HOW MANY SIGNIFICANT FIGURES ARE USEFUL FOR PUBLIC RISK ESTIMATES?

Federal Aviation Administration

6th IAASS Conference

Session 25: Launch Safety – Part 3

By: Paul D. Wilde, Ph.D., P.E. and Jim Duffy

Date: May 2013

Outline

- Purpose
- Background on Uncertainties
  - Definitions
  - History of 321
- Relationship of EC point estimate to mean when epistemic uncertainties are accounted for
- Examples
- Precedent in nuclear power risk

Purpose

- **Recommend the use of only one significant figure as the default for reporting Expected Casualties (EC) results to a decision-maker unless there are other analyses, data, or circumstances to justify the use of an additional significant figure**
  - For FAA: when making a license determination (baseline risk analysis) and for day-of-launch collective risk analyses used to determine if a launch can be initiated
  - Focus is on new and mature orbital ELVs

Definitions

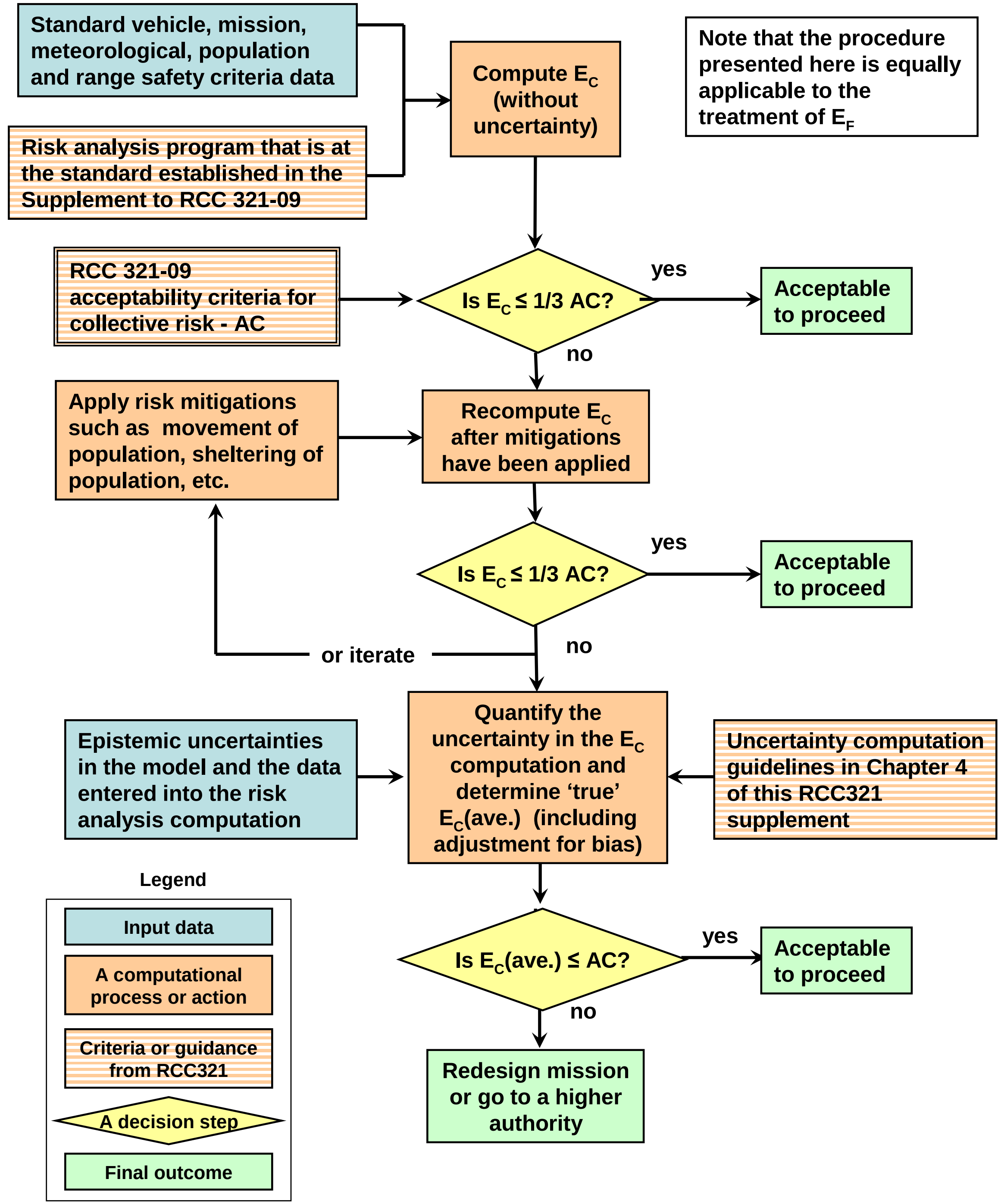
- **Expected Casualties (per 321)** **-** The mean number of casualties predicted to occur as a result of an operation if the operation were to be repeated many times.
- **Aleatory uncertainty** – random uncertainty that cannot be removed by improving the model, e.g. wind. A typical risk analysis program has models for the aleatory uncertainty and the resulting E_C is an average loss considering aleatory uncertainty.
- **Epistemic uncertainty** – uncertainty in the computed result due to the inability of the mathematical/ computer model to simulate the actual process perfectly.
- **Bias** – a shift in the computed result from the true value due to typically “conservative” modeling decisions.

RCC 321 History of Uncertainty Treatment

- **321-07 first to acknowledge uncertainty (see notes pages), but deferred treatment to future.**
  - “Ninety percent confidence bounds describing the uncertainty in the computed risk can have a range of several orders of magnitude.”
- **321-10 acknowledged that there is uncertainty in the estimates of the risk of launches and considered if/how this could affect the selection of launch acceptability criteria.**
  - Produced a flow diagram to guide when uncertainties should be assessed quantitatively

Flow Diagram for the Launch Risk Acceptability Process Considering Uncertainty

– Adopted in the RCC 321-10 Standard



Relationship of EC point estimate to mean when epistemic uncertainties are accounted for

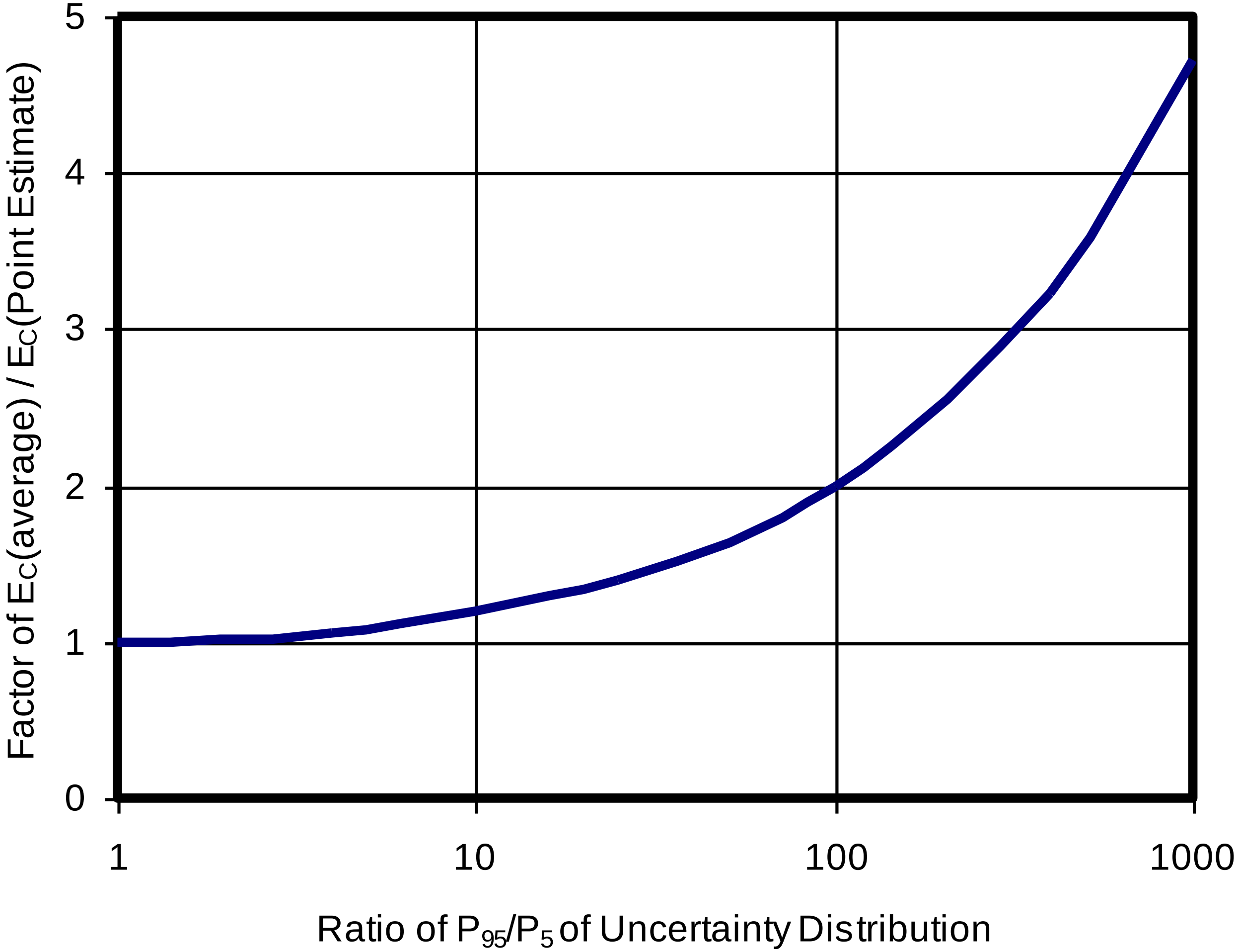
- There is a difference between the point estimate of E_C made by a single run of a risk analysis program and the average E_C resulting from averaging the results of many E_Cs from an uncertainty analysis.
  - **The average is always larger than the point estimate of the E_C unless biases are accounted for**

The Relationship Between Median (Point Estimate) and Mean (Average) for a E_C Uncertainties Modeled with a Lognormal Distribution

Ratio of value at P_U to the value at P_L for 95% Confidence	E_C(avg.)/E_C(median or pt. est.)
1	1
4	1.06
25	1.40
100	1.99
400	3.22
1000	4.72

Note: The actual uncertainty distribution could vary from a lognormal distribution. These ratios are only indicative of the ratios to be expected.

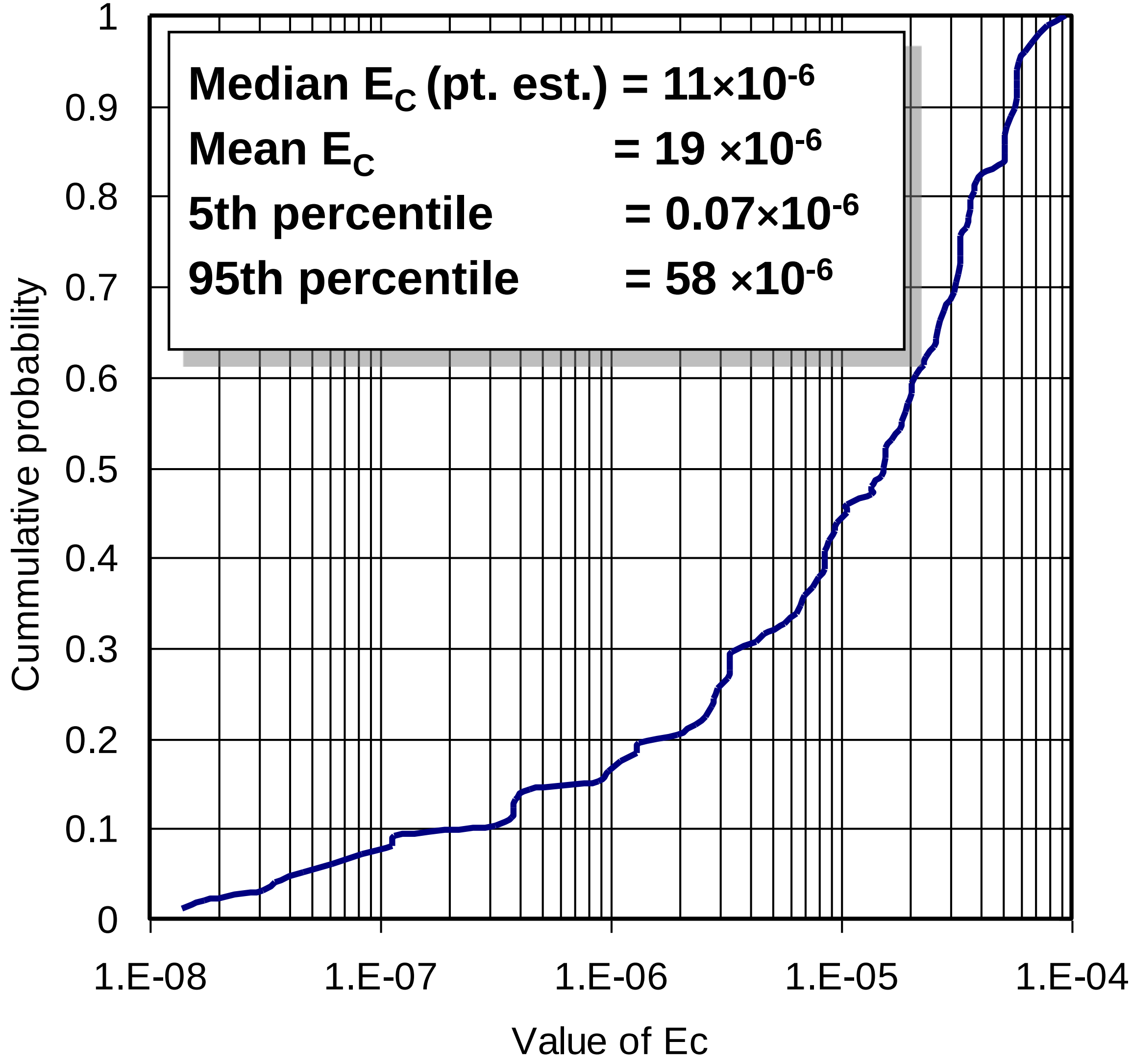
The Relationship Between Median (Point Estimate) and Mean (Average) for a E_C Uncertainties Modeled with a Lognormal Distribution



Uncertainty and Mean EC Issue

- **If uncertainty is computed, the average E_C resulting from the uncertainty analysis will often about twice the point estimate of the E_C**
  - **This would mean that, effectively, vehicles would have twice the risk and a higher likelihood of launches being held with current criteria, UNLESS the biases in the model have been accounted for.**

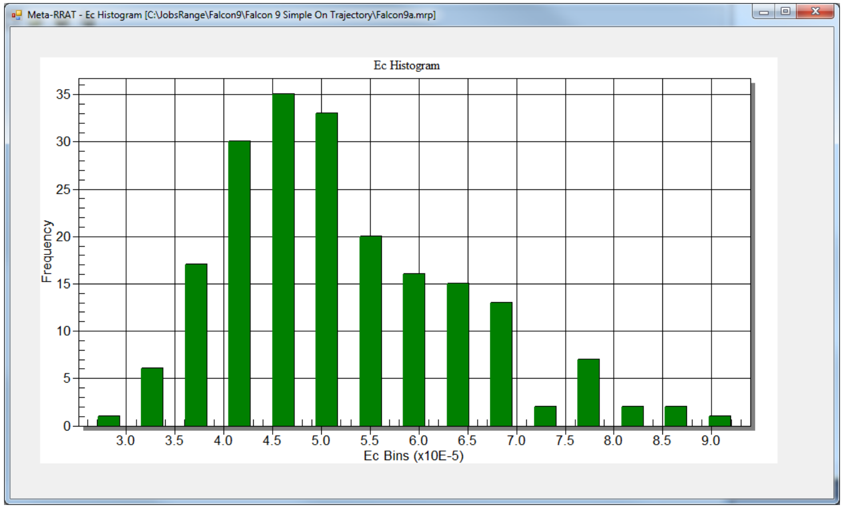
Atlas V Launch Area Risk for VAFB

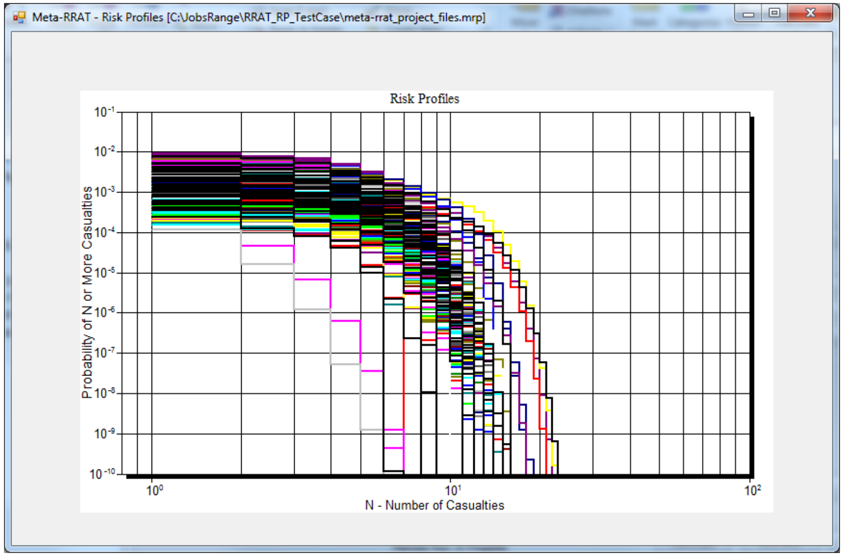


Meta-RRAT Overview

ACTA Inc

- Meta-RRAT is a PC-based risk analysis tool with a Monte Carlo approach to estimate the uncertainty and bias in the results of a normal RRAT analysis
- Provides a GUI interface to facilitate input of a set of sources of uncertainty
  - **Model uncertainties and bias**
  - **Wind profiles**
  - **Debris lists**
  - **Failure probability as a function of time in flight**
- Produces risk profiles and total E_C histogram plots to reveal effects of uncertainties and biases
- Computes a distribution for the E_C in linear and log space



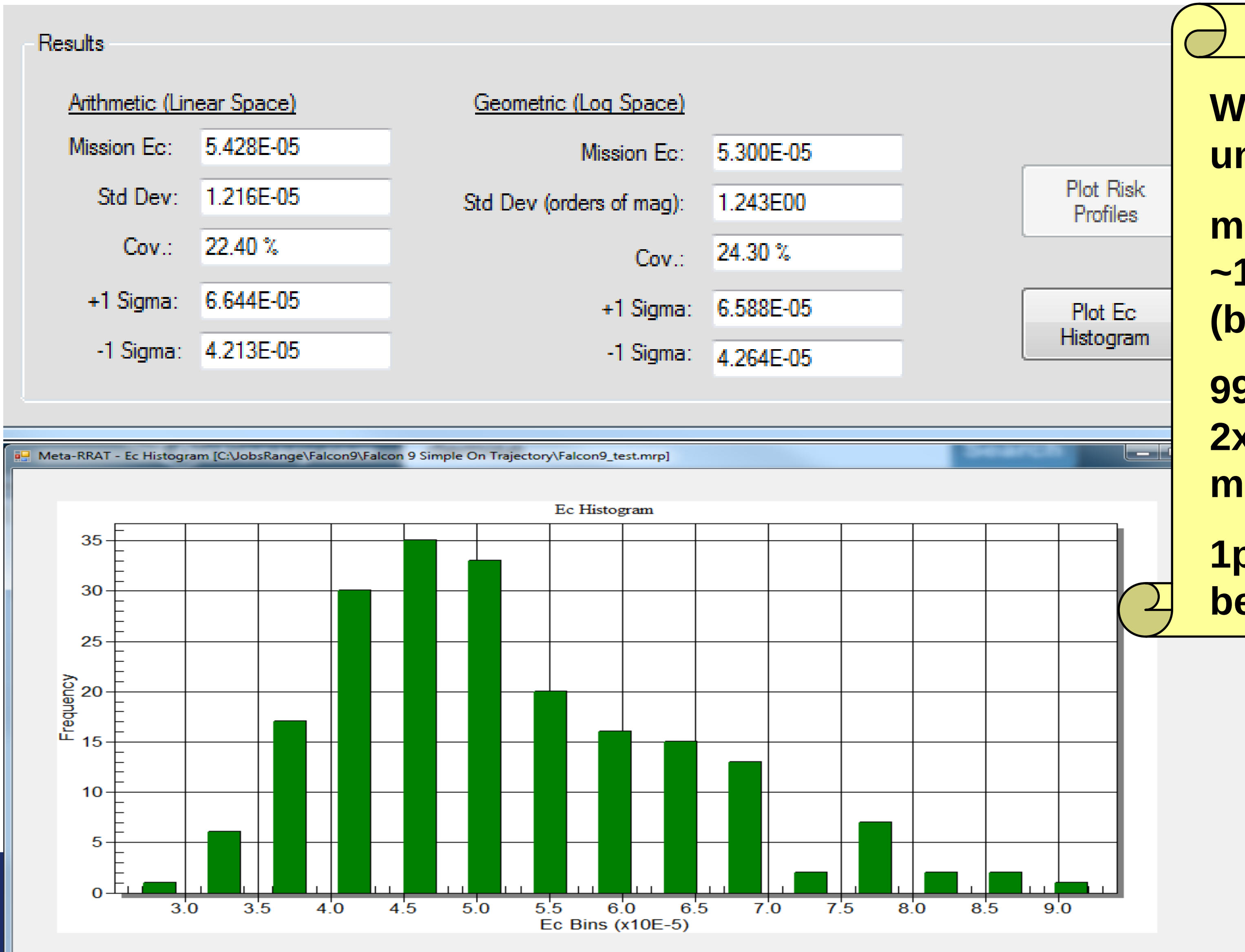


Top Level Modeling Uncertainties

- **CV for Dispersion**
  - Uncertainty in the total footprint size for each fragment group
- **CV for Population**
  - Uncertainty in the number of people in each population center
- **Debris Lists**
  - Input multiple debris lists or input estimated uncertainty in casualty area that would result from variations in the debris list.
- **Yield Uncertainty**
  - This models uncertainty in the explosive yields from solid and liquid propellants of various types
- **Human Vulnerability**
  - Uncertainty in the modeled vulnerability of humans to debris impact
- **Inert debris sheltered casualty area model uncertainties**
  - Each roof type can have it's own uncertainty
- **Vulnerability to explosive debris from structural failures**
- **Vulnerability to explosive debris from window breakage**

Over-flight Uncertainty Analysis for Modeling Uncertainties Only (No POF or debris list uncertainties)

RRAT baseline mission E_C= 60E-6 (no modeling uncertainties in baseline)



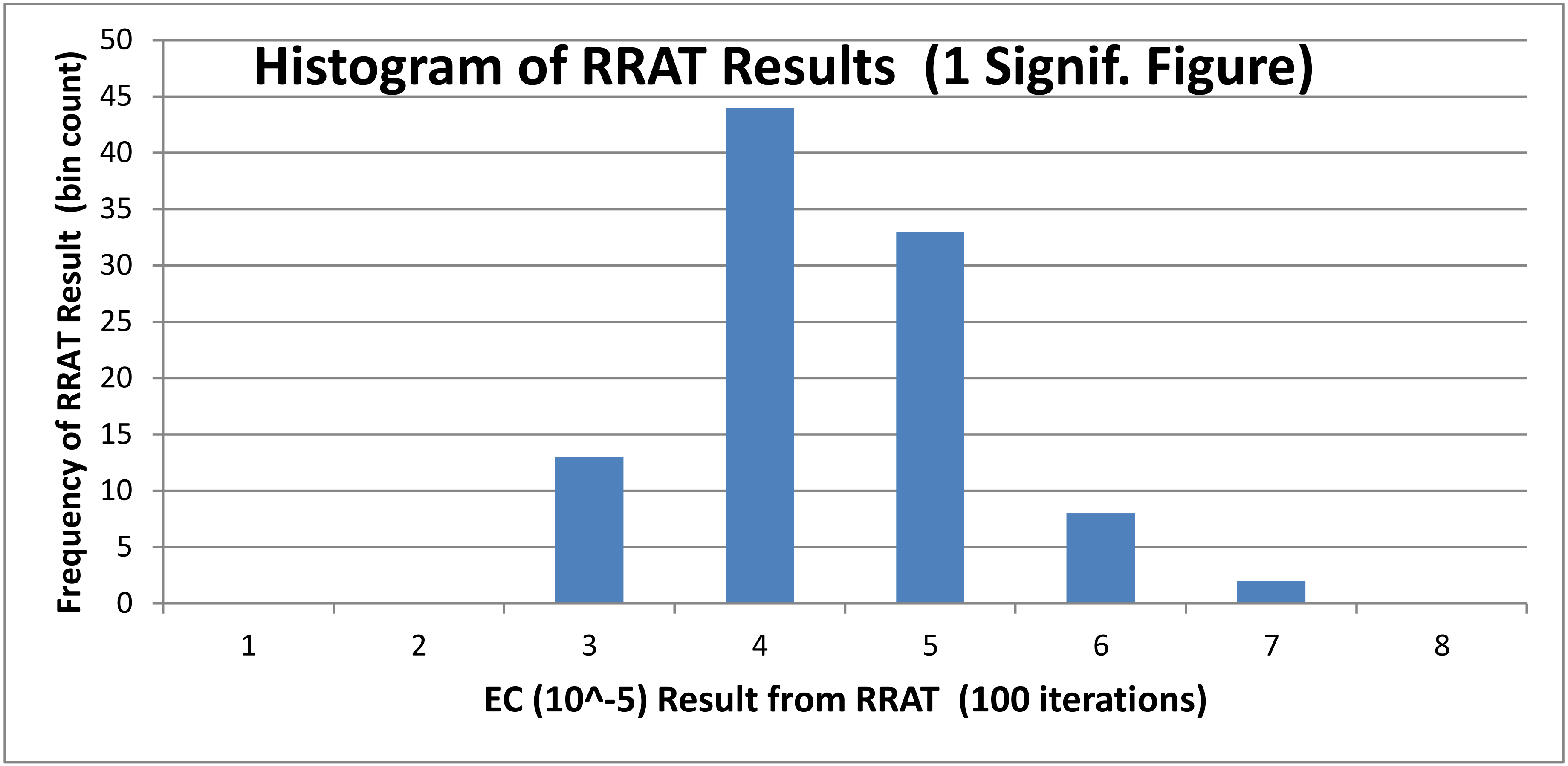
With model uncertainties

mean EC is ~10% lower (biases)

99 percentile 2x above mean

1percentile 3x below mean

F-9 Over-flight Uncertainty Analysis for Modeling Uncertainties Only (No POF, debris list uncertainties)



§A417.25: 60% Confidence for POF from Binomial

<——Success Failure ——>

Next Launch	0	1	2	3	4	5	6	7	8	9	10
3	0.55 **0.28** 0.00	0.89 **0.50** 0.11	1.00 **0.72** 0.45								
4	0.42 **0.21** 0.00	0.71 **0.39** 0.07	0.93 **0.61** 0.29	1.00 **0.79** 0.58							
5	0.33 **0.17** 0.00	0.58 **0.32** 0.05	0.79 **0.50** 0.21	0.95 **0.68** 0.42	1.00 **0.83** 0.67						
6	0.28 **0.14** 0.00	0.49 **0.27** 0.04	0.67 **0.42** 0.17	0.83 **0.58** 0.33	0.96 **0.73** 0.51	1.00 **0.86** 0.72					
7	0.24 **0.12** 0.00	0.42 **0.23** 0.04	0.59 **0.36** 0.14	0.73 **0.50** 0.27	0.86 **0.64** 0.41	0.96 **0.77** 0.58	1.00 **0.88** 0.76				
8	0.21 **0.10** 0.00	0.37 **0.20** 0.03	0.52 **0.32** 0.12	0.65 **0.44** 0.23	0.77 **0.56** 0.35	0.88 **0.68** 0.48	0.97 **0.80** 0.63	1.00 **0.90** 0.79			
9	0.18 **0.09** 0.00	0.33 **0.18** 0.03	0.46 **0.28** 0.10	0.58 **0.39** 0.20	0.70 **0.50** 0.30	0.80 **0.61** 0.42	0.90 **0.72** 0.54	0.97 **0.82** 0.67	1.00 **0.91** 0.82		
10	0.16 **0.08** 0.00	0.30 **0.16** 0.02	0.42 **0.26** 0.09	0.53 **0.35** 0.18	0.63 **0.45** 0.27	0.73 **0.55** 0.37	0.82 **0.65** 0.47	0.91 **0.74** 0.58	0.98 **0.84** 0.70	1.00 **0.92** 0.84	
11	0.15 **0.07** 0.00	0.27 **0.15** 0.02	0.38 **0.23** 0.08	0.48 **0.32** 0.16	0.58 **0.41** 0.24	0.67 **0.50** 0.33	0.76 **0.59** 0.42	0.84 **0.68** 0.52	0.92 **0.77** 0.62	0.98 **0.85** 0.73	1.00 **0.93** 0.85

Failures on Previous *n* Launches

After 4 flights with 2 failures: credible POF range for 5th launch is 0.21 – 0.79, with a reference value of 0.50

Key Point for Public Risk Uncertainty

- **Dominant source of uncertainty depends on the specifics of the launch/re-entry and risks of concern.**
- **For example:**
  - Columbia conditional ground risk (given the event, location, and time) uncertainty was dominated by the fraction of people outside.
  - Uncertainty in risk to people in an aircraft assumed present during Columbia event likely dominated by the uncertainty in the consequence of an impact.
  - Uncertainty in EC for aircraft from a launch/re-entry at an unspecified time of day dominated by air-traffic density
  - New ELV launch risks uncertainty often dominated by POF

Precedents in Nuclear Power Industry

- **The Nuclear Regulatory Commission was forced to recognize uncertainty.**
  - **They had used an acceptability standard of 1×10^{-6} which was used against their risk predictions. 1×10^{-6} was an aspired safety goal.**
  - **They acknowledged the uncertainty and raised the aspired safety goal to 10×10^{-6}.**
  - **They use the average from the risk uncertainty distribution for their measure of risk against criteria**