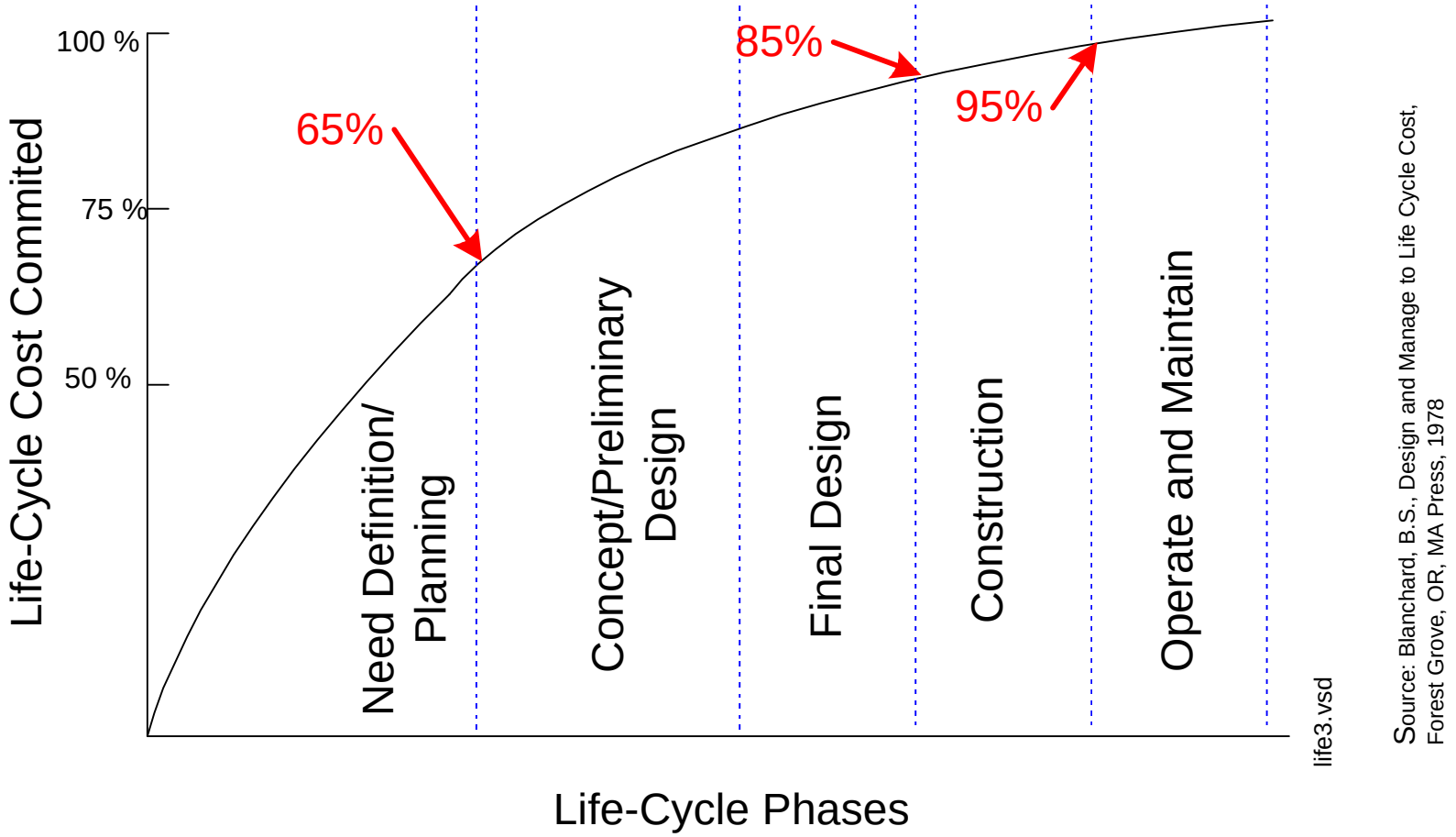
# NATIONAL AERONAUTICS and SPACE ADMINISTRATION

## Reliability Centered Maintenance & Commissioning

**February 16, 2000**

# Life-Cycle Cost Commitment



# Building Construction: Pre-RCM

- A new Federal office building, 92% of the rotating equipment was found to be improperly installed - primarily balance and alignment.
  - Similar problems were encountered at Goddard Space Flight Center and Kennedy Space Center
- National Security Agency (NSA) discovered 100% of their new rotating equipment had defects
- Department of State found that greater than 80% of the rotating equipment in 2 New Office Buildings had installed defects
- P.T. Badak and Antibioticos, S.p.A experienced significant problems with new construction projects.
- In all cases:
  - the specifications did not address the current best reliability practices.
  - commissioning practices had not been updated to reflect the changes in system/component testing capabilities

**Sources:**

**Report on RCM Implementation Plan, Phase 3, Johnson Space Center, 1994**

**Reliability Assessment Report, Goddard Space Flight Center, 1997**

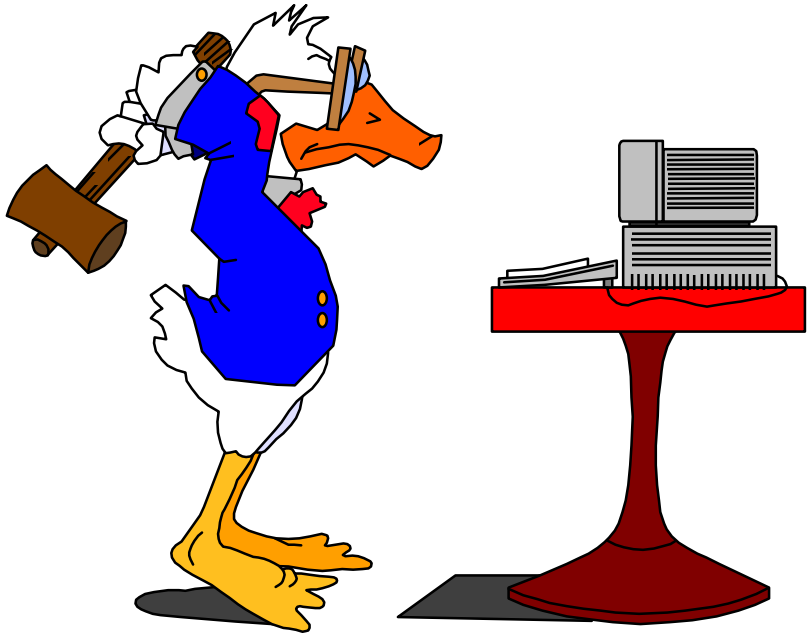
**Reliability Maintenance Assessment Report: Antibioticos, S.p.A (Settimo), 1994**

**Reliability Assessment P.T. Badak, 1996**

# Why RCM and Commissioning...

## Must know system:

- Function in quantifiable terms
- Failure modes
- Consequences of failure (criticality)



## Otherwise you do not know:

- What to test
- Acceptance criteria for the test
- Cost effectiveness of testing
- What level of performance is acceptable to both the builder and the owner

***The traditional approach is that if it is new it is good. How about new cars, houses, computers, and people?***

# Reliability Goals and Logic

## *RCM Goals*

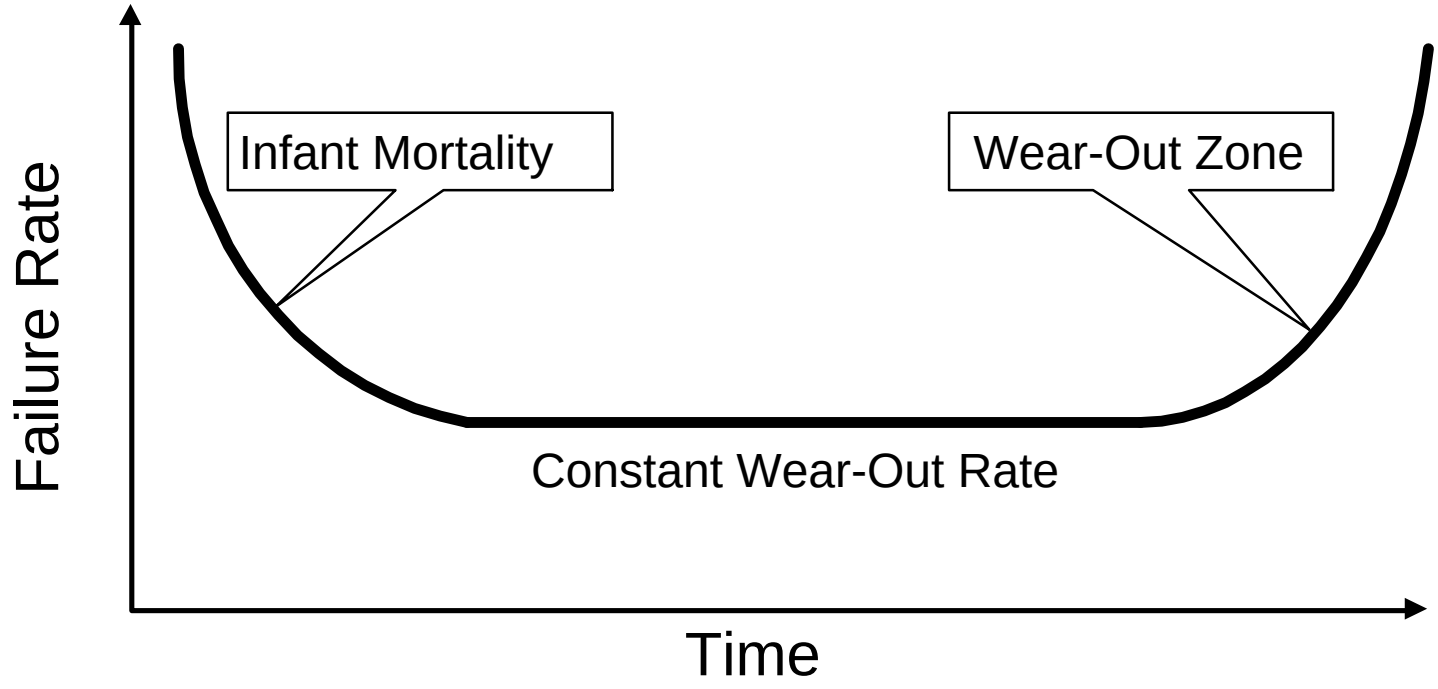
- **Ensure realization of inherent safety and reliability of the equipment**
- **Restore equipment to required levels when deterioration occurs**
- **Obtain the information necessary for design improvements where inherent reliability is insufficient**
- **Accomplish these goals at a minimum total life cycle cost**

## *RCM Logic*

- **Determine the function of the system/component**
- **Define what is a functional failure**
- **Evaluate the consequences of failure**
- **Assign a maintenance task to prevent the failure**

# The Perception of Equipment Life is...

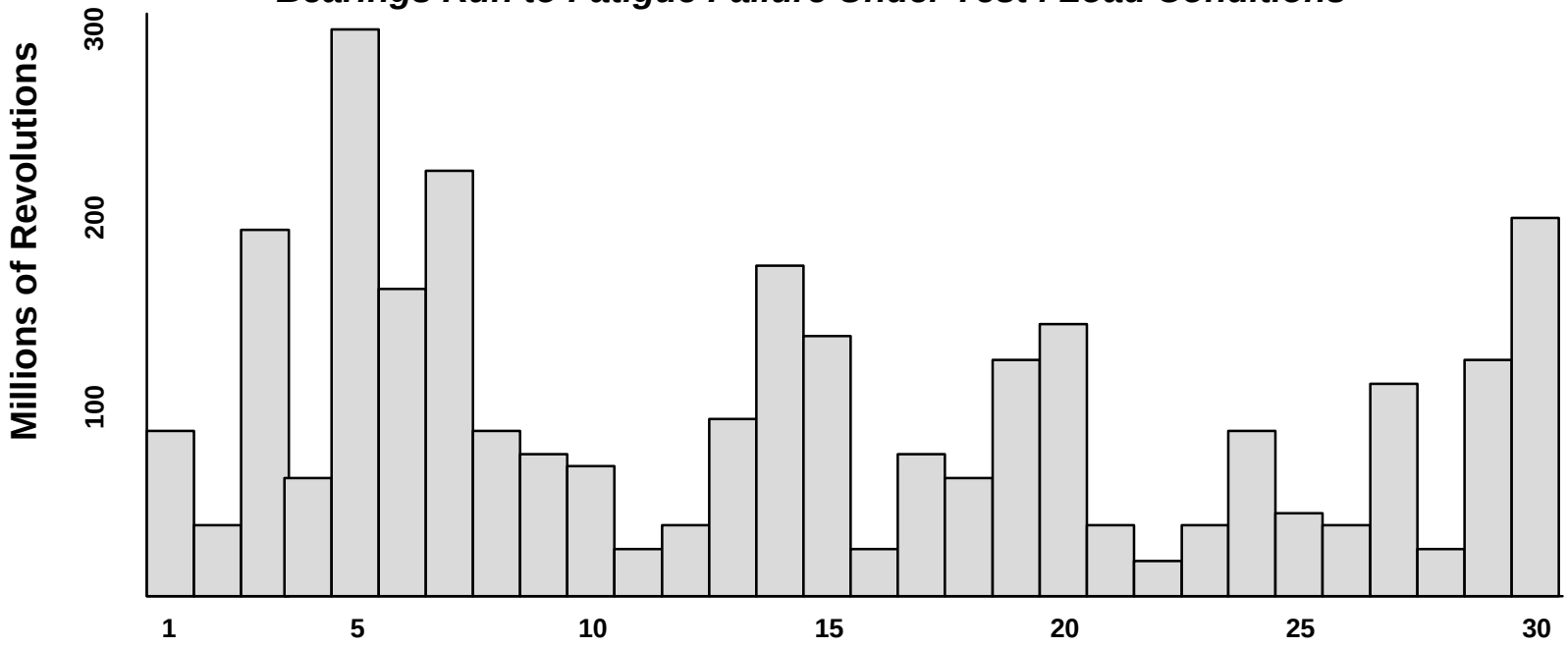
***Standard "Bathtub" Curve***




***The traditional approach to maintenance is based on a misunderstanding of failure distributions. Only a small percentage of equipment follows this curve***

# At Times, We Assume the Life of Components is Known

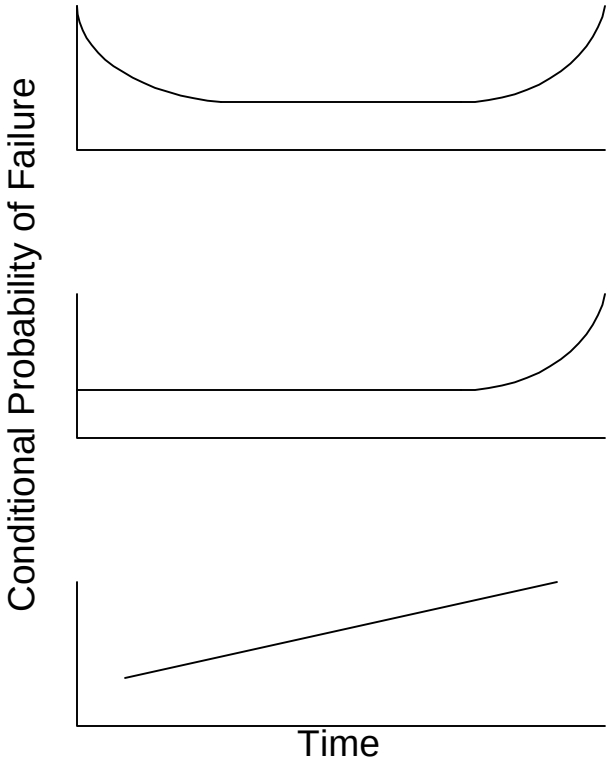
***Thirty Identical 6309 Deep Groove Ball Bearings Run to Fatigue Failure Under Test l Load Conditions***




From: *Ball and Roller Bearings: Theory, Design, & Application, Eschmann, et al*
John Wiley & Sons. 1985

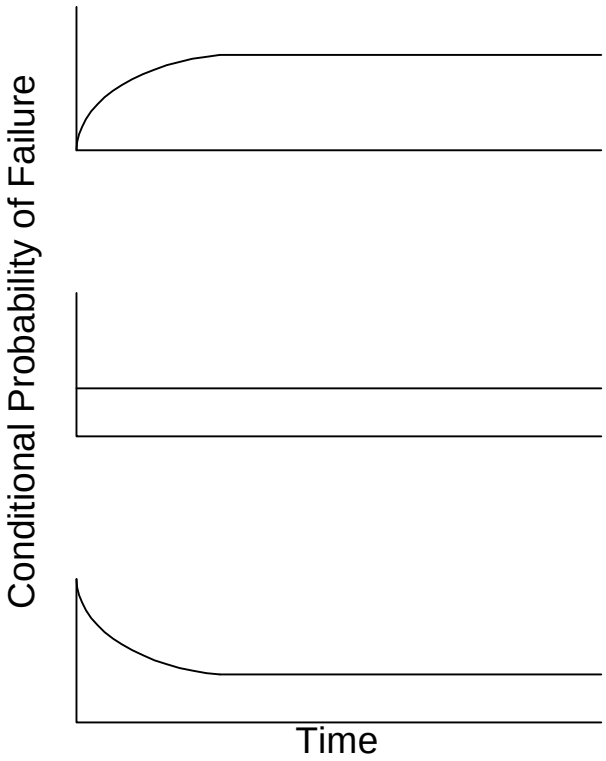
***Random failure is the dominant failure distribution***

# Age Related Failure Curves




| | UAL 1968 | BROMBERG 1973 | U.S. NAVY 1982 |
|---|---|---|---|
| | 4% | 3% | 3% |
| | 2% | 1% | 17% |
| | 5% | 4% | 3% |

# Random Failure Curves




| | UAL 1968 | BROMBERG 1973 | U.S. NAVY 1982 |
|---|---|---|---|
| | 7% | 11% | 6% |
| | 14% | 15% | 42% |
| | 68% | 66% | 29% |

# Failure Definitions

**Failure Definitions:**

- **A failure is an unsatisfactory condition. It may be catastrophic or merely out-of-tolerance.**
- **A functional failure is the inability of an item or system to meet a specified performance standard.**
- **A potential failure is an identifiable and quantifiable physical condition which indicates a functional failure is imminent.**

***What about hidden failures?***

# Consequences Of Functional Failure

- **Production or Mission Impact**
  - **Quantity**
  - **Quality**
- **Environmental, Health or Safety**
- **Life Cycle Cost**
- **Morale**

# Multiple Independent Failures

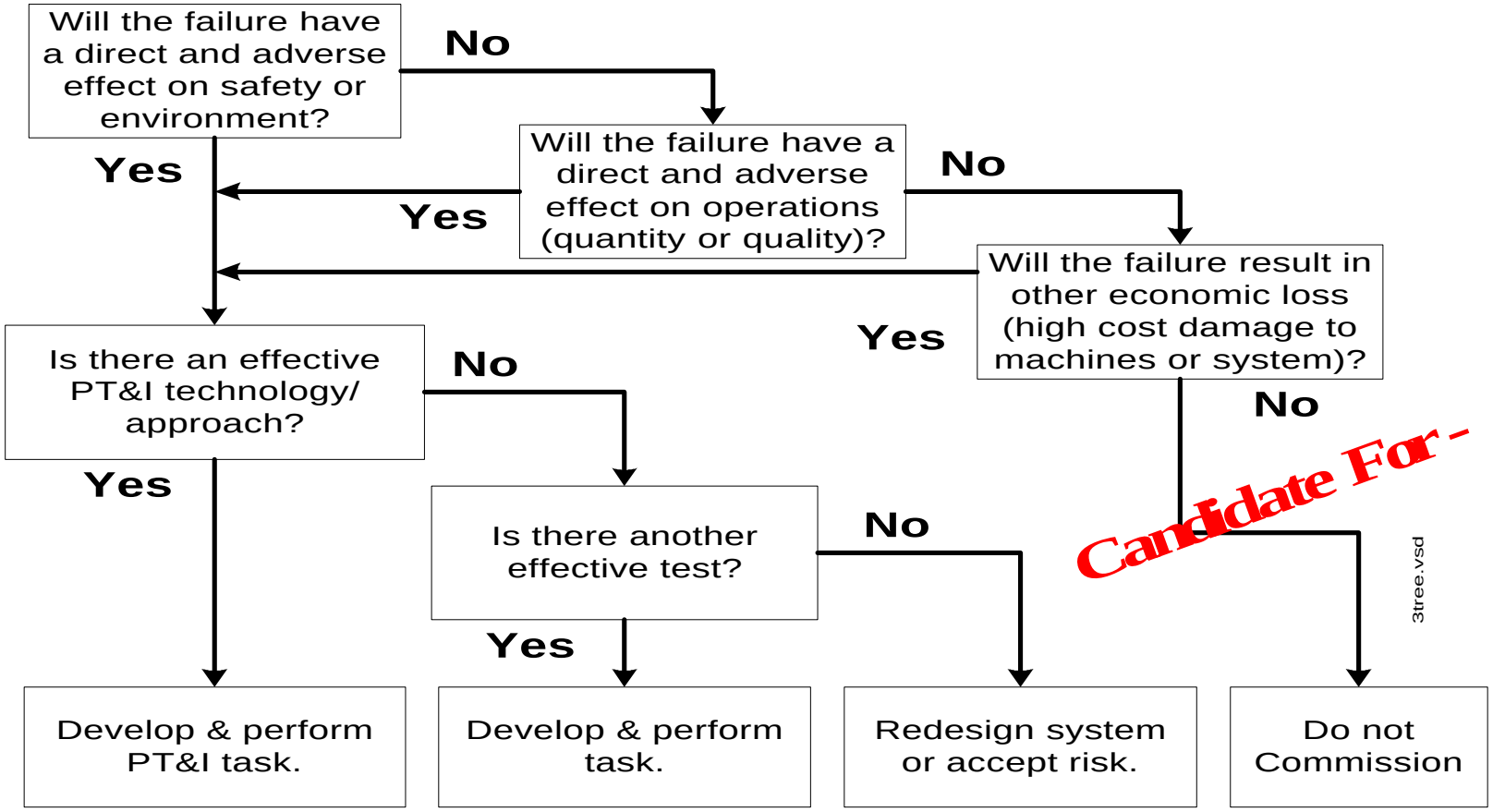
- **Independent Failure: One does not influence the other.**
  - **If a machine has a failure rate of 1 failure every 100 days, the probability of failure on any given day is 1/100.**
  - **If a second machine has the same probability of failure, the probability that both machines fail on the same day is $1/(100)^2$ or 1 in 10,000.**

# Failure Modes And Effects Analysis (FMEA)

- **A failure analysis conducted in the design phase of an equipment or system; also used as a tool for analysis in Reliability Centered Maintenance (RCM).**
- **The FMEA contains:**
  - **Description of Failure Modes**
  - **Cause and Effects of failure**
  - **Probability of Failure**
  - **Criticality of Failure**
  - **Corrective/Preventive Measures**

***FMEA is the key to a successful Commissioning Program.***

# RCM Logic Tree



# Failure Mode & Effects Worksheet

**Area**: Identify Plant Area or Process
**System**: System Name
**FMEA Number**: If Used
**Team Members**: Who prepared this FMEA

Date FMEA Started:

Date FMEA Completed:

fmea1.vsd

| Control Number | Name & Function/ Performance Requirement | Potential Failure Mode | Potential Failure Effects | Crit | Prob | MA Code | Maintenance Approach | Remarks/Continue |
|---|---|---|---|---|---|---|---|---|
| | | | | | | | | |

# Sample Failure Modes and Effects Data Sheet

| | | | AREA: Central Utilities | | | TEAM: Utilities | | PAGE 1 0F 1 |
|---|---|---|---|---|---|---|---|---|
| | | | SYSTEM: Chilled Water | | | START: | | DATE PRINTED: 3/24/99 |
| | | | FMEA NO. CW001 | | | END: | | |
| CONTROL NUMBER | NAME & FUNCTION | FAILURE MODE | FAILURE EFFECT | CRIT | PROB | MA CODE | MAINTENANCE ACTION | COMMENTS |
| CW1 | CWP MOTOR 101 | SEIZED BEARING | LOSS OF FLOW | 8 | 4 | V1 | NARROWBAND VIBRATION | QUARTERLY |
| | | STATOR INSUL. | LOSS OF FLOW | 8 | 3 | E1 | MEGGER | BIENNIAL |
| | | ROTOR BAR | LOW FLOW | 4 | 2 | E2 | MOTOR CIRCUIT EVALUATION | ANNUAL |
| | | | LOSS OF FLOW | 8 | 2 | | | |
| | | | | | | | | |
| | | | | | | | | |

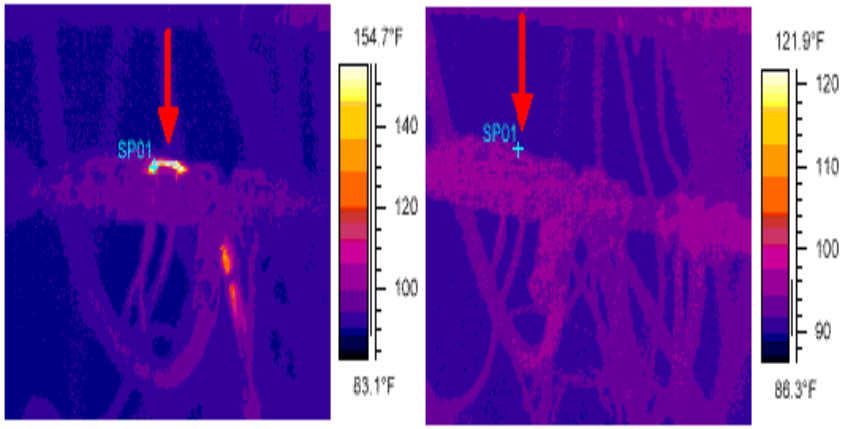
# PT&I and Commissioning

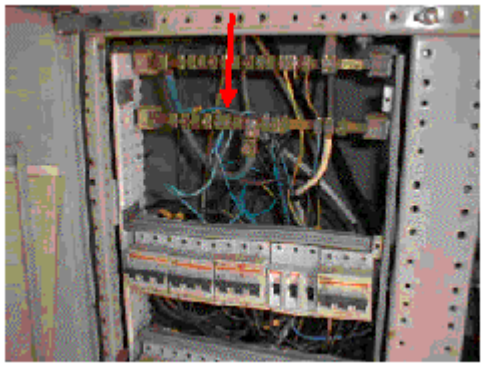
**PT&I is the use of advanced technology to sense machinery operating characteristics such as vibration, temperature, pressure, etc. and to compare the measured values of these characteristics with historical data and pre-established criteria (ISO, ASNT, etc.) to assess machinery condition. PT&I permits the quantifiable condition of systems and equipment to be determined rather than rely on opinion.**

***PT&I provides the data to substantiate warranty claims.***

# Infrared Thermography: A Versatile Monitoring Tool

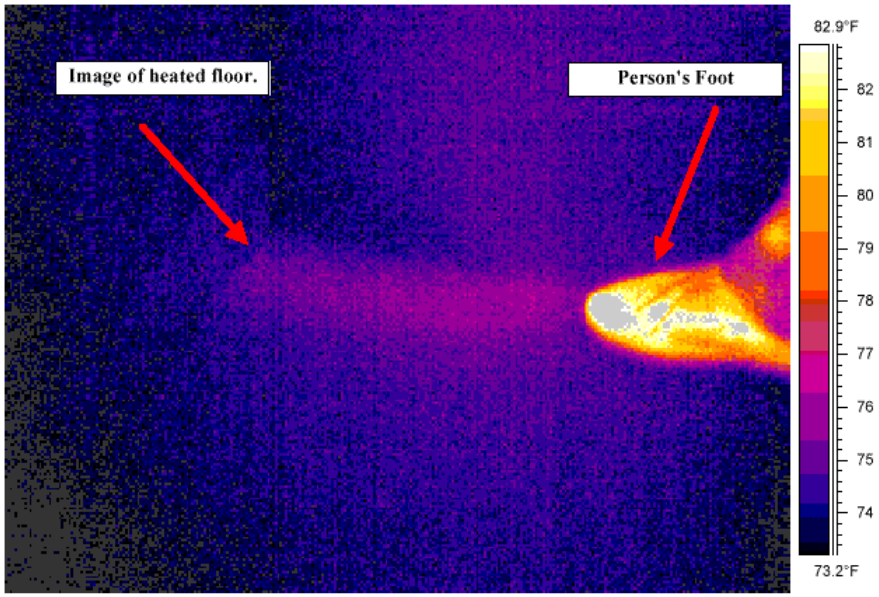
*Conakry / Nongo Compound / Generator Room / Main Distribution Panel*



Elevated temperature on a neutral wire caused by loose connection. IR image on right is after repair - tightening of connection

*Praia / Ambassador's Residence / Pantry*




Blocked drain pipe underneath concrete floor. Blockage was located through thermal contrast minimizing excavation area.

# Potential Failures Detected in 50% of the Buildings/Areas Inspected in Conakry

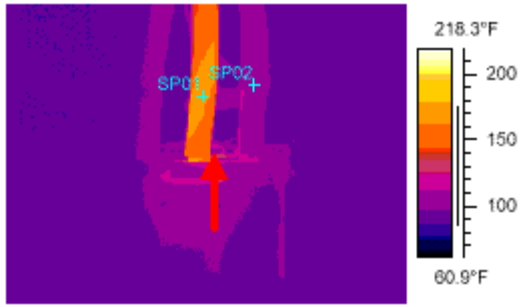
## Chancery Transfer Switch

Repaired in 5 Hours on Weekend
With Minimum Disruption To Post

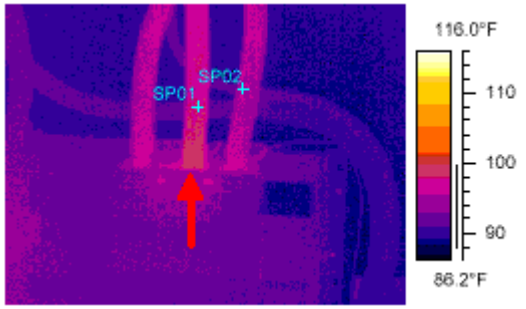
- Over half of the items detected in Conakry were corrected before the Thermographer left Post.

***10 of the 13 Buildings/Areas at Praia, Cape Verde, had thermography finds (potential failures).***

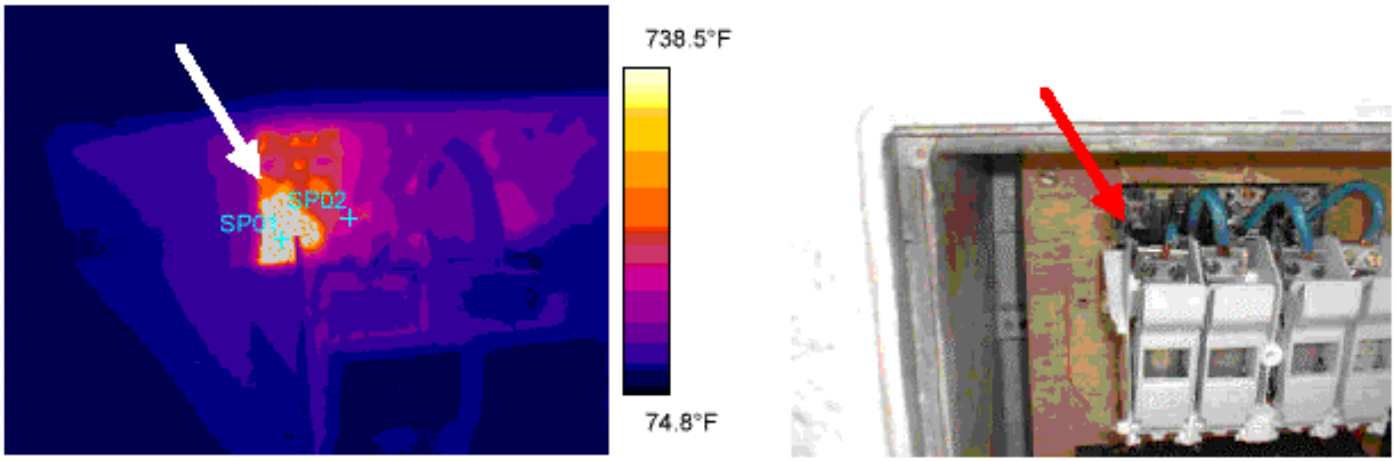
**Before: Phase B**
**Approximately 170 F**




**After: All Phases**
**Approximately 100 F**



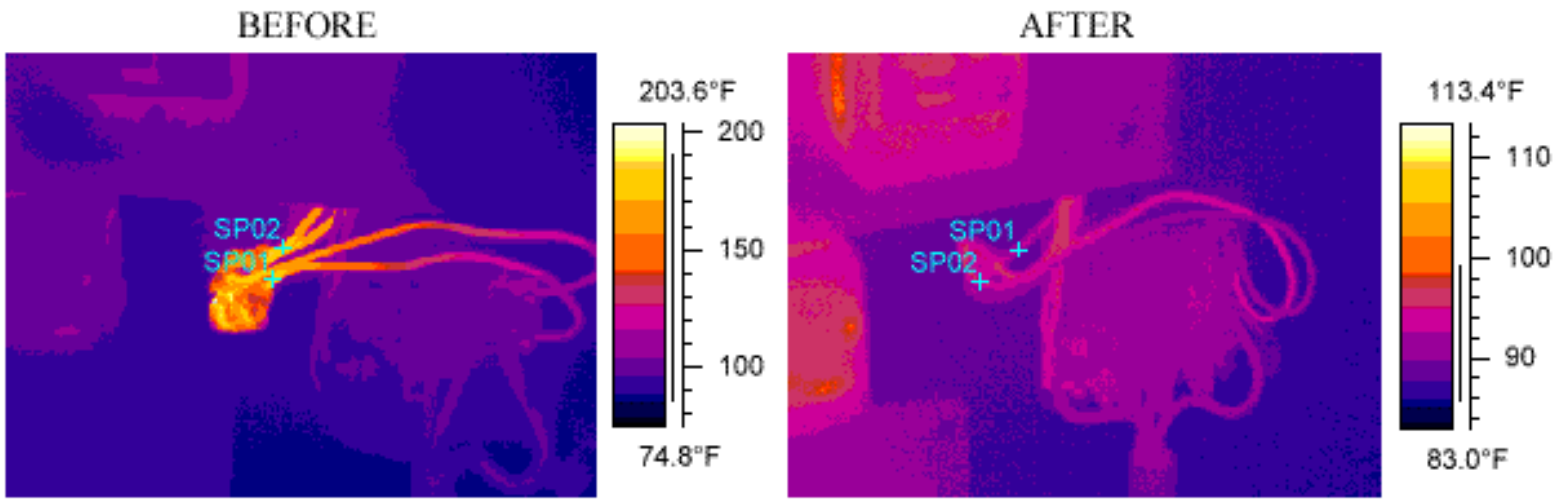
# Abidjan - Residence, Outside Gate Meter House




" …extremely elevated temperature … notified the Post FMS… residence put on generator power until the problem is solved."

*- From thermographers report, April 1999.*

# Abidjan - Residence, Distribution Connector



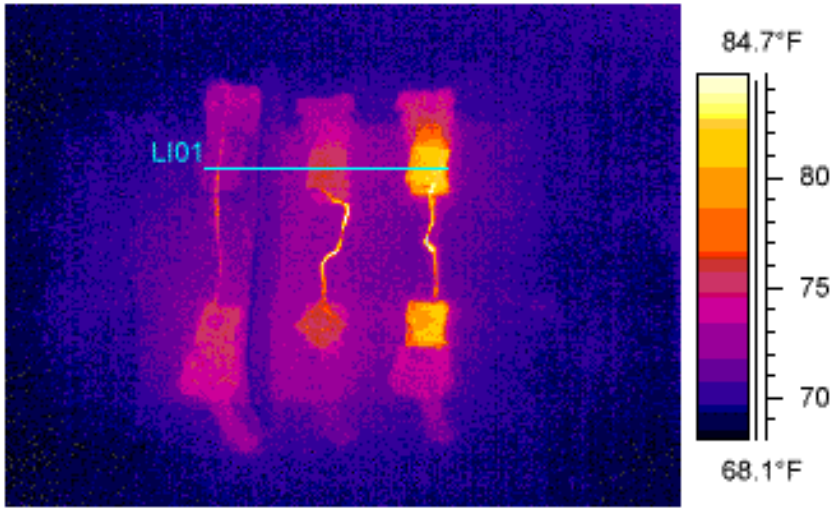

**Spot temperature approximately 175 F.**

**Spot temperature approximately 95 F.**

" …were two separate phases that had melted together … GSO electricians remade the connection… elevated temperature cleared."

*- From thermographers report, April 1999.*

# Dakar - Residence, Fuse




Post is planning to replace fuse wire with a fuse box.

*- From thermographers report, March1999.*

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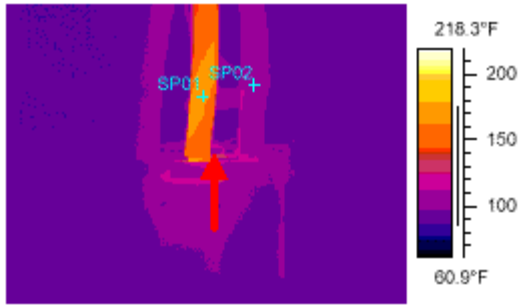
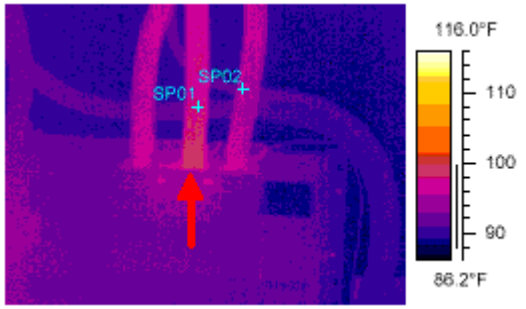
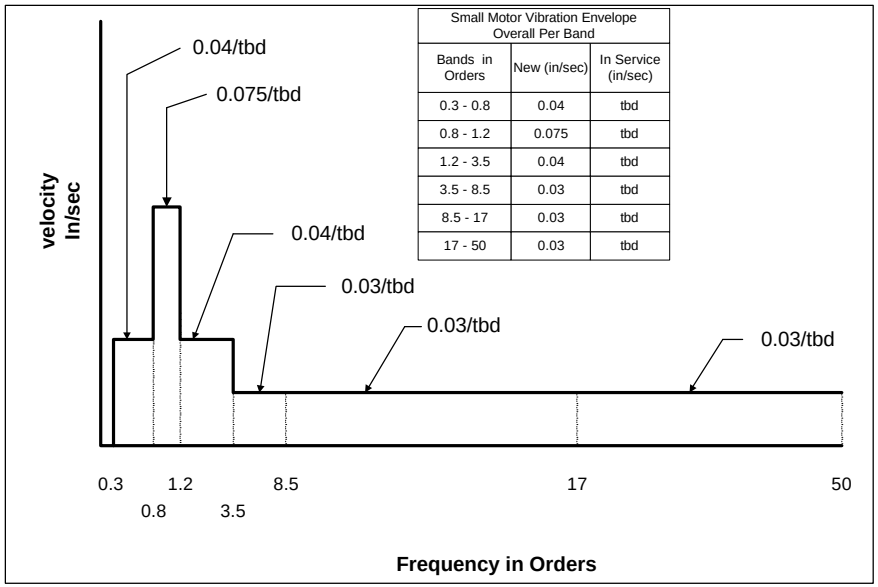



**After: All Phases**
**Approximately 100 F**



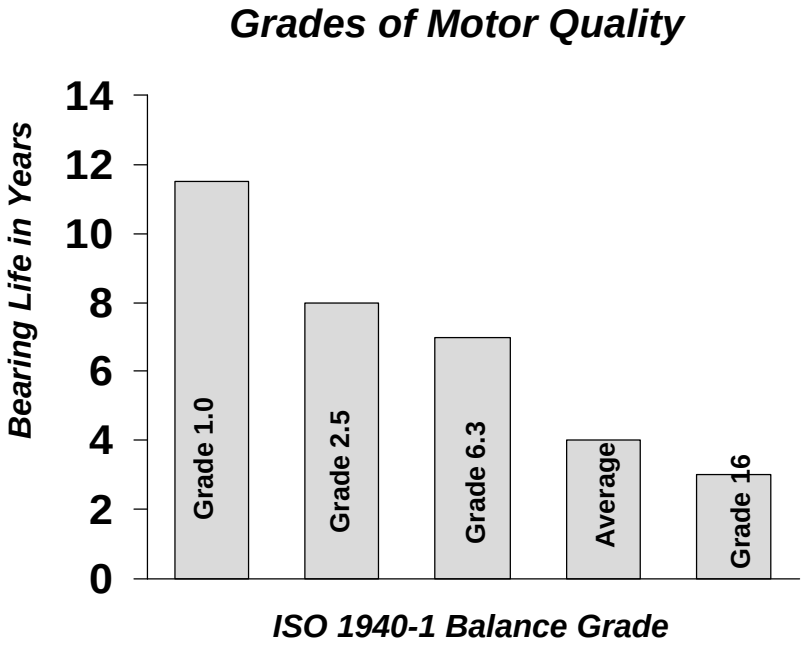
# Vibration Acceptance

- **Used to verify balance and alignment.**
- **Will be specified in bands.**
- **Will require test equipment that is capable of performing measurements.**



# Singapore NOB Inspection Identified:

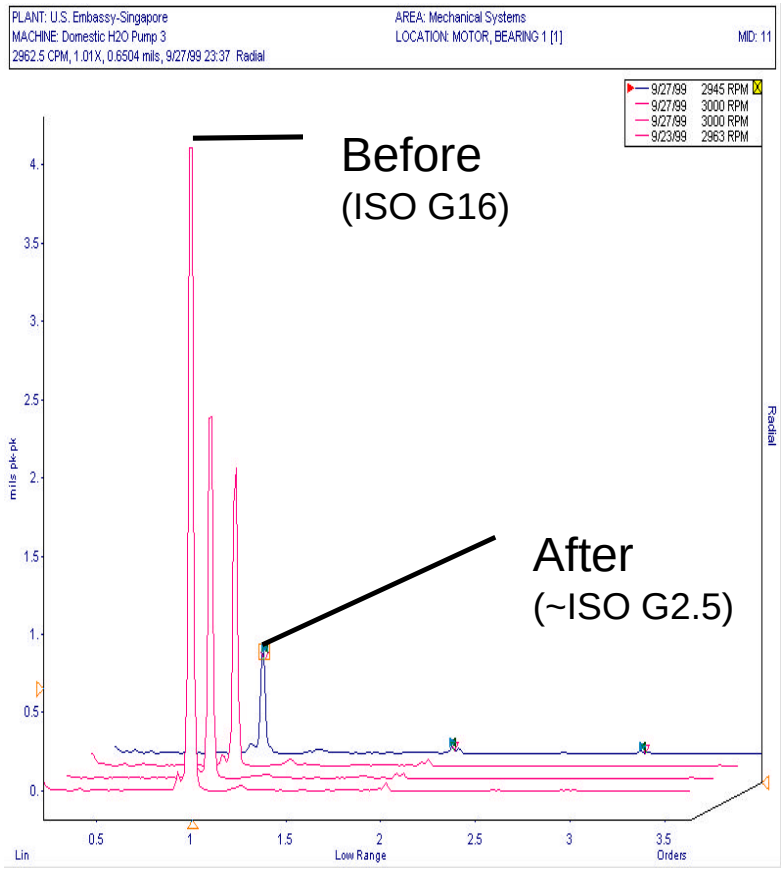
- All HVAC pumps were misaligned at installation
- All HVAC pumps had inadequate shims
- 90% of HVAC fans had improper sheaves specified and installed
- 80% of all fans tested had excessive vibration
- All fan vibration problems were traceable to balance and/or sheave problems
- 2 out of 3 Vertical pumps had extreme vibration caused by imbalance




Source: "Balanced Parts, Waking to Reality", SMRP Winter Newsletter, M. Span, Champion International, Pensacola, FL

***These findings are consistent with NASA, NSA, and others prior to RCM implementation.***

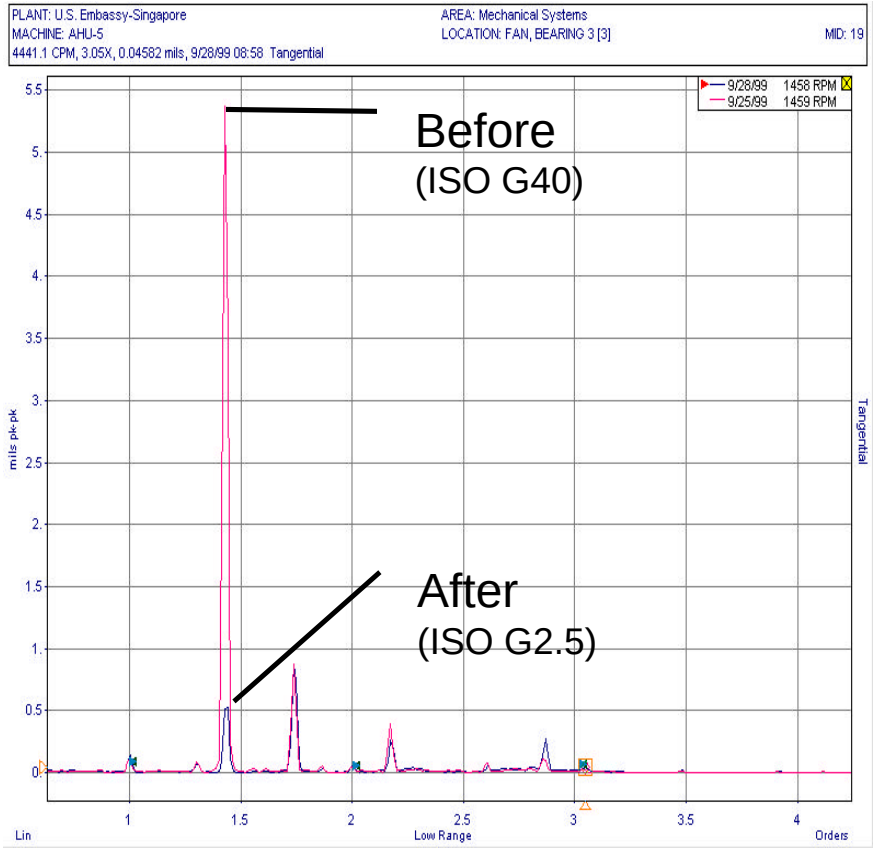
# Singapore Pump Vibration, Before & After Balancing




Pump Vibration

Domestic $H_2O$ Pumps

# Singapore Fan Vibration, Before & After Balancing




Fan Vibration

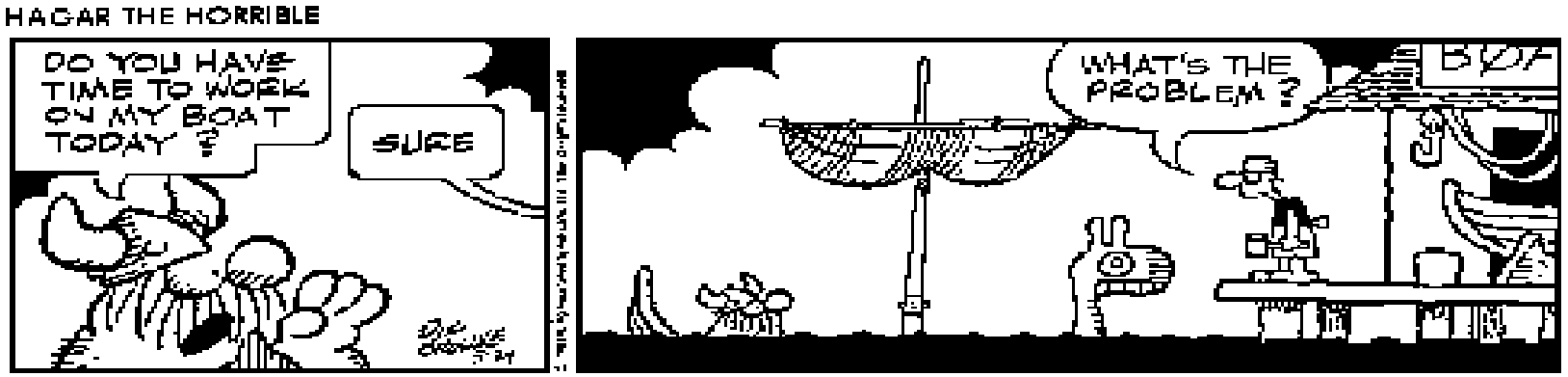
Fan

# AEDG and RCM Process

| RCM Process | AEDG Reliability and Maintainability | Compliant (Y/N) | Comments |
|---|---|---|---|
| The RCM process seeks to attain the required building and system availability at the lowest Life Cycle Cost (LCC) while meeting all standards for Security, Environmental Health and Safety and Mission requirements.<br><br>The RCM process is to be incorporated into all designs. | 3.1.3 Design Policy "….The concept of whole-building performance shall be incorporated into the design so that a balance between function, security, safety, environmental, energy, and operational factors is achieved. Sensitivity to economic costs of a building's initial construction and life-cycle operations shall reflect a commitment to providing high standards of comfort, productivity, and quality of life for its occupants."<br>4.4.1 Design Scope "..define design, construction, operation, and maintenance requirements for the Project."<br>4.4.16.1 O&M Design Guidelines "…It is during the design phase that operations and maintenance (O&M) considerations must be first addressed | | |

# Proactive Maintenance

**Proactive Maintenance is defined as the application of PT&I during the design, procurement, installation, and operation phases of facility construction and/or repair, the use of Root Cause Failure Analysis, Age Exploration, and the application of precision alignment and balancing during the Facility Life Cycle.**



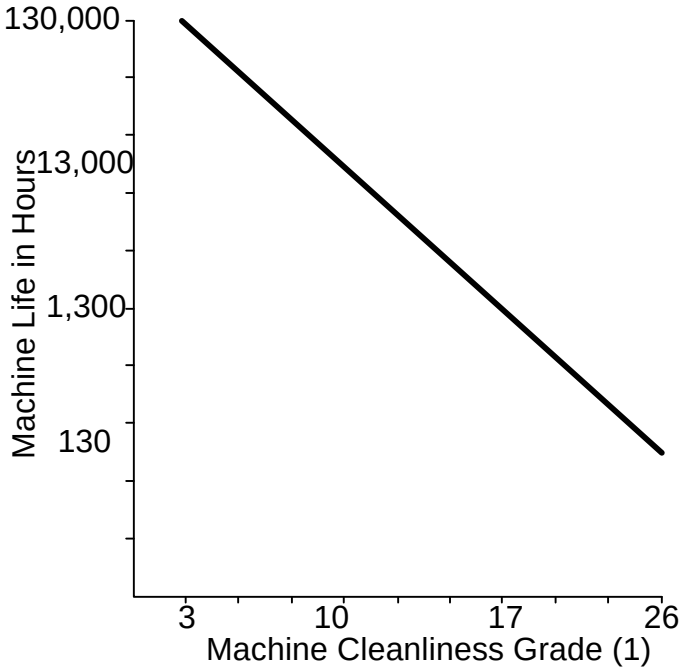

***We test drive cars, why not our facilities?***

# What is the Impact of...

- **Balance**
  - **Mechanical**
  - **Electrical**
  - **System thermodynamics**
- **Alignment**
- **Fluid cleanliness**
- **Electrical performance**
- **Mechanical integrity**

***Small differences in performance significantly increase Life Cycle Cost***

# Effect of Hydraulic System Contamination




**Notes:**

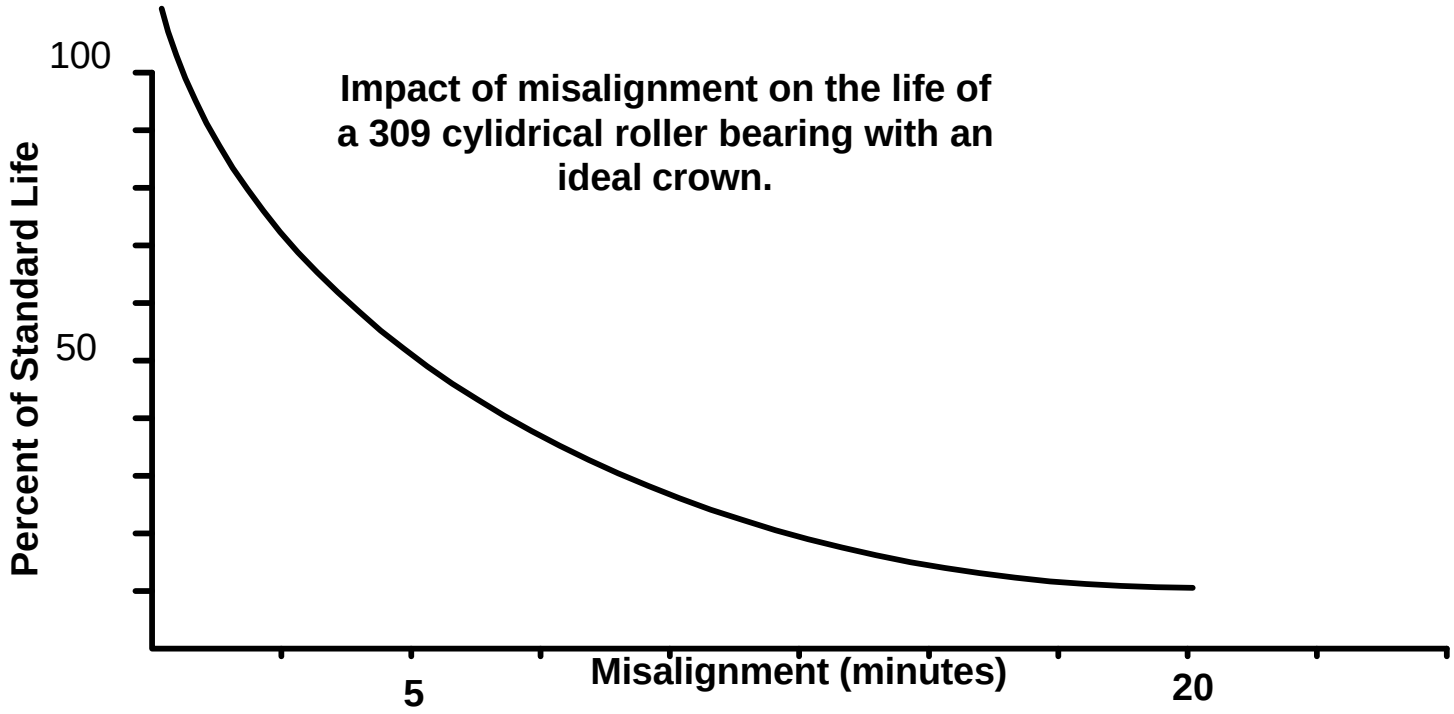
**1. ISO Code - 5 microns**

**2. Rec. ISO code 16/13, i.e., 320-640 particles > 5 microns and 40-80 particles > 15 microns.**

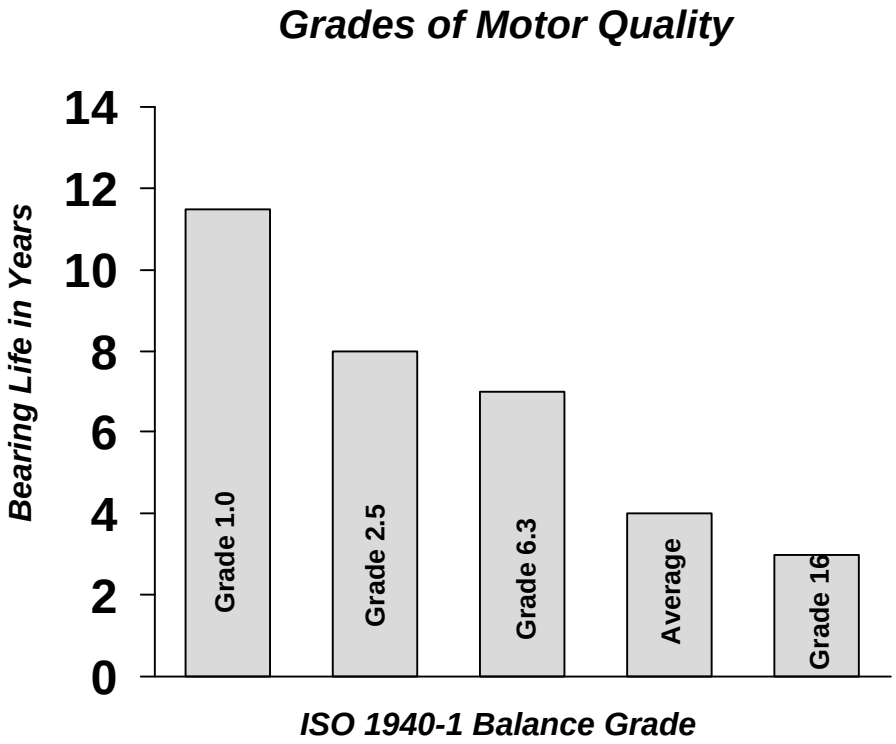
**3. Component annual costs were cut to $0 from $13K.**

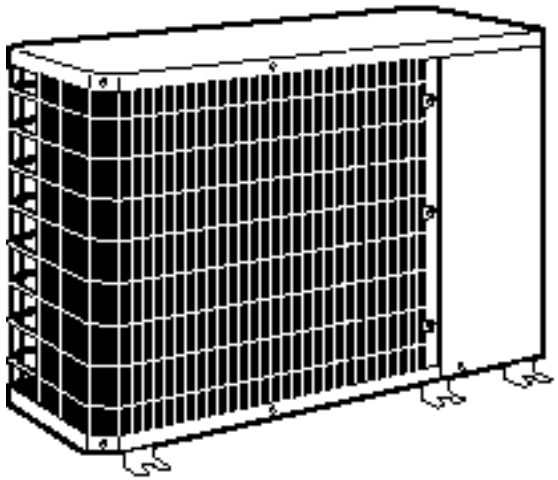
**Source: "Extending Hydraulic Component Life at Alumax of South Carolina", J. Mayo and D. Troyer, Reliability Magazine, Jan 1995**

# Effects of Misalignment



# By not Addressing Motor Specifications We are Potentially Forgoing 2/3 of Motor Life



Source: "Balanced Parts, Waking to Reality", SMRP Winter Newsletter, M. Span, Champion International, Pensacola, FL

***Which motor do we buy with current specifications?***

# Impact Of Voltage Imbalance

- **"A modest phase imbalance of 2% can increase losses by 25%."** Nadal, et al, Energy Efficient Motor Systems, 1991
- **"A 3.5% voltage imbalance can produce as much as a 25% increase in temperature rise of at least part of the winding."** Handbook to Assess the Insulation Condition of Large Rotating Machines, EPRI, 1991
- **"Excess heat generation in a motor running on a 2% unbalance can reduce insulation by a factor of 8."** Energy Efficient Electric Motors: Selection and Application, 1982

# Sample Motor Specifications

- **Max 5% Inductive Reactance in any one phase vs average of all phases.**
- **Max 3% voltage drop due to resistance imbalance.**
- **Min of 500 Megohm insulation resistance.**
- **Polarization Index (IEEE) of 3.**
- **Rebuild - core loss: none. (EASA tech note 17 - Oct 1992)**
- **Balance : ISO Grade G1.0 (ISO 1940/1)**
- **Flat feet within 0.005 (IEEE 841-1994)**
- **Sound power level less than 80dBa (IEEE 85 for measuring).**
  - **Also expected for any rotating machine.**

***Information from paper presented at the 6th Annual Predictive Maintenance Technology Conference (1994) and printed in P/PM Technology, Volume 8, Issue 4 - August 1995, Developing Corporate Standards and Specifications, Page 68 - 75.***