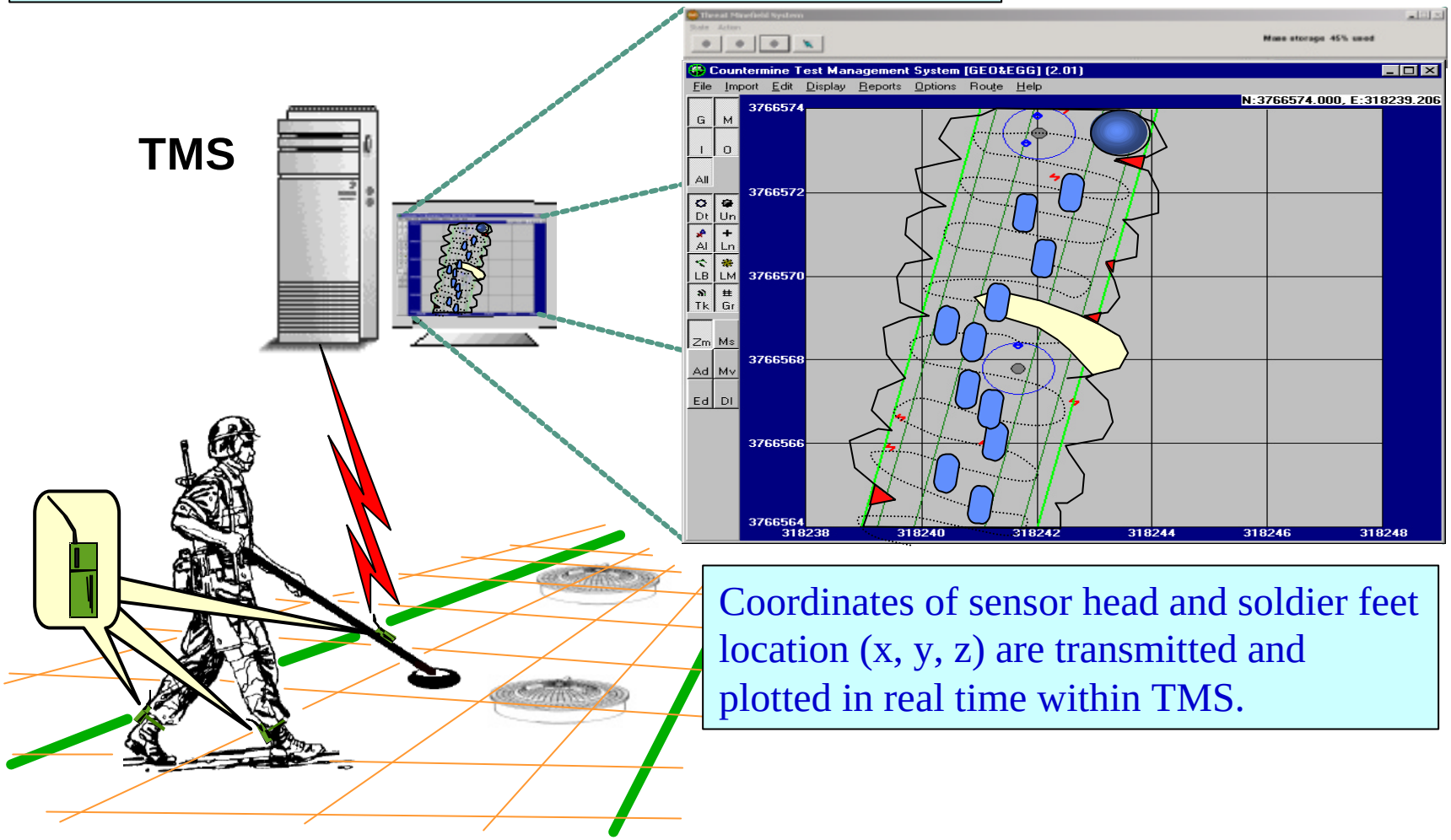
Lethality to Humans Due to Blast Effects from Buried Landmines

Sponsored by
U. S. Army
Project Manager Instrumentation, Targets and Threat Simulators (PM ITTS)

Presented by
Scientific Research Corporation
Norman Morris, Sr. Engineer

Motivation: Threat Minefield System (TMS)

TMS supports countermine testing and training with real time position and sensor data collection and analysis.

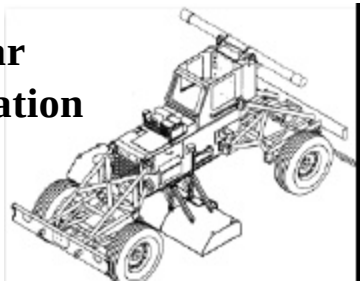


Coordinates of sensor head and soldier feet location (x, y, z) are transmitted and plotted in real time within TMS.

Threat Minefield System Overview

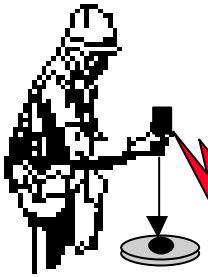
Operator Instrumentation

Vehicular Instrumentation

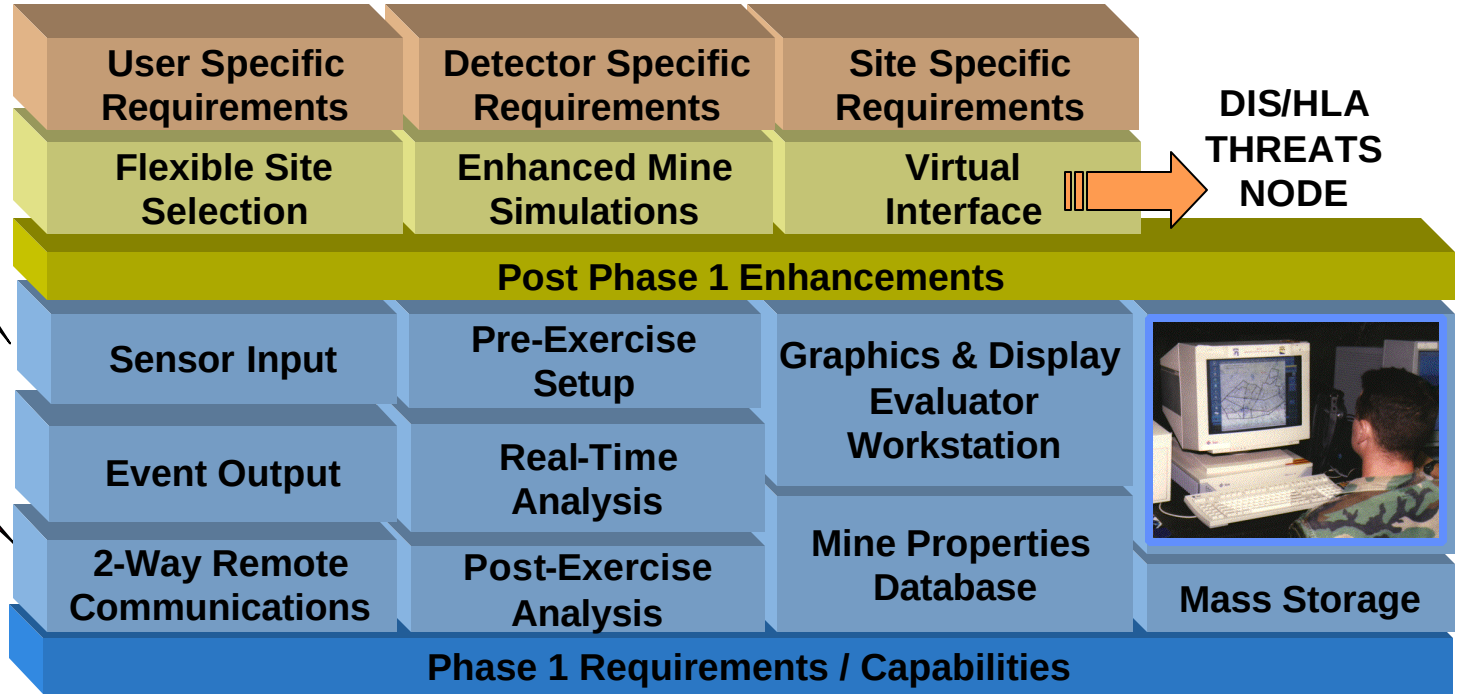


TMS will Enable:

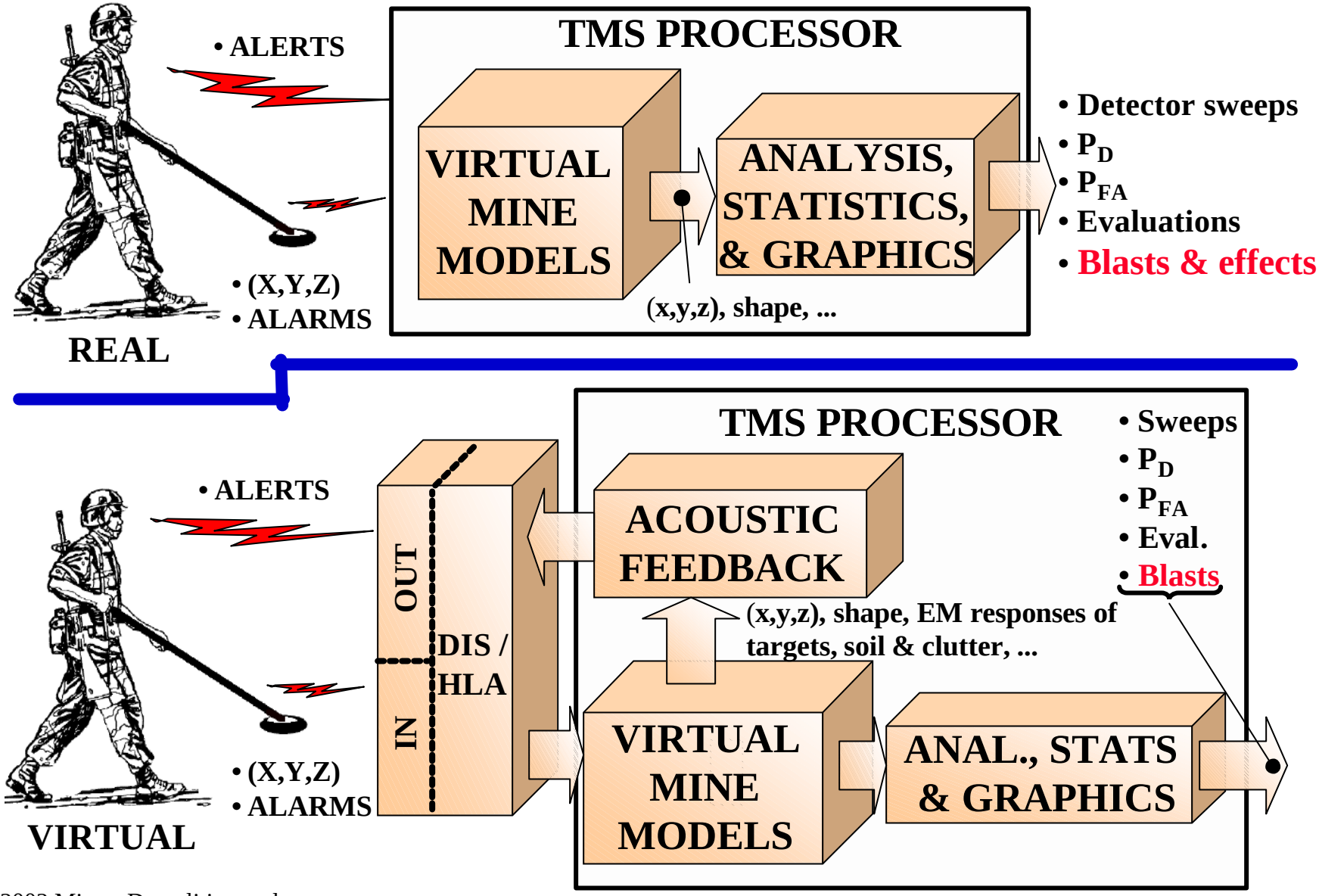
- Actual and Virtual Minefield Environments
- Real-time Operator Analysis Capability for Training
- Testbed for De-mining Instrumentation Development



Surveyor Instrumentation



TMS Real and Virtual Processing

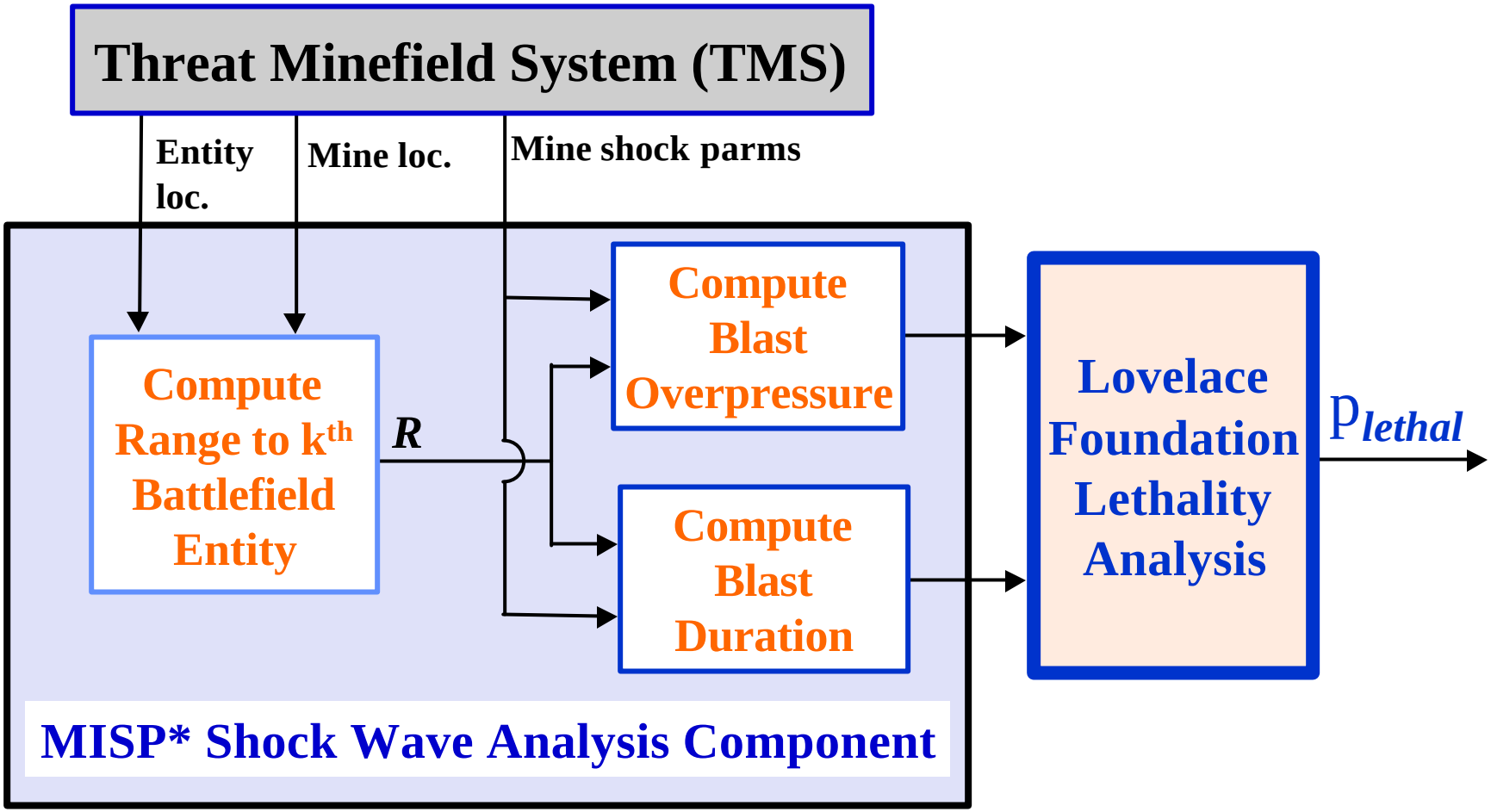


I

LETHALITIES DUE TO SHOCK WAVES

TMS/MISP Blast Effects System - Shock Wave

When a mine detonation occurs:

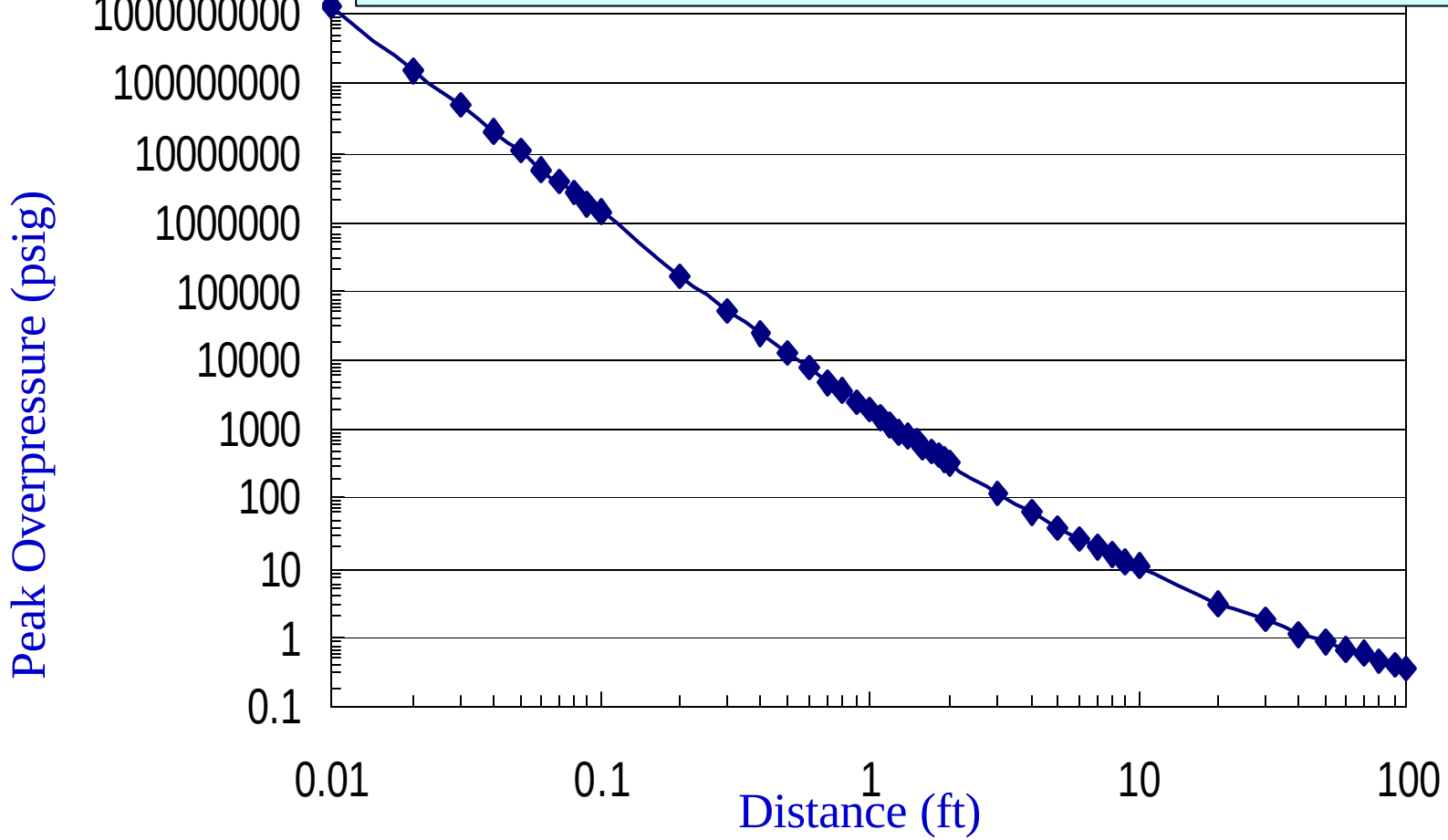


*Mine Interaction Simulation Program

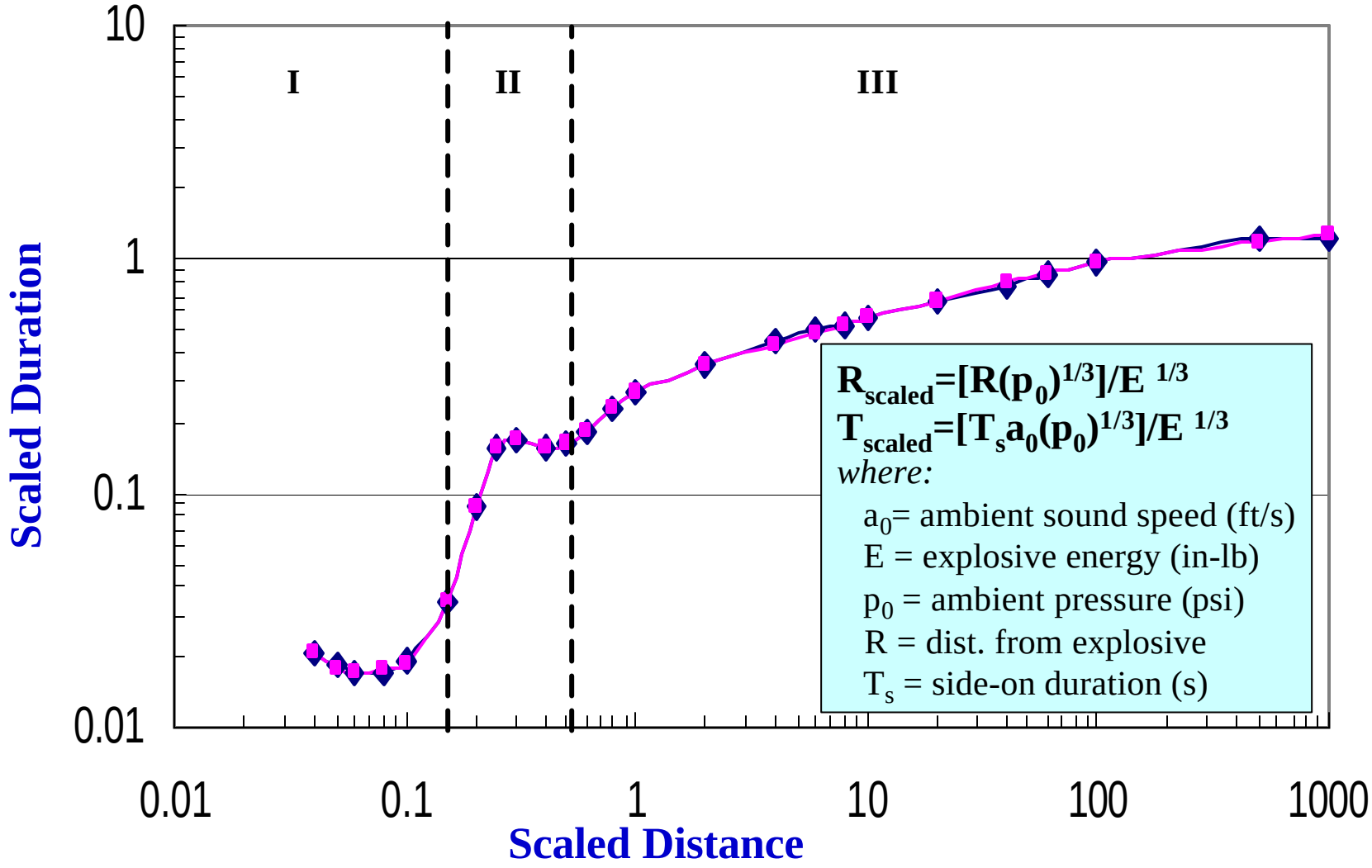
Peak Overpressure vs. Distance (Mahn)

$$P_{over} \simeq 29/Z + 552/Z^2 + 1106/Z^3$$ *where:*

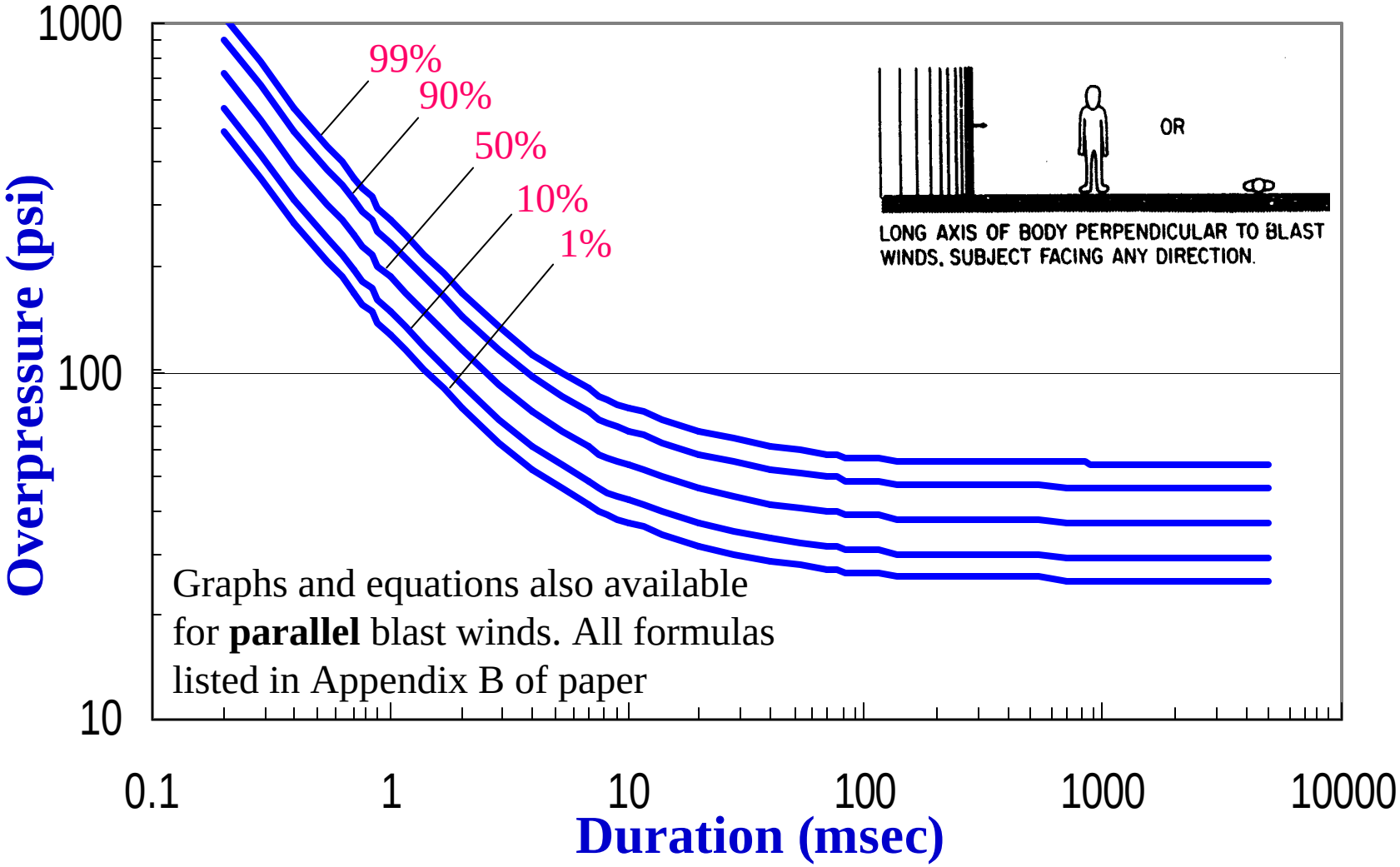
Z = (dist. from explosive) ÷ (wt. of TNT to match explosive effect)$^{1/3}$



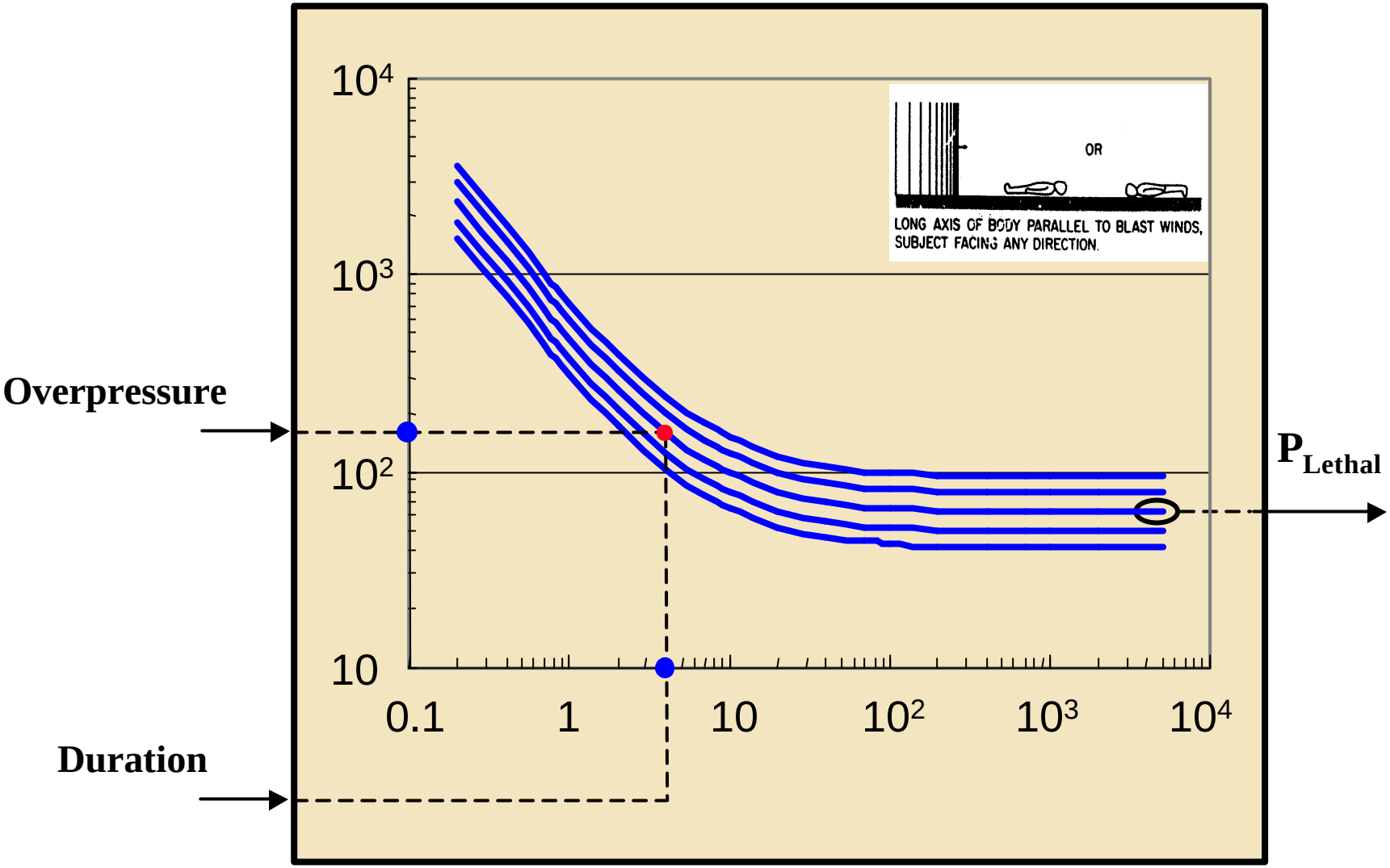
Shock Wave Duration vs. Distance (Baker)



Lethality Due to Shock Waves (Lovelace)



Use of Lovelace Foundation Analyses

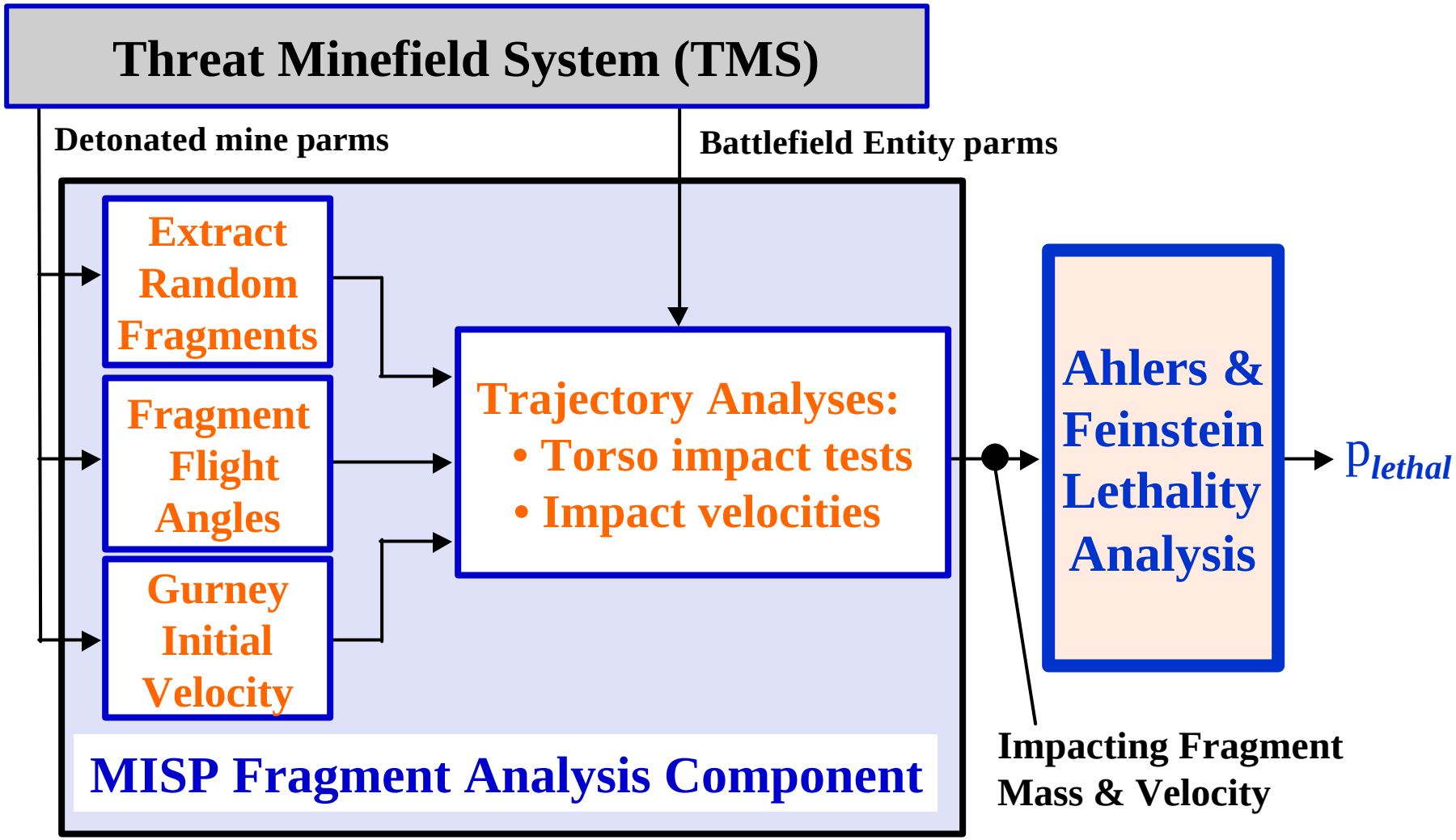


II

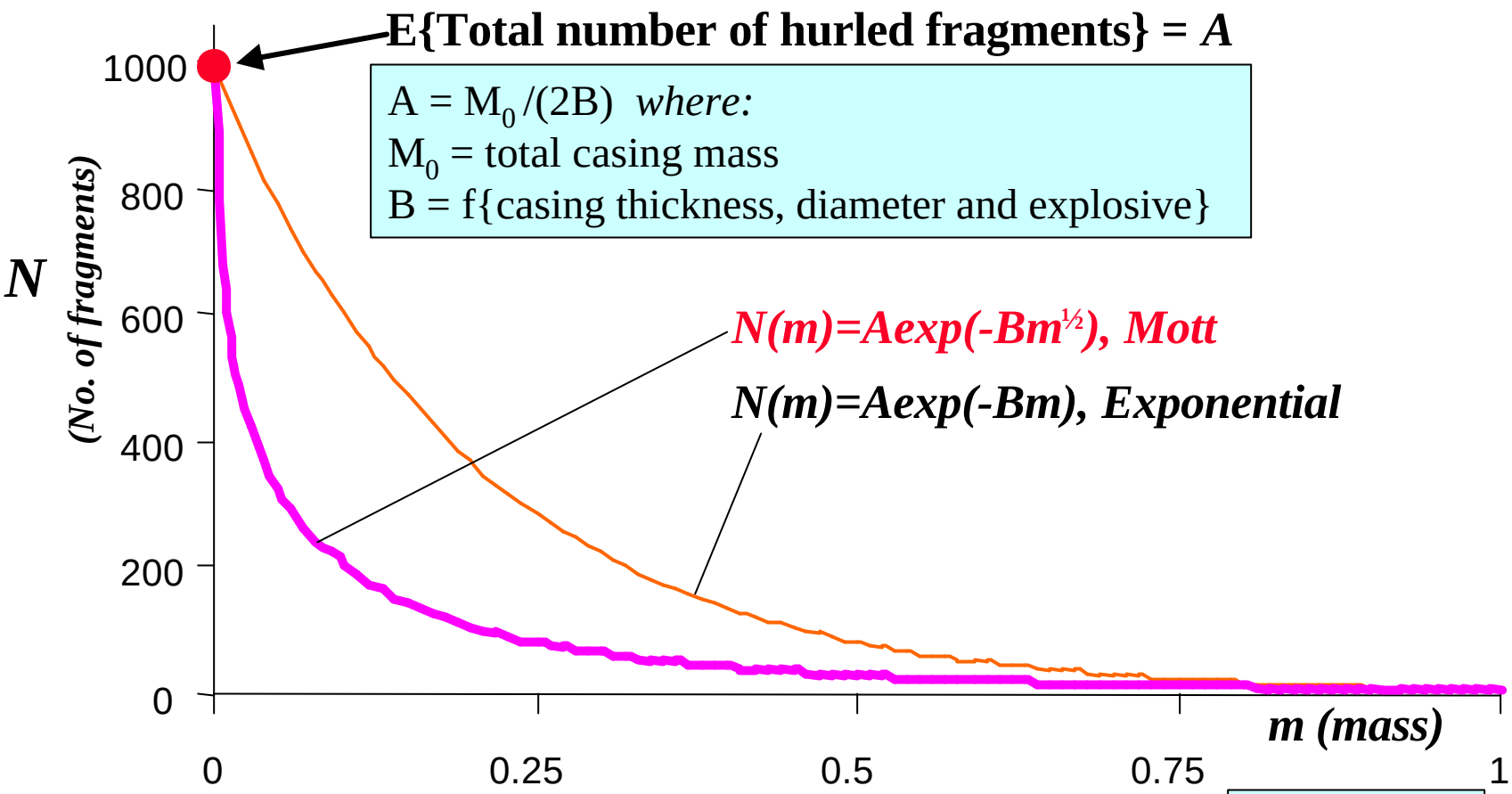
LETHALITIES DUE TO CASE (PRIMARY) FRAGMENTATION

TMS/MISP Blast Effects System - Fragmentation

When a mine detonation occurs:

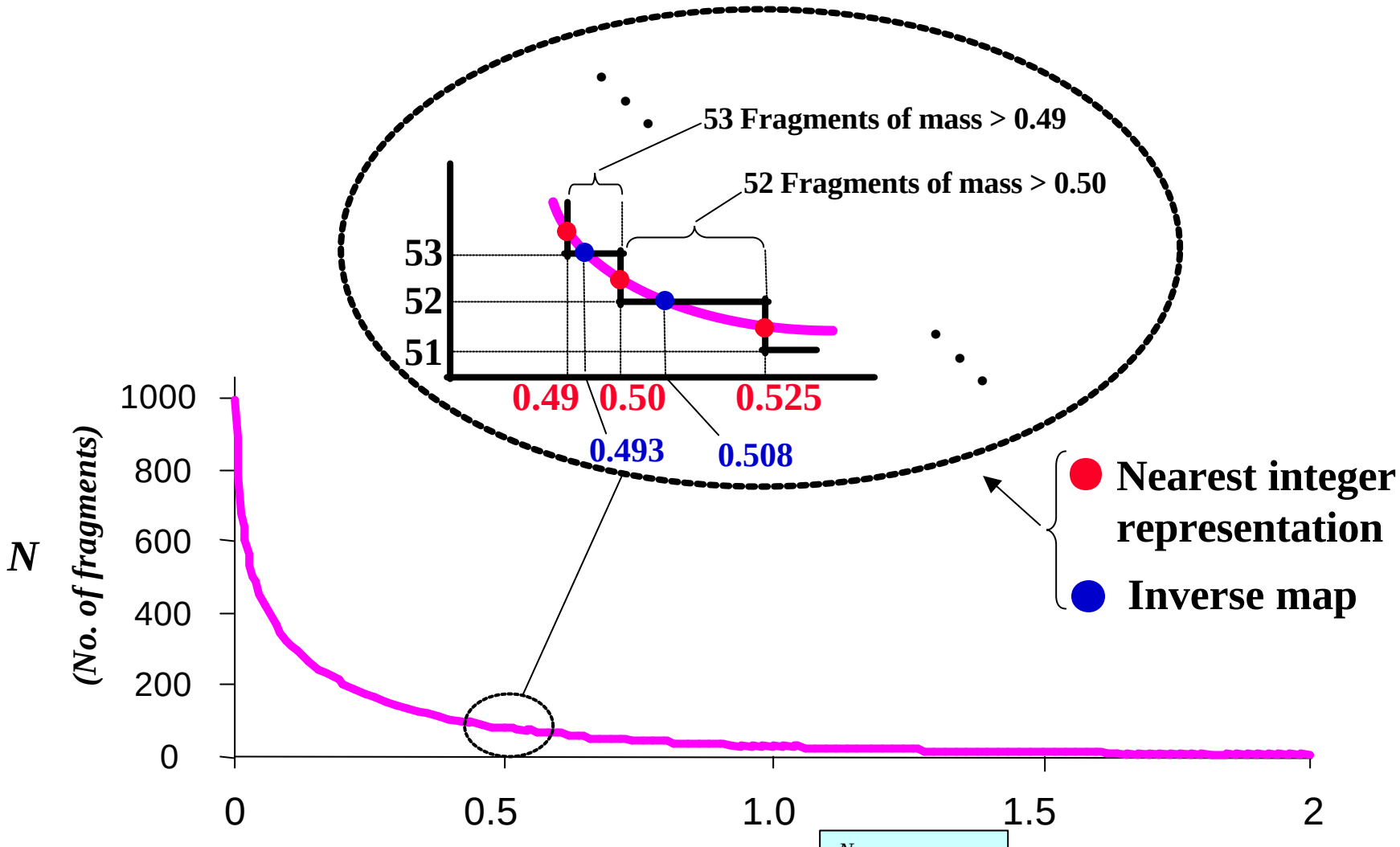


Mott's Distribution of Fragments



$$\sum_{i=1}^{N} m_i = M_0$$

Illustrative Example for Mott's Usage

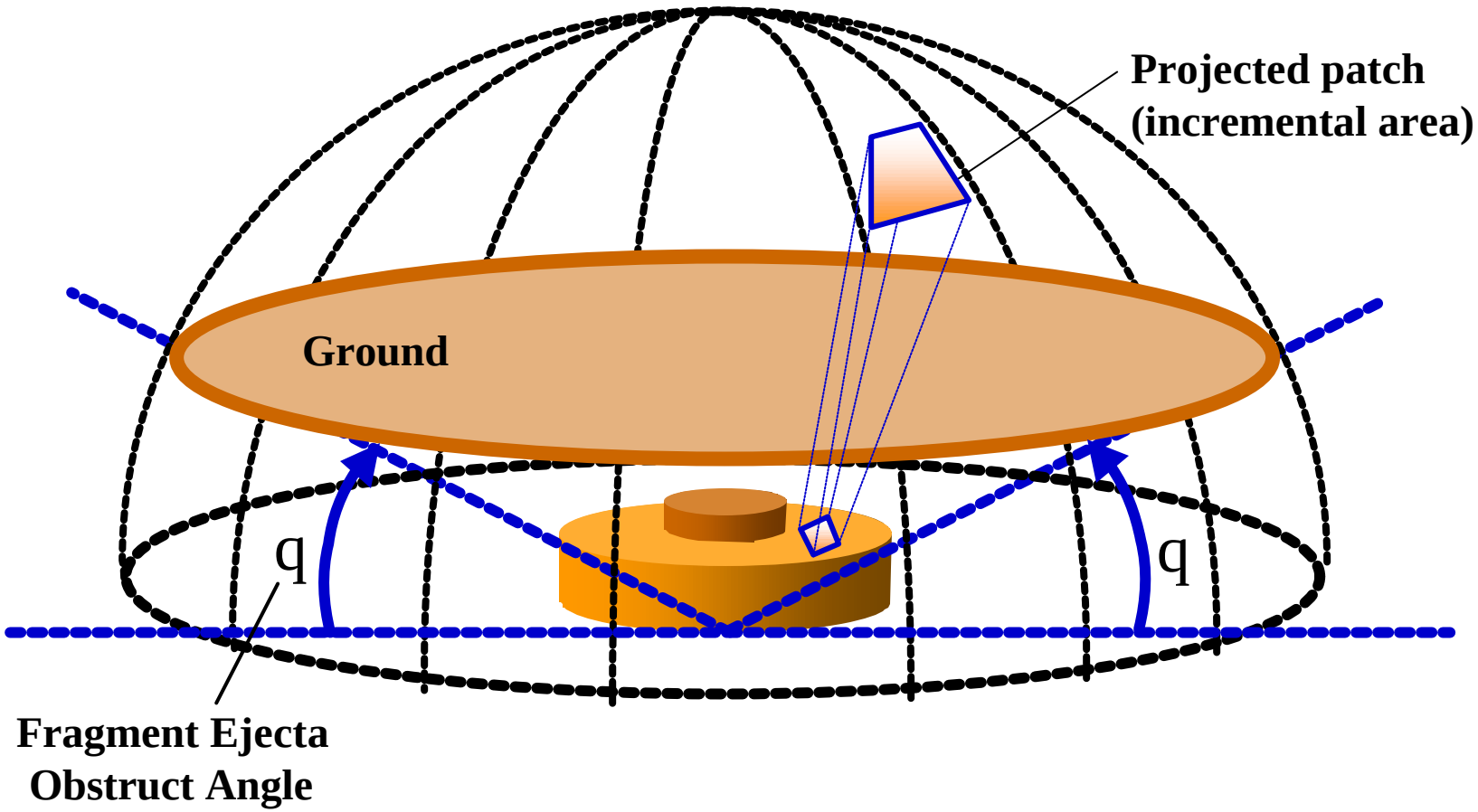


$$\sum_{i=1}^{N} m_i = M_0$$

Ejected Fragment Flight Angles and Densities

Assume:

- **Fragments eject at right angles to the surface.**
- **Fragment density is uniform on casing.**



Initial Fragment Velocity Formula (Gurney)

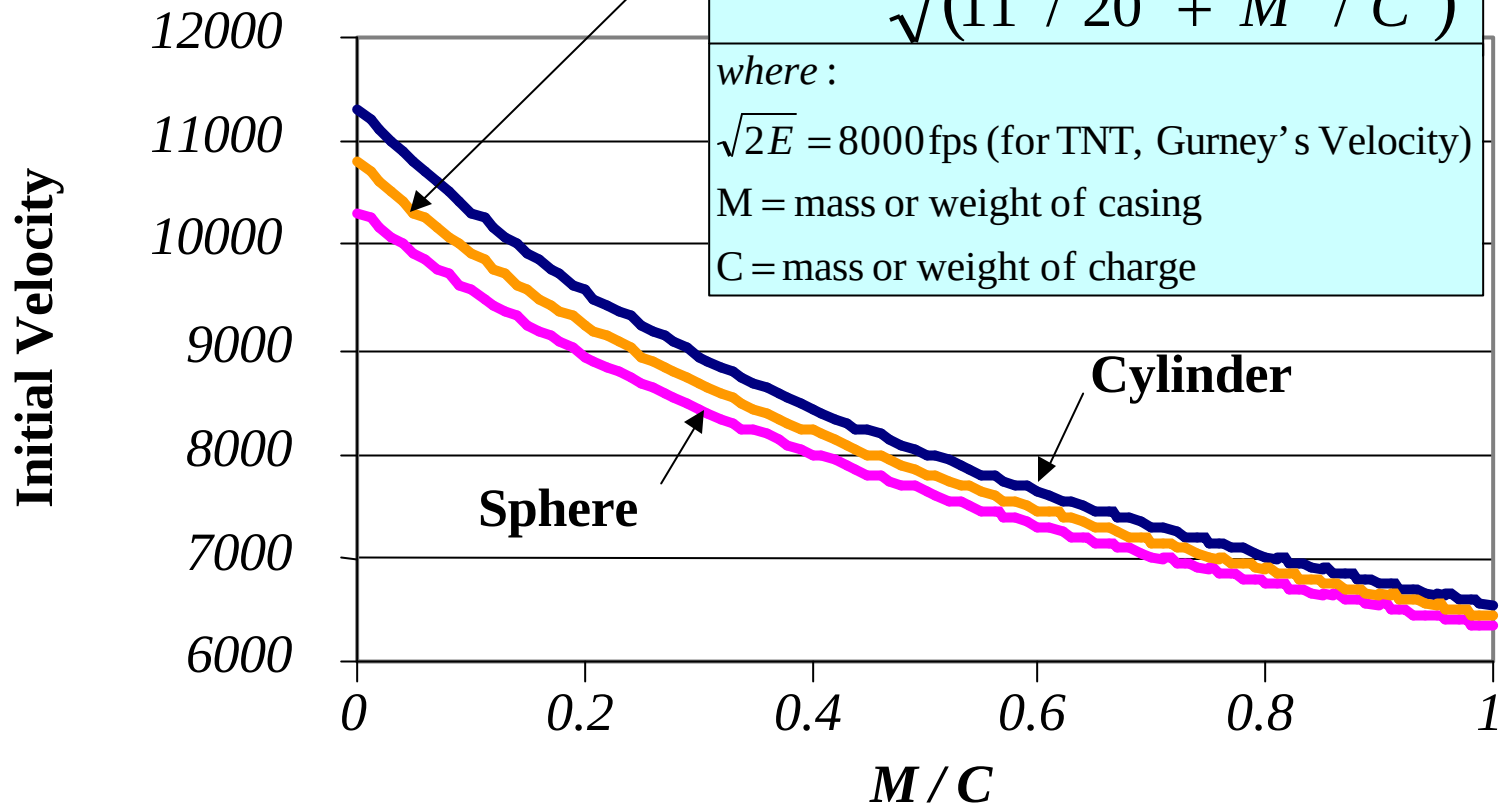
$$V_0 = \frac{\sqrt{2E}}{\sqrt{(11/20 + M/C)}}$$

where:

$\sqrt{2E} = 8000$ fps (for TNT, Gurney's Velocity)

M = mass or weight of casing

C = mass or weight of charge



TMS/MISP Blast Effects System - Fragmentation

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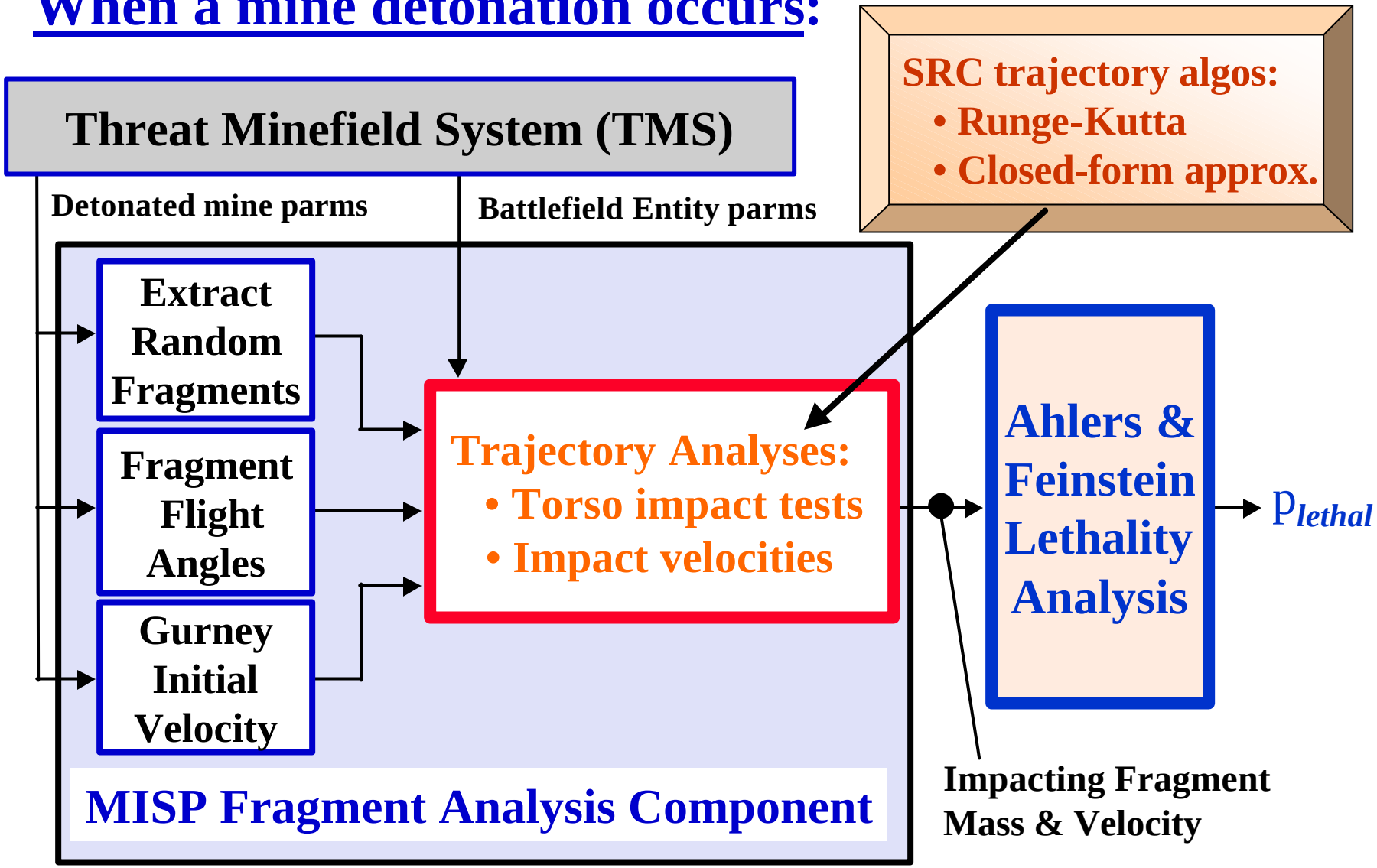
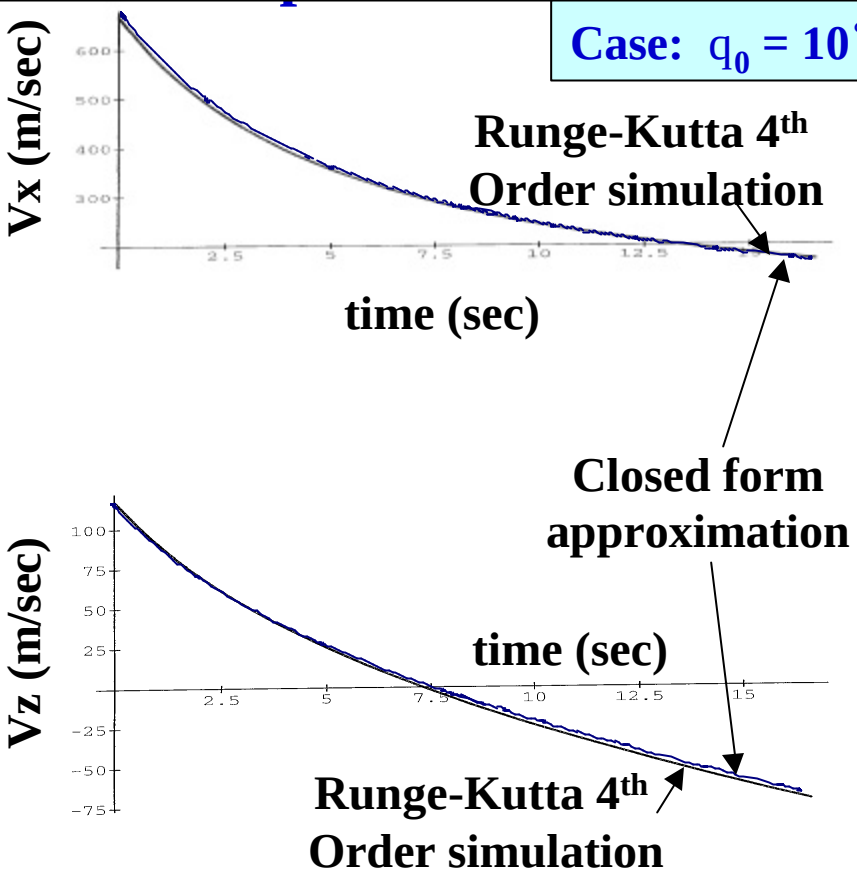


Trajectories & Velocities

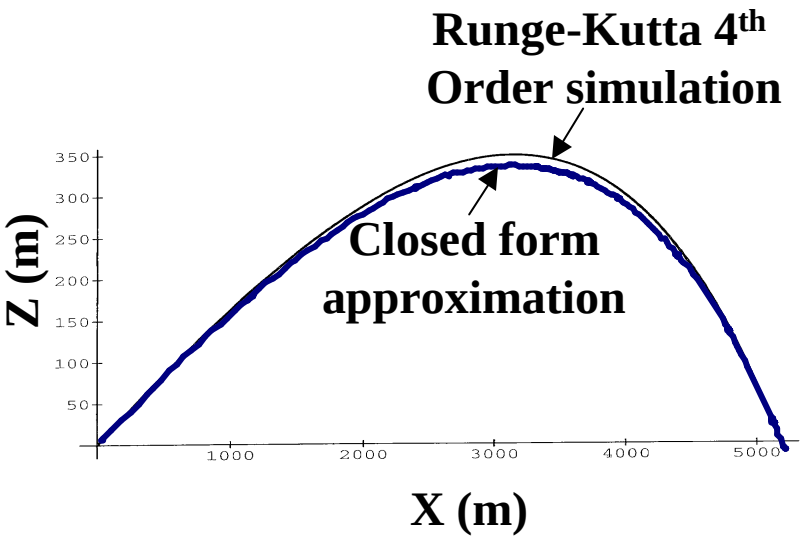
Runge-Kutta vs. Closed-Form

Component Velocities

Case: $q_0 = 10^\circ$, $v_0 = 677$ m/sec

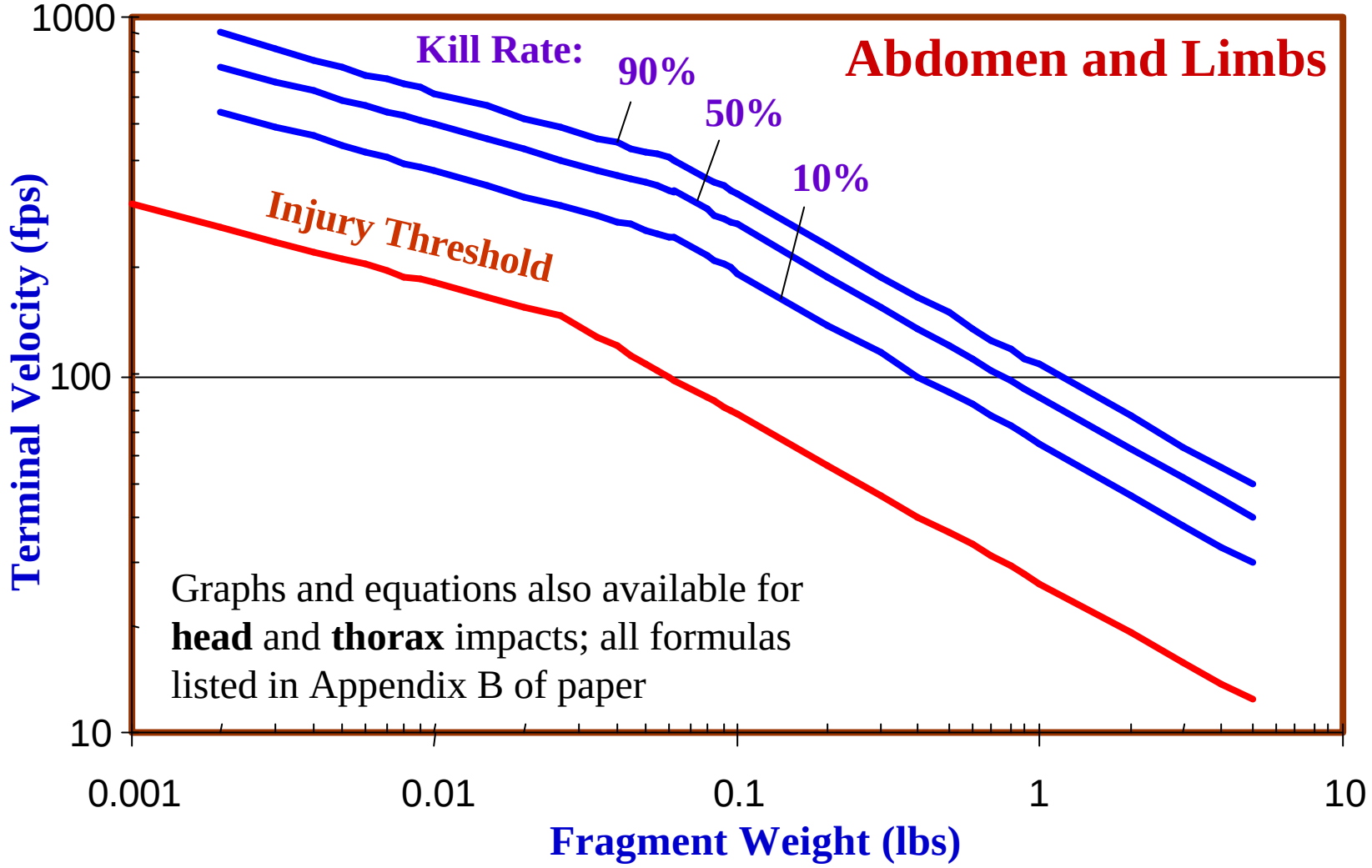


Trajectory



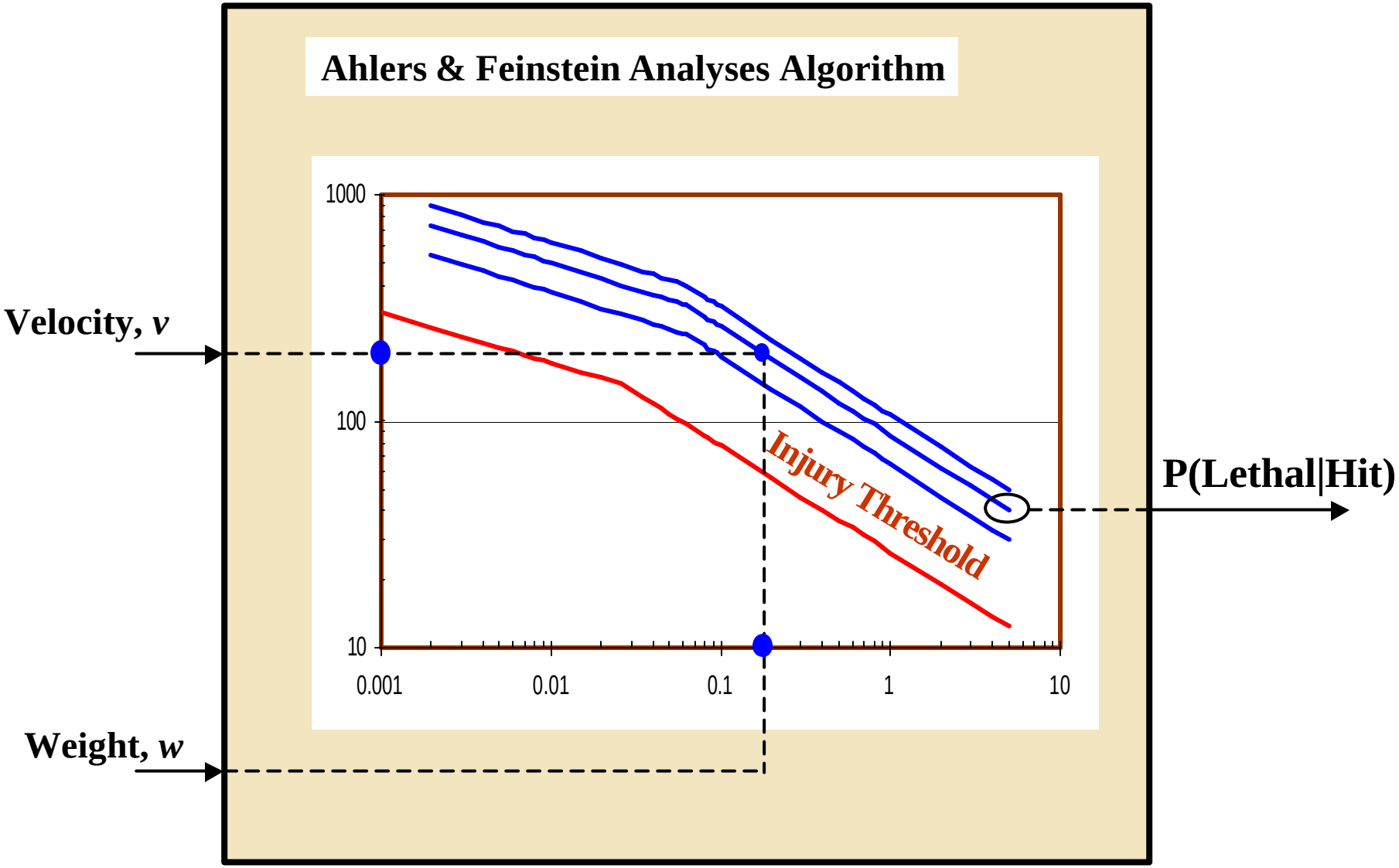
Formulas and algorithms for above approaches listed in Appendix A of paper.

Lethality Due to Fragment Impact (Ahlers)



Graphs and equations also available for **head** and **thorax** impacts; all formulas listed in Appendix B of paper

Use of Ahlers & Feinstein Analyses



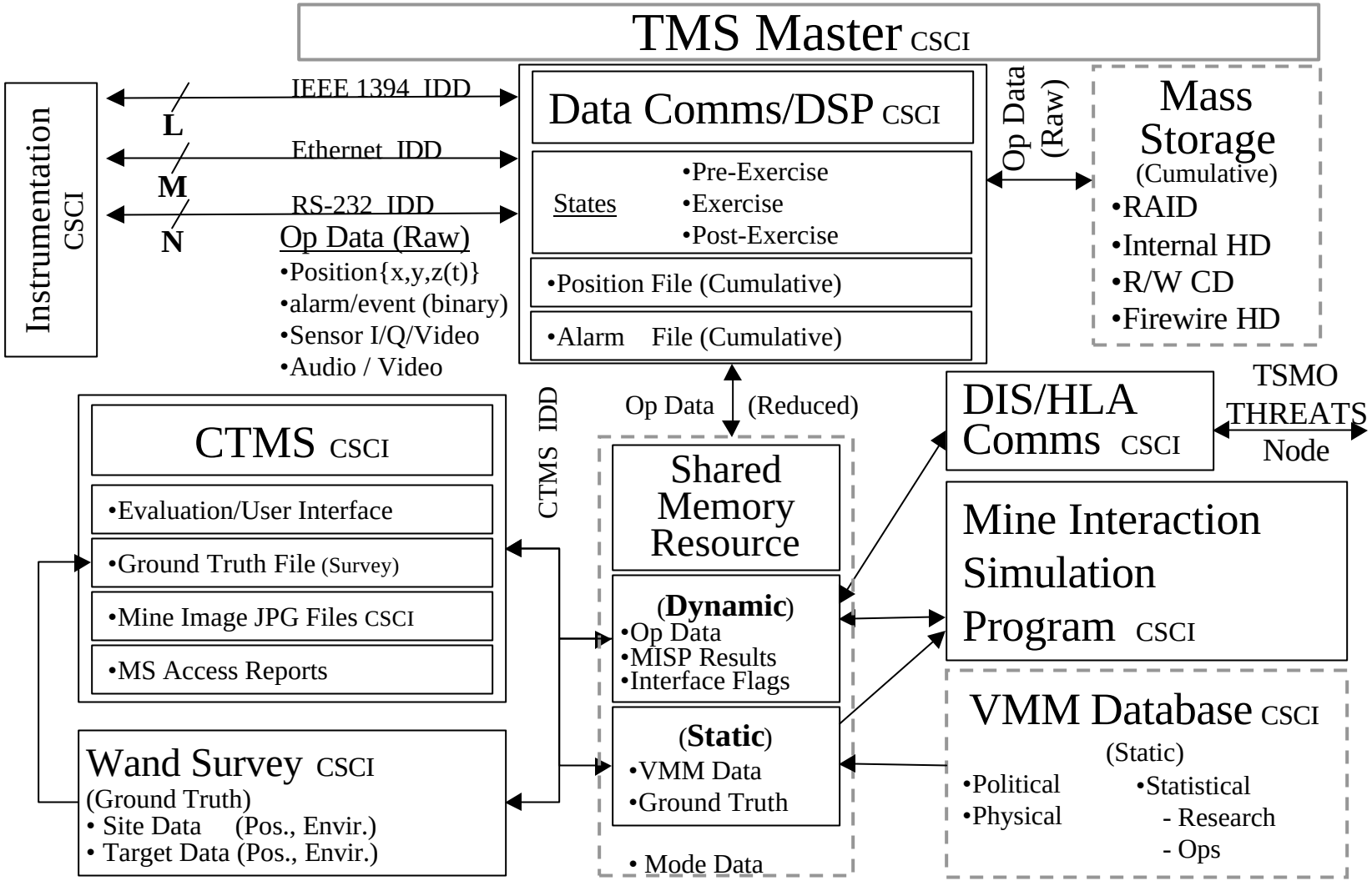
Summary

- **Motivation...The Threat Minefield System (TMS)**
- **Shock wave lethality**
  - Shock wave duration (Baker)
  - Shock wave overpressure (Mahn)
  - Lethality computations (Lovelace Foundation)
- **Fragmentation lethality**
  - Mass distribution (Mott)
  - Ejection angle of flight (geometry)
  - Fragment initial velocity (Gurney)
  - Fragment trajectories & impact velocities (SRC)
  - Lethality computations (Ahlers & Feinstein)

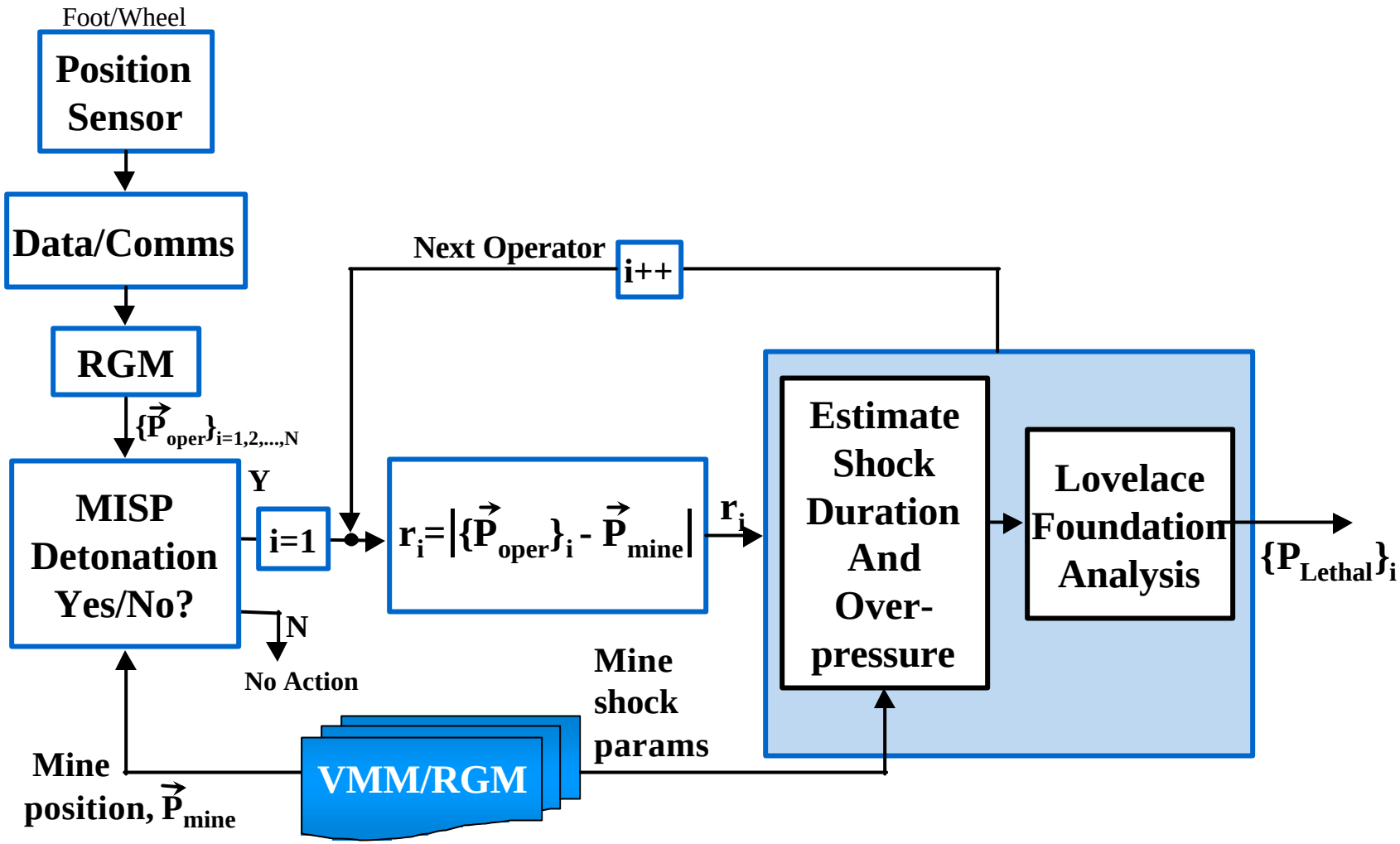
Backup (Support) Slides

Backup

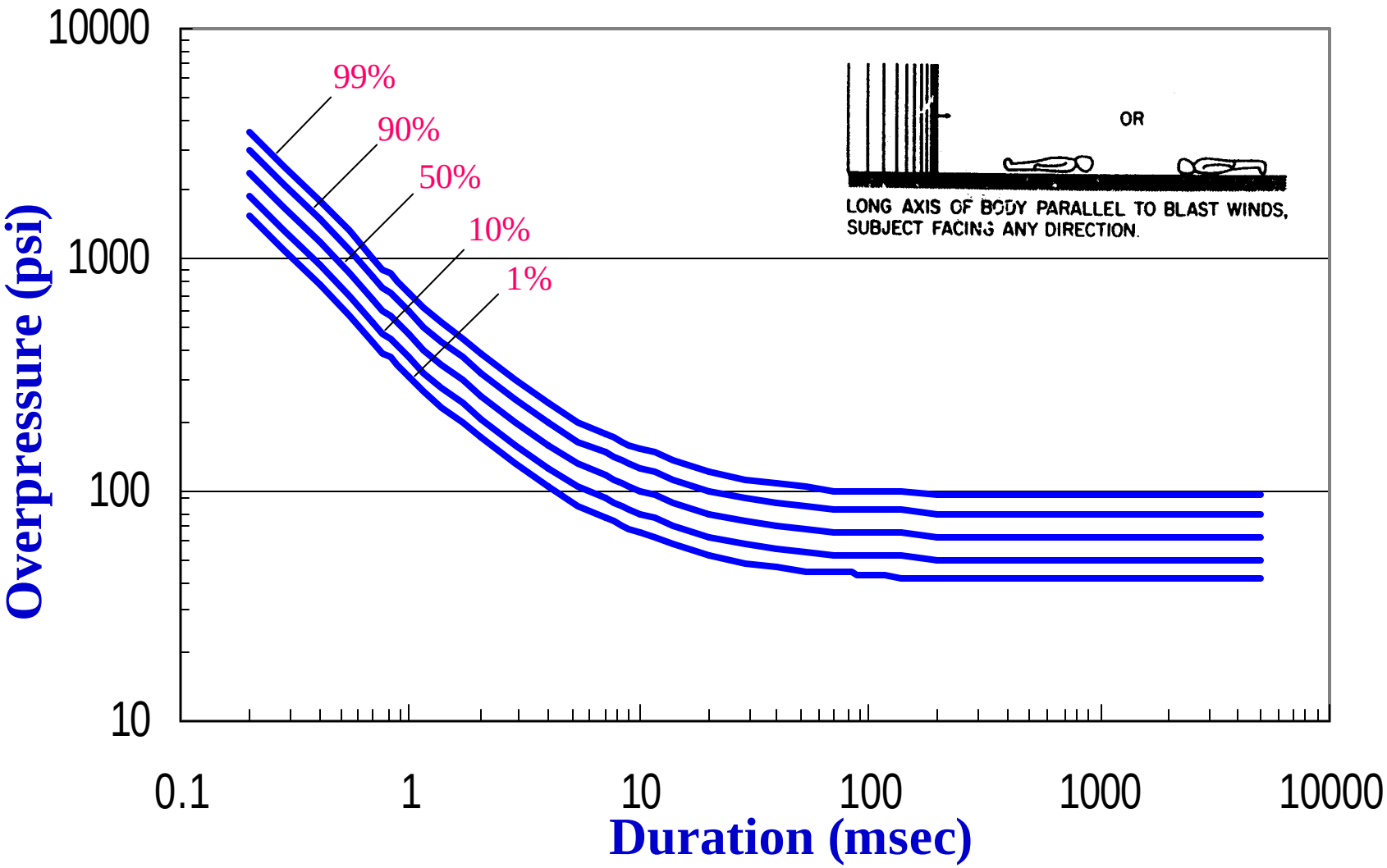
TMS ARCHITECTURE ELEMENTS



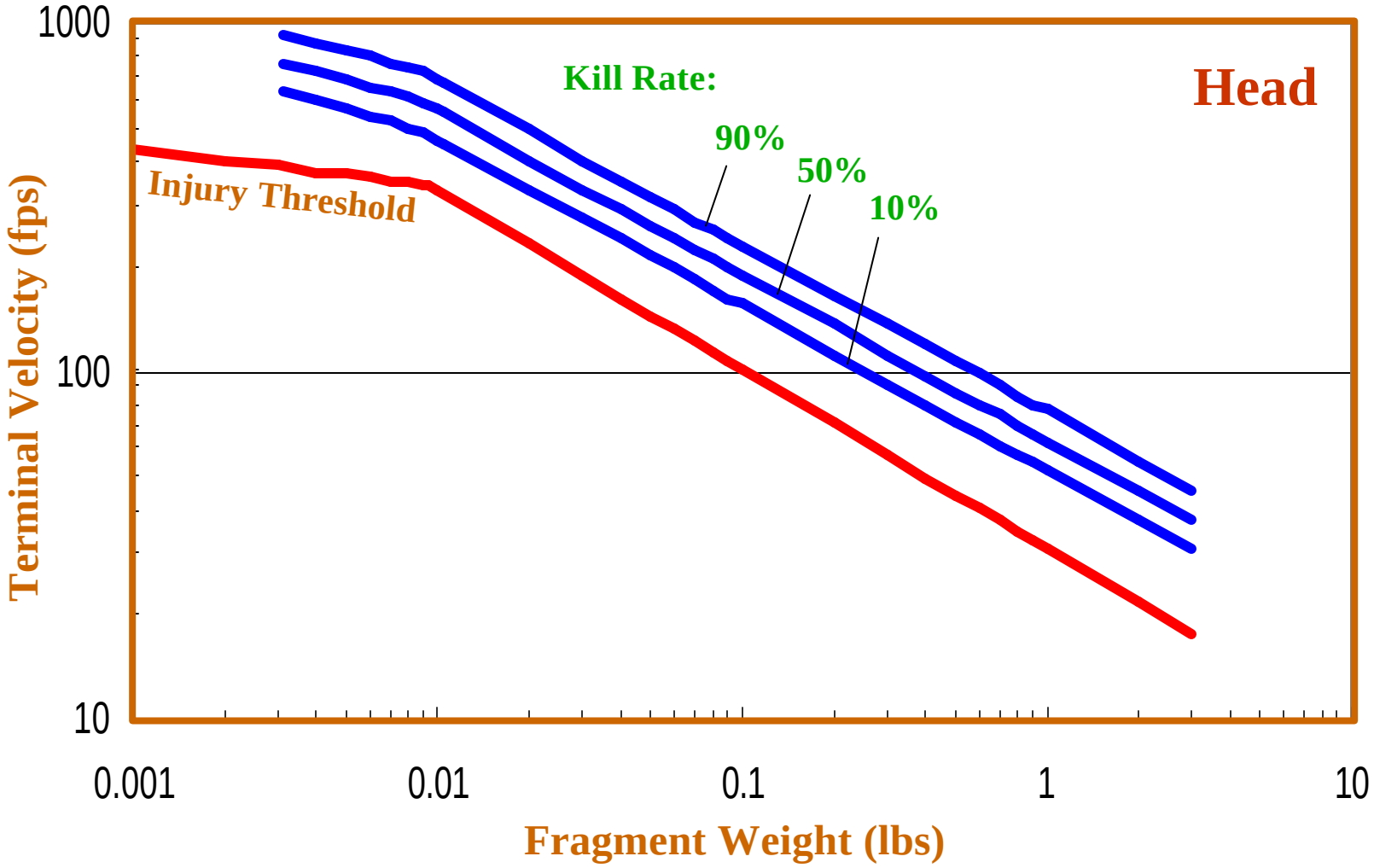
MISP System for Lethal Probabilities



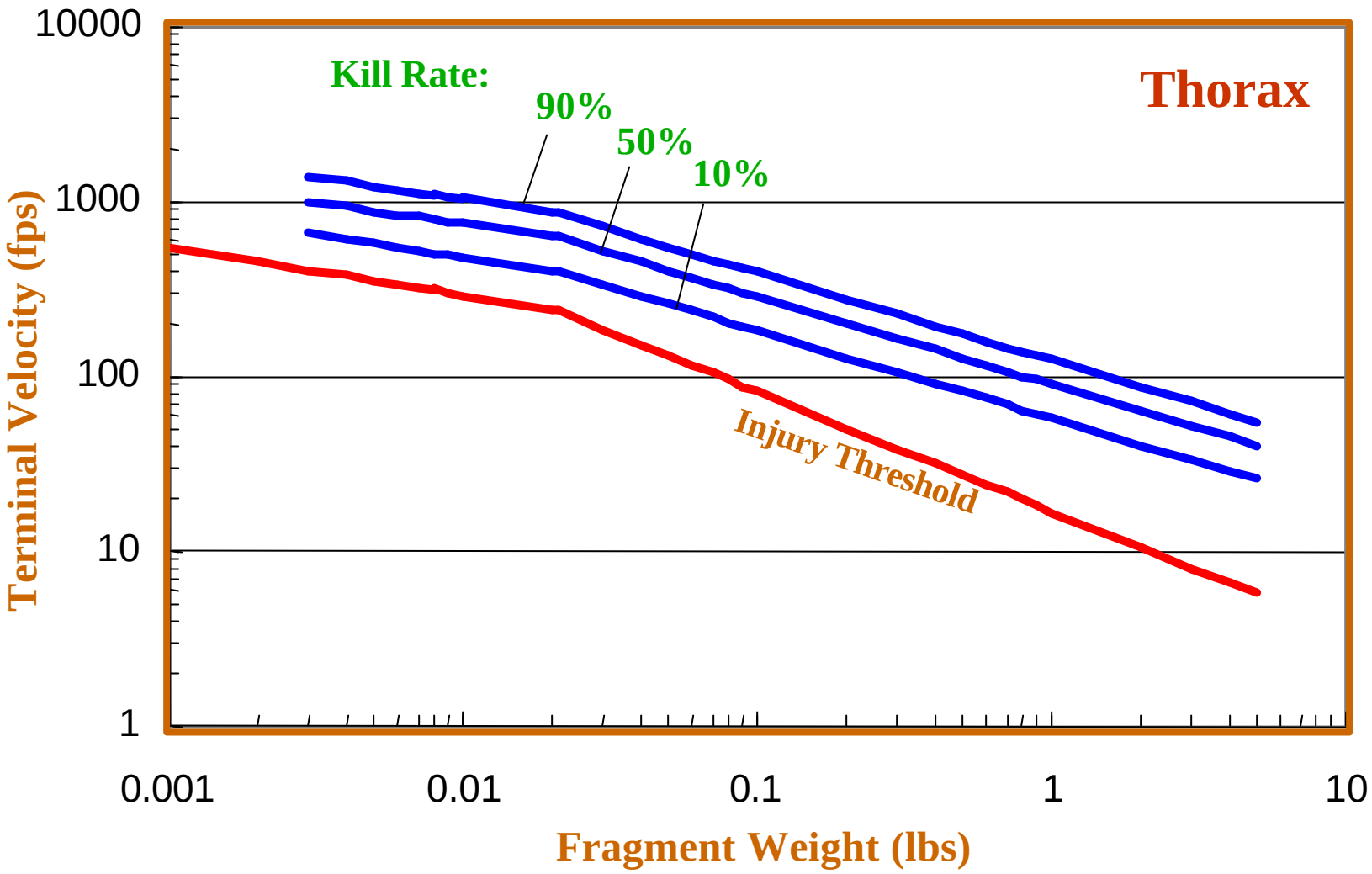
Lethality Due to Shock Wave (Lovelace)



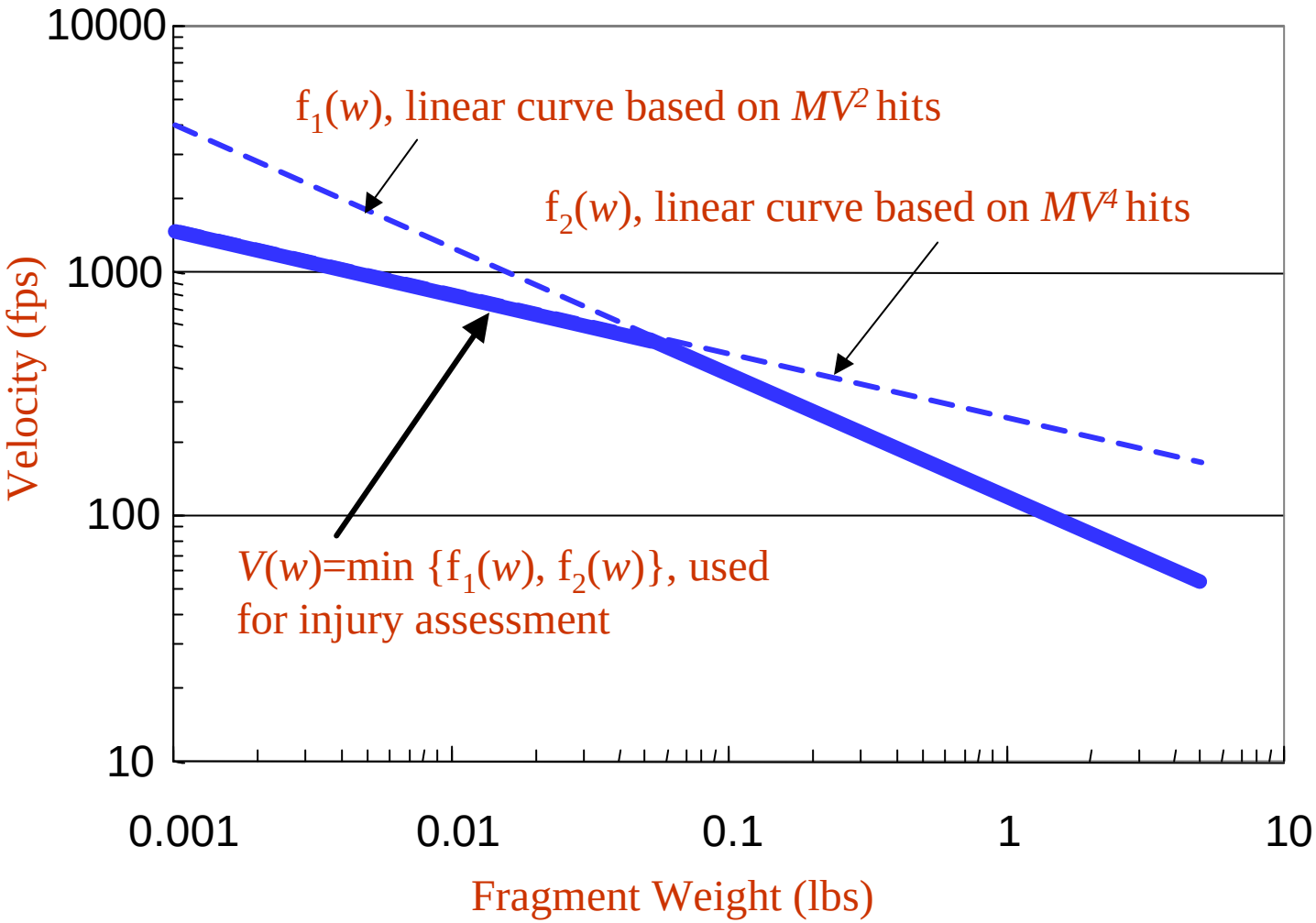
Lethality Due to Fragment Impact (Feinstein)



Lethality Due to Fragment Impact (Feinstein)



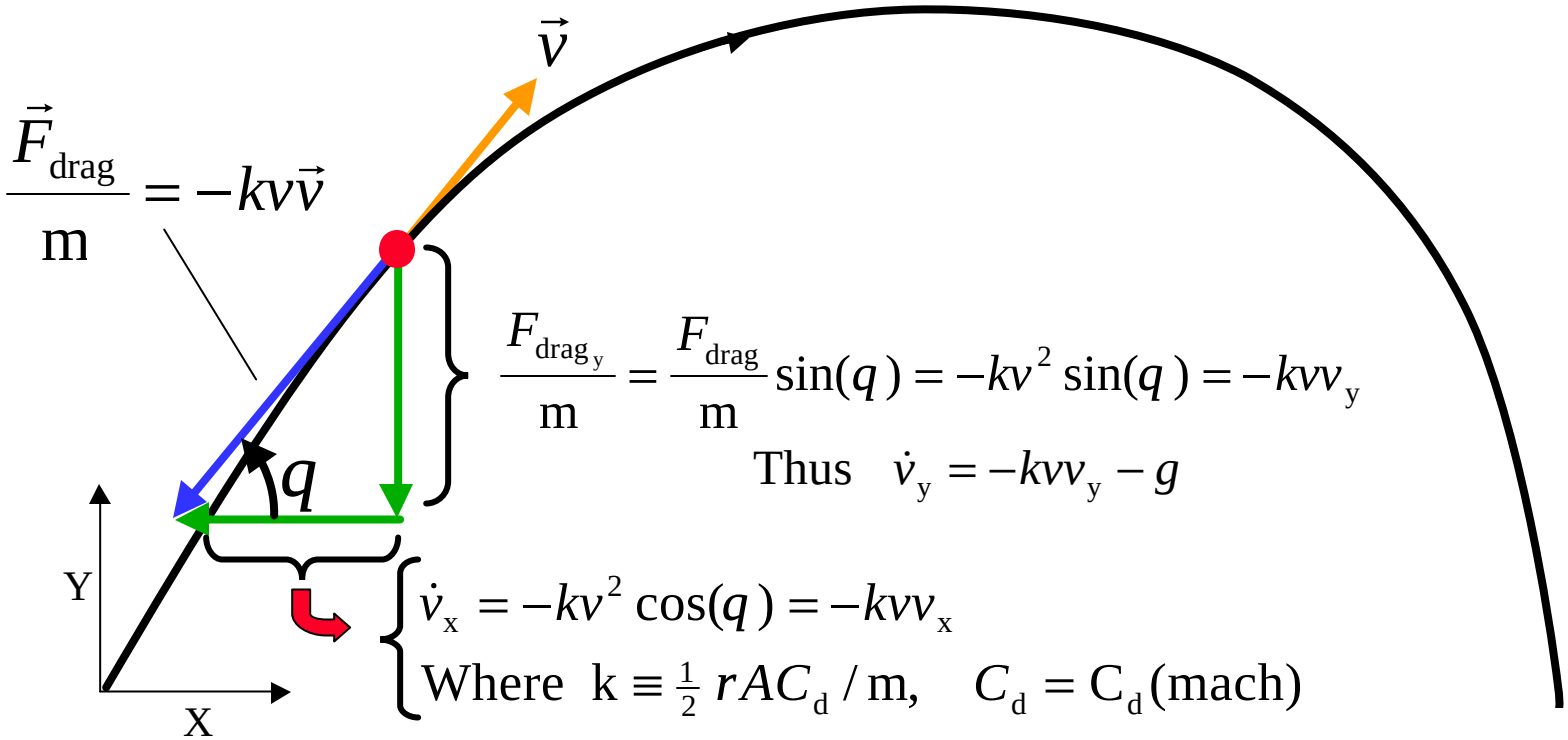
Determination of the Weight-Velocity Curve



Some Gurney Energy Constants (Henry)

EXPLOSIVE	$\sqrt{2E}$, fps
Baratol - 33 TNT, 67 $BA(NO_3)_2$	5200
Tritonal - 20 Aluminum, 80 TNT	7200
TNT	8000
HBX-1 - 11 TNT, 67 Comp B, 17 Aluminum, 5 D-2	8100
Comp B - 40 TNT, 60 RDX	8800
Cyclotol - 30 TNT, 70 RDX	8860
Cyclotol - 25 TNT, 75 RDX	8900
Comp A3 - 9 wax, 91 RDX	9000
RDX - 3 wax, 97 RDX	9200
RDX - 100%	9300
Black powder - 10 S, 16 C, 74 KNO_3	3100
Smokeless powder - double base	5500

Trajectory Equations of Motion



$$\frac{\vec{F}_{\text{drag}}}{\text{m}} = -kv\vec{v}$$

$$\frac{F_{\text{drag}_y}}{\text{m}} = \frac{F_{\text{drag}}}{\text{m}}\sin(q) = -kv^2\sin(q) = -kvv_y$$

Thus $\dot{v}_y = -kvv_y - g$

$$\dot{v}_x = -kv^2\cos(q) = -kvv_x$$

Where $\text{k} \equiv \frac{1}{2} rAC_d / \text{m}, \quad C_d = \text{C}_d(\text{mach})$

$$\{v_x, v_y, x, y\} = \int_0^t \{\dot{v}_x, \dot{v}_y, v_x, v_y\} dt$$

Which integration is performed by 4th-order Runge-Kutta*

*Note: Closed form exact solutions do not exist. Runge-Kutta numerical integration is superior to closed-form *approximate* solutions for accuracy/speed/data-access.

Trajectory Generation (Runge-Kutta)

User Inputs

v_0

q_0

$j \equiv AC_{d_{M1}}$

m (mass)

h ($\Delta t \le .2$sec)

Initialization

$v = v_0$

$q = q_0$

$r = 1.225$

$v_x = v \cos q$

$v_y = v \sin q$

Run Numerical Integration

$v = \sqrt{v_x^2 + v_y^2}$

Calculate R from C_d(mach) table[1]

Calculate r from r - equation[2]

$k = (\frac{1}{2} r A C_d / m) = \frac{1}{2} r j R / m$

$\dot{v}_x = -k v_x v \qquad \dot{v}_y = -k v_y v - g$

4th - order Runge - Kutta Integration

$\{t, \dot{v}_x, \dot{v}_y, v_x, v_y\} \Rightarrow \{t + h, v_x, v_y, x, y\}$

Repeat from top until touchdown.

C_d(Mach) Factor Table[1]

Mach	$R \equiv C_d / C_{d_{M1}}$
0	.915
.6	.915
1	1
1.2	1.12
1.6	1.18
2	1.14
2.5	1.09
3	1.08
10	1.08

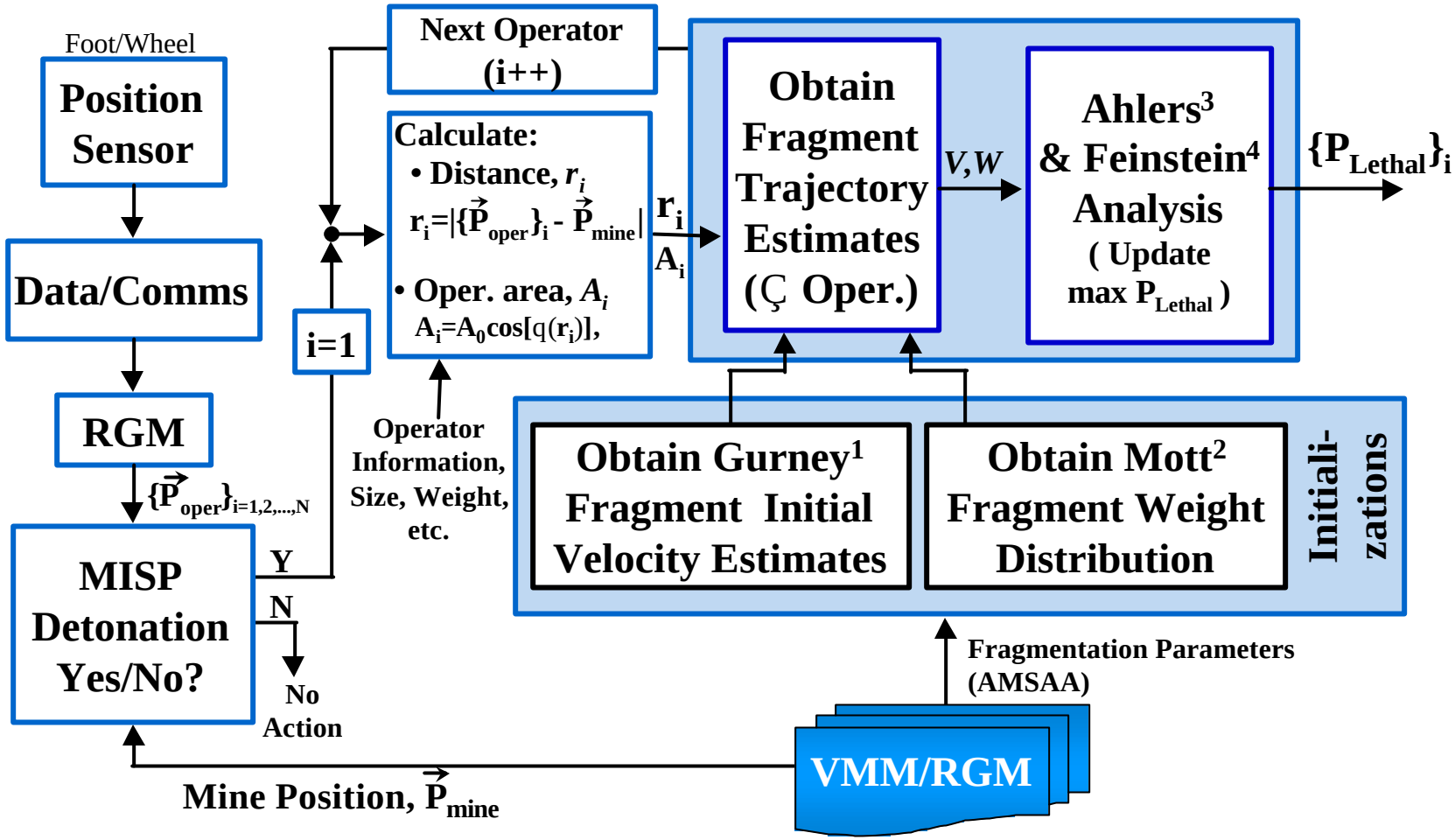
[2] $ht = y/1000.$

$$r = 1.225/(1. + ht(.07757 + ht(.0152585 - ht(.00134459 - .000102895ht))))$$

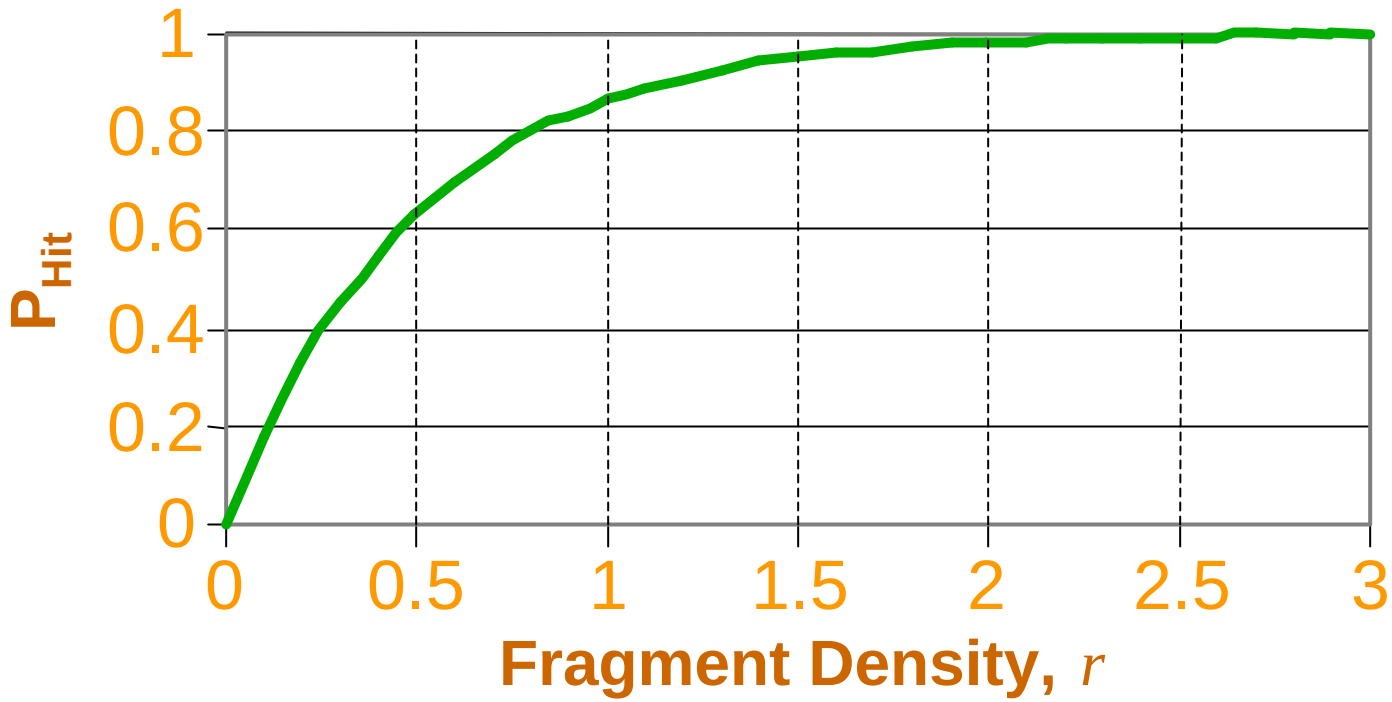
Drag Coefficient C_D vs. Velocity

Velocity (Mach)	$C_D/C_{D,Mach1}$
0	0.915
0.6	0.915
1.0	1.0
1.2	1.12
1.6	1.18
2.0	1.14
2.5	1.09
3.0	1.08
10.0	1.08

MISP System for Fragmentation Lethalities



Prob. of at Least One Hit vs. Density

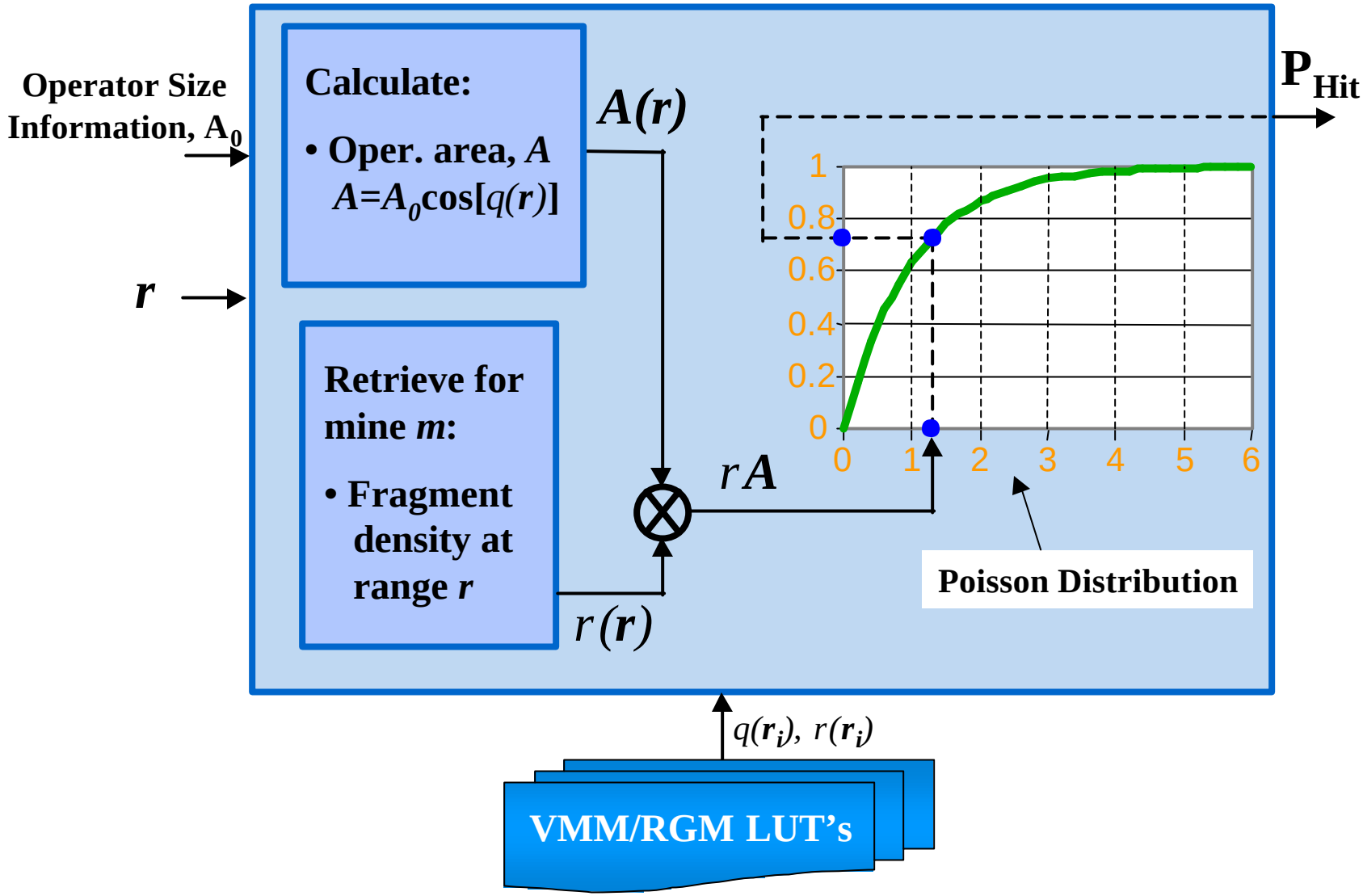


Using the Poisson Distribution* (with A_{oper}=2 ft^2),

$$P(K, A_{oper}) = \frac{(rA_{oper})^K \exp(-rA_{oper})}{K!} \Rightarrow P_{Hit} = 1 - P(0, A_{oper}) = 1 - \exp(-rA_{oper})$$

*See Wilbur B. Davenport, Jr.., William L. Root, "An Introduction to the Theory of Random Signals and Noise" McGraw-Hill, 1958, §7-2 (pp. 115-117)...Note that here we replace shot noise electron-emission times with fragment spatial locations and time intervals with spatial areas.

Probability of Hit Calculations



Equivalent Weights for Free Air Effects[1]

MATERIAL	Peak Pressure $(P_M)_{TNT}$	Impulse $(I)_{TNT}$
TNT	1.00	1.00
Explosive D	0.85	0.81
Picratol	0.90	0.93
Tritonal - 20 Aluminum, 80 TNT	1.07	1.11
Comp A-3	1.09	1.07
Comp B - 40 TNT, 60 RDX	1.13	1.06
TNETB	1.13	0.96
Comp B/TiH_2 70/30	1.13	1.13
Cyclotol - 30 TNT, 70 RDX	1.14	1.09
HBX-3	1.16	1.25
Pentolite	1.16	1.15
RDX - 2 wax, 98 RDX	1.19	1.16
RDX - 5 wax, 95 RDX	1.19	1.16
HBX-1 - 11 TNT, 67 Comp B, 17 Aluminum, 5 D-2	1.21	1.21
Torpex II	1.23	1.28
Minol II	1.24	1.22
H-6	1.27	1.38

[1]Joseph Petes, "Part IV. Explosive Effects: Blast and Fragmentation Characteristics" Annals of the New York Academy of Sciences, Vol. 152, 1968, pp. 283-316