U.S. Army Research, Development and Engineering Command

Characterizing Collateral Damage to Dismounted Troops and Other Personnel Located Near Active Countermeasures

MANPRINT Practitioner Workshop
17-18 March 2010

TECHNOLOGY DRIVEN. WARFIGHTER FOCUSED.

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Outline

- Introduction and Terminology
- Test Variables
- Data Collection Method
- Data Analysis
  - Characterizing Each Fragment
  - Characterizing Each Trajectory
- Additional Analysis and Testing

Hazards to Dismounted Troops from Active Countermeasures

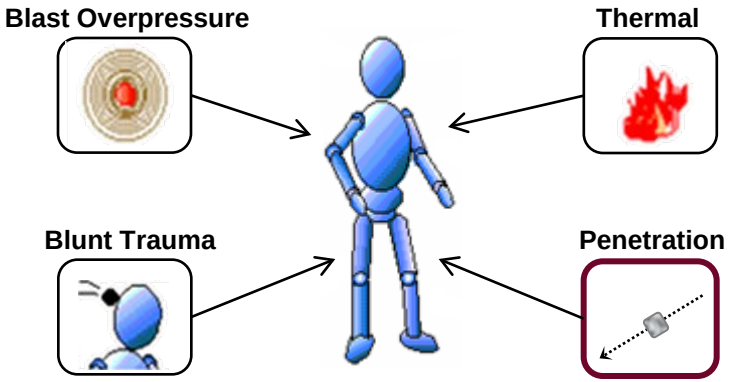
Example Vehicle Active Countermeasures (ACMs):

Reactive Armor

Active Protection System (APS)

Primary injury mechanisms that cause the most hazards for dismounted personnel:

- **Penetrating fragments**
  - **Injuries range from superficial skin penetration to maximum levels of trauma**
  - **Severity depends on size, density, velocity, and shape of penetrating fragments**
- Blast overpressure (BOP)
  - Lung damage
  - Eardrum rupture
  - TBI
- Thermal energy
- Blunt trauma



Terminology

Casualty (Joint Pub 1-02):

Any person who is lost to the organization by reason of having been declared dead, wounded, injured, interned, captured, missing, missing in action, beleaguered, or besieged.

Serious or Greater Wound (AIS score of 3 or higher):

A wound that would require medical intervention. Untreated serious injuries could deteriorate and cause loss of life. Personnel who receive a serious or greater wound would be considered a **medical casualty**.

Abbreviated Injury Scale (AIS):

AIS is an anatomically-based, consensus-derived, international severity scoring system that classifies each injury by body region according to its relative importance on a 6-point ordinal scale. AIS values provide information on the type, location, and severity of anatomical injuries. AIS scores each single injury. AIS is currently being used to code injuries received by Coalition forces, for both WIAs and KIAs, occurring in theater.

Incapacitation:

The inability to perform, at a level required for combat effectiveness, the physical or mental tasks required in a particular combat role at a specific time after wounding. Incapacitated personnel are impaired to a level below minimal capabilities and are considered an **operational casualty.**

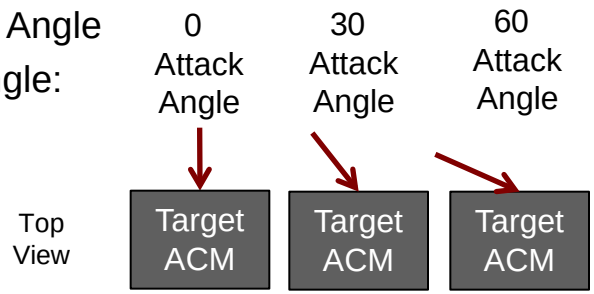
Considerations and Caveats

- Considerations
  - Design cost-effective tests to capture fragments from ACM-threat interaction
  - Quantify and assess hazards from penetrating insults to personnel in proximity to military platform with ACM
    - Define in terms of injury severity and/or potential for incapacitation
    - Map fragment spray at varying distances
    - Determine hazards at locations around the detonation point
    - Determine where hazards potentially go to zero
  - Support determination of areas around the ACM-threat interaction where personnel are predicted to receive injuries
  - Compare hazards caused by different ACM solutions
- Caveats:
  - Based on a limited number of test events (typically time and funding do not permit statistically strong test matrices)
  - Limited to the test conditions
  - Not a safety assessment

Experiment Variables

Threat

- Type
- Dynamic vs. static detonation
- Impact location
- Shot line
  - Elevation Angle
  - Attack Angle:

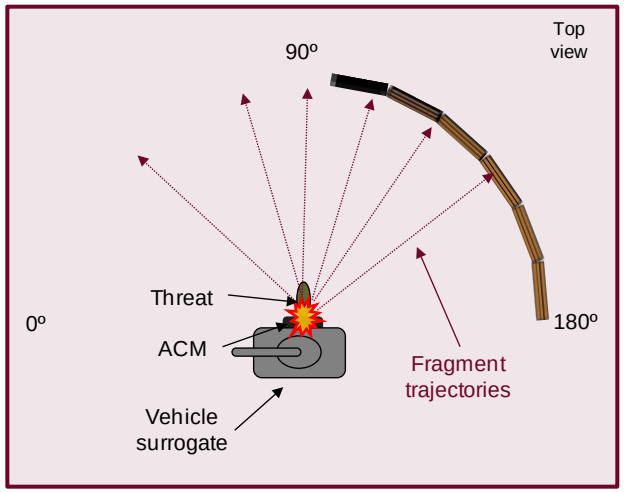


Target ACM

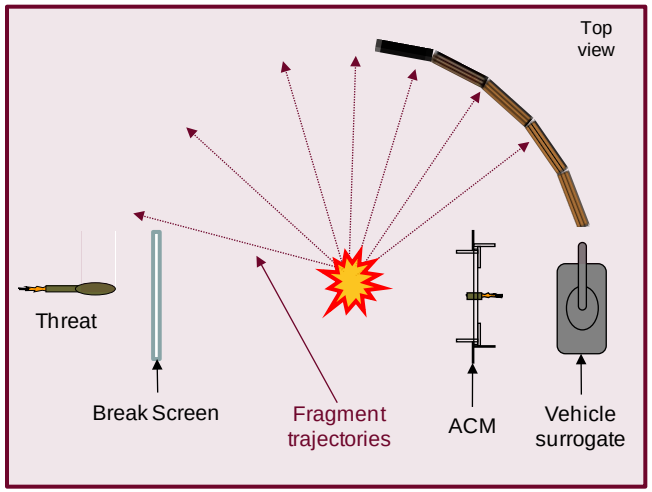
- Impact configuration
- Impact conditions
  - Surrogate vehicle availability or use of correct mounting scheme on test stand
  - Production hardware availability
  - Mounting heights consistent with appropriate vehicle mounting heights
- Intended intercept distance for dynamic ACM events
- Defeat mechanism

Recovery Arena Examples

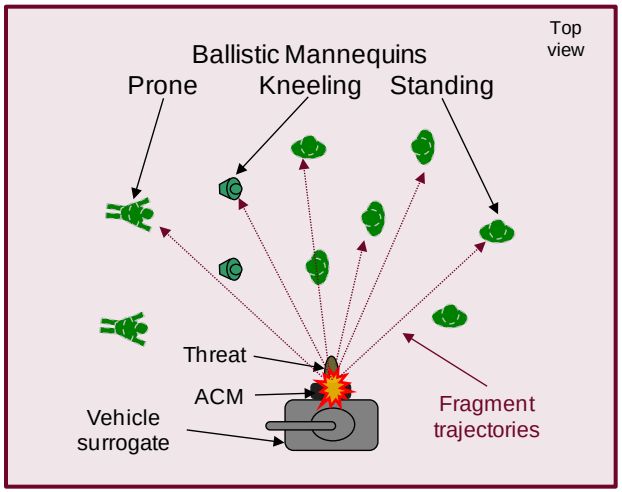
- Static



- Dynamic

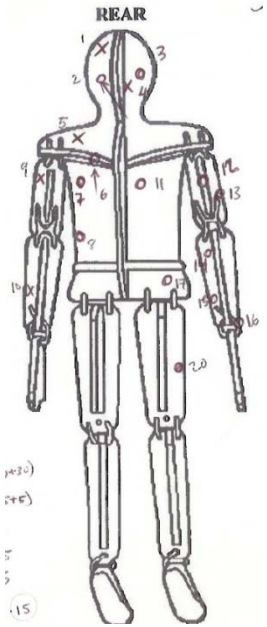


- Operational Environment



Data Collection Method

- Overall Damage
  - Note debris within arena
  - Assess adjacent ACM
    - Any damage?
    - Any displacement?
- Panel/Ballistic Mannequin Damage
  - Note overall damage and any displacement
  - Note panel number and event number
  - Circle and number each hole
    - Note hole location
      - Record x,y with respect to a reference point
      - Mark hole location on pre-made mannequin sheets
    - Note hole dimensions (L × W × D)
    - Recover any debris lodged in the panel
      - Note recovery
      - Note fragment material
- Pre- and post-shot photographs
- High-speed and standard video recording of the events



Mannequin sheet

Data Analysis:
Characterizing Each Fragment

Plywood Mannequin Analysis Tool (PMAT):

- Uses panel damage collected as inputs
- Estimates striking velocity and mass based on uniform density of the plywood

$$v_s = K_1 \left(\frac{A_p t}{m} \right)^{K_2}$$

$$m = \rho \left(\frac{A_p}{\gamma} \right)^{\frac{3}{2}}$$

where:

$\boldsymbol{v_s}$ = fragment striking velocity

$\boldsymbol{A_p}$ = fragment presented area (hole size)

$\boldsymbol{K_1}$, $\boldsymbol{K_2}$ = curve fitting constants

$\boldsymbol{t}$ = fragment penetration depth (hole depth)

$\boldsymbol{m}$ = fragment mass

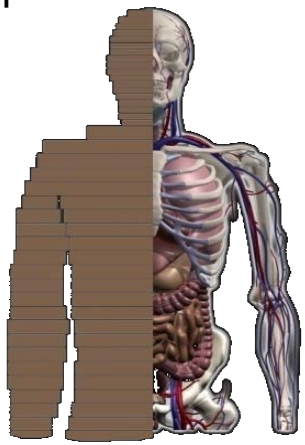
$\boldsymbol{\rho}$ = fragment material density

$\boldsymbol{\gamma}$ = fragment shape factor

Data Analysis:
Characterizing Each Fragment

Operational Requirement-based Casualty Assessment (ORCA) Model:

- Uses fragment characteristics and the simulated dismounted troop properties as inputs
  - Fragment properties:
    - Mass
    - Striking velocity
    - Shape factor
    - Material density
  - Troop properties:
    - Posture (i.e., standing, kneeling, prone)
    - Unarmored (without Personal Protective Equipment (PPE)) and Armored (With PPE)



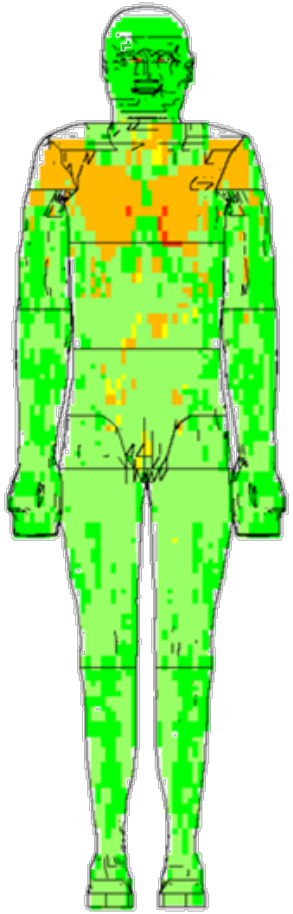
- Models injuries caused by each fragment to provide severity characterization
- Models incapacitation for a particular combat role at a given post-wounding time
- Uses serious injury as the threshold of unacceptable risk for example analysis

MAIS	Injury Level	Head Injury Example	Type of Injury
0	None	No injury	None
1	Minor	Minor laceration of scalp	Superficial
2	Moderate	Major laceration of scalp, blood loss < 20%	Reversible injuries; medical attention required
3	Serious	Fracture of skull, penetration < 2 cm	Reversible injuries; hospitalization required
4	Severe	Depressed skull fracture, penetration > 2 cm	Non-reversible injuries; not fully recoverable without medical care
5	Critical	Depressed skull fracture, laceration of spinal artery	Non-reversible injuries; not fully recoverable even with medical care
6	Maximal	Massive brain stem crush	Virtually Unsurvivable

Example Analysis:
Characterizing Each Fragment

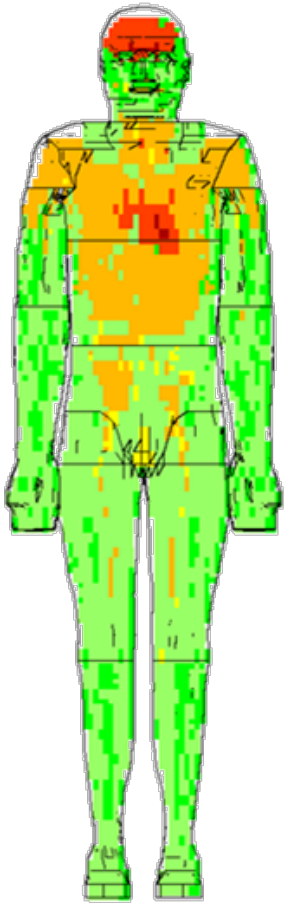
MAIS	Injury Level
0	None
1	Minor
2	Moderate
3	Serious
4	Severe
5	Critical
6	Maximal

Injury plots modeled using same fragment threat conditions with a uniform grid of shot lines in a front-only view with zero degrees azimuth and elevation



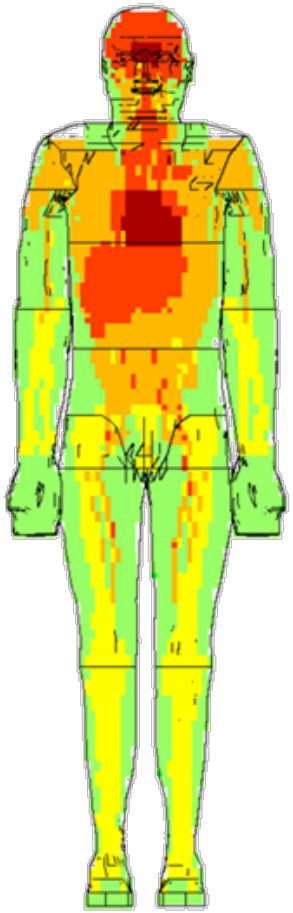
Fragment A

$P(MAIS \geq 3 \mid hit) = 0.2$



Fragment B

$P(MAIS \geq 3 \mid hit) = 0.5$



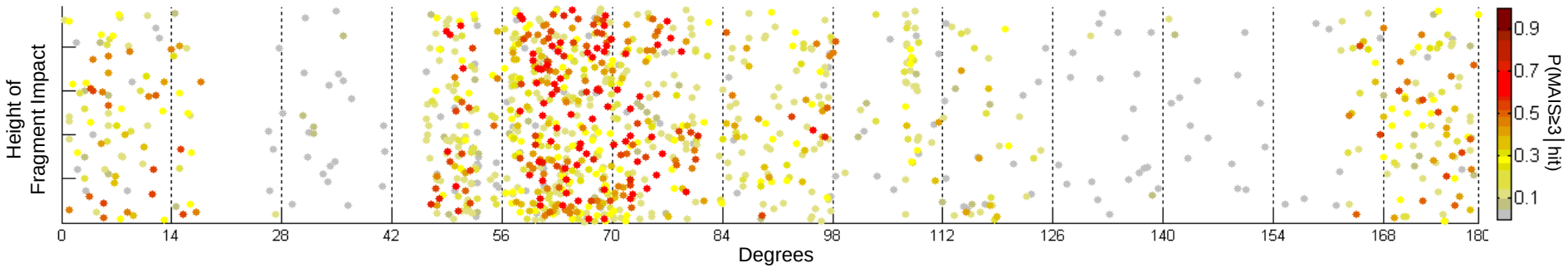
Fragment C

$P(MAIS \geq 3 \mid hit) = 0.8$

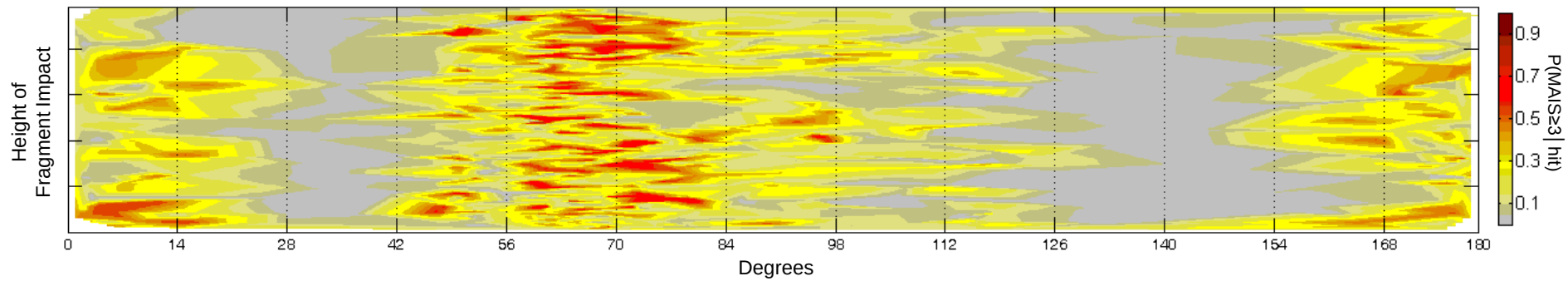
Probability of a serious or greater injury given a hit = $P(MAIS \geq 3 \mid hit)$

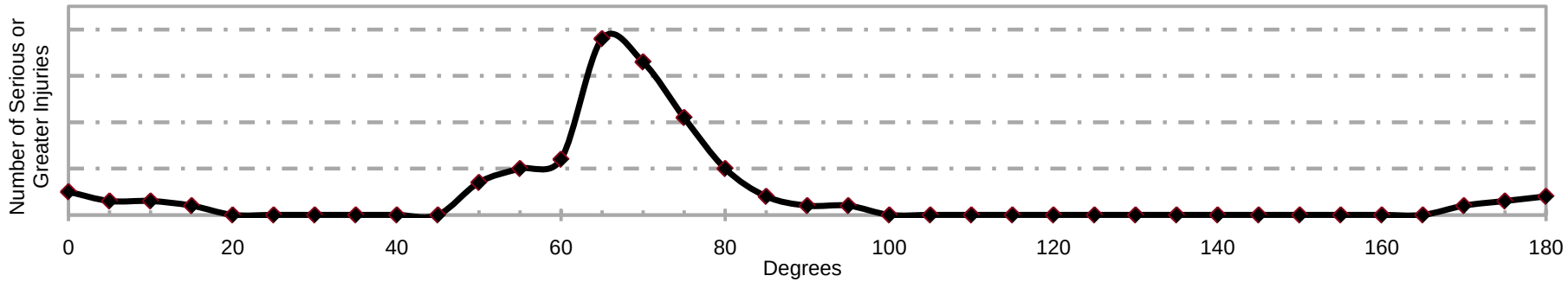
Example Analysis Continued:
Characterizing Each Fragment

Fragment Dispersion



Areas of Most Concern

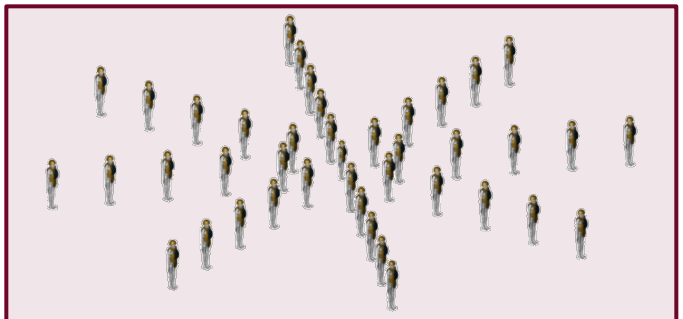




Data Analysis:
Characterizing Each Trajectory

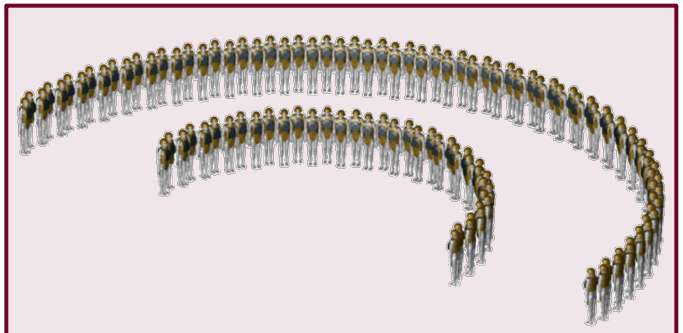
MUVES/ORCA:

- Uses fragment characteristics, fragment trajectories, and a dismounted troop target array as inputs
  - Fragment trajectories:
    - Based on impact locations on panels
    - Assumed linear trajectories from single point of origin
  - Troop target arrays:
    - Polar array around detonation point
    - Grid array
    - Concentric array: facing detonation, along an 180 degree arc
    - Custom array variables:
      - Soldier postures
      - Distances away from ACM-threat interaction
      - PPE protection levels
      - Level, slanted, or uneven terrain
- Models each event's discrete trajectories
- Computes an injury or incapacitation level as a result of each fragment trajectory at each distance
- Uses serious injury as the threshold of unacceptable risk for example analysis



Example Polar Array

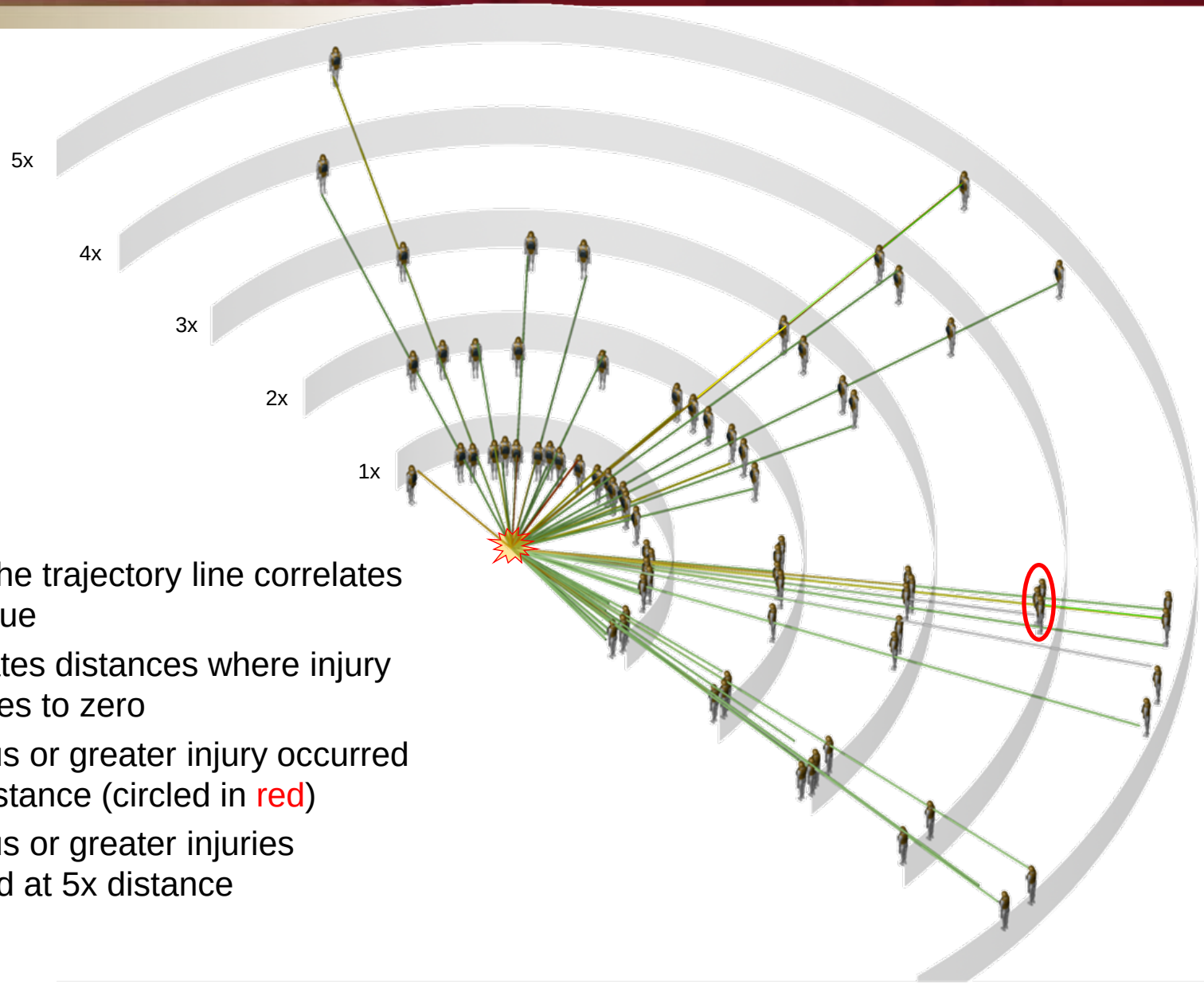
Example Grid Array



Example Concentric Array

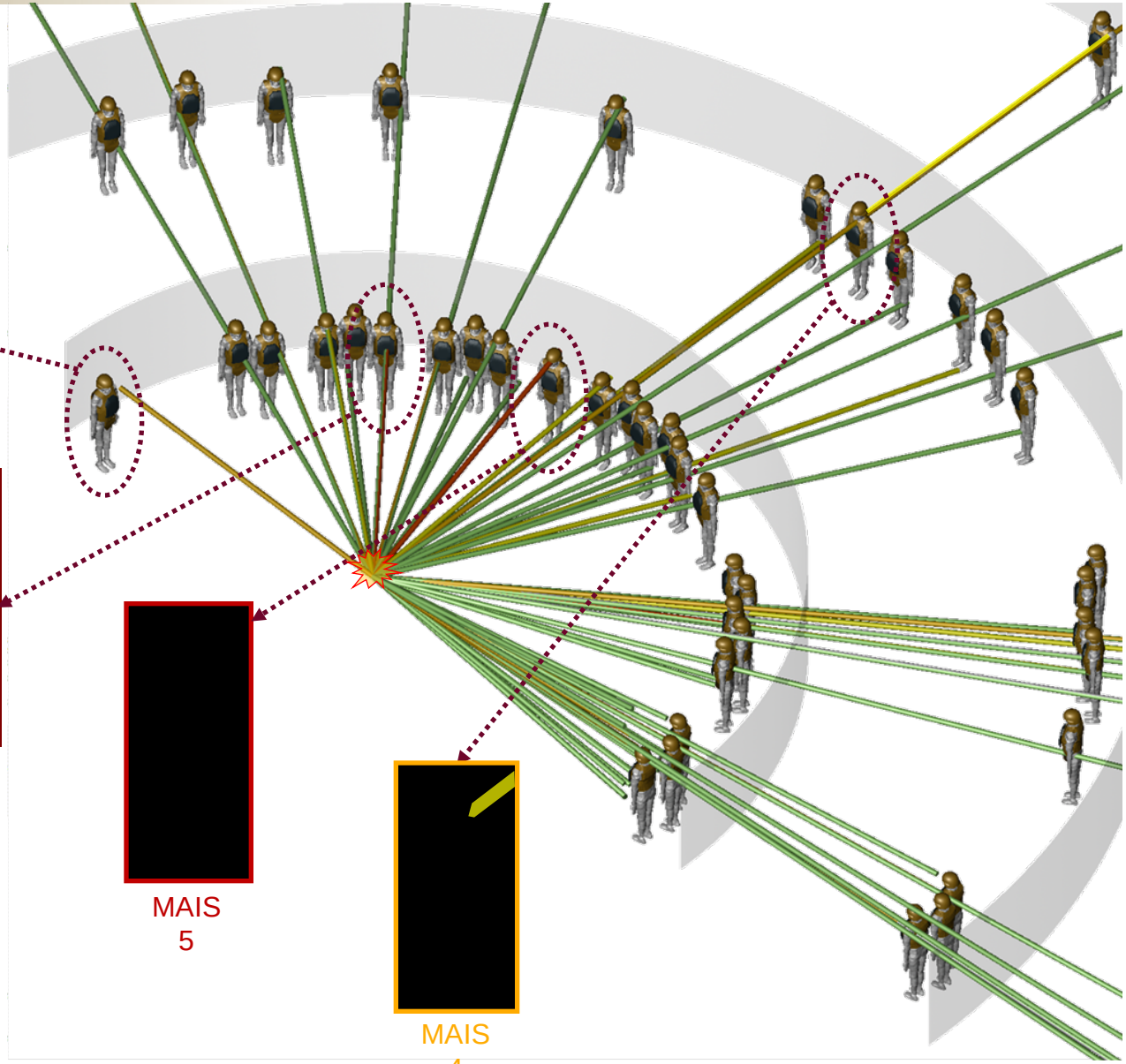
Example Analysis:
Characterizing Each Trajectory

MAIS	Injury Level
0	None
1	Minor
2	Moderate
3	Serious
4	Severe
5	Critical
6	Maximal



- The color of the trajectory line correlates to a MAIS value
- Figure illustrates distances where injury potentially goes to zero
  - 1 serious or greater injury occurred at 4x distance (circled in red)
  - 0 serious or greater injuries occurred at 5x distance

Example Analysis Continued:
Characterizing Each Trajectory



MAIS 4

MAIS 6

MAIS 5

MAIS 4

MAIS	Injury Level
0	None
1	Minor
2	Moderate
3	Serious
4	Severe
5	Critical
6	Maximal

Additional Testing and Analysis

- Characterize fragment spray with small scale arena tests
  - Additional threats
  - Additional attack angles
  - Different impact points on ACM (e.g., center of RA vs. side of RA)
  - Static vs. dynamic threat interaction
  - Multiple active ACM detonation
- Evaluate worse case test scenario (largest possible fragment spray)
  - Collect data at further distances
  - Use plywood mannequins in a representative troop formation
- Evaluate collateral damage to vehicles within proximity to ACM
  - Traffic scenarios
  - Patrolling scenarios
  - Other possible urban scenarios
- Evaluate collateral damage to ACM host vehicle and crew
  - Fragment spray in hatch area (if applicable)
- Evaluate injury from large projectiles
- Evaluate injury from blast overpressure

Questions