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# Report of Results of Nuclear Power Plant Aging Workshops

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Prepared by
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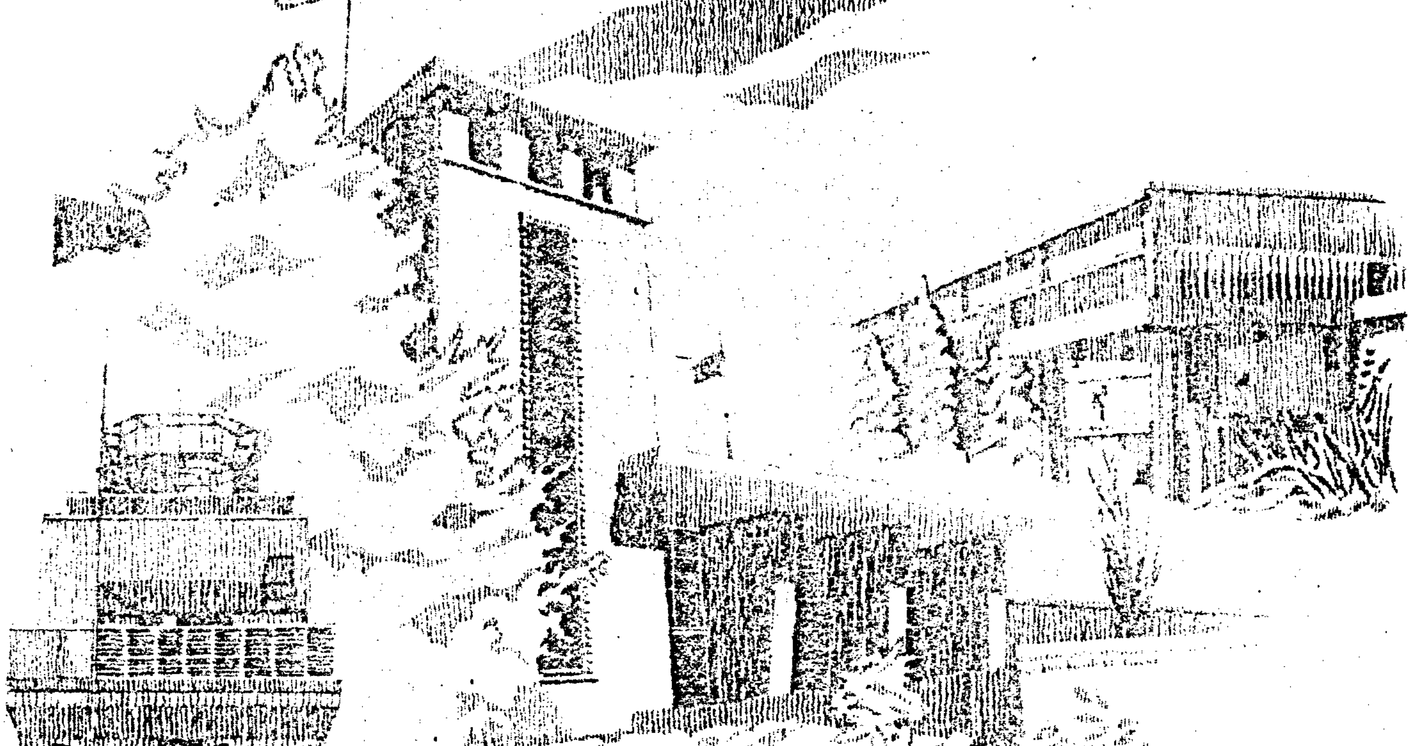

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# REPORT OF RESULTS OF NUCLEAR POWER PLANT AGING WORKSHOPS

N. H. Clark and D. L. Berry

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Albuquerque, NM 87185
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## Abstract

Two workshops were conducted to identify whether there is any evidence of component or structural aging problems in nuclear power plants, and, if so, what problems are of greatest importance. Fifteen representatives from national laboratories, architect/engineers, nuclear steam supply system vendors, research firms, and a university participated in the workshops. Based on completed questionnaires and group discussions which screened over 112 components believed to be susceptible to excessive aging, pressure/temperature sensors, valve operators, and snubbers emerged by consensus as the most important aging issues. Potential aging problems related to off-normal common mode effects or aging problems which are just now developing were found to be outside the scope of the workshops, because little or no first hand experience is available for these off-normal or yet to develop circumstances. Recommendations are made for a systematic approach to rate components in terms of overall safety and for a cooperative effort between industry research groups and regulatory research groups to resolve known aging problems and to identify off-normal or yet to develop aging issues.

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# Introduction

Several research efforts are being pursued by the United States Nuclear Regulatory Commission (NRC) and industry to investigate time-related degradation (or aging) of nuclear power plant safety components. Most of this work was started because of some well known type of aging mechanism (e.g., neutron embrittlement of pressure vessels) or because of problems that have manifested themselves as equipment failures (e.g., steam generator tube degradation). There is a concern that other types of aging problems may be developing as nuclear power plants get older, and that some aging problems could eventually impact power plant availability or safety.

The workshops described in this report were conducted to help identify whether there is any evidence of aging problems, and if so, what issues are of greatest importance.

The report is organized in three sections: (1) Objectives of the Workshops, (2) Organization and Running of the Workshops, and (3) Findings and Observations from the Workshops.

## Objectives of the Workshops

The primary objectives of the workshops were to identify if there is any evidence of aging problems and if so what aging issues are of the greatest importance. In order to meet these objectives, the workshop participants were asked to answer four basic questions:

(1) What are believed to be potential aging problems in nuclear power plants?

(2) What is the relative ranking of the problems in terms of their impact on safety and what is the basis for the ranking?

(3) What has been or could be done to detect, prevent and cope with significant aging issues?

(4) What is the best mechanism to address and solve each problem?

The primary result of meeting these objectives was a list of components that merit concern as aging issues.

## Organization and Running of the Workshops

Since the goal of the workshops was to identify aging issues for an entire nuclear plant, twelve participants covering a wide range of backgrounds were chosen to work with the organizers of the workshops from Sandia. The participants came from utilities, nuclear steam supply system vendors, architect/engineering firms, universities, national laboratories and consultants. Their backgrounds included material science and phenomena, power plant systems, power plant operations, and structural, electrical and mechanical engineering. A list of the participants is included in Table 1.

Because of the volume of material to be covered, two separate workshops were held. The first workshop addressed the first two basic aging questions:

1. What are believed to be potential aging problems, and

2. What is the relative ranking of the problems in terms of their impact and what is the basis for the ranking?

The second workshop extended the findings of the first workshop and addressed the third and fourth aging questions:

3. What has been or could be done to detect, prevent and cope with significant aging issues, and

4. What is the best mechanism to address and solve each problem?

In order to use the workshop participants' time most effectively, a structured questionnaire was sent to each person before the first workshop. (The questionnaire is included as Appendix 1). Each participant completed the questionnaire before the first workshop. The results of the individual questionnaires were then compiled. The compilation resulted in a list of 112 components which the workshop participants believed to be susceptible to aging problems (Appendix 2). The first workshop involved two days. On the first day each participant used a set of 10 questions (Table 2) to guide him in rating the 112 components in terms of their overall importance. The participants were also asked to judge which five of the ten questions they felt were of the greatest importance to aging issues and which five questions they were most knowledgeable answering. The summary of those results can be seen in Table 3.

Using the ratings of overall importance, the 112 component issues were ranked by the workshop participants. Based on a compilation of the ranking results, 14 generic types of components receiving the highest percentage of votes were selected for further review at the second workshop (Table 4). In addition, discussions were held at the first workshop to speculate on the importance of other component aging issues not listed with the original 112. This resulted in a supplementary group of new issues for consideration at the second workshop. Before the second workshop, the compilation of 14 generic types of components was sent to each workshop participant to consider the final two basic aging questions.

At the second workshop for each of the 14 generic issues, a table was developed that listed first how one detects each issue and second how one prevents/copes with/handles each issue. The resulting table is shown in Appendix 3. For each of the speculative issues identified during the first workshop as going beyond the 14 generic component types, a five minute brainstorming session was conducted to solicit comments and recommendations. Using the results of these sessions, plus the written input provided by some participants, Appendix 4 was developed which lists each speculative issue, some pertinent comments on each issue, and an assessment of the perceived importance of the issue.

As a final step at the second workshop, each participant was asked to rate the safety importance of each of the 14 generic safety issues as high, medium or low. For those issues which a participant rated high, he was asked to state a reason and to suggest a mechanism for resolving the issue. The results of that rating are included in Table 5. If one looks at only those issues which have a high number of "high" ratings only three components (pressure/temperature sensors, valve operators and snubbers) are of most importance.* If one looks at the data concerning a mechanism for resolving each aging issue, it appears there is no consensus. For each issue, at least three different mechanisms have been suggested.

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*Steam generator tubes, BWR stainless steel pipe cracking, radiation induced embrittlement have been excluded from consideration here because of the already high level of research and engineering attention which these issues are receiving.

## Findings and Observations from the Workshops

The workshops identified a wide range of components (as evidenced by the 112 components listed in Appendix 2) whose aging may affect plant safety. Using the ranking technique of the workshops, three components emerge as the most important aging issues (pressure/temperature sensors, valve operators, and snubbers).

There are several observations to be made before one states that the three components identified are in fact the most important ones.

1. Although the participants did not feel knowledgeable about systems safety, most felt that aging problems relating to component effects on safety systems are most important. Despite this feeling, however, there is a concern that participants, knowledgeable about components and component problems, may be expected to rate particular components as important simply because of an awareness of component troubles, not necessarily because of the overall safety significance of the components.

2. Most participants considered aging in terms of how it can affect the performance of a component's normal operation. However, during any off normal conditions such as a loss of coolant accident or earthquake, aged components that may meet performance specifications for normal conditions may fail. The major concern here is that a common-mode type failure could occur.

3. Component aging issues identified as important, also appear to be well known, as evidenced by the fact that some aging work could be cited for most of the components listed in Table 5. Since these components are known to be troublesome, utilities should be taking steps on their own to prevent them from being a safety issue.

4. The priorities were identified by a method of the participants voting. A real concern is that a problem which has been seen only once or twice and thus is not now of general concern may not receive a proper rating because of lack of knowledge by the participants of the potential significance of this one failure.

Based on these observations, several recommendations on work that should be done can be made.

1. Work should be done to provide utilities and regulators a systematic approach to rate components in terms of overall safety system significance.

2. Work should be done to see if the aging of components affects safety differently under accident conditions as compared to normal operating conditions.

3. Work should be done to evaluate the importance of failures that have only been seen once or twice.

4. Work should continue on the three components (pressure/temperature sensors, valve operators, and snubbers) identified by the participants as important to safety until a better system is identified to rate safety importance.

5. Work should continue to assure that utilities are in fact taking steps to insure that components that are known to be potential aging concerns are adequately being handled by utilities.

The workshops not only concerned themselves with what work needs to be done, but who is best qualified to do that work. Table 5 shows recommendations by the group of who should resolve a specific concern. It is clear that no one group can solve all concerns, but that each concern must be carefully analyzed and then industry, vendors, utilities and NRC must work together to develop an appropriate solution. The recommendations of work that should be done are all of the nature which require cooperative efforts as well.

In some cases, for example insuring known aging concerns are adequately being handled, an industrial utility standards group may take the lead to resolve the concerns. In other cases, such as evaluating the importance of failures that have only been seen once or twice or seeing if aging of components affects safety differently under accident conditions a lack of immediate economic return to industry may dictate the need for NRC to play an active role in resolving the concern.

Finally, work of the sort that has broad uses for both industry and the NRC, such as providing a systematic approach to rate components in terms of overall safety and work on components already identified as potential concerns, might best be resolved with cooperation between an industry research group such as EPRI and the NRC research groups in the national laboratories.

Table 1

Workshop Attendees

| | |
|---|---|
| Bill Andrews[2] | Pacific Northwest Laboratories |
| Dennis Berry | Sandia National Laboratories |
| Lloyd Bonzon | Sandia National Laboratories |
| Sal P. Carfagno | Franklin Research Center |
| Nancy Clark[2] | Sandia National Laboratories |
| William G. Conn | Burns & Roe |
| Jim Donovan | University of Massachusetts |
| John H. Ferguson[1] | Connecticut Yankee Atomic Power Company |
| Jerry Glazman | Combustion Engineering |
| Pat Higgins | General Electric Company |
| Bob Kennedy | Babcock & Wilcox |
| George M. Langford | Bechtel Power Corporation |
| Dinker Mehta | Burns & Roe |
| George Murphy | Oak Ridge National Laboratory |
| Bobby A. Terwilliger | Arkansas Power & Light |
| John W. Wanless | NUS Corporation |

1. Attended 1st workshop only.
2. Attended 2nd workshop only.

Table 2

Component Ranking Questions

1. Have examples of the problem been observed?
2. Is the problem potentially widespread?
3. Does or could the problem involve safety system components?
4. Can the problem jeopardize an entire safety function?
5. Is the resulting component degradation rapid?
6. Can the problem occur with little or no warning?
7. Can the problem escape current T&M practices?
8. Can a frequently challenged safety function be affected?
9. Can the problem result in common-mode failure during design-basis events?
10. Is little or no work being done to address the problem?

Table 3

The Six Component Questions Judged to be of Greatest Importance to Aging Issues and the State-of-Knowledge of the Voters[1]

| | Importance | State-of-Knowledge |
|---|---|---|
| 1. Can the problem jeopardize an entire safety function? | 10 | 2 |
| 2. Can the problem escape current T&M practices? | 8 | 5 |
| 3. Does or could the problem involve safety system components? | 8 | 7 |
| 4. Can the problem result in common-mode failures during design-basis events? | 8 | 4 |
| 5. Is the problem potentially widespread? | 6 | 6 |
| 6. Can the problem occur with little or no warning? | 6 | 8 |

[1]Based on the number of people who rated questions as the five most important questions and the five questions they felt most comfortable answering based on their State-of-Knowledge. Because of a tie between the questions rated 5 and 6, the overall six highest rated questions are listed here.

Table 4

List of Generic Components

| | Questionnaire Item # (From Appendix 2) | Component | Actual or Potential Failure Mode | Observed or Suspected Fundamental Cause of Failure | Observed or Suspected Aging Environment or Aging Problems |
|---|---|---|---|---|---|
| 1. | 2,32,44,62, 87,91 | Pressure/temp sensors | Decalibration | Mech. aging of bellows, springs | Vibration, connector cabling degradation |
| | | | Insufficient/ no output | Binding | Waterhammer |
| | | | | Electronics drift or sensor degradation | Thermal degradation, voltage transients, impurity introduction |
| | | | | Brittle connector | High temperatures |
| | | | Open circuits | Set point drift | High temperatures |
| | | | Decalibration | Moving parts wear | |
| 2. | 11,30,90 | Electrical connectors/ | Open circuit | Oxidation of contact surface | Normal cabinet environment |
| | | Terminal blocks | Spurious response | Tracking (carbonizing) | Dirt/dust/salt |
| | | | Open circuit | Worn screws and parts | Too much surveillance |
| 3. | 15,33 | Valves/solenoid valves | Seat leakage | Wear and wire drawing | Normal design environment |
| | | | Hampered operation | Flow blockage | Oil in airline, failure of seals |

Table 4 (Con't)

| | Questionnaire Item # (From Appendix 2) | Component | Actual or Potential Failure Mode | Observed or Suspected Fundamental Cause of Failure | Observed or Suspected Aging Environment or Aging Problems |
|---|---|---|---|---|---|
| 4. | 16,39,50,80 | Valve operators | Function impaired | Hardening of lubricant, pneumatic seal failure | Normal design environment |
| | | | Loosening of components | Spring type lock washers allow chafing of surfaces and loosening bolts | Vibration |
| | | | Excessive torque | Packing too tight | Overtightening to handle leaks |
| | | | Failure to operate | Lubricant hardens | Temperature variations |
| 5. | 28,35,36,40, 53,54,68 | Switch/relay/ circuit breaker | Open circuit | Fatigue of spring | Vibration |
| | | | Failure to trip | Grease binding | Normal design environment |
| | | | | Wear-induced friction | Lack of periodic lubrication |
| | | | Opening/clogging wrong contacts | Cam wear and coupling wear | Normal design environment |
| | | | Failure to operate in required time | Fatigue of spring | Wear/dirt impartment |
| | | | | Pitting/thinning of contacts | Environment corrosion of voltage areas |
| | | | Spurious response | Binding | Dirt/dust |
| 6. | 29,92 | Diesel generator | Piping failure | Cracking | |
| | | | Structure failure | Wear | |
| 7. | 46,47,103 | Motors/pump motors | Bearing failure of pump | Wear | High temperature wear |
| | | | Insulation failure | Turn-to-turn short | Thermal/voltage degradation |

Table 4 (Con't)

| | Questionnaire Item # (From Appendix 2) | Component | Actual or Potential Failure Mode | Observed or Suspected Fundamental Cause of Failure | Observed or Suspected Aging Environment or Aging Problems |
|---|---|---|---|---|---|
| 8. | 48 | Transformers | Insulation failure | Turn-to-turn short | Thermal/voltage degradation |
| 9. | 49/55 | Cables | Insulation failure | Short to ground | Corrosive fluids<br>Voltage stress |
| | | | Strand breakage | Open circuit | Vibration, corrosion at interface, temperature cycles, radiation |
| 10. | 51 | Snubbers | Leakage or nonfunction | Seal embrittlement or blockage | Thermal/radiation/overstress |
| 11. | 58,75,83 | Piping | Leakage | Wall thinning | Erosive silt in water |
| 12. | 66 | Steam generator tubes | Leakage | Denting, cracking | Chemistry-induced corrosion |
| 13. | 67 | Relief valves | Leakage | Erosion | Normal design conditions |
| 14. | 26 | Concrete/anchors tendons | Loss of pretension | Inadequate torque, grout creep | Vibrations, excess stress |

Table 5

Rating of Generic Component Issues

| COMPONENT | R&D PRIORITY High | Medium | Low | REASONS FOR HIGH PRIORITY | WHO SHOULD DO R&D? |
|---|---|---|---|---|---|
| 1. Pressure/Temp Sensors | 8 | 3 | 0 | a. Need to fundamentally understand drift limits, need historical data | a. EPRI and National Labs |
| | | | | b. Need to assess if they will function under additional adverse conditions that come from TMI and Appendix R | b. Industry with EPRI assistance |
| | | | | c. LER experiences and common-mode failure potential | c. NRC/National Labs/ sometimes owners or users groups |
| | | | | d. Wide use in plants and safety systems | d. EPRI or NRC with vendor/ industry involvement or utilities by use of incentives and/or INPO |
| 2. Electrical connectors Terminal Blocks | 3 | 3 | 5 | a. Often composed of age sensitive materials whose life is short compared to plant life | a. Industry program coordinated by National Labs or EPRI |
| | | | | b. Ubiquitous use, failures seen in LER's and common mode failure potential | b. NRC/AE/National Labs and manufacturers |

Table 5 (Con't)

| COMPONENT | R&D PRIORITY High | Medium | Low | REASONS FOR HIGH PRIORITY | WHO SHOULD DO R&D? |
|---|---|---|---|---|---|
| 3. Valves/Solenoid | 3 | 7 | 1 | a. Elastometric components do not meet environmental aging demands | a. EPRI/industry |
| | | | | b. Large numbers of systems sensitive to their failure and failure not apparent until too late | b. Manufacturers with industry group or National Labs |
| | | | | c. Maintenance problems | c. Utilities |
| 4. Valve Operators | 7 | 4 | 0 | a. Need to develop packing standards-specs./quality control | a. EPRI |
| | | | | b. Concerned about heat and temperature degradation of lubricant, packing, etc. | b. Utility/manufacturer |
| | | | | c. Large numbers of systems sensitive to their failure and failure not apparent until too late | c. Manufacturers with industry group or vendor with EPRI that could result in IEEE Standards |
| | | | | d. Significant number of problems seen | d. Utilities |
| 5. Switch/Relay/ Circuit Breakers | 4 | 6 | 1 | a. Possible safety concern | a. Manufacturers/industry or utilities via incentives and/or INPO, vendors, consultants |

Table 5 (Con't)

| COMPONENT | R&D PRIORITY High | R&D PRIORITY Medium | R&D PRIORITY Low | REASONS FOR HIGH PRIORITY | WHO SHOULD DO R&D? |
|---|---|---|---|---|---|
| 6. Diesel Generator | 4 | 3 | 4 | a. Problem real and related to safety | a. DG manufacturers and owners group/EPRI or industry/NRC |
| 7. Motors/Pump Motors | 2 | 6 | 3 | a. Need to establish standards for lubrication and relationship to wear | a. EPRI/pump vendors |
| | | | | b. Need to quantify and specify testing | b. ASME with EPRI |
| 8. Transformers | 0 | 3 | 8 | a. No reason given | |
| 9. Cables | 3 | 4 | 4 | a. Need test specifications to predict failure | a. NRC driven |
| | | | | b. Potential of common-mode failure and ubiquitous use | b. NRC/National Labs/manufacturers |
| 10. Snubbers | 5 | 6 | 0 | a. Cause of failures not established | a. EPRI |
| | | | | b. Potential for common-mode failure | b. EPRI |
| | | | | c. Need to establish technical basis for seal replacement or select new seal materials | c. National Labs |
| | | | | d. Significant known problems | d. Snubber manufacturers |

Table 5 (Con't)

| COMPONENT | R&D PRIORITY High | Medium | Low | REASONS FOR HIGH PRIORITY | WHO SHOULD DO R&D? |
|---|---|---|---|---|---|
| 11. Piping | 1 | 4 | 6 | a. Continue to develop leaks/cracks that could not be predicted | a. Research organization such as EPRI with vendors, manufacturers, and utilities |
| 12. Steam Generator Tubes | 7 | 2 | 2 | a. Economic concerns | a. Owners group/EPRI |
| | | | | b. Widespread problem that has significant impact on plant operability | b. NSSS Suppliers with EPRI |
| 13. Relief Valves | 4 | 5 | 2 | a. Known drift off set points and leakage | a. Manufacturers and NRC/ASME |
| | | | | b. Problem is widespread/few valves function properly | b. Manufacturers with industry group or National Labs |
| | | | | c. Affects primary safety, TMI experiences, known to leak, and the need for appropriate testing and design specification | c. EPRI/Manufacturers NRC/National Labs |
| 14. Concrete Anchors | 0 | 2 | 9 | No reasons given | |

# APPENDIX 1

## SAMPLE QUESTIONNAIRE

## QUESTIONNAIRE

| Component | Actual or Potential Failure Mode | Manner of Discovery | Observed or Suspected Fundamental Cause of Failure | Observed or Suspected Aging Environment or Aging Problems | Comments |
|---|---|---|---|---|---|

QUESTIONNAIRE (HYPOTHETICAL EXAMPLES)*

| System | Component | Actual or Potential Failure Mode | Manner of Discovery | Observed or Suspected Fundamental Cause of Failure | Observed or Suspected Aging Environment or Aging Problems | Comments |
|---|---|---|---|---|---|---|
| HVAC | High pressure injection pump room unit cooler | Insufficient output | Failure during operation | Air flow blockage through cooler | Dirt/dust | ---- |
| Component Cooling Water | Piping | Pressure boundary | Routine walk through | Wall thinning | Liquid Erosion | High flow rate |
| Component Cooling Water | Heat exchanger | Insufficient output | Operational parameter change ( T) | Poor heat transfer coefficient | Corrosive service water | Organic growth buildup |
| Emergency DC | MCC's for low pressure injection valves | Delayed response | Routine testing | Binding of switches | Corrosive vapors | Salt moisture in air |
| Service Air | Air compressor foundations | Foundation failure | Special surveillance | Cracking of concrete | Vibration | ---- |
| Emergency AC | Cabling | Insufficient Fire Protection | Routine maintenance | Cracking of fire retardant coating | Insufficient moisture and high temperatures | Coatings separated from cabling |
| HVAC | Fire damper | Insufficient fire protection | Special surveillance | Binding of damper | Dirt/dust | ---- |

*QUESTIONNAIRES NEED NOT BE TYPED

EXAMPLES OF PWR SYSTEMS

AUXILIARY FEEDWATER SYSTEM

HIGH PRESSURE COOLANT INJECTION

CHEMICAL AND VOLUME CONTROL SYSTEM

LOW PRESSURE COOLANT INJECTION SYSTEM

REACTOR PRIMARY COOLANT SYSTEM-PORVs and SRVs

SECONDARY COOLANT SYSTEM-RELIEF VALVES, BY-PASS VALVES, AND BLOCK VALVES

RESIDUAL HEAT REMOVAL SYSTEM

EMERGENCY AC AND DC POWER SYSTEMS

COMPONENT COOLING WATER SYSTEM

HVAC SYSTEM

INSTRUMENTATION AND CONTROL

SERVICE AIR SYSTEM

INSTRUMENT AIR SYSTEM

SERVICE WATER SYSTEM

CONTAINMENT SPRAY SYSTEM

CONTAINMENT HEAT REMOVAL SYSTEM

FUEL HANDLING SYSTEM

RADIOLOGICAL WASTE CONTROL SYSTEM

POWER CONVERSION SYSTEM

REACTOR PROTECTION SYSTEM

## EXAMPLES OF BWR SYSTEMS

REACTOR CORE ISOLATION COOLING SYSTEM

HIGH PRESSURE COOLANT INJECTION/SPRAY

EMERGENCY DIESEL GENERATOR SYSTEM

LOW PRESSURE CORE SPRAY

AUTOMATIC DEPRESSURIZATION AND RPV OVERPRESSURE PROTECTION SYSTEM

ESSENTIAL SPACE COOLING SYSTEM

RESIDUAL HEAT REMOVAL SYSTEM

EMERGENCY AC AND DC POWER SYSTEM

HVAC SYSTEM

INSTRUMENTATION AND CONTROL

SERVICE AIR SYSTEM

INSTRUMENT AIR SYSTEM

EMERGENCY SERVICE WATER SYSTEM

ISOLATION CONDENSERS

FUEL HANDLING SYSTEM

RADIOLOGICAL WASTE CONTROL SYSTEM

POWER CONVERSION SYSTEM

REACTOR PROTECTION SYSTEM

## EXAMPLES OF COMPONENTS OF CONCERN

Switchgear
Motor control centers
Valves
Valve operators
Motors
Logic equipment
Cable
Diesels
Diesel generator starting and control equipment
Sensors (pressure, pressure differential, flow, level, temperature, and neutron)
Limit switches
Heaters
Coolers
Fans
Control boards
Transformers
Instrument racks and panels
Connectors
Electrical penetrations
Splices
Terminal blocks
Equipment supports or foundations
Piping, orifices, flanges
Tanks
Heat exchangers
Ducting
Filters
Building structures or foundations
Cranes

## AGING-RELATED INFORMATION CATEGORIES FOR COMPONENTS

| Actual or Potential Failure Mode | Manner of Discovery | Observed or Suspected Fundamental Cause of Failure | Observed or Suspected Aging Environments or Aging Problems |
|---|---|---|---|
| Delayed response | Routine maintenance | Short circuits (inc. partial) | Radiation |
| Slow response | Routine walk through | Open circuits (inc. partial) | Excessive moisture |
| Premature response | Special surveillance | Binding | Insufficient moisture |
| Fast response | Failure on demand | Excessive free play | Corrosive liquids |
| Spurious response | Failure during operation | Cracking | Corrosive vapors/gases |
| Insufficient/no output | On-line diagnostics | Ductile failure | Abrasion (internal/ external) |
| Excessive output | Operational parameter change | Brittle failure | High temperatures |
| Pressuring boundary failure | Routine testing | Flow blockage | Low temperatures |
| Structure failure | Other | Wall thinning | Temperature cycles |
| Foundation failure | | Other | Liquid erosion |
| Other | | | Vapor/gas explosion (inc. steam) |
| | | | Material incompatibilities (e.g. lubricants) |
| | | | Galvanic effects |
| | | | Excessive test/maintenance cycles |
| | | | Dirt/dust |
| | | | Other |

# APPENDIX 2

## COMPILATION OF INDIVIDUAL RESPONSES TO QUESTIONNAIRES

## QUESTIONNAIRE RESPONSES

| | Component | Actual or Potential Failure Mode | Manner of Discovery | Observed or Suspected Fundamental Cause of Failure | Observed or Suspected Aging Environment or Aging Problems | Comments |
|---|---|---|---|---|---|---|
| 1. | Neutron sensors | Decalibration | Comparison/ calculations | Burnup/loss of gas/ unknown behavior in radiation | Misapplied/unknown correlation factors | |
| 2. | Press/temp sensors (RTD/TC) | Decalibration | Maintenance | Mech. aging of bellows/ springs/GDS | High freq. vibrations/ environment - connectors/ cabling degradation | |
| 3. | Analog amps. | Loss of function decalibration | Maintenance | Moisture/temp. of components | Degradation over time of noise filter capacitors common-mode susceptibility | |
| 4. | Digital comp. software | Decalibration | On-line test | Loss of response time | Fundamental changes in algorithm structure due to compounded changes in equipment response times | |
| 5. | Instrument ground grid | Common-mode faults | None | Station design changes on piecemeal basis | Addition of instrument without fundamental design review causes violation of good grounding practices | |
| 6. | Replacement parts | Do not meet design specs | Installation audit | Stress original designs now aged | Systematic upgrade of static documentation, replacement of obsolescence parts with "best available" | |
| 7. | High pressure injection water nozzle | Crack at pipe-to-valve weld | Visual | Low cycle fatigue (thermal) | Periodic temperature variation \|400°F | |
| 8. | Reactor vessel internal bolting | Crack under head | Visual and UT | Stress corrosion cracking | RC system | |
| 9. | Reactor coolant pump motor | Lubricating oil degradation | Oil examination | Air entrainment | Air pockets on lubricating surface resulted in excessive temp. | |

QUESTIONNAIRE RESPONSES (Con't)

| | Component | Actual or Potential Failure Mode | Manner of Discovery | Observed or Suspected Fundamental Cause of Failure | Observed or Suspected Aging Environment or Aging Problems | Comments |
|---|---|---|---|---|---|---|
| 10. | RC system letdown coolers | Primary to secondary side leakage | Increased radiation on secondary side | Low cycle fatigue (thermal) | Periodic start/stops of primary (RCS) flow | |
| 11. | Electrical connectors and contacts | Loss of plating material | Open circuit | Oxidation of contact surface | Normal electrical cabinet environment | |
| 12. | Decay heat system pump | Wear of close fit assembly surfaces | Visual | Maintenance (numerous disassembly activities) | Normal system environment | |
| 13. | Orifice | Erosion | High flow | High $\Delta P$ for extended period of time | Normal design environment | |
| 14. | Valve | Leaking packing | Visual | Hardens with age and extrudes with operation | Normal design environment | |
| 15. | Valve | Leaking seat | Visual or test | Wear and wire drawing | Normal design environment | |
| 16. | Valve operator | Function impaired | Improper response to manual/auto demand | Hardening of lubrication; pneumatic seal failure | Normal design environment | |
| 17. | Concrete structs. | Disintegration of concrete | Routine inspection | Freeze-thaw cycles | Weather changes | |
| 18. | Concrete structs. | Expansion and disruption of concrete | Routine inspection | Sulphate-cement reaction | Sulphates in groundwater | |
| 19. | Concrete structs. | Random (map) cracking | Routine inspection | High-alkali cement and aggregate reaction | Reactive aggregates (opaline silica coating on aggregate, silicious limestones, and rocks) | |
| 20. | Concrete structs. | Concrete spalling | Routine inspection | Corrosion of reinforcing steel | Salt and chloride pentr. | |

QUESTIONNAIRE RESPONSES (Con't)

| | Component | Actual or Potential Failure Mode | Manner of Discovery | Observed or Suspected Fundamental Cause of Failure | Observed or Suspected Aging Environment or Aging Problems | Comments |
|---|---|---|---|---|---|---|
| 21. | Concrete structs. | Abrasion | Routine inspection | Sand or gravel particles in flowing water | Suspended particles in flowing water | |
| 22. | Concrete structs. | Irregular, jagged, and pitted surface | Routine inspection | Cavitation damage caused by water flow | Flowing water | |
| 23. | Concrete structs. | Disintegration of concrete | Routine inspection | Leaching of calcium hydroxide by water leaking through joints and pores | Exposure to water | |
| 24. | Building struct. steel | Loss of structural integrity | Routine inspection | Corrosion of steel | Salt, moisture, and oxidizing agents | |
| 25. | Tendons | Loss of prestress | Routine in inspection walk-through | Failure of anchors, tendons, and accessories | Stress and general corrosion, fatigue loads, and time-dependent losses | |
| 26. | Concrete anchors | Loss of pretension | Routine inspection and walk-through | Vibrations and inadequate initial torque | Normal plant operation and inadequate constr. practices | |
| 27. | Epoxy product | Loss of structural integrity and adhesion | Product tests | Loss of structural strength | High temperature and radiation exposure | Suitable product testing minimizes |
| 28. | Control switch | Switch contacts inoperative | Failure during operation | Open circuits | Vibration | Fatigue failure of spring |
| 29. | Diesel generator | Structural failure | Routine testing | Cracking | Fatigue hardening | Cooling water jumpers from header failed |
| 30. | Terminal block | Spurious response | Failure during operation | Tracking (carbonizing) | Dirt/dust/salt | Junction boxes - connection points |

QUESTIONNAIRE RESPONSES (Con't)

| | Component | Actual or Potential Failure Mode | Manner of Discovery | Observed or Suspected Fundamental Cause of Failure | Observed or Suspected Aging Environment or Aging Problems | Comments |
|---|---|---|---|---|---|---|
| 31. | Penetration | Spurious response | Failure during operation | Short circuits | Radiation/moisture | Epoxy seal degraded |
| 32. | Sensor (pres. transmitter) | Insufficient/ no output | Operational parameter change | Binding | Waterhammer | Excessive pres. spikes distorted bellows |
| 33. | Solenoid valve | Pressure boundary failure | Routine maintenance | Flow blockage | Material incompatibilities | Oil in airline - failure of seals |
| 34. | RHR motor | Bearing and winding failure | Motor tripped during operation | Bearing failed causing winding damage and electrical failure | Pump-motor vibration is believed to have caused bearing failure | |
| 35. | Reactor trip circuit breaker | Failure to trip on undervoltage trip operation | Failure of special test | Aging of trip mechanism grease increased trip force requirement | Normal aging of grease used (mild environment) | |
| 36. | Reactor trip circuit breaker | Failure to trip on undervoltage trip operation | Failure in service | Mechanical wear and increased friction of latch components | Lack of periodic lubrication and maintenance | |
| 37. | ECCS pumps | Reduced output | Surveillance test | Impeller wear | Impeller wear from operation | |
| 38. | BWR feedwater and CRD nozzles | Stress corrosion cracking | In-service inspection (ISI) | Temperature shock from high frequency bypass flow cycling, followed by start-up/shutdown temperature swings | High frequency temperature swings initiate crack, start-up/shutdown swings propogate cracks | |

| | Component | Actual or Potential Failure Mode | Manner of Discovery | Observed or Suspected Fundamental Cause of Failure | Observed or Suspected Aging Environment or Aging Problems | Comments |
|---|---|---|---|---|---|---|
| 39. | Valve operators | Loosening of components during operation | Vibration testing | Vibration causes wearing of mounting components | Spring type lockwashers allow chafing of mounting surfaces and loosening of screws and bolts | |
| 40. | Rotary control switches | Closing or opening of wrong contacts | Evaluation of failed device | Cumulative effects of cam and coupling wear | Operation of switch | |
| 41. | Low voltage circuit breakers | Failure of control cable | Inspection | Chafing of cable insulation at compartment door | Mounting of cable allowed compartment door to wear cable insulation when opened and closed | |
| 42. | Batteries | Loss/reduction of output voltage | Metering/ electrolyte testing | Plate swell due to increased moisture absorption | Voltage discharge/ chemical change in plates | |
| 43. | Batteries | Loss of electrolyte | Visual inspection/failure to operate | Case cracking due to embrittlement or $H_2$ generation | Thermal/chemical embrittlement due to hot electrolyte | |
| 44. | Transmitters | Failure to produce correct output | Surveillance calibration/ cross check with other instruments | Electronics drift or sensor degradation | Thermal degradation/ voltage transients/ impurity introduction into component | May be able to predict by trending |
| 45. | Active/passive solid state devices | Failure to operate or produce correct output | Surveillance calibration/ cross check with other instruments | Electronics drift | Thermal/voltage degradation or impurity introduction into component | May be able to predict by trending or self testing |

## QUESTIONNAIRE RESPONSES (Con't)

| | Component | Actual or Potential Failure Mode | Manner of Discovery | Observed or Suspected Fundamental Cause of Failure | Observed or Suspected Aging Environment or Aging Problems | Comments |
|---|---|---|---|---|---|---|
| 46. | Motors | Bearing failure | Audible noise or vibration monitoring | Wear of bearing surface | Thermal/wear | Also pump bearings dominant motor failure mode |
| 47. | Motors | Insulation failure | Failure to operate/RF monitoring | Turn to turn short circuit | Thermal/voltage degradation | |
| 48. | Transformers | Insulation failure | Failure to operate/internal pressure rise/ RF Monitoring | Turn to turn short circuit | Thermal/voltage degradation | |
| 49. | Cables | Insulation failure | Fault locator/ failure to operate/low insulation resistance | Short to ground<br><br>Open circuit | Corrosive fluids thermal/ volt stress<br><br>Strand breakage due to excessive movement/vibration corrosion at interface | |
| 50. | Valve operator | Excessive open/ close torque | Torque switch trip/surveillance testing | Valve stem packing deterioration binding | 1) Wear causes leakage<br>2) Packing tightened to control leaks<br>3) Motor fails because torque switch set too high to prevent excessive tripping | |
| 51. | Snubbers (hydraulic) | Leakage | Fluid observation | Seal embrittlement | Attributed to radiation/ thermal degradation | Could be due to over-stress rather than degradation - also may be caused by vibration |

## QUESTIONNAIRE RESPONSES (Con't)

| | Component | Actual or Potential Failure Mode | Manner of Discovery | Observed or Suspected Fundamental Cause of Failure | Observed or Suspected Aging Environment or Aging Problems | Comments |
|---|---|---|---|---|---|---|
| 52. | Pump seals | Leakage | Fluid observation | Seal embrittlement or loss of strength | Thermal/radiation/ vibration degradation | |
| 53. | Relays | Failure to open/ close in required time | Calibration testing/operation testing | Relaxation of spring tension | Fatigue or dirt impairing spring | May be predictable by trending |
| 54. | Relays | Failure to make/ break contact | Operation testing | Pitting/thinning of contacts | Corrosion from environment and voltage arcs | May be predictable by trending |
| 55. | Cabling | Insulation failure | Leakage/ insulation breakdown testing | Short/open circuit | Temp. cycles and radiation | |
| 56. | Diesel generators | Fail to start | Failure on demand | Piping connection cracking | Vibration | Cold start requirements |
| 57. | Safety related pump | Bearing failure | Degraded flow on surveillance testing | Erosion Corrosion | High temperature vibration | |
| 58. | Piping systems | Leakage | Fluid/observation inspection | Erosion corrosion | Turbulent flow vibration | |
| 59. | Central valves | Leaking | Routine testing | Erosion corrosion | | |
| 60. | Battery cases | Structural failure | Routine walk-through | Plate swelling | Chemical reaction | |
| 61. | Demister baskets | Structural failure | Inspection | Ductile failure | Vibration | |
| 62. | R.T.D.s | Incorrect response | On-line Diagnostics | Open circuits (partial) Brittle Connector | High temperature | |
| 63. | NIS cables | Spurious response | Operational parameter change | Cracking open circuits | High temperature radiation | |

## QUESTIONNAIRE RESPONSES (Con't)

| | Component | Actual or Potential Failure Mode | Manner of Discovery | Observed or Suspected Fundamental Cause of Failure | Observed or Suspected Aging Environment or Aging Problems | Comments |
|---|---|---|---|---|---|---|
| 64. | Thermocouple leads | Spurious response | Operational parameter change | Open circuits | High temperature radiation | |
| 65. | Condenser tubes | Steam generator chemistry | Routine surveillance | Cracking | Chemistry of circ. water or | |
| 66. | SG tubes | Pressure boundary | ISI inspection | Denting; cracking | Chemistry crud buildup | |
| 67. | Pressurized safety valves | Pressure boundary | Inspection failure during operation | Leaking; erosion | Stress | |
| 68. | Relays | Spurious response | Failure during operation | Open circuits | Dirt/dust | |
| 69. | Valve positioner (air operated) | Spurious response | Failure during operation | Brittle failure cracking | Vibration | |
| 70. | Baffels impingement plates | Structural failure | Special testing | Cracking ductil failure | Excessive moisture vibration | |
| 71. | Control rod drive shaft | Disconnected | Low power physics testing | Handling throughout years | Bumping | |
| 72. | Control rod drive cable connectors | No contact | Dropped rod | Handling throughout years | Wear | |
| 73. | Valve diaphrams | Cracking | Leak | Too much torque | Time | |
| 74. | Dampers on containment recirc. fans | Cracking; breaking of actuator arms | Position indication | Vibration | Vibration; rough usage | |
| 75. | Service water piping | Leak | Routine inspection | Wall thinning | Erosion; silt in water | |

QUESTIONNAIRE RESPONSES (Con't)

| | Component | Actual or Potential Failure Mode | Manner of Discovery | Observed or Suspected Fundamental Cause of Failure | Observed or Suspected Aging Environment or Aging Problems | Comments |
|---|---|---|---|---|---|---|
| 76. | Control switches vital bus | No contact | Open circuits | Worn out | Material | |
| 77. | Diaphrams in controllers | No response | Failures during operation | Brittle failure | High temperature | |
| 78. | Station battery | Decreased D.C. voltage and power | Walk-through | Leaking cell tanks | Expansion and construction | |
| 79. | AC power transformers | Possible loss of power | Refueling PMs | Insulation breakdown | Heat | |
| 80. | MOV lubricants | Failure to open or close valve | Refueling PMs | Lubricant breakdown | Temp. variations | Grease hardens |
| 81. | M.C.C. motor protection | Failure to protect motor from overload | PMs destroy motor | Failure to open under overload; destroy motors; fire | Constant temp. old age | |
| 82. | Valve(s) | Pressure boundary | Failure during operation | Failed body to Bonneni gasket(s) | Liquid erosion | |
| 83. | Service water piping | Pressure boundary | Routine walk-through | Wall thinning | Liquid erosion | |
| 84. | Charging pump recirc. line orifice isolation valve | Pressure boundary | Routine walk-through | Wall thinning | Liquid erosion | |
| 85. | Emerg. diesel heat exchanger inlet line | Pressure boundary | Routine walk-through | Wall thinning | Liquid erosion | |

QUESTIONNAIRE RESPONSES (Con't)

| | Component | Actual or Potential Failure Mode | Manner of Discovery | Observed or Suspected Fundamental Cause of Failure | Observed or Suspected Aging Environment or Aging Problems | Comments |
|---|---|---|---|---|---|---|
| 86. | Capacitors electrolytic | Open or short circuited | Set point drift or calibration shift | Drying out of electrolyte | From being constantly energized | Replace with tantalum capacitors |
| 87. | Reactor coolant R.T.D.s | Mostly open circuit | Indication off scale or alarm | Vibration, due to flow of coolant | Flow of coolant system causes vibration | Replace with military spec. components |
| 88. | Amplifiers in general | Open resistors, capacitors, coils, transistors | Many times poor or no indication | Alarm, set, point drift poor or no indication | In reactor containment, heat is usually the culprit | Repair with military spec. components |
| 89. | Neutrons sensors $BF_3$ and $B_{10}$ | Depletion of $BF_3$ and $B_{10}$; short circuit of connectors | Erratic or loss of indication | Neutrons deplete $B_{10}$ and $BF_3$, causing low, high, or erratic readings | Neutrons deplete $BF_3$ and $B_{10}$, heat and/or neutrons break down connector material | Replace detectors |
| 90. | Terminal blocks | Worn screws and parts which cause open circuits | Surveillance, alarms, poor indication low or high, or no indication | Loss of protection, or trip signal, loss of control | Too much surveillance | Replace connectors |
| 91. | $\Delta P$, and pressure | Worn moving parts due to system or process dynamic characteristic | Low, high, erroneous, or no reading. alarms | Loss of protection, calibration drift, alarms | Natural characteristic of process or controlled variable | Replace or repair transmitter |
| 92. | Diesel starters | Structural failure | Routine surveillance | Wear | Excessive test cycles | |
| 93. | Engineered safety features equipment | Structural failure | Routine surveillance | Wear | Excessive test cycles | |

## QUESTIONNAIRE RESPONSES (Con't)

| | Component | Actual or Potential Failure Mode | Manner of Discovery | Observed or Suspected Fundamental Cause of Failure | Observed or Suspected Aging Environment or Aging Problems | Comments |
|---|---|---|---|---|---|---|
| 94. | Valve | Through wall leakage | Water on floor | Cavitation | High vacuum; valve returns feed water to condenser | |
| 95. | SW pump | Degraded output | Testing | Erosion | Silt in water | |
| 96. | RHR heat exchanger | Tube failure | Conductivity | Vibration | Loose tube support | |
| 97. | Condenser | Tube failure | Conductivity | High steam velocity | High vacuum (low CW temp.) | |
| 98. | Pump turbine aux. oil pressure switch | Seal failure set point change | Observation turbine trip | Abrasion vibration | Dirty water switch mounted on turbine pedestal | |
| 99. | MOV CS min. flow | Motor failure | Failure during operation | Change to torque switch settings | Vibration | |
| 100. | Containment fan coil unit | Bearing/shaft failure | Shutdown inspection | | High temperature, high speed, low quality | |
| 101. | Stainless steel recirculation system piping | Cracks | ISI or leak detection | Intergranular stress corrosion cracking (IGSCC) | Normal service in earlier plant designs | Resolved by improved material or stress/envir. modification |
| 102. | Recirc. flow control valves | Wear | Test for function | Bearing failure | Material incompatibility | Redesign |
| 103. | Pump motors (continuous duty) | Insulation deterioration (postulated) | Probably during maintenance checks | High dry well/motor temperatures leading to shorts | Temperature | |
| 104. | Valves (recirc.) | Cracks in valve stem | Test for function | Fatigue | Normal service | Redesign |

QUESTIONNAIRE RESPONSES (Con't)

| | Component | Actual or Potential Failure Mode | Manner of Discovery | Observed or Suspected Fundamental Cause of Failure | Observed or Suspected Aging Environment or Aging Problems | Comments |
|---|---|---|---|---|---|---|
| 105. | CRD system | Wear (postulated) of CRD indexing | Test for function | Wear due to crud in CRD | Normal service | |
| 106. | Core spray spargers | Cracks in sparger arms | ISI | IGSCC (postulated) | Normal service | Replace with improved material/design |
| 107. | Jet pump beams | Cracks | Test for function (surveillance) | IGSCC | Stress and heat treatment of beam material | Replace material and stress reduction |
| 108. | Steam dryer assembly | Cracking | ISI | Fatigue | Limited to early designs/ may be unique | |
| 109. | Feed water sparger assembly | Cracking | ISI | Fatigue (thermal and high cycle) | Early plant design features | |
| 110. | Sensors | Signal loss | Test for function | Degradation/ | Impurities in component | |
| 111. | Feed water sparger nozzles | Cracks | ISI | Thermal fatigue | Startup cycles and hot/ cold cycling during normal operation due to thermal sleeve leakage | Limited to early designs |
| 112. | Earthen dikes | Rupture; collapse; erosion | Leaks; wet | Erosion; piping, seepage | Soil compaction | |

## APPENDIX 3

### TABLE OF GENERIC ISSUES
### (How to Detect and How to Prevent/Cope/Handle Them)

## PRESSURE SENSORS

| FAILURE MODE AND/OR MECHANISM OF FAILURE | DETECT | PREVENT/COPE/HANDLE |
|---|---|---|
| 1. Insufficient/No Output or Open Circuits | • Anomalous signals<br>• Comparative outputs<br>• Known signal (devise check)<br>• Loop check<br>• Annunciators | • Protect against entry of moisture and chemicals<br>• Use higher quality electronics with more fatigue-resistant materials<br>• Use drift information with historical data to recalibrate or replace<br>• Preventive maintenance<br>• Failsafe design<br>• Use redundancy |
| 2. Decalibration by Mechanical Aging of Bellow Springs | • Trending analysis<br>• Anomalous signal<br>• Comparative outputs<br>• Known signal (devise test)<br>• Loop check<br>• Comparative Channel | • Less exercise<br>• Recalibrate<br>• Change springs<br>• Change material |
| 3. Decalibration by Binding | • Same Method as 2 | • Avoid extreme ranges in cycles by flow limiting orifice or accumulators |

PRESSURE SENSORS (Cont.)

| FAILURE MODE AND/OR MECHANISM OF FAILURE | DETECT | PREVENT/COPE/HANDLE |
|---|---|---|
| 4. Decalibration by Electronic Drift or Sensor Degradation | • Same methods as 2 | • Environment protection<br>• Environment control<br>• Use nonelectronics transmitter<br>• Recalibrate routinely |
| 5. Decalibration Because Brittle Connector | • Same methods as 2 | • Check set point drift |
| 6. Decalibration Because of Wear in Moving Parts | • Same methods as 2 | • Lubricate<br>• Change clearances<br>• Use different material |

## TEMP SENSORS (RTD & TC)

| FAILURE MODE AND/OR MECHANISM OF FAILURE | DETECT | PREVENT/COPE/HANDLE |
| --- | --- | --- |
| 1. Decalibration by Mechanical Aging of Springs and Bellow | · Anomalous signal<br>· Comparative outputs<br>· Devise test<br>· Loop test<br>· Annunciators | · Use product that is appropriate to functional requirement |
| 2. Decalibration by TC Junction Failure | · Same methods as 1 | · Use product that is appropriate to functional requirements |
| 3. Insufficient/No Output or Open Circuits because of Junction | · Same methods as 1 | · Minimize vibration from insulation<br>Minimize thermal cycles that can cause junction failure<br>· Replace thermal conductivity lubricant or use different material or protect from environment<br>· Gold plate RTD, change RTD, use custom fitted pair |

## INTERCONNECTIONS

### (Electrical Connectors and Terminal Blocks)

| FAILURE MODE AND/OR MECHANISM OF FAILURE | DETECT | PREVENT/COPE/HANDLE |
|---|---|---|
| 1. Fail to Operate on Demand | • Circuit continuity check<br>• No operation when required<br>• Visual (worn, corroded, rusted)<br>• Infrared temperature sensors<br>• Time domain reflectometer | • Don't change leads if possible, if not minimize changes<br>• Better material (gold)<br>• Minimize use in containment |
| 2. Spurious Response (Usually Restricted to Terminal Blocks Only) | • Spurious signal<br>• Trips<br>• Blown fuses (Circuit interruptions)<br>• Visual | • Improved conformal coatings<br>• Tighter seals on enclosures<br>• Use ceramic materials<br>• Revise mounting to reduce thermal stress |

VALVES (GENERAL)

| FAILURE MODE AND/OR MECHANISM OF FAILURE | DETECT | PREVENT/COPE/HANDLE |
|---|---|---|
| 1. Seat Leakage of Containment Isolation Valves | • 10CRF50 Appendix J (Containment penetration test)<br>• Downstream temperature<br>• Inventory measurements<br>• Acoustic<br>• Visual<br>• Operational (cannot get isolation)<br>• Hydro test | • Resurface seats at each outage (MSIV) - BWRs<br>• Routine maintenance including relap seats and resurface with stellite (welding)<br>• Use correct valve for application |

## VALVES SOLENOID

| FAILURE MODE AND/OR MECHANISM OF FAILURE | DETECT | PREVENT/COPE/HANDLE |
|---|---|---|
| 1. Valve Fails to Operate due to Hampered Operation of Pneumatic Valve Controllers | • Operational (valve doesn't move)<br>• Moisture detector for $H_2O$ | • Switch to more stable seal materials such as VITON or EPDM<br>• Ensure oil free and dry air supply<br>• Choose more stable valve solenoid material<br>• Use right "Dope"<br>• Use different pipe material, i.e., ensure use of nonrusting materials |

## VALVE OPERATORS - MOTOR

| FAILURE MODE AND/OR MECHANISM OF FAILURE | DETECT | PREVENT/COPE/HANDLE |
|---|---|---|
| 1. Function of Motor Impaired due to Lubrication Hardening | • Trips due to high torque<br>• Stroking time increased<br>• Analyze lubricant<br>• Electrical current draw on motor<br>• Use torque wrench compare new to aged | • Integrate maintenance of electrical/ mechanical parts<br>• Periodic lubrication chang<br>• Use a different lubricant |
| 2. Function of Motor Impaired due to Loosening of Parts | • Check operation of valve<br>• Electrical current checks<br>• Stroking time increased | • Monitor vibrating systems for signs of wear<br>• Periodic torque check |
| 3. Function of Motor Impaired due to Excessive Torque | • Trips due to high torque<br>• Stroking time increased<br>• Electrical current draw on motor<br>• Use torque wrench compare new to aged | • Packing too tight<br>• Design to prevent over-tightening<br>• Integrate maintenance-electrical/mechanical<br>• Check packing - so does not go due to "over-torque"<br>• Educate operator<br>• Redesign packing materials<br>• Follow manufacturer's instructions |

PNUEMATIC VALVE OPERATORS

| FAILURE MODE AND/OR MECHANISM OF FAILURE | DETECT | PREVENT/COPE/HANDLE |
|---|---|---|
| 1. Failure due to too Tight Packing | • Non operational<br>• Erratic stroke<br>• Slow stroke | • Good maintenance practices by educating operator<br>• Redesign packing methods, shape or material<br>• Establish required torque values for various packing systems/configurations<br>• Improved quality control of packing |

## SWITCH/RELAY/CIRCUIT BREAKERS

| FAILURE MODE AND/OR MECHANISM OF FAILURE | DETECT | PREVENT/COPE/HANDLE |
|---|---|---|
| 1. Nonoperation due to Open Circuit or Fatigue of Spring | • Nonoperation/slow operation<br>• Failure of downline equipment<br>• Measure spring tension (likely impractical except for circuit breaker)<br>• Visual inspection | • Use some solid state circuits<br>• Cause may be in quality control-know how and not heeding vendor recall notices |
| 2. Nonoperation due to Grease Binding | • Nonoperation/slow response on periodic testing | • Correct lubrication<br>• Choose compatible lubricate<br>• Circuit redundancy change<br>• Periodic cleaning |
| 3. Nonoperation due to Wear-Induced Friction | • Nonoperation/slow response on periodic testing | • Assure relay is in the correct application<br>• Mount correctly<br>• Reduce testing and/or consider design and lubrication change based on testing |
| 4. Nonoperation due to Dirt/Dust/Corrosion | • Inspection<br>• Nonoperation/slow response on periodic testing | • Do regular preventative maintenance to keep clean<br>• Use carbon paper to determine surface irregularities such as pitting |

DIESEL GENERATOR

| FAILURE MODE AND/OR MECHANISM OF FAILURE | DETECT | PREVENT/COPE/HANDLE |
|---|---|---|
| 1. Nonoperation due to Piping Failure Such as Cracking | • Visual inspection for discolorization of copper on carbon steels<br>• Visual leakage | • Use flexible piping<br>• Reduce stress concentration by using welded fittings, not threaded fittings, or use rolled, not cut, threads<br>• Use something besides copper |
| 2. Nonoperation due to Structural Failure, i.e., Wear Breakage | • Fail to start on demand<br>• Strain gauges<br>• Compression test<br>• Exhaust gas analyzer<br>• Analyze lube oil for water glycol and metal | • Reduce testing<br>• Better dynamic balancing to protect from vibration<br>• Improved testing sequence, e.g., reassess requirements |

## ROTATING EQUIPMENT
(Motors/Pump Motors, Fans, Blowers)

| FAILURE MODE AND/OR MECHANISM OF FAILURE | DETECT | PREVENT/COPE/HANDLE |
|---|---|---|
| 1. Fails to Operate due to Bearing Failures | · Acoustic<br>· Vibration<br>· Audio<br>· Temperature (direct or lubricant)<br>· Oil analysis (sludge) | · Periodic replacement based on manufacturer's specs<br>· Lubrication quality control<br>· Periodic alignment checks<br>· Reduce start loads |

## TRANSFORMERS

| FAILURE MODE AND/OR MECHANISM OF FAILURE | DETECT | PREVENT/COPE/HANDLE |
|---|---|---|
| 1. Turn-to-Turn Shorts Caused by Insulation Failures | • IR hot spot scope<br>• High frequency voltage test<br>• Oil analysis<br>• High pressure indicator for oil<br>• Off-gasing (oil-filled) transformers | • Operate within design limits<br>• Better insulation material, design<br>• Replace aged transformers |

CABLES

| FAILURE MODE AND/OR MECHANISM OF FAILURE | DETECT | PREVENT/COPE/HANDLE |
|---|---|---|
| 1. Failure to Operate due to Insulation Failure | • Meggar (insulation test)<br>• Polarization index<br>• Dielectric measurements<br>• Time domain reflectometer<br>• Visual<br>• Sacrificial sample physical tests electrical tests | • Control and/or characterize environments- temperature, heat, radiation (on a plant basis, if possible)<br>• Devise accelerated tests to predict end-of-life<br>• Don't use PVC, Teflon, EPR, Polyethylene<br>• Minimize mechanical stress<br>• Replace cabling if important to safety basis<br>• Use better insulation<br>• Keep cables clean |
| 2. Failure to Operate due to Strand Breakage | • Basically connector problem (see connector data sheet) | |

## SNUBBERS

| FAILURE MODE AND/OR MECHANISM OF FAILURE | DETECT | PREVENT/COPE/HANDLE |
|---|---|---|
| 1. Nonfunction due to Leakage Caused Seal Embrittlement | • Visual inspection<br>• Use sacrificial material to predict problems | • Change materials, e.g., Butyl, to EPR<br>• Perform seal life to temperature fluid sensitivity study<br>• Go to mechanical system |
| 2. Nonfunction due to Orifice Blockage | • Periodic cycling<br>• Oil purity checks | • Contaminants in oil, so use clean oil |
| 3. Nonfunction due to Lock Nut Loose | • Visual inspection | • Design change or tack weld |

## SNUBBERS (Mechanical)

| FAILURE MODE AND/OR MECHANISM OF FAILURE | DETECT | PREVENT/COPE/HANDLE |
|---|---|---|
| 1. Nonfunction due to binding | • Cycling<br>• Visual | • Bind by corrosion, overstress, too many cycles<br>• Redesign<br>• Control corrosion |

PIPING WELDS AND WALLS

| FAILURE MODE AND/OR MECHANISM OF FAILURE | DETECT | PREVENT/COPE/HANDLE |
|---|---|---|
| 1. Leakage/Potential Leakage of Pipes and Welds | • Visual inspection<br>• Inventory balance<br>• NDT<br>a. X-Rays<br>b. Acoustics<br>• Level detection systems<br>• Humidity measurements | • Reduce velocities/ turbulence<br>• Maintain water purity<br>• Reduce 90° bends<br>• Reduce cavitation causing bends |

STEAM GENERATOR TUBES

| FAILURE MODE AND/OR MECHANISM OF FAILURE | DETECT | PREVENT/COPE/HANDLE |
|---|---|---|
| 1. Leakage | • Much work already in progress, therefore, not considered in this workshop | |

## RELIEF VALVES

| FAILURE MODE AND/OR MECHANISM OF FAILURE | DETECT | PREVENT/COPE/HANDLE |
|---|---|---|
| 1. Nonoperation due to Leakage and/or Sticking | • Visual<br>• Acoustical<br>• Downstream temperature<br>• High dry well temperature<br>• High environmental temp/humidity/ radiation<br>• Inventory balance (good for PWR only) | • Use block valves where allowed<br>• For wire drawing reduce tests and seat erosion<br>• Use better seat and seal materials |

## CONCRETE ANCHORS

| | FAILURE MODE AND/OR MECHANISM OF FAILURE | DETECT | PREVENT/COPE/HANDLE |
|---|---|---|---|
| 1. | Loss of Pretension due to Wrong Torque | • Visual gap inspection<br>• Torque wrench tests by IEEE/7902 (Base Plate) and IEEE/7914 (system) tests | • Give initial torque correctly and assure by better QA during construction<br>• Reduce vibration<br>• Use lug nuts to solve vibration problems |
| 2. | Loss of Pretension due to Grout Disintegration Then Creep | • Visual inspection | • Use materials with higher stress limits<br>• Replace with cement/sand grout or other radiation- and temperature-resistant grouts |

## CONTAINMENT TENDON ANCHORS/TENDONS

| FAILURE MODE AND/OR MECHANISM OF FAILURE | DETECT | PREVENT/COPE/HANDLE |
|---|---|---|
| 1. Tendon Anchors and/or Tendons Fail | • Pressure test periodically by Appendix J<br>• Structure integrity test | • Use good design |

## APPENDIX 4

## COMMENTS ON ISSUES GENERATED IN WORKSHOPS BUT NOT INCLUDED IN 14 GENERIC ISSUES

## POTENTIAL ISSUES IDENTIFIED BUT NOT FINALLY ANALYZED

| | Issue or Component | Comments | Considered Important and An Aging Issue |
|---|---|---|---|
| 1. | Marine fouling of heat exchangers and systems | Flow blockage is possible, but most feel problem is or has been solved by appropriate cleaning intervals or addition of additives | Not considered this a high priority item |
| 2. | Anchor/Tendon Failures | Already considered in generic issues | |
| 3. | Concrete degradation by sumpwater, irradiation, salt attack, or high temperature | Loss of structural integrity possible, but choice of appropriate compositions can resolve problem | Not considered a high priority item |
| 4. | Transformer and electrical failures due to salt | Corrosion may cause arcing but solutions as sealed containers known | Not considered a high priority item |
| 5. | Corrosion under pipe insulation | In older plants stress corrosion cracking possible, but expect leak before break | Not considered a high priority item |
| 6. | Sludge buildup in diesel generator fuel tanks | Algae growth could result in blockage but solutions to problem known such as filtering and additives to kill algae | Not considered a high priority item |
| 7. | Sulfur in lubricants | If appropriate knowledge of lubricants used with QA not a problem | Not considered a high priority item |

| | Issue or Component | Comments | Considered Important and An Aging Issue |
|---|---|---|---|
| 8. | Sensitive electronics under high heat loads | Problem may occur if instrument cabinets overheated in control room - but known methods to control | Not considered a high priority item |
| 9. | Epoxies and similar sealants | Problems with cracking in containment penetrations, due to cracking and solvent effects | May be a high priority item, is an aging consideration |
| 10. | Fire protection equipment (seldom used) | Possible to have problems with dampers and doors that won't close, sprinklers that corrode, penetration seals, (Block-out seals), and smoke detectors (not enough experience exists to judge these problems) | May be important |
| 11. | Drains seldom used | Some data exists that drains may plug up and cause flood; issue, however, between INPO recommendations and Appendix R not felt to be a problem | Not considered a high priority item |
| 12. | Cable insulation degraded by water absorption | Migration of water into insulation occurs, but appropriate choice of materials will solve problem | Not considered a high priority item |
| 13. | Core support structures | High fluxes may change ductility; problem will be in seismic events | May be important since possible containment loss may occur |

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