NUREG/CR–3818
SAND84–0374
RV
Printed May 1984

Report of Results of Nuclear Power Plant Aging Workshops

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Prepared by
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Albuquerque, New Mexico 87185 and Livermore, California 94550
for the United States Department of Energy
under Contract DE-AC04-76DP00789

Prepared for
U. S. NUCLEAR REGULATORY COMMISSION

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GPO Sales Program
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U.S. Nuclear Regulatory Commission
Washington, D.C. 20555

and

National Technical Information Service
Springfield, Virginia 22161

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REPORT OF RESULTS OF NUCLEAR POWER PLANT AGING WORKSHOPS

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Operated by
Sandia Corporation
for the
U.S. Department of Energy

Prepared for
Electrical Engineering Branch
Division of Engineering Technology
Office of Nuclear Regulatory Research
U. S. Nuclear Regulatory Commission
Washington, DC 20555
Under Memorandum of Understanding DOE 40-55-75
NRC FIN NO. A-1357

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 cf 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 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	R&D PRIORITY Medium	R&D PRIORITY 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	R&D PRIORITY Medium	R&D PRIORITY 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	R&D PRIORITY Medium	R&D PRIORITY 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

- Delayed response
- Slow response
- Premature response
- Fast response
- Spurious response
- Insufficient/no output
- Excessive output
- Pressuring boundary failure
- Structure failure
- Foundation failure
- Other

Manner of Discovery

- Routine maintenance
- Routine walk through
- Special surveillance
- Failure on demand
- Failure during operation
- On-line diagnostics
- Operational parameter change
- Routine testing
- Other

Observed or Suspected Fundamental Cause of Failure

- Short circuits (inc. partial)
- Open circuits (inc. partial)
- Binding
- Excessive free play
- Cracking
- Ductile failure
- Brittle failure
- Flow blockage
- Wall thinning
- Other

Observed or Suspected Aging Environments or Aging Problems

- Radiation
- Excessive moisture
- Insufficient moisture
- Corrosive liquids
- Corrosive vapors/gases
- Abrasion (internal/external)
- High temperatures
- Low temperatures
- Temperature cycles
- Liquid erosion
- 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 ΔP 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	

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
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 Open circuit	Corrosive fluids thermal/ volt stress 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 2) Packing tightened to control leaks 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	

	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.	ΔP, 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 · Comparative outputs · Known signal (devise check) · Loop check · Annunciators	· Protect against entry of moisture and chemicals · Use higher quality electronics with more fatigue-resistant materials · Use drift information with historical data to recalibrate or replace · Preventive maintenance · Failsafe design · Use redundancy
2. Decalibration by Mechanical Aging of Bellow Springs	· Trending analysis · Anomalous signal · Comparative outputs · Known signal (devise test) · Loop check · Comparative Channel	· Less exercise · Recalibrate · Change springs · Change material
3. Decalibration by Binding	· Same Method as 2	· Avoid extreme ranges in cycles by flow limiting orifice or accumulators

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 · Environment control · Use nonelectronics transmitter · 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 · Change clearances · 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 · Comparative outputs · Devise test · Loop test · 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 Minimize thermal cycles that can cause junction failure · Replace thermal conductivity lubricant or use different material or protect from environment · 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 · No operation when required · Visual (worn, corroded, rusted) · Infrared temperature sensors · Time domain reflectometer	· Don't change leads if possible, if not minimize changes · Better material (gold) · Minimize use in containment
2. Spurious Response (Usually Restricted to Terminal Blocks Only)	· Spurious signal · Trips · Blown fuses (Circuit interruptions) · Visual	· Improved conformal coatings · Tighter seals on enclosures · Use ceramic materials · 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) · Downstream temperature · Inventory measurements · Acoustic · Visual · Operational (cannot get isolation) · Hydro test	· Resurface seats at each outage (MSIV) - BWRs · Routine maintenance including relap seats and resurface with stellite (welding) · 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) · Moisture detector for H_2O	· Switch to more stable seal materials such as VITON or EPDM · Ensure oil free and dry air supply · Choose more stable valve solenoid material · Use right "Dope" · 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 · Stroking time increased · Analyze lubricant · Electrical current draw on motor · Use torque wrench compare new to aged	· Integrate maintenance of electrical/ mechanical parts · Periodic lubrication change · Use a different lubricant
2. Function of Motor Impaired due to Loosening of Parts	· Check operation of valve · Electrical current checks · Stroking time increased	· Monitor vibrating systems for signs of wear · Periodic torque check
3. Function of Motor Impaired due to Excessive Torque	· Trips due to high torque · Stroking time increased · Electrical current draw on motor · Use torque wrench compare new to aged	· Packing too tight · Design to prevent over-tightening · Integrate maintenance-electrical/mechanical · Check packing - so does not go due to "over-torque" · Educate operator · Redesign packing materials · 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 · Erratic stroke · Slow stroke	· Good maintenance practices by educating operator · Redesign packing methods, shape or material · Establish required torque values for various packing systems/configurations · 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 · Failure of downline equipment · Measure spring tension (likely impractical except for circuit breaker) · Visual inspection	· Use some solid state circuits · 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 · Choose compatible lubricate · Circuit redundancy change · Periodic cleaning
3. Nonoperation due to Wear-Induced Friction	· Nonoperation/slow response on periodic testing	· Assure relay is in the correct application · Mount correctly · Reduce testing and/or consider design and lubrication change based on testing
4. Nonoperation due to Dirt/Dust/Corrosion	· Inspection · Nonoperation/slow response on periodic testing	· Do regular preventative maintenance to keep clean · 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 · Visual leakage	· Use flexible piping · Reduce stress concentration by using welded fittings, not threaded fittings, or use rolled, not cut, threads · Use something besides copper
2. Nonoperation due to Structural Failure, i.e., Wear Breakage	· Fail to start on demand · Strain gauges · Compression test · Exhaust gas analyzer · Analyze lube oil for water glycol and metal	· Reduce testing · Better dynamic balancing to protect from vibration · 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 · Vibration · Audio · Temperature (direct or lubricant) · Oil analysis (sludge)	· Periodic replacement based on manufacturer's specs · Lubrication quality control · Periodic alignment checks · 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 · High frequency voltage test · Oil analysis · High pressure indicator for oil · Off-gasing (oil-filled) transformers	· Operate within design limits · Better insulation material, design · 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) · Polarization index · Dielectric measurements · Time domain reflectometer · Visual · Sacrificial sample physical tests electrical tests	· Control and/or characterize environments-temperature, heat, radiation (on a plant basis, if possible) · Devise accelerated tests to predict end-of-life · Don't use PVC, Teflon, EPR, Polyethylene · Minimize mechanical stress · Replace cabling if important to safety basis · Use better insulation · 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 · Use sacrificial material to predict problems	· Change materials, e.g., Butyl, to EPR · Perform seal life to temperature fluid sensitivity study · Go to mechanical system
2. Nonfunction due to Orifice Blockage	· Periodic cycling · 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 · Visual	· Bind by corrosion, overstress, too many cycles · Redesign · 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 · Inventory balance · NDT a. X-Rays b. Acoustics · Level detection systems · Humidity measurements	· Reduce velocities/ turbulence · Maintain water purity · Reduce 90° bends · 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 · Acoustical · Downstream temperature · High dry well temperature · High environmental temp/humidity/ radiation · Inventory balance (good for PWR only)	· Use block valves where allowed · For wire drawing reduce tests and seat erosion · 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 · Torque wrench tests by IEEE/7902 (Base Plate) and IEEE/7914 (system) tests	· Give initial torque correctly and assure by better QA during construction · Reduce vibration · 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 · 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 · 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

Distribution:
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Distribution Contractor (CDSI)
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NRC FORM 335 (2-84) NRCM 1102, 3201, 3202

U.S. NUCLEAR REGULATORY COMMISSION

BIBLIOGRAPHIC DATA SHEET

SEE INSTRUCTIONS ON THE REVERSE

1 REPORT NUMBER (Assigned by TIDC, add Vol. No., if any)

NUREG/CR-3818
SAND84-0374

2 TITLE AND SUBTITLE

REPORT OF RESULTS OF NUCLEAR POWER PLANT AGING WORKSHOPS

3 LEAVE BLANK

4 DATE REPORT COMPLETED

MONTH	YEAR
May	84

5 AUTHOR(S)

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6 DATE REPORT ISSUED

MONTH	YEAR
May	84

7 PERFORMING ORGANIZATION NAME AND MAILING ADDRESS (Include Zip Code)

SANDIA NATIONAL LABORATORIES
P.O. BOX 5800
ALBUQUERQUE, NM 87185

8 PROJECT TASK WORK UNIT NUMBER

9 FIN OR GRANT NUMBER

A-1357

10 SPONSORING ORGANIZATION NAME AND MAILING ADDRESS (Include Zip Code)

ELECTRICAL ENGINEERING BRANCH DIVISION OF ENGINEERING TECHNOLOGY
OFFICE OF NUCLEAR REGULATORY RESEARCH
U. S. NUCLEAR REGULATORY COMMISSION
WASHINGTON, DC 20555

11a TYPE OF REPORT

Technical

b PERIOD COVERED (Inclusive dates)

12 SUPPLEMENTARY NOTES

13 ABSTRACT (200 words or less)

14 DOCUMENT ANALYSIS – a KEYWORDS/DESCRIPTORS

b IDENTIFIERS/OPEN ENDED TERMS

15 AVAILABILITY STATEMENT

16 SECURITY CLASSIFICATION

(This page)

(This report)

17 NUMBER OF PAGES

18 PRICE

U.S. GOVERNMENT PRINTING OFFICE: 1984-0-776-026/4323

Org.	Bldg.	Name	Rec'd by	Org.	Bldg.	Name	Rec'd by

120555078877 1 IAN1RV
US NRC
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POLICY & PUB MGT BR-PDR NUREG
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WASHINGTON DC 20555

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