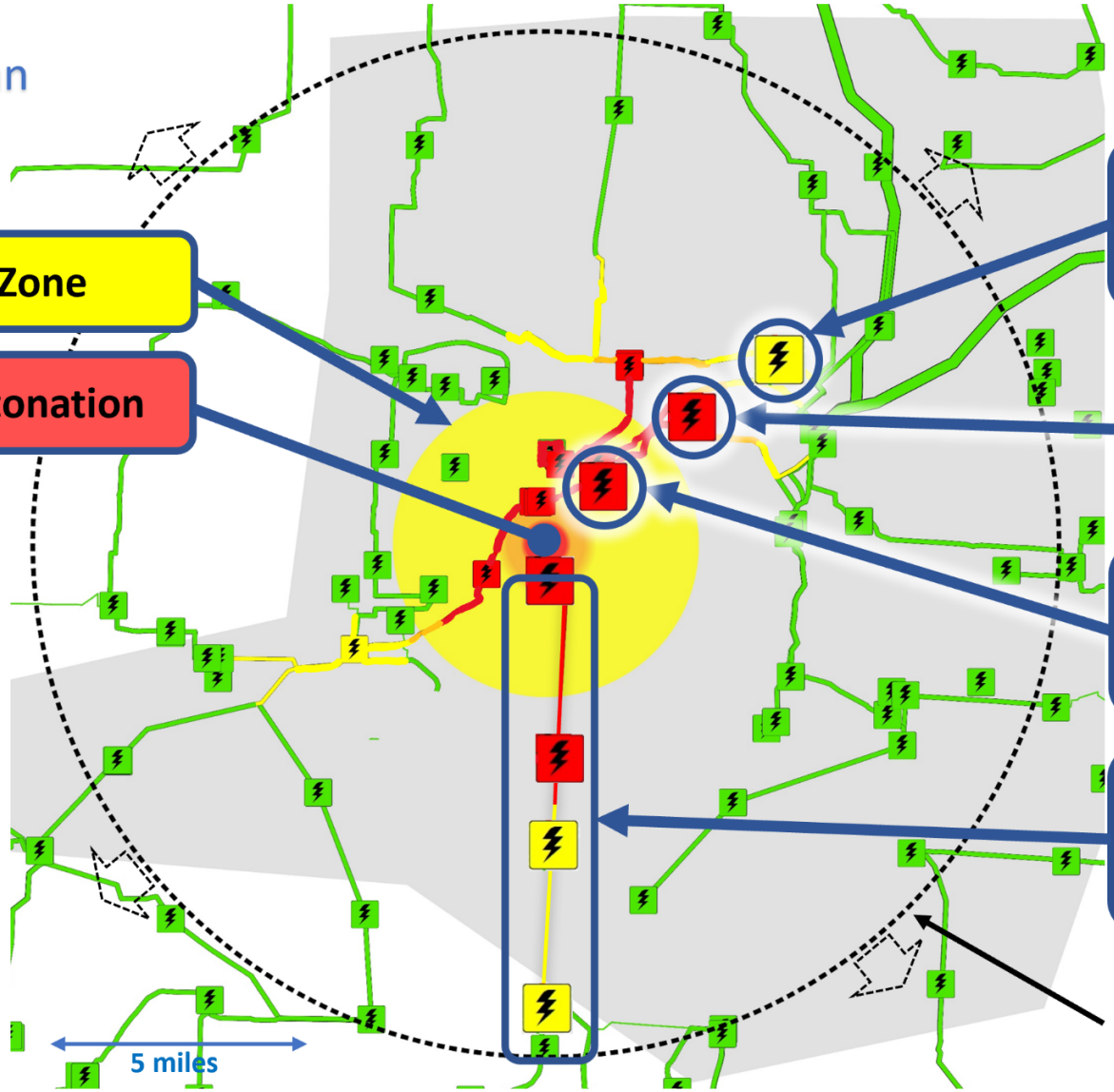
Electromagnetic Pulse from Near Earth Detonations (< 5 km Height of Burst)



Transmission line resistance and junctions reduce the distance at which surge impacts are expected

Notional Urban Power Grid

Artist's interpretation of Source Region Electromagnetic Pulse (SREMP) impacts



Blast Damage Zone

Notional 10kt Detonation

Substations

- Damaged
- Upset
- Not Affected

Transmission Lines

- Significant Surge
- Moderate Surge
- No or Minimal Surge

Circuit Breaker / Protective Equipment trip (temporary upset)

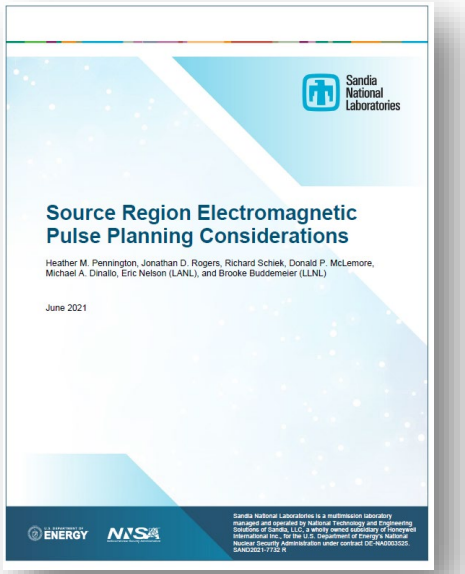
EMP line coupling causes relay burnout (permanent failure until repaired)

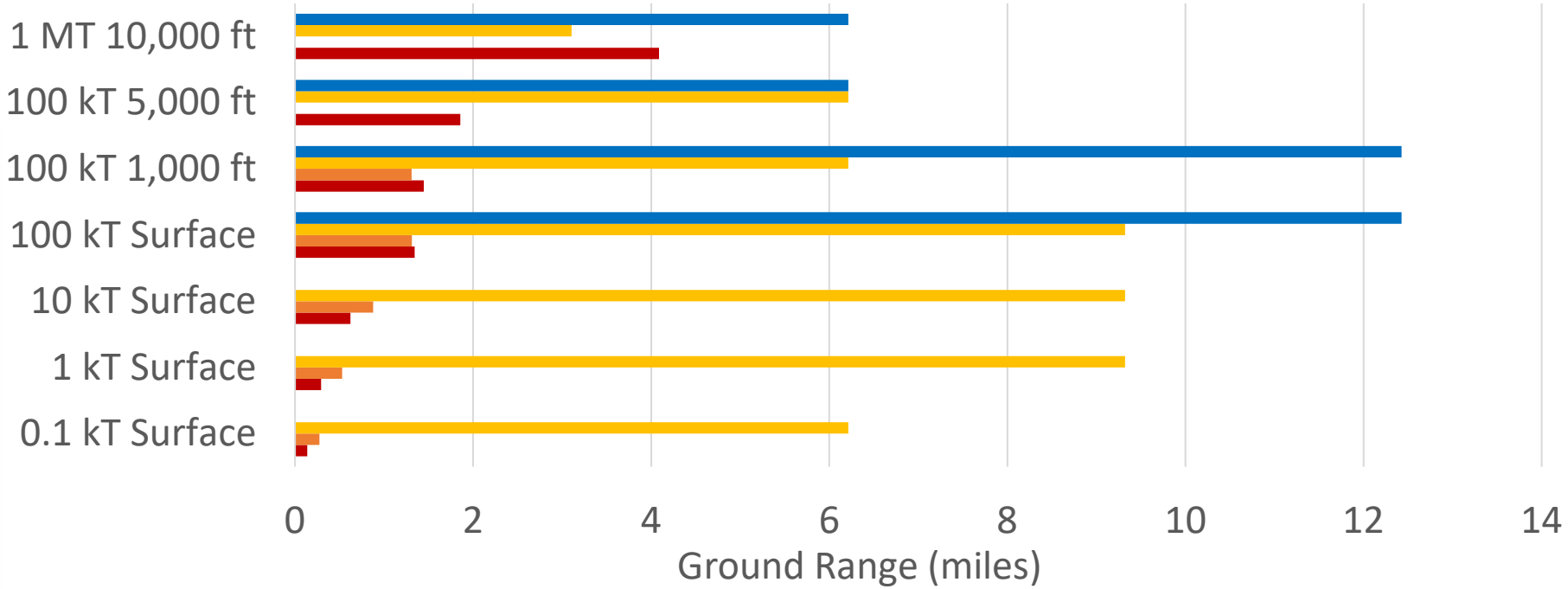
Blast Effects causes Substation Damage (permanent failure until repaired)

Long running, non-branching transmission lines can create some impacts at long distances

Most line propagated damage would occur within 12 miles, but some disruptions/damage can occur beyond

EMP Ranges Not Very Yield Dependent





- High voltage transmission line propagation will cause electric grid substation burnout/damage. Power outages likely to occur outside this range.
- 1 Joule line induced surge can potentially permanently damage unprotected equipment plugged into the wall-socket due to coupling into the grid.
- 20 kV/m EM illumination and coupling into the grid can cause permanent failure to some electronics.

Decontamination Issues

Fallout Decon

Entering Shelter

Actual Fallout Decon

- Simple self-decontamination techniques (such as removing outer clothing, showering, and brushing away fallout material) are effective.
- Techniques should be used as the impacted population leaves the high-hazard zone or enters a shelter

Quiz: Evaluate the Following Statement

Radioactive Contamination is Highly Dangerous and Requires Extraordinary Protective Measures

Fact 1

"Skin or wound contamination is never immediately life threatening to affected people or medical personnel"

~ International Commission on Radiological Protection, report # 96

Quiz: Evaluate the Following Statement

Decontamination of the Patient is the Highest Medical Priority

Fact 2

"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

Quiz: Evaluate the Following Statement

You need “special skills” to handle radioactive patients

Fact 3

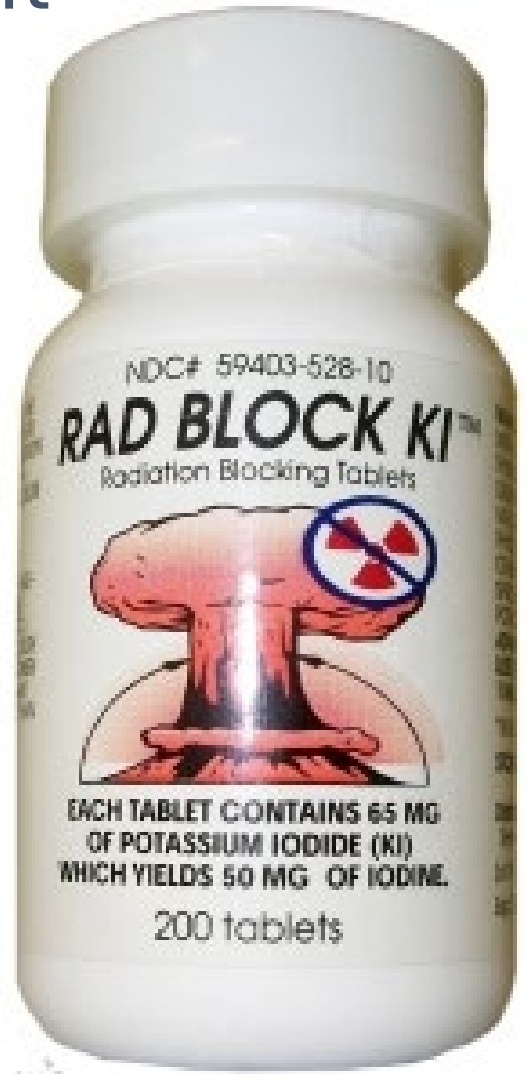
"Universal precautions (i.e., standard hospital personal protection procedures) in the emergency room are generally sufficient for treatment of victims of nuclear and radiological incidents"

~ National Council on Radiation Protection and Measurements, Commentary # 19

- Radioactivity can be easily and immediately measured with radiation meters (e.g., Geiger counters) are needed.
  - They are easy to use
  - Many hospitals already have them
  - Most fire departments now have meters
- Contamination surveys are easily taught and easily performed

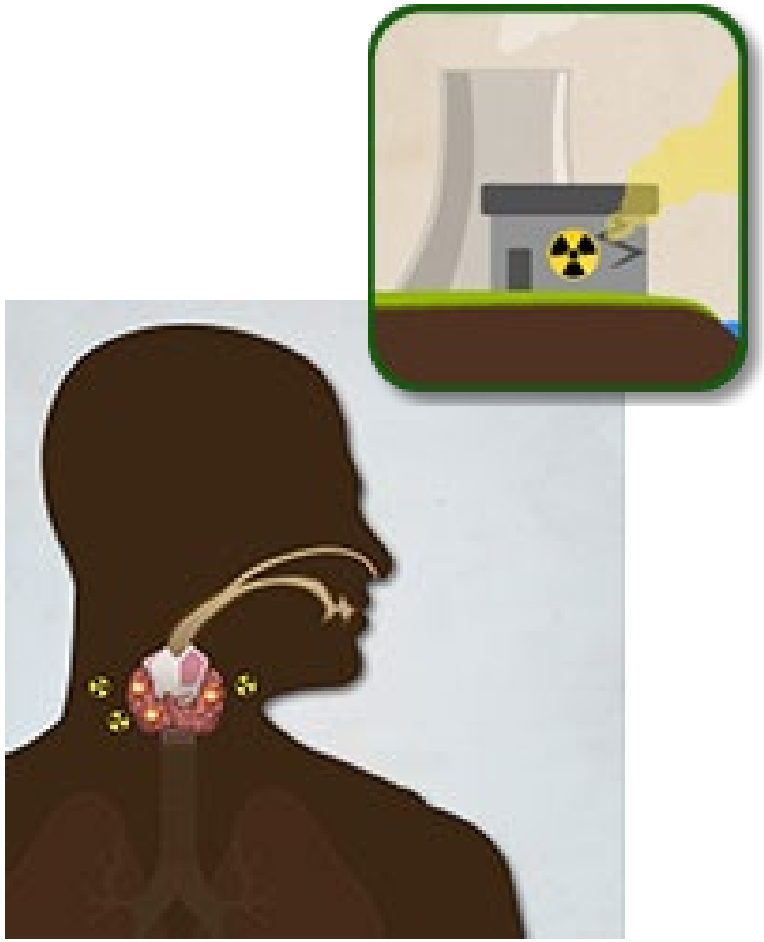
Quiz: Evaluate the Following Statement

Potassium Iodine (KI) Blocks Radiation from Nuclear Detonations



Get the Facts!

- **Potassium Iodine (KI) only reduces the absorption of radioactive Iodine into thyroid.**
- For a Nuclear Detonation, radioactive Iodine is NOT a significant hazard compared to external radiation.
- KI can be effective for nuclear power plant accidents which are more likely to release significant quantities of radioactive iodine (among other radionuclides).
- When a person takes KI, the stable iodine in the medicine gets absorbed by the thyroid, the thyroid gland becomes “full” and cannot absorb any more iodine, stable or radioactive. It is most effective when taken just before inhaling or ingesting radio-iodine, embargoing contaminated foodstuffs can be just as effective.



Click to

- 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