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AGING MECHANISMS IN THE WESTINGHOUSE PWR CONTROL ROD DRIVE SYSTEM*

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ABSTRACT

An aging assessment of the Westinghouse Pressurized Water Reactor (PWR) Control Rod System (CRD) has been completed as part of the U.S. NRC's Nuclear Plant Aging Research, (NPAR) Program (1). This study examined the design, construction, maintenance, and operation of the system to determine its potential for degradation as the plant ages (2). Selected results from this study are presented in this paper.

The operating experience data were evaluated to identify the predominant failure modes, causes, and effects. From our evaluation of the data, coupled with an assessment of the materials of construction and the operating environment, we conclude that the Westinghouse CRD system is subject to degradation which, if unchecked, could affect its safety function as a plant ages.

Ways to detect and mitigate the effects of aging are included in this paper. The current maintenance for the control rod drive system at fifteen Westinghouse PWRs was obtained through a survey conducted in cooperation with EPRI and NUMARC. The results of the survey indicate that some plants have modified the system, replaced components, or expanded preventive maintenance. Several of these activities have effectively addressed the aging issue.

INTRODUCTION

The control rod drive (CRD) system plays a vital role in the safe and reliable operation of nuclear power plants. As defined in this paper, the CRD system consists of the control rods and the mechanical and electrical components which provide the means for control rod motion. As illustrated in Figure 1, these components include the control rod drive mechanism (CRDM), the power and logic cabinets, and the interconnecting cables and connectors. The Rod Position Indication System (RPIS) is also within the system boundary.

The purpose of the NPAR study was to examine the design, construction, maintenance and operation of the system to assess its potential for degradation as the plant ages. In particular, the study focused on the effects of aging on the following safety issues:

- structural integrity of the system,
- inadvertent rod withdrawal,
- the integrity of the pressure boundary,
- the ability to scram,
- inadvertent rod drop, and
- incorrect rod position.

CONTROL ROD DRIVE SYSTEM
Westinghouse PWRs

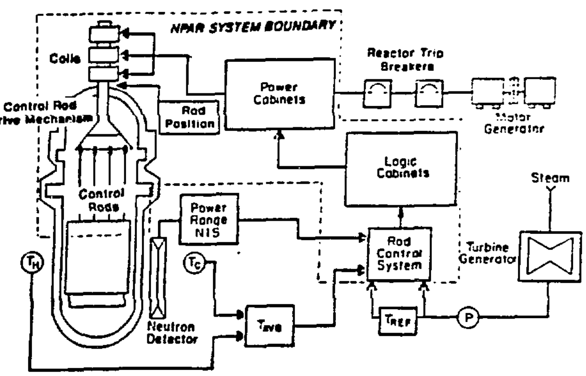

Figure 1 System Boundary

To achieve the goal of this study, the operating experience data from forty-seven operating nuclear power plants were reviewed. These data were obtained from Licensee Event Reports (LERs), the Nuclear Plant Reliability Data System (NPRDS), and the Nuclear Power Experience (NPE) database. The impact that operating demands and the environment have on CRD system performance was also evaluated. The influence of required testing was considered along with more obvious factors such as cyclic wear, high temperatures, and accident conditions.

An evaluation of inspection, surveillance, monitoring, and maintenance was accomplished with support from industry. Results from a survey of fifteen plants representing ten utilities were used to obtain this important input.

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OPERATING EXPERIENCE ASSESSMENT

Failure data obtained from NPRDS and NPEs covered a nine year period between January 1, 1980 and December 31, 1988. Information obtained from the Sequence Coding and Search System, which contains LERs, includes failure reports submitted during a five year period between January 1, 1984 and December 31, 1988. Each failure record obtained from the three national databases was individually reviewed and encoded into a computerized database. These sources provided an average of 30 unique failure events per year over a 10 year period, of which approximately 35% were directly attributable to aging related degradation.

When the failure reports were categorized in accordance with the subassembly in which the failure occurred, it was noted that the majority of the reported failures were in the electrical portion of the system, namely the power and logic cabinets, and the rod position indication subsystem (Figure 2).

A further review of this data was performed to evaluate the distribution of failures within the power and logic cabinets and to identify any dominant failure trends in the subcomponents. The results were that printed circuit boards were the most frequently failed part (47%), followed by fuses (26%), dc power supplies (17%), and discrete components (10%). The most frequent circuit board failures involved "firing circuit" cards of the power cabinet and "slave cycler counter" cards located in the logic cabinet. These logic card failures significantly affect CRD system and plant performance. Of the circuit board failures described in the LER data, 60% resulted in a reactor trip. In fact, of the 125 CRD system LERs, 40 resulted in a reactor trip from power, 13 caused a reactor trip during startup, and 10 initiated a turbine runback. Further examination of these failures led to the finding that integrated circuits and semiconductor devices are susceptible to premature failure when exposed to environmental stressors of heat and humidity in excess of their rated design operating range. For instance, in the NPE database, 33% of the logic card failures were attributed to an elevated temperature within the cabinet.

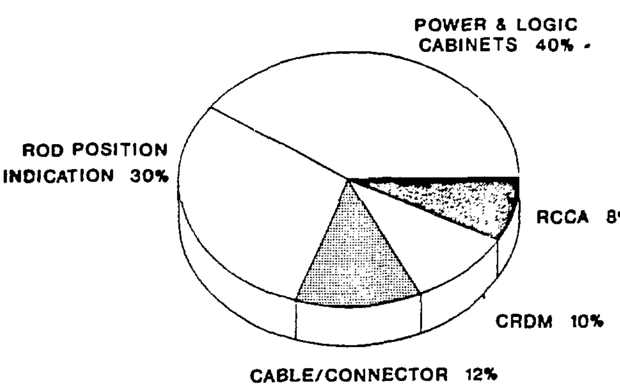

Figure 2 CRD System Failures

The rod position indicating subsystem also accounted for a substantial amount of failure reports, with the majority due to calibration drift. Problems related to drift of the analog portion of the system appear to be due to temperature variations that are induced in the CRDM during the heat-up of the primary system. The RPIS failures did not significantly affect CRD system or plant operation. However, the potential safety significance of misleading rod position information resulting from failures within the system should not be overlooked.

The failure of electrical cabling and connectors, which link the power cabinets to their associated CRDM operating coil stack assembly, were also found to be a contributor to CRD system unavailability. About 70% of the connector failures were caused by open circuits resulting from mechanical wear of the connector mating surfaces. The degradation mechanisms of coil stack connectors also includes corrosion in the mating areas of the connector pin.

The evaluation of the data has also led to other findings, such as:

- The normally energized stationary gripper coils have experienced a much higher failure rate than the movable gripper and lift coils.
- Wear of the rod cluster control assemblies is due to three independent types of age-related degradation: sliding wear, fretting wear, and stress corrosion cracking.
- Stress corrosion cracking has been identified as a source of degradation in two areas, fuel assembly hold down spring clamp screws and control rod guide tubes, including the split pins.
- Approximately 30% of the combined failures in the power and logic cabinets were associated with the fuse protection circuits, including the fuse and its mounting hardware (fuse clip). Several instances of observed fuse degradation, such as "fatigue" or "normal end-of-life", were found in the operating experience data.

Table 1 summarizes the review and analysis of operational experience data related to selected components of the Westinghouse CRD system and briefly describes the failure modes, causes, and mechanisms.

DETECTING AND MITIGATING DEGRADATION

An evaluation of inspection, surveillance, monitoring, and maintenance activities which could be used to detect and mitigate degradation of CRD system components was accomplished with the support of industry. Fifteen plants representing ten utilities provided information on preventive maintenance practices, design changes to reduce stresses imposed on the system, and some advanced techniques for monitoring system performance.

Table 2 is a summary of the survey results for PM on the mechanical portion of the system such as the CRD mechanism (drive rod and latch) and the control rod (RCCA and guide tube).

Table 2 Preventive Maintenance for Mechanical Components Within Containment

COMPONENT	MAINTENANCE PRACTICE	# OF PLANTS INVOLVED & FREQUENCY *
RCCA/Guide Tube	Eddy current testing Profilometry	3 1
Latches	None	N/A
Drive Rod	Visual inspection for wear and crud buildup	1
Seal Welds	NPE Hydro Remote visual	3-10% every 10 years 6 2
Vent Valves/Plugs	Hydro	4
Ventilation	Clean and inspect Lubricate fan bearings Megger motors	15 6 8

* Interval is refueling unless otherwise noted.

Preventive maintenance on the electrical equipment is performed during refueling outages and consists primarily of insulation resistance checks, conductor resistance tests, and visual inspections for signs of degradation such as wear, corrosion, or looseness. Of a more unique nature is the monitoring of coil stack degradation by three of the plants. Coil traces of in and out control rod motions are taken before startup, following a refueling outage. This technique can be performed at any time during operation, as well to detect changes in coil characteristics. Two plants also perform an inspection of all watertight seal connections at every refueling outage.

Table 3 is a summary of the preventive maintenance for the CRD system electrical components within containment. It should be noted that all but one of the plants perform some form of electrical testing on the CRDM and rod position coils, and routinely inspect the electrical connectors for any signs of degradation.

Table 3 Preventive Maintenance Practices for Electrical Components Within Containment

COMPONENT	PRACTICE	# OF PLANTS INVOLVED & FREQUENCY*
Coil stack assembly	Insulation resistance Coil resistance Coil timing signature traces Polarity check	7 14 4 3
Cable	Insulation resistance Visual	7 6
Connectors	Inspect for tightness Check watertight seal	14 2
Rod Position Indication sub-system wiring	Visual Resistance measurements Insulation resistances	4 10 3

*All frequency intervals are refueling outage.

RECOMMENDATIONS

To more effectively detect and mitigate the effects of aging in the Westinghouse control rod drive system, it is recommended that design changes be considered. The goals of design modifications are to reduce or eliminate the stresses which contribute to aging degradation, or improve the materials to better withstand the existing stressors. Areas where this could be obtained are with the ventilation system and the cable and coil specifications.

The ventilation systems in the upper head region and in the area where the power and logic cabinets are located should maintain low ambient temperatures. It is important that operating personnel be made aware of unsatisfactory conditions so that prompt action can be taken. Based on the insulation ratings for the cable and the coils, the ventilation system should be designed to prevent temperatures from exceeding 150°F and 80°F for the upper head and cabinet areas, respectively. Similarly, operating personnel should be aware of the importance of the ventilation system on CRD performance.

The integrity of the control rod drive system cables located in containment can be improved by using higher temperature rated assemblies. Several plants have upgraded their cable system to Tefzel insulation with a chlorosulfonated polyethylene jacket rated at 194°F. Other cable systems offered for the CRDMs are rated as high as 1000°F.

The coils are designed for a temperature of 400°F. It is not clear why the stationary gripper coils are failing at a much higher rate than the movable or lift coils. The only apparent difference is that current (4.4 amps) is continuously applied to the stationary gripper coil to hold the control rods in position. The ohmic heating generated may contribute to the coil's degradation.

Monitoring techniques are available to detect degradation in the system. Because of the inaccessibility during operation of the mechanical and structural portions of the CRD system, it is extremely important to conduct and document a thorough inspection during refueling outages. Using underwater TV cameras, areas of wear should be noted and their cause determined. While it may be advantageous to contract some of this work to the nuclear steam supplier, it is recommended that records be maintained on site to document the conditions of critical parameters such as:

- guide tube wear,
- drive rod and latch wear,
- rodlet fretting, cracking, or bulging, and
- cable, connector, coil appearance.

In addition, techniques are being successfully implemented at some utilities to supplement these visual inspections. Ultrasonics, eddy current, and profilometry are three of these techniques which could effectively determine the rate of component degradation as a plant ages.

Monitoring the CRD system mechanical and electrical integrity is justified based on its safety significance and operational performance. It is recommended that a current signature analysis technique being used at one plant be evaluated by other utilities. With this technique, each coil current is traced during rod motion. Analysis of the recorded data determines the acceptability of the power and logic circuitry and the coil integrity. In addition, a rough indication of mechanical interferences can be ascertained. Refinement of this technique for on-line monitoring has been completed and is being marketed commercially.

A common maintenance practice of measuring the resistances of cables, connectors, and coils resistances at regulated conditions (base-line temperature) is also recommended following each refueling. Measurements of loop inductance or dissipation factor as provided by commercial systems may also be beneficial.

Other functional indicators of possible value in detecting degradation of the CRD system are:

1. CRDM Cycle Counter: Since the amount of wear on components, such as the drive rod and latch, is directly related to rod movement, it is recommended that the numb er of control rod steps for each of the rods in the control bank(s) be counted.

2. CRD Housing Temperature: Thermal embrittlement of the pressure boundary may be a problem as plants age. To more accurately predict the performance of these materials, it is recommended that the temperature of selected housings be monitored at power conditions.

3. Operating Experience: With essentially fifty plants using the same CRD system design, tremendous benefits can be derived from shared information. Degradation experienced at older plants, for example, should influence the maintenance at newer plants.

REFERENCES

1. Vora, J.P., "Nuclear Plant Aging Research (NPAR) Program Plan," NUREG-1144, Rev. 1, September 1987.

2. Gunther, W., and Sullivan, K., "Aging Assessment of the Westinghouse PWR Control Rod Drive System," NUREG/CR-5555, March 1991.

APPENDIX A
Operating Experience Summary

COMPONENT	FAILURE MODE	FAILURE CAUSE	FAILURE MECH.
1. Power and Logic Cabinet Subassembly			
P.C. Logic Card	Incorrect output	Subcomponent failure	environmental stress heat/humidity vibration voltage/current transients
		Connector pin	corrosion/oxidation vibration mechanical wear
Fuse	Fails open	Fusible link material fatigue	vibration cyclical load transients heat spurious current transient
	Excessive voltage drop	Degraded condition of fuse contact material	corrosion
DC Power Supply	Loss of output voltage	Trip of thermal protection circuits	Environmental stress (heat)
		Internal component failure	Environmental stress (heat) Overvoltage/overcurrent transient
		Overvoltage protection circuit actuation	Lightning induced voltage surge
2. Rod Position Indication			
Analog RPI Signal	Incorrect output	Instrument calibration drift	Thermal variations in CRDM during primary system heatup
	No output	Internal component failure	Normal wear Overcurrent/overvoltage transient
Analog Detector Coil (LVDT)	Open	Degradation of conductor	Material fatigue Thermal stress
	Shorted	Degradation of coil insulation	Thermal stress
DC Power Supply	No Output	Internal component failure	Normal wear Age Overcurrent/overvoltage transient
	Degraded output	Internal component failure	Normal wear Age Overcurrent/overvoltage transient
3. Cables/Connectors			
CRDM Operating Coil Stack Connection	Open circuit	Connector degradation	Mechanical fatigue Vibration
		Corrosion	Environmental stress (heat, boric acid)
Containment Electrical Penetration	Shorted	Insulation breakdown Insulation wear	Environmental stress Vibration Mechanical stress
4. RCCA Subassembly			
CRGT Support Pin	Degradation/cracking of Inconel material	Inadequate heat treatment of Alloy X-750 (Inconel) material during fabrication	Stress corrosion cracking

COMPONENT	FAILURE MODE	FAILURE CAUSE	FAILURE MECH.
Spider Assembly	Dropped rods due to vane weld failure	Structural cracks	Mechanical/material fatigue
5. CRD Subassembly			
Operating Coil Stack	Open circuit	Conductor degradation	vibration fatigue mechanical
		Corrosion	Environmental stress (steam/boric acid)
Operating Coils	Short	Degradation of coil insulation	Environmental stress (steam/boric acid, absorption heat)
	Open	Degradation of conductor	Conductor material fatigue thermal stress
Latch Assembly	Control rod mis-stepping	Foreign material/crud buildup	Small particle debris present in RCS
	Failure to withdraw	Binding	Thermal cycling