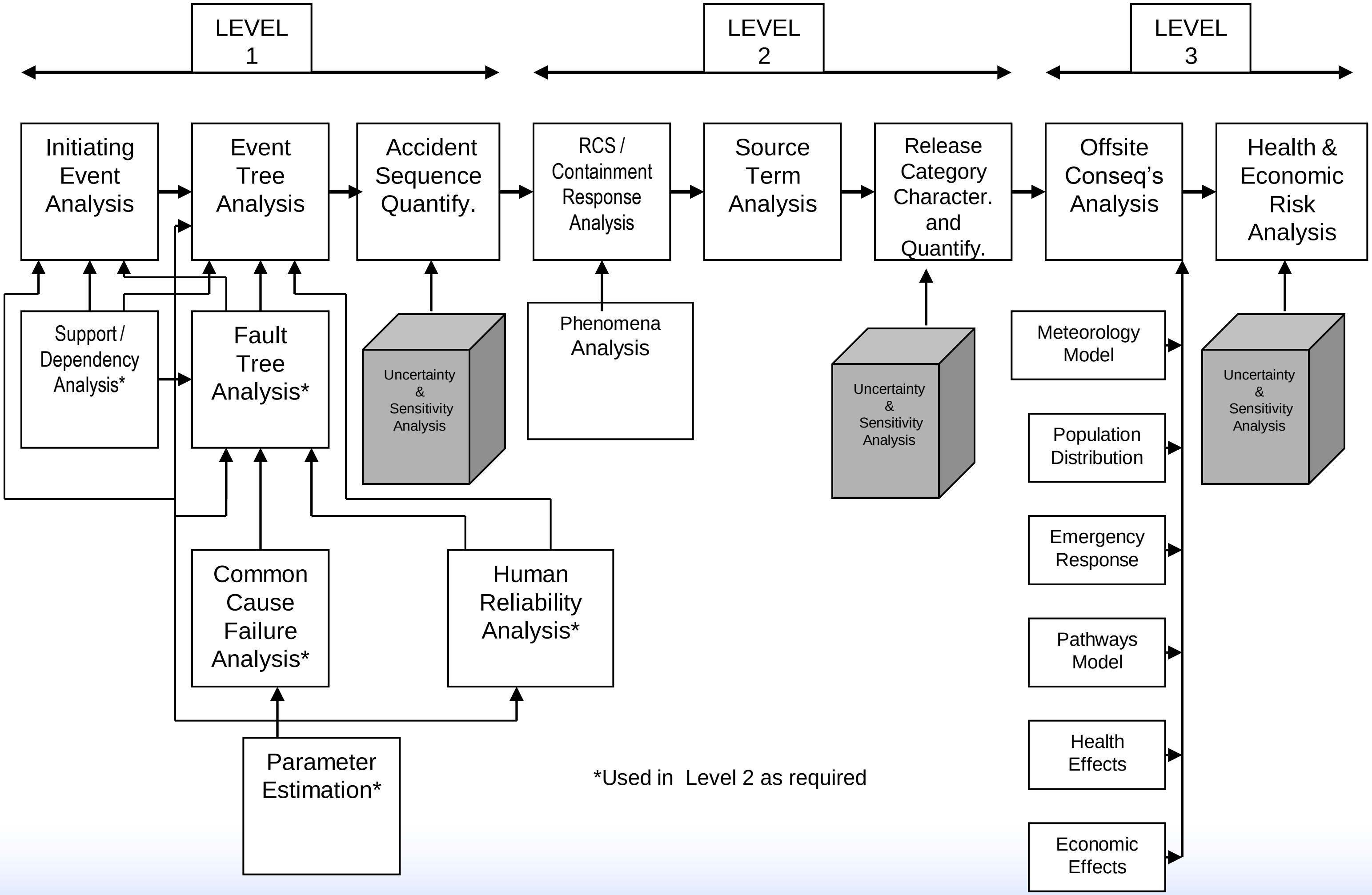
MODULE O

UNCERTAINTY –
TRADITIONAL ENGINEERING AND PROBABILISTIC

Uncertainties in PRA

- **Purpose: To acquaint students with concept of uncertainty both from a traditional engineering and a PRA perspective. Students will understand the types of uncertainty encountered, their sources, and how they are treated**
- **Objectives: Upon completion of this module, the students;**
  - **Will be able to list the types of uncertainty and their sources**
  - **Understand how uncertainty is accounted for in PRA**

Principal Steps in PRA



LEVEL 1

LEVEL 2

LEVEL 3

Initiating Event Analysis

Event Tree Analysis

Accident Sequence Quantify.

RCS / Containment Response Analysis

Source Term Analysis

Release Category Character. and Quantify.

Offsite Conseq's Analysis

Health & Economic Risk Analysis

Support / Dependency Analysis*

Fault Tree Analysis*

Uncertainty & Sensitivity Analysis

Phenomena Analysis

Uncertainty & Sensitivity Analysis

Meteorology Model

Population Distribution

Emergency Response

Pathways Model

Health Effects

Economic Effects

Uncertainty & Sensitivity Analysis

Common Cause Failure Analysis*

Human Reliability Analysis*

Parameter Estimation*

*Used in Level 2 as required

Uncertainty

- **Historically, the term "uncertainty" has been used to describe either of the following concepts:**
  - **random variability in some observable quantity**
  - **imprecision in state-of-knowledge regarding models, their parameters, their assumptions, and how well they reflect reality**

Uncertainty Arises From Many Sources

- Inability to specify initial and boundary conditions precisely
  - Cannot specify result with deterministic model
  - Instead, use probabilistic models (e.g., tossing a coin)
- Sparse data on initiating events, component failures, and human errors
- Lack of understanding of phenomena
- Modeling assumptions (e.g., success criteria)
- Modeling limitations (e.g., inability to model errors of commission)
- Incompleteness (e.g., failure to identify system failure mode, not all modes of operation modeled, external events not included)

Sources of Uncertainty

Uncertainty in Results

Type Of Uncertainty	Parameters	Model *	Completeness**
Examples of Sources of Uncertainty	• IE Frequency • Equipment Failure Rate • Human Error Probability	• Phenomena • Model Structure • Model Assumptions	• Organizational performance not considered • Other issues not addressed

* Model is approximation of reality; some models cause greater uncertainty in results than others
** Lack of completeness in models contributes to uncertainty in results

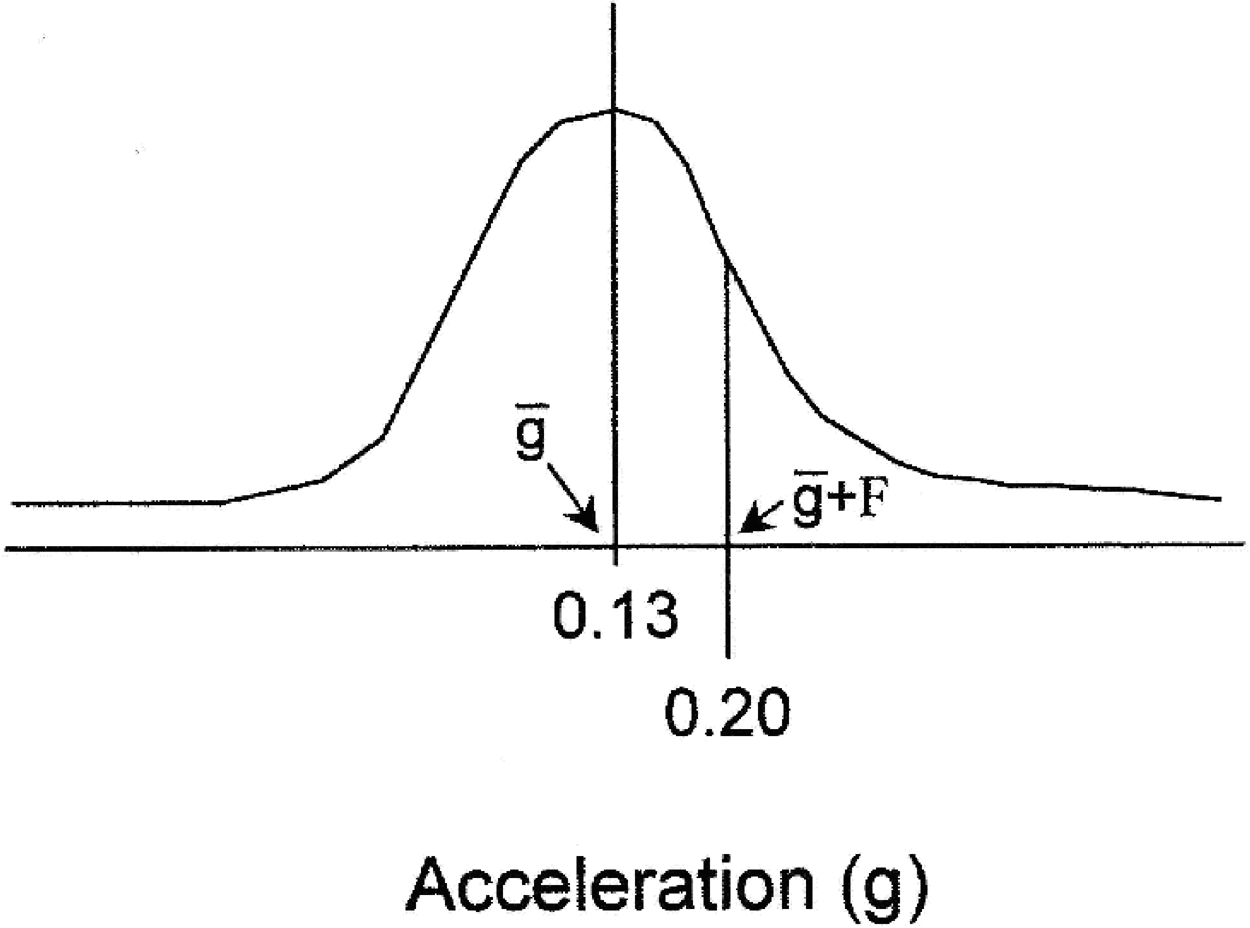
Traditional Engineering Approaches to Uncertainty

- Traditional engineering approach involves use of defense-in-depth to establish safety margins in design basis accidents
  - Assumes occurrence of initiating event and single system failure
  - Uses conservative values for plant conditions and equipment performance to account for lack of knowledge about plant performance and phenomenological processes

SEISMIC EXAMPLE
(Hope Creek FSAR Chapter 2)

- Observations indicated mean value of peak horizontal acceleration is approximately 13% of gravity for recording sites where Intensity VII damage was sustained.
- ..on the basis of the above relationships, it is recommended that the design acceleration for Hope Creek be considered as 20% of gravity at foundation level.
- This value is considered conservative, as it is the equivalent to the ground motion of the mean plus one standard deviation for recording sites where MMI VII damage was sustained.

Seismic Example (cont.)



ANOTHER CHAPTER 2 (SITING) EXAMPLE

- **Plume dispersion depends on time-varying parameters, limiting predictability of radionuclide concentration and position**
- **To overcome this limitation, empirically-based, conservative assumptions are made about how long fumigation and other atmospheric conditions exist (R.G.s 1.3 and 1.4).**

AIRCRAFT HAZARD EXAMPLE

(Hope Creek FSAR Chapter 3)

- **For general aviation small fixed-wing traffic near Hope Creek, the following equation has been used (for crash density), because it is difficult to establish exact location -- distance from plant and altitude of aircraft when the trouble leading to crash originated**

$$\rho = 1/2\ \gamma\ e^{-\gamma / |x|}$$

where:

x = lateral distance (flight path to plant)

γ = crash decay rate = 2 mi^{-1} for general aviation small fixed-wing aircraft.

THERMAL-HYDRAULIC EXAMPLE (GESSAR II Chapter 4)

- Uncertainties in thermal-hydraulic parameters are considered in statistical analysis performed to establish fuel cladding integrity safety limit, such that at least 99.95 of fuel rods in core are not expected to experience boiling transition during any moderate frequency transient event
- ...The uncertainties considered and their values are shown in the following Table...

Description of Uncertainties (GESSAR II Chapter 4)

Quantity	Standard Deviation (% of point)	Comment
Feedwater Flow	1.76	This is the largest component of total reactor power uncertainty
Feedwater Temperature	0.76	These are the other significant parameters in core power distribution
Reactor Pressure	0.5	
Core Inlet Temperature	0.2	Affect quality and boiling length.
Core Total Flow		Flow is not measured directly, but is calculated from jet pump ΔP. The listed uncertainty in flow corresponds to 11.2% standard deviation in each individual pump difference.

Examples from GESSAR II Chapter 4 (cont.)

Quantity	Standard Deviation (% of point)	Comment
Channel Flow Area	2.5	This accounts for manufacturing and service induced variations in the free flow area within the channel
Friction Factor Multiplier	10.0	Accounts for uncertainty in the correlation representing two-phase pressure losses

PRAs Identify Two Types of Uncertainty

- **Distinction between aleatory and epistemic uncertainty:**
  - **"Aleatory" from the Latin Alea (dice), of or relating to random or stochastic phenomena. Also called "random uncertainty or variability."**
  - **"Epistemic" of, relating to, or involving knowledge; cognitive. [From Greek episteme, knowledge.] Also called "state-of-knowledge uncertainty."**

Aleatory Uncertainty

- **Variability in or lack of precise knowledge about underlying conditions makes events unpredictable. Such events are modeled as being probabilistic in nature. In PRAs, these include initiating events, component failures, and human errors.**
    - **For example, PRAs model initiating events as a Poisson process, similar to the decay of radioactive atoms**
    - **Poisson process characterized by frequency of initiating event, usually denoted by parameter λ**

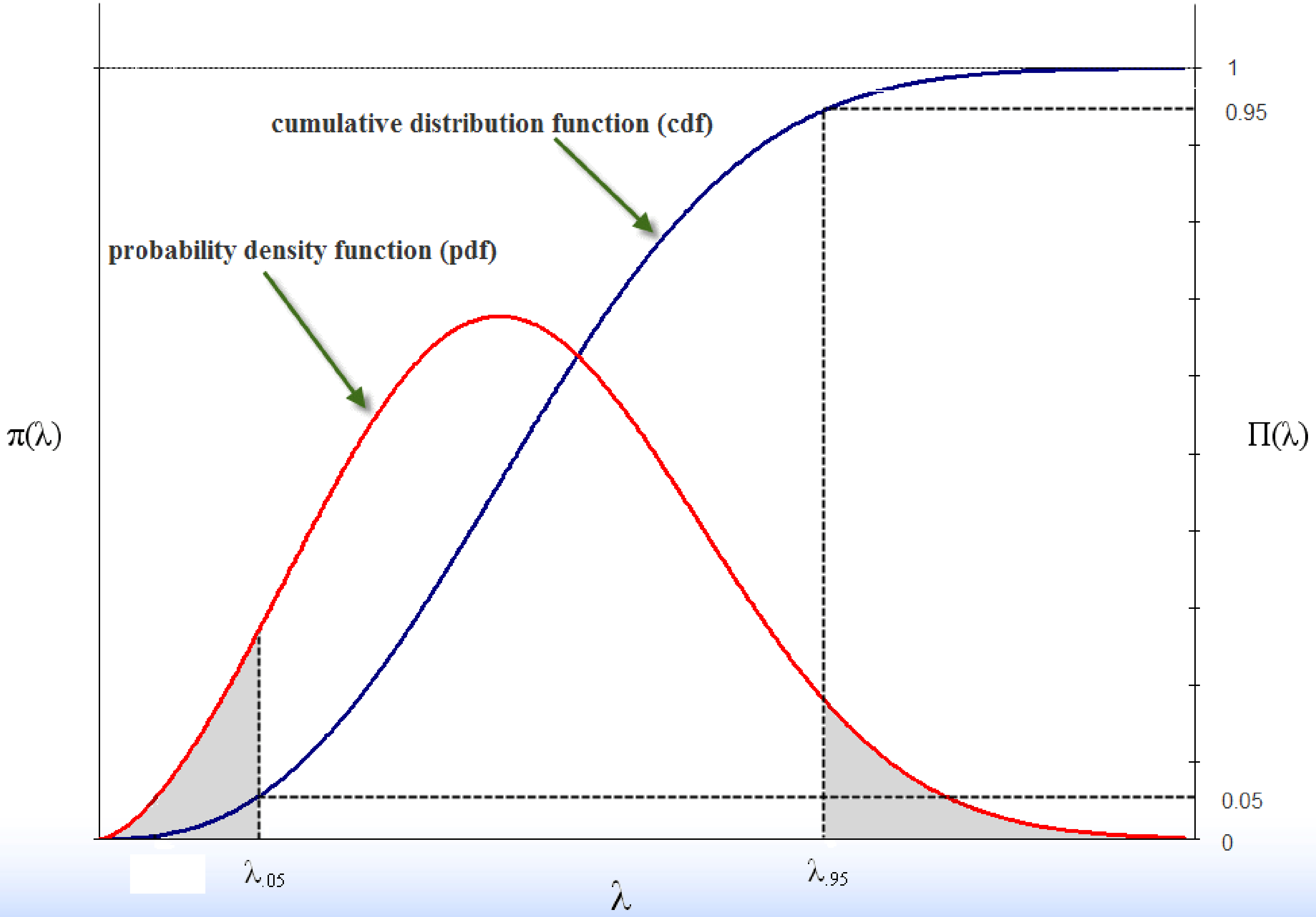
Epistemic Uncertainty

- Value of λ is not known precisely
- Could model uncertainty in estimate of λ using statistical confidence interval
  - Can't propagate confidence intervals through PRA models
  - Can't interpret confidence intervals as probability statements about value of λ
  - May have non-empirical information available
    - Cannot include this in confidence interval
- PRAs model lack of knowledge about value of λ by assigning (usually subjectively) a probability distribution to λ
  - Probability distribution for λ can be generated using Bayesian methods

Epistemic Uncertainty

- **Advantages to Bayesian Approach**
  - **Allows uncertainties to be propagated easily through PRA models**
  - **Allows probability statements to be made concerning λ and outputs that depend upon λ**
  - **Provides unified, consistent framework for parameter estimation**
    - **Allows inclusion of non-empirical information**

Uncertainty in λ Expressed as Probability Distribution



Uncertainty Propagation

- **Uncertainties propagated via Monte Carlo sampling**
- **In this approach, output probability distribution is generated empirically by repeated sampling from input parameter distributions**

Other Epistemic Uncertainties in PRA and How They are Addressed

- **Modeling uncertainty**
  - **System success criteria**
  - **Accident progression phenomenology**
  - **Health effects models (linear versus nonlinear, threshold versus nonthreshold dose-response model)**
- **Modeling uncertainty usually addressed through sensitivity studies**

Other Epistemic Uncertainties in PRA and How They are Addressed (cont.)

- Completeness
  - Complex errors of commission
  - Design and construction errors
  - Unexpected failure modes and system interactions
  - All modes of operation not modeled
- Completeness addressed through comparison with other studies and peer review
  - Some issues (e.g., design errors) are simply acknowledged as limitations
  - Other issues (e.g., errors of commission) are topics of ongoing research

Other Epistemic Uncertainties in PRA and How They are Addressed (cont.)

- Errors in analysis
  - Failure to model all trains of a system
  - Data input errors
  - Analysis errors
- Errors in analysis may be difficult to catch and are typically addressed through peer review and validation process