Duke
DEPARTMENT OF
Biomedical Engineering

Eruditio et Religio

Prediction of Human Injury Risk in High Speed Craft

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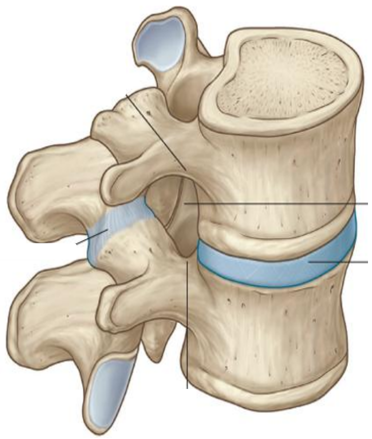
Overview of HSC Efforts

- ~20 years of work on repeated impact injury
  — *NSWC PCD/Duke(Virginia)*



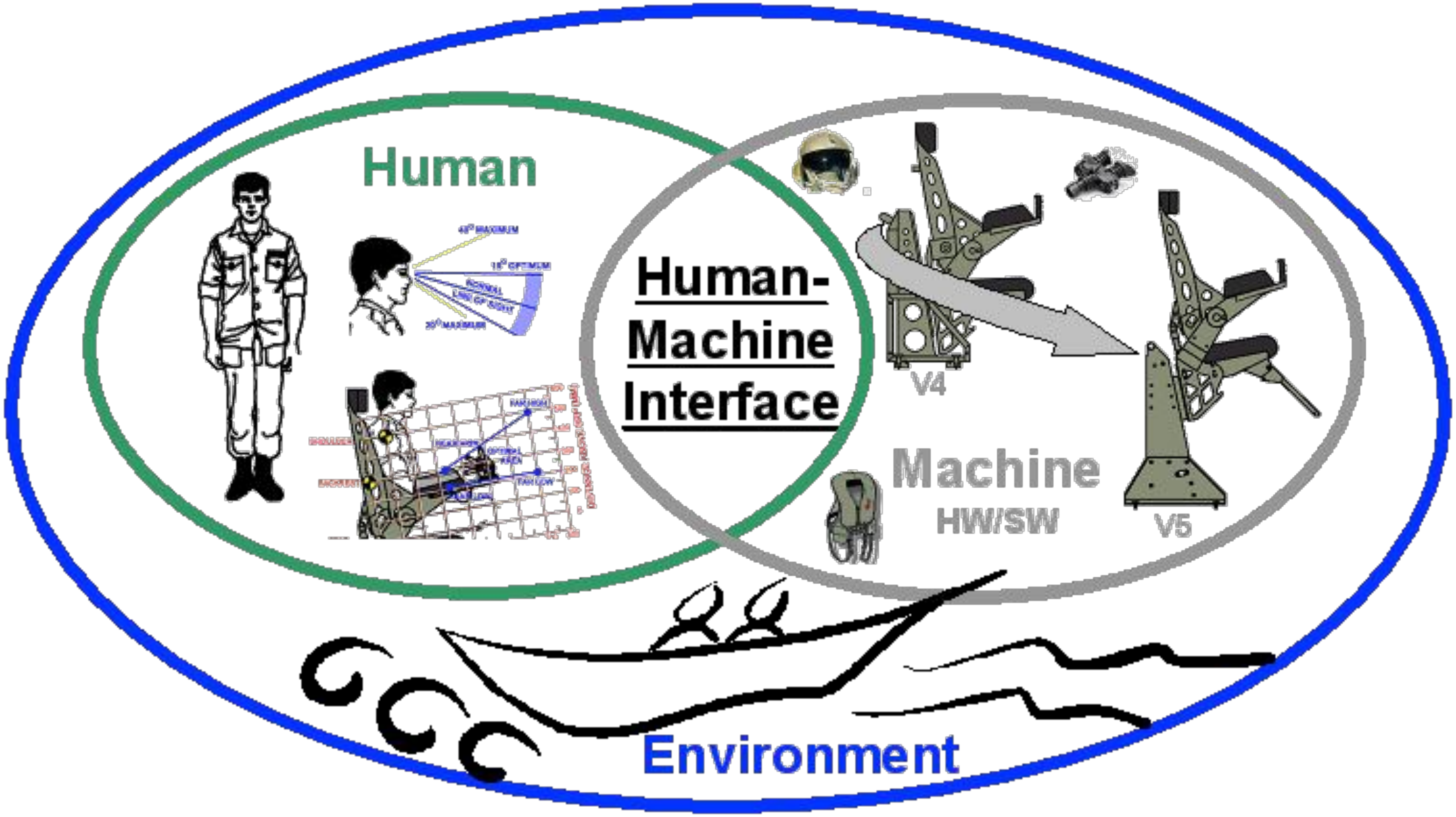
- Metrics
  — *Repeated motion metric by age* (Bass, 2006, Schmidt, 2012)
  — *Draft Impact injury standard (ISO 2631-5) for HSC*
  — *Development/evaluation of human performance measurements*
    - Cognitive and physical

Overview of HSC Efforts

- Technology/Solutions/Essential Tools
  - Health monitoring/Motion Data Acquisition System
    - Wireless human worn accelerometers
  - Impact injury metrics (models & standards)
    - Modification and validation of impact injury standard (ISO 2631 PT5) for HSC
    - Basis for ASTM-F1166, Mil Std 1472G,
  - Development of shock mitigation technology solutions
    - STIDD/Taylor V5 Passive Suspension Seats for MKV SOC
    - Semi-active suspension
    - Seat mounted controls and displays

Holistic Approach – Human Based

Total System Assessment/Design



Humans (operator, maintainer, and supervisor) considered essential components of system

Recent Work (Schmidt et al, 2012)

- Provides the Basis for High Speed Craft Repeated Motion Injury Assessment

- Using existing framework (ISO2631 pt. 5)
  - Separated male and female risk functions
  - Recalculated age coefficient for each sex
  - Determined injury risk based on *repeated loading* conditions with survival analysis

Basis for Injury Risk

- Repeated loading tests from 6 studies

  (Brinckmann 1988, Hardy 1958, Liu 1983, Hansson 1987, Gallagher 2005, Huber 2010)

- 105 (77 male and 28 female) cadaveric lumbar specimens
  – Ages 19-93
- Repeated axial compression
  – To over a million cycles

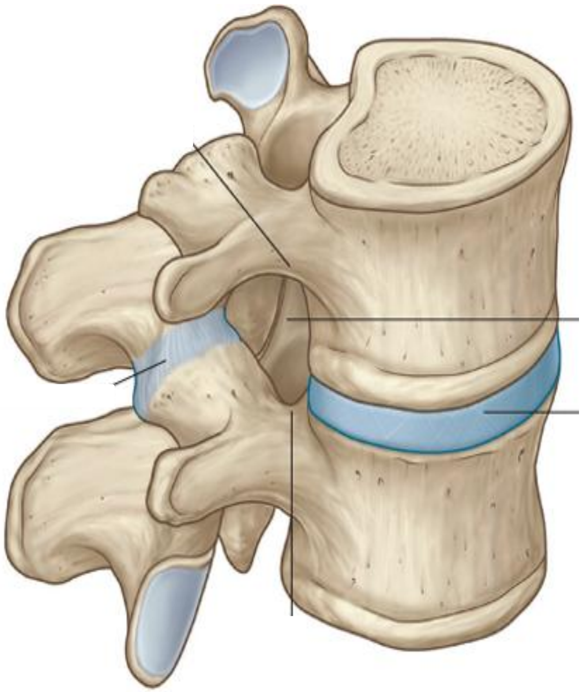
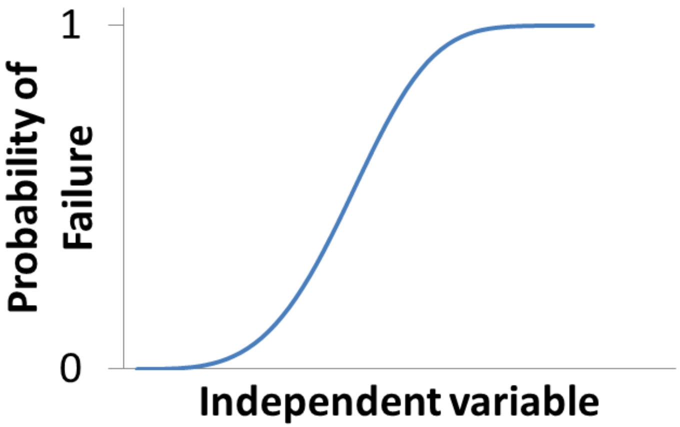


Image: Drake, Gray's Anatomy for Students, 2nd Edition. Copyright © 2009 by Churchill Livingstone; Elsevier, Inc.

Statistical Injury Risk Model

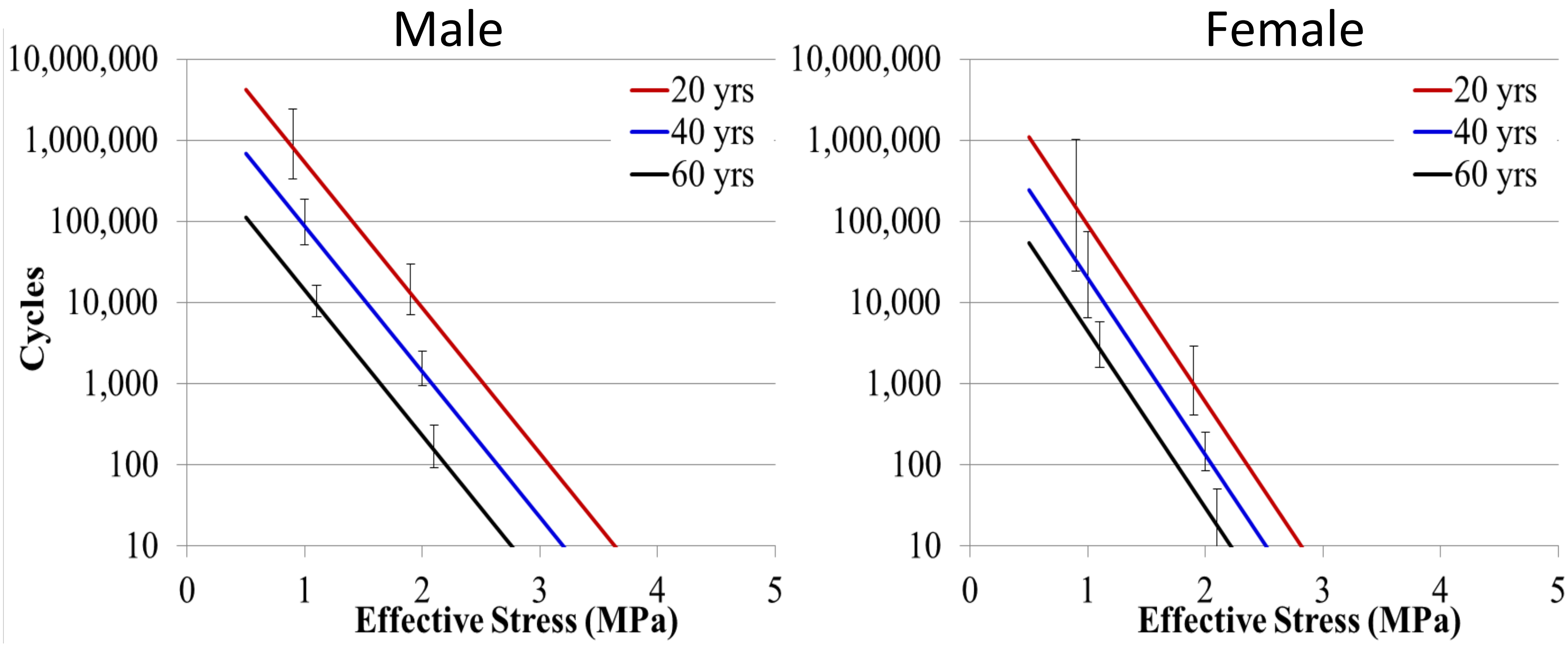
Weibull distribution to predict probability of failure for given exposure in terms of cycles, age, and stress

$$\Pi = 1 - \exp\left[-\left(C/\alpha\right)^{\beta}\right]$$



$$\alpha = \exp\left(K_0 + K_1 \cdot Age + K_2 \cdot Stress\right)$$

50% Risk Functions
Cycles vs Stress



Gender, Stress and Age are Important!

Combining

- ISO 2631-5 (current and draft) combines multiple important variables into single parameter R, associated with probability of failure

$$R = \sigma_{max} \cdot C^{1/6} / 6.75 - 0.066 \cdot Age$$

σ_{max} - peak spinal stress during cycle

C – number of cycles

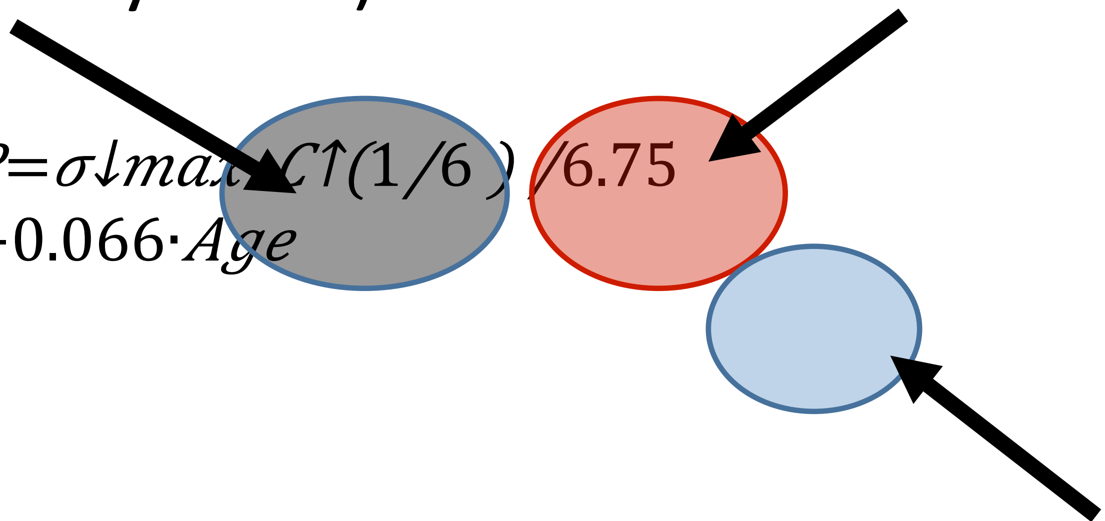
Age – age

Combining

Impact Stress at Spine
(g, upper body mass)

# of Impacts @ Stress
(Distribution)

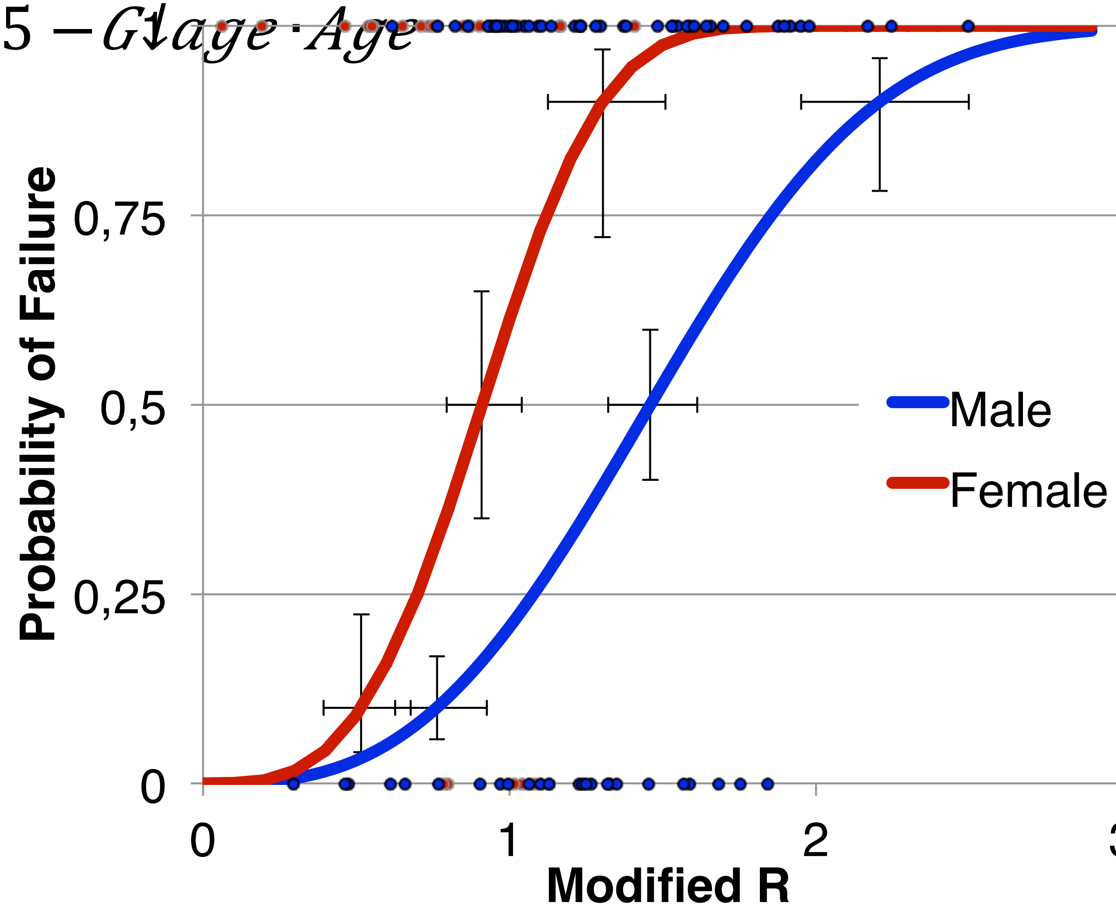
$R=\sigma_{max}\cdot C^{(1/6)}/6.75 - 0.066\cdot Age$



Design
Population
(Distribution)

Injury Risk by Modified R Value

$$R = \frac{\sigma_{max} \cdot C^{1/6}}{6.75} - G_{age} \cdot Age$$

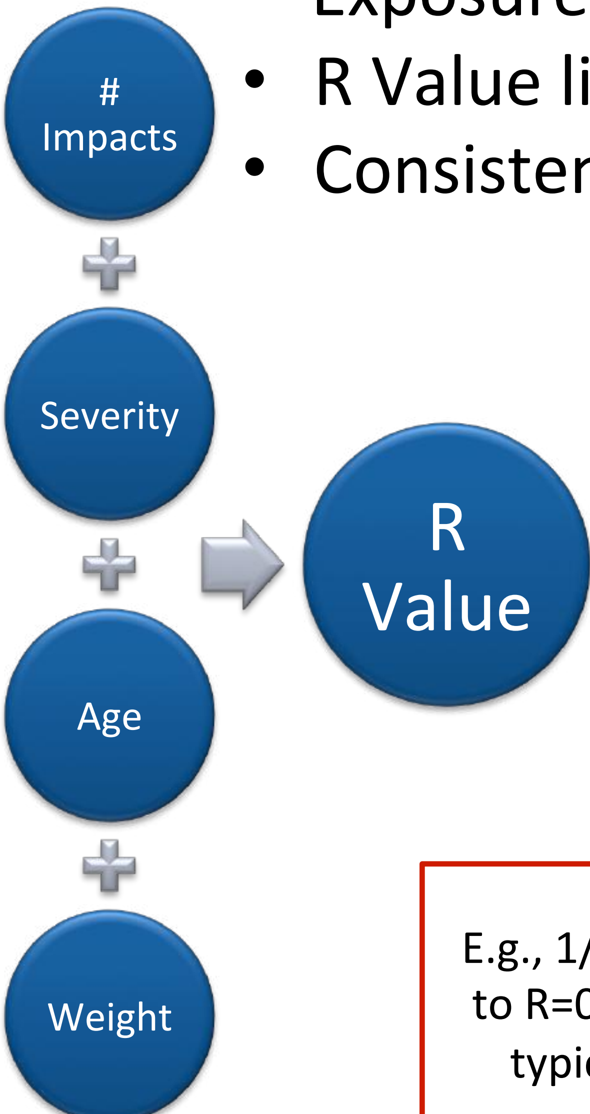


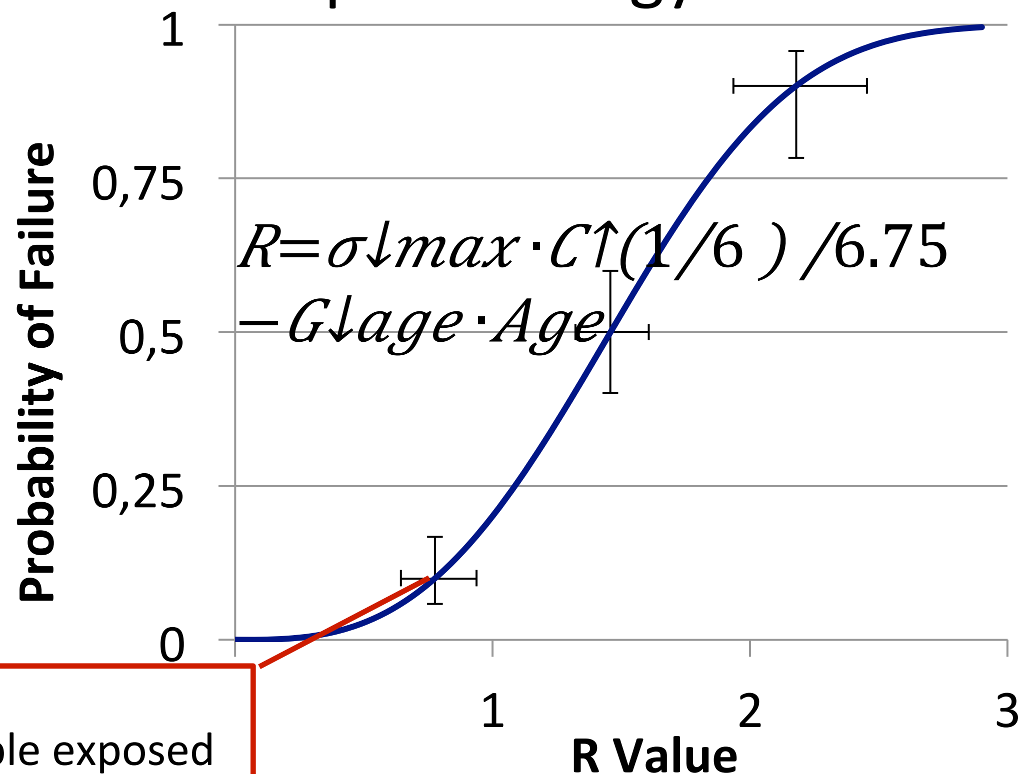
Modifications

- **Sex:** Males and females modeled separately
- G_{age} : Tuned separately for males and females

Injury Criterion

- Exposure for an individual quantified by R Value
- R Value linked to risk of fracture
- Consistent with available epidemiology

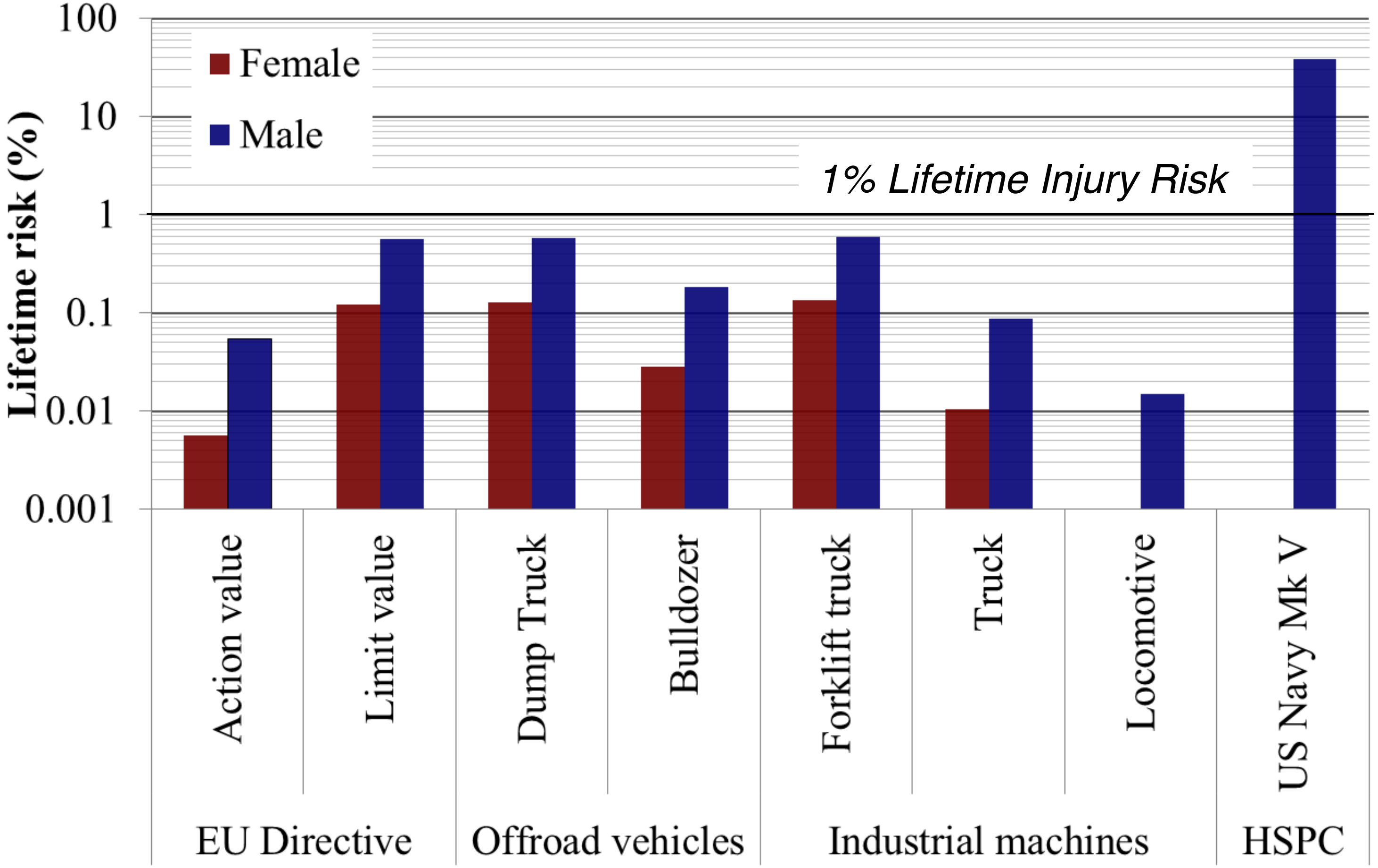




E.g., 1/10 of people exposed to R=0.78 exhibit fracture – typically on endplate of vertebral body

Predicted risks with current injury risk functions

From mean estimate of RMS exposure:



Johanning E. Evaluation and management of occupational low back disorders. Am. J. Ind. Med. 2000;37(1):94-111.
Bass CR, et al The modeling and measurement of humans in high speed planing boats under repeated vertical impacts. IRCOBI 2005.

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Note on the EU Directive

The EU Limit Value Represents a Lifetime Risk[1] of Spine Injury of 0.5%

(Without the effects of healing, including the effects of aging)

[1]Men, career of 45 year, 8 hours/day

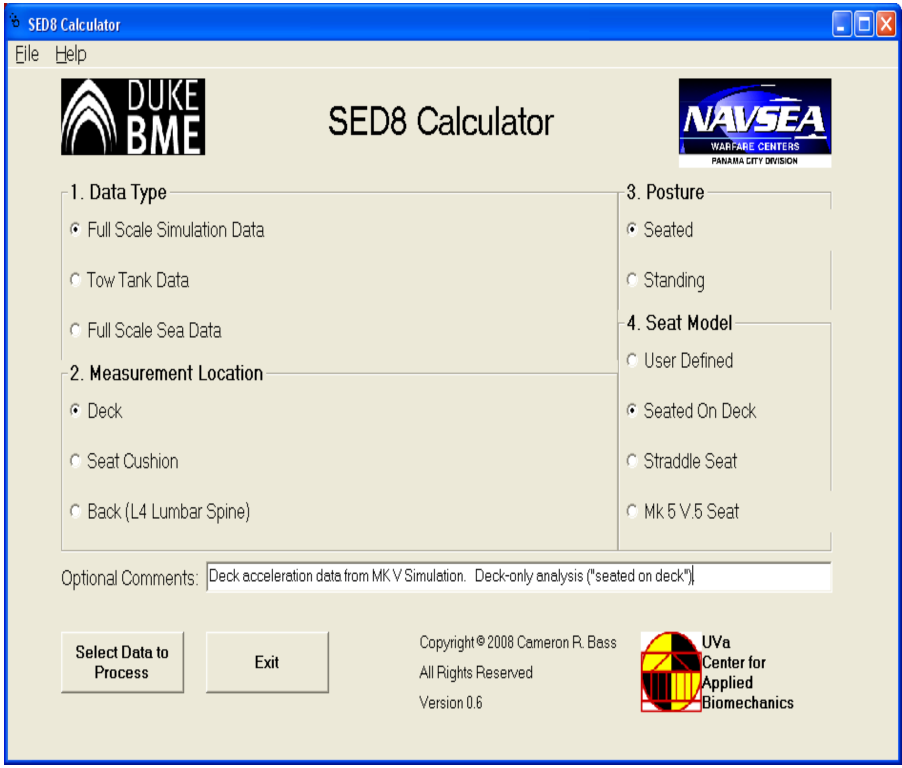
Note on the EU Directive

Opinion: This is an absurdly low limit.

1. Not supported by epidemiology.
2. Home Depot career back injury rate ~1.5%
3. Questionable how well we know
   the risk at these miniscule levels, but
   actual risk value likely lower (healing)…

Injury Calculator

- Developed by US Navy, Duke
- Basis for ASTM-F1166, Mil Std 1472G,
- Current work towards ANSI S2, ISO2631 pt. 5
- Injury Assessment for US Naval Craft
  - *Transfer function/development can be shared with the community*
  - *Used by US HSC Boat-Building Industry starting in Fall 2008*
  - *Used for Combatant Craft Medium Acquisition*



Essential Question

How Long Must Sea Trials Be

to Achieve a Level of Confidence (Statistical)

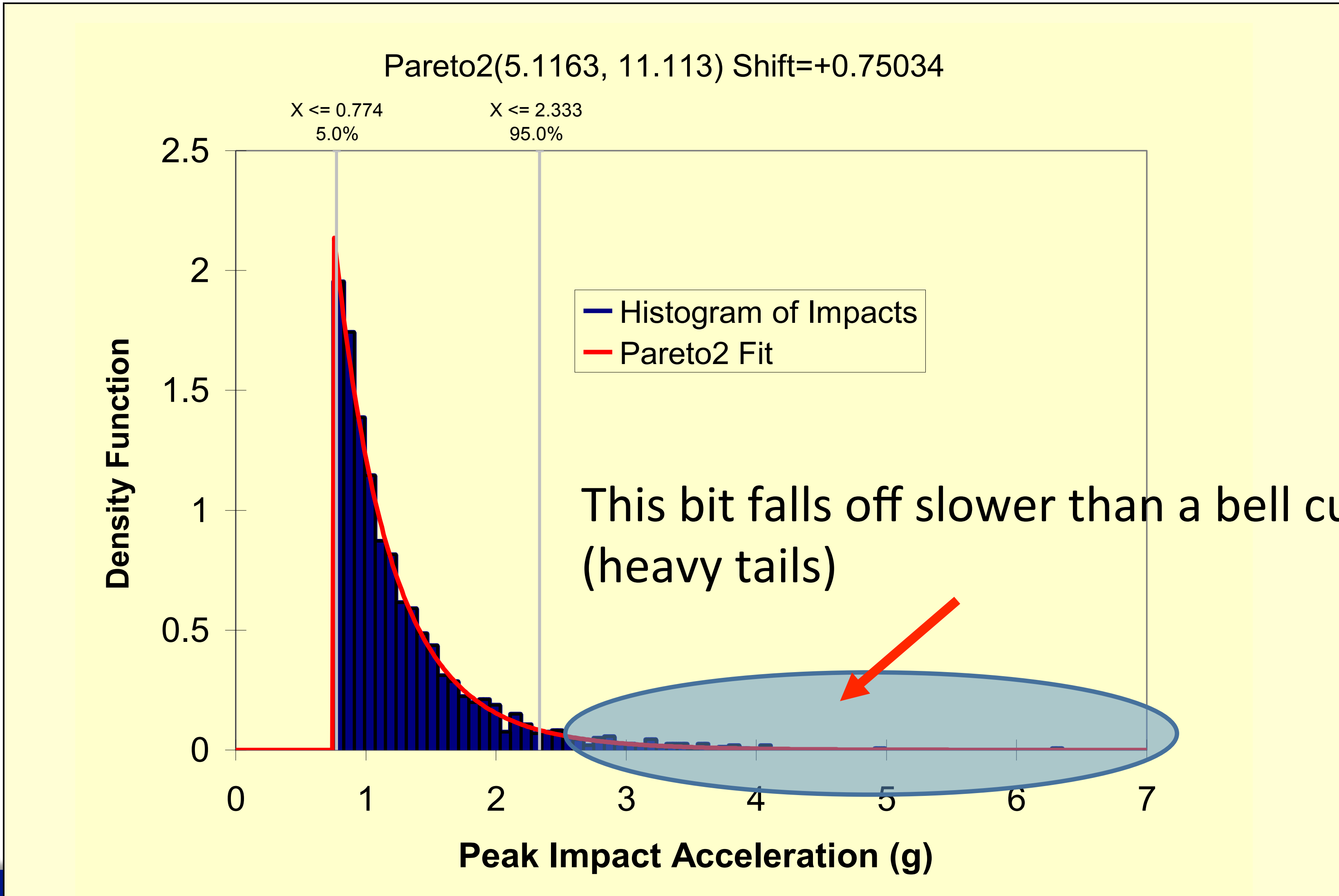
in Injury Assessment

?

Get a Distribution of Impacts

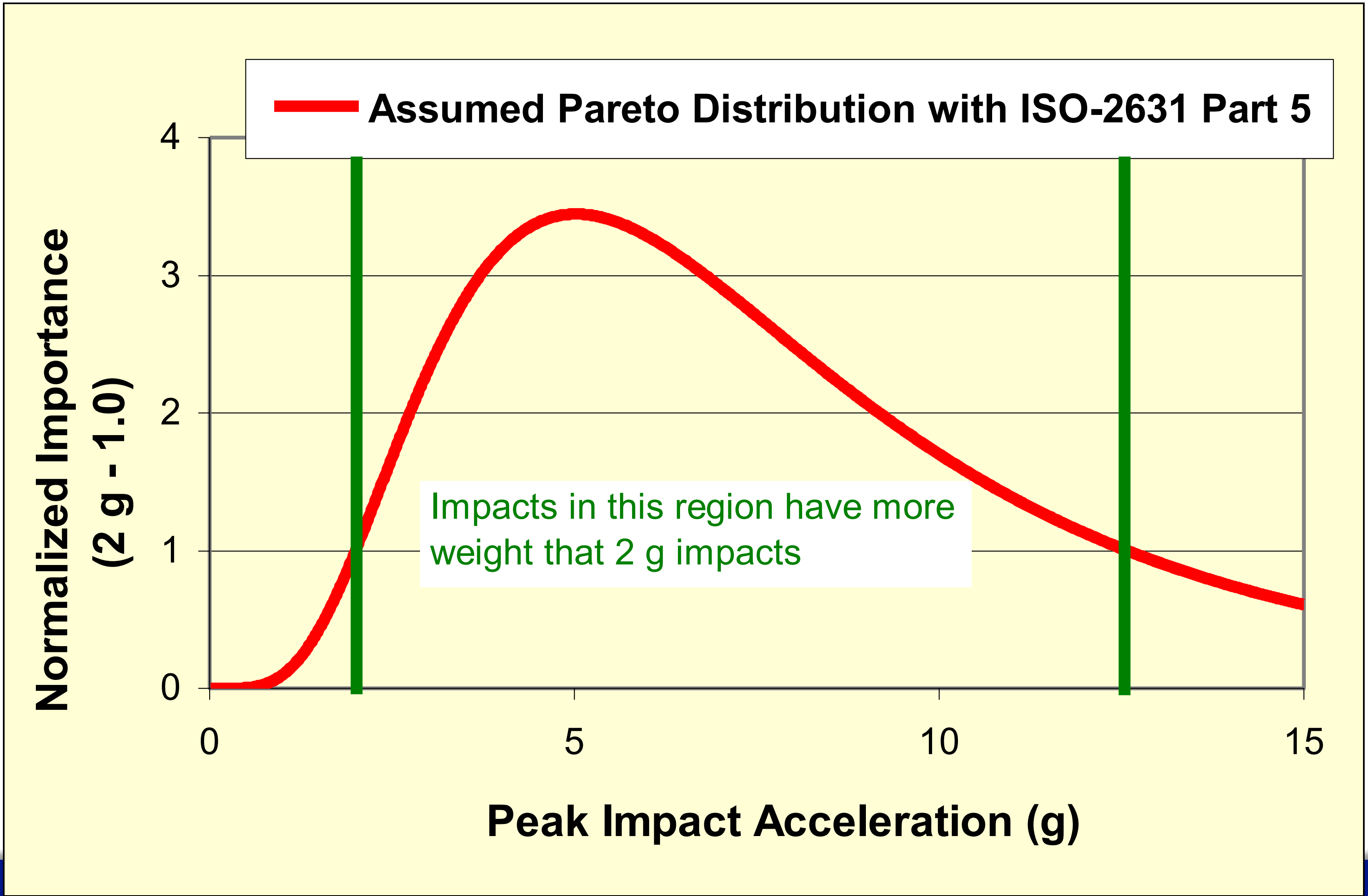
- January 2003 Transit, Day 2, Mk V
  - Speed = 29.5 ± 1.6 kt
  - Heading = $228.8^0 \pm 3.7^0$
  - Heave acceleration at crew station (deck)
  - 5752 impacts (2009 above 0.75 g)
- Distribution Best Fit (of 22 Candidates)
  - > 0.75 g – Pareto2 (Good)
    - ChiSq 27.25
    - P > 0.9

Tail Fit (Important Region)



This bit falls off slower than a bell curve (heavy tails)

'Importance' Function

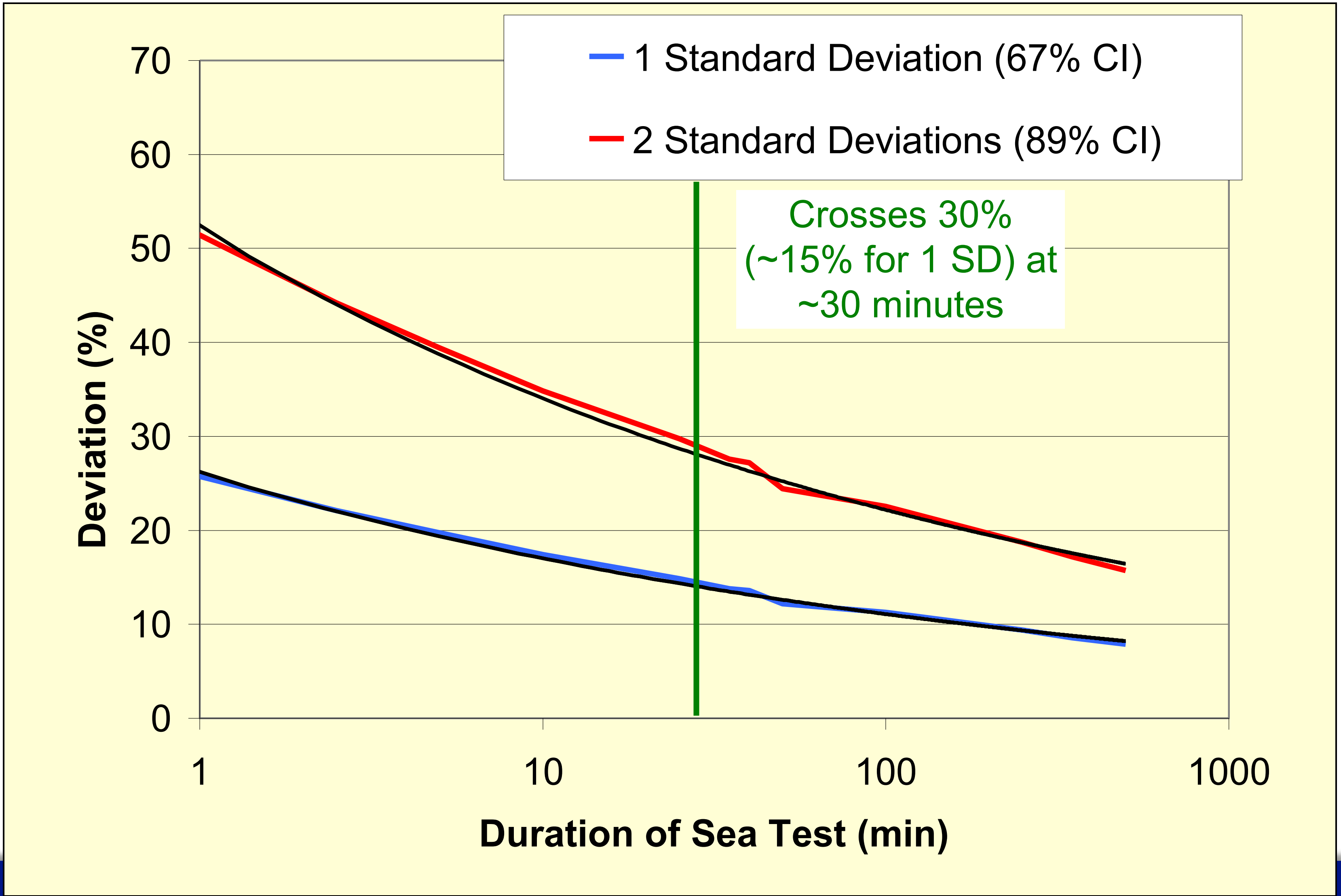


Why is All This 'Important"?

- For Injury Large Impacts are 'Important'
- Large Impacts are Rare

  But Occur More Often than Expected from Bell Curve (Gaussian)…
- So, Must Test To Characterize these 'Important' Impacts

Bottom Line



1 Standard Deviation (67% CI)
2 Standard Deviations (89% CI)
Crosses 30% (~15% for 1 SD) at ~30 minutes
70
60
50
40
30
20
10
0
Deviation (%)
1
10
100
1000
Duration of Sea Test (min)

Sea Test Duration

- Answer–

Graph of Duration vs. Confidence Interval =>

± 30% (2 SD CI) @ 30 minutes, etc.

(Note: For Tank Tests, Distribution May be Selected)

Discussion and Conclusion

- **For High Speed Craft Design**
  - Injury prediction model for <u>cycles</u>, <u>stress</u>, <u>age</u>, and <u>sex</u>
  - Model predicts *in vitro* failure within narrow confidence interval
  - Age and sex are important effects; sex effects extend beyond simple size-related differences
- **For Injury – Long Duration Tests**
- **Further Investigation**
  - Healing effects not included
  - Disc injury and the effects of posture

For Injury Models Contact

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Prediction of Human Injury Risk Under Repeated Heave/Surge Impact

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Confidence Intervals (1)