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SPECIAL STUDY REPORT

POTTER & BRUMFIELD MODEL MDR ROTARY RELAY FAILURES

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Reactor Operations Analysis Branch
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of Operational Data

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EXECUTIVE SUMMARY

About 3000 Potter & Brumfield, model "MDR" series rotary relays are installed in 16 Westinghouse, 10 General Electric, 8 Combustion Engineering, and 1 Babcock & Wilcox nuclear power plant units. They are used in both safety-related and nonsafety-related applications including reactor protection systems, emergency core cooling systems, engineered safety feature systems, and emergency power systems.

All MDR relays were constructed of the same materials, making each subject to the same failure mechanisms. Similar failures have occurred in ac; dc; latching; and non-latching, normally energized and normally de-energized relays. About 124 such failures occurred from 1984 through 1992. About 1/3 of these occurred in 10, multiple-relay, simultaneous-failure events. Five of these events involved simultaneous failures of redundant actuated components. Failures were often not detected until relay operation was tested or demanded and some MDR relays failed to reset after testing. A number of failures were nonrecoverable, because of specific relay function. A number of these failures defeated the single failure assumption relied on in nuclear power plant designs.

The mechanisms that caused these failures were influenced by a number of variables making the failure of a specific relay unpredictable. The failure mechanisms include:

Material Problems

1. Mechanical binding of the rotor shaft may slow or prevent the shaft from fully rotating when the relay coils are energized or de-energized. This is caused by deposits from coil varnish outgassing and chlorine corrosion from rubber grommets and polyvinyl chloride wiring on the end bell bearings and brass sleeves as the relay breathes. (MDR relays made prior to 5/90)

2. Intermittent continuity and high resistance of electrical contacts may occur from chemical reactions on the fixed and movable silver contacts with sulfur from the coil varnish outgassing. (MDR relays made prior to 5/90)

3. Failure of ac MDR relays to reset may be caused by detachment and wedging of a copper shading coil between the rotor and the stator. This may occur when the epoxy, attaching the shading coil to the stator, cracks due to temperature-induced expansion, stretching and vibration. (MDR relays made prior to 1/92)

4. Relay actuation may be prevented due to chlorine induced stress corrosion cracking of rotor return springs, permitting a broken spring part to lodge between the rotor and stator. (Applicable to 172 MDR relays made in 1992)

5. Binding of the rotor at ≥137° F due to insufficient shaft end-play may be caused by an oversized coil, over-shimming, and tolerance stackups. (MDR relays made in 1992)

6. Rotor response time may be slowed at lower temperatures (e.g., 40° F), due to uncured epoxy on the stator interfering with rotor movement. (MDR relays made in 1992)

7. MDR relays may be unable to meet 40-year life span under all environmental conditions due to aging of several relay materials.

Misapplication problems

1. Increased contact resistance may be caused by switching low level loads that permit contact resistance to build up.

2. Intermittent contact continuity may be caused by contact erosion in direct current applications where there is a substantial difference between the relay contacts' ac and dc current ratings and inductive loads not included in the circuit design.

3. Contact failure may be caused by paralleling sets of relay contacts to switch loads greater than a single set can handle, when lack of simultaneous contact opening results in one contact taking all the load.

Potter & Brumfield has implemented a series of design and manufacturing modifications since 1985 to eliminate a number of these failure mechanisms in their MDR relays due to design, manufacturing, and material defects. Although many of the MDR relays were purchased as 1E components, Potter & Brumfield was cited in 1992 for not informing licensees of these problems in accordance with 10 CFR Part 21 and currently manufactures them only as commercial grade products.

This study suggests that:

A supplement to NRC Information Notice 92-04 be issued to inform all commercial nuclear power plants licensees of the additional MDR relay failure mechanisms identified since the Information Notice was initially issued.

An increase in reliability and a reduction in challenges to safety-related systems could be effected by replacing MDR relays, subject to the dependent failure mechanisms identified above, that are relied upon to actuate or operate safety-related systems.

Licensees may benefit from performing more root cause analysis of relay failures, increasing contact with relay and NSSS vendors, and submitting more detailed NPRDS reports to identify and minimize common-cause failures in the future.

ACKNOWLEDGEMENTS

River Bend Station personnel identified the common-cause failure of several Potter & Brumfield MDR relays and brought this to the attention of the NRC through a Licensee Event Report. We appreciated Mr. Don Jernigan's invitation to visit River Bend Station to better understand the relay's failure mechanism. We thank Mr. Ronnie Cole for his explanation of the failures and their potential affect on a boiling water reactor.

We very much appreciate the efforts of Mr. Kamalakar Naidu of the NRC's Vendor Inspection Branch in meeting with Mr. William Lamb's staff at the Potter & Brumfield offices to better understand the MDR relay's operation, design, and modification history and in the Information Notices regarding their failures.

We thank Joe Rimsky at Susquehanna Steam Electric Station for his assistance in providing information about their multiple MDR relay failures, and Tom Payne and Bob Murillo of Waterford 3 and Marty Ryan, et al. of Combustion Engineering for providing and discussing their MDR relay failure analyses.

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ABBREVIATIONS

AEOD	Office for Analysis and Evaluation of Operational Data
APS	Arizona Public Service Co.
B&W	Babcock & Wilcox Co.
BOP	balance of plant
BWR	boiling-water reactor
CE	Combustion Engineering, Inc.
ECCS	emergency core cooling system
EDG	emergency diesel generator
ESFAS	engineered safety feature actuation system
ESF	engineered safety feature
GE	General Electric Company
GSU	Gulf States Utilities
HRL	Hi-Rel Laboratories
LER	licensee event report
NPRDS	Nuclear Plant Reliability Data System
NPP	nuclear power plant
NRC	Nuclear Regulatory Commission
NSSS	nuclear steam supply system
P&B	Potter & Brumfield
PWR	pressurized-water reactor
PRA	probabilistic risk assessment
RPS	reactor protection system
RTB	reactor trip breaker
SRV	safety relief valve
W	Westinghouse Electric Corporation

1. INTRODUCTION

Potter & Brumfield (P&B) [owned by Siemans] makes a series of "MDR" rotary relays. These are used in many safety-related applications in commercial nuclear power plants (NPPs) with reactors manufactured by the Babcock & Wilcox Co. (B&W); Combustion Engineering, Inc. (CE); the General Electric Company (GE); and the Westinghouse Electric Corporation (W). They are relied on in reactor protection systems (RPSs), emergency core cooling systems (ECCS), and engineered safety feature (ESF) systems.

This study was initiated as a result of River Bend Licensee Event Report (LER) No. 91-14, which described two similar MDR relay failures that caused spurious ESF actuations within a 4-day period. An initial search of industry data showed that many MDR relay failures occurred repeatedly in a wide variety of MDR relay series with similar symptoms. Therefore, the Nuclear Regulatory Commission (NRC), Office for Analysis and Evaluation of Operational Data (AEOD) reviewed and participated in followup work that the licensee and P&B performed on these and other River Bend P&B MDR relays.

Palo Verde 1988 failure analysis reports and P&B engineers contributed to the identification of several common-cause failure mechanisms. In July 1991, San Onofre prompted a P&B investigation into its MDR ac rotary relay shading coil failures. An NRC onsite study of Susquehanna's analysis of their MDR relay performance in November 1992 found simultaneous common-cause failures.

This study describes P&B MDR series rotary relays, explains their failure mechanisms, lists MDR relay modifications to avoid such failures, and traces MDR relay failure history from LERs, industry data, reactor vendor guidance, NRC inspection reports, NRC site visits, and manufacturer relay design modifications. It identifies the safety significance of potential simultaneous common-cause failures of multiple MDR relays used in safety-related applications and decisions licensees have made.

2. DESCRIPTION

2.1 "MDR" Rotary Relay Description

The P&B "MDR" series rotary relays are dual-coil rotary relays. P&B technical data and sketches of these relays are contained in Appendix A. These describe various series of relays rated for 28 and 125 V dc, and 115 and 440 V ac service, with 4 to 24 contacts. The relays are furnished in either a latching or a non-latching two-position version. While each series has different coil wattage and current capacities, they are constructed of the same materials, depending upon the manufacturing date, and are therefore subject to identical failure mechanisms.

2.1.1 Latching Relay

A "latching" MDR relay has two sets of coils, connected in series inside the relay, which provide a latching two-position operation. When one set of coils is energized, the rotor shaft rotates, changing the state of the contacts. The other set of coils must be energized to return the relay to its original position.

2.1.2 Non-Latching Relay

A "non-latching" MDR relay has two coils connected in series inside the relay which, when energized, rotate the relay rotor shaft, to operate the contacts through a shaft extension. The stator faces and stop ring limit the rotor movement to a 30-degree arc. Two springs return the rotor to the stop ring and the contacts to their normal positions when the coils are de-energized. The non-latching MDR relays have two positions: "energized" and "de-energized."

2.1.3 AC Relay

P&B MDR ac rotary relays also have two shading coils mounted on stator pole pieces to eliminate the heat generation and vibration of ac buzzing of the relay. A shading coil is an elliptical, 0.06 oz. ring, 1-1/2 inch long by 3/8-inch wide in the middle, which is fitted into a slot on the stator pole and secured with epoxy beads at the top and bottom of the pole. When the relay is energized, the two shading coils are also held in place by the rotor contacting with the stator.

2.2 Dependent Failure Mechanisms

NUREG/CR-5993, "Methods for Dependency Estimation and System Unavailability Evaluation Based on Failure Data Statistics," July 1993, defined "dependent failure" or "common-cause failure" as failure of several components due to a common-cause. This NUREG relaxed the conventional assumption that dependent failures must be simultaneous and result from a severe shock. It recognized that component failure rates will increase, that the components will eventually fail at some short interval from each other, and that the common-cause contribution for a particular plant may be quite different from the population average.[1]

These distinguishing characteristics were found in the MDR relay failure history; of 124 failures that occurred due to the causes described below, from 1984 through 1992, about 1/3 occurred during 10, multiple-relay, simultaneous-failure events. In five of these events multiple, simultaneous, MDR failures caused the failure of other redundant components in redundant trains of safety systems.

Each MDR relay is constructed of the same materials, making each subject to identical failures. A series of LERs, P&B investigations, independent laboratory analyses, and reactor vendor generic reports indicate that a number of discrete failure mechanisms affected the operation of certain P&B model MDR rotary relays in similar ways. Similar failures have been found to have occurred in ac; dc; latching; and non-latching, normally energized and normally de-energized relays.

Each MDR relay failure had a single root cause (i.e., the basic reason for failure, which if corrected, could prevent recurrence) or "coupling factor/mechanism" (which explains why and how a failure is systematically induced in several components). A number of failure mechanisms have been identified which cause dependent MDR relay failures:

Material Problems

1. Mechanical binding of the rotor due to organic outgassing and deposition of contaminants and corrosion particles. The contaminants accumulated on the rotor shaft, upper and lower bearing races, magnet, coil, top brass plate, and brass spacers as the relay breathes. This has also produced shaft wear and metal chips in some cases, which could also bind the shaft. The binding caused the rotor shaft to bond or stick to the bearing, preventing the rotor shaft from rotating and the contacts from opening or closing when the relay coils are energized or de-energized. The binding failures ranged from slow shaft rotation, to partial rotation, to being completely frozen in place.

The principal contaminant, which was not always apparent to the naked eye, was outgassed material emitted from the brown enamel varnish used to coat the relay coils.

Chlorine and sulfur, released from the Neoprene rubber grommets and the polyvinyl chloride wiring sleeves, and moisture from relay breathing corrosively attack the metallic components of the relay and the corrosion by-products combine to penetrate the bushings surface to prevent operation of the relay.

P&B has changed the coil coating from varnish to epoxy, brass components to stainless steel, and other wiring materials to eliminate chlorine, as listed in Section 2.3. (MDR relays made prior to 5/90)

2. Intermittent continuity and high resistance of the electrical contacts resulting from chemical reactions on the fixed and movable silver contacts with sulfur from the coil varnish outgassing. P&B found intermittent continuity on used as well as unused contacts and changed movable contacts from silver to silver-cadmium-oxide, as described in Section 2.3. (MDR relays made prior to 5/90)

3. Failure of ac MDR rotary relays to reset due to the detachment of a shading coil and its wedging between the rotor and the stator, preventing full rotor shaft rotation and contact opening or closure. The copper stator mounted shading coils are very susceptible to temperature-induced expansion/stretching. When the epoxy used to attach it to the stator becomes brittle due to the heat and expansion forces, it cracks, permitting the shading coil to detach.

P&B changed the shading coil from copper to beryllium-copper, as identified in Section 2.3. (MDR relays made prior to 1/92)

4. Relay actuation may be prevented from chlorine induced stress corrosion cracking of rotor return springs, permitting a broken spring part to lodge between the rotor and stator. (172 MDR relays made in 1992)

5. Binding of the rotor at higher temperatures (e.g., 137° F), due to insufficient shaft end-play may be caused by an oversized coil, over-shimming, and tolerance stackups. (MDR relays made in 1992)

6. Rotor response time may be slowed at lower temperatures (e.g., 40° F), due to uncured epoxy on the stator interfering with rotor movement. (MDR relays made in 1992)

7. MDR relays may be unable to meet 40-year life span under all environmental conditions due to aging of several relay materials.

Misapplication problems

1. Increased contact resistance may be caused by switching low level loads.

2. Intermittent contact continuity may be caused by contact erosion in direct current applications where there is a substantial difference between the ac and dc current ratings of the relay contacts and inductive loads not included in the circuit design.

3. Contact failure may be caused by paralleling sets of relay contacts to switch loads greater than a single set can handle, when lack of simultaneous contact opening results in one contact taking all the load.

A number of "proximate causes" (i.e., conditions that are readily identifiable as leading to failure) contributed to the timing of MDR relay failures and reduced the operating life of the P&B MDR rotary relays. These include coil wattage, applied ac or dc voltage, equalizing voltages and frequencies, normally energized or de-energized coils, manufacturing tolerances, ambient and coil temperatures, varnish thickness, mounting configurations and enclosures, cabinet ventilation, bearing opening size for relay breathing, testing frequency, operational cycling, number of contact decks, and the amperage and voltage applied to the contacts. These factors may contribute to an apparent random failure history, especially between plants. Routine surveillance testing may not necessarily reveal a degraded condition, as the relay may degrade when it is reset after testing.

The reports from the data sources were sufficient to be able to determine if an MDR relay failure was a dependent failure by root cause analysis conclusions or the relay's characteristic dependent failure systems. The remainder were judged to be independent failures. Using all the failures in a time continuum to estimate the potential for multiple failures in a window of time arrives at a more accurate value for system unavailability.[2]

2.3 MDR Relay Modifications

P&B modified the design of their production model MDR rotary relay over a period of years to improve its reliability, while maintaining a standardized product. These modifications are listed in chronological order in Table 2-1.

Table 2-1 P&B MDR relay modifications

Date	Modification
10/85	Movable contacts changed from silver to silver-cadmium-oxide
02/86	Coil finish changed from Dolph BC-340 varnish to Dolph CC-1090 epoxy
08/86	Elastic stop nuts changed from stainless steel to nickel plated steel
11/86	Switch mounting studs redesigned for press fit into switch plate
03/87	Paint from light gray alkyd to light gray polyurethane enamel
06/88	NYE Nyogel 718B grease lubricant added to end bell bearing
10/88	Coil leadwire sleeving changed from PVC coated fiberglass to polyester acrylic coated fiberglass
12/88	Paint changed from light gray polyurethane enamel to light gray alkyd
06/89	Coil leadwire grommets changed from neoprene to polyetherimide
06/89	Coil finishing tape changed from polyester film to polyimide film
06/89	Magnet wire changed from nylon jacketed polyurethane to modified polyester with a polyamid-imid jacket
05/90	Rotor spacers and spring retainer changed from brass to stainless steel
05/90	Shims changed from brass to phosphor bronze
01/92	AC relay shading coil changed from copper to beryllium copper

3. DISCUSSION

This section traces the history of MDR relay failures and their affect on safety systems through LERs submitted to the NRC, industry data, independent failure analyses, reactor vendors response to MDR relay failures, and NRC site visits. The safety significance of the relay's failure has been included.

3.1 LaSalle Unit 1

On December 8, 1987, with LaSalle Unit 1 in cold shutdown, a "1A" emergency diesel generator (EDG) operability surveillance test was performed. When the operator tried to synchronize the EDG to its bus, its output breaker would not close, despite several attempts. The cause of the event was the failure of a P&B model MDR-137-8, 125 V dc normally-energized relay's contacts to close.[3] This relay failure could prevent the operation of the EDG in the event of a loss-of-offsite power.

Because the failure was of an intermittent nature, it was believed to be the cause of a previous event on September 17, 1987.[4] Testing after this prior event could not duplicate the failure to determine its cause.

Another similar event had occurred on January 14, 1986 on Unit 2 and the licensee replaced a P&B model MDR-138-8 relay.[5]

As a corrective action, the licensee committed to replacing all the P&B MDR relays in the output breaker closing circuits with GE HFA relays to improve the EDG output breaker closing circuitry reliability. The NRC staff has received no reports of relay failures at LaSalle Unit 1 affecting EDGs since the MDR relays were replaced.

3.2 Palo Verde Units 1, 2, and 3

Palo Verde Units 1, 2 and 3 use P&B MDR rotary relays in the nuclear steam supply system (NSSS), engineered safety feature actuation system (ESFAS), the balance of plant (BOP) ESFAS, and the reactor trip switchgear.

On August 3, 1988, Arizona Public Service Co. (APS) submitted LER No. 88-18, Rev. 0 as a 10 CFR 21 report on 15 P&B MDR relay failures occurring at Palo Verde Units 1, 2, and 3 over a 2-year period, that could have prevented the fulfillment of various safety functions.[6] This was detected during either routine surveillance testing or during actuations of the ESFAS. The relay failures would have prevented the associated valves, pump motors, etc. from operating as required for a safe plant shutdown or to mitigate an accident. The failure of the MDR relays in the reactor trip switchgear would result in erroneous indication of reactor trip breaker (RTB) position to both the plant protection system and the control room operators.

The MDR relay malfunctions occurred when the relays did not change position after they were de-energized, preventing safety equipment from actuating as required. Failed relays were submitted to two independent laboratories for failure analyses.

Several MDR-7032 rotary relays, examined by Scanning Electron Analysis Lab, were found to have brown powdery material (varnish) in the magnet, coil, and top brass plate areas. They found evidence of shaft wear and metal chips, but no evidence of corrosion on the shaft or brass bushings. The lab concluded that contaminants led to wear and binding of the shafts.

Other relays, MDR-7032, -7034 and -136-1 were sent to Hi-Rel Laboratories (HRL) for failure analyses. Three of these could not move more than 12 degrees of the complete 30 degree arc. Internal inspection found corrosion of the rotor, the dome-shaped metal shield over the coils, and the upper and lower races. There was extensive chlorine contamination on the brass races, the armature and the metal coil shield. The lab believed that these corrosion products may have mechanically bound the relays in the energized positions.

APS tested seven of the 18 failed relays on an 18 month frequency, while 10 were tested on a 62 day frequency.

The licensee found that the failure rates for these MDR relays ranged from $1.4x10^{-6}$ to $1.36x10^{-5}$ failures per hour, compared with a generic relay average of $4.0x10^{-7}$ failures per hour.

On October 10, 1988, APS submitted LER 88-18, Rev. 1 on 18 P&B relay failures. The impact of coil voltage on the relay was investigated and identified as one of the root causes of the failures. Excessive voltage increased the temperature of the coil and increased the outgassing rate. The rated coil voltage was 28 V dc, but voltage was measured at an average 31 V dc, after CE changed power supplies to 36 V dc to alleviate problems which had been experienced with relay pickup at other CE plants.

Another contributor to the premature failures investigated was the operating environment. The P&B specification for ambient temperature requires that ambient temperature be maintained less than 149° F; the NSSS ESFAS cabinets ambient temperatures were measured between 95° and 104° F. The NSSS ESFAS cabinets did not have forced ventilation; the external surface of a relay in this cabinet was 157° F.

The BOP ESFAS cabinet in Unit 2 had an ambient temperature of 81° F, while the maximum external surface temperature of a relay in this cabinet was 112° F. The BOP ESFAS cabinets had forced ventilation. The BOP and reactor trip switchgear ESFAS cabinets had no MDR relay failures while all the failures occurred in the NSSS ESFAS cabinets.

The revised LER stated that "the cabinet air temperatures, air flow, and normal frequency of operation were not considered significant contributors to the relay failures" and the root cause of the outgassing was attributed to excessive coil temperatures that occurred when the coils were continuously energized at voltages above their nominal ratings.

While this LER specifically addressed P&B MDR-7032, MDR-7033, and MDR-7034 relays, it also indicated that all models could be subject to the same failure mechanism due to the similarities in construction and materials. There are 342 relays in the NSSS ESFAS systems, 180 in the BOP ESFAS systems, and 12 in the reactor trip switchgear systems for the three Palo Verde units. All but six of these relays are normally energized.

As a long term corrective action, APS committed to replacing all MDR series relays in all their systems during each unit's next refueling outage. The following design changes to the MDR series relays were to be implemented:

- Relays in the NSSS ESFAS cabinets were to be modified to increase the nominal voltage rating.

- Coils were to be the high temperature version instead of the previously supplied standard coil.

- PVC sleeving used as an insulator inside the coil was to be replaced with polyester acrylic coated fiberglass.

- Neoprene grommets were to be replaced with polyether imide.

- Medium MDR brass contact studs were to be replaced with stainless steel.

- Small MDR spring retainer was to be stainless steel.

- Spacers were to be stainless steel instead of brass.

- Shims were to be phosphor bronze instead of brass.

- Coils were to be coated with an epoxy resin instead of varnish.

- Lubricant was to be used on some metallic surfaces.

- Contact deck and plate to shaft clearance was to be enlarged.

On August 24, 1988, the NRC determined that a generic communication on this issue was unnecessary. This decision was based on the root cause of the outgassing, which was incompletely understood as excessive temperatures in coils continuously energized at above-design voltages. This over-voltage condition affected only two other CE plants, who were already aware of the issue.[7]

On April 24 and 25, 1989, 10 of 44 modified MDR relays tested in Palo Verde Unit 3 had problems within their first week of continuous energization. Five totally failed due to a complete lack of rotation on de-energizing the coils. The failures were not isolated to any particular model number or circuit location. On May 8, 1989, HRL reported the results of failure analyses on three of these improved MDR-7062 and -7063 rotary relays to APS[8]. The rotor shaft did not move when power was removed and reconnected to two relays which had failed functional testing by APS. A third relay was "sluggish" (i.e., experienced delayed turn off after removal of power).

Epoxy was found on the stator faces and mating rotor breaker plate. It was believed that epoxy had been deposited on the stator surface and laminations during the relay manufacturing process. There was no corrosion, contamination or chemical degradation found.

Six additional MDR-5146, -7064, and -7065 operable relays were subsequently inspected by HRL and found to have tearing of the fiberglass cloth tape on the coils, brown spot discolorations on rotor laminations (on three of six relays), and epoxy buildup on top of coils and the coil retainer plates, but no epoxy on the stator or rotor interface.

As part of this investigation, Engineering Research Group[9] independently attributed the failures to the curing of the epoxy on the closed rotor-stator interface during initial actuation of the installed relays. This caused the rotor and stator to bond together after sufficient energization time elapsed to cure the epoxy, thereby preventing free rotation of the rotor by spring pressure when the coil de-energized.

A number of factors were determined to contribute to this failure mechanism during the manufacturing process:

- Epoxy was splashed on the stator when the lead wires were pulled into the stator assembly to coat both sides of the coils with epoxy.

- Epoxy was used for touch up of coil surfaces after the two cure cycles, but did not receive addition cure time in an oven.

- The stator and coil assemblies were placed in and removed from the oven to cure the epoxy with the same gloves by P&B personnel.

- P&B stored the Dolphon epoxy in normal room ambient conditions, instead of below 70° F, as recommended by the manufacturer, decreasing its shelf-life.

To eliminate these factors, P&B instituted new methods of epoxy storage, handling (including coating and curing of the epoxy prior to mounting the coil on the stator assembly) and black light inspection. Touching up coil assemblies using epoxy was discontinued. Calculations by the Engineering Research Group verified that a 6-hour cure time was sufficient to cure the Dolphon CC-1090 epoxy in the MDR relays, even given temperature uncertainties. P&B uses atmospheric dip impregnation of the MDR relay coils, in accordance with the epoxy manufacturer's recommendations[10].

3.3 Combustion Engineering

On August 5, 1988, CE submitted a letter[11] to the NRC regarding the APS 10 CFR 21 report of August 3, 1988, described above. This letter identified four units, Arkansas Nuclear One Unit 2, San Onofre Units 2 and 3, and Waterford Unit 3, as being facilities that also had P&B MDR-7032, -7033, and -7034 relays in their ESFAS.

3.4 Information Notice No. 90-57, "Substandard, Refurbished Potter & Brumfield Relays Misrepresented as New"

NRC Information Notice No. 90-57, "Substandard, Refurbished Potter & Brumfield Relays Misrepresented as New," concerned modified or refurbished P&B MDR relays, including but not limited to, MDR-138-8, MDR-173-1, MDR-134-1 and MDR-142-1, that may not operate as required. Stokley Enterprises or the Martin Company supplied these relays to Shearon Harris, Watts Bar and Sequoyah and various vendors to nuclear plants. Receipt inspection found them to be improperly adjusted, lacking lubrication, having nonstandard parts, having incorrect and nonoriginal configurations, and failing one or more P&B tests.

3.5 General Electric Rapid Information Communication Services Information Letter No. 53

On September 10, 1990, GE published a Rapid Information Communication Services Information Letter (RICSIL) No. 053,[12] as a result of two GE boiling-water reactors (BWRs') reports of failures of P&B MDR relays. P&B performed a failure analysis of the rotary relays, which concluded that:

> ... corrosion occurred from chlorine released from rubber grommets and polyvinyl chloride sleeving. Also, outgassing occurred from varnish on the coil while continuously energized. The released chlorine and outgassing accumulated in the area of the bottom end bell bearing and caused the rotor shaft to bond to the bearing.

P&B believed that "the failed relays were exposed to high ambient temperatures and possible high coil voltages or exceptionally infrequent de-energizing." To eliminate outgassing, P&B changed the finish coating used on the relay coil from varnish to epoxy on relays manufactured after September 10, 1986.

3.6 General Electric Potentially Reportable Condition 90-11

On November 1, 1990, GE issued Potentially Reportable Condition 90-11 concerning P&B MDR relay failures due to outgassing.[13] In a cover letter to River Bend, GE concluded that the P&B failure mechanism "did not constitute a significant safety hazard," and hence was not a reportable condition. This conclusion was based on the following analysis:

1. A GE BWR/4 reported that 3 of 18 P&B MDR, 125 V dc, 15.6 watt, normally energized relays failed and 4 others exhibited rotor binding. Since these relays were used to monitor position rather than actuate valves in the primary containment isolation system, GE concluded no safety problem occurred. GE noted that plants frequently exceed the 125 V dc nominal coil voltage because plants typically maintain a full battery charge.

2. A GE BWR/6 used seven 125 V dc relays, three in the Remote Shutdown System and four in the RPS. Five were normally de-energized and were not considered to be vulnerable to this failure mode. A failure of the two normally-energized relays may have resulted in failure to initiate Backup Scram when required by the RPS. Since the backup scram was functionally redundant to the normal scram, GE concluded that no substantial safety hazard existed.

3. GE BWR plants used P&B MDR relays with a 24 V dc, 9.6 watt coil. GE considered that the 24 V dc supply was carefully regulated and was not identified as a problem by P&B. Therefore, GE did not consider them vulnerable to this failure mode and concluded that no safety concern existed for the 24 V dc relays.

4. The most frequent use of MDR relays was 120 V ac in the RPS and NSSS. These had a coil power of 6.0 watts, the nominal voltage of 120 V ac was carefully regulated, and were typically exercised monthly. GE concluded these had not experienced a high failure rate.

GE calculated the qualified life of a 125 V dc relay coils with varnish to be 0.4 years, while field experience demonstrated 3 years or more without similar reported failures.

GE recommended licensee confirmation that normally energized P&B MDR relays: (1) were being exercised during routine operation or periodic testing, (2) were not in high ambient temperatures, and (3) were not subject to sustained overvoltage conditions.

3.7 Harris Unit 1

On April 12, 1991, Carolina Power & Light Company, the licensee for Shearon Harris NPP Unit 1 (W) issued LER 91-5 addressing entry into Technical Specification 3.0.3 due to the failure of a P&B MDR relay.[14]

On March 13, 1991, while at 96 percent power, during an engineering performance test conducted on the 1B-SB Emergency Bus Load Sequencer, a P&B MDR-138-8 relay failed to function as required. While the relay energized and rotated, two contacts in the relay failed to pass current. This rendered the "B" train ESF components actuated by this sequencer inoperable. If a loss-of-offsite power had occurred concurrent with a safety injection signal, control room operators would have still had the ability to manually start any required "B" train ESF components. During this time period, the "A" train charging/safety injection pump was also inoperable for maintenance, necessitating entry into Technical Specification 3.0.3.

The "A" train charging/safety injection pump was restored and Technical Specification 3.0.3 was exited within 10 minutes. The 1B-SB sequencer was restored to operable status 5-½ hours later after replacement of the faulty relay and subsequent testing.

The failed relay was later bench tested and all contacts operated properly; the cause of failure was not determined, but was attributed to a random, intermittent failure.

3.8 San Onofre Units 2 and 3

San Onofre Units 2 and 3 each used four P&B model MDR-170-1 ac rotary relays to actuate the RTBs. Each relay actuated two RTBs through contacts in the undervoltage and shunt trip device circuitry. All 3-1 automatic reactor trip signals were processed through these relays, which were normally energized with closed contacts.

During a surveillance test in the summer of 1991 (contradictory documentation exists regarding the unit number and date of test), one of these RPS relays failed to reset following the successful RPS surveillance testing. This maintained the two open RTBs in the tripped condition and caused the one-amp power supply circuit breaker to open on overcurrent. These relays were supplied by P&B as commercial grade components and dedicated by the licensee for use in the safety-related RPS. These relays were installed in mid 1989, to solve the problems identified with varnish offgassing.

Failure analysis of the failed relay revealed that both shading coils had become detached due to a design deficiency. The failure to reset was caused by a shading coil falling between the rotor and the stator when the relay was de-energized, preventing enough rotor travel to change the relay contact positions on re-energization. An inspection of the other three relays found that a shading coil had completely detached from one relay and another coil was loose on the stator of a second relay. The copper shading coil appeared to be extremely susceptible to temperature-induced expansion/stretching and vibration. The epoxy used to attach the shading coils became brittle due to heat and cracked under the excessive copper expansion. The failure at San Onofre occurred after the relay had been continuously energized for over 18 months. This problem also affected MDR-141-1 model relays, used in a nonsafety-related pressurizer level system to control back-up and proportional heaters.

A loud buzzing or chattering of the relay during energization may be a sign of shading coil detachment. The symptoms given for several 115 and 120 V ac relay failures listed in Appendix C, "P&B MDR Relay Failure Data," may have been caused by this failure mechanism.

By December 1991, P&B had stopped production and changed the shading coil to beryllium copper, a harder material that would not stretch as much as copper, to avoid this problem.

Although Southern California Edison did not consider their failures to be reportable to the NRC under 10 CFR Part 21 at San Onofre, they recommended that P&B formally notify their customers that procured these model relays of the potential shading coil detachment problem on March 3, 1992.

3.9 River Bend Unit 1

On August 16, 1991, Gulf States Utilities (GSU), the licensee for River Bend (GE BWR/6) issued LER 91-14, Rev 0, addressing two separate ESF actuations within 4 days, due to P&B MDR relay malfunctions having the same failure mode, while the plant was at 100 percent power. The final revision of this LER, Rev. 3, was issued August 18, 1992.[15]

On July 19, 1991, ESF actuation of numerous containment isolation valves, control room filter trains, standby gas treatment system, and the fuel building filter trains occurred during a surveillance test, when two switches were taken to their test position. This was due to a high resistance on one set of contacts on a normally energized, 24 V dc, MDR-5111-1 relay, which caused an excessive voltage drop on downstream relays, causing them to drop out, which resulted in the isolations. Initial bench testing verified that the relay actuated and the contacts closed properly. All contacts appeared clean and shiny. There was no foreign material or residue on the shaft. The relay was operated numerous times and operated properly each time.

On July 23, 1991, an ESF isolation of a reactor water upstream sample valve occurred when a switch was taken to its test position. Investigation revealed that two contacts on an MDR-5111-1 relay were open and the coil was in its normally energized state, whereas the contacts should have been closed. Further testing determined that sometimes the contacts would close several minutes after voltage was applied and sometimes would not close at all. The temperature inside the relay housing measured 113° F.

GSU determined that 17 days prior to the July 19th relay failure, a loss of power occurred to the RPS "B" bus, which feeds the first failed MDR relay. One day prior to the July 23rd relay failure, a loss of power occurred to the RPS "A" bus, which feeds the second failed MDR relay. The RPS power losses would have resulted in the relays dropping out and picking up on power restoration a few minutes later, but it was likely that the relay cycled and all contacts did not make proper continuity.

River Bend uses a total of 132 MDR relays; 113 are 120 V ac, 12 are 24 V dc, and seven are 125 V dc. Of these, 92 are installed in the RPS, 35 in the NSSS, three in the remote shutdown system and two in the standby service water system.

River Bend calculated the internal relay temperature from their relay's dimensions and a finite-element computer model:

Relay Voltage	Relay Power (watts)	Temperature (° F)
125 V dc	15.6	149
25 V dc	9.6	135
120 V dc	6.0	127

Both of the failed relays were mounted in stainless steel "isolation cans" for divisional separation, inside the control room cabinets, where internal air temperature averaged 92° F. According to the manufacturer's specifications, the relays should have been capable of functioning properly in an ambient environment of 120° F with a minimum of

20 V dc applied to the coil and 156° F with 21 V dc applied to the coil. Voltage at the coil was measured at 21.45 V dc. Voltage was supplied by a nonadjustable, regulated dc power supply between 23.5 V dc and 26.5 V dc, which was measured at 24.19 V dc.

The root case of the failures was determined by P&B to be small deposits of material released from the outgassing of the varnished coil and chlorine corrosion of the relay shaft or bearings. The combination of varnish deposits and corrosion accumulated by the bottom end-bell bearing, resulting in bonding or sticking of the relay shaft to the bearing. The licensee noted that small deposits may not have been obvious to the naked eye, but were apparent under magnification. The relay contacts can then stick in either the normally energized or de-energized states. It is also possible for the rotary motion of the relay to be impaired such that it may not turn through its full arc of 30° F, such that some or all the relay contacts may exhibit intermittent operation.

GSU also removed six operable 120 V dc relays from service and inspected them with P&B engineers. All six tested satisfactorily. However, each was found to have deposits on the relay rotor and in the area of the end bearings indicative of the same outgassing phenomenon found on the failed relays.

GSU theorized that the 125 V dc relays were the most susceptible to this phenomenon, followed in order by the 24 V dc, and 120 V dc relays, due to the lower coil wattages indicated above. GSU's experience also supported the P&B position that the relays that are cycled most frequently are least susceptible to the failure; the River Bend relays cycled on an 18 month basis were found with heavier deposits that those which were cycled monthly. However, actual failure history did not prove this to be the case. GSU cited a number of variables which influenced the actual failure rate, which could not be quantified. These included: wattage, normal energization state, manufacturing tolerances, mounting configuration and enclosures, temperature, test frequency, operational cycling, etc. The varnish coating applied to the relay coils was done by hand without strict acceptance criteria and the varnish was supplied by a third party as an off-the-shelf item without strict control over the ingredients. The coils of the eight relays inspected displayed wide variations in varnish thickness, uniformity, and color. GSU concluded that the outgassing phenomenon led to a failure distribution that was essentially random.

GSU found two other cases of MDR relay failures at River Bend since commercial operation. These occurred on December 16, 1987, and September 15, 1988. The relay failure of December 16, 1987, was of an MDR relay which actuated the backup scram valve on any full scram signal. These failures were initially judged to be random and the relays were discarded.

GSU performed a PRA analysis of the RPS, based on River Bend MDR relay failure rates. There were a total of four failures on demand. The licensee used the River Bend surveillance test frequencies in estimating the total number of demands on the MDR relays in the RPS to be 6026. Thus, the independent failure on demand probability was 4 failures/6026 demands, or 6.64×10^{-4} failures/demand. GSU estimated the common-cause failure probability using a modified Beta approach. Since two of the four failures occurred at the same time, GSU estimated the Beta factor as 2/4. GSU assumed that the failure of two relays simultaneously was sufficient to cause system failure. GSU calculated the River Bend common-cause failure probability of the RPS to be $6.64x10^{-4}$ x 2/4 2/4 = 3.32 x 10^{-4} failures per demand. GSU calculated the RPS failure probability, using generic relay failure rates from WASH-1400, at $1.3x10^{-5}$. Thus, the use of River Bend P&B MDR relay failure rates resulted in an increase in RPS failure probability by $3.32x10^{-4}/1.3x10^{-5}$ or a factor of 25 above WASH 1400 values.

GSU committed to replace all 132 P&B MDR series relays over several refueling cycles by a prioritization list based on relay function, model number, surveillance frequency, difficulty of replacement and retest, relay voltage and wattage rating, and length of service.

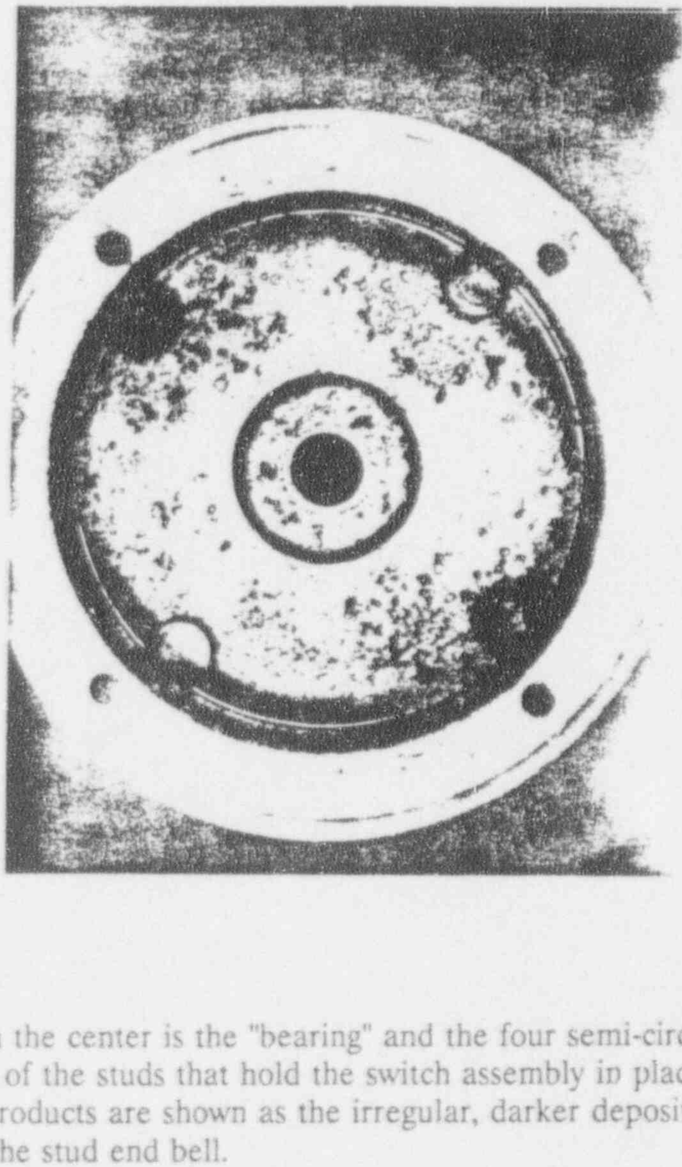
On November 14, 1991, NRC inspectors and P&B engineers disassembled several River Bend relays, including the redundant backup 120 V dc scram valve relay. This MDR relay was found to have a set of unused Deck No. 1 contacts, No. J-H, that did not make proper continuity. A P&B MDR-5112-1, 125 V dc relay, also exhibited intermittent failure of Deck No. 1, No. J-H contacts. When an MDR relay is mounted horizontally, with coil terminals at the bottom, these contacts are the top contacts closest to the bearing. If the hot coil outgassing material vents through the bearing instead of condensing on the rotor, this set of contacts would be closest to provide a cold surface for deposition. The surfaces of each set of contacts appeared shiny, but no metallurgical examination of the contact surface was performed. Figures 1, 2, and 3 show typical deposition of contaminates on an MDR relay bell, rotor, and spacer from this inspection.

The failure rates given above did not include the additional failure observed by the NRC on November 14, 1991, at P&B's test facilities. GSU determined that if this failure on demand was included, the River Bend failure probability increases to 5 failures/6027 demands or $8.3x10^{-4}$ failures per demand. If this failure was included in the determination of the failure rate per relay operating hour, that value would increase to 5 failures/5,983,956 hours or $8.3x10^{-7}$ failures per relay hour. The Beta factor would become 2/5 but failures per demand was not changed.[16]

3.10 Potter & Brumfield 10 CFR 21 Compliance

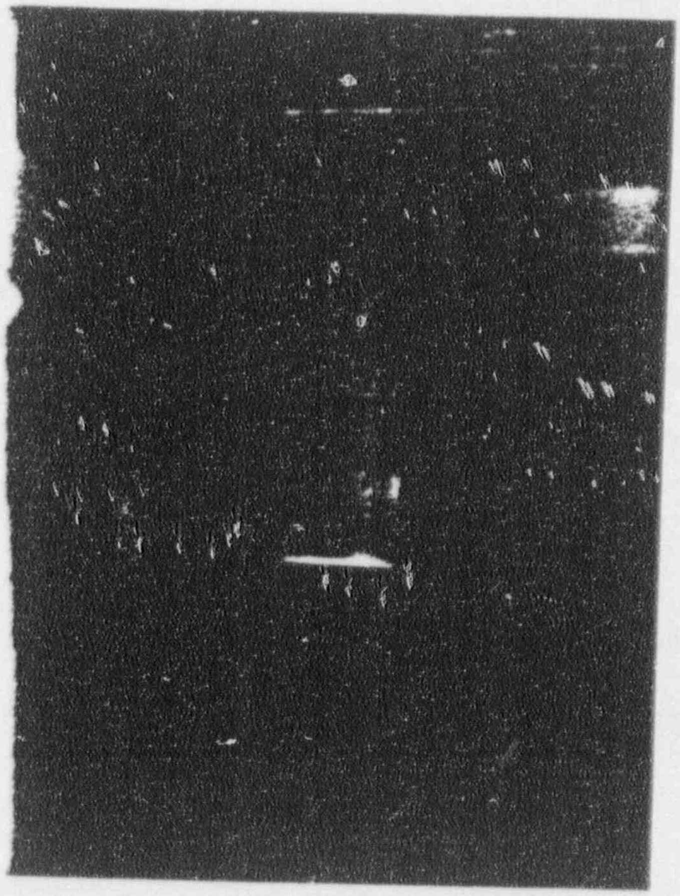
On September 6, 1991, the P&B Manager of Quality Planning wrote to the NRC that conformity to 10 CFR 21 requirements was raised approximately 3 years ago, and P&B informed several users that MDR series relays are supplied only as commercial grade equipment. However, the G.E. Nuclear Energy Division (GE) was overlooked as one of the users governed by the NRC requirement. The P&B sales personnel were reminded to immediately take exception to any terminology referring to safety-related products.[17]

An NRC inspection of P&B, conducted on November 12-14, 1991, determined that P&B had previously produced the MDR rotary relay as 1E and had a procedure that P&B thought complied with 10 CFR 21. GE's purchase orders to P&B referenced the relevant MDR relay drawing number, which contained all the technical requirements and included a statement that the relay was a Class 1E component. P&B did not inform GE



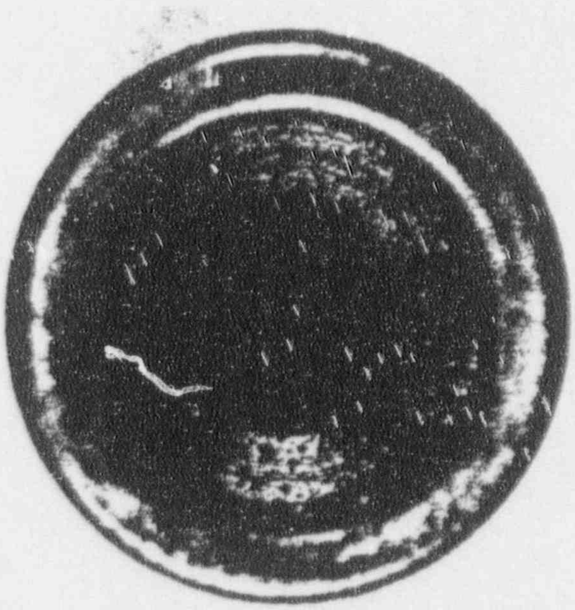
The hole in the center is the "bearing" and the four semi-circular areas are the bottom of the studs that hold the switch assembly in place. Varnish and corrosion products are shown as the irregular, darker deposits on the inside surface of the stud end bell.

Figure 3-1 P&B MDR relay stud bell and bearing assembly



The two dark bands on the rotor assembly lower shaft is the area in the relief spaces of the bottom spacer. Varnish and corrosion deposits are shown on the lower section of the rotor assembly lower shaft as irregular lighter areas above and below the lower dark band.

Figure 3-2 P&B MDR relay rotor assembly



The dark circle in the center of the bottom spacer is the hole for the rotor assembly upper shaft. The next concentric circular area is the relief area of the bottom spacer, where varnish and corrosion product deposits are shown as irregular lighter areas. The outer concentric circular area is the bottom spacer mating surface with the bottom shock plate, which is free of deposits.

Figure 3-3 P&B MDR relay bottom spacer

November 18, 1992 that caused the loss of a pressurizer heater control circuit. The failure analysis showed that the failure could have been caused by chlorine induced stress corrosion cracking of a rotor return spring, which allowed a broken part of a spring to lodge between the rotor and stator, preventing the relay from actuating. It was found that this could have occurred during the wire manufacturing process or as a result of improper passivation in removing surface contamination. Other spring samples from the same lot supplied by the Lewis Spring Co. verified this conclusion.

The investigation also found that a circuit board failure elsewhere in the system caused the relay to chatter for two weeks before its failure. Thus, the relay could have had hundreds of thousands of cycles on it when it failed, whereas P&B qualifies the relay to 100,000 cycles.

ABB CE submitted a 10 CFR Part 21 Report to the NRC on this issue, as being applicable to 172 relays with date codes between 09228 and 09251 (manufactured from the 28th week to the 51st week in 1992), and concurrently prepared a CE Infobulletin for distribution to all CE plants.

3.20 Overall Industry Experience

About 3000 MDR series rotary relays are used in safety-related applications in RPSs, ECCSs, ESF systems, or emergency power systems in at least 35 commercial NPP units: 1 B&W pressurized-water reactor (PWR), 8 CE PWRs, 10 GE BWRs, and 16 W PWRs. Many identical MDR relays are used in nonsafety-related applications.

MDR relay failure numbers, failure rates, and other derived statistics presented in this section, should be viewed with caution. They are based on the best information available from the Nuclear Plant Reliability Data System (NPRDS), LERs, NRC site visits, and NRC inspection reports, but are known to be incomplete for a variety of reasons:

- Searches of the primary information source, the NPRDS database, contained the warning that relays were among specific components that are "reportable only on failure," that "population data is generally incomplete," and that "results may be incomplete."

- Inconsistencies in MDR relay usage and failure data were found between the voluntary NPRDS database and information provided by some licensees to the NRC. Several licensees were found to have a much larger number of MDR relays in service than listed in the NPRDS database population figures, as described in Section 3.20.4 of this report. Several licensees have listed only one MDR relay failure in a questionable population of one relay. One licensee submitted only 1 failure report out of 16 MDR relay failures (many nonsafety-related). Sixteen units have not reported any MDR failures, whereas 15 plants have had more than a 100 failures. At least one plant replaced all normally energized MDR relays after a 1983 industry publication. In addition, the industry database does not contain information on the many identical MDR relays used in nonsafety-related applications or their failures.

- P&B provided MDR relays as "1E" or commercial grade relays to reactor vendors, architect engineers, and licensees but were often unaware of which plant received specific relays.

- Industry and LER data repeatedly noted that a failed MDR relay bench tested acceptably. The LaSalle Unit 1 LER experience noted in Section 3.1 of this study demonstrated the difficulty of determining the root cause of an intermittent problem, which does not reoccur during trouble shooting.

- Licensee event reporting under 10 CFR 50.73 and 10 CFR 21 has not been complete. Licensees identified and reported only 2 of 10 common-cause events involving simultaneous failures of 2 or more MDR relays.

3.20.1 MDR Relay Usage

Appendix B of this report provides a list developed from the NPRDS database, LERs, NRC site visits, and NRC inspection reports, describing P&B MDR relay usage. Without verifying every power plant, this Appendix provides an estimate of the number of safety-related MDR relays in use, the safety-related systems they serve, the model numbers of the failed relays reported from 1984 through 1992, and plant-specific failure rates based on the incomplete data, as described above.

Because many of the plants having MDR relays went into service after 1984, plant specific failure rates were calculated from the time of initial criticality through 1992, for lack of better operational information. It is recognized that plant specific failure rates contain an error because an indeterminant number of MDR relays were in service for an undetermined period prior to initial criticality in some undetermined coil energization state, which has not been considered in the failure rate calculation.

Figure 3-4, "P&B MDR Relay Usage and Failures vs Reactor Supplier," and Figure 3-5, "P&B MDR Relay Failures vs Model No.," were derived from the data in Appendix B to compare MDR usage and failures by reactor suppliers and model numbers.

Figure 3-4 shows that CE plants have the highest failure rate of 82 out of 1097 relays, followed distantly by GE plants with 35 out of 1088 relays. This may be only partially explained by CE's use of excessive voltage on 28 V dc relays to ensure the relays latched. Why W plants experienced only 8 failures out of 802 relays has not been explained.

Figure 3-5 shows that the dependent failure mechanisms described in this study affected many different MDR relays used in NPPs, as may be expected, because of identical construction materials and configuration that contribute to the identified failure mechanisms. The MDR dc relays shown with higher numbers of failures were widely used in CE plants, where excess voltage was applied to the coils.

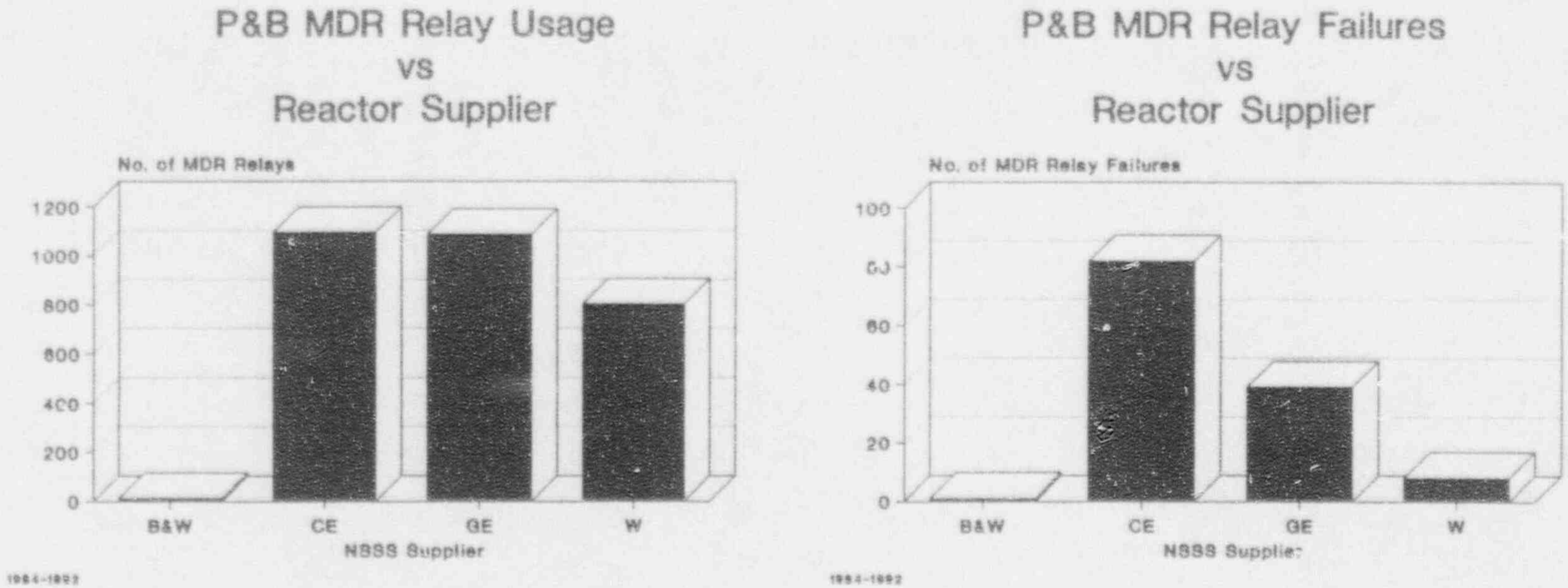


Figure 3-4 P&B MDR relay usage & failures vs reactor supplier

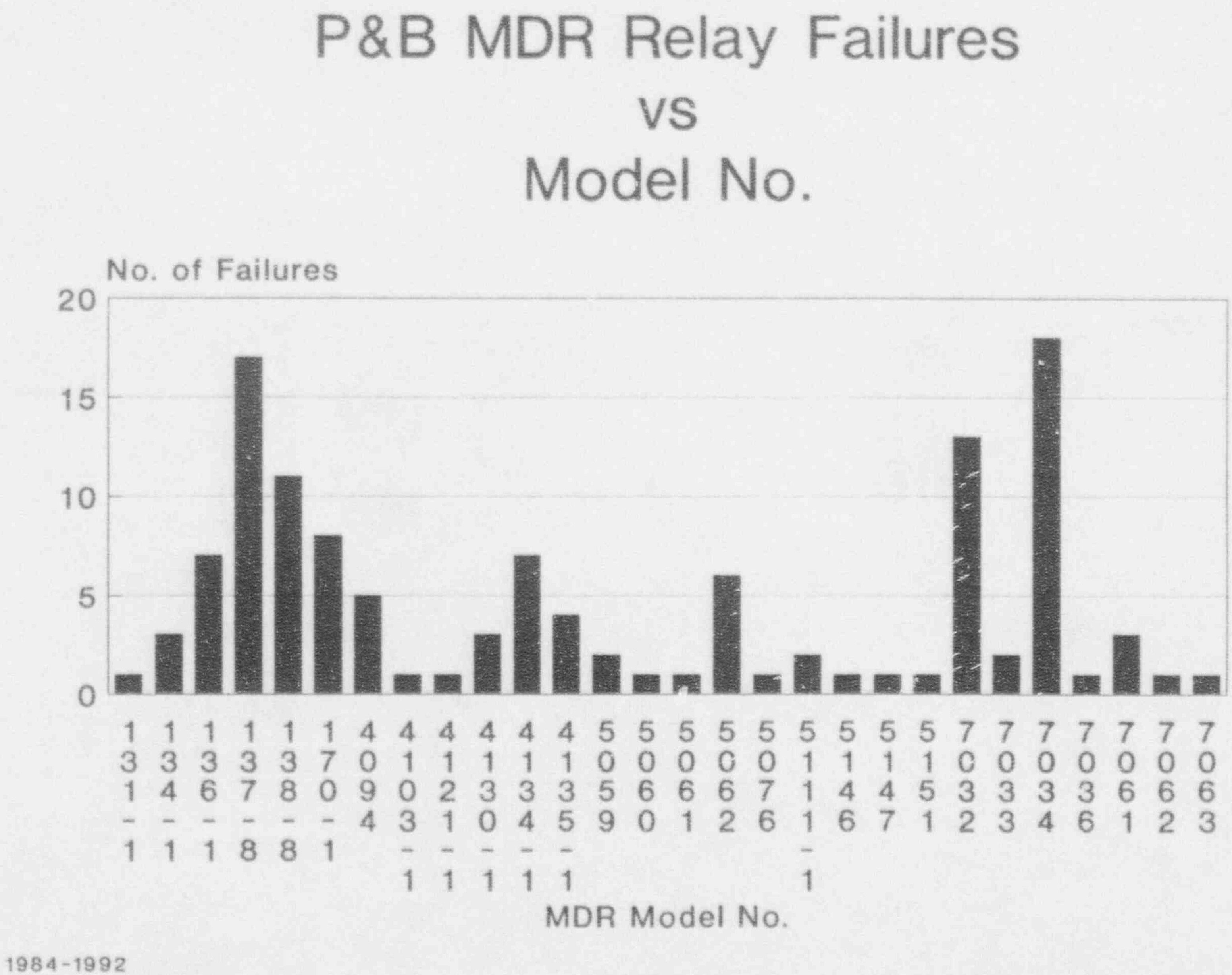


Figure 3-5 P&B MDR relay failures vs model number

3.20.2 Dependent Potter & Brumfield MDR Relay Failures

Appendix C lists P&B MDR rotary relay failures by model number and date of failure, from the NPRDS database, LERs, NRC site visits, and NRC inspection reports. This Appendix lists only failures that were identified as common-cause failures or whose failure symptoms appeared to be caused by the dependent failure mechanisms described above. Licensees often treated MDR relays as disposable components, their failures as random, and usually performed little root cause analysis, unless many failures occurred. Licensees rarely returned MDR relays to the vendor or an independent laboratory for analysis. Licensee explanations of failure causes in the NPRDS database were sometimes not very descriptive, viz, "contacts sticking," "failure to change state," "acting abnormally," or "premature end-of-life."

Of the 99 MDR relay failures listed in the NPRDS database, 7 MDR relay failures, attributed to lose connections, diode failures, blown fuses, or uncertainty of MDR relay failure, were not included in this table. About 25 percent (32) of the MDR failures were added from licensee-supplied, NRC documentation sources, which were often not as well documented as those from the industry database. This also contributed to incomplete tabulations in some of the comparison figures in this study.

P&B MDR Relay Failures by Year

Table 3-1, "P&B MDR Relay Failures by Year" compares the number of MDR relay failures by year, coil voltage, and energization state. MDR relays have averaged 13.7 failures per year or 5.E-7 failures per hour per relay since 1984, using all the data in this table. A least squares fit of a straight line shows a slight upward trend to this failure data.

While varnish offgassing is affected by coil temperature, Figure 3-6 "P&B MDR Relay Failures vs Coil Parameters," taken from Appendix C and Table 3-1, does not show a relationship between higher coil wattages (with higher temperatures) and MDR failures, as may have intuitively been expected. While the charts show that normal energization of MDR relays has a greater correlation with MDR relay failures, it also includes more than 25 percent (32) of the MDR relay failures that were in normally de-energized ac and dc relays. More than 70 percent (21) of normally de-energized MDR relay failures occurred to non-latching relays, while less than 30 percent ([illegible]) of the normally de-energized relay failures occurred in latching type relays, which have either of two coils continuously energized. This may reflect that some normally de-energized relays may be normally energized during plant outages. Thus, normally de-energized MDR relays should not be ignored by licensees in responding to NRC IN 92-04.

The highest number of MDR relay failures occurred in 1987 (23), 1988 (25), and 1989 (18), reflecting the excessive voltage applied to the MDR coils at CE plants for several years and the replacement of these relays. If this can be viewed as premature aging of the relays, based on operation at higher coil temperatures similar to environmental qualification testing, this experience may predict increasing MDR failure rates at some point in the future, as the coils age naturally. The total number of failures increased each year from 6 in 1990, nearly doubled in 1991 to 11, and tripled in 1992 to 18.

Table 3-1 P&B MDR relay failures by year

Year	Coil Type[1]		Normal Coil State[2]		Total Failures
	ac	dc	Energized	De-energized	
1984	1	4	4	1	5
1985	4	6	4	6	10
1986	2	6	6	2	8
1987	5	13	13	5	23
1988	5	20	15	10	25
1989	2	15	12	5	18
1990	1	4	4	1	6
1991	5	6	9	2	11
1992	7	9	15	2	18
Total	32	83	82	34	124[3]
Percentage	(28%)	(72%)	(71%)	(29%)	

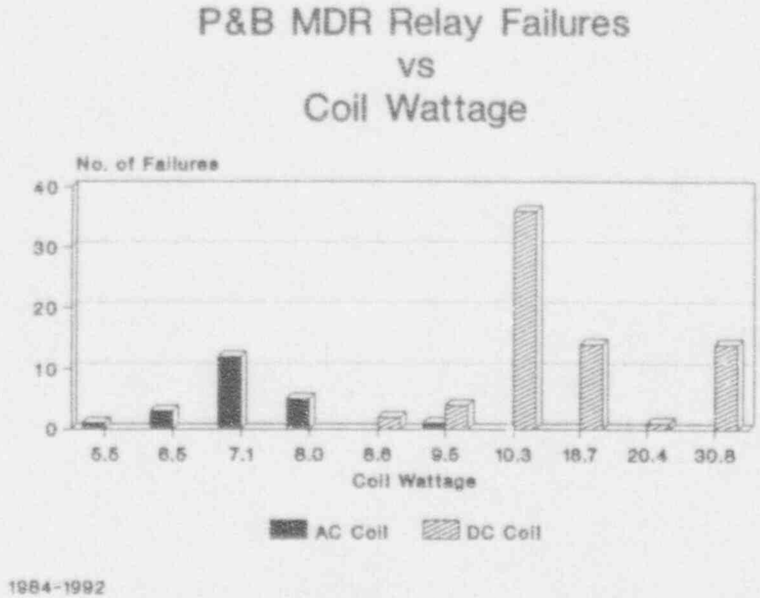
[1] Missing data prevents AC and DC coils and coil state columns from always adding up to the total number of relay failures.

[2] See Figure 3.6 for graphical representation of this data.

[3] This total does not include two MDR relay failures that occurred in early January, 1993, that are included in Appendix B.

3.20.3 Simultaneous Dependent Potter & Brumfield MDR Relay Failures

NUREG/CR-5993, "Methods for Dependency Estimation and System Unavailability Evaluation Based on Failure Data Statistics," July 1993, relaxed "the conventional assumption that dependent failures must be simultaneous and result from a severe shock" and allowed use of "all the failures in a time continuum to estimate the potential for multiple failures in a window of time" to arrive at a more accurate value for system unavailability. It recognized that component failure rates will increase, that the components will eventually fail at some short interval from each other, and that the common-cause contribution for a particular plant may be quite different from the population average.[27] These concepts were corroborated in this study by the identification of multiple, simultaneous MDR relay failures in addition to the many single, dependent failures found.



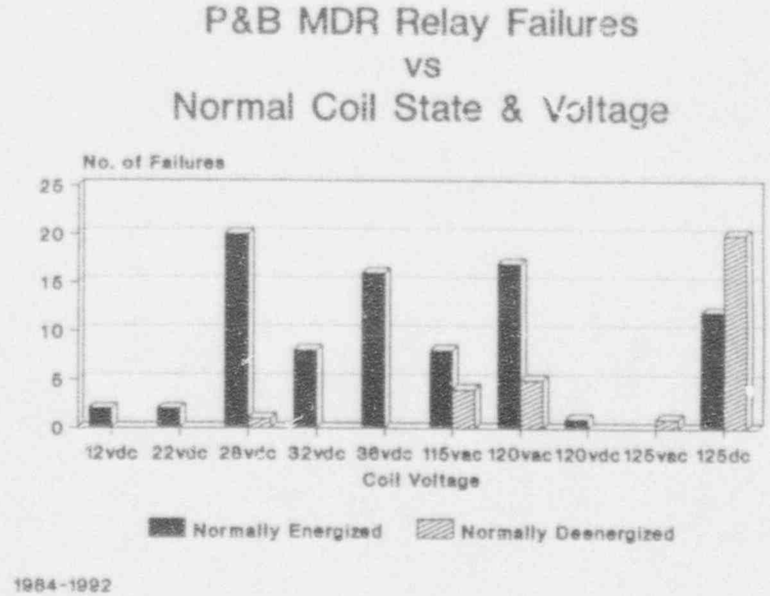


Figure 3-6 P&B MDR relay failures vs coil parameters

Appendix B identifies 26 MDR relay dependent failures that occurred in eight simultaneous-failure events. Appendix B points out five "Common Mode" events, which involved simultaneous, dependent failures of 12 MDR relays that had identical functions operating redundant equipment. It also includes three events (denoted in the table as "multiple simultaneous failures"), involving simultaneous dependent failures of 14 MDR relays that affected the same train of a system or different systems. In this table, "common-mode" and "multiple simultaneous failures" were used only to differentiate between failures that affected redundant components from failures that affected nonredundant components since each type of event may have a different safety significance.

The 26 MDR relay failures addressed in Table 3-2 are a subset representing 20 percent of the 124 dependent MDR relay failures in Appendix C of this study. There may be a number of reasons for the simultaneous MDR relay failures, including: multiple dependent failure mechanisms; relay aging; and similar environments, cycling duties, voltages, temperatures, cooling and installation.

This table does not include two other events, in which 3 and 5 relays were replaced concurrently, because the NPRDS database did not indicate that particular problems were found with more than one MDR relay. However, the identified failure mechanisms in this study often have been unreproducible during bench testing after a failure. If these were included, the percentage of simultaneous multiple failures would increase to about 26 percent of the total.

Figure 3-7, "P&B MDR Relay Failures vs Year," taken from the data in Tables 3-2 and 3-4, reflects simultaneous, multiple MDR relay dependent failure events that occurred three times in 1991 and three times in 1992, due to failures of older relays. In this figure, "single failures" refers to dependent MDR relay failures that occurred one at a time, as identified in Appendix C. "Multiple failures" is a subset of dependent MDR relay failures that occurred simultaneously to multiple MDR relays that did not affect redundant components of a specific system, as indicated in Table 3-2. "Common mode failures" is a subset of dependent MDR relay failures that occurred simultaneously to multiple MDR relays that affected redundant components, as indicated in Table 3-2.

3.20.4 Potter & Brumfield MDR Relay Failure Rates

The NPRDS database specifically noted that relays are among the components that are "reportable only on failure," that "population data is generally incomplete," and that "results may be incomplete." The least credible statistics in this study are MDR relay failure rates because of the questionable completeness of the MDR relay population and the reporting of failures.

However, best estimates were made with the available data to compare this study's MDR failure rates with the calculated NPRDS database generic relay failure rates and MDR relay failure rates. These are given in Figure 3-8, "P&B MDR Relay Failure Rates vs Year." In all but a few cases, MDR relay failure rates meet or exceed NPRDS generic relay failure rates.

Table 3-2 Simultaneous P&B MDR relay failures

EVENT DATE	PLANT/ PLANT NO.	MDR NO.	RELAY FAILURES	FAILURE TYPE	RESULT OF FAILURE
7/85	Susquehanna 1	4094	2	Common Mode	Intermittent SRV position lights
6/88	San Onofre 3[1]	137-8 138-8	5 3	Multiple Simultaneous Failures	EDG control system maintenance
6/91	No. 3	170-1	3	Common Mode	Loss of plant protection Channel C – would not reset RTB
7/91	River Bend	5111-1	2	Multiple Simultaneous Failures	1) ESF actuation of containment isolation SBGT and HVAC 2) Reactor water sample valve isolation
10/91	No. 3	170-1	3	Common Mode	Channel D and B RTBs would not energize and reset and master relay failed to close
6/92	No. 28	4130-1	2	Common Mode	Degraded "A" and "B" RPS reactor pump trip logic to turbine control valve fast closure
6/92	No. 28	4134-1	4	Multiple Simultaneous Failures	Degraded "B" RPS response to turbine control valve fast closure
9/92	Susquehanna 2	5062	2	Common Mode	Prevented reactor recirculation pump MG set 1A and 1B drive motors from tripping

	NO. OF EVENTS	RELAY FAILURES	FAILURE TYPE
	5	12	Common mode
	3	14	Multiple simultaneous failures
TOTAL	8	26*	
		*20 percent of MDR dependent failures in Appendix C	

[1] These failures were exacerbated by higher than design relay coil voltages.

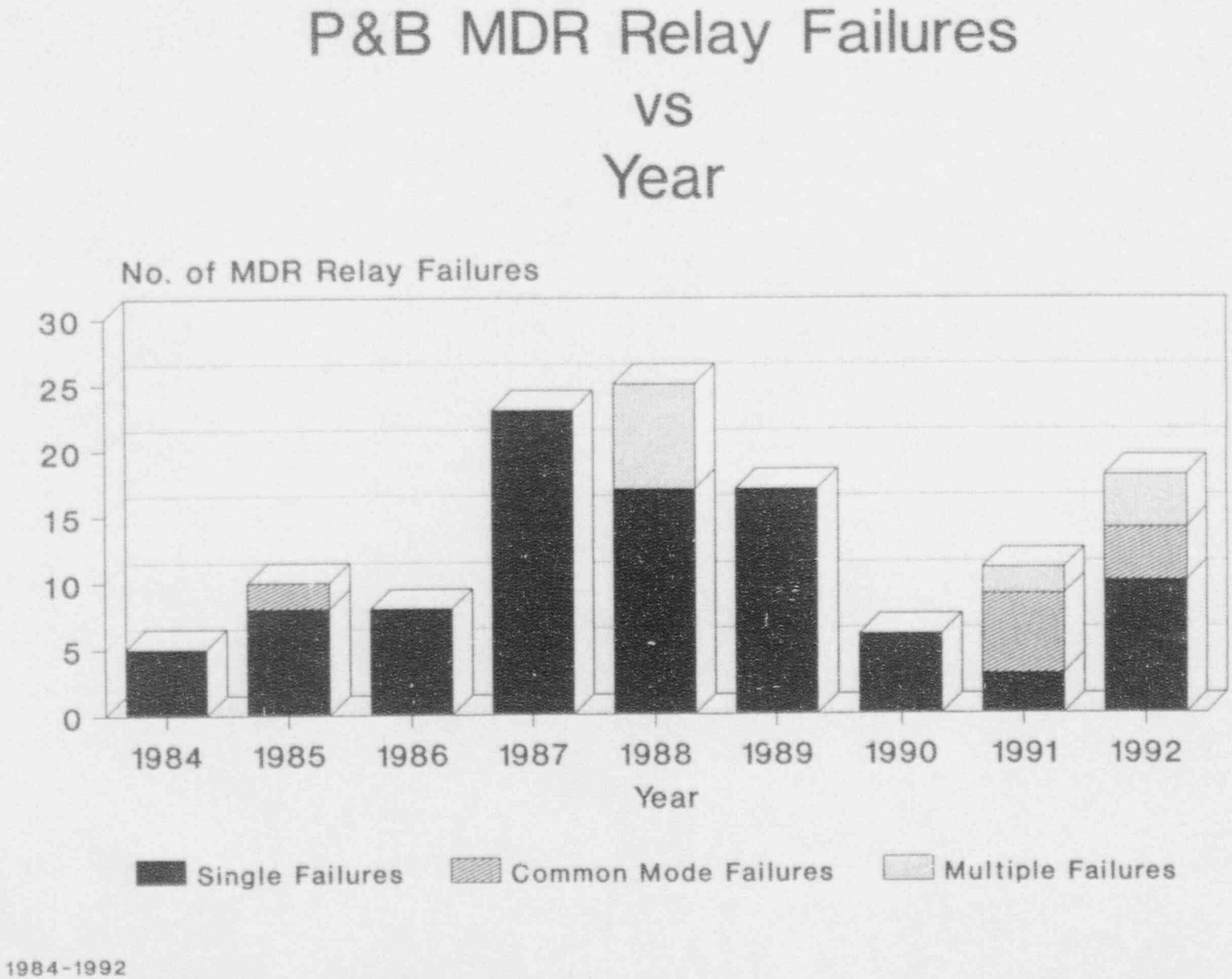


Figure 3-7 P&B MDR relay failures vs year

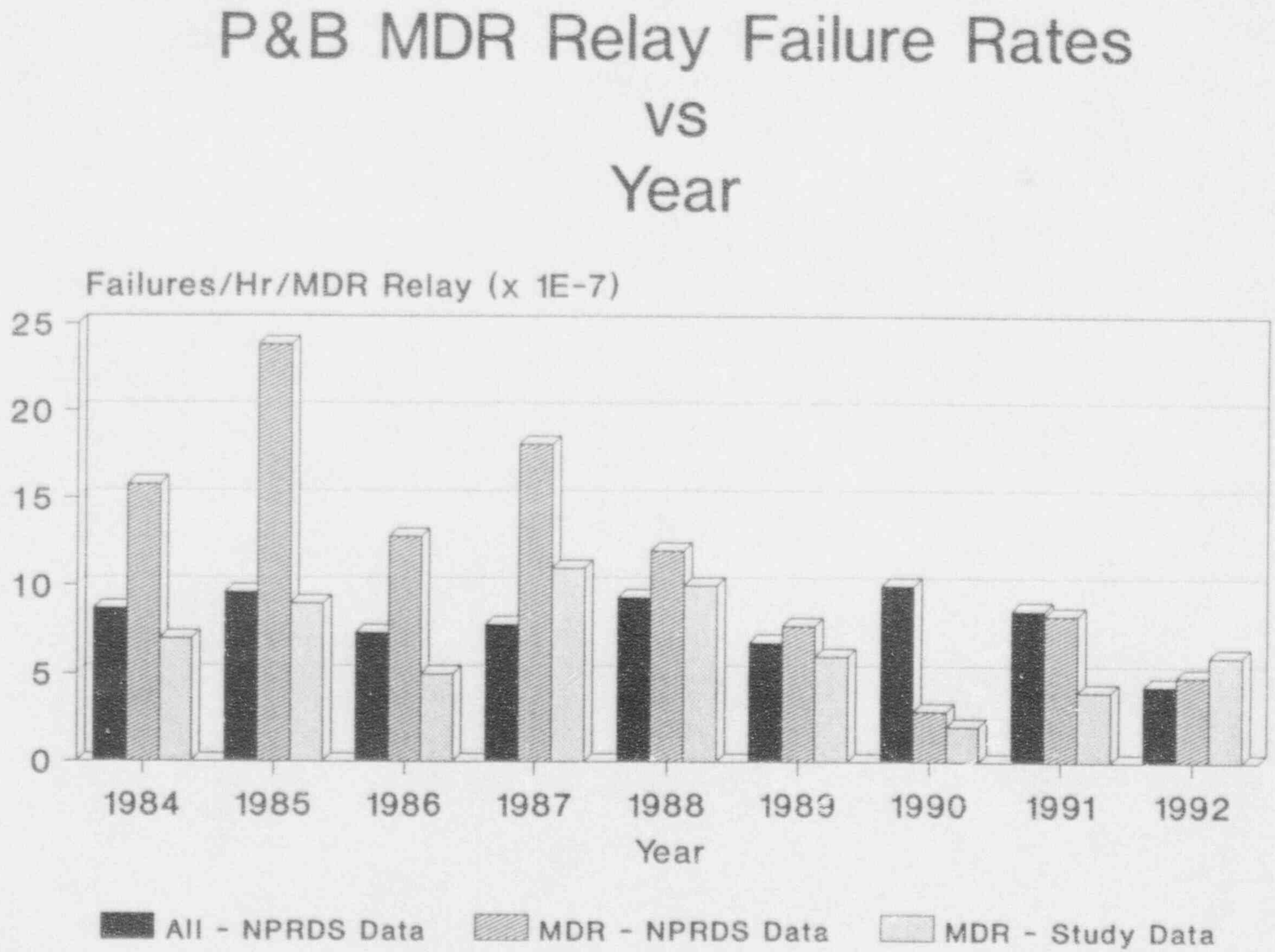


Figure 3-8 P&B MDR relay failure rates vs year

Figure 3-9, "P&B MDR Relays in Service vs Year" helps explain some of the differences between the industry database MDR relay failure rates and this study's. While the industry database included 319 MDR relays in its population in 1984, this study found 767 (140 percent more) in service. Discrepancies occurred in each year as more MDR relays were put into service. The largest difference occurred in 1989, when the database listed 2034 in service and this study found 2999. In addition, only 75 percent (92) of the MDR failures included in the 124 failures considered in this study were the same as those from the NPRDS database.

Plant Specific MDR Relay Failure Rates

NUREG/CR-5993 notes that "to evaluate the common-cause contribution in a PSA [probabilistic safety analysis], generic data sources are consulted, and they present the average behavior of a large population of plants over a long period. However, the common-cause contribution for a particular plant may be quite different from the population average. This difference can underestimate or overestimate the common-cause contribution."[28]

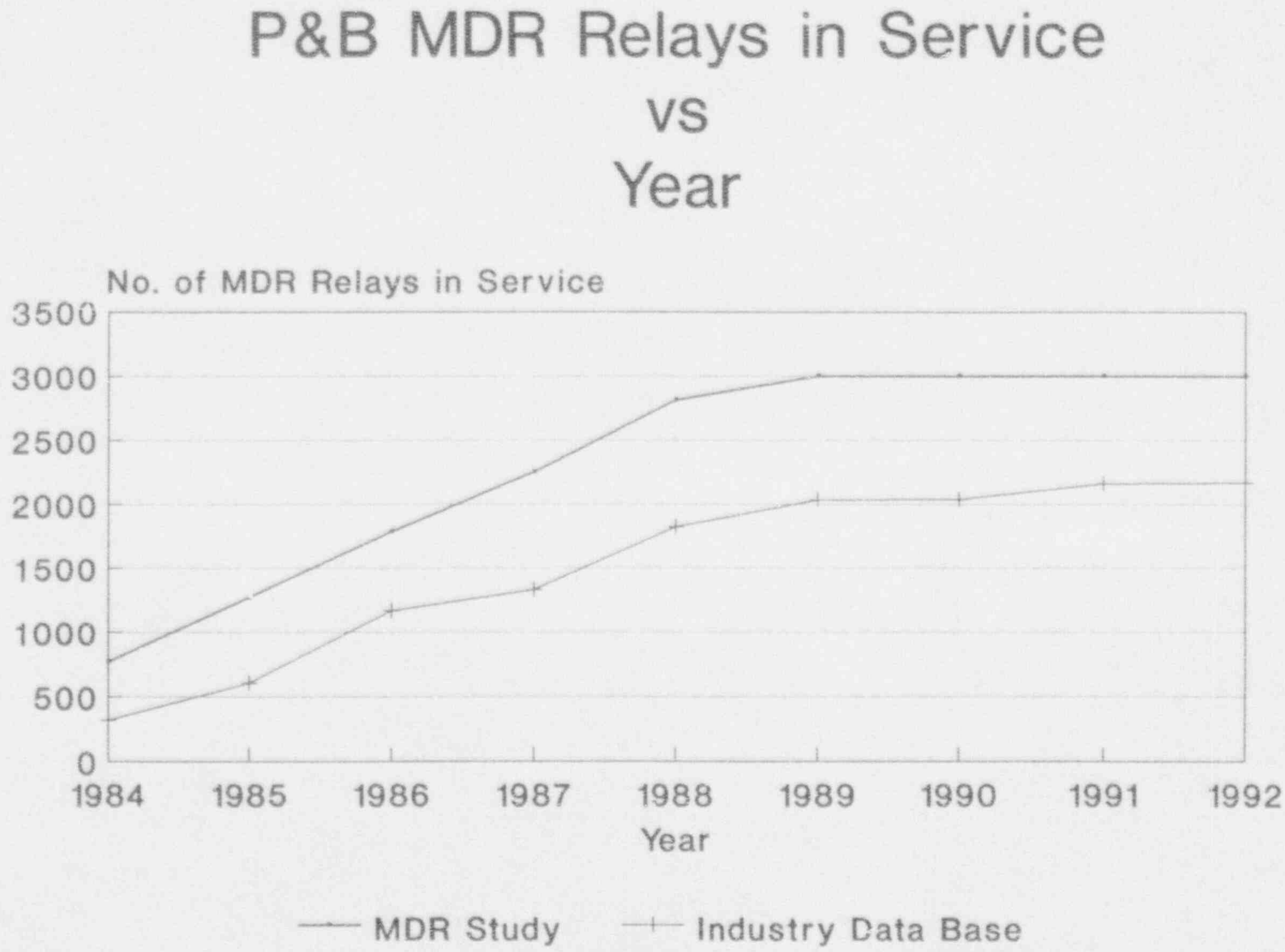
The plant specific failure rates listed in Table Appendix B were graphed vs the plant specific number of MDR relays in service in Figure 3-10, "P&B MDR Relay Failure Rate by Unit vs No. in Service/Unit." This shows the wide diversity of plant specific MDR relay failure rates, from 0 to .21 failures per year per MDR relay. This again corroborates NUREG/CR-5993 in that replacement decisions based solely on plant specific MDR relay failure rates could be expected to vary greatly.

Nine plants having 309 MDR relays in service reported no failures from 1984 through 1992, which leads to questioning the reporting accuracy. Seven other plants, with fewer than 6 MDR relays in service each (17 total MDR relays) with MDR failure rates ranging from .21 to .023 failures/year/MDR relay, may be discounted because of the lack of a statistically significant database. Using the remainder of the data on 2673 MDR relays as a sample, the average MDR failure rate was about .0068 failures per year per MDR relay (or about 18 failures per year, which is also in line with the 1992 reported MDR relay failure history).

3.20.5 MDR Relay Service Life Failure Rates

Because many of the plants having MDR relays went into service after 1984, service life failure rates were calculated from the time of initial criticality through 1992, for reasons similar to those given above for plant specific failure rates.

Figure 3-11, "P&B MDR Relay Failures vs Service Life at Failure by NSSS" and Figure 3-12 "P&B MDR Relay Failure Rate vs Service Life by NSSS" shows the number of MDR relay failures and failure rates vs service life at failure by each reactor vendor. The highest number of CE failures appeared at about 4 to 6 years service life. This may reflect: (1) the accumulated service life of the MDR relay population shown in



1984-1992

Figure 3-9 P&B MDR relays in service vs year

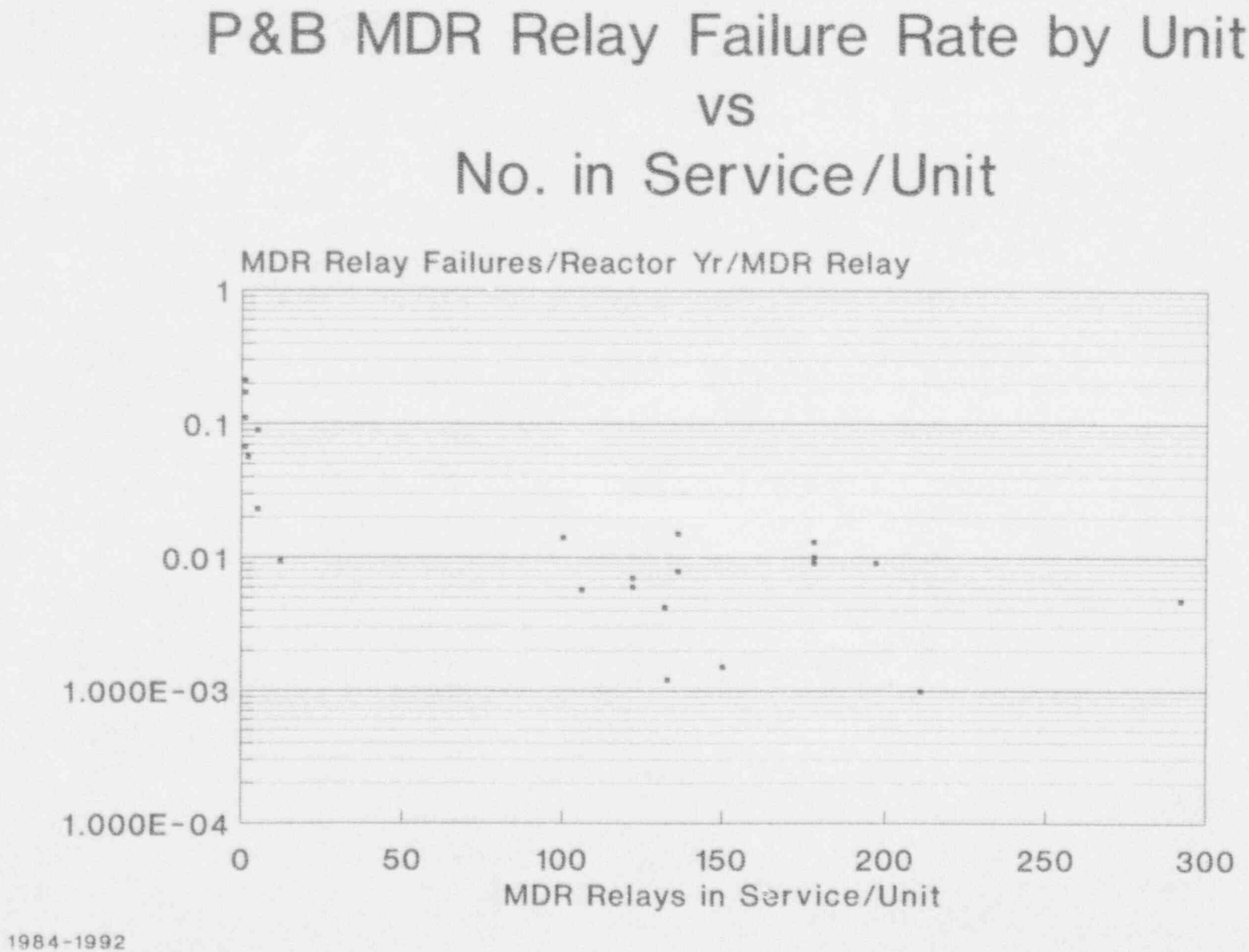


Figure 3-10 P&B MDR relay failure rate by unit vs number in service/unit

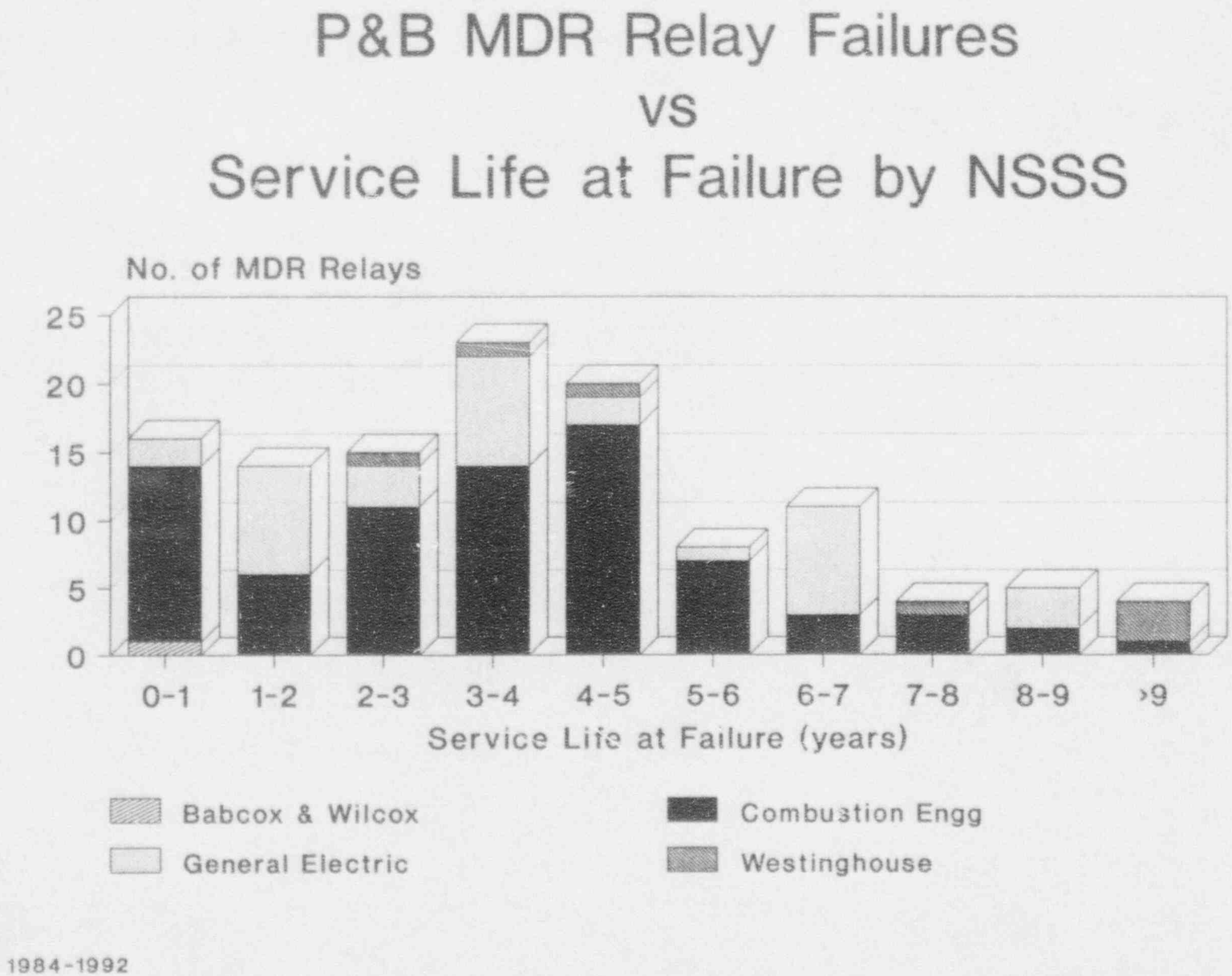
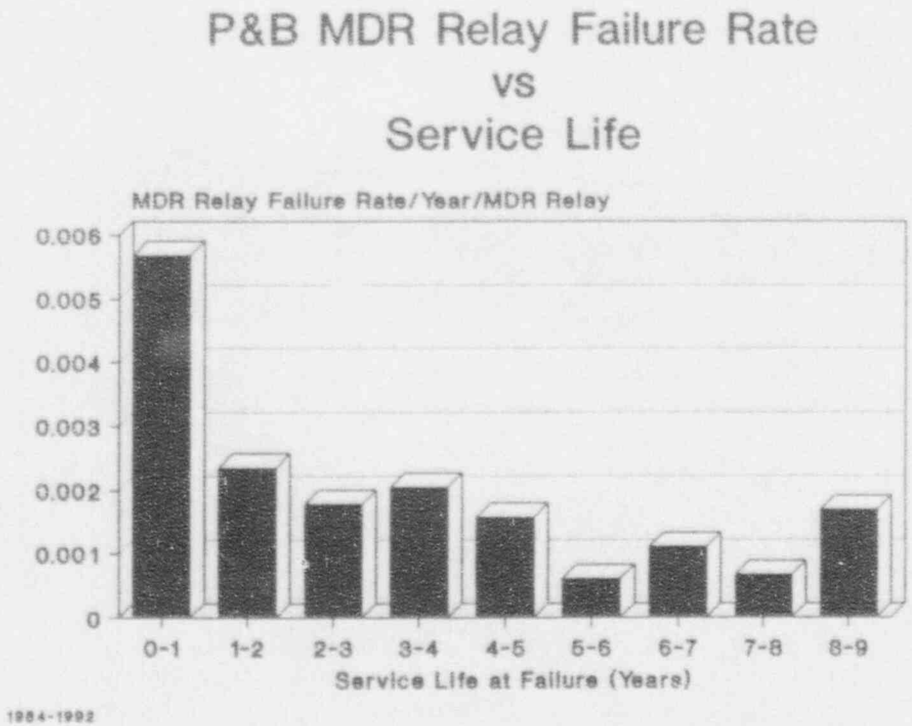
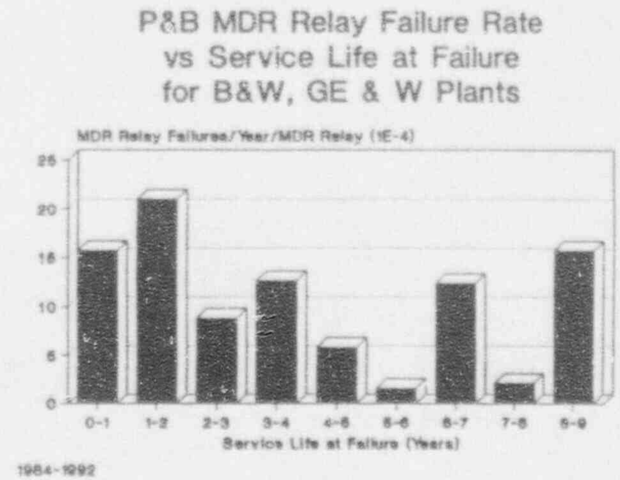


Figure 3-11 P&B MDR relay failures vs service life at failure by NSSS





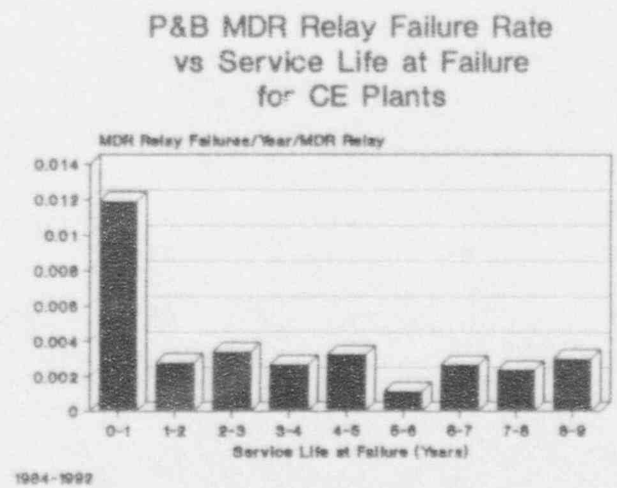


Figure 3.12 P&B MDR relay failure rate vs service life by NSSS

Figures 3-9 and 3-13, "P&B MDR Relay Accumulated Service Life," representing 1.83E+7 hours of relay operation, and (2) the history of excessive voltage applied to certain MDR dc coils at CE plants for several years and the replacement of those relays. Thereafter, CE plant MDR failure rates leveled off.

The inservice MDR relay failure rate for the other reactor vendor plants' MDR relays increased again after 7 or 9 years inservice life. Most MDR relays used in CE plants do not have inservice lives in that range. The older relays were the ones failing most often in the MDR relay failure increases in 1991 and 1992. This may be a harbinger that increased age may affect MDR relay dependent failure rates and simultaneous failures in the future.

Figure 3-14, "P&B MDR Relay Failures vs Year, Service Life, and Coil Type," and Figure 3-15, "P&B MDR Relay Failures vs Year, Service Life and Normal Coil State," address MDR relay failures vs ac or dc coil type and normally energized or normally de-energized state by year and service life. This data is not normalized for the number of relays in service and may in part reflect the total population in service. Even so, it is reasonable that these figures show a higher number of failures of MDR relays with dc coils. The failures peaked at a service life of 3 to 5 years, which may reflect the influence of the in-service population. Both ac and dc coil failures increased from 1990 to 1992. Normally energized relays failed at a higher rate than normally de-energized relays. The number of normally energized relay failures tripled from 1990 to 1992.

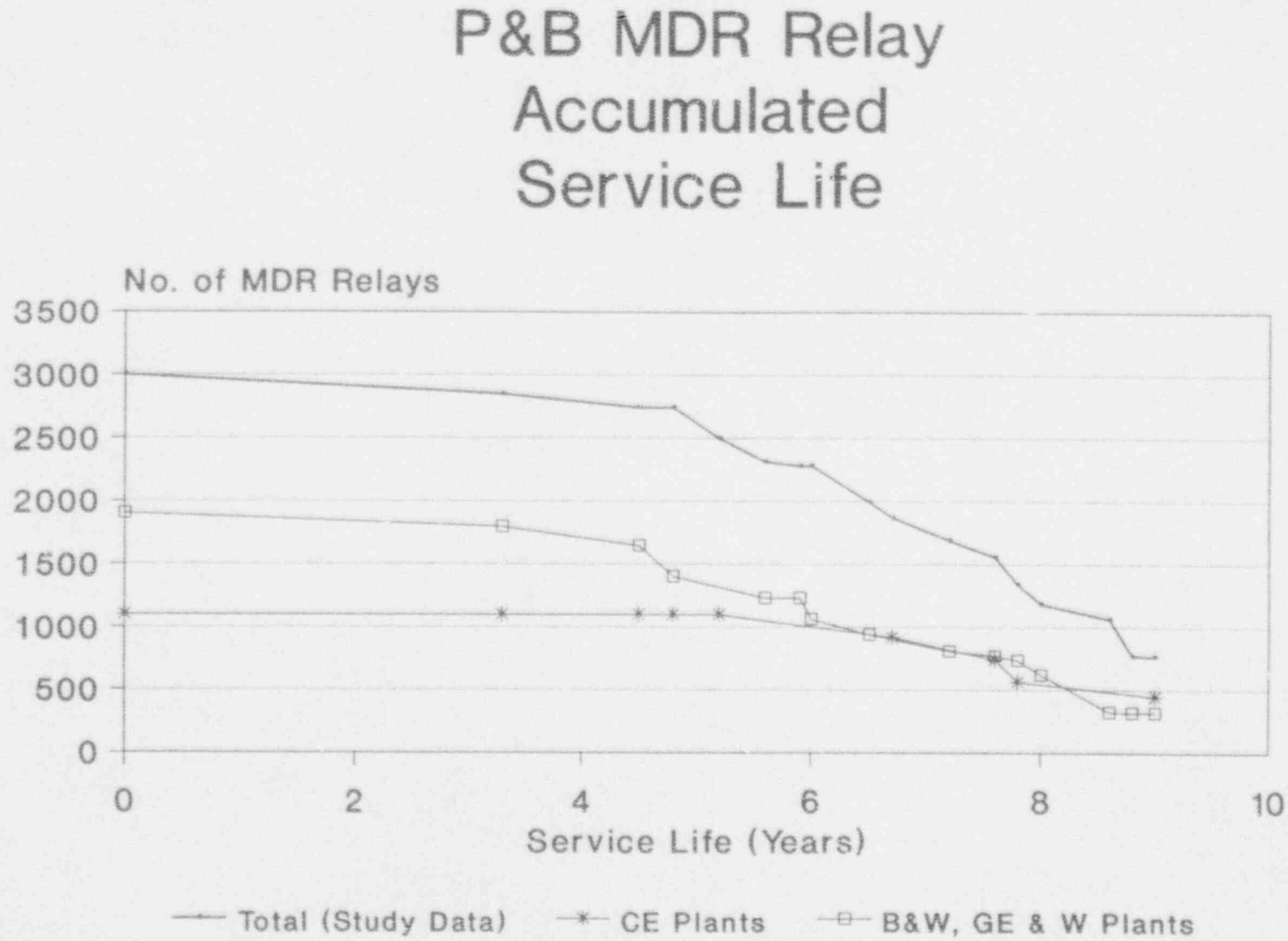
3.20.6 Surveillance Testing Frequency

MDR relay surveillance testing or demand frequency varied widely from weekly to 18 months, depending upon system usage and relay function. Sometimes relay timing was important, as in scram response time after a main steam isolation valve closure. Many times relay timing was not critical and therefore, was usually not tested. A number of MDR relays were replaced due to slow actuation. Slow MDR relay response may be a precursor to actual failure and at least one plant is considering verifying MDR relay timing during valve testing.

3.20.7 Preventative Maintenance

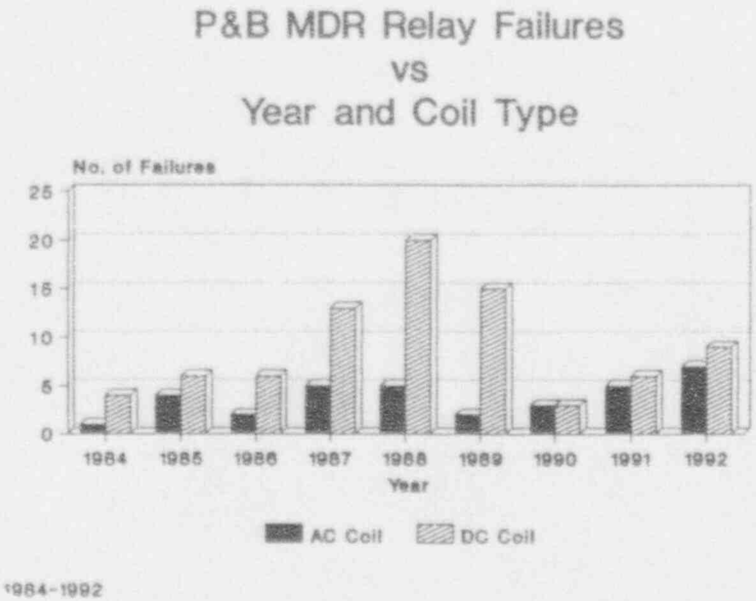
A sampling of six plants found no preventative maintenance program established for MDR relays and only one with a EQ replacement schedule. When MDR relays fail, they are replaced rather than repaired due to their low cost and lack of vendor repair information and parts.

A sampling of receipt inspection of replacement MDR relays found it varied greatly from plant to plant. Some licensees were not aware of temperature affects on tramp epoxy. Some licensees accepted P&B electrical testing for lack of their own program to time relay operation. P&B did not publish information about the relay, such as torque requirements on the switch assembly stud stop nuts or rotor shaft end play clearance requirements. To avoid recent problems, receipt inspection of dedicated relays could



12/31/1992

Figure 3-13 P&B MDR relay accumulated service life



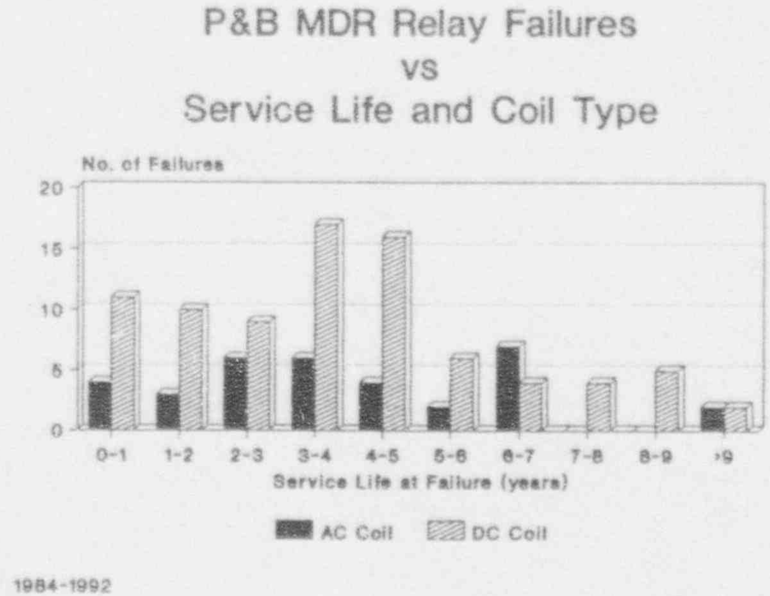


Figure 3-14 P&B MDR relay failures vs year, service life, and coil type

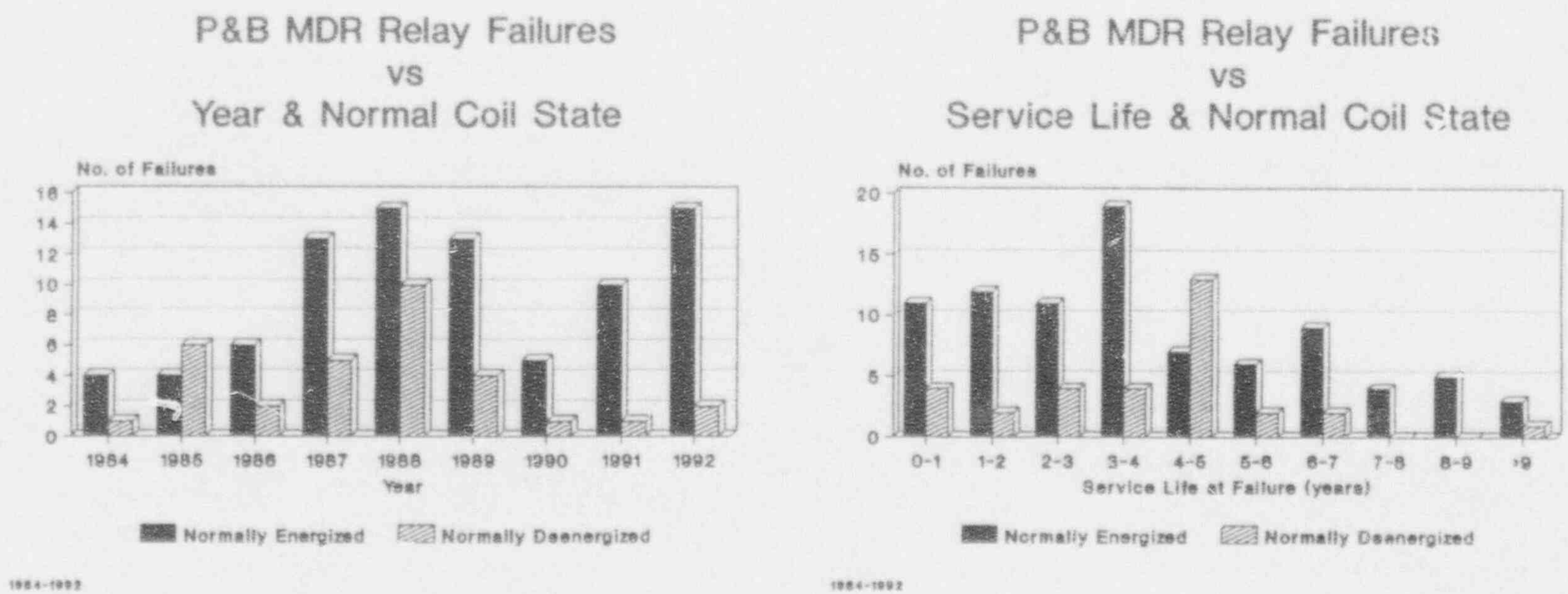


Figure 3-15 P&B MDR relay failures vs year, service life, and normal coil state

benefit from black light or energization testing to detect tramp epoxy defects and verification of moving part clearances, bolt torques, and electrical parameters, prior to placing MDR relays in service.

3.21 Safety Significance of MDR Relay Failures

The safety significance of common-cause failures, exhibited by MDR relays, is that common-cause and common mode failures compromise the single failure assumptions that underpin the design of NPPs and represent a major uncertainty in the bottom line of probabilistic risk assessments (PRAs) of NPPs.[29]

3.21.1 Qualitative effects of MDR Relay Failures

The multiple, simultaneous MDR relay failures, described in Section 3.20.3 of this study, whether they affect redundant or nonredundant components, share a safety significance that is higher than single MDR relay failures. Such failures could disable a safety-related system or opposite trains of different safety-related systems and defeat a NPPs single failure design criteria. The effect depends on the function of the particular relays that fail.

The MDR relay common-cause failures addressed here have often been nonrecoverable. Their failures have been found usually as a result of failed surveillance tests or on a valid demand. The primary safety-related application of P&B MDR relays are in ESF, ECCS and RPS actuation logic. MDR relay contacts are also used to provide status and annunciation for the operators. MDR relay failures have resulted in inadvertent operation, delayed operation, or lack of operation of safety-related pumps, valves, breakers, emergency power supplies, and ECCS and RPS control systems. These actual failures appeared to have been caused by one of the dependent failure mechanisms identified. An accident requiring the use of a safety system may be the initiating event for a demand and a relay failure.

Because these relays have a wide variety of safety-related applications, various failures have effected safety-related systems, as described in Appendix C, including:

Reactor Protection System

- one-half scram prevented
- trip path would not trip
- trip timing degraded
- multiple channels of turbine control valve fast closure trip logic degraded
- trip on spurious MSIV closure
- spurious channel trip
- multiple channels failed to reset RTBs

Emergency Core Cooling Systems

- recirculation actuation signal did not actuate
- safety injection train signal did not actuate
- low pressure safety injection pump did not start
- emergency service water pump did not start
- low pressure safety injection recirculation valve did not open
- train of ESFAS did not reset after a reactor trip

Engineered Safety Features Systems

- ESFAS did not actuate
- ESF signal could not be bypassed
- spurious main steam isolation valve closure prompted reactor trip
- main steam isolation valves did not close within time limits
- 125 V dc control was inoperable
- emergency power sequencer failed to operate
- EDG output breaker did not close
- EDG voltage regulator failed to operable
- prevented two reactor recirculation pump MG set drive motors from tripping
- containment isolation signal or valve did not actuate
- emergency pond service water valve did not open
- emergency feedwater system or signal could not operate
- backup pressurizer heaters did not shut off
- recirculation actuation signal did not operate
- sodium hydroxide pump would not stop
- inadvertent containment isolation
- inadvertent standby gas treatment system and control room HVac actuation
- intermittent SRV position lights

Many factors influence an MDR relay's failure, such as coil temperature, energization state, coil wattage, length of service, variation in coil varnish, vertical or horizontal position, testing and operation frequency, etc. that varies from relay-to-relay and plant-to-plant. These present a very complicated matrix that prevents an accurate estimate of when a particular relay will fail.

The River Bend experience has demonstrated how a loss of power to a group of relays can potentially result in multiple failures. The probability of a relay failure may increase with its length of time in service, due to the nature of varnish outgassing and silver contact corrosion failure mechanisms, as shown in Figure 3-12.

3.21.2 Probabilistic Risk Assessment

The AEOD study on "Insights from Common-Mode Failure Events" noted that "common-mode failure has been cited on several occasions as a significant contributor to uncertainty in the bottom line estimates of core damage likelihood in probabilistic risk assessments." This also quoted NRC Chairman Carr in a 1990 letter as stating that "These uncertainties result from lack of data to fully quantify the potential for multiple failure from common-causes... ."[30] The MDR relay failure data in this study is no exception to these conclusions.

About 3,000 multiple-contact, P&B MDR relays are used in various systems in the four reactor vendor's plants. It is not unusual to find a number of MDR relays relied upon for proper operation of an ESF system, but it can take the failure of only one of the MDR relays to incapacitate the safety function of a train.

It is impracticable to perform a PRA for each application of P&B MDR relays and many plant-specific PRAs are not modelled in the detail needed to analyze such failures. If such a study could be undertaken, a wide range of safety significance would be determined, depending upon the plant-specific safety significance of the contacts assumed to fail and the failure mode assumed. The core damage probability would be most affected by the availability of alternative trains or systems that could perform the safety function of the failed system (as in the case of the River Bend case discussed below). This may, in general, yield worse results for emergency power supplies and ultimate heat sinks, where there are minimal alternatives.

The only simple, plant-specific, PRA analysis performed by a licensee, based on River Bend MDR relay failure rates determined the River Bend (BWR/6) RPS failure rate increased by a factor of 25, from $1.31x10^{-5}$ to $3.32x10^{-4}$, as noted in Section 3.9 of this report.

The River Bend MDR relay common-cause failure rate of $6.64x10^{-4}$ failures/demand equated to a failure every 1506 demands, which was significantly less than the MDR relay design life of 50,000 mechanical operations over a 40 year period. However, the calculated $6.8x10^{-7}$ failures/relay-hour experienced was slightly better than the MDR relay design reliability failure rate of 10^{-6} failures per hour.[31] These two failure rates may be contrasted with the WASH-1400 generic median relay failure rate of 1 to $3x10^{-7}$ failures/hour of normally open or closed contacts to operate normally used in PRA studies.[32]

Table 3-2 in this report shows that simultaneous dependent failures of two or more MDR relays occurred at least eight times, and multiple relays were replaced in response to two other events. Thus, multiple, simultaneous failures occurred in about 10 percent of the dependent failure events identified.

In addition, a plant simultaneously replaced four 28 V dc MDR relays in 1986, when one of them had high contact resistance and caused a main steam isolation valve to spuriously close. In 1987, a second plant simultaneously replaced six 125 V dc MDR relays, which "did not respond properly" in their EDG control system during preventative maintenance. In 1991, an MDR relay failure in a third plant prevented operation of "B" train emergency power system safeguards sequencer, while "A" train emergency power was not operable. Although these events were not included as simultaneous failures, voluntary multiple MDR relay replacements tend to indicate licensees had identified a significant potential for near term failures. About one-third of all MDR relay dependent failures occurred during events or tests which involved dependent failures of two or more MDR relays simultaneously. This reflects the potential for multiple train or multiple system failures and illustrates the importance of thorough testing of other MDR relays when a dependent failure is found.

Identification of simultaneous MDR relay failures affecting both trains of a safety system during surveillance testing is not likely given the staggering of such testing in use. Actual simultaneous failures would be more likely to be identified during an valid demand, unless the redundant safety system train is tested immediately after an MDR relay failure is detected. The most likely identification of additional degraded MDR relays appears to have been during troubleshooting of similar relays after a failure.

4. FINDINGS AND CONCLUSIONS

4.1 Findings

4.1.1 Dependent Failure Mechanisms

This study identified about 124 MDR relay failures in about 100 events from 1984 through 1992 that appeared to have resulted from common causes.

Material Problems

1. Mechanical binding of the rotor shaft was caused by deposits from coil varnish outgassing and corrosion from rubber grommets and polyvinyl chloride wiring that accumulate in the end bell bearings and brass sleeves as the relay breathes. This slowed or prevented the rotor from rotating when the relay coils were energized or de-energized and typically occurred intermittently or was impossible to duplicate. (MDR relays made prior to 5/90)

2. Intermittent continuity and high resistance of electrical contacts was caused by chemical reactions on fixed and movable silver contacts. (MDR relays made prior to 5/90)

3. Failure of ac MDR relays to reset was caused by the detachment and wedging of a copper shading coil between the rotor and the stator because the epoxy attaching the shading coil to the stator cracked due to temperature-induced expansion and stretching. (MDR relays made prior to 1/92)

4. Prevention of relay actuation was caused by chlorine induced stress corrosion cracking of rotor return springs, permitting a broken spring part to lodge between the rotor and stator (Applicable to 172 relays manufactured in 1992)

5. Binding of the rotor at 137° F was caused by insufficient end-play of the shaft due to an oversized coil, over-shimming, and tolerance stackups. (MDR relays made in 1992)

6. Rotor response time may be slowed at lower temperatures, such as 40° F, caused by uncured epoxy on the stator interfering with rotor movement. (MDR relays made in 1992)

Application problems

1. Increased contact resistance was caused by misapplication of MDR relays in switching low level loads that permit contact resistance to build up.

2. Intermittent contact continuity was caused by contact erosion in direct current applications where there is a substantial difference between the ac and dc current ratings of the relay contacts and inductive loads not included in the circuit design.

3. Contact failure was caused by paralleling sets of relay contacts to switch loads greater than a single set can handle, when lack of simultaneous contact opening results in one contact taking all the load.

4.1.2 Study Insights

The safety significance of the simultaneous MDR relay common-cause failures is that they compromise the single failure assumptions that underpin the design of NPPs and represent a major uncertainty in the bottom line of PRAs of NPPs.[33]

MDR relay dependent failure statistics developed in this study could be misleading, because of recognized uncertainties in NPRDS data regarding the number and cause of MDR relay failures, population of MDR relays in service, length of coil energization, and operational cycling frequency. The NPRDS data showed that licensees did not usually perform detailed root cause analysis of MDR relay failures until a number of failures occurred at their plant. Despite this, the data in this report leads to the following general insights:

1. Most of the MDR relay failures occurred in normally energized relays, while 30 percent occurred in normally de-energized relays, which may have been energized during shutdown conditions.

2. The clustering of failures of CE plant MDR relays with over-design coil voltage appears to indicate that the rate of varnish offgassing effected the relay failure rate.

3. Twelve MDR relays that had identical functions in redundant equipment failed simultaneously in five events due to the dependent failure mechanisms identified in Section 2.3 in this study.

4. About 1/3 of the 124 MDR relay dependent failures identified occurred during events or tests which involved dependent failures of two or more MDR relays simultaneously. These failures occurred in about 10 percent of the dependent failure events identified.

5. The MDR relay failure history confirms a finding in AEOD study E92-02 that "design related common-mode failures generally go undetected for long periods of time."[34]

6. Surveillance testing that included MDR relay timing has located some types of degraded MDR relays. Increased surveillance testing recommended by P&B and reactor vendors may not detect several types of MDR relay dependent failures occurring during resetting after completion of the testing.

A number of proximate causes contributed to the timing of MDR relay failures, including: applied ac or dc voltage, equalizing voltages and frequencies, normal coil energization state, manufacturing tolerances, ambient coil temperatures, varnish application, mounting configurations and enclosures, cabinet ventilation methods and rates, end bell bearing aperture size, testing frequency, operational cycling, number of contact decks, and the amperage and voltage of the contacts.

An environmental qualification report showed that some improved MDR relays have to be replaced, under certain conditions, before its 40-year life span because of aging of NYE Nyogel 718B grease end bell bearing lubricant and Exar 400 coil leadwire and shading insulation.

Licensee receipt inspections of replacement MDR relays varied in thoroughness from plant to plant, such that deficiencies in modified MDR relays caused by over-sized coils, insufficient end play clearances, and tramp epoxy deficiencies could go undetected.

P&B instituted a series of design modifications over a number of years to correct material deficiencies. For example, the epoxy that P&B used to replace the coil varnish has less offgassing by a factor of 100.

P&B has taken exception to 10 CFR 21 reporting when supplying new relays and has not issued such a report or made any generic recommendations to MDR relay users. CE and GE informed their plants about some MDR relay failure mechanisms in 1988, 1990, and 1992. NRC INs 92-04 and 92-19 informed licensees about some of these MDR failure mechanisms.

A sample of plants surveyed found that most licensees that responded to IN 92-04 addressed only normally energized MDR relays, whereas 30 percent of the failures occurred in normally de-energized relays.

4.2 Conclusions

The tendency for MDR relays to fail simultaneously in clusters is caused by a number of dependent failure mechanisms that appear to be influenced by similar design, materials, environment, and operational history. These may be nonrecoverable and nonrevealing failures which negate the single failure design of NPP safety-related systems.

The many contributors to MDR relay failures result in an unpredictable failure history that makes it unlikely that a scheduled surveillance testing, preventative maintenance, or replacement program can be effectively applied to pre-1990 MDR dc relays or pre-1992 MDR ac relays.

Premature failure experience from above-design coil voltages and increasing failure rates since 1990 may portend higher failure rates as pre-1990 MDR relays age.

If the MDR relay NPRDS data can be considered representative of licensee root case analysis, licensees may benefit from performing more root cause analysis of relay failures, increasing contact with relay and NSSS vendors, and submitting more detailed NPRDS reports to identify and minimize common-cause failures in the future.

Licensees may benefit from increasing the scope of their response to NRC IN 92-04 from only normally energized MDR relays to all MDR relays due to the additional dependent failure mechanisms identified in this study. This study suggests that licensee MDR relay replacement programs should not be based on only plant-specific failure history or be limited to only normally-energized MDR relays.

Licensees may benefit from a replacement program for new MDR relays based on plant-specific environmental qualifications and improved dedicated relay receipt inspection programs to cover the identified dependent failure mechanisms. A compilation of relay failure mechanisms, in general, and appropriate inspection criteria may be useful to licensees for this general purpose.

More complete NPRDS data, including license root cause determinations, would permit more reliable failure rate analysis.

Reliability of relays used in NPPs may be increased by use of epoxy in lieu of varnish to minimize offgassing corrosion of moving parts and electrical contacts.

5. SUGGESTIONS

It is suggested that a supplement to NRC Information Notice 92-04 be issued to inform all commercial NPP licensees of the MDR relay dependent failure mechanisms identified since the IN was initially issued.

An increase in reliability and a reduction in challenges to safety-related systems could be effected by replacing MDR relays, subject to the dependent failure mechanisms identified in this study, that are relied upon to actuate or operate safety-related systems.

Licensees may benefit from performing more root cause analysis of relay failures, increasing contact with relay and NSSS vendors, and submitting more detailed NPRDS reports to identify and minimize common-cause failures in the future.

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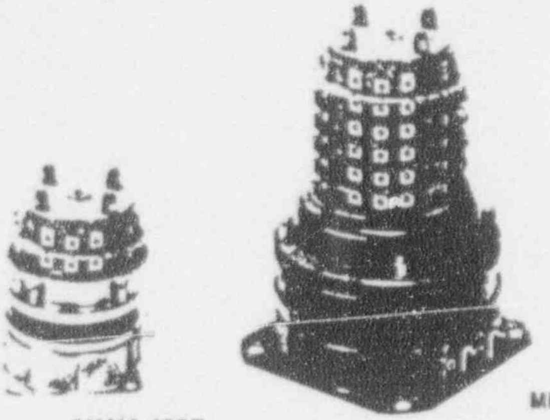
APPENDIX A

P&B MDR Relay Technical Data

MDR series

10 AMP ROTARY RELAYS



SMALL 8PDT MEDIUM 24PDT

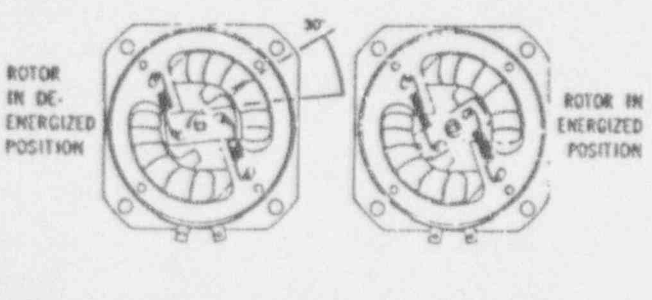
ENGINEERING DATA

Designed and constructed to meet or exceed the most rigorous requirements of military specifications, MDR series rotary relays are used in control circuits of nuclear reactors, missile systems, gun fire apparatus and computers.

MDR relays meet the most rigorous requirements of specifications MIL-R-19523 which includes the rugged requirements of MIL-STD-167 for vibration and MIL-S-901 for shock. The contacts will not chatter when relays are subjected to high-impact shock blows of 2000 ft-lbs. Endurance ratings are 100,000 operations for series 141, 170, and all latching series and 500,000 for all others. MDR relays are designed to operate over an ambient temperature range of 0°C to +65°C. MDR relays designed for operation over range of 0°C to +90°C are available on special order. Please consult factory.

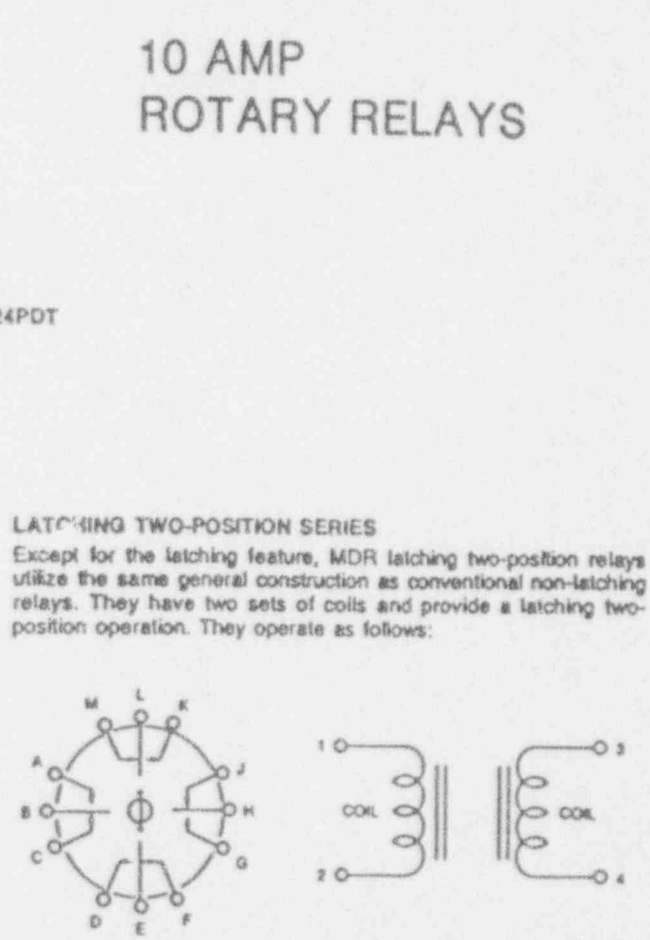
CONVENTIONAL NON-LATCHING SERIES

The basic construction of the conventional MDR relay consists of a rotary actuator mechanism with the contact sections mounted in insulating rings on top. The actuator mechanism embodies a stator assembly on which two relay coils are mounted. The two coils are connected in series inside the relay. When the coils are energized, a rotor turns through an arc of approximately 30 degrees, thereby operating the contact section through the extension of the rotor shaft. The travel of the rotor is confined to a 30 degree arc between the stator faces and the stop ring. Two springs return the rotor to the stop ring when the coils are de-energized. This also returns the contacts to their normal positions. Thus, the conventional non-latching series provide an "energized" and "de-energized" position.



LATCHING TWO-POSITION SERIES

Except for the latching feature, MDR latching two-position relays utilize the same general construction as conventional non-latching relays. They have two sets of coils and provide a latching two-position operation. They operate as follows:



When coil 1-2 is energized, contacts A-B, D-E, G-H and K-L close. The indicator line on the rotor shaft and the two dots on the top are not in alignment.

When coil 1-2 has been de-energized and coil 3-4 is energized, contacts B-C, E-F, H-J and L-M close. The indicator line and the two dots are aligned.

The armature is held by positive spring action in its last energized position when both coils are de-energized. Coils must be energized alternately, not simultaneously.

AVAILABLE IN SMALL AND MEDIUM SIZES

MDR rotary relays are offered in two basic sizes, small and medium. Each of these is available in conventional nonlatching and latching two-position versions. The small non-latching MDR is furnished with AC coils to 12PDT and with DC coils to 8PDT. The small latching relay with AC or DC coils is equipped with contacts to 8PDT. The medium non-latching series is provided with AC or DC coils to 24PDT, while latching version features AC or DC coils with contacts to 16PDT. All contact arrangements are Form C (break-before-make).

Models in this series are available from stock. The last section of this databook lists by part number those units which are normally stocked. Non-stock items are subject to normal OEM leadtimes.

TYPICAL OPERATE AND RELEASE TIMES AT NOMINAL COIL VOLTAGE AT +25°C

TYPE	OPERATE TIME IN MILLISECONDS	RELEASE TIME IN MILLISECONDS
SMALL AC NON-LATCHING	5 to 12	5 to 16
SMALL DC NON-LATCHING	15 to 30	5 to 15
SMALL AC LATCHING	6 to 12	N/A
SMALL DC LATCHING	10 to 16	N/A
MEDIUM AC NON-LATCHING	6 to 12	6 to 20
MEDIUM DC NON-LATCHING	65 to 90	10 to 30
MEDIUM AC LATCHING	8 to 14	N/A
MEDIUM DC LATCHING	30 to 80	N/A

COIL CHARACTERISTICS OF SMALL NON-LATCHING MDR ROTARY RELAYS

SMALL NON-LATCHING

SERIES	CONTACTS	COIL VOLTAGE 60 Hz for AC	COIL CURRENT AMPERES	DC COIL RESISTANCE OHMS	COIL POWER WATTS*	BREAKDOWN VOLTS RMS
MDR-131-1	4PDT	115VAC	0.215	66	6.5	1230
MDR-131-2	4PDT	440 VAC	0.045	1256	5.1	1880
MDR-135-1	4PDT	28 VDC	0.362	76	10.0	1308
MDR-137-8	4PDT	125VDC	0.082	1520	10.3	2375
MDR-134-1	8PDT	115 VAC	0.215	66	6.5	1230
MDR-134-2	8PDT	440 VAC	0.045	1256	5.1	1880
MDR-136-1	8PDT	28 VDC	0.362	76	10.0	1308
MDR-138-8	8PDT	125 VDC	0.082	1520	10.3	2375
MDR-163-1	12PDT	115 VAC	0.230	62	6.9	1230
MDR-163-2	12PDT	440 VAC	0.055	940	6.3	1880

*Actual Wattmeter readings

COIL CHARACTARISTICS OF MEDIUM NON-LATCHING MDR ROTARY RELAYS

MEDIUM NON-LATCHING

SERIES	CONTACTS	COIL VOLTAGE 60 Hz for AC	COIL CURRENT AMPERES	DC COIL RESISTANCE OHMS	COIL POWER WATTS*	BREAKDOWN VOLTS RMS
MDR-170-1	16PDT	115 VAC	0.620	8.4	17.0	1230
MDR-170-2	16PDT	440 VAC	0.160	107	17.0	1880
MDR-172-1	16PDT	28 VDC	0.667	42	18.7	1308
MDR-173-1	16PDT	125 VDC	0.125	1024	16.0	2375
MDR-141-1	24PDT	115 VAC	0.620	8.4	17.0	1230
MDR-141-2	24PDT	440 VAC	0.160	107	17.0	1880
MDR-167-1	24PDT	28 VDC	0.667	42	18.7	1308
MDR-142-1	24PDT	125 VDC	0.125	1024	16.0	2375

*Actual Wattmeter readings

COIL CHARACTERISTICS OF SMALL LATCHING MDR ROTARY RELAYS

SMALL LATCHING

SERIES	CONTACTS	COIL VOLTAGE 60 Hz for AC	COIL CURRENT AMPERES	DC COIL RESISTANCE OHMS	COIL POWER WATTS	BREAKDOWN VOLTS RMS
MDR-67-2	4PDT	115 VAC	0.150	210	5.5	1230
MDR-4091	4PDT	440 VAC	0.020	4500	3.0	1880
MDR-67-3	4PDT	28 VDC	0.778	36	21.8	1308
MDR-5060	4PDT	125 VDC	0.164	760	20.6	2375
MDR-4076	8PDT	115 VAC	0.150	210	5.5	1230
MDR-4092	8PDT	440 VAC	0.020	4500	3.0	1880
MDR-5035	8PDT	28 VDC	0.778	36	21.8	1308
MDR-5061	8PDT	125 VDC	0.164	760	20.6	2375

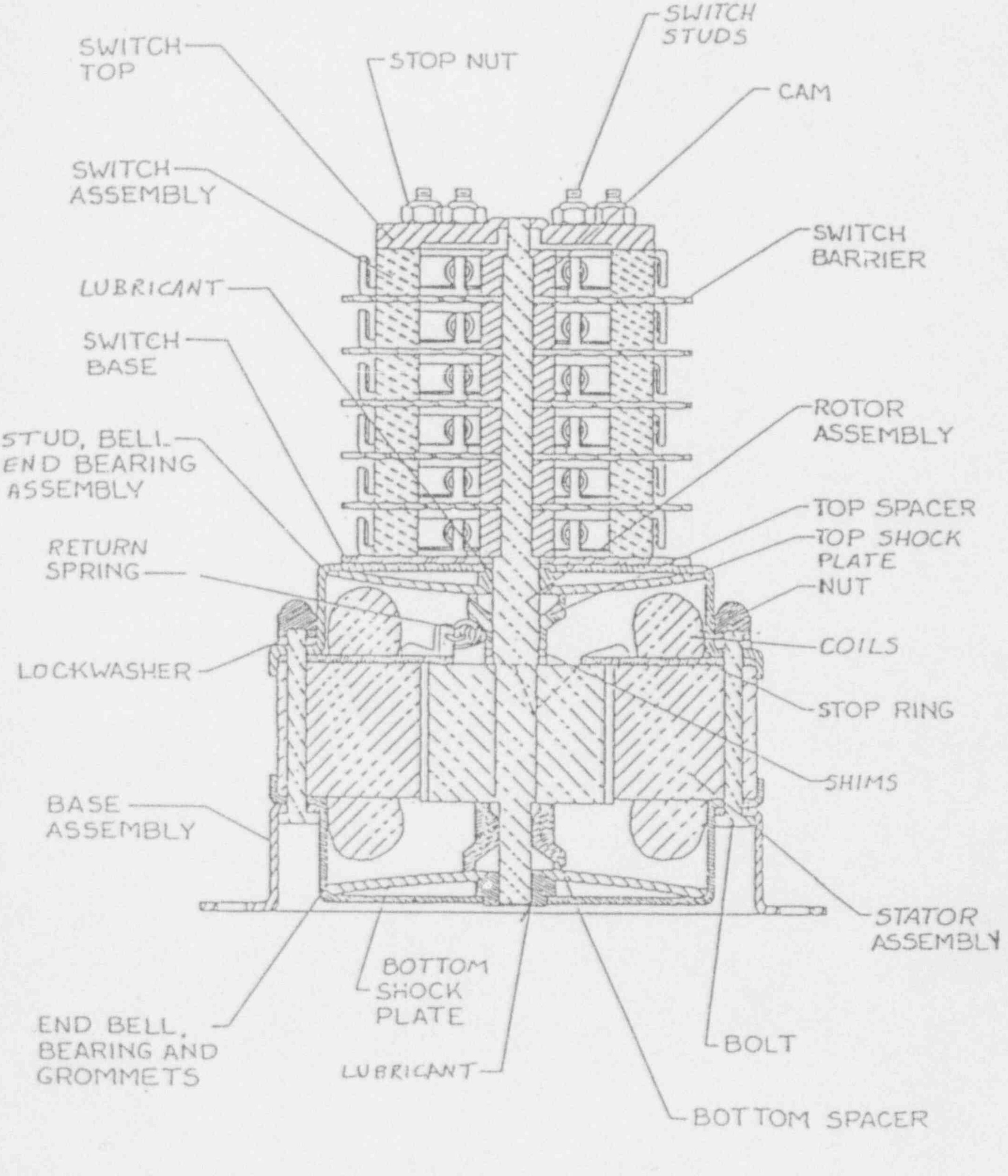
COIL CHARACTERISTICS OF MEDIUM LATCHING MDR ROTARY RELAYS

MEDIUM LATCHING

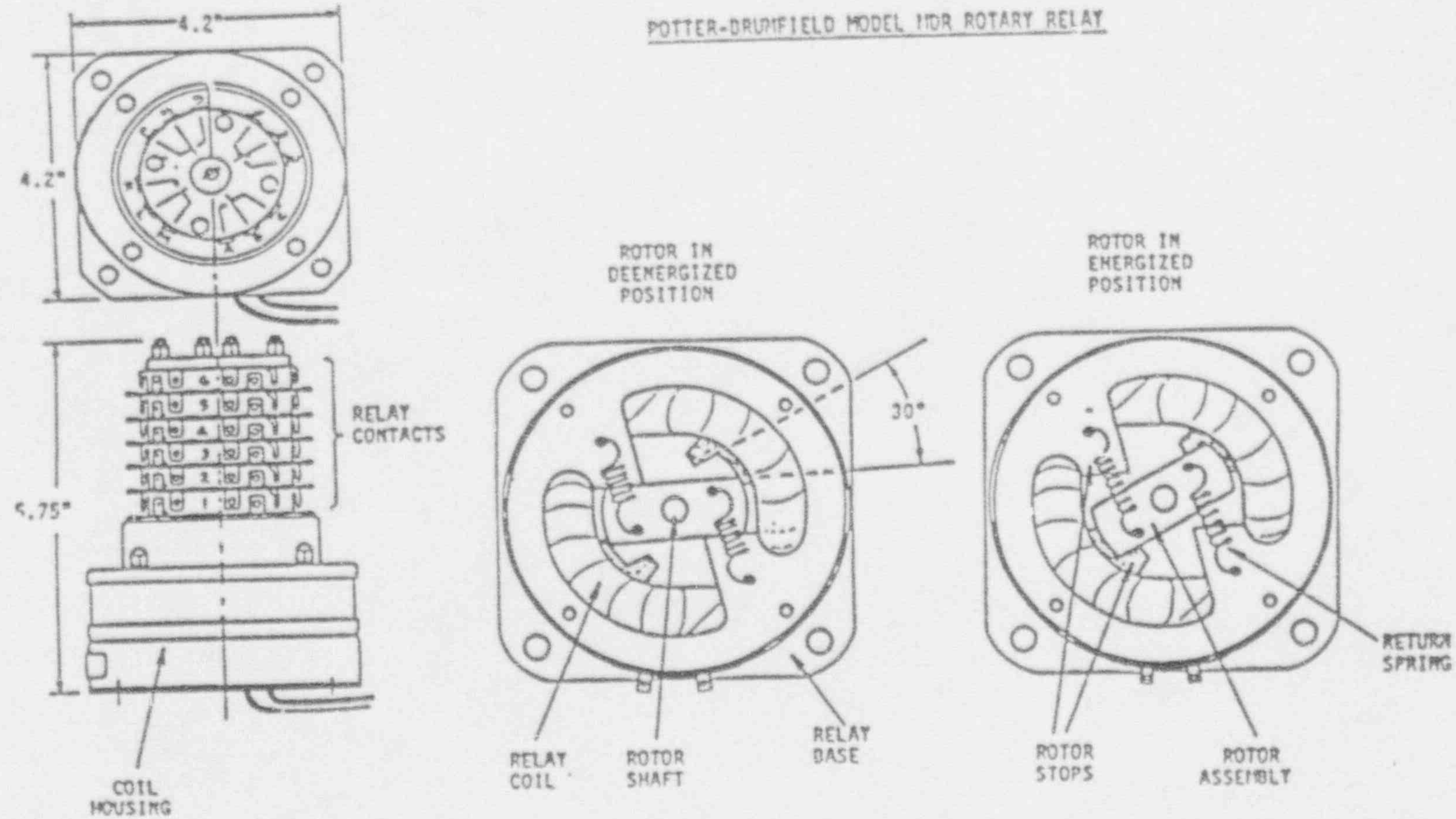
SERIES	CONTACTS	COIL VOLTAGE 60 Hz for AC	COIL CURRENT AMPERES	DC COIL RESISTANCE OHMS	COIL POWER WATTS	BREAKDOWN VOLTS RMS
MDR-6064	12PDT	115 VAC	0.380	24	12.0	1230
MDR-6065	12PDT	440 VAC	0.055	540	5.7	1880
MDR-7020	12PDT	28 VDC	0.316	88.6	8.8	1308
MDR-7035	12PDT	125 VDC	0.083	1500	10.4	2375
MDR-66-4	16PDT	115 VAC	0.380	24	12.0	1230
MDR-6066	16PDT	440 VAC	0.055	540	5.7	1880
MDR-7025	16PDT	28 VDC	0.316	88.6	8.8	1308
MDR-7036	16PDT	125 VDC	0.083	1500	10.4	2375

MDR NON-LATCHING RELAY

(MEDIUM)



POTTER-DRUMFIELD MODEL 11DR ROTARY RELAY

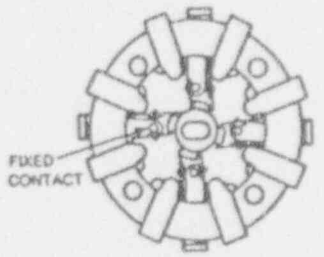


MDR CONTACT RATINGS

SINGLE CONTACTS:	TWO CONTACTS IN SERIES:
10.0 amp. 115 VAC 3.0 amp. 28 VDC 0.8 amp. 125 VDC	3.0 amp. 440 VAC 15.0 amp. 115 VAC 1.5 amp. 125 VDC

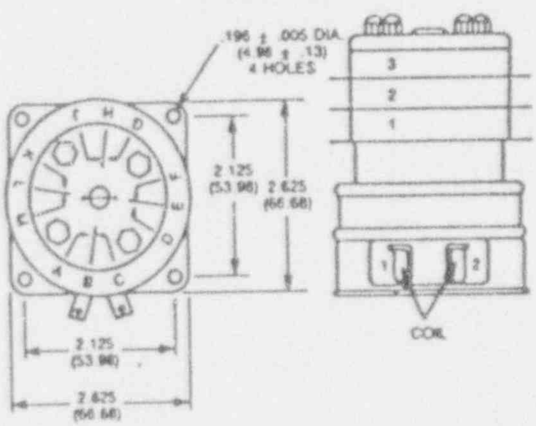
The above AC contact ratings are based on contact loads having a 50% power factor. The DC contact ratings are based on resistive loads.

CONTACT SECTION



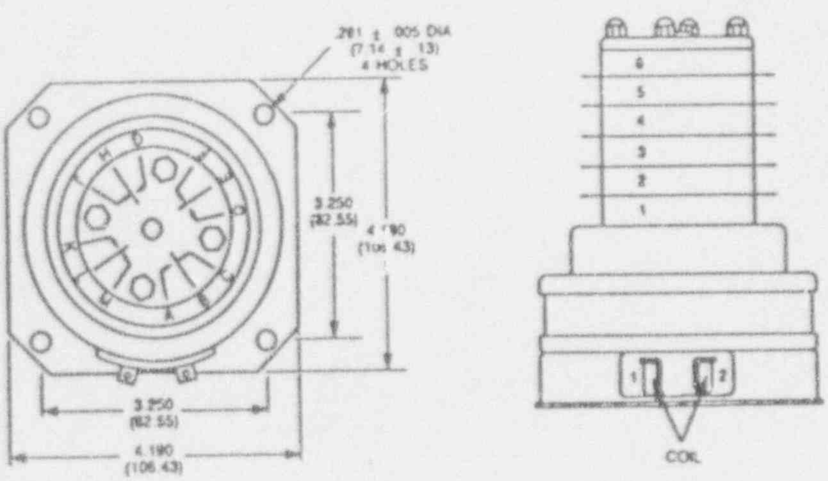
OUTLINE DIMENSIONS

TOLERANCES: DECIMALS ± .010 (± .25) UNLESS OTHERWISE SPECIFIED.



OVERALL HEIGHT
4PDT 3.13" (79.5 mm) MAX.
8PDT 3.53" (89.7 mm) MAX.
12PDT 3.88" (98.6 mm) MAX.

COIL AND CONTACT TERMINAL SCREWS #5 - 40 SUPPLIED



OVERALL HEIGHT
12PDT 4.63" (117.6 mm) MAX.
16PDT 5.00" (127.0 mm) MAX.
24PDT 5.75" (146.1 mm) MAX.

COIL AND CONTACT TERMINAL SCREWS #5 - 40 SUPPLIED

APPENDIX B

P&B MDR Relay Usage

P&B MDR RELAY USAGE

Plant[1]	NSSS	System	MDR Model No.	No. of MDRs[2]	Failures Reported	Failure Rate[3]
1/2	GE	EWS	MDR-131-1	?	0	.0047
		RHR	MDR-134-1	?	0	
		RB	MDR-138-8	?	0	failures per
		HVAC	MDR-4094	?	5	reactor year
		CS	MDR-4165	?	0	per MDR
		RCS	MDR-5061	?	0	relay
		EDG	MDR-5062	?	6	
		RWCU	MDR-5151	?	1	
			all models	585		
3	CE	ESFAS	MDR-136-1	4	0	.0090
		ELECT	MDR-137-8	7	4	
		CVCS	MDR-138-8	2	2	
		RPS	MDR-170-1	9	3	
		CIS	MDR-5060	2	1	
		ESFAS	MDR-7032	35	2	
		ESFAS	MDR-7033	28	1	
		ESFAS	MDR-7034	110	3	
4	CE	ESFAS	MDR-136-1	2	1	.0147
		ELECT	MDR-137-8	12	8	
		ELECT	MDR-138-8	6	4	
		RPS	MDR-138-8	1	0	
		RPS	MDR-170-1	11	2	
		ESFAS	MDR-7032	21	2	
		ESFAS	MDR-7033	16	0	
		ESFAS	MDR-7034	67	1	
5	W	RPS	MDR-5076-1	8	NONE REPORTED	0
6	CE	ESFAS	MDR-7032	10	2	.0059
		ESFAS	MDR-7033	8	0	
		ESFAS	MDR-7034	33	0	
		ESFAS	MDR-167-1	3	0	
		ESFAS	MDR-136-1	27	0	
		ESFAS	MDR-172-1	6	0	
		PPS	MDR-5053	2	0	
		PPS	MDR-5147	4	0	
		PPS	MDR-4094	2	0	
		PPS	MDR-7061	10	1	
		PPS	MDR-7062	12	0	
		PPS	MDR-7063	52	1	
		ESFAS	MDR-5147	8	0	
		ESFAS	MDR-7061	10	3	
		ESFAS	MDR-7062	6	1	
		ESFAS	MDR-7063	12	0	
			LER Total	178[4]		

Footnotes at end of table

P&B MDR RELAY USAGE (Cont.)

Plant[1]	NSSS	System	MDR Model No.	No. of MDRs	Failures Reported	Failure Rate
7	CE	ESFAS	MDR-7032	10	4	.0092
		ESFAS	MDR-7033	8	0	
		ESFAS	MDR-7034	33	5	
		ESFAS	MDR-167-1	3	0	
		ESFAS	MDR-136-1	27	0	
		ESFAS	MDR-172-1	6	0	
		PPS	MDR-5053	2	0	
		PPS	MDR-5147	4	1	
		PPS	MDR-4094	2	0	
		PPS	MDR-7061	10	0	
		PPS	MDR-7062	12	0	
		PPS	MDR-7063	52	0	
		ESFAS	MDR-5147	8	0	
		ESFAS	MDR-7061	10	0	
		ESFAS	MDR-7062	6	0	
		ESFAS	MDR-7063	12	1	
			LER Total	178[4]		
8	CE	ESFAS	MDR-7032	10	6[5]	.0097
		ESFAS	MDR-7033	8	1[5]	
		ESFAS	MDR-7034	33	1	
		ESFAS	MDR-167-1	3	0	
		ESFAS	MDR-136-1	27	0	
		ESFAS	MDR-172-1	6	0	
		PPS	MDR-5053	2	0	
		PPS	MDR-5147	4	0	
		PPS	MDR-4094	2	0	
		PPS	MDR-7061	10	0	
		PPS	MDR-7062	12	0	
		PPS	MDR-7063	52	0	
		ESFAS	MDR-5147	8	0	
		ESFAS	MDR-7061	10	0	
		ESFAS	MDR-7062	6	0	
		ESFAS	MDR-7063	12	0	
			MDR-5146	?	1	
			LER Total	178[4]		
9	CE	ESF	MDR-136-1	12	1	.0073
		CS	MDR-137-8	1	1	
		ELECT	MDR-138-8	1	1	
		RPS	MDR-170-1	4	1	
		VENT	MDR-5061	1	1	
		ESF	MDR-7032	18	0	
		ESF	MDR-7033	24	0	
		ESF	MDR-7034	61	2	

Footnotes at end of table

P&B MDR RELAY USAGE (Cont.)

Plant	NSSS	System	MDR Model No.	No. of MDRs	Failures Reported	Failure Rate
10	GE	RPS	MDR-4130-1	12	1	.0042
		RPS	MDR-4134-1	32	1	
		RPS	MDR-4135-1	36	0	
		RPS	MDR-5111-1	8	1	
		RPS	MDR-5112-1	4	0	
		NSSS	MDR-4130-1	18	0	
		NSSS	MDR-4134-1	11	0	
		NSSS	MDR-4135-1	2	0	
		NSSS	MDR-5111-1	4	1	
		RCIC	MDR-5118	3	0	
		SSW	MDR-4134-1	2	0	
11	GE	ESW	MDR-4134-1	1	1	.0063
		NSSS	MDR-4135-1	36	2	
		RPS	MDR-4135-1	81	2	
		RPS	MDR-5111-1	4	0	
12	W	MS	MDR-4121-1	2	1	.056
13	W	MS	MDR-134-1	2	1	.056
14	GE	HPCS	MDR-137-8	1	1	.089
		ELECT	MDR-137-8	2	1	
		ELECT	MDR-138-8	2	2	
15	GE	HPCS	MDR-137-8	1	0	.023
		ELECT	MDR-137-8	3	1	
		ELECT	MDR-138-8	1	0	
16	W	ESFAS	MDR-137-8	6	0	.0012
		EDG	MDR-138-8	1	1	
		ESFAS	MDR-4103-1	34	0	
		MS	MDR4103-1	6	0	
		RPS	MDR-4121-1	10	0	
		CVCS	MDR-4121-1	4	0	
		ESFAS	MDR-4121-1	66	0	
		RPS		6	0	
17	B&W	HPI	MDR-131-1	1	0	.0093
		ESFAS	MDR-134-1	1	1	
		CRD	MDR-137-8	4	0	
		RPS	MDR-137-8	2	0	
		CRD	MDR-138-8	2	0	
		CRD	MDR-5138	2	0	

Footnotes at end of table

P&B MDR RELAY USAGE (Cont.)

Plant	NSSS	System	MDR Model No.	No. of MDRs	Failures Reported	Failure Rate
18	CE	RCS	MDR-131-1	1	1	.0144
		RPS	MDR-131-1	2	0	
		LPSI	MDR-134-1	3	1	
		RPS	MDR-134-1	4	0	
		ESFAS	MDR-136-1	13	5	
		Cond	MDR-137-8	2	1	
		CS	MDR-137-8	1	0	
		ESFAS	MDR-137-8	4	0	
		RPS	MDR-170-1	1	1	
		CS	MDR-7032	2	1	
		ESFAS	MDR-7032	10	1	
		ESFAS	MDR-7033	14	0	
		ESFAS	MDR-7034	43	2	
19	W	ESFAS	MDR-66-4	31	NONE	0
		ESFAS	MDR-134-1	2	REPORTED	
20	W	ESFAS	MDR-66-4	31	NONE REPORTED	0
21	W	ESFAS	MDR-66-4	31	NONE	0
		ESFAS	MDR-134-1	2	REPORTED	
22	W	ESFAS	MDR-66-4	31	NONE	0
		ESFAS	MDR-134-1	2	REPORTED	
23	GE	EDG	MDR-5095	1	1	.170
24	CE	EDG	MDR-131-1	8	NONE REPORTED	0
25/26	GE	ELECT	MDR-4094	10	0	.0057
		COND	MDR-4094	8	0	
		NSSSS	MDR-4134-1	9	0	
		RPS	MDR-4134-1	72	1	
		RPS	MDR-5111-1	8	0	
		RHR	?	2	1	
27	W	RPS	MDR-134-1	16	0	0
		ESFAS	MDR-134-1	46	0	
		ESFAS	MDR-4076	58	0	
28	GE	RPS	MDR-4130-1	8	2	.0079
		RPS	MDR-4134-1	59	4	
		NSSSS	MDR-4134-1	34	0	
		MS	MDR-5117	4	0	
		RPS	MDR-5117	4	0	
		SLC	?			
		SW	?			
		VENT	?			
				20	0	

Footnotes at end of table

P&B MDR RELAY USAGE (Cont.)

Plant	NSSS	System	MDR Model No.	No. of MDRs	Failures Reported	Failure Rate
29	W	ESFAS	MDR-134-1	4	NONE REPORTED	0
30	W	ESFAS ESFAS	MDR-4103-1 MDR-6091	87 124	1 0	.00098
31	W	ESFAS RPS ESFAS	MDR-4103-1 MDR-4103-1 MDR-4121-1	6 7 26	NONE REPORTED	0
32	W	AFW	MDR-5059	1	1	.11
33	W	CONT	MDR-137-8	1	1	.21
34	W	SSPS	?	150	1	.0015
35	W	CONT	MDR-5076	1	1	.067
Total Units	NSSS			MDRs	Failures	
1	B&W			12	1	
8	CE			1097	82	
10	GE			1088	35	
16	W			802	8	
35				2999	126	

[1] Since much of this data came from the proprietary voluntary NPRDS database, specific plants could not be identified.

[2] Record of plant MDR relay usage is incomplete due to lack of data in the NPRDS database and manufacturer's purchase orders.

[3] The failure rates, in failures/reactor year per MDR, were calculated by the following formula for each unit individually:

$$\text{Failure rate}_x = F_x /((Y_x)(N_x))$$

where,

F_x = Number of reported MDR relay failures from 1984 through 1992 by unit x
Y_x = Time in service measured in years from initial criticality through 1992 for unit x
N_x = Number of MDRs in service at unit x

The failure rates in this table can not be relied on for high accuracy, because this calculation assumed:

- The number of reported failures is correct, despite the inconsistencies noted above. Fewer reported failures would decrease the calculated failure rate.

- Each failed relay is replaced by an MDR relay which has the same failure mechanisms. The validity of this assumption depends on the replacement relay's manufactured date. While P&B was improving the materials of construction on a yearly basis, the number of failure mechanisms built into the replacement relay depended on when the unit purchased it, which is unknown. This calculation assumes each replacement relay was in service during the entire period, instead of individually calculating N_s yearly and subtracting the MDR relays replaced during previous years. A few plants replaced many their MDR relays on a wholesale basis during this period. This assumption may increase N_s, which would minimize the calculated failure rate.

- The number of MDR relays listed in service is correct, despite the inconsistencies noted above. Based on the discrepancies found, this assumption may decrease N_s, which would increase the calculated failure rate for some plants.

- The MDR relays' energization or environmental states remain constant from initial criticality through 1992. It does not include any change in state resulting from reactor shutdown conditions. This could have greatly varying affects on the relay, depending upon whether it was latching or non-latching and whether its energization state was changed upon plant shutdown. This assumption may increase Y_s which could minimize the calculated failure rate.

- The time in service excludes MDR relay energization or usage prior to initial criticality, which would vary greatly, depending upon a specific relay's normal position during a plant shutdown and the amount of testing performed. This assumption may or may not affect Y_s which could affect the calculated failure rate for those plants with initial criticality after January 1984.

[4] Where MDRs were replaced with new models during the 1984-1992 period, both new and old models are indicated even though specific relay totals do not match overall plant relay use. The total number of MDR relays in service are used for plant specific failure rates.

[5] Includes five failures identified in a plant specific LER that were not included in the NPRDS database. The LER did not contain sufficient detail for their inclusion into Appendix C.

APPENDIX C

P&B MDR Relay Failure Data

APPENDIX C

P&B MDR relay failure data

MDR Model No.	Volts	Coil Watts	State	Failure Date	Inservice Date	Fail Time (yr)	NSSS	System	Results of Failure	Relay Failure Mechanism
MDR-131-1	120VAC	7.1	E	27-Aug-85	19-Dec-79	5.7	CE	CS	BKUP PRZR HTRS DIDN'T SHUT OFF	RELAY BURNT OUT
MDR-134-1	115VAC	6.5	E	22-Jun-87	16-Jun-74	13.0	W	MS	S/G BLOWDOWN ISO VLV CLOSED-ST	CONTACTS STICKING
MDR-134-1	115VAC	6.5	D	20-Jun-86	26-Mar-80	6.2	CE	LPSI	LPSI VALVE DIDN'T OPEN - ST	MECHANICAL BINDING
MDR-134-1	115VAC	6.5	D	17-May-85	01-Jan-85	0.5	B&W	ESFAS	EFW ISOL VALVE DIDN'T OPEN - ST	CONTACTS STUCK
MDR-136-1	36VDC		E	04-Jan-93	27-May-85	7.5	CE	ESFAS	EFW FLOW CONTROL VLV INOP-ST	OPEN SET OF CONTACTS
MDR-136-1	28VDC	10.3	E	06-Sep-92	01-Apr-84	8.4	CE	ESFAS	AFW CONT ISO VALVE TO S/G INOP	OVERSIZED COIL STUCK SHAFT
MDR-136-1	28VDC	10.3	E	20-Nov-87	26-Mar-80	7.6	CE	ESFAS	"B" EFW VLV TO "A" S/G INOP-ST	OXIDE FILM ON CONTACTS
MDR-136-1	28VDC	10.3	E	20-Nov-87	26-Mar-80	7.7	CE	ESFAS	"A" EFW VALVE TO S/G INOP - ST	CONTACT FAILURE, BUT TESTED OK
MDR-136-1	28VDC	10.3	E	11-Aug-87	01-Jan-84	3.8	CE	ESFAS	EFW PUMP DIS VALVE TO S/G INOP	DEFECTIVE CONTACTS
MDR-136-1	28VDC	10.3	E	30-Jul-85	26-Mar-80	5.3	CE	ESFAS	1 ESFAS DIDN'T RESET POST RXTRIP	RELAY STUCK
MDR-136-1	28VDC	10.3	E	13-Jan-84	26-Mar-80	3.7	CE	ESFAS	EFW DIS ISO VALVE INOP - ST	MECHANICAL BINDING
MDR-137-8	125VDC	10.3	E	28-Dec-92	01-Nov-90	2.2	GE	ELECT	EDG DIDN'T PICK UP LOAD ON GRID	STICKING CONTACTS DIDN'T OPEN
MDR-137-8	125VDC	10.3	E	04-Jul-90	19-May-89	1.1	GE	CIS	S/G SAMPLE VLV DIDN'T STAY OPEN	CONTACTS DID NOT PICK UP
MDR-137-8	125VDC	10.3	E	01-May-89	24-Sep-85	3.6	CE	CS	CSP ISOLATION VALVE INOP - ST	CONTACTS STUCK INTERMITENTLY
MDR-137-8	120VDC	9.5	D	16-Nov-88	08-Aug-83	5.3	CE	ELECT	EDG VOLTAGE REGULATOR INOP	STUCK IN ENERGIZED STATE
MDR-137-8	125VDC	10.3	D	17-Jun-88	01-Apr-84	4.2	CE	ELECT	EDG CONTROL SYSTEM - PM	RELAY DID NOT RESPOND PROPERLY
MDR-137-8	125VDC	10.3	D	16-Jun-88	01-Apr-84	4.2	CE	ELECT	EDG CONTROL SYSTEM - PM	RELAY DID NOT RESPOND PROPERLY
MDR-137-8	125VDC	10.3	D	15-Jun-88	01-Apr-84	4.2	CE	ELECT	EDG CONTROL SYSTEM - PM	RELAY DID NOT RESPOND PROPERLY
MDR-137-8	125VDC	10.3	D	15-Jun-88	01-Apr-84	4.2	CE	ELECT	EDG START RELAY FOUND BAD - PM	RELAY DID NOT RESPOND PROPERLY
MDR-137-8	128VDC	10.3	D	13-Jun-88	01-Apr-84	4.2	CE	ELECT	D/G VOLT. REG. ADJUSTMENT PROB	2 CONTACTS WOULDN'T CLOSE
MDR-137-8	120VDC	9.5	D	13-Jun-88	01-Apr-84	4.2	CE	ELECT	EDG VOLT. REG. RELAY INOP	2 CONTACTS INOP WITHOUT TAPPING
MDR-137-8	120VAC	9.5	E	09-May-88	01-Apr-84	4.1	CE	ELECT	EDG PROT. RELAY INOP - PM	DID NOT MEET MANF SPECS
MDR-137-8	120VDC	9.5	D	15-Oct-87	01-Apr-84	3.5	CE	ELECT	EDG CONTROL SYSTEM PM	WOULD NOT RESPOND PROPERLY
MDR-137-8	125VDC	10.3	D	10-Sep-87	08-Aug-83	4.1	CE	ELECT	EDG CONTROLS PM	RELAY OUT OF TOLERANCE
MDR-137-8	28VDC		D	20-May-87	01-Apr-87	0.1	CE	ELECT	"B" EDG VOLT REG LIGHT INOP	FAILED RELAY - END OF LIFE
MDR-137-8	115VAC	9.5	D	13-Jan-87	01-Apr-84	2.7	CE	ELECT	EDG TROUBLE ALARM DIDN'T RESET	UNKNOWN
MDR-137-8	125VDC	10.3	E	21-Aug-85	10-Mar-84	1.4	GE	ELECT	EDG UNDERVOLTAGE ALARM INOP	CONTACTS OPEN
MDR-137-8	125VDC	10.3	D	03-Aug-85	26-Mar-80	5.4	CE	COND	COND PP DIDN'T STOP POST RX TRIP	RELAY FAILED
MDR-138-8	125VDC	10.3	D	21-Nov-92	01-Nov-90	2.0	GE	HPCS	HPCS DG OVERSPEED PROT. INOP	RELAY BINDING
MDR-138-8	125VAC		D	04-Nov-92	01-Nov-90	2.0	GE	ELECT	EDG OVERVOLTAGE RELAY INOP	FAILED TO OP AT SET VOLTAGE
MDR-138-8	125VDC	10.3	D	13-Mar-91	17-Nov-86	4.3	W	ELECT	"B" EDG SEQUENCER FAILED - ST	CONTACTS DIDN'T MAKE-TESTED OK
MDR-138-8	125VDC	10.3	D	25-Dec-89	08-Aug-83	6.3	CE	CVCS	ION EXCHANGER BYPASS VALVE INOP	CHATTERED/DIDN'T STAY CLOSED
MDR-138-8	125VDC	10.3	D	09-Oct-89	27-May-85	4.4	CE	ELECT	EDG CLG WATER PP DIDNT START-ST	LOAD SEQUENCER CONTACTS STUCK
MDR-138-8	125VDC	10.3	D	17-Jun-88	01-Apr-84	4.2	CE	ELECT	EDG CONTROL SYSTEM - PM	RELAY DID NOT RESPOND PROPERLY
MDR-138-8	125VDC	10.3	D	17-Jun-88	01-Apr-84	4.2	CE	ELECT	EDG CONTROL SYSTEM - PM	RELAY DID NOT RESPOND PROPERLY
MDR-138-8	125VDC	10.3	D	15-Jun-88	01-Apr-84	4.2	CE	ELECT	EDG CONTROL SYSTEM - PM	RELAY DID NOT RESPOND PROPERLY
MDR-138-8	120VDC	9.5	E	05-May-88	01-Apr-84	4.1	CE	ELECT	EDG PREVENT. MAINT.	RELAY DIDN'T MEET MANF SPECS
MDR-138-8	125VDC	10.3	E	14-Jan-86	04-Sep-82	3.3	GE	ELECT	EDG OUTPUT BRKR DIDN'T CLOSE-ST	SOME CONTACTS DID NOT CLOSE
MDR-138-8	125VDC	10.3	D	25-Nov-85	08-Aug-83	2.3	CE	ELECT	LOSS OF EDG 125VDC CONTROL - ST	END OF LIFE

APPENDIX C (Cont.)

P&B MDR relay failure data

MDR Model No.	Volts	Coil Watts	State	Failure Date	Inservice Date	Fail Time (yr)	NSSS	System	Results of Failure	Relay Failure Mechanism
MDR-170-1				13-Jan-92		0.0	CE	RCS	LOST PRZR HTR CONTROL CIRCUIT	ROTOR STUCK WHEN SPRING BROKE
MDR-170-1	115VAC		E	03-Oct-91	17-Sep-89	2.1	CE	RPS	"B" RPS BREAKER KEPT TRIPPING	NORMAL WEAR OUT OF RELAY
MDR-170-1	115VAC		E	01-Oct-91	17-Sep-89	2.1	CE	RPS	MASTER RPS RELAY DIDN'T TRIP-ST	NORMAL WEAROUT OF RELAY
MDR-170-1	115VAC		E	01-Oct-91	17-Sep-89	2.1	CE	RPS	"D" RPS BRKR CONTINUOUS TRIP-ST	MASTER RELAY WOULDN'T ENERGERIZE
MDR-170-1	115VAC		E	11-Jun-91	22-Jun-90	1.0	CE	RPS	"C" RPS FAILED TO RESET - ST	RELAY FAILED TO RESET
MDR-170-1	12VDC		E	13-Aug-87	01-Apr-84	3.4	CE	RPS	SPURIOUS TRIP OF RX BREAKERS	FEEDER CABLE HOT
MDR-170-1	12VDC		E	22-Sep-86	01-Apr-84	2.5	CE	RPS	"B" RPS PATH 2 DID NOT TRIP	STUCK IN ENERGIZED STATE
MDR-170-1	120VAC		E	06-Jun-84	25-Mar-80	4.2	CE	RPS	FALSE RPS CHANNEL 2 TRIP	1 OF 3 RELAYS ACTING ABNORMALLY
MDR-4094	115VAC	8.	E	15-Jan-88	01-May-84	3.7	GE	RWCU	RWCU PUMP COULD NOT SHUTDOWN	RELAY STUCK
MDR-4094	115VAC	8.	E	09-Feb-87	01-Sep-82	4.3	GE	ESSW	ESSW PUMP FAN DIDN'T SHUTDOWN	RELAY STICKING
MDR-4094	115VAC	8.	E	11-Sep-86	01-Sep-82	4.0	GE	ESW	ESW PUMP FAN RUNNING IN AUTO	RELAY CONTACTS STUCK
MDR-4094	115VAC	8.	D	06-Jul-85	01-Jan-85	0.5	GE	MS	SRV POSITION INDICATION INOP	INTERMITTENT OPERATION IN ST
MDR-4094	115VAC	8.	D	06-Jul-85	01-Jan-85	0.5	GE	MS	SRV POSITION INDICATION INOP	INTERMITTENT OPERATION IN ST
MDR-4103-1	118VAC		E	15-Sep-89	10-Oct-85	3.9	W	RPS	CHRG PP MIN FLOW VALVE OPENED-ST	STUCK IN ENERGIZED POSITION
MDR-4121-1	120VAC	5.5	D	04-Oct-87	06-Jun-78	9.3	W	MS	MSIV DIDN'T SHUT IN TIME	RELAY OPERATED SLOWLY
MDR-4130-1	120VAC		E	01-Jun-92	01-Oct-86	6.7	GE	RPS	CH A/RPT A TCV SCRAM RESPONSE>TS	SLOW OPENING CONTACTS
MDR-4130-1	120VAC		E	01-Jun-92	01-Oct-86	6.7	GE	RPS	CH B/RPT A TCV SCRAM RESPONSE>TS	SLOW OPENING CONTACTS
MDR-4130-1	120VAC		E	16-Dec-87	15-Jan-85	2.9	GE	RPS	BACKUP SCRAM VALVE FAILED	RELAY FAILURE
MDR-4134-1	120VAC	7.1	E	09-Jan-93	23-Jun-89	3.5	GE	RPS	RPS/MSIV CLOSURE TIME>TS LIMIT	"EXPECTED WEAR"
MDR-4134-1	120VAC	7.1	E	14-Jun-92	01-Oct-86	6.8	GE	RPS	CH B/B2 TCV SCRAM RESPONSE > TS	SLOW OPENING CONTACTS
MDR-4134-1	120VAC	7.1	E	14-Jun-92	01-Oct-86	6.8	GE	RPS	CH B/B1 TCV SCRAM RESPONSE > TS	SLOW OPENING CONTACTS
MDR-4134-1	120VAC	7.1	E	12-Jun-92	01-Oct-86	6.8	GE	RPS	CH B/B1 TCV SCRAM RESPONSE > TS	SLOW OPENING CONTACTS
MDR-4134-1	120VAC	7.1	E	12-Jun-92	01-Oct-86	6.8	GE	RPS	CH B/B1 TCV SCRAM RESPONSE > TS	SLOW OPENING CONTACTS
MDR-4134-1	120VAC	7.1	D	21-Sep-90	11-Apr-86	4.4	GE	ESW	BACKWASH VALVE DIDN'T CLOSE-ST	BURNED OUT RELAY COIL
MDR-4134-1	120VAC	7.1	E	15-Sep-88	15-Jan-85	3.7	GE	RPS	PREVENTED RPS HALF SCRAM	SMALL END COVER HOLE ROUND SHAFT
MDR-4135-1	120VAC	7.1	E	03-Aug-91	28-Jun-86	5.1	GE	RPS	"B" APRM RPS TRIP INPUT - PM	EXCESS NOISE: EXPECTED FAILURE
MDR-4135-1	120VAC	7.1	E	13-Nov-89	18-Feb-86	3.4	GE	RWCU	RWCU CONT ISO VALVE DIDN'T OPEN	CONTACTS DIDN'T CLOSE-CORROSION
MDR-4135-1	120VAC	7.1	E	05-Apr-88	28-Jun-86	1.7	GE	RPS	"D" MAIN STEAM HI RAD TRIP SLOW	DEFECTIVE RESPONSE TIME
MDR-4135-1	120VAC	7.1	E	02-Apr-88	28-Jun-86	1.7	GE	RPS	RPS DIV. 2 & 4 RELAY FAILED ST	RELAY OPERATED SLOWLY
MDR-5059	125VDC	10.3	E	11-Jan-92	01-Jan-84	8.0	W	AFW	CHANGED AFW STEAM TO ALT SUPPLY	FAILED TO DE-ENERGIZED POSITION
MDR-5060	125VDC	10.3	D	03-Sep-85	08-Aug-83	2.1	CE	CIS	SAMPLE CONT ISO VALVE INOP - ST	PREMATURE END OF LIFE
MDR-5061	125VDC	10.3	D	29-May-89	24-Sep-85	3.7	CE	HVAC	EDG ROOM EXHST FAN DAMPER INOP	COIL HAD OPEN CIRCUIT
MDR-5062	125VDC	10.3	E	02-Nov-92	01-Jan-90	1.8	GE	CAC	ISOLATION VALVE POSITION INOP	RELAY STUCK
MDR-5062	125VDC	10.3	E	29-Sep-92	01-May-84	8.4	GE	RCS	RECIRC PUMP 1B WOULDN'T TRIP	RELAY STUCK IN ENERG POSITION
MDR-5062	125VDC	10.3	E	29-Sep-92	01-May-84	8.4	GE	RCS	RECIRC PUMP 1A WOULDN'T TRIP	RELAY STUCK IN ENERGIZED STATE
MDR-5062	125VDC	10.3	E	13-Sep-92	01-May-84	8.4	GE	CS	NO DIV 1 CONTROL PWR LOSS ALARM	RELAY STUCK IN ENERGIZED STATE
MDR-5062	125VDC	10.3	D	05-Apr-86	08-Jun-83	3.8	GE	ELECT	ESW/RHRESW PPS INOP ON EDG -ST	SEQUENCER CONTACTS STUCK OPEN
MDR-5062	125VDC	10.3	D	15-Feb-84	01-Sep-82	2.4	GE	CS	CS PUMP BKR DIDN'T OPEN IN ST	NOT WORKING PROPERLY

APPENDIX C (Cont.)

P&B MDR relay failure data

MDR Model No.	Volts	Coil Watts	State	Failure Date	Inservice Date	Fail Time (yr)	NSSS	System	Results of Failure	Relay Failure Mechanism
MDR-5076	125VDC		E	22-Mar-91	22-May-76	14.8	W	CI	PRT ISO VALVE DIDN'T CLOSE - ST	RELAY FAILED CLOSED
MDR-5095	125VDC		D	30-Dec-89	03-Jan-86	3.9	GE	ELECT	DIV 1 EDG FAILED TO START	MISAPPLICATION/CURRENT LOAD LOW
MDR-5111-1	22VDC	8.6	E	23-Jul-91	15-Jan-85	6.6	GE	ESF	CONT ISO OF RWCU SAMPLE VLV-ST	RELAY STUCK
MDR-5111-1	22VDC	8.6	E	19-Jul-91	15-Jan-85	6.6	GE	ESF	CIS, SBGT START, CRHVAC ACT.	HIGH CONTACT RESIST, BUT TEST OK
MDR-5146	28VDC		E	12-Apr-91	15-Jan-88	3.2	CE	ELECT	B ECWS PP FAILED TO RUN - ST	CONTACTS FAILED TO CLOSE
MDR-5147	32VDC		E	06-Jul-90	19-Sep-86	3.7	CE	RPS	A MSIS RPS TRIP DIDN'T RESET-ST	ALL CONTACTS FOUND OPEN
MDR-5151		10.3	E	09-May-92	01-Jan-91	1.4	GE	CAM	CONT ATM VALVE POSITION INOP	RELAY STUCK
MDR-6091	118VAC		E	25-Jul-90	01-Mar-88	2.3	W	ESFAS	EDG - ST	2 CONTACTS FAILED TO CLOSE
MDR-7032	28VDC	18.7	E	25-Sep-92	30-Sep-91	1.0	CE	ESFAS	ESFAS CHANNEL INOP - ST	SHAFT BINDING: MANUFACTURE DEFECT
MDR-7032	28VDC	18.7	E	11-Nov-89	26-Mar-80	9.6	CE	CS	CSAS BYPASS DIDN'T STOP NaOH PP	CONTACTS CLOSED SLOWLY
MDR-7032	36VDC	30.8	E	28-Mar-89	27-Jan-86	3.2	CE	ESFAS	VALVE OVERRIDE INDICATION INOP	OVERVOLTAGE OUTGASSING FAILURE
MDR-7032	36VDC	30.8	E	25-Jan-89	18-Jan-88	1.0	CE	ESFAS	B LPSI PP RECIRC VLV INOP-ST	OVERVOLTAGE OUTGASSING FAILURE
MDR-7032	36VDC	30.8	E	10-Jan-89	18-Jan-88	1.0	CE	ESFAS	ESFAS OVERRIDE SWITCH INOP - ST	OVERVOLTAGE OUTGASSING FAILURE
MDR-7032	36VDC	30.8	E	09-Jan-89	18-Sep-86	2.2	CE	ESFAS	SIAS TRAIN SIGNAL FAILED - ST	OVERVOLTAGE OUTGASSING FAILURE
MDR-7032	36VDC	30.8	E	02-Aug-88	18-Sep-86	1.8	CE	ESFAS	"B" AFAS SIGNAL FAILURE - ST	OVERVOLTAGE OUTGASSING FAILURE
MDR-7032	36VDC	30.8	E	03-Jun-87	27-Jan-86	1.3	CE	ESFAS	"B" CONT. SPRAY SIGNAL INOP	OVERVOLTAGE OUTGASSING FAILURE
MDR-7032	36VDC	30.8	E	26-May-87	18-Sep-86	0.7	CE	ESFAS	"B" SIAS SIGNAL FAILURE - ST	OVERVOLTAGE OUTGASSING FAILURE
MDR-7032	36VDC	30.8	E	26-Nov-86	18-Sep-86	0.2	CE	ESFAS	"B" AUX FW SIGNAL FAILURE - ST	OVERVOLTAGE OUTGASSING FAILURE
MDR-7032	28VDC	18.7	E	07-Mar-85	01-Apr-84	0.9	CE	ESFAS	ESF TESTING FOUND BAD RELAY	END OF LIFE
MDR-7032	28VDC	18.7	E	12-Sep-84	01-Apr-84	0.4	CE	EFW	RELAY FOUND BAD IN ESF ST	"END OF LIFE"
MDR-7032	28VDC	18.7	E	13-Aug-84	08-Aug-83	1.0	CE	ESFAS	PREVENTATIVE MAINTENANCE	NOT OPERATING PROPERLY
MDR-7033	28VDC	18.7	E	07-Nov-87	08-Aug-83	4.2	CE	ESFAS	"A" SIAS TRAIN INOP - ST	WEAROUT DUE TO AGING
MDR-7034	36VDC	18.7	E	08-Dec-91	27-May-85	6.5	CE	EFW	"B" EFW INOP - ST	ROTOR STUCK:OUTGASSING/CORROSION
MDR-7034	28VDC	18.7	E	27-Jun-89	24-Sep-85	3.8	CE	CIS	EFW & S/G BLOWDOWN VLVS INOP -ST	STUCK IN ENERGIZED POSITION
MDR-7034	28VDC	18.7	E	22-Jan-89	08-Aug-83	5.4	CE	ESFAS	DIDN'T ACT. ALL "B" SAIS EQUIP	RELAY NOT WORKING PROPERLY
MDR-7034	36VDC	30.8	E	19-Dec-88	18-Sep-86	2.3	CE	ESFAS	MSIS CHANNEL INOP IN BYPASS -ST	CONTACT CORROSION - OFFGASSING
MDR-7034	28VDC	18.7	E	07-Nov-88	08-Aug-83	5.2	CE	ESFAS	LPSI PUMP FAILED IN 2ND TEST	CYCLING/CONTACT RESIST.
MDR-7034	36VDC	30.8	E	05-Aug-88	18-Sep-86	1.9	CE	ESFAS	"B" MSIS INOP -ST	OVERVOLTAGE OUTGASSING FAILURE
MDR-7034	36VDC	30.8	E	09-May-88	18-Jan-88	0.3	CE	ESFAS	"A" CSAS INOP -ST	OVERVOLTAGE OUTGASSING FAILURE
MDR-7034	36VDC	30.8	E	03-May-88	18-Sep-86	1.6	CE	ESFAS	"B" RECIRC ACT SIG FAILED - ST	OVERVOLTAGE OUTGASSING FAILURE
MDR-7034	28VDC	18.7	E	07-Apr-88	26-Mar-80	8.1	CE	NSW	EMERG POND SW VALVE INOP - ST	RELAY STUCK ON DE-ENERGIZATION
MDR-7034	36VDC	30.8	E	31-Dec-87	18-Sep-86	1.3	CE	ESFAS	"B" SIAS SIGNAL FAILURE - ST	OVERVOLTAGE OUTGASSING FAILURE
MDR-7034	28VDC	18.7	E	01-Apr-87	01-Apr-84	3.0	CE	ESFAS	INTERMITANT CONT. ISO. SIGNAL	SPURIOUS SIGNAL
MDR-7034	36VDC	30.8	E	11-Feb-87	18-Sep-86	0.4	CE	ESFAS	CHILLED WATER VALVE INOP	OVERVOLTAGE OUTGASSING FAILURE
MDR-7034	28VDC	18.7	E	09-Nov-86	08-Aug-83	3.2	CE	ESFAS	"B" CIAS INOP - ST	HIGH CONTACT RESISTANCE
MDR-7034	28VDC	18.7	E	11-Feb-86	26-Mar-80	5.9	CE	ESFAS	REACTOR TRIP ON "A" MSIV CLOSURE	HIGH CONTACT OHMS-5 MDRS REPLACED

APPENDIX C (Cont.)

P&B MDR relay failure data

MDR Model No.	Volts	Coil Watts	State	Failure Date	Inservice Date	Fail Time (yr)	NSSS	System	Results of Failure	Relay Failure Mechanism
MDR-7061	32VDC	20.4	E	04-Oct-90	28-Jan-86	4.7	CE	ESFAS	SPRAY CHEM PP VALVE INOP - ST	DEFECTIVE CONTACTS DIDN'T CLOSE
MDR-7061	32VDC	20.4	E	16-Mar-89	28-Jan-86	3.2	CE	CS	ESFAS SUBGROUP FAILED - ST	CONTACTS DIDN'T CLOSE-OFFGASSING
MDR-7061	32VDC	20.4	E	13-Feb-89	28-Jan-86	3.1	CE	RPS	"D" SIAS INOP - ST	CONTACTS DIDN'T CLOSE-OFFGASSING
MDR-7061	32VDC	20.4	E	02-Feb-89	28-Jan-86	3.1	CE	ESFAS	DIDN'T CLOSE RWT ISO VALVE - ST	ROTOR STUCK - OFF GASSING
MDR-7062	32VDC		E	05-Apr-90	28-Jan-86	4.3	CE	ESFAS	"B" ESFAS CHANNEL LOST - ST	2 CONTACTS DIDN'T CHANGE STATE
MDR-7063	32VDC		E	13-Dec-88	19-Sep-86	2.2	CE	ESFAS	ESFAS FAILED, THEN OK - ST	INTERMITTENT OP FROM OFFGASSING
MDR-7063	32VDC		E	01-Nov-88	28-Jan-86	1.9	CE	RPS	"B" CIAS CHANNEL LOST - ST	ROTOR STUCK - OFF GASSING