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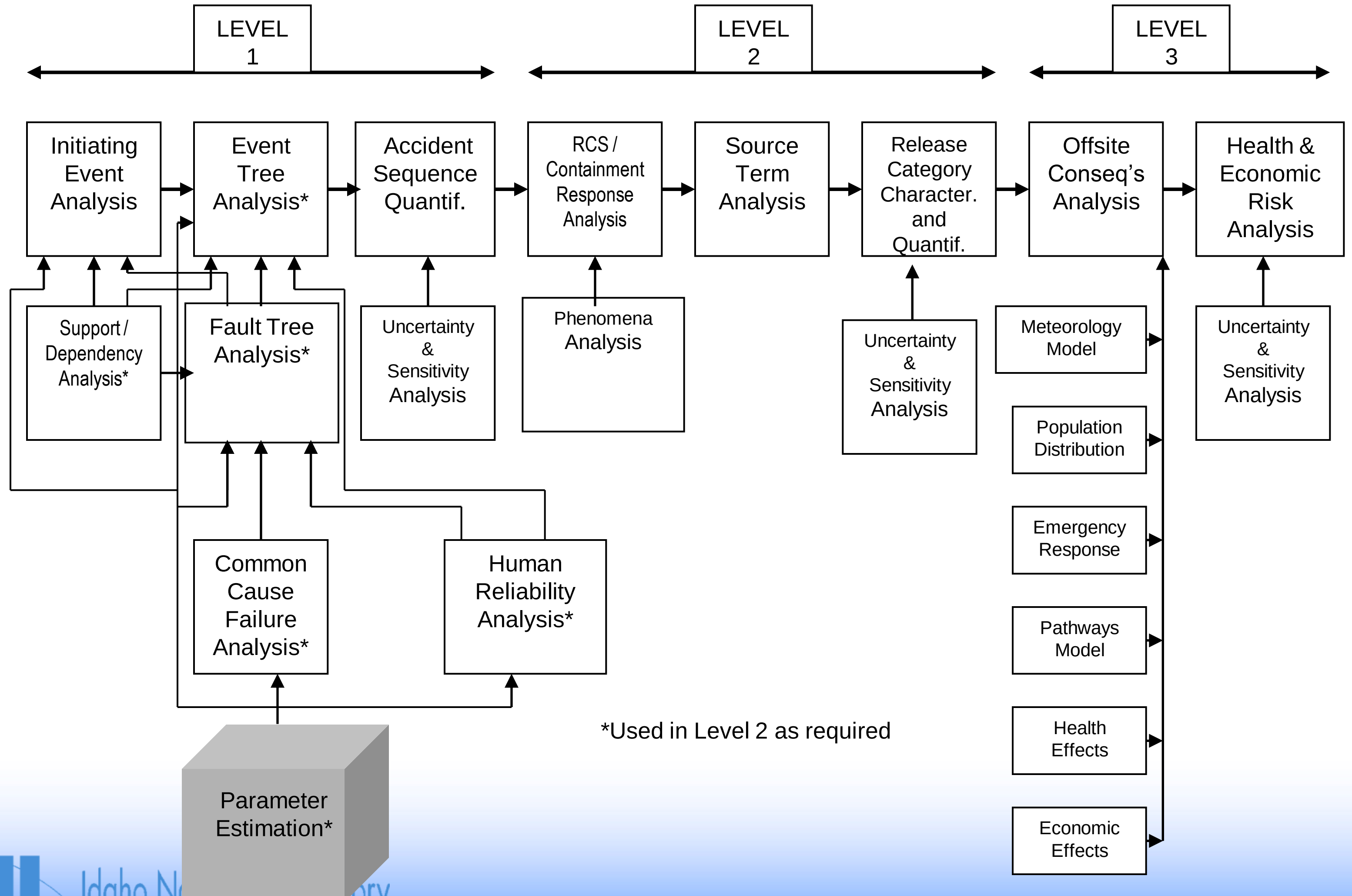
MODULE G

EQUIPMENT FAILURE MODES AND DATA SOURCES FOR PARAMETER ESTIMATION

Equipment Failure Modes and Data Sources for Parameter Estimation

- **Purpose: Students will be presented with equipment failure modes included in PRA, parameters to be estimated for each failure mode, sources of data for these parameters, both generic and plant-specific, and limitations of plant-specific data. Finally, students will be presented with a qualitative description of Bayesian updating.**
- **Objectives: Students will be able to:**
  - **Understand failure modes typically modeled in PRA and what information is needed to estimate the parameter for each failure mode**
  - **Define what is meant by "generic data" and list common sources**
  - **List limitations associated with plant-specific data**
  - **Explain qualitatively what Bayesian updating accomplishes**
- **References**
  - **NUREG/CR-6823, Handbook of Parameter Estimation for PRA**

Principal Steps in PRA



Parameter Estimation

- **Purpose:**
  - Estimates parameter values for component failure and initiating events in the PRA model
- **Quantitative inputs to basic events for fault tree and event tree models**
  - Must gather data for:
  - Random failure (failure rates and demand failure probabilities)
  - Unavailability due to test and maintenance
  - Common cause failure (see Module H)
  - Initiating event frequencies (see Module D)

System Models Need Following Types of Component Parameter Estimates

Failure Contribution	Calculational Formula	Type of Measure	Parameter Definition
Hardware Failure on Demand	$q_d = p$	Demand failure probability	p = Demand failure probability; need number of failures and number of demands
Hardware Failure of Operating Component	$q_r = 1 - e^{-\lambda_o t_m}$ $q_r \approx \lambda_o t_m$ (for small λt; when $\lambda t < 0.1$)	Unreliability (mission failure)	λ_o = Operating failure rate; need number of failures and total operating time t_m = Mission time
Test/Maintenance Outage	$q_m = f_m J_m$	Unavailability (Average)	f_m = Frequency of test or maintenance J_m = Test or maintenance outage time
Hardware Failure while in standby of Standby Component	$q_s \approx 1/2\ \lambda_s t_i$	Standby failure probability Unavailability (Average)	λ_s = Standby failure rate; need number of failures and total time in standby t_i = Test interval

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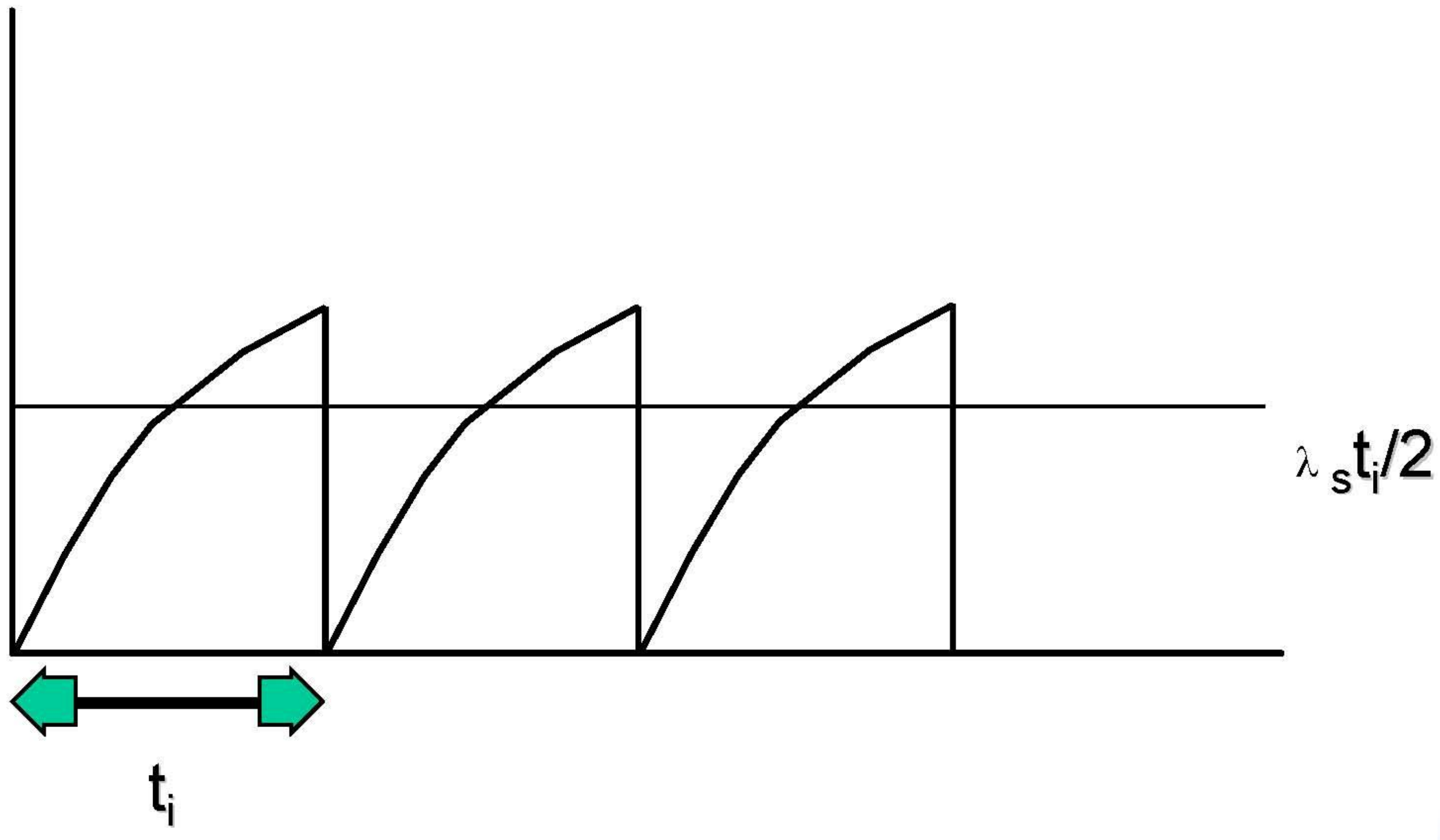
On Average, Standby Equipment can be Unavailable for ½ the Test Interval



****Parameter Estimation Exercise* * * *

- Over five years, a standby component has the following operating history:
  - 60 test/maintenance outages (test interval is 720 hours and each outage has a demand) and 4 unplanned demands
  - Failures: 1 demand failure, 1 failure in standby (failure uncovered during testing), and 1 failure to run
  - Total run time is 200 hours
  - Average test/maintenance outage time is 1.8 hours
- From this history, estimate:
  - Demand failure probability
  - Standby failure rate and standby unavailability
  - Operating failure rate and unreliability for a mission time of 12 hours
  - Test/maintenance unavailability

Data Collection and Analysis to Support Parameter Estimation

- Identify systems and components for which data should be collected
- Define component boundaries and failure modes
- If plant-specific data is not available or time does not permit collection and analysis, identify generic data sources

Data Sources

- Generic data
- Plant-specific data
- Bayesian updated data
  - Prior distribution
  - Plant-specific data
  - Updated estimate

Typical Generic Data Sources

- NUREG-1150 supporting documents (NUREG/CR-4550 series, pre-1987)
- WASH-1400 (pre-1975)
- IEEE Standard 500 (1990)
- NUREG/CR-3862 for initiating events (pre-1986)
- NUREG/CR-5750 for initiating events (1987-1995)
- NUREG-1032 for loss of offsite power(pre-1988)
- NUREG/CR-5496 loss of offsite power (1980-1996)
- NUREG/CR-6890 loss of offsite power (1986-2004)
- NUREG/CR-6928, Industry-Average Performance for Components and Initiating Events at U.S. Commercial Nuclear Power Plants, February 2007

Typical Generic Data Sources

- **SECY 04-0060 Loss-of-Coolant Accident Break Frequencies for the Option III Risk-Informed Reevaluation of 10 CFR 50.46, Appendix K to 10 CFR Part 50, and General Design Criteria (GDC) 35 (April 2004)**
- **NUREG-1829 Estimating Loss-of-Coolant Accident (LOCA) Frequencies Through the Elicitation Process (June 2005)**
- **Institute of Nuclear Power Operations Nuclear Plant Reliability Data System (NPRDS) – archival only (no longer maintained)**
- **Institute of Nuclear Power Operations Equipment Performance Information Exchange (EPIX) – replaced NPRDS**

Generic Data Issues

- **Key issue is whether data is applicable for the specific plant being analyzed**
  - **Data of mid-1980s or earlier vintage**
  - **Some IE frequencies known to have decreased over the last decade**
    - **Frequencies updated in NUREG/CRs 5750 and 6890**
  - **Criteria for judging data applicability not well defined - do not forget important engineering considerations that could affect data applicability**

Plant-Specific Data Collection and Analysis

- Objective: Gather data to obtain raw information needed for estimating event parameters
  - Determine period of time for obtaining plant data
    - Most recent data should be used to represent current maintenance practices and component performance (Maintenance Rule and Performance Indicators will enhance collection of this information for some components)
    - Five to seven years of data is desirable for most components
  - Collect plant data information from plant records and documents
    - Licensee Event Reports (LERs)
      - Can also be a source of generic data
    - Maintenance reports and work orders
    - System Engineer files
    - Control room logs
  - Interpret the information to obtain variables of interest (e.g., failures, demands, operating hours)
  - Estimate parameter values from these data

Plant-Specific Data Issues

- **Combining data from different sources can result in:**
  - double counting of the same failure events
  - inconsistent component boundaries
  - inconsistent definition of "failure"
- **Plant-specific data is typically very limited**
  - small statistical sample size
- **Inaccuracy and non-uniformity of reporting**
  - LER reporting rule changes
- **Difficulty in interpreting "raw" failure data**
  - Administratively declared inoperable, does not necessarily equate to a "PRA" failure
- **Completeness and uncertainty issues with the data bases**

Bayes' Theorem is Basis for Bayesian Updating of Data

- **Typical use: sparse plant-specific data combined with generic data using Bayes' Theorem:**

$$\pi_1(\theta | E) = \frac{L(E | \theta)\, \pi_0(\theta)}{\int L(E | \theta)\, \pi_0(\theta)\, d\theta}$$

- **Where:**
  - θ **is parameter of interest**
  - $\pi_o(\theta)$ **is prior distribution (generic data)**
  - **L(E|θ) is likelihood function (plant-specific data)**
  - $\pi_1(\theta|E)$ **is posterior distribution (updated estimate)**

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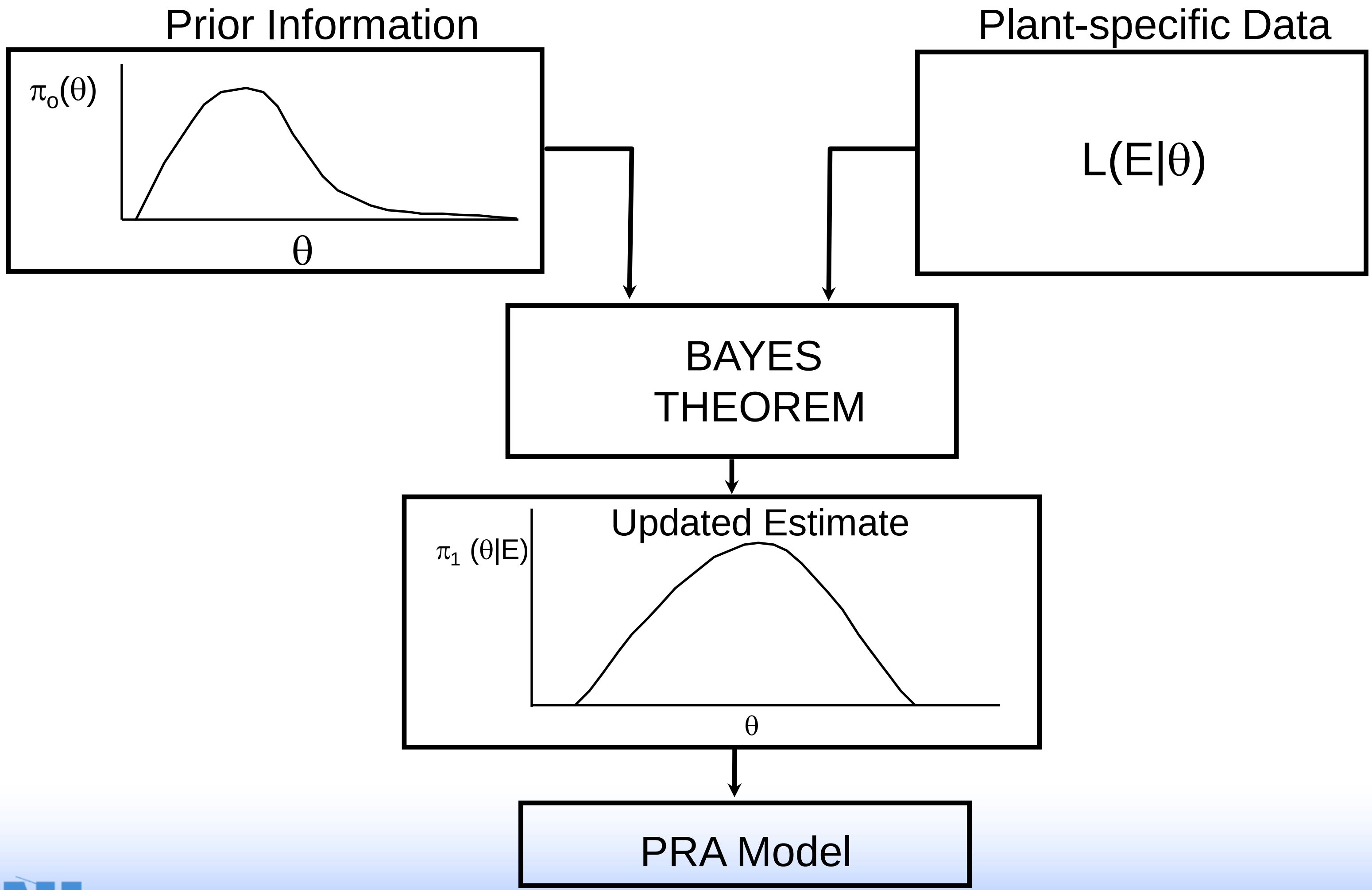
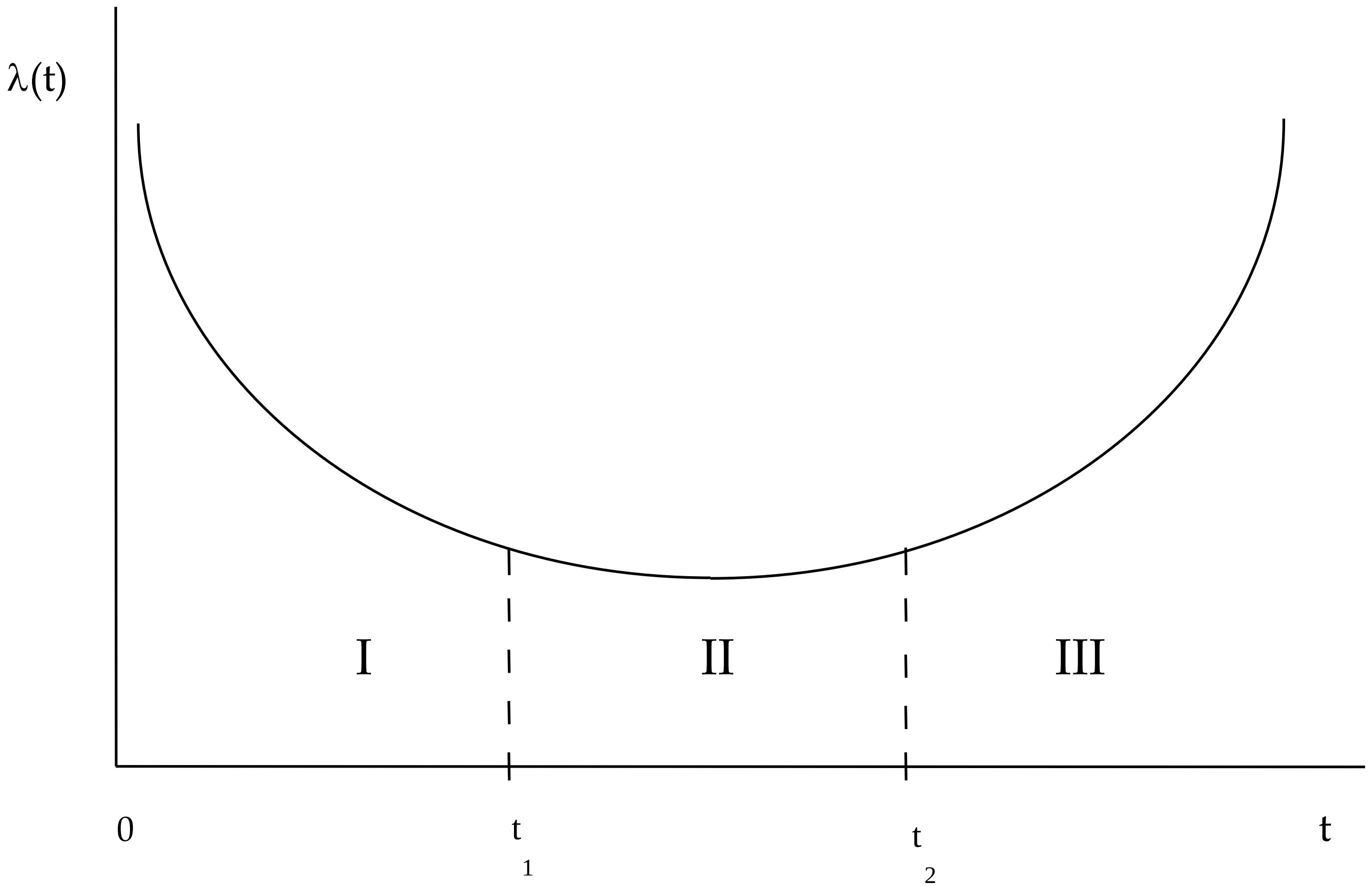
Bayesian Updating



Component Data Not Truly Time Independent

- PRAs typically assume time-independence of component failure rates
  - One of the assumptions for a Poisson process (i.e., failures in time)
- However, experience has shown failure rates can change with time
  - Improved maintenance can cause λ or p to decrease over time
  - Aging can cause λ or p to increase
    - "Bathtub" curve

The “Bathtub” Curve



I: Burn-in (Infant Mortality) II: Maturity (Useful Life) III: Wear-out (Aging)

The “Bathtub” Curve

- **Most PRAs assume failure rates are a constant -- in “flat” portion of bathtub curve**
  - **May not be all that bad of an assumption considering quality level of equipment, maintenance, and testing requirements**
  - **However, this assumption does imply that aging (increasing failure rate) may not be modeled in the PRA**

Class Exercise on PRA Component Failure Data

- **As a class - Based on experience, determine a consensus ranking of the following component failure modes (highest to lowest)**
  - Diesel generator fails to start on demand
  - Check valve fails to open on demand
  - Motor-operated valve fails to open on demand
  - Motor-driven pump fails to start on demand
  - Turbine-driven pump fails to start on demand
- **Individually - Based on typical values found in your IPE/PRA, how does the class qualitative ranking agree with the a quantitative ranking? Any comments on the PRA values?**