Flash Blindness

PRESENTED BY:

LTC Jeff Kendellen

Countering Weapons of Mass Destruction (CWMD) Planner, Defense Threat Reduction Agency (DTRA)

MODERATED BY:

Steve Redifer

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Homeland Defense & Security Information Analysis Center

Flash Blindness on the Battlefield

LTC Jeff Kendellen

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Agenda

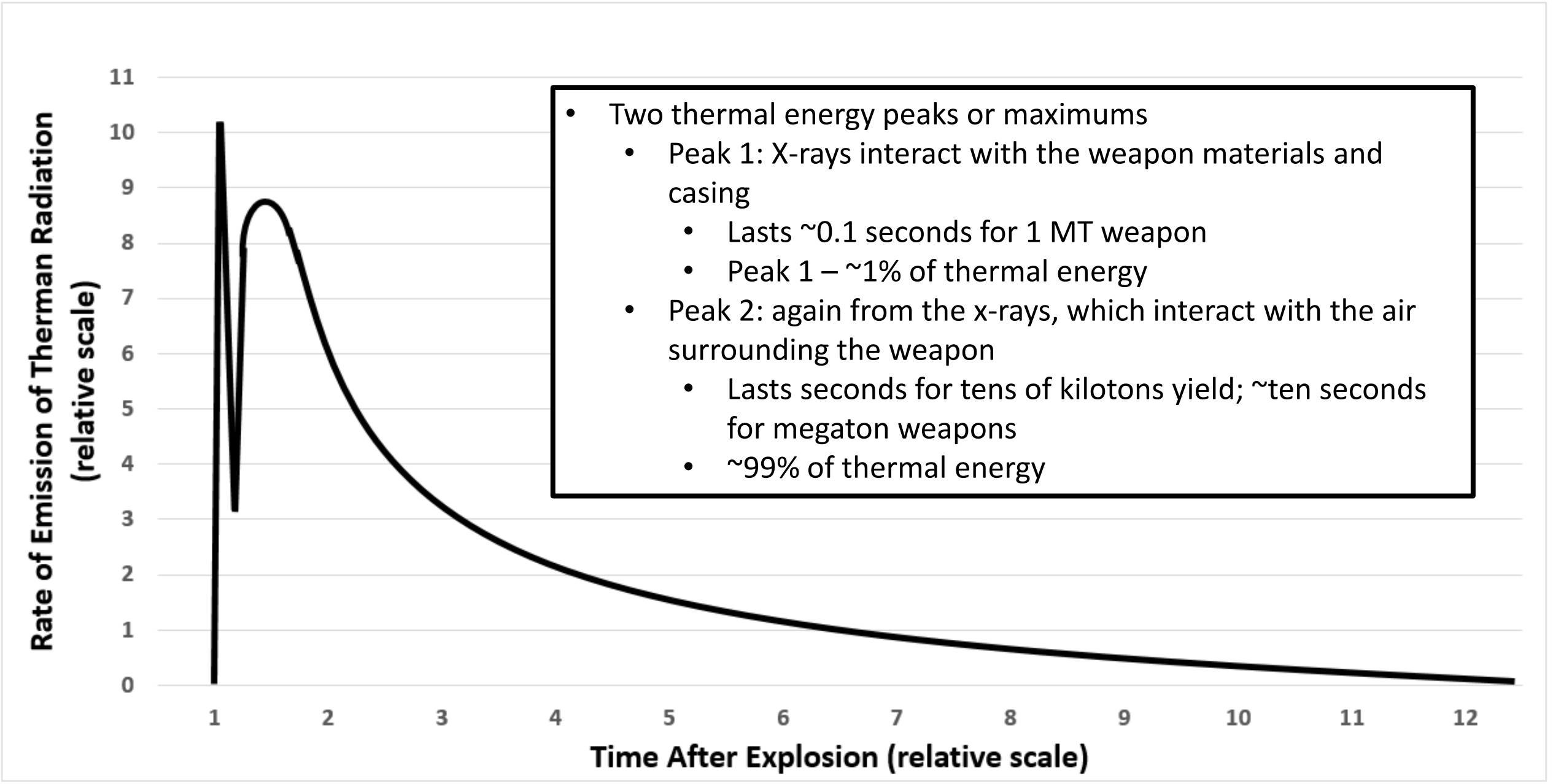
- Question: What is the risk of retinal burns or flash blindness to friendly troops following nuclear weapon use?
  - Nuclear weapon effects
  - Anatomy of the eye

  } Thermal effects on the eyes and injury mechanisms

  - Literature review; Airmen (in the air) versus soldiers (on the ground)
  - The answers…
  - Future research

Nuclear Weapon Effects - Thermal

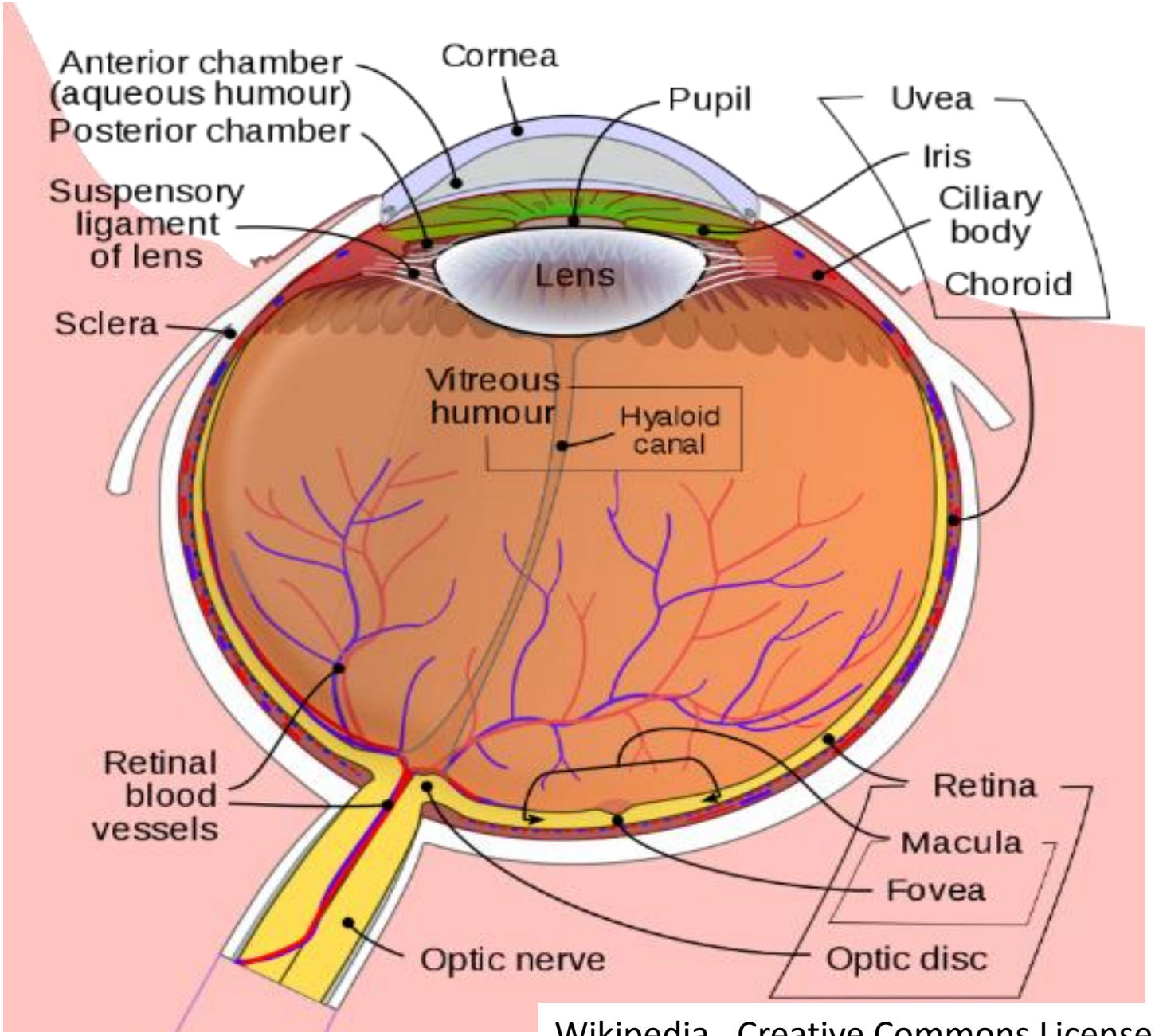
- ~35% of nuclear weapon output is thermal (i.e., light and heat)
- Thermal energy can extend well beyond blast and radiation effects
- Consequently, many kilometers away:
  - Eye injuries (retinal burns) and/or temporary blindness (flash blindness) can occur
  - Optical / sensor systems can be damaged
- Counterintuitive concepts
  - How does the $\frac{1}{r^2}$ concept apply?
  - What role does weapon yield play?



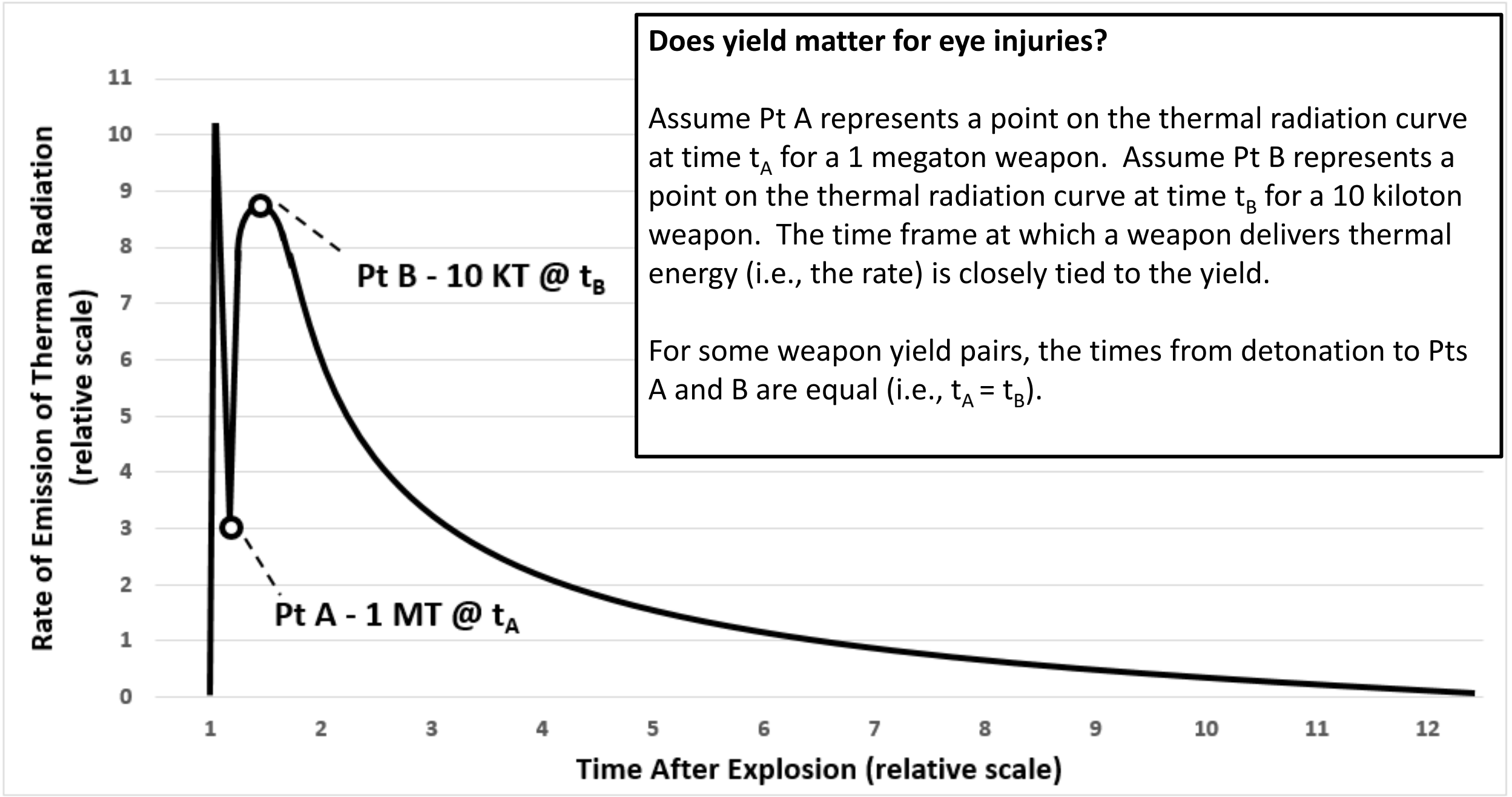
Glasstone & Dolan

Anatomy of the Eye

- Iris adjusts based on light conditions
  - Day – narrower - 2-3 mm diameter
  - Night – wider - 7-8 mm diameter
- Retina is made up of rods and cones
  - Fovea – only cones – visual acuity and color
  - Elsewhere – rods and cones
- Night vision
  - Eye adapts using photo pigment
  - Pupil 16x larger at night
- Protective features
  - Redundancy
  - Eye lids (~0.1 sec closure time)



Wikipedia. Creative Commons License

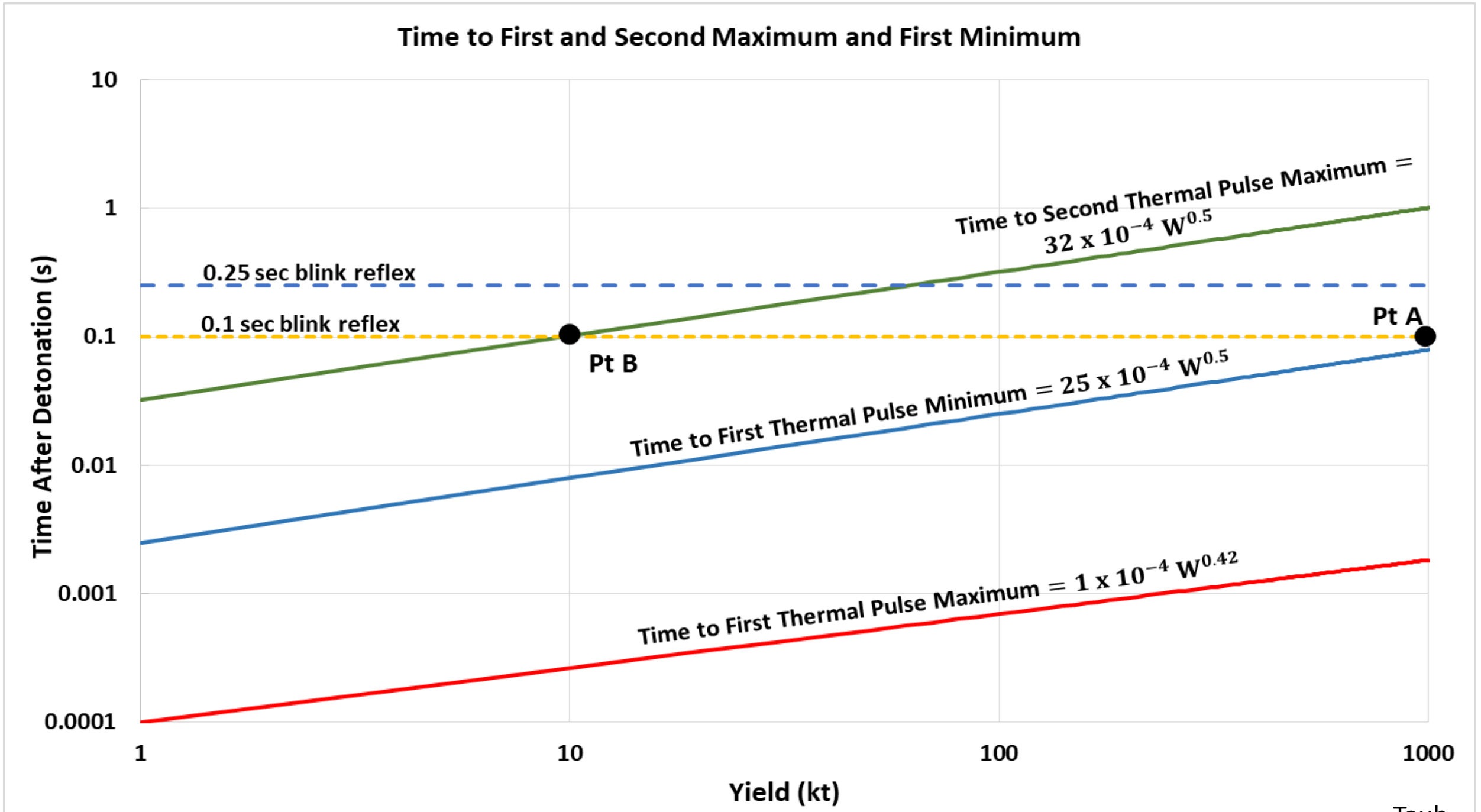


Does yield matter for eye injuries?

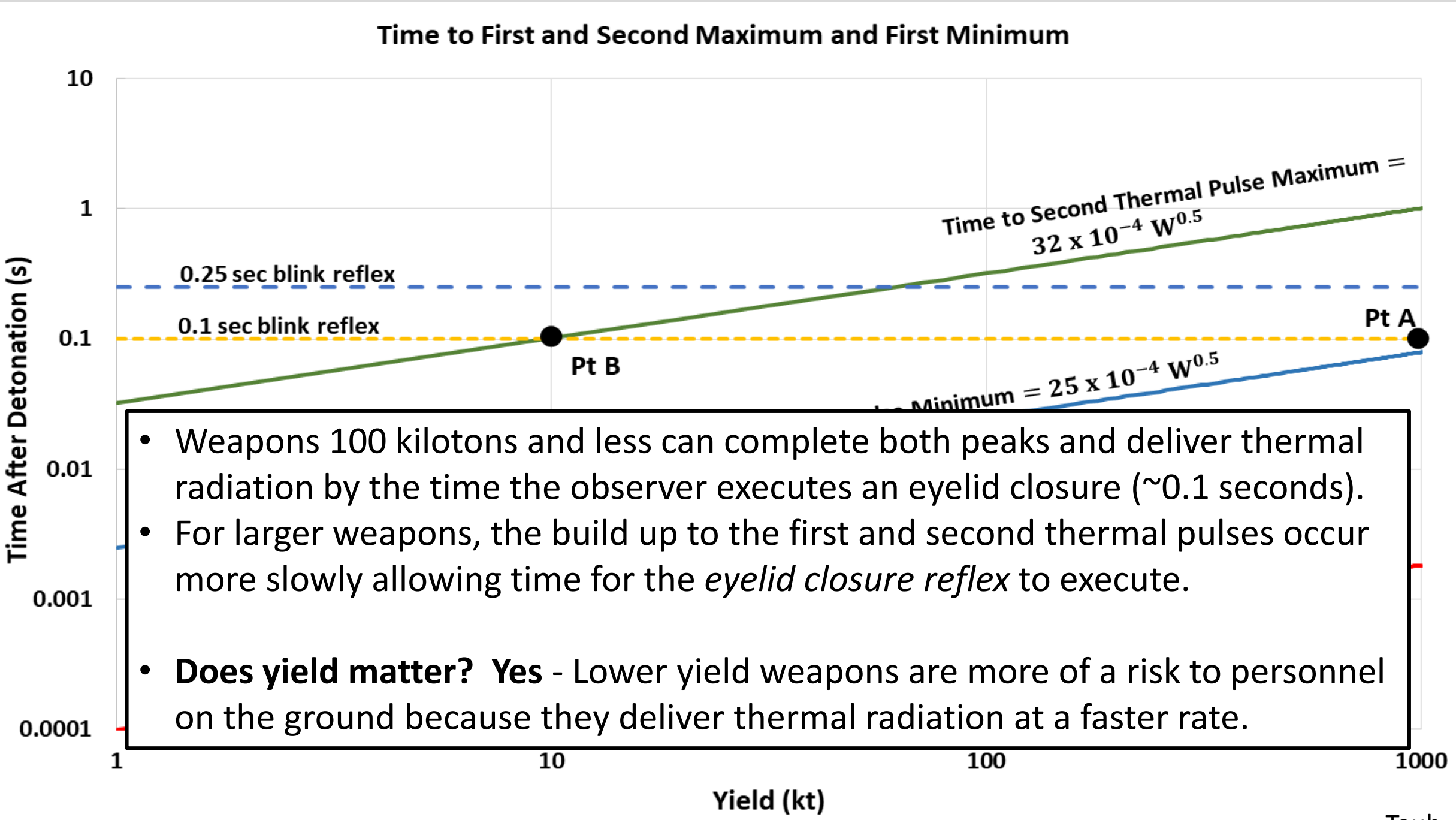
Assume Pt A represents a point on the thermal radiation curve at time t_A for a 1 megaton weapon. Assume Pt B represents a point on the thermal radiation curve at time t_B for a 10 kiloton weapon. The time frame at which a weapon delivers thermal energy (i.e., the rate) is closely tied to the yield.

For some weapon yield pairs, the times from detonation to Pts A and B are equal (i.e., $t_A = t_B$).

Glasstone & Dolan


Time to First and Second Maximum and First Minimum
10
1
0.1
0.01
0.001
0.0001
Time After Detonation (s)
0.25 sec blink reflex
0.1 sec blink reflex
Time to Second Thermal Pulse Maximum = 32 x 10^-4 W^0.5
Pt A
Pt B
Time to First Thermal Pulse Minimum = 25 x 10^-4 W^0.5
Time to First Thermal Pulse Maximum = 1 x 10^-4 W^0.42
1
10
100
1000
Yield (kt)

Taub



- Weapons 100 kilotons and less can complete both peaks and deliver thermal radiation by the time the observer executes an eyelid closure (~0.1 seconds).
- For larger weapons, the build up to the first and second thermal pulses occur more slowly allowing time for the *eyelid closure reflex* to execute.

- **Does yield matter? Yes** - Lower yield weapons are more of a risk to personnel on the ground because they deliver thermal radiation at a faster rate.

Temporary Blindness and Eye Injuries

- Flash blindness: temporary blindness induced by the photochemical bleaching of the rod and cone photoreceptors in the retina by extremely bright light.
- Experienced via two phenomena:
  - ‘Dazzle’ - bleaching of the rods and cones throughout the retina due to the intensity of the luminous fireball and reflected light illuminating the environment (e.g., on clouds, ground, and buildings). Dazzle can occur when the fireball is not in the field of view.
  - ‘After image’ - which occurs when the fireball is in the field of view. The *after image* is a visual representation of the fireball that exists even after the eye lid is shut or the person looks away.
- During the day, when the eyes are adjusted, flash blindness can last seconds to minutes after the light source is removed as the rods and cones have time to chemically recover. At night, flash blindness can last minutes to hours as the rods and cones recover and the eye readapts to night vision.

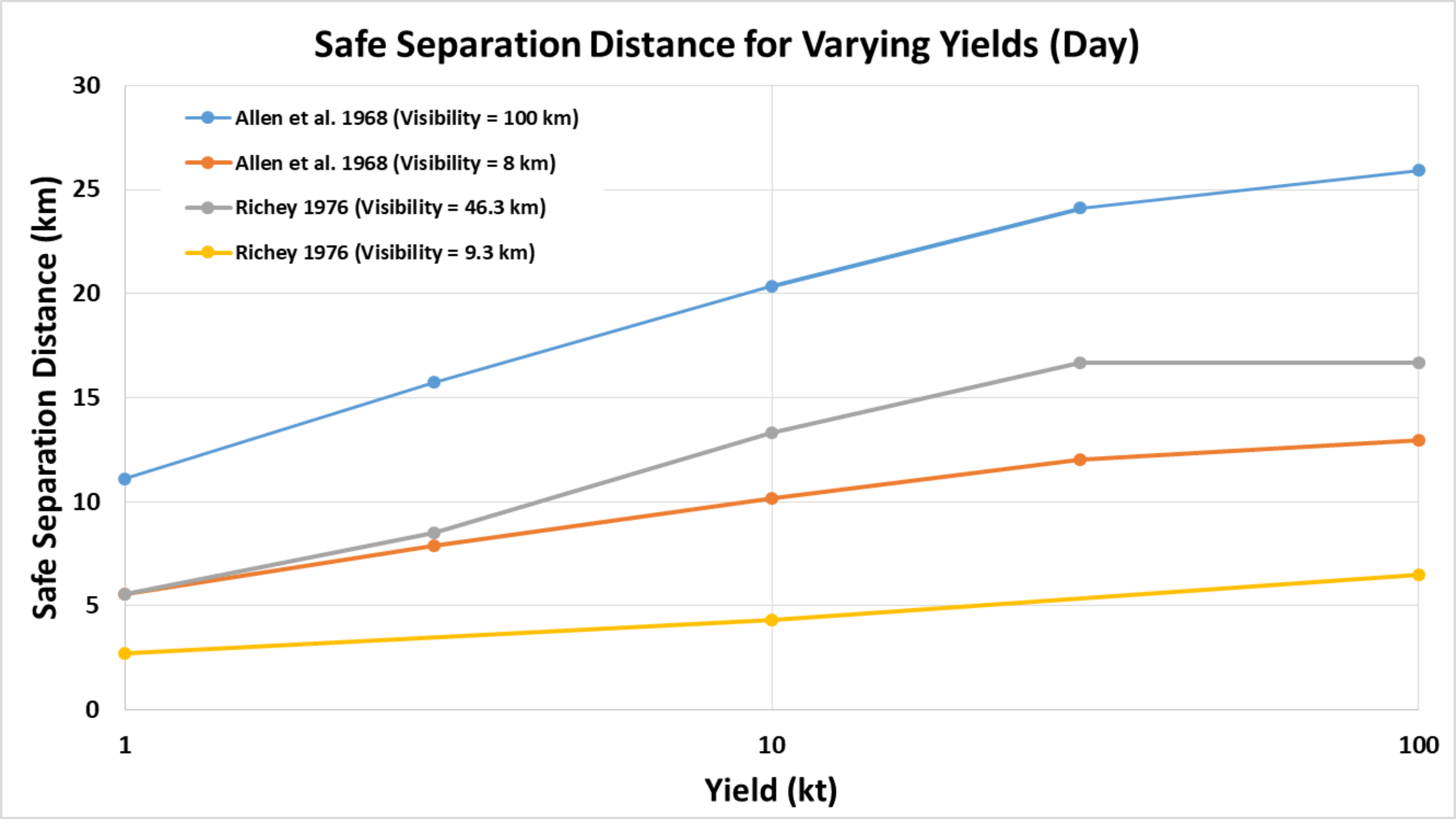
Temporary Blindness and Eye Injuries (cont.)

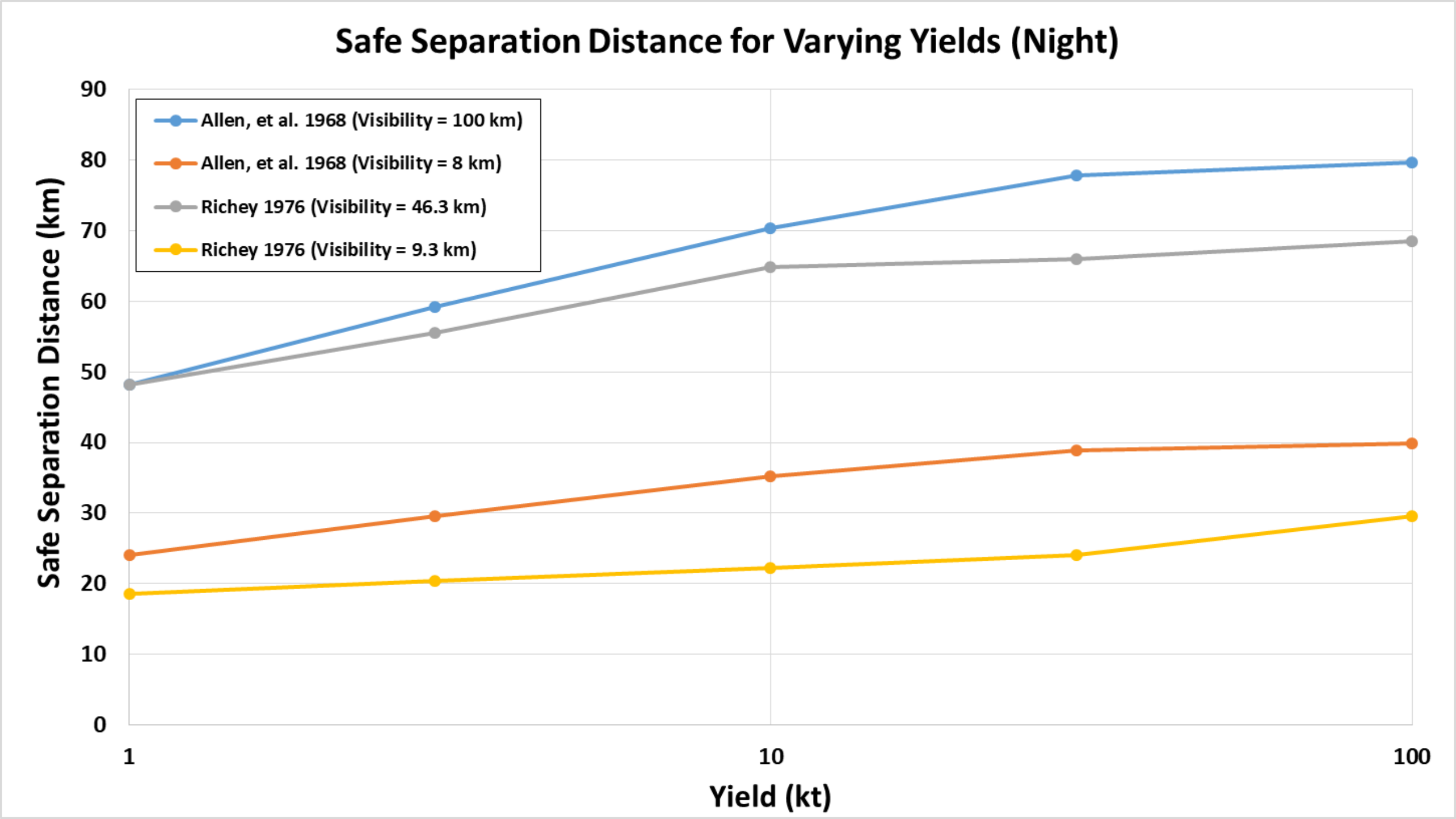
- Retinal burn: permanent eye injury that occurs whenever the retinal tissue is heated excessively when the radiant fireball is in the field of view.
  - Quite literally, the thermal energy from the fireball is deposited on the retina thereby raising the surface temperature and burning the retina.
  - Due to both the focusing of the lens and the sensitive nature of the retina, the amount of energy required for a retinal burn is magnitudes less than that which is required to burn the skin.
- Does distance from the fireball matter?
  - Even though the fireball's thermal energy dissipates as $\frac{1}{r^2}$, the eye's lens counteracts this effects such that the "irradiance at the retina in the image of the fireball is independent of the distance from the fireball."

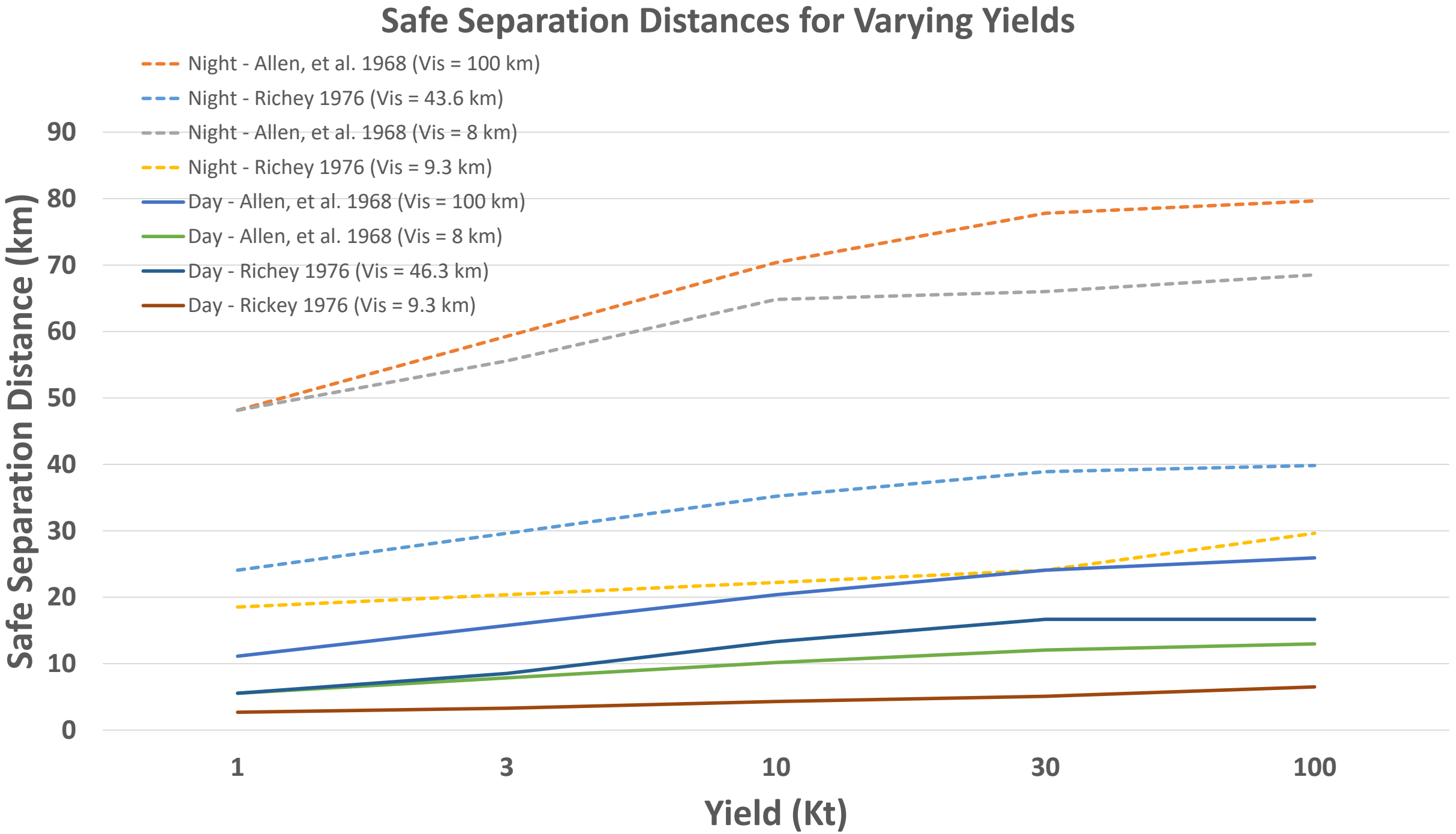
Literature Review

- Flash blindness, retinal burns, eye injuries thoroughly studied (see EM-1 Ch 14, my article, Glasstone & Dolan, etc.)
- Focused on aircraft and airmen at cruising altitude
- Assumptions and components of safe separation distances calculations:
  - Blink time of 0.25 seconds
  - Visibility of 100 kilometers
  - 1,000 feet (0.304 km) height of burst
  - Additional safety factors due to errors in extrapolations from animal testing data, visual acuity, iris color
- Flash blindness SSDs based on 10 second recovery time to read a gage
- Retinal burn SSDs based on receiving no permanent damage

- In short, very few resources exist for calculating SSDs for personnel on the ground in meaningful scenarios.


Safe Separation Distance for Varying Yields (Day)
Allen et al. 1968 (Visibility = 100 km)
Allen et al. 1968 (Visibility = 8 km)
Richey 1976 (Visibility = 46.3 km)
Richey 1976 (Visibility = 9.3 km)
Safe Separation Distance (km)
30
25
20
15
10
5
0
1
10
100
Yield (kt)


Safe Separation Distance for Varying Yields (Night)
Allen, et al. 1968 (Visibility = 100 km)
Allen, et al. 1968 (Visibility = 8 km)
Richey 1976 (Visibility = 46.3 km)
Richey 1976 (Visibility = 9.3 km)
Safe Separation Distance (km)
90
80
70
60
50
40
30
20
10
0
1
10
100
Yield (kt)


Safe Separation Distances for Varying Yields
Night - Allen, et al. 1968 (Vis = 100 km)
Night - Richey 1976 (Vis = 43.6 km)
Night - Allen, et al. 1968 (Vis = 8 km)
Night - Richey 1976 (Vis = 9.3 km)
Day - Allen, et al. 1968 (Vis = 100 km)
Day - Allen, et al. 1968 (Vis = 8 km)
Day - Richey 1976 (Vis = 46.3 km)
Day - Rickey 1976 (Vis = 9.3 km)
Safe Separation Distance (km)
0
10
20
30
40
50
60
70
80
90
1
3
10
30
100
Yield (Kt)

Major Take Aways

- Are retinal burns a concern? Day? Night?
- Is flash blindness a concern? Day? Night?
- The human factor…
- How do Night Vision Goggles play a role?
- Review of counterintuitive principles: $1/r^2$ and yields

Enhanced Night Vision Goggle – Binocular (ENVG-B)

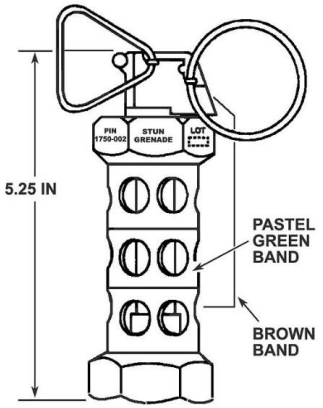
https://asc.army.mil/web/portfolio-item/enhanced-night-vision-goggle-envg-b/

Major Take Aways

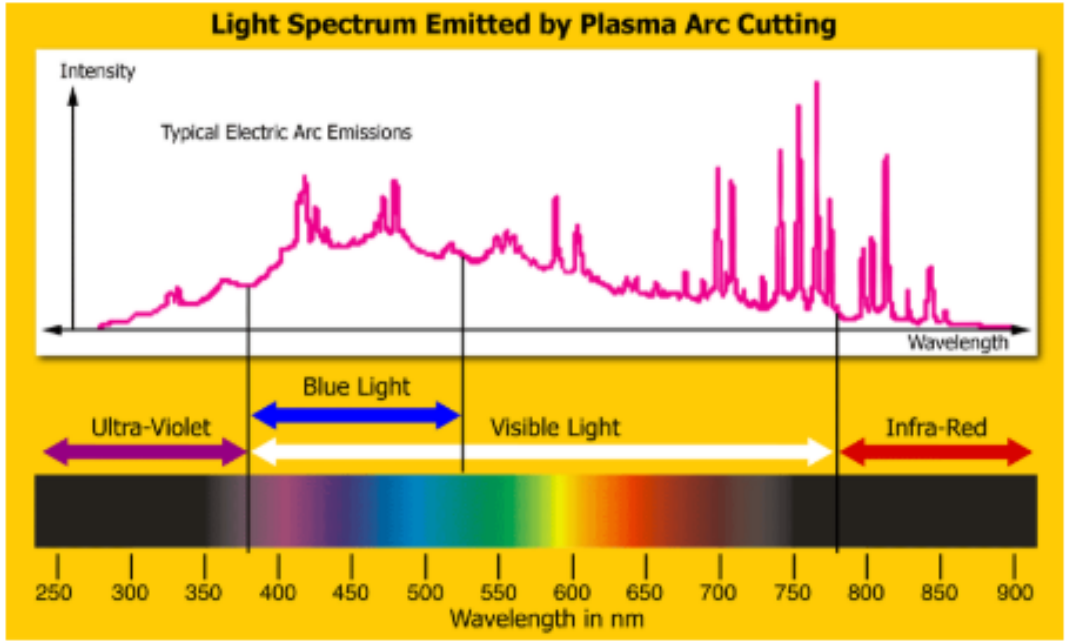
- Are retinal burns a concern? Day? Night?
- Is flash blindness a concern? Day? Night?
- How do Night Vision Goggles play a role?
- Review of counterintuitive principles: $1/r^2$ and yields

Follow-on Research

- Sensitivity of optical sensors (ISR, night vision goggles) to severe thermal insults
  - Same 1/r2 problem; perhaps worse
  - CMOS or similar sensors sensitive to thermal deposition
- Thermal output comparison: Nuclear weapon vs. plasma cutters vs. flash bang grenades
  - Plasma cutter: wide spectrum; intense in the blue light region
  - Flash bang grenades: 19 million candela
- Inform sensor program offices, R&D, survivability efforts



MK 20 Mod 0
Flash Bang Grenade



Sources:

- Allen, Ralph., Jungbauer, David., Isgitt, Donald., Arment, Brian., Russell, John., “Nuclear Flash Eye Effects Technical Report for Military Planners”, February 1967.
- Richey, Everett., “Predicting Eye Safe Separation Distances from Nuclear Detonations”, January 1976.
- Verheul, R., Lowrey, A., Browning, L., “Operation HARDTACK – Project 4.3 Effect of Light From Very-Low-Yield Nuclear Detonations on Vision (Dazzle) of Combat Personnel”, April 1960.
- Daytime pupil radius is ~1 mm and night is ~4 mm. $Area = \pi r^2$ for a circle. Daytime area = 3.14 mm^2; Night is 50.2 mm^2.
- Taub, Arthur., Levy, Charles., Wargo, Michael., Hodgson, David., Cummings, Thomas., Goff, Jennifer., Chamberlin, Henry., Moody, John., “Review of Research on Flash Blindness, Chorioretinal Burns, Countermeasures, and Related Topics”, 1965.
- Glasstone, Samuel., Dolan, Philip., *The Effects of Nuclear Weapons*, 1977.
- Even though the fireball’s thermal energy dissipates as $\frac{1}{r^2}$, the lens counteracts this effects such that the “irradiance at the retina in the image of the fireball is independent of the distance from the fireball.” Allen, Ralph., White, T., Isgitt, D., Jungbauer, D., Tips, J., Richey, E., “The Calculation of Retinal Burns and Flash Blindness Safe Separation Distances”, September 1968.
- Assuming: 1) 1000 ft (0.304 km) height of burst; 2) direct visual line of sight to the weapon; 3) a person of average height; then the maximum distance to view the fireball is ~ 60 km.

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