

# Part 2:

## Using FMEA, DFR, Test and Failure Analysis in Lean NPD

# Overview

- Introduction and Definitions
- Part 1: Lean Product Development
  - Lean vs. Traditional Product Development
  - Key Elements of Lean NPD
    - Customer Defines Value
    - Front Loaded and Knowledge Based
    - Eliminate Redesign Waste
  - Reliability Requirements
- Part 2: Reliability Elements of Lean NPD
  - Lean FMEA and DRBFM
  - Critical Characteristics
  - DFR and Physics of Failure
  - Accelerated Testing to Failure
  - Failure Analysis and Knowledge Capture

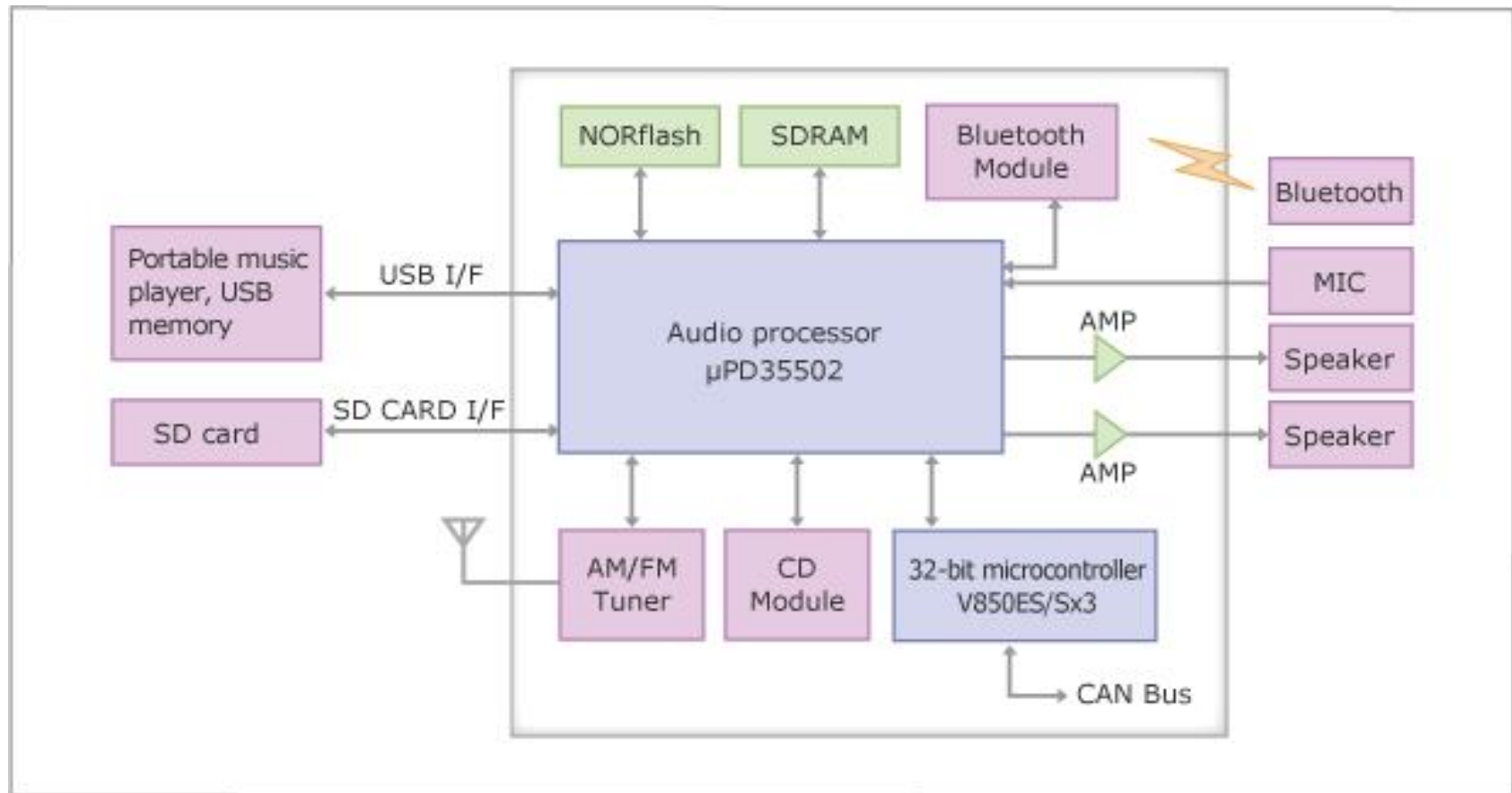
# Lean FMEA

- Some teams attempt to lean FMEA process by creating product family FMEAs but fail to update FMEA for new applications or changes
- Instead Lean FMEA Should Focus on New Design Features and Changes to Baseline Design to Assess Associated Risks

# Tools to Focus Lean FMEA

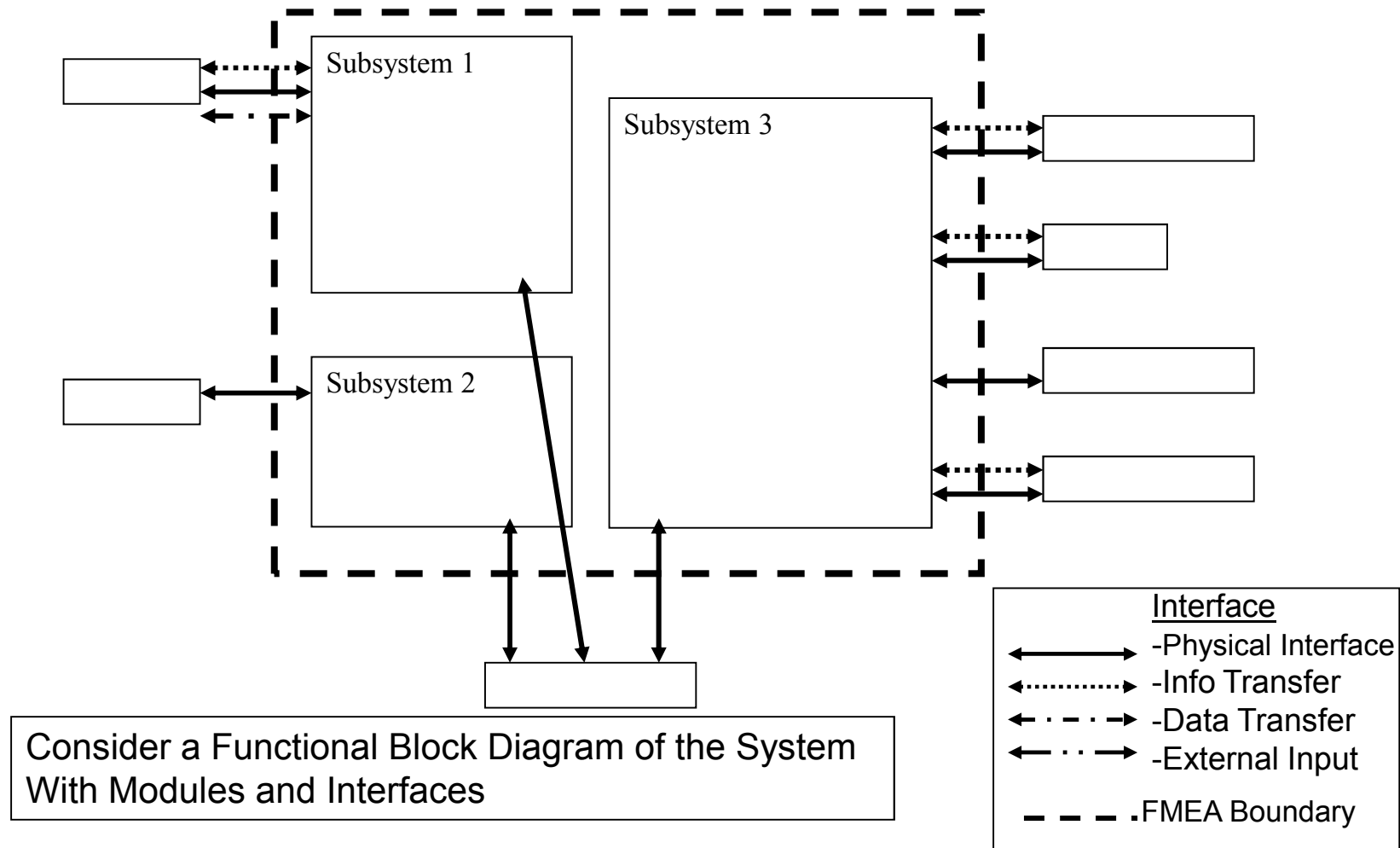
- Diagramming Tools
  - Functional Block Diagram
  - Boundary Diagram
  - Parameter Diagram
  - Process Flow Diagram
- Highlight Changes to Product or Process on the Diagrams

# Functional Block Diagram

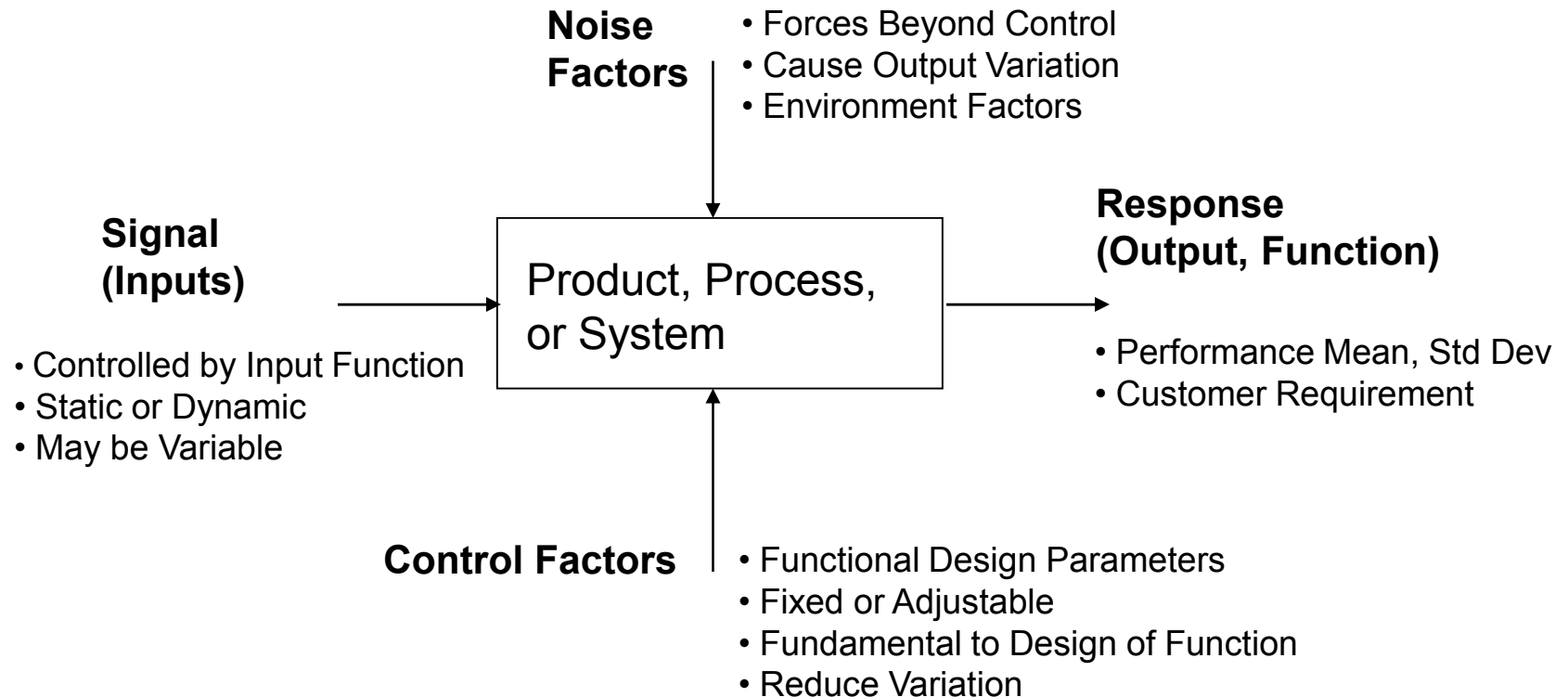


Annotate Retained and Changed Items & Functions

# Boundary Diagram Construction



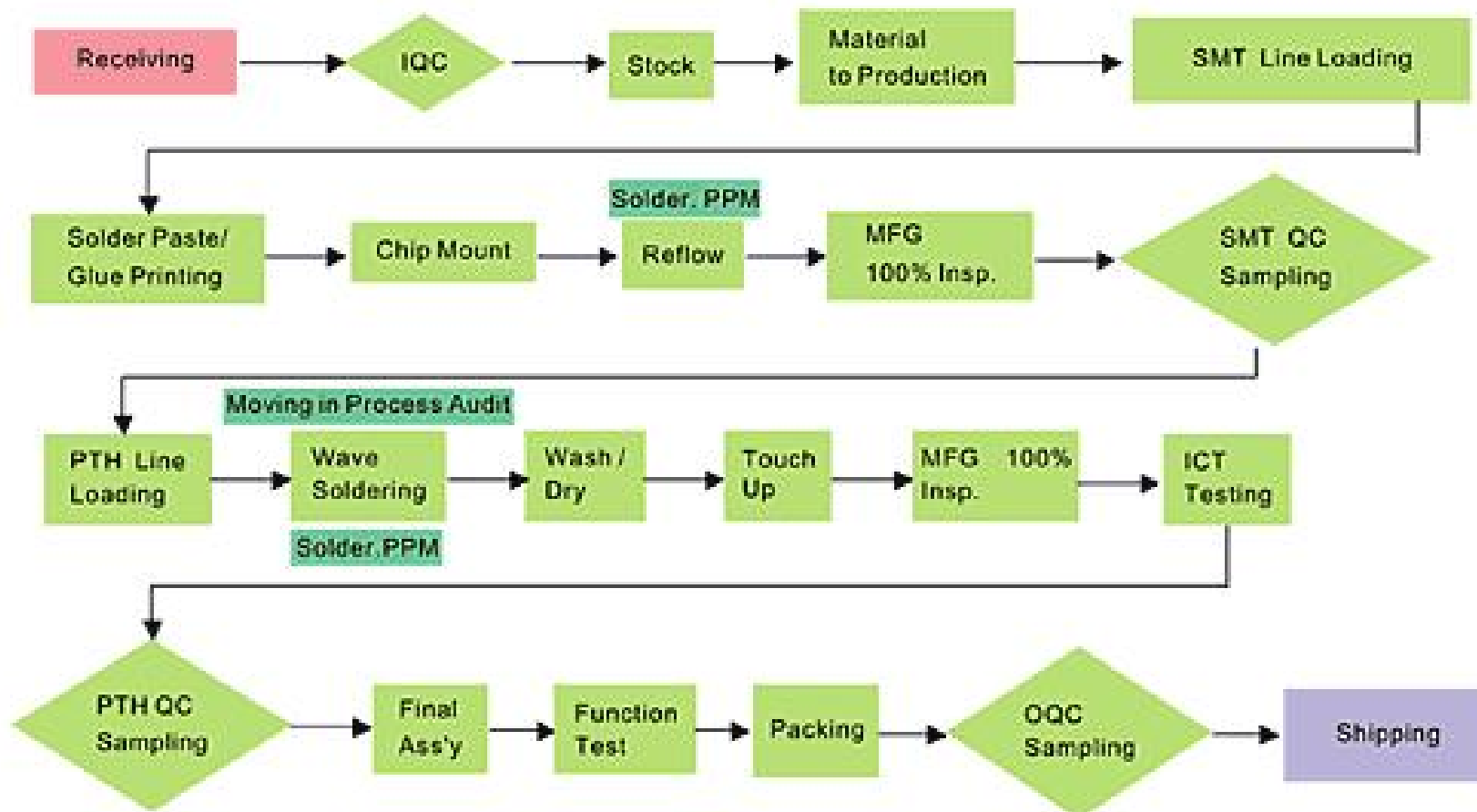
# Parameter Diagram of Product, Process, System



**Elements of the P-Diagram**

# Process Flow Diagram

## MANUFACTURING FLOW



**Annotate Retained and Changed Process Steps**



# Selecting Process Steps for Analysis

- On Process Flow Map:
  - Identify Steps Being Modified
  - Identify New Steps Required for New Product
- Drill Down to Identify Sub-Steps Within the Target Steps Identified for Analysis
- Complete Lean PFMEA on Selected Process Steps
- Integrate with Previous PFMEA on Standard / Unchanged Process Steps

# Key Characteristics

- Include:
  - Product Features
  - Manufacturing Processes
  - Assembly Characteristics
- That Significantly Affect:
  - Product Performance
  - Form, Fit, Function
- Lean NPD Focuses on the Critical Few Characteristics the Customer Values

## Key Characteristics

## Requirements Documents

- Customer Specification
- Regulatory
- Dimensions
- Appearance

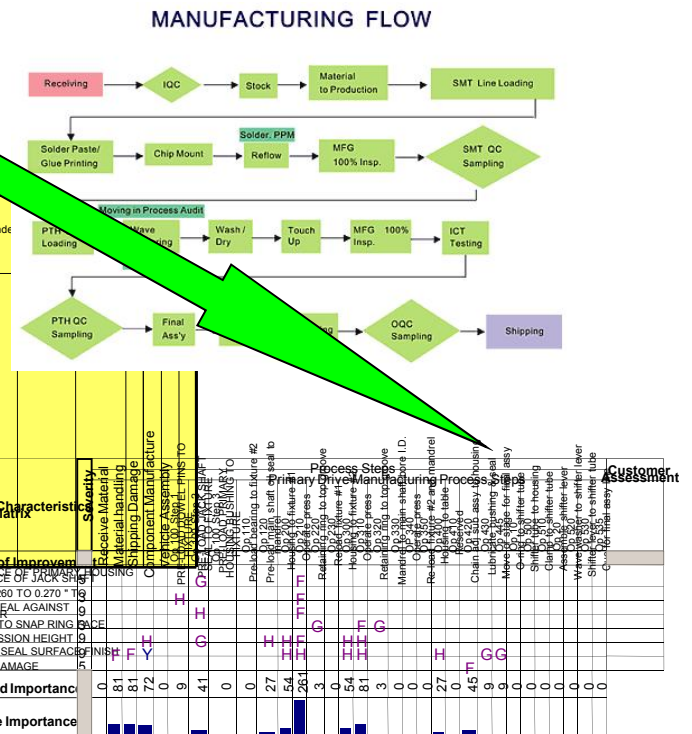
Requirements Document  
Drawings  
Field History

## Robustness Tools

- Functional Block Diagram
- Boundary Diagram
- P-Diagram
- Interface Matrix

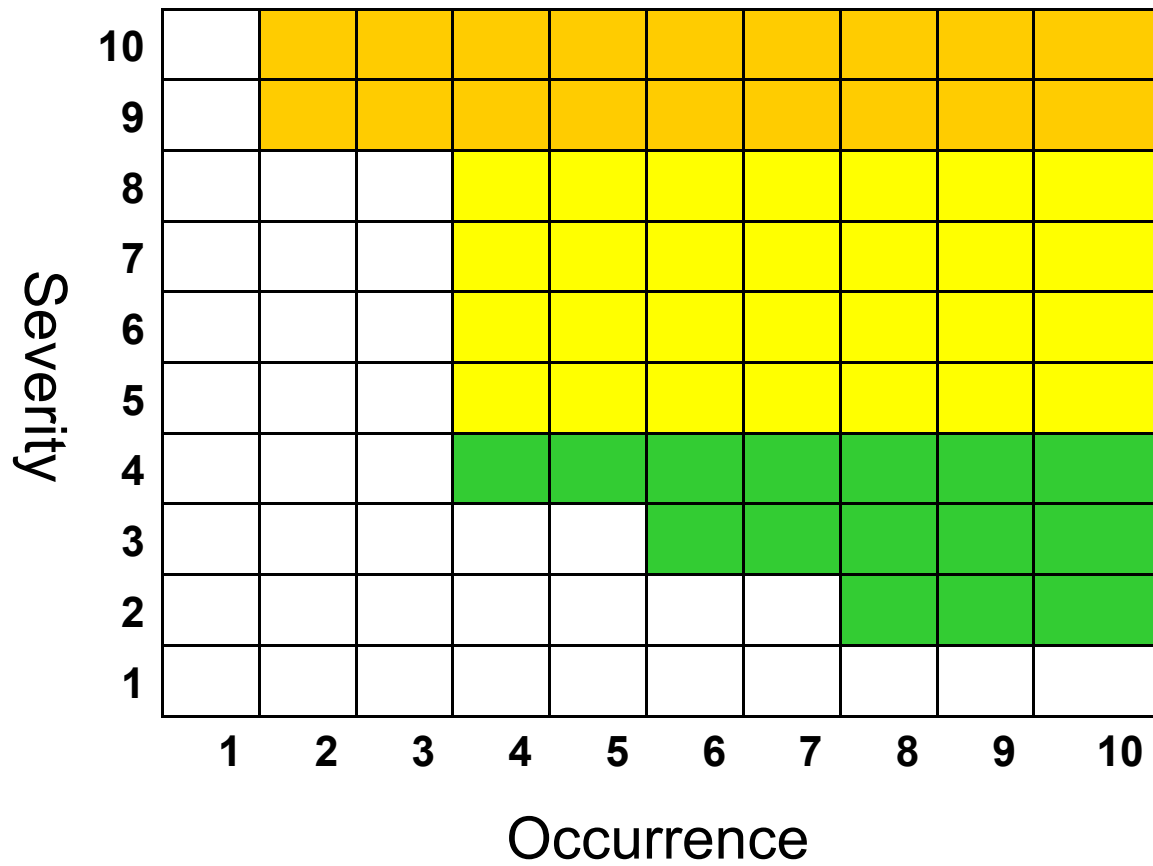
# DFMEA & PFMEA

## Technical Requirements, Tools Identify Special Product Characteristics



## Characteristics Matrix

# Identifying Key Characteristics



Potential Critical Characteristic



Potential Key Characteristic



Possible Annoyance Zone

# Special Characteristics Matrix

Process Steps from Flow Chart

Special Characteristics Matrix		Severity	Process Steps																															Customer Assessment
			Primary Drive Manufacturing Process Steps																															
			Receive Material	Material handling	Shipping Damage	Component Manufacture	Vehicle Assembly	Op 100 Step 1 PRE-LOAD DOWEL PINS TO FIXTURE	Op 100 Step 2 PRE-LOAD JACK SHAFT SEAL TO FIXTURE	Op 100 Step 3 PRE-LOAD PRIMARY HOUSING BUSHING TO FIXTURE	Op 110 Pre-load bearing to fixture #2	Op 120 Pre-load main shaft oil seal to mandrel	Op 200 Housing to fixture #1	Op 210 Operate press	Op 220 Retaining ring to top groove	Op 230 Reload fixture #1	Op 300 Housing to fixture #2	Op 310 Operate press	Op 320 Retaining ring to top groove	Op 330 Mandrel to main shaft bore I.D.	Op 340 Operate press	Op 350 Re-load fixture #2 and mandrel	Op 400 Housing to table	Op 410 Reserved	Op 420 Chain adj sub assy to housing	Op 430 Lubricate bushing & seal	Op 445 Move or stage for final assy	Op 10 O-ring to shifter tube	Op 500 Shifter tube to housing	Op 510 Clamp to shifter tube	Op 20 Assemble shifter lever	Op 520 Wave washer to shifter lever	Op 530 Shifter lever to shifter tube	
Direction of Improvement																																		
Potential Critical and Significant	1,090 TO 1,110 ° FACE OF PRIMARY HOUSING BUSHING TO FACE OF JACK SHAFT SEAL	5						L					H																					
	DOWEL PINS 0.260 TO 0.270 ° TO FACE	3					M						H																					
	JACK SHAFT SEAL AGAINST SHOULDER	9						M					H																					
	BEARING FLUSH TO SNAP RING FACE	3												L				H	H															
	SEAL COMPRESSION HEIGHT	9				M			L			M	M	H			M	M																
	PRIMARY GASKET SEAL SURFACE FINISH	9		H	H	M						M	M				M	M					M				L	L						
	SERATION DAMAGE	5																							H									
Weighted Importance			0	81	81	72	0	9	41	0	0	27	54	261	3	0	54	81	3	0	0	0	27	0	45	9	9	0	0	0	0	0	0	0
Relative Importance																																		

Characteristics from Requirements and DFMEA

Effect of Step on Characteristics

# Developing the Control Plan

- Prioritize Process Risks Identified in the PFMEA and the Special Characteristics Matrix
- Process Flow Diagram
- Lessons Learned from Similar Processes
- Process Control Data from Related Processes
- Measurements Required for Process Control
- SPC Control Limits
- Complete the Items in Control Plan Template

# Control Plan Items

<b>Machine, Device, Jig, Tools for Mfg.</b>	For each operation that is described, <b>identify the processing equipment machine, device, jig, or other tools</b> for manufacturing, as appropriate.
<b>No.</b>	Enter a <b>cross reference number</b> from all applicable documents such as, but not limited to, process flow diagram, numbered blue print, FMEAs, and sketches.
<b>Product</b>	<b>Features or properties of a part, component or assembly</b> that are described on drawings or other primary engineering info. Compilation of important product characteristics.
<b>Process</b>	Process variables that have a cause and effect relationship with the identified product characteristic. <b>Identify those process characteristics for which variation must be controlled to minimize product variation.</b> There may be more than one process characteristic for each product characteristic.
<b>Product/Process Specifications/Tolerance</b>	<b>Specifications/tolerance</b> may be obtained from various engineering documents, such as, but not limited to, drawings, design reviews, material standard, computer aided design data, manufacturing, and/or assembly requirements.
<b>Evaluation/Measurement/Technique</b>	<b>Identify the measurement system</b> being used, including, gages, fixtures, tools, and/or test equipment required to measure the part/process/manufacturing equipment.
<b>Sample</b>	When sampling is required list the <b>corresponding size and frequency</b> .
<b>Control Method</b>	Brief description of <b>how the operation will be controlled</b> , including procedure numbers where applicable. <b>Operations may be controlled by SPC, inspection, attribute data, mistake proofing, sampling plans</b> , and other. If elaborate control procedures are used, reference document by ID name/number.
<b>Reaction Plan</b>	<b>Specify the corrective actions necessary to avoid producing nonconforming products</b> or operating out of control. May also refer to a specific reaction plan number and identify the person responsible for the action.

# Using the Control Plan

- For Critical Characteristics, Use Control Plan to Identify:
  - Measurements: How, When, How Often
  - Controls to Keep Characteristic in Tolerance
  - Actions if Characteristic Out of Tolerance
    - Containment
    - Corrective Actions
- Robust Design + Controlled Processes = Reliable Products



# **DRBFM and DRBTR**

**Design Review Based on Failure Modes & Test Results**

Key Elements of Mizenboushi  
(Reliability Problem Prevention)

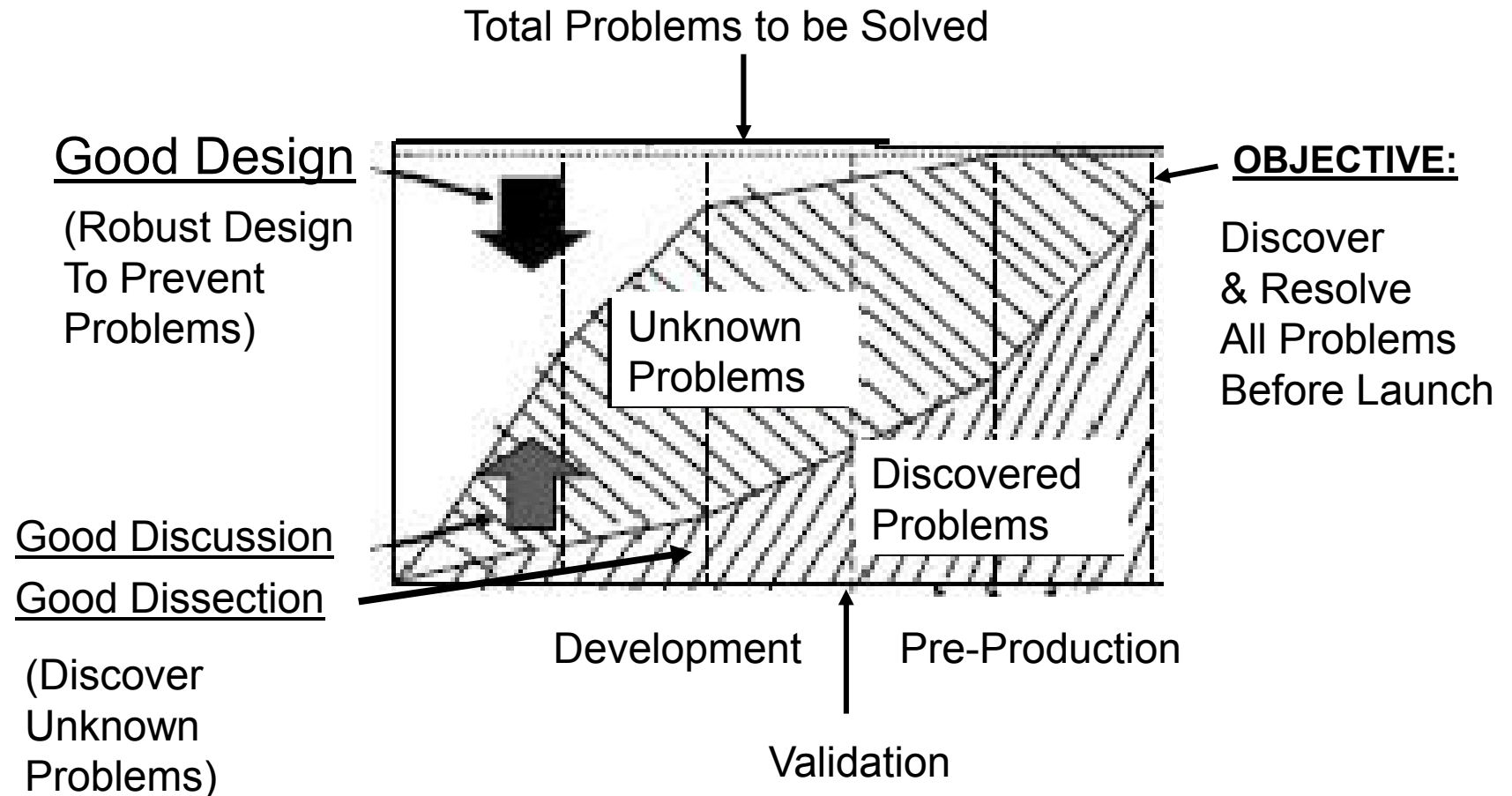
GD<sup>3</sup> (Good Design, Good Discussion,  
Good Dissection)

Toyota's "Creative FMEA" Method

# Problem Prevention – GD<sup>3</sup>

- Good Design = Robust Design
  - Design for Reliability (DFR)
  - Design for Six Sigma (DFSS)
- Good Discussion = Eliminate Risk
  - Apply Design Review Based on Failure Modes (DRBFM) to identify problems and develop countermeasures or corrections
- Good Dissection = Effective Validation
  - Apply Design Review Based on Test Results (DRBTR) to Evaluate Effectiveness. Test to Failure & Analysis of Test Failures is Critical

# GD<sup>3</sup> Problem Resolution

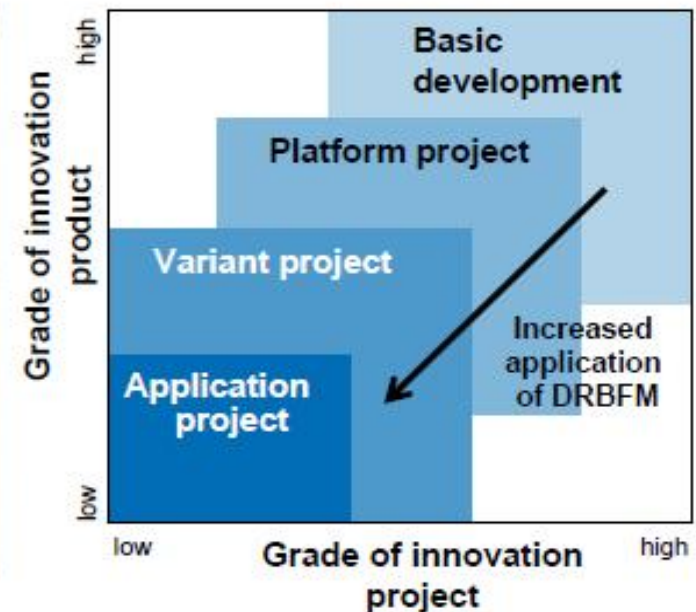
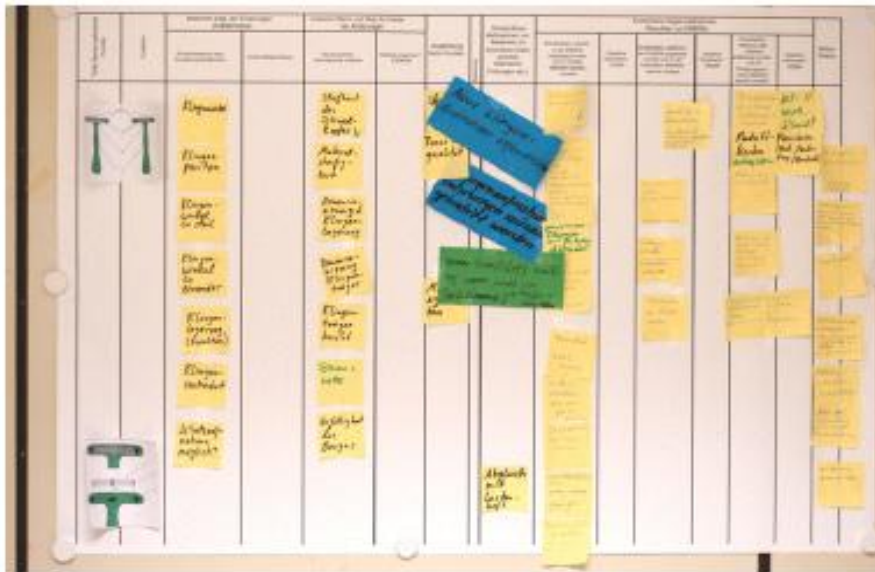


# DRBFM Approach

- Elements from FMEA, FTA, and Design Review
  - These tools previously used for management and control of projects
  - Toyota developed “creative FMEA” approach
  - Shift focus to improve perceptiveness and problem solving
- Focus is on finding and preventing problems – not completing forms and checklists (which de-motivate participants)

# DRBFM Application

## DRBFM – General Information



DRBFM is a method which is focused on the changes within a design in the process of development. Variant and application development projects provide the highest potentials and benefit for DRBFM.

Source: QZ 10/2005

# DRBFM is a Forum for Thinking

## Teamwork and Participation

**What has changed?**

- \* What did you change? Why?**
- \* What surrounding conditions have changed outside your control?**



**Concerns about the changes?**

- \*Your Concerns? What other concerns?**
- \* Draw on expertise and knowledge of past problems**



**When will concerns appear?**

- \*Could concerns become causes of failures or incidents? Visualize concerns & causes**



**What effects will there be?**

- \*How will causes effect the customer?**
- \* Consider effects on the OEM and end user**



**What preventive measures have been & should be taken?**

- \*What has been done to assure concerns will not actually appear?**
- \*Consider other measures that can be implemented**

# How is DRBFM Done?

- Preparation for the Design Review
- Conducting the DRBFM
- Capturing the Inputs
- Assigning and Tracking Actions to Completion

# Pre-Work for the DRBFM

- Design Engineer or Core Team:
  - Functional Diagram, Operating Environment
  - Changes from Previous Baseline Design
  - Drawings and Analysis
  - Failed and Sectioned Parts
  - Draft DRBFM with Components / Changes, Concerns with Causes and Factors, Effect on Customer, Design to Eliminate Concerns
- Participants (Functional Experts):
  - Perceptive mindset, interest in improving product
  - Past experience and knowledge on similar items



# Capturing the Data

## DRBFM – Work Sheet (cp. Noguchi et al. 2003)

① Component Name Changes	② Concerned Functions and Requirements	Concerns Regarding Change (Failure Mode)		When and How Concern Points appear?		⑤ Effect to Customer (System)	Evaluation	
		Potential Failure Mode due to Change	③ Any other Concerns?	④ Causes	Any other Causes?			
⑥ Current Design Steps to avoid Concerns		Recommended Actions (Results of Design Review)						⑩ Action Results
		⑦ Items to reflect in „Design“	Responsibility and Deadline	⑧ Items to reflect in „Evaluation“	Responsibility and Deadline	⑨ Items to reflect in „Production Process“	Responsibility and Deadline	


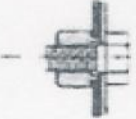

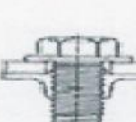

„creative FMEA“ (Phase 1)
  Design Review (Phase 2)

# Typical DRBFM Session



Source: A Guide to GD3 Activities and DRBFM Technique to Prevent Trouble, Kano & Shimizu, Toyota 2001

# Changes and Results Documented

Ziele Name: geordnete Punkte	Funktion	in der Anwendung benutzte Punkte (Grundwissen)		Werte und was eintrifft der benutzte Punkt		Auswertung des Kunden	Anwendungsbereiche von der benutzten Punkte	Ergebnisse: Folgerungen (Bewertung ELOF 90)		Folgerungen aufgrund der Bewertung in der Bewertung
		Werte: Auswertung durch die Anwendung	Werte: Auswertung durch die Anwendung	Werte: Auswertung durch die Anwendung	Werte: Auswertung durch die Anwendung			Werte: Auswertung durch die Anwendung	Werte: Auswertung durch die Anwendung	
	Montage-Schraube	Verstellung der Schraube mit einem großen Schraubendreher nicht möglich		Verstellung der Schraube mit einem großen Schraubendreher nicht möglich			Verstellung der Schraube mit einem großen Schraubendreher nicht möglich			
	Werte: Schraubendreher mit einem großen Schraubendreher nicht möglich	Verstellung der Schraube mit einem großen Schraubendreher nicht möglich		Verstellung der Schraube mit einem großen Schraubendreher nicht möglich			Verstellung der Schraube mit einem großen Schraubendreher nicht möglich			
	Schraube mit Schraubendreher Verstellung der Schraube mit einem großen Schraubendreher nicht möglich	Schraube mit Schraubendreher Verstellung der Schraube mit einem großen Schraubendreher nicht möglich		Schraube mit Schraubendreher Verstellung der Schraube mit einem großen Schraubendreher nicht möglich			Schraube mit Schraubendreher Verstellung der Schraube mit einem großen Schraubendreher nicht möglich			
	Einfluss der Folienstruktur auf die Schraubendreher	Einfluss der Folienstruktur auf die Schraubendreher		Einfluss der Folienstruktur auf die Schraubendreher			Einfluss der Folienstruktur auf die Schraubendreher			
	Einfluss der Folienstruktur auf die Schraubendreher	Einfluss der Folienstruktur auf die Schraubendreher		Einfluss der Folienstruktur auf die Schraubendreher			Einfluss der Folienstruktur auf die Schraubendreher			

Source: Carl Hanser Verlag, QZ, Munich, 4-2005

# Linking DRBFM with FMEA

- DRBFM captures the information needed for FMEA except scoring
- Scoring columns can be added to fill need for FMEA if required by customer or standards

# DRBFM to FMEA (1)

DRBFM Form:

Component name/ Intentionally & Incidentally Changed Portions	Function	Points of Concern regarding change (Failure mode)		When and how do points of concern appear		Effect to customer	
		Potential failure mode due to change	Any other concern? (DRBFM)	Root cause/ dominant cause	Any other consideration for cause? (DRBFM)		Importance

Item	Item Function	Potential	Potential	S	C	Potential	O	Current Design Controls	D	R
		Failure	Effect(s) of	e	a	Cause(s) /	c		e	P
		Mode	Failure	V	s	Mechanism(s)	c		t	N
				s	s	of Failure	u		e	

FMEA Form

Add Scores



# DRBFM to FMEA (2)

DRBFM Form:

Current design to avoid points of concern (Incl. Design rule items, Design standard, Check items)	Recommended actions (Results of DRBFM)						Action results
	Items to be reflected to "Design"	Resp. & Dead-line	Items to be reflected to "Evaluation"	Resp. & Dead-line	Items to be reflected to "Production process"	Resp. & Dead-line	

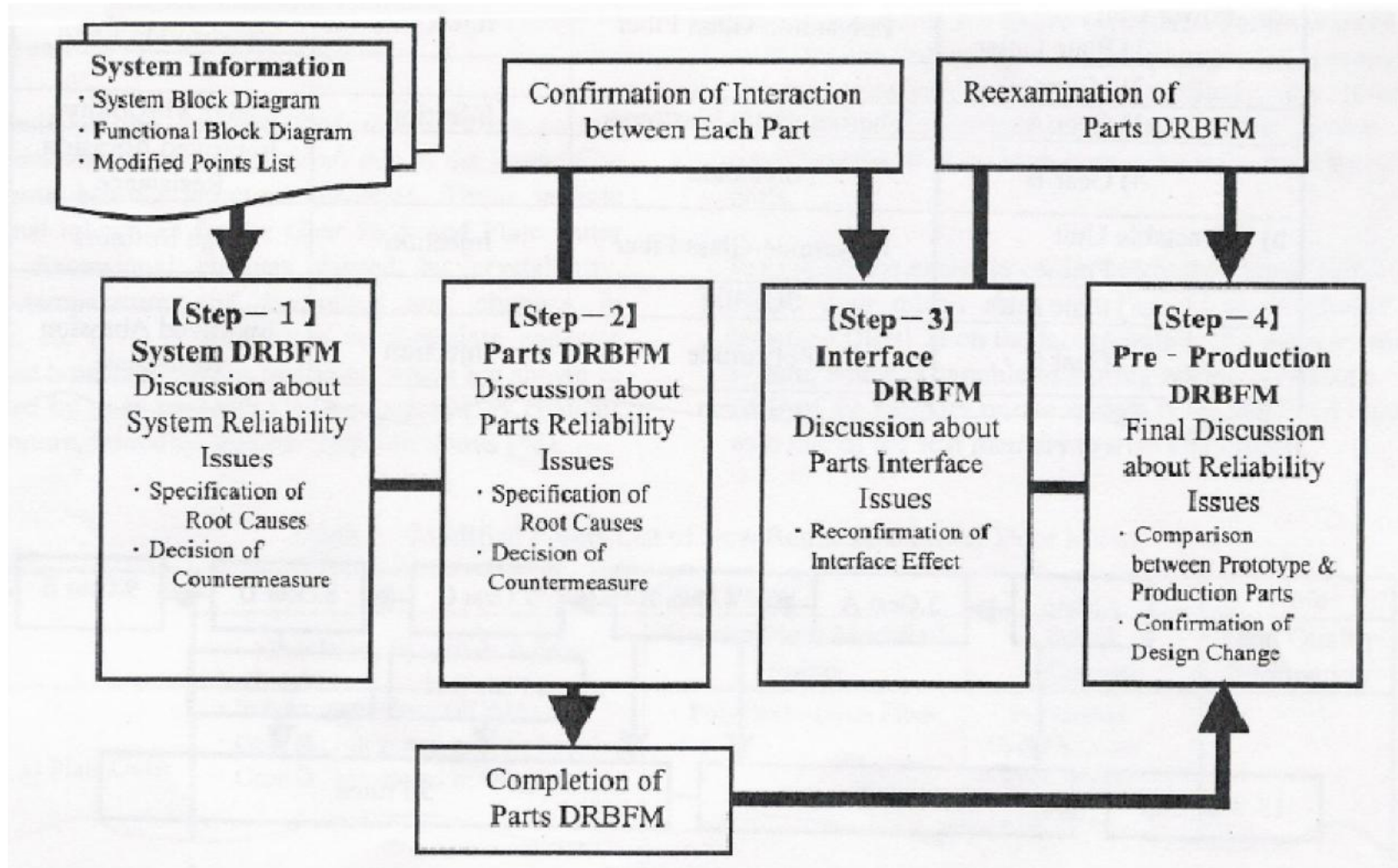
Current Design Controls	D e t e c	R. P. N.	Recommended Actions	Responsibility & Target Date	Action Results				
					Actions Taken	S e v	O c c	D e t	R. P. N.

FMEA Form:

Add Scores

Add Scores

# DRBFM System Integration



# Applying DRBFM in Lean NPD

- Use “Missing Knowledge” Decision Flow from Lean QFD as starting point
- These unknowns and known changes from current technology or design are the greatest risks
- Focus DRBFM on these unknown and changed areas during concept and prototype team reviews & Integration Points



# Integrating Product & Process Design

- DFMA – Design for Manufacturing and Assembly
- Integrated Product and Process FMEA / DRBFM
- Concurrent Engineering Team
- Visual Management – Decision Flow and Value Stream Map to Manage Tasks

# Impact of Lean Focused FMEA

- Allocation of Resources Targeted to Reduce Highest Risks and Unknowns
- Impact Product and Process Design
- Drive Test Planning and Analysis to Resolve Issues and Understand Unknowns
- Verify Corrective Action Effectiveness
- Critical Characteristics and Process Measurement / Control

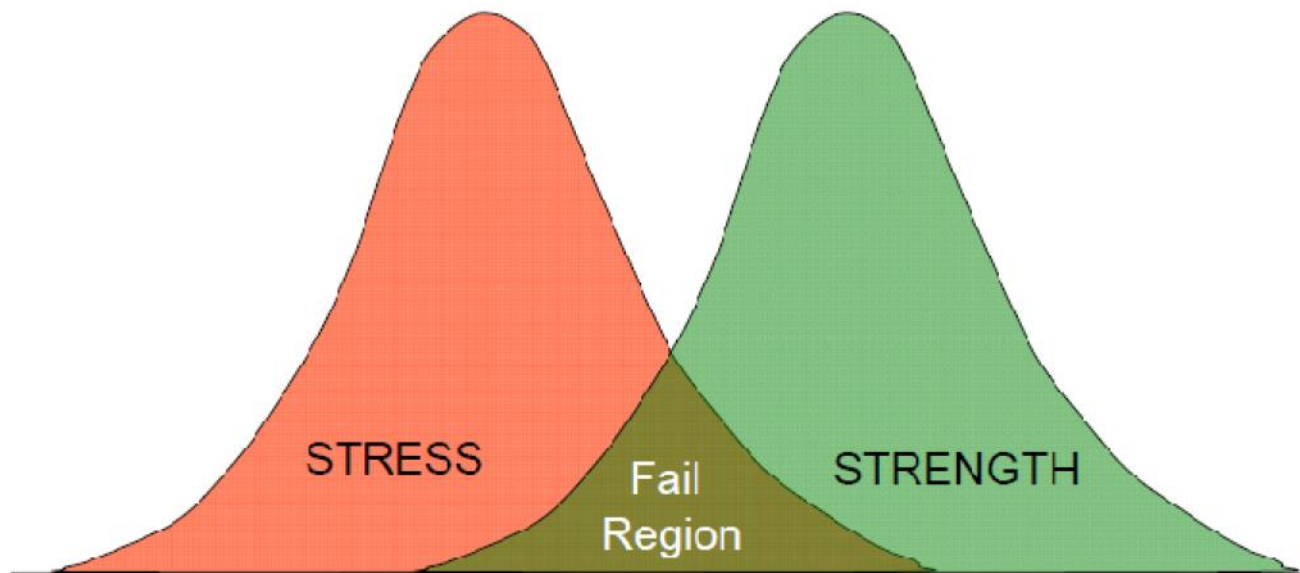
# Lean FMEA Summary

- Focus FMEA on Changes in Design or Process
- Use Supporting Tools to Narrow Focus:
  - Parameter & Boundary Diagrams
  - Process Flow Charts
  - DRBFM Techniques
  - Characteristics Matrix
- Use Lean NPD Tools to Identify Unknowns, Apply Resources, Assign Tasks

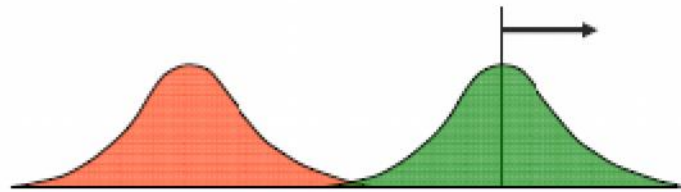
# Design for Reliability and Robustness

# How do we Design-in Reliability?

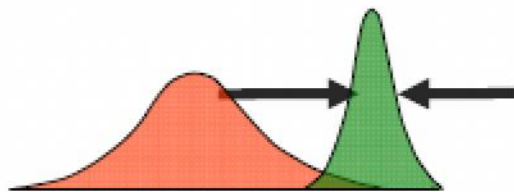
- Stress Analysis and Test
  - Find Product Limits & Understand User Needs
  - Products fail due to variation or in limit environments where stress exceeds strength
  - Stress and strength distributions:



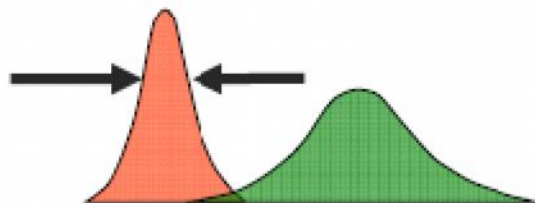
# DFR Strategies



Increase Design  
Margins

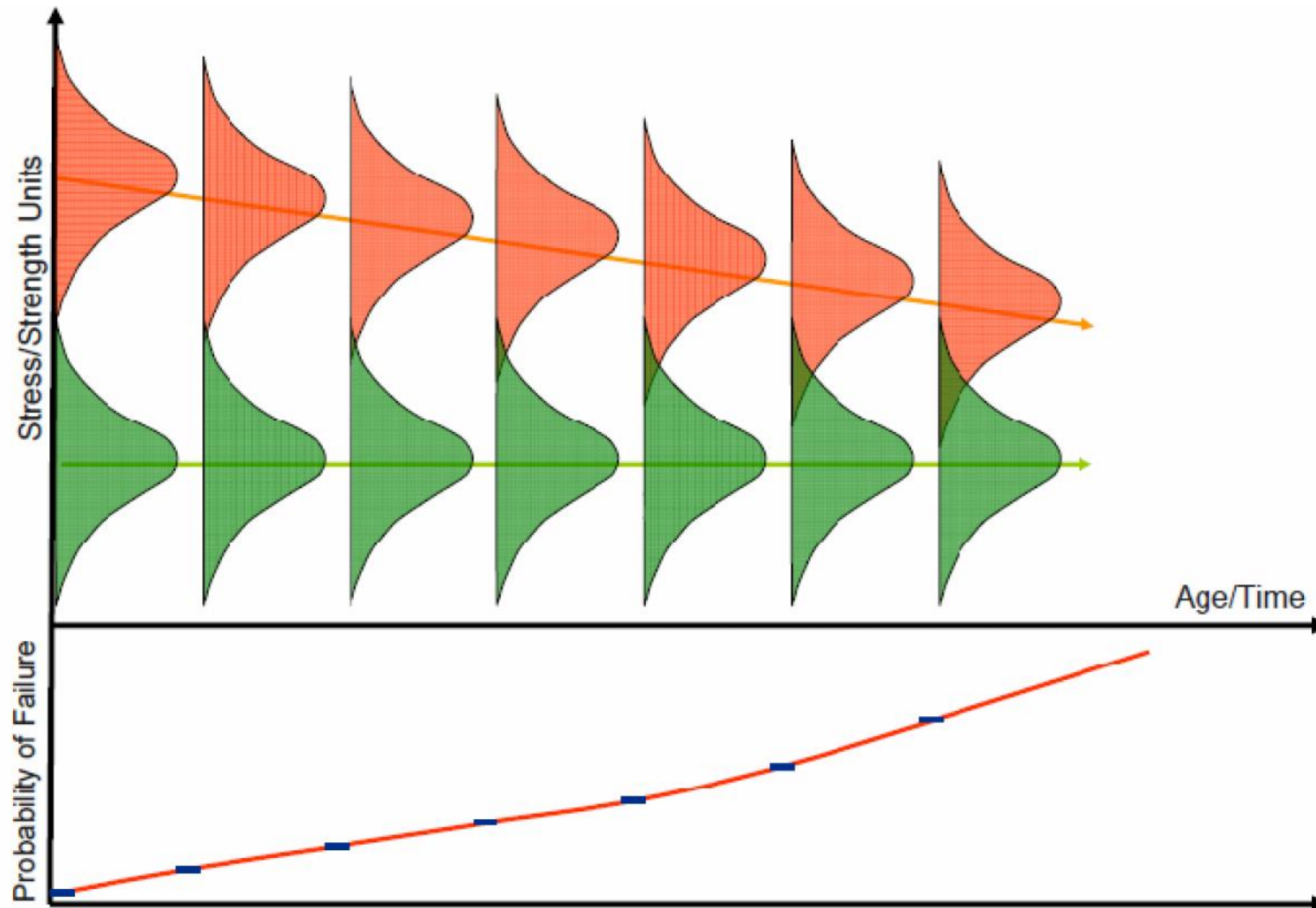


Reduce Variation  
in Product Strength



Reduce Effect  
of Usage/ Environment

# Stress-Strength vs. Age

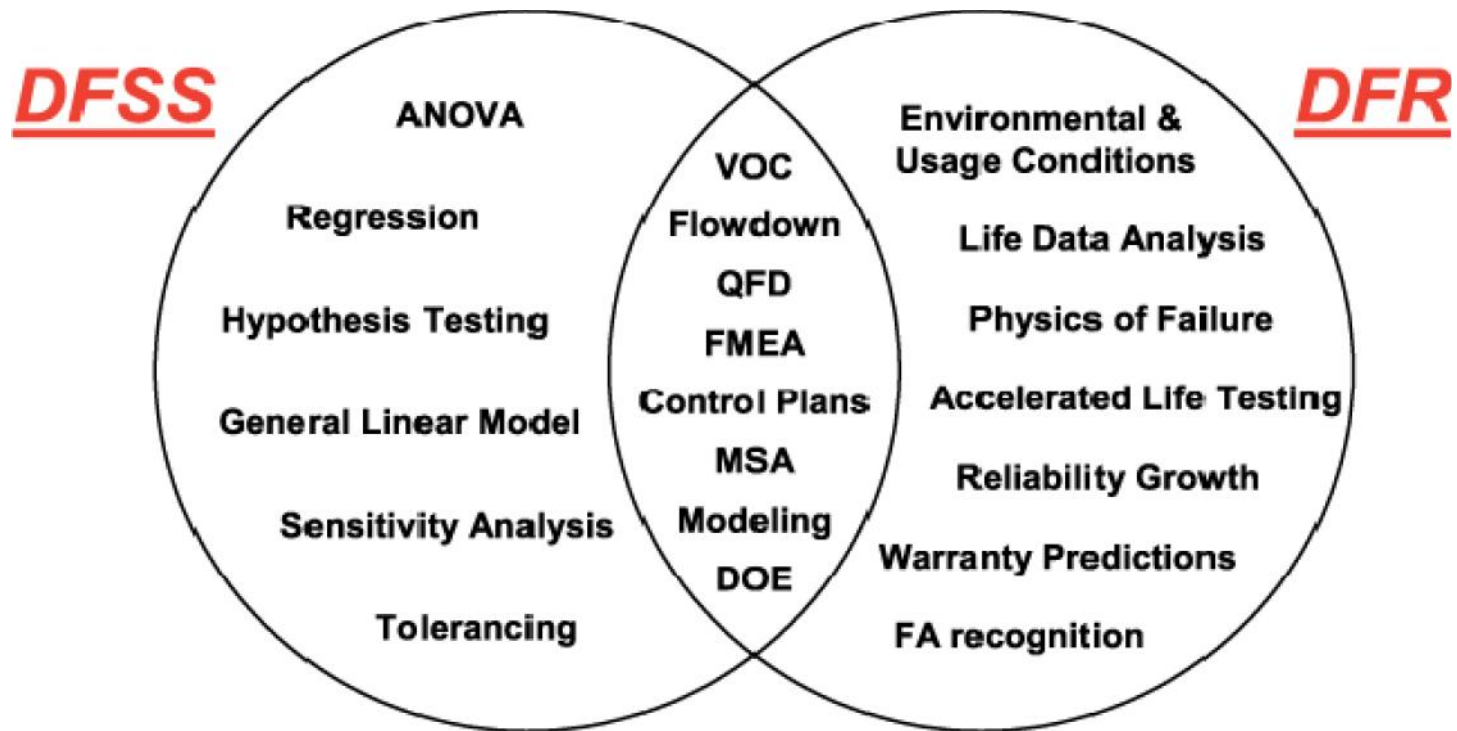


# Reducing Stress / Strength Interference

- Increase strength of the part
  - Understand operating environment stresses
  - Select more robust parts or materials
  - Increase design margin
  - Supplement deterministic design with probabilistic tools
- Reduce part strength variability
  - Understand sources of part variation and deterioration
  - Controlled production process (SPC)
  - Protect vulnerable components
- **ROBUST DESIGN + CONTROLLED PROCESSES = RELIABLE PRODUCT**



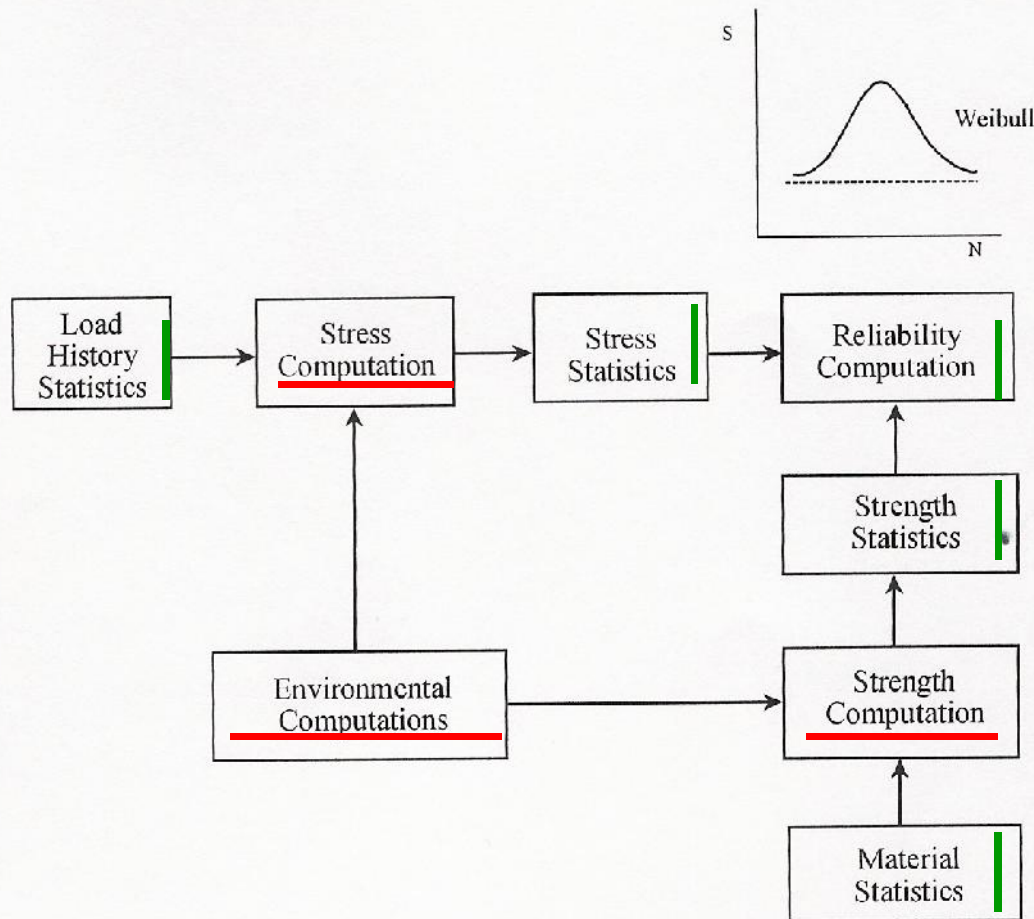
# Robust Design Tools



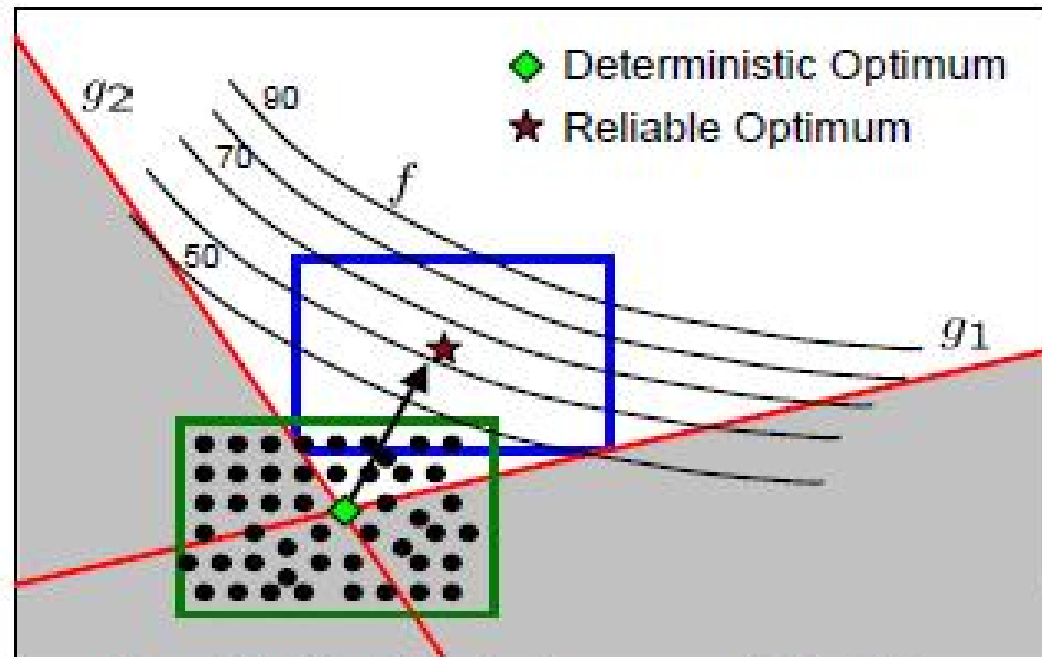
DFSS and DFR Tools: Differences and Commonality

# Probabilistic Design

Traditional design – Safety factors versus Probabilistic approach



# Reliability Based Design Optimization



Almost 75% of the designs around ◆ fails

# Elements of Probabilistic Design

- Understand physics of failure and stresses that precipitate failure
- Use predictive modeling and accelerated test to failure to estimate probability of failure
- Consider variability of applied stresses and variability of product strength
- Eliminate stress-strength interference

# Physics of Failure Approach

- Robust Design Considerations
- FMEA or DRBFM Methods
  - Design Review Based on Failure Modes  
Integrates FMEA and Design Review
- Test to Failure and Understand Cause Mechanisms
- Failure Analysis Methods

# Understand Physics of Failure

- What physical phenomenon in the part is caused by the stresses applied?
- If we understand the root cause, we can improve strength or reduce variability to prevent or mitigate the failure.
- Most hardware failures can be traced to four physical categories / mechanisms:
  - Wear
  - Corrosion / Contamination
  - Mechanical Failure (fatigue, vibration resonance, etc.)
  - Overstress (electrical or mechanical, transients)

# Physics of Failure Tools

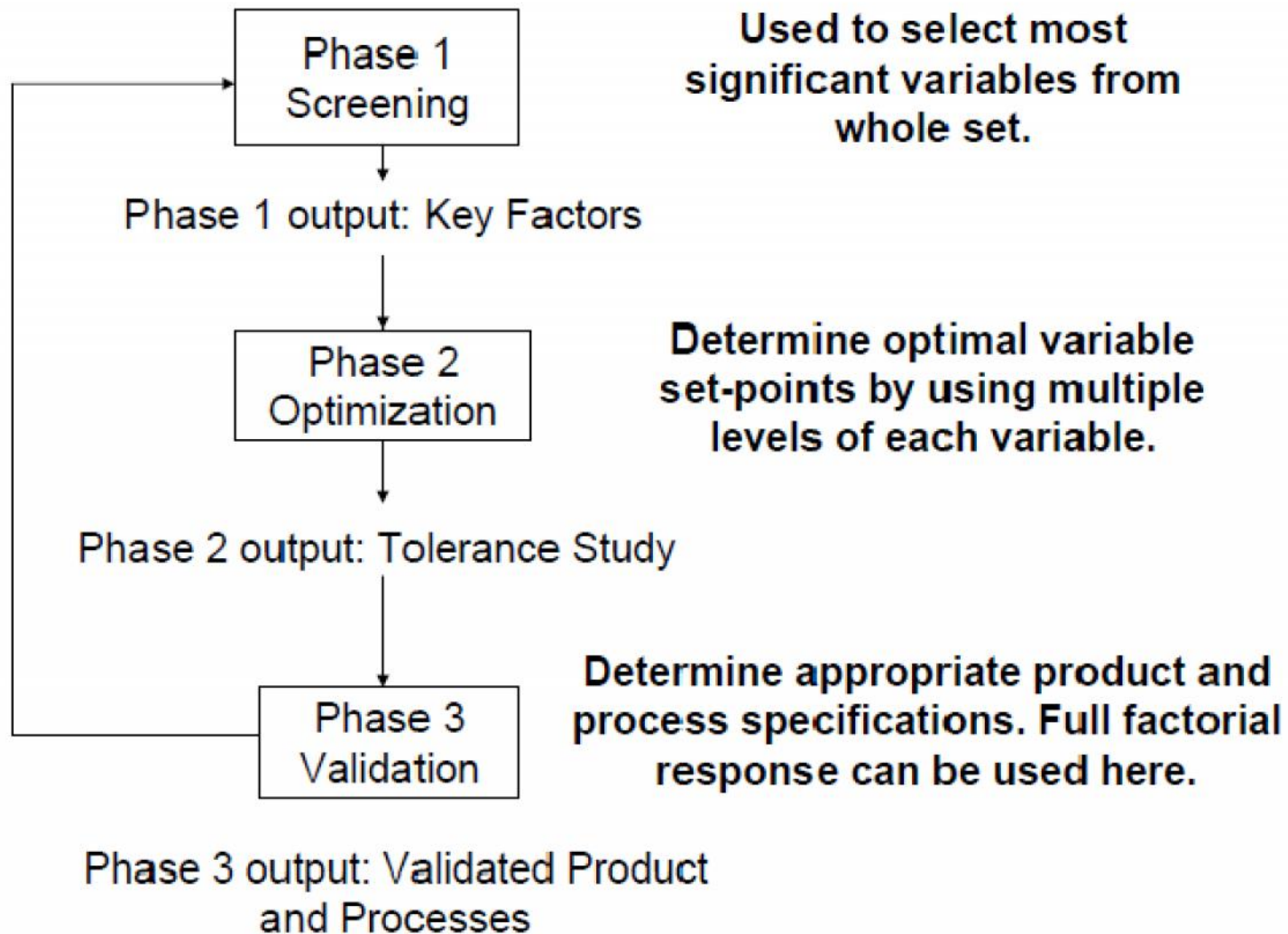
- Tools Used in Physics of Failure Analysis
  - Principal Physics Model
  - CAD Drawings / Solid Modeling
  - Finite Element Analysis
- Dynamic Simulation (Transients)
- Fatigue Analysis (Cumulative Damage)
- Thermal Analysis
- Accelerated Testing
- Simulation

# Design of Experiments (DOE)

- Tool to Evaluate Design Alternatives
- Determine Factors and Response
- May need Two Phased DOE Approach
  - Fractional Design to Find Main Factors
  - Full Factorial Design to Evaluate Effects and Interactions on Reduced Set of Factors
  - Consider Time and Cost
- Analysis of Results and Optimization of Solution



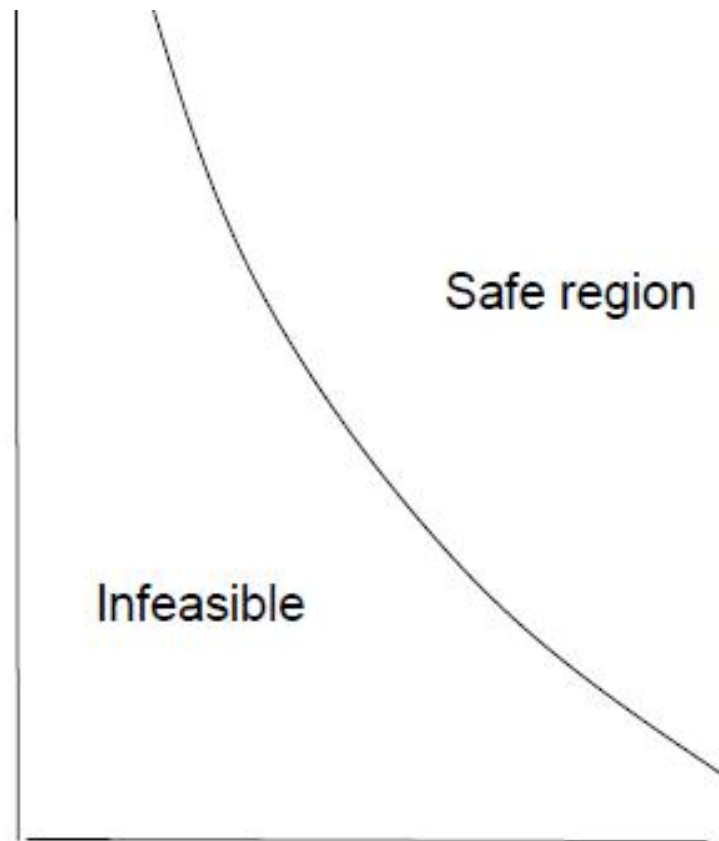
# Iterative DOE Process



# Use Trade-Off Curves to Capture Knowledge

- Point Data from Analysis and Experiments
- Relationship Between Key Parameters
- Apply to Support Design Decisions

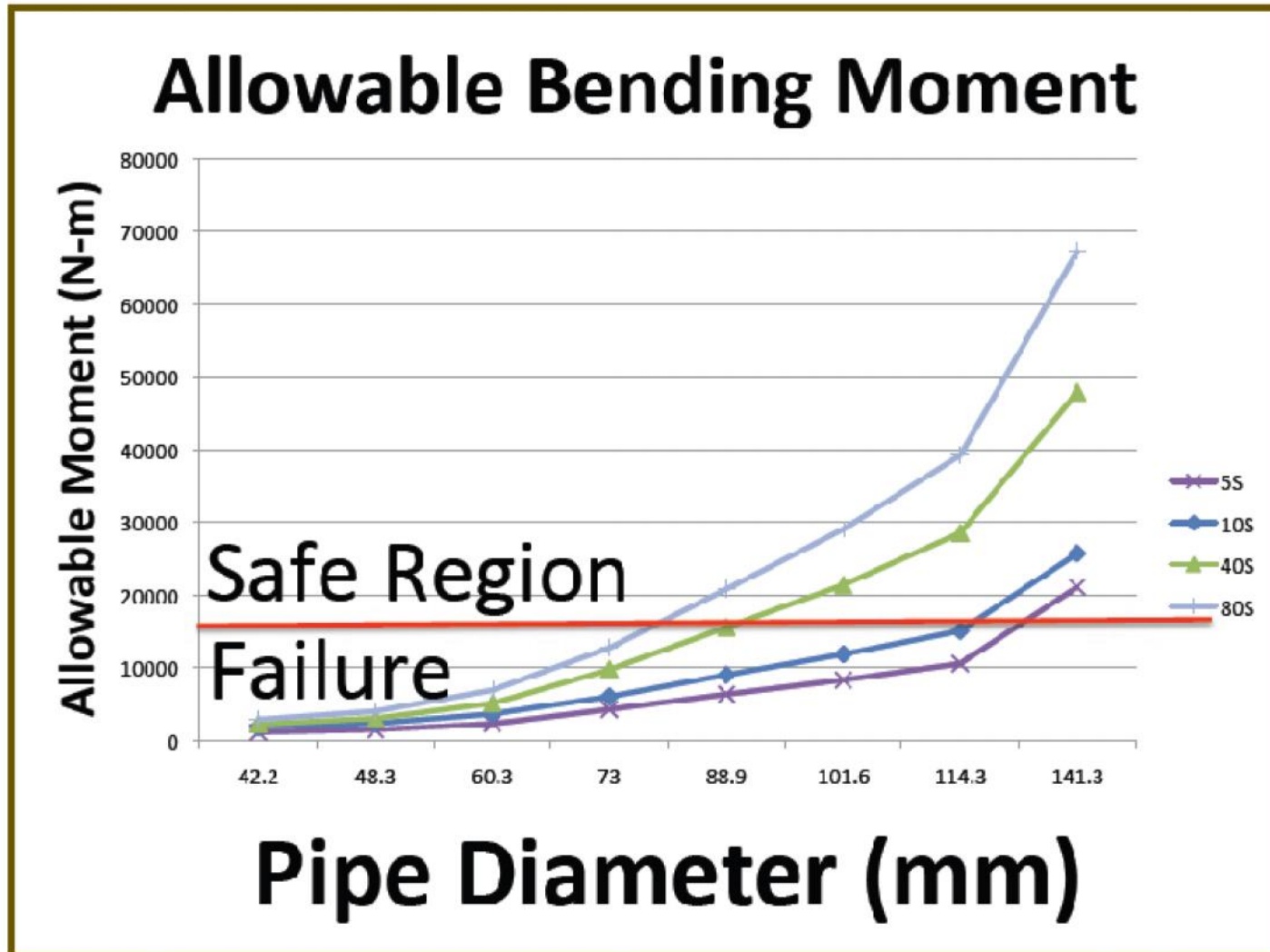
# Trade-Off Curves



- Understand
- Communicate and negotiate between specialties and functions
- Train new engineers
- Record knowledge
- Negotiate and communicate between customer and supplier
- Conduct design reviews
- Communicate between developers and managers
- Design quality into the product

Capture Knowledge from Point Solutions

# Trade Off Curve Example



# Key is Understanding

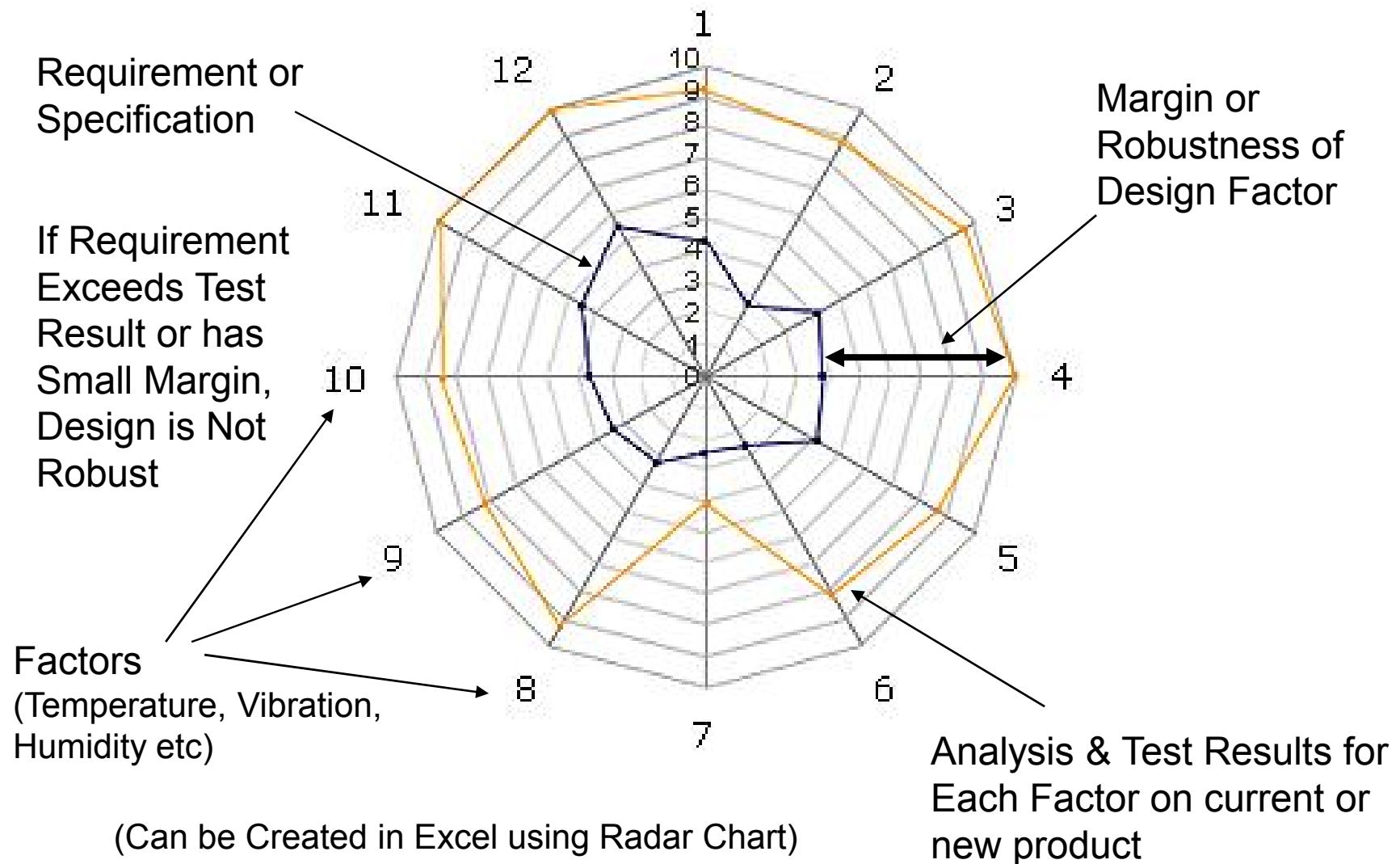
- Methods Build Knowledge of Alternatives
  - Physics of Failure
  - Design of Experiments
  - Design for Robustness and Reliability
- Enable Better Design Decisions
- Eliminate or Reduce Redesign Waste

# Reliability Testing and Data Analysis

# Phased Robustness Testing

- Prototype Phase
  - Accelerated Test to Failure (Well beyond Spec – HALT, Step Stress, Specific Stresses and Failure Modes)
- Design Verification Phase
  - Quantitative Accelerated Life Test
  - Selected Qualification Tests
- Production Validation
  - Demonstrate Corrective Action is Effective
  - Validate Final Product Made on Production Tools

# Robustness Indicator Figure





# General Approach to Accelerated Life Test (ALT)

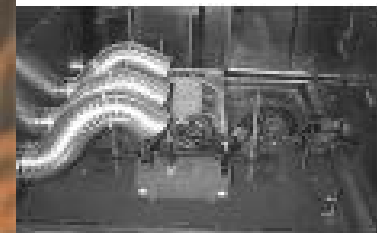
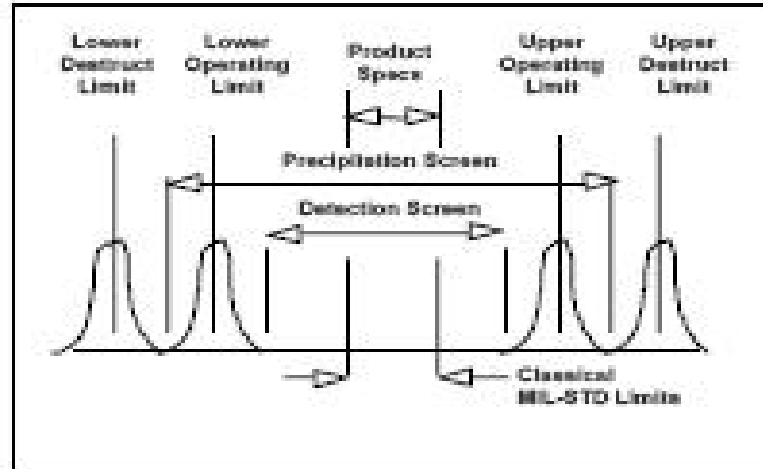
- Understand Failure mechanisms
- Understand Operating and Design Limits
- Clarify Use Level Stress Application
- Conduct Qualitative tests like HALT or step-stress tests to define product limits and failure modes
- Conduct Quantitative ALT to extrapolate life at use level conditions
  - Times to Failure at Accelerated Stress Levels
  - Use life-stress relationships and distributions

# ALT Plan

- Stresses to be Considered
- Life-Stress Relationship for Each Stress
- Application Use Level for Each Stress
- Use Level Failure Criteria / Threshold
- Test Duration and Resources Available
- Consider Use of DOE to help estimate:
  - Stress Factors with Most Effect
  - Probability of Failure at Specified Use Level
  - Probability of Failure at Maximum Stress
  - Interactions to Help Define Life-Stress Relationship

# Highly Accelerated Life Test (HALT) – Qualitative ALT

1. Improve Reliability by Finding Weaknesses and Correcting Them Early.
2. Establish Upper and Lower Operating and Destruct Limits of Environmental Stressors
3. Typically done in Temperature & Vibration Chamber for Electronics & Electromechanical Products
4. Concept can be Applied to Other Stressors (Voltage, Current, Mechanical Loads, etc.)



- Liquid Nitrogen Cooled
  - rapid thermal transitions
  - up to 60°C/min on product
- Repetitive Shock Vibration
  - 6 degrees of freedom
  - 3 axes & 3 rotations, simultaneous
  - broad frequency band (2-10,000 Hz)

# Quantitative ALT

- Test to Failure at Multiple Accelerated Stress Levels
- Use Analysis to Extrapolate Reliability or Life at Application Use Level Stress
- Can be Used to Demonstrate Ability to Meet Reliability Requirements

# Cautions on Acceleration

- Understanding product limits helps prevent accelerating to unrepresentative stresses and failure modes
- Time
  - Consider Heat Buildup
  - Effects of Cycling
- Temperature
  - Material Phase transitions
  - Non-linear response
  - High temperature or thermal cycling?
- Power
  - Protective and limit devices
  - Transients
- Vibration
  - Mechanical limits or resonances
- What failure mechanism are we accelerating?

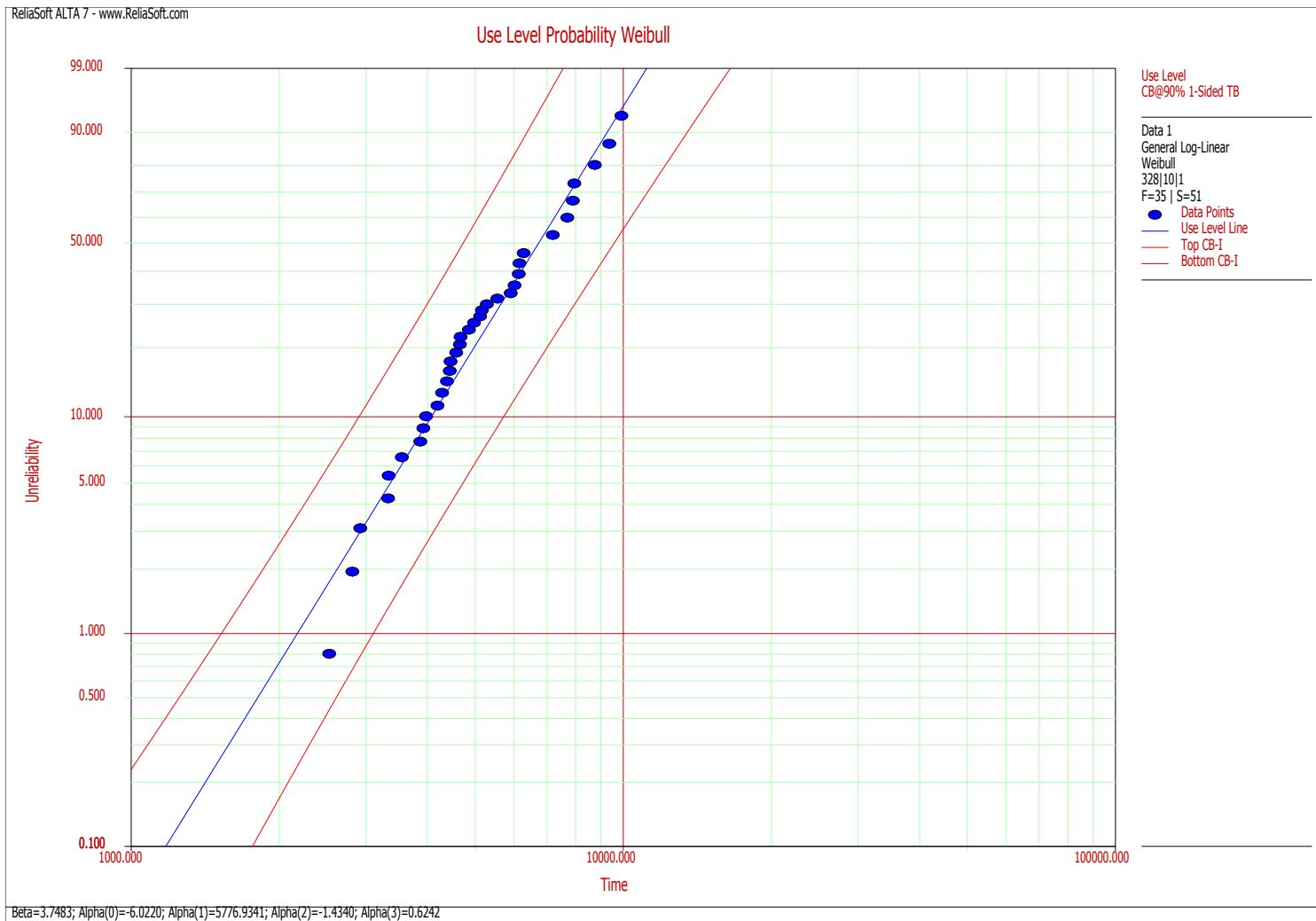
# Data Collected

- Test Parameters Measured
  - Temperature, Power Density, Cycle Rate, Vibration, Humidity, Voltage, etc. applied
  - Product Response or Function (monitor during test)
- Time to Failure or Run Time (Suspended)
  - At least 3 Different Stress Levels
  - Fit Data Points to Appropriate Distribution
- Product Limits from Step Stress Test
- Failure Mode Observations

# Data Analysis

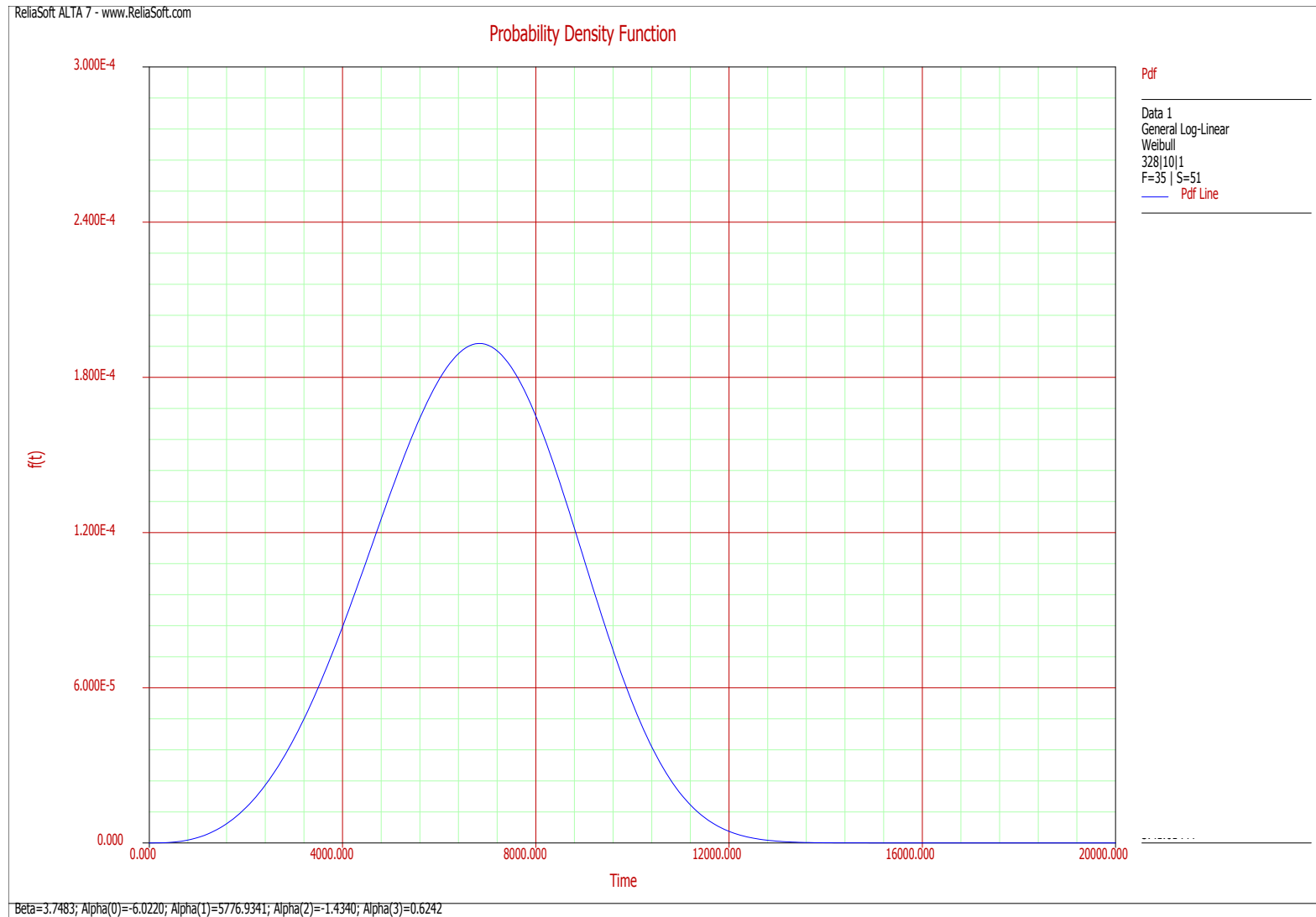
- Analyze Data and Extrapolate Life at Use Level Stress
- Life-Stress Relationships (predictive models)
  - Arrhenius – Temperature
  - Eyring – Temperature or humidity
  - Inverse Power Law – Voltage, Power, Mechanical
  - Multiple Life-Stress Models
    - Temperature / Humidity
    - Temperature / Non-Thermal: Temp / Voltage or Power
    - General Log Linear: multiple accelerating stresses
    - Proportional Hazards: multiple covariates
    - Cumulative Damage – Time varying stress profiles

# Data Analysis – Use Level



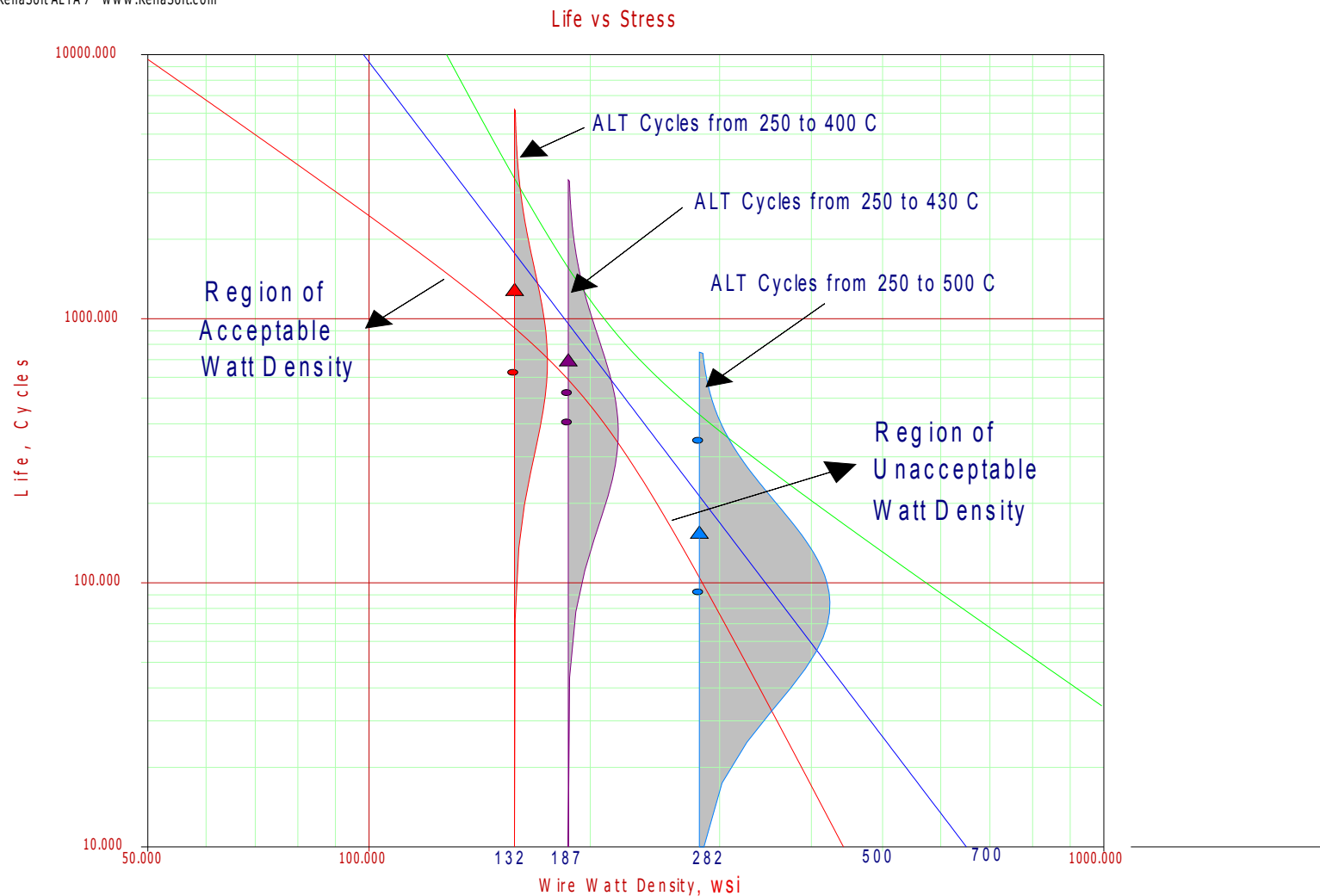


# Data Analysis - Distribution



# Life vs. Stress as Trade-Off

ReliaSoft ALTA 7 - www.ReliaSoft.com



# Production Validation Test

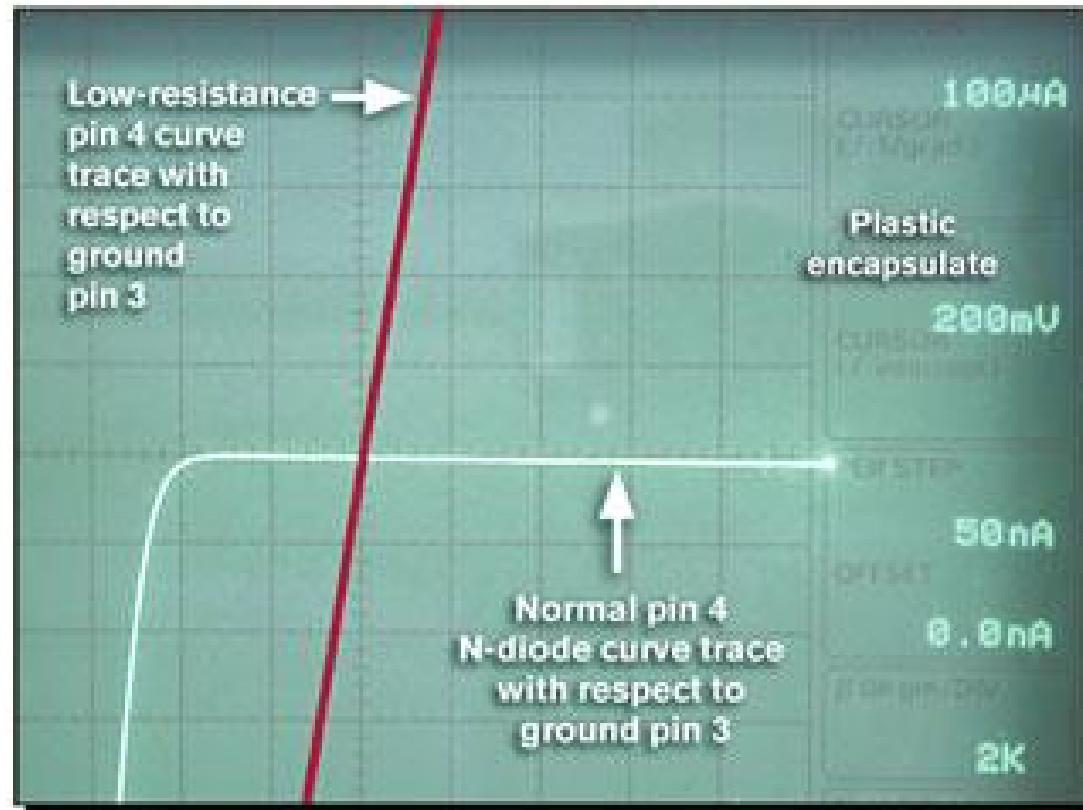
- Repeat selected Qualification Tests on any Changes in Product or Process
- Test Samples made on Production Processes
- On-Going Reliability Test (ORT)
  - HASS – Highly Accelerated Stress Screening
  - HASA – Highly Accelerated Stress Audit
  - Periodic HALT Re-Test on Production Units

# Failure Analysis / FRACAS

# Failure Analysis Tools

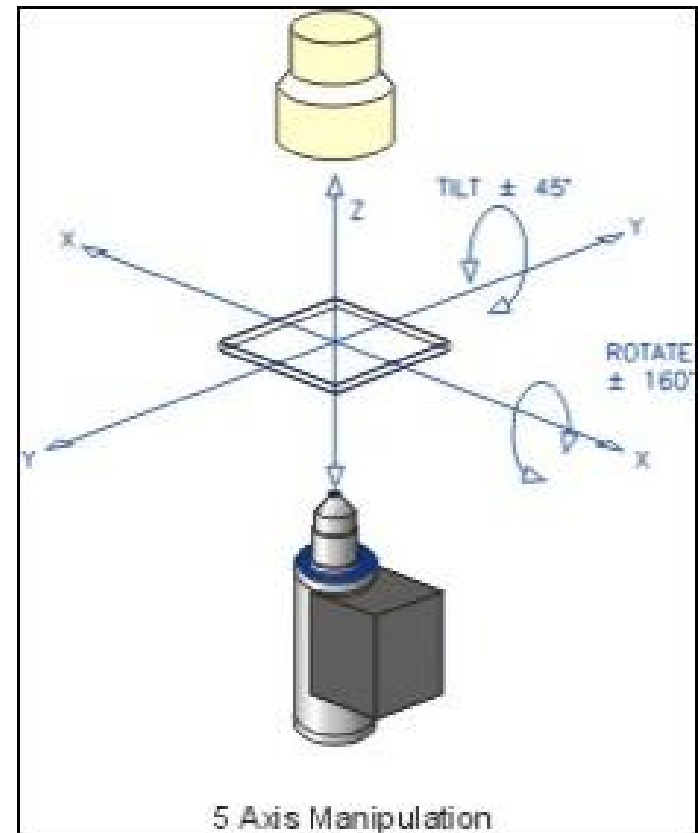
- Basic
  - Recovery of Failed Samples
  - Electrical Test, Microscopy, Digital Photography
- Non-Destructive Methods
  - X-Ray (Real Time Digital is Particularly Helpful)
- Disassembly / De-capsulation
  - Tools or Chemicals to remove layers
- Scanning Electron Microscopy & EDS
  - Defects, Corrosion, Material Failure
- Acoustic Microscopy / Imaging (Voids / Defects)
- Some Internal, Others at Outside Labs

# NDT – Electrical Characteristics



Curve Tracer – Showing Good and Failed Part Response

# Real Time Digital X-Ray

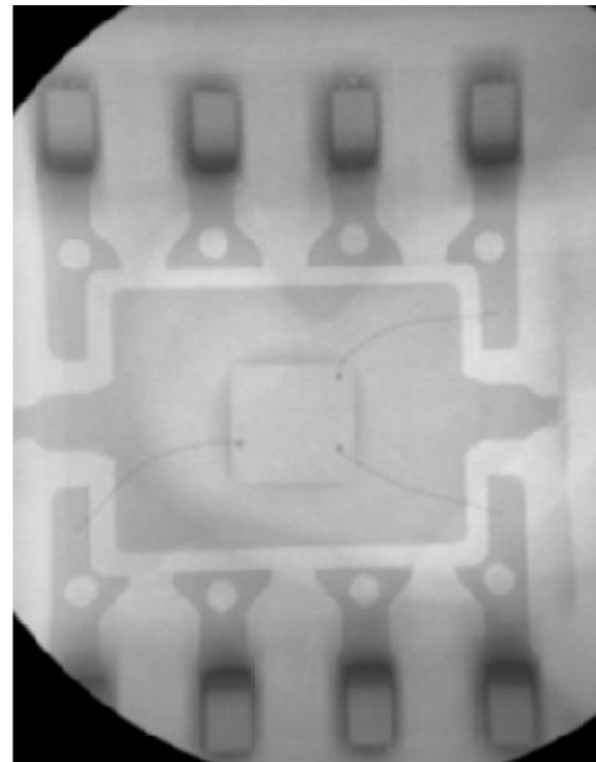
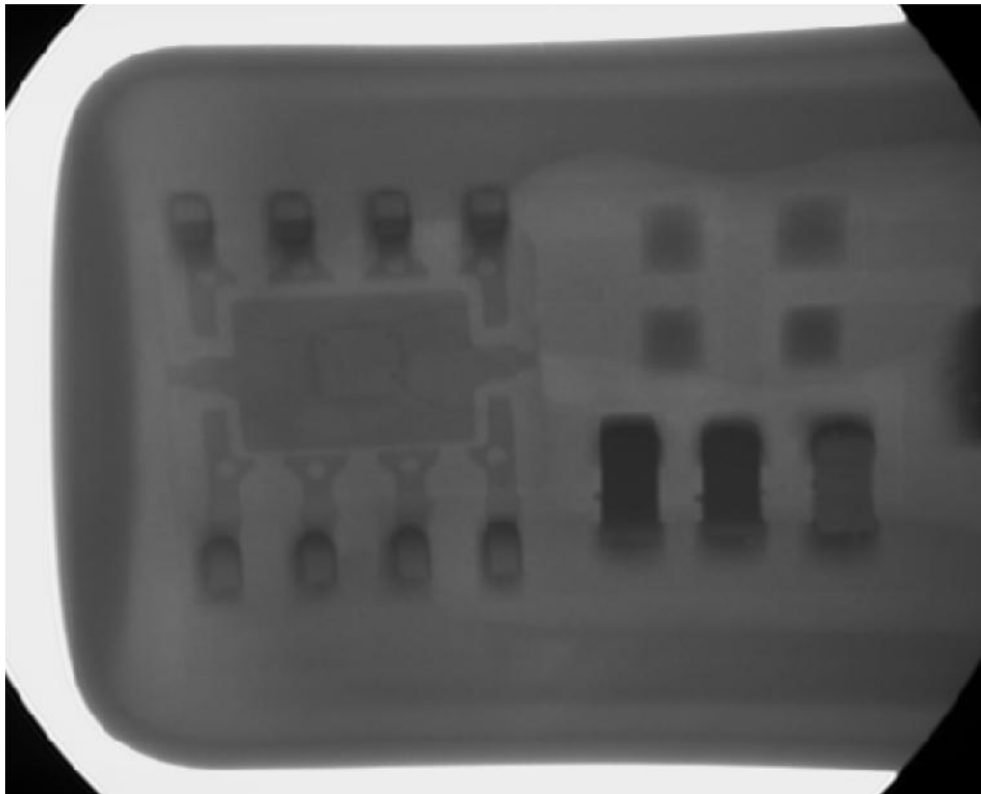


# Real Time X-Ray Example





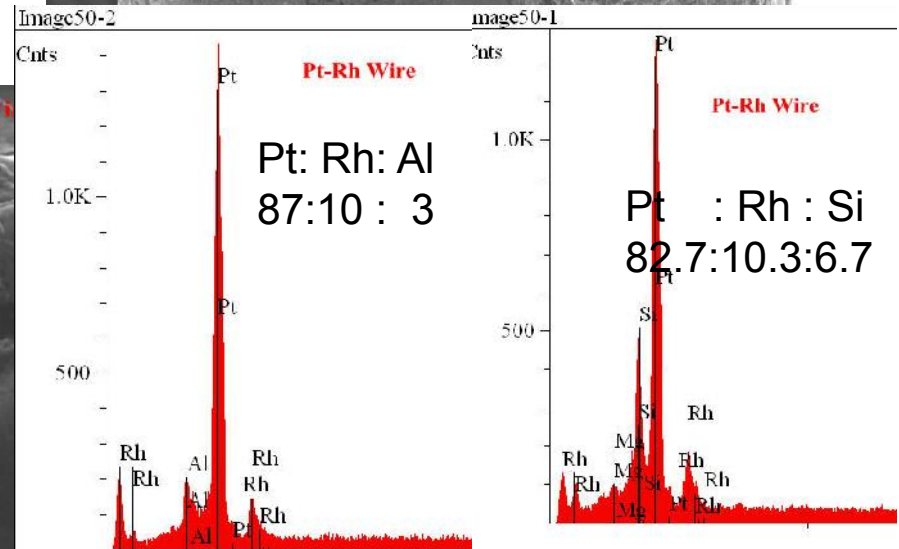
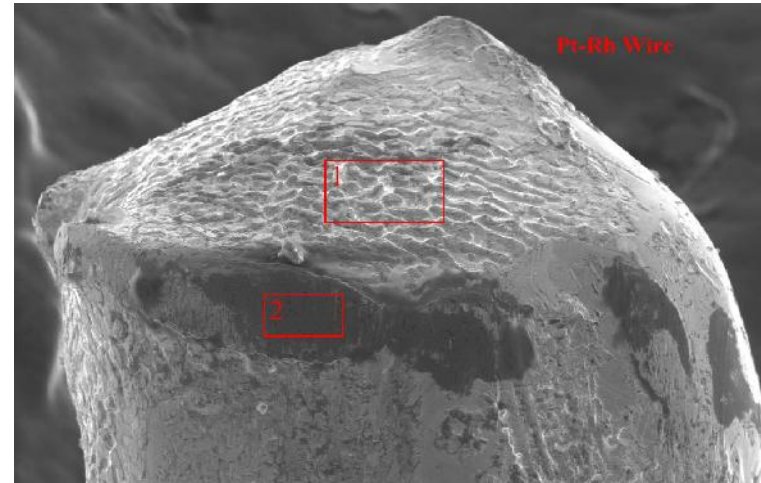
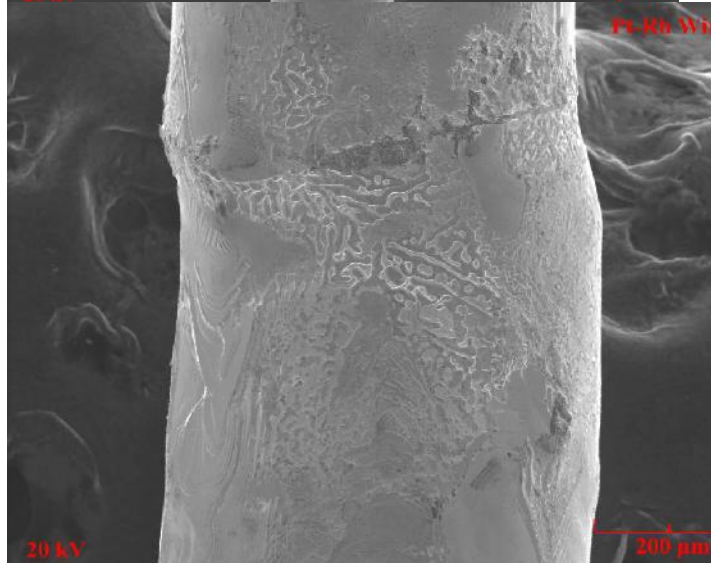
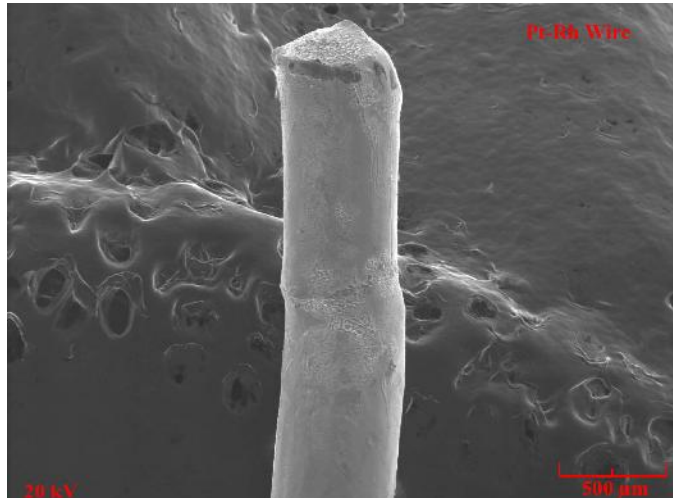
# Digital X-Ray Examples



# SEM / EDS



# Example of SEM / EDS Analysis



# PCB Failure Analysis Methods

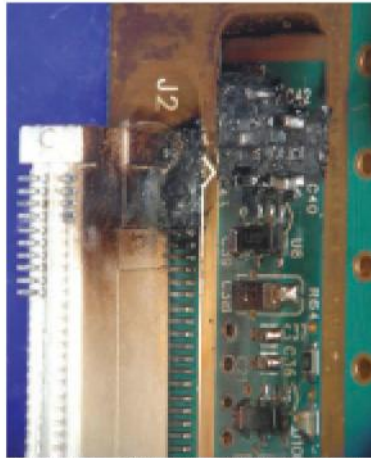


FIGURE 1. A burned PCA shows charring near the J2 label. Note the damage to the component area. The high temperature in this area melted solder and let several components fall off the PCB.

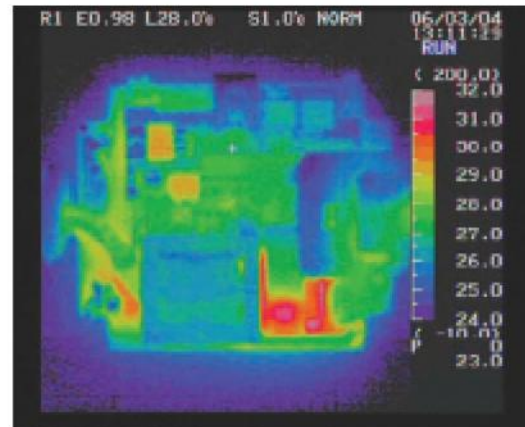


FIGURE 2. This infrared image shows two hot areas (red and pink) and cooler areas (purple) on a PCA. Analysts use such images to locate abnormally hot areas that may indicate or cause failures.

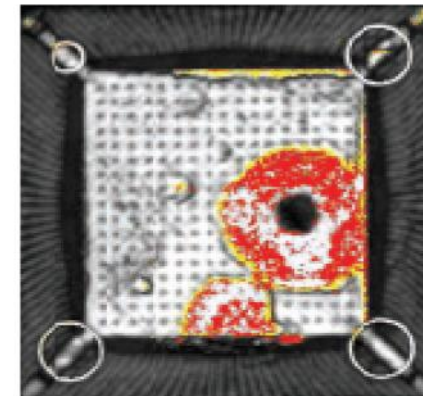


FIGURE 3. The red area in this acoustic-microscopy image shows delamination (separation) of the die and the packaging material. The large black dot indicates carbonized plastic caused by excessive heat.

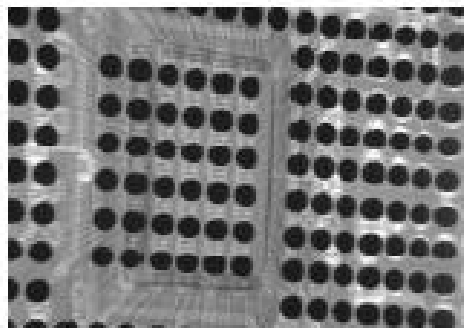


FIGURE 4. An x-ray view taken at an angle through a BGA shows individual solder balls and wire bonds but reveals little about micro-cracks and corrosion on PCB solder pads.



FIGURE 5. Liquid dye placed between this BGA and the PCB it was soldered to penetrated a space that existed between the center solder ball and its solder pad. The other balls were soldered properly to their respective pads, so no dye penetrated these junctions.

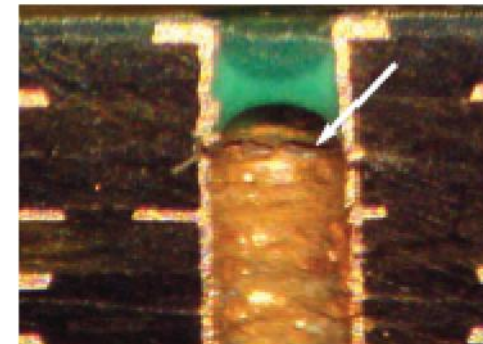


FIGURE 6. This cross-section image of a PCB via shows a crack that caused an open circuit. Stress, contamination, or insufficient plating might have caused the crack.

Thomas Paquette, Insight Analytical Labs, *Test & Measurement World*, August 2006.

# Failure Analysis Summary

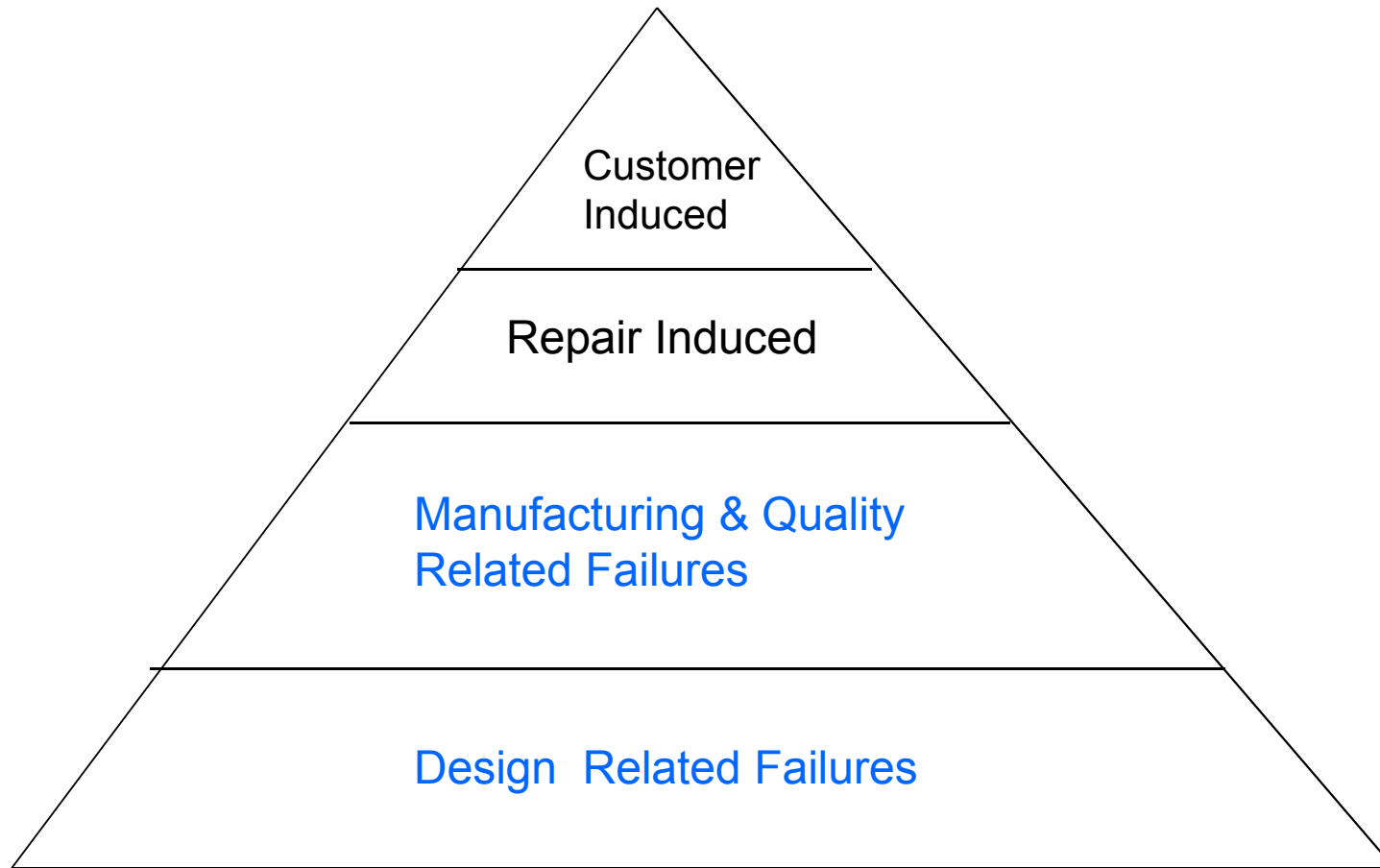
- Progressive Use of Tools from NDT to Dissection and Cross-Section Exam
- Objective is to Find Physical Evidence of Failure Mechanism
- Document with Photos and Analysis to Capture Knowledge Gained
- Update FMEA or DRBFM with FA Findings

# FRACAS

Failure Reporting, Analysis & Corrective Action System

- Build Knowledge Base
- Process and Tool
  - Reliability & Quality of Product, Service, Process or Software is Tracked, Measured, and Improved
  - Applies to Entire Product Life Cycle
  - Consistently Ranked Among the Most Important Reliability Tasks
  - Closed Loop: Ability to Feed Root Cause & Corrective Action Information Back Into Design Process for Further Improvement

# Hierarchy of Failure Causes



Capture Failures from Verification Test to Field Operation

# Capturing FA Knowledge

- Capture Failure Analysis Results in Searchable Tool
  - Commercial Data Base Tool
  - A3 Format Documents with Keywords
  - SharePoint (Microsoft)
- Key is Ability to Retrieve Knowledge with Minimal Search Effort
- Lean NPD is Knowledge Based – Key is Continually Adding to Accessible Knowledge



# Summary

- Features of Lean NPD for Reliability
  - Front End Focus to Gain Knowledge
    - Basis for Better Design Decisions
  - Design for Robustness, Reliability
  - Understand Physics of Failure
- Testing to Learn and Verify
  - Test to Failure and Understand Causes
- Knowledge Capture for Future Re-use
- Develop & Control Critical Characteristics

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- Bill Haughey, DRBFM, Applied Reliability Symposium, June 2007, March 2008
- Lean FMEA Training, Quality Associates International, at [www.quality-one.com](http://www.quality-one.com)
- AIAG, FMEA, 4<sup>th</sup> Edition, June 2008, pp.135-138.

# Feedback / Follow-up

- Please provide your feedback on this web based short course: e-mail to [jjpengr@gmail.com](mailto:jjpengr@gmail.com) or to ASQ RD
- One day seminar on this topic available through:  
[http://www.hobbsengr.com/Accelerated\\_Reliability\\_Seminar\\_Schedule.htm](http://www.hobbsengr.com/Accelerated_Reliability_Seminar_Schedule.htm)
  - Apr 13, 2011 in Chicago, IL
  - May 2, 2011 in Minneapolis, MN