Westinghouse Non-Proprietary Class 3

WCAP-14117-NP-A
Revision 2

Reliability Assessment of Potter & Brumfield MDR Series Relays

Westinghouse Electric Company LLC

WESTINGHOUSE NON-PROPRIETARY CLASS 3

WCAP-14117-NP-A
Revision 2

Reliability Assessment of Potter & Brumfield MDR Series Relays

August 2000

This report (WCAP-14117-NP-A Revision 2) supersedes and replaces all earlier versions of WCAP-14117.

WESTINGHOUSE ELECTRIC COMPANY LLC
P.O. Box 355
Pittsburgh, Pennsylvania 15230-0355

LEGAL NOTICE

This report was prepared by Westinghouse Electric Company LLC as an account of work sponsored by the Westinghouse Owners Group (WOG) SRT Subgroup. Neither the WOG SRT Subgroup, any member of the WOG SRT Subgroup, Westinghouse Electric Company LLC, nor any person acting on behalf of any of them:

(A) Makes any warranty or representation whatsoever, express or implied (I) with respect to the use of any information, apparatus, method, process, or similar item disclosed in this report, including merchantability and fitness for a particular purpose, (II) that such use does not infringe on or interfere with privately owned rights, including any party's intellectual property, or (III) that this report is suitable to any particular user's circumstance; or

(B) Assumes responsibility for any damages or other liability whatsoever (including any consequential damages, even if the WOG SRT Subgroup or any WOG SRT Subgroup representative has been advised of the possibility of such damages) resulting from any selection or use of this report or any information apparatus, method, process, or similar item disclosed in this report.

UNITED STATES
NUCLEAR REGULATORY COMMISSION
WASHINGTON, D.C. 20555-0001

July 12, 2000

RECEIVED JUL 18 2000 H. A. ...

Mr. H. A. Sepp, Manager
Regulatory and Licensing Engineering
Westinghouse Electric Company
P.O. Box 355
Pittsburgh, PA 15230-0355

SUBJECT: REVIEW OF WESTINGHOUSE TOPICAL REPORTS WCAP-13877, REVISION 2-P AND WCAP-13878-P, REVISION 2 ON SOLID STATE PROTECTION SYSTEM (SSPS) SLAVE RELAYS (TAC NO. MA7264)

Dear Mr. Sepp:

The NRC staff has completed its review of the subject Westinghouse Electric Company (WEC) topical reports (TRs) which were submitted by letter dated November 5, 1999. The NRC staff had previously reviewed and approved Revision 1 of these TRs. A May 31, 1996, letter from Bruce A. Boger of the NRC to Tom Green, Chairman of the Westinghouse Owners Group (WOG), documents the NRC's acceptance of WCAP-13878, Revision 1, and an October 26, 1998, letter from Thomas E. Essig of the NRC to Louis F. Liberatori of the WOG documents the NRC acceptance of WCAP-13877, Revision 1. However, WEC subsequently discovered certain errors in the TRs and therefore submitted Revision 2 of these TRs to the NRC for review and approval. WEC has further determined that the changes do not affect the conclusions of the WCAPs and the NRC safety evaluations. The NRC staff has reviewed the changes and finds them acceptable. The enclosed safety evaluation (SE) confirms the acceptability of the proposed changes.

Pursuant to 10 CFR 2.790, we have determined that the enclosed SE does not contain proprietary information. However, we will delay placing the SE in the public document room for a period of ten (10) working days from the date of this letter to provide you with the opportunity to comment on the proprietary aspects only. If you believe that any information in the enclosure is proprietary, please identify such information line by line and define the basis pursuant to the criteria of 10 CFR 2.790.

We do not intend to repeat our review of the matters described in the reports, and found acceptable, when the reports appear as references in license applications, except to assure that the material presented is applicable to the specific plant involved. Our acceptance applies only to matters described in the reports.

In accordance with procedures established in NUREG-0390, "Topical Report Review Status," we request that Westinghouse Electric Company publish accepted versions of the topical reports, proprietary and non-proprietary, within 3 months of receipt of this letter. The accepted versions shall incorporate this letter and the enclosed SE between the title page and the abstract. It must be well indexed such that information is readily located. Also, it must contain in appendices historical review information, such as questions and accepted responses, and original report pages that were replaced. The accepted versions shall include an "-A" (designating accepted) following the report identification symbol.

Should our criteria or regulations change so that our conclusions as to the acceptability of the reports are invalid, Westinghouse Electric Company and/or the applicants referencing the topical reports will be expected to revise and resubmit their respective documentation, or submit justification for the continued applicability of the topical reports without revision of their respective documentation.

Sincerely,

Stuart A. Richards, Director
Project Directorate IV & Decommissioning
Division of Licensing Project Management
Office of Nuclear Reactor Regulation

Project No. 694

Enclosure: Safety Evaluation

cc w/encl:
Mr. Andrew Drake, Project Manager
Westinghouse Owners Group
Westinghouse Electric Company
Mail Stop ECE 5-16
P.O. Box 355
Pittsburgh, PA 15230-0355

UNITED STATES
NUCLEAR REGULATORY COMMISSION
WASHINGTON, D.C. 20555-0001

SAFETY EVALUATION BY THE OFFICE OF NUCLEAR REACTOR REGULATION

WESTINGHOUSE ELECTRIC COMPANY TOPICAL REPORTS

WCAP-13877 AND WCAP-13878

RELIABILITY ASSESSMENT OF WESTINGHOUSE TYPE AR RELAYS

USED AS SSPS SLAVE RELAYS

1.0 INTRODUCTION

By letter dated November 5, 1999, Westinghouse Electric Company (WEC) submitted Topical Reports (TRs) WCAP-13877, Revision 2-P, "Reliability Assessment of Westinghouse Type AR Relays Used as SSPS Slave Relays," and WCAP-13878-P, Revision 2, "Reliability Assessment of Potter & Brumfield MDR Series Relays." The NRC staff had previously reviewed and accepted Revision 1 of these TRs. A May 31, 1996, letter from Bruce A. Boger of the NRC to Tom Green, Chairman of the Westinghouse Owners Group (WOG), documents the NRC acceptance of WCAP-13878-P, Revision 1, and an October 26, 1998, letter from Thomas E. Essig of NRC to Louis F. Liberatori of WOG documents the NRC acceptance of WCAP-13877, Revision 1-P. However, WEC subsequently discovered certain errors in the TRs and therefore revised these TRs and submitted the revisions to NRC for review and approval. The revisions (1) use the correct Arrhenius equation to calculate the total service life for the relays energized 20 percent of the time (Section 8.2.2 and Appendix C of WCAP-13878-P, Revision 2, and Appendix D of WCAP-13877 Revision 2-P), and (2) change the aging reference temperature of nylon Zytel 101 from 160°C to 175°C and the activation energy from 1.37 eV to 0.8787 eV. The revisions also correct typographical and numerical errors in the text associated with the changes in the tables.

2.0 EVALUATION

The proposed changes to the TRs and the staff's evaluation of the changes are discussed below:

1. Proposed change

   Correct Arrhenius equation to calculate the service lives of slave relays energized 20 percent of the time.

   Evaluation

   The original aging assessment of solid state protection system (SSPS) slave relays used a non-conservative Arrhenius equation for calculating the service life for a defined duty cycle other than 0 percent and 100 percent. The original equation assumed that when a device is energized for a certain fraction of its calculated service life, the remaining fraction of the energized condition can then be expanded into a much longer time in a de-energized condition. These two times are not related to the duty cycle which is a fraction of the total service. For example, a relay with 20 percent duty cycle is energized for 20 percent of its total service life and de-energized for 80 percent. Revision 2 of the WCAPs use the correct Arrhenius equation to calculate the total service life of the SSPS slave relays for any defined duty cycle. This results in shorter service lives of all materials at a 20 percent duty cycle. The staff's evaluation of this change is discussed in items 3 and 4 below. Small numerical differences appear in the TRs for the 0 percent and 10 percent duty cycles because of rounding off of numbers and differences in calculation software. The staff finds the application of the revised more conservative Arrhenius equation acceptable.

2. <u>Proposed change</u>

The aging reference temperature and activation energy of nylon Zytel 101.

<u>Evaluation</u>

In Revision 1 (Table 8-1), both TRs use the incorrect aging reference temperature of 160°C, instead of 175°C. The correction lengthens the service life of nylon Zytel 101. However, WCAP-13878P, Revision 1 also uses the incorrect activation energy of 1.37 eV, instead of 0.8787 eV. This correction will shorten the service life of the nylon Zytel 101 for all duty cycles. WCAP-13877, Revision 1-P uses the correct activation energy. The staff finds the corrections acceptable. The staff's evaluation of this change is discussed in items 3 and 4 below.

3. <u>Specific Changes to WCAP-13878-P</u>

The changes discussed in items (1) and (2) affect WCAP-13878-P, Revision 2, and the staff's corresponding evaluation as follows:

<u>The service life of materials is significantly shortened for a 20 percent duty cycle, but the affected materials are not essential for operation of the relay.</u>

The service life of neoprene rubber (Tables 8-4, 8-4a, 8-4b, 8-5, 8-5a and 8-5b, Section 8.3.1) and polyvinyl chloride (PVC) (Tables 8-8, 8-8a, and 8-8b, Section 8.1.2.2) is considerably shortened for a 20 percent duty cycle. However, PVC has not been used in motor-driven rotary (MDR) relays used as slave relays in the WEC SSPS, and the failure of the neoprene rubber will likely not result in the failure of MDR relays. Neoprene rubber has been used in lead wire grommets for MDR relays manufactured up to December 1988. The purpose of the rubber grommets is to minimize abrasion of the lead wire during handling and installation. The grommets are not essential for the operation of the relay and WEC has determined that even after complete disintegration of the grommets, failure of the MDR relay is neither expected nor likely and therefore the shortened service life of neoprene rubber does not affect the conclusions of the WCAP and the staff's SEs. Therefore, the staff finds it acceptable.

The recalculated service life values are greater than 40 years for a 20 percent duty cycle.

WCAP Tables 8-6, 8-7, 8-9, 8-9a, 8-9b, 8-12, 8-13, 8-14, 8-14a, 8-14b, 8-15, 8-15a, 8-15b, 8-16, 8-16a, 8-18, 8-20, 8-20a, 8-21, 8-21a, 8-21b, 8-22, and 8-23 have been revised to give new calculated service lives. However, since the new calculated service lives in these tables are all greater than 40 years, the revision does not affect the conclusions of the staff's previous SE.

The service life of nylon Zytel 101 is significantly shortened for all duty cycles.

WCAP Tables 8-10, 8-10a, and 8-10b have been revised to give the new calculated service lives of the MDR relays based on 50 percent retention of tensile strength. The recalculated service lives are all less than the original calculated service lives. The MDR relay cam is made of nylon Zytel 101. The total force applied to all four lobes of a cam would not exceed 400 grams. The 50 percent retension of tensile strength reduces the tensile strength to a value of approximately 1350 psi. Based on the engineering judgement, WEC has determined, because of the low cam loads and the absence of reported cam failures, the recalculated service lives do not change the conclusions of the WCAP and the staff's SE. Therefore, the staff finds it acceptable.

Tables are intentionally left blank.

WCAP Tables 8-11, 8-11a, 8-11b, 8-17, 8-17a, 8-17b, 8-19, 8-24, 8-24a, and 8-24b are intentionally left blank either because the service lives are accurately given in other tables or because the properties of the materials are not critical for the operation of the relay. Therefore, this change has no impact on the conclusions of the WCAP or the staff's SE.

4. Specific changes to WCAP-13877

The changes discussed in items (1) and (2) affect WCAP-13877, Revision 2-P as follows:

Changes in the calculated service lives of ARD relays.

Section 8.3.3 of WCAP-13877 discuss the service life values of the ARD relay that failed at North Anna. The recalculated service lives are more conservative than the actual time the ARD relay was in service. Therefore, the recalculated service lives of the ARD relays do not change the conclusions of the WCAP or the staff's SE.

Recalculated service lives of AR relay based on nylon Zytel 101.

Tables 8-3 and 8-4 have been revised to give the new calculated service lives of AR relays. The recalculated service lives are greater than the original calculated values. This change is discussed in Section 8.3.4 and does not affect the WCAP recommendations or the staff's SE.

<u>Recalculated service lives > 40 years.</u>

Tables 8-6 through 8-15 were revised to give new calculated service lives. However, since the recalculated service lives are > 40 years, the revision does not affect the conclusions of the staff's SE.

<u>Small decreases in service lives.</u>

Tables 8-16 and 8-17 were revised to give new calculated service lives. According to the revised calculation, a 5°C temperature rise results in a small decrease (5.1 percent maximum) in the service lives of the relays with a 20 percent duty cycle. Since the staff's previous SE requires each plant to determine the qualified life of the relays based on the plant-specific environmental conditions, the revision does not affect the conclusions of the staff's SE.

3.0 CONCLUSION

On the basis of the staff's review of WCAP-13878-P, Revision 2 and WCAP-13877, Revision 2-P, the staff concludes that the changes do not affect the conclusions of the staff's safety evaluations of Revision 1 of the WCAPs. The previous safety evaluations are still applicable to Revision 2 of the WCAPs, and the plant-specific TS change request for an extended surveillance test interval should meet the requirements identified in the previous staff safety evaluations.

Principal Contributor: Hukam Garg

Date: July 12, 2000

UNITED STATES
NUCLEAR REGULATORY COMMISSION
WASHINGTON, D.C. 20555-0001

May 31, 1996

JUN 1996

Mr. Tom Green
Westinghouse Owners Group Chairman
Georgia Power Company
40 Inverness Center Parkway
P.O. Box 1295
Birmingham, Alabama 35201

SUBJECT: REVIEW OF WESTINGHOUSE ELECTRIC CORPORATION TOPICAL REPORTS WCAP-13878, REVISION 1, WCAP-14117, REVISION 1 AND WCAP-13900, REVISION 0, "ESFAS SUBGROUP TEST INTERVAL EXTENSION," WESTINGHOUSE OWNERS GROUP PROGRAM MUHP-7040, REVISION 0

Dear Mr. Green:

The NRC staff has completed its review of the subject topical reports prepared by Westinghouse Electric Corporation for the Westinghouse Owners Group. The enclosure provides the staff's safety evaluation report (SER) approving these topical reports. The topical reports describe the Westinghouse Owners Group Program MUHP-7040, Revision 0, which was completed as an industry effort to demonstrate the acceptability of engineered safety feature actuation system (ESFAS) subgroup relay test interval extension.

The enclosed SER was prepared by the Division of Reactor Controls and Human Factors and accepts topical reports WCAP-13878, "Reliability Assessment of Potter & Brumfield MDR Series Relays," Revision 1, dated April 1996 (proprietary version), WCAP-14117, Revision 1, dated April 1996 (non-proprietary version), and WCAP-13900, "Extension of Slave Relay Surveillance Test Intervals," dated April 1994, for referencing in plant specific license amendment applications. WCAP-13900 is acceptable for only Potter and Brumfield (P&B) MDR relays and not for Westinghouse AR relays that are also included in the topical report.

WCAP-13878, Rev. 1, describes the Westighouse analyses that justify extending surveillance intervals for the ESFAS P&B MDR relays. The NRC staff finds that data and analyses presented in WCAP-13878, Rev. 1, support the proposed refueling interval staggered test frequency for ESFAS P&B MDR relays proposed in WCAP-13900. Data was not provided to support the proposed surveillance interval extension for Westinghouse AR relays. As stated in the staff's SER, if two or more P&B MDR ESFAS subgroup relays fail in a 12-month period, the referencing licensee should reevaluate the adequacy of the extended surveillance interval. The reevaluation should consider the design, maintenance, and testing of all P&B MDR ESFAS subgroup relays. If the licensee determines that the test interval is inadequate for detecting a single relay failure, the interval should be decreased and should be such that the licensee can detect a P&B MDR subgroup relay failure prior to the occurrence of a second failure.

JUN 19 1996

Additionally, licensees that use P&B MDR relays for ESFAS subgroup relay applications and are proposing test interval extensions based on WCAP-13878, Rev. 1 and WCAP-13900, Rev.0 should also:

1. Confirm the applicability of the WCAP-13878, Rev. 1 analyses for their plant.

2. Ensure that their procurement program for P&B MDR relays is adequate for detecting the types of failures that are discussed in References 9, 10, 11, and 12 of the SER.

3. Ensure that all pre-1992 P&B MDR relays which are used in either normally energized or a 20% duty cycle have been removed from ESFAS applications.

4. Ensure that the contact loading analysis for P&B MDR relays has been performed to determine the acceptability of these relays.

Should you have any questions or wish further clarification, please call me at (301) 415-1004, or Hukam Garg at (301) 415-2929.

Sincerely,

Bruce A. Boger, Director
Division of Reactor Controls
and Human Factors
Office of Nuclear Reactor Regulation

Enclosure: As stated

cc: L. Bush, CECo.
J. Andrachek, Westinghouse

UNITED STATES
NUCLEAR REGULATORY COMMISSION
WASHINGTON, D.C. 20555-0001

SAFETY EVALUATION BY THE OFFICE OF NUCLEAR REACTOR REGULATION

TECHNICAL SPECIFICATION CHANGES REGARDING TEST INTERVAL EXTENSION

FOR SLAVE RELAY TESTING

WESTINGHOUSE OWNERS GROUP TOPICAL REPORTS WCAP-13878, 14117 AND 13900

1.0 INTRODUCTION

By letter dated November 14, 1994, the Pacific Gas and Electric Company (PG&E), as the lead plant, submitted proposed Technical Specification (TS) changes for the Diablo Canyon Power Plant, (DCPP), Units 1 & 2 based on generic Westinghouse Owners Group topical reports. The proposed changes would allow a test interval extension for slave relays. Currently at DCPP and other Westinghouse plants, slave relays for the Engineered Safety Features Actuation System (ESFAS) are tested quarterly with the exception of some relays which were previously approved by the NRC to be tested every 18 months. The proposed changes to the TS would extend the test interval for all Potter and Brumfield MDR slave relays in Westinghouse plant ESFAS to 18 months. In order to justify these changes PG&E provided generic Westinghouse Topical Reports, WCAP-13878, Rev. 0 "Reliability & Assessment of Potter & Brumfield MDR Series Relays," dated June 1994, (proprietary version) (Ref. 1), WCAP-14117, Rev. 0 dated June 1994, (non-proprietary version), (Ref. 2) and WCAP-13900, Rev. 0

ENCLOSURE

"Extension of Slave Relay Surveillance Test Intervals," dated April 1994 (Ref. 3). Following review of the above topical reports, the staff, by letter dated April 25, 1995 (Ref. 4) requested additional information and PG&E responded by letters dated December 7, 1995 and February 2, 1996 (Refs. 5 and 6). In addition, by letter dated April 12, 1996, the Westinghouse Owners Group submitted Revision 1 to WCAP-13878 and WCAP-14117.

2.0 BACKGROUND

The NRC staff formed a Task Group in August 1983 to investigate problems concerning surveillance testing required by Technical Specifications (TS), and to recommend improvements. The results of the study were published in November 1983 (Ref. 7) in NUREG-1024, "Technical Specifications - Enhancing the Safety Impact." NUREG-1024 recommended that the staff review the bases for TS test frequencies; ensure that the TS required tests promote safety and do not degrade equipment; and review surveillance tests to ensure that they do not unnecessarily burden personnel.

The Technical Specifications Improvement Program (TSIP) was established in December 1984 to provide the framework for addressing the NUREG-1024 recommendations, and for rewriting and improving the TS. As an element of the TSIP, TS surveillance requirements were comprehensively examined as recommended in NUREG-1024. The results of the TSIP effort are presented in NUREG-1366, "Improvements to Technical Specifications Surveillance Requirements" (Ref. 8). The study concluded that, while some testing at power is essential, safety can be improved, equipment degradation decreased, and unnecessary personnel burden prevented by reducing the amount of testing at power. These three conclusions formed the basis for the four criteria that justify changes to surveillance intervals as follows:

Criterion 1 - The surveillance could lead to a plant transient,

Criterion 2 - The surveillance results in unnecessary wear to equipment,

Criterion 3 - The surveillance results in radiation exposure to plant personnel that is not justified by the safety significance of the surveillance,

Criterion 4 - The surveillance places an unnecessary burden on plant personnel because the time required is not justified by the safety significance of the surveillance.

3.0 EVALUATION

At DCPP there are 40 Potter & Brumfield (P&B) MDR relays installed in each of the Solid State Protection System (SSPS) bays. Of these 40 relays, only 2 relays are normally energized at power, and neither relay performs a function covered by TS. Also at DCPP, none of the slave relays required by TS are energized during an outage since the SSPS is removed from service at that time. WCAP-13878 provides generic justification for extension of the surveillance interval from quarterly to every refueling outage for P&B MDR relays. Slave relays used at DCPP are P&B MDR Model 4102 (latching) and 4103 (non-latching) type. Although WCAP-13878 analyzed P&B MDR model 4121-1 (latching) and 4103 (non-latching) type relays, the DCPP relays are similar in design to those analyzed in the WCAP, and therefore, the analysis adequately covers the DCPP relays.

In WCAP-13878, Rev. 0, Westinghouse analyzed P&B MDR slave relay failure data in Westinghouse plants beginning with the commercial operation of these plants, for one, two, three and 18 month test intervals. No failures were found for the one month and the 18 month surveillance intervals and only four failures were found for relays being tested at 2 and 3 month intervals. These failures resulted from 50,570 actuations, and constitute a failure rate of 7.91E-05 per demand. The four failures occurred within the first two years of service and three of the four occurred during the first few months. These three failures, therefore, could be considered as "infant mortality," or early life failures.

An FMEA, conducted by Westinghouse has determined that the failures were temperature induced. WCAP-13878, Rev. 0 recommends replacement of all P&B MDR relays that are used in normally energized service with relays made after May of 1990. The thermal aging analysis in WCAP-13878 utilizes the Arrhenius methodology previously accepted by the staff for qualification of components in harsh environments, as long as good judgement is exercised in the interpretation of calculated results to avoid excessive conservatism and misinterpretation. Based on the above analysis, WCAP-13878 recommends replacement of all normally energized relays after 30 years of service.

In addition to the four failures discussed above in Westinghouse plants, there were other failures of P&B MDR relays in other nuclear power plants that were not sufficiently discussed in WCAP-13878. Therefore, the staff requested that PG&E provide a generic assessment of these additional failures. The PG&E response to the request is discussed below.

1. De-energized Relays

Report S93-06 from the NRC Office for Analysis and Evaluation of Operational Data (AEOD) (Ref. 9) states that 30 percent of the P&B MDR relay failures occurred in normally de-energized relays which may have been energized during shutdown conditions. PG&E analyzed the failures identified in the AEOD report and determined that out of 120 failures, only 6 occurred in normally de-energized relays similar to the P&B MDR relays used in DCPP. Of the 6 failures, 3 are considered "infant mortality," and one a random manufacturing defect. The other two failures were believed to have been caused by varnish offgassing. There was insufficient data regarding ambient temperature or significant energization periods during plant shutdown to determine the exact root cause of the failures. However, PG&E believes that the failure history represents a satisfactory performance for small normally de-energized ac coil P&B MDR relays. Based on the review of the information provided, the staff agrees that the data shows a very low P&B MDR relay failure rate in normally de-energized applications.

2. Refurbished P&B MDR Relays

Topical Report WCAP-13878, Rev. 0, considers refurbished P&B MDR relays, in substandard fashion, to be beyond the scope of the report. Based on Information Notice (IN) 90-57 and Supplement 1 to IN 90-57 (Refs. 10 and 11), and a 10 CFR Part 21 notification from San Onofre Nuclear Generating Station (Ref. 12), PG&E has put in place an enhanced commercial grade dedication program to prevent substandard or refurbished relays from being installed in the plant. All existing relays in the warehouse will be re-inspected based on the enhanced dedication criteria. Only three relays procured as commercial grade were installed at DCPP. They have been verified to have passed sufficient dedication criteria and testing to assure their acceptability. Based on this, the staff finds that PG&E has an adequate commercial grade dedication program for P&B MDR relays. Rev. 1 of WCAP-13878 (Ref. 15) requires that all plants requesting a test interval extension for P&B MDR relays review various failure modes associated with P&B MDR relays and ensure that their procurement program is adequate to address these failures. Based on this, the staff finds that WCAP-13878, Rev. 1 has acceptably addressed the staff's concerns.

3. Pre-1992 MDR AC Relays

AEOD report S93-06 identified failure modes in pre-1992 P&B MDR ac relays but WCAP-13878 Rev. 0, did not discuss the basis for accepting these relays. The PG&E response to the staff's request for additional information states that pre-1992 de-energized small ac coil P&B MDR relays are not subject to the excessive failures identified in the AEOD report, that installed DCPP slave relays have provided years of satisfactory service, and are, therefore, not implicated by the 1992 problem reports or current industry concerns with the quality of new P&B MDR relays. This determination is based on the analysis of applicable failures and inspection of eight normally energized P&B MDR relays which were replaced in response to IN 92-04 (Ref. 13). Nevertheless, Revision 1 to WCAP-13878, requires that all plants requesting a test interval extension for P&B MDR relays, which are either normally energized or are used in a 20% duty cycle, to replace these relays with relays manufactured after 1992. This satisfactorily resolves the staff's concern in this area.

4. Misapplication of Relay Contacts

IN 92-19 (Ref. 14) and AEOD Report S93-06 reported contact failures due to misapplication of P&B MDR relays. WCAP-13878, Rev. 0, considered contact failures to be beyond the scope of the report. However, PG&E completed a loading study covering each contact on every DCPP SSPS slave relay for Unit 1 and found them acceptable. The DCPP Unit 2 design and loading is similar to

Unit 1 and hence was not reviewed. Revision 1 to WCAP-13878 addressed the contact issue and requires all licensees requesting a test interval extension for P&B MDR relays to perform a study of contact loading. This satisfactorily resolves the staff's concern in this area.

5. Relays Manufactured in 1992

AEOD report S93-06 identified problems with P&B MDR relays manufactured in 1992. PG&E, in their response to the staff request for additional information stated that DCPP does not use the relay models identified in the AEOD report. However, PG&E recognized that failure modes identified in the AEOD report may apply to other P&B MDR relays and has enhanced their commercial grade dedication program to ensure that safety related P&B MDR relays are not affected by those failure modes. WCAP-13878, Rev. 1, requires that all plants requesting a test interval extension for P&B MDR relays, which are either normally energized or used in a 20% duty cycle, to replace these relays with relays manufactured after 1992. This satisfactorily resolves the staff's concern in this area.

6. Aging

WCAP-13878, Rev. 0, stated that normally energized P&B MDR relays can operate satisfactorily for 30 years without aging concerns. The staff requested additional information to assess the acceptability of the proposed 30 year life for these relays. In their response, PG&E stated that 1) very few relays are energized and therefore, close spacing of relays is not a factor under normal operating conditions since temperatures around the relays which would tend to reduce their life are not excessive and, 2) based on experiments and measurements at DCPP, the temperature rise recorded in the area of the SSPS slave relays is less than or equal to 33°C, not 58°C as reported in the WCAP-13878. The staff believes that since temperature measurements at DCPP were taken at the surface of the SSPS relays, the readings may not represent the actual temperature rise inside normally energized relays. However, since the SSPS slave relays are not normally energized and there are only two energized relays in the SSPS cabinet, the staff agrees with the licensee that SSPS slave relays will not see excessive temperature rises.

The SSPS slave relays in Westinghouse plants are located in a mild environment and do not require an aging analysis for common mode failure due to a sudden temperature rise. WCAP-13878 has adequately considered failure modes related to age for P&B MDR relays and has adequately addressed the effects of temperature for P&B MDR relays used in SSPS applications. Therefore, WCAP-13878, Rev. 1 has satisfactorily resolved the staff's concern in this area.

4.0 CONCLUSION

Based on the review of the WCAP-13878, Rev. 1, WCAP-14117, Rev. 1, and WCAP-13900, Rev. 0, the staff concludes that the failure data provided for P&B MDR slave relays support the proposed test interval extension to every refueling outage. The staff, therefore, finds the above topical reports acceptable for proposed extensions of P&B MDR ESFAS slave relay tests to a refueling outage frequency. However, the staff further concludes that if two or more P&B MDR ESFAS subgroup relays fail in a 12-month period, a referencing licensee should reevaluate the adequacy of the extended surveillance interval. The reevaluation should consider design, maintenance and testing of all P&B MDR ESFAS subgroup relays. If the licensee determines that the surveillance interval is inadequate for detecting a single relay failure, the surveillance interval should be decreased. The revised surveillance interval should be such that the licensee can detect an ESFAS subgroup relay failure prior to the occurrence of a second failure.

Additionally, licensees that use WCAP-13878, Rev. 1 and WCAP-13900, Rev. 0 to implement plant specific TS changes for test interval extensions involving P&B MDR relays for ESFAS slave applications should also:

1. Confirm the applicability of the WCAP-13878, Rev. 1 analyses for their plant.

2. Ensure that their procurement program for P&B MDR relays is adequate for detecting the types of failures that are discussed in References 9, 10, 11 and 12.

3. Ensure that all pre-1992 P&B MDR relays which are used in either normally energized or a 20% duty cycle have been removed from ESFAS applications.

4. Ensure that the contact loading analysis for P&B MDR relays has been performed to determine the acceptability of these relays.

5.0 REFERENCES

1. Westinghouse Topical Report WCAP-13878, "Reliability Assessment of Potter & Brumfield MDR Series Relays", (proprietary version) dated June 1994, transmitted to NRC by Gregory M. Rueger (Pacific Gas and Electric Company for Diablo Canyon) letter DCL-94-254, dated November 14, 1994.

2. Westinghouse Topical Report WCAP-14117, "Reliability Assessment of Potter & Brumfield MDR Service Relays," (non-proprietary version) dated June 1994, transmitted to NRC by Gregory M. Rueger (Pacific Gas and Electric Company for Diablo Canyon) letter DCL-94-254, dated November 14, 1994.

3. Westinghouse Topical Report WCAP-13900, "Extension of Slave Relay Surveillance Test Intervals," dated April 1994, transmitted to NRC by Gregory M. Rueger (Pacific Gas and Electric Company for Diablo Canyon) letter DCL-94-254, dated November 14, 1994.

4. Melanie A. Miller (NRC) letter to Gregory M. Rueger (PG&E), dated April 27, 1995, "Request for Additional Information on Slave Relay Test Frequency Extension for Diablo Canyon Nuclear Power Plant, Units 1 and 2."

5. Gregory M. Rueger (PG&E) letter (DCL-95-268) to USNRC, dated December 7, 1995, "Response to NRC Request for Additional Information on Slave Relay Test Frequency Relaxation Amendment."

6. Warren H. Fujimoto (PG&E) letter (DCL-96034) to USNRC, dated February 2, 1996, "Response to NRC Request on Slave Relay Test Frequency Relaxation Amendment."

7. NUREG-1024, "Technical Specifications - Enhancing the Safety Impact," dated November 1983.

8. NUREG-1366, "Improvements to Technical Specifications Surveillance Requirements," dated December 1992.

9. Office for Analysis and Evaluation of Operational Data Special Study Report AEOD/S93-06, "Potter & Brumfield Model MDR Rotary Relay Failures," dated December 1993.

10. NRC Information Notice 90-57, "Substandard, Refurbished Potter & Brumfield Relays Misrepresented as New," dated September 5, 1990.

11. NRC Information Notice 90-57 Supplement 1, "Substandard, Refurbished Potter & Brumfield Relays Represented as New," dated November 27, 1991.

12. 10 CFR Part 21 Notification dated July 21, 1995 from San Onofre Nuclear Generating Stating (SONGS) concerning relays that were returned to SONGS with bent contact arms following P&B rework.

13. NRC Information Notice 92-04, "Potter & Brumfield Model MDR Rotary Relay Failures," dated January 6, 1992.

14. NRC Information Notice 92-19, "Misapplications of Potter & Brumfield MDR Rotary Relays," dated March 2, 1992.

15. Lee Bush (WOG) letter (WOG-SRT-96-005) to USNRC, dated April 12, 1996, "Transmittal of Page Revisions to WCAP-13878 (proprietary), to address NRC review issues."

TABLE OF CONTENTS

TABLE OF CONTENTS (cont.)

TABLE OF CONTENTS (cont.)

TABLE OF CONTENTS (cont.)

LIST OF TABLES

LIST OF TABLES (cont.)

LIST OF TABLES (cont.)

LIST OF FIGURES

ACRONYMS

AC	-	Alternating Current
AEOD	-	Analysis and Evaluation of Operational Data (Dept. of NRC)
AMP	-	Ampere
AR	-	Westinghouse Type AR Relay (with AC Coil)
ARD	-	Westinghouse Type ARD Relay (with DC Coil)
ASC	-	Auxiliary Safeguards Cabinet (also ASGC)
ASGC	-	Auxiliary Safeguards Cabinet
BF	-	Westinghouse Relay (with AC Coil)
BFD	-	Westinghouse Relay (with DC Coil)
DC	-	Direct Current
EOP	-	Emergency Operating Procedure
EPRI NP	-	Electric Power Research Institute Nuclear Power
EQ	-	Equipment Qualification
ERP	-	Emergency Response Procedure
ESFAS	-	Engineered Safety Features Actuation System
EQ	-	Equipment Qualification
FAT	-	Factory Acceptance Test
FMEA	-	Failure Mode and Effects Analysis
FNP	-	Farley Nuclear Plant
HCl	-	Hydrochloric Acid
HVAC	-	Heating Ventilating and Air Conditioning
LER	-	Licensee Event Report
I&E	-	Instrumentation and Electronics
IEEE	-	Institute of Electrical and Electronic Engineers
INPO	-	Institute of Nuclear Power Operations
MDR	-	Motor-driven Rotary Relay Manufactured by Potter & Brumfield
NC	-	Normally Closed
ND	-	Normally De-Energized
NE	-	Normally Energized
NO	-	Normally Open
NPE	-	Nuclear Power Experience
NPRDS	-	Nuclear Plant Reliability Data System
NRC	-	Nuclear Regulatory Commission
NRMA	-	National Relay Manufacturers Association
NSDTB	-	Nuclear Services Division Technical Bulletin

ACRONYMS (cont.)

NSIDTB	-	Nuclear Services Integration Division Technical Bulletin
NUREG/CR	-	
P & B	-	Potter & Brumfield
PVC	-	Polyvinyl Chloride
RCS	-	Replacement Component Services
RO	-	Reactor Operations
SI	-	Safety Injection
SGTC	-	Safeguard Test Cabinet
SSPS	-	Solid State Protection System
STC	-	Safeguard Test Cabinet (also SGTC)
TGA	-	Thermogravimetric Analyses
VAC	-	Volts Alternating Current
VDC	-	Volts Direct Current
WCAP	-	Westinghouse Commercial Atomic Power (Topical Report)
WOG	-	Westinghouse Owners Group

FORWARD

A generic Safety Evaluation Report (SER) has been issued based on the NRC review of the lead plant Licensing Amendment Request (LAR) - the SER is included behind the cover page of this report.

Revision 1 of this report incorporates the results of the lead plant licensing review by the NRC. The following items must be addressed by plants implementing slave relay test extension for MDR relays.

1) Revision of recommendations for 20% duty cycle and normally energized relays. For those relays which are proposed for extended (18- to 24-month) test intervals, the relays must be replaced with relays manufactured after 1992. Potter & Brumfield (P&B) MDR series relays of all vintages continue to be acceptable for use in normally de-energized relay applications, subject to the guidance provided in the previous and current revision of this report.

2) Plants must review the various failure modes associated with MDR relays and ensure that their procurement program for MDR relays is sufficient to identify those failures.

3) Plants must confirm that they have performed a study of the contact loading on MDR relays.

Concern for items 1 & 2 above arises from a spate of quality issues that have affected the P&B MDR Series relay product line in recent years attributable to, among other issues detailed in this report, the relocation of the manufacturing facility. Item 3 affirms that each plant has addressed the concerns raised in NRC IN 92-19 (Reference 13.1-45), which is discussed in Section 6.5 of this report.

It is necessary that all future plant submittals (LARs) requesting the SSPS slave relay test interval extension specifically address each of the above items. Appendices D and E, added to Rev. 1 of this report, provide PG&E response to comments and questions generated during the NRC review of the lead plant LAR. These appendices extend the technical work of the original report, and should be consulted for guidance in addressing the three items above.

The scope of revision was limited to only those changes/additions necessary to address the NRC requested changes. All significant changes incorporated in this revision are highlighted by side bars in the page margins (typographical corrections are not noted).

Revision 2 of this report has the corrections listed below. The changes were found to be acceptable via the safety evaluation attached to NRC Letter from Stuart A. Richards to H. A. Sepp (Westinghouse Electric Company), "Review of Westinghouse Topical Reports WCAP-13877, Revision 2-P and WCAP-13878-P, Revision 2 on Solid State Protection System (SSPR) Slave Relays (TAC No. MA7264)," dated July 12, 2000. The letter (with attached safety evaluation) is located immediately behind the title page.

1. A corrected form of the Arrhenius equation was used to calculate service lives at energization times other than at 0% and 100%.

2. The aging reference temperature to calculate the service life of Nylon Zytel 101 was corrected.

3. The activation energy (eV) of Nylon Zytel 101 was corrected.

All significant changes incorporated in this revision are highlighted by side bars in the page margin on the right side (typographical errors are not noted.)

1.0 INTRODUCTION

The objective of this Reliability Assessment is to establish a basis for determining the reliability of the Potter & Brumfield MDR rotary relay. This assessment is comprised of a Failure Mode and Effects Analysis (FMEA), and an aging assessment of the MDR relay. The assessment is intended to aid in the determination of maintenance and surveillance intervals consistent with reliability goals. A particular objective is to demonstrate that surveillance testing during refueling would not adversely affect the reliability of Solid State Protection System (SSPS) slave relays.

2.0 SCOPE

The scope of this analysis is the Potter & Brumfield MDR rotary relay when used in the SSPS slave relay application (i.e., when discussing the impacts of relay failure on a system, the reference case is the SSPS slave relay function). The SSPS slave relays are P&B MDR models 4103-1 or 4121-1. These numbers were established by P&B for units manufactured to Westinghouse requirements.

- Model 4103-1 is a small non-latching, 8-pole MDR relay equipped with a 118 Vac coil.

- Model 4121-1 is a small, latching, 8-pole MDR relay equipped with a 118 Vac coil.

Models 4103-1 and 4121-1 are similar in materials (subject to changes with vintage) and construction to the P&B MDR models 134-1 and 4076, respectively. Models 4103-1 and 4121-1 are distinguished by their partially rotated switch assembly. P&B, per Westinghouse requirements, manufactures these models with switch assemblies rotated 45 ° from the orientation specified for the models 134-1 and 4076. This permits the close-spacing of relays desired in the SSPS cabinet output bay.

The MDR series relay can be analyzed as consisting of two fundamental components. The MDR relay major building blocks are the coil assembly and the switch assembly. Differences between the small and medium MDR relays are coil assembly (motor) size and the number of switch decks. Small and medium coil assemblies are similar in design and materials of construction (subject to changes in vintage). All switch assembly components are of the same design and materials of construction (subject to changes in vintage). The small motor is used for applications where one or two switch decks (i.e., 4 or 8 poles; 4 poles per deck) are needed. Where three to six switch decks are required, the medium motor is used.

In many respects the only significant difference between small and medium MDR relays is the coil assembly size and, consequently, the coil temperature rise. However, these differences do effect relay life.

Though the subject of this evaluation is the small latching and non-latching MDR relays, most of the information and conclusions of this document apply equally to the medium MDR relay. However, the estimation of service life based on total temperature in service will differ due to the greater temperature rises expected for the MDR medium relay when energized.

3.0 METHODOLOGY

This WCAP describes the methodology used to perform a reliability assessment of the MDR Relay, to include a FMEA and an aging assessment.

In a typical high-level FMEA (e.g., of a control system), a relay might be shown at the "subsystem" or "component" level. This simplifies considerations of relay operability to a generic level, and establishes the concept that relay reliability is sometimes seen as being generic. For the purposes of this FMEA, however, the Potter & Brumfield MDR rotary relay itself is designated as the "system". This allows for a more detailed evaluation at the relay component level.

The FMEA was constructed based on information obtained from review of the following:

- MDR relay product line designs
- Product line assembly drawings
- Disassembly and inspection
- Qualification test experience
- MDR relay failure history
- Generic issues for relays in nuclear plant service

General guidance for the FMEA was taken from IEEE Standard 352-1987 (Reference 13-1). Results of the FMEA are presented as a collection of tables in Section 7.0 of this report. The FMEA tables identify temperature-induced, age-related material degradation mechanisms applicable to the relay component materials. The FMEA also includes remarks which qualify applicability and likelihood of certain MDR series relay failure modes in the SSPS application. The intent is to address both a) the failures that result from material degradation and b) material degradation which can cause secondary failure mechanisms. Section 8.0 presents the aging assessment of the MDR series relay component materials.

3.1 DESIGN REVIEW

The design review consisted of discussions with the cognizant Potter & Brumfield design engineer and a visit to the P&B manufacturing facility. The visit provided valuable hands-on insight into the assembly and testing process of the MDR series relays and a thorough review of design changes in the relay since November, 1983 (see Section 5.4, Design Changes). The discussions and manufacturing facility visit were essential and contributed substantially to the completeness of this assessment.

3.2 REVIEW OF DESIGN DEVELOPMENT

Review of the design development was intended to establish a benchmark for expectations of reliability. Indeed, this portion of the FMEA provides a bases for discounting certain postulated failure modes. The development tests were conducted on an as needed basis to verify that the MDR series relay product line would meet specific design objectives. The MDR series relay was designed to meet Military Specification No. MIL-R-19523 Rev. A (Reference 13-12), for Naval gunships.

3.3 DRAWING REVIEW

A review of top-level MDR series Relay Engineering Drawings, found in Figures 3-1 through 3-4 (Reference 13.4-1) was performed. The review was intended to augment the disassembly and inspection efforts, and to verify component material types.

3.4 DISASSEMBLY AND INSPECTION

Different models of MDR series relays were disassembled and examined to determine likely failure modes. Both new and used relays were examined to include one that exhibited a potential failure mode of the MDR coil. Specimens were items readily available and represented features available in the MDR series relay product line. In particular, one specimen exhibiting the failure mechanisms discussed in NRC Information Notice 92-04 (Reference 13.1-43 (see Section 6.3)) was examined. Specimens including the P&B catalog model numbers and Westinghouse Replacement Component Services (RCS) model numbers are provided below.

Model	WRCS	P&B
118 VAC Non-Latching	MDR-4103-1	MDR-134-1
118 VAC Latching	MDR-4121-1	MDR-4076
125 VDC Non-Latching*	MDR-5076-1	MDR-138-8

* This relay is not used as an SSPS slave relay.

3.5 QUALIFICATION TEST EXPERIENCE

The MDR series relay has been included in Westinghouse generic Equipment Qualification (EQ) programs. The EQ program experience contributed significantly to the determination and assessment of failure modes that are related to temperature/age-degradation. Materials aging analysis is used to address failure modes and effects for which little data, if any, is available on which to base a quantitative analysis of reliability.

3.6 REVIEW OF FAILURE HISTORY

Failure history of MDR series relays in the SSPS slave relay application was gathered to:

- Establish a quantitative reliability basis specific to the SSPS slave relay application,
- Demonstrate that MDR series relays in the SSPS slave application would have a greater quantitative reliability than MDR series relays used in typical commercial industrial applications as reflected in sources such as IEEE Std. 500 (Reference 13-2),
- Demonstrate that reliability of the MDR series relays in the SSPS slave relay application is independent of the test intervals (i.e., quarterly versus "at-refueling"),
- Facilitate comparison with the FMEA results to justify qualitatively the expectations of superior performance of MDR series relays when used as SSPS slave relays.

Failure history of MDR series relays was gathered from several sources. Primary sources were the Nuclear Plant Reliability Data System (NPRDS), MDR failures recorded by Potter & Brumfield for all applications, and a survey of the Westinghouse designed SSPS plants which was conducted by a Westinghouse Owner's Group (WOG) subgroup. In Section 9.0 the failure history is discussed and compared to the FMEA for MDR series relays.

The NPRDS database was searched using criteria developed to identify reports involving SSPS slave relays. The intent was to focus attention only on relays which have similar operating requirements and service conditions. However, the quantitative value of the NPRDS data is limited due to utility reporting inconsistencies. Where available, License Event Reports (LERs) referenced in the NPRDS database entries were reviewed to clarify what actually happened to the relays. A number of the NPRDS entries were found to be "problems encountered during the performance of SSPS slave relay tests" rather than specific failure of the SSPS slave relays themselves. Reliance on the NPRDS database was minimal beyond early efforts to assess the feasibility for determining a specific quantitative reliability for MDR series relays in the SSPS slave relay application.

The listing of failures reported to and recorded by P&B included failures of all MDR model numbers. Of those failures listed, none were found to have occurred in an SSPS application at a nuclear plant. This data served primarily to highlight potential failures to be postulated in the FMEA. The failure modes/failure mechanisms, along with the necessary and sufficient conditions which give rise to their occurrence, were identified by the design engineer.

The WOG survey sought to gather data from domestic operating plants that could be used to compare the reliability of SSPS slave relays when tested at three month and eighteen month intervals. Data was requested for SSPS slave relays and for MDR series relays used in applications with similar service requirements and conditions, such as the Auxiliary Safeguards Cabinet (ASGC) or the Safeguards Test Cabinet (SGTC). Respondents were requested to complete the sheets and tables similar to those in Appendix C of this report (names and phone numbers of Westinghouse personnel are omitted as a matter of policy).

The FMEA results include remarks which qualify applicability and likelihood of certain MDR series relay failure modes in the SSPS slave relay application.

3.7 REVIEW OF RELAY GENERIC ISSUES

Nuclear Regulatory Commission (NRC) generic communication (i.e., Bulletins, Circulars, Information Notices) also provided a broad range of lessons learned from relay failures reported in the nuclear industry. References 13.1-1 through 13.1-49 provide detailed discussion of relay failure modes and mechanisms, their effects, and root cause analyses for a variety of relays. Also reviewed were Westinghouse Technical Bulletins, References 13.3-1 through 13.3-10 which have applicability to MDR series relays in the SSPS. The lessons were applied in the analysis of the MDR series relays as used in the SSPS slave relay application. Generic documents with direct applicability to MDR series relays are discussed in Section 6.0.

References 13.2-1 through 13.2-15 are NRC generic communications which discuss general problems with Emergency Safeguards Features Actuations Systems (ESFAS).

3.8 AGING ASSESSMENT

Standard approaches to relay reliability are based on empirical methods which determine a number of failures expected per number of demands (e.g., 10,000 or one million; Reference 13-3). Implicit in this statement of reliability are the premises that relays, particularly those of the industrial control type,

- Operate frequently,
- Will wear out before component materials are degraded by other factors of environment,
- Failures occur upon demand for operation.

The first two premises do not apply in the case of the SSPS slave relays. The SSPS slave relays operate infrequently, most often in response to test demands. There is little likelihood that the SSPS slave relays will wear-to-failure within the current 40-year life of a nuclear plant. The third premise, which is in part derived from the other two, is the catch-all for "stand-by failures" which may arise from age-related degradation of relay materials. In the case of the SSPS slave relays, so-called stand-by failures are more likely to be the dominant failure mechanism.

The aging assessment addresses the time/temperature degradation of organic materials used in Potter & Brumfield MDR series rotary relays. The intent is to demonstrate that the age-related degradation of the relay is sufficiently slow enough that detection of age-related failures is equally effective at the refueling-based test interval as it is at the quarterly test interval.

The FMEA results include failure modes and mechanisms based on MDR series relay failure history, materials performance data and thermogravimetric analyses (TGA) which is an empirical method for determination of material degradation products. Thus, in addition to the classic FMEA approach, these efforts are extended to include the aging assessment of the MDR series relay.

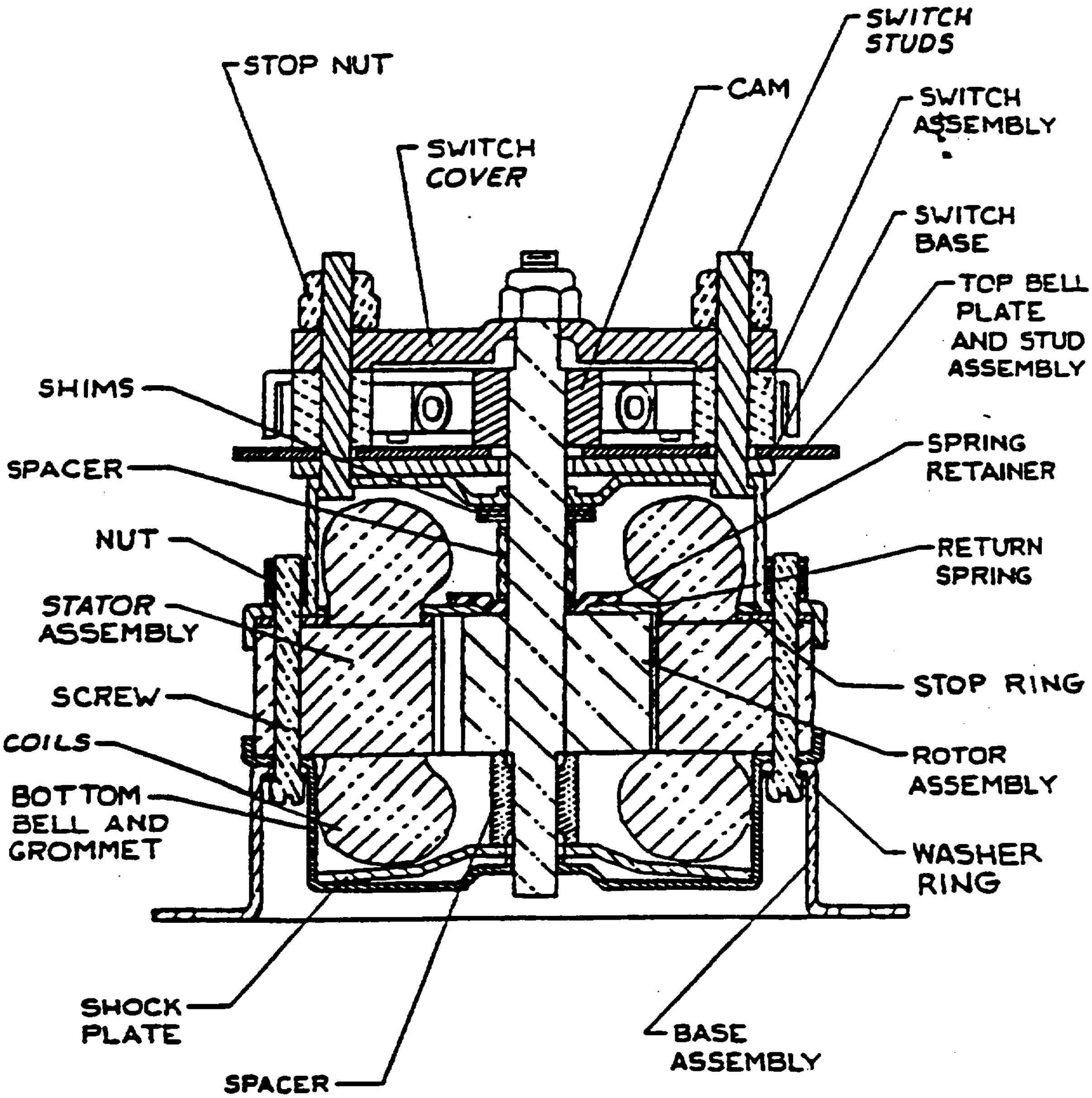


Figure 3-1: Small Non-Latching MDR Relay

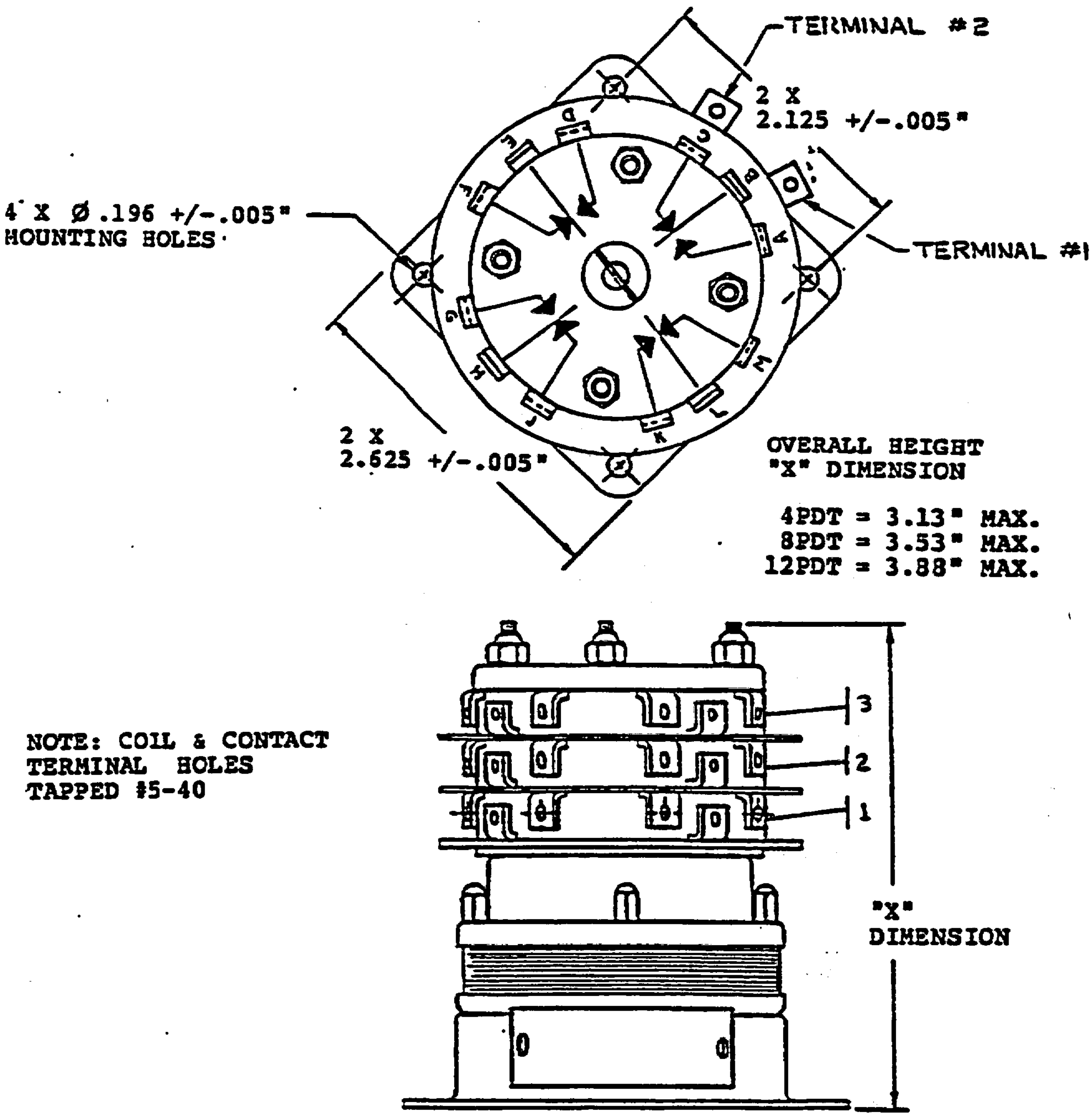


Figure 3-2: Small Non-Latching MDR Relay Outline

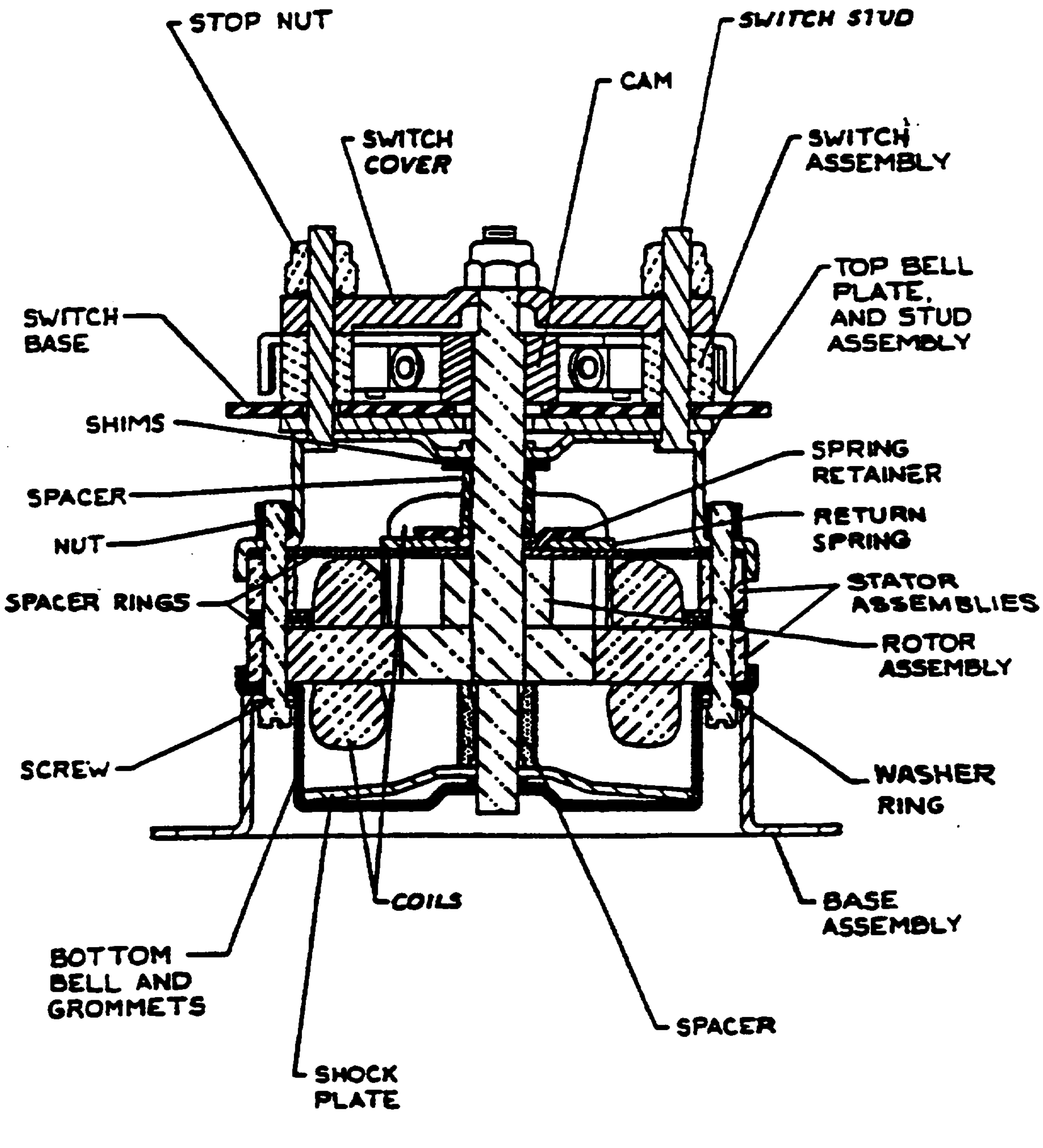


Figure 3-3: Small Latching MDR Relay

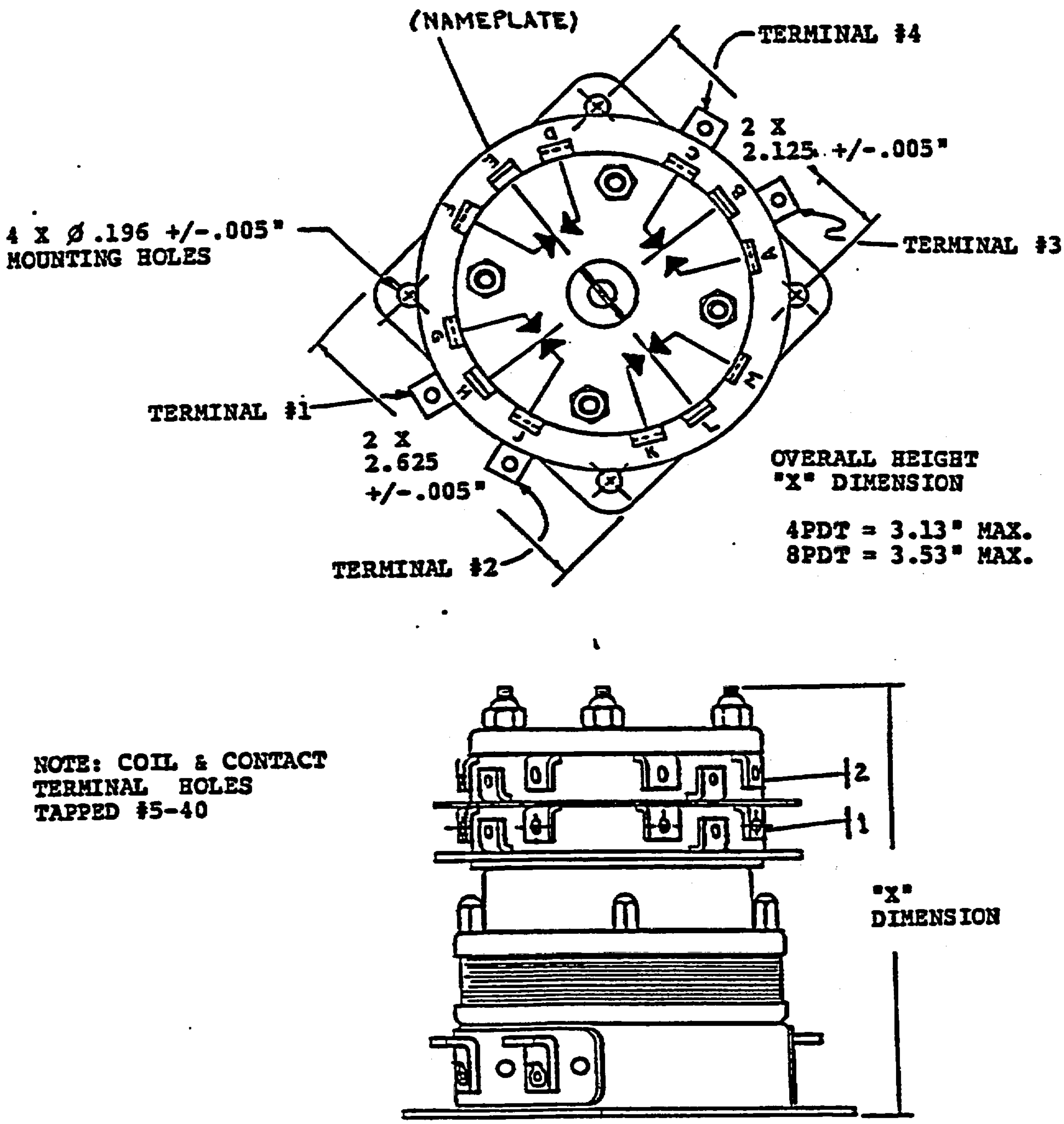


Figure 3-4: Small Latching MDR Relay Outline Drawing

4.0 DESCRIPTION OF PRODUCT LINE

The MDR series relay consists of a coil assembly and a switch assembly (See Figures 3-1 and 3-3). The MDR series includes both alternating current (AC) voltage and direct current (DC) voltage actuated relays designed to operate at nominal voltages of 120 VAC, 28 VDC or 125 VDC (others are available). MDR series latching relays differ slightly from the non-latching version. Differences affect only the coil assembly.

4.1 COIL ASSEMBLY

Of the four MDR series models that this report has studied, two of the relays are AC type (MDR-4103-1, 118 VAC non-latching, and MDR-4121-1, 118 VAC latching) and two of the relays are DC type (MDR-5076-1, 125 VDC non-latching, and MDR-5134, 48 VDC non-latching).

Both AC and DC non-latching coil assemblies consist of coils of glass cloth tape/polyamide film tape/fiberglass tape insulated magnet wire. A coil assembly consists of two series-connected coils of insulated magnet wire random-wound on separate coil bobbins. A pair of coil terminations are set into a glass-filled nylon insulator on the exterior of the relay base assembly. The coil terminal insulator is set into the stator assembly.

The AC coil assemblies differ from the DC coil assemblies in that they also have shading coils. A shading coil is a shorted turn surrounding a portion of the stator pole of an AC coil that delays the change of the magnetic field in that part, thereby tending to prevent chatter and reduce hum in the AC MDR relay (Reference 13-3).

The AC and DC latching coil assemblies consist of two identical sets of coils. The two pairs of coil terminations are set into glass-filled nylon insulators, one on each side of the relay base assembly, directly opposite from each other.

4.1.1 Rotor Assembly

The rotor assembly consists of a stainless steel rotor shaft that extends through a stack of nickel-plated silicon steel laminations. The laminations and a top and bottom end plate are compressed and riveted together. Stainless steel breaker plates are found on the surfaces of the rotor that make contact with the stator face.

Also considered as part of the rotor assembly are tin-coated rotor return springs. These springs (2) are attached to the top end plate and to the stator frame. In the non-latching MDR relay, these springs serve to return the rotor to the stop ring when the coils are de-energized. In the latching version of the relay, the "latch springs" (called this instead of a "return springs") serve more to guide the rotation of the rotor; the stop ring in the latching relay does not physically stop rotor travel (refer to Tables 7-1 and 7-3).

4.1.2 Stator Assembly

The stator assembly consists of a stack of silicon steel rings welded together that fit into the rim of the lower endbell. The assembly is finished with one coat of primer and one coat of gray polyurethane enamel paint. Four motor bolts run through the relay base, the lower endbell, the stator and the upper endbell, and are capped with motor nuts.

4.1.3 Endbells

The upper and lower endbells house the coil, rotor and stator assemblies. Inside of the lower endbell sits a washer-like disk made of phosphor bronze called the motor shock plate that serves to absorb some of the mechanical shock received by the coil assembly when the relay is actuated. Located between the top rotor end plate and the bottom of the upper endbell is a spring retainer, a spacer, and a shim. The spring retainer and spacers were formerly made of brass, but changed to stainless steel, and the shim were formerly brass, but changed to phosphor bronze (See Table 5.2a and 5.2b).

Also located in the lower endbell is a pair of rubber grommets (now made of polyetherimide) through which the coil leadwires run. The latching version of the MDR relay has a pair of leadwires for each set of coils, and therefore four grommets in the endbell.

4.2 SWITCH ASSEMBLY

The switch assembly includes those parts of the MDR relay above and including the switch base plate. Directly above the base plate is the switch ring base, followed by the switch ring insulators and switch ring barriers (located between two switch rings), and the switch cover. The switch ring base and barriers serve to preserve dielectric integrity between two adjacent switch rings insulators (switch rings) by preventing shorting across the switch rings.

Each switch ring provides four sets of contacts or poles. Each pole consists of three screw terminations. The center termination is a common contact and is fixed. To either side of the fixed contact termination are the moving contact terminations, one of which provides a normally closed pole, the other provides a normally open pole. Either or both of the moving contacts may be used.

4.2.1 Contact Terminals

The contact assemblies, to include the contact terminals, springs and washers, spring studs, and the movable and stationary contacts, are fitted onto the switch ring insulators. The terminals and spring studs are made of brass and the springs and washers of are made of phosphor bronze.

The movable contacts, formerly made of silver, are now made of silver-cadmium-oxide (see table 5.2a and 5.2b) and the stationary contacts are made of fine silver.

4.2.2 Contact Cams

The contact cams are located on the extended rotor shaft and made of glass-filled nylon. Each of the four pawls on a cam have two contact springs resting on its surface. Rotation of the shaft is translated to the cam which then makes or breaks contact faces.

4.2.3 Switch Ring Insulators/Cover

The switch rings and the switch ring cover are made of diallyl phthalate (formerly of alkyd) and they provide rigidity to the switch assembly. Switch studs are fastened above the switch ring base and then run through the barriers, switch rings and switch cover, before being capped with stop nuts lined with nylon.

4.3 RELAY OPERATION

MDR series relays are designed to operate without the aid of gravity. The de-energized contact state is maintained (or restored) by a pair of return springs. The springs are redundant, in that either is capable of maintaining the relays position. When the relay coil is energized, the rotor is turned by the coil assembly, overcoming the resistance of the return springs. Cams located along the rotor shaft in the switch assembly change the state of the relay contacts.

4.4 LATCHING RELAY OPERATION

A latching MDR series relay is best described as a bi-directional spring-maintained relay. Individual coil pairs are energized to place the relay in either of two positions. In either position, a pair of springs serve primarily to maintain the relay "as-is" until the other coil pair is energized. The springs are redundant, in that either is capable of maintaining the relays position.

4.5 RELAY OPERATING MODES

For the purposes of this analysis, the MDR relay is considered to have two operating modes. The modes are normally energized (NE) and normally de-energized (ND). MDR latching relays are normally de-energized.

A relay is considered to be normally energized (NE) if its coil is energized to maintain a desired contact position under normal plant operating conditions. A normally energized SSPS slave relay is, therefore, de-energized to perform its safety-related function.

A relay is considered to be normally de-energized (ND) if its coil is de-energized under normal plant operating conditions. A normally de-energized SSPS slave relay is, therefore, energized to perform its safety-related function.

A latching relay is normally de-energized. Typically, a latching relay is used in the control of functions where loss of power should not cause an inadvertent reset, or where a deliberate action is required to reset/terminate the function, such as Safety Injection.

4.6 DIFFERENCES BETWEEN THE SMALL AND MEDIUM RELAYS

The design of the small and medium MDR series relays are basically the same, with minor exceptions in the coil assemblies. The switch assemblies are identical (same design and materials) regardless of the model of relay and the same switch assemblies used for the small are used on the medium relay.

The design of the medium coil is the same as for the small coil, but the medium coils are larger (the differences between the AC and DC coils are still the same). The medium relay also has extension-type rotor return springs instead of the wire return springs found in the small coil. The small relay has no upper motor shock plate because the switch base serves this purpose. Because the diameter of the medium MDR series relay is wider than the switch assembly, the medium MDR relay has an additional shock plate found in the upper endbell.

4.7 MDR SERIES RELAY PHOTOGRAPHS

Figures 4-1 through 4-7 show the latching (P&B model number 4076) and non-latching (P&B model number 138-8) relays. The following is a title listing of Figures 4-1 through 4-7 and parts identified on the photographs:

Figure 4-1: Completely Assembled - Latching Relay (Top) and Non-Latching Relay (Bottom)

Switch Studs
Switch Cover
Upper Endbell
Lower Endbell
Base Assembly
Terminals
Switch Ring Barrier
Rotor Shaft

Figure 4-2: Cover Removed

Cam
Contact Terminal
Contact Spring Stud
Contact Spring
Switch Ring
Switch Ring Barrier
Rotor Shaft

Figure 4-3: Switch Ring(s), Cams(s), Barriers Removed

Switch Base
Switch Stud
Rotor Shaft
Upper Endbell
Motor Nut

Figure 4-4a: Switch Base, Top Endbell, and Spring Retainer Removed - Non-Latching Relay

Coil Pair
Coil Retainer
Spacer
Spring Retainer
Return Spring

Figure 4-4b: Switch Base and Top Endbell Removed - Latching Relay

Coil Pair
Coil Retainer
Spacer
Spring Retainer
Latch Spring
Stop Ring

Figure 4-5a: Stop Ring and Latch Springs Removed - Latching Relay

Rotor Endplates/Laminations
Stator Assembly
Shading Coil
Coil Retainer

Figure 4-5b: Stop Ring and Return Springs Removed - Non-Latching Relay

Rotor Endplates/Laminations
Stator Assembly
Coil Retainer

Figure 4-6: Rotor Assembly and Stator Assembly Removed - Non-Latching Relay

Bottom Endbell
Shock Plate (removed from inside Bottom Endbell)
Grommets
Coil Leadwire

Figure 4-7: Underside of Relay - Latching Relay

Terminal Outlets
Base
Grommets
Motor Bolts and Retainers
Bottom Endbell
Rotor Shaft

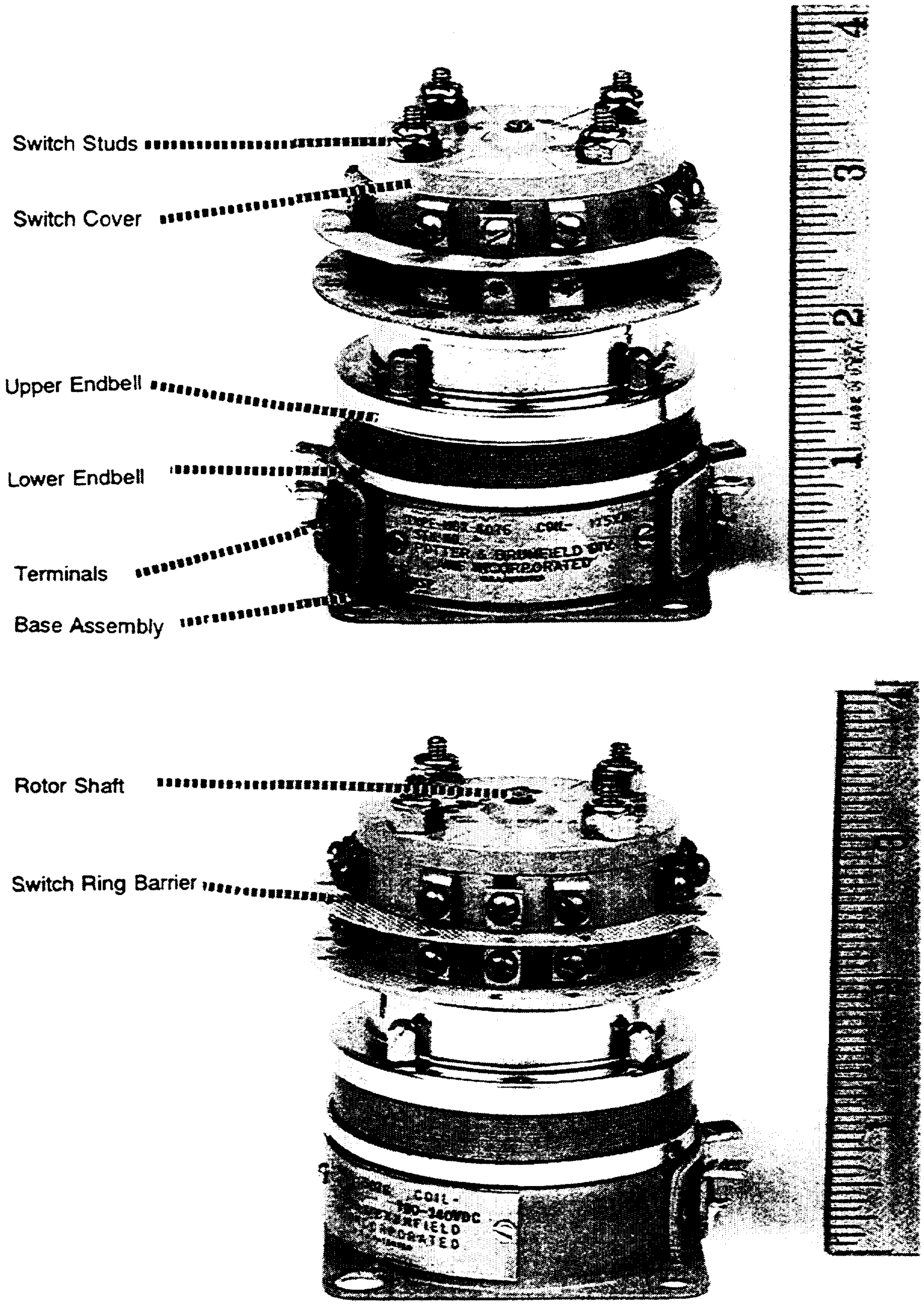


Figure 4-1: Completely Assembled – Latching Relay (Top) and Non-Latching Relay (Bottom)

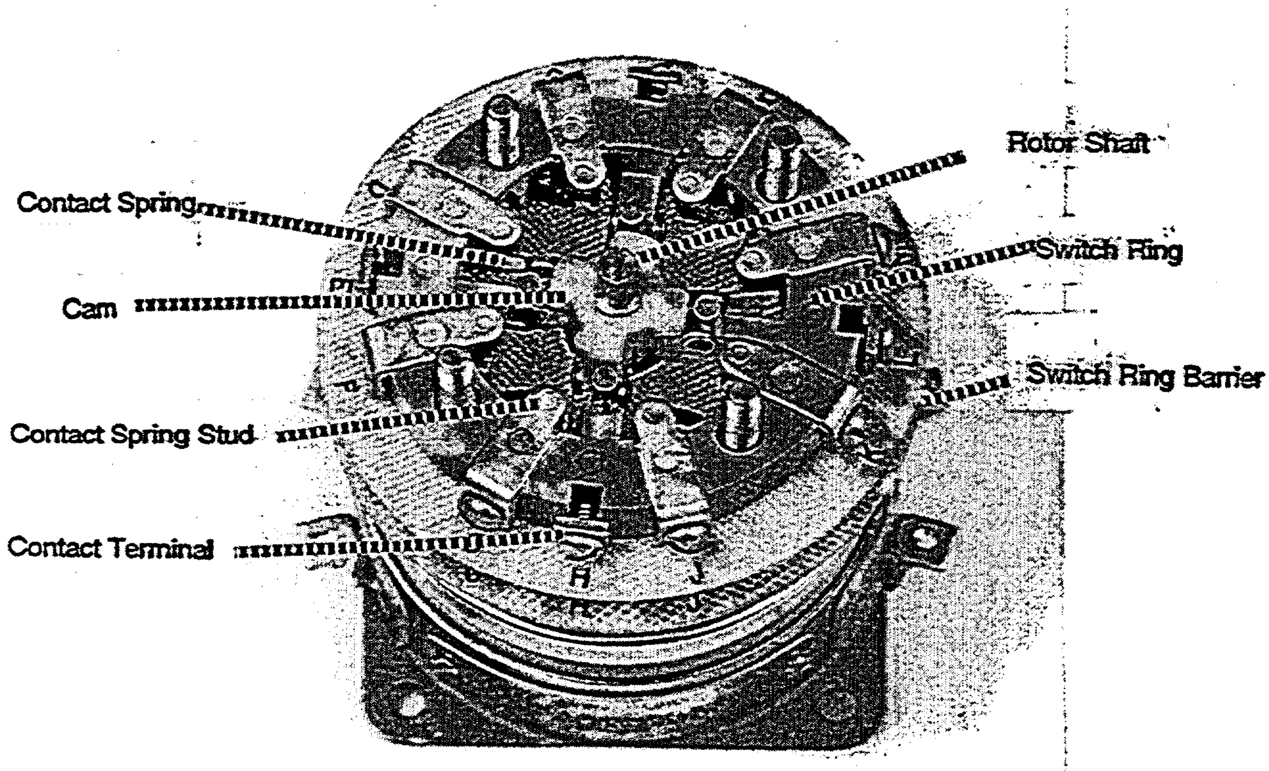


Figure 4-2: Cover Removed

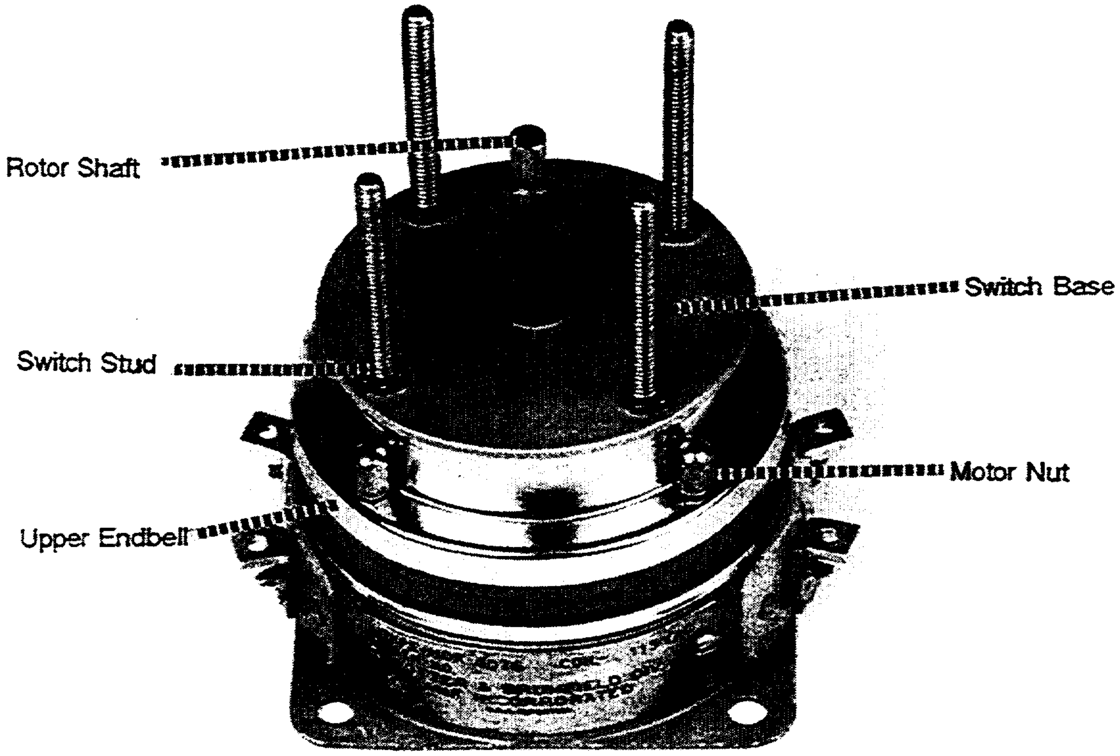


Figure 4-3: Switch Ring(s), Cam(s), Barriers Removed

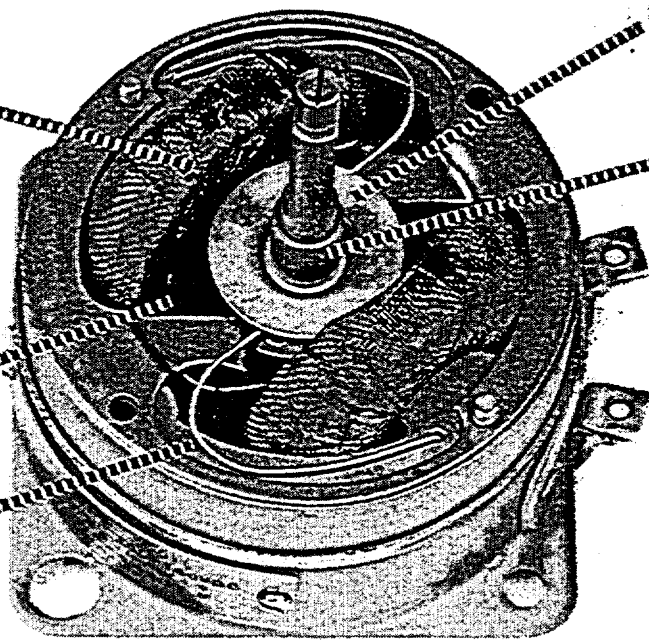


Figure 4-4a: Switch Base, Top Endbell, and Spring Retainer Removed – Non-Latching Relay

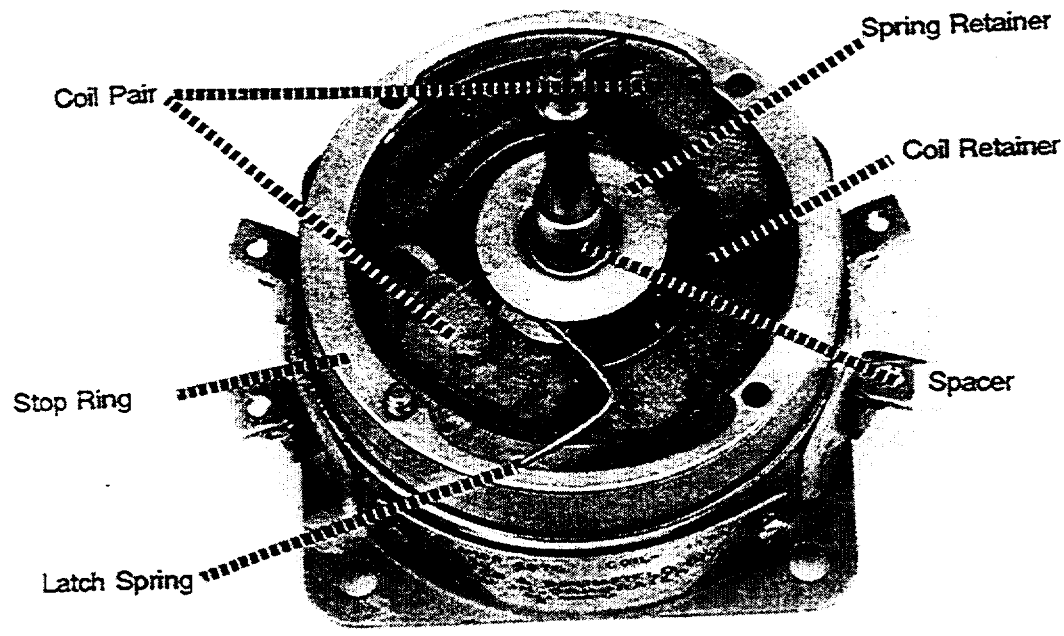


Figure 4-4b: Switch Base and Top Endbell Removed – Latching Relay

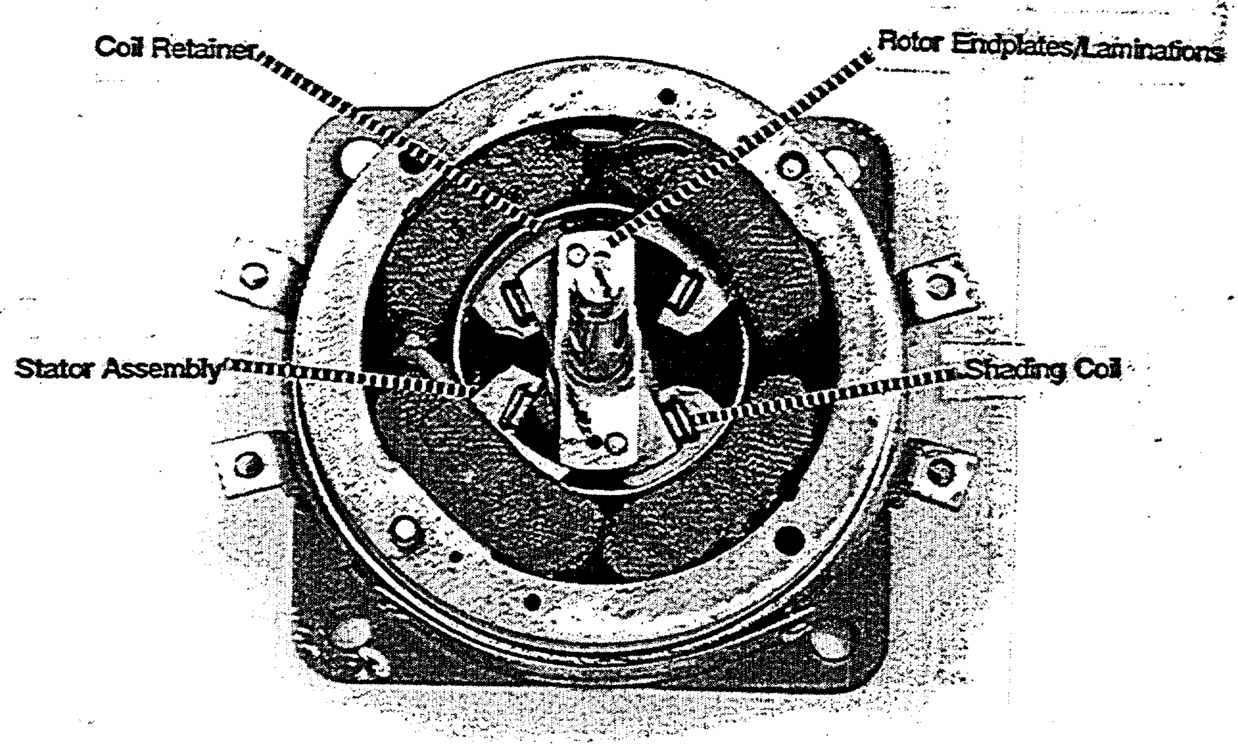


Figure 4-5a: Stop Ring and Latch Springs Removed – Latching Relay

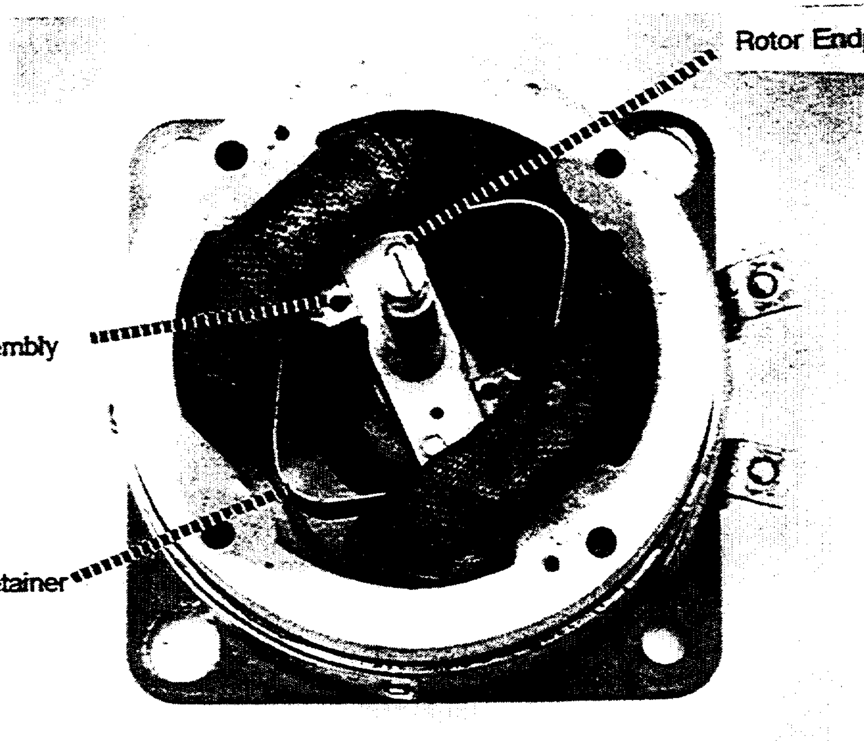


Figure 4-5b: Stop Ring and Return Springs Removed – Non-Latching Relay

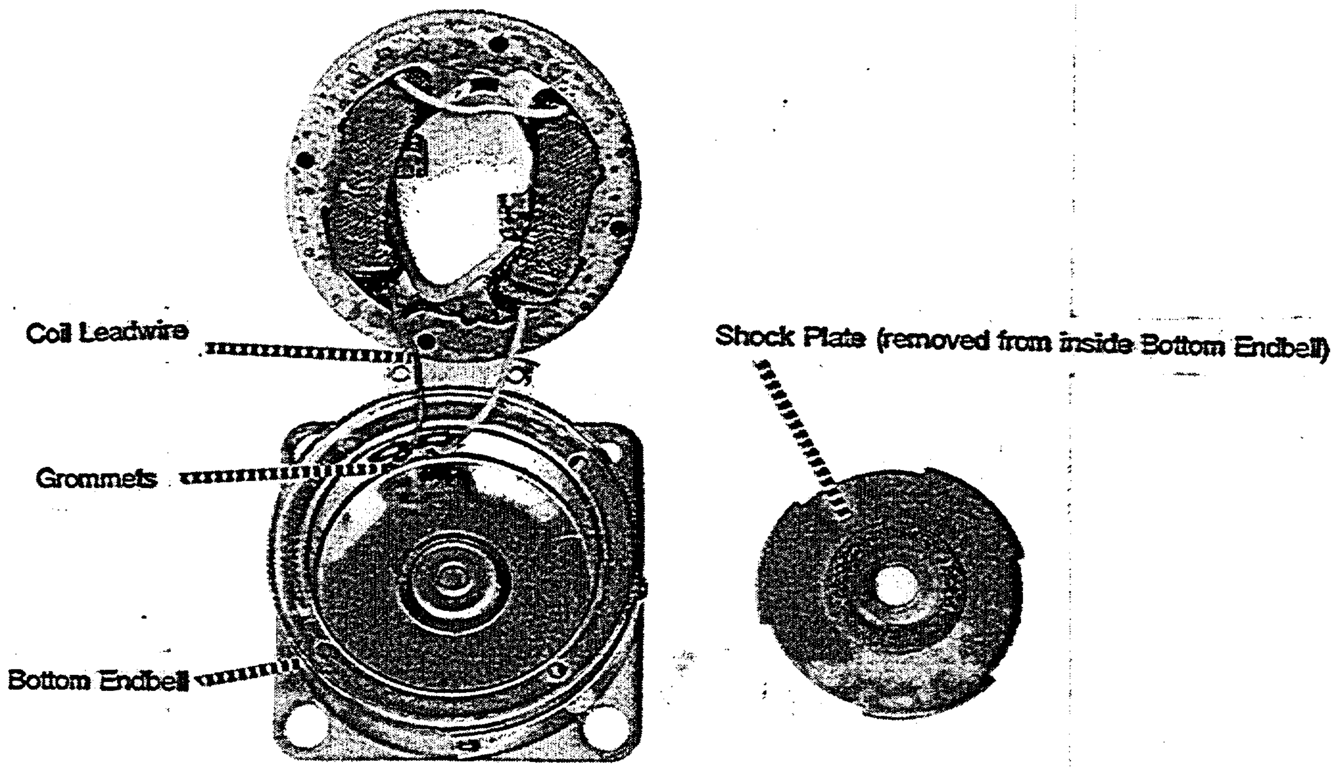


Figure 4-6: Rotor Assembly and Stator Assembly Removed – Non-Latching Relay

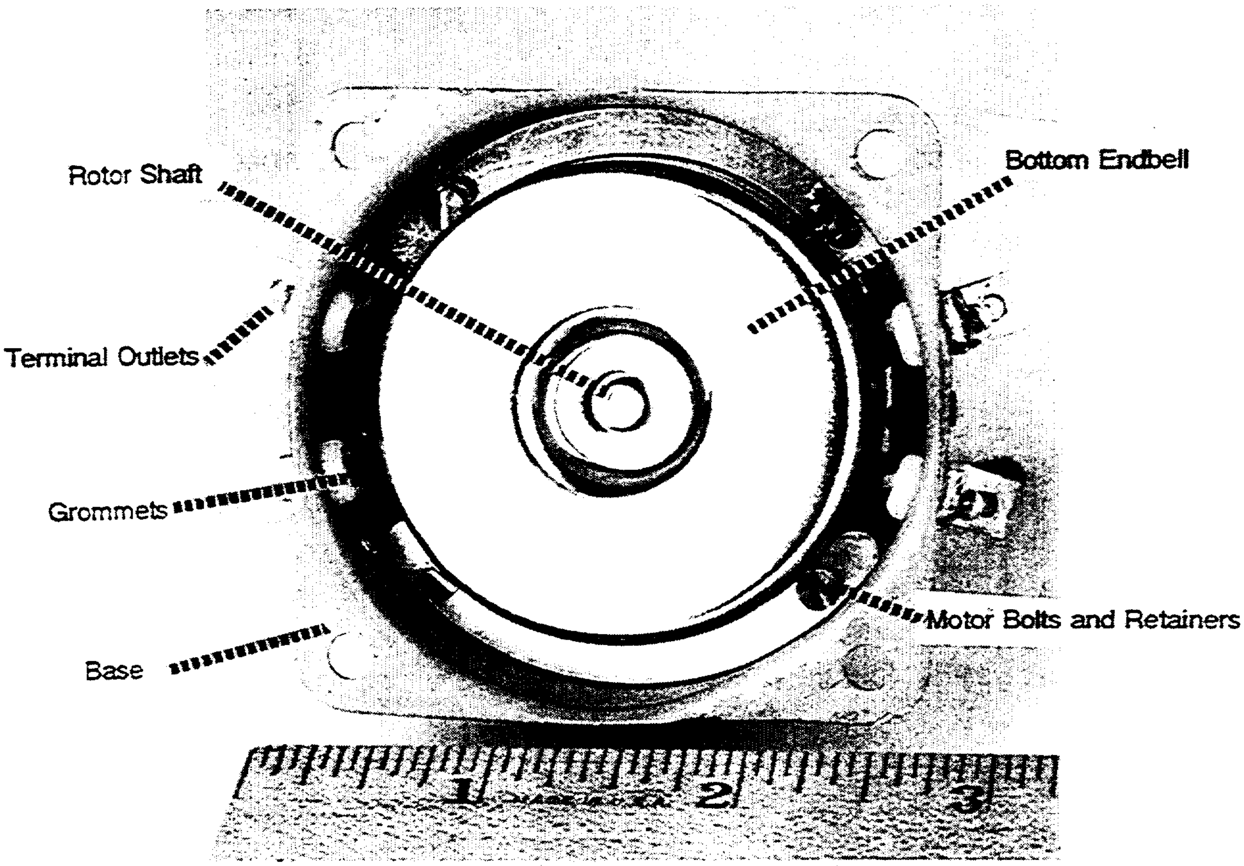


Figure 4-7: Underside of Relay – Latching Relay

5.0 DESIGN REVIEW

The Potter & Brumfield MDR rotary relays have a design and cycle life capability greatly in excess of that required for the SSPS slave relay application. The following sections summarize results of the design review which support this conclusion.

5.1 DESIGN LIFE

The Potter & Brumfield MDR series relays are rotary actuated relays that were designed to meet or exceed the rigorous requirements of military and power plant applications. The requirements include high-impact shock blows of 2000 ft-lbs, extreme vibration levels, and operation in the ambient temperature range of 0°C to 65°C (32°C to 149°F). The manufacturer estimates a design life of 500,000 operations for small, non-latching models and an estimated 100,000 cycles for all small latching and medium relays. Small MDR series relays are used as the SSPS slave relays and in the Auxiliary Safeguards Cabinets (ASGC), while medium relays are used in the ASGC. The shelf life specified by Westinghouse Replacement Component Services (RCS) is 40 years when stored at ambient temperatures of up to 120°F.

Table 5-1 identifies all component materials for the MDR series Relays. Since acquiring the MDR series relay product line from another vendor, P&B has made a significant effort to improve relay performance, reliability, and service life. A number of design improvements (i.e., component material substitutions) have been implemented in the MDR series relay product line based on field performance reports or component availability/cost. In general, the changes consist of efforts to minimize corrosion of metallic components, eliminate organic materials which produce corrosive by-products, and ultimately increase the temperature endurance of the relay coil insulating materials.

Table 5-2 lists all components subjected to changes and the various design vintages of MDR series relays since November of 1983. Section 5.4 provides further discussion of the design evolution of MDR series relays. Not all design vintages of the MDR series relays differ significantly. Those vintages which significantly improve relay life and reliability are summarized in Section 5.5. Further discussion of MDR series relay aging and temperature endurance is deferred to Section 8.0.

5.1.1 Maintenance

Any maintenance activity requiring disassembly of a MDR series relay is strongly discouraged by the manufacturer. The manufacture of the MDR series relay involves hand-fitting and several stages of testing which verify compliance with critical design tolerances. Handling during field disassembly/assembly may compromise contact integrity by degrading spring tension of contact arms (springs). Disassembly of the coil assembly (or motor) may cause damage to the coil leads, rotor (latch or return) springs, and can affect rotor end play which is critical to proper operation. Disassembly could also allow dust to enter the switch assembly and can adversely affect contact performance. In some cases, handling during field maintenance has compromised relay operability and has resulted in cases of irreversible damage to the relay. For this reason, any field disassembly of Westinghouse-supplied Class 1E MDR series relays voids any qualification established by Westinghouse.

5.2 MECHANICAL OPERABILITY

Early design development testing of the MDR series relay product line is no longer retrievable. The MDR relay was designed to meet requirements set forth in Military Specification MIL-R-19523A (Reference 13-2). The estimated design life of the small, non-latching MDR is 500,000 cycles of operation; the estimated design life for the medium MDR and all latching models is 100,000 cycles. Most SSPS slave relays are the small, latching models of the MDR series. The SSPS slave relay application estimated cycle life is 1000 cycles of operation during the forty-year plant life, with most operations occurring during periodic surveillance testing. The difference between estimated operations in design and service lives is approximately two orders of magnitude and provides confidence that the MDR series relays have substantial mechanical life in excess of SSPS operability requirements.

5.3 ELECTRICAL OPERABILITY

5.3.1 Relay Coils

The MDR relay coil was originally designed to meet Class A insulation requirements, defined per the Institute of Electrical and Electronic Engineers (IEEE). The Class A rating signifies that the coil is suitable for operation at 105 °C (total temperature; sum of ambient environment temperature and maximum estimated coil heat rise). The maximum estimated temperature rise is 40 °C to 45 °C, dependent upon coil voltage type (i.e., AC or DC) and rating (e.g., 118 VAC or 125 VDC). This is consistent with the manufacturer's recommendation for use at an ambient temperature not exceeding 65 °C. This recommendation is based on use in a typical control application (which does not include long-term continuous energization). However, the materials selected for use in the MDR relay coil meet Class B requirements, and are suitable for operation at 130 °C (total temperature). The added margin in coil temperature durability provides confidence that the MDR series relay could have a forty-year design life typically desired in quality electrical products for control applications.

MDR series relays made after June of 1989 are equipped with coils meeting Class F requirements - suitable for operation at 155 °C (total temperature). See Sections 5.4 and 5.5 for further discussion.

5.3.2 Relay Contacts

MDR series relays have contact ratings as follows:

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

These ratings apply to small and medium P&B MDR series relays of all vintages. Section 5.4.5 discusses design improvements of the movable contact materials.

Problems with excessive electrical contact loading in some SSPS slave relay applications, when used with certain DC current solenoid valves, have been identified in References 13.1-45 and 13.3-10. Further discussion is provided in Section 6.5.

5.4 DESIGN CHANGES

Design change history for the MDR series relay is summarized below. Some changes are improvements to the manufacturing process and are insignificant to the reliability of the product. However, most are upgrades based on field experience which are aimed at improving the quality and reliability of the MDR product line.

The earliest use of MDR relays in the manufacture of SSPS cabinets was in units provided to Diablo Canyon Units 1 and 2. Date codes for these relays indicate that some were manufactured mid-year of 1975. In 1983, the MDR series relay became the preferred relay for use in the SSPS after obsolescence of the ARLA latch mechanism for Type AR relays (see Section 6.1).

P&B reports there were no significant design changes to the MDR series relay product line prior to 1983. The following subsections trace all design changes made from 1983 to date.

5.4.1 November '83

The elastic-filled lock nuts used on the top of the switch assembly were changed from brass to stainless steel. The change in material was aimed at cost reduction and does not effect relay operability. Stainless steel lock nuts are considered to be of greater quality, though there is no significant impact to relay life or reliability. See Section 5.4.7 for subsequent change from stainless steel to nickel-plated lock nuts.

Nickel plating of the rotor assembly was added. The laminations of the rotor assembly are made of silicon steel, which is prone to corrosion. Corrosion observed in certain non-nuclear applications had caused excessive resistance to rotor movement. The nickel plating precludes corrosion that would lead to this failure mechanism. The change contributes significantly to relay life and reliability.

The above changes are not a significant design change (with respect to SSPS application). Therefore, the changes do not constitute a new design/vintage for the MDR relay.

5.4.2 December '83

The switch mounting stud material was changed from brass to stainless steel. The change from brass to stainless steel is an improvement in the manufacturing process. The change increases the strength of the switch mounting stud. The change is of little significance to the reliability of the product but is considered an improvement in quality.

The above change is not a significant design change. Therefore, the change does not constitute a new design/vintage for the MDR relay.

5.4.3 May '84

The coil terminal insulators were changed from a two-piece G10 (Glass filled melamine) and nylon to a single-piece glass-filled nylon. The change was implemented to achieve a net cost reduction in manufacturing. However, the resultant component simplification, i.e., substituting a single component for two, is considered to improve product quality. The insulation change is judged to be of little significance to product reliability.

The above change is not a significant design change. Both materials, both components have outstanding age and temperature resistance. Therefore, the change does not constitute a new design/vintage for the MDR relay.

5.4.4 March '85

The switch cover material was changed form alkyd to diallyl phthalate. A reduced availability of the alkyd material necessitated the change. Diallyl phthalate was chosen as the replacement switch cover material for its relative ease of molding, greater mechanical properties, and for use as the switch ring material. The change also reduced the rejection rate of the molded switch cover pieces. This material change represents an improvement in product quality, and is judged to be of little significance to product reliability.

The above change is not a significant design change. Both materials have outstanding age and temperature resistance. Therefore, the change does not constitute a new design/vintage for the MDR relay.

5.4.5 October '85

The moveable contacts material was changed from silver to silver-cadmium-oxide. Use of the new contact material significantly increases contact life. The change is significant to product quality, reliability, and estimated life. However, the estimated design life for the latching and medium relays remains 100,000 cycles of operations (500,000 for small non-latching relays).

The above change is not a significant design change. Therefore, the change does not constitute a new design/vintage for the MDR relay.

5.4.6 February '86

The coil sealing material was changed from a varnish to an epoxy resin (Dolph CC-1090). The change is an improvement in coil construction (greater rigidity) and eliminated the varnish material which was later found to be the root cause of a life-limiting failure mode (Reference 13.1-43). The change significantly improved product quality, reliability, and estimated life.

The new coil sealing material does represent a significant design change (improvement) with respect to temperature-induced, age-related degradation of critical organic materials. The new sealing material has an outstanding age and temperature resistance and has a positive impact on the postulated end-of-life failure for the MDR relay. Therefore, the change does constitute a new design/vintage for the MDR relay.

5.4.7 August '86

The elastic-filled lock nuts used on the top of the switch assembly were changed from stainless steel to nickel-plated steel (Also see Section 5.4.1). The change in material was aimed at cost reduction due to increased availability of the nickel-plated lock nuts and does not effect relay operability. Nickel-plated steel lock nuts are considered to be of equal quality (i.e., resistance to corrosion when compared to the original brass material), however, there is no significant impact to relay life or reliability.

The above change is not a significant design change. Therefore, the change does not constitute a new design/vintage for the MDR relay.

5.4.8 November '86

The switch mounting studs were redesigned to have a flat side on the outer circumference of the stud head and be press fitted into the upper endbell. The flat side of the stud head prevents rotation of the stud due to the minimal design clearance between the flat side on the stud head and the endbell case. Previously, the assemblers were required to prevent rotation of the round stud head while attaching the upper assembly to the stud. The new stud head configuration reduces the complexity of assembly. The change is a manufacturing improvement easing component assembly, and may represent a minor improvement in product quality. The change is judged to be insignificant to product reliability.

The above change is not a significant design change. Therefore, the change does not constitute a new design/vintage for the MDR relay.

5.4.9 March '87

Paint applied to the exterior of the coil stator assembly was changed from a gray alkyd type paint to a light gray polyurethane enamel. The change improved the paint integrity, and had a minor impact on product appearance. The change is an insignificant improvement in product quality with no impact on reliability or estimated life. See Section 5.4.12 for subsequent change to the coil stator assembly paint.

The above change is not a significant design change. Therefore, the change does not constitute a new design/vintage for the MDR relay.

5.4.10 June '88

The lubricant NYE Nyogel 718B grease was added. It is applied to both the upper and lower endbells of the stator assembly to improve the mechanical life of the MDR series relays. The lubricant is neither a critical component of the relay nor does the lubricant impact the MDR series relay thermal life. The change is judged to represent a marginal improvement in the relay reliability and service life.

The above change is not a significant design change. Therefore, the change does not constitute a new design/vintage for the MDR relay.

5.4.11 October '88

The relay coil lead wire material was changed from PVC coated fiberglass to polyester acrylic coated fiberglass. The objective was to eliminate the PVC material which releases chlorides/chlorine gas as part of its temperature-induced age-related degradation. The change is significant to improving product quality, reliability, and service life.

The above materials changes represent a significant design change (improvement) with respect to temperature-induced, age-related degradation of critical organic materials. The new material has an outstanding age and temperature resistance and has a positive impact on the postulated end-of-life failure for the MDR relay. Therefore, the change does constitute a new design/vintage for the MDR relay.

5.4.12 December '88

Paint applied to the exterior of the coil stator assembly was changed back to the gray alkyd type originally used. At issue was compliance with MIL Spec. R-19523A (Reference 13-12), which did not permit the Navy to accept the change in paint material. This reverses the change discussed in Section 5.4.9

The above change is not a significant design change. Therefore, the change does not constitute a new design/vintage for the MDR relay.

5.4.13 June '89

Three component material substitutions were implemented in the MDR series Relays. All materials changed were organic.

- The coil lead wire grommet material was changed from neoprene to polyetherimide,
- The coil tape (one of the insulating materials) was changed from polyester to polyimide,
- The magnet wire used in the relay coils was changed from polyurethane with a nylon jacket to modified polyester with a polyamid-imid jacket.

The objective of the three changes was to eliminate chlorine/chloride "out-gasser" materials in the relay coil assembly. The changes also increase the coil temperature rating from Class A (105 °C) to 150°C (Greater than Class B; 130°C but short of Class F; 155°C). The change represents an improvement in product quality, reliability, and service life.

The above materials changes represent a significant design change (improvement) with respect to temperature-induced, age-related degradation of critical organic materials. All outgassing materials were eliminated by this change and the temperature class rating of the MDR relay was uprated. The material changes increase the postulated end-of-life failure time for the MDR relay. Therefore, this change does constitute a new design/vintage for the MDR relay.

It is recommended that only MDR relays manufactured after 1992 should be used in applications where the relays are required to be normally energized. MDR relays of earlier vintage are suitable for normally de-energized service in the SSPS slave relay cabinets.

5.4.14 May '90

Three component material substitutions were implemented in the MDR series Relays. All materials changed were metallic.

- The rotor spacers were changed from brass to stainless steel,
- The spring retainer was changed from brass to stainless steel,
- The shims were changed from brass to phosphor bronze.

The objective of the three changes was to eliminate brass by replacing the brass with metals having greater corrosion resistance. Previous changes have eliminated organic materials known to be out-gassers of corrosion-inducing substances. The elimination of brass components was aimed at further improving product quality. The material changes from brass to stainless steel and from brass to phosphor bronze are considered to be a marginal improvement in reliability, with no apparent improvement to service life.

The above changes are significant design improvements, but do not constitute a new design vintage for MDR series relays. That is, there is no impact to temperature-sensitive organic materials.

In reaction to NRC IN 92-04 (Reference 13-1.43), Westinghouse RCS established the position that only MDR series relays made in or after May 1990 would be supplied as replacement parts for Class 1E applications. The additional corrosion resistance provided by the above changes is highly desirable, though the significance to relay life or reliability is not quantifiable.

5.4.15 May '93

The coil sealing material was changed from Dolph CC-1090 epoxy resin to Sterling E-100 epoxy resin. The change was initiated based upon the epoxy manufacturer's expressed intent to discontinue manufacture of the Dolph CC-1090 epoxy resin. Sterling E-100 epoxy resin was selected for its similar material performance characteristics. P&B's decision to implement the change was based on the availability of the Sterling E-100 in smaller unit quantities more appropriate to their rate of consumption. The change is of little significance to product quality, reliability, or service life.

The above change is not a significant design change. Both materials have outstanding age and temperature resistance. Therefore, the change does not constitute a new design/vintage for the MDR relay.

5.5 SIGNIFICANT DESIGN/VINTAGES

Section 5.4 discusses each of the fifteen design changes for the MDR relay from November 1983 through May 1993. Only three of the fifteen changes are considered to be significant design/vintage changes (see sections 5.4.6, 5.4.11 and 5.4.13). A significant design/vintage change is any change that affects the end-of-service life in SSPS applications, i.e., 1) out-gassing of organic materials and its impact on critical relay components, and 2) time/temperature degradation of critical organic materials.

The significant design/vintage time periods for the MDR series relay are:

- Earliest production to February 1986
- February 1986 to October 1988
- October 1988 to June 1989
- June 1989 to current date (October 1993)

Chemical out-gassing of certain relay components due to coil temperature rise has resulted in early end-of-life failures in the MDR relays. Sections 6.3 and 6.6 summarize information provided in NRC generic documents on the chemical out-gassing phenomena which occurs in normally-energized MDR relays, particularly those equipped with DC coils. Section 8 (Aging Assessment) addresses the time/temperature degradation of organic materials used in the MDR series relays for each of the above four design/vintage time periods.

It is recommended that only MDR relays manufactured after 1992 should be used in applications where the relays are required to be normally energized. MDR relays of earlier vintage are suitable for normally de-energized service in the SSPS slave relay cabinets.

5.5.1 Special Requirement for NE and 20% Duty Relays

A requirement resulting from the NRC review of the PG&E LAR and RAI response for SSPS slave relay test interval extension requires that only P&B MDR relays manufactured after 1992 should be used in normally energized or 20% duty cycle applications. This is based on review of issues that occurred and evolved during and after the research and evaluation documented in the original issue of this report.

Appendix D provides further discussion on three issues that affect P&B MDR relays manufactured in 1992. These issues address concerns for relay rotor return springs, binding caused by insufficient end play of the rotor shaft or oversized relay coils (tall coils), and inadvertent accumulation of epoxy in undesired locations during manufacture (tramp epoxy). Each of these concerns tends to affect the operation of normally energized relays, and is a concern for relays used in 20% duty cycle applications. A conservative resolution of these concerns would be to reject use of MDR series relays made in or before 1992 for applications requiring continuous energization of the relays for any significant period of time.

TABLE 5-1 MATERIALS FOR MDR SERIES RELAYS		
PARTS	MATERIAL	NOTES
Base	Cold rolled steel (Also See Paint)	
Coil Finishing Insulation	See Table 5-2 and Section 5.4.13	
Coil Impregnation	See Table 5-2 and Sections 5.4.6 and 5.4.15	3
Coil Leadwire	#22 (7 x 30) teflon, 1000 Volt	
Coil Leadwire Sleeving	See Table 5-2 and Section 5.4.11	
Coil Magnet Wire	See Table 5-2 and Section 5.4.13	
Coil Retainer Adhesive	Thermoset 103 epoxy resin	3
Coil Retainers	Brass	
Coil Terminal Insulator	See Table 5-2 and Section 5.4.3	
Coil Terminal and Eyelets	Brass, tin plated	
Contact and Coil Terminal Screws	Brass	
Contact Cams	Glass filled nylon	
Contact Spring Studs	Brass	
Contact Springs and Washers	Phosphor bronze	
Contact Terminals	Brass	
Endbell Lubricant	See Table 5-2 and Section 5.4.10	3
Endbells	Cold-rolled steel (Also See Paint)	
Grommet (Coil Lead)	See Table 5-2 and Section 5.4.13	
Lock Washer	Stainless steel	
Motor Nuts	Brass, nickel plated	
Motor Bolts	Brass, nickel plated	
Motor Shock Plates	Phosphor bronze	2
Movable Contacts	See Table 5-2 and Section 5.4.5	
Nameplate Screws	Stainless steel	
Nameplate	Nickel silver	
Paint (Stator Assembly and Base Assembly)	See Table 5-2 and Sections 5.4.9 and 5.4.12	
Rotor Breaker Plates	Stainless steel	4
Rotor End Plates	Cold rolled steel	

TABLE 5-1 MATERIALS FOR MDR SERIES RELAYS		
PARTS	MATERIAL	NOTES
Rotor Finish (laminations)	Nickel plating	
Rotor Laminations	Silicon steel	
Rotor Latch Springs	Stainless steel	5
Rotor Return Springs	Stainless steel	5
Rotor Rivets	Galvanized steel	
Rotor Shaft	Stainless steel	
Rotor Shims	See Table 5-2 and Section 5.4.14	
Shading Coils	Beryllium copper	1
Spacer Ring and Stop Ring	Cold rolled steel, nickel plated	
Spacers	See Table 5-2 and Section 5.4.14	
Stationary Contacts	Fine silver	
Stator Laminations	Silicon steel	
Stop Nuts	See Table 5-2 and Sections 5.4.1 and 5.4.7	
Switch Cover	See Table 5-2 and Section 5.4.4	
Switch Ring Base and Barriers	G9 Glass Melamine laminated plastic	
Switch Ring Insulators	Diallyl phthalate	
Switch Studs	See Table 5-2 and Sections 5.4.2 and 5.4.8	
Terminal Rivets	Steel, tin plated	

NOTES:

1. AC relays only.
2. Motor Shock Plates serve as Rotor Shaft Bearings.
3. Components are designated "assembly materials".
4. DC relays only
5. Rotor Return Springs used in non-latching relay only. In the latching relay, the Latch Springs are substituted for the Return Springs.

TABLE 5-2a MATERIAL CHANGES IN MDR SERIES RELAYS

PARTS	MATERIAL					NOTES
	May 1993	May 1990	June 1989	December 1988	October 1988	
Coil Finishing Insulation	Glass cloth tape, polyimide film tape, fiberglass tape	Glass cloth tape, polyimide film tape, fiberglass tape	Glass cloth tape, polyester film tape, fiberglass tape	Glass cloth tape, polyester film tape, fiberglass tape	Glass cloth tape, polyester film tape, fiberglass tape	
Coil Impregnation	Sterling E-100 epoxy resin	Dolph Dolphon CC-1090 epoxy resin	Dolph Dolphon CC-1090 epoxy resin	Dolph Dolphon CC-1090 epoxy resin	Dolph Dolphon CC-1090 epoxy resin	1
Coil Leadwire Sleeving	Polyester-acrylic coated fiberglass	Polyester-acrylic coated fiberglass	Polyester-acrylic coated fiberglass	Polyester-acrylic coated fiberglass	Polyester-acrylic coated fiberglass	
Coil Magnet Wire	Copper with insulation of modified polyester and polyamid-imid jacket	Copper with insulation of modified polyester and polyamid-imid jacket	Copper with insulation of modified polyester and polyamid-imid jacket	Copper with insulation of polyurethane with nylon jacket	Copper with insulation of polyurethane with nylon jacket	
Coil Terminal Insulator	Glass filled nylon	Glass filled nylon	Glass filled nylon	Glass filled nylon	Glass filled nylon	
Endbell Lubricant	NYE Nyogel 718B grease	NYE Nyogel 718B grease	NYE Nyogel 718B grease	NYE Nyogel 718B grease	NYE Nyogel 718B grease	1
Grommet (Coil Lead)	Polyetherimide (GE Ultem or equivalent)	Polyetherimide (GE Ultem or equivalent)	Polyetherimide (GE Ultem or equivalent)	Neoprene	Neoprene	
Movable Contacts	Silver-cad-oxide	Silver-cad-oxide	Silver-cad-oxide	Silver-cad-oxide	Silver-cad-oxide	
Paint (Stator Assembly)	Finish (1) coat primer and (1) coat gray alkyd enamel	Finish (1) coat primer and (1) coat gray alkyd enamel	Finish (1) coat primer and (1) coat gray alkyd enamel	Finish (1) coat primer and (1) coat gray alkyd enamel	Finish (1) coat primer and (1) coat gray polyurethane enamel	
Rotor Shims	Phosphor bronze	Phosphor bronze	Brass	Brass	Brass	
Spacers	Stainless steel	Stainless steel	Brass	Brass	Brass	
Stop Nuts	Steel, nickel plated	Steel, nickel plated	Steel, nickel plated	Steel, nickel plated	Steel, nickel plated	
Switch Cover	Diallyl phthalate	Diallyl phthalate	Diallyl phthalate	Diallyl phthalate	Diallyl phthalate	
Switch Studs	Stainless steel(press fit)	Stainless steel(press fit)	Stainless steel(press fit)	Stainless steel(press fit)	Stainless steel(press fit)	

NOTES:

1. Components are designated "assembly materials".

o:\3378w.non:1b/080800

TABLE 5-2b MATERIAL CHANGES IN MDR SERIES RELAYS

PARTS	MATERIAL					
	June 1988	March 1987	November 1986	August 1986	February 1986	NOTES
Coil Finishing Insulation	Glass cloth tape, polyester film tape, fiberglass tape	Glass cloth tape, polyester film tape, fiberglass tape	Glass cloth tape, polyester film tape, fiberglass tape	Glass cloth tape, polyester film tape, fiberglass tape	Glass cloth tape, polyester film tape, fiberglass tape	
Coil Impregnation	Dolph Dolphon CC-1090 epoxy resin	Dolph Dolphon CC-1090 epoxy resin	Dolph Dolphon CC-1090 epoxy resin	Dolph Dolphon CC-1090 epoxy resin	**Dolph Dolphon CC-1090 epoxy resin**	1
Coil Leadwire Sleeving	PVC coated fiberglass	PVC coated fiberglass	PVC coated fiberglass	PVC coated fiberglass	PVC coated fiberglass	
Coil Magnet Wire	Copper with insulation of polyurethane with nylon jacket	Copper with insulation of polyurethane with nylon jacket	Copper with insulation of polyurethane with nylon jacket	Copper with insulation of polyurethane with nylon jacket	Copper with insulation of polyurethane with nylon jacket	
Coil Terminal Insulator	Glass filled nylon	Glass filled nylon	Glass filled nylon	Glass filled nylon	Glass filled nylon	
Endbell Lubricant	**NYE Nyogel 718B grease**	Not used	Not used	Not used	Not used	1
Grommet (Coil Lead)	Neoprene	Neoprene	Neoprene	Neoprene	Neoprene	
Movable Contacts	Silver-cad-oxide	Silver-cad-oxide	Silver-cad-oxide	Silver-cad-oxide	Silver-cad-oxide	
Paint (Stator Assembly)	Finish (1) coat primer and (1) coat gray polyurethane enamel	Finish (1) coat primer and (1) **coat gray polyurethane enamel**	Finish (1) coat primer and (1) coat gray alkyd enamel	Finish (1) coat primer and (1) coat gray alkyd enamel	Finish (1) coat primer and (1) coat gray alkyd enamel	
Rotor Shims	Brass	Brass	Brass	Brass	Brass	
Spacers	Brass	Brass	Brass	Brass	Brass	
Stop Nuts	Steel, nickel plated	Steel, nickel plated	Steel, nickel plated	**Steel, nickel plated**	Stainless steel	
Switch Cover	Diallyl phthalate	Diallyl phthalate	Diallyl phthalate	Diallyl phthalate	Diallyl phthalate	
Switch Studs	Stainless steel(press fit)	Stainless steel(press fit)	Stainless steel**(press fit)**	Stainless steel	Stainless steel	

NOTES:

1. Components are designated "assembly materials".

o:\3378w.non:1b/080800

TABLE 5-2c MATERIAL CHANGES IN MDR SERIES RELAYS

PARTS	MATERIAL					
	October 1985	March 1985	May 1984	December 1983	November 1983	NOTES
Coil Finishing Insulation	Glass cloth tape, polyester film tape, fiberglass tape	Glass cloth tape, polyester film tape, fiberglass tape	Glass cloth tape, polyester film tape, fiberglass tape	Glass cloth tape, polyester film tape, fiberglass tape	Glass cloth tape, polyester film tape, fiberglass tape	
Coil Impregnation	Dolph's BC-340 phenolic-filled polyester resin	Dolph's BC-340 phenolic-filled polyester resin	Dolph's BC-340 phenolic-filled polyester resin	Dolph's BC-340 phenolic-filled polyester resin	Dolph's BC-340 phenolic-filled polyester resin	1
Coil Leadwire Sleeving	PVC coated fiberglass	PVC coated fiberglass	PVC coated fiberglass	PVC coated fiberglass	PVC coated fiberglass	
Coil Magnet Wire	Copper with insulation of polyurethane with nylon jacket	Copper with insulation of polyurethane with nylon jacket	Copper with insulation of polyurethane with nylon jacket	Copper with insulation of polyurethane with nylon jacket	Copper with insulation of polyurethane with nylon jacket	
Coil Terminal Insulator	Glass filled nylon	Glass filled nylon	Glass filled nylon	Two-pieces made of G10 and nylon	Two-pieces made of G10 and nylon	
Endbell Lubricant	Not used	Not used	Not used	Not used	Not used	1
Grommet (Coil Lead)	Neoprene	Neoprene	Neoprene	Neoprene	Neoprene	
Movable Contacts	Silver-cad-oxide	Silver	Silver	Silver	Silver	
Paint (Stator Assembly)	Finish (1) coat primer and (1) coat gray alkyd enamel	Finish (1) coat primer and (1) coat gray alkyd enamel	Finish (1) coat primer and (1) coat gray alkyd enamel	Finish (1) coat primer and (1) coat gray alkyd enamel	Finish (1) coat primer and (1) coat gray alkyd enamel	
Rotor Shims	Brass	Brass	Brass	Brass	Brass	
Spacers	Brass	Brass	Brass	Brass	Brass	
Stop Nuts	Stainless steel	Stainless steel	Stainless steel	Stainless steel	Stainless steel(formerly brass)	
Switch Cover	Diallyl phthalate	Diallyl phthalate	Alkyd	Alkyd	Alkyd	
Switch Studs	Stainless steel	Stainless steel	Stainless steel	Stainless steel	Brass	

NOTES:

1. Components are designated "assembly materials".

6.0 REVIEW OF GENERIC COMMUNICATIONS

This section references the generic communication documents applicable to relays used in the SSPS. In particular, generic communication documents applicable to the MDR series relay used in the SSPS are discussed.

References 13.1-1 through 13.1-49 and 13.2-1 through 13.2-15 are the NRC generic communication reviewed as part to the FMEA (and aging assessment) for MDR series relays. All of the generic communications were reviewed in order to consider all relay failure modes or mechanisms identified for relays that might also apply to the MDR series relay. References 13.3-1 through 13.3-10 are the Westinghouse Technical Bulletins written for relays used in various applications.

The NRC communications that apply specifically to the MDR series relay are:

Reference 13.1-40, NRC Information Notice 90-57, "Substandard, Refurbished Potter & Brumfield Relays Misrepresented as New"

Reference 13.1-41, NRC Information Notice 90-57, Supplement 1, "Substandard, Refurbished Potter & Brumfield Relays Misrepresented as New"

Reference 13.1-43, NRC Information Notice 92-04, "Potter & Brumfield Model MDR Rotary Relay Failures"

Reference 13.1-45, NRC Information Notice 92-19. "Misapplication of Potter & Brumfield MDR rotary Relays"

I&E Notices that apply specifically to the MDR series relay are:

References 13.1-22, I&E Notice 82-55, "Seismic Qualification of Westinghouse AR Relay With Latch Attachments Used In Westinghouse Solid State Protection System"

Reference 13.1-27, I&E Notice 84-20, "Service Life of Relays in Safety-Related Systems"

Only the above generic communications have direct applicability to the MDR series relays and are discussed in the following subsections.

6.1 SEISMIC QUALIFICATION

The Potter & Brumfield MDR series relay is included in the Westinghouse generic Equipment Qualification (EQ) programs. Because of seismic concerns, the following documents recommend that the MDR series latching relay be used as a replacement relay (for Type AR relays with an ARMLA attachment) in safety-related applications. While the titles of the following documents do not mention the MDR series relay, each document states that the MDR series relay is seismically qualified.

> Reference 13.3-7, NSD-TB-82-03, "AR Relay Latch Attachments", Systems(s): Solid State Protection System and Auxiliary Safeguards Cabinets
>
> Reference 13.3-7, NSD-TB-82-03 Rev 1, "AR Relay Latch Attachments", Systems(s): Solid State Protection System and Auxiliary Safeguards Cabinets
>
> Reference 13.1-22, I&E Notice 82-55, "Seismic Qualification of Westinghouse AR Relay With Latch Attachments Used in Westinghouse Solid State Protection System"

It is assumed that the recommendations in the above documents have been implemented and that all relays not seismically qualified for safety-related applications have been replaced. It is beyond the scope of this report to address the seismic qualification of any relay other than the P&B MDR series relay.

6.2 SERVICE LIFE

The NRC issued Information Notice 84-20 (Reference 13.1-27, "Service Life of Relays in Safety-Related System", 3/21/84) to advise licensees that, "in general, the service life of all relays in the normally energized state is significantly shorter than when used in a cycled or normally de-energized application". The notice also advised "that preventative maintenance programs should recognize the application-dependent (energized/de-energized) service life of these relays (Agastat GP series relays and GTE Sylvania AC relays) and the service life of other relay manufacturers".

Section 8.0 of this report is an aging assessment for MDR series relays when used as SSPS slave relays. It addresses the aging of normally energized and normally de-energized relays, thermogravimetric analysis (TGA) of age-degradable materials, and provides service life calculation results based on evaluation of the postulated end-of-life failure mechanism for MDR series relays. The conclusions from the aging assessment are:

- Normally energized relays require replacement during the 40-year plant life.
- Normally de-energized relays have a service life in-excess of 40 years.

6.3 MATERIALS DEGRADATION PRODUCTS

NRC Information Notice 92-04 (Reference 13.1-43) discusses failures caused by out-gassing of the coil varnish, rubber grommets and polyvinyl chloride sleeves in normally energized MDR rotary relays.

Deposits of the coil varnish and chlorine corrosion products resulted in binding of the relay and contact intermittence. The deposited material accumulated between the rotor shaft, the end-bell bearings and sleeve. This deposition caused the rotor shaft to bond or stick to the end-bell bearings and sleeves and prevented the rotor shaft from fully rotating when the relay coils were energized or de-energized.

The FMEA results of Section 7.0 include consideration of failure modes and mechanisms that might arise from degradation products of MDR series relay component materials. The aging assessment of the MDR series relay includes review of available Thermogravimetric Analyses (TGAs) applicable to various organic materials used in relay components (See Table 5-1 and Section 8.0). TGA is discussed for materials that are likely out-gassers. TGA is not discussed for other organic materials of the MDR series relay that are not subject to significant dimensional change, weight loss, or loss of flexural strength in response to high temperature, or as a factor of long term aging. As such, there is little likelihood of significant out-gassing or evolution of aggressive species (e.g., hydrochloric acid).

Based on conclusions of the aging assessment, a relay replacement interval is recommended. It is intended that relay reliability will be optimized by replacement prior to the occurrence of significant aging degradation. Normally energized relays should be replaced more frequently. The actual replacement interval should be based on the aging assessment (Section 8.3) and calculations using plant-specific temperature data. Section 8.3.4 includes an example calculation based on temperature data gathered for the Farley Nuclear Plant.

6.4 SUBSTANDARD REFURBISHMENT

NRC Information Notice 90-57 and 90-57 Supplement 1 (References 13.1-40 and 13.1.41) discuss willful wrongdoing by a particular individual/company in regards to the refurbishment of the P&B MDR relays. The wrongfully refurbished MDR relays were found to be materially and functionally substandard, such that the relays may not have operated as required. Prior to installation, visual inspections and tests of the refurbished relays verified that the relays were substandard and not fit for use.

Prior to installation, all replacement components (including MDR relays) to be used in safety-related applications should be subject to the site Quality Assurance program (i.e., inspection, testing, etc.). For the purposes of this assessment, it is assumed that the site Quality Assurance program is effective and that substandard MDR relays have not been installed into safety-related applications. MDR relays that have been refurbished in a substandard fashion is a separate concern beyond the scope of this report.

Based on the NRC review of the lead plant Licensing Amendment Request (LAR), the NRC requests that all plants seeking the SSPS Slave Relay Test Frequency Relaxation submit with each LAR confirmation that the plant procurement program is adequate to assure that only MDR Series relays suitable for safety-related service would be accepted for use in the future. Each plant is instructed to review the various failure modes of MDR Series relays (References 13.1-27, 13.1-40, 13.1-41, 13.1-43, 13.1-50, and this report; WCAP-13878), and affirm that procurement plans/procedures for MDR Series relays have, or will be updated to include, measures which are capable of identifying and eliminating MDR relays susceptible to the known failure modes. Appendix D includes the lead plant (PG&E) discussions of this issue.

6.5 EXCESSIVE LOADS ON RELAY CONTACTS

NRC Information Notice 92-19 (Reference 13.1-45) reports cases of excessive contact loading in Potter & Brumfield MDR rotary relays in various applications. Noted are the differences between current rating of contacts used with direct current and the rating of contacts used with alternating current. Failures of the MDR relay contacts were due to consideration of only resistive loads and failure to consider inductive loads. Reference 13.1-45 characterizes the reported failures as misapplication of P&B MDR relays.

Technical Bulletin NSD-TB-92-02 (Reference 13.3-10) was issued by Westinghouse in response to reports of excess contact loading failures which occurred in MDR relays used as SSPS slave relays. The concern is for circuits in which the MDR relay contacts are required to open in response to ESFAS signals, de-energizing normally energized solenoid valves with DC coils (specifically Valcor and Target Rock solenoid valves). References 13.3-10 states that the concern also applies to Type AR relays required to perform the same function.

Situations of excessive contact loading should be corrected by circuit modification. For the purposes of this evaluation, it is assumed that any previously existing cases have been eliminated by circuit modification. This failure mode is included in the FMEA (Section 7, Table 7-3). However, incidents of such failure have been omitted in the calculation of relay reliability (See Section 9.0).

Misapplication of the relay contacts is a separate concern beyond the scope of this report.

Based on the NRC review of the lead plant Licensing Amendment Request (LAR), the NRC requests that all plants seeking the SSPS Slave Relay Test Frequency Relaxation submit with their LAR confirmation that a study of the contact loading on MDR relays has been performed. Appendix D provides a copy of the PG&E response to NRC questions from the LAR review, and includes a recommended response on the contact loading issue.

6.6 REVIEW OF AEOD/S93-06

The Office for Analysis and Evaluation of Operational Data's (AEOD) report, AEOD/S93-06, "Potter & Brumfield Model MDR Rotary Relay Failures" (Reference 13.1-50), provides a compilation and analysis of MDR failure statistics for NE, ND, AC coil, and DC coil relays based on research of LERs, industry data, reactor vendor guidance, NRC inspection reports and site visits, and P&B design modifications. It does not address in detail, however, the design, history, or manufacture of the MDR relay, no misapplications of the relays, that could result in failures due to out-gassing of compounds in the varnish and grommet materials. The AEOD report recognizes, as does this WCAP, that the failure history available is insufficient to arrive at a quantitative failure rate for the MDR relay.

The AEOD report asks the question why there were numerous failures at Combustion Engineering and General Electric designed plants, but so few (8 of the report's 124 failures found in MDR history from 1984 through 1992) found at Westinghouse designed plants. Most of the failures noted for CE and GE plants occurred in normally energized relays equipped with DC coils. Some failures were attributed to over-voltage conditions which greatly increased the effective wattage and temperature rise of the relay coils. Locally high ambient temperatures and/or significant cabinet temperature rise may also have accelerated temperature-induced degradation and, ultimately, the observed failures. Data presented in the AEOD report can be interpreted to suggest that failures were occurring under service conditions which exceeded the relay manufacturer's NEMA Class A rating for the relay coils.

The MDR relays used as the SSPS slave relays, if manufactured prior to June of 1989, are not free of the potential for failure due to the out-gassing phenomenon. However, their susceptibility to this failure mechanism is substantially reduced by four factors.

- All SSPS slave relays (and STC test relays) are equipped with AC coils having a lower wattage and, thus, a lower coil temperature rise than the typical DC coil relays.

- Most SSPS slave relays (and STC test relays) are normally de-energized in service, and not subject to rapid degradation due to coil temperature rise. The out-gassing phenomenon should not occur in normally de-energized relays.

- The SSPS cabinets are located in temperature controlled environments ranging from 65 °F to 90°F (see Table 8-1).

- The SSPS output bays have very low cabinet temperature rises (heat is generated only by the few relays which are normally energized; see Table 8-2).

The majority of MDR relays utilized in Westinghouse designed systems are found in the SSPS or the Safeguards Test Cabinet (STC). The out-gassing phenomenon will not occur in normally de-energized relays. When supplied as Class 1E by Westinghouse, the MDR series relays are subject to a conservative qualified life. The factors of service cited above, and prudent replacement by the utilities, has effectively minimized the incidence of failure.

This report, WCAP-13878, addresses in greater detail the significance of normally energized service, coil wattage, ambient environment temperatures and temperature rises in normally energized relays.

Recognizing that both relay life and reliability are tied to conditions of service, this report includes an aging assessment of the MDR series relay organic materials. The Arrhenius Time/Temperature Relationship is applied in the calculation of reasonable service lives for the MDR relay components when used in the SSPS output bays (see Section 8.0). The results of the aging assessment are applied with the conclusions of rigorous FMEA of the MDR series relay (see Section 7.0) to conclude that the MDR relay performs with exceptional reliability when used as an SSPS slave relay. This report also provides a failure history analysis specific to the MDR relay when used as an SSPS slave relay (Section 9.0). Section 9.0 affirms that the MDR relays have performed better than commercial/industrial averages, based on available data. The conclusions of this report (Section 10.0) are aimed not only at establishing the reliability of the MDR relays to date, but also at affirming expectations for continued high reliability in the future. Thus, periodic replacement of some SSPS slave relays is necessary. It is intended that users of this report will apply its data and analyses to determine their optimal replacement intervals.

Revision 1 of this report, WCAP-13878, includes additional detail requested by the NRC on the issues cited in the AEOD report S93-06 (Reference 13.1.50). This information was generated during the lead plant licensing support effort, issued to the NRC via PG&E Letter (Reference 13-19), and is attached to Revision 1 of the report as Appendix D. Attachment 1 of Reference 13-19 addresses the tabulation of failure data provided in AE0D/S93-06. Notes to the table clarify the differences in MDR relay model and conditions of service which differentiate most of the reported failures from the MDR models and conditions of service in found in the typical SSPS slave relay application. (The additional information is also useful in addressing maintenance and life issues for other MDR relays, and for MDR relays in a variety of other relay applications.

7.0 FAILURE MODES AND EFFECTS RESULTS

The results of the FMEA for Potter and Brumfield MDR series relays are presented in Tables 7-1 through 7-3. Table 7-1 is the FMEA for the DC and AC coil assemblies of the MDR series non-latching relay. Table 7-2 is the FMEA for the switch assembly of the MDR series relay. Table 7-3 is the FMEA for the DC and AC coil assemblies of the MDR series latching relay.

Tables 7-1 through 7-3 identify temperature-induced and age-related failure mechanisms of relay components. Also included are considerations of adverse impacts due to material degradation products. These are based on review of thermogravimetric analyses reviewed as part of the aging assessment (Section 8.0). Qualifying remarks are included to gage the significance of postulated degradation mechanisms with respect to SSPS slave relay service. Further discussion of aging is deferred to Section 8.0.

7.1 FMEA TABLE FORMAT

The FMEA (Tables 7-1 through 7-3) has seven columns containing basic failure analysis information. The PART DESCRIPTION shows the part(s) of the relay being analyzed and may also have information in parentheses stating its applicability in AC or DC models of the relay.

The FAILURE MODE block for each relay component is a postulated failure as would be seen in a root cause evaluation of a failed relay.

The FAILURE MECHANISM block describes the actual cause that leads to the failure mode in the adjacent block.

The FAILURE EFFECTS block describes the effects on the relay itself and on the system function (the ESFAS in this case) when the part fails.

The DEGRADATION MECHANISM block identifies the process that leads to the Failure Mechanism listed for a part. Where temperature-induced age-related failures are cited, the specific material in question is identified.

The REMARKS block provides statement of qualitative likelihood of the failure occurring (i.e., failure of a normally de-energized relay in an ESFAS cabinet is unlikely), or any other general notes not found in the last column, NOTES.

The NOTES column describes failure mechanisms and sequences of events that can lead to these mechanisms, known design changes made to the component, cautions and references.

a,b,c,e

TABLE 7-1 MDR RELAY COIL ASSEMBLY (NON-LATCHING)

							Notes
							1

a,b,c,e

TABLE 7-1 MDR RELAY COIL ASSEMBLY (NON-LATCHING)

							Notes

o:\3378w.non:1b/080800

a,b,c,e

TABLE 7-1 MDR RELAY COIL ASSEMBLY (NON-LATCHING)

							Notes

a,b,c,e

TABLE 7-1 MDR RELAY COIL ASSEMBLY (NON-LATCHING)

							Notes

a,b,c,c

TABLE 7-1 MDR RELAY COIL ASSEMBLY (NON-LATCHING)							
							Notes

a,b,c,e

TABLE 7-1 MDR RELAY COIL ASSEMBLY (NON-LATCHING)							
							Notes

a,b,c,c

TABLE 7-2 MDR RELAY SWITCH ASSEMBLY

a,b,c,e

TABLE 7-2 MDR RELAY SWITCH ASSEMBLY

o:\3378w.non:1b/080800

a,b,c,e

TABLE 7-2 MDR RELAY SWITCH ASSEMBLY

o:\3378w.non:1b/080800

a,b,c,e

TABLE 7-2 MDR RELAY SWITCH ASSEMBLY

a,b,c,e

TABLE 7-2 MDR RELAY SWITCH ASSEMBLY

a,b,c,e

TABLE 7-2 MDR RELAY SWITCH ASSEMBLY

a,b,c,e

TABLE 7-3 MDR RELAY COIL ASSEMBLY (LATCHING)

o:\3378w.non:1b/080800

a,b,c,e

TABLE 7-3 MDR RELAY COIL ASSEMBLY (LATCHING)

8.0 AGING ASSESSMENT

The aging assessment addresses the time/temperature degradation of organic materials used in Potter & Brumfield (P&B) MDR series relays. The intent is to demonstrate that the age-related degradation of the relay is sufficiently slow that failure detection is equally effective at both three-month and refueling-based test intervals. The recommended approach to maximizing reliability is to minimize test frequency, monitor and control relevant environmental factors, and replacement equipment, as necessary, on the basis of service life predictions determined specifically for the relay based on the relay service requirements, location and environment.

Section 8.1 discusses the end-of-life failure and the out-gassing phenomenon observed in MDR series relays of older vintage. Other subsections provide a comparison of aging effects in normally energized (NE) and normally de-energized (ND) relays, and discuss the degradation by-products expected from various organic materials. Available thermogravimetric analysis for materials used in MDR series relays are summarized in Section 8.1.2. Section 8.1.3 concludes the discussion of the end-of-life failure mechanism expected in MDR series relays of older vintage, and summarizes recommendations for precluding concern in the SSPS slave relay application.

Subsections of Section 8.2 are devoted to each of the relay materials; not all materials appear in all vintages of the MDR series relays. Separate sets of conclusions for this section are stated for each of the significant design vintages of MDR series relays, as defined in Section 5.5. Section 8.3 discusses the Arrhenius calculation results for organic materials used in various vintages of the MDR relay. The conclusions are stated in Section 8.4.

8.1 END-OF-LIFE FAILURE AND OUT-GASSING PHENOMENON

Recently, much attention has been given to early end-of-life failures in normally energized MDR relays. At issue is the chemical out-gassing of certain relay component materials due to the coil temperature rise. NRC Information Notice 92-04 (Reference 13.1-43; also see Section 6.3) provides details of the root cause for the affected design vintages of the MDR series Relays when normally energized. A more detailed summary of actual failures is provided in AEOD report S93/06, (Reference 13.1-50).

The out-gassing related failure mechanism has not been observed in normally de-energized MDR relays. It can be postulated in normally de-energized relays and relays used in typical industrial control-type applications (e.g., intermittent energization and frequent cycling). However, in the absence of the enduring high-temperatures necessary to catalyze the degradation phenomenon, it is considered to be very unlikely, occurring only after a substantial relay service life. Also, recent design changes in the MDR series relays replaced the materials which contribute to the out-gassing phenomenon, substantially reducing (or eliminating) the early end-of-life failure mechanism (See Sections 5.4.13 and 5.5).

The out-gassing phenomenon was eliminated in MDR series relays made after May of 1990 (See Section 5.4.13).

8.1.1 Aging of Normally Energized vs. Normally De-energized Relays

In most nuclear plant applications, and particularly for the SSPS slave relay application, aging degradation is the single greatest challenge to the operability and reliability of electrical equipment. The typical SSPS slave relay is normally de-energized, operates only in response to trip demands or during periodic testing, is protected from the damaging effects of debris and contamination, and is protected from the extremes of high ambient temperature and high relative humidity by HVAC provided to the rooms in which the SSPS is installed. Most plants provide redundant, Class-1E-powered HVAC in the rooms where the SSPS is installed, further assuring minimal ambient temperature and humidity under all plant operating modes. In SSPS slave relay application, the MDR relays experience environmental conditions which are milder than those specified by Westinghouse Replacement Component Services (RCS) shelf life requirements (i.e., <120 °F for 40 years).

Aging effects apply equally to normally energized (NE) and normally de-energized (ND) relays. However, thermal aging effects are accelerated in NE relays by the coil assembly temperature rise. Coil temperature rise is a function of coil wattage and will vary with MDR relay size and coil ratings. Coil temperature rise causes heating of other relay components, however, the magnitude of temperature rise will in most cases be less than that experienced by the coil. Acceleration of thermal aging effects may also accelerate the effects of wear. For example, lubricants may become less effective. Such secondary aging degradation mechanisms may become significant in normally-energized relays (and relays which experience high-cycle demands).

For MDR relays of early vintage, i.e., prior to June of 1989, a significant aging degradation mechanism has been observed in normally energized applications of DC-coil relays (See Sections 6.3 and 6.6). It is likely that the occurrence of this failure mechanism in NE relays would have been precluded if a periodic replacement interval had been established for the relays. Consideration of the temperature/aging degradation of relay materials would have provided a basis for a service life (or identified the need for certain design changes) based on the ambient environment, relay service conditions and resultant temperature rise. However, it is likely that efforts to establish an appropriate replacement interval without consideration of the thermogravimetry of the component materials (or other conservatism) would not have reached an accurate conclusion.

Lessons learned through this evaluation conclude that MDR relays made prior to June of 1989 are not suitable for use in normally energized applications. In June of 1989 a design change eliminated the organic materials known to release chlorine, chlorides, and hydrochloric acid (HCl) as by-products of temperature-induced, age-related degradation. In May of 1990 further design improvements of the P&B MDR series relay eliminated the use of brass in several vital components, replacing it with metals much less susceptible to corrosion.

8.1.2 Thermogravimetric Analysis (TGA)

The aging assessment of the MDR relay product line includes review of available Thermogravimetric Analyses (TGAs) for the temperature sensitive organic materials used in the construction of the relay. The materials identified as likely out-gassers are neoprene rubber, polyvinyl chloride (PVC) and phenolic/polyester resin (Reference 13-7). Also considered are the materials which replaced neoprene and PVC in recent vintages of the MDR relays; polyetherimide and Teflon, respectively. Other organic materials in the MDR relays are not subject to significant dimensional change, weight loss, or loss of flexural strength in response to high temperature, or as a factor of long term aging. As such, there is little likelihood of significant out-gassing or evolution of aggressive species (e.g., hydrochloric acid) from materials such as diallyl phthalate or melamine.

Materials discussed in the following subsections do not appear in all vintages of the MDR relay. Recent vintages of the relays have eliminated materials that are likely out-gassers. See Section 8.4 for application of the individual material evaluations to the determination of service life for the various vintages of the MDR relay.

8.1.2.1 Neoprene Rubber

Neoprene rubber is the material used in the lead wire grommets of the MDR relay coil assembly. The grommets perform the function of preventing abrasions of the relay coil lead wires during handling and installation. Degradation of the grommets is, in itself, of little or no direct consequence to the relay. Even after a substantial loss of material properties, they will retain sufficient insulating properties. The relay will operate with either or both grommets removed.

However, degradation of the neoprene rubber is a secondary concern. The thermogravimetry of the neoprene rubber indicates that chlorine/chlorides or hydrochloric acid will evolve as a result of the age/temperature degradation process. Chlorine may accelerate surface corrosion of metallic relay components, while hydrochloric acid will accelerate degradation of either the glass-filled nylon switch cams (remote possibility), or will greatly accelerate the degradation of the BC-340 coil varnish material used in early vintages of the MDR relay (pre-February 1986).

The evolution of chlorine or hydrochloric acid occurs insignificantly, if at all, prior to depletion of the anti-oxidant compound included in the neoprene formulation. How quickly these effects will occur will be determined by the total temperature of the relay, the specific neoprene formulation involved, and the amount and rate of gasses evolved.

An anti-oxidant compound is added to the neoprene rubber formulation during processing to stabilize the material from oxidative attack and degradation. It is this oxidative attack which results in the formation of hydrochloric acid and chlorine containing by-products. A study performed by Westinghouse (Reference 13-8) showed that loss of oxidant from neoprene rubber could occur even at relatively low temperatures (< 80 °C). Using the diffusion rate data from Reference 13-8, the following anti-oxidant lifetime values can be calculated.

Time for complete loss of anti-oxidant;

1) 10,000 hours @ 40 °C
2) 20,000 hours @ 30 °C
3) 40,000 hours @ 20 °C

This data indicates that after 30,000 hours at ambient (25 °C), approximately 3.4 years, complete loss of anti-oxidant would occur from Neoprene thereby making it vulnerable to oxidative attack with rapid loss of properties and evolution of chlorine/chloride and hydrochloric acid gasses.

Other calculations preformed during the aging assessment of MDR relays indicate a complete loss of anti-oxidant compound can be expected in as little as one to two months in NE relays (See Section 5.1). This also suggests that a relatively large amount of hydro-chloric acid (HCl) will be released in a very short time. Thus, it is reasonable to expect that the concentration of chlorine and HCl in the relay coil assembly is sufficiently high that accelerated degradation of other relay materials will occur. This would include the chemical attack of brass components used in earlier vintages of the MDR relay.

8.1.2.2 Polyvinyl Chloride (PVC)

PVC is used as the wire insulating sleeve material in older vintage MDR relays. The sleeves are applied to the coil assembly lead wires and extend through the lower bell housing and base of the relay. (PVC was also used as the switch assembly stud sleeves in very old vintages of the MDR relays. This component was eliminated prior to applications of MDR relays in the Westinghouse SSPS, and is mentioned here only for completeness.) The essential function of the wire insulating sleeve is to prevent shorting or grounding of the coil lead wires. (Note that the grommets also perform this function). However, even after a substantial loss of material properties, adequate capability will remain to assure integrity of the electrical insulating function.

As discussed for Neoprene, above, the degradation of PVC components also creates a secondary concern. The thermogravimetry of the PVC materials indicates that HCl or chlorides will evolve as a result of the age/temperature degradation process. Chlorine/chlorides may accelerate surface corrosion of metallic relay components, while hydrochloric acid will accelerate degradation of either the glass-filled nylon switch cams (remote possibility), or will greatly accelerate the degradation of the BC-340 coil varnish material used in early vintages of the MDR relay (pre-February 1986).

Typically, PVC wire insulation will retain its properties close to room temperature but will lose them rapidly when temperatures exceed 100 °C for prolonged periods of time. PVC (extruded flexible insulation) tubing has similar temperature rating and temperature stability near room temperature, typically having a 40 year service life at temperatures of 70 °C. Temperatures of 70°C to 100°C or greater will indeed occur in NE MDR relays. The major concern with using PVC at elevated temperatures is the evolution of acidic vapors (mainly HCl) from the thermal degradation of the PVC polymer structure. A study on PVC thermal stability (See Reference 13-7) using Thermogravimetric Analysis (TGA) indicates that PVC polymer begins to lose weight and evolves volatiles at temperatures above 190°C. At 300°C, the weight loss is greater than 50% - mainly due to the formation of HCl gas. Prolonged exposure to lower temperatures (e.g., in the range of 100 °C to 190°C) will cause some weight loss and evolution of acidic vapors. Finally, the corrosive and degradation potency of the HCl is dependent on the presence of moisture. In the absence of moisture, the gasses would tend to disperse.

8.1.2.3 Polyetherimide (Ultem)

Polyetherimide is the material substituted for Neoprene as the lead wire grommet material in recent and current vintages of MDR relays. Polyetherimide belongs to the polyimide class of materials known for exceptional thermal stability. Unlike Neoprene and PVC, no corrosive volatiles or by-products are formed during thermal aging and degradation of polyetherimide.

8.1.2.4 Polyester/acrylic

The PVC lead wire sleeves were replaced by a polyester/acrylic (over fiberglass) sleeve in October 1988. Thus, eliminating a contributing cause of the out-gassing phenomenon. However, neoprene remains as the lead wire grommet material. The grommets were changed to polyetherimide in June of 1989.

The thermogravimetry does not indicate an evolution of aggressive species from polyester or acrylic materials. However, as is further discussed in Section 4.2.7, some polyester materials may be affected by the chlorine or HCl evolved from the neoprene grommet. The specific formulation of polyester used in the lead wire sleeves is not known. Therefore, it is assumed here that the lead wire sleeves are of a material type that is degraded by chlorine or HCl.

In the absence of moisture, polyester will not be affected by the chlorine or HCl evolved from the degradation of neoprene. In a normally energized relay, no moisture exits due to the substantial coil temperature rise. Thus, it is unlikely that significant degradation will occur to the lead wire sleeve. Portions of the lead wire sleeves in direct contact with the neoprene grommets, however, will likely be degraded. The primary insulation material of the sleeve is fiberglass which is not susceptible to attack by chlorine or HCl. If the polyester were completely degraded, it is likely that the fiberglass would continue to prevent any shorting or grounding of the coil lead wires. Finally, the function of the neoprene grommet is to prevent shorting and grounding of the coil lead wires passing through the endbell and base of the relay. Degradation of the lead wire sleeves when in direct contact with the neoprene grommet is of no consequence.

Thus, the degradation of the polyester in the lead wire sleeves of MDR relays made between October 1988 and June of 1989 would not result in failure of the relay. Regardless, MDR relays made between October 1988 and June of 1989 are unacceptable in NE service for other reasons. The substantially reduced temperature conditions of normally de-energized relays precludes the likelihood of degradation to the lead wires sleeves.

8.1.2.5 Polytetrafluoroethylene (Teflon)

Teflon is the relay coil lead wire insulating material in all vintages of the MDR relays considered in this assessment. Teflon only begins to lose weight at temperatures of 450 °C to 550°C. At temperatures experienced in the MDR relay, no evolution of corrosive gases or volatiles would be expected from Teflon; certainly not below 150 °C.

8.1.2.6 Glass-Filled Nylon (Nylon Zytel 101)

The thermogravimetry of (glass-filled) nylon does not indicate evolution of an aggressive species as a result of the age/temperature degradation process. However, hydrochloric acid (HCl) which may evolve from the degradation of the neoprene rubber grommets and the PVC wire sleeves can accelerate the degradation of the nylon cam pieces in the switch assembly.

At issue is the possibility that the out-gassing products will reach the switch cams. In general, the entry of chlorine/chlorides into the MDR relay switch assembly is unlikely. However, it has been observed that in NE DC relays, where voltage applied to the coils greatly exceeded the manufacturer's rating, a substantial increase in coil temperature rise can cause out-gassed chlorine and HCl to be forced into the switch assembly (Reference 13.1-50). Conversely, there is no concern for this phenomenon in ND relays. NE AC coil relays may be susceptible to this phenomenon, but the combinations of lower coil wattage and lower coil temperature rise substantially reduces this possibility, and the potential for adverse impact to relay operation or reliability.

8.1.2.7 Polyester-Based Coil Varnish (BC-340)

The thermogravimetry of the polyester-based coil varnish (glass-filled) nylon does not indicate evolution of an aggressive species as a result of the age/temperature degradation process. However, hydrochloric acid (HCl) which may evolve from the degradation of the neoprene rubber grommets and the PVC wire sleeves may accelerate the degradation of the BC-340.

Arrhenius data applicable to an earlier formulation of the BC-340, that used in the MDR relays of early vintage, indicates it has an aliphatic polyester base. Such early formulations of polyester had relatively low temperature stability and were susceptible to attack by HCl. More recent polyester formulations are aromatic-based with both good thermal stability and minimal susceptibility to attack by HCl. Current data sheets for BC-340 indicate that it now has an aromatic polyester base. However, this is not the material used in older vintage MDR relays.

At issue is the possibility that the by-product of neoprene and PVC degradation (out-gassing) will affect the coil assembly varnish. In general, in a normally de-energized relay this is an extremely remote possibility. Time/temperature degradation will be very slow with minimal release of aggressive species over time.

It has been observed that in NE MDR relays with DC coils, particularly where voltage applied to the coils greatly exceeded the manufacturer's rating (Reference 13.1-50), the substantial coil temperature rise causes out-gassed chlorine/chlorides and HCl to accumulate in the relay coil assembly. NE AC coil relays can be susceptible to this phenomenon, but the combinations of lower coil wattage and lower coil temperature rise reduce this possibility, and the potential for adverse impact to relay operation or reliability. Nonetheless, this report concludes that MDR relays of this vintage (made prior to June 1989) are unsuitable for NE service.

8.1.2.8 Epoxy Resin Coil Varnishes (CC-1090 and E-100)

Epoxy resin coil varnishes have been substituted for the BC-340 polyester-based varnish discussed above. The epoxy resin varnishes, CC-1090 or E-100, both have much higher temperature stability and resistance to attach by chlorides and HCl evolved from the degradation of neoprene and PVC. With either epoxy serving as the coil varnish material, the susceptibility to out-gassing related failure mechanism is reduced, however, it is not eliminated. Most significant to precluding the likelihood of the out-gassing related failure mechanism is the replacement of neoprene rubber and PVC with other materials.

8.1.2.9 Assessment of Impact

The grommets represent a minute fraction of the total relay, both in weight and volume. Very little chlorine and hydrochloric gas will be evolved through the degradation of the neoprene components. In the absence of condensing relative humidity or other condensable gases, most, if not all, of the evolved gases will be vented from the relay with little consequence to relay life or reliability. Eventually the evolution of gases will cease leaving the neoprene rubber rigid and, to some degree, brittle. A specific end time for the reaction was not determined. However, it is reasonable to expect that this will occur in five to ten years in ND relays.

Normally energized MDR relays, however, have an estimated temperature rise (65 °C). Calculations summarized in Sections 5.0 and 7.0 indicate that neoprene and PVC will rapidly reach an end of life condition in NE relays. This is expected to occur in several months. As such, it is very likely that the chlorine/chloride or HCl released from neoprene will occur suddenly and be exhausted in a very short time. At some later time, PVC will begin to experience weight loss with the release of HCl and, possibly, other chlorides. Significant degradation can occur in as little as six months. Other phenomenon involved in the degradation mechanism are of a random nature.

The reaction affecting PVC will occur slowly, if at all, and continue for sometime. The principle concern is for the degradation of neoprene rubber.

In light of recent reports of field failures (Reference 13.1-50), it is known that the by-products of degradation will significantly degrade relay performance and reliability. However, it appears that even after significant degradation of neoprene and PVC, and the degradation that their by-products cause in the BC-340 coil varnish material, a substantial time is required before the relay failure mechanisms are realized.

This is due in part to the need for the corrosive materials to condense with the coil varnish residue forming a film on the inside surfaces of the relay coil assembly. Subsequent heating and cooling cycles act to transport the chloride-rich film to the relay rotor and stator pole surfaces, and into the interfaces of the rotor, spacers, and endbells of the coil assembly. It would appear that a gradual drying/curing of the film is necessary to increase the adhesive strength of the film to the extent that mechanical movement is inhibited. Eventually the film attains the capability to "glue" the relay components together, even when experiencing the coil temperature rise (65 °C).

8.1.2.10 Inspection of Used MDR Relays

Three of the four MDR relays which were disassembled and inspected were relays that had been removed from service. Two of these relays were removed from service at the Diablo Canyon plant. The third had been removed from service, but not necessarily from Class 1E service or prior use in SSPS cabinets. It has been in the possession of Westinghouse Nuclear Safety Licensing for at least eleven years. Its origin is unknown. It is believed to be a returned defective unit provided by P&B as an example of the outward appearance of the MDR relay. The fourth relay was new and unused. It had be deleted from available stock at Westinghouse RCS upon determination that Westinghouse would only provide MDR relays manufactured after May of 1990. This specimen served as the reference case in the assessment of the used specimens provided from the Diablo Canyon plant.

In the three used relays disassembled and inspected, the neoprene grommets were found to have taken a hard set and dulled from the original low-luster black color. The neoprene grommets had a rough appearance with some surface striation in evidence. This is indicative of significant surface oxidation. It was concluded that the neoprene had "aged" significantly, the hard/brittle condition of the grommets indicated that the anti-oxidant was effectively depleted and that significant oxidation had occurred. Though not in a true end-of-life state (this is very loosely defined for the grommet application), it was evident that the grommets had experienced a substantial loss of the original mechanical and surface properties.

However, no evidence of significant corrosion was observed in any of the specimens. The electrical contacts appeared to be in an acceptable condition, with moderate signs of wear due to use. Other metallic interior surfaces of the relay coil assemblies were dulled, with minimal surface corrosion in evidence. Both the armature assembly and return spring evinced spotty surface corrosion. A thin, caramel colored film, was visible on interior surfaces of the relay coil assembly. The film had an adhesive quality, though it was very weak (at room temperature). Unaffected areas were clean and even bright in appearance. No evidence of the film coating was found in the relay switch assembly.

The relay coils were darkened, due obviously to temperature aging. The coils had taken the same caramel color as that evinced in the film coatings found on other surfaces of the coil assembly. The coloration appeared to be in the coil varnish (BC-340) and not necessarily in or on the underlying insulating materials.

It appeared that the BC-340 coil varnish had been degraded, though it was still capable of performing its critical function. It is further postulated that degradation of the BC-340 was accelerated by the out-gassed compounds from neoprene and PVC. This would explain the further conclusion that the BC-340 coil varnish was contributing to the composition of the film in the relay coil assembly, as evidenced by the coloration of the coils and the film deposits.

It is concluded that evolution of chlorine and hydrochloric gases had minimal effect, if any, on the specimens viewed. However, this is in part due to efforts, notably at Diablo Canyon, in response to IN 92-04 (Reference 13.1-43). Clearly the conditions which would lead to manifestation of the binding failure mode were in evidence. That the failure had not occurred in service was due to proactive removal of the relays from service.

Regarding the condition of the two remaining specimens, neither exhibited the out-gassing phenomenon. As mentioned above, one was new and unused, the other predates specimens used in nuclear service.

8.1.3 End-of-Life Failure

There is a dominant end-of-life failure mode/mechanism which affects MDR relays made prior to June of 1989. The failure mechanism is related to the total temperature experienced in the relay coil assembly. The total temperature is the sum of the ambient environment temperature and the coil heat rise if the relay is energized. There are no reports of this failure mechanism occurring in normally de-energized (ND) or low duty cycle applications of the MDR relay. The failure mode/mechanism has been discovered/reported to occur only in normally energized (NE) applications of the relay. (In this report, a relay is NE if its coil is energized virtually 100% of the time with infrequent de-energization. This is not a typical or recommended application of any relay. In general, control relays are not designed to be used in this manner.)

The end-of-life failure has been determined to result from temperature-related degradation of relay coil assembly insulation materials. The process is believed to involve two, possibly three, of the organic materials used in the coil assembly. Also involved are certain metal components which are attacked by the degradation byproducts of organic materials. P&B MDR relays made prior to June of 1989 contain some or all of the suspect materials. The design evolution of the MDR product line has been gradually replacing these materials throughout the mid-to-late 1980's. Notably, design changes in June, 1989, and May, 1990, have eliminated the corrosive-out-gassing organic materials and the corrosion-susceptible metals, respectively. Relays manufactured after May of 1990 contain none of the culprit materials. While the new materials of construction will, like most organic materials, yield some gaseous byproducts as a result of temperature/age-related degradation, these by-products are non-corrosive. It can be said that the out-gassing phenomenon which occurred in NE applications of P&B MDR relays made prior to June of 1989 has been substantially reduced, if not altogether eliminated.

The following sections detail the aging assessment of the various organic materials used in the various vintages of the P&B MDR rotary relay. The general conclusion are as follows:

- MDR relays made prior to June of 1989 will experience early end-of-life-failures in normally energized applications due to high total temperature, and coil temperature rise in particular.

- MDR relays made prior to June of 1989 should have a substantial service life in normally de-energized or typical industrial control applications, particularly when used in low/mild temperature environments. The dominant age-related failure expected for pre-May-1990 vintages of the MDR relays, when not normally energized, is mechanical wear or contact degradation due to switching of electrical loads (after 100,000 cycles of operation; 500,000 for small AC-coil models).

- MDR relays made after May of 1990 have substantially improved temperature durability. Such relays, when used in normally energized applications, will not experience the early end-of-life failures observed in earlier vintages of the relays. It is expected that mechanical wear/fatigue and contact degradation will dominate end-of-life failures for these relays (after 100,000 cycles of operation for most MDR relay models; 500,000 for small AC-coil non-latching models), or that relay coil burn-out will occur after a substantial installed life (> 20 years).

- Similarly, post-May-1990 MDR relays in normally de-energized or typical industrial control applications should have a useful life of forty years, limited only by the estimated mechanical cycle life (100,000 cycles for most MDR relay models; 500,000 for small AC-coil non-latching models).

The out-gassing phenomenon was eliminated in MDR relays made after May of 1990. However, it is required that only MDR series relays manufactured after 1992 be used in normally energized or 20% duty cycle applications for which an extended test interval (18 to 24 months) is to be implemented (See Section 5.5.1). Also, it is assumed that the estimated mechanical cycle life is imposed as the alternate replacement criteria for any safety-related application of MDR series rotary relays. Section 8.4 summarizes the service lives established for MDR series relay vintages.

8.2 ARRHENIUS CALCULATIONS

The aging assessment of MDR series relays is performed using the Arrhenius time/temperature relationship. Calculations are based on:

- Materials performance data,
- Temperature conditions for the SSPS,
- Temperature rise(s) expected in MDR series relays

Table 5-1 identifies the various component materials used in the MDR series relays. Tables 5-2a, 5-2b, and 5-2c detail the materials changes made in MDR series relay manufacture. Table 8-1 identifies aging test/reference data applicable to materials used in MDR series relays. Data consists of:

- Test time
- Test temperature
- Activation energy (in electron-volts; eV),
- Material property measured/tested

Other cross reference information is provided. Table 8-1 includes a column titled "temperature rise". It indicates the relative temperature rise of the component/material with respect to the maximum estimated temperature rise stated by P&B for the MDR series relay (all sizes, all coil types; see Section 8.2.1).

8.2.1 Temperature Rise Data and Service Life Estimates

For conservatism, the estimated maximum temperature rise (65 °C) for MDR series relays provided by Potter & Brumfield is used in the estimation of material/component service life. In many cases, application of the maximum estimated temperature rise in Arrhenius calculations yields estimated service lives for specific components/materials greatly in excess of the 40-year plant life - even for relays in normally energized service.

Variations in coil wattage, line voltage magnitude and type, and ambient environmental temperatures affect the actual temperature rise of any particular relay. As appropriate or necessary, other lesser temperature rises (58 °C and 25 °C) specific to MDR series relay models or specific safety-related applications are considered, particularly where there is benefit in demonstrating the greater, yet conservative, service life estimate. Ultimately, the estimated service lives for all materials and components in the various vintages of the MDR series relays are considered in the final determination of estimated service life on a "per vintage" basis. Ideal application of the results of this calculation note to a particular plant's MDR series relays will require that temperature data be taken at the installed location.

8.2.2 Arrhenius Equation for Aging at One or More Temperatures

Assuming that the accelerated thermal aging process expressed by the Arrhenius Model correctly simulates the change in properties due to aging at a different temperature than the accelerated aging temperature, then:

$$t_s \exp(-E/KT_s) = t_o \exp(-E/KT_o) \qquad \text{(E1)}$$

where:

t_s	=	total service life at temperature T_s
exp	=	base of natural log (2.71828)
t_o	=	time at temperature T_o (accelerated aging temperature)
T_s	=	material temperature at total service life conditions (°K)
T_o	=	material temperature at accelerated aging conditions (°K)
E	=	material activation energy (eV) for property of interest
K	=	Boltzmann's Constant (8.62E-05)

The total service life (t_s) may be split into two time periods at different temperatures:

$$f_{s1}\, t_s \exp(-E/KT_{s1}) + f_{s2}\, t_s \exp(-E/KT_{s2}) = t_o \exp(-E/KT_o) \qquad \text{(E2)}$$

where:

f_s	=	fraction of total service life (t_s) at defined temperature

The above equation E2 is useful in calculating the total service life (t_s) based on known accelerated aging test parameters and a defined duty cycle, e.g., energized fraction f_{s1} and deenergized fraction f_{s2}. Solving for t_s:

$$t_s = t_o/(f_{s1} \exp((-E/K)(1/T_{s1}-1/T_o)) + f_{s2} \exp((-E/K)(1/T_{s2} - 1/T_o))) \qquad \text{(E3)}$$

The above equation E3 may be expanded to include multiple fractions of the service life or used to determine the required aging time (t_o) for a test when other parameters are known or defined, e.g., t_s could be defined.

8.2.2.1 Limitations in Arrhenius Methodology

Although a strict Arrhenius calculation may yield an extended qualified life, care should be exercised in utilizing this extrapolation due to uncertainties in the methodology. It is cautioned that the Arrhenius time/temperature relationship relies on empirically determined activation energies of materials. This parameter has been determined for a number of materials to at least a good approximation for small temperature extrapolations. Extrapolation of the Arrhenius model to time periods of temperature beyond the range of materials test data is questionable, and may result in large errors. Also, in some cases material samples utilized to determine activation energies may not account for uniqueness which arises from a given application or configuration of the material, for variances in the component manufacturing process, or the dynamic stresses associated with component functional modes. For this reason, it is recommended that calculated qualified lives based on this methodology should be limited to 20 years unless sound technical bases can be cited. This position is consistent with industry guidelines such as IEEE Std. 98-1984, NUREG/CR-3156, and EPRI NP-1558 (References 13-9, 13-10, and 13-11, respectively).

8.2.2.2 Interpretation of Calculation Results

Arrhenius data is established for given material properties based on assumptions of tolerable levels of degradation of that property. The data consists of test temperatures and times (durations). From this data, an activation energy is determined for a specific material property. The empirically determined activation energy can then be used to calculate an approximate amount of time required at a lower temperature to reach the same degree of degradation in material property.

The rate of change may not be the same for all properties of a material. In general, it is advisable to base calculations on the most conservative activation energy applicable to the material. Some judgement is necessary in determining the relevance of a particular material property, and its activation energy, to any given application of the material.

The degree of degradation that is tolerable in a given material application must be considered. For example, most electrical insulating materials are assessed on their retention of dielectric strength. Typically, Arrhenius data is developed to aid the user in determining the point at which dielectric strength is reduced to 50% of its original (virgin material) value. Given other conservatism in component design (thickness of insulation, applied voltage in service), degradation of up to 90% may be acceptable in a given application. Thus, unless otherwise stated, it is implicit that the degree of degradation at the calculated end-point is acceptable - often it is extremely conservative.

Continuing the example, it is of equal importance that an insulating material remain intact. Cases exist where Arrhenius data indicates outstanding retention of dielectric strength, and even improvements, over time, while rapid degradation of mechanical properties (due either to temperature or radiation) indicate that the material will not retain either shape or integrity. Simply put, wire insulation must remain on the wire regardless of its dielectric strength.

Thus, the user must exercise good judgement in the interpretation of calculated results based on Arrhenius data, both to avoid excessive conservatism and misinterpretation.

8.3 CALCULATIONS

Each of the following subsections addresses a component material used in one or more of the MDR series relay vintages. Section 8.4 provides conclusions specific to the significant vintages (Section 5.5) of the MDR series relays.

8.3.1 Neoprene Rubber

The lead wire grommet material is neoprene rubber. The function performed by the lead wire grommet requires only that it remain intact. The grommet is not essential to relay operability. Its purpose is to minimize potential for abrasion to the lead wire during handling and installation. Once installed, its contribution to relay operability is minimal to non-essential. However, it can be postulated that in applications where vibration is a significant factor of the operating environment, the grommet is necessary. This is not the case in the SSPS slave relay applications.

More significant to the SSPS slave relay application, the thermogravimetry of the neoprene rubber indicates that chlorine/chlorides or hydrochloric acid will evolve as a result of the age/temperature degradation process. The degradation byproducts created by degradation of the neoprene rubber can accelerate the degradation of other relay components (See Reference 13-7). Chlorine may accelerate surface corrosion of metallic relay components, while hydrochloric acid will accelerate degradation of either the glass-filled nylon switch cams (remote possibility), or will greatly accelerate the degradation of the BC-340 coil varnish material used in early vintages of the MDR relay (pre-February 1986). Further discussion and calculated threshold of chlorine/chloride out-gassing is presented in Section 8.3.1.1.

Neoprene rubbers are rated for continuous use at a temperature of 105 °C, but have an estimated 40-year life at 65 °C (for both tensile strength and elongation). Use at higher temperatures will result in a rapid loss of mechanical properties. A 40-year service life in normally de-energized (ND) applications of MDR series relay can reasonably be expected. This is because the maximum normal ambient temperature expected in the SSPS cabinets is 90 °F (32 °C; maximum). However, a 40-year service life should not be expected in normally energized (NE) applications of the MDR series relay. Total temperature inside a NE MDR series relay will be in the range of 90 °C to 100 °C, which significantly exceeds the 65 °C 40-year life temperature. The direct impact, i.e., degradation of neoprene rubber material properties, is of little concern. Even after a complete disintegration of the grommets, failure of the MDR relay is neither expected nor likely.

The degradation of material properties occurring in the neoprene rubber grommets is not a significant factor in the determination of service life for MDR relays used in SSPS slave relay applications. However, the byproducts created by degradation of neoprene rubber are known to contribute to the failure of the NE MDR series relays in some applications (Reference 13.1-50). The remainder of this evaluation focuses on the impact of neoprene byproducts on other MDR series relay components/materials.

It is concluded that failure modes/mechanisms postulated to result from temperature-induced, age-related degradation of the neoprene rubber lead wire grommet will not occur in NE SSPS slave relays within the 40-year plant life. The point at which chlorine/chloride out-gassing begins is assessed in Section 8.3.1.1.

8.3.1.1 Out-Gassing of Neoprene Rubbers

Neoprene rubber formulations include anti-oxidant compounds which delay the oxidation of the material and ultimately the beginning of chlorine/chloride out-gassing. Neoprene rubbers experience little or no degradation prior to the depletion of their anti-oxidant compound. The anti-oxidant is added to the formulation prior to vulcanization. Virtually all anti-oxidant must dissipate before the degradation of neoprene begins. It is the degradation of the neoprene which results in the release of the chlorine/chloride by-products. Thus, the evolution of chlorine gas or hydrochloric acid occurs insignificantly, if at all, prior to depletion of the anti-oxidant compound. Rates of anti-oxidant depletion vary dependent on the:

- Specific neoprene formulation
- Specific anti-oxidant used,
- Ambient environment temperature experienced by the neoprene.

On the last point, Arrhenius data for neoprene rubbers do not yield a single activation energy over the useful temperature range. This indicates that several chemical processes are involved in the time/temperature aging degradation mechanism. A treatise on the actual degradation processes is beyond the scope of this effort. For now it is sufficient to note that change in the material properties of neoprene rubbers:

- Begins after the depletion of the anti-oxidant compound,
- Varies in rate with temperature, and
- Varies with other changes in the neoprene formulation.

Of particular interest is that the depletion of the anti-oxidant can be quite rapid at low temperatures (Reference 13-8). A study performed by Westinghouse (Reference 13-8) showed that loss of oxidant from neoprene rubber could occur even at relatively low temperatures (< 80 °C). Based on diffusion rate data from Reference 13-8, the following anti-oxidant lifetime values can be calculated.

Time for complete loss of anti-oxidant;

1) 10,000 hours @ 40°C
2) 20,000 hours @ 30°C
3) 40,000 hours @ 20°C

Using the material aging data (Table 8-1), the ambient environment temperatures typical of SSPS locations (Table 8-2), and the FNP temperature data (Table 8-3), the estimated service life of the neoprene rubber grommets have been calculated. Tables 8-4, 8-4a, and 8-4b summarize the results of these calculations, based on relay coil temperature rises of 65 °C, 58°C, and 25°C, respectively, and a 60% retention of elongation at low temperatures. Tables 8-4, 8-4a, and 8-4b are more accurately representative of the aging expected in normally de-energized (ND) relays and relays operating at a 20% duty cycle. Tables 8-5, 8-5a, and 8-5b summarize the results of these calculations, based on relay coil temperature rises of 65°C, 58°C, and 25°C, respectively, and a 100% retention of elongation at high temperatures. Tables 8-5, 8-5a, and 8-5b are more accurately representative of the aging expected in normally energized (NE) relays.

In no case in Tables 8-4, 8-4a, and 8-4b do the calculated results indicate a 40-year service life for neoprene rubber based on the retention of elongation. But neither is the loss of this property important to MDR series relay operability. Rather, what is sought is the point at which degradation is beginning to occur; the point at which corrosive byproducts begin to dissipate from the neoprene rubber.

It is unlikely that significant out-gassing begins until some time after each respective service life (years) shown in the Tables 8-4, 8-4a, 8-4b, 8-5, 8-5a, and 8-5b. The principle concern is the rate of chlorine/chloride release. This, of course, is related to temperature. It is expected that temperature rise in NE relays will cause a rapid dissipation of anti-oxidant followed by the release of all corrosive byproducts within a short period of time. Conversely, the lower temperatures in ND relays will significantly postpone depletion of the anti-oxidant and, later, inhibit the dissipation of the corrosive byproducts to a long-term slow release. The long-term, slow-release would result in minimal concentration of chlorine/chlorides at any particular time. Consequently, the impact to other component/materials would be reduced; cumulative damage effects would occur over a greatly protracted time-frame and to a significantly reduced degree (particularly in the absence of moisture).

The out-gassing of neoprene rubbers is of concern due to the potential for impact to other relay components. An analysis of the MDR series relay materials concludes that this concern applies to NE relay applications. Components which may be effected by neoprene out-gassing are:

- Glass-Filled Nylon (switch cam):

  It is known that degradation of the critical properties of glass-filled nylons (e.g., Nylon Zytel 101) is accelerated in the presence of chlorine gas and hydrochloric acid. The switch cam is not directly exposed. There is limited air exchanged between the coil assembly and the switch assembly. In the absence of the extreme case coil temperature rises caused by over-voltage conditions (Reference 13.1-50), it is unlikely that the cams would be exposed to chlorine gas or hydrochloric acid in MDR series relays.

- Silver/Silver-oxide (contacts):

Concern for chlorine impact to relay contacts is considerably reduced for several reasons. The relay contacts benefit from limited air exchange between the coil assembly and the switch assembly. The relay contacts are silver or silver oxide (See Tables 5-2a, 5-2b, and 5-2c for dates of usage) which have reasonably high resistance to chlorine induced corrosion. The contact design increases "contact making" and reliability even in dusty or corrosive environments.

Field experience reveals no significant cases of accelerated contact corrosion in MDR series relays which would indicate a common-mode occurrence. Failure experience specifically for the SSPS slave relays indicates only two cases of contact corrosion. These cases did not occur in normally energized relays which would likely experience a greater release of chlorine per unit of time caused by the coil temperature rise. Rather, the normally energized relays in the same cabinets did not experience contact corrosion. As the effect was not common to all contact of the relay(s) in question, it is concluded that the corrosion is not the result of chlorine out-gassing from neoprene rubbers.

- Phenolic-Filled Polyester Resin (coil varnish):

The vintage of the BC-340 resin used in MDR series relays is believed to be an aliphatic-based polyester. Review of material performance data for BC-340 provided by Potter & Brumfield indicates that the material procured and used in early vintages of MDR series relays is an aliphatic-based polyester. The aliphatic-based polyesters have characteristically low thermal stability and susceptibility to attack by chlorine. (More recent vintages of polyesters are aromatic-based and have very good temperature stability.)

The combination of coil temperature rise and the presence of chlorine gas and HCl out-gassed from the neoprene rubber grommets (and PVC lead wire sleeves) would cause significant degradation of the BC-340 coil varnish. This is a concern only in normally energized relays. There is no concern for normally de-energized relays, and the impact to relays with 20% duty cycle should be minimal.

8.3.2 Polyetherimide

Recent vintages of the MDR series relay (See Section 5.4.13) replace the neoprene rubber lead wire grommets with grommets made of a polyetherimide material (GE Ultem). See Tables 5-2a, 5-2b, 5-2c for dates of usage for the two grommet materials. As discussed in Section 8.3.1, the lead wire grommets are used to prevent shorting or grounding of the relay coil lead wires. The critical material parameter is dielectric strength, and some minimal assurance of mechanical integrity is also needed.

In the comparison of materials properties of neoprene rubbers and polyetherimide there is a significant difference in estimated service life and the effects of temperature and aging. Most significant is that polyetherimide produces no aggressive species as a byproduct of temperature/age degradation. As discussed above, neoprene evolves chlorine gas and HCl as a byproduct of temperature/age degradation. Polyetherimide materials can be rated for a 40-year service life at temperatures greater than 110 °C with minimal shrinkage and good retention of dielectric strength.

The estimated temperature rise is a maximum of 65 °C for the relay coil assembly. The coil heat rise is assumed to cause a 65 °C temperature rise in the grommets. Thus, it should be concluded that a forty year service life would be expected for normally energized relays in an ambient environment which does not exceed 45 °C (= 110°C - 65°C). However, this exceeds both the manufacturer's recommendations and the normal ambient temperature expected in the SSPS cabinets (90 °F or 32°C, maximum).

Using the material aging data (Table 8-1), the ambient environment temperatures typical of SSPS locations (Table 8-2), and the FNP temperature data (Table 8-3), the estimated service life of polyetherimide has been calculated. Tables 8-6 and 8-7 summarize the results of these calculations based on dielectric strength and shrinkage, respectively. From Table 8-6, the calculated service life ranging from 1.97E+3 to 8.48E+6 for 100% and 0%, respectively, duty relay applications, at ambient temperatures of 75 °F to 100°F, respectively. Similarly, Table 8-7 shows calculated service life ranging from 1.68E+4 to 1.79E+8. Such results are unrealistic, but do indicate that material changes over a 40-year period should be minimal. Proper interpretation should be that the relay is unlikely to fail over the 40-year plant life as a result of failure mechanisms postulated to result from temperature-induced, age-related degradation of the polyetherimide grommets.

8.3.3 Polyvinyl Chloride (PVC)

The relay coil assembly lead wires rely on the insulation provided by a "lead wire sleeve" made of polyvinyl chloride (PVC). The lead wire sleeves are used to prevent shorting or grounding of the relay coil lead wires. The critical material parameter is dielectric strength, yet the PVC must remain intact; unbroken, free from cracks, to perform its electrical function. Service life estimates based on static elongation provide a good measure of PVC's mechanical integrity.

PVC wire insulation is rated for continuous service at temperatures up to 100 °C (Reference 13-14). PVC (flexible vinyl resin insulated) tubing can be estimated to have a 40-year service life at an ambient temperature of 70 °C, though this value will vary with the particular plasticizer used in any specific PVC formulation (Reference 13-14). Higher temperatures can be endured with a consequent reduction in expected life.

The estimated temperature rise is a maximum of 65 °C for the relay coil assembly. The coil heat rise may cause a temperature rise of up to 65 °C in PVC wire sleeve, though lower temperature rises would be expected over most of the sleeve surface. A forty year service life would be expected for normally de-energized relays, or relays used in typical industrial control (switching) applications where the maximum coil temperature rise does not endure at all times.

A forty-year service life should not be expected in normally energized applications of the MDR series relay. It should be expected that in some NE relay applications significant weight loss will occur, accompanied by the out-gassing of hydrochloric acid (HCl) and other chloride compounds. (See Section 8.1-3). For this reason, MDR series relays equipped with PVC coil lead wire sleeves may be unsuitable for use in some normally energized relay applications.

Using the material aging data (Table 8-1), the ambient environment temperatures typical of SSPS locations (Table 8-2), and the FNP temperature data (Table 8-3), the estimated service life of the PVC wire sleeves has been calculated. Tables 8-8, 8-8a, and 8-8b summarize the results of these calculations, based on relay coil temperature rises of 65 °C, 58 °C, and 25 °C, respectively. For applications where the relays are normally de-energized with ambient temperatures ranging from 75 °F to 100 °F, service lives greater than 1.94E+3 years are calculated based on a 50% retention of static elongation. For relay applications having a 20% duty cycle with ambient temperatures ranging from 75 ° F to 100 °F with a relay coil temperature rise of 25 °C, services lives greater than 3.48E+2 years are calculated based on a 50% retention of static elongation. Such results are unrealistic, but do indicate that material changes over a 40-year period should be minimal. Proper interpretation should be that the relay is unlikely to fail over the 40-year plant life as a result of failure mechanisms postulated to result from temperature-induced, age-related degradation of the PVC wire sleeves.

For applications where the relays are normally energized (100% duty cycle) in ambient temperatures ranging from 75 °F to 100 °F with a relay coil temperature rise of 25 °C (Table 8-8b), service lives range from 81.4 to 445 years, indicating that a 40-year life can reasonably be expected. However, the calculated service lives range from 1.23 to 48.7 years where relays are normally energized (100% duty cycle) or have a 20% duty cycle with ambient temperatures ranging from 75 °F to 100 °F with relay coil temperature rises of 65 °C (maximum) and 58 °C (typical) (See Tables 8-8 and 8-8a, respectively). It is not clear that electrical failures (shorting or grounding) due to degradation of the PVC lead wire sleeves would occur in NE SSPS slave relays. However, the estimated lives based on higher coil temperature rises indicate a that significant degradation of the PVC should be expected within a ten year life, perhaps in as little as 1.5 years. Degradation of the PVC results in the release of HCl gases which, in the presence of moisture, will cause degradation of other MDR series relay components. In particular, the failure modes and mechanisms related to material out-gassing should be expected (See Sections 8.1 and 8.3.1.1).

It is concluded that temperature-induced, age-related failures postulated for the PVC wire sleeves will not occur within the 40-year plant life with normally de-energized relays, relays with low duty cycle (20%), or normally energized relays with low coil temperature rise (approximately 25 °C; <<58 °C) and ambient temperatures ranging from 75 °F to 100°F. However, it is also concluded that both normally energized and 20% duty cycle MDR series relays exhibiting the high coil temperature rise may experience significant degradation of the PVC wire sleeves, and will exhibit the on-set of the out-gassing related failure mode(s) in as little as one to six years. For this reason, MDR series relays equipped with the PVC wire sleeves are not recommended for use in normally energized and 20% duty cycle applications. Section 8.4 provides further discussion and conclusions as they apply to specific vintages of the MDR series relays when used as SSPS slave relays.

8.3.4 Polyester/Acrylic

Recent vintages of the MDR series relay (See Section 5.4.11) replace the PVC lead wire sleeves with sleeves made of polyester/glass. See Tables 5-2a, 5-2b, 5-2c for dates of usage for the two lead wire sleeve materials. As discussed in Section 8.1.2.4, the lead wire sleeves are used to prevent shorting or grounding of the relay coil lead wires. The critical material parameter is dielectric strength, but it is necessary to consider measures of mechanical integrity to assure that the polyester/acrylic insulation will remain on the lead wires.

In the comparison of materials properties of the polyester/glass and PVC sleeve there in no substantial difference in dielectric strength, maximum temperature durability, or estimated service life. The pertinent difference is the aging byproducts. As discussed above, PVC evolves HCl as a byproduct of temperature/age degradation. Polyester/acrylic evolves no corrosive byproducts. Based on data and calculations herein, polyester/acrylic can be rated for a 40 service life at temperatures up to 100 °C. Higher temperatures can be endured with a consequent reduction in expected life.

The estimated temperature rise is a maximum of 65 °C for the relay coil assembly. The coil heat rise directly results in a 65 °C temperature rise in the polyester acrylic. Thus, it should be concluded that a forty year service life would be expected for normally energized relays in an ambient environment which does not exceed 35 °C (= 100°C - 65 °C). This exceeds both the manufacturer's recommendations and the normal ambient temperature expected in the SSPS cabinets (90 °F or 32 °C maximum).

Using the material aging data (Table 8-1), the ambient environment temperatures typical of SSPS locations (Table 8-2), and the FNP temperature data (Table 8-3), the estimated service life of the polyester/acrylic wire sleeves has been calculated. Tables 8-9, 8-9a, and 8-9b summarize the results of these calculations, based on relay coil temperature rises of 65 °C, 58 °C, and 25 °C, respectively. For applications where the relays are normally de-energized or have a 20% duty cycle with ambient temperatures ranging from 75 °F to 100°F, service lives greater than or equal to 1.40E+2 years are calculated based on the IEEE 57 Dielectric Twist Test. With a 140 year service life the relay is unlikely to fail over the 40-year plant life as a result of failure mechanisms postulated to result from temperature-induced, age-related degradation of the polyester/acrylic wire sleeves.

For applications where the relays are normally energized (100% duty) in ambient temperatures ranging from 75°F to 100°F with a relay coil temperature rises of 58 °C or 25°C (Tables 8-9a and 8-9b, respectively), service lives range from 54.4 to 9.64E+03 years, indicating that a 40-year life can reasonable be expected. However, the calculated service lives of less than 40 years result for ambient environment temperatures greater than 90 °F (32°C) when the 65 °C (maximum) relay coil temperature rise is assumed (See Table 8-9).

Considering the ambient environment temperature range typical for SSPS locations and the temperature rise provided by PSE&G (Diablo Canyon; Reference 13-14) for MDR series relays with AC coils, it is reasonable to expect a 40 year life for the polyester/acrylic lead wire sleeves. Barring other life limiting considerations for the relay, it is prudent to:

- Determine the actual temperature data for any particular SSPS cabinet and affirm that estimated life exceeds 40 years with some margin (to cover other uncertainties).

- Impose a conservative service life limit for the normally energized MDR series relays.

It is concluded that temperature-induced, age-related failures postulated for the polyester/acrylic wire sleeves will not occur within the 40-year plant life with normally de-energized relays, relays with low duty cycle (20%), or normally energized relays with (low) coil temperature rises not exceeding 58 °C and ambient temperatures ranging from 75 °F to 100°F. However, it is necessary that actual temperature data be applied to validate the estimated service life of a particular plant's MDR series relays in normally energized applications. It is probable that plant specific data and calculations may demonstrate a 40-year service life even when assuming the 65 °C relay coil temperature rise.

Section 8.4 provides further discussion and conclusions as they apply to specific vintages of the MDR series relays when used as SSPS slave relays.

8.3.5 Glass-Filled Nylon

Degradation of the contact cams will lead to the postulated failure mechanisms affecting contact making. The contact cam will eventually lose dimensional stability due to temperature-induced degradation. In its degraded state, the contact cam will swell or creep with exposure to high temperatures (e.g., 100 °F ambient with temperature rise on the order of 58 °C). In the end-of-life condition, the contact cam will change shape when experiencing the coil temperature rise and cause one of the following:

- intermittent contact making on demand, or
- failure of contacts to break on demand, or
- contact making or breaking without demand.

The failure modes described above are not dominant or limiting-case in the basis for determining service life of the MDR series relays. Other sections of this Calc Note include calculations which affirm this conclusion. Degradation of the contact cam is not the limiting time/temperature-dependent failure mechanism to be considered in assessing the service life of MDR series relays.

A particular concern in assessing the service life of glass-filled nylon is the presence of chlorine gases. Experience in the service life assessment of Westinghouse Type AR relays (Reference 13-15) suggest that degradation of materials releasing chlorine, chlorides, or HCl, when in close proximity to the glass filled nylon would be the determining factor of life. In both the Type AR and certain vintages of MDR series relays, neoprene rubbers are used. However, in the MDR series relay the two materials are not in the close proximity as is the case in Type AR relays. Thus, it is postulated that convection must carry a sufficient quantity of out-gassed chlorine into the MDR series relay switch assembly in order for the glass-filled nylon cams to be affected. This is only expected to be the case in normally energized relays for which coil temperature rises on the order of 58 °C or 65 °C are expected.

Note that failures of MDR series relays due to the out-gassing phenomenon have not appeared as problems with contact making, but rather the on-set of binding in the relay coil assembly. No case of switch cam failure caused by aging or the out-gassing of chlorine/chloride has been reported in MDR relays to date. Even in relays exhibiting binding due to out-gassing, there are no reports of problems affecting the switch cams. It should be concluded that the binding failure mode is dominant and that the potential for chlorine expedited degradation of the contact cams would require additional time to occur.

It is recommended that MDR relays made prior to June 1989 should not be used in normally energized applications. Thus, there would be little value in calculating the estimated service life of the switch cam in the presence of out-gassed chlorine from the relay coil assembly.

Using the material aging data (Table 8-1), the ambient environment temperatures typical of SSPS locations (Table 8-2), and the FNP temperature data (Table 8-3), the estimated service life of the glass-filled nylon switch cams has been calculated. Tables 8-10, 8-10a, and 8-10b summarize the results of these calculations, based on relay coil temperature rises of 65 °C, 58 °C, and 25 °C, respectively. For applications where the relays are normally de-energized with ambient temperatures ranging from 75 °F to 100 °F, service lives greater than 264 years are calculated, based on a 50% retention of tensile strength. Such service lives indicate that material changes over a 40-year period should be minimal. For normally energized relay applications, the calculated results do not support service lives of 40 years at all temperatures and temperature rises, based on a 50% retention of tensile strength.

For relays having a 20% duty cycle with ambient temperatures ranging from 75 °F to 100°F and relay temperature rise of 25 °F, service lives are greater than 85 years. For relays having a 100% duty cycle with ambient temperatures ranging from 75 °F to 85 °F and relay temperature rise of 25 °F, service lives are 50 years or more.

The tensile strength of glass filled nylon (e.g., Nylon Zytel 101) is 2700 psi when new. A 50% reduction in tensile strength would reduce this property to a value of approximately 1350 psi. Even when reduced to 50%, the material will retain tensile strength greatly in excess of the minimum necessary for switch cam function in MDR series relays. Each "lobe" of the switch cam will experience a maximum 100 grams spring force; the factory set maximum spring tension for the moving contacts. The total force applied to all four lobes of a cam would not exceed 400 grams.

Considering the ambient environment temperature range typical for SSPS locations and the temperature rise provided by PSE&G (Diablo Canyon) for MDR series relays with AC coils, it is reasonable to expect a 40 year life for the glass-filled nylon components (switch cams and relay coil terminal insulator of older relays). Barring other life limiting considerations for the relay, it is prudent to:

- Determine the actual temperature data for any particular SSPS cabinet and affirm that estimated life exceeds 40 years with some margin (to cover other uncertainties).

- Impose a conservative service life limit for the normally energized MDR series relays.

It is concluded that temperature-induced, age-related failures postulated for the glass-filled nylon components will not occur within the 40-year plant life with normally de-energized relays and relays with low duty cycle (20%) with low coil temperature rises not exceeding 25 °C. However, it is necessary that actual temperature data be applied to validate the estimated service life of a particular plant's MDR series relays.

Section 8.4 provides further discussion and conclusions as they apply to specific vintages of the MDR series relays when used as SSPS slave relays.

8.3.6 Phenolic/Polyester Resin

The finishing material of the coil assembly is a glass-filled polyester resin (Dolph's Hi Therm BC-340) applied to protect and seal the primary coil insulation. The glass-filled polyester resin is applied as a varnish to the insulated coils. As such, its principal function is as a moisture barrier. It also contributes to the dielectric strength of the coil insulation through the significance of its dielectric strength is minimal.

Phenolic-filled polyester materials are rated for continuous 40-year service at an ambient temperature of 100°C (Reference 13-14) with regard to their retention of dielectric strength. Higher temperatures can be endured with a consequent reduction in expected life.

The estimated temperature rise is a maximum of 65 °C for the relay coil assembly. The coil heat rise directly results in a 65 °C temperature rise in the phenolic-filled polyester coil varnish.

Using the material aging data (Table 8-1), the ambient environment temperatures typical of SSPS locations (Table 8-2), and the FNP temperature data (Table 8-3), the estimated service life of the phenolic/polyester resin has been calculated. Table 8-12 summarizes the results of these calculations which are based on IEEE 57 dielectric twist test data. The calculated results range from 198 to 5.23E+4 years for ND, NE, and 20% duty relay applications at ambient temperatures of 75 °F to 100°F. Such results are unrealistic, but do indicate that material changes over a 40-year period should be minimal. Proper interpretation should be that the relay is unlikely to fail over the 40-year plant life as a result of failure mechanisms postulated to result from temperature-induced, age-related degradation of the phenolic/polyester resin components.

It is concluded that temperature-induced, age-related failures postulated for the MDR series Relay coils (i.e., electrical open, shorting, or grounding) will not occur in SSPS slave relays within the 40-year plant life when used in NE, ND, or light duty applications. However, it is reasonable to expect that an indirect failure mechanism will occur in normally energized (NE) MDR series relays within a forty year service life. The estimate of life until the out-gassing-related failure mechanism occurs is dependent on the degradation of other materials (neoprene rubber and PVC) for those relay vintages which included the BC-340 and neoprene rubber and/or PVC.

8.3.7 Epoxy Resins

Recent vintages of the MDR series relay replace the glass-filled polyester resin with epoxy resins (Dolphon CC-1090 & Sterling E-100; See Sections 5.4.6 and 5.4.14) as the coil varnish material. See Tables 5-2a, 5-2b, 5-2c for dates of usage for the various coil varnish materials; Sterling E-100 is used in current manufacture. As discussed in Section 10.0, the coil varnish is used to protect and seal the primary coil insulating materials. The varnish serves as a moisture barrier, gives rigidity to the coils, and contributes to the dielectric strength of the coil assembly.

In general, epoxy resins are superior (and somewhat more expensive) as coil varnish materials than polyester resins. Both the Dolphon CC-1090 and Sterling E-100 epoxy varnishes can be rated for a 40-year service life at temperatures up to 139 °C. Higher temperatures can be endured with a consequent reduction in expected life.

The estimated temperature rise is a maximum of 65 °C for the relay coil assembly. The coil heat rise directly results in a 65 °C temperature rise in the epoxy resin. Thus, it should be concluded that a forty year service life would be expected for normally energized relays in an ambient environment which does not exceed 74°C (= 139°C - 65°C). However, this greatly exceeds both the manufacturer's recommendations and the normal ambient temperature expected in the SSPS cabinets (90 °F or 32°C, maximum).

Using the material aging data (Table 8-1), the ambient environment temperatures typical of SSPS locations (Table 8-2), and the FNP temperature data (Table 8-3), the estimated service life of the epoxy resins has been calculated. Table 8-13 summarizes the results of these calculations. The calculated results range from 570 to 1.63E+06 years for ND, NE, and 20% duty relay applications at ambient temperatures of 75°F to 100°F. Such service lives are unrealistic, but do indicate that material changes over a 40-year period should be minimal. Proper interpretation should be that the relay is unlikely to fail over the 40-year plant life as a result of failure mechanisms postulated to result from temperature-induced, age-related degradation of the epoxy resins coil varnish.

It is concluded that temperature-induced, age-related failures postulated for the MDR series relay coils (i.e., electrical open, shorting, or grounding) will not occur in SSPS slave relays within the 40-year plant life when used in NE or ND applications.

8.3.8 Polyurethane/Nylon

The primary insulation material for the relay coil is polyurethane (with nylon jacket). Polyurethane materials are rated for continuous 40-year service at an ambient temperature of approximately 90 °C (Reference 13-14). Higher temperatures can be endured with a consequent reduction in expected life. Some retardation of the aging process of the polyurethane should be expected. This is due to the oxygen deprivation created by the nylon jacket and the coil varnish material. No data is available to accurately calculate the benefit, however, the expected impact is taken to be a conservatism in the calculations.

The estimated temperature rise is a maximum of 65 °C for the relay coil assembly. The coil head rise directly results in a 65 °C temperature rise in the polyurethane/nylon magnet wire insulation. Thus, it should be concluded that a forty year service life would be expected for normally energized relays in an ambient environment which does not exceed 25 °C (= 90°C - 65°C). Higher temperatures can be endured with a consequent reduction in service life. However, it is clear that the normal ambient temperature expected in the SSPS cabinets (90°F or 32°C, maximum) will yield a less than 40-year life for the normally energized MDR series relays.

Using the material aging data (Table 8-1), the ambient environment temperatures typical of SSPS locations (Table 8-2), and the FNP temperature data (Table 8-3), the estimated service life of the polyurethane/nylon magnet wire insulation has been calculated. Tables 8-14, 8-14a, and 8-14b summarize the results of these calculations, based on relay coil temperature rises of 65 °C, 58 °C, and 25 °C, respectively. For applications where the relays are normally de-energized or have a 20% duty cycle in ambient temperatures ranging from 75 °F to 100 °F, service lives greater than 86 years are calculated based on the IEEE 57 Dielectric Twist Test. This is a good indication that material degradation over a 40-year period should be minimal and that the relay is unlikely to fail over the 40-year plant life as a result of failure mechanisms postulated to result from temperature-induced, age-related degradation of the polyurethane/nylon wire sleeves.

For applications where the relays are normally energized in ambient temperatures ranging from 75 °F to 100 °F with a relay coil temperature rises of 65 °C, 58 °C or 25 °C (Tables 8-14, 8-14a and 8-14b, respectively), service lives range as follows:

Temperature Rise	Range of Estimated Service Lives
25 °C	714 to 3220 years
58 °C	31.4 to 109 years
65 °C	17.4 to 57.6 years

For applications where the relays are normally energized in ambient temperatures ranging from 75 °F to 100 °F with a relay coil temperature rise of 25 °C (Table 8-14b), the calculations demonstrate that a 40-year life can reasonable be expected. Temperature rises of 65 °C (maximum) and 58 °C (typical) suggest a service life of less than 40 years dependent on ambient environment temperature. Considering the ambient environment temperature range typical of SSPS locations (Table 8-2) and the maximum estimated temperature rise provided by P&B for MDR series relays (i.e., 90 °F ambient, 65 °C temperature rise), it is reasonable to expect at least a 25 year life for the polyurethane/nylon magnet wire insulation (Table 8-14) in normally energized MDR series relays. Considering the maximum ambient temperature for SSPS location at Diablo Canyon and the temperature rise provided by PG&E (Diablo Canyon) for MDR series relays with AC coils (i.e., temperature rise of 58 °C), it is reasonable to expect at a service life in excess of 40 years. Barring other life limiting considerations for the relay, it is prudent to:

- Determine the actual temperature data for any particular SSPS cabinet and affirm that estimated life exceeds 40 years with some margin (to cover other uncertainties), or
- Impose a conservative service life limit for the normally energized MDR series relays.

It is concluded that temperature-induced, age-related failures postulated for the polyurethane/nylon magnet wire insulation will not occur within the 40-year plant life with normally de-energized relays, relays with low duty cycle (20%), or normally energized relays with low coil temperature rises. However, it is necessary that actual temperature data be applied to validate the estimated service life of a particular plant's MDR series relays in normally energized applications. It is probable that plant specific data and calculations may demonstrate a 40-year service life even when assuming the 65 °C relay coil temperature rise. Data collected for the FNP SSPS cabinets and temperature rise data taken at Diablo Canyon supports a 40 year service life for the relay coil wire insulation.

Section 8.4 provides further discussion and conclusions as they apply to specific vintages of the MDR series relays when used as SSPS slave relays.

8.3.9 Alkyd (Glycerylphthalate)

Alkyd (Glycerylphthalate) was used as the switch cover material prior to March of 1985 (See Section 5.4-4). The switch cover serves two functions in the MDR series relay. It holds the contacts/terminals in the top switch deck in place and is a protective barrier for the switch assembly. Its function is strictly mechanical. Use of alkyd was discontinued because of its rigidity. P&B learned that tightening of the cover nuts was causing cracking of the switch cover. This was a product quality issue, and is mentioned here only for completeness - it has little relevance to the service life of the relay.

The estimated temperature rise is a maximum of 65 °C for the relay coil assembly. The coil heat rise causes a proportional, though considerably lesser heat rise in the switch cover and switch ring insulators. Based on testing performed at the Diablo Canyon plant the maximum temperature rise experienced by the alkyd switch cover is 58 °C. Based on data and calculations herein, alkyd can be rated for a 40-year service life at temperatures up to 110 °C based on retention of dielectric strength. Thus, it should be concluded that a forty year service life would be expected for normally energized relays in an ambient environment which does not exceed 52 °C (= 110°C - 58 °C). However, this greatly exceeds both the manufacturer's recommendations and the normal ambient temperature expected in the SSPS cabinets (90 °F or 32 °C, maximum).

Using the material aging data (Table 8-1), the ambient environment temperatures typical of SSPS locations (Table 8-2), and the FNP temperature data (Table 8-3), the estimated service life of the alkyd has been calculated. Tables 8-15, 8-15a and 8-15b summarize the conclusions of these calculations. The calculated results range from 77.9 to 2.04E+6 years for ND, NE, and 20% duty relay applications at ambient temperatures of 75 °F to 100 °F. Such results are unrealistic, but do indicate that material changes over a 40-year period should be minimal. Proper interpretation should be that the relay is unlikely to fail over the 40-year plant life as a result of failure mechanisms postulated to result from temperature-induced, age-related degradation of the alkyd components.

8.3.10 Diallyl Phthalate

Diallyl phthalate is the switch ring insulator material. Also, in recent vintages of the MDR series relays, diallyl phthalate was substituted for alkyd as the switch cover material (See Section 5.4.4). See Tables 5-2a, 5-2b, 5-2c for dates of usage for the two switch cover materials. As the switch cover material, diallyl phthalate is used primarily for its mechanical properties. In the switch ring insulator application, dielectric strength is also required. The diallyl phthalate components must maintain dimensional stability, resist cracking caused by forces in tension or compression, and retain sufficient insulation resistance to maintain contact isolation/separation.

The critical material parameter is retention of flexural strength. This is because a marginally lower activation energy (1.12 eV) is assigned to this property than for the retention of dielectric strength (1.17 eV).

Regarding, the comparison of mechanical properties required for the switch cover application, diallyl phthalate is superior to alkyd, and from a limited comparison of activation energies, represents a marginal improvement in resistance to temperature/age degradation. Based on data and calculations here in, diallyl phthalate can be rated for a 40-year service life at temperatures up to 114 °C for a 50% retention of flexural strength. Higher temperatures can be endured with a consequent reduction in expected life.

The estimated temperature rise is a maximum of 65 °C for the relay coil assembly. The coil heat rise causes a proportional, though considerably lesser heat rise in the switch cover and switch ring insulators. For conservatism it is assumed that a 65 °C temperature rise is experienced by the diallyl phthalate components. Thus, it should be concluded that a forty year service life would be expected for normally energized relays in an ambient environment which does not exceed
49°C (= 114°C - 65°C). However, this greatly exceeds both the manufacturer's recommendations and the normal ambient temperature expected in the SSPS cabinets 90 °F or 32°C, maximum).

Using the material aging data (Table 8-1), the ambient environment temperatures typical of SSPS locations (Table 8-2), and the FNP temperature data (Table 8-3), the estimated service life of the glass filled phenolic has been calculated. Tables 8-16 and 8-16a, summarize the conclusions of these calculations. The calculated results range from 113 to 1.1E+6 years based on a 50% retention of flexural strength for ND, NE, and 20% duty relay applications at ambient temperatures of 75 °F to 100°F. Such results are unrealistic, but do indicate that material changes over a 40-year period should be minimal. Proper interpretation should be that the relay is unlikely to fail over the 40-year plant life as a result of failure mechanisms postulated to result from temperature-induced, age-related degradation of the glass-filled phenolic components.

8.3.11 G-9 Glass Melamine

Glass-filled melamine laminates (G-9) are used as the switch ring base and barrier materials. This is the same material commonly used to make printed circuit boards. G-9 is known both for its dielectric and impact strength. Its application in MDR series relays differs slightly from more common use in printed circuit boards.

The critical material parameter retention of flexural strength (activation energy of 2.48 eV). This is because a substantially lower activation energy (0.52 eV) is assigned to its retention is dielectric strength. While the loss of dielectric strength can be substantial, the residual strength is more than sufficient for typical control voltage applications (nominally 100 to 200 VAC).

An estimated forty-year service life temperature of 125 °C is typical for printed circuit board applications of G-9 based on retention flexural strength. As stated above, G-9 has very poor ability to retain is original dielectric strength with time and temperature. However, the G-9 switch ring base and barriers will perform their function adequately by simply maintaining the physical barrier between the contacts of adjacent switch decks (G-9 will not become conductive while in a solid state).

The estimated temperature rise is a maximum of 65 °C for the relay coil assembly. The coil heat rise causes a proportional, though considerably lesser heat rise in the switch ring base and barriers. For conservatism it is assumed that a 65 °C temperature rise is experienced by the G-9 laminate components. Thus, it should be concluded that a forty year service life would be expected for normally energized relays in an ambient environment which does not exceed 60 °C (= 125°C - 65°C). However, this greatly exceeds both the manufacturer's recommendations and the normal ambient temperature expected in the SSPS cabinets (90°F or 32°C, maximum).

Using the material aging data (Table 8-1), the ambient environment temperatures typical of SSPS locations (Table 8-2), and the FNP temperature data (Table 8-3), the estimated service life of the G-9 laminates has been calculated. Table 8-18 summarizes the conclusions of these calculations. The calculated results range from 2.83E+03 to 1.94E+12 years for temperatures expected in SSPS slave relays for ND, NE, and 20% duty relay applications at ambient temperatures of 75 °F to 100°F. Such results are unrealistic, but do indicate that material changes over a 40-year period should be minimal. Proper interpretation should be that the relay is unlikely to fail over the 40-year plant life as a result of failure mechanisms postulated to result from temperature-induced, age-related degradation of the glass melamine switch ring base and barriers.

8.3.12 Epoxy/Glass G-10 Laminate

Glass-filled epoxy laminate (G-10) is one component in the relay coil terminal/insulators. It functions to mechanically support the terminal posts and to insulate them from the metal body of the relay coil assembly. Thus, both electrical and mechanical properties of the material are critical to the function of the relay coil terminal insulator. However, it is debatable that the loss of dielectric strength in the G-10 laminate would result in failure of the relay (shorting or ground of the relay coil circuit). Vintages of the MDR series relay in which the G-10 laminate is used, had a two piece relay coil terminal insulator, the other material being nylon on which the coil terminals are directly mounted. While calculations are based on the retention of flexural and dielectric strength, greater weight is placed on calculations based on a retention of flexural strength.

The estimated temperature rise is a maximum of 65 °C for the relay coil assembly. The coil heat rise causes a proportional, though considerably lesser heat rise in the coil terminal insulators. For conservatism it is assumed that a 65 °C temperature rise is experienced by the G-10 laminate. Calculations demonstrate that there is no real significance to the estimation of relay service life based on the flexural strength. Rather it increases the assurance that failure modes postulated for the relay coil terminals are not credible within a relay service life of 40 years. However, there is minor concern for the impact to dielectric strength of the G-10 laminate.

Using the material aging data (Table 8-1), the ambient environment temperatures typical of SSPS locations (Table 8-2), and the FNP temperature data (Table 8-3), the estimated service life of the G-10 laminate has been calculated. Tables 8-20, 8-20a, 8-21, 8-21a, and 8-21b summarize the conclusions of these calculations. The calculated results range from 159 to 6.75E+07 years (Tables 8-20 and 8-20a) for ND, NE, and 20% duty relay applications at ambient temperatures of 75 °F to 100°F. Such results are unrealistic, but do indicate that material changes over a 40-year period should be minimal. Proper interpretation should be that the relay is unlikely to fail over the 40-year plant life as a result of failure mechanisms postulated to result from temperature-induced, age-related degradation of coil terminal insulator component consisting of G-10 laminate.

Regarding the dielectric strength of G-10 laminates, similar calculations demonstrate a 40 year life (based on 50% retention of original value) for normally de-energized relays, relays with 20% duty cycle, and most normally energized applications as well (Tables 8-21, 8-21a, and 8-21b). The exception is cases where the maximum coil temperature rise (65 °C) is applied with ambient temperatures exceeding 80°F (27°C). Considering the maximum ambient temperature for SSPS location at Diablo Canyon and the temperature rise provided by PG&E (Diablo Canyon) for MDR series relays with AC coils (i.e., temperature rise of 58°C), it is reasonable to expect a service life in excess of 40 years (Table 8-21a). Also considering that a 50% retention of dielectric strength is not necessarily a level indicative of a threshold of failure, it is reasonable to expect that the G-10 laminate component of the coil terminal insulator would perform as required over a forty-year service life in the SSPS slave relay application. Finally, there are other service life considerations which are more limiting in the determination of service life for MDR series relay vintages which include the G-10 laminate in the coil terminal insulator. Section 8.4 provides further discussion and conclusions as they apply to specific vintages of the MDR series relays when used as SSPS slave relays.

8.3.13 Teflon (Polytetrafluoroethylene)

Teflon (polytetrafluoroethylene) is the relay coil lead wire insulation. Portions of the relay coil lead wires are covered with the lead wire sleeves (See Sections 8.3.2 and 8.3.3). Important material properties are dielectric and flexural strength - typical of any wire/cable application.

The estimated temperature rise is a maximum of 65 °C for the relay coil assembly. The coil heat rise causes a proportional, though considerably lesser heat rise in the lead wires. The critical portions of the relay coil lead wire are outside the relay coil assembly, and likely to experience substantially reduced heat rise. However, for conservatism, it is assumed that the 65 °C temperature rise applies to the entire length of lead wire.

Teflon wire insulation is distinguished with one of the highest temperature ratings available. Teflon wire insulation is typically rated for continuous duty at 200 °C. Studies have found essentially no change in physical properties after six months at 250 °C (in air). An estimated forty-year service life temperature of 200°C is typical for all applications of Teflon as an electrical insulator. Thus, it should be concluded that a forty year service life would be expected for normally energized MDR series relays in an ambient environment which does not exceed 135°C (= 200°C - 65°C). However, this greatly exceeds both the manufacturer's recommendations and the normal ambient temperature expected in the SSPS cabinets (90°F or 32°C, maximum).

Using the material aging data (Table 8-1), the ambient environment temperatures typical of SSPS locations (Table 8-2), and the FNP temperature data (Table 8-3), the estimated service life of the glass filled phenolic has been calculated. Tables 8-22 and 8-23 summarize the conclusions of these calculations. The calculated results range from 813 to 5.45E+23 years for ND, NE, and 20% duty relay applications at ambient temperatures of 75 °F to 100°F. Such results are unrealistic, but do indicate that material changes over a 40-year period should be minimal. Proper interpretation should be that the relay is unlikely to fail over the 40-year plant life as a result of failure mechanisms postulated to result from temperature-induced, age-related degradation of the Teflon lead wire insulation.

8.4 CONCLUSION OF AGING ASSESSMENT

Normally energized relays experience significant self heating. The expected temperature rise for MDR series relays when energized continuously is 25 °C to 65 °C, the latter being the manufacturer's estimate of the maximum temperature rise based on testing of medium MDR relays. Actual temperature rises are dependent on ambient temperature, coil wattage, and the voltage applied to the coil. Based on Reference 13-14, 58 °C is a bounding approximation of the expected temperature rise for NE MDR series relays used in the SSPS.

Relay temperature rise decreases expected service life and reliability by accelerating age/temperature dependent degradation. This is why normally energized relays and relays with high duty cycle generally exhibit a lesser service life, and consequentially a lesser reliability, than normally de-energized relays. To maintain a consistent level of reliability among NE and ND relays, NE relays will require replacement one or more times during a 40-year plant life. More specifically, a range of maintenance and surveillance intervals will apply dependent upon the duty cycle of the relay application and ambient environment temperature. Finally, MDR series relay made prior to May of 1990 are considered to be unsuitable for use in normally energized applications due to their short life caused by the high probability that out-gassing related failure modes will occur. While an immediate replacement of "older"

MDR series relays may not be necessary dependent of several factors, it is recommended that those SSPS slave relay that are normally energized should be replaced as part of the efforts to achieve a relaxed surveillance test interval. See further discussion of surveillance test intervals below and in Section 8.4.5.

MDR series relays used as normally de-energized SSPS slave relays will not experience temperature-induced age-related degradation sufficient to result in failure within the 40-year plant life. Degradation of critical components requires substantial time, and would result in no perceptible change in component performance. Degradation of non-critical components, e.g., the neoprene rubber lead wire grommet, will result in perceptible changes to both appearance and material characteristics. However, no adverse impact to relay performance or reliability would be visually, electrically, or mechanically detectable.

MDR series relays used as normally energized (NE) SSPS slave relays will experience temperature-induced age-related degradation sufficient to result in failure within the 40-year plant life. In particular, an end-of-life failure mechanism observed in MDR series relays with DC-coils will necessitate replacement of NE relays. However, it is not clear that this end-of-life failure will occur in MDR series relays with AC-coils (those actually used as SSPS slave relays) due to differences in temperature/time history and service requirements. Lacking other experience or test data, it is recommended that both DC-coil and AC-coil NE MDR series SSPS slave relays should be replaced based on actual plant temperature data. Furthermore, it is required that only MDR series relays manufactured after 1992 should be used in normally energized and 20% duty applications. (See Section 5.5.1.)

It is also prudent to consider replacement of MDR series SSPS slave relays which are energized continuously during refueling outages. However, the real need to implement these replacements should be evaluated on a plant by plant basis. It is reasonable to expect at least a 10 year service life for the "20% duty cycle" relays. It is equally conceivable that other mitigating factors of environment and service would support longer service lives. In the face of remaining uncertainty concerning the prediction of the out-gassing phenomenon and its impact, it is prudent to limit the service life of any "20% duty cycle" manufactured prior to May of 1990 to the 10 year life currently supported by Westinghouse. However, with consideration of plant-specific, installation/location specific temperature conditions it is equally reasonable that a 20 service life can be demonstrated.

The following sections detail conclusion and recommendations for the significant design vintages (Section 5.5) of MDR series relays. The section titles are the dates of manufacture for each of the four design vintages. Westinghouse believes the following recommended service lives are adequate for the various vintages of MDR relays on their current surveillance frequencies. However. It is required that only MDR series relays manufactured after 1992 be used in normally energized or 20% duty cycle applications for which an extended test interval (18 to 24 months) is to be implemented. (See Section 5.5.1.)

8.4.1 Prior to February 1986

Relays of this vintage have the following components which make them prone to the out-gassing related failure mechanism.

Neoprene rubber lead wire grommets - Section 8.3.1
PVC lead wire sleeves - Section 8.3.3
BC-340 resin as coil varnish - Section 8.3.6

Brass components in the relay coil assembly can become corroded.

Service life estimates based on duty cycle and ambient temperature reduce to the following:

- > 40 years for normally de-energized relays

- > 40 years for relays with 20% duty cycle in ambient temperatures up to 85 °F. 20-year service life limit is recommended.

- Unsuitable for normally energized service except in cases were very low temperature rise can be demonstrated.

- 10-year service life with temperature rise of 25 °C and ambient temperatures < 90 °F. However, a periodic surveillance should be performed.

- However, it is required that only MDR series relays manufactured after 1992 be used in normally energized or 20% duty cycle applications for which an extended test interval (18 to 24 months) is to be implemented. (See Section 5.5.1.)

8.4.2 February 1986 up to October 1988

Relays of this vintage have the following components which make them prone to the out-gassing related failure mechanism.

Neoprene rubber lead wire grommets - Section 8.3.1
PVC lead wire sleeves - Section 8.3.3

Brass components in the relay coil assembly can become corroded.

Replacement of the BC-340 resin with the CC-1090 epoxy resin effectively increases the temperature rating of the coil. However, the out-gassing related failure mechanism expected in normally energized applications remain.

Service life estimates based on duty cycle and ambient temperature reduce to the following:

- > 40 years for normally de-energized relays
- > 40 years for relays with 20% duty cycle in ambient temperatures up to 85 °F. 20-year service life limit is recommended.
- Unsuitable for normally energized service except in cases were very low temperature rise can be demonstrated.
- 10-year service life with temperature rise of 25 °C and ambient temperatures < 90 °F. However, a periodic surveillance should be performed.
- However, it is required that only MDR series relays manufactured after 1992 be used in normally energized or 20% duty cycle applications for which an extended test interval (18 to 24 months) is to be implemented. (See Section 5.5.1.)

8.4.3 October 1988 up to June 1989

Relays of this vintage have the following components which make them prone to the out-gassing related failure mechanism.

Neoprene rubber lead wire grommets - Section 8.3.1

Brass components in the relay coil assembly can become corroded.

Polyester/acrylic has been substituted for PVC as the lead wire sleeve material. PVC lead wire sleeve may be a contributor to the out-gassing related failure mechanism expected in normally energized applications, but the neoprene rubber is considered to be the principal contributor of evolved chlorine/chlorides and HCl.

Service life estimates based on duty cycle and ambient temperature reduce to the following:

- > 40 years for normally de-energized relays
- > 40 years for relays with 20% duty cycle in ambient temperatures up to 85 °F. 20-year service life limit is recommended.
- Unsuitable for normally energized service except in cases were very low temperature rise can be demonstrated.

- 10-year service life with temperature rise of 25 °C and ambient temperatures < 90 °F. However, a periodic surveillance should be performed.

- However, it is required that only MDR series relays manufactured after 1992 be used in normally energized or 20% duty cycle applications for which an extended test interval (18 to 24 months) is to be implemented. (See Section 5.5.1.)

8.4.4 June 1989 to Present

In June of 1989 the sources of chlorine/chloride and HCl outgassing were eliminated from the relay. This results in a virtual elimination of the out-gassing related failure mechanism. However, brass components remain in the coil assembly. In May of 1990 the brass components are replaced with metals with substantially greater resistance to corrosion. Thus, MDR series relays made after May of 1990 are preferred in normally energized applications.

Service life estimates based on duty cycle and ambient temperature reduce to the following:

- > 40 years for normally de-energized relays

- > 40 years for relays with 20% duty cycle relays.

- A conservative service life limit of 30 years is recommended for normally energized relays, based upon an assumption of 65 °C coil temperature rise and aging degradation expected in the switch cams (glass-filled nylon).

- A 40 year service life is possible in normally energized relays exhibiting low temperature rise.

- However, it is required that only MDR series relays manufactured after 1992 be used in normally energized or 20% duty cycle applications for which an extended test interval (18 to 24 months) is to be implemented. (See Section 5.5.1.)

8.4.5 Surveillance Test Intervals for SSPS Slave Relays

For most materials used in the various manufacturing vintages of MDR series relays, the current SSPS surveillance test intervals of one, two or three months have little significance to detection of relay degradation or impending failure. Furthermore, calculations documented herein demonstrate that, with few exceptions, age-related degradation of the materials occurs sufficiently slow that a refueling interval test frequency (e.g., 18 to 24 months) is more than adequate to affirm reliability and continuing operability.

Regarding the exceptions, these are more appropriately addressed by replacement of the MDR relays. This applies to MDR series relays manufactured prior to June of 1989. These relays will be short-lived due to the high probability that corrosive compounds will be out-gassed from certain component materials when subjected to temperatures expected in normally energized service, and that this will cause a binding failure mode to occur. It is impossible to specify at what "service life age" binding will occur. Thus, calculations address the threshold of the out-gassing phenomenon itself. On the basis of these calculations, it is concluded that MDR series relays manufactured prior to June 1989 are not entirely suitable for NE energized relay applications. Exceptions exist where a relative low ambient temperature persist and a relatively low relay temperature rise can be demonstrated (e.g., the Auto Shunt Trip Panel relays in the Reactor Trip System; independent of the SSPS applications).

Similarly, MDR series relays of the pre-June 1989 vintages utilized in application where they are intermittently energized for non-trivial periods of time are regarded as prone to the out-gassing related failure mode(s). For SSPS slave relays a bounding estimate of this case is the 20% duty cycle i.e., the relay would be energized continuously for a time period not exceeding 20% of a calendar year. Calculations demonstrate that a reasonable service life prior to the advent of the out-gassing phenomenon is expected. There is substantially reduced likelihood that the on-set of relay binding would occur early in life. However, it is prudent that service life for these relays be limited to 10 to 20 years, depending on service conditions. Equally, should any one relay fail to perform as expected, all relays with similar duty cycle and service conditions should be replaced immediately.

The SSPS slave relay test intervals can be extended to once per refueling outage (i.e., 18 to 24 months), provided that the pre-1992 MDR series relays are replaced when used in normally energized or 20% duty cycle applications. (See Section 5.5.1.)

TABLE 8-1 MDR SERIES RELAY MATERIALS & AGING DATA

Component Material	Relay Components	Temperature Rise (Note 1)	Activation Energy/ Material Property	Aging Test Reference Data	Notes
Neoprene Rubber	Lead Wire Grommet	65°C	1.30 eV Elongation (100% Retention)	800 hrs. @ 120°C	2
			0.84 eV Elongation (60% Retention)	40,000 hrs. @ 40°C	
Glass-Filled Nylon (Nylon Zytel 101)	Switch Cams, Coil Lead Wire Terminal Base	65°C	0.8787eV Tensile strength (50% Retention)	100 hrs. @ 175°C	
Polyurethane (With Nylon Jacket)	Coil Wire Insulation	65°C	1.01 eV Dielectric Strength (Note 3)	1,000 hrs. @ 175°C	
Phenolic/Polyester Resin (BC-340)	Coil Varnish	65°C	0.68 eV Dielectric Strength (Note 3)	40,000 hrs. @ 185°C	
Epoxy Resins (BF_3 Cured) (CC-1090 or E-100)	Coil Varnish	65°C	0.97 eV Weight Loss of 16% (Thermal Stability)	40,000 hrs. @ 175°C	
Polyvinyl Chloride (PVC)	Lead Wire Sleeves	<65°C	1.14 eV Static Elongation (50% Retention)	1,000 hrs @ 130°C	
Polyester/Acrylic	Lead Wire Sleeves	<65°C	1.13 eV IEEE 57 Dielectric Twist Test	5,000 hrs @ 150°C	
Epoxy-Glass Laminate (G10)	Coil Lead Wire Terminal Base	<65°C	1.58 eV Flexural Strength (50% Retention)	6,000 hrs @ 150°C	
			1.04 eV Dielectric Strength (50% Retention)	4,000 hrs @ 150°C	
Polyethermide	Lead Wire Grommet	<65°C	1.02 eV Dielectric Strength	6,000 hrs @ 230°C	
			1.13 eV 2.5% Shrinkage	8,000 hrs @ 250°C	

TABLE 8-1 MDR SERIES RELAY MATERIALS & AGING DATA (Con't)

Component Material	Relay Components	Temperature Rise (Note 1)	Activation Energy/ Material Property	Aging Test Reference Data	Notes
Alkyd (Glyceryl Phthalate)	Switch Cover	<65°C	1.24 eV Dielectric Strength (50% Retention)	1,000 hrs @ 180°C	
Diallyl Phthalate	Switch Ring Insulator Switch Cover	<65°C	1.12 eV Flexural Strength (50% Retention)	10,250 hrs @ 160°C	
			1.17 eV Dielectric Strength (50% Retention)	1,000 hrs @ 130°C	
Teflon	Lead Wire Insulation	<65°C	1.44 eV Weight Loss	20,000 hrs @ 160°C	
			3.7 eV Thermal Stability	20,000 hrs @ 200°C	
G-9 Glass Melamine	Switch Ring Base, Switch Ring Barriers	<65°C	2.48 eV Flexural Strength (50% Retention)	1,000 hrs @ 160°C	
			0.52 eV Dielectric Strength (50% Retention)	20 hrs @ 100°C	

NOTES:

1. Expected temperature rise in component when relay is normally energized.
2. Aging test reference data is for low temperature extrapolation which is conservative and more realistic for component.
3. Based on IEEE 57 Dielectric Twist Test.
4. Aging test reference data is an interpolation of Arrhenius plot - no test data points shown.

TABLE 8-2 AMBIENT TEMPERATURES AT SSPS LOCATION				
	Ambient Temperature Range			
Plant	Low (°F)	High (°F)	Relay Types	Notes
Beaver Valley 1 & 2	NR	NR	AR & MDR	
Braidwood 1 & 2	70	90	AR & MDR	
Byron 1 & 2	NR	NR	AR & MDR	
Callaway 1	65	75	MDR	
Catawba 1 & 2	65	80	AR	peak 90°F
Comanche Peak 1 & 2	70	80	AR	peak <80°F
Cook 1 & 2	NR	NR	AR	
Diablo Canyon 1 & 2	65	80	MDR	
Farley 1 & 2	Table 5	Table 5	AR	(a)
McGuire 1 & 2	70	80	AR	
Millstone 3	(b)	(b)	MDR	
North Anna 1 & 2	70	85	AR & MDR	
Salem 1 & 2	NR	NR	AR	
Seabrook 1 & 2	NR	NR	MDR	
Sequoyah 1 & 2	75	85	AR & MDR	
Shearon Harris	72	85	MDR	peak 79°F; setpoint 72.5°F
South Texas 1 & 2	NR	78	MDR	
Summer	NR	NR	AR	
Trojan	NR	NR	AR	
Vogtle 1 & 2	75	85	MDR	
Watts Bar 1 & 2	(c)	(c)	AR	
Wolf Creek	66	71	MDR	peak 74°F

NOTES:
NR Not reported.
(a) Temperatures inside and outside the SSPS were monitored from May '92 through July '93. See Table 8-3.
(b) Reported as 75°F. This is taken to be the setpoint value.
(c) No plant operating history data to report.

TABLE 8-3 FARLEY SSPS TEMPERATURE DATA SUMMARY[1]					
File #	Datum Type	Ambient Temperature	Node 1 Temperature	Node 2 Temperature	Notes
1	MAX Avg min	79.26 75.45 72.20	81.87 78.36 72.20	80.56 77.19 72.20	
2	MAX Avg min	80.56 76.48 74.11	82.53 80.25 76.04	81.22 78.42 76.04	
3	MAX Avg min	80.56 76.25 71.57	82.53 80.67 76.04	81.22 78.57 74.75	
4	MAX Avg min	83.85 77.56 74.11	86.52 80.99 76.04	85.18 79.35 74.11	
5	MAX Avg min	78.61 75.03 70.93	82.53 78.30 70.93	81.22 76.52 72.20	
6	MAX Avg min	78.61 74.69 72.20	79.26 77.13 72.84	77.97 76.04 73.48	
7	MAX Avg min	79.26 75.45 72.20	81.87 78.36 72.20	80.56 77.19 72.20	
8	MAX Avg min	79.26 75.45 72.20	81.87 78.36 72.20	80.56 77.19 72.20	
9	MAX Avg min	79.26 75.30 72.20	79.91 74.35 70.93	79.26 75.45 72.84	
10	MAX Avg min	81.22 77.37 73.48	82.53 77.64 73.48	81.87 77.95 75.39	
11	MAX Avg min	80.56 77.74 72.20	81.87 78.25 73.48	81.22 78.69 74.75	
ALL	MAX Avg min	83.85 76.07 70.93	86.5 78.4 70.9	85.2 77.5 72.2	

Notes: [1] Summary of data provided via Reference 13-18.

TABLE 8-4 LIFE OF NEOPRENE RUBBER BASED ON ELONGATION (60%ETENTION)				
Temperature[1]		Service Life Years Based on Duty Cycle[2]		
(°F)	(°C)	(100%)	(20%)	(0%)
75.0	23.9	6.81E-02	3.36E-01	2.47E+01
80.0	26.7	5.54E-02	2.73E-01	1.82E+01
85.0	29.4	4.53E-02	2.24E-01	1.35E+01
90.0	32.2	3.71E-02	1.83E-01	1.01E+01
95.0	35.0	3.05E-02	1.50E-01	7.57E+00
100.0	37.8	2.52E-02	1.23E-01	5.70E+00
105.0	40.6	2.08E-02	1.02E-01	4.32E+00
110.0	43.3	1.72E-02	8.45E-02	3.29E+00
115.0	46.1	1.43E-02	7.00E-02	2.52E+00
120.0	48.9	1.19E-02	5.81E-02	1.93E+00
125.0	51.7	9.98E-03	4.84E-02	1.49E+00
86.5[3]	30.3	4.27E-02	2.10E-01	1.24E+01
78.4[3]	25.8	5.92E-02	2.92E-01	2.01E+01
85.2[3]	29.6	4.49E-02	2.21E-01	1.34E+01
77.5[3]	25.3	6.14E-02	3.03E-01	2.12E+01

NOTES:

1. Relay temperature rise (when energized) is 65°C.
2. Aging test/reference data consists of 0.84 eV, 40000 hours, 40°C.
3. In-cabinet temperature data provided by Farley Nuclear Plant is considered to be typical of other SSPS plants. Calculations based on this data provide a reasonable approximation of SSPS slave relay (material) life.

TABLE 8-4a LIFE OF NEOPRENE RUBBER BASED ON ELONGATION (60% RETENTION)				
Temperature[1]		Service Life Years Based on Duty Cycle[2]		
(°F)	(°C)	(100%)	(20%)	(0%)
75.0	23.9	1.16E-01	5.67E-01	2.47E+01
80.0	26.7	9.35E-02	4.57E-01	1.82E+01
85.0	29.4	7.58E-02	3.72E-01	1.35E+01
90.0	32.2	6.17E-02	3.01E-01	1.01E+01
95.0	35.0	5.03E-02	2.45E-01	7.57E+00
100.0	37.8	4.12E-02	1.99E-01	5.70E+00
105.0	40.6	3.38E-02	1.63E-01	4.32E+00
110.0	43.3	2.78E-02	1.35E-01	3.29E+00
115.0	46.1	2.30E-02	1.11E-01	2.52E+00
120.0	48.9	1.90E-02	9.11E-02	1.93E+00
125.0	51.7	1.58E-02	7.54E-02	1.49E+00
86.5[3]	30.3	7.12E-02	3.47E-01	1.24E+01
78.4[3]	25.8	1.00E-01	4.89E-01	2.01E+01
85.2[3]	29.6	7.52E-02	3.66E-01	1.34E+01
77.5[3]	25.3	1.04E-01	5.09E-01	2.12E+01

NOTES:
1. Relay temperature rise (when energized) is 58°C.
2. Aging test/reference data consists of 0.84 eV, 40000 hours, 40°C.
3. In-cabinet temperature data provided by Farley Nuclear Plant is considered to be typical of other SSPS plants. Calculations based on this data provide a reasonable approximation of SSPS slave relay (material) life.

TABLE 8-4b LIFE OF NEOPRENE RUBBER BASED ON ELONGATION (60% RETENTION)				
Temperature[1]		Service Life Years Based on Duty Cycle[2]		
(°F)	(°C)	(100%)	(20%)	(0%)
75.0	23.9	1.93E+00	7.35E+00	2.47E+01
80.0	26.7	1.49E+00	5.60E+00	1.82E+01
85.0	29.4	1.16E+00	4.33E+00	1.35E+01
90.0	32.2	9.00E-01	3.32E+00	1.01E+01
95.0	35.0	7.04E-01	2.56E+00	7.57E+00
100.0	37.8	5.53E-01	1.99E+00	5.70E+00
105.0	40.6	4.35E-01	1.54E+00	4.32E+00
110.0	43.3	3.45E-01	1.22E+00	3.29E+00
115.0	46.1	2.74E-01	9.53E-01	2.52E+00
120.0	48.9	2.18E-01	7.50E-01	1.93E+00
125.0	51.7	1.74E-01	5.92E-01	1.49E+00
86.5[3]	30.3	1.07E+00	3.97E+00	1.24E+01
78.4[3]	25.8	1.62E+00	6.11E+00	2.01E+01
85.2[3]	29.6	1.14E+00	4.25E+00	1.34E+01
77.5[3]	25.3	1.70E+00	6.41E+00	2.12E+01

NOTES:
1. Relay temperature rise (when energized) is 25°C.
2. Aging test/reference data consists of 0.84 eV, 40000 hours, 40°C.
3. In-cabinet temperature data provided by Farley Nuclear Plant is considered to be typical of other SSPS plants. Calculations based on this data provide a reasonable approximation of SSPS slave relay (material) life.

TABLE 8-5 LIFE OF NEOPRENE RUBBER BASED ON ELONGATION (100% RETENTION)				
Temperature[1]		Service Life Years Based on Duty Cycle[2]		
(°F)	(°C)	(100%)	(20%)	(0%)
75.0	23.9	2.47E+00	1.24E+01	2.27E+04
80.0	26.7	1.80E+00	8.97E+00	1.42E+04
85.0	29.4	1.32E+00	6.62E+00	8.92E+03
90.0	32.2	9.68E-01	4.85E+00	5.67E+03
95.0	35.0	7.15E-01	3.57E+00	3.63E+03
100.0	37.8	5.30E-01	2.64E+00	2.34E+03
105.0	40.6	3.95E-01	1.96E+00	1.52E+03
110.0	43.3	2.95E-01	1.48E+00	9.99E+02
115.0	46.1	2.22E-01	1.11E+00	6.60E+02
120.0	48.9	1.67E-01	8.35E-01	4.39E+02
125.0	51.7	1.27E-01	6.31E-01	2.94E+02
86.5[3]	30.3	1.20E+00	5.99E+00	7.78E+03
78.4[3]	25.8	1.99E+00	9.94E+00	1.65E+04
85.2[3]	29.6	1.30E+00	6.48E+00	8.76E+03
77.5[3]	25.3	2.11E+00	1.05E+01	1.79E+04

NOTES:

1. Relay temperature rise (when energized) is 65°C.
2. Aging test/reference data consists of 1.3 eV, 800 hours, 120°C.
3. In-cabinet temperature data provided by Farley Nuclear Plant is considered to be typical of other SSPS plants. Calculations based on this data provide a reasonable approximation of SSPS slave relay (material) life.

TABLE 8-5a LIFE OF NEOPRENE RUBBER BASED ON ELONGATION (100% RETENTION)				
Temperature[1]		Service Life Years Based on Duty Cycle[2]		
(°F)	(°C)	(100%)	(20%)	(0%)
75.0	23.9	5.63E+00	2.81E+01	2.27E+04
80.0	26.7	4.05E+00	2.02E+01	1.42E+04
85.0	29.4	2.92E+00	1.47E+01	8.92E+03
90.0	32.2	2.12E+00	1.06E+01	5.67E+03
95.0	35.0	1.55E+00	7.74E+00	3.63E+03
100.0	37.8	1.14E+00	5.66E+00	2.34E+03
105.0	40.6	8.36E-01	4.16E+00	1.52E+03
110.0	43.3	6.19E-01	3.10E+00	9.99E+02
115.0	46.1	4.60E-01	2.30E+00	6.60E+02
120.0	48.9	3.43E-01	1.71E+00	4.39E+02
125.0	51.7	2.57E-01	1.28E+00	2.94E+02
86.5[3]	30.3	2.65E+00	1.32E+01	7.78E+03
78.4[3]	25.8	4.49E+00	2.24E+01	1.65E+04
85.2[3]	29.6	2.89E+00	1.44E+01	8.76E+03
77.5[3]	25.3	4.77E+00	2.38E+01	1.79E+04

NOTES:
1. Relay temperature rise (when energized) is 58°C.
2. Aging test/reference data consists of 1.3 eV, 800 hours, 120°C.
3. In-cabinet temperature data provided by Farley Nuclear Plant is considered to be typical of other SSPS plants. Calculations based on this data provide a reasonable approximation of SSPS slave relay (material) life.

TABLE 8-5b LIFE OF NEOPRENE RUBBER BASED ON ELONGATION (100% RETENTION)

Temperature[1]		Service Life Years Based on Duty Cycle[2]		
(°F)	(°C)	(100%)	(20%)	(0%)
75.0	23.9	4.39E+02	2.04E+03	2.27E+04
80.0	26.7	2.94E+02	1.35E+03	1.42E+04
85.0	29.4	1.98E+02	9.18E+02	8.92E+03
90.0	32.2	1.35E+02	6.18E+02	5.67E+03
95.0	35.0	9.19E+01	4.18E+02	3.63E+03
100.0	37.8	6.32E+01	2.85E+02	2.34E+03
105.0	40.6	4.37E+01	1.95E+02	1.52E+03
110.0	43.3	3.04E+01	1.37E+02	9.99E+02
115.0	46.1	2.13E+01	9.46E+01	6.60E+02
120.0	48.9	1.50E+01	6.60E+01	4.39E+02
125.0	51.7	1.06E+01	4.63E+01	2.94E+02
86.5[3]	30.3	1.76E+02	8.08E+02	7.78E+03
78.4[3]	25.8	3.34E+02	1.54E+03	1.65E+04
85.2[3]	29.6	1.95E+02	8.93E+02	8.76E+03
77.5[3]	25.3	3.59E+02	1.67E+03	1.79E+04

NOTES:

1. Relay temperature rise (when energized) is 25°C.
2. Aging test/reference data consists of 1.3 eV, 800 hours, 120°C.
3. In-cabinet temperature data provided by Farley Nuclear Plant is considered to be typical of other SSPS plants. Calculations based on this data provide a reasonable approximation of SSPS slave relay (material) life.

TABLE 8-6 LIFE OF POLYETHERIMIDE BASED ON DIELECTRIC STRENGTH-RETENTION AT 1.5kV				
Temperature[1]		Service Life Years Based on Duty Cycle[2]		
(°F)	(°C)	(100%)	(20%)	(0%)
75.0	23.9	6.60E+03	3.30E+04	8.48E+06
80.0	26.7	5.14E+03	2.56E+04	5.86E+06
85.0	29.4	4.02E+03	2.02E+04	4.08E+06
90.0	32.2	3.16E+03	1.58E+04	2.86E+06
95.0	35.0	2.49E+03	1.24E+04	2.01E+06
100.0	37.8	1.97E+03	9.81E+03	1.43E+06
105.0	40.6	1.56E+03	7.76E+03	1.02E+06
110.0	43.3	1.25E+03	6.22E+03	7.32E+05
115.0	46.1	9.95E+02	4.96E+03	5.28E+05
120.0	48.9	7.98E+02	3.96E+03	3.84E+05
125.0	51.7	6.41E+02	3.18E+03	2.80E+05
86.5[3]	30.3	3.74E+03	1.87E+04	3.66E+06
78.4[3]	25.8	5.57E+03	2.78E+04	6.59E+06
85.2[3]	29.6	3.99E+03	1.98E+04	4.02E+06
77.5[3]	25.3	5.82E+03	2.91E+04	7.04E+06

NOTES:
1. Relay temperature rise (when energized) is 65°C.
2. Aging test/reference data consists of 1.02 eV, 6000 hours, 230°C.
3. In-cabinet temperature data provided by Farley Nuclear Plant is considered to be typical of other SSPS plants. Calculations based on this data provide a reasonable approximation of SSPS slave relay (material) life.

TABLE 8-7 LIFE OF POLYETHERIMODE BASED ON 2.5% SHRINKAGE				
Temperature[1]		**Service Life Years Based on Duty Cycle[2]**		
(°F)	**(°C)**	**(100%)**	**(20%)**	**(0%)**
75.0	23.9	6.41E+04	3.21E+05	1.78E+08
80.0	26.7	4.86E+04	2.43E+05	1.18E+08
85.0	29.4	3.71E+04	1.86E+05	7.92E+07
90.0	32.2	2.84E+04	1.42E+05	5.34E+07
95.0	35.0	2.18E+04	1.09E+05	3.63E+07
100.0	37.8	1.68E+04	8.39E+04	2.48E+07
105.0	40.6	1.30E+04	6.48E+04	1.71E+07
110.0	43.3	1.01E+04	5.07E+04	1.18E+07
115.0	46.1	7.88E+03	3.94E+04	8.24E+06
120.0	48.9	6.17E+03	3.08E+04	5.78E+06
125.0	51.7	4.85E+03	2.41E+04	4.08E+06
86.5[3]	30.3	3.42E+04	1.71E+05	7.03E+07
78.4[3]	25.8	5.31E+04	2.66E+05	1.35E+08
85.2[3]	29.6	3.67E+04	1.83E+05	7.80E+07
77.5[3]	25.3	5.58E+04	2.79E+05	1.45E+08

NOTES:
1. Relay temperature rise (when energized) is 65°C.
2. Aging test/reference data consists of 1.13 eV, 8000 hours, 250°C.
3. In-cabinet temperature data provided by Farley Nuclear Plant is considered to be typical of other SSPS plants. Calculations based on this data provide a reasonable approximation of SSPS slave relay (material) life.

TABLE 8-8 LIFE OF PVC BASED ON STATIC ELONGATION (50% RETENTION)				
Temperature[1]		Service Life Years Based on Duty Cycle[2]		
(°F)	(°C)	(100%)	(20%)	(0%)
75.0	23.9	4.75E+00	2.37E+01	1.42E+04
80.0	26.7	3.59E+00	1.79E+01	9.38E+03
85.0	29.4	2.73E+00	1.37E+01	6.25E+03
90.0	32.2	2.09E+00	1.04E+01	4.20E+03
95.0	35.0	1.60E+00	7.98E+00	2.84E+03
100.0	37.8	1.23E+00	6.13E+00	1.94E+03
105.0	40.6	9.50E-01	4.72E+00	1.33E+03
110.0	43.3	7.37E-01	3.69E+00	9.17E+02
115.0	46.1	5.73E-01	2.86E+00	6.37E+02
120.0	48.9	4.48E-01	2.23E+00	4.45E+02
125.0	51.7	3.51E-01	1.74E+00	3.13E+02
86.5[3]	30.3	2.52E+00	1.26E+01	5.54E+03
78.4[3]	25.8	3.93E+00	1.96E+01	1.07E+04
85.2[3]	29.6	2.70E+00	1.34E+01	6.15E+03
77.5[3]	25.3	4.13E+00	2.06E+01	1.15E+04

NOTES:
1. Relay temperature rise (when energized) is 65°C.
2. Aging test/reference data consists of 1.14 eV, 1000 hours, 130°C.
3. In-cabinet temperature data provided by Farley Nuclear Plant is considered to be typical of other SSPS plants. Calculations based on this data provide a reasonable approximation of SSPS slave relay (material) life.

TABLE 8-8a LIFE OF PVC BASED ON STATIC ELONGATION (50% RETENTION)				
Temperature[1]		**Service Life Years Based on Duty Cycle[2]**		
(°F)	(°C)	(100%)	(20%)	(0%)
75.0	23.9	9.76E+00	4.87E+01	1.42E+04
80.0	26.7	7.31E+00	3.64E+01	9.38E+03
85.0	29.4	5.50E+00	2.76E+01	6.25E+03
90.0	32.2	4.15E+00	2.08E+01	4.20E+03
95.0	35.0	3.15E+00	1.57E+01	2.84E+03
100.0	37.8	2.40E+00	1.19E+01	1.94E+03
105.0	40.6	1.83E+00	9.09E+00	1.33E+03
110.0	43.3	1.41E+00	7.03E+00	9.17E+02
115.0	46.1	1.09E+00	5.40E+00	6.37E+02
120.0	48.9	8.41E-01	4.17E+00	4.45E+02
125.0	51.7	6.53E-01	3.23E+00	3.13E+02
86.5[3]	30.3	5.05E+00	2.51E+01	5.54E+03
78.4[3]	25.8	8.02E+00	3.99E+01	1.07E+04
85.2[3]	29.6	5.44E+00	2.70E+01	6.15E+03
77.5[3]	25.3	8.44E+00	4.21E+01	1.15E+04

NOTES:

1. Relay temperature rise (when energized) is 58°C.
2. Aging test/reference data consists of 1.14 eV, 1000 hours, 130°C.
3. In-cabinet temperature data provided by Farley Nuclear Plant is considered to be typical of other SSPS plants. Calculations based on this data provide a reasonable approximation of SSPS slave relay (material) life.

TABLE 8-8b LIFE OF PVC BASED ON STATIC ELONGATION (50% RETENTION)				
Temperature[1]		Service Life Years Based on Duty Cycle[2]		
(°F)	(°C)	(100%)	(20%)	(0%)
75.0	23.9	4.45E+02	1.98E+03	1.42E+04
80.0	26.7	3.13E+02	1.38E+03	9.38E+03
85.0	29.4	2.22E+02	9.80E+02	6.25E+03
90.0	32.2	1.58E+02	6.90E+02	4.20E+03
95.0	35.0	1.13E+02	4.89E+02	2.84E+03
100.0	37.8	8.14E+01	3.48E+02	1.94E+03
105.0	40.6	5.89E+01	2.50E+02	1.33E+03
110.0	43.3	4.29E+01	1.82E+02	9.17E+02
115.0	46.1	3.14E+01	1.31E+02	6.37E+02
120.0	48.9	2.31E+01	9.56E+01	4.45E+02
125.0	51.7	1.70E+01	6.98E+01	3.13E+02
86.5[3]	30.3	2.00E+02	8.75E+02	5.54E+03
78.4[3]	25.8	3.51E+02	1.55E+03	1.07E+04
85.2[3]	29.6	2.19E+02	9.55E+02	6.15E+03
77.5[3]	25.3	3.73E+02	1.65E+03	1.15E+04

NOTES:
1. Relay temperature rise (when energized) is 25°C.
2. Aging test/reference data consists of 1.14 eV, 1000 hours, 130°C.
3. In-cabinet temperature data provided by Farley Nuclear Plant is considered to be typical of other SSPS plants. Calculations based on this data provide a reasonable approximation of SSPS slave relay (material) life.

TABLE 8-9 LIFE OF POLYESTER/ACRYLIC BASED ON IEEE #57 DIELECTRIC TWIST TEST				
Temperature[1]		**Service Life Years Based on Duty Cycle[2]**		
(°F)	**(°C)**	**(100%)**	**(20%)**	**(0%)**
75.0	23.9	1.07E+02	5.34E+02	2.98E+05
80.0	26.7	8.12E+01	4.05E+02	1.98E+05
85.0	29.4	6.19E+01	3.11E+02	1.32E+05
90.0	32.2	4.73E+01	2.37E+02	8.91E+04
95.0	35.0	3.64E+01	1.82E+02	6.05E+04
100.0	37.8	2.80E+01	1.40E+02	4.14E+04
105.0	40.6	2.17E+01	1.08E+02	2.85E+04
110.0	43.3	1.69E+01	8.44E+01	1.97E+04
115.0	46.1	1.32E+01	6.57E+01	1.37E+04
120.0	48.9	1.03E+01	5.13E+01	9.64E+03
125.0	51.7	8.09E+00	4.02E+01	6.81E+03
86.5[3]	30.3	5.71E+01	2.85E+02	1.17E+05
78.4[3]	25.8	8.86E+01	4.42E+02	2.25E+05
85.2[3]	29.6	6.12E+01	3.05E+02	1.30E+05
77.5[3]	25.3	9.31E+01	4.65E+02	2.42E+05

NOTES:

1. Relay temperature rise (when energized) is 65°C.
2. Aging test/reference data consists of 1.13 eV, 5000 hours, 150°C.
3. In-cabinet temperature data provided by Farley Nuclear Plant is considered to be typical of other SSPS plants. Calculations based on this data provide a reasonable approximation of SSPS slave relay (material) life.

TABLE 8-9a LIFE OF POLYESTER/ACRYLIC BASED ON IEEE #57 DIELECTRIC TWIST TEST				
Temperature[1]		Service Life Years Based on Duty Cycle[2]		
(°F)	(°C)	(100%)	(20%)	(0%)
75.0	23.9	2.19E+02	1.09E+03	2.98E+05
80.0	26.7	1.64E+02	8.16E+02	1.98E+05
85.0	29.4	1.24E+02	6.20E+02	1.32E+05
90.0	32.2	9.37E+01	4.68E+02	8.91E+04
95.0	35.0	7.12E+01	3.55E+02	6.05E+04
100.0	37.8	5.44E+01	2.70E+02	4.14E+04
105.0	40.6	4.17E+01	2.07E+02	2.85E+04
110.0	43.3	3.21E+01	1.60E+02	1.97E+04
115.0	46.1	2.48E+01	1.23E+02	1.37E+04
120.0	48.9	1.92E+01	9.54E+01	9.64E+03
125.0	51.7	1.50E+01	7.40E+01	6.81E+03
86.5[3]	30.3	1.14E+02	5.66E+02	1.17E+05
78.4[3]	25.8	1.80E+02	8.96E+02	2.25E+05
85.2[3]	29.6	1.22E+02	6.08E+02	1.30E+05
77.5[3]	25.3	1.89E+02	9.43E+02	2.42E+05

NOTES:
1. Relay temperature rise (when energized) is 58°C.
2. Aging test/reference data consists of 1.13 eV, 5000 hours, 150°C.
3. In-cabinet temperature data provided by Farley Nuclear Plant is considered to be typical of other SSPS plants. Calculations based on this data provide a reasonable approximation of SSPS slave relay (material) life.

TABLE 8-9b LIFE OF POLYESTER/ACRYLIC BASED ON IEEE #57 DIELECTRIC TWIST TEST				
Temperature(1)		**Service Life Years Based on Duty Cycle(2)**		
(°F)	**(°C)**	**(100%)**	**(20%)**	**(0%)**
75.0	23.9	9.64E+03	4.28E+04	2.98E+05
80.0	26.7	6.81E+03	2.99E+04	1.98E+05
85.0	29.4	4.83E+03	2.13E+04	1.32E+05
90.0	32.2	3.45E+03	1.50E+04	8.91E+04
95.0	35.0	2.48E+03	1.07E+04	6.05E+04
100.0	37.8	1.79E+03	7.63E+03	4.14E+04
105.0	40.6	1.30E+03	5.48E+03	2.85E+04
110.0	43.3	9.48E+02	4.00E+03	1.97E+04
115.0	46.1	6.95E+02	2.90E+03	1.37E+04
120.0	48.9	5.12E+02	2.12E+03	9.64E+03
125.0	51.7	3.79E+02	1.55E+03	6.81E+03
86.5(3)	30.3	4.37E+03	1.90E+04	1.17E+05
78.4(3)	25.8	7.60E+03	3.35E+04	2.25E+05
85.2(3)	29.6	4.77E+03	2.07E+04	1.30E+05
77.5(3)	25.3	8.09E+03	3.57E+04	2.42E+05

NOTES:
1. Relay temperature rise (when energized) is 25°C.
2. Aging test/reference data consists of 1.13 eV, 5000 hours, 150°C.
3. In-cabinet temperature data provided by Farley Nuclear Plant is considered to be typical of other SSPS plants. Calculations based on this data provide a reasonable approximation of SSPS slave relay (material) life.

TABLE 8-10 LIFE OF NYLON ZYTEL 101 BASED ON TENSILE STRENGTH (50% RETENTION)

Temperature[1]		Service Life Years Based on Duty Cycle[2]		
(deg. F)	(deg. C)	(100%)	(20%)	(0%)
75.0	23.9	2.57E+00	1.28E+01	1.23E+03
80.0	26.7	2.07E+00	1.03E+01	8.89E+02
85.0	29.4	1.68E+00	8.33E+00	6.56E+02
90.0	32.2	1.36E+00	6.75E+00	4.82E+02
95.0	35.0	1.11E+00	5.48E+00	3.55E+02
100.0	37.8	9.05E-01	4.46E+00	2.64E+02
105.0	40.6	7.41E-01	3.65E+00	1.97E+02
110.0	43.3	6.12E-01	3.01E+00	1.49E+02
115.0	46.1	5.04E-01	2.47E+00	1.12E+02
120.0	48.9	4.16E-01	2.04E+00	8.51E+02
125.0	51.7	3.44E-01	1.68E+00	6.48E+01
86.5[3]	30.3	1.57E+00	7.78E+00	5.94E+02
78.4[3]	25.8	2.22E+00	1.10E+01	9.85E+02
85.2[3]	29.6	1.66E+00	8.21E+00	6.42E+02
77.5[3]	25.3	2.30E+00	1.14E+01	1.04E+02

NOTES:
1. Relay temperature rise (when energized) is 65°C.
2. Aging test/reference data consists of 0.8787 eV, 100 hours, 175°C.
3. In-cabinet temperature data provided by Farley Nuclear Plant is considered to be typical of other SSPS plants. Calculations based on this data provide a reasonable approximation of SSPS slave relay (material) life.

TABLE 8-10a LIFE OF NYLON ZYTEL 101 BASED ON TENSILE STRENGTH (50% RETENTION)				
Temperature[1]		Service Life Years Based on Duty Cycle[2]		
(deg. F)	(deg. C)	(100%)	(20%)	(0%)
75.0	23.9	4.47E+00	2.20E+01	1.23E+03
80.0	26.7	3.57E+00	1.76E+01	8.89E+02
85.0	29.4	2.89E+00	1.42E+01	6.56E+02
90.0	32.2	2.32E+00	1.14E+01	4.82E+02
95.0	35.0	1.87E+00	9.17E+00	3.55E+02
100.0	37.8	1.51E+00	7.40E+00	2.64E+02
105.0	40.6	1.23E+00	6.00E+00	1.97E+02
110.0	43.3	1.01E+00	4.91E+00	1.49E+02
115.0	46.1	8.24E-01	4.00E+00	1.12E+02
120.0	48.9	6.75E-01	3.27E+00	8.51E+01
125.0	51.7	5.55E-01	2.68E+00	6.48E+01
86.5[3]	30.3	2.69E+00	1.32E+01	5.94E+02
78.4[3]	25.8	3.84E+00	1.89E+01	9.85E+02
85.2[3]	29.6	2.84E+00	1.40E+01	6.42E+02
77.5[3]	25.3	4.00E+00	1.97E+01	1.04E+03

NOTES:
1. Relay temperature rise (when energized) is 58°C.
2. Aging test/reference data consists of 0.8787 eV, 100 hours, 175°C.
3. In-cabinet temperature data provided by Farley Nuclear Plant is considered to be typical of other SSPS plants. Calculations based on this data provide a reasonable approximation of SSPS slave relay (material) life.

TABLE 8-10b LIFE OF NYLON ZYTEL 101 BASED ON TENSILE STRENGTH (50% RETENTION)

Temperature[1]		Service Life Years Based on Duty Cycle[2]		
(deg. F)	(deg. C)	(100%)	(20%)	(0%)
75.0	23.9	8.51E+01	3.33E+02	1.23E+03
80.0	26.7	6.48E+01	2.51E+02	8.89E+02
85.0	29.4	5.00E+01	1.92E+02	6.56E+02
90.0	32.2	3.84E+01	1.46E+02	4.82E+02
95.0	35.0	2.96E+01	1.11E+02	3.55E+02
100.0	37.8	2.29E+01	8.51E+01	2.64E+02
105.0	40.6	1.78E+01	6.55E+01	1.97E+02
110.0	43.3	1.41E+01	5.10E+01	1.49E+02
115.0	46.1	1.10E+01	3.96E+01	1.12E+02
120.0	48.9	8.68E+00	3.08E+01	8.51E+01
125.0	51.7	6.86E+00	2.41E+01	6.48E+01
86.5[3]	30.3	4.59E+01	1.75E+02	5.94E+02
78.4[3]	25.8	7.07E+01	2.75E+02	9.85E+02
85.2[3]	29.6	4.90E+01	1.88E+02	6.42E+02
77.5[3]	25.3	7.42E+01	2.89E+02	1.04E+03

NOTES:
1. Relay temperature rise (when energized) is 25°C.
2. Aging test/reference data consists of 0.8787 eV, 100 hours, 175°C.
3. In-cabinet temperature data provided by Farley Nuclear Plant is considered to be typical of other SSPS plants. Calculations based on this data provide a reasonable approximation of SSPS slave relay (material) life.

TABLE 8-11 THIS TABLE LEFT BLANK INTENTIONALLY				
Temperature		Service Life Years Based on Duty Cycle		
(deg. F)	(deg. C)	(100%)	(20%)	(0%)
NOTES:				

TABLE 8-11a THIS TABLE LEFT BLANK INTENTIONALLY				
Temperature		Service Life Years Based on Duty Cycle		
(deg. F)	(deg. C)	(100%)	(20%)	(0%)
NOTES:				

TABLE 8-11b THIS TABLE LEFT BLANK INTENTIONALLY				
Temperature		Service Life Years Based on Duty Cycle		
(deg. F)	(deg. C)	(100%)	(20%)	(0%)
NOTES:				

o:\3378w.non:1b/080800

TABLE 8-12 LIFE OF PHENOLIC POLYESTER BASED ON IEEE #57 DIELECTRIC TWIST TEST

Temperature[1]		Service Life Years Based on Duty Cycle[2]		
(°F)	(°C)	(100%)	(20%)	(0%)
75.0	23.9	4.43E+02	2.14E+03	5.23E+04
80.0	26.7	3.75E+02	1.81E+03	4.09E+04
85.0	29.4	3.18E+02	1.54E+03	3.21E+04
90.0	32.2	2.71E+02	1.30E+03	2.53E+04
95.0	35.0	2.31E+02	1.11E+03	2.01E+04
100.0	37.8	1.98E+02	9.43E+02	1.60E+04
105.0	40.6	1.70E+02	8.04E+02	1.27E+04
110.0	43.3	1.46E+02	6.91E+02	1.02E+04
115.0	46.1	1.25E+02	5.92E+02	8.23E+03
120.0	48.9	1.08E+02	5.08E+02	6.65E+03
125.0	51.7	9.36E+01	4.37E+02	5.39E+03
86.5[3]	30.3	3.03E+02	1.46E+03	2.99E+04
78.4[3]	25.8	3.95E+02	1.91E+03	4.42E+04
85.2[3]	29.6	3.16E+02	1.52E+03	3.18E+04
77.5[3]	25.3	4.07E+02	1.97E+03	4.63E+04

NOTES:
1. Relay temperature rise (when energized) is 65°C.
2. Aging test/reference data consists of 0.68 eV, 40000 hours, 185°C.
3. In-cabinet temperature data provided by Farley Nuclear Plant is considered to be typical of other SSPS plants. Calculations based on this data provide a reasonable approximation of SSPS slave relay (material) life.

TABLE 8-13 LIFE OF EPOXY RESIN (DOLPHON CC-1090/STERLING E-100) BASED ON WEIGHT LOSS (16%)				
Temperature[1]		**Service Life Years Based on Duty Cycle[2]**		
(°F)	**(°C)**	**(100%)**	**(20%)**	**(0%)**
75.0	23.9	1.80E+03	8.97E+03	1.63E+06
80.0	26.7	1.42E+03	7.06E+03	1.15E+06
85.0	29.4	1.12E+03	5.62E+03	8.12E+05
90.0	32.2	8.94E+02	4.46E+03	5.79E+05
95.0	35.0	7.13E+02	3.55E+03	4.15E+05
100.0	37.8	5.70E+02	2.83E+03	2.99E+05
105.0	40.6	4.58E+02	2.27E+03	2.17E+05
110.0	43.3	3.69E+02	1.83E+03	1.59E+05
115.0	46.1	2.98E+02	1.48E+03	1.16E+05
120.0	48.9	2.41E+02	1.19E+03	8.58E+04
125.0	51.7	1.96E+02	9.68E+02	6.36E+04
86.5[3]	30.3	1.05E+03	5.22E+03	7.33E+05
78.4[3]	25.8	1.53E+03	7.62E+03	1.28E+06
85.2[3]	29.6	1.11E+03	5.53E+03	8.01E+05
77.5[3]	25.3	1.60E+03	7.95E+03	1.37E+06

NOTES:
1. Relay temperature rise (when energized) is 65°C.
2. Aging test/reference data consists of 0.97 eV, 40000 hours, 175°C.
3. In-cabinet temperature data provided by Farley Nuclear Plant is considered to be typical of other SSPS plants. Calculations based on this data provide a reasonable approximation of SSPS slave relay (material) life.

TABLE 8-14 LIFE OF POLYURETHANE/NYLON BASED ON IEEE #57 DIELECTRIC TWIST TEST

Temperature[1]		Service Life Years Based on Duty Cycle[2]		
(°F)	(°C)	(100%)	(20%)	(0%)
75.0	23.9	5.76E+01	2.87E+02	6.90E+04
80.0	26.7	4.50E+01	2.24E+02	4.79E+04
85.0	29.4	3.53E+01	1.77E+02	3.34E+04
90.0	32.2	2.78E+01	1.39E+02	2.35E+04
95.0	35.0	2.19E+01	1.09E+02	1.66E+04
100.0	37.8	1.74E+01	8.65E+01	1.18E+04
105.0	40.6	1.38E+01	6.86E+01	8.47E+03
110.0	43.3	1.10E+01	5.51E+01	6.10E+03
115.0	46.1	8.85E+00	4.40E+01	4.42E+03
120.0	48.9	7.11E+00	3.52E+01	3.22E+03
125.0	51.7	5.73E+00	2.83E+01	2.36E+03
86.5[3]	30.3	3.28E+01	1.63E+02	3.00E+04
78.4[3]	25.8	4.87E+01	2.42E+02	5.38E+04
85.2[3]	29.6	3.50E+01	1.74E+02	3.29E+04
77.5[3]	25.3	5.09E+01	2.54E+02	5.74E+04

NOTES:
1. Relay temperature rise (when energized) is 65°C.
2. Aging test/reference data consists of 1.01 eV, 1000 hours, 175°C.
3. In-cabinet temperature data provided by Farley Nuclear Plant is considered to be typical of other SSPS plants. Calculations based on this data provide a reasonable approximation of SSPS slave relay (material) life.

TABLE 8-14a LIFE OF POLYURETHANE/NYLON BASED ON IEEE #57 DIELECTRIC TWIST TEST				
Temperature[1]		**Service Life Years Based on Duty Cycle[2]**		
(°F)	**(°C)**	**(100%)**	**(20%)**	**(0%)**
75.0	23.9	1.09E+02	5.43E+02	6.90E+04
80.0	26.7	8.44E+01	4.19E+02	4.79E+04
85.0	29.4	6.56E+01	3.27E+02	3.34E+04
90.0	32.2	5.11E+01	2.54E+02	2.35E+04
95.0	35.0	4.00E+01	1.99E+02	1.66E+04
100.0	37.8	3.14E+01	1.56E+02	1.18E+04
105.0	40.6	2.48E+01	1.22E+02	8.47E+03
110.0	43.3	1.96E+01	9.73E+01	6.10E+03
115.0	46.1	1.56E+01	7.70E+01	4.42E+03
120.0	48.9	1.24E+01	6.12E+01	3.22E+03
125.0	51.7	9.93E+00	4.88E+01	2.36E+03
86.5[3]	30.3	6.08E+01	3.02E+02	3.00E+04
78.4[3]	25.8	9.16E+01	4.55E+02	5.38E+04
85.2[3]	29.6	6.49E+01	3.21E+02	3.29E+04
77.5[3]	25.3	9.59E+01	4.76E+02	5.74E+04

NOTES:
1. Relay temperature rise (when energized) is 58°C.
2. Aging test/reference data consists of 1.01 eV, 1000 hours, 175°C.
3. In-cabinet temperature data provided by Farley Nuclear Plant is considered to be typical of other SSPS plants. Calculations based on this data provide a reasonable approximation of SSPS slave relay (material) life.

TABLE 8-14b LIFE OF POLYURETHANE/NYLON BASED ON IEEE #57 DIELECTRIC TWIST TEST				
Temperature[1]		Service Life Years Based on Duty Cycle[2]		
(°F)	(°C)	(100%)	(20%)	(0%)
75.0	23.9	3.22E+03	1.36E+04	6.90E+04
80.0	26.7	2.36E+03	9.84E+03	4.79E+04
85.0	29.4	1.74E+03	7.25E+03	3.34E+04
90.0	32.2	1.28E+03	5.30E+03	2.35E+04
95.0	35.0	9.55E+02	3.90E+03	1.66E+04
100.0	37.8	7.14E+02	2.88E+03	1.18E+04
105.0	40.6	5.36E+02	2.14E+03	8.47E+03
110.0	43.3	4.05E+02	1.61E+03	6.10E+03
115.0	46.1	3.07E+02	1.21E+03	4.42E+03
120.0	48.9	2.33E+02	9.06E+02	3.22E+03
125.0	51.7	1.79E+02	6.85E+02	2.36E+03
86.5[3]	30.3	1.58E+03	6.55E+03	3.00E+04
78.4[3]	25.8	2.60E+03	1.09E+04	5.38E+04
85.2[3]	29.6	1.71E+03	7.08E+03	3.29E+04
77.5[3]	25.3	2.75E+03	1.16E+04	5.74E+04

NOTES:
1. Relay temperature rise (when energized) is 25°C.
2. Aging test/reference data consists of 1.01 eV, 1000 hours, 175°C.
3. In-cabinet temperature data provided by Farley Nuclear Plant is considered to be typical of other SSPS plants. Calculations based on this data provide a reasonable approximation of SSPS slave relay (material) life.

TABLE 8-15 LIFE OF ALKYD BASED ON DIELECTRIC STRENGTH (50% RETENTION)				
Temperature[1]		Service Life Years Based on Duty Cycle[2]		
(°F)	(°C)	(100%)	(20%)	(0%)
75.0	23.9	3.39E+02	1.69E+03	2.04E+06
80.0	26.7	2.50E+02	1.25E+03	1.30E+06
85.0	29.4	1.86E+02	9.34E+02	8.37E+05
90.0	32.2	1.38E+02	6.94E+02	5.43E+05
95.0	35.0	1.04E+02	5.19E+02	3.55E+05
100.0	37.8	7.79E+01	3.89E+02	2.34E+05
105.0	40.6	5.88E+01	2.93E+02	1.55E+05
110.0	43.3	4.46E+01	2.24E+02	1.04E+05
115.0	46.1	3.40E+01	1.70E+02	6.98E+04
120.0	48.9	2.59E+01	1.30E+02	4.73E+04
125.0	51.7	1.99E+01	9.92E+01	3.23E+04
86.5[3]	30.3	1.70E+02	8.49E+02	7.34E+05
78.4[3]	25.8	2.75E+02	1.38E+03	1.50E+06
85.2[3]	29.6	1.83E+02	9.14E+02	8.22E+05
77.5[3]	25.3	2.91E+02	1.45E+03	1.63E+06

NOTES:
1. Relay temperature rise (when energized) is 65°C.
2. Aging test/reference data consists of 1.24 eV, 1000 hours, 180°C.
3. In-cabinet temperature data provided by Farley Nuclear Plant is considered to be typical of other SSPS plants. Calculations based on this data provide a reasonable approximation of SSPS slave relay (material) life.

TABLE 8-15a LIFE OF ALKYD BASED ON DIELECTRIC STRENGTH (50% RETENTION)				
Temperature[1]		Service Life Years Based on Duty Cycle[2]		
(°F)	(°C)	(100%)	(20%)	(0%)
75.0	23.9	7.42E+02	3.71E+03	2.04E+06
80.0	26.7	5.41E+02	2.70E+03	1.30E+06
85.0	29.4	3.97E+02	2.00E+03	8.37E+05
90.0	32.2	2.93E+02	1.47E+03	5.43E+05
95.0	35.0	2.17E+02	1.08E+03	3.55E+05
100.0	37.8	1.61E+02	8.03E+02	2.34E+05
105.0	40.6	1.20E+02	5.99E+02	1.55E+05
110.0	43.3	9.03E+01	4.53E+02	1.04E+05
115.0	46.1	6.80E+01	3.40E+02	6.98E+04
120.0	48.9	5.15E+01	2.57E+02	4.73E+04
125.0	51.7	3.91E+01	1.94E+02	3.23E+04
86.5[3]	30.3	3.62E+02	1.81E+03	7.34E+05
78.4[3]	25.8	5.98E+02	2.99E+03	1.50E+06
85.2[3]	29.6	3.92E+02	1.95E+03	8.22E+05
77.5[3]	25.3	6.33E+02	3.16E+03	1.63E+06

NOTES:
1. Relay temperature rise (when energized) is 58°C.
2. Aging test/reference data consists of 1.24 eV, 1000 hours, 180°C.
3. In-cabinet temperature data provided by Farley Nuclear Plant is considered to be typical of other SSPS plants. Calculations based on this data provide a reasonable approximation of SSPS slave relay (material) life.

TABLE 8-15b LIFE OF ALKYD BASED ON DIELECTRIC STRENGTH (50% RETENTION)				
Temperature[1]		Service Life Years Based on Duty Cycle[2]		
(°F)	(°C)	(100%)	(20%)	(0%)
75.0	23.9	4.73E+04	2.17E+05	2.04E+06
80.0	26.7	3.23E+04	1.47E+05	1.30E+06
85.0	29.4	2.22E+04	1.01E+05	8.37E+05
90.0	32.2	1.53E+04	6.93E+04	5.43E+05
95.0	35.0	1.06E+04	4.77E+04	3.55E+05
100.0	37.8	7.45E+03	3.31E+04	2.34E+05
105.0	40.6	5.24E+03	2.30E+04	1.55E+05
110.0	43.3	3.71E+03	1.64E+04	1.04E+05
115.0	46.1	2.64E+03	1.15E+04	6.98E+04
120.0	48.9	1.89E+03	8.16E+03	4.73E+04
125.0	51.7	1.36E+03	5.81E+03	3.23E+04
86.5[3]	30.3	1.98E+04	8.96E+04	7.34E+05
78.4[3]	25.8	3.64E+04	1.66E+05	1.50E+06
85.2[3]	29.6	2.18E+04	9.85E+04	8.22E+05
77.5[3]	25.3	3.90E+04	1.78E+05	1.63E+06

NOTES:

1. Relay temperature rise (when energized) is 25°C.
2. Aging test/reference data consists of 1.24 eV, 1000 hours, 180°C.
3. In-cabinet temperature data provided by Farley Nuclear Plant is considered to be typical of other SSPS plants. Calculations based on this data provide a reasonable approximation of SSPS slave relay (material) life.

TABLE 8-16 LIFE OF DIALLYL PHTHALATE BASED ON FLEXURAL STRENGTH (50% RETENTION)				
Temperature[1]		Service Life Years Based on Duty Cycle[2]		
(°F)	(°C)	(100%)	(20%)	(0%)
75.0	23.9	4.26E+02	2.13E+03	1.10E+06
80.0	26.7	3.24E+02	1.61E+03	7.36E+05
85.0	29.4	2.47E+02	1.24E+03	4.94E+05
90.0	32.2	1.90E+02	9.50E+02	3.34E+05
95.0	35.0	1.46E+02	7.30E+02	2.28E+05
100.0	37.8	1.13E+02	5.63E+02	1.56E+05
105.0	40.6	8.76E+01	4.35E+02	1.08E+05
110.0	43.3	6.82E+01	3.41E+02	7.49E+04
115.0	46.1	5.33E+01	2.66E+02	5.24E+04
120.0	48.9	4.18E+01	2.08E+02	3.69E+04
125.0	51.7	3.29E+01	1.63E+02	2.61E+04
86.5[3]	30.3	2.28E+02	1.14E+03	4.39E+05
78.4[3]	25.8	3.53E+02	1.76E+03	8.37E+05
85.2[3]	29.6	2.45E+02	1.22E+03	4.86E+05
77.5[3]	25.3	3.71E+02	1.85E+03	9.00E+05

NOTES:
1. Relay temperature rise (when energized) is 65°C.
2. Aging test/reference data consists of 1.12 eV, 10250 hours, 160°C.
3. In-cabinet temperature data provided by Farley Nuclear Plant is considered to be typical of other SSPS plants. Calculations based on this data provide a reasonable approximation of SSPS slave relay (material) life.

TABLE 8-16a LIFE OF DIALLYL PHTHALATE BASED ON FLEXURAL STRENGTH (50% RETENTION)				
Temperature[1]		**Service Life Years Based on Duty Cycle[2]**		
(°F)	**(°C)**	**(100%)**	**(20%)**	**(0%)**
75.0	23.9	8.64E+02	4.31E+03	1.10E+06
80.0	26.7	6.50E+02	3.24E+03	7.36E+05
85.0	29.4	4.91E+02	2.46E+03	4.94E+05
90.0	32.2	3.73E+02	1.86E+03	3.34E+05
95.0	35.0	2.84E+02	1.42E+03	2.28E+05
100.0	37.8	2.18E+02	1.08E+03	1.56E+05
105.0	40.6	1.67E+02	8.29E+02	1.08E+05
110.0	43.3	1.29E+02	6.44E+02	7.49E+04
115.0	46.1	9.99E+01	4.97E+02	5.24E+04
120.0	48.9	7.77E+01	3.85E+02	3.69E+04
125.0	51.7	6.06E+01	3.00E+02	2.61E+04
86.5[3]	30.3	4.52E+02	2.25E+03	4.39E+05
78.4[3]	25.8	7.12E+02	3.55E+03	8.37E+05
85.2[3]	29.6	4.86E+02	2.41E+03	4.86E+05
77.5[3]	25.3	7.49E+02	3.73E+03	9.00E+05

NOTES:

1. Relay temperature rise (when energized) is 58°C.
2. Aging test/reference data consists of 1.12 eV, 10250 hours, 160°C.
3. In-cabinet temperature data provided by Farley Nuclear Plant is considered to be typical of other SSPS plants. Calculations based on this data provide a reasonable approximation of SSPS slave relay (material) life.

TABLE 8-17 THIS TABLE LEFT BLANK INTENTIONALLY				
Temperature		Service Life Years Based on Duty Cycle		
(°F)	(°C)	(100%)	(20%)	(0%)

NOTES:

TABLE 8-17a THIS TABLE LEFT BLANK INTENTIONALLY

Temperature		Service Life Years Based on Duty Cycle		
(°F)	(°C)	(100%)	(20%)	(0%)

NOTES:

TABLE 8-17b THIS TABLE LEFT BLANK INTENTIONALLY				
Temperature		Service Life Years Based on Duty Cycle		
(°F)	(°C)	(100%)	(20%)	(0%)

NOTES:

TABLE 8-18 LIFE OF G-9 GLASS-MELAMINE BASED ON FLEXURAL STRENGTH (50% RETENTION)				
Temperature[1]		Service Life Years Based on Duty Cycle[2]		
(°F)	(°C)	(100%)	(20%)	(0%)
75.0	23.9	5.34E+04	2.68E+05	1.94E+12
80.0	26.7	2.92E+04	1.45E+05	7.88E+11
85.0	29.4	1.61E+04	8.14E+04	3.26E+11
90.0	32.2	8.92E+03	4.50E+04	1.37E+11
95.0	35.0	5.00E+03	2.51E+04	5.87E+10
100.0	37.8	2.83E+03	1.41E+04	2.55E+10
105.0	40.6	1.61E+03	8.02E+03	1.12E+10
110.0	43.3	9.27E+02	4.68E+03	5.01E+09
115.0	46.1	5.37E+02	2.70E+03	2.27E+09
120.0	48.9	3.14E+02	1.57E+03	1.04E+09
125.0	51.7	1.85E+02	9.20E+02	4.85E+08
86.5[3]	30.3	1.35E+04	6.72E+04	2.51E+11
78.4[3]	25.8	3.54E+04	1.77E+05	1.05E+12
85.2[3]	29.6	1.57E+04	7.80E+04	3.15E+11
77.5[3]	25.3	3.94E+04	1.97E+05	1.23E+12

NOTES:
1. Relay temperature rise (when energized) is 65°C.
2. Aging test/reference data consists of 2.48 eV, 1000 hours, 160°C.
3. In-cabinet temperature data provided by Farley Nuclear Plant is considered to be typical of other SSPS plants. Calculations based on this data provide a reasonable approximation of SSPS slave relay (material) life.

TABLE 8-19 THIS TABLE LEFT BLANK INTENTIONALLY				
Temperature		Service Life Years Based on Duty Cycle		
(°F)	(°C)	(100%)	(20%)	(0%)

NOTES:

TABLE 8-20 LIFE OF G-10 LAMINATE BASED ON FLEXURAL STRENGTH (50% RETENTION)				
Temperature[1]		**Service Life Years Based on Duty Cycle**[2]		
(°F)	**(°C)**	**(100%)**	**(20%)**	**(0%)**
75.0	23.9	1.03E+03	5.16E+03	6.75E+07
80.0	26.7	7.01E+02	3.50E+03	3.81E+07
85.0	29.4	4.80E+02	2.42E+03	2.17E+07
90.0	32.2	3.30E+02	1.66E+03	1.25E+07
95.0	35.0	2.28E+02	1.14E+03	7.28E+06
100.0	37.8	1.59E+02	7.93E+02	4.28E+06
105.0	40.6	1.11E+02	5.52E+02	2.54E+06
110.0	43.3	7.80E+01	3.92E+02	1.52E+06
115.0	46.1	5.51E+01	2.76E+02	9.17E+05
120.0	48.9	3.91E+01	1.95E+02	5.58E+05
125.0	51.7	2.79E+01	1.39E+02	3.43E+05
86.5[3]	30.3	4.28E+02	2.14E+03	1.84E+07
78.4[3]	25.8	7.93E+02	3.96E+03	4.57E+07
85.2[3]	29.6	4.73E+02	2.35E+03	2.12E+07
77.5[3]	25.3	8.50E+02	4.25E+03	5.07E+07

NOTES:

1. Relay temperature rise (when energized) is 65°C.
2. Aging test/reference data consists of 1.58 eV, 6000 hours, 150°C.
3. In-cabinet temperature data provided by Farley Nuclear Plant is considered to be typical of other SSPS plants. Calculations based on this data provide a reasonable approximation of SSPS slave relay (material) life.

TABLE 8-20a LIFE OF G-10 LAMINATE BASED ON FLEXURAL STRENGTH (50% RETENTION)				
Temperature[1]		Service Life Years Based on Duty Cycle[2]		
(°F)	(°C)	(100%)	(20%)	(0%)
75.0	23.9	2.80E+03	1.40E+04	6.75E+07
80.0	26.7	1.88E+03	9.36E+03	3.81E+07
85.0	29.4	1.26E+03	6.37E+03	2.17E+07
90.0	32.2	8.57E+02	4.31E+03	1.25E+07
95.0	35.0	5.84E+02	2.93E+03	7.28E+06
100.0	37.8	4.01E+02	2.00E+03	4.28E+06
105.0	40.6	2.76E+02	1.38E+03	2.54E+06
110.0	43.3	1.92E+02	9.63E+02	1.52E+06
115.0	46.1	1.34E+02	6.70E+02	9.17E+05
120.0	48.9	9.36E+01	4.68E+02	5.58E+05
125.0	51.7	6.59E+01	3.29E+02	3.43E+05
86.5[3]	30.3	1.12E+03	5.62E+03	1.84E+07
78.4[3]	25.8	2.13E+03	1.07E+04	4.57E+07
85.2[3]	29.6	1.24E+03	6.20E+03	2.12E+07
77.5[3]	25.3	2.29E+03	1.14E+04	5.07E+07

NOTES:
1. Relay temperature rise (when energized) is 58°C.
2. Aging test/reference data consists of 1.58 eV, 6000 hours, 150°C.
3. In-cabinet temperature data provided by Farley Nuclear Plant is considered to be typical of other SSPS plants. Calculations based on this data provide a reasonable approximation of SSPS slave relay (material) life.

TABLE 8-21 LIFE OF G-10 LAMINATE BASED ON DIELECTRIC STRENGTH (50% RETENTION)				
Temperature[1]		**Service Life Years Based on Duty Cycle[2]**		
(°F)	**(°C)**	**(100%)**	**(20%)**	**(0%)**
75.0	23.9	5.64E+01	2.81E+02	8.34E+04
80.0	26.7	4.38E+01	2.18E+02	5.72E+04
85.0	29.4	3.41E+01	1.71E+02	3.95E+04
90.0	32.2	2.66E+01	1.33E+02	2.75E+04
95.0	35.0	2.09E+01	1.04E+02	1.93E+04
100.0	37.8	1.65E+01	8.18E+01	1.36E+04
105.0	40.6	1.30E+01	6.45E+01	9.62E+03
110.0	43.3	1.03E+01	5.14E+01	6.86E+03
115.0	46.1	8.20E+00	4.08E+01	4.92E+03
120.0	48.9	6.54E+00	3.25E+01	3.55E+03
125.0	51.7	5.24E+00	2.59E+01	2.58E+03
86.5[3]	30.3	3.16E+01	1.58E+02	3.54E+04
78.4[3]	25.8	4.74E+01	2.36E+02	6.45E+04
85.2[3]	29.6	3.37E+01	1.68E+02	3.90E+04
77.5[3]	25.3	4.97E+01	2.47E+02	6.90E +04

NOTES:
1. Relay temperature rise (when energized) is 65°C.
2. Aging test/reference data consists of 1.04 eV, 4000 hours, 150°C.
3. In-cabinet temperature data provided by Farley Nuclear Plant is considered to be typical of other SSPS plants. Calculations based on this data provide a reasonable approximation of SSPS slave relay (material) life.

TABLE 8-21a LIFE OF G-10 LAMINATE BASED ON DIELECTRIC STRENGTH (50% RETENTION)

Temperature[1]		Service Life Years Based on Duty Cycle[2]		
(°F)	(°C)	(100%)	(20%)	(0%)
75.0	23.9	1.09E+02	5.42E+02	8.34E+04
80.0	26.7	8.36E+01	4.15E+02	5.72E+04
85.0	29.4	6.45E+01	3.22E+02	3.95E+04
90.0	32.2	4.99E+01	2.49E+02	2.75E+04
95.0	35.0	3.88E+01	1.93E+02	1.93E+04
100.0	37.8	3.03E+01	1.50E+02	1.36E+04
105.0	40.6	2.37E+01	1.17E+02	9.62E+03
110.0	43.3	1.86E+01	9.25E+01	6.86E+03
115.0	46.1	1.47E+01	7.27E+01	4.92E+03
120.0	48.9	1.16E+01	5.74E+01	3.55E+03
125.0	51.7	9.23E+00	4.54E+01	2.58E+03
86.5[3]	30.3	5.97E+01	2.96E+02	3.54E+04
78.4[3]	25.8	9.09E+01	4.52E+02	6.45E+04
85.2[3]	29.6	6.38E+01	3.16E+02	3.90E+04
77.5[3]	25.3	9.54E+01	4.74E+02	6.90E+04

NOTES:
1. Relay temperature rise (when energized) is 58°C.
2. Aging test/reference data consists of 1.04 eV, 4000 hours, 150°C.
3. In-cabinet temperature data provided by Farley Nuclear Plant is considered to be typical of other SSPS plants. Calculations based on this data provide a reasonable approximation of SSPS slave relay (material) life.

TABLE 8-21b LIFE OF G-10 LAMINATE BASED ON DIELECTRIC STRENGTH (50% RETENTION)				
Temperature[1]		Service Life Years Based on Duty Cycle[2]		
(°F)	(°C)	(100%)	(20%)	(0%)
75.0	23.9	3.55E+03	1.52E+04	8.34E+04
80.0	26.7	2.58E+03	1.09E+04	5.72E+04
85.0	29.4	1.88E+03	7.97E+03	3.95E+04
90.0	32.2	1.38E+03	5.78E+03	2.75E+04
95.0	35.0	1.02E+03	4.21E+03	1.93E+04
100.0	37.8	7.54E+02	3.08E+03	1.36E+04
105.0	40.6	5.61E+02	2.27E+03	9.62E+03
110.0	43.3	4.20E+02	1.70E+03	6.86E+03
115.0	46.1	3.16E+02	1.26E+03	4.92E+03
120.0	48.9	2.38E+02	9.41E+02	3.55E+03
125.0	51.7	1.81E+02	7.05E+02	2.58E+03
86.5[3]	30.3	1.71E+03	7.18E+03	3.54E+04
78.4[3]	25.8	2.85E+03	1.21E+04	6.45E+04
85.2[3]	29.6	1.86E+03	7.78E+03	3.90E+04
77.5[3]	25.3	3.02E+03	1.29E+04	6.90E+04

NOTES:
1. Relay temperature rise (when energized) is 25°C.
2. Aging test/reference data consists of 1.04 eV, 4000 hours, 150°C.
3. In-cabinet temperature data provided by Farley Nuclear Plant is considered to be typical of other SSPS plants. Calculations based on this data provide a reasonable approximation of SSPS slave relay (material) life.

TABLE 8-22 LIFE OF POLYTETRAFLUOROETHYLENE BASED ON WEIGHT LOSS (TGA DATA)

Temperature[1]		Service Life Years Based on Duty Cycle[2]		
(°F)	(°C)	(100%)	(20%)	(0%)
75.0	23.9	4.48E+03	2.24E+04	1.10E+08
80.0	26.7	3.15E+03	1.57E+04	6.51E+07
85.0	29.4	2.23E+03	1.12E+04	3.90E+07
90.0	32.2	1.58E+03	7.96E+03	2.36E+07
95.0	35.0	1.13E+03	5.67E+03	1.44E+07
100.0	37.8	8.13E+02	4.06E+03	8.87E+06
105.0	40.6	5.87E+02	2.92E+03	5.51E+06
110.0	43.3	4.25E+02	2.14E+03	3.45E+06
115.0	46.1	3.10E+02	1.55E+03	2.18E+06
120.0	48.9	2.27E+02	1.13E+03	1.39E+06
125.0	51.7	1.67E+02	8.30E+02	8.90E+05
86.5[3]	30.3	2.01E+03	1.00E+04	3.35E+07
78.4[3]	25.8	3.52E+03	1.76E+04	7.68E+07
85.2[3]	29.6	2.20E+03	1.09E+04	3.82E+07
77.5[3]	25.3	3.75E+03	1.88E+04	8.44E+07

NOTES:
1. Relay temperature rise (when energized) is 65°C.
2. Aging test/reference data consists of 1.44 eV, 20000 hours, 160°C.
3. In-cabinet temperature data provided by Farley Nuclear Plant is considered to be typical of other SSPS plants. Calculations based on this data provide a reasonable approximation of SSPS slave relay (material) life.

TABLE 8-23 LIFE OF POLYTETRAFLUOROETHYLENE BASED ON THERMAL STABILITY LONG TERM

Temperature[1]		Service Life Years Based on Duty Cycle[2]		
(°F)	(°C)	(100%)	(20%)	(0%)
75.0	23.9	2.88E+12	1.45E+13	5.45E+23
80.0	26.7	1.17E+12	5.82E+12	1.43E+23
85.0	29.4	4.79E+11	2.45E+12	3.83E+22
90.0	32.2	1.99E+11	1.01E+12	1.05E+22
95.0	35.0	8.40E+10	4.24E+11	2.96E+21
100.0	37.8	3.59E+10	1.80E+11	8.52E+20
105.0	40.6	1.55E+10	7.72E+10	2.51E+20
110.0	43.3	6.80E+09	3.46E+10	7.54E+19
115.0	46.1	3.01E+09	1.52E+10	2.31E+19
120.0	48.9	1.35E+09	6.78E+09	7.25E+18
125.0	51.7	6.12E+08	3.05E+09	2.32E+18
86.5[3]	30.3	3.68E+11	1.84E+12	2.59E+22
78.4[3]	25.8	1.55E+12	7.79E+12	2.19E+23
85.2[3]	29.6	4.62E+11	2.30E+12	3.64E+22
77.5[3]	25.3	1.83E+12	9.16E+12	2.78E+23

NOTES:

1. Relay temperature rise (when energized) is 65°C.
2. Aging test/reference data consists of 3.7 eV, 20000 hours, 200°C.
3. In-cabinet temperature data provided by Farley Nuclear Plant is considered to be typical of other SSPS plants. Calculations based on this data provide a reasonable approximation of SSPS slave relay (material) life.

TABLE 8-24 THIS TABLE LEFT BLANK INTENTIONALLY

Temperature		Service Life Years Based on Duty Cycle		
(°F)	(°C)	(100%)	(20%)	(0%)

NOTES:

TABLE 8-24a THIS TABLE LEFT BLANK INTENTIONALLY				
Temperature		Service Life Years Based on Duty Cycle		
(°F)	(°C)	(100%)	(20%)	(0%)
NOTES:				

TABLE 8-24b THIS TABLE LEFT BLANK INTENTIONALLY

Temperature		Service Life Years Based on Duty Cycle		
(°F)	(°C)	(100%)	(20%)	(0%)

NOTES:

9.0 FAILURE EXPERIENCE

The failure experience for SSPS slave relays was derived from the NPRDS database and supplemented by a WOG survey of Westinghouse-designed plants. As expected, both sources reveal that MDR series SSPS slave relay failures have been few and infrequent. Table 9-1 summarizes the point failure data for each of the plants responding to the survey and includes the calculation of a failure rate for the MDR series relay. However, the statistical assessment of the data gathered concludes that both the actuation-based and time-based assessment of the data is statistically inconclusive. This is further discussed in Section 9.1.

Table 9-4 identifies the six (6) reported incidents of problems encountered during SSPS slave (MDR series) relay testing. Of the six (6) events in Table 9-4, one was the result of a valve limit switch failure, and was not a failure of the relay itself. The remaining five events are discussed in Section 9.2.

9.1 STATISTICAL ASSESSMENT OF RELAY FAILURE DATA

There are an insufficient number of relay failures in each of the test intervals to perform rigorous statistical calculations comparing the failure rate for relays tested at a 3-month interval with the failure rate for relays tested at an 18-month interval. The actuation-based failure rates at the 18-month test interval are roughly three times the actuation-based failure rate at the 3-month test interval although the failure rate at 18 months was calculated very conservatively assuming one failure, though no failures were reported. With so small a population and so few failures in each category, a change in failure rate of less than an order of magnitude is not considered indicative of any real difference in the actual failure rate of the device.

Even though statistical comparisons and confidence boundaries may not provide meaningful information, engineering judgement can be applied using other tools to draw conclusions that we would expect to be confirmed if more data were available. In this case, the data was presented graphically to try to provide insight into factors affecting relay failures.

The number of operations accumulated for a relay were graphed against the total number of relays in all plants that have experienced that number of actuations. If the relay failure rate is a constant value, reflecting random failures rather than infant mortality or end-of-life failures, then graphing the number of actuations until failure for each of the failed relays should produce a scattering within the range of actuations which the bulk of the relays have experienced to date.

Figure 9-1 shows the MDR failures occurring early in the actuation history of the relays. All of the relays have experienced at least a few actuations, none have been operated more than about 100 times after plant entry into commercial service. Figure 9-1 shows a significant decline in population versus accumulated cycles of operation after about 25 operations. The failures occurred in the relay actuation range from one to ten. It is uncertain whether this may indicate an infant mortality range for the relays, inferring a need for actuating the relay past this break-in period before installation in the plant, or whether there just were not enough failures to truly show a random failure history.

Figure 9-2 depicts the same data shown in Figure 9-1 from a time (hourly failure rate) perspective rather than an actuation (demand based failure rate) perspective. Again, the zero reference of the graph is plant entry into commercial service. Again, the four failures occur early in the relay service life, within the first two years of service. However, since three of the four failures occurred in the first year of service, and in fact in only the first few months of service, this is felt to represent a possible in fault mortality range for relays.

Figures 9-1 and 9-2 show no evidence of end-of-life failures that would be represented by a clustering of failures at some large number of actuations or some long service life value. The relays were designed to undergo thousands actuations over their service life. In comparison, the SSPS slave relays making up the sample populations have accumulated orders of magnitude fewer actuations. Even with consideration of the cycle life estimate based on high-demand applications in high-ambient temperature, the relays are actuated several orders of magnitude less than their ultimate capability during the 40-year plant life.

In conclusion, though there are too few failures to draw any solid statistical conclusions, the minimal number of failures seem to indicate a minor infant mortality failure rate that can be readily detected and avoided with adequate post-installation testing.

9.2 REPORTS OF SSPS SLAVE RELAY FAILURES

The following subsections discuss events of suspected relay failures. Plant-specific data on reported MDR series relay events is found in Table 9-3. Few failures of the MDR series relays have occurred in the SSPS slave relay application. Below and in notes to Table 9-4 explanation is provided for discounting two events in reliability calculations for the MDR series relay. Some events counted as actual failures in reliability calculations (Section 9.1) are questionable.

9.2.1 Beaver Valley

At Beaver Valley Unit 2, in May 1989, relay K606X, a small MDR 4-pole latching relay, did not actuate on demand. It was determined that the contacts were fused (welded). The relay was replaced (contact repair or replacement cannot be performed in the field). On the new relay, a second contact was connected in series. It was recognized that the failed contacts had been overloaded. This event is counted (though it should not have been) as a failure in the statistical assessment of reliability (Section 9.1).

This event is the only case of contact failure reported for MDR series relays in response to the WOG Survey. Others may have occurred (See Section 6.5, References 13.1-45 and 13.3-10). The root cause of contact fusing is not the fault of the relay, but rather a failure to have properly considered the contact load limitations for the relay application.

9.2.2 Diablo Canyon

At Diablo Canyon Unit 2, relay K645-A, a small MDR 8-pole latching relay, was found to be mispositioned (latched) after a reactor trip & safety injection. The relay was replaced. The root cause was not determined. This event is counted as a failure in the statistical assessment of reliability (Section 9.1).

9.2.3 Millstone

At Millstone Unit 3, relay K645-B, a small MDR 4-pole latching relay, was suspected of failure to actuate during periodic testing. Root cause of the anomaly was determined to be a failure of a valve limit switch. This event is not a relay failure, and is not counted in the statistical assessment of reliability (Section 9.1).

9.2.4 South Texas

At South Texas Unit 2, relays K947-A and K948-A failed to actuate during periodic testing in January and March, respectively, of 1989. Both are small MDR 8-pole latching relays. The root cause is reported as coil failure - relay coils were found to be open (no continuity; coil wire severed). Both events are counted as failures in the statistical assessment of reliability (Section 9.1).

Given the very short service life of these relays, it is extremely unlikely that the failure mechanism resulted from age- or temperature-induced degradation of the relay coil insulation. It is more likely both relays had minor defects in the coil insulation or terminal wires. Both of these failures are considered to be infant mortalities.

9.2.5 Wolf Creek

At Wolf Creek, relay K637, a small MDR 8-pole latching relay was found to be stuck in the "energized" position. K637 is a normally energized relay application (despite the latching capability of the relay). The root cause was determined to be relay binding due to out-gassing and corrosion by-product accumulation in the relay coil assembly. The failed relay was replaced September 18, 1989. A repeat occurrence in the same relay resulted in the replacement of all similar MDR relays used in NE applications on October 25, 1991 (using MDR relays of the post-May 1990 vintage).

The events described resulted from the out-gassing related failure mode which is very likely to occur in normally energized applications of MDR series relays manufactured prior to June of 1989. This event could have been precluded if the failure mechanism was known or had been anticipated at that time. As recommended in Section 8.0 of this report:

- Pre-June-1989 MDR series relays should not be used in normally energized applications.

- A service life should be established for normally energized relays (regardless of vintage) based on plant-specific service conditions.

The MDR relays at Wolf Creek would have been precluded by an adherence to the above recommendations. Equally, significant attention has been focused on this issue via References 13.1-43 and 13.1-50 (Also see Sections 6.3 and 6.6). It is recommended that pre-June-1989 MDR relays used in the few normally energized SSPS slave relay applications be replaced with units manufactured in or after May of 1990. It is considered essential that this recommendation be implemented prior to extending the periodic surveillance test interval for normally energized SSPS slave relays.

Finally, the relay failure(s) at Wolf Creek is not considered in the statistical assessment for reliability. The reliability assessment is based on the experience of normally de-energized relays only. With proper consideration of the temperature/age sensitivity of normally energized relays, their reliability will be no less than that of normally de-energized relays.

TABLE 9-1 MDR SLAVE RELAY FAILURE DATA					
Plant	**Test Period (months)**	**Number of Relays**	**Number of Actuations**	**Failures**	**Failure Rate**
Braidwood	3	4	113	0	
Byron	3	4	123	0	
	18	2	8	0	
Callaway	3	80	4556	0	
	18	20	306	0	
Catawba	3	1	15	0	
Diablo Canyon	1	8	6300	0	
	2	6	160	0	
	3	153	10020	1	
	18	34	1030	0	
South Texas	1	24	2160	0	
	2	10	340	2	
	3	242	7380	0	
	18	14	56	0	
Millstone	1	2	200	0	
	3	100	3557	0	
	18	8	24	0	
Shearon Harris	3	48	2015	0	
	18	50	969	0	
Wolf Creek	3	72	3004	0	
	18	30	462	0	
Beaver Valley (Aux Relays)	3	30	644	1	
Vogtle	3	216	7128	0	
Totals:	1	34	8660	0	1.15E-04
	2 or 3	966	39055	4	1.02E-04
	18	158	2855	0	3.50E-04

Note: 1-Month and 18-month failure rates were calculated assuming one failure.

TABLE 9-2 SERVICE HOURS OF MDR RELAYS				
Plant	Date Critical	Service Hours	Number of Relays	Relay Hours
1 Month STI				
Diablo Canyon 1	15-Apr-84	81816	4	3.27E+05
Diablo Canyon 2	15-Aug-85	70128	4	2.81E+05
South Texas 1	15-Mar-88	47496	12	5.70E+05
South Texas 2	15-Mar-89	38736	12	4.65E+05
Millstone 3	15-Jan-86	66456	2	1.33E+05
Total:				1.78E+06
3 Month STI				
Braidwood 1	15-May-87	54816	2	1.10E+05
Braidwood 2	15-Mar-88	47496	2	9.50E+04
Byron 1	15-Feb-85	74472	2	1.49E+05
Byron 2	15-Jan-87	57696	2	1.15E+05
Callaway	15-Oct-84	77424	80	6.19E+06
Catawba 1 (1)	06-Oct-88	42576	1	4.26E+04
Diablo Canyon 1	15-Apr-84	81816	79	6.46E+06
Diablo Canyon 2	15-Aug-85	70128	80	5.61E+06
South Texas 1	15-Mar-88	47496	126	5.98E+06
South Texas 2	15-Mar-89	38736	126	4.88E+06
Millstone 3	15-Jan-86	66456	100	6.65E+06
Shearon Harris	15-Jan-87	57696	48	2.77E+06
Wolf Creek	15-May-85	72336	72	5.21E+06
Beaver Valley 2	15-Aug-87	52608	30	1.58E+06
Vogtle 1	09-Mar-87	56424	108	6.09E+06
Vogtle 2	28-Mar-89	38424	108	4.15E+06
Total:				5.61E+07

TABLE 9-2 SERVICE HOURS OF MDR RELAYS

Plant	Date Critical	Service Hours	Number of Relays	Relay Hours
18 Month STI				
Byron 2	15-Jan-87	57696	2	1.15E+05
Callaway	15-Oct-84	77424	20	1.55E+06
Diablo Canyon 1	15-Apr-84	81816	17	1.39E+06
Diablo Canyon 2	15-Aug-85	70128	17	1.19E+06
South Texas 1	15-Mar-88	47496	7	3.32E+05
South Texas 2	15-Mar-89	38736	7	2.71E+05
Millstone 3	15-Jan-86	66456	8	5.32E+05
Shearon Harris	15-Jan-87	57696	50	2.88E+06
Wolf Creek	15-May-85	72336	30	2.17E+06
Total:				1.04E+07

NOTES:

(1) Relay installed on October 6, 1988
(2) Present is taken as August 15, 1993

TABLE 9-3 FAILURE SUMMARY - MDR RELAYS

FAILURES PER DEMAND

1 Month STI	(1 Failures)/(8660 Actuations) = 1.15E-04 Failures/Demand *
3 Month STI	(4 Failures)/(39055 Actuations) = 1.02E-04 Failures/Demand
18 Month STI	(1 Failures)/(2855 Actuations) = 3.50E-04 Failures/Demand *
All STI's	(4 Failures)/(50570 Actuations) = 7.91E-05 Failures/Demand

FAILURES PER HOUR

1 Month STI	(1 Failures)/(1.78E+06 Relay Hours) = 5.62E-07 Failures/Hr *
3 Month STI	(4 Failures)/(5.61E+07 Relay Hours) = 7.13E-08 Failures/Hr
18 Month STI	(1 Failures)/(1.04E+07 Relay Hours) = 9.62E-08 Failures/Hr *
All STI's	(4 Failures)/(6.87E+07 Relay Hours) = 5.86E-08 Failures/Hr

* 1 failure assumed for a point failure estimate.

TABLE 9-4 RELAY EVENTS

Plant	Unit/ Train	Relay ID#	Relay Type	Test Period[1] (months)	Operat. Cycles	Event/ Date	Failures	Root Causes	Notes
Beaver Valley	2A	K606X	M4L	3	23	Replaced 5/89	A	CF	Did not actuate - contacts fused - contact load excessive (See Sections 6.5 and 9.2.1)
Diablo Canyon	2A	K645	M8L	3	10	Replaced 8/85	N	U	May not have unlatched on reset
Millstone	3B	K645	M4L	3	31	X	A[2]	X	Valve limit switch failure[2] caused relay not to actuate during test.
South Texas	2A	K947	M8L	2	2	Replaced 3/89	A	O	Did not actuate on demand - coil failed. No LER
South Texas	2A	K948	M8L	2	2	Replaced 1/89	A	O	Did not actuate on demand - coil failed. No LER
Wolf Creek	A	K637	M8L	3	43	Replaced 9/18/89 and 10/25/91	N	BM	Out-gassing related binding of a normally energized relay[1].

Note:

(1) No reported failures of MDR series SSPS slave relays tested at the refueling (18-month) interval. One failure is assumed in the calculation of failure rate.

(2) Event is not a failure of the relay.

(3) Event involves the out-gassing related failure mode of a normally energized relay. This event would have been precluded by other recommendations for use and service life presented in this report. This failure is not included in the reliability calculations for this reason. The utility replaced all NE SSPS slave relays. This is also consistent with the recommendations of this report.

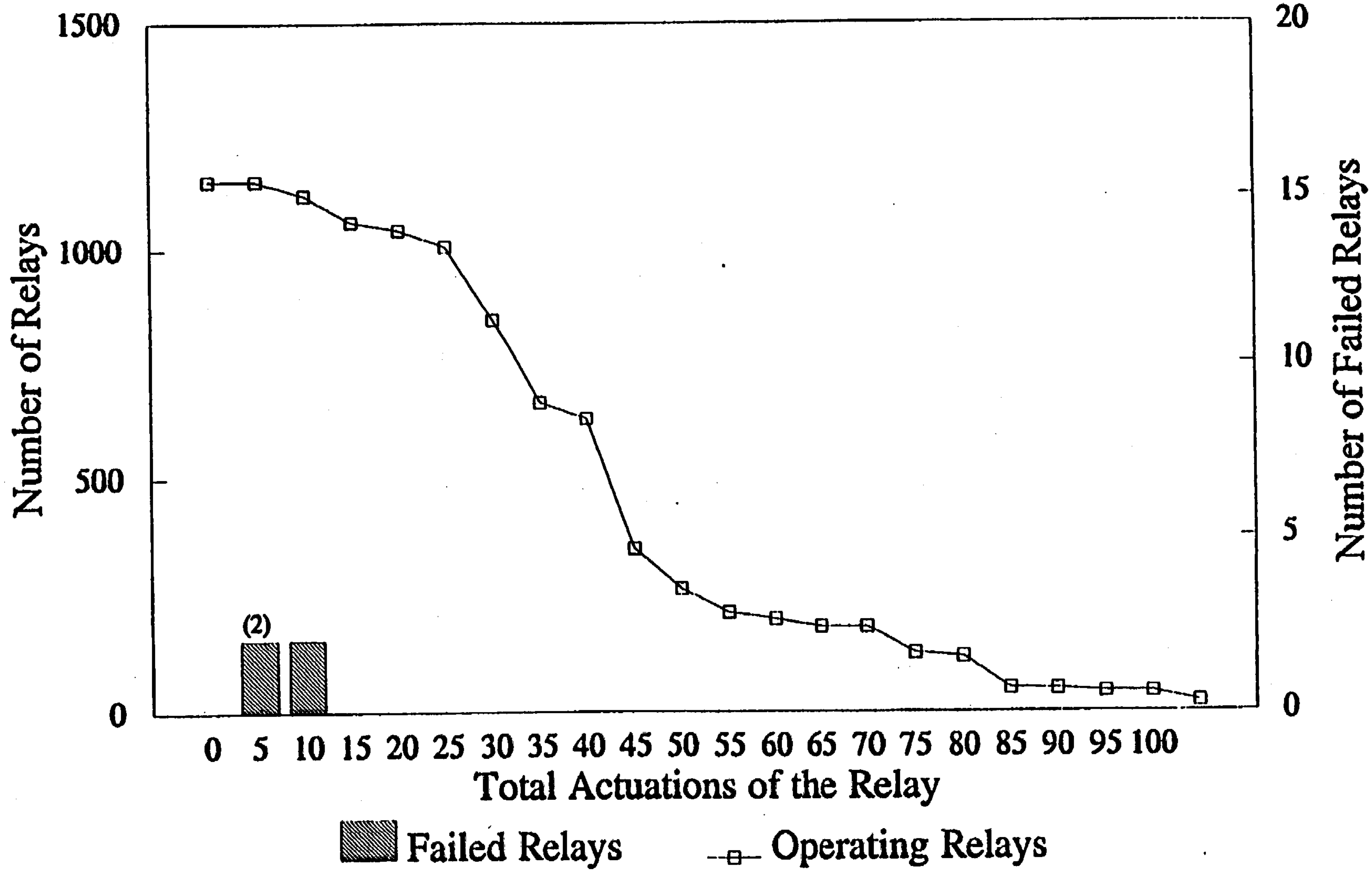


Figure 9-1. Distribution of Relay Actuations

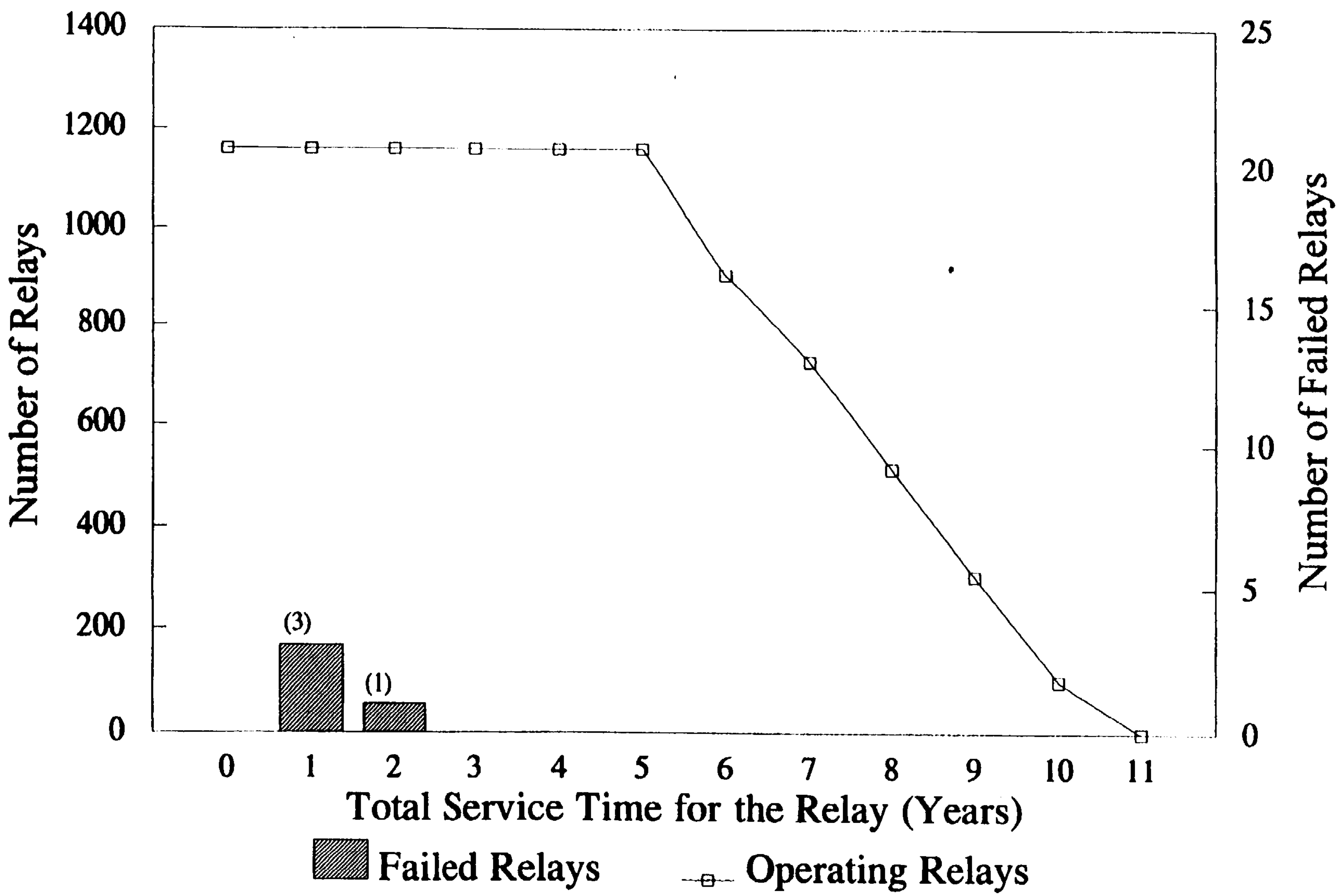


Figure 9-2. Distribution of Relay Service Times

10.0 CONCLUSIONS OF FMEA

10.1 GENERAL CONCLUSIONS

Failure modes for normally de-energized (ND) and normally energized (NE) relays are fundamentally the same. However, effects of coil assembly failures differ significantly for the two operating modes (see Section 10.2).

Failures mechanisms dependent on age/temperature effects can be accelerated by relay operating mode or duty cycle. Thus, the probability that a given age-related failure mechanism may occur differs for ND and NE relays. Even among ND relays, the duty cycle during refueling outages will affect the probability of age/temperature related failure mechanisms.

It is expected that a replacement interval will be established to minimize or preclude the possibility of certain age/temperature-related failures, particularly for NE relays. This is addressed in Section 8.0. In practice, the assessment should be applied on a relay-specific basis to account for the actual ambient temperature environment, relay duty cycle, and relay self heating.

10.2 COIL ASSEMBLY

Failure modes for the MDR series relay AC and DC coils are fundamentally the same. Differences in coil assembly configuration and relay duty cycle effect the probability of the postulated failures. The AC coil has an additional failure mode not seen in the DC coil due to vibration and dislodging of the shading coil, resulting in blocking of the rotation of the rotor/rotorshaft. The medium-sized MDR relay coils, though larger than the small MDR relay coils, have the same failure modes with the same effects.

The shorting or open failure of coil wire insulation in a NE relay should immediately result in an ESFAS actuation. In ND relays, the short or open coil failure occurs concurrent with demand. This failure can be viewed as a hidden failure which will not be detected until an attempt to actuate the relay. The much lower total temperature and temperature impact to ND relays, however, makes this age-related failure highly improbable.

Excessive friction between stationary and moving relay components results from several potential root causes. Increased friction between components may be caused by normal wear, age-related degradation of component materials, or debris created by degradation of certain relay components. Routine wear is not postulated to result in excessive friction or binding of the relay, or contact wear degradation, particularly because of the very low number of relay operating cycles (approximately 1000) expected over the plant life versus the designed and test-demonstrated capability of the relay.

The cases of temperature/age-related end-of-life failures are postulated for the MDR coil assembly, and is predictable based on the Arrhenius time/temperature relationship. For MDR series relays manufactured prior to June 1989, there is a single dominant failure mode (binding) related to the out-gassing of certain materials located in the relay coil assembly. This failure mode is of particular concern for the SSPS slave relays if surveillance testing on a refueling basis is adopted.

The degradation mechanism which leads to this failure mode is driven by the temperature rise of normally energized relay coils. Thus, it will certainly occur in all NE relays, however, the time to occurrence is not easily predicted. At best, use of materials aging data in the Arrhenius relationship can approximate service lives, based on total temperature, at which the out-gassing should begin. However, other random factors are involved in the process which causes binding of the relays. Given that the out-gassing can begin very early in life (e.g., << 1 years), it is recommended that normally energized relays be replace with units manufactured after 1992 as a criteria for relaxing the SSPS slave relay surveillance test interval.

> Other NE applications of MDR series relays may involve relatively low ambient temperature (< 100°F) and low temperature rise (e.g., 25°C versus the 65°C maximum estimated by P&B, or the 58°C observed in small, AC-coil relays). Testing and inspection of relays returned from the Salem plant have shown that NE DC-coil MDR relays operating at lower-than-nominal voltage will exhibit the signs of out-gassing related degradation and perform to specification even after 8 years of service life.

In summary, neither time nor temperature related failure is likely in ND relays. In NE relays, these degradation mechanisms are accelerated by the coil temperature rise such that they are probable within plant life. As such, replacement may be necessary to assure operability and reliability of the NE MDR type SSPS slave relays.

10.3 SWITCH ASSEMBLY

For the switch assembly, it is postulated that prolonged exposure to high temperatures may result in a loss of mechanical strength or dimensional changes in the contact cams. The contact cams are made of a glass-filled nylon which has outstanding resistance to both the degradation and deformation mechanisms. It is more likely that the contact cams would experience damage or degradation due to excessive contact loading. The causes would be contact flashing at closure or high temperature due to resistive heating. Either case would not result in instantaneous failure, but would evolve over time with repeated actuation.

Thermal degradation of the contact cams is considered to be highly improbable in SSPS slave relays. Normally energized SSPS slave relays are expected to reach end-of-life condition due to coil heating effects in advance of any significant degradation of the contact cams. As such, the relays would be replaced in advance of the postulated contact cam failure modes/mechanisms.

The SSPS slave relays, whether NE or ND, are located in areas where temperatures are maintained in the range of 70°F to 90°F. Normally de-energized SSPS slave relays will not experience sufficient temperatures to cause temperature-induced, age-related failures within a forty year plant life. Section 8.0 concludes that temperature/aging conditions for the SSPS cabinets do not result in sufficient degradation of the contact cams (nylon) to accelerate any postulated failure mechanism in ND relays.

All other switch assembly materials have outstanding resistance to temperature induced degradation. No other significant age-related degradation or failure mechanism has been identified for the organic materials used in the MDR series relay switch assembly. It is reasonable to expect that the MDR series relay switch assembles should have at least a 40 year service life in the SSPS slave relay application. This, of course, assumes the relays are properly applied; that contact loading has been properly addressed (See Section 6.5).

10.3.1 Contacts

Failure modes and effects postulated for the relay contacts are generic to all relay types. Failures shown in Table 7-2 (see "Contacts") are not unique to the MDR series relay. Most failures are germane to relay application and the operating environment, than to relay design.

For ND SSPS MDR series slave relays, primary concern is for fused normally closed (NC) contacts which would prevent the relay from changing state. The fusing of contacts most commonly results from relay misapplication. This failure mechanism is the direct result of contacts experiencing currents in excess of their maximum rating. Section 6.5 discusses specific cases of excessive contact loading in SSPS slave relays. For the purposes of this evaluation, it was assumed that previously existing cases of excessive contact loading have been resolved. Confidence in this assumption is affirmed by:

- Very few contact failures have been reported
- Factory acceptance testing and plant start-up testing have identified no significant design flaws
- Good housekeeping prevails at the SSPS cabinet locations
- High relative humidity is not a concern due to plant heating, ventilation, and air-conditioning (HVAC) systems.

Therefore, the probability of contact failures in Potter & Brumfield MDR series SSPS slave relays should be significantly less than that for industrial applications of control relays.

10.4 ADDITIONAL CONCLUSIONS

The following subsections address environmental factors postulated to cause certain relay failures or accelerate failure mechanisms which are time/temperature-dependent. Conditions in typical industrial areas are discussed and compared to conditions in nuclear plant areas where the SSPS is installed. Extreme or damaging forms of these environs exist in many industries, but are virtually absent form the normal operating conditions of most nuclear plant "mild" environment areas. The exception is high temperature, a particular concern for normally-energized relays because of the resistive heating in the relay coil. For ND SSPS MDR type slave relays, time and temperature play little or no role in the reliability of the SSPS slave relays. The few cases of normally energized MDR type slave relays should be addressed by commitment to mandatory replacement based on plant specific calculations of service life, per Section 8.4.

10.4.1 Dirt, Debris and Contamination

Among the challenges to reliability of industrial control relays are adverse effects of dirt, debris and contamination. In typical industrial applications these factors may, at times, represent the greatest challenge to relay operability. Ultimately, adverse effects of dirt, debris, and contamination will lead to some of the failure modes described in Section 7.0.

10.4.1.1 Large accumulations of dust may foul contacts or increase friction between moving parts of the relay. Contact fouling may contribute directly and indirectly to high contact resistance. Dust "flashing" on contact closure/energization will leave carbon residue. The effect can be additive with successive operations. Extreme cases of flashing will "pit" the contact surface. Pitting, alone, will degrade contact performance reducing the effective contact surface and or increasing contact resistance. Pitting can also increase the potential for contact corrosion. In particularly dirty environments, contact fusing will eventually result from increasing contact resistance and abrasive degradation of the contact surface.

10.4.1.2 Debris (e.g., chips, loose screws) may become lodged in the relay, preventing mechanical movement.

10.4.1.3 Chemical contamination (e.g., oil, corrosive chemistry) may be the result of inadvertent spray from adjacent mounted equipment or processes. The degradation process is similar to that described in Section 10.4.1.1. Again, the leading concern is for degradation of the relay contacts, though in general, other relay components and materials may be equally vulnerable.

Typical industrial environments provide significant opportunity for the above mechanisms to occur in extreme. This is not the case in nuclear power plants. Housekeeping conditions in nuclear plant control rooms are exceptional by comparison to most primary industry or mining operations. The SSPS is located in or adjacent to the main control rooms where environmental conditions generally are milder than the shipping/storage conditions specified by the vendors. While these nuclear plant areas are not "dust-free", there are no large accumulations of dust or dirt as might be expected near lathes or on mining equipment. Periodic inspection of the SSPS cabinets typically include housekeeping checks, with cleaning performed as needed.

The SSPS cabinets are normally closed, except during surveillance testing and inspection. This requirement arises from seismic qualification requirements and concern for "missile" damage by flying debris during a seismic event. Even during plant surveillance access to the cabinets, and permissible actions when working in the cabinets are subject to rigorous procedural control. Under normal operating conditions there are no sources of missiles or inadvertent chemical/oil spray (as might result from rupture of a hydraulic cylinder or hose) in nuclear plant control rooms.

The SSPS cabinets have an exceptional defense against sources of dust, debris and contamination. They are located in plant areas where dust is minimal and where debris and contamination are non-existent. Random, non-time dependent failure modes associated with dirt, debris and contamination are considered to have a very low probability. For this reason, the SSPS slave relays are expected to perform with above average reliability.

10.4.2 High Ambient Temperature

High ambient temperatures will accelerate thermal/age-related degradation of relay component materials. High ambient temperatures may accelerate wear-aging of lubricated components in the MDR series relay. This is postulated to be the result of decreased lubricant viscosity. For these reasons, high ambient temperatures can become a factor of reliability within the service life of MDR series relays.

Temperature-induced aging degradation of materials is minimized by temperature controls in the SSPS cabinet locations. Most plants provide HVAC. Some are equipped with Class 1E powered redundant systems. Table 8-1 lists the ambient temperature ranges for plants which responded to the WOG data sheets. Westinghouse RCS recommends a 40 year shelf life for MDR series relays when stored at or below 120°F. Normal ambient temperatures in SSPS cabinet areas are well within the shelf life conditions currently specified by Westinghouse Replacement Component Services (RCS). This is best evinced in the calculations summarized in Sections 8.3.3 and 8.3.4, for the expected end-of-life failure of MDR series relays.

Extensive temperature monitoring efforts for the Farley Nuclear Plant (FNP) spanning (May 12, 1992 through July 26, 1993) are summarized in Table 8-2. These are considered to be typical of domestic nuclear plants. As such, the FNP data is used in the aging assessment calculations.

10.4.3 High Relative Humidity

High relative humidity will accelerate corrosion of relay contacts, especially in applications where there are few and infrequent operations of normally open relay contacts. Room heating and air-conditioning in the SSPS cabinet locations minimizes relative humidity. In general, nuclear plant environmental controls maintain the relative humidity in the main control room and adjacent equipment rooms at non-condensing levels. Thus, it is expected that corrosion of the SSPS MDR slave relay contacts would be at a minimum throughout the service life of the slave relay.

11.0 BASIS FOR ASSESSING SLAVE RELAY RELIABILITY

Standard sources of relay reliability such as IEEE 500-1984 (Reference 13-2), base the reliability of relays on numbers of failures per accumulated cycles of operation. For industrial control relays, reliability is assessed on the number of failures expected per 10,000, 100,000, or 1 million relay operations, as recommended in the National Relay Manufacturers Association (NRMA) Handbook (Reference 13-3). These bases are derived from expectations that industrial control relays will accumulate 10,000 to over a million cycles of operation over their service life, and that failure, when it ultimately occurs, will be the result of wear. Furthermore, some applications of industrial control relays demand 10,000 to a million cycles of operation in one or two years.

Service in the SSPS slave relay application (or in naval gunships, as originally designed for) is not typical of industrial control relay applications. The MDR series relay was designed for at least 100,000 operations over its service life. However, SSPS slave relays are estimated to perform approximately 1000 operations within a 40-year service life in nuclear power plants. For some plants the estimate may be as high as 1500 operations, though this is not typical. It can be concluded that the standard references for industrial control relay reliability have little relevance to the SSPS slave relay application. Thus, it is very unlikely that the SSPS slave relays will be degraded by factors of wear or frequent operational stress. It is more likely that the SSPS slave relays will experience component degradation due to the effects of temperature and age, and that failures will occur as isolated random events over the majority of their service life.

Based on the above, the reliability of SSPS slave relays should be assessed on the basis of their resistance to temperature-induced and aging-related degradation. The aging assessment, Section 8.0, demonstrates that the degradation of SSPS slave relays (MDR series) requires substantial time, given the mild temperature environments which prevail in the typical SSPS location, and the absence of other environmental challenges to relay operation and reliability. Furthermore, the rate of degradation is sufficiently slow that testing at a three-month interval is no more likely to detect significant changes in the SSPS slave relays than testing on a refueling basis.

12.0 CONCLUSION

In the absence of high ambient temperatures, significant accumulations of dirt and debris, and sources of contamination, no failure modes have been identified that would be accelerated or catalyzed in the normally de-energized MDR series relays. The FMEA (Section 7.0) cites failure mechanisms which are postulated due to the degradation of the MDR series relay materials. However, conditions in the SSPS output bay are sufficiently mild that the time dependent failure modes are not likely to occur within the 40-year plant life. Furthermore, the very slow rate of degradation in material properties is equally insignificant if tested on a three month basis or on a refueling basis. The aging assessment (Section 8.0) concludes that ND SSPS MDR slave relays are suitable for use throughout the life of the nuclear plant with minimal need for testing and surveillance.

Several SSPS MDR slave relays in each train are normally energized (NE). The resultant heat rise of NE MDR relays accelerates the aging of MDR series relays such that operability will be compromised within the 40-year nuclear plant life. Adverse impact to operability and reliability can be avoided by replacement at an appropriate interval. The estimated life of NE MDR series relays should be based on the example calculation presented in Section 8.3.4 and should rely on temperature data specific to the SSPS location in each plant.

With replacement at a conservative interval, NE MDR series relays will exhibit the same reliability as normally de-energized (ND) MDR series relays. As such, it is also concluded that testing of NE MDR series SSPS slave relays is equally effective if tested on a three month basis as testing on a refueling basis.

12.1 NRC REQUIREMENTS FOR IMPLEMENTATION OF TEST FREQUENCY RELAXATION

A generic Safety Evaluation Report (SER) has been issued based on the NRC review of the lead plant Licensing Amendment Request (LAR) - the SER is included behind the cover page of this report.

Revision 1 of this report incorporates the results of the lead plant licensing review by the NRC. The following items must be addressed by plants implementing slave relay test extension for MDR relays.

1) Normally energized and 20% duty relays which are proposed for 18 month test intervals must be replaced with relays manufactured after 1992. Potter & Brumfield (P&B) MDR series relays of all vintages continue to be acceptable for use in normally de-energized relay applications, subject to the guidance provided in the previous and current revision of this report. (See Sections 5.5.1 and 6.6)

2) Plants must review the various failure modes associated with MDR relays and ensure that their procurement program for MDR relays is sufficient to identify those failures. (See Section 6.4)

3) Plants must confirm that they have performed a study of the contact loading on MDR relays. (See Section 6.5)

It is necessary that all future plant submittals (LARs) requesting the SSPS slave relay test interval extension specifically address each of the above items. Appendices D and E, added to Rev. 1 of this report, provide PG&E response to comments and questions generated during the NRC review of the lead plant LAR. These appendices extend the technical work of the original report, and should be consulted for guidance in addressing the three items above.

13.0 REFERENCES

13-1 IEEE Standard 352-1987, "IEEE Guide for General Principles of Reliability Analysis of Nuclear Power Generating Stations Safety Systems."

13-2 IEEE Standard 500-1984, "Guide to the Collection and Presentation of Electrical, Electronic, Sensing Component, and Mechanical Equipment Reliability Data for Nuclear-Power Generating Stations."

13-3 National Relay Manufacturer's Association Handbook, fourth edition, 1991.

13-4 NUREG-4715, "An Aging assessment of Relays and Circuit Breakers and System Interactions," June 1987.

13-5 NUREG-1366, "Improvements to Technical Specification Surveillance Requirements," (recently issued).

13-6 Specification No. ES-MDR, Pages 1A-1D, each drawing is Rev. 0, dated January 10, 1991.

13-7 Westinghouse STC Document No. 93-7TC-MATEV-L2, "Materials Properties Assessment of P&B MDR Series Rotary Relays."

13-8 Smith et al., Journal of Polymer Science, vol. 18, pp. 3543-3554, 1974.

13-9 IEEE Standard 98-1984, "IEEE Standard for Preparation of Test Procedures for Thermal Evaluation of Solid Electrical Insulating Materials."

13-10 NUREG/CR-3156, "Survey of State-of-the-Art in Aging of Electronics with Application to Nuclear Power Plant Instrumentation."

13-11 EPRI NP-1558, "A Review of Equipment Aging Theory and Technology."

13-12 Military Specification MIL-R-19523 A, "RELAYS, CONTROL, NAVAL SHIPBOARD," Dated 30 December 1966.

13-13 This reference left blank intentionally.

13-14 Westinghouse Calculation Note ET-NSL-SSL-GEN-115, Rev. 1, "Aging Assessment of MDR Series Relays" (Proprietary).

13-15 Westinghouse Calculation Note ET-NSL-SSL-GEN-113, Rev. 1, "Aging Assessment of TYPE AR Relays" (Proprietary).

13-16 WCAP-8687, Supp. 2-APP.A4, Volume 2, "Equipment Qualification Test Report: Long Term Aging Program (For 7.5 kVA Transformer & Relays)," (Proprietary).

13-17 Westinghouse Calculation Note CN-PORI-93-240-R0, "WOG Slave Relay STI Extension Program," (Proprietary).

13-18 Bechtel letter W-2718, "Auxiliary Building Temperature Monitoring - MCR Panels (ES-90-1659)," dated May 7, 1993.

13-19 PG&E letter DCL-95-269, "Response to NRC Request for Additional Information on Slave Relay Test Frequency Relaxation Amendment (LAR-94-11, dated November 14, 1994), December 7, 1995 (included as Appendix D of this report).

13-20 PG&E letter DCL-96-034, "Response to NRC Request on Slave Relay Test Frequency Relaxation Amendment (LAR-94-11, dated November 14, 1994), February 2, 1996 (included as Appendix E of this report).

13.1 GENERIC COMMUNICATIONS ON RELAYS

13.1-1 RO Bulletin 74-12, "Incorrect Coils in Westinghouse Type SG Relays at Trojan," 10/21/74.

13.1-2 I&E Bulletin 76-02, "Relay Coil Failures - GE Type HFA, HGA, HKA, HMA Relays," 3/12/76.

13.1-3 I&E Bulletin 76-03, "Relay Malfunctions - GE Type STD Relays," 3/15/76.

13.1-4 I&E Bulletin 76-05, "Relay Failures - Westinghouse BFD Relays," (Not Dated).

13.1-5 I&E Bulletin 77-02, "Potential Failure Mechanism in Certain Westinghouse AR Relays with Latch Attachments," 9/12/77.

13.1-6 I&E Bulletin 78-01, "Flammable Contact-Arm Retainers in GE CR120A Relays," 1/16/78.

13.1-7 I&E Bulletin 78-06, "Defective Cuttlerhammer, Type M Relays with DC Coils," 5/31/78.

13.1-8 I&E Bulletin 79-25, "Failures of Westinghouse BFD Relays in Safety-Related Systems," 11/2/79; includes excerpts from Westinghouse letter TS-E-412, December 6, 1978.

13.1-9 I&E Bulletin 80-19 Revision 1, "Failures of Mercury-Wetted Matrix Relay in Reactor Protective Systems of Operating Nuclear Power Plants Designed by Combustion Engineering," 8/13/80.

13.1-10 I&E Bulletin 84-02, "Failures of General Electric Type HFA Relays in use in Class 1E Safety Systems," 3/12/84.

13.1-11 I&E Bulletin 88-03, "Inadequate Latch Engagement in HFA Type Latching Relays Manufactured By General Electric (GE) Company," 3/10/88.

13.1-12 I&E Circular 76-02, "Relay Failures Westinghouse BF (ac) and BFD (dc) Relays," 8/18/76.

13.1-13 I&E Circular 79-20, "Failure of GTE Sylvania Relay, Type PM Bulletin 7305, Catalog 5U12-11-AC with 1 120V AC Coil," 9/24/79

13.1-14 I&E Circular 80-01, "Service Advice for General Electric Induction Disc Relays," 1/17/8

13.1-15 I&E Notice 81-01, "Possible Failure of General Electric Type HFA Relays," 1/16/81.

13.1-16 I&E Notice 82-02, "Westinghouse NBFD Relay Failures in Reactor Protection Systems at Certain Nuclear Power Plants," 1/27/82.

13.1-17 I&E Notice 82-04, "Potential Deficiency of Certain Agastat E-7000 Series Time-Delay Relays," 3/10/82.

13.1-18 I&E Notice 82-13, "Failures of General Electric Type HFA Relays," 5/10/82.

13.1-19 I&E Notice 82-48, "Failures of Agastat CR 0095 Relay Sockets," 12/3/82.

13.1-20 I&E Notice 82-50, "Modification of Solid State AS Undervoltage Relays Type ITE-27," 12/20/82.

13.1-21 I&E Notice 82-54, "Westinghouse NBFD Relays Failures in Reactor Protection Systems, 12/27/82.

13.1-22 I&E Notice 82-55, "Seismic Qualification of Westinghouse AR Relay With Latch Attachments Used In Westinghouse Solid State Protection System," 12/28/82.

13.1-23 I&E Notice 83-19, "General Electric Type HFA Contact Gap and Wipe Setting Adjustments," 3/5/83

13.1-24 I&E Notice 83-38, "Defective Heat Sink Adhesive and Seismically Induced Chatter in relays Within Printed Circuit Cards," 6/13/83

13.1-25 I&E Notice 83-63, "Potential Failures of Westinghouse Electric Corporation Type SA-1 Differential Relays," 9/26/83.

13.1-26 I&E Notice 83-63 Supplement 1, "Potential Failures of Westinghouse Electric Corporation Type SA-1 Differential Relays," 2/15/84.

13.1-27 I&E Notice 84-20, "Service Life of Relays in Safety-Related Systems," 3/21/84

13.1-28 I&E Notice 85-49, "Relay Calibration Problem," 7/1/85.

13.1-29 I&E Notice 85-82, "Diesel Generator Differential Protection Relay Not Seismically Qualified," 10/18/85.

13.1-30 NRC Information Notice 87-66, "Inappropriate Application of Commercial Grade Components," 12/31/87.

13.1-31 NRC Information Notice 88-14, "Potential Problems With Electrical Relays," 4/18/88

13.1-32 NRC Information Notice 88-45, "Problems in Protective Relay and Circuit Breaker Coordination," 7/7/88

13.1-33 NRC Information Notice 88-58, "Potential Problems With ASEA Brown Boveri ITE-51L Time-Over Current Relays," 8/8/88

13.1-34 NRC Information Notice 88-69, "Movable Contact Finger Binding in HFA Relays Manufactured by General Electric (GE)," 8/19/88

13.1-35 NRC Information Notice 88-69 Supplement 1, "Movable Contact Finger Binding in HFA Relays Manufactured by General Electric (GE)," 9/29/88

13.1-36 NRC Information Notice 88-83, "Inadequate Testing of Relay Contacts in Safety-Related Logic Systems," 10/19/88.

13.1-37 NRC Information Notice 88-88, "Degradation of Westinghouse ARD Relays," 11/16/88.

13.1-38 NRC Information Notice 88-88 Supplement 1, "Degradation of Westinghouse ARD Relays," 5/31/89.

13.1-39 NRC Information Notice 88-98, "Electrical Relay Degradation Caused by Oxidation of Contact Surfaces," 12/19/88.

13.1-40 NRC Information Notice 90-57, "Substandard, Refurbished Potter & Brumfield Relays Misrepresented as New," 9/5/90.

13.1-41 NRC Information Notice 90-57, Supplement 1, "Substandard, Refurbished Potter & Brumfield Relays Misrepresented as New," 11/27/91

13.1-42 NRC Information Notice 91-45, "Possible Malfunction of Westinghouse ARD, BFD, and NBFD Relays, and A200 DC and DPC 250 Magnetic Contactors," 7/5/91

13.1-43 NRC Information Notice 92-04, "Potter & Brumfield Model MDR Rotary Relay Failures," 1/6/92.

13.1-44 NRC Information Notice 92-05, "Potential Coil Insulation Breakdown in ABB RXMH2 Relays," 1/8/92.

13.1-45 NRC Information Notice 92-19, "Misapplication of Potter & Brumfield MDR Rotary Relays," 3/2/92.

13.1-46 NRC Information Notice 92-24, "Distributor Modification to Certain Commercial-Grade Agastat Electrical Relays," 3/30/92.

13.1-47 NRC Information Notice 92-27, "Thermally Induced Accelerated Aging and Failure of ITE/Gould AC Relays Used in Safety-Related Applications," 4/3/92

13.1-48 NRC Information Notice 92-45, "Incorrect Relay Used in Emergency Diesel Generator Output Breaker Control Circuitry," 6/22/92

13.1-49 NRC Information Notice 92-77, "Questionable Selection and Review to Determine Suitability of Electropneumatic Relays for Certain Applications," 11/17/92.

13.1-50 Office for Analysis and Evaluation of Operational Data's (AEOD) report, AEOD/S93-06, "Potter & Brumfield Model MDR Rotary Relay Failures."

13.2 GENERIC COMMUNICATIONS RELATED TO EFSAS SYSTEMS

13.2-1 I&E Bulletin 77-03, "On-Line Testing of Westinghouse Solid State Protection System (SSPS)," 9/12/77.

13.2-2 Actuation block/reset circuitry is not being verified during periodic semi-automatic testing of SSPS. Concern for undetectable failures. Cites Westinghouse Technical Bulletin NSD-TB-77-11.

13.2-3 I&E Bulletin 80-06, "Engineered Safety Feature (ESF) Reset Controls," 3/13/80.

13.2-4 I&E Notice 79-04, "Degradation of Engineered Safety Features."

13.2-5 I&E Notice 81-10, "Inadvertent Containment Spray Due to Personnel Error," 3/25/81.

13.2-6 I&E Notice 81-15, "Degradation of Automatic ECCS Actuation Capability by Isolation of Instrument Lines."

13.2-7 I&E Notice 82-10, "Following Up Symptomatic Repairs to Assure Resolution of the Problem," 3/31/82

13.2-8 I&E Notice 82-19, "Loss of High Head Safety Injection Emergency Boration and Reactor Coolant Makeup Capability," 6/18/82.

13.2-9 I&E Notice 84-37, "Use of Lifted Leads and Jumpers During Maintenance or Surveillance Testing," 5/10/84.

13.2-10 I&E Notice 84-39, "Inadvertent Isolation of Containment Spray Systems," 5/25/84.

13.2-11 I&E Notice 85-18, "Failures of Undervoltage Output Circuit Boards in the Westinghouse Designed Solid State Protection System," 3/7/85.

13.2-12 I&E Notice 85-18 Supplement 1, "Failures of Undervoltage Output Circuit Boards in the Westinghouse Designed Solid State Protection System," 9/10/91.

13.2-13 I&E Notice 85-23, "Inadequate Surveillance and Postmaintenance and Postmodification System Testing," 3/22/85.

13.2-14 I&E Notice 85-51, "Inadvertent Loss or Improper Actuation of Safety-Related Equipment, 7/10/85.

13.2-15 I&E Notice 87-01, "RHR Valve Misalignment Causes Degradation of ECCS in PWRs," 1/6/87.

13.3 WESTINGHOUSE TECHNICAL BULLETINS

13.3-1 NSD-TB-76-2, February 18, 1976, "BFD Relays," System(s): Reactor Protection System.

13.3-2 NSD-TB-76-16, November 22, 1976, "BFD & NBFD Relays," System(s): Relay Reactor Protection Systems, Relay Engineered Safeguards Systems.

13.3-3 NSD-TB-77-10, July 21, 1977, "AR Relays with Latch Attachments," System(s): Solid State Protection System (SSPS) and Auxiliary Safeguards Cabinets (ASG).

13.3-4 NSD-TB-79-05, August 14, 1979, "NBFD Relays," System(s): Relay Reactor Protection System, and Relay Engineered Safeguards Systems.

13.3-5 NSD-TB-81-14, December 7, 1981, "BFD (NBFD) Relays," System(s): Reactor Protection and Safeguard Systems.

13.3-6 NSD-TB-81-14, Rev. 1, January 15, 1982, "BFD (NBFD) Relays," System(s): Reactor Protection and Safeguard Systems.

13.3-7 NSD-TB-82-03, June 24, 1982, "AR Relay Latch Attachments," System(s): Solid State Protection System and Auxiliary Safeguards Cabinets.

13.3-8 NSD-TB-82-03, Rev. 1, December 14, 1982, "AR Relay Latch Attachments," System(s): Solid State Protection System and Auxiliary Safeguards Cabinets.

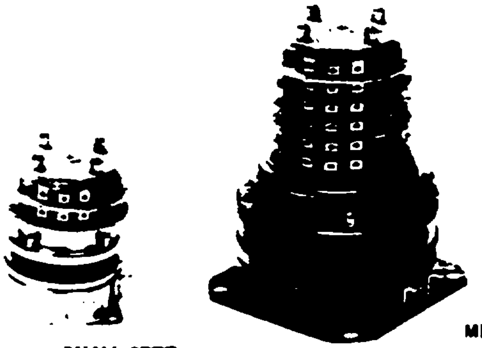
13.3-9 NSID-TB-85-16, July 31, 1985, "SSPS Undervoltage Output Driver Card," System(s): Solid State Protection System (SSPS).

13.3-10 NSD-TB-92-02, Rev. 0, January 24, 1992, "Misapplied Relay Contacts," System(s): Solid State Protection System (SSPS).

13.4 POTTER AND BRUMFIELD DRAWINGS

13.4-1 Specification No. ES-MDR Page 1A, 1B, 1C and 1D Dated 1/10/91.

APPENDIX A - MDR SERIES RELAY DATA SHEETS



SMALL 8PDT

MEDIUM 24PDT

MDR series

10 AMP ROTARY RELAYS

ENGINEERING DATA

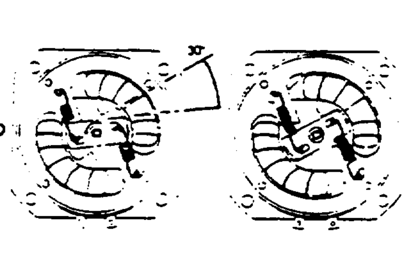
Designed and constructed to meet or exceed the most rigorous requirements of military specifications. MDR series rotary relays are used in control circuits of nuclear reactors, missile systems, gun fire apparatus and computers.

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.

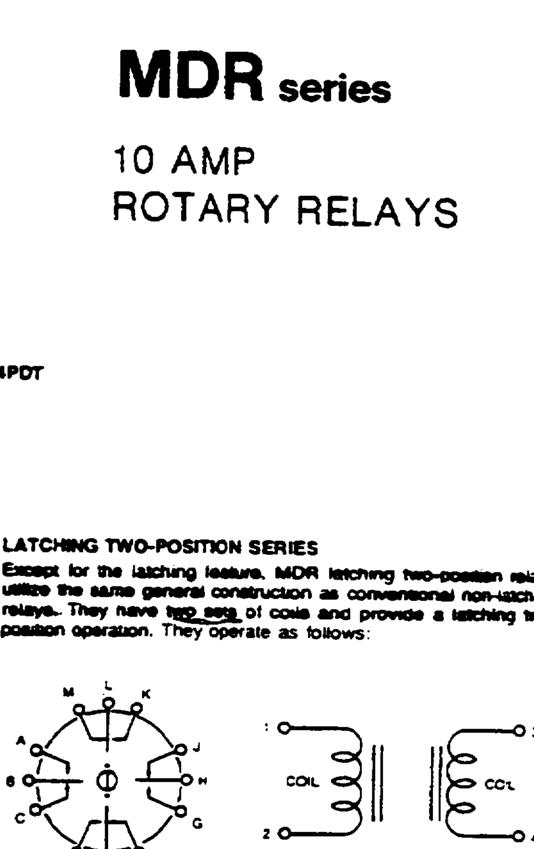
ROTOR IN DE-ENERGIZED POSITION



ROTOR IN 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 18
SMALL DC NON-LATCHING	15 to 30	5 to 15
SMALL AC LATCHING	8 to 12	N/A
SMALL DC LATCHING	10 to 18	N/A
MEDIUM AC NON-LATCHING	8 to 12	8 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	78	10.0	1308
MDR-137-8	4PDT	125VDC	0.082	1520	10.3	2375
MDR-134-1	8PDT	115 VAC	0.215	68	6.5	1230
MDR-134-2	8PDT	440 VAC	0.045	1256	5.1	1880
MDR-136-1	8PDT	28 VDC	0.362	78	10.0	1308
MDR-136-6	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
[redacted]	[redacted]	115 VAC	[redacted]	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

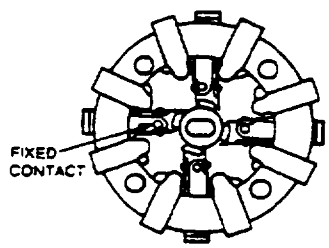
SERIES	CONTACTS	COIL VOLTAGE 60 Hz for AC	COIL CURRENT AMPERES	DC COIL RESISTANCE OHMS	COIL POWER WATTS	BREAKDOWN VOLTS RMS
MDR-6064	12PDT	115 VAC	0.380	24	12.0	1230
MDR-6065	12PDT	440 VAC	0.055	540	5.7	1880
MDR-7020	12PDT	28 VDC	0.316	88.6	8.8	1308
MDR-7035	12PDT	125 VDC	0.083	1500	10.4	2375
MDR-66-4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

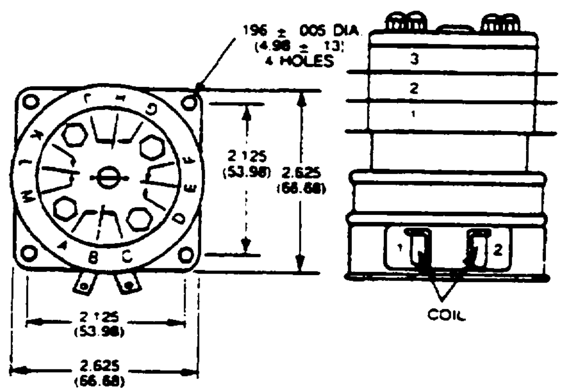
The above AC contact ratings are based on contact loads having a 50% power factor. The DC contact ratings are based on resistive loads.

CONTACT SECTION



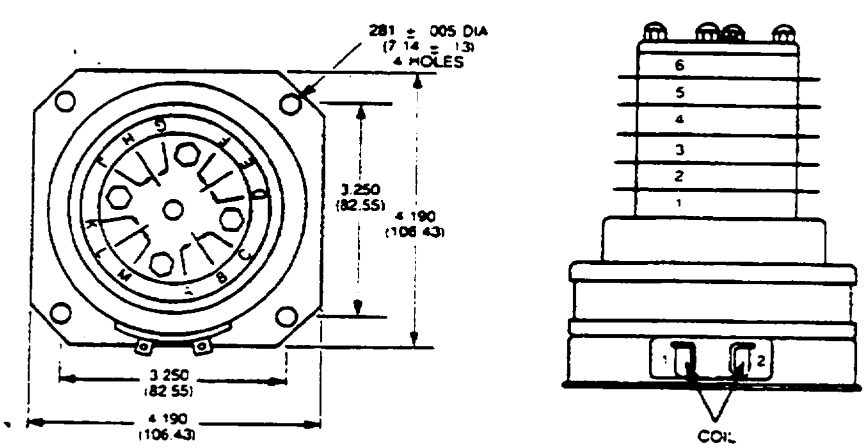
OUTLINE DIMENSIONS

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 - WOG SURVEY DATA SHEETS

SLAVE RELAY TEST DATA SHEET

You are requested to complete this data sheet and the attached table in support of a WOG sponsored program. The program objective is to develop a generic technical basis for requesting relaxation of SSPS Slave Relay Test Frequency. The data sheet and the attached table seek to gather any existing data which is indicative of SSPS Slave Relay reliability. The data sheet seeks information applicable to slave relays in both trains. The data table is intended to focus on specific slave relays (See further instructions attached to the data table). Please respond as completely as plant records permit. The data should reflect the operating experience after receipt of the plant operating licensing. (It is assumed that pre-operational testing will have successfully identified/resolved most "infant mortalities".)

Experience data is also requested for Westinghouse Type AR and Potter-Brumfield Type MDR relays in other relay applications where operating conditions and demands are similar to those for the SSPS Slave Relays. Use the data table attached. Such data will be meaningful if the following criteria are met.

1. Relays should be normally de-energized.

2. Operating demands are infrequent; once a month or less often (specify).

3. Ambient environment at the relay location is similar to that where the SSPS cabinets are installed (similar temperature and relative humidity).

4. "Housekeeping" in the area where the relays are located should be similar to conditions for the SSPS cabinets. The area should be free from sources of contamination or excessive dust and moisture.

Should you have any questions or require further clarification of the intent of the data sheet or table, please contact:

B. J. (Bern) Metro

G. R. (Jerry) Andre

* ** ***** ** *

1. Plant Name: ______________________

2.1 Date SSPS installed (month/year), if known: _____

2.2 Date of reactor initial criticality (month/year): __

SLAVE RELAY TEST DATA SHEET

3.1 Number of SSPS Slave Relays in-service: ____

3.2 All SSPS Slave Relays of same type? Yes _ No _

AR _
MDR _
Other _, Specify ________________

3.3 If there was a general replacement of AR relays, supplied as original equipment, with MDR relays, state date of change-out: ____

It is desired that the test experience for both types of relays be reported. Please take care to clearly distinguish AR relay data and MDR relay data in the data table.

4.1 List tests which impact the SSPS slave relays. The list should include all procedures which cause actuation of SSPS slave relays or collect data indicative of the relay condition or environment. The test period should be on a per-relay basis (enter "NO" if not periodic). Test Duration is the time the SSPS is out of service for the test. Describe impact to slave relays (e.g., relay actuates, coil energized but no actuation, contacts continuity verified).

Item No.	Plant Procedure No.	Test Period	Test Duration	Description
_	________	___	___	____________________________
_	________	___	___	____________________________
_	________	___	___	____________________________
_	________	___	___	____________________________
_	________	___	___	____________________________
_	________	___	___	____________________________

4.2 All SSPS Slave Relays tested with same period? Yes _ No _

In "No", explain. Cite Item number(s) above.

SLAVE RELAY TEST DATA SHEET

4.3 Routine maintenance/surveillance programs inspect for:

Relay condition or appearance? Yes _ No _

In-Cabinet "housekeeping"? Yes _ No _

If "Yes" to either, please add to list in question 4.1.

4.4 "Failures" of the SSPS slave relays have been observed? Yes _ No _

Complete the table attached, listing all slave relays (include Aux. Safeguards Cabinet, if applicable).

5.1 Is temperature controlled in the area of the SSPS (e.g., via Class 1E HVAC)? Yes _ No _

Range: ___ to ___

5.2 Is the local area temperature monitored and recorded? Yes _ No _

Peak value recorded ___

5.3 Is the SSPS in-cabinet temperature monitored? Yes _ No _

Range: ___ to ___

Peak value recorded ___

6. Please attach a descriptive summary of any incidents where components in the Safeguards Test Cabinet (SGTC) have caused inadvertent actuations or plant trips during testing. Include reference to applicable plant documents or LERs

7. Please identify person(s) to be contacted if clarification is necessary.

Name: ________________________ Phone No.: ____________

Name: ________________________ Phone No.: ____________

Mail to:

Bill Schivley (ECE MS 4-01)
P.O. Box 355
Pittsburgh, PA 15230-0355

SLAVE RELAY TEST DATA SHEET

SLAVE RELAY DATA TABLE sheet _ of _

Plant/Utility Name: ____________ Contact: ____________

RELAY ID (1)	RELAY TYPE (2)	RELAY COIL (3)	INSTALLED/ REPAIRED/ REPLACED (4)	TEST PERIOD (5)	TEST TYPE (6)	TOTAL ACTUA-TIONS (7)	FAILURES (8)	ROOT CAUSE (9)	NOTES (10)	REFS (11)

Mail to: Bill Schivley (ECE MS 4-01), P.O. Box 355, Pittsburgh, PA 15230-0355

SLAVE RELAY TEST DATA SHEET

INSTRUCTIONS FOR DATA TABLE

Ideal data would be specific to each of the SSPS slave relay by Tag/ID numbers (See SSPS Technical Manual). Answer as completely as possible. Please identify any data "estimated" by circling. If relay replacements have occurred, such should be identified in Column (4); see instruction (4) below.

Questions or requests for clarification on the data sheet or table, please contact: **B. J. (Bern) Metro**
G. R. (Jerry) Andre

(1) Preferred response consists of Relay ID Number (refer to Tech Manual schematic) and Train A or B; i.e., K624-A. At minimum, enter the quantity of relays for which all other items of the line apply identically.

(2) Enter: "A" for AR relays: "A4" for AR440 or "A8" for AR880; add "L" for latching relays (e.g., A4L = AR440 relay with latch). "M" for MDR rotary relays; "ML" for MDRs with latch; specify 4 or 8 contact types (e.g., M4L = a 4-contact MDR with latch). Any others, please specify. SSPS MDRs are the "small" variety, outside the SSPS MDRs may be the "medium" with up to 16 contacts. Use Notes, as necessary.

(3) Please specify the relay coil type and state (during normal plant operation), as follows (e.g., AC-NE = an AC coil relay normally energized during plant operation).

Enter: "AC" for AC current coils
"DC" for DC current coils

Enter: "ND" for normally de-energized coils
"NE" for normally energized
"NX" for normally de-energized; but energized during plant shutdown. (Please specify cumulative outage time relay energized in NOTES.

(4) Enter "X" for relays that are original equipment. If relay was replaced, enter date (month/year) on following line and respond in any columns that apply since the new relay was installed. State whether the relay or a part was repaired or replaced. Recall that the objective is to gather data after issuance of the plant operating license. Use Notes to provide details.

(5) Enter number of months between periodic tests (e.g., "4"). Enter "R" if relay(s) are tested only during plant/refueling outage.

(6) Enter: "G" for "Go" testing, or
"B" for "Block" testing.

Also add notes identifying equipment actuated via the slave relay.

INSTRUCTIONS FOR DATA TABLE (cont.)

(7) Total actions should include all experienced since issuance of operating license to date or until failure/replacement. This is to include any actuations which have involved other system tests which result in slave relay actuations and any due to plant trips.

(8) Failures should be characterized as one of the following:

"A" Did not actuate on demand.
"L" Did not latch when actuated.
"UL" Did not unlatch when reset.
"CO" Contact(s) did not make.
"CI" Contact(s) intermittence.
"N" None apply; add Notes (9) to describe.

(9) Root causes should be characterized as one of the following:

"U" if unknown or not determined.
"X" Failure was not in relay, but due to other circuit problem. Specify in Notes.
"B" Binding of the relay; "BD" if caused by dirt or debris;
"BM" Binding of an MDR relay due to coil outgassing/corrosion product accumulation (See NRC IN 92-04)

"O" Relay coil failed open or short.
"CA" Contact alignment
"CW" Contact wear; note if corroded (CWC), pitted (CWP), or high resistance (CWR)
"CF" Contacts fused or welded; "CFL" if due to excessive loading of contacts.
"LA" Latch alignment (poor or needed)
"LR" Latch reset coil open or shorted
"M" Latch magnet would not "hold" (AR-type relays)
"S" Return spring broken or misaligned
"N" None apply; add Notes (9) to describe.

(10) Compile notes on separate sheet and attach. Make reference to all LERs or other documents which provide details.

(11) Enter applicable reference numbers. Compile list of references and attach.

APPENDIX C

ARRHENIUS EQUATION FOR AGING AT ONE OR MORE TEMPERATURES

Assuming that the accelerated thermal aging process expressed by the Arrhenius Model correctly simulates the change in properties due to aging at a different temperature than the accelerated aging temperature, then:

$$t_s \exp(-E/KT_s) = t_o \exp(-E/KT_o) \quad \text{(E1)}$$

where:

t_s	=	total service life at temperature T_s
exp	=	base of natural log (2.71828)
t_o	=	time at temperature T_o (accelerated aging temperature)
T_s	=	material temperature at total service life conditions (°K)
T_o	=	material temperature at accelerated aging conditions (°K)
E	=	material activation energy (eV) for property of interest
K	=	Boltzmann's Constant (8.62E-05)

The total service life (t_s) may be split into two time periods at different temperatures:

$$f_{s1}\, t_s \exp(-E/KT_{s1}) + f_{s2}\, t_s \exp(-E/KT_{s2}) = t_o \exp(-E/KT_o) \quad \text{(E2)}$$

where

f_s	=	fraction of total service life (t_s) at defined temperature

The above equation E2 is useful in calculating the total service life (t_s) based on known accelerated aging test parameters and a defined duty cycle, e.g., energized fraction f_{s1} and deenergized fraction f_{s2}. Solving for t_s:

$$t_s = t_o/(f_{s1} \exp((-E/K)(1/T_{s1}-1/T_o)) + f_{s2} \exp((-E/K)(1/T_{s2}-1/T_o))) \quad \text{(E3)}$$

The above equation E3 may be expanded to include multiple fractions of the service life or used to determine the required aging time (t_o) for a test when other parameters are known or defined, e.g., t_s could be defined.

APPENDIX D
LEAD PLANT RESPONSE TO NRC COMMENTS AND QUESTIONS

P&GE LETTER DCL-95-268
December 7, 1995

(Reference 13-19)

Pacific Gas and Electric Company

77 Beale Street, Room 1451-B14A
San Francisco, CA 94105
Mailing Address
Mail Code B14A
P.O. Box 770000
San Francisco, CA 94177
415 973-4684
Fax 415/973-2313

Gregory M. Rueger
Senior Vice President and
General Manager
Nuclear Power Generation

December 7, 1995

PG&E Letter DCL-95-268

U.S. Nuclear Regulatory Commission
ATTN: Document Control Desk
Washington, D.C. 20555

Docket No. 50-275, OL-DPR-80
Docket No. 50-323, OL-DPR-82
Diablo Canyon Units 1 and 2
<u>Response to NRC Request for Additional Information on Slave Relay Test Frequency Relaxation Amendment (LAR 94-11, dated November 14, 1994)</u>

Gentlemen:

PG&E Letter DCL-95-254, dated November 14, 1994, submitted License Amendment Request (LAR) 94-11. LAR 94-11 proposed a revision to the Diablo Canyon Power Plant (DCPP) Technical Specifications (TS) to relax the slave relay test frequency from quarterly to refueling frequency. The LAR submittal included WCAP-13878 (proprietary), "Reliability Assessment of Potter & Brumfield MDR Series Relays," June 1994. PG&E is the lead plant for the Westinghouse Owners Group for this TS change.

NRC letter dated April 27, 1995, identified six questions regarding WCAP-13878 and the reliability of Potter & Brumfield MDR relays used at DCPP. In addition, a 10CFR Part 21 report was submitted by San Onofre Nuclear Generating Station on July 21, 1995, on MDR relays with potentially damaged contact arms. The applicability of this problem and its potential effects on slave relay reliability was evaluated and is discussed in this submittal. PG&E's responses and supporting attachments are enclosed.

The enclosed additional information does not affect the conclusions of the safety evaluation or the no significant hazards consideration determination performed for LAR 94-11.

Sincerely,

Gregory M. Rueger

7 1995

Document Control Desk
December 7, 1995
Page 2

cc: Edgar Bailey, DHS
Steve Bloom
L. J. Callan
Kenneth E. Perkins
Michael D. Tschiltz
Jennifer Dixon-Herrity
Diablo Distribution

Enclosure
Attachments

RESPONSE TO NRC REQUEST FOR ADDITIONAL INFORMATION ON SLAVE RELAY TEST FREQUENCY RELAXATION AMENDMENT (LAR 94-11, DATED NOVEMBER 14, 1994)

NRC Question 1: De-energized Relays

With regard to relay failures, Information Notice (IN) 92-04, dated January 6, 1992, page 2, under the discussion section, third paragraph, states that, "...Failures may occur regardless of current or power, the use of ac or dc power or normally energized or de-energized." Also the report S93-06 from the Office for Analysis and Evaluation of Operation Data (AEOD), page 49, section 4.1.2, paragraph 1, states that, "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."

The Westinghouse topical report WCAP-13878, "Reliability Assessment of Potter & Brumfield [P&B] MDR Series Relays", does not address failures of normally de-energized P&B MDR relays. Therefore, in order for the staff to determine acceptability of the normally de-energized MDR relays, we request that you discuss the root cause for all these failures identified with these relays.

PG&E Response

The failure data for Potter & Brumfield motor driven relays (MDRs) was analyzed for those relays specifically used as slave relays in the Solid State Protection System (SSPS) at Westinghouse Owners Group (WOG) plants and for all MDR relay failures in the industry as reported in AEOD Report S93-06, Appendix C.

The analysis that follows applies to WOG plants that have complied with the recommendations for MDR slave relay replacement and whose SSPS is exposed to environmental conditions similar to those experienced at Diablo Canyon Power Plant (DCPP) and Farley Nuclear Plant. The recommendations are provided in WCAP-13878, sections 8.4.1 through 8.4.5. Each plant should provide a site specific response confirming 1) the similarity of models of MDR relays used, 2) energization state of SSPS relays, 3) SSPS ambient conditions, 4) status of relay replacement based on the WCAP recommendations, 5) contact loading review, and 6) procurement program review for those MDR relays which are proposed for surveillance extension.

SSPS Configuration

The standard Westinghouse SSPS uses normally de-energized slave relays for all Technical Specification (TS) required functions. In general, only two of the 40 or more MDR relays are normally energized at power. In addition, a small number of relays may be energized during shutdown. At DCPP, only two of the 40 relays installed in each of the SSPS output bays are normally energized at power, and neither relay performs a TS function. No DCPP TS slave relays are normally energized during outages since the SSPS is removed from service then. Additional information on SSPS configuration is provided in PG&E's response to NRC Question #6.

SSPS Slave Relay Failure Data

WCAP-13878, section 9.0, addresses the failures of P&B MDR relays used as slave relays in the Westinghouse SSPS. As noted in Table 9-3 on page 156, 1,158 MDR relays installed in Westinghouse plants with the SSPS have experienced a combined failure rate of 7.9E-05 failures/demand.

WCAP Table 9-4 on page 157 and Section 9.2 present and discuss six MDR relay failures. Of the 1,158 slave relays reported on by 16 nuclear plants with SSPS, six failure events were reported. Two of the six failure events are not relevant to normally de-energized slave relay failures; one caused by offgassing in a normally energized relay and one caused by valve limit switch failure, not slave relay failure.

The remaining four failures involved normally de-energized slave relays. Two of the failures were determined to be infant mortalities caused by open coils in 1989 at South Texas. One failure root cause was contact fusing due to overloading caused by inadequate circuit design in 1989 at Beaver Valley. One failure was attributed to a latching slave relay after a single containment spray pump was found running after a reactor trip and safety injection at DCPP Unit 2. The 1985 LER (85-007-00) concluded that after thorough testing and investigation, the exact cause of the pump start could not be determined. Since one possible cause was mechanical failure of the relay, the relay was replaced.

The small number of failures of normally de-energized SSPS slave relays, and the absence of failures since 1991 despite enhanced reporting mechanisms, are indicative of satisfactory service of the normally de-energized P&B MDR relays.

AEOD Report S93-06 Failure Data

PG&E and Westinghouse completed an evaluation of the MDR relay failures reported in AEOD Report S93-06, Appendix C, "P&B MDR Relay Failure Data."

The table in Appendix C of the report was copied and expanded to add two additional columns: 1) the relay size, and 2) notations on the cause of the failure and implications for SSPS slave relays. In addition, missing coil wattage ratings were added and rated coil voltages were corrected in some cases where the relays were incorrectly identified. The revised AEOD table is enclosed as Attachment 1, "Table 1: Expanded Appendix C of AEOD Report S93-06." Blocks where information was added or changed from the original table are indicated by bold type, with the original information, if any, shown in parentheses.

The final column in the table provides table notations. These notations indicate features of the relay, circumstances of usage, or failure modes that differentiate the relay from the small, de-energized, ac coil relays used at DCPP and other WOG plants as SSPS slave relays. Failure events involving relays of significantly different construction or usage than SSPS slave relays are shaded. A discussion of the table notations and their relevance to slave relay reliability follows.

Notation 1: (M) Medium MDR Relays

Latching and non-latching MDR relays are furnished in two sizes: small and medium. There are significant differences between the two sizes' physical and electrical characteristics such that many failure modes are either restricted to or much more likely to occur in medium relays.

Physically, the medium relay is 1.57" wider than the small relay at the base, and up to 1.87" taller than the small relay when each is configured with its maximum contact decks. The two sizes utilize the same switch ring (contact) sections, but the medium relays are provided with up to twice as many contact decks as the small relays. Physically larger coils, stators, and shading coils are used to permit the medium relays to reliably switch against the larger contact spring forces resulting from the additional decks. The larger components generate additional rotational force to make and maintain contact closure.

Failures due to shading coil detachment are limited to medium size relays due to design differences. Shading coil configurations are addressed in detail in PG&E's response to Question #3.

The coil wattage column of Table 1 indicates that the medium MDR relay coils dissipate between 12 and 30.8 watts, and that small MDR relays dissipate between 5.5 and 20.6 watts. Due to the lower power requirements and lower associated heat dissipation, small ac relays experience slower material degradation than medium relays for those aging mechanisms related to heating.

DCPP uses small models 4102 and 4103 relays as SSPS slave relays. The 4102 relays are physically the same as the 4120 relays used in the SSPS at other WOG plants. Due to the differences in relay components' sizes and design, power requirements, and heat dissipation, failures associated with medium relays are not relevant to SSPS slave relay reliability.

Notation 2: (DC) dc Coil Relays

SSPS slave relays are all small 115 to120 Vac coil relays in latching and non-latching configurations. Small ac relays experience fewer problems than small dc relays because the coils draw less power and because the coils are physically smaller.

DCPP's small ac latching (model 4102) and non-latching (model 4103) relays with two contact decks have power requirements of 5.5 and 6.5 watts respectively. Small 125 Vdc latching and non-latching relays with two contact decks require 20.6 and 10.3 watts, respectively. The difference in power requirements directly affects the amount of heat dissipated, so that the small ac relays experience a smaller temperature rise than dc relays. Consequently, the energized small ac relays experience slower material degradation for those aging mechanisms related to heating.

Inspection of relays removed from DCPP and disassembled and correspondence from P&B confirmed that small ac relays have physically smaller coils than similar configuration dc relays. Manufacturing defects related to oversize coils interfering with the fit of the top end bell are unlikely to affect the ac relays because of the coil size difference.

Since the Westinghouse SSPS uses low power requirement, physically smaller coil ac coil relays, failures of dc coil relays are not relevant to the reliability of the SSPS slave relays.

Notation 3: (V) Varnish Offgassing

The primary failure mechanism for pre-1986 small and medium MDR relays is coil varnish offgassing and recondensing on bearing surfaces inside the relay, resulting in the relay failing to operate on demand. Elevated relay temperature is the dominant factor in the rate of offgassing experienced in older MDR relays. Most older MDR relays that operate sluggishly, slowly, or are stuck in either the energized or de-energized position failed due to varnish offgassing. In 1986, P&B changed the coil coating material from polyester-based varnish to non-offgassing epoxy resin, eliminating this failure mechanism.

Between 1986 and 1990, P&B made additional substitutions to remove all materials which offgassed hydrochloric acid or chloride vapors and all materials subject to corrosive attack by those vapors. Residues from these vapors and signs of corrosion had been noted in some of the varnish offgas failed relays. See WCAP-13878, Section 5.4, for a discussion of the materials changed in the relays.

The rate of coil varnish offgassing is dependent on the temperature in the relay motor housing. Elevated temperatures caused by coil self-heating directly affect the energized relay and may affect other relays mounted nearby. There is very little offgas deposition in a relay with a varnished coil maintained at ambient room temperature over a long period of time. However, there may be heavy offgassing to the point of relay failure in either an energized relay or a relay mounted in a hot environment.

WCAP-13878 concludes that older MDR relays with polyester-based varnished coils, which are either normally energized or periodically energized for significant periods of time, are subject to coil varnish offgassing failure. In sections 8.4.1 through 8.4.5, the WCAP provides recommendations for replacement of older relays based on the month and year of manufacture and service usage (energization period). Relays which are energized each refueling outage but are normally de-energized during power operation were defined as 20 percent duty cycle relays. The 20 percent duty cycle relays have specific replacement recommendations based on the year of manufacture.

DCPP has complied with the recommendations provided in WCAP-13878 sections 8.4.1 through 8.4.5. All normally energized SSPS MDR relays were replaced with relays made after May 1990 prior to the issuance of WCAP-13878. DCPP has no 20 percent duty cycle relays because the SSPS is removed from service during refueling outages.

WOG plants which have completed normally energized and 20 percent duty cycle relay replacements as recommended by WCAP-13878, and maintain the original normally de-energized MDR relays at a mild ambient temperature, are not subject to the varnish offgassing failure mechanism.

Notation 4: (MD) Manufacturing Defects

The dominant failure mode for older MDR relays is coil varnish offgassing in energized relays, resulting in relay failure to operate, as discussed in Notation #3. Manufacturing defects (1990-1995) have been noted by the NRC, NSSS vendors, and other nuclear plants, including San Onofre Nuclear Generating Station (SONGS). These defects do not affect the SSPS slave relays installed as original equipment in the 1970s and early 1980s. Many of the identified defects are associated with medium size or dc coil relays, and do not affect the small ac coil relays used in the SSPS. Analysis indicates that identified manufacturing defects generate relay failures before installation or early in life for energized MDR relays.

At DCPP, energized replacement relays have provided acceptable service for over 2.5 years in both units, indicating they were not affected by manufacturing defects. Manufacturing defects and PG&E's commercial grade dedication program are further discussed in response to NRC Question #2 on page 9 of this submittal.

Notation 5: (CL) Contact Loading

Failures related to improper contact loading (low-level, overload, and series or parallel contacts) are related to actuation circuit design. DCPP has completed loading studies for SSPS slave relay contacts to ensure that all of the contacts are used within their capabilities. No improper slave relay contact loading has occurred at DCPP. Consequently, this failure mode is not applicable . Contact loading is further discussed in response to NRC Question #4 on page 13 of this submittal.

Notation 6: (OV) Coil Over-voltage Application

Overvoltage conditions are most likely to be associated with dc coil MDR relays. Two overvoltage conditions are of particular note.

The first condition is the utilization of 24 and 28 Vdc coil relays in 36 Vdc circuits in normally energized applications in plant reactor protection systems (RPS) furnished by a different vendor. The overvoltage condition resulted in higher power dissipation in the relay and a higher rate of varnish offgassing. These relays were the first to reach end-of-life and expose this failure mechanism.

The second overvoltage condition is the routine dc power supply voltage elevation used to ensure sufficient battery capability. The result of the elevated voltage on energized dc relays is additional internal and external heat dissipation, increasing the offgassing rate inside the relay and raising the internal cabinet temperature for nearby relays. For example, River Bend calculated internal relay temperatures using a finite element model for relays energized at 120 Vac and 125 Vdc as 127°F and 149°F, respectively (AEOD S93-06, page 13).

In contrast, the vital instrument ac power system that supplies the SSPS slave relays at DCPP is maintained at a nominal output voltage of 120 Vac at all times.

Since the relays are not exposed to high coil voltages, they do not experience accelerated offgassing when energized.

Notation 7: (NE) Normally Energized

Many MDR relays are used in close-packed <u>energized</u> applications in reactor protection and safeguards systems in other NSSS vendor designs. Due to the self-heating and relay-to-relay heating effects that accompany normally energized usage, these relays experience accelerated aging. Failure modes associated with normally energized usage include varnish offgassing and the manufacturing defects of over-size coil binding, coils opening, and tramp epoxy sticking.

DCPP uses normally de-energized small MDR models as SSPS slave relays for all TS applications. Due to the difference in heat dissipation, failures associated with normally energized relays are not relevant to normally de-energized SSPS slave relay reliability.

Summary of AEOD S93-06 Appendix C Review

Table 1 indicates that of the 120 failures listed in the AEOD report, 95 may be eliminated as not applicable to DCPP SSPS slave relays because the failed relays were either medium sized or had dc coils.

Twenty-five failures occurred in small 115-120 Vac coil relays. Of these failures, 19 occurred in normally energized relays: 11 due to slow operation indicative of offgassing, 1 burnt out coil, 2 stuck contact and 1 corroded contact failures, 1 noisy relay (replaced prior to failure), 1 end cover binding, and 2 uncategorized failures. A majority of the categorized failures are not applicable to the normally de-energized usage found in the SSPS. Failures due to offgassing, burnt out coils, noisy relays and end cover binding are associated with energized usage. Stuck contacts may be caused by either offgassing or contact overloading, neither of which is applicable to the TS slave relays used in the DCPP SSPS. The corroded contact is most indicative of contact overloading and is also not applicable. The two uncategorized failures cannot be addressed due to insufficient information.

Six of the 120 failures noted in the AEOD report involved small, de-energized, 120 Vac coil relays. These six failures are shown in Table 2, on the next page.

Table 2 AEOD Report Failures of De-Energized 120 Vac Coil MDR Relays				
Failure	Model	In-Service to Failure Dates	NSSS	Failure Mechanism
1	134-1	3/80 to 6/88	CE	mechanical binding
2	134-1	1/85 to 5/85	B&W	contacts stuck
3	4094	1/85 to 7/85	GE	intermittent operation
4	4094	1/85 to 7/85	GE	intermittent operation
5	4121-1	6/78 to 10/87	W	relay operated slowly
6	4134-1	4/88 to 9/90	GE	burnt out coil

Based on the in-service dates, the six failures involved polyester-based varnish coil relays, since P&B did not change to epoxy-dipped coils until mid-1986.

Failure 1 due to mechanical binding and failure 5 due to slow operation were potentially caused by varnish offgassing. Insufficient information is given to determine factors which may have influenced these failures, such as location in cabinets with high ambient temperatures or significant energization periods during plant shutdown (i.e. 20 percent duty cycle).

Failures 2, 3, and 4 are cases of infant mortality in 1985. There is insufficient information presented to allow determination of relevance of these three failures. The most likely causes of these failures are manufacturing defects or failures due to problems generated elsewhere in the electrical circuit and incorrectly attributed to the relay. Manufacturing defects are commonly associated with incidents of infant mortality, since a new relay used in an application within the design specifications of the relay would not be expected to fail at the beginning of life.

Failure 6 may be the result of a random manufacturing defect resulting in a burnt out coil within the relay. Insufficient information is provided to determine whether this relay may have been energized for significant periods of time during shutdown.

Failure History Summary

The six failures presented in Table 2 and the five failures noted in WCAP-13878 together represent the best available data on failures associated with small ac coil de-energized MDR relays. Of the eleven known relay replacements reported as failures, five were infant mortality events, three were potentially related to varnish offgassing, one was replaced after a reactor trip although no failure was documented, one was induced by a design weakness allowing contacts to be overloaded, and one was due to a burnt open coil. It is notable that the most recent failure in either table was in 1991, with the great majority of the failures occurring 8-10 years ago. Procurement programs. reporting practices, and industry communication have improved markedly since that time.

A review of these failures indicates that two actions will provide substantial protection against MDR relay failure. First, only relays which have been procured via thorough commercial grade dedication and testing activities should be installed. Second, relays susceptible to varnish offgassing should be replaced pursuant to the recommendations presented in WCAP-13878.

PG&E and the WOG believe the failure history presented in the WCAP together with a review of the applicable failures from the AEOD report represent a satisfactory performance history for small, normally de-energized, ac coil MDR relays used in a suitable design application.

NRC Question 2: Refurbished P&B MDR Relays

IN 90-57 and Supplement 1 alerted licensees to refurbished MDR relays which were found to be materially and functionally substandard and may not have operated as required. However, WCAP-13878, page 43, last paragraph, considers the MDR relays that have been refurbished in substandard fashion to be beyond the scope of this report.

Your submittal does not discuss whether DCPP has any refurbished MDR relays and whether your program for commercial grade equipment certification is adequate to detect the problems identified by the information notices. Please provide this information.

PG&E Response

IN 90-57 concerned a particular company and individual that willfully misrepresented and sold refurbished, substandard MDR relays. On receipt of the notice, PG&E verified that no receipts were on record from the associated companies for any type of materials. Additionally, PG&E inspected every MDR relay in the DCPP warehouse using the criteria of the information notice. All relays on site were determined to be acceptable. Finally, PG&E reviewed maintenance records to identify any MDR relays installed in the plant which were procured commercial grade. Three installed relays were identified, and verified to have passed sufficient dedication criteria and testing to assure their acceptability.

Manufacturing defects occurring since May 1990 include shading coil detachment (medium ac relays only), tramp epoxy deposition (all models experiencing rework), oversize coils causing relays to bind (dc coil relays), incorrectly wrapped coils (all models), deficient springs (all relays have been identified), and bent contact arms (reworked models).

In addition to the problem reports noted in AEOD Report S93-06, on July 21, 1995, San Onofre Nuclear Generating Station (SONGS) issued a 10CFR Part 21 report concerning relays that were returned to SONGS with bent contact arms following P&B rework. Some of the reworked relays experienced subsequent failures during commercial grade dedication activities. Past reports have identified other instances of new MDR relays failing commercial grade dedication activities.

PG&E has completed evaluating the SONGS Part 21 report along with other industry experience reports regarding MDR relays. As a result of the evaluations, DCPP has put into place an enhanced commercial grade dedication process to prevent substandard or refurbished relays from being installed in the plant. All existing MDR relay warehouse stocks were placed on hold during the evaluation period, and will be re-inspected using the new enhanced criteria.

Elements of the DCPP commercial grade dedication program for safety related ac coil MDR relays follow. The dedication program may be changed from time to time based on new information, in accordance with the plant replacement parts equivalency evaluation program.

1. No DCPP MDR relays will be sent out for rework. No relays will be accepted if rework or refurbishment is known to have been performed.

2. Each relay will receive either a detailed source inspection during the assembly process or verification of operability via additional testing.

   a) The source inspection requirements include 100 percent sample size worksmanship verification of contact arm assembly, black light inspection, coil tape wrapping overlap at edges and corners, and coil dimensions. These inspections will eliminate the failure modes of bent contact arms, tramp epoxy sticking, coil failure due to insufficient wrapping, and oversize coils.

   or,

   b) In lieu of source inspection, non-destructive testing may be performed on receipt. A sample population of the relays will be baked at a temperature and time sufficient to permit coil cold flow relaxation and tramp epoxy setup to occur. Then, relay response time testing and 100 percent contact operation verification will be performed.

In addition to the above source inspection or non-destructive testing, each MDR relay will receive the following inspections on receipt:

3. Each MDR relay will receive visual inspection to verify configuration and manufacture date;

4. Each MDR relay will receive electrical testing consisting of verification of pickup and dropout voltages and coil resistance, dielectric withstand voltage testing, and contact voltage drop, current carrying, and current interrupting capacity testing;

5. Each MDR relay must be accompanied by a certificate from the manufacturer stating black light examinations have been performed on the relay prior to assembly, to prevent tramp epoxy problems. Although P&B does not furnish MDR relays as safety grade components, requiring this extra inspection should help assure that satisfactory relays are received.

PG&E believes this testing program will ensure that substandard MDR relays will be detected on receipt and not installed in the plant.

NRC Question 3: Pre-1992 MDR ac Relays

AEOD Report S-93-06, page 48, section 4.1.1, item 3, states that, "Failure of the ac MDR relays to reset was caused by the detachment and wedging of a copper (sic) shedding coil between the rotor and the stator because the epoxy attaching the shading coil to the stator cracked due to temperature-induced expansion and stretch (MDR relays made prior to 1/92)." Also, page 51, first full paragraph, states that, "The many contributors to MDR relay failures result in an unpredictable failure history that makes it unlikely that a scheduled surveillance testing, preventive maintenance, or replacement program can be effectively applied to pre-1990 MDR dc relays or pre-1992 MDR ac relays."

WCAP-13878 does not discuss any basis for accepting pre-1992 ac MDR relays. Therefore if these relays are used at DCPP, provide your basis for their acceptability.

PG&E Response

Shading Coils

Shading coils are copper rings mounted on the relay stator pole pieces of ac coil relays that delay the change of the magnetic field in the stator, tending to prevent chatter and reduce hum. Relays with dc coils do not have shading coils. Small and medium sized ac coil MDR relays have different designs of shading coils.

The small ac coil MDR relay shading coil design utilizes an insulated wire inserted in two keyhole shaped slots in the stator face with the wire ends twisted to form a mechanical connection and then soldered together at the bottom of the stator. The wire is physically restrained by the configuration of the slots, the mechanical twist connection, and the solder joint. Epoxy is not used to restrain the shading coil. WCAP-13878, Figure 4-5a on page 23, shows a small relay's motor cavity and shading coils.

The medium ac coil MDR relay originally used a formed ring of copper installed over the end of the stator and resting in an open slot on the stator. The ring is secured with beads of epoxy at the top and bottom of the stator pole. The copper rings are susceptible to temperature-induced expansion when the relays are energized. P&B used the same polyester-based varnish as was used on the coils to attach the copper shading rings to the stator. The original polyester-based varnish remained flexible when the copper shading ring expanded, and held the ring in place. The epoxy which replaced the coil varnish was susceptible to cracking under excess copper ring expansion.

To eliminate this problem, P&B replaced the copper ring in medium size ac coil relays with a ring made of beryllium-copper. The beryllium-copper is a harder material and does not deform or stretch as much as copper, so the shading rings are sufficiently restrained by the epoxy beads.

DCPP slave relays are small ac coil MDR relays which are not susceptible to this shading coil failure since they do not use the copper ring shading coil design. Medium sized MDR relays are not used to perform safety related functions at DCPP.

Pre-1992 ac MDR Relays

PG&E and Westinghouse have reviewed the various failure incidents reported for MDR relays. As discussed in the response to Question 1, the majority of the failures noted in AEOD Report S93-06 have occurred in energized, dc coil, or medium sized relays. Many of the failures were associated with excessive heating due to exceeding the rated voltage or mounting the relays in isolation cans. When small MDR relays are used in normally de-energized applications in mild environments, few failures occur.

The majority of the slave relays for both Unit 1 and 2 were manufactured in 1975 or 1976, and installed in the SSPS at DCPP in 1976. Since that time, the relays have demonstrated highly reliable performance. There have been no confirmed slave relay failures during testing or required actuations since DCPP started power operation in 1985.

Nine SSPS MDR relays at DCPP have been replaced. One Unit 2 slave relay was replaced in 1985 after a reactor trip when the cause of an ESF actuation could not be determined (LER 85-007-00). Since one possible cause was mechanical relay failure, the relay was replaced. No actuation problems or sticking were noted when the removed relay was tested on the bench. The relay was disposed of after bench testing, and no record of disassembly inspection exists. Eight (two per SSPS train) energized SSPS relays were replaced with new MDR relays as part of PG&E's response to IN 92-04. None of the eight relays performed TS functions. All eight relays were disassembled and inspected for the presence of offgas material or other readily visible problems. Four of the eight relays were from the same lots as the original slave relays. The other four relays were installed in the mid-1980's as part of a design modification. As discussed in LAR 94-11, the good material condition of the eight energized slave relays was judged to bound the remaining normally de-energized slave relay population.

Based on past performance and the defects found in new MDR relays, PG&E does not believe that replacing the older, de-energized MDR relays with new relays will increase safety or the reliability of SSPS performance. The maintenance activities associated with unwiring and replacing the relays on a programmatic basis would introduce the potential for wiring errors, inadvertent ESF equipment operation, infant mortality failures, and require extensive testing. The satisfactory performance of the de-energized slave relays in this application does not warrant replacement of the relays.

In summary, the pre-1992, de-energized, small, ac coil SSPS MDR relays are not subject to the excessive failures identified in the AEOD report. The installed DCPP slave relays have given years of satisfactory service, and are not implicated by the 1992 problem reports or current industry concerns with the quality of new MDR relays.

NRC Question 4: Misapplication of Relay Contacts

AEOD Report S93-06, page 49, discusses application problems and states that:

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 application 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 loads.*

The NRC staff has also issued IN 92-19 regarding this problem and WCAP-13878, page 44, section 6.5, states that this is beyond the scope of this report. Identify corrective actions you have taken to address this problem.

PG&E Response

In 1991, in response to an operational experience report concerning MDR relay contact failure at Beaver Valley, PG&E completed a loading study covering each contact on every SSPS slave relay for Unit 1. The loading study recorded the manufacturer, model, and device ratings of each actuation device (solenoid or relay) operated by each slave relay contact. Unit 2 SSPS design and loads are similar to Unit 1, and were not reviewed. All slave relay contact loading was found to be acceptable.

In 1992, PG&E expanded the study to include other safety related relays and to specifically consider low-level loading. Again, all slave relay contact loading was found to be acceptable. Finally, in 1995, the loading study was reviewed to incorporate plant modifications completed since 1992. All contact loading was found to be acceptable.

Changes in circuit loading which could affect slave relay contact loading are reviewed in the design process. The design modification electrical review process includes direction to review the effect of changes in control circuit loading on the ratings of contacts in the circuit.

Discussion of the three specific NRC concerns identified in Question #4 follows.

Low-Level Loading

In the loading studies, four slave relays per train were identified that switch low-level loads. In the study, low-level loads were defined as loads less than 20 mA. This cutoff is consistent with the concerns raised in the IN, Attachment B, where low-level loads were discussed using an example of 10 mA.

In each of the four relays, the contacts used to switch low-level loads provide multiplexed ESF annunciation to the main control room. None of the low-level load contacts provide safety-related functions; consequently, low-level loading is not a concern for DCPP slave relay circuitry.

Single Contact Overloading

In the loading studies, all slave relay single contacts were evaluated for overload, for both ac and dc contact applications. Contact derating required for inductive loads was considered in determining the acceptability of the loading.

All DCPP slave relay single contact ac and dc loads are within the continuous current carrying and switching capabilities of the slave relay contacts. Additionally, a review of slave relay surveillance history found no intermittent contact failures indicative of contact erosion. Since all single contact loads are acceptable and adequate guidance is provided in the design modification process, single contact overloading is not a concern for DCPP slave relay circuitry.

Contact Pair Overloading

DCPP does not use parallel contacts on slave relays to increase the contact continuous current and break ratings. However, in several cases, two contacts in series are used to increase dc contact current make and break capability. The two contacts in series act to increase contact separation, which increases both the maximum dc voltage and current that can be controlled. Series contacts are subject to some of the same concerns as parallel contacts, since independent contacts may not operate at exactly the same time. If one contact opens or closes earlier than the other, most of the arcing will still occur on one contact.

The series contact usage for slave relays performing TS required functions can be broken into three applications: 1) to provide blocking signals to 4KV switchgear breaker closing coils, 2) to energize Electroswitch relays for bus transfer, and 3) to energize various loads which are within a single contact rating.

The blocking signal contact application is used in two relays per train in engineered safety feature (ESF) pump control schemes to open the autotransfer closure circuit if a safety injection signal is received. Opening the autotransfer circuit permits the safety injection loading sequence to be followed instead of the standard bus autotransfer loading sequence. The slave relay is actuated by a safety injection signal and opens its series contacts within 12 to 15 milliseconds of actuation. The first affected load will not receive an autotransfer start signal for at least 4 seconds (minimum time setting for component cooling water pumps, see TS Table 4.8-2b). Consequently, the slave relay contacts open under no load conditions and are not subject to circuit breaker closing coil loading.

The second contact application is used in one relay per train in the vital 4KV bus autotransfer control circuit to initiate a bus transfer to startup power. The slave relay is actuated by a safety injection signal and closes its series contacts to energize an autotransfer trip relay. The Electroswitch trip relay is self-clearing, and de-energizes its trip coil within 20 milliseconds. The Electroswitch relay coil loads are within the short term current carrying rating of single slave relay contacts. The actuation contacts are further protected by a contact protector around the Electroswitch trip coil. Because of the self-clearing design of the trip relay, the slave relay contacts neither break nor carry excessive current.

The third series contact application is used in a small number of relays to actuate equipment that has design loading below the contact ratings for single contacts. Past design changes may have reduced the circuit loading to single contact range, accounting for the presence of series contact design in applications which do not require it. For these circuits, there are no design loading concerns.

Slave relay surveillance history was reviewed, and no instances of contact failure or intermittent actuation in series contact applications were found.

DCPP does not use parallel contacts to increase contact current carrying capacity. Series contacts are used in applications where increased load break capability may be required. Evaluation of the slave relay circuits where series contacts are used indicates that the MDR relay contacts are used within their design capabilities. Consequently, neither parallel or series contact applications are a concern for DCPP slave relay circuitry.

NRC Question 5: Relays Manufactured in 1992

AEOD Report S93-06, pages 48 and 49, states that:

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 degrees Fahrenheit 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 degrees Fahrenheit, caused by uncured epoxy on the stator interfering with rotor movement (MDR relays made in 1992).*

WCAP-13878 and your submittal does not discuss the basis for acceptability of these relays made in 1992. If these relays are used at DCPP, provide your basis for their acceptability.

PG&E Response

Rotor Return Springs

According to the Asea Brown Boveri (ABB) 10CFR Part 21 report, LD-93-003, this problem was limited to 172 relays with one lot of return springs made from improperly manufactured or passivated wire. PG&E does not use any of the various models of relays (170-1, 7032, 7033, and 7034) identified in the report. All of the identified models are medium sized MDR relays. This problem is not applicable to the small ac coil relays used in the SSPS.

Binding Caused by Insufficient End-Play of Shaft or Oversize Coils

According to the ABB 10CFR Part 21 report, LD-93-177, this problem occurred in 1992, in medium sized relays furnished to Waterford. The relays identified in the part 21 are medium models 7032, 7033, and 7034 with date codes between 9239 and 9349. P&B identified an error in the manufacturing process where the coil size was gauged to the wrong specification resulting in coils which were too large, which in turn, resulted in insufficient end-play of the shaft. PG&E does not use these models of medium sized relays.

Root cause evaluation work performed at San Onofre indicates that this failure mode applies to both small and medium dc coil relays. Coils of dc relays are significantly larger than ac relay coils for any given relay size. Oversized dc coils can impede installation of the top and bottom endbells, requiring additional rotor spacers. Once the relay is heated for a period of time, the coil epoxy or varnish cold flows away from the end bell pressure points, allowing the end bell to move and exert additional force on the rotor causing the rotor to bind.

The original SSPS MDR relays were produced as safety-related parts approximately 20 years ago. If these relays were susceptible to the end bell binding failure mechanism, failure would have been evident, since cold flow would have occurred during this period. The eight non-TS, energized ac SSPS relays replaced for IN 92-04 have been in service over 2.5 years with no indication of relay binding or failure to operate. Laboratory testing performed at San Onofre indicates that essentially all coil relaxation affecting end bell tolerances occurs within the first week of energization. Therefore, end bell binding failure is not an expected failure mechanism for DCPP SSPS relays.

Tramp Epoxy

Tramp epoxy, defined as epoxy deposited in undesired locations, was found in reworked relays undergoing commercial grade dedication at ABB as documented in CE Tech Note No. 92-05. Tramp epoxy sufficient to impede rotor movement was found on the stator and rotor faces and the stator body. Uncured epoxy and tramp epoxy have also been found in medium sized ac and dc MDR relays undergoing commercial dedication at San Onofre.

Tramp epoxy problems previously occurred in 1989 at Palo Verde, as documented in AEOD Report S-93-06, section 3.2, page 8. At Palo Verde, several reworked relays failed in their first week of energization due to complete lack of rotation on de-energizing the coils. Epoxy was found on the stator faces and mating rotor surface. It was believed that epoxy had been inadvertently deposited during the relay manufacturing process.

DCPP does not use the relay models implicated in the reported events. The only medium sized relays used at DCPP are used as a normally de-energized test relays, and have no safety function. However, PG&E recognizes that this failure mode may apply to other MDR relays, and has enhanced the commercial grade process to ensure that safety related MDR relays are not affected by this failure mechanism.

NRC Question 6: Aging

Your submittal and WCAP-13878 proposes a 30-year life for normally energized MDR relays. This determination is based on the use of the Arrhenius Methodology. The staff needs the following information on the input data used with the Arrhenius methodology in order to assess the acceptability of these relays:

1. *For the ambient temperature data collected at Farley describe:*

   a. *How the data were taken, e.g., forced ventilation vs. natural circulation, cabinet door open vs. closed, and how long the cabinet door was open before the measurements were taken.*

   b. *How many relays were energized and duration of energization prior to measurement.*

2. *Temperature rise is assumed to be 58 degrees centigrade. Provide the basis for assuming this temperature rise since the MDR relays used at Westinghouse plants are designed to facilitate close spacing for mounting in cabinets that may result in higher temperature rise than the vendor prediction.*

3. *Table 8.24a for normally energized relays based on the 58 degrees centigrade ambient condition (Farley data) predicts the life of relays to be less than 30 years. However, WCAP-13878 proposes 30-year life for the MDR relays. Provide justification for this discrepancy.*

4. *Tables 8.4, 8.4a and 8.19 list higher service life for 100 percent duty cycles vs. 20 percent duty cycle. Justify or correct the discrepancies.*

5. *Tables 8.4, 8.4a and 8.4b indicate life of Neoprene rubber based on elongation (60 percent retention), while Tables 8.5, 8.5a and 8.5b indicate life for Neoprene rubber based on elongation (100 percent retention) for 65 degrees centigrade, 58 degrees centigrade, and 25 degrees centigrade temperature rise respectively. However, the life for 100 percent retention is listed as more than for 60 percent retention. Provide justification or correct the discrepancies.*

PG&E Response

6.1.a. Farley Temperature Data

The temperature data were recorded with three thermistor-based data logger units installed in and around the Farley SSPS output bays. The units were installed for a period of approximately fourteen months, for the period May 11, 1992, through July 26, 1993, and recorded actual air temperatures inside and outside the cabinet at 20 minute intervals.

Two temperature data loggers were installed in the cabinet, with one being located adjacent to a normally energized relay (worst case) and the other measuring internal cabinet ambient air temperature in the upper section of the cabinet. Additionally, one data logger was mounted external to the cabinet to record ambient air temperature.

The Farley SSPS was operated normally, with both trains in service and cabinet doors maintained closed at all times, unless surveillance activities required that they be opened. During the majority of this time the plant was in Mode 1.

The monitored conditions reflected temperature fluctuations corresponding to ambient room temperatures, nominal seasonal and day/night temperatures, and the position of the cabinet doors (open vs. closed). The data provides a record of the times when the cabinet doors were opened as evidence by an abrupt drop in internal recorded temperatures. The data characterize the cabinet temperature rise that should be expected in a typical SSPS output cabinet during normal plant operation.

The Farley temperature data is summarized in WCAP-13878 Table 8-3, on page 103. The table presents the data as grouped in data files, with each file covering approximately 6 weeks. Comparison of the ambient temperature data with the node 1 and node 2 data quantify the temperature rise expected inside the SSPS output bay.

The temperature rise experienced at the worst case location (node 1) compared to the external ambient temperature was consistent throughout the test period. Temperature ranges for the Farley SSPS output cabinet were:

Nominal	3°F rise	worst case vs. external
Typical Range	1 to 4°F rise	" "
Maximum	8°F rise	one time, maximum difference between worst case and ambient as determined from a review of the raw data

6.1.b. Energized Relays: Farley vs. DCPP Configuration

The Farley SSPS is located in the main control room area, and consists of two redundant trains of the standard three bay Westinghouse SSPS. In accordance with standard system design, the SSPS has no forced ventilation and is not equipped with cabinet blowers or ventilating fans. Natural circulation heat removal is provided through louvers on the front and back cabinet doors.

Farley has two normally energized slave relays in the output cabinet during Mode 1 operation, and as many as six energized during shutdown periods. Farley's slave relays are AR type relays. According to Westinghouse work completed on AR type relays, energized AR relays dissipate 14 watts of power and have a rated temperature rise of 30°C.

The DCPP SSPS trains are of the same standard three bay Westinghouse design as the Farley SSPS. The two trains share a small room located next to the main control room. SSPS room ventilation is provided by the safety related control room ventilation system, and is maintained in the same temperature range as the control room, year-around.

Temperatures in the DCPP SSPS are comparable to Farley. WCAP-13878, Table 8-3 on page 103, indicates that the Farley ambient room temperature ranged from 70.9°F to 83.9°F over the entire data period. Although DCPP does not have comparable records, SSPS room temperature data was recorded twice on random occasions during the preparation of this response. On June 23, 1995, DCPP Unit 1 SSPS room was 69°F and Unit 2 was 76°F, as measured by the TS-required engineered safety features (ESF) room temperature monitoring system. On November 22, 1995, Unit 1 SSPS room was 68.8°F and Unit 2 SSPS room was 75.3°F, by the same system. The room sensors are located outside of the cabinets near the ceiling. Control room temperatures are normally maintained in the range of 65 - 80°F by the operators to provide a comfortable working environment.

Similar to Farley, during normal power operations, DCPP has only two non-latching, non-TS relays energized in the SSPS. The energized small, non-latching MDR slave relays dissipate 6.5 watts each, substantially less than the Farley AR relays. Therefore, the heating effect provided by these two relays is bounded by the cabinet heating effects recorded at Farley.

During refueling outages and cold shutdowns, DCPP removes both the logic and output cabinets of the SSPS from service. Only the 15 Vdc test voltage is available to the slave relay coils, and this voltage is insufficient to actuate any of the relays. Consequently, DCPP does not have any 20 percent-duty cycle slave relays energized for the duration of refueling outages or cold shutdowns.

DCPP and Farley SSPS installations are sufficiently similar that the Farley temperature data is indicative of the normal cabinet temperature rise that would be experienced at DCPP.

6.2. Relay Spacing and Temperature Rise

Relay Spacing

Although the MDR relays used at DCPP are closely packed in their mounting arrangement, only two relays per train are normally energized. One of the energized slave relays is located in the bottom right corner of the cabinet, and the other relay is located near the left center of the cabinet. The heat generated by these two relays is removed by natural convection, and does not substantially affect the relays located nearby. Consequently, the temperature rise for individual MDR relays in the cabinet is not affected by the close pack mounting arrangement.

DCPP Relay Temperature Rise Testing

Relay temperature rise testing was completed at DCPP in January 1994. Additional temperature measurements of the energized ac coil slave relays in Unit 1 were taken in July 1995.

In 1994, two ac coil relays were tested, one small model 4121-1 latching relay with no date code (same configuration as the model 4102 slave relays), and one small model 4103 non-latching relay manufactured in December 1976. The second relay is from the same batch as many of the installed slave relays at DCPP. The relays were energized at 120V ac on the test bench in a horizontal orientation similar to that used in the SSPS, and relay temperatures were allowed to stabilize. Temperatures were measured using a calibrated contact pyrometer at various external points on the relay motor and switch sections.

Initially, the energized relays were placed in a cardboard box to eliminate air currents (no air flow) and allow the relays to self-heat to a point of equilibrium. Closed box temperature was measured at 91.2°F, and then the box was briefly opened to measure the temperature on the external relay locations. Then the energized relays were removed from the box and allowed to reach equilibrium again for the ambient room air temperature tests, where the relays were exposed to normal room air currents. The ambient room air temperature was measured at 76°F.

The highest temperatures on both relays were measured at the top center of the stator laminations. This position would be expected to be the hottest on the relay, since the stator laminations contain the energized relay coils. Table 3 presents the temperatures measured at top center for each of the conditions. and the temperature rise over closed box conditions in both °F and °C.

Table 3: DCPP MDR Relay Temperature Rise Data

Model	Temp. °F (box at 91.2°F)	Temp. °F (room at 76°F)	Max. Temperature Rise (closed box at 91.2°F)	
			Δ °F	Δ °C
4121-1 latching ac no date code	119.7 °F	111.5 °F	28.5 °F	15.8 °C
4103 non-latching ac date code 7652	148.3 °F	139.6 °F	57.1 °F	31.7 °C

In July 1995, confirmatory temperature measurements were acquired during power operation. The four normally energized Unit 1 SSPS slave relays were measured (two per train). A contact pyrometer was used to measure the temperature at the warmest point found in the 1994 testing, the top center of the stator laminations. All four relays were model 4103-1 non-latching small ac coil relays manufactured in August 1992. Ambient room temperature measured outside the relay cabinets was 76°F. The four temperatures at the stator laminations ranged from 115°F to 118.9°F. This temperature rise corresponds to a range of 21.7°C to 23.8°C. All readings were taken expeditiously to preclude cabinet cooldown while the doors were open.

WCAP-13878 Temperature Rise Data

The manufacturer states a maximum temperature rise of 65°C bounds the MDR model series. This is a conservative maximum based on testing of the medium MDR relays. Medium relays have larger coils and higher coil power dissipation than small relays for most relay configurations. P&B has data demonstrating a peak temperature rise of 58°C for a medium MDR relay with dc coil when energized continuously "for a significant time." This temperature rise is substantially greater than would be expected for the lower coil wattage small MDR ac relays, based on the testing and measurements performed at DCPP.

As noted above, PG&E performed temperature rise testing on two small ac MDR relays, and measured a maximum temperature rise of 58°F (33°C if each temperature is rounded up) for relays energized in a box with no air flow. It was intended that this temperature data be used for calculations presented in WCAP-13878. Inadvertently, because of the similarity in numbers, the 58°C temperature associated with medium MDR relays was used in calculations. Therefore, most calculations in WCAP-13878, Chapter 8, are very conservative.

Additional temperature measurements were made in July 1995 on the four normally energized MDR relays in Unit 1 SSPS. The maximum temperature rise was 23.8°C. These readings place the energized SSPS relays within the 25°C data columns of WCAP-13878.

In summary:

- So few relays are normally energized that close spacing is not a factor under normal operating conditions.

- Temperature rise experienced by the SSPS slave relays is less than or equal to 33°C, not 58°C.

- Temperature rise data used in the aging assessment calculations is very conservative since it was calculated using the 58°C term in error, instead of 33°C. In addition, the energized relays are actually experiencing less than 25°C temperature rise.

6.3. Table 8.24a Results vs. Thirty Year MDR Life

WCAP-13878, Tables 8-24, 8-24a, and 8-24b, provide the results of Arrhenius calculations performed on the basis of Westinghouse Long-Term Component Aging Program test data. The purpose of the long-term program was to verify that the relays would not experience common mode failure due to age-related, temperature-induced degradation if they were subjected to a design basis seismic event. The program completed accelerated aging of the relays for one year at 130°C (234°F) prior to performing seismic testing on the relays. The relays passed the seismic testing.

The long-term program assumed a 0.5 eV activation energy. This is more conservative than the lowest activation energy presented in Table 8-1 of WCAP-13878 for any component in the relay. Employing a low value of activation energy in deriving the accelerated aging parameters causes all materials having a higher activation energy to be over-aged with respect to the simulated conditions, providing conservatism. The long-term program data does not reflect consideration of the failure modes and effects analysis or the out-gassing phenomenon.

The Tables 8-24 data calculations provide a backfit of the long-term data down to temperatures corresponding to the Farley SSPS room ambient and maximum temperatures. The data indicate that MDR relays of the three duty cycles, experiencing the temperature rises given in table notation 1 of each table, would not fail due to material degradation if they experienced a design basis seismic event.

The service life estimates presented in Tables 8-24 would be most applicable to relays manufactured after May of 1990, which are not subject to accelerated offgassing failures, due to significant improvements in materials of construction. Normally de-energized MDR relays of all vintages should have a useful life greatly in excess of the plant design life (40 years).

Energized 100 percent or 20 percent duty cycle MDR relays of pre-1989 vintage are unlikely to reach the service lives estimated in Table 8-24a (58°C rise) or 8-24b (25°C rise) of WCAP-13878, due to the varnish offgassing degradation mechanism. The calculated Arrhenius service lives in the tables range from 5.12 to 25.7 years for 58°C and 25°C rise, respectively, for a 100 percent duty cycle relay at the maximum cabinet temperature measured at Farley of 86.5°F.

As discussed previously in response 6.2 of this submittal, the expected relay temperature rise in the SSPS is less than 33°C. Additional Arrhenius calculations were completed by Westinghouse for all of the materials using a 33°C temperature rise. Although the lifetimes were extended slightly over those for a 58°C temperature rise, the recommendations on replacement times in WCAP-13878, Section 8.4, were unchanged.

In summary, the Tables 8-24 data are not directly applicable to SSPS MDR relay lifetimes. The data were based on more conservative activation energies than those applicable to the most limiting materials in the relay. The tables provide a confirmatory assessment for the recommended lifetimes found in WCAP-13878.

6.4 Tables 8.4, 8.4a, 8.19 Service Lives

The data are consistent in these tables. The service lives for 20 percent duty relays are longer than the 100 percent duty relays in each table. These tables use negative exponents for the 100 percent duty relays in every case.

6.5 Neoprene Rubber

WCAP-13878 section 8.3.1.1, page 78, contains an error. The two groups of tables (8-4, 8-4a, 8-4b, and 8-5, 8-5a, 8-5b) are identified with incorrect elongation criteria. Tables 8-4, 8-4a, and 8-4b should be identified with 60 percent elongation at low temperatures. Tables 8-5, 8-5a, and 8-5b should be identified with 100 percent elongation criteria at high temperatures. The tables themselves, on pages 104-109, are correct. The WCAP will be corrected in a future revision.

Neoprene rubber was used in the lead wire grommets of the MDR relay coil assembly, as shown in WCAP-13878 Figure 4-6, on page 25. Neoprene was replaced by polyetherimide in June 1989. to eliminate chloride compound offgassing. The grommets protect the incoming coil wires from abrasion if the relay is exposed to shock or vibration. Physical degradation (loss of elasticity or hardening) or complete removal of the grommets has no direct consequence to the relay, and will not affect relay operation. The degradation of Neoprene is only significant because it is eventually accompanied by the release of chlorine and hydrochloric acid, which can be predatory to other materials in the relays.

WCAP-13878, Sections 8.1.2.1 and 8.3.1.1, discuss age-related degradation of Neoprene and evolution of chlorides and hydrochloric acid. There are at least two mechanisms involved in the degradation of Neoprene rubber. The first mechanism is anti-oxidant dissipation and the second mechanism is oxidation of Neoprene, releasing chlorides and hydrochloric acid. A study performed at Westinghouse showed that the rate of degradation for Neoprene rubbers differs with temperature. Only one of these two degradation mechanisms will be dominant at a given temperature and age. Therefore, more than one activation energy could be determined dependent on the temperature conditions used for testing. Attachment 2 provides details of work performed by Westinghouse, which characterizes the low temperature dissipation of Neoprene anti-oxidant compounds.

The differences in lifetimes apparent in Table family 8.4 (60 percent elongation) and Table family 8.5 (100 percent elongation) are due to the different tests the tables are based on. The test cited in Tables 8.4 was run at "cool" temperature: 40°C, for 40,000 hours, using an activation energy of 0.84eV (associated with dissipation of the anti-oxidant). The acceptance criteria for this test was retention of 60 percent of the material's original elongation property. The test cited in Tables 8.5 was run at a "hot" temperature: 120°C, for 800 hours, using an activation energy of 1.3eV (associated with oxidation of the Neoprene) and an acceptance criteria of 100 percent retention of the material's original elongation property.

Since the Neoprene rubber grommets are of little importance to MDR relays not exposed to shock and vibration, Arrhenius-based estimates of Neoprene life only serve to provide an approximation of when the release of chlorine or hydrochloric acid should be expected to begin. The estimates also indicate whether the release is abrupt and completed in short time, or very slow, resulting in minimal, ineffective concentrations of the predatory species occurring over a number of years. There are two degradation cases to be considered; first, normally energized and 20 percent duty cycle relays, which will experience accelerated Neoprene aging, and second, normally de-energized relays, with very slow degradation.

For energized relays, the Neoprene anti-oxidant will quickly dissipate and the offgassing should occur over a relatively short time. This creates a localized environment internal to the relay, with high chlorine and/or HCl concentrations at relatively high temperature. There is cause for concern that the presence of chlorine/HCl will initiate or expedite the degradation of other relay component materials. Components which may be affected by chlorine/HCl are discussed in Section 8.3.1.1 of WCAP-13878 on pages 79-80.

Since neoprene has not been used in MDR relays since 1989, older energized relays would have already experienced both anti-oxidant dissipation and hydrochloric acid offgassing. Since DCPP replaced all pre-1990 energized MDR relays in safety related service, there is no further concern with hydrochloric acid offgassing in energized relays.

For de-energized relays, the degradation occurs much more slowly. The Neoprene anti-oxidant is depleted slowly and the release of chlorine/HCl, when it begins, produces very little predatory species at any one time. This, coupled with the absence of the relay temperature rise, neither causes nor expedites the degradation of other relay materials. Consequently, the normally de-energized SSPS slave relays are not likely to experience Neoprene out-gassing related failure modes.

Additionally, chlorides were found on the broken rotor springs noted in response to Question #3. However, in that instance, the chlorides were noted to most probably have been left during an incomplete passivation process, and are mentioned here only for completeness. Rotor springs removed from DCPP relays, which had been in energized service for over ten years, showed no appreciable signs of corrosion or weakness.

TABLE 1:

EXPANDED APPENDIX C of AEOD REPORT S93-06

TABLE 1: EXPANDED APPENDIX C of AEOD REPORT S93-06

NOTATIONS:

Two or more notes apply in many failure events. For example, Notes M, DC, V, and OV are cited in the cases of medium, dc coil relays applied in an over-voltage conditions conducive to varnish offgassing. Each of these factors contributes to reducing both relay life and reliability; none apply in the case of the SSPS slave relays.

Failure events involving relays of significantly different construction or usage than SSPS slave relays are shaded.

Where data was missing or clearly erroneous in the AEOD report, additional data is supplied. Blocks where information was added or changed from the original table are indicated by bold, italicized type. The original information, if any, is shown in parentheses.

N1 (M) Medium-size MDR relay

N2 (DC) dc coil relay

N3 (V) Possible varnish offgassing failure

N4 (MD) Manufacturing defects

N5 (CL) Contact loading

N6 (OV) Over-voltage application

N7 (NE) Normally Energized

** Insufficient Information.

o:\3378w-3.non:1b/080800

218

Table 1: Expanded Appendix C of AEOD Report S93-06

P&B MDR Relay Failure Data

Model No (MDR-)	Coil Rated Volts	Coil Watts	*Coil Size*	E/D	Failure/ Inservice Date(s)	Fail Time (Yr)	NSSS	System	Results of Failure	Relay Failure Mechanism	*NOTES*
131-1	120V ac	7.1	*S*	E	27-AUG-85/ 19-DEC-79	5.7	CE	CS	BKUP PRZR HTRS DIDN'T SHUT OFF	RELAY BURNT OUT	***NE***
134-1	115V ac	6.5	*S*	E	22-JUN-87/ 16-JUN-74	13.0	W	MS	S/G BLOWDOWN ISO VLV CLOSED - ST	CONTACTS STICKING	***NE, possible V or CL***
134-1	115V ac	6.5	*S*	D	20-JUN-86/ 26-MAR-80	6.2	CE	LPSI	LPSI VALVE DIDN'T OPEN - ST	MECHANICAL BINDING	***possible V FAILURE 1***
134-1	115V ac	6.5	*S*	D	17-MAY-85/ 01-JAN-85	0.5	B&W	ESFAS	EFW ISOL VALVE DIDN'T OPEN - ST	CONTACTS STUCK	***possible V or CL FAILURE 2***
136-1	***28 Vdc*** (36 Vdc)	***10.3***	*S*	E	04-JAN-93/ 27-MAY-85	7.5	CE	ESFAS	EFW FLOW CONTROL VLV INOP - ST	OPEN SET OF CONTACTS	***DC, NE, OV (36 Vdc), V***
136-1	28 Vdc	10.3	*S*	E	06-SEP-92/ 01-APR-84	8.4	CE	ESFAS	AFW CONT ISO VALVE TO S/G INOP	OVERSIZED COIL STUCK SHAFT	***DC, NE, MD, OV (36 Vdc)***
136-1	28V dc	10.3	*S*	E	20-NOV-87/ 26-MAR-80	7.6	CE	ESFAS	"B" EFW VLV TO "A" S/G INOP - ST	OXIDE FIM ON CONTACTS	***DC, NE, CL, OV (36 V dc)***
136-1	28V dc	10.3	*S*	E	20-NOV-87/ 26-MAR-80	7.7	CE	ESFAS	"A" EFW VALVE TO S/G INOP - ST	CONTACT FAILURE, BUT TESTED OK	***DC, NE, **, OV (36 V dc)***
136-1	28V dc	10.3	*S*	E	11-AUG-87/ 01-JAN-84	3.6	CE	ESFAS	EFW PUMP DIS VALVE TO S/G INOP	DEFECTIVE CONTACTS	***DC, NE, **, OV (36 V dc)***
136-1	28V dc	10.3	*S*	E	30-JUL-85/ 26-MAR-80	5.3	CE	ESFAS	1 ESFAS DIDN'T RESET POST RXTRIP	RELAY STUCK	***DC, NE, V, OV (36Vdc)***
136-1	28V dc	10.3	*S*	E	13-JAN-84/ 26-MAR-80	3.7	CE	ESFAS	EFV DIS ISO VALVE INOP - ST	MECHANICAL BINDING	***DC, NE, V, OV (36 Vdc)***
137-8	125V dc	10.3	*S*	E	28-DEC-92/ 01-NOV-90	2.2	CE	ELECT	EDG DIDN'T PICK UP LOAD ON GRID	STICKING CONTACTS DIDN'T OPEN	***DC, NE, possible V,CL or MD***
137-8	125V dc	10.3	*S*	E	04-JUL-90/ 19-MAY-89	1.1	CE	CIS	S/G SAMPLE VLV DIDN'T STAY OPEN	CONTACTS DID NOT PICK UP	***DC, NE, possible V or MD***

Table 1: Expanded Appendix C of AEOD Report S93-06

P&B MDR Relay Failure Data

Model No (MDR-)	Coil Rated Volts	Coil Watts	*Coil Size*	E/D	Failure/ Inservice Date(s)	Fail Time (Yr)	NSSS	System	Results of Failure	Relay Failure Mechanism	*NOTES*
137-8	125V dc	10.3	*S*	E	01-MAY-89/ 24-SEP-85	3.6	CE	CS	CSP ISOLATION VALVE INOP - ST	CONTACTS STUCK INTERMITTENLY	*DC, NE, possible V*
137-8	120V dc	9.5	*S*	E	16-NOV-88/ 08-AUG-83	5.3	CE	ELECT	EDG VOLTAGE REGULATOR INOP	STUCK IN ENERGIZED STATE	*DC, NE, possible V*
137-8	125V dc	10.3	*S*	D	17-JUN-88/ 01-APR-84	4.2	CE	ELECT	EDG CONTROL SYSTEM - PM	RELAY DID NOT RESPOND PROPERLY	*DC, ***
137-8	125V dc	10.3	*S*	D	16-JUN-88/ 01-APR-84	4.2	CE	ELECT	EDG CONTROL SYSTEM - PM	RELAY DID NOT RESPOND PROPERLY	*DC, ***
137-8	125V dc	10.3	*S*	D	15-JUN-88/ 01-APR-84	4.2	CE	ELECT	EDG CONTROL SYSTEM - PM	RELAY DID NOT RESPOND PROPERLY	*DC, ***
137-8	125V dc	10.3	*S*	D	15-JUN-88/ 01-APR-84	4.2	CE	ELECT	EDG START RELAY FOUND BAD - PM	RELAY DID NOT RESPOND PROPERLY	*DC, ***
137-8	128 Vdc	10.3	*S*	D	13-JUN-88/ 01-APR-84	4.2	CE	ELECT	D/G VOLT. REG ADJUSTMENT PROB	2 CONTACTS WOULDN'T CLOSE	*DC, possible V*
137-8	120V dc	9.5	*S*	D	13-JUN-88/ 01-APR-84	4.2	CE	ELECT	EDG VOLT. REG. RELAY INOP	2 CONTACTS INOP WITHOUT TAPPING	*DC, possible V*
137-8	120V dc	9.5	*S*	E	09-MAY-88/ 01-APR-84	4.1	CE	ELECT	EDG PROT. RELAY INOP - PM	DID NOT MEET MANF. SPECS.	*DC, NE, ***
137-8	120V dc	9.5	*S*	D	15-OCT-87/ 01-APR-84	3.6	CE	ELECT	EDG CONTROL SYSTEM - PM	WOULD NOT RESPOND PROPERLY	*DC, ***
137-8	125V dc	10.3	*S*	D	10-SEP-87/ 08-AUG-83	4.1	CE	ELECT	EDG CONTROLS - PM	RELAY OUT OF TOLERANCE	*DC, ***
137-8	*125V dc* (28 Vdc)	*10.3*	*S*	D	20-MAY-87/ 01-APR-87	0.1	CE	ELECT	"B" EDG VOLT REG LIGHT INOP	FAILED RELAY - END OF LIFE	*DC, ***
137-8	115V dc	9.5	*S*	D	13-JAN-87/ 01-APR-84	2.7	CE	ELECT	EDG TROUBLE ALARM DIDN'T RESET	UNKNOWN	*DC, ***

Table 1: Expanded Appendix C of AEOD Report S93-06

P&B MDR Relay Failure Data

Model No (MDR)	Coil Rated Volts	Coil Watts	Coil Size	E/D	Failure/ Inservice Date(s)	Fail Time (Yr)	NSSS	System	Results of Failure	Relay Failure Mechanism	NOTES
137-8	125V dc	10.3	S	E	21-AUG-85/ 10-MAR-84	1.4	CE	ELECT	EDG UNDERVOLTAGE ALARM INOP	CONTACTS OPEN	*DC, NE, possible V or MD*
137-8	125V dc	10.3	S	D	03-AUG-85/ 26-MAR-80	5.4	CE	COND	COND PP DIDN'T STOP POST RX TRIP	RELAY FAILED	*DC, ***
138-8	125V dc	10.3	S	D	21-NOV-92/ 01-NOV-90	2.0	GE	HPCS	HPCS DG OVERSPEED PROT. INOP	RELAY BINDING	*DC,, possible V or MD*
138-8	125V dc	10.3	S	D	04-NOV-92/ 01-NOV-90	2.0	GE	ELECT	EDG OVERVOLTAGE RELAY INOP	FAILED TO OP AT SET VOLTAGE	*DC, possible V or MD*
138-8	125V dc	10.3	S	D	13-MAR-91/ 17-NOV-86	4.3	W	ELECT	"B" EDG SEQUENCER FAILED - ST	CONTRACTS DIDN'T MAKE - TEST OK	*DC, ***
138-8	125V dc	10.3	S	D	26-DEC-89/ 08-AUG-83	6.3	CE	CVCS	ION EXCHANGER BYPASS VALVE INOP	CHATTERED/DIDN'T STAY CLOSED	*DC, possible V or MD*
138-8	125V dc	10.3	S	D	09-OCT-89/ 27-MAY-85	4.4	CE	ELECT	EDG CLG WATER PP DIDN'T START - ST	LOAD SEQUENCER CONTACTS STUCK	*DC, possible V or MD*
138-8	125V dc	10.3	S	D	17-JUN-88/ 01-APR-84	4.2	CE	ELECT	EDG CONTROL SYSTEM - PM	RELAY DID NOT RESPOND PROPERLY	*DC,***
138-8	125V dc	10.3	S	D	17-JUN-88/ 01-APR-84	4.2	CE	ELECT	EDG CONTROL SYSTEM - PM	RELAY DID NOT RESPOND PROPERLY	*DC, ***
138-8	125V dc	10.3	S	D	16-JUN-88/ 01-APR-84	4.2	CE	ELECT	EDG CONTROL SYSTEM - PM	RELAY DID NOT RESPOND PROPERLY	*DC,***
138-8	120V dc	9.5	S	E	05-MAY-88/ 01-APR-84	4.1	CE	ELECT	EDG PREVENT, MAINT.	RELAY DIDN'T MEET MANF. SPECS.	*DC, NE, ***
138-8	125V dc	10.3	S	E	14-JAN-86/ 04-SEP-82	3.3	GE	ELECT	EDG OUTPUT BRKR DIDN'T CLOSE - ST	SOME CONTACTS DID NOT CLOSE (LA SALLE)	*DC, NE, possible V or MD*
138-8	125V dc	10.3	S	D	26-NOV-85/ 08-AUG-83	2.3	CE	ELECT	LOSS OF EDG 125VDC CONTROL - ST	END OF LIFE	*DC, ***

o:\3378w-3.non:1b/080800

221

Table 1: Expanded Appendix C of AEOD Report S93-06

P&B MOR Relay Failure Data

Model No. (MDR)	Coil Rated Volts	Coil Watts	Coil Size	E/D	Failure/ Inservice Date(s)	Fail Time (Yr)	NSSS	System	Results of Failure	Relay Failure Mechanism	NOTES
170-1	115V ac	17.0	M	**	13-JAN-92/	**	CE	RCS	LOST PRZR HTR CONTROL CIRCUIT	ROTOR STUCK WHEN SPRING BROKE	M, MD
170-1	115V ac	17.0	M	E	03-OCT-91/ 17-SEP-89	2.1	CE	RPS	"B" RPS BREAKER KEPT TRIPPING	NORMAL WEAR OUT OF RELAY	M, NE
170-1	115V ac	17.0	M	E	01-OCT-91/ 17-SEP-89	2.1	CE	RPS	MASTER RPS RELAY DIDN'T TRIP - ST	NORMAL WEAROUT OF RELAY	M, NE
170-1	115V ac	17.0	M	E	01-OCT-91/ 17-SEP-89	2.1	CE	RPS	"D" RPS BRKR CONTINUOUS TRIP - ST	MASTER RELAY WOULDN'T ENERGIZE	M, NE, possible V or MD
170-1	115V ac	17.0	M	E	11-JUN-91/ 22-JUN-90	1.0	CE	RPS	"C" RPS FAILED TO RESET - ST	RELAY FAILED TO RESET	M, NE, possible V or MD
170-1	115V ac (12V dc)	17.0	M	E	13-AUG-87/ 01-APR-84	3.4	CE	RPS	SPURIOUS TRIP OF RX BREAKERS	FEEDER CABLE HOT	M, NE, V
170-1	115V ac (12V dc)	17.0	M	E	22-SEP-86/ 01-APR-84	2.5	CE	RPS	"B" RPS PATH 2 DID NOT TRIP	STUCK IN ENERGIZED STATE	M, NE, V
170-1	120 Vac	17.0	M	E	06-JUN-84/ 25-MAR-80	4.2	GE	RPS	FALSE RPS CHANNEL 2 TRIP	1 OF 3 RELAYS ACTING ABNORMALLY	M, NE, V, OV
4094	115V ac	8	S	E	15-JAN-88/ 01-MAY-84	3.7	GE	RWCU	RWCU PUMP COULD NOT SHUTDOWN	RELAY STUCK	NE, V
4094	115V ac	8	S	E	09-FEB-87/ 01-SEP-82	4.3	GE	ESSW	ESSW PUMP FAN DIDN'T SHUTDOWN	RELAY STICKING	NE, V
4094	115V ac	8	S	E	11-SEP-86/ 01-SEP-82	4.0	GE	ESW	ESW PUMP FAN RUNNING IN AUTO	RELAY CONTACTS STUCK	NE, V or CL
4094	115V ac	8	S	D	06-JUL-85/ 01-JAN-85	0.5	GE	MS	SRV POSITION INDICATION INOP	INTERMITTENT OPERATION IN - ST	CL or MD FAILURE 3
4094	115V ac	8	S	D	06-JUL-85/ 01-JAN-85	0.5	GE	MS	SRV POSITION INDICATION INOP	INTERMITTENT OPERATION IN - ST	CL or MD FAILURE 4

Table 1: Expanded Appendix C of AEOD Report S93-06

P&B MDR Relay Failure Data

Model No (MDR-)	Coil Rated Volts	Coil Watts	*Coil Size*	E/D	Failure/ Inservice Date(s)	Fail Time (Yr)	NSSS	System	Results of Failure	Relay Failure Mechanism	*NOTES*
4103-1	118V ac	6.6	*S*	E	15-SEP-89/ 10-OCT-85	3.9	W	RPS	CHRG PP MIN FLOW VALVE OPENED - ST	STUCK IN ENERGIZED POSTION	*NE, V*
4121-1	120V ac	5.5	*S*	D	04-OCT-87/ 06-JUN-78	9.3	W	MS	MSIV DIDN'T SHUT IN TIME	RELAY OPERATED SLOWLY	*V FAILURE 5*
4130-1	120V ac	6.6	*S*	E	01-JUN-92/ 01-OCT-86	6.7	GE	RPS	CH A/RPT A TCV SCRAM RESPONSE> TS	SLOW OPENING CONTACTS	*NE, possible V*
4130-1	120V ac	6.6	*S*	E	01-JUN-92/ 01-OCT-86	6.7	GE	RPS	CH B/RPT A TCV SCRAM RESPONSE> TS	SLOW OPENING CONTACTS	*NE, possible V*
4130-1	120V ac	6.6	*S*	E	16-DEC-87/ 15-JAN-85	2.9	GE	RPS	BACKUP SCRAN VALVE FAILED	RELAY FAILURE	*NE,***
4134-1	120V ac	7.1	*S*	E	09-JAN-93/ 23-JUN-89	3.6	GE	RPS	RPS/MSIV CLOSURE TIME>IS LIMIT	"EXPECTED WEAR"	*NE,***
4134-1	120V ac	7.1	*S*	E	14-JUN-92/ 01-OCT-86	6.8	GE	RPS	CH B/B2 TCV SCRAN RESPONSE> TS	SLOW OPENING CONTACTS	*NE, V*
4134-1	120V ac	7.1	*S*	E	14-JUN-92/ 01-OCT-86	6.8	GE	RPS	CH B/B1 TCV SCRAN RESPONSE> TS	SLOW OPENING CONTACTS	*NE, V*
4134-1	120V ac	7.1	*S*	E	12-JUN-92/ 01-OCT-86	6.8	GE	RPS	CH B/B1 TCV SCRAN RESPONSE> TS	SLOW OPENING CONTACTS	*NE, V*
4134-1	120V ac	7.1	*S*	E	12-JUN-92/ 01-OCT-86	6.8	GE	RPS	CH B/B1 TCV SCRAN RESPONSE> TS	SLOW OPENING CONTACTS	*NE, V*
4134-1	120V ac	7.1	*S*	D	21-SEP-90/ 11-APR-86	4.4	GE	ESV	BACKWASH VALVE DIDN'T CLOSE - ST	BURNED OUT RELAY COIL	*open coil FAILURE 6*
4134-1	120V ac	7.1	*S*	E	15-SEP-88/ 15-JAN-85	3.7	GE	RPS	PREVENTED RPS HALF SCRAM	SMALL END COVER HOLE BOUND SHAFT	*NE, MD*
4135-1	120V ac	7.1	*S*	E	03-AUG-91/ 26-JUN-86	5.1	GE	RPS	"B" APRM RPS TRIP INPUT - PM	EXCESS NOISE: EXPECTED FAILURE	*NE, MD, ***

o:\3378w-3.non:1b/080800

223

Table 1: Expanded Appendix C of AEOD Report S93-06

P&B MOR Relay Failure Data

Model No (MDR-)	Coil Rated Volts	Coil Watts	*Coil Size*	E/D	Failure/ Inservice Date(s)	Fail Time (Yr)	NSSS	System	Results of Failure	Relay Failure Mechanism	*NOTES*
4135-1	120V ac	7.1	*S*	E	13-NOV-89/ 18-FEB-86	3.4	GE	RWCU	RWCU CONT ISO VALVE DIDN'T OPEN	CONTACTS DIDN'T CLOSE-CORROSION	*NE, V*
4135-1	120V ac	7.1	*S*	E	05-APR-88/ 28-JUN-86	1.7	GE	RPS	"D" MAIN STEAM MI RAD TRIP SLOW	DEFECTIVE RESPONSE TIME	*NE, V*
4135-1	120V ac	7.1	*S*	E	02-APR-88/ 28-JUN-86	1.7	GE	RPS	RPS DIV. 2 & 4 RELAY FAILED ST	RELAY OPERATED SLOWLY	*NE, V*
5059	125V dc	10.3	*S*	E	11-JAN-92/ 01-JAN-84	8.0	W	AFW	CHANGED AFW STEAM TO ALT SUPPLY	FAILED TO DE-ENERGIZE POSITION	*DC,V*
5060	125V dc	10.3	*S*	D	03-SEP-85/ 08-AUG-83	2.1	CE	CIS	SAMPLE CONT ISO VALVE INOP - ST	PREMATURE END OF LIFE	*DC,***
5061	125V dc	*10.3 (20.6)*	*S*	D	29-MAY-89/ 24-SEP-85	3.7	CE	HVAC	EDG ROOM EXHST FAN DAMPER INOP	COIL HAD OPEN CIRCUIT	*DC, open coil*
5062	125V dc	10.3	*S*	E	02-NOV-92/ 01-JAN-90	1.8	GE	CAC	ISOLATION VALVE POSITION INOP	RELAY STUCK	*DC, NE, V*
5062	125V dc	10.3	*S*	E	28-SEP-92/ 01-MAY-84	8.4	GE	RCS	RECIRC PUMP 1B WOULDN'T TRIP	RELAY STUCK IN ENERG POSTION	*DC, NE, V*
5062	125V dc	10.3	*S*	E	29-SEP-92/ 01-MAY-84	8.4	GE	RCS	RECIRC PUMP 1A WOULDN'T TRIP	RELAY STUCK IN ENERGIZED STATE	*DC, NE, V*
5062	125V dc	10.3	*S*	E	13-SEP-92/ 01-MAY-84	8.4	GE	CS	NO DIV 1 CONTROL PWR LOSS ALARM	RELAY STUCK IN ENERGIZED STATE	*DC, NE, V*
5062	125V dc	10.3	*S*	D	05-APR-86/ 08-JUN-83	3.8	GE	ELECT	ESW/RHRESW PPS INOP ON EDG - ST	SEQUENCER CONTACTS STUCK OPEN	*DC, V*
5062	125V dc	10.3	*S*	D	15-FEB-84/ 01-SEP-82	2.4	GE	CS	CS PUMP BKR DIDN'T OPEN IN - ST	NOT WORKING PROPERLY	*DC, ***
5076	125V dc	*10.3*	*S*	E	22-MAR-91/ 22-MAY-76	14.8	W	CI	PRT ISO VALVE DIDN'T CLOSE - ST	RELAY FAILED CLOSED	*DC, NE, V*

o:\3378w-3.non:1b/080800

224

Table 1: Expanded Appendix C of AEOD Report S93-06

P&B MOR Relay Failure Data

Model No. (MDR-)	Coil Rated Volts	Coil Watts	*Coil Size*	E/D	Failure/ Inservice Date(s)	Fail Time (Yr)	NSSS	System	Results of Failure	Relay Failure Mechanism	*NOTES*
5095	125V dc	*20.8*	*S*	D	30-DEC-89/ 03-JAN-86	3.9	GE	ELECT	DIV 1 EDG FAILED TO START	MISAPPLICATION/CURRENT LOAD LOW	*CL*
5111-1	22V dc	8.6	*S*	E	23-JUL-91/ 15-JAN-85	6.6	GE	ESF	CONT ISO OF RWCU SAMPLE VLV - ST	RELAY STUCK	*DC, NE, V, OV (24Vdc)*
5111-1	22V dc	8.6	*S*	E	19-JUL-91/ 15-JAN-85	6.6	GE	ESF	CIS, SBGT START, CRHVAC ACT.	HIGH CONTACT RESIST, BUT TEST OK	*DC, NE, CL, OV (24 Vdc)*
5146	28V dc	*10.3*	*S*	E	12-APR-91/ 15-JAN-88	3.2	CE	ELECT	B ECWS PP FAILED TO RUN - ST	CONTACTS FAILED TO CLOSE *PALO VERDE - OVERSIZE COIL*	*DC, NE, MD, OV (24 Vdc)*
5147	32V dc	*10.3*	*S*	E	06-JUL-90/ 19-SEP-86	3.7	CE	RSP	A MSIS RPS TRIP DIDN'T RESET - ST	ALL CONTACTS FOUND OPEN	*DC,NE, V*
5151	*125V dc*	10.3	*S*	E	09-MAY-92/ 01-JAN-91	1.4	GE	CAN	CONT ATM VALVE POSITION INOP	RELAY STUCK	*V, NE*
6091	118V ac	*12*	*M*	E	25-JUL-90/ 01-MAR-88	2.3	W	ESFAS	EDG - ST	2 CONTACTS FAILED TO CLOSE	*M, DC, NE*
7032	28V dc	18.7	*M*	E	25-SEP-92/ 30-SEP-91	1.0	CE	ESFAS	ESFAS CHANNEL INOP - ST	SHAFT BINDING: MANUFACTURE DEFECTS	*M, DC, MD, NE*
7032	28V dc	18.7	*M*	E	11-NOV-89/ 28-MAR-80	9.6	CE	CS	CSAS BYPASS DIDN'T STOP NaOH PP	CONTACTS CLOSED SLOWLY	*M, DC, V, NE*
7032	28V dc	30.8	*M*	E	28-MAR-89/ 27-JAN-86	3.2	CE	ESFAS	VALVE OVERRIDE INDICATION INOP	OVERVOLTAGE OUTGASSING FAILURE	*M, DC, V, NE OV*
7032	28V dc	30.8	*M*	E	25-JAN-89/ 18-JAN-88	1.0	CE	ESFAS	B LPSI PP RECIRC VLV INOP - ST	OVERVOLTAGE OUTGASSING FAILURE	*M, DC, V, NE OV*
7032	28V dc	30.8	*M*	E	10-JAN-89/ 18-JAN-88	1.0	CE	ESFAS	ESFAS OVERRIDE SWITCH INOP - ST	OVERVOLTAGE OUTGASSING FAILURE	*M, DC, V, NE OV*
7032	28V dc	30.8	*M*	E	09-JAN-89/	2.2	CE	ESFAS	BIAS TRAIN SIGNAL FAILED -	OVERVOLTAGE OUTGASSING	*M, DC, V, NE*

Table 1: Expanded Appendix C of AEOD Report S93-06

P&B MOR Relay Failure Data

Model No (MDR-)	Coil Rated Volts	Coil Watts	*Coil Size*	E/D	Failure/ Inservice Date(s)	Fail Time (Yr)	NSSS	System	Results of Failure	Relay Failure Mechanism	*NOTES*
					18-SEP-88				ST	FAILURE	OV
7032	28V dc	30.8	M	E	02-AUG-88/ 18-SEP-88	1.6	CE	ESFAS	"B" AFAS SIGNAL FAILURE - ST	OVERVOLTAGE OUTGASSING FAILURE	M, DC, V, NE OV
7032	28V dc	30.8	M	E	03-JUN-87/ 27-JAN-86	1.3	CE	ESFAS	"B" CONT. SPRAY SIGNAL INOP	OVERVOLTAGE OUTGASSING FAILURE	M, DC, V, NE OV
7032	28V dc	30.8	M	E	25-MAY-87/ 18-SEP-86	0.2	CE	ESFAS	"B" SIAS SIGNAL FAILURE - ST	OVERVOLTAGE OUTGASSING FAILURE	M, DC, V, NE OV
7032	28V dc	30.8	M	E	26-NOV-86/ 18-SEP-86	0.2	CE	ESFAS	"B" AUX FW SIGNAL FAILURE - ST	OVERVOLTAGE OUTGASSING FAILURE	M, DC, V, NE OV
7032	28V dc	18.7	M	E	07-MAR-85/ 01-APR-84	0.9	CE	ESFAS	ESF TESTING FOUND BAD RELAY	END OF LIFE	M, NE, DC
7032	28V dc	18.7	M	E	12-SEP-84/ 01-APR-84	0.4	CE	EFW	RELAY FOUND BAD IN ESE - ST	END OF LIFE	M, NE, DC
7032	28V dc	18.7	M	E	13-AUG-84/ 08-AUG-83	1.0	CE	ESFAS	PREVENTATIVE MAINTENANCE	NOT OPERATING PROPERLY	M, NE, DC
7033	28V dc	18.7	M	E	07-NOV-87/ 08-AUG-83	4.2	CE	ESFAS	"A" SIAS TRAIN INOP - ST	WEAROUT DUE TO AGING	M, NE, DC
7034	36 Vdc	30.8	M	E	08-DEC-91/ 27-MAY-85	6.5	CE	EFW	"B" EFW INOP - ST	ROTOR STUCK-OUTGASSING/CORROSION	M, DC, NE, V, OV
7034	28V dc	18.7	M	E	27-JUN-89/ 24-SEP-85	3.8	CE	CIS	EFW & S/g BLOWDOWN VLVS INOP - ST	STUCK IN ENERGIZED POSITION	M, NE, DC, V
7034	28V dc	18.7	M	E	22-JAN-89/ 08-AUG-83	5.4	CE	ESFAS	DIDN'T ACT. ALL "B" SATS EQUIP	RELAY NOT WORKING PROPERLY	M, NE, DC, V
7034	36V dc	30.8	M	E	19-DEC-88/ 18-SEP-86	2.3	CE	ESFAS	MSIS CHANNEL INOP IN BYPASS - ST	CONTACT CORROSION - OFFGASSING	M, DC, NE, V, OV
7034	28V dc	18.7	M	E	07-NOV-88/ 08-AUG-83	5.2	CE	ESFAS	LPSI PUMP FAILED IN 2ND TEST	CYCLING/CONTACT RESIST	M, NE, DC, V

o:\3378w-3.non:1b/080800

226

Table 1: Expanded Appendix C of AEOD Report S93-06

P&B MOR Relay Failure Data

Model No (MDR-)	Coil Rated Volts	Coil Watts	***Coil Size***	E/D	Failure/ Inservice Date(s)	Fail Time (Yr)	NSSS	System	Results of Failure	Relay Failure Mechanism	***NOTES***
7034	36V dc	30.8	***M***	E	05-AUG-88/ 18-SEP-86	1.9	CE	ESFAS	"B" MSIS INOP - ST	OVERVOLTAGE OUTGASSING FAILURE	***M, DC, NE, V, OV***
7034	36V dc	30.8	***M***	E	09-MAY-88/ 18-JAN-88	0.3	CE	ESFAS	"A" CSAS INOP - ST	OVERVOLTAGE OUTGASSING FAILURE	***M, DC, NE, V, OV***
7034	36V dc	30.8	***M***	E	03-MAY-88/ 18-SEP-86	1.6	CE	ESFAS	"B" RECIRC ACT SIG FAILED - ST	OVERVOLTAGE OUTGASSING FAILURE	***M, DC, NE, V, OV***
7034	28V dc	18.7	***M***	E	07-APR-88/ 28-MAR-80	8.1	CE	NSW	ENERG POND SW VALVE INOP - ST	RELAY STUCK ON DE-ENERGIZATION	***M, NE, DC, V***
7034	36V dc	30.8	***M***	E	31-DEC-87/ 18-SEP-86	1.3	CE	ESFAS	"B" SIAS SIGNAL FAILURE - ST	OVERVOLTAGE OUTGASSING FAILURE	***M, DC, NE, V, OV***
7034	28V dc	18.7	***M***	E	01-APR-87/ 01-APR-84	3.0	CE	ESFAS	INTERMITANT CONT. ISO, SIGNAL	SPURIOUS SIGNAL	***M, NE, DC, *****
7034	36V dc	30.8	***M***	E	11-FEB-87/ 18-SEP-86	0.4	CE	ESFAS	CHILLED WATER VALVE INOP	OVERVOLTAGE OUTGASSING FAILURE	***M, DC, NE, V, OV***
7034	28V dc	18.7	***M***	E	09-NOV-86/ 08-AUG-83	3.2	CE	ESFAS	"B" CIAS INOP - ST	HIGH CONTACT RESISTANCE	***M, DC, NE, *****
7034	28V dc	18.7	***M***	E	11-FEB-86/ 28-MAR-80	5.9	CE	ESFAS	REACTOR TRIP ON "A" MSIV CLOSURE	HIGH CONTACT OHMS - 5 MDRs REPLACED	***M, NE, DC***
7061	32V dc	20.4	***M***	E	04-OCT-90/ 28-JAN-85	4.7	CE	ESFAS	SPRAY CHEM PP VALVE INOP - ST	DEFECTIVE CONTACTS DIDN'T CLOSE	***M, NE, DC***
7061	32V dc	20.4	***M***	E	16-MAR-89/ 28-JAN-86	3.2	CE	CS	ESFAS SUBGROUP FAILED - ST	CONTACTS DIDN'T CLOSE- OFFGASSING	***M, DC, NE, V***
7061	32V dc	20.4	***M***	E	13-FEB-89/ 28-JAN-86	3.1	CE	RPS	"D" SIAS INOP - ST	CONTACTS DIDN'T CLOSE- OFFGASSING	***M, DC, NE, V***
7061	32V dc	20.4	***M***	E	02-FEB0-89/ 28-JAN-86	3.1	CE	ESFAS	DIDN'T CLOSE RWT ISO VALVE - ST	ROTOR STUCK - OFFGASSING	***M, DC, NE, V***

o:\3378w-3.non:1b/080800

227

Table 1: Expanded Appendix C of AEOD Report S93-06

P&B MOR Relay Failure Data

Model No. (MDR-)	Coil Rated Volts	Coil Watts	*Coil Size*	E/D	Failure/ Inservice Date(s)	Fail Time (Yr)	NSSS	System	Results of Failure	Relay Failure Mechanism	*NOTES*
7062	32V dc	*20.4*	*M*	E	06-APR-90/ 28-JAN-85	4.3	CE	ESFAS	"B" ESFAS CHANNEL LOST - ST	2 CONTACTS DIDN'T CHANGE STATE	*M, DC, NE, **

Table 1: Expanded Appendix C of AEOD Report S93-06

P&B MDR Relay Failure Data

Model No (MDR-)	Coil Rated Volts	Coil Watts	*Coil Size*	E/D	Failure/ Inservice Date(s)	Fail Time (Yr)	NSSS	System	Results of Failure	Relay Failure Mechanism	*NOTES*
7083	32V dc	*20.4*	*M*	E	13-DEC-88/ 19-SEP-86	2.2	CE	ESFAS	ESFAS FAILED, THEN OK - ST	INTERMITTENT OP FROM OFFGASSING	*M, DC, NE, V*
7083	32V dc	*20.4*	*M*	E	01-NOV-88/ 28-JAN-86	1.9	CE	RPS	"B" CIAS CHANNEL LOST - ST	ROTOR STUCK - OFFGASSING	*M, DC, NE, V*

Attachment 2
PG&E Letter DCL-95-__

REPRINT OF ARTICLE:

STUDIES ON AKROFLEX CD ANTIOXIDANT LOSS FROM NEOPRENE RUBBER

JOURNAL OF APPLIED POLYMER SCIENCE VOL. 18, PP. 3543–3553 (1974)

Studies on Akroflex CD Antioxidant Loss from Neoprene Rubber. I. The Determination of Antioxidant Content and the Loss Mechanism During Aging

J. D. B. SMITH, D. D. JERSON, and J. F. MEIER, *Insulation Chemistry, Westinghouse Research Laboratories, Pittsburgh, Pennsylvania 15235*

Synopsis

An analytical procedure for determining the antioxidant (i.e., Akroflex CD) content in neoprene rubber has been developed. The method is based on the infrared absorption analyses of chloroform extractables from the cured rubber at 1600 cm^{-1} and 1300 cm^{-1}. Good agreement is found between these two independent sets of measurements. In an attempt to elucidate the antioxidant loss mechanism found with neoprene, thermal aging studies were carried out over the temperature range of 80°–200°C. Using the infrared analytical procedure, antioxidant loss rates at the different temperatures were established. The activation energy value (5.1 kcal/mole) for the loss rate as well as other aging data suggest that the antioxidant is lost by a diffusion mechanism.

INTRODUCTION

Neoprene elastomers have found widespread usage in recent years, particularly in areas where a high degree of resiliency has to be combined with oil, solvent, heat, and weather-resistant properties, e.g., for lining tanks and chemical equipment. It is common practice in the cure of neoprene formulations to add a small amount of an antioxidant (usually about 1.0%) to prevent oxidative degradation of the polymer and subsequent deterioration of the elastomers' engineering properties. Most of these antioxidants are fugitive in nature, and significant loss can be found under normal service conditions.

In the absence of other available criteria, it has been suggested that the serviceable lifetime of an elastomer such as neoprene can be predicted by determining the rate of consumption of the antioxidant used in any particular formulation. This is based on the premise that, after all the antioxidant has been consumed, the rubber becomes vulnerable to rapid oxidative degradation and its useful service life is reduced significantly.

Consequently, there is a real need for simple analytical techniques for determining the antioxidant contents of rubbers such as neoprene during service and storage conditions so that the effective lifetime of the elastomer can be determined. Sometimes, a further stipulation on these analytical techniques is that only small plug samples should be removed from "in service" elastomers so that loss of function can be prevented.

This paper describes an analytical method based on absorption infrared spectroscopy which has been developed to monitor the antioxidant content in a standard neoprene rubber formulation referred to as MINS-132.

The antioxidant in question (Akroflex CD from du Pont[1]) has a composition consisting of 65% phenyl-beta-naphthylamine and 35% N,N'-diphenyl-*p*-phenylenediamine and is present in the neoprene formulation at a level of ~1.0% (by weight).

As an aid to elucidate the mechanism responsible for the loss of antioxidant from the neoprene, accelerated aging studies have also been carried out over the temperature range of 80°–200°C both on the neat Akroflex CD antioxidant and on fully compounded neoprene elastomer samples containing the antioxidant. The infrared analytical method was used to determine the antioxidant loss from the cured neoprene compound at each temperature.

EXPERIMENTAL

Solvents

Several solvents were initially screened as a selective extraction medium for the antioxidant. Chloroform was finally selected for this analytical work for the following reasons: (1) It is anhydrous and will not fog the NaCl plates used in infrared work. (2) It has a clear "window" area in the infrared part of the spectrum of most direct interest to this work (i.e., 2500 cm^{-1} to 1250 cm^{-1}). (3) It is an excellent solvent for Akroflex CD. (4) Because it is volatile, the extracts from the neoprene rubber can be easily concentrated by solvent evaporation.

Although chloroform also dissolved some of the other organic components used in the neoprene formulation, these materials did not appear to interfere with the infrared analyses.

Infrared Spectral Analyses

A Perkin-Elmer-6700 spectrophotometer was used for this study. Demountable, NaCl-window, liquid cells with 1-mm spacers were found to be useful for this work. Fisher C-298 chloroform was used for both the extraction media and the reference cell.

Akroflex CD antioxidant (0.11–0.01 g) was dissolved in 25 ml chloroform, and an aliquot was placed in the sample cell with fresh chloroform in the reference cell. The heat-aged antioxidant samples were treated in the same manner. Spectrum 1 in Figure 1 shows a typical infrared spectrum obtained from a 0.114 g/25 ml solution of Akroflex CD in chloroform. The extracts from the neoprene samples were diluted to 25 ml with chloroform and run on the spectrophotometer as described previously. A typical infrared trace thus obtained is shown by spectrum 2 of Figure 1.

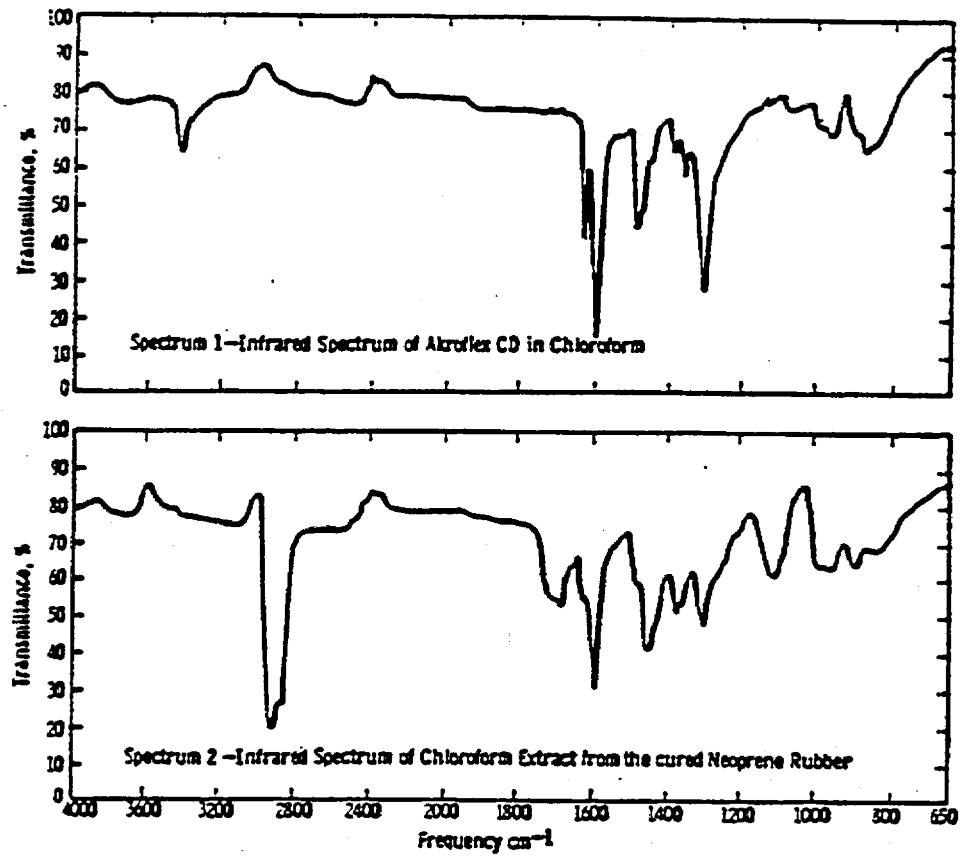


Fig. 1. Chloroform solution infrared spectra.

Accelerated Thermal Aging Tests

Antioxidant. Approximately 2-g samples (weighed to 0.1 mg) of Akroflex CD were placed in a 50-ml Pyrex beaker, covered with a watch glass, and then aged in a forced-air oven at the desired temperature for the prescribed time. The aging temperatures chosen for these studies were 80°C, 110°C, 150°C, 175°C, and 200°C. A total aging time of 192 hr was employed on each sample.

Elastomer. Plugs, $^3/_8$-in. diameter, were cut with a cork borer from the neoprene material and masticated on a two-roll, cold rubber mill. The mill was set to an opening of approximately 0.001 in., and each plug was passed through the rolls ten times. Both cured and uncured samples were prepared in the same manner.

Approximately 5.2 g (weighed to 0.1 mg) of the milled material was placed in 3-in. glazed crucibles, with covers, and aged as described above.

Extraction Method

A Soxhlet extraction apparatus was employed consisting of a 300-ml round flask, a Soxhlet extraction tube, and an Allihn-type condenser, all

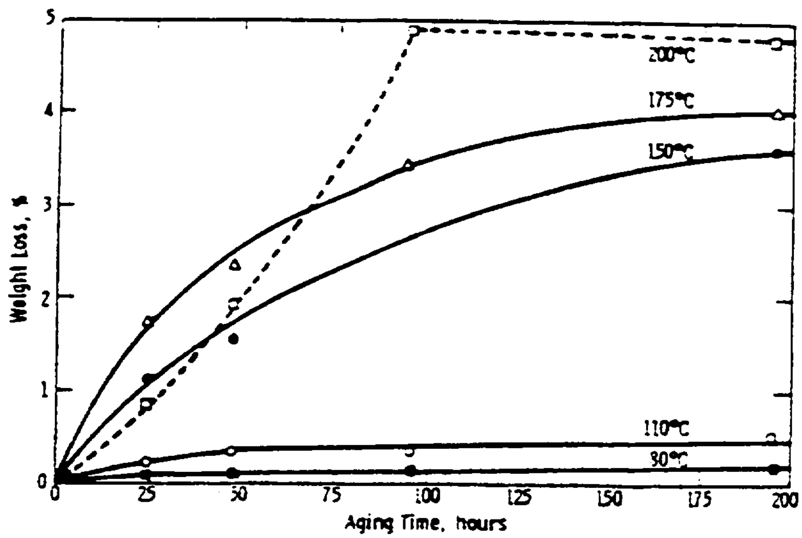


Fig. 2. Thermal aging weight loss data for neat Akroflex CD.

connected by interchangeable ground-glass joints. The extraction thimble (33 mm × 80 mm) used was of the single-thickness cellulose type. Chloroform (125 ml, Fisher C-298) was charged to the flask, and one Boileezer (Fisher B-365) was added to prevent bumping of the solvent upon heating. The weighed sample (~5 g), prepared as described above, was then placed in the extraction thimble and inserted into the extraction tube. The extraction tube with condenser attached was then fitted to the flask. All ground-glass joints were lubricated with a minimum of Dow Corning High-Vacuum Grease (Silicone). Cold water was passed through the condenser continuously throughout the extraction operation. A rate of 15 to 20 passes per hour of fresh solvent through the sample was maintained for 2 hr after the initial charging of the extraction tube. The extract was then removed from the apparatus and the chloroform solution concentrated by gentle heating to a volume of 15–20 ml. After cooling the solution to ambient temperature, the volume was adjusted to give a concentration of 5.2 g sample/25 ml chloroform. The infrared analyses were then carried out on the extracts as described above.

Weight Loss

Weight loss was determined by the differential weighing method. The aged samples were cooled to ambient temperature in a desiccator (containing Drierite to prevent moisture absorption) and then weighed. Weight loss data at 80°C, 110°C, 150°C, 175°C, and 200°C are shown in Figure 2 for neat Akroflex CD and in Figure 3 for the fully cured neoprene formulation.

Infrared Calibration Curve

The relationship between the absorption of a particular wavelength of radiation and the number of molecules absorbing (i.e., molecular concen-

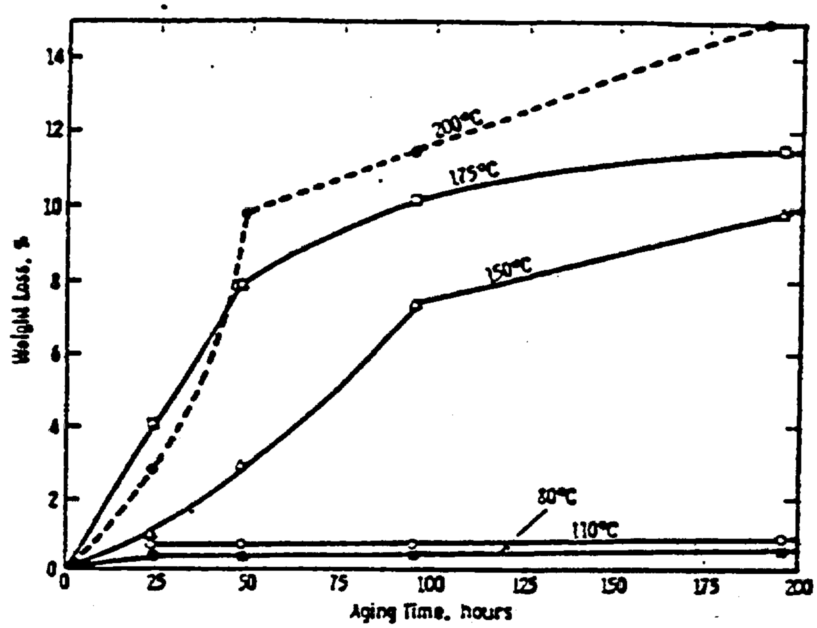


Fig. 3. Thermal aging weight loss data for the cured neoprene rubber.

tration) is referred to as the Beer-Lambert absorption law.[3] This can be written as

$$I = I_0 e^{-abc}$$

or more normally as

$$A = \log_{10} I_0/I = \log_{10} 1/T = abc$$

where A = absorbance or "optical density," b = cell path, cm, c = material concentration, g/l., a = specific absorptivity of the material, I_0 = intensity of infrared radiation incident on the sample, I = intensity of infrared radiation transmitted by the sample, and $T = I/I_0$ = transmittance = fraction of infrared radiation transmitted.

The infrared spectrum of Akroflex CD in chloroform solution (at a concentration of 4.560 g/l.) in a 1.0-mm cell is shown in spectrum 1. It can be seen that the spectrum exhibits strong absorption bands at 1600 cm^{-1} and 1300 cm^{-1} (from the $>C{=}C<$ and $C_6H_5{-}N<$ stretching vibrations); both of these were used to construct Beer-Lambert calibration curves for Akroflex CD in chloroform.

In this calibration curve, six different concentrations of Akroflex CD in chloroform were made up (ranging from 4.560 g/l. to 0.285 g/l.) and the infrared spectra were recorded in 1-mm liquid cells. The % transmittance (T_s) was determined for each sample at 1600 cm^{-1} and 1300 cm^{-1}; and, after correcting for the "baseline" absorbance (T_0), a plot of $\log_{10} (1/T_c)$ versus absorbance (A/b) was made, as shown in Figure 4. In this computation,

$$T_c = T_0 + T_s$$

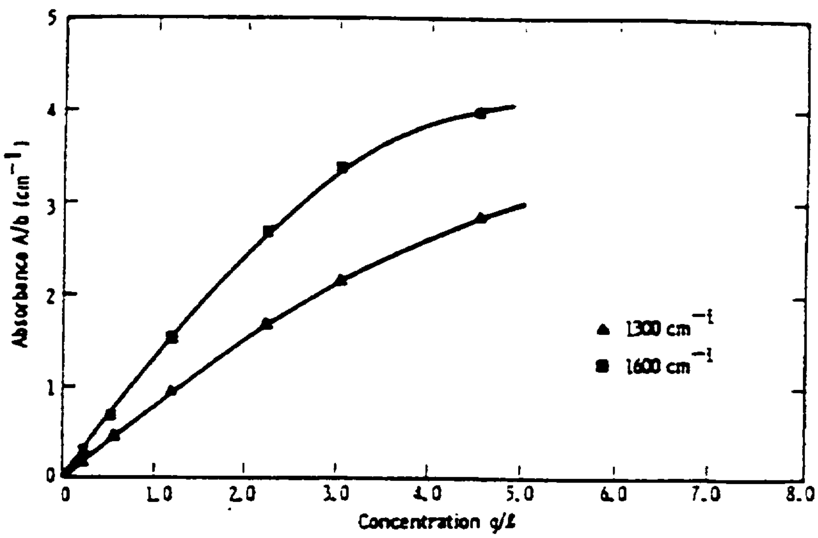


Fig. 4. Akroflex CD calibration curve (infrared absorption) in chloroform using bands at 1300 cm^{-1} and 1600 cm^{-1}.

where T_0 = baseline transmittance, T_s = sample transmittance, and b = cell thickness (0.1 cm).

It can be seen from Figure 4 that neither 1600 cm^{-1} nor the 1300 cm^{-1} absorption bands give linear dependence of absorbance on Akroflex CD concentration, thereby showing that deviations from the Beer-Lambert law are occurring. (However, below a concentration of 2.5 g/l., linearity does seem to be observed by both absorption bands.) The deviations in the absorption law in no way render this analytical procedure invalid since the concentration values can be read directly from the calibration curves. (If the Beer-Lambert law is obeyed, the values can normally be calculated algebraically.)

Thus, this analytical method can be used to measure Akroflex CD contents in the neoprene rubber. The statistical treatment of several determinations on the Perkin-Elmer 700 spectrophotometer showed that the experimental accuracy of these measurements was ±4%. A greater degree of accuracy would be anticipated on a higher resolution infrared spectrophotometer.

Sources of Contamination

Early spectra gave rise to some unexplained peaks for the known samples in solution as compared to similar samples in KBr pellets. It was found that contamination from some or all of the following items led to erroneous spectra: (1) contaminated solvent, (2) dirty NaCl windows, (3) plasticizer from washing bottle, (4) Fisher Cello-Seal lubricant (used for glass joints), (5) moisture from the atmosphere, and (6) leaking sample cells. However, with due care and attention, these sources of contamination can be eliminated.

RESULTS

Weight Loss Data

As might be expected, greater weight losses are shown by the higher temperature samples with the neoprene rubber (Fig. 3) showing considerably more than the neat Akroflex CD (Fig. 2). This suggests that oxidative degradation or volatilization of some of the organic components in MINS-132, in addition to Akroflex CD loss, is occurring. Below 110°C, the data suggest that for both the neat Akroflex CD and the neoprene samples, the oxidative degradation is proceeding at a very low rate (after a more rapid initial rate). Above 110°C, the degradation proceeds at appreciably higher rates.

Infrared Spectral Studies

The studies on the neat Akroflex CD samples showed that after aging at elevated temperatures for periods more than 24 hr, some minor changes in the spectra were detectable. This is shown in Figure 5, where a comparison of the thermally aged material (200°C for 192 hr) is made with the original. (These samples were recorded as pressed KBr pellets.)

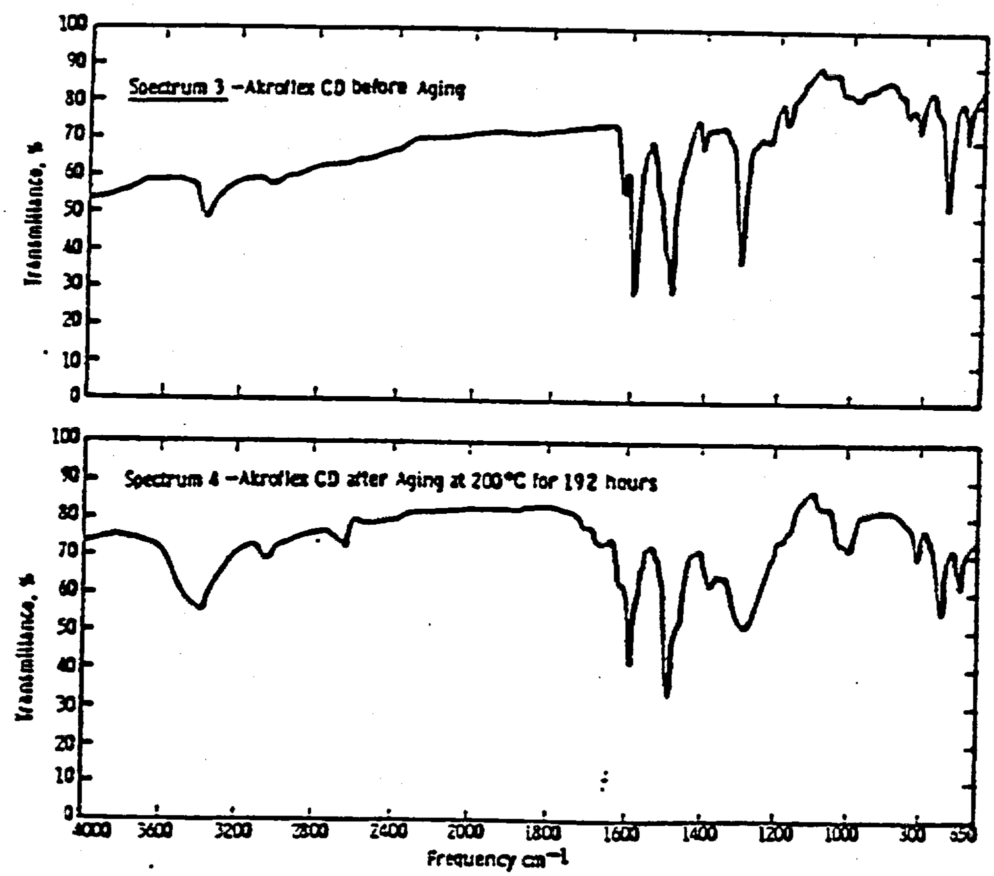


Fig. 5. Infrared spectra of neat Akroflex CD before and after aging.

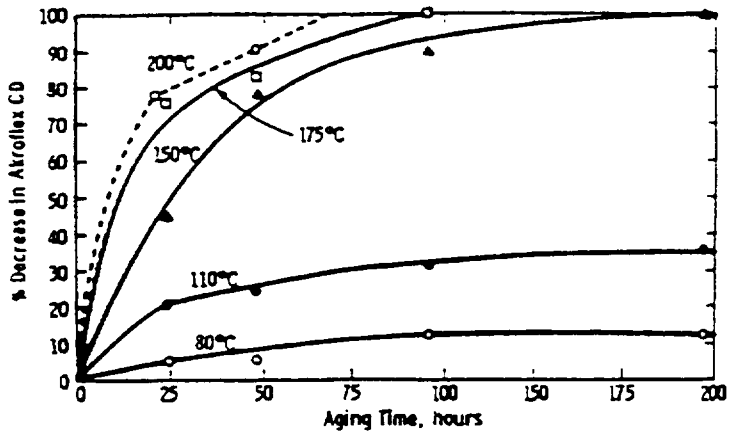


Fig. 6. Loss rate of Akroflex CD from cured neoprene with aging at different temperatures (using 1600 cm^{-1} infrared band).

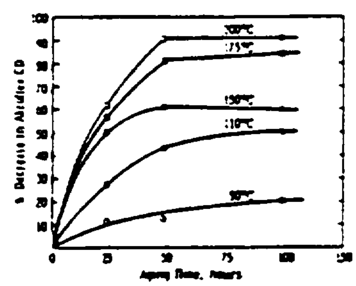


Fig. 7. Loss of rate of Akroflex CD from cured neoprene with aging at different temperatures (using 1300 cm^{-1} infrared band).

It is observed that this aged sample does exhibit noticeable changes in its spectrum. The sharp absorption band at 1300 cm^{-1} (from the C_6H_5—N< stretching vibration) shows a reduction in intensity compared to the other bands (e.g., at 1500 cm^{-1}). The absorption band at 1300 cm^{-1} also becomes broader, and a shoulder peak develops at 1380 cm^{-1}.

The spectrum of the aged material also exhibits enhanced absorptions at 3400 cm^{-1} and 1000 cm^{-1} compared to the original sample. These spectral changes would appear to be associated with oxidative modification of the amine groups in the antioxidant.[3] These spectral modifications were also shown by the samples that were aged at the lower temperatures, but the changes were somewhat less marked than those found with the 200°C samples.

The neoprene samples that had been subjected to thermal aging were analyzed for Akroflex CD content using the chloroform extraction procedure described previously. From the calibration curves, the rate of disappearance of the antioxidant at the different temperatures could be estimated. Two separate and independent sets of curves could be constructed, i.e., for the infrared absorption measurements at 1600 cm^{-1} and 1300 cm^{-1}, as shown in Figures 6 and 7, respectively.

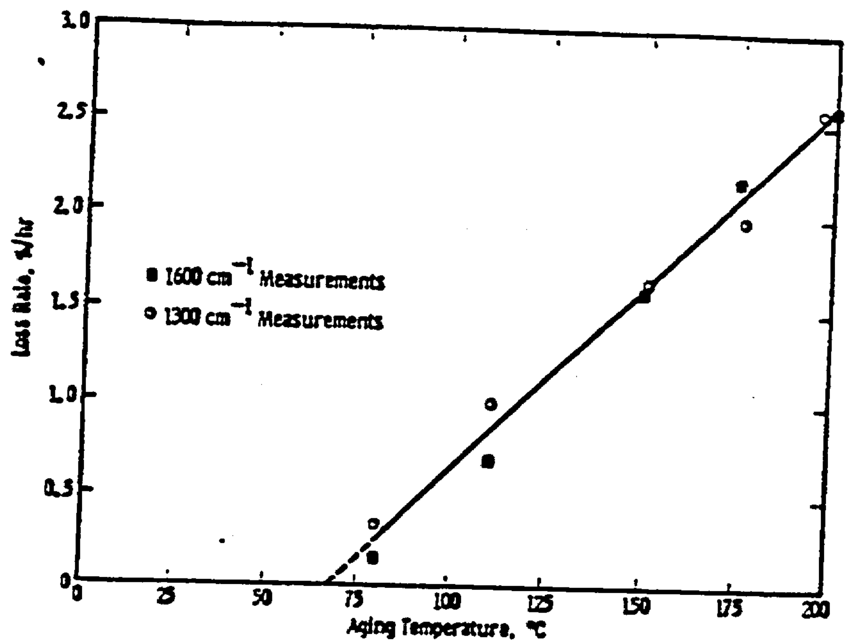


Fig. 8. Dependence of Akroflex CD loss rate (initial) on aging temperature of cured neoprene.

In the case of the 1300 cm^{-1} data, the Akroflex CD rate of disappearance was only followed up to 96 hr as shown in Figure 7. Interference of an oxidized by-product from the neoprene in the infrared measurements at that wavelength gave rise to erratic results. However, the similarities between the rate data obtained at 1600 cm^{-1} and 1300 cm^{-1} are very striking (i.e., a very rapid initial loss rate followed by a slower one).

This is shown more clearly by making a plot of the initial loss rate (i.e., the *average* % rate of decrease in Akroflex CD content over the first 50 hr of aging) against the aging temperature. This is shown in Figure 8, where it can be seen that very good agreement is obtained by the Akroflex CD initial loss rate values for the two methods of measurement.

Extrapolation of these data to "zero % loss rate" suggests that below 68°C, no decrease in the Akroflex CD content will occur during aging (at least not under *static* aging conditions). This then suggests that below ~68°C the decrease of Akroflex CD content due to diffusion will be extremely slow. However, losses that occur below 68°C will most likely be due to the interaction of the antioxidant with oxygen from air diffusing into the rubber. This type of antioxidant consumption is not defined by the present mechanism.

DISCUSSION

Using the data of Figure 8, an Arrhenius plot, i.e., $\log_{10}$ rate versus $1/T(°K)$, can be made for the neoprene samples. This is shown in Figure 9. In this plot, the 80°C rate data have been omitted because of the temperature spread.

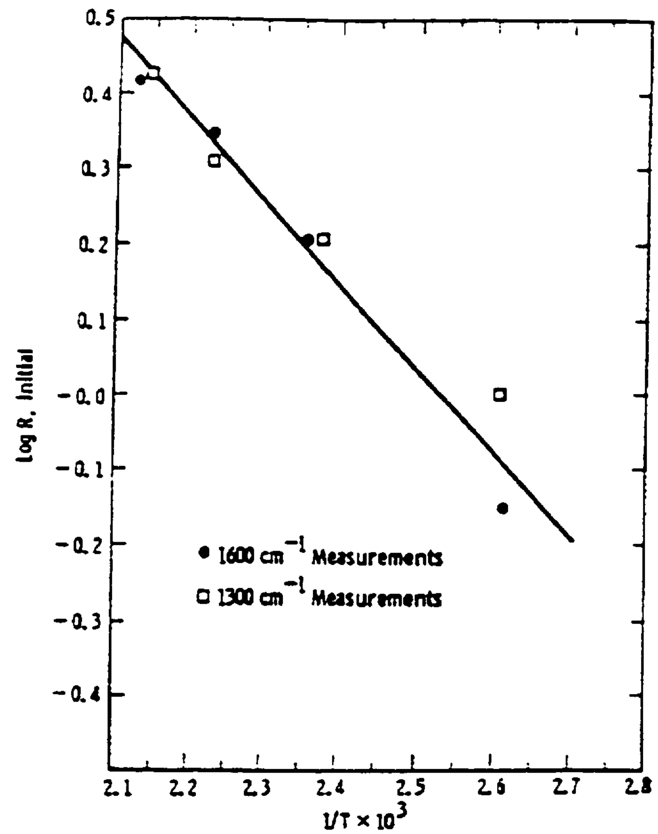


Fig. 9. Arrhenius plot for Akroflex CD loss rate from cured neoprene.

It is noted that a fairly good linear plot is obtained with the eight rate values. From this gradient, the activation energy (ΔE) was calculated to be 5.1 kcal/mole.

This value is somewhat low for a normal free-radical oxidative-type reaction where values four to five times higher are usually obtained. This is predictable on the basis of the oxidative aging studies on the neat Akroflex CD samples where it was found that only minor changes in the structure of the antioxidant will occur even after prolonged heating at 200°C. It has long been suspected that the Akroflex CD is fugitive in neoprene rubber formulations and that loss occurs by migration to the surface during aging. This would be consistent with the low activation energy value obtained in this work. The migration of Akroflex CD through this neoprene rubber can be interpreted as a diffusion phenomenon. Low activation energies are usually found in such reactions. Barrer[4] has determined the activation energies of diffusion for a series of gases (including water vapor) through neoprene rubber and found that the values lie in the range of 6.0–11.1 kcal/mole.

Corman et al.[5,6] have studied the activation energies of diffusion for hydrocarbon oils through a series of rubbers using ^{14}C-labeled compounds. The activation energies found ranged from 3.1 to 9.9 kcal/mole. They concluded that the similarities of the activation energies for the various hydrocarbon oils provided evidence that the diffusion of large organic molecules in rubber is much more dependent upon the nature of the polymer than on the nature of the diffusing species.

On this basis, it would seem that the antioxidant loss in this particular neoprene formulation is almost completely a thermally induced diffusion effect. The contribution from oxidative degradations to this loss would be very minor.

Although the effects of ozone were not evaluated in this work (the aging tests were run in forced-air ovens), it would be expected that exposure to the more severe ozone environment would result in more rapid oxidation of the residual unsaturation of the neoprene rubber. However, it is unlikely that the loss rate values for the Akroflex CD at the different temperatures would deviate greatly under these conditions from the values found in this work.

It should also be pointed out that the neoprene accelerated aging tests in this work were carried out under essentially *static* conditions (i.e., the rubber samples were not subjected to any stress or strain during aging). It would be anticipated that under more *dynamic* conditions of testing, e.g., continuous flipping, higher diffusion rates would be encountered.

Thus, the diffusion rate values found in this series of experiments are only valid for neoprene rubber under static conditions of aging in the temperature range of 80° to 200°C. Below 80°C, the thermal diffusion of antioxidant becomes less important and other loss mechanisms may predominate.

The effect of dynamic aging on antioxidant loss and the influence of these losses on the physical properties of neoprene will be the subjects of future publications in this area.

References

1. du Pont Elastomer Chemicals Dept., Technical Bulletin No. 23, Nov. 1963.
2. Infrared Spectroscopy Committee of the Chicago Society for Paint Technology, *Infrared Spectroscopy; Its Use in the Coatings Industry*, 1969, Chap. IV, p. 52.
3. C. Walling, *Advan. Chem. Ser.*, **75**, 166 (1968).
4. R. M. Barrer, *Trans. Faraday Soc.*, **35**, 623 (1939).
5. J. E. Lewis, M. L. Deviney, Jr., and B. G. Corman, *Rubber Chem. Technol.*, **42**, 474 (1969).
6. B. G. Corman, M. L. Deviney, Jr., and L. E. Whittington, *Rubber Chem. Technol.*, **43**, 1349 (1970).

Received April 23, 1974
Revised May 22, 1974

APPENDIX E
FINAL LEAD PLANT RESPONSE TO NRC COMMENTS

PG&E LETTER DCL-96-034
February 2, 1996

(Reference 13-20)

Pacific Gas and Electric Company

Diablo Canyon Power Plant
P.O. Box 56
Avila Beach, CA 93424
805/545-6000

Warren H. Fujimoto
Vice President–Diablo Canyon
Operations and Plant Manager

February 2, 1996

PG&E Letter DCL-96-034

U.S. Nuclear Regulatory Commission
ATTN: Document Control Desk
Washington, D.C. 20555

Docket No. 50-275, OL-DPR-80
Docket No. 50-323, OL-DPR-82
Diablo Canyon Units 1 and 2
Response to NRC Request on Slave Relay Test Frequency Relaxation Amendment (LAR 94-11, dated November 14, 1994)

Dear Commissioners and Staff:

PG&E letter DCL-94-254, dated November 14, 1994, submitted License Amendment Request (LAR) 94-11. LAR 94-11 proposed a revision to the Diablo Canyon Power Plant (DCPP) Technical Specifications (TS) to relax the slave relay test frequency from quarterly to refueling frequency. DCPP is the lead plant for the Westinghouse Owner's Group for this TS change. NRC letter dated April 27, 1995, identified six questions regarding WCAP-13878 and the reliability of Potter & Brumfield motor-driven relays (MDR) used at DCPP. PG&E responded to those questions via PG&E letter DCL-95-268, dated December 7, 1995.

In addition, the NRC Project Manger for DCPP requested that PG&E review an event related to MDR relays which occurred at the Carolina Power and Light (CP&L) Shearon Harris Unit 1 on November 5, 1995. PG&E reviewed CP&L License Event Report 95-011-00, submitted on December 5, 1995, and discussed the event with CP&L's instrumentation and controls engineers. The event does not affect the conclusions reached in LAR 94-11 or PG&E letter DCL-95-268.

On November 5, 1995, Shearon Harris Unit 1 operators were performing solid state protection system (SSPS) slave relay testing on the main steam isolation valve (MSIV) circuits. During the test, one MSIV inadvertently closed, resulting in a reactor trip and safety injection. Root cause investigations indicated that the MSIV actuation was caused by a test relay contact which failed to remain closed in a continuity test circuit. The SSPS continuity test circuits are designed to provide a current path to the MSIV solenoids while the slave relay contacts in the actuation path are cycled. The MSIV solenoids at Shearon Harris are normally energized, and momentary de-energization of the solenoid will allow the valve to close.

The continuity circuit design used at Shearon Harris is similar to that used at DCPP and other Westinghouse plants for normally energized solenoid loads. The continuity circuits are composed of blocking relays, test lamps, and surge suppression devices. The devices are wired in a shunt arrangement to the actuation path and do not affect operation of the safeguards equipment in their normal, non-test condition. The test circuit components, and specifically the failed test relay, do not perform safety-related functions. See Attachment 1 for a typical continuity circuit schematic and operation details.

The test relays used at Shearon Harris are Potter & Brumfield MDR Model 66-4, medium-sized, latching, 120 Vac coil relays with four contact decks. The relays are the same model as those used at DCPP and other Westinghouse plants for the test relay function. When MDR model relays are used as slave relays in the Westinghouse SSPS, small-sized, 120 Vac coil relays with two contact decks are used.

The DCPP response to the NRC, submitted in PG&E letter DCL-95-268, provides information on the differences between the small-size MDR slave relays and medium-size MDR relays used as test relays. Because of substantial differences in relay size, component differences, and internal forces required to operate the relays, the DCPP response concluded that medium-sized relay failure modes are not applicable to small-sized MDR relays.

In conclusion, because the test relay is a significantly different model than the SSPS slave relays, and because it does not have a safety-related function, the Shearon Harris event does not impact SSPS slave relay reliability. The conclusions of Westinghouse WCAP-13878 and the DCPP response to the request for additional information (ref. DCL 95-268) are not affected by this event. CP&L is still completing their evaluation of the event, but does not anticipate any new information that would affect the conclusions of this letter.

This event provides further support for eliminating quarterly slave relay testing. Quarterly slave relay testing has accelerated the failure of active continuity test circuit components during testing (test switches, push-to-test type lamps and relays). Failures of the test circuit devices result in indeterminate functionality of the associated slave relays until the failure can be diagnosed. As noted in the justification provided in DCPP LAR 94-11, and demonstrated by the event at Shearon Harris, slave relay testing has caused reactor trips and inadvertent equipment actuations.

The enclosed information does not affect the conclusions of the safety evaluation or the no significant hazards consideration determination performed for LAR 94-11.

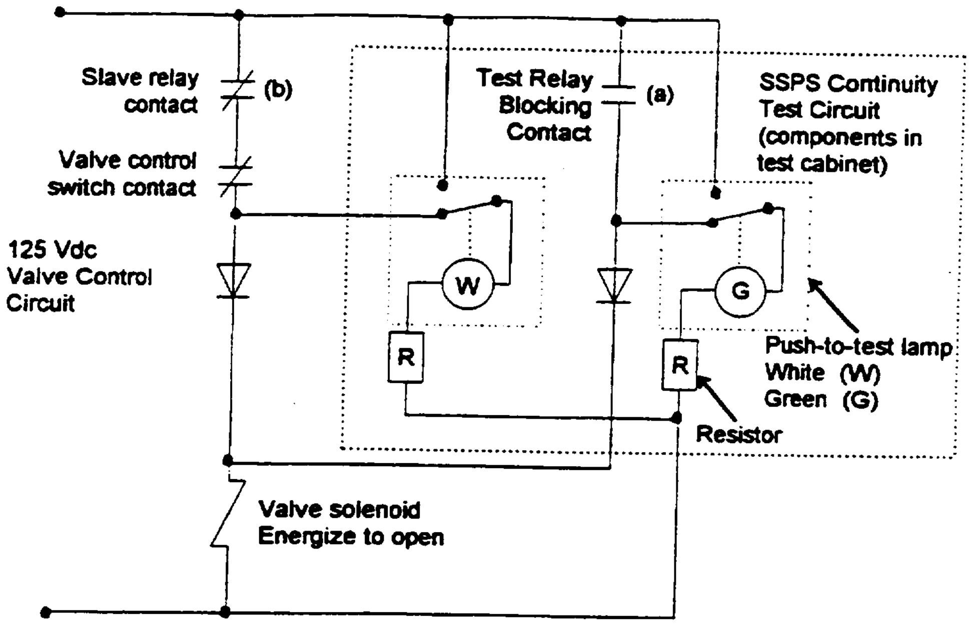
Sincerely,

Warren H. Fujimoto

cc: Edgar Bailey, DHS
Steve Bloom
L. J. Callan
Kenneth E. Perkins
Michael D. Tschiltz
Diablo Distribution

Attachment

TYPICAL SSPS CONTINUITY TEST CIRCUIT FOR NORMALLY ENERGIZED LOADS



Note: Circuit shown in normal operating condition for an open valve. The push-to-test lamps can be depressed at any time to verify lamp will light. Additional circuitry with the slave and test relay coil energization paths is not shown.

DESCRIPTION OF OPERATION

Slave relay actuation: Solid State Protection System (SSPS) master relay energizes the slave relay. The slave relay contact shown above opens, de-energizing the valve solenoid. The valve fails closed.

Slave relay continuity test: Initial conditions are verified to be white lamp on, stays on when depressed; and green lamp off, but lights when depressed. Then, the test relay is energized, closing the test relay blocking contact and lighting the green lamp in its normal position. The blocking contact provides an alternate current path to the valve solenoid during the time the slave relay contact will be open. The lighted green lamp provides verification that the blocking contact is closed and that it is safe to proceed. The slave relay is energized, opening the slave relay contact, and the white lamp goes off to provide verification of operability. The circuit is restored to normal and the test is complete.

At Shearon Harris, when the slave relay was energized, the blocking contact failed to provide an adequate current path to the main steam isolation valve solenoid, allowing it to de-energize and close the valve.

APPENDIX F
CORRESPONDENCE

- AW-00-1412, "Application for Withholding Proprietary Information from Public Disclosure," Dated 8/15/00
- AW-99-1370, "Application for Withholding Proprietary Information from Public Disclosure," Dated 11/9/99

Westinghouse Electric Company LLC

Box 355
Pittsburgh Pennsylvania 15230-0355

August 15, 2000

AW-00-1412

Document Control Desk
U.S. Nuclear Regulatory Commission
Washington, DC 20555

Attention: Mr. Samuel J. Collins

APPLICATION FOR WITHHOLDING PROPRIETARY
INFORMATION FROM PUBLIC DISCLOSURE

Subject: "Reliability Assessment of Potter & Brumfield MDR Series Relays", WCAP-13878-P-A, Rev. 2, (Proprietary), August 2000

Dear Mr. Collins:

The application for withholding is submitted by Westinghouse Electric Company LLC, pursuant to the provisions of paragraph (b)(1) of Section 2.790 of the Commission's regulations. It contains commercial strategic information proprietary to Westinghouse and customarily held in confidence.

The proprietary material for which withholding is being requested is identified in the proprietary version of the subject report. In conformance with 10 CFR Section 2.790, Affidavit AW-00-1412 accompanies this application for withholding, setting forth the basis on which the identified proprietary information may be withheld from public disclosure.

Accordingly, it is respectfully requested that the subject information which is proprietary to Westinghouse be withheld from public disclosure in accordance with 10CFR Section 2.790 of the Commission's regulations.

Correspondence with respect to this application for withholding or the accompanying affidavit should reference AW-00-1412 and should be addressed to the undersigned.

Very truly yours,

H. A. Sepp, Manager
Regulatory and Licensing Engineering

Enclosure

cc: S. Bloom, NRR/OWFN/DRPW/PDIV2 (Rockville, MD) 1L, 1A

AFFIDAVIT

COMMONWEALTH OF PENNSYLVANIA:

ss

COUNTY OF ALLEGHENY:

Before me, the undersigned authority, personally appeared Henry A. Sepp, who, being by me duly sworn according to law, deposes and says that he is authorized to execute this Affidavit on behalf of Westinghouse Electric Company LLC, and that the averments of fact set forth in this Affidavit are true and correct to the best of his knowledge, information, and belief:

Henry A. Sepp, Manager
Regulatory and Licensing Engineering

Sworn to and subscribed
before me this 21st day
of August, 2000

Notary Public

Notarial Seal
Lorraine M. Piplica, Notary Public
Monroeville Boro, Allegheny County
My Commission Expires Dec. 14, 2003
Member, Pennsylvania Association of Notaries

(1) I am Manager, Regulatory and Licensing Engineering, in the Nuclear Services Business Unit of the Westinghouse Electric Company LLC and as such, I have been specifically delegated the function of reviewing the proprietary information sought to be withheld from public disclosure in connection with nuclear power plant licensing and rulemaking proceedings, and am authorized to apply for its withholding on behalf of the Westinghouse Nuclear Services Business Unit.

(2) I am making this Affidavit in conformance with the provisions of 10CFR Section 2.790 of the Commission's regulations and in conjunction with the Westinghouse application for withholding accompanying this Affidavit.

(3) I have personal knowledge of the criteria and procedures utilized by the Westinghouse Nuclear Services Business Unit in designating information as a trade secret, privileged or as confidential commercial or financial information.

(4) Pursuant to the provisions of paragraph (b)(4) of Section 2.790 of the Commission's regulations, the following is furnished for consideration by the Commission in determining whether the information sought to be withheld from public disclosure should be withheld.

(i) The information sought to be withheld from public disclosure is owned and has been held in confidence by Westinghouse

(ii) The information is of a type customarily held in confidence by Westinghouse and not customarily disclosed to the public. Westinghouse has a rational basis for determining the types of information customarily held in confidence by it and, in that connection, utilizes a system to determine when and whether to hold certain types of information in confidence. The application of that system and the substance of that system constitutes Westinghouse policy and provides the rational basis required.

Under that system, information is held in confidence if it falls in one or more of several types, the release of which might result in the loss of an existing or potential competitive advantage, as follows:

(a) The information reveals the distinguishing aspects of a process (or component, structure, tool, method, etc.) where prevention of its use by any of Westinghouse's competitors without license from Westinghouse constitutes a competitive economic advantage over other companies.

(b) It consists of supporting data, including test data, relative to a process (or component, structure, tool, method, etc.), the application of which data secures a competitive economic advantage, e.g., by optimization or improved marketability.

(c) Its use by a competitor would reduce his expenditure of resources or improve his competitive position in the design, manufacture, shipment, installation, assurance of quality, or licensing a similar product.

(d) It reveals cost or price information, production capacities, budget levels, or commercial strategies of Westinghouse, its customers or suppliers.

(e) It reveals aspects of past, present, or future Westinghouse or customer funded development plans and programs of potential commercial value to Westinghouse.

(f) It contains patentable ideas, for which patent protection may be desirable.

(g) The information is not the property of Westinghouse but must be treated as proprietary by Westinghouse according to agreements with the Owner.

There are sound policy reasons behind the Westinghouse system which include the following:

(a) The use of such information by Westinghouse gives Westinghouse a competitive advantage over its competitors. It is, therefore, withheld from disclosure to protect the Westinghouse competitive position.

(b) It is information which is marketable in many ways. The extent to which such information is available to competitors diminishes the Westinghouse ability to sell products and services involving the use of the information.

(c) Use by our competitor would put Westinghouse at a competitive disadvantage by reducing his expenditure of resources at our expense.

(d) Each component of proprietary information pertinent to a particular competitive advantage is potentially as valuable as the total competitive advantage. If competitors acquire components of proprietary information, any one component may be the key to the entire puzzle, thereby depriving Westinghouse of a competitive advantage.

(e) Unrestricted disclosure would jeopardize the position of prominence of Westinghouse in the world market, and thereby give a market advantage to the competition of those countries.

(f) The Westinghouse capacity to invest corporate assets in research and development depends upon the success in obtaining and maintaining a competitive advantage.

(iii) The information is being transmitted to the Commission in confidence and, under the provisions of 10CFR Section 2.790, it is to be received in confidence by the Commission.

(iv) The information sought to be protected is not available in public sources or available information has not been previously employed in the same original manner or method to the best of our knowledge and belief.

(v) The proprietary information sought to be withheld in this submittal is that which is appropriately marked in "Reliability Assessment of Potter & Brumfield MDR Series Relays", WCAP-13878-P-A, Rev. 2, August 2000 being transmitted by Westinghouse Letter and Application for Withholding Proprietary Information from Public Disclosure, to the Document Control Desk, Attention Mr. Samuel J. Collins. The proprietary information as submitted by Westinghouse is expected to be applicable in licensee submittals in response to certain NRC requirements.

This information is part of that which will enable Westinghouse to:

(a) The use of such information by Westinghouse gives Westinghouse a competitive advantage over its competitors. It is, therefore, withheld from disclosure to protect the Westinghouse competitive position.

(b) It is information which is marketable in many ways. The extent to which such information is available to competitors diminishes the Westinghouse ability to sell products and services involving the use of the information.

(c) Use by our competitor would put Westinghouse at a competitive disadvantage by reducing his expenditure of resources at our expense.

Further this information has substantial commercial value as follows:

(a) Westinghouse plans to sell the use of similar information to its customers for purposes of meeting NRC requirements for licensing documentation.

(b) Westinghouse can sell support and defense of the technology to its customers in the licensing process.

Public disclosure of this proprietary information is likely to cause substantial harm to the competitive position of Westinghouse because it would enhance the ability of competitors to provide similar calculation, evaluation and licensing defense services for commercial power reactors without commensurate expenses. Also, public disclosure of the information would enable others to use the information to meet NRC requirements for licensing documentation without purchasing the right to use the information.

The development of the technology described in part by the information is the result of applying the results of many years of experience in an intensive Westinghouse effort and the expenditure of a considerable sum of money.

In order for competitors of Westinghouse to duplicate this information, similar technical programs would have to be performed and a significant manpower effort, having the requisite talent and experience, would have to be expended for developing testing and analytical methods and performing tests.

Further the deponent sayeth not.

PROPRIETARY INFORMATION NOTICE

Transmitted herewith are proprietary and/or non-proprietary versions of documents furnished to the NRC in connection with requests for generic and/or plant-specific review and approval.

In order to conform to the requirements of 10 CFR 2.790 of the Commission's regulations concerning the protection of proprietary information so submitted to the NRC, the information which is proprietary in the proprietary versions is contained within brackets, and where the proprietary information has been deleted in the non-proprietary versions, only the brackets remain (the information that was contained within the brackets in the proprietary versions having been deleted). The justification for claiming the information so designated as proprietary is indicated in both versions by means of lower case letters (a) through (g) contained within parentheses located as a superscript immediately following the brackets enclosing each item of information being identified as proprietary or in the margin opposite such information. These lower case letters refer to the types of information Westinghouse customarily holds in confidence identified in Sections (4)(ii)(a) through (4)(ii)(g) of the affidavit accompanying this transmittal pursuant to 10 CFR 2.790(b)(1).

COPYRIGHT NOTICE

Westinghouse Electric Company LLC

Box 355
Pittsburgh Pennsylvania 15230-0355

November 9, 1999

AW-99-1370

Document Control Desk
U.S. Nuclear Regulatory Commission
Washington, DC 20555

Attention: Mr. Samuel J. Collins

APPLICATION FOR WITHHOLDING PROPRIETARY INFORMATION FROM PUBLIC DISCLOSURE

Subject: "Reliability Assessment of Potter & Brumfield MDR Series Relays", WCAP-13878-P, Rev. 2, October, 1999

Dear Mr. Collins:

The application for withholding is submitted by Westinghouse Electric Company LLC, pursuant to the provisions of paragraph (b)(1) of Section 2.790 of the Commission's regulations. It contains commercial strategic information proprietary to Westinghouse and customarily held in confidence.

The proprietary material for which withholding is being requested is identified in the proprietary version of the subject report. In conformance with 10 CFR Section 2.790, Affidavit AW-99-1370 accompanies this application for withholding, setting forth the basis on which the identified proprietary information may be withheld from public disclosure.

Accordingly, it is respectfully requested that the subject information which is proprietary to Westinghouse be withheld from public disclosure in accordance with 10CFR Section 2.790 of the Commission's regulations.

Correspondence with respect to this application for withholding or the accompanying affidavit should reference AW-99-1370 and should be addressed to the undersigned.

Very truly yours,

H. A. Sepp, Manager
Regulatory and Licensing Engineering

Enclosure

cc: T. Carter/NRC (5E7)

AW-99-1370

AFFIDAVIT

COMMONWEALTH OF PENNSYLVANIA:

ss

COUNTY OF ALLEGHENY:

Before me, the undersigned authority, personally appeared Henry A. Sepp, who, being by me duly sworn according to law, deposes and says that he is authorized to execute this Affidavit on behalf of Westinghouse Electric Company LLC, and that the averments of fact set forth in this Affidavit are true and correct to the best of his knowledge, information, and belief:

Henry A. Sepp, Manager
Regulatory and Licensing Engineering

Sworn to and subscribed
before me this 10th day
of November, 1999

Notarial Seal
Janet A. Schwab, Notary Public
Monroeville Boro, Allegheny County
My Commission Expires May 22, 2000
Member, Pennsylvania Association of Notaries

Notary Public

(1) I am Manager, Regulatory and Licensing Engineering, in the Nuclear Services Business Unit of the Westinghouse Electric Company LLC and as such, I have been specifically delegated the function of reviewing the proprietary information sought to be withheld from public disclosure in connection with nuclear power plant licensing and rulemaking proceedings, and am authorized to apply for its withholding on behalf of the Westinghouse Nuclear Services Business Unit.

(2) I am making this Affidavit in conformance with the provisions of 10CFR Section 2.790 of the Commission's regulations and in conjunction with the Westinghouse application for withholding accompanying this Affidavit.

(3) I have personal knowledge of the criteria and procedures utilized by the Westinghouse Nuclear Services Business Unit in designating information as a trade secret, privileged or as confidential commercial or financial information.

(4) Pursuant to the provisions of paragraph (b)(4) of Section 2.790 of the Commission's regulations, the following is furnished for consideration by the Commission in determining whether the information sought to be withheld from public disclosure should be withheld.

(i) The information sought to be withheld from public disclosure is owned and has been held in confidence by Westinghouse

(ii) The information is of a type customarily held in confidence by Westinghouse and not customarily disclosed to the public. Westinghouse has a rational basis for determining the types of information customarily held in confidence by it and, in that connection, utilizes a system to determine when and whether to hold certain types of information in confidence. The application of that system and the substance of that system constitutes Westinghouse policy and provides the rational basis required.

Under that system, information is held in confidence if it falls in one or more of several types, the release of which might result in the loss of an existing or potential competitive advantage, as follows:

(a) The information reveals the distinguishing aspects of a process (or component, structure, tool, method, etc.) where prevention of its use by any of Westinghouse's competitors without license from Westinghouse constitutes a competitive economic advantage over other companies.

(b) It consists of supporting data, including test data, relative to a process (or component, structure, tool, method, etc.), the application of which data secures a competitive economic advantage, e.g., by optimization or improved marketability.

(c) Its use by a competitor would reduce his expenditure of resources or improve his competitive position in the design, manufacture, shipment, installation, assurance of quality, or licensing a similar product.

(d) It reveals cost or price information, production capacities, budget levels, or commercial strategies of Westinghouse, its customers or suppliers.

(e) It reveals aspects of past, present, or future Westinghouse or customer funded development plans and programs of potential commercial value to Westinghouse.

(f) It contains patentable ideas, for which patent protection may be desirable.

(g) The information is not the property of Westinghouse but must be treated as proprietary by Westinghouse according to agreements with the Owner.

There are sound policy reasons behind the Westinghouse system which include the following:

(a) The use of such information by Westinghouse gives Westinghouse a competitive advantage over its competitors. It is, therefore, withheld from disclosure to protect the Westinghouse competitive position.

(b) It is information which is marketable in many ways. The extent to which such information is available to competitors diminishes the Westinghouse ability to sell products and services involving the use of the information.

(c) Use by our competitor would put Westinghouse at a competitive disadvantage by reducing his expenditure of resources at our expense.

(d) Each component of proprietary information pertinent to a particular competitive advantage is potentially as valuable as the total competitive advantage. If competitors acquire components of proprietary information, any one component may be the key to the entire puzzle, thereby depriving Westinghouse of a competitive advantage.

(e) Unrestricted disclosure would jeopardize the position of prominence of Westinghouse in the world market, and thereby give a market advantage to the competition of those countries.

(f) The Westinghouse capacity to invest corporate assets in research and development depends upon the success in obtaining and maintaining a competitive advantage.

(iii) The information is being transmitted to the Commission in confidence and, under the provisions of 10CFR Section 2.790, it is to be received in confidence by the Commission.

(iv) The information sought to be protected is not available in public sources or available information has not been previously employed in the same original manner or method to the best of our knowledge and belief.

(v) The proprietary information sought to be withheld in this submittal is that which is appropriately marked in "Reliability Assessment of Potter & Brumfield MDR Series Relays", WCAP-13878-P, Rev. 2, October, 1999, being transmitted by Westinghouse Letter and Application for Withholding Proprietary Information from Public Disclosure, to the Document Control Desk, Attention Mr. Samuel J. Collins. The proprietary information as submitted by Westinghouse is expected to be applicable in licensee submittals in response to certain NRC requirements.

This information is part of that which will enable Westinghouse to:

(a) The use of such information by Westinghouse gives Westinghouse a competitive advantage over its competitors. It is, therefore, withheld from disclosure to protect the Westinghouse competitive position.

(b) It is information which is marketable in many ways. The extent to which such information is available to competitors diminishes the Westinghouse ability to sell products and services involving the use of the information.

(c) Use by our competitor would put Westinghouse at a competitive disadvantage by reducing his expenditure of resources at our expense.

Further this information has substantial commercial value as follows:

(a) Westinghouse plans to sell the use of similar information to its customers for purposes of meeting NRC requirements for licensing documentation.

(b) Westinghouse can sell support and defense of the technology to its customers in the licensing process.

Public disclosure of this proprietary information is likely to cause substantial harm to the competitive position of Westinghouse because it would enhance the ability of competitors to provide similar calculation, evaluation and licensing defense services for commercial power reactors without commensurate expenses. Also, public disclosure of the information would enable others to use the information to meet NRC requirements for licensing documentation without purchasing the right to use the information.

The development of the technology described in part by the information is the result of applying the results of many years of experience in an intensive Westinghouse effort and the expenditure of a considerable sum of money.

In order for competitors of Westinghouse to duplicate this information, similar technical programs would have to be performed and a significant manpower effort, having the requisite talent and experience, would have to be expended for developing testing and analytical methods and performing tests.

Further the deponent sayeth not.

PROPRIETARY INFORMATION NOTICE

Transmitted herewith are proprietary and/or non-proprietary versions of documents furnished to the NRC in connection with requests for generic and/or plant-specific review and approval.

In order to conform to the requirements of 10 CFR 2.790 of the Commission's regulations concerning the protection of proprietary information so submitted to the NRC, the information which is proprietary in the proprietary versions is contained within brackets, and where the proprietary information has been deleted in the non-proprietary versions, only the brackets remain (the information that was contained within the brackets in the proprietary versions having been deleted). The justification for claiming the information so designated as proprietary is indicated in both versions by means of lower case letters (a) through (g) contained within parentheses located as a superscript immediately following the brackets enclosing each item of information being identified as proprietary or in the margin opposite such information. These lower case letters refer to the types of information Westinghouse customarily holds in confidence identified in Sections (4)(ii)(a) through (4)(ii)(g) of the affidavit accompanying this transmittal pursuant to 10 CFR 2.790(b)(1).

COPYRIGHT NOTICE