Teaching PRA and conducting PRA research at universities

George Apostolakis
Head, Nuclear Risk Research Center
apostola@mit.edu

Presented at the
Symposium on Risk Integrated Engineering
University of Tokyo
January 21, 2019

PRA Methodology

- **What universities can teach**
  - **Probability**
  - **Statistics**
  - **PRA structure and models**
  - **PRA calculations**
  - **Risk management process and safety goals**
- **What they cannot teach**
  - **Accident sequence development**

Probability and Statistics

- U.S. nuclear and mechanical engineers do not, in general, have a background in probability and statistics
- An introductory PRA course must cover the essentials of probability and statistics
- Doing so limits the time for teaching PRA methods
- Topics specific to PRA
  - Bayesian methods
  - Aleatory and epistemic uncertainties
  - However, there is only one kind of uncertainty
  - Importance measure
- Practitioners are uncomfortable defending their judgment (as opposed to classical statistics)

The Model of the "World"

- **Deterministic, e.g., a mechanistic computer code**

- **Probabilistic *(Aleatory) model,***
  e.g., $R(t/\lambda) = \exp(-\lambda t)$

- **Both deterministic and aleatory models of the world have assumptions and parameters.**

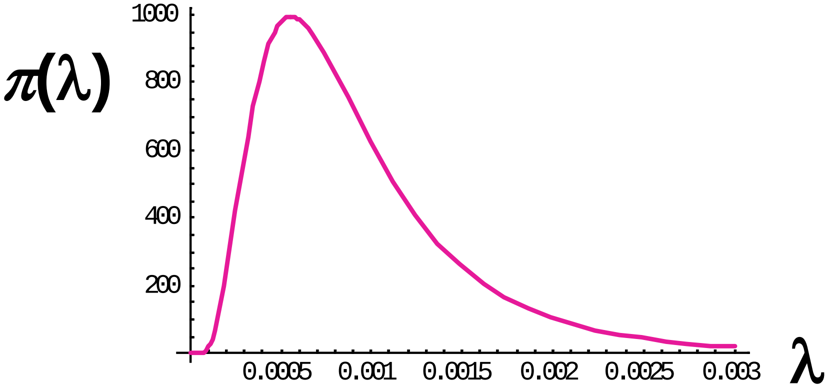
- **How confident are we about the validity of these assumptions and the numerical values of the parameters?**

Epistemic Model

- Uncertainties in assumptions are not handled routinely. If necessary, sensitivity studies are performed.

- Parameter uncertainties are reflected on appropriate epistemic distributions.

- For the failure rate:



- $\pi(\lambda)d\lambda$ = Pr(the failure rate has a value in dλ about λ)

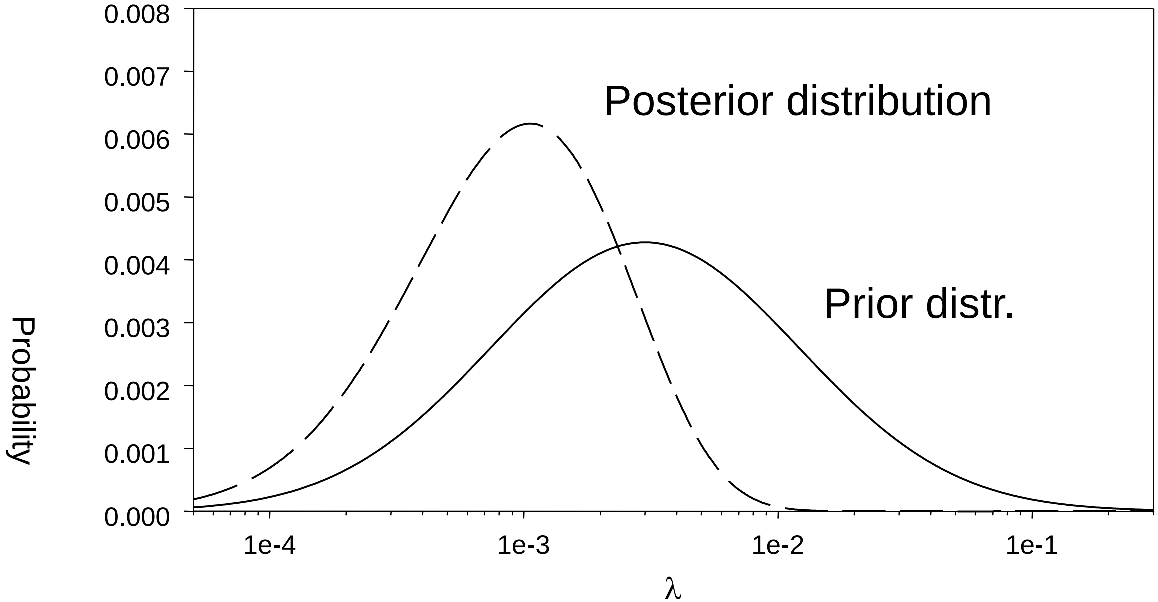
WASH-1400 Failure Rates

Component/Primary Failure Modes	Assessed Values: Lower Bound	Assessed Values: Upper Bound
	Mechanical Hardware	
Pumps		
Failure to start, Q_d:	3×10^{-4}/d	3×10^{-3}/d
Failure to run, λ_o: (Normal Environments)	3×10^{-6}/hr	3×10^{-4}/hr
Valves		
Motor Operated		
Failure to operate, Q_d:	3×10^{-4}/d	3×10^{-3}/d
Plug, Q_d:	3×10^{-5}/d	3×10^{-4}/d
Solenoid Operated		
Failure to operate, Q_d:	3×10^{-4}/d	3×10^{-3}/d
Plug, Q_d:	3×10^{-5}/d	3×10^{-4}/d
Air Operated		
Failure to operate, Q_d:	1×10^{-4}/d	1×10^{-3}/d
Plug, Q_d:	3×10^{-5}/d	3×10^{-4}/d
Check		
Failure to open, Q_d:	3×10^{-5}/d	3×10^{-4}/d
Relief		
Failure to open, Q_d:	3×10^{-6}/d	3×10^{-5}/d
Manual		
Plug, Q_d:	3×10^{-5}/d	3×10^{-4}/d
Pipe		
Plug/rupture		
≤ 3" diameter, λ_o:	3×10^{-11}/hr	3×10^{-8}/hr
> 3" diameter, λ_o:	3×10^{-12}/hr	3×10^{-9}/hr
Clutches		
Mechanical		
Failure to engage/disengage	1×10^{-4}/d	1×10^{-3}/d
	Electrical Hardware	
Electrical Clutches		
Failure to operate, Q_d:	1×10^{-4}/d	1×10^{-3}/d

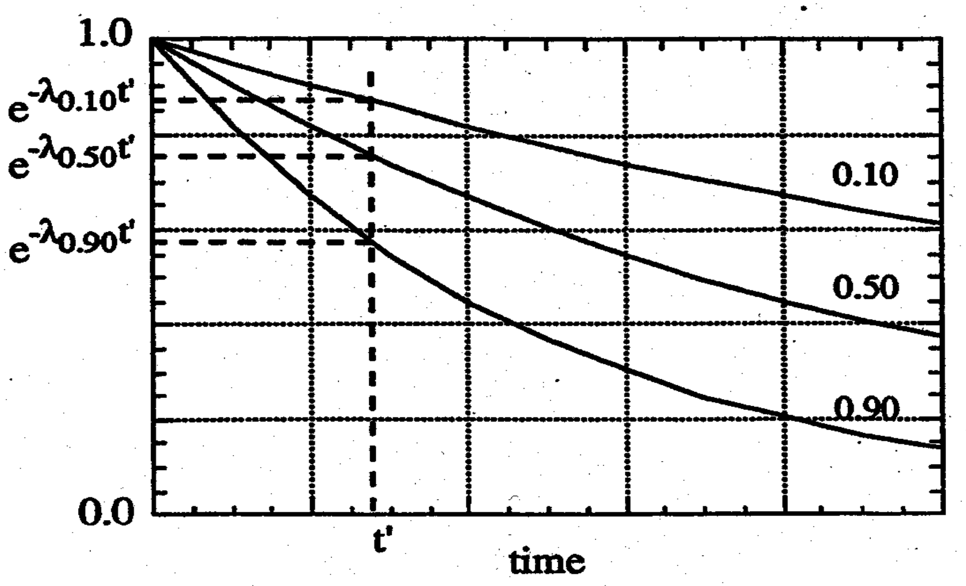
Example of Bayesian updating of epistemic distributions

Five components were tested for 100 hours each and no failures were observed.

$$\pi'(\lambda / E) = \frac{L(E / \lambda)\pi(\lambda)}{\int L(E / \lambda)\pi(\lambda)d\lambda}$$



Communication of Epistemic Uncertainties



Epistemic Correlation

- Consider two nominally identical isolation valves
- They share the epistemic distribution of failure rate

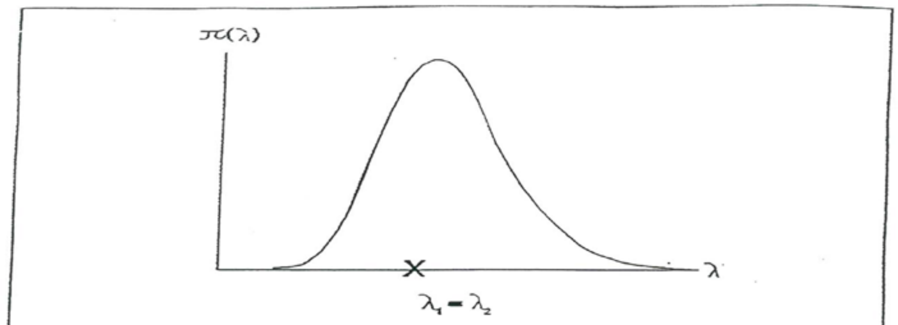


Figure C.3.6. Sampling the same value for both λ1 and λ2.

$Q = q^2$, $a_Q = a_q^2 + \beta_q^2$

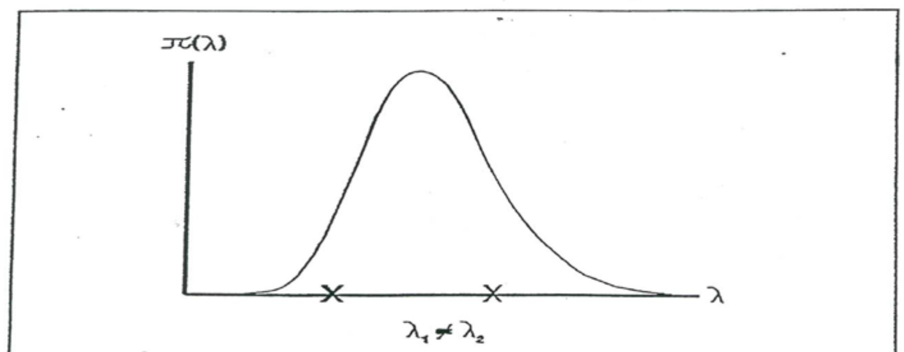
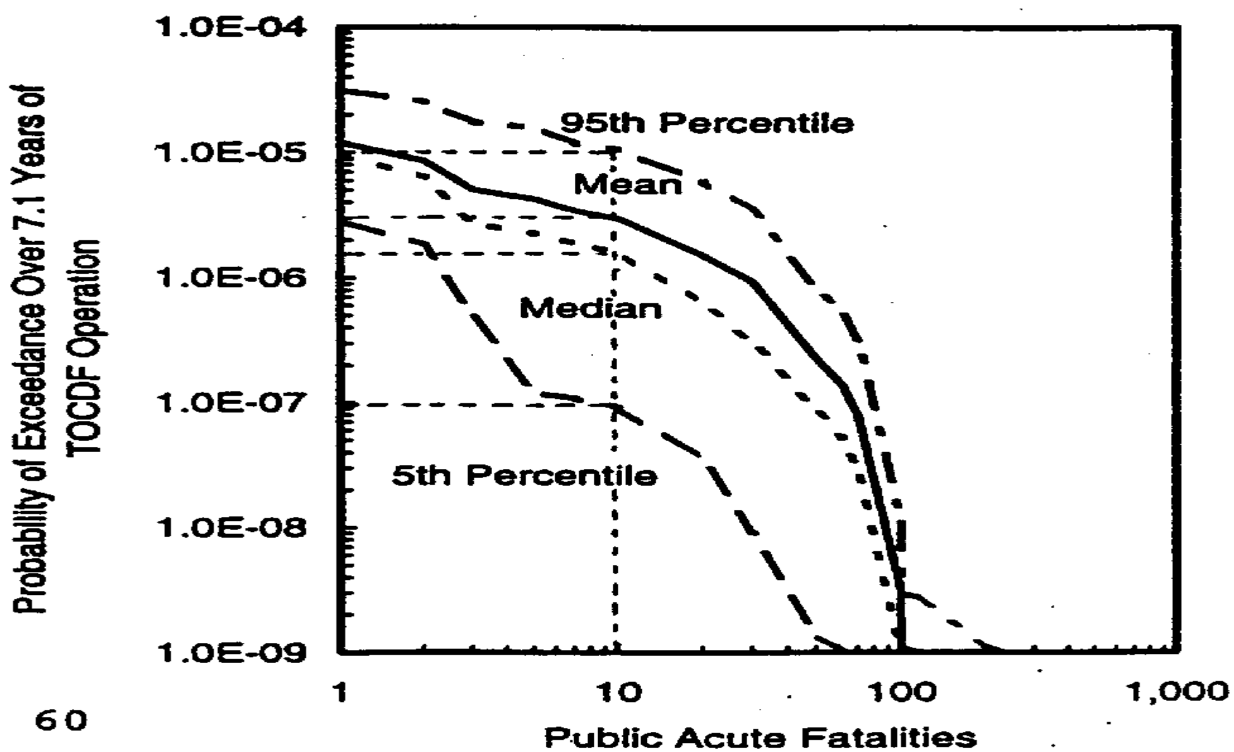


Figure C.3.7. Sampling different values for λ1 and λ2 (incorrect).

$Q^* = q_1 q_2$, $a_{q^*} = a_q a_q = a_q^2$

Risk Curves

Propagating epistemic uncertainties through the PRA models (usually via Monte Carlo simulation), we produce the risk curves.



PRA Models

- Event and fault trees
- Human reliability
- Reliability physics models
- Common-cause failures
- Examples from PRAs
- External events

PRA Methodological Research

- Data specialization using Bayes theorem
- Epistemic correlation of parameter distributions
- Plant-to-plant variability
- Fire methodology
- Human Reliability Analysis
- Uncertainties in phenomenological work
- Model uncertainty
- Safety goals
- Risk management
- Simulation methods

Plant-to-Plant Variability

- Suppose the evidence from two plants is
  - (1 fire in 8 years) and
  - (0 fires in 6 years)
- If we say that the evidence is (1 fire in 14 years), we will be increasing the strength of the evidence artificially resulting in a narrower distribution for the fire rate
- The evidence from the two plants must be processed separately so that the distribution will be broader

Concluding Remarks

- Teaching a course in PRA is usually hampered by the students' lack of background in probability and statistics
- Most students have been exposed to classical (frequentist) statistics; they have difficulty switching to Bayesian (subjectivist) statistics
- A PRA course is necessarily limited to methodology
- Ideally, traditional engineering courses would discuss uncertainties in their models.