Risk Assessment Sensitivities for Very Low Probability Events with Severe Consequences

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Introduction

- **Aerospace Systems Commonly Have *Stringent* Risk Requirements**
  - **Safety**
  - **Reliability**
  - **Mission Assurance**
- **Commonalities for these Risks**
  - **Very Low Probability Events – Systems are Designed such that Events are Very Rare**
  - **Severe Consequences if Event is Realized**
- **Assessment of Risks is Difficult *if not Impossible* Using Classical Approaches**

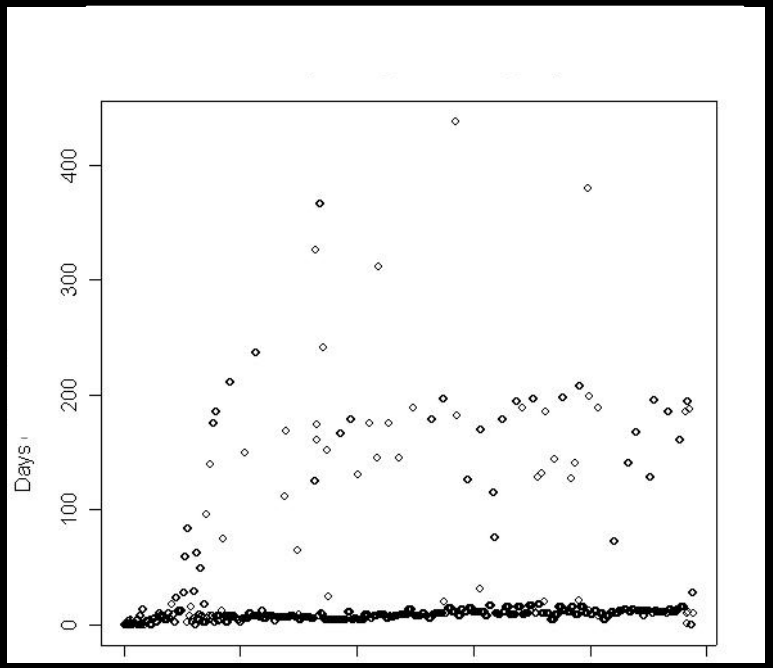
Why are Such Risk Assessments So Difficult?

- **Limited Data – Few *if Any* Events Observed**
  - **Systems Designed to Meet Stringent Requirements Rarely Experience the Events to Realize the Severe Consequences in Testing**
  - **Often Not even in Operations**
- **Classical Statistical Procedures Require *Many* Event Data to Produce Quantitative Assessments that will Comfort Decision Makers**
- **Usually, Many Assumptions are Needed to Produce Quantitative Assessments**

This Does Not Help Much Either!

Intellectually, We can Assess Risk

- **Suppose You had *NO* Observed Failures in 977 Missions of Varying Durations up to 434 Days?**
- **Qualitatively – What is the Risk of a Failure on the next Mission of 270 Days?**
- **What would you think if you got a Failure on Day 1 of the next Mission?**
- **What would you think if you got a Failure on Day 50 of the next Mission?**
- **What would you think if you got a Failure on Day 300 of the next Mission?**



The Typical Response

- **Resort to Qualitative Approaches**
  - **Guessing at Probabilities**
  - **Hopefully based on Some Heuristics**
- **Unsatisfying for Making Expensive Mitigation Decisions**
  - **If Guess is Too High - Mitigation Costs Perhaps Unnecessary**
  - **If Guess is Too Low – More Risk Exposure than Acceptable**
  - **Decision Maker is Always Subject to Question**

An Effective Solution

- **Return to the Basics of Decision Theory**

  The Point is to make a Decision on Risk Mitigation

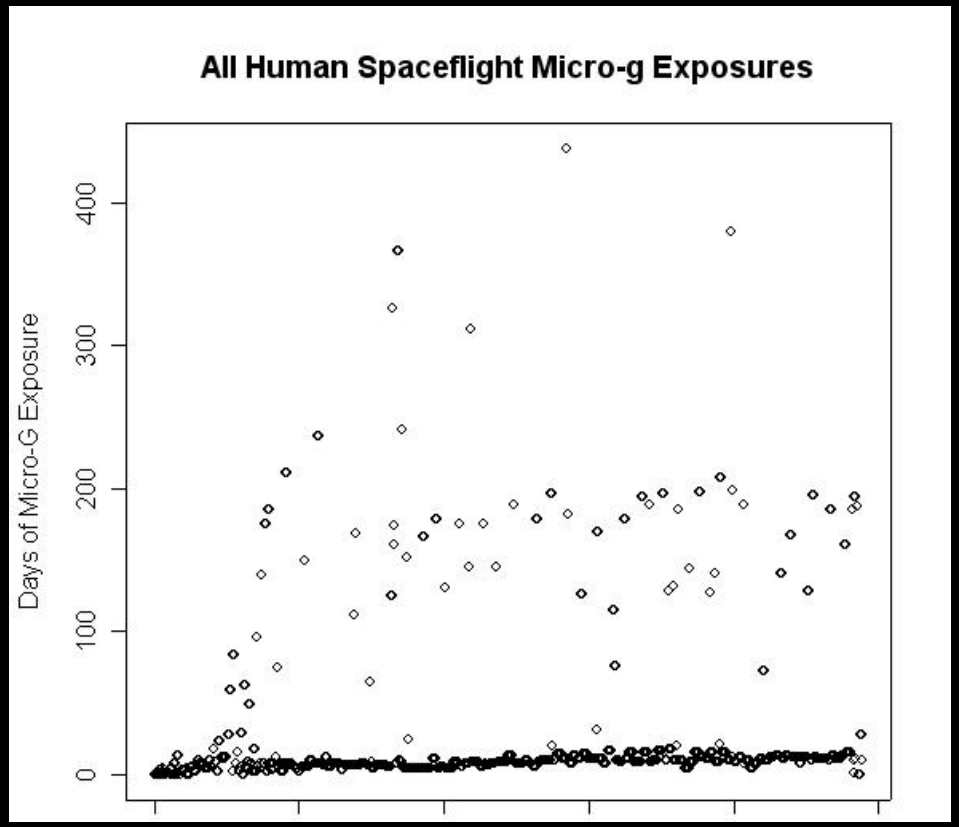
- **Formulate Risk Density Functions Using Bayesian Methods and *Objective Prior Models***
- **Use *Markov Chain Monte Carlo* Numerical Methods to Solve Probability Integrals (Risk Calculations) for Bayesian Formulations**
- **If Necessary for Markov Chain Stabilization, Use *Pseudo-Ignorance Models* for Priors**

An Example - Astronaut Bone Fracture Risk

- **On-Orbit Astronaut Bone Fractures could have Severe Consequences**
  - **To the Astronaut**
  - **To the Mission**
- **Very Low Probability Event – No Astronaut has Ever Broken a Bone during a Mission in History**
- **Example Risk Questions**
  - ***What is the Risk of Bone Fracture for Long Mars Missions?***
  - ***How Much will the Risk Increase if International Space Station Missions extend from 180 to 365 Days?***

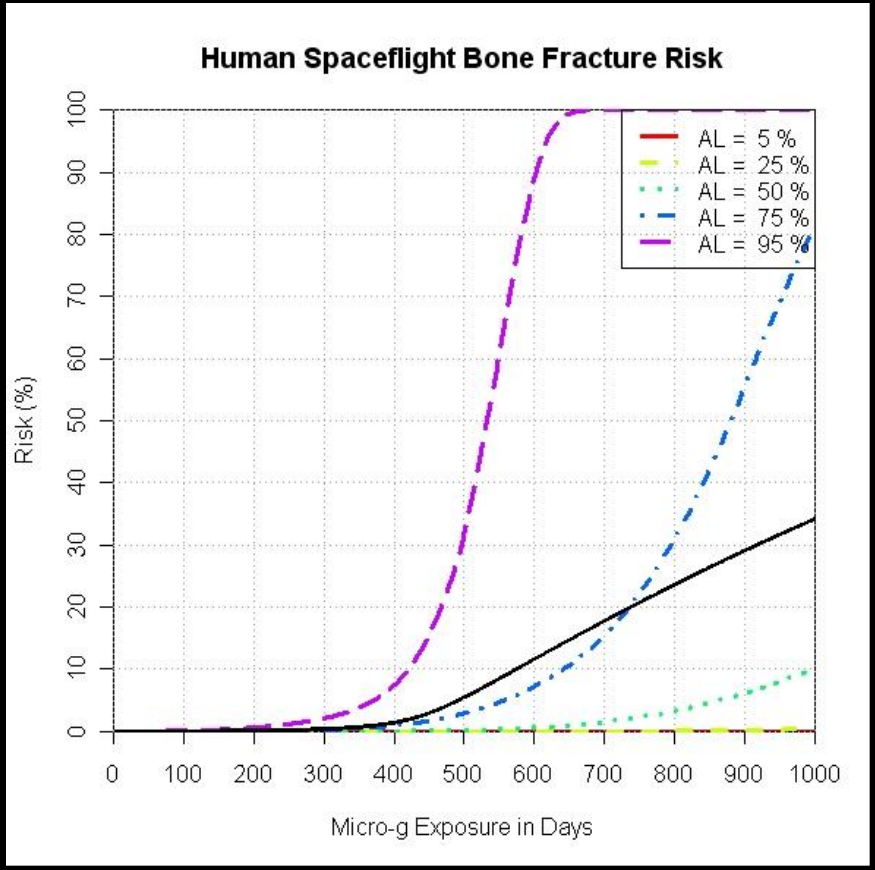
The Available Information (DATA)

- **977 Astronaut Missions of Varying Lengths (as of May 2005)**
- **No Events Observed**
  - **No Bones Broken**
  - **Did Observe 977 Mission Lengths without a Broken Bone**



Risk Results Parameterized for Mission Duration

- **Plotted Various Assurance Levels**
- **As a Function of Mission Duration**
- **For Mars Missions of 270 Days – We Can be 95% Certain that Risk of fracture during the Mission is < 3%, *Based on the Information Available***
- **Quantified Result consistent with *Intuition!***



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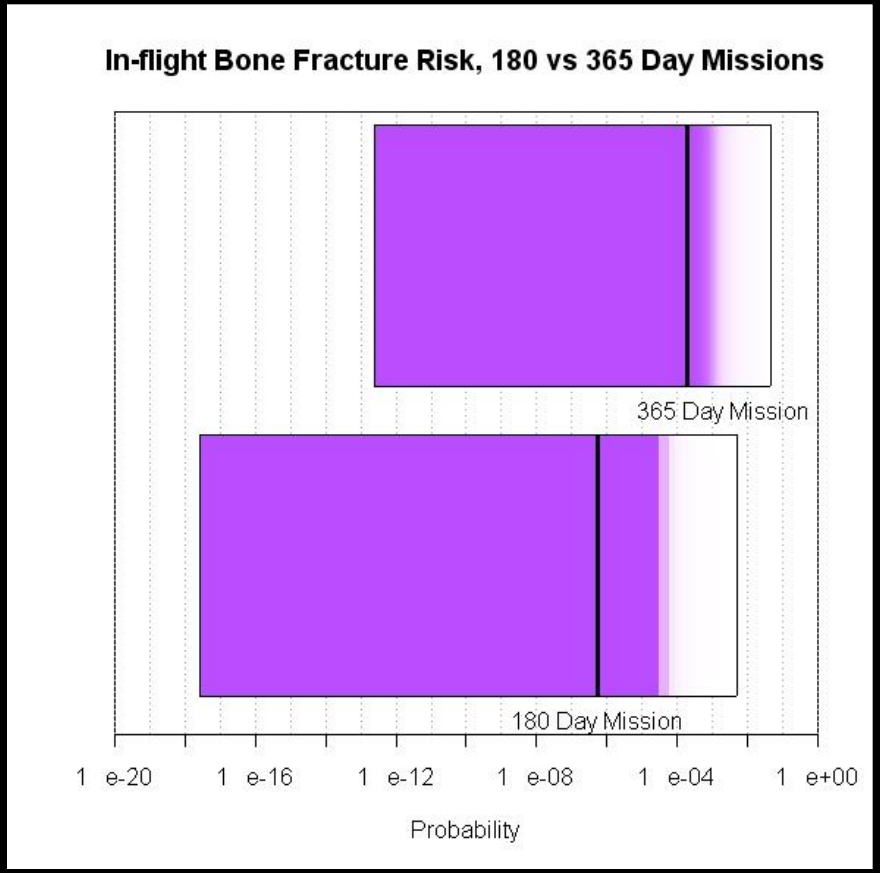
The ISS Mission Extension Question

- **Bar Legend**
  - **Left Side at 5th Quantile**
  - **Right Side at 95th Quantile**
  - **Color Density Proportional to Probability Density**
  - **Black Bar at Median (50th Quantile)**
- **Can you Feel Better about Making Such a Decision?**

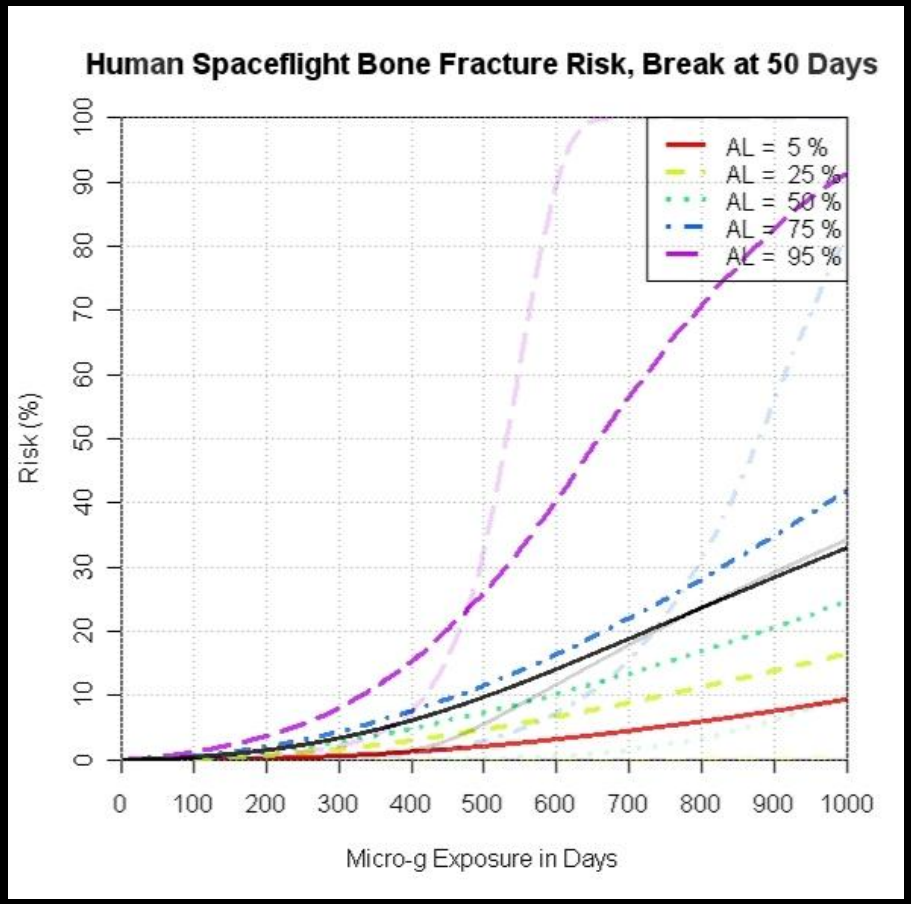


Now, Let's Look at Fracture Risks if We Observe a Fracture on the Next Mission

- **We will Have many More Missions before a Long Duration Mars Mission**
- **We are making Decisions Today Based on Risks, such as Fracture Risks**
- **What happens to Our Decisions if a Fracture Occurs on Some Mission before the Mars Mission?**

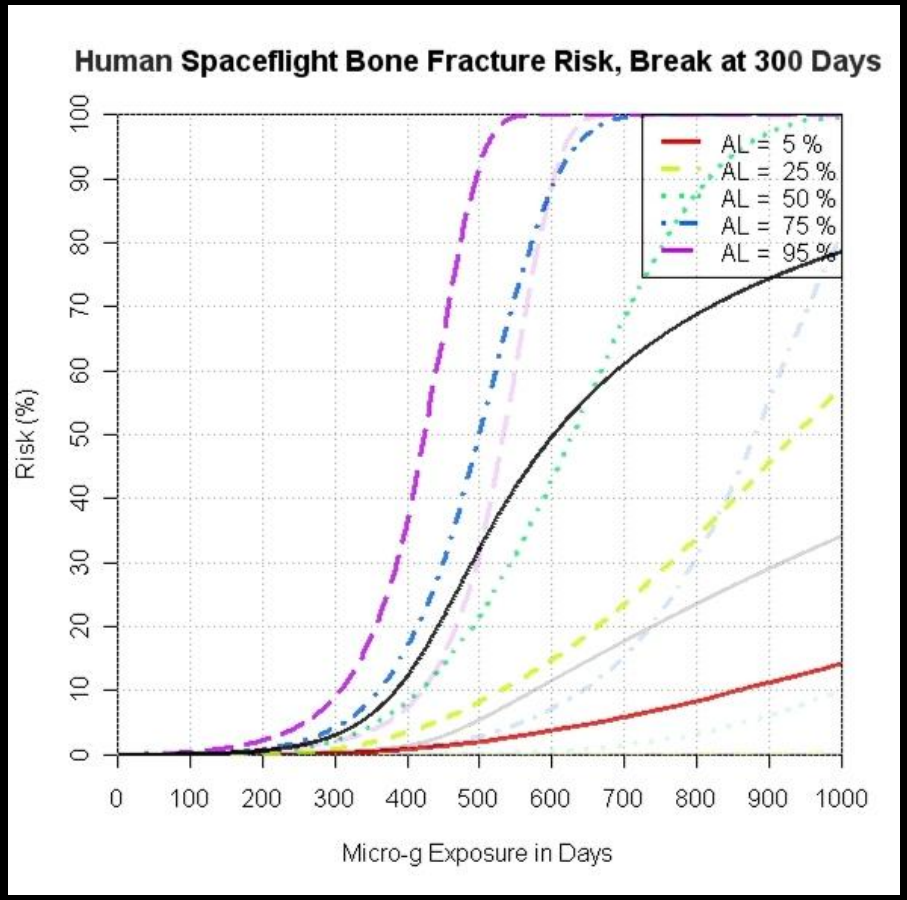
Fracture Risks with a Fracture Event at 50 Days

- **Insert a Hypothetical Fracture at 50 Days**
- **Overlay New Results with Fracture on Faded Original Results**
- **More Risk Earlier, 95% Certain Risk below 8% at 270 Days**
- **Longer Duration Risks Lessened – Not Intuitive**



Fracture Risks with a Fracture Event at 300 Days

- **Insert a Hypothetical Fracture at 300 Days**
- **Overlay New Results with Fracture on Faded Original Results**
- **More Risk Earlier, 95% Certain Risk below 7%**
- **Longer Duration Risks Increased – Actually Agrees with Intuition**



Conclusions

- **Conditional Inferential Methods combined with Markov Chain Monte Carlo numerical Methods Enable *Useable* Risk Assessments**
  Without Any Event Data!
- **Can Make Decisions Based on Risk**
- **Quantitative Risk Results Are Usually Less than Intuitive Guesses**
  This is Very Good News!
- **Large Numbers of Survivor Data affect Quantitative Risk Assessments in Very Non-Intuitive Ways**
- **Welcome Contact about Your Problem**