



Idaho National Laboratory

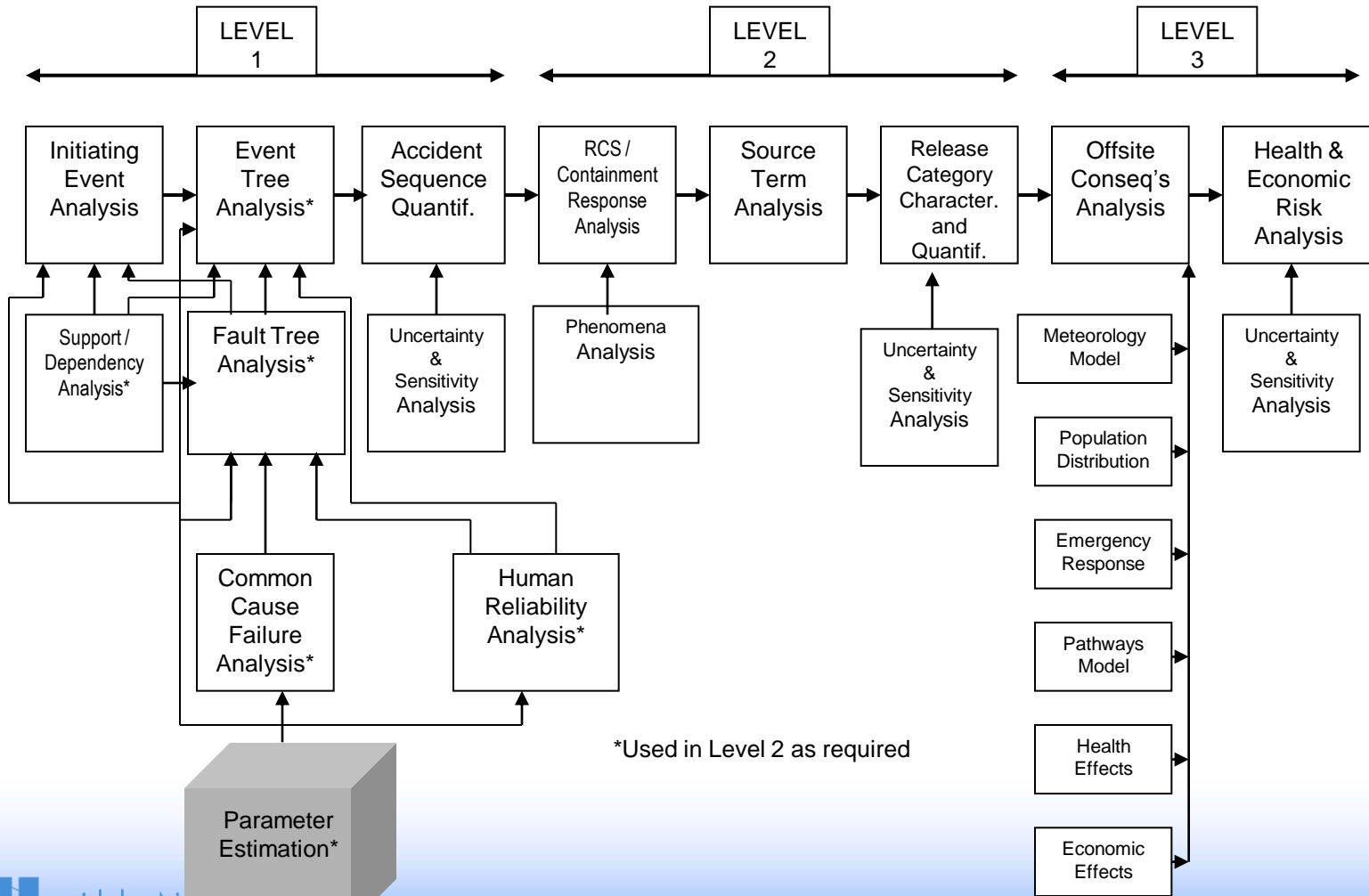
# MODULE G

## 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



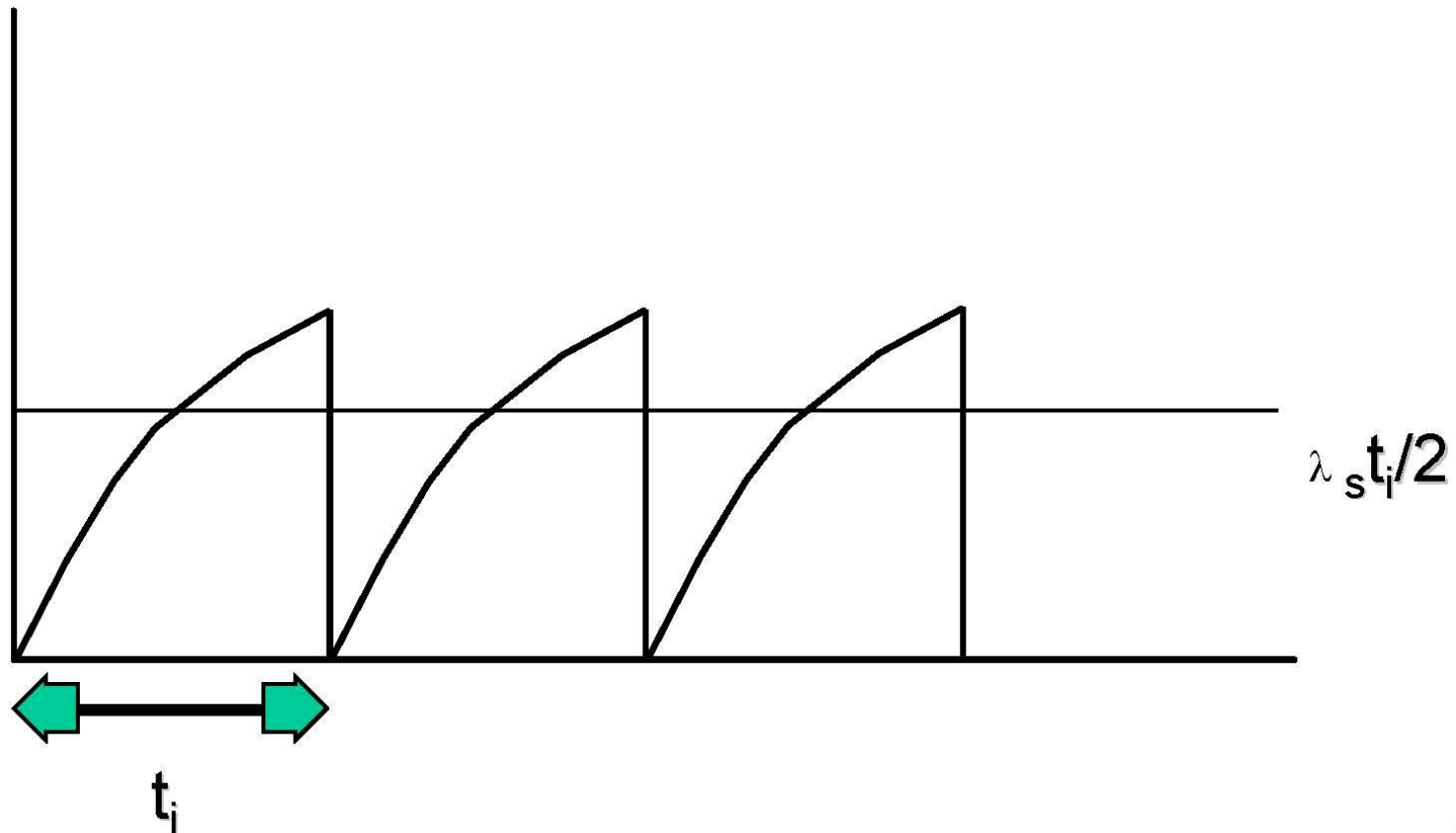
# Parameter Estimation

- **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

<u>Failure Contribution</u>	<u>Calculational Formula</u>	<u>Type of Measure</u>	<u>Parameter Definition</u>
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 $\lambda t$ ; when $\lambda t < 0.1$ )	Unreliability (mission failure)	$\lambda_o$ = 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)	$\lambda_s$ = Standby failure rate; need number of failures and total time in standby $t_i$ = Test interval

# On Average, Standby Equipment can be Unavailable for $\frac{1}{2}$ 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**

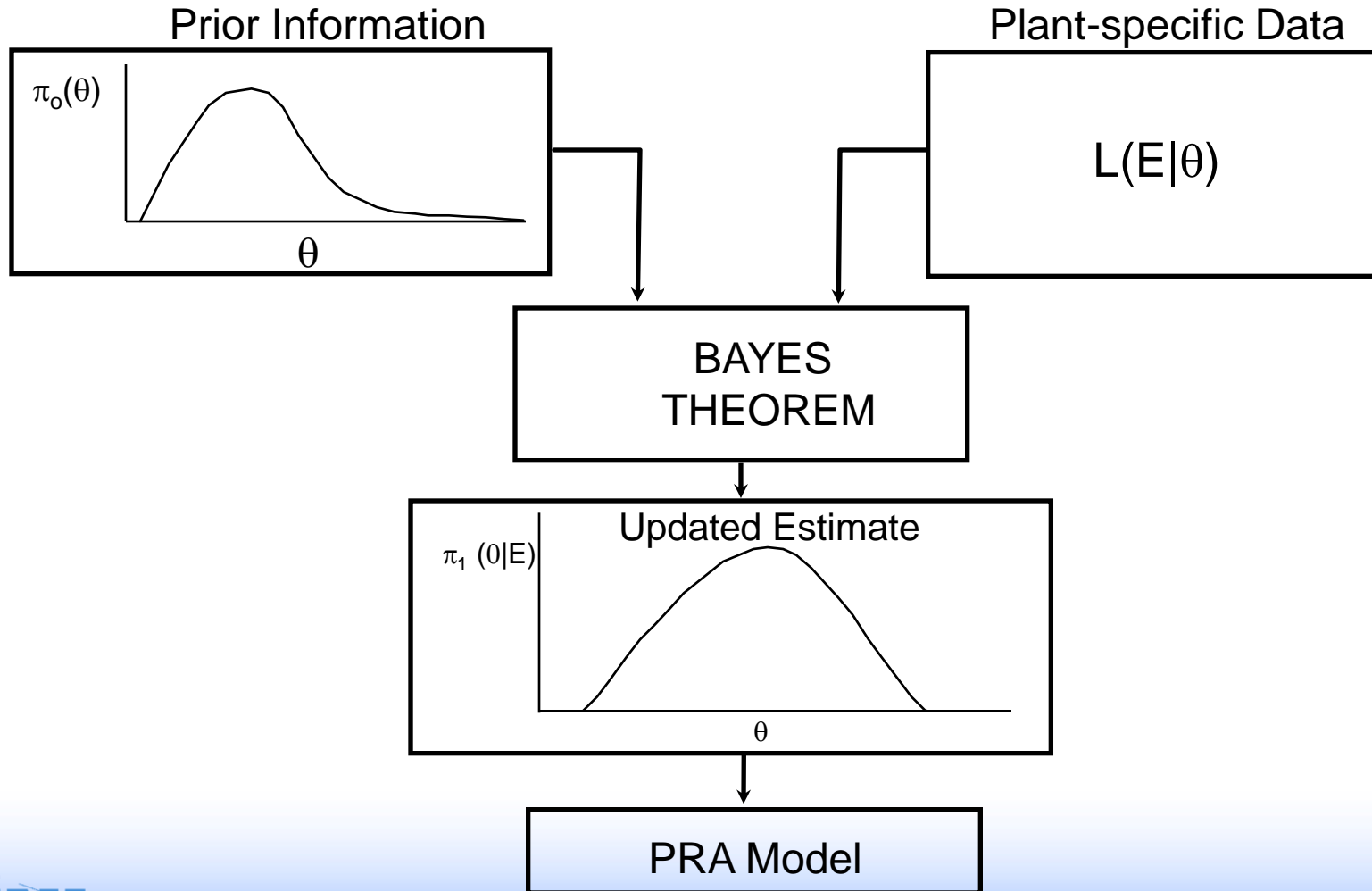
# Bayes' Theorem is Basis for Bayesian Updating of Data

- 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:
  - $\theta$  is parameter of interest
  - $\pi_0(\theta)$  is prior distribution (generic data)
  - $L(E|\theta)$  is likelihood function (plant-specific data)
  - $\pi_1(\theta|E)$  is posterior distribution (updated estimate)

# Bayesian Updating

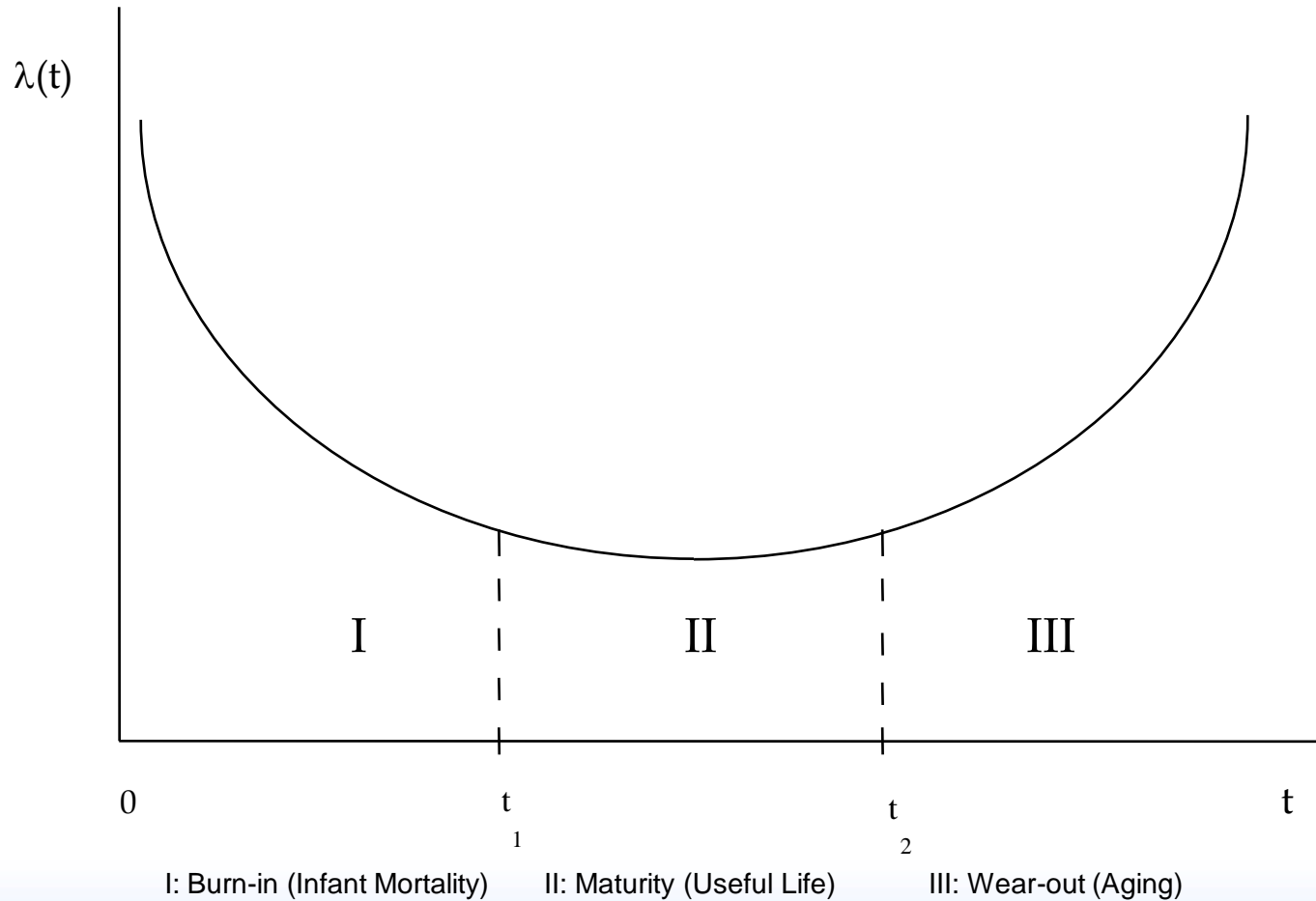




# Component Data Not Truly Time Independent

- **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  $\lambda$  or  $p$  to decrease over time
  - Aging can cause  $\lambda$  or  $p$  to increase
    - “Bathtub” curve

# The “Bathtub” Curve



# 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?**