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GUN & ELECTRIC WEAPON SYSTEMS DEPARTMENT (E)

Methodology and Results of a Safe Separation Study for Navy 5-Inch Projectiles

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Jason Koonts
Naval Surface Warfare Center, Dahlgren Division
jason.koonts@navy.mil
540-284-0179

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Agenda

- Define Safe Separation
- Scope of Study
- Model Parameters
- Modeling Methodology
  - Simulation Program
  - Casualty Criteria
- Results
- Questions?

What is Safe Separation?

- From MIL-STD-1316:
  - "A safety feature of the fuze shall provide an arming delay which assures that a **safe separation** distance can be achieved for **all defined operational conditions**."
  - Safe separation is: "The **minimum distance** between the delivery system (or launcher) and the launched munition beyond which the **hazards** to the delivery system and its personnel resulting from the functioning of the munition **are acceptable**."

Scope of Safe Separation Study

- Prior study evaluated PBXN-106
  - Change in explosive fill to PBXN-9 and improvement opportunities identified in original study prompted reexamination
  - Goal to generalize study to use results for PBXN-106 and PBXN-9 filled 5-inch projectiles

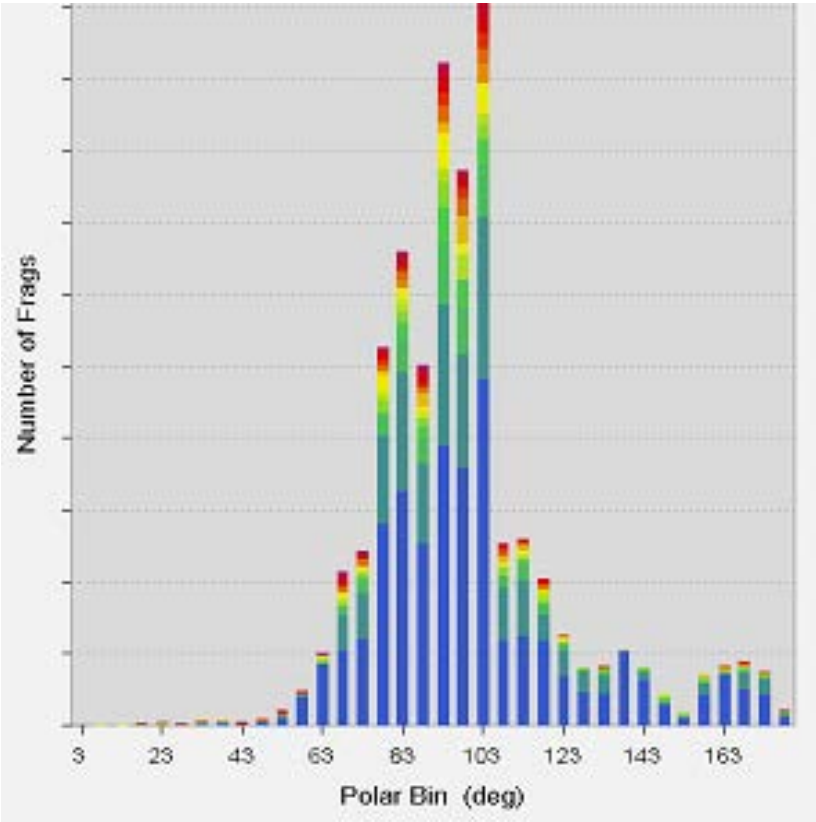
Model Parameters

- Warhead Output
- Vulnerability of the Launch Platform and Personnel
- Launch Conditions
- Acceptable Hazard Criteria

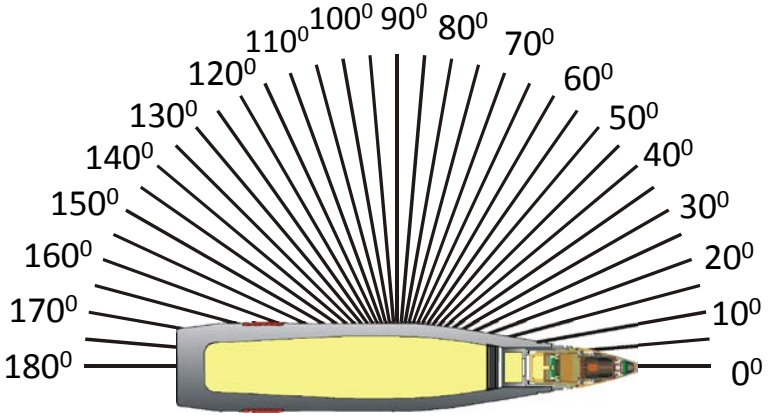
Parameter 1 - Warhead Output

- 5-inch projectile is a fragmentation weapon
- Arena test generates ZData
  - Contains fragment size, pattern of breakup, fragmentation velocity
  - Feeds modeling program to determine fragmentation hazard at specified distances from warhead function

Parameter 1 – Warhead Output (cont)



- Data entered into JMEMs* format
- For each 5 degree arc:
  - Fragment size quantized into bins and averaged
  - Fragment velocities averaged



*Joint Munition Effectiveness Manuals

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MK 186 HE-MOF High Order Function

Parameter 2 – Vulnerability of Launch Platform and Personnel

- 5-inch gun employed on CG and DDG
- Cruiser used for study because it is larger of the two classes
- Forward gun selected due to greater range of motion

Cruiser (CG)

Destroyer (DDG)

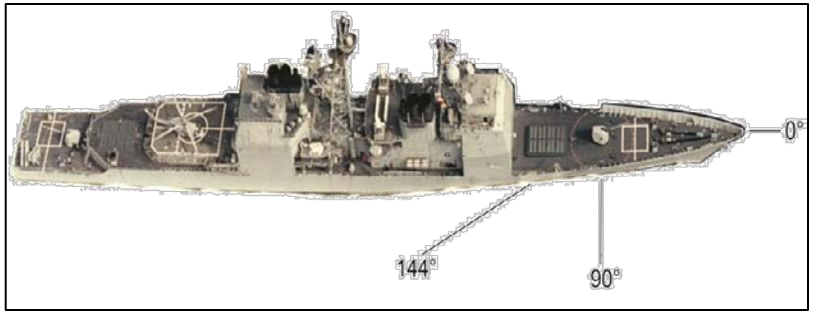
Parameter 2 – Vulnerability of Launch Platform and Personnel (cont)

- Analysis of ship structure vulnerability concluded that ship material structures are less susceptible than personnel on deck
- Personnel vulnerability is the driving criteria
  - Dressed in summer uniforms
  - Presented area of 8.1 square feet
    - Full frontal area, very conservative assumption (lying down on the deck)
  - Can be anywhere topside including restricted areas

Parameter 3 – Launch Conditions

- Worst-case scenarios developed for Anti-Air (AAW), Naval Surface Fire Support (NSFS), and Anti-Surface (ASuW)
- High gun elevation and worst-case azimuth
- Full and reduced propelling charges

Summary of Launch Conditions				
Scenario No.	Mission	Gun Elevation	Gun Azimuth	Muzzle Velocity
1	AAW	65°	144°	1500 fps (457 m/s)
2				2650 fps (808 m/s)
3	NSFS	46°	90°	1500 fps (457 m/s)
4				2650 fps (808 m/s)
5	ASuW	0°	144°	1500 fps (457 m/s)
6				2650 fps (808 m/s)



Parameter 4 – Acceptable Hazard

- Army Fuze Safety Board guidelines used to determine acceptable hazard:
  - "Safe Separation is the minimum distance between the end of the gun barrel and the projectile, where detonation of the projectile generates hazardous fragments with a probability of hitting a crew member of one in ten thousand (0.0001). A hazardous fragment is defined as one with energy sufficient to penetrate bare skin with a probability of 50%."

Modeling Methodology

- For each scenario, detonation simulated at 0.05-second increments until fragments cleared the ship
- Lethal wounding, serious wounding, and skin penetration were the casualty criteria
  - Lethal wounding: hazard category 1, death or permanent disability
  - Serious wounding: hazard category 2, hospitalization or permanent partial disability
  - Skin penetration: hazard category 3 and 4, one or more lost work days or no lost work days
    - Skin penetration results used to determine safe separation, other categories used for hazard assessment

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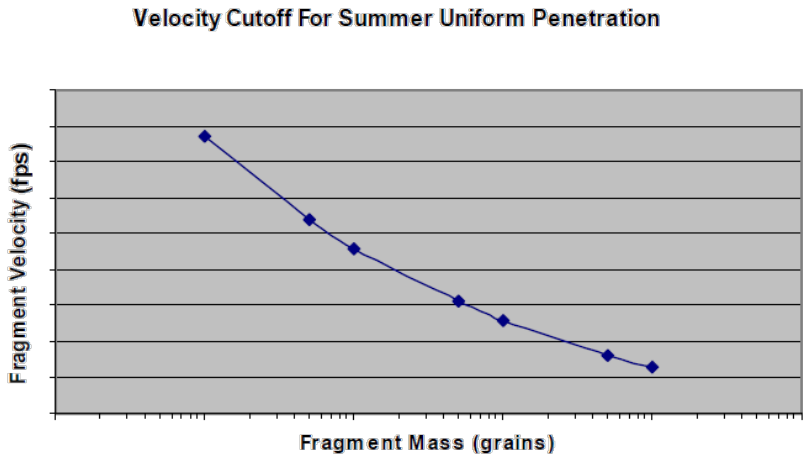
WarheadView Simulation

- Warhead fragment visualization program developed by NSWC Dahlgren's Lethality and Weapons Effectiveness Branch
- ZData is approved by JTCG/ME*
- For each fragment the trajectory is simulated from burst to ground impact accounting for drag and shape factor of fragments
- Can be run in Monte Carlo mode
- Produces full color pictures and movies of the event

*Joint Technical Coordinating Group for Munitions Effectiveness

Casualty Criteria – Lethal and Serious Wounding

- Velocity cutoff for summer uniform penetration
- Warhead produces small fragments, so blunt trauma is ignored



- Probability of incapacitation computer using Sperrazza-Kokinakis equation: $P_{I/H} = 1 - e^{-a\left(mV^{2/3} - b\right)^{n}}$
  - a, b, and n empirically derived based on casualty criteria
  - M is the mass of the fragment
  - V is the impact velocity of the fragment

Casualty Criteria – Lethal and Serious Wounding (cont)

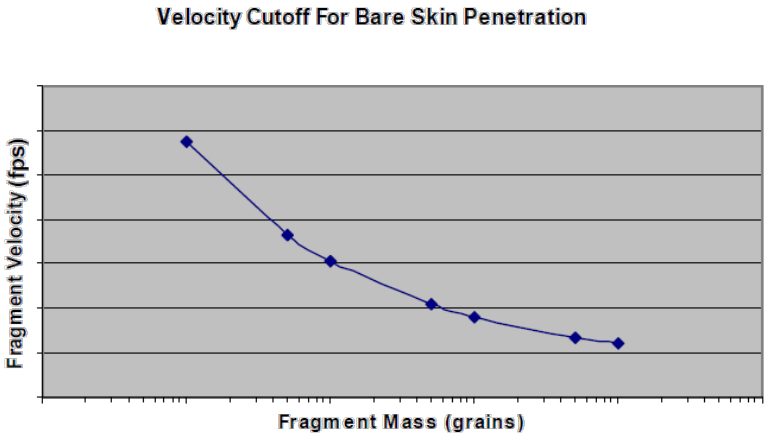
- Total number of incapacitating hits given by:

$$N_{I/D} = \left(\frac{A_{pers}}{A_{Ship}} \right) \sum_{N_{Hits}} P_{I/H}$$

  - A_{pers} is the area of a single person
  - A_{Ship} is the area of the ship
  - N_{Hits} are all hits on the ship above the cutoff velocity
- Monte Carlo simulation performed, $N_{I/D}$ is determined for each run, these are added and divided by number of Monte Carlo runs to calculate average number of incapacitating hits
- Probability of incapacitation is: $P_I = 1 - e^{-N_I}$
  - Poisson distribution

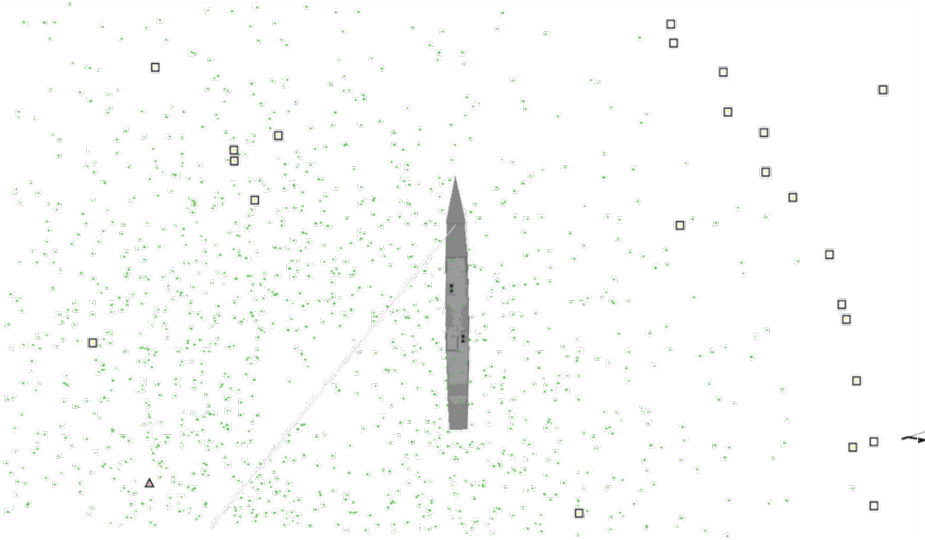
Casualty Criteria – Skin Penetration

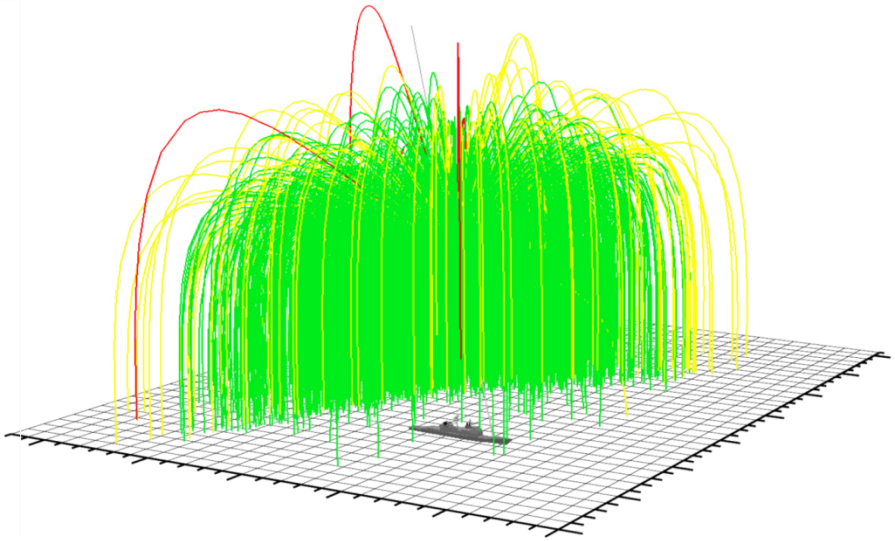
- Velocity cutoff for bare skin penetration
- $P_{I/H}$ = 1 for hits greater than velocity cutoff and $P_{I/H}$ = 0 for hits less than cutoff



- Similarly to lethal and serious wounding:
  - Number of skin penetrating hits = $N_{P/D} = \frac{A_{pers}}{A_{Ship}} \sum_{N_{Hits}} P_{I/H}$
  - Probability of skin penetrating hit = $P_P = 1 - e^{-N_P}$

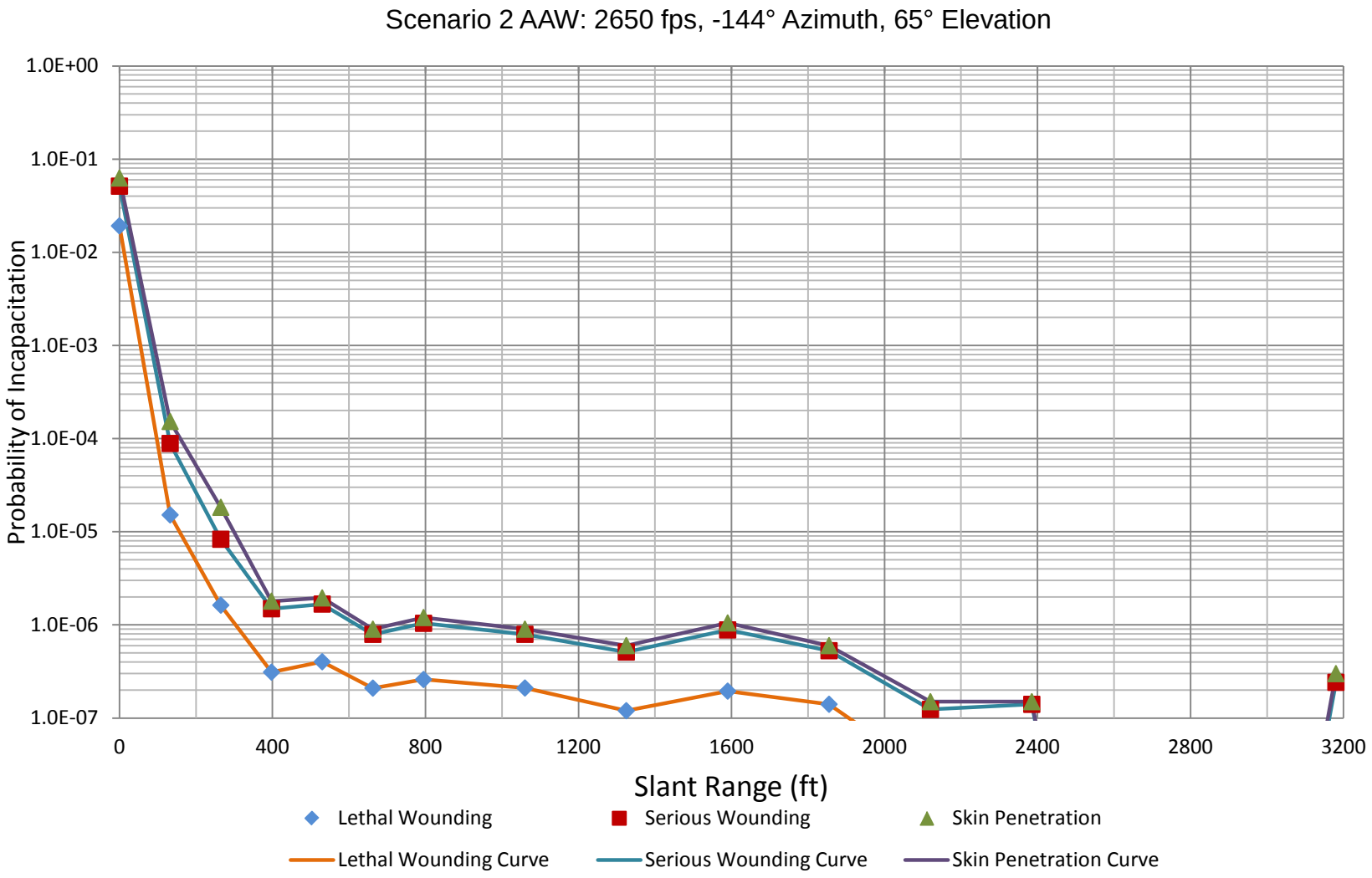
Model Results – Full Charge



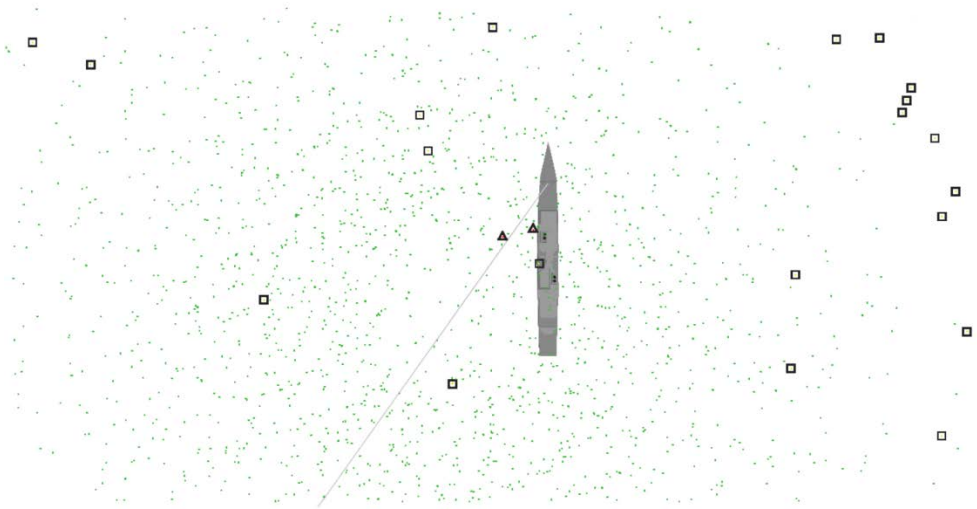


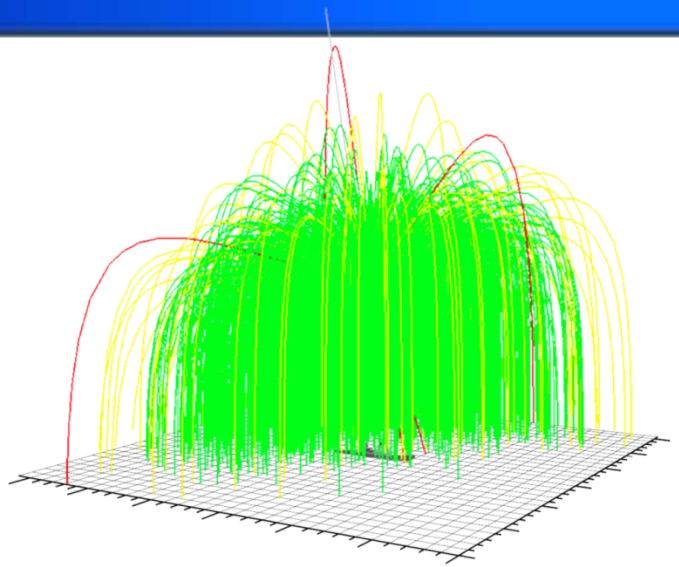
- Linear interpolation used for standard charge scenarios
- It is obvious that standard charge will not drive safe separation

Probability Curve Example – Full Charge



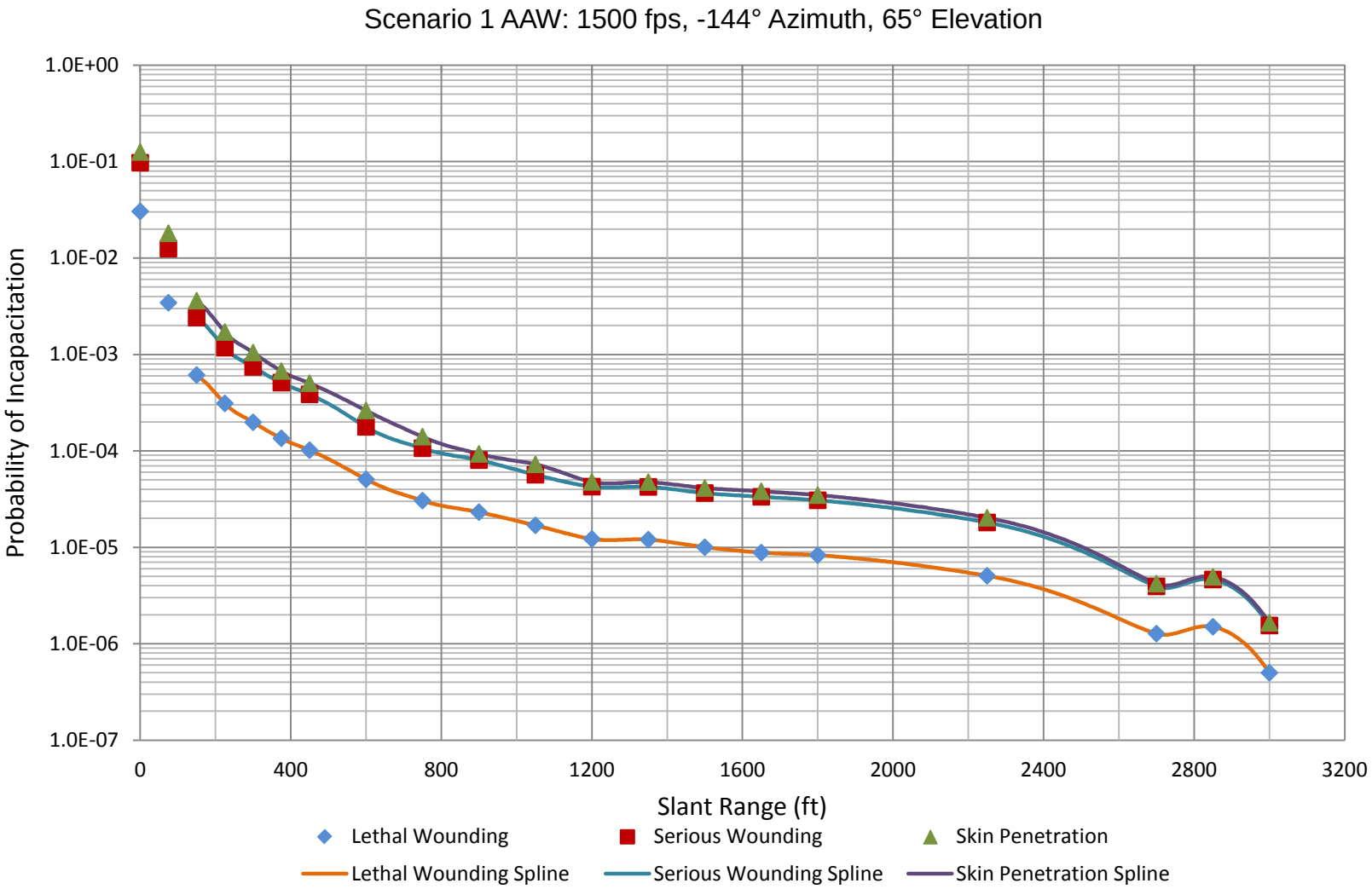
Model Results – Reduced Charge



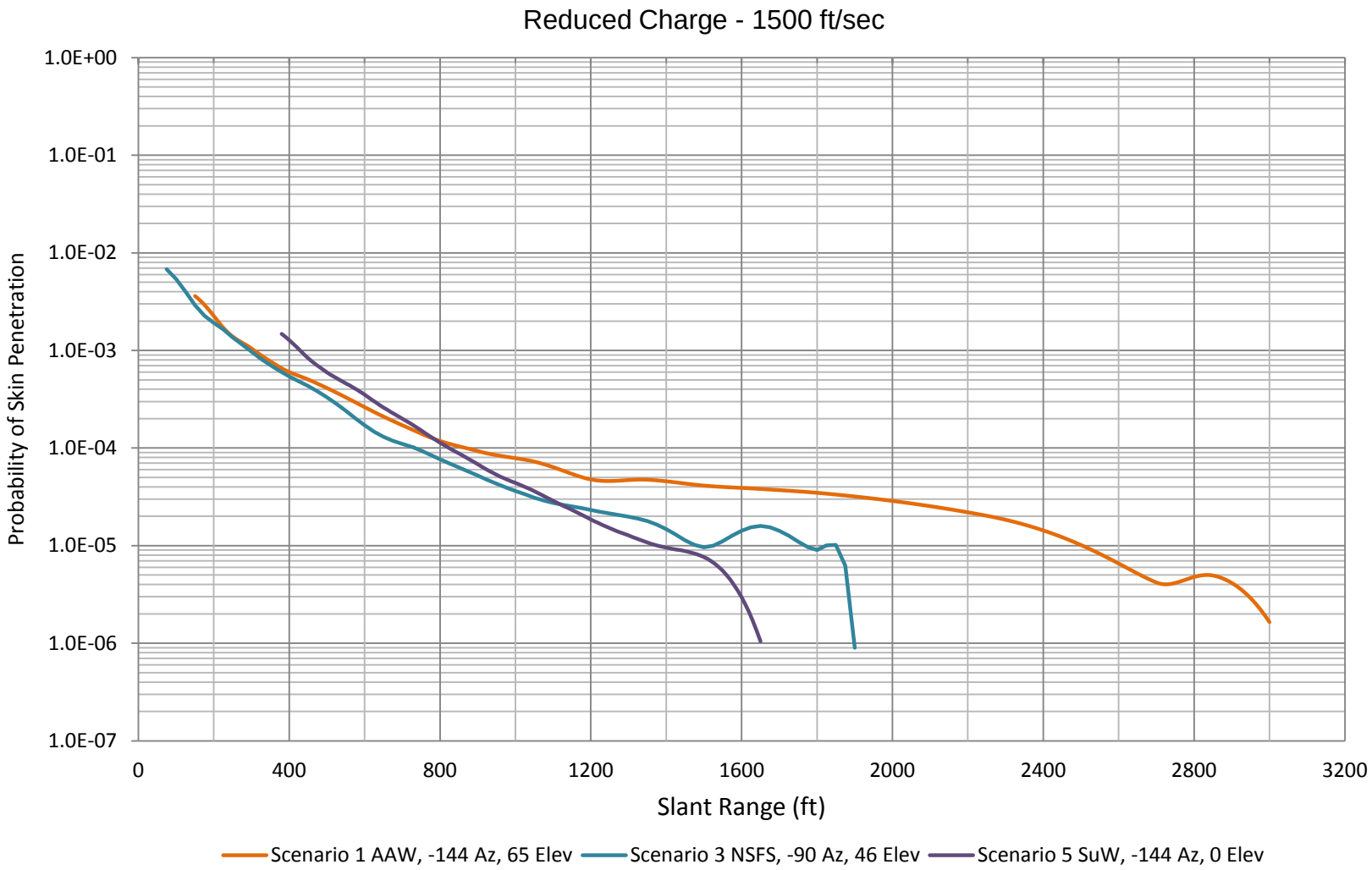


- Cubic spline algorithm used to curve fit reduced charge scenarios
  - Different cubic equation for every pair of adjacent values
  - Smooth curve between data points interpolated to determine safe separation

Probability Curve Example – Reduced Charge



Reduced Charge Probability Curves



Final Results of Safe Separation Study

SAFE SEPARATION RESULTS SUMMARY				
Projectile	Engagement	Propelling Charge	Scenario	Safe Separation Distance (feet)
5-inch with PBXN-9 Explosive Fill	AAW	MK 68 Reduced (1500 fps)	1	869
	NSFS		3	734
	ASuW		5	825
	AAW	MK 67 Standard (2650 fps)	2	159
	NSFS		4	121
	ASuW		6	339

- Fuzes for 5-inch projectiles should delay arming to a minimum of 869 feet to meet MIL-STD-1316 safe separation requirements
- PBXN-9 warhead provides more lethal fragments than PBXN-106 warhead, so results from this study can be conservatively applied to PBXN-106 projectiles as well

Questions?

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Full Test Report is Distribution D