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EFFECT OF AGING UPON CE AND B&W CONTROL ROD DRIVES*

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ABSTRACT

The effect of aging upon the Babcock & Wilcox (B&W) and Combustion Engineering (CE) Control Rod Drive (CRD) systems has been evaluated as part of the U.S. NRC Nuclear Plant Aging Research (NPAR) program. Operating experience data for the 1980-1990 time period was reviewed to identify predominant failure modes, causes, and effects. These results, in conjunction with an assessment of component materials and operating environment, conclude that both systems are susceptible to age degradation. System failures have resulted in significant plant effects, including power reductions, plant shutdowns, scrams, and Engineered Safety Feature (ESF) actuation. Current industry inspection and maintenance practices were assessed. Some of these practices effectively address aging, while others do not.

INTRODUCTION

The Babcock & Wilcox (B&W) and Combustion Engineering (CE) control rod drive (CRD) systems consist of the mechanical and electrical components necessary to position the control rod assemblies in the core in response to automatic or manual reactivity control signals. Both systems are designed to provide a rapid insertion of the control rods upon loss of AC power. As part of the USNRC Nuclear Plant Aging Research (NPAR) program, the design, materials, maintenance, and operation of both designs were evaluated to determine the potential for age degradation.

The system boundaries used for this aging study included the control rod drive mechanisms (CRDMs), CRDM power and control systems, rod position indication systems, CRDM cooling systems, and the control rod assemblies. The fuel assembly and upper internal guide tubes were also included, since failure of these components could preclude control rod insertion.

SYSTEM DESIGN

Reactivity control in B&W reactors is supplied by a combination of control rod assemblies (CRAs) and axial power shaping rod assemblies (APSRAs). Each B&W control rod assembly consists of sixteen individual poison rods connected to a spider assembly which geometrically arranges the rods for insertion into the fuel assembly guide tubes. The spider assembly also provides for attachment between the CRA and the CRDM leadscrew. APSRAs mechanically resemble the CRAs, and are used to control the axial power shape across the core during the fuel cycle. The APSRA drive mechanisms are modified to prevent them from inserting rapidly during a reactor scram.

All eight of the B&W plants use the roller nut type CRDM. These consist of an electrically driven, rotating nut assembly within the primary coolant pressure boundary; a four pole six phase, water cooled, stator; and a translating leadscrew which converts the rotary motion of the nut assembly to linear travel of the leadscrew and CRA. The CRDMs are flange mounted on top of the reactor vessel head, allowing for removal and maintenance without compromising system integrity. A vent valve located on top of the CRDM allows for remote coupling/decoupling of the CRA and bleeding all non-condensible gases from the top of the vessel following reactor head removal.

When sequentially energized by the power and control system, the stator coils produce a rotating magnetic field which causes the roller nut assembly to engage and rotate about the leadscrew as illustrated in Figure 1. CRA motion results either into or out of the core, depending upon roller nut rotational direction. Magnetically actuated reed switches, located in a housing adjacent to the CRDM pressure housing, provide actual rod position indication. Demanded rod position is provided by monitoring the pulses supplied to the CRDM.

When compared to the B&W CRA design, each CE control element assembly (CEA) consists of fewer, but larger diameter, absorber rods. The CEAs consist of four, five, or twelve full and part length absorber rods attached to a spider. Each CEA is attached to a control element drive mechanism (CEDM) which is threaded and welded to the top of the reactor vessel head. All but two CE plants use the magnetic jack CEDM (Figure 2), consisting of four or five electrical coils which, when energized, actuate a series of grippers. The grippers engage a notched drive shaft to insert or withdraw the CEA. The gripper coils are cooled by a forced air cooling system. Similar to B&W, actual rod position is provided by a series of magnetically actuated reed switches, while the plant computer monitors the command pulses supplied to the coils to provide the demanded position.

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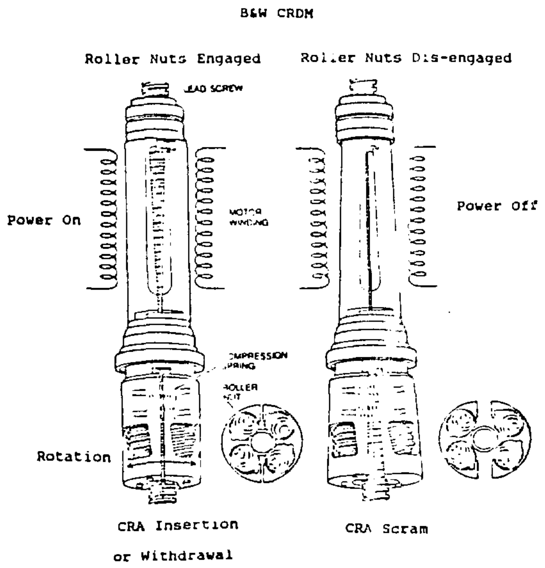

Figure 1. B&W CRDM Rotor Assembly and Leadscrew

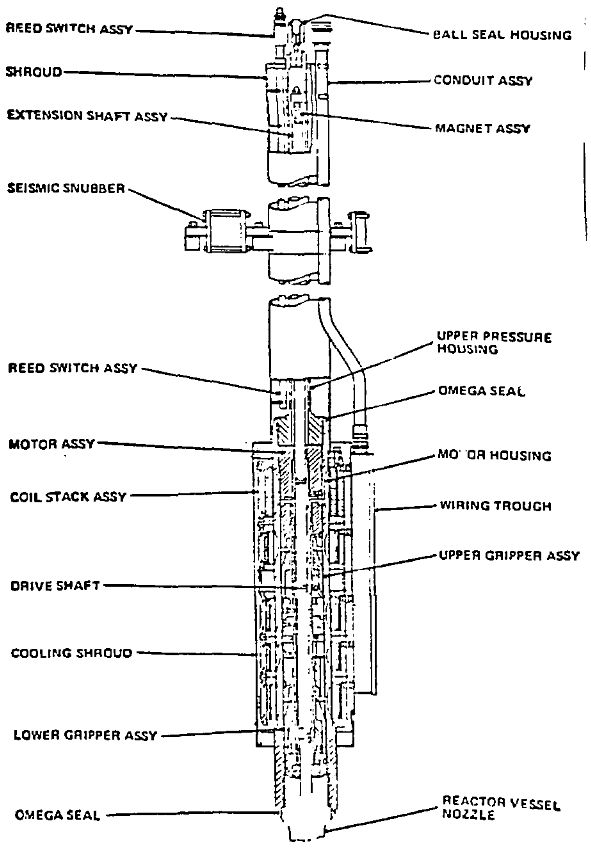

Figure 2. CE Magnetic Jack Control Element Drive Mechanism

Depending upon the vintage of the plant, CE has two power and control system designs. The older plants use the Control Element Drive System (CEDS), which supplies electrical signals to coil power programmers (CPP) which actuate the coils. The newer plants use theControl Element Drive Mechanism Control System (CEDMCS), which combines the CEDS and the CPP into one integrated system. Digital techniques are used in the CEDMCS to increase the accuracy and flexibility of the coil timing functions. CEDMCS also incorporates an on-line monitor to check and modify the voltage supplied to the coils to ensure proper functioning.

Palisades and Fort Calhoun are the two CE plants which use the rack and pinion type CEDM. This CEDM is an electric motor driven mechanism which has a drive shaft running parallel to the rack. The electric motor, operating through a gear reducer and magnetic clutch, drives the attached CEA. When the magnetic clutch is de-energized, the CEA inserts freely into the core.

OPERATING EXPERIENCE

A detailed operating experience review of three commercially available databases (Licensee Event Report or SCSS Database, Nuclear Plant Reliability Data System, and Nuclear Power Experience), plus applicable NRC and industry research was conducted to determine the affect of aging on the control rod drive systems for the 1980-1990 time period. As illustrated on Figure 3, degradation and failures of the power and control system accounted for the majority of CE CEDM failures. Failures of the CRDM accounted for the majority of B&W control rod drive system failures. The differences between the databases is due to the type of failures reported to each. Failures which occurred during plant operation, and directly affected the functioning of the system, were normally reported on an LER. Failures and degradation which were discovered at other times (outages, shutdowns, etc.), and did not affect plant operation, were normally reported to the NPRDS database.

As shown in Figure 4, aging was the direct failure cause for 40% of the CE power and control system failures, and 55% of the B&W CRDM failures as reported to the NPRDS database. Also a significant percentage of the reported failures were classified as "potentially due to aging." This reflects the reported failures with no defined cause. When compared to similar failures at other plants, which were identified as being the result of aging, engineering judgement dictates that a majority of these unknown failure cause events were also due to aging. However, no such assumptions were made in this study, and these events were classified as potentially aging. Failures of electrical cables and connectors and the RPI sub-system commonly did not have failure causes reported, due primarily to the replaceability of these components.

It is important to note that the operating experience review for CE and B&W indicated that neither control rod drive system ever failed to perform its primary safety function. This is due to the fail safe design of the CRD system. Any loss of power to the system results in the rapid insertion of the control rods. However, component degradation and failure resulted in increased component stresses, and unnecessary thermal and pressure cycles which challenged the operation of other safety systems. These occurrences may represent a significant increase in plant risk.

The majority of significant plant effects resulted from slipped rods, resulting in power reductions while efforts to recover and re-align the slipped rods were performed. Multiple dropped rods resulted in plant scrams and ESF actuations on some occasions.

An example of the most significant failures for the major sub-systems are described below:

a) *Cables and Connectors* - Cables and connectors are used extensively throughout the system. The power and control cables located on the top of the reactor head are located in a much more severe environment (radiation, temperature, humidity) than those used in the power and control cabinets located outside of the containment. Brittle and cracked CEDM electrical cabling has been found and replaced at several plants. Loose and broken electrical connections were also frequently noted.

b) *Power and Control System Failures* - This system consists primarily of modularized electrical components centrally located in control cabinets outside of the primary containment. Numerous instances of failed system power supplies were reported resulting in dropped rods. No actual cause of failure was provided. As a corrective action, many utilities are modifying their system design to incorporate redundant power supplies. Another common reported failure early in the 1980's was slipped or dropped rods due to the improper or sluggish actuation of the grippers. As previously described, CE has modified the power and control system design to incorporate the Automatic CEDM Timer Module (ACTM). The ACTM monitors and adjusts the current waveshape supplied to the grippers to ensure proper gripper actuation. This has improved the reliability of the gripper actuation. Control system breaker failures were not common, however one plant experienced a manual trip due to this type of failure. Subsequent testing indicated that the breaker opened at 30 amps, 25% less than the designed 40 amps. All of the sub-system molded case circuit breakers were subsequently added to the plants PM program to insure continued reliability for the 40 year design life.

c) *Control Rod Drive Mechanisms* - Numerous instances of primary coolant leakage resulting from failed gaskets and cracked pressure housings were reported. Gasket embrittlement due to aging was the primary failure cause for the B&W flexitallic gaskets. B&W has replaced the original asbestos impregnated spiral wound design with a graphite impregnated stainless steel spiral wound design. Primary coolant leakage in a high temperature area, will cause the boric acid to boil and concentrate, increasing its corrosiveness and acidity. Uncorrected, the boric acid crystals may accumulate and block cooling passages.

Though only two plants use the rack and pinion CEDM, failures of the rotating seals used in the mechanism accounted for 60% of the CE primary coolant leakage occurrences. Cracked pressure housings resulting from stress corrosion cracking has also been identified on the rack and pinion CEDMs. The design of this CEDM is conducive to this type of failure if the drives are not adequately vented.

Immovable control rod assemblies caused by fractured internal CRDM components were also reported. These fragments became lodged between the roller nuts and the leadscrew, preventing movement. Plant operational procedures were modified to include visual verification of proper CRDM component alignment each time a CRA was coupled to a CRDM.

d) *Rod Position Indication* - Due to the redundancy provided by the two position indication systems, RPI failure primarily resulted in a redundancy loss, and operational procedure changes designed to verify the proper positioning of the rods while the RPI system is inoperable. The location of the reed switches in the same severe environment as the CRDM has been the primary failure cause. Moisture intrusion has caused reed switch corrosion. Failures of the CE Control Element Assembly Calculator (CEAC) has resulted in reactor power reductions and subsequent scrams. The CEAC monitors CEA position in the core and provides this information to the Core Protection Calculator (CPC). The CPC, based upon this information, provides overly conservative penalty factors to the automatic protection and control systems resulting in the power reductions and scrams.

e) *Control Rod Assembly* - Failures of the control rod assemblies and the fuel assembly and upper internal guide tubes may be significant since they can interfere with or prevent the insertion of the CRAs. A CE plant recently reported the failure of a control rod due to the radiation induced swelling of the B4C poison. This resulted in an increase in the clad stress which eventually led to the propagation of a crack around the rod. The lower portion of the rod and the poison pellets fell out of the rod into the guide tube, preventing the insertion of the CRA. Subsequent inspections revealed other similarly cracked rods. Other instances of immovable CRAs due to loose parts in the reactor core being wedged between the rod and the guide tubes, were noted.

CE fuel assembly guide tubes have also experienced through wall wear caused by the control element rods. When fully withdrawn, the tips of the rods remain engaged with the upper portion of the fuel assembly guide tube. Flow induced vibration caused by the coolant was the root cause of the failure. To prevent this wear, a stainless steel sleeve is inserted in the upper portion of the guide tubes. Though CE has subsequently modified the fuel flow characteristics of the fuel assembly to preclude this type of wear, the sleeves are still being used.

Since 1980, B&W plants have reported 64 instances of cracked fuel assembly hold down springs. Though none of these cases has interfered with control rod insertion, they remain a cause of concern. Due to the close proximity of the hold down spring with the control rods, failures resulting in the displacement of spring material may interfere with the movement of the control rods.

In addition to the sub-system failures, the operational experience review also demonstrated that the CRD system was susceptible to failures and degradation due to human error and inadequate maintenance. Examples of these were errors during the performance of normal system maintenance and refueling operations. System maintenance errors typically resulted in dropped or slipped rods, while errors during refueling resulted in damaged CEDM extension shafts. Numerous instances of Technical Specification violations, primarily due to missed surveillance intervals, were also noted.

A significant number of failures were also reported which either gave no failure report or listed the cause as unknown. These occurrences resulted in significant plant effects, and on several occasions, similar failures were reported before the root failure cause was determined. As noted, this may be indicative of an inadequate root failure cause program. Though the modularized design of many electrical components allows easy replacement, efforts to identify and correct the failure causes are still needed.

CURRENT UTILITY INSPECTION, MAINTENANCE, AND SURVEILLANCE PRACTICES

An operating survey was conducted to obtain information on current utility system maintenance and inspection practices. Responses were received from two B&W plants, and four CE plants (representing eight units). Meetings were also held with cognizant vendor system design personnel.

Combustion Engineering and Babcock & Wilcox recommended annual system inspections are listed in Table 1. The majority of the recommended inspections are electrical. The actual inspections performed on the control rod drive system, as determined by the survey, are provided in Table 2. A comparison between these tables indicate that not all of the vendor recommended system maintenance is actually performed.

Most utilities commonly use meggering to check electrical integrity of the system components. Meggering is a go/no-go test which is not capable of providing data which can be trended to detect age degradation. Also, failure of meggering is not conclusive of component failure, since moisture intrusion will result in low megohm readings. CE plants obtain gripper coil traces each cycle. These traces document the current and actuation time of each of the gripper coils. The results are visually compared to those obtained from the previous cycle. CE recommends that traces which represent a 10% difference be dispositioned by them. Again, aging degradation may not be clearly discernable from this type of test.

Visual inspections for primary coolant leakage are conducted following each cycle. If the leakage is judged unacceptable (>1 gpm.) the mechanism is removed, and the gasket replaced or weld repaired. The lack of space between mechanisms on the top of the reactor head makes this inspection very difficult to perform.

Visual inspections are also performed on the vent valve for any leakage indication. If the leak cannot be readily corrected, some utilities have seal welded the valve shut. CE recommends that the internal ball and o-ring be replaced each time the valve is used.

All respondents reported as being in compliance with the ten year ISI inspections applicable to CRDMs. The current requirement is that only 10% of the peripheral housings be inspected every 10 years. Given the continued instances of housing defects and failures, modification of this requirement should be considered to include interior mechanisms as well.

The majority of the respondents reported that they do not have a reliability program. Such a program should be established, and include accessing one (or more) of the operating data bases. This would result in a more efficient predictive maintenance program capable of alerting utility personnel to failures at other plants, and allowing for corrective maintenance before component failure. Relying solely on vendor supplied information may not be timely enough.

The use of commercially available, advanced system monitoring and inspection techniques should be evaluated for use with the CRD system. These methods are non-invasive, and capable of detecting and trending age degradation. These methods include infrared thermography for electronic components, motor current signature analysis to verify proper CRDM mechanical operation, and alternatives to meggering, [such as Electronic Characterization and Diagnostics (ECAD)] for assessing electrical integrity.

CONCLUSIONS

The results of this NPAR study show that aging degradation and failures have occurred in both the B&W and CE Control Rod Drive Systems. Though these occurrences have not prevented the system from performing its primary safety function, they do present unnecessary challenges to the operation of other plant safety systems when they result in unplanned reactor scrams. As the results of the utility survey indicate, CRD aging has been recognized and is being addressed, to varying degrees, by the utilities' inspection and maintenance programs. However, aging degradation and failures are still occurring. The results of this study highlight these areas, and recommendations are provided regarding preventive and predictive maintenance which may further reduce aging failures.

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DISCLAIMER

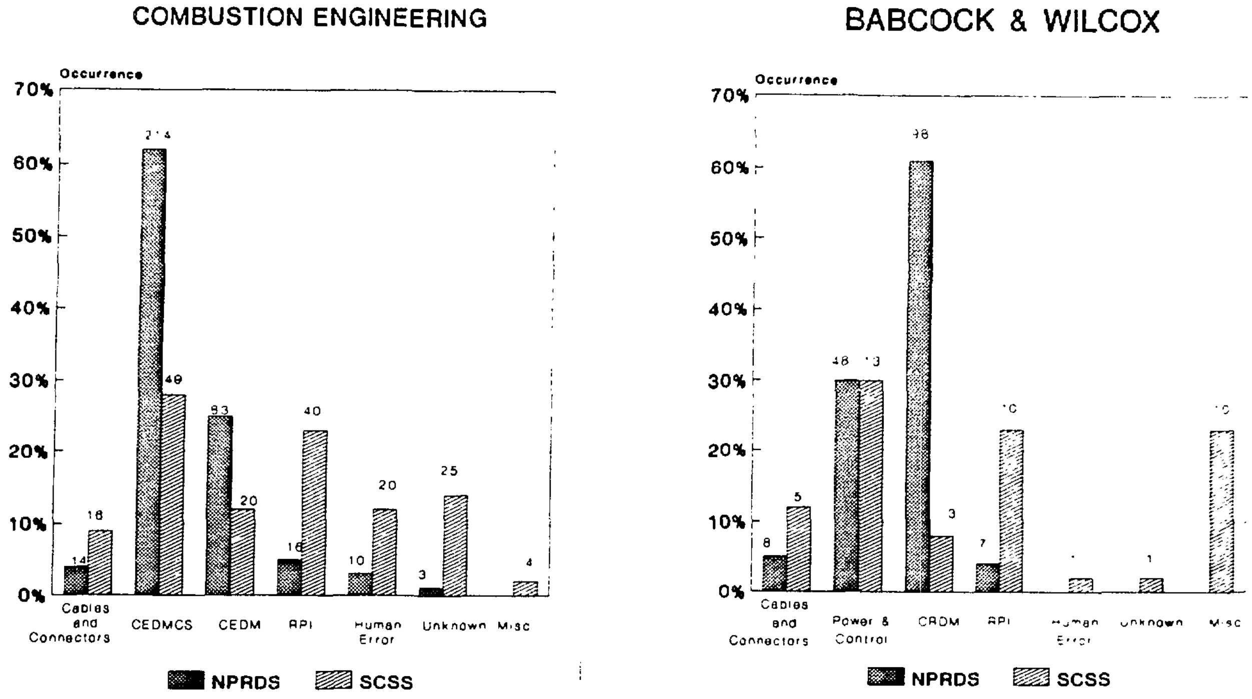

Figure 3. CRD Sub-system Failures

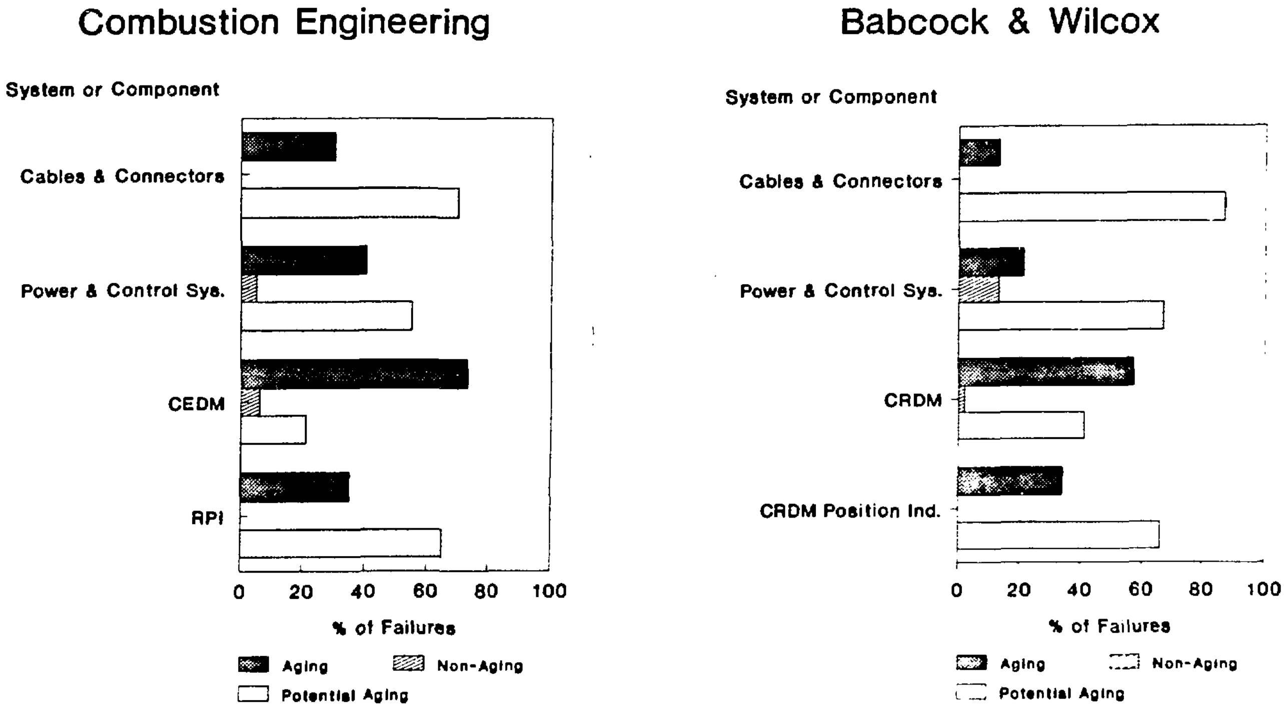

Figure 4. CRD System Failures Due to Aging

Table 1. Recommended CRD System Annual Preventive Maintenance

Combustion Engineering

- I. Gripper Coils
  - a) Coil Operating Traces
  - b) Coil Resistance
  - c) Visual Inspection (in the event of CEDM Cooling System degradation)
- II. Vent Valve
  - a) Replace O-Rings
  - b) Replace Stainless Steel Sealing Ball
- III. Drive Shafts
  - a) Visual Inspection (when upper reactor internals are removed)

Babcock & Wilcox

- I. Stator
  - A. Electrical Tests
    - 1. DC Resistance
    - 2. Insulation Resistance
    - 3. Thermocouple Resistance
  - B. Functional Tests
    - 1. Minimum Run Current
    - 2. Latching and Unlatching Current

Table 2. CRD System Preventive Maintenance Performed by Survey Respondents

CRD Inspection	B&W Plants		CE Plants			
	A	B	C	D	E	F
Control Rod Drive Visual Inspection			X	X		
CRD Pressure Housing 10 Year ISI	X	X	X	X	X	X
CRD Flange Inspection	X	X	X	X	X	X
CRDM Vent Valve Inspection			X	X		
Stator Coil						
- Visual Inspection					X	
- Electrical (Meggering)	X	X	X	X	X	
Electrical Cables						
- Insulation Integrity	X	X	X	X	X	
- Electrical Connectors	X	X	X		X	
- Moisture Seal Integrity	X		X			
Power Supply Inspection	X	X	X	X	X	X
Electronic Cabinet Inspection	X				X	X
RPI						
- Visual Inspection	X					
- Electrical Test	X				X	X
CRDM Cooling System			X	X	X	X
Control Rod Assembly, Fuel Assembly Guide Tube			X		X	
System Tests						
- Position Verification	X	X	X	X	X	X
- Rod Drop Time	X	X	X	X	X	X
- CRA Exercising	X	X	X	X		X