DUKE BME

Brain vs. Pulmonary Blast Injury Tolerance and the Effect of Ballistic Protective Vests

Cameron R. 'Dale' Bass, Karin Rafaels,
Matthew Panzer, Garrett Woods, Jay Shridharani,
Elissa Palm, Bruce Capehart, Robert Salzar

Duke University/University of Virginia

July 2010

Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE	2. REPORT TYPE	3. DATES COVERED
JUL 2010	**N/A**	**-**

4. TITLE AND SUBTITLE	5a. CONTRACT NUMBER
Brain vs. Pulmonary Blast Injury Tolerance and the Effect of Ballistic Protective Vests	5b. GRANT NUMBER
	5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)	5d. PROJECT NUMBER
	5e. TASK NUMBER
	5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **Duke University/University of Virginia**	8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)	10. SPONSOR/MONITOR'S ACRONYM(S)
	11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release, distribution unlimited

13. SUPPLEMENTARY NOTES
See also ADM002313. Department of Defense Explosives Safety Board Seminar (34th) held in Portland, Oregon on 13-15 July 2010, The original document contains color images.

14. ABSTRACT

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT	b. ABSTRACT	c. THIS PAGE			
unclassified	**unclassified**	**unclassified**	**SAR**	**31**	

Effects of Blast on the Brain?

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- Evidence of Blast Injury Old (Pare, 1500's)
- By late 1800's -> High Explosives ->Primary Blast Deaths
  - E.g. Rusca, 1915
  - Brain or pulmonary/gut?
- WWI
  - Trench warfare
  - Exploding shells overhead
  - French ->

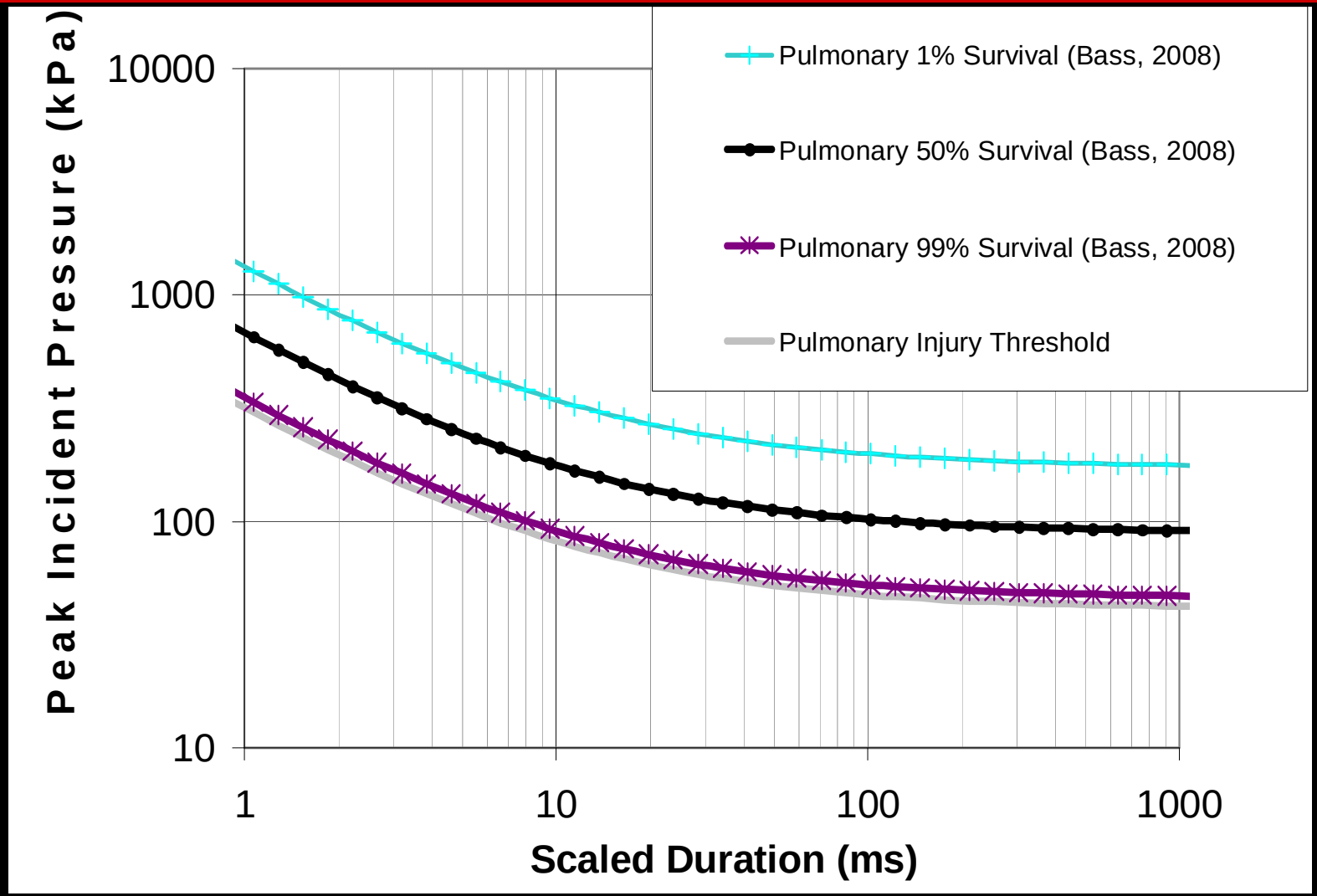
    Organic Neurotrauma caused by blast
  - British ->

    Buck up, get back in the trench (e.g. Mott-1916)

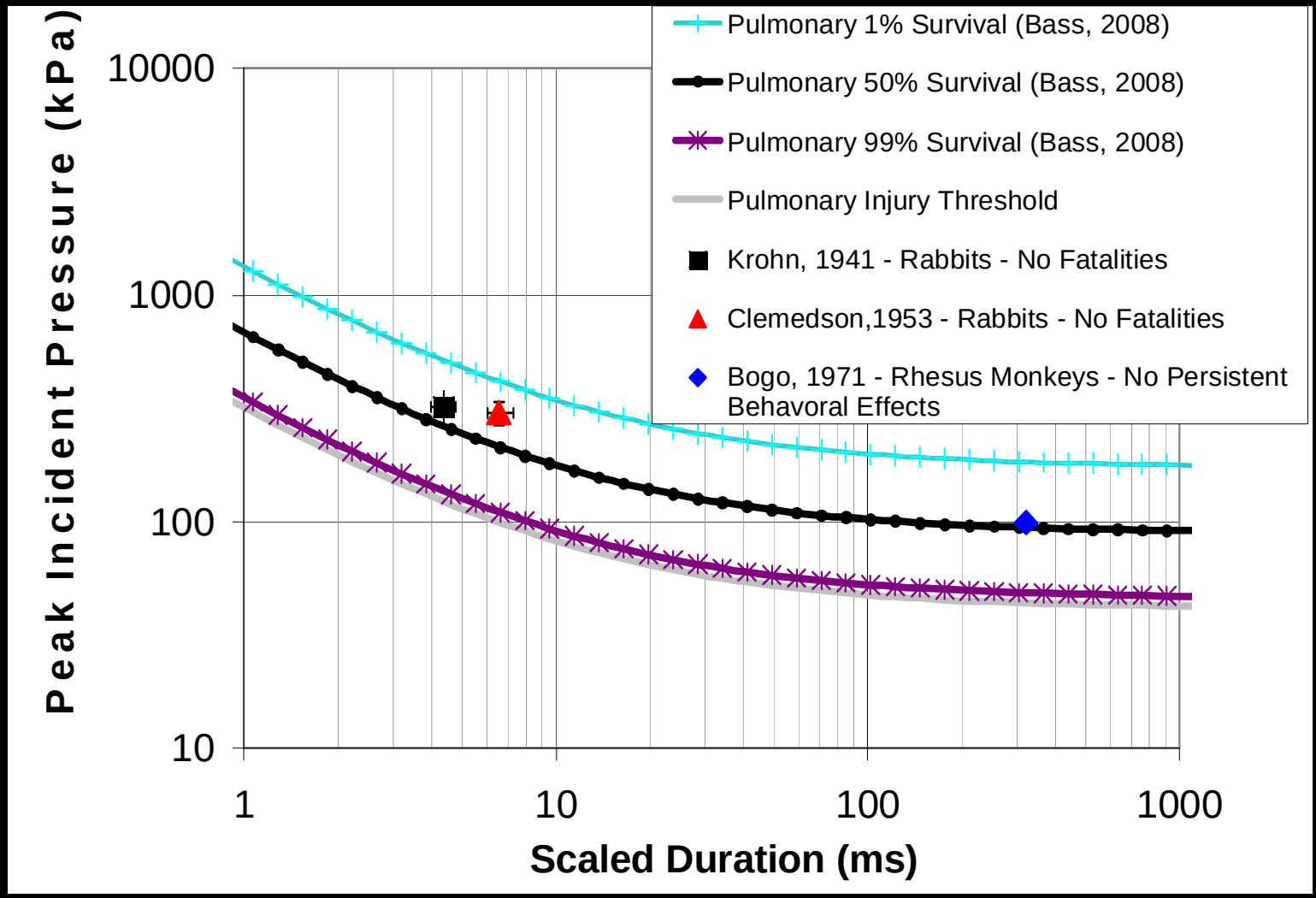
Brain Fatalities?

- Post WWI …
- *Tolerance for Primary Blast Brain Fatalities Much Greater than for Pulmonary Fatalities*
  - Hooker-1924, Zuckerman-1942, Clemedson-1949, Richmond-1962, Bogo-1971, and implied by many others …
- Air Containing Organs
  - Lungs, intestines, ears
- Pulmonary Injury Criteria
  - Lovelace (Bowen-1968), MRMC (Dodd-1990, Stuhmiller-1996), Bass-2008, etc.
- No Primary Blast Brain Survival/Lethality Criteria!

Blast Lung /Survival Injury Tolerance (Bass *et al*, *J Trauma*, 2008)



Previous Studies Head Injury Risk
(Blast - Protected Thorax - Not Rodents)



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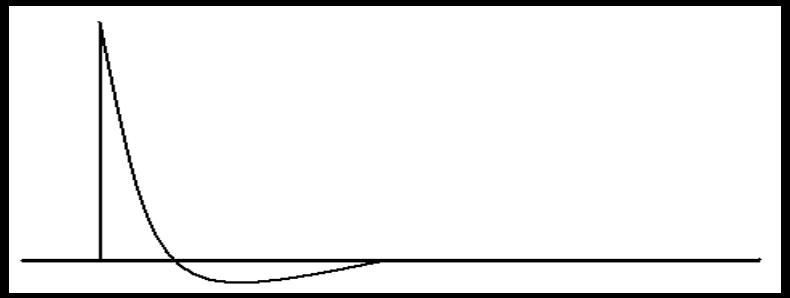
Primary Blast Brain Tolerance Not Established!

Goal: *Establish Brain Injury Criterion for Short Duration Primary Blast*

Blast Overpressure

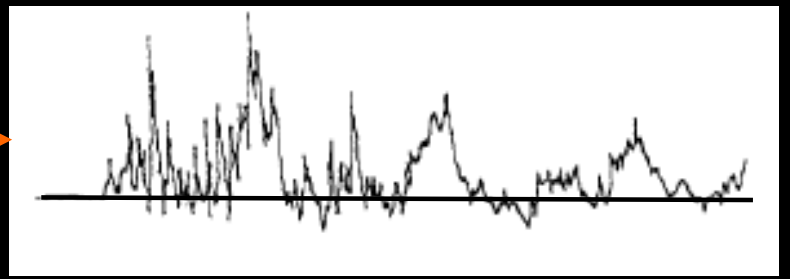
Open Space



Simple or Friedlander or "Free Field"

Pressure vs Time

Reflecting Surfaces



Complex

Pressure vs Time – Fixed Location

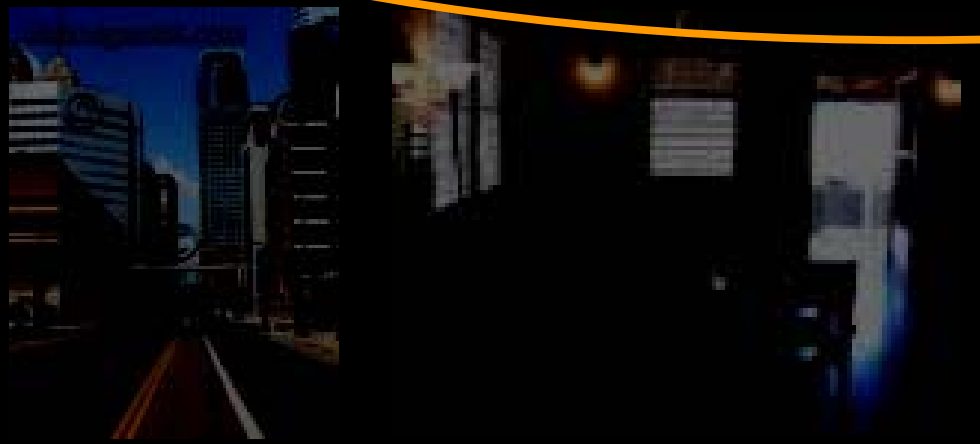
Blast Overpressure

Simple Blast

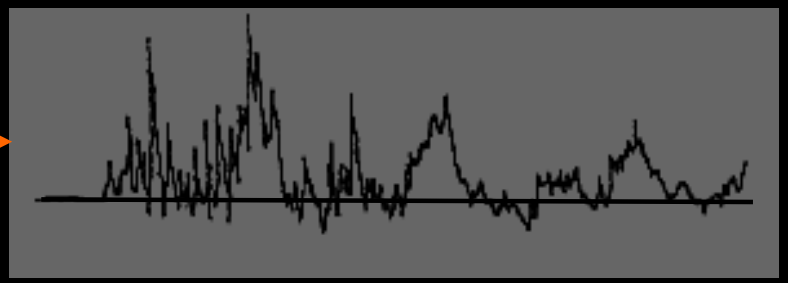
Open Space

Simple or Friedlander or
"Free Field"

Pressure vs Time



Reflecting Surfaces



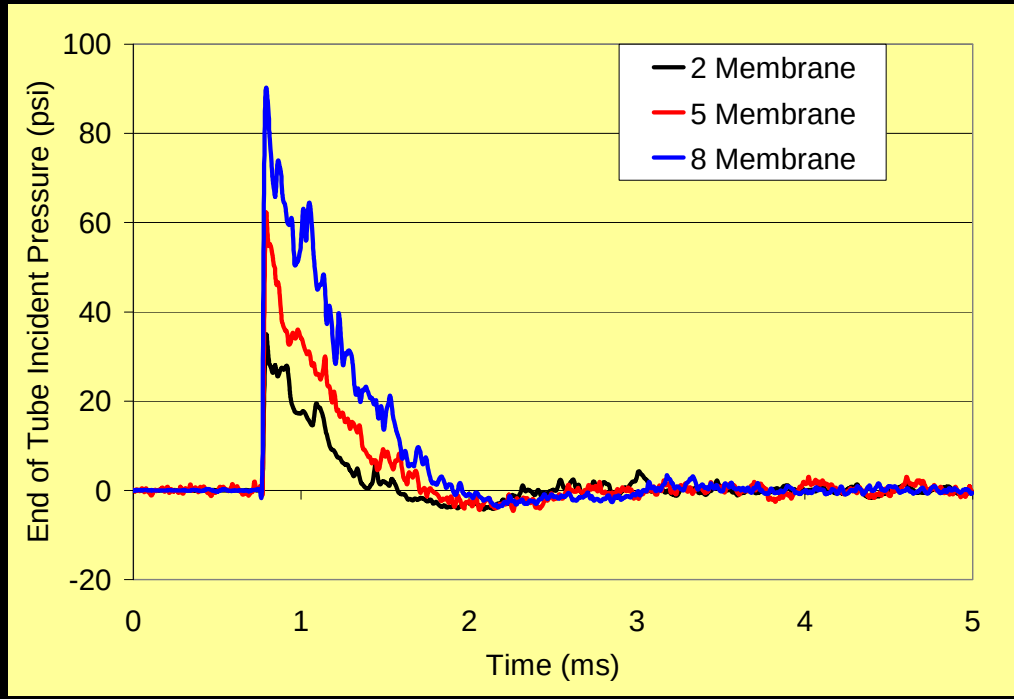
Complex

Pressure vs Time – Fixed Location

Methods

Test Setup/Shock Tube

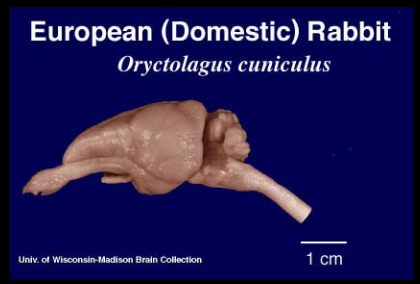
- 8” Shock Tube, Simple Blast Incident Profile ~10 μs rise
  - 1.5-3 ms duration
- Specimen - New Zealand Rabbits
  - Match previous data (Krohn, 1941, Clemedson, 1953)
  - Body mass ~4 kg
  - 12 blast specimens, 3 controls
- Head exposed, Thorax Protected by Steel Tube
  - Reduction of peak overpressure by factor of 10



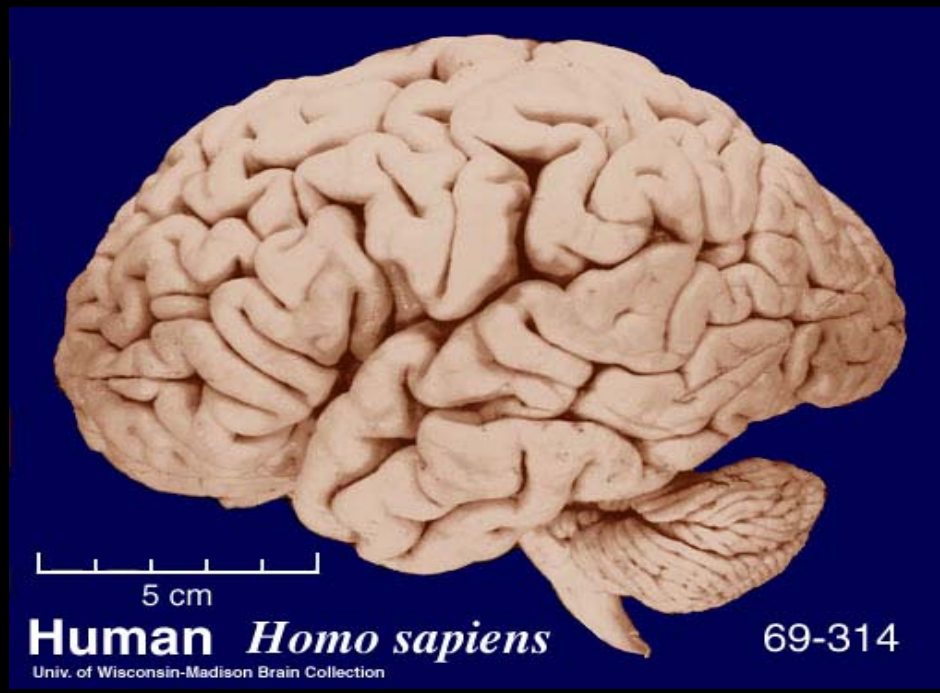
Scaling (Intraspecies)

- Crucial (Rarely Verified)
- Structural/Geometric Differences Often Large (Rarely Accounted For)

Mouse Brains (4)



Rabbit Brain



Human Brain

Wisconsin Brain Collection - 2006

Subject Response Scaling

Mass Ratio $\lambda = \left(\frac{M}{M_{ref}} \right)^{\frac{1}{3}}$

Velocity $V_s = V_i$

Acceleration $A_s = \frac{A_i}{\lambda}$

Length $L_s = \lambda \times L_i$

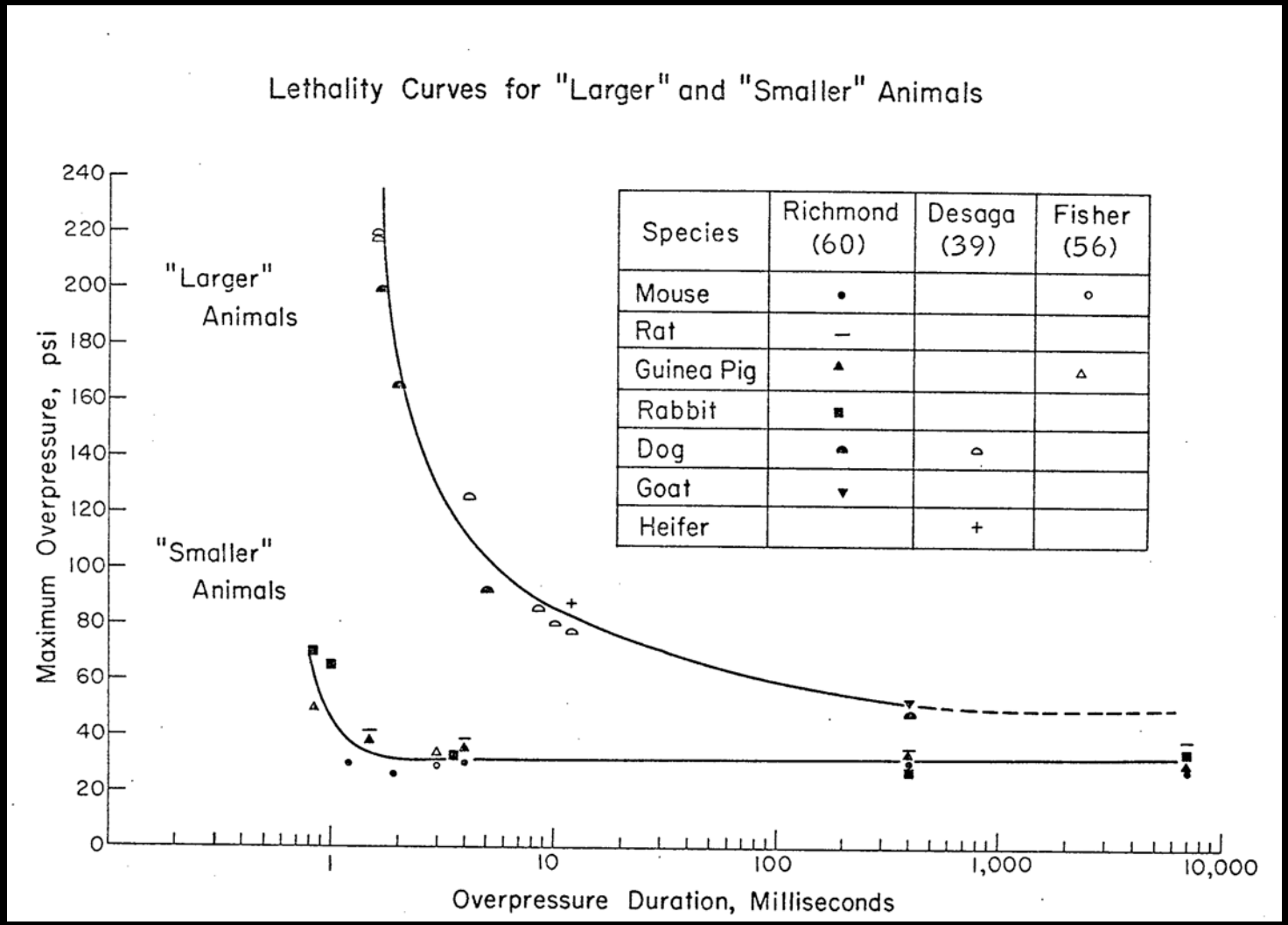
Force $F_s = \lambda^2 \times F_i$

Time $T_s = \lambda \times T_i$ *

Assumptions: mass density and modulus of elasticity constant among subjects (cf. Eppinger et al, 1984)

Appropriate for Blast Brain Injury? *Don't Know*

Scaling
(From Pulmonary Blast Work)

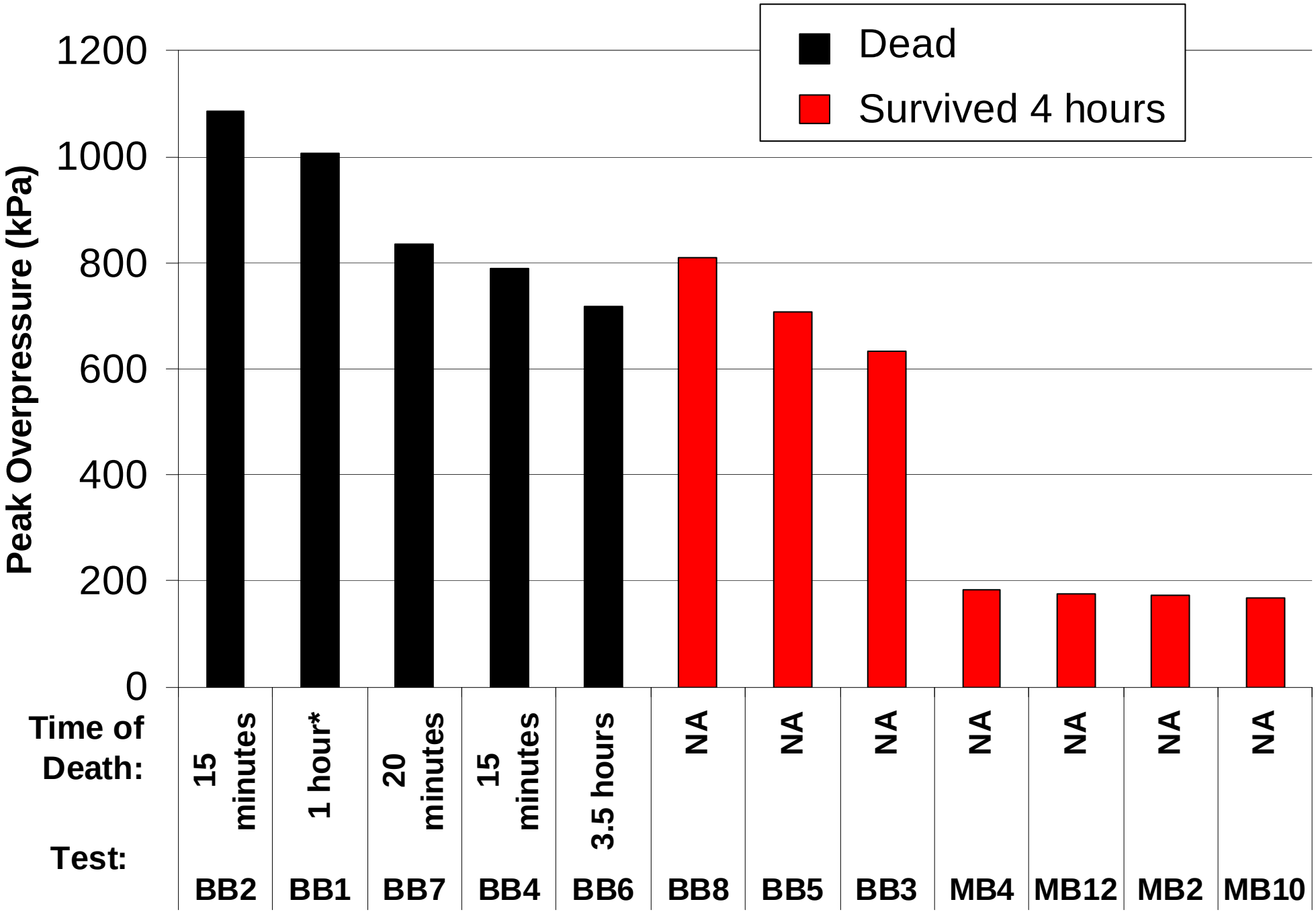


White et al, 1971

Results

Results

- Typical History
  - Immediate Apnea (N=5 with > 600 kPa)
  - Resumes breathing spontaneously < 700 kPa
  - Needs ventilatory support > ~700 kPa
  - Death associated with subdural bleeding
  - No serious GI, pulmonary injuries
- Current Dataset
  - 12 blast specimens, 3 controls
  - Highest nonfatal – 810 kPa
  - Lowest fatal – 729 kPa


Dead
Survived 4 hours
Peak Overpressure (kPa)
1200
1000
800
600
400
200
0
Time of Death:
Test:
15 minutes
BB2
1 hour*
BB1
20 minutes
BB7
15 minutes
BB4
3.5 hours
BB6
NA
BB8
NA
BB5
NA
BB3
NA
MB4
NA
MB12
NA
MB2
NA
MB10

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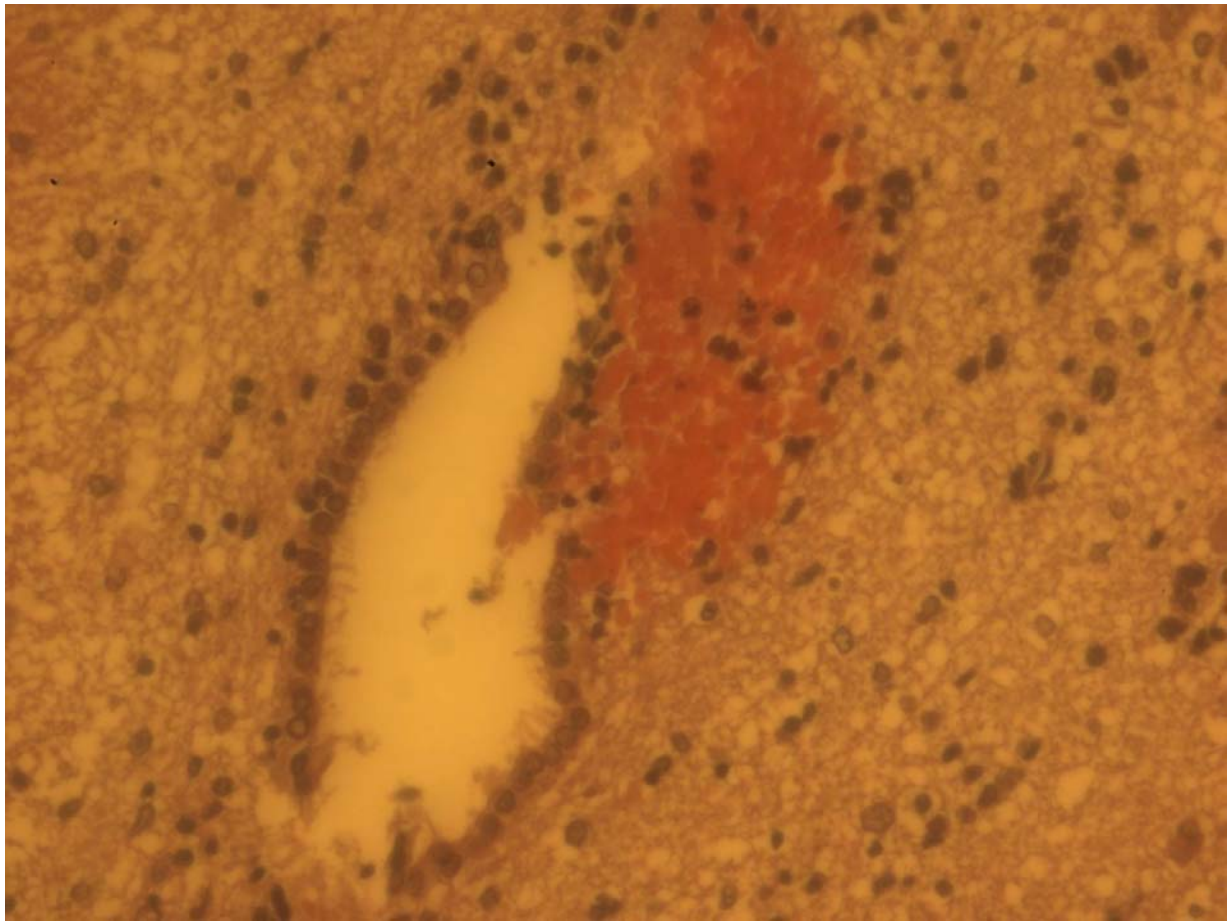
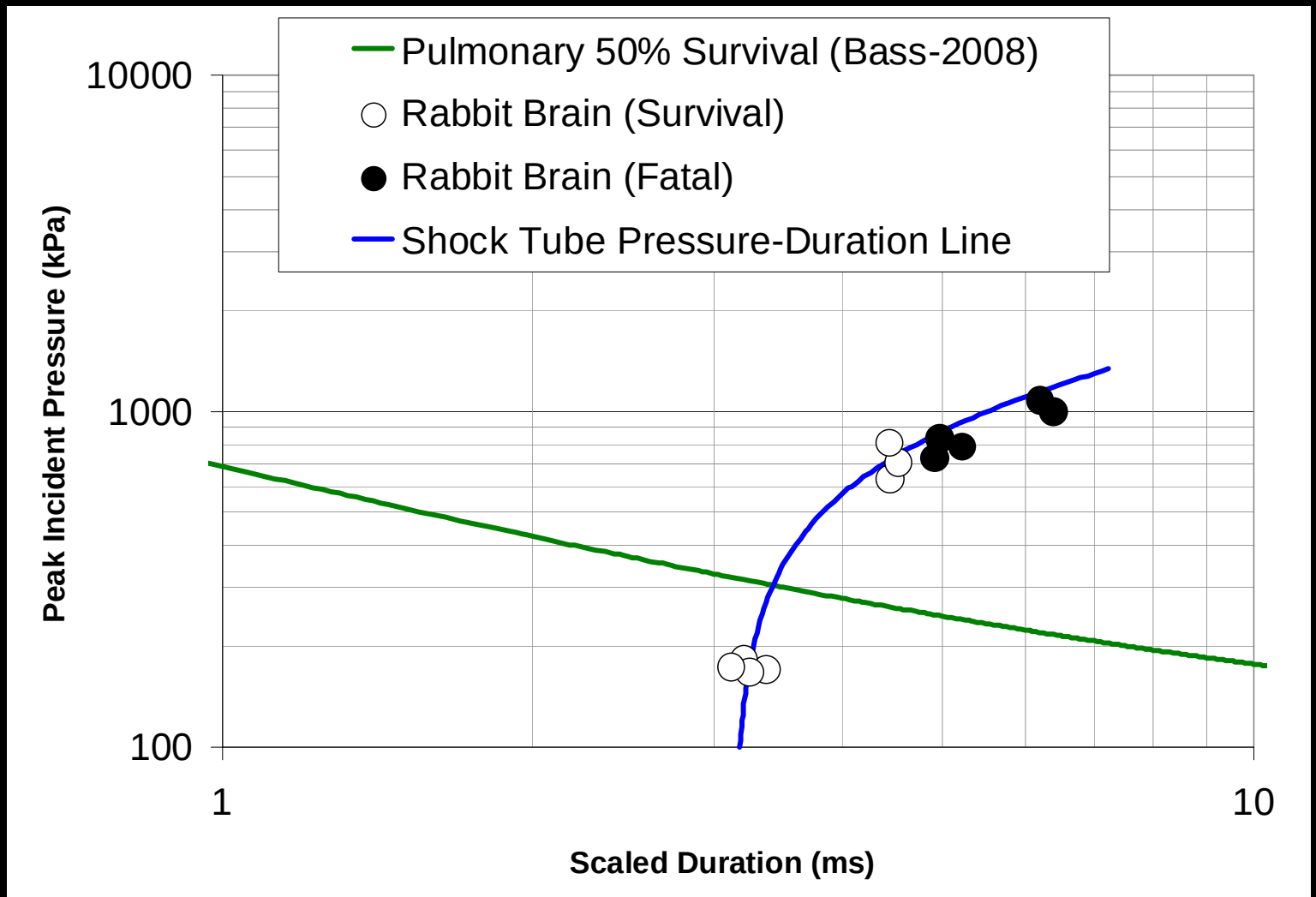
Typical Brain Bleeding

- Lateral Ventricle – Coronal Section

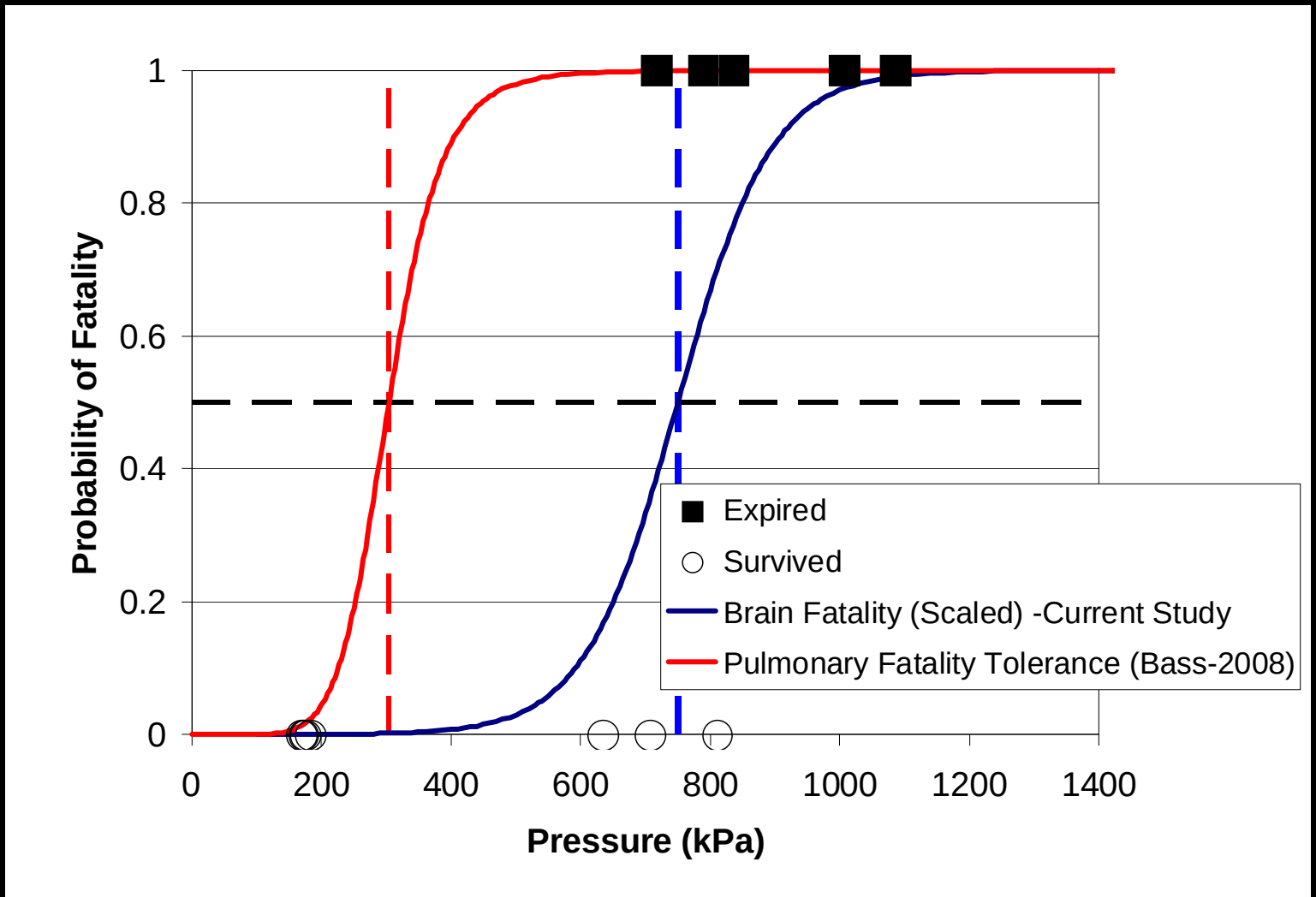


Fatal Blast Case (40X)

Primary Brain vs. Pulmonary



Primary Brain vs. Pulmonary

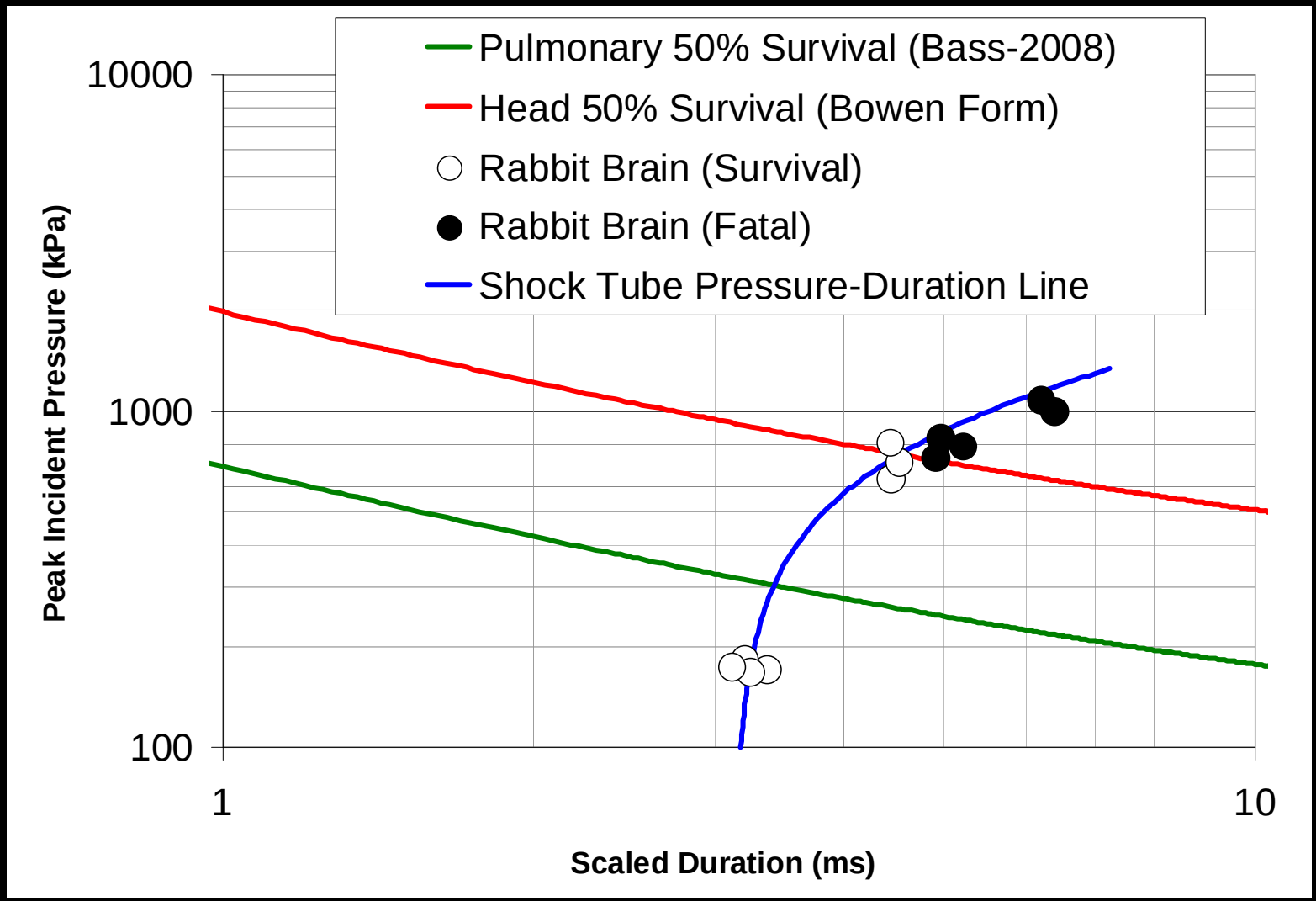


Extension in Pressure/Duration Range

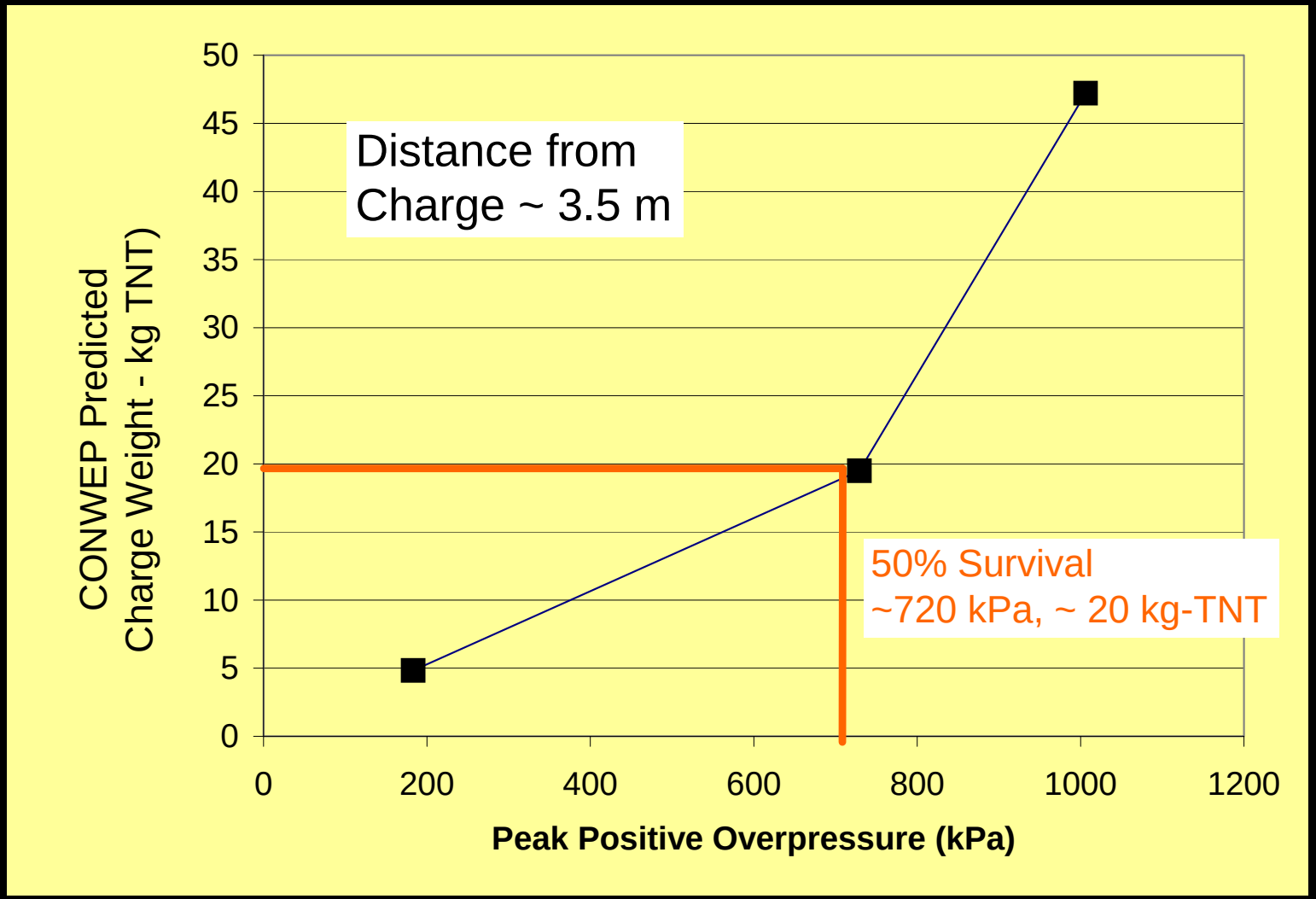
- Results
  - Generally only valid along shock tube line
- Bowen Form for Pressure/Duration

  (Bowen, 1968, Bass, 2008)
  - $P = P^* (1 + a \Delta T^{-b})$
  - Parallel to pulmonary results of Bass (2008)

Estimates Using Bowen Form



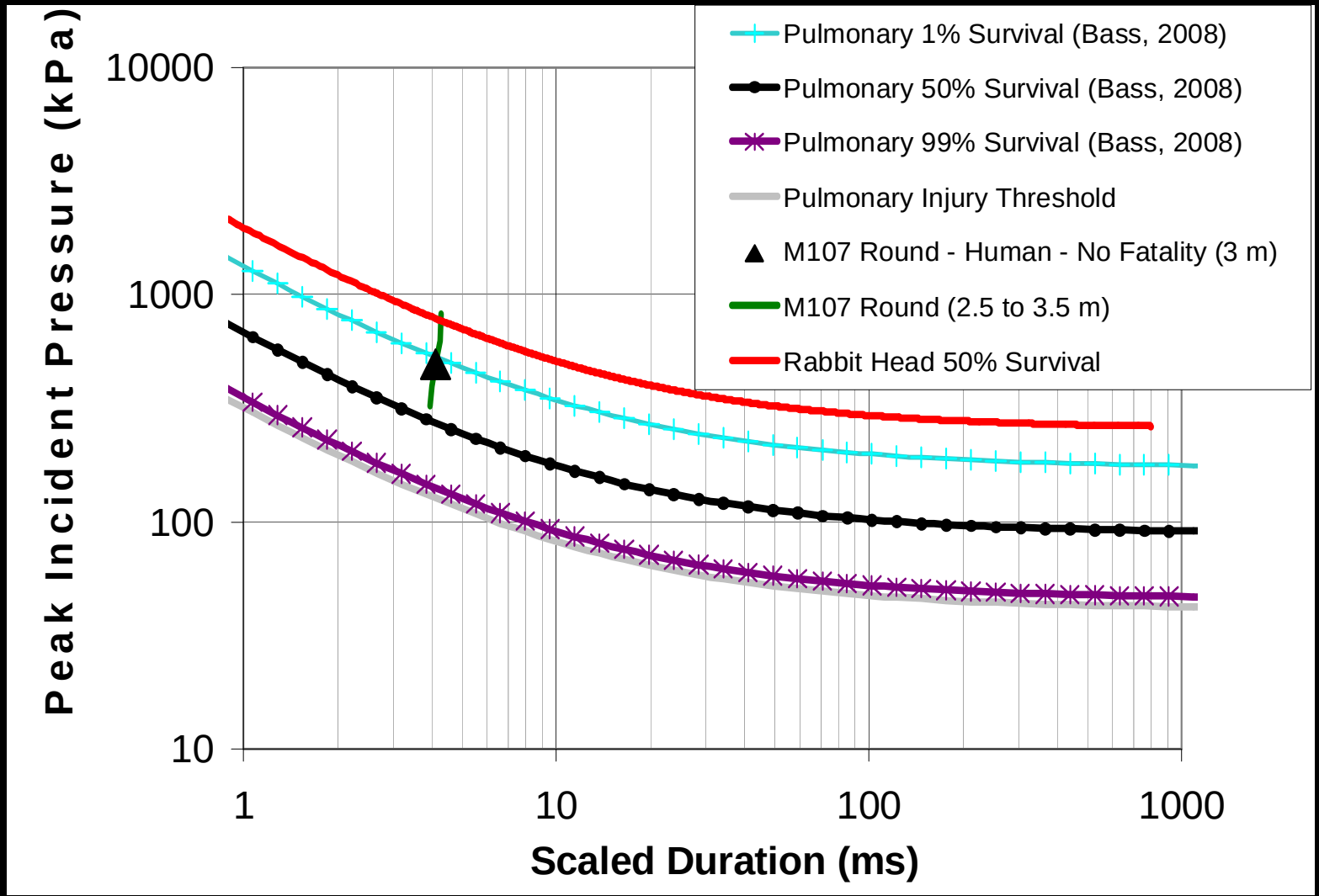
CONWEP Predictions with TNT



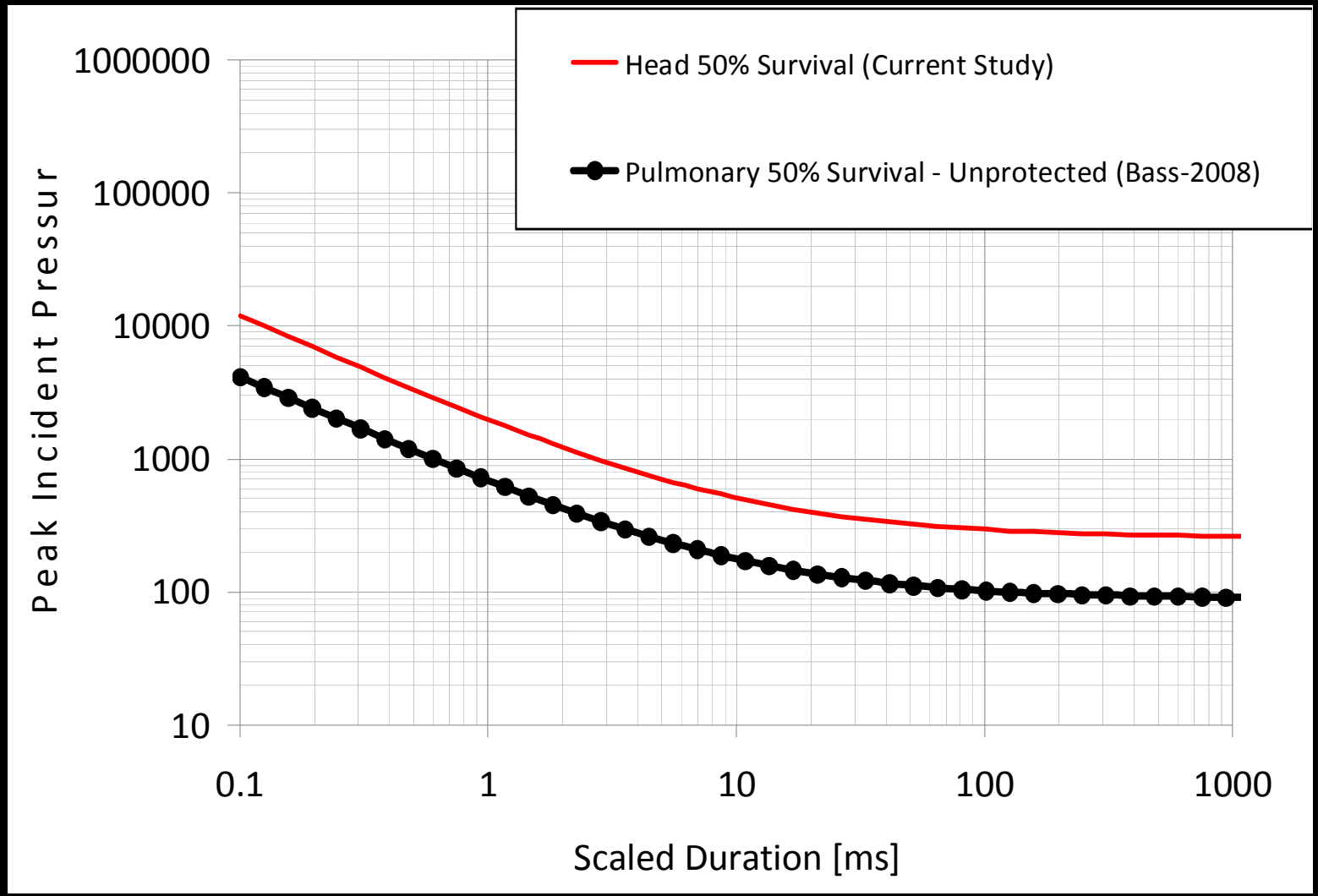
Discussion

- Anecdotal Injuries from Theater
  - Mild/moderate
  - Fatalities associated with blunt trauma, fragmentation
- How is this Study Useful?
  - Range fatalities to mild/moderate
- Why no fatalities?
  - Effect of body armor

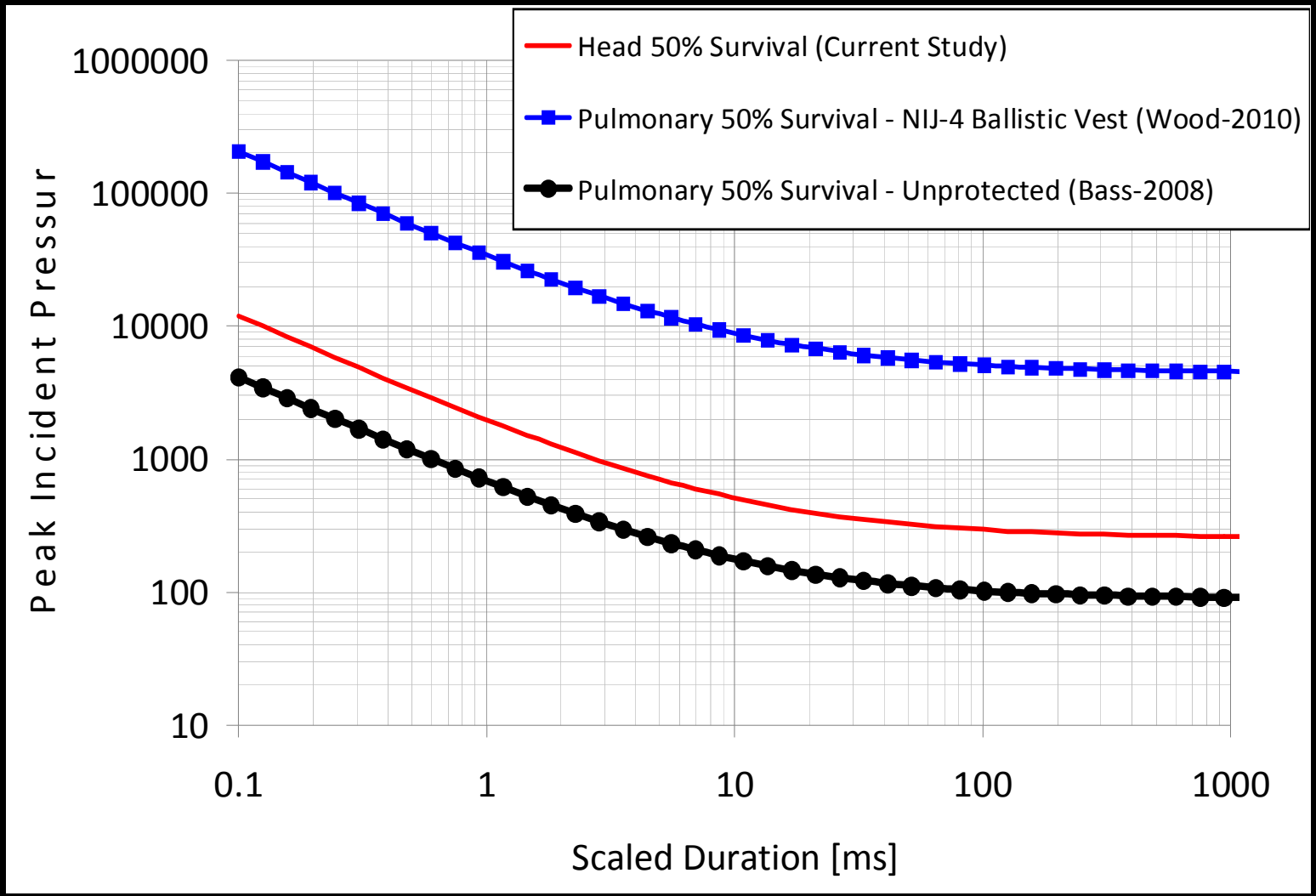
Epidemiology / Range



Effect of Body Armor



Effect of Body Armor



Conclusions

Conclusions

- *Blast Brain Fatality >> Blast Pulmonary Fatality*
  - Evidence of damage at lower than fatal levels
  - Primary blast brain 50% fatality, close to large charges
- Scaling to Human
  - Fatalities from large momentum event, scaling used likely okay for fatality/survival tolerance
  - For mild bTBI??? Unknown.
- Hard Body Armor Increases Pulmonary Tolerance

Upcoming Work

- Pulmonary
  - Long Duration Blast (Accepted for J Trauma, 2010)
  - Effect of Multiple Blast (Submitted to J Trauma)
    - Application to complex blast?
- Brain
  - This study (Submitted to J Neurotrauma, 2010)
  - Larger study (Manuscript in preparation)
    - Other mild/moderate injury criteria
- Effects of Blast Behind Body Armor
  - Accepted for Personal Armor Systems Symposium (Sept, 2010)

Acknowledgements

- Work supported by internal funds
  - Duke University
  - University of Virginia.

Source

This presentation has been produced by staff of

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