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NUCLEAR EXPLOSIVE SAFETY NES WORKSHOP 2018

Estimating Uncertainty for Meeting Probabilistic Goals

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We Have Probabilistic Goals

- Reliability
  - About 0.9, probability failure about 0.1
- Safety
  - Walske
    - Normal environments: probability ND 10^{-9} over lifetime
    - Abnormal environments: probability ND 10^{-6} given accident

If No Uncertainty in the Probability

- We know the probability with certainty
- We either meet or do not meet the goal
  - Goal is not exceed 10^{-6}
  - The probability is 5×10^{-7}

In reality we never know the probability with certainty

  - The probability is 5×10^{-6}
    - We do not meet the goal

Using the Mean is Misleading

- Test 10 components, find no failures
  - Mean probability failure is 0
- Test 1,000,000 components, find no failures
  - Mean probability failure is 0
- ... of

With 10 tests 90% confidence value for probability is 0.20

With 1,000,000 tests 90% confidence value for probability is 2.3 x 10^{-6}

probability of failure

- Re **An estimate of the uncertainty of the probability should be provided** as the me...

Definition of Probability

- Probability of event E

$$P(E) = \lim_{N \to \infty} \frac{N(E)}{N}$$

- Event occurs N(E) times in N total trials
- To know P(E) with certainty require infinite number trials

We never know P(E) with certainty.
How estimate uncertainty in P(E)?

Three Approaches for Estimating Uncertainty in Probability

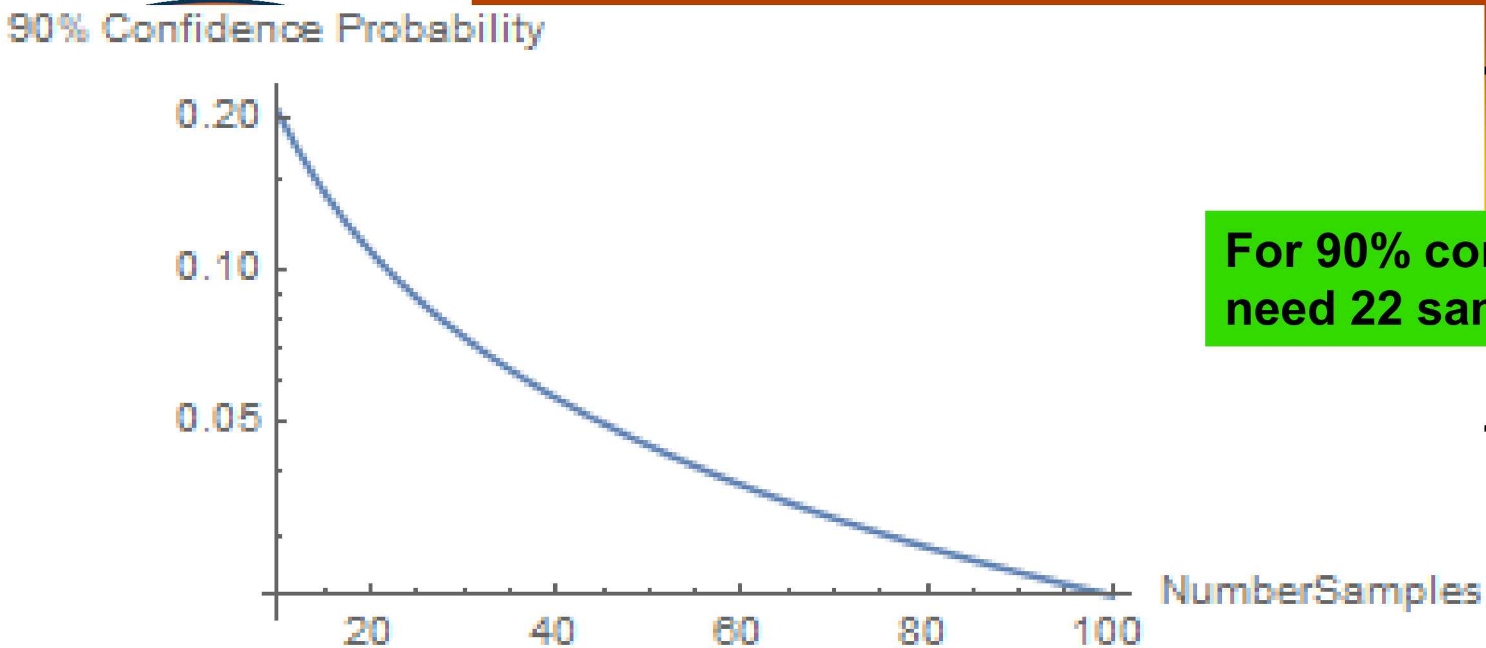
- Classical statistical inference
- Bayesian
- Belief/plausibility

Under what conditions is each approach appropriate?

With no Uncertainty

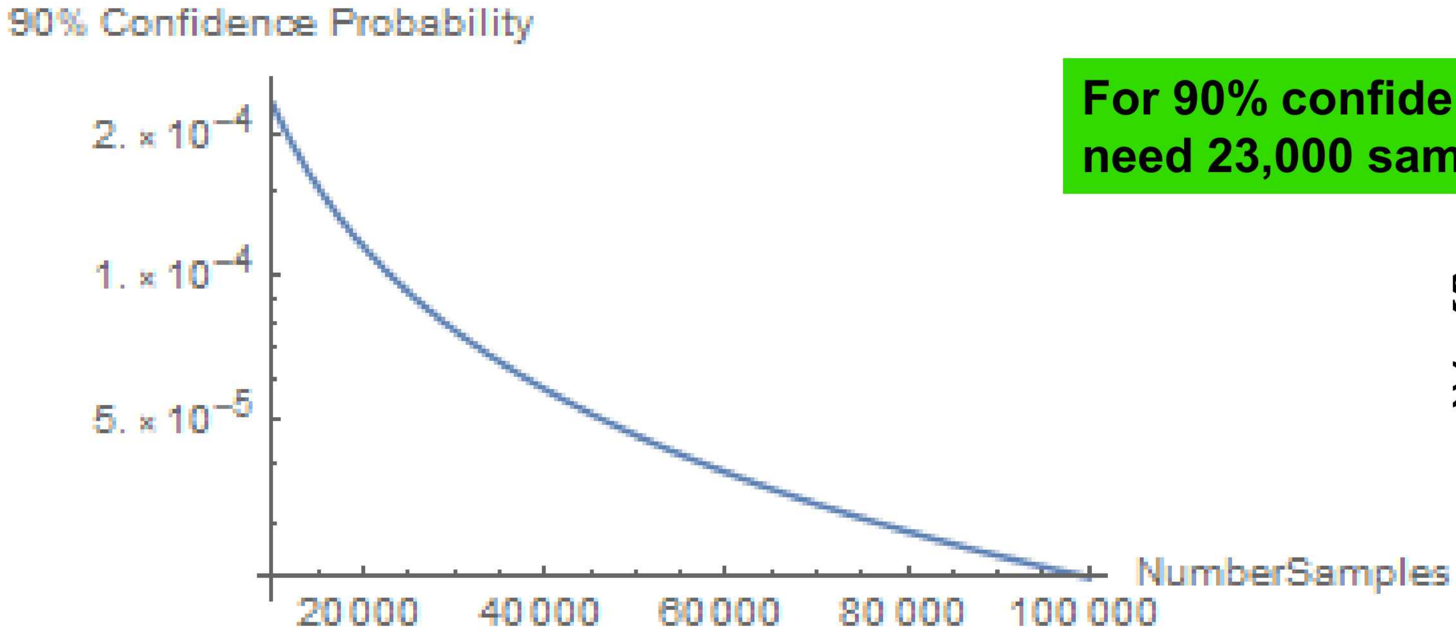
- All three approaches give same probability

nference



For 90% confidence Pfail 0.1 need 22 samples no failures

n N,



For 90% confidence Pfail 10^{-4} need 23,000 samples no failures

no

size)

95%

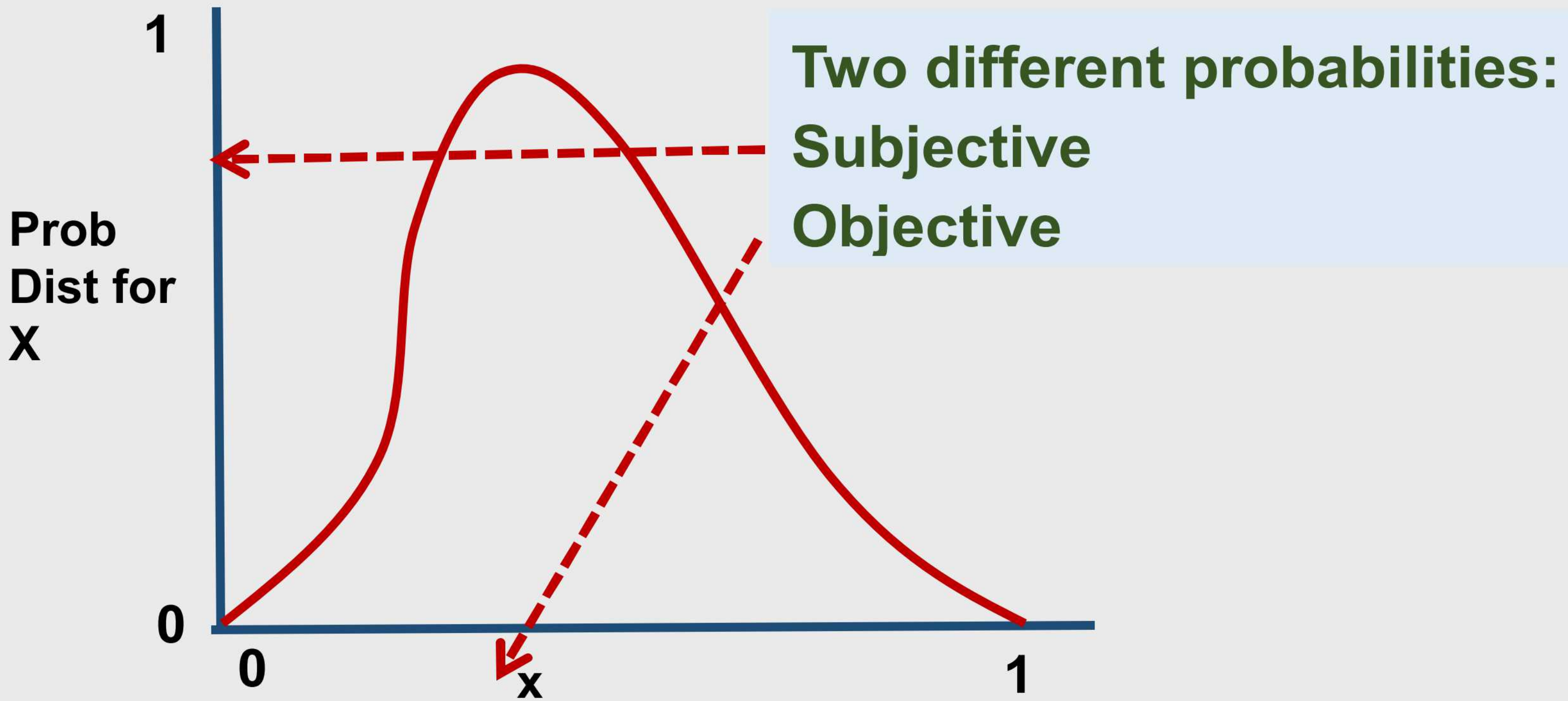
When Use Classical Statistical Inference

- Sample size required for high confidence for probability goal is not prohibitively large
  - If probability goal is not low (e.g. 0.1) sample size may not be prohibitive
    - Reliability
  - If probability goal is low (e.g. 10^{-4}) sample size may not be prohibitive
    - Safety normal environment, common component (e.g. transistor), much test data

When Not Use Classical Statistical Inference

- Sample size required for high confidence for probability goal is prohibitively large
  - If probability goal is low (e.g. 10^{-4}) sample size may be prohibitive
    - Safety abnormal environment sample size is prohibitively large for destructive testing unique components
- Require combine confidence levels for numerous events (e.g. fault tree)
  - Almost impossible to combine confidence levels for many events (NUREG/CR-6823)

Bayesian Approach

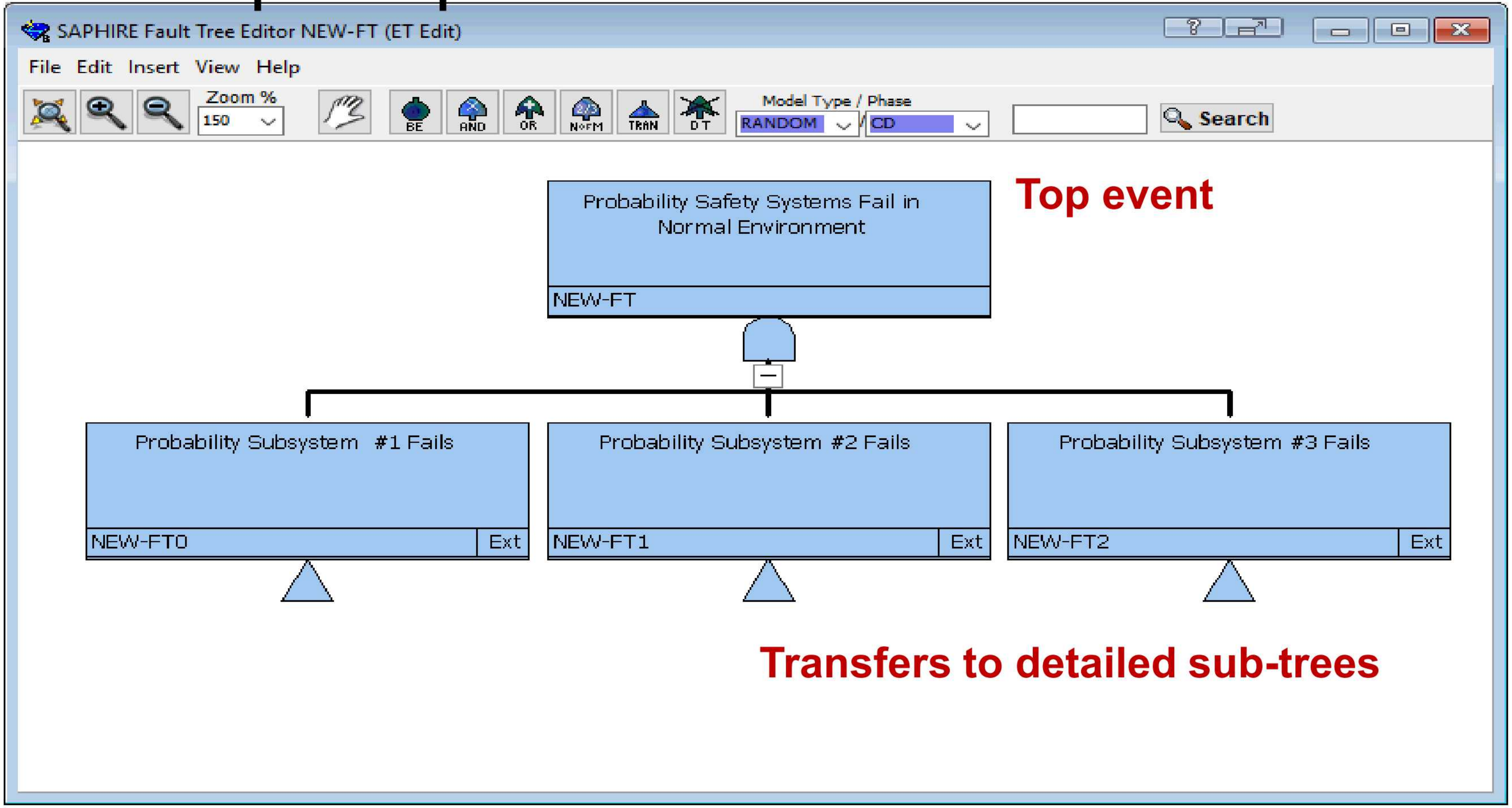


An Application of Bayesian Approach

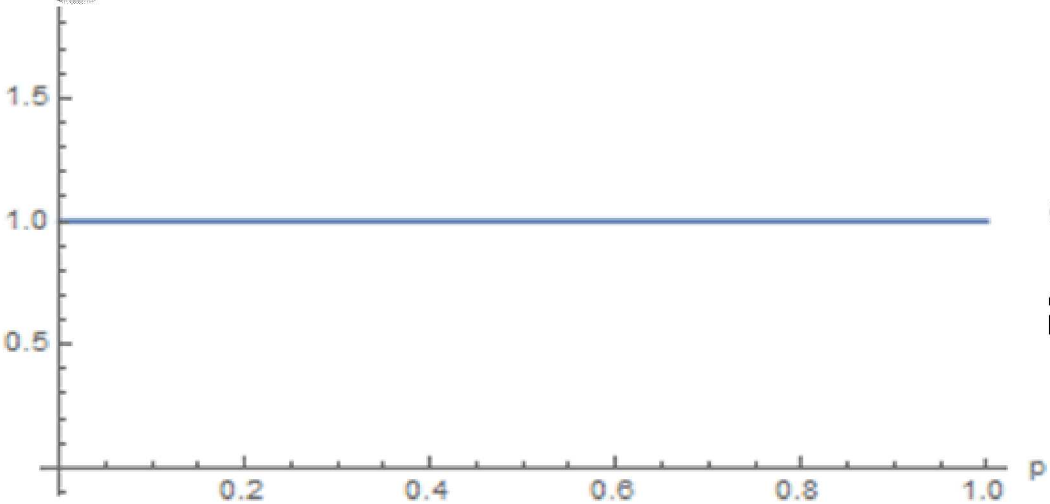
- Assign probability distributions to failure probability events in a fault tree
- Convolve distributions to produce uncertainty in probability of fault tree top event
  - Automated in SAPHIRE fault tree software
    - Past safety evaluations of new weapon systems
    - Current evaluations of off-normal detonation

An Application of Bayesian Approach

- Example top level fault tree



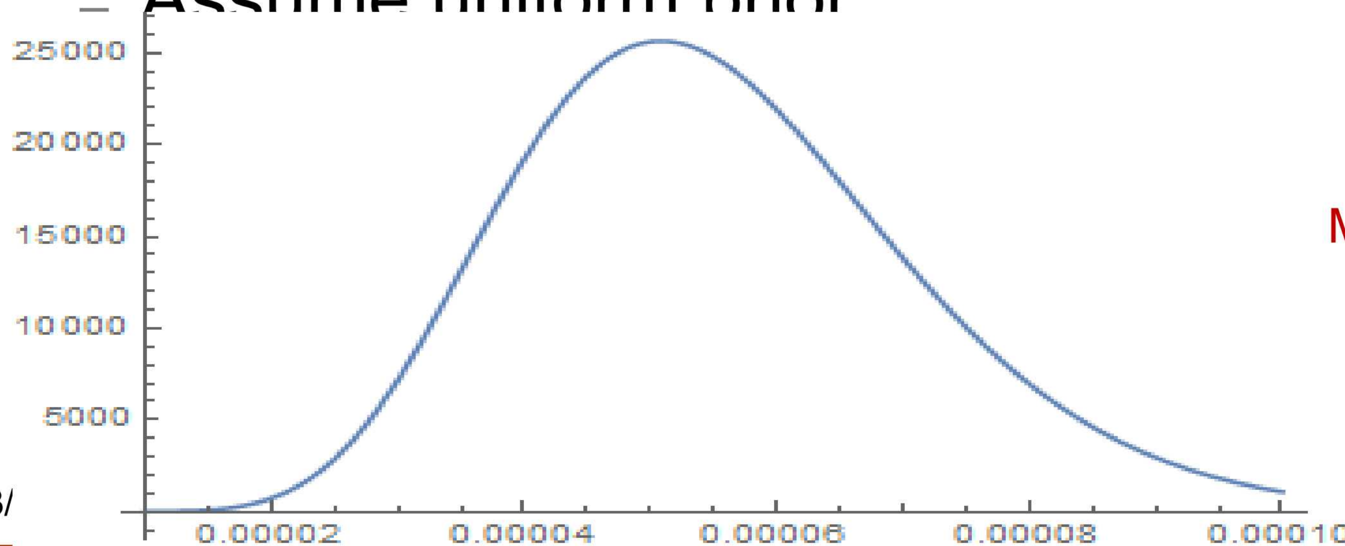
Example Bayesian: One Event



the parameter is
e beta distribution
ameter

Assume uniform prior.

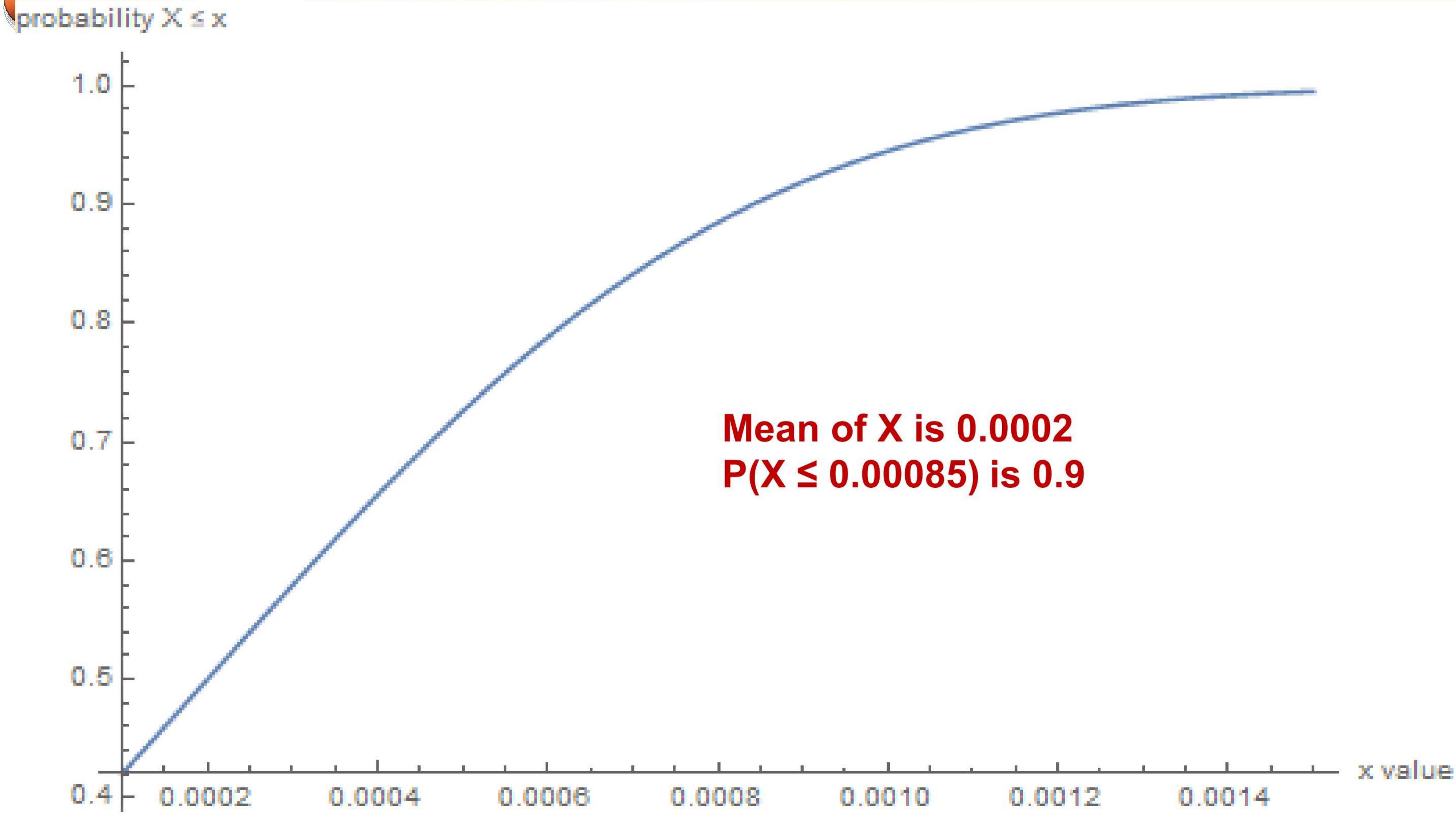
– Assume uniform prior



Observe 11 failures from 213,254 tests.

Mean is 4.8 x 10^{-5}.

Notional Result
Fault Tree Top Event



When is Bayesian Approach Applicable?

- Prior probability distribution can be supported by state of knowledge
- Sufficient information available to update prior to posterior

When is Bayesian Approach Not Applicable?

- Prior probability distribution not supported by state of knowledge
  - Biased prior dominates the updated posterior and posterior is incorrect

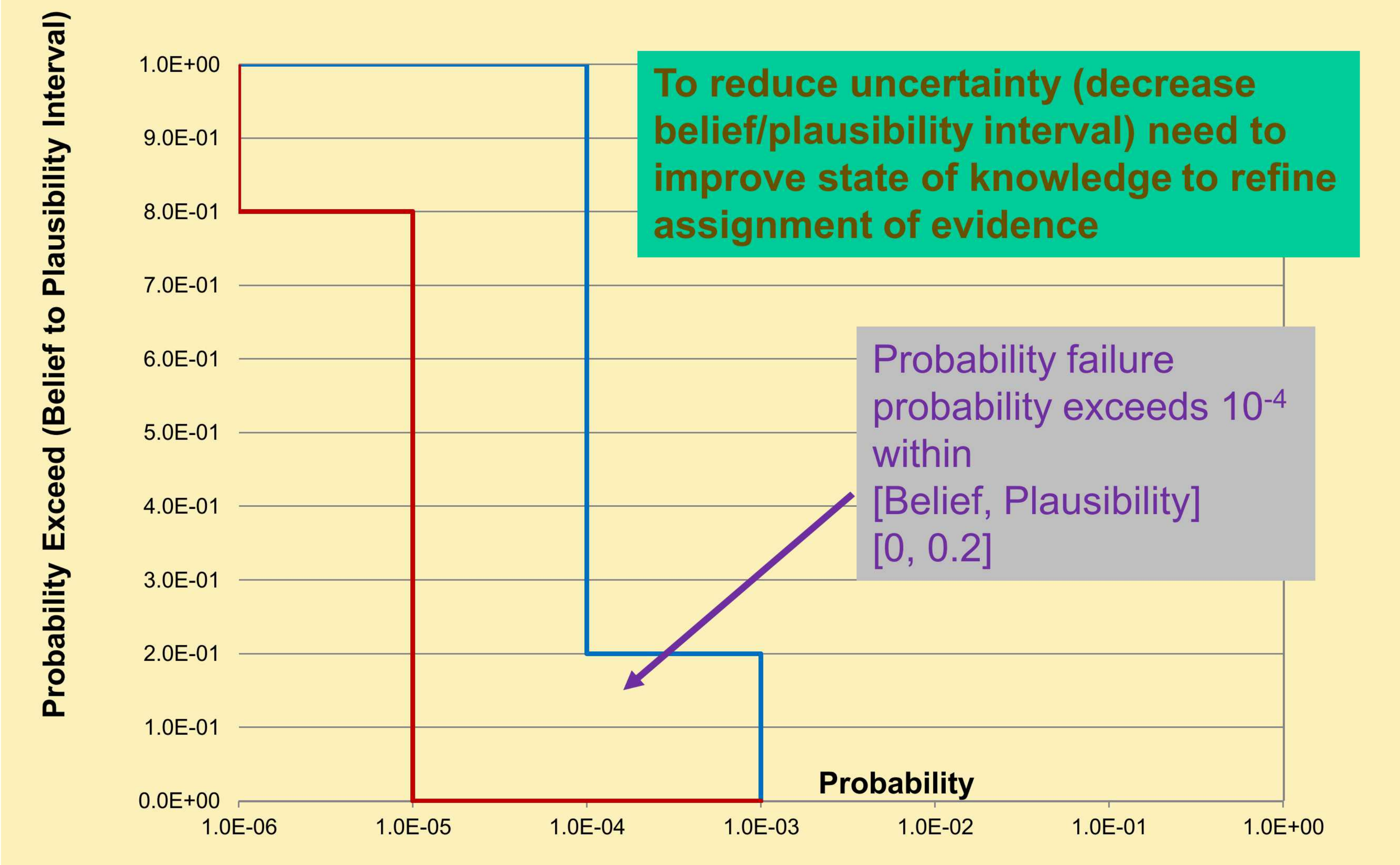
Belief/Plausibility

- Belief/plausibility are lower/upper bounds on probability, respectively
- Based on assignment of evidence
- Evidence assigned to intervals instead of probability distribution assigned to values
  - State of knowledge insufficient to support assignment of probability distribution
- Probability is a special case
  - Evidence assigned to each outcome
  - Belief = plausibility is the probability

Belief/Plausibility

- State of knowledge supports following assignment of evidence for probability a safety component fails to provide isolation, given specific abnormal environment.

Evidence


Probability Exceed (Belief to Plausibility Interval)
1.0E+00
9.0E-01
8.0E-01
7.0E-01
6.0E-01
5.0E-01
4.0E-01
3.0E-01
2.0E-01
1.0E-01
0.0E+00
1.0E-06
1.0E-05
1.0E-04
1.0E-03
1.0E-02
1.0E-01
1.0E+00
Probability
To reduce uncertainty (decrease belief/plausibility interval) need to improve state of knowledge to refine assignment of evidence
Probability failure probability exceeds 10^{-4} within [Belief, Plausibility] [0, 0.2]

When is Belief/Plausibility Applicable?

- Insufficient state of knowledge to assign probability distributions
  - poor prior and little information for Bayesian approach

Advantages and Disadvantages of Belief/Plausibility

- Advantage: allows mathematically-based structure for capturing expert opinion
- Disadvantage: relies on expert opinion

Belief/plausibility approach most appropriate if significant state of knowledge available, but insufficient to assign probability distributions

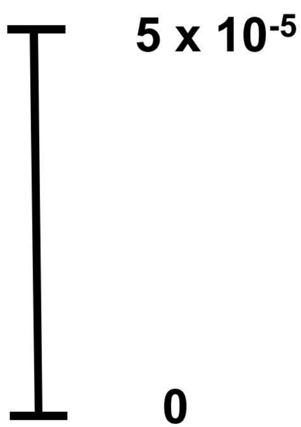
Applications of Belief/Plausibility

- Combined credible abnormal environments
- Loss of assured safety in abnormal thermal environments (thermal race: weaklink does not fail before stronglinks)
- Malevolent, intentional acts
  - Use control

Summarizing Uncertainty for Probabilistic Goals with Classical Statistical Inference

- Assume goal is probability failure of component not exceed 10^{-4}
- Establish confidence level
  - 90%, 95%, ?   Assume 90% here
- Calculate the 90% confidence for probability of failure based on the sample: assume 90% confidence value is 5×10^{-5}

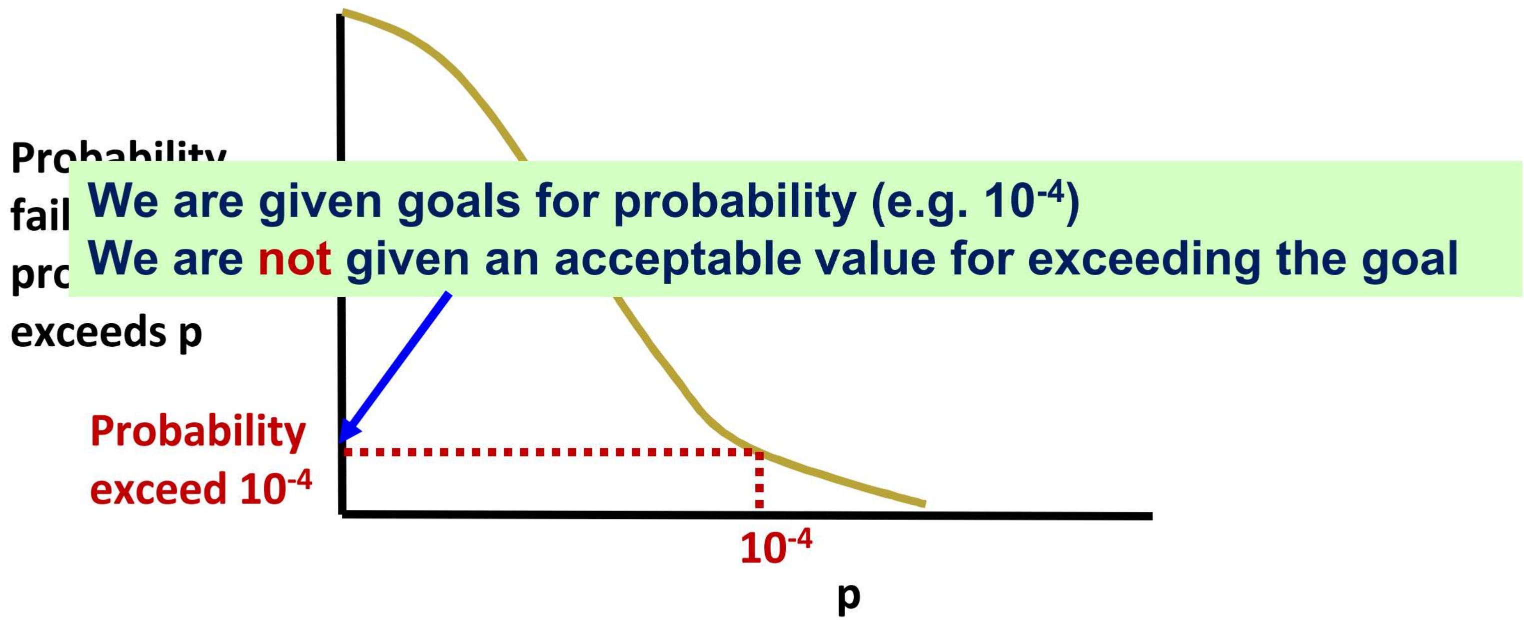
We are given goals for probability (e.g. 10^{-4})
We are not given the confidence level for the goal (90%, 95%,?)



90% Upper One Sided Upper Confidence Interval

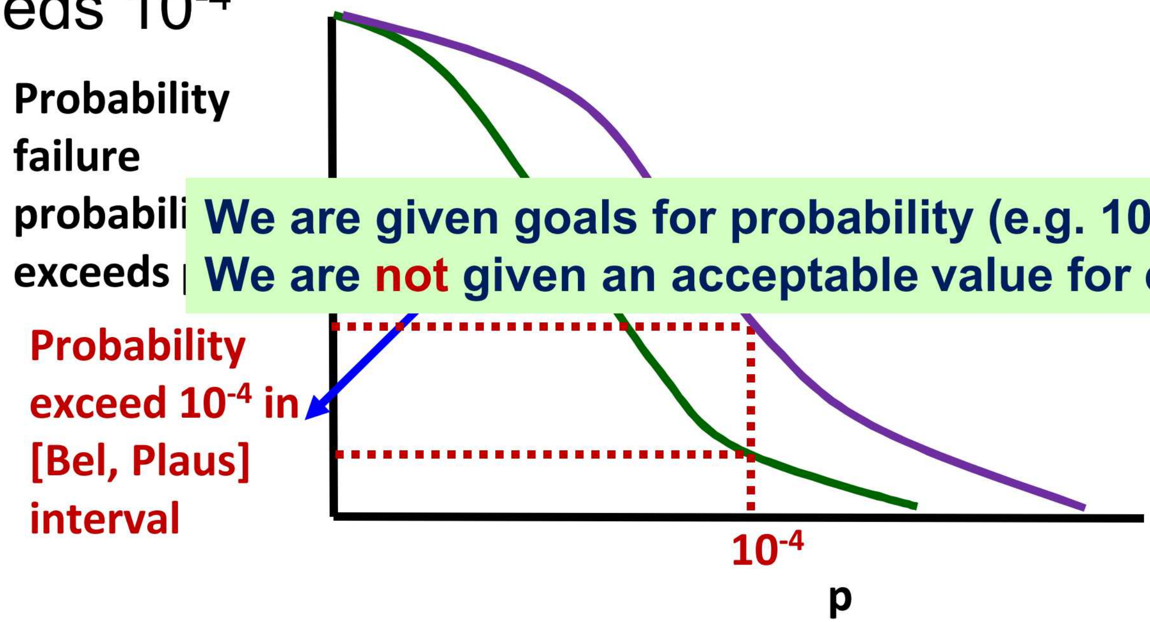
Summarizing Uncertainty for Probabilistic Goals with Bayesian Approach

- Assume goal is probability failure of component not exceed 10^{-4}
- Generate posterior probability distribution: complementary cumulative distribution function
- Calculate probability the probability of failure exceeds 10^{-4}



Summarizing Uncertainty for Probabilistic Goals with Belief/Plausibility Approach

- Assume goal is probability failure of component not exceed 10^{-4}
- Generate complementary cumulative belief and plausibility distribution functions
- Calculate belief/plausibility interval the probability of failure exceeds 10^{-4}



We are given goals for probability (e.g. 10^{-4})
We are not given an acceptable value for exceeding the goal

Software Tools

- Software is available that automates all three approaches

Conclusion

- We are given probabilistic goals to meet
- We always have uncertainty in the probability
- We have approaches/software to estimate the uncertainty in the probability
- Result without uncertainty is misleading
- We are not given any guidance for the acceptable uncertainty for the probabilistic goals

Why Important to NESS

- We always have uncertainty in our estimate of a probability
- Not providing the uncertainty gives an incomplete and perhaps misleading result