Review of Methodologies for Assessing the Blunt Trauma Potential of Free Flying Projectiles Used in Non-Lethal Weapons

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Acknowledgements

The National Institute of Justice
For
Supporting this Work
&
Donald Butz
For
Assistance and Guidance

Assessment & Methodologies

Basic Objective:

- Assess the likelihood of permanent injuries or those requiring medical treatment beyond simple first aid

Issues/Challenges:

- Numerous techniques/models for predicting injury
  - None consider all important parameters
- None of the techniques/models are validated
- May only be valid for only few projectiles and impact locations
- Impact may occur on any part of the body

Important Projectile Parameters

- Terminal kinetic energy
- Terminal momentum
  - Impulse delivered
- Impact duration
- Impact (contact) area
- Cross-sectional density and shape
- Compliance of projectile

The Combined Influence of These Parameters Produces the Terminal Effect

Important Target Parameters

- Age
- Weight
- Sex
- Health
  - Geographic health effects
- Location of impact

The Combined Influence of These Parameters Determines the Physiological Response/Outcome

Methodologies, Thresholds, and Test Methods to be Discussed/Compared

Kinetic Energy Based:

- Edgewood Arsenal Test Methodology and Thresholds
- Land Warfare Laboratory
- Swedish Ministry of Defense, Clemedson *et al.*
- British Ministry of Defence, Cooper *et al.*

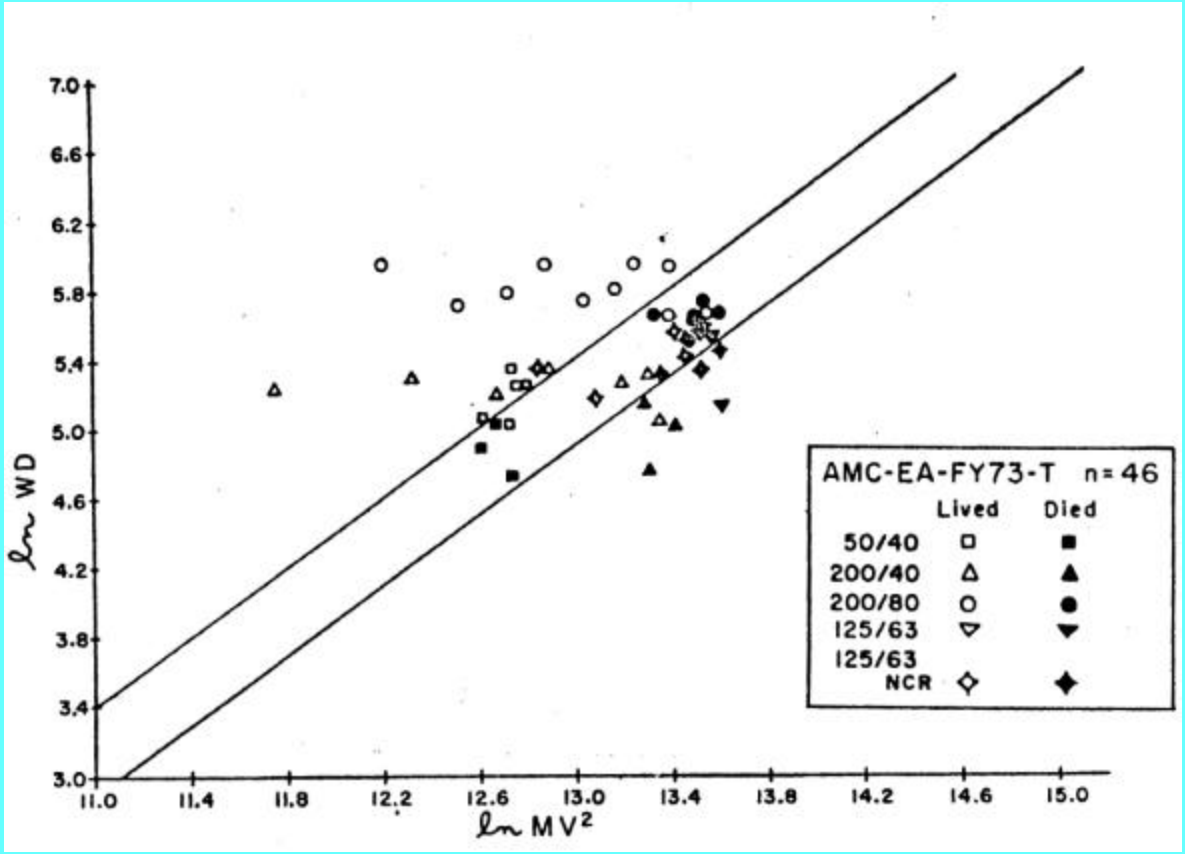
Anthropomorphic Simulator Based:

- Viscous Criteria, Cindy Bir
- WRAIR/JAYCOR Finite Element Model

Calculations with Estimated Impact Conditions

- WRAIR/JAYCOR Interim Total Body Model

Edgewood Arsenal Goat Data



W = mass of target, kg D = diameter of projectile, cm

M = mass of projectile g V = velocity of projectile m/sec.

"Blunt Trauma Data Correlation" V. R. Clare, et al, Edgewood Arsenal report AD-A012 716, Fig 7, pg. 21. (1975).

Regression Analysis of Data

$$P_{(\text{Edgewood})} = \frac{1}{1+\exp[\alpha+\beta \ln(MV^2/WD)]}$$

P = probability of death due to thorax impact

$$P_{(\text{Sturdivan})} = \frac{1}{1+\exp[\alpha+\beta \ln(MV^2/TW^{1/3}D)]}$$

P = probability of death within 24 hr due to thorax impact

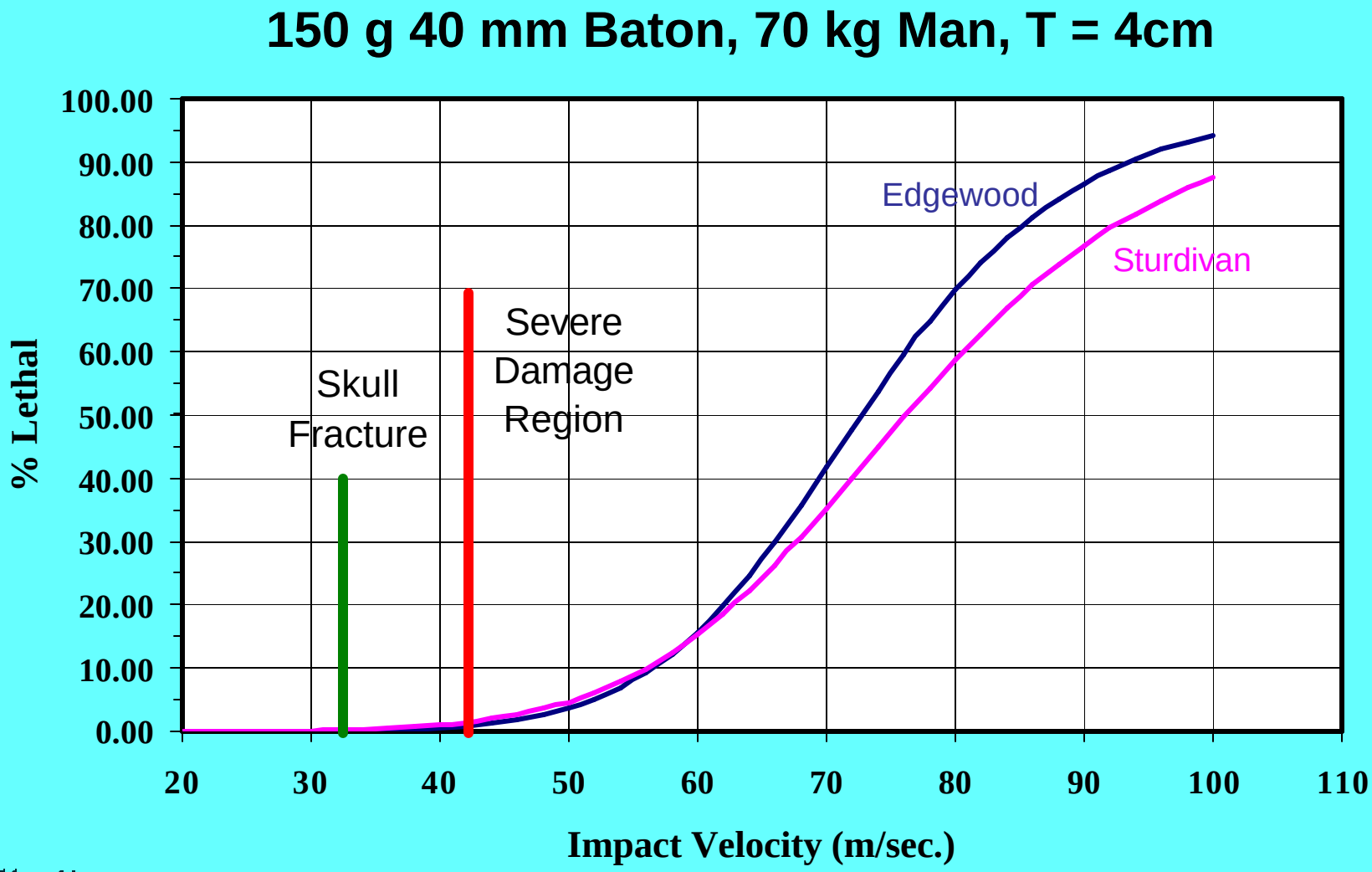
Land Warfare Laboratory Results

- Kinetic energy thresholds
- Probability of undesirable effect (P_{ue})
  - Animal necropsy results
  - Extrapolated to humans
- 90 ft-lbs. and above severe damage region, 90-30 ft-lbs. dangerous, below 30 ft-lbs. safe
- Heart is one of the least vulnerable organs
- Liver is one of the most vulnerable organs
- Other findings releasable to US Gov. only

Clemedson's Results

- Skull fracture at 33-75 ft-lb., (avg. 50) for 5 oz steel ball; liver is critical abdominal organ. (similar to automobile drop weight tests)
- Relative tolerances
  - Small liver fractures heal naturally
  - Low vel. liver injury more extensive than brain injury
  - Liver injury occurs at lower impact vel. than lung injury (excluding blast injury)
  - Fatal head injury occurs at much higher velocity than fatal liver injury

Comparison of EA Models and Kinetic Energy Thresholds



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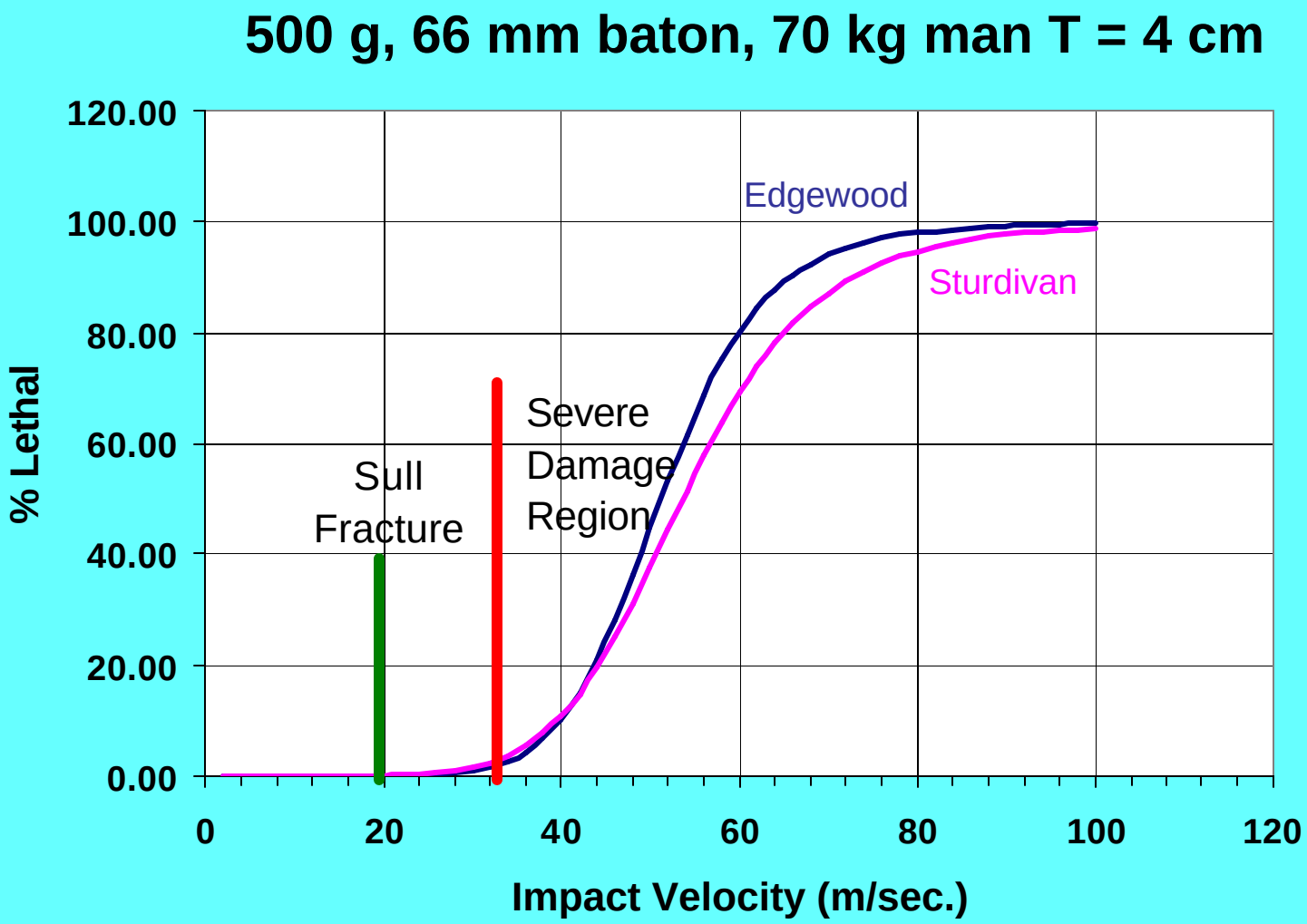
Comparison of EA Models and Kinetic Energy Thresholds for Heavy Projectiles



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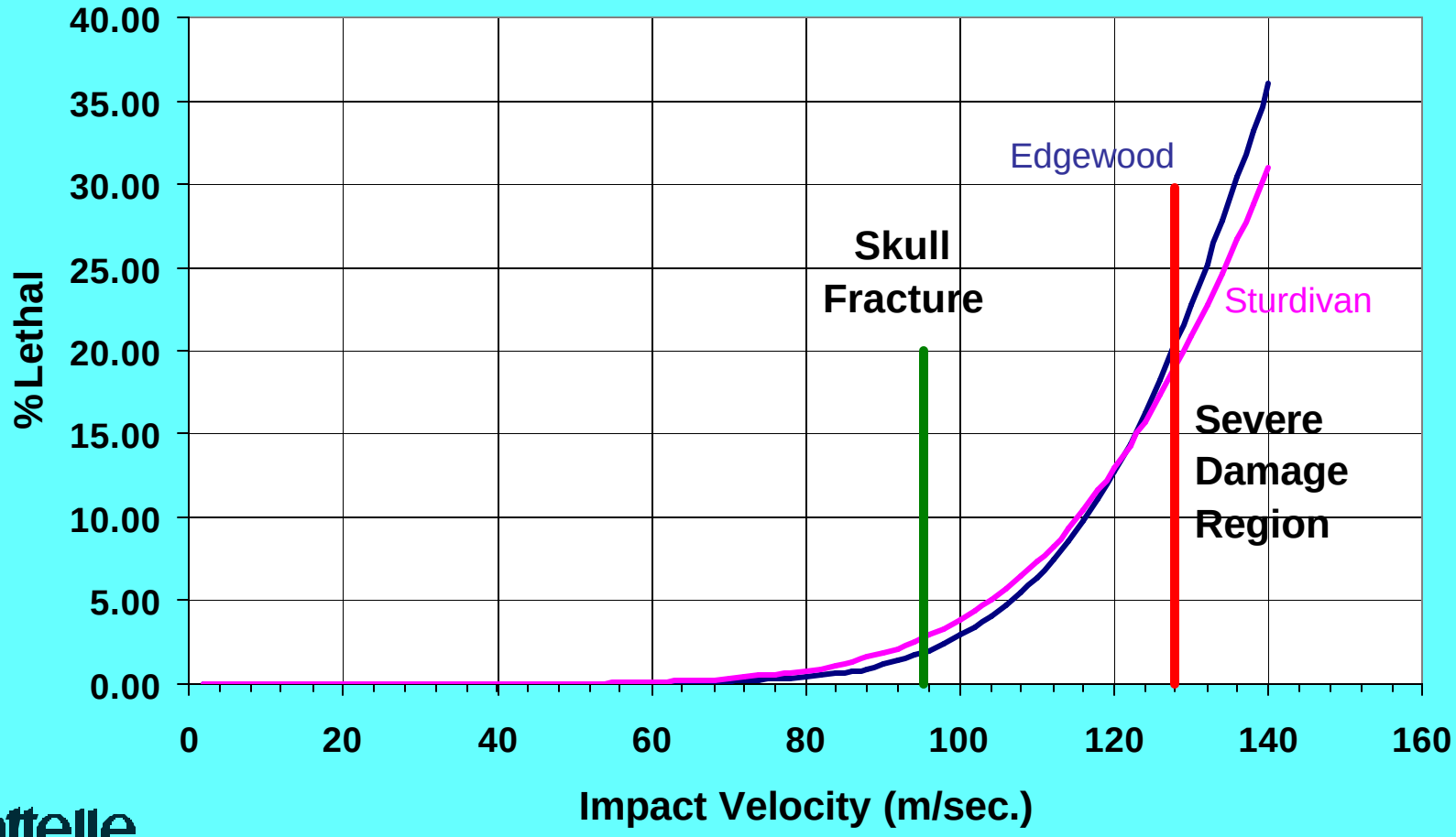
Comparison of EA Models and Kinetic Energy Thresholds for Light Projectiles

15 g, 18 mm rubber bullet, 70 kg man T=4 cm



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Cooper's Chest Deflection Equations

Chest deflection = $10.3\ (1-e^{-0.6(E/D(AP))})$

Normalized chest deflec. = $0.4(1-e^{-0.95(E/WD)})$

where:

E = kinetic energy (joule)
D = projectile diameter (cm)
(AP) = anterior to posterior chest dim. (cm)
W = animal mass (kg)

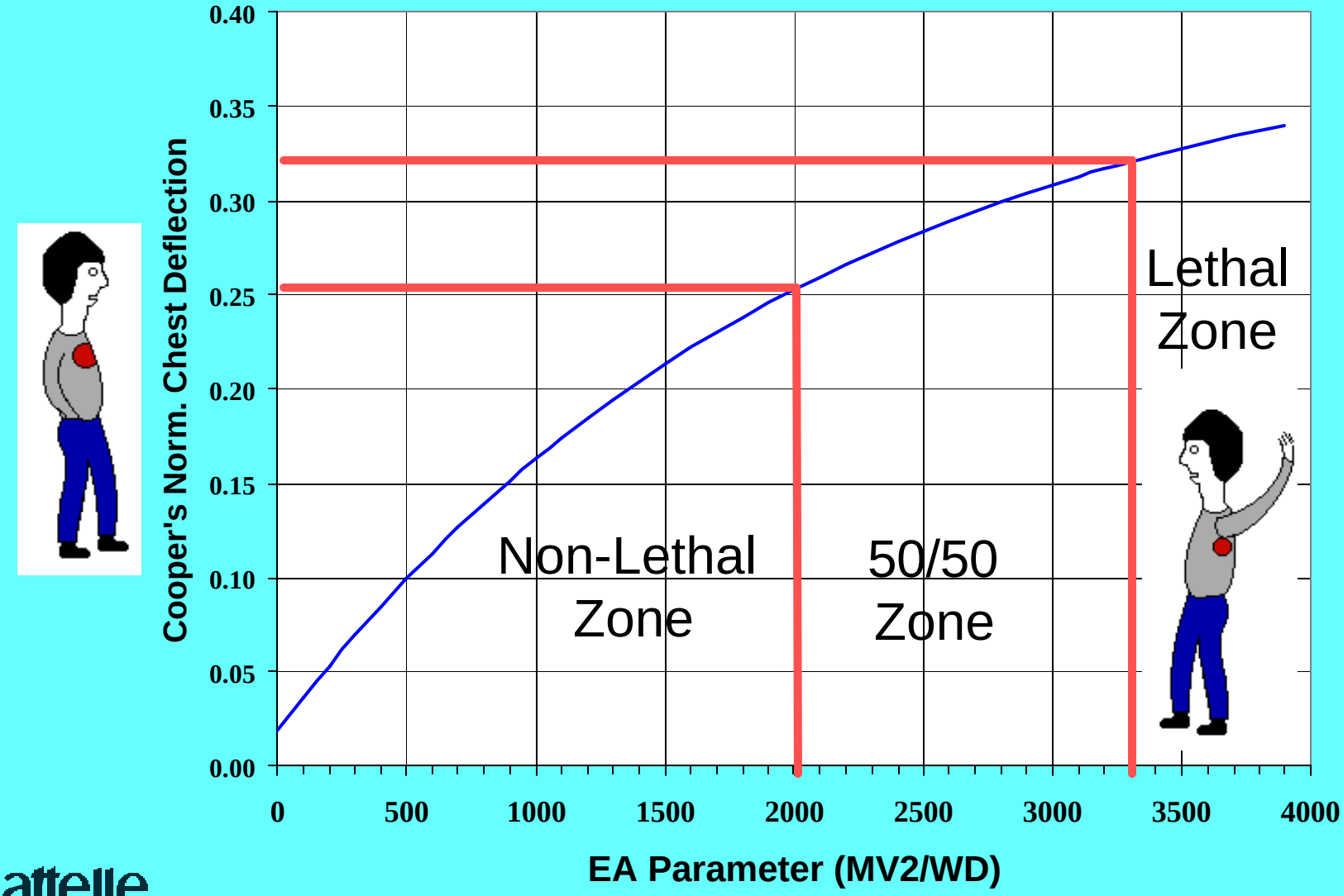
Cooper's NCD Equation and EA Parameter (MV^2/WD)

$$\text{Normalized chest deflec.} = 0.4(1-e^{-0.95(E/WD)})$$

$$\text{Cooper's } (E/WD) = \frac{1}{2(1000\ g/kg)} \text{ X } (MV^2/WD)$$

EA Parameter

Cooper's Normalized Chest Deflection as a Function of EA Parameter MV^2/WD



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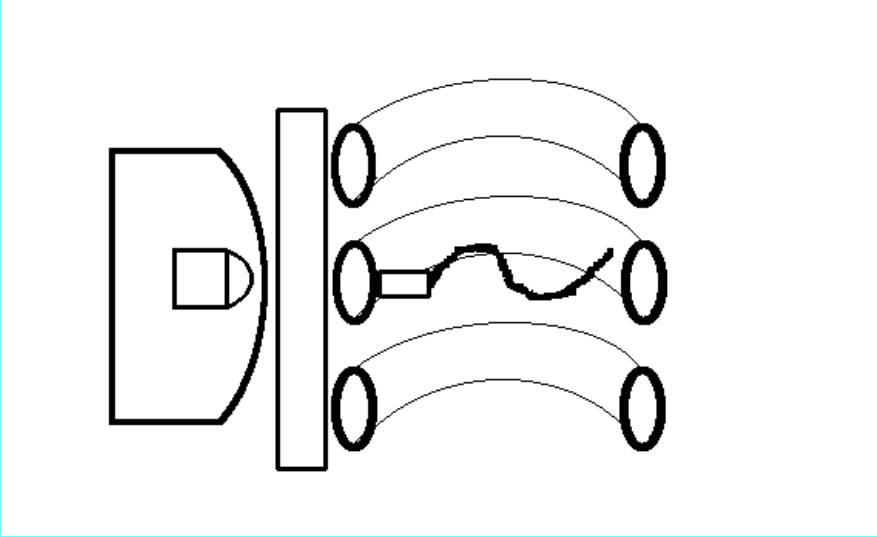
Three-Rib Chest Structure for Blunt Impacts

VC_{max} of 1 m/sec = 25% chance of >AIS level 3 injury



Linear transducer or accelerometer attached to center rib

- Impact location can affect measurement value
- **Does impactor diameter change interpretation of measurement?**
- Resulting "rib" velocity may be outside linear range of measurement device and validation range for VC

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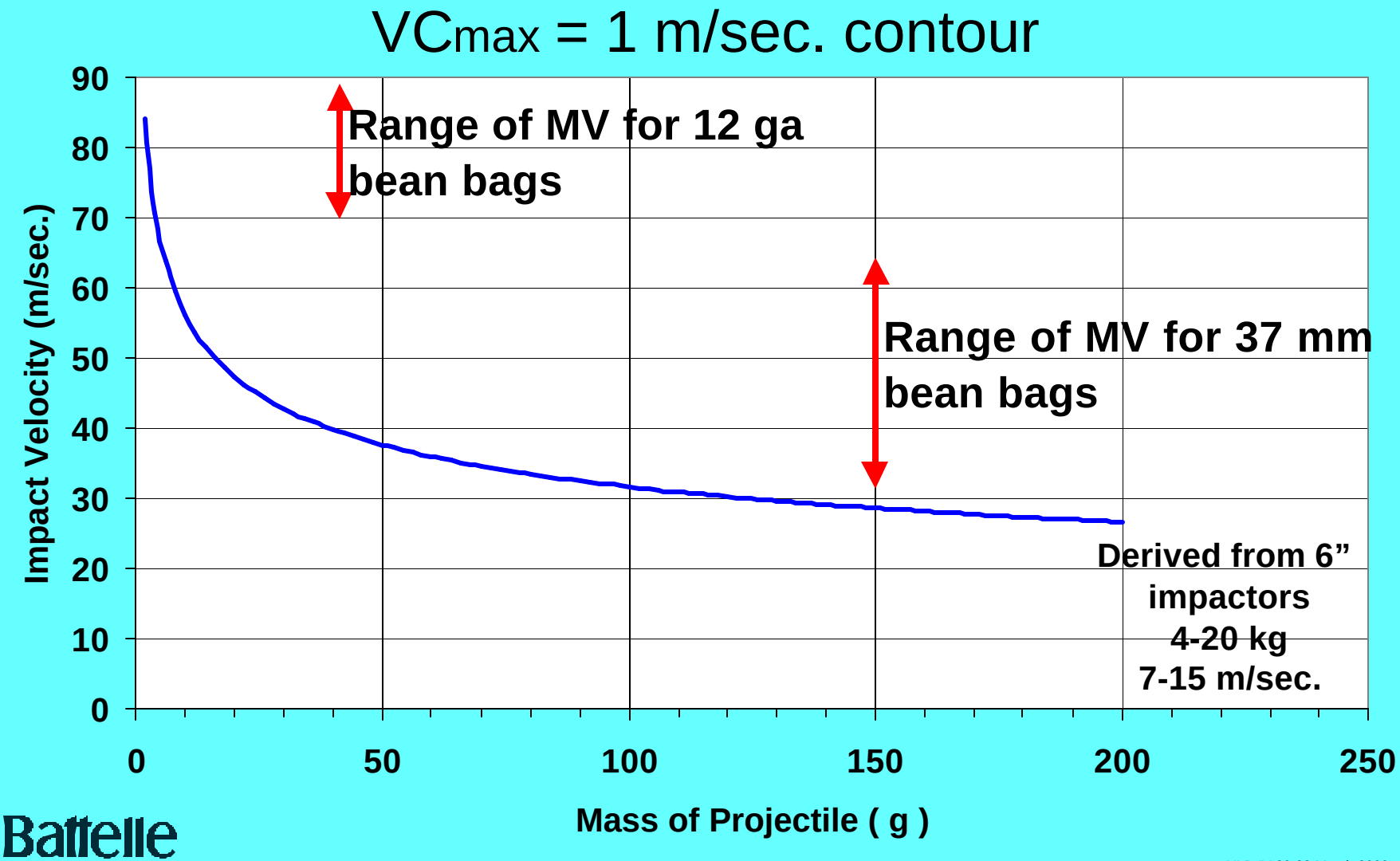
1 m/sec. Viscous Criterion, Tolerance Threshold



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WRAIR Interim Whole Body Model

Presently Consists of Simple Calculations to Estimate Impact Effects

- Head impact effects calculated from impactor momentum and impact duration.
- Torso effects calculated from impactor mass, velocity, diameter and target mass and tissue thickness.

Future Versions will Use a Finite Element Model of the Torso

- Irreversible work done to the lungs and other terminal effects calculated from experimentally measured force time curves.

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JAYCOR Test Device for NLW Impacts

- Impact force is transferred across a linear bearing to a force gage.
- Force/Time record is used as input to calculate irreversible work done to the lungs
- Rubber padding on impact surface increases duration of impact and may simulate soft tissue

✷ In the absence of biofidelity -- **Are the force time histories appropriate for calculating work done to the lungs?**

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ITBM Injuries & Tolerances

Type of Injury	Tolerance
Head	
Cerebral Concussion I	V_{max} = 2.70 m/sec
Cerebral Concussion II	V_{max} = 4.90 m/sec
Diffused Axonal Injury	V_{max} = 6.20 m/sec
Skull Fracture	HIC = 450
Mandible Fracture	F_{max} = 1780 N
Thorax	
Severe Lung Contusion (1%)	Work = 0.0195
Fracture of Ribs (1%)	VC_{max} = 0.26 m/sec
AIS > 4 (1%)	VC_{max} = 0.38 m/sec
Heart Lesion (1%)	VC_{max} = 0.50 m/sec
Heart Rupture (1%)	VC_{max} = 0.64 m/sec
Ventricular Fibrillation	V_{max} = 10.70 m/sec
Lethality (1%)	S = 8.21
Abdomen	
Liver Laceration (1%)	VC_{max} = 0.72 m/sec
Lethality (1%)	S = 8.85
Penetration	
Skin	E/A = 2.10 mkgf/cm^2

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Issues of Models and Thresholds Discussed

- Edgewood Arsenal Models
  - Impact location corresponds to under the armpit on humans
  - Gross level estimate: live or die within 24 hr. no information on severity of injury
  - Degree of accuracy unknown for body masses above 70 kg
  - Severity of sternum impacts is overestimated
- Other Kinetic Energy Thresholds
  - Do not take into account many of the important projectile and target properties only valid for a narrow range of situations

Issues of Models and Thresholds Discussed Continued

- **Viscous Criteria**
  - Are the tolerance levels used appropriate for NLW?
  - What is the influence of projectile diameter on the interpretation of the VC_{max}?
- **Interim Total Body Model**
  - Heavily dependent on projectile momentum
  - Heavily dependent on estimates of impulse
  - Heavily dependent on estimates of impact duration
  - Concussion and skull fracture thresholds are inconsistent
  - Can lung tissue be modeled as a gas?
- **JAYCOR Test Device**
  - Lacks biofidelity, measurements relate to properties of the test device materials

Conclusions and Recommendations

Conclusions:

- Anthropomorphic based test methodologies are the most suitable for evaluating blunt impact weapons
  - However, the presently used thresholds may not be correct for NLW

Recommendations:

- Determine if the injury tolerances used for estimating injury under automobile accident conditions are applicable to typical NLW
- Determine if impactor diameter effects the measurement and calculation of VC_{max}
- Develop an understanding of the influence of projectile parameters on the thresholds