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Aging and Qualification Research on Solenoid Operated Valves

Prepared by V. P. Bacanskas, G. J. Toman, S. P. Carfagno

Franklin Research Center

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ABSTRACT

A research program was conducted on the aging and qualification of solenoid operated valves (SOVs) used in nuclear power generating stations. Tests were conducted on three-way, direct acting SOVs, manufactured by Automatic Switch Co. (ASCO) and Valcor Engineering Corp. Some SOVs had been aged naturally through service in nuclear power plants and others were subjected to accelerated aging. Thermal aging was conducted both with air and nitrogen as the process gas. Operational aging was simulated by putting the specimens through operational cycles at intervals during the accelerated thermal aging, with the environmental temperature controlled at a level representative of service conditions. The program also included simulation of a design basis event (DBE), that consisted of DBE gamma irradiation and a 30-d main steam line break/loss of coolant accident (MSLB/LOCA) simulation. After each major segment of the test program (aging, irradiation, and MSLB/LOCA simulation), some of the valve specimens were subjected to operational testing, then disassembled for inspection of all parts and measurement of physical properties (Shore A durometer hardness, elongation at break, and relaxation after compression) of the elastomeric parts.

Performance of the ASCO SOVs was affected in the early stages of the program by an organic deposit of undetermined origin at a metal-to-metal interface. Removal of the deposit eliminated the problem; however, it was not possible to identify the source of the deposit within the constraints of time and money available to the program. Following DBE irradiation, some ASCO SOVs experienced slight leakage. A naturally aged ASCO SOV with Buna N seals and a new ASCO SOV, with EPDM seals, that was subjected to accelerated aging with nitrogen as the process gas, were the only ones to go through the entire test program without any failures to transfer or any significant leakage. The naturally aged ASCO SOV with EPDM seals began to malfunction 21 h after the start of the second transient of the MSLB/LOCA simulation.

Valcor SOVs suffered from sticking of the shaft seal O-rings, which made it impossible to complete accelerated thermal aging. Repeated tests and changes in test procedures failed to alter this situation even though the accelerated thermal aging of the Valcor SOVs complied with stress limits identified by the manufacturer. It is possible that the stresses of accelerated aging produced effects not representative of service aging. Seal deterioration in the Valcor SOVs caused leakage and delays in transferring following DBE irradiation. The naturally aged Valcor SOV performed satisfactorily during the first high-temperature portion of the MSLB/LOCA profile, but malfunctioned during most of the rest of the test. The new Valcor SOV that had not been subjected to aging transferred properly throughout the DBE simulation, but had high leakage starting about 8 h after the start of the second transient of the MSLB/LOCA simulation.

Deterioration of the elastomeric parts of the ASCO SOVs did not appear to be sufficient to account for the observed failures to transfer, which evidently were caused by coil deterioration. Elastomeric parts of Valcor SOVs, both the naturally aged SOV and the one that had not been aged, experienced substantial deterioration.

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SUMMARY*

An aging and qualification research program was conducted at Franklin Research Center (FRC) on solenoid operated valves (SOVs) to investigate their performance under normal and accident conditions in a nuclear power generating station. The major segments of the aging and accident test sequence were: thermal and operational aging, gamma irradiation to the equivalent of an accident dose, and main-steam-line-break/loss-of-coolant accident (MSLB/LOCA) simulation. The effects of the use of air versus nitrogen as the process medium during accelerated aging and the effects of natural (in-service) versus accelerated aging were investigated. The program was initiated with enough valve specimens so that specimens could be removed for functional testing, disassembly, and measurement of component properties after each major segment of the program.

Three-way, direct-acting ASCO and Valcor SOVs removed from actual service in two nuclear power plants were made available as naturally aged specimens for the research program. New valves of the same type were purchased for use in producing specimens subjected to accelerated aging.

The valve specimens were divided into four groups based on their removal after each test segment: (I) new, unaged reference specimens, (II) natural and accelerated aging only, (III) aging plus irradiation, and (IV) aging plus irradiation plus MSLB/LOCA simulation. Groups I, II, III, and IV initially included specimens representing both manufacturers. The ASCO specimens included two sets of naturally aged SOVs (removed from the Ft. Calhoun plant after 1.5 and 8 years service) and new SOVs subjected to accelerated thermal aging using air or nitrogen as the process medium. The Valcor specimens included new SOVs and naturally aged SOVs removed from the McGuire plant after 5 years of service. No Valcor SOVs subjected to accelerated aging were included in the design basis event (DBE) simulation (irradiation plus MSLB/LOCA), because all efforts at accelerated aging of the Valcor SOVs resulted in their failure to transfer.

The accelerated thermal aging of the new ASCO SOVs was intended to simulate 4 years of energized service in an environment at 140°F (60°C). The thermal aging conditions were calculated on the basis of the activation energy of the critical components, the temperature distribution in the SOV when energized, and the assumption that the components were in contact with air. The same aging temperatures were used for the specimens in which nitrogen was the process medium as for the specimens with air as the process medium. After the program was completed, ASCO informed FRC that it had performed more recent calibration experiments in essentially still air and observed much higher seat and coil temperatures than those observed by FRC in calibration experiments with air circulation through the oven. Using the more recent, higher ASCO temperatures gave the aging equivalent of 1 year of service for the critical elastomeric components and negligible aging for the coils. The actual in-plant conditions vary by location, and range from strong air flow past the valves in pipe tunnels to relatively stagnant air in open regions of containment.

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*The rationale for the elements of the test program is given in the test plan, revised January 1987, which is included as Appendix A of this report.

Accelerated aging of the Valcor SOVs was intended to simulate 5 years of energized service at 140°F (60°C). However, the SOVs failed to operate early during the accelerated aging exposure. Failure analysis indicated that the shaft seal O-ring is more critical than the lower seal O-ring, which had previously been assumed to be the most critical component. The thermal aging procedure was modified accordingly, and additional changes in test procedures were made with the intention of eliminating any possible unrepresentative overstressing of Valcor SOVs while retaining the equivalence of 5 years of thermal aging. In spite of such changes in the procedures, the Valcor SOVs failed to operate during two additional attempts at artificial thermal aging. Due to limitations of funding and time the program was continued with Valcor SOV specimens that had not been through accelerated thermal aging. Disassembly and inspection of the failed SOVs revealed that the shaft seal O-rings were hard and had started to become powdery and were disintegrating. The upper O-ring on the seal assembly was severely deteriorated and adhered to the seat.

The accelerated aging sequence also included operational cycling: 2000 cycles were conducted on the ASCO SOVs, and it had been planned to conduct 2500 cycles on the Valcor SOVs. The cycling was done in increments of 500 cycles following the completion of each 25% increment of thermal aging. As mentioned above, the Valcor SOVs failed to operate during accelerated thermal aging; hence, only new (unaged) and naturally aged Valcor SOVs were put through the DBE simulation (irradiation plus MSLB/LOCA).

The ASCO SOVs failed to transfer when approximately one-fourth of the accelerated thermal aging had been completed and it was time to perform the first increment of 500 operational cycles. Examination of all six new ASCO SOVs undergoing accelerated thermal aging revealed an organic deposit at the metal-to-metal interface between the solenoid base subassembly and the top of the core assembly. The deposit appeared to have acted as a sticky substance that prevented transfer.* After it was cleaned away and the SOVs were reassembled, the ASCO SOVs went through the remainder of the thermal aging and operational cycling without further difficulty.

The organic deposit was also found in the naturally aged ASCO SOVs (6096-6, -7, and -8) obtained from the Ft. Calhoun plant, when they were examined after receipt at FRC; and these SOVs were likewise cleaned of the deposit before use in the test program. The sticky deposit may be due to an organic compound introduced during valve assembly; but a detailed analysis (e.g., using IR techniques) and final determination of the source of the deposit was not possible within the budgetary restraints of the program.

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*Sticking solenoid valves have been reported at several nuclear power generating stations (NPGSs), but the exact cause is uncertain. Recent investigation of one such event by a utility attributed the cause to a silicone fluid applied to the core face when the valves are assembled. However, ASCO has reported that the silicone fluid was not applied to the SOVs used in this research program.

The SOVs in groups III and IV were subjected to 200 Mrd (2000 kGy) of gamma radiation to simulate the DBE dose. Because of the relatively short service lives of the SOVs and the low actual plant dose rates (see Table 2), the dose attributable to radiation aging was considered negligible; therefore, the SOVs were exposed only to the equivalent of a DBE radiation dose.

The high temperature portion of the MSLB/LOCA profile included a transient rise and a 3-min dwell at 420°F (216°C), a 6-min dwell at 365°F (185°C), and a 3-h dwell at 350°F (177°C). This high temperature portion was conducted twice, after which the temperature was reduced in steps during the course of 1 d to 280°F (138°C), where it was maintained for 3 d. The test was concluded by a 26-d dwell at 200°F (93°C), for a total test duration of 30 d. A chemical spray was applied to the specimens for 25 h, encompassing the 19-h dwell at 312°F (156°C) and the first few hours of the dwell at 280°F (138°C). Superheated steam conditions existed during approximately the first 13 min of the two high temperature portions of the profile, i.e., during the dwells at 420°F (216°C) and 365°F (185°C).

During the MSLB/LOCA simulation, the SOVs were normally deenergized; they were energized at various intervals to check their functional capability. They were also energized for 2 h after the start of the chemical spray to simulate applications in which SOVs are used in containment environment sampling systems.

The new, unaged ASCO reference SOV (6096-16) functioned satisfactorily. However, the new, unaged Valcor reference SOV (6096-25) experienced a 5-s delay to transfer during the initial energization, and it experienced similar delays thereafter. Another new Valcor SOV (6096-26) also experienced problems when tested prior to attempts to conduct accelerated aging. It had transfer delays of 2 to 8 s and considerable leakage.

Most of the naturally aged SOVs obtained from the nuclear power generating stations functioned satisfactorily when tested after receipt at FRC, i.e., there was no notable degradation as a consequence of their service in the nuclear plants. One exception was Valcor SOV 6096-21, which failed to transfer during the first attempt after receipt but transferred properly during a second try.

Except for minor leakage, all ASCO SOVs also functioned satisfactorily after exposure to the 200 Mrd (2000 kGy) of gamma radiation simulating an accident. A naturally aged ASCO SOV (6096-2) exhibited some leakage during the first energization following irradiation, but it did not leak during subsequent energizations. The ASCO SOV (6096-10) which had been subjected to accelerated aging with air as the process medium also had slight leakage after irradiation. The new Valcor SOVs 6096-26 and -27, which had no aging, experienced delays in transfer following irradiation; in addition Valcor SOV 6096-26 leaked during the transfer period. Naturally aged Valcor SOV 6096-21 transferred slowly after irradiation.

Performance during the MSLB/LOCA simulation varied considerably among the specimens. The naturally aged ASCO SOV (6096-3), that had been in service at the Ft. Calhoun plant, and the new ASCO SOV (6096-14) subjected to accelerated aging with nitrogen as the process gas were the only two valves that went through the entire test sequence with no failure to transfer and no significant leakage. The naturally aged ASCO SOV (6096-8) operated satisfactorily until 21 h after the start of the second MSLB/LOCA transient, when it failed to transfer, probably as a consequence of what appeared by circuit test to be an open coil. It continued to fail to transfer until the 10th day of the LOCA test, when the open circuit was evidently bridged; and it transferred satisfactorily throughout the remainder of the test. However, it again failed to operate during functional testing following the MSLB/LOCA test. The new ASCO SOV (6096-15) subjected to artificial accelerated aging, with air as the process medium, failed to transfer between approximately 8 h and 99 h after the start of the second MSLB/LOCA transient.

The naturally aged Valcor SOV (6096-21) transferred properly during the first MSLB/LOCA transient and high-temperature dwell, but it did not perform satisfactorily during most of the rest of the test. The new Valcor SOV (6096-26) that had no aging transferred properly throughout the test, but it had high leakage beginning about 8 h after the start of the second MSLB/LOCA transient.

Shore A durometer, elongation at break, and compression/relaxation properties were measured on elastomeric parts (O-rings and core discs) removed from the SOVs in the new state, and after natural aging, accelerated aging, irradiation, and MSLB/LOCA simulation. The properties of the elastomeric parts were found to be affected significantly by each of the test exposures. For those elastomeric parts of the SOVs exposed to the process medium, more deterioration occurred when air was used as the process medium than with nitrogen.

Accelerated aging in air using the Arrhenius equation correlated poorly with natural aging of EPDM materials. The accelerated aging appeared to lead to much greater degradation than natural aging in the plant.

Based on disassembly and inspection of the ASCO SOVs after testing, the deterioration of the elastomeric parts (particularly the static seals) of the ASCO SOVs did not appear to be sufficient to account for the failure of some of them to transfer. The failure to transfer early during thermal aging was caused by an organic deposit of unknown origin at a metal-to-metal interface. Failures to transfer during the MSLB/LOCA simulation were probably caused by coil failures.

Disassembly and inspection of the two Valcor SOVs after MSLB/LOCA simulation revealed substantial deterioration of the elastomeric components. The shaft seal O-ring of the naturally aged Valcor SOV (6096-21) had deteriorated and coated the shaft and guide tube, causing them to bind. In addition, it was confirmed that the coil had shorted. The seal assembly O-ring of the new Valcor SOV 6096-26, which had not been aged, had become fragmented during the MSLB/LOCA simulation; this is believed to have prevented proper closure and caused excessive leakage.

ACRONYMS AND ABBREVIATIONS

ASCO	Automatic Switch Company
ASTM	American Society for Testing and Materials
DBE	Design Basis Event
EPDM	Ethylene Propylene Diene Monomer (Ethylene Propylene Terpolymer)
FRC	Franklin Research Center
IEEE	Institute of Electrical and Electronics Engineers, Inc.
LOCA	Loss of Coolant Accident
MSLB	Main Steam Line Break
NC	Normally Closed to Process Fluid when Deenergized
NEMA	National Electrical Manufacturers' Association
NO	Normally Open to Process Fluid when Deenergized
NPAR	Nuclear Plant Aging Research
NPT	National Pipe Taper
NRC	Nuclear Regulatory Commission
ORNL	Oak Ridge National Laboratory
SOV	Solenoid Operated Valve
TID	Total Integrated Dose

1. INTRODUCTION

1.1 Objectives

The objectives of the research program were to:

1. Identify the incremental deterioration of elastomeric materials contained in solenoid operated valves (SOVs) due to thermal and operational aging, accident irradiation, and exposure to a main-steam-line-break/loss-of-coolant-accident MSLB/LOCA.
2. Compare the material property changes caused by natural and accelerated aging.
3. Compare the changes in material properties and functional capability caused by accelerated aging with air and nitrogen as the process media.

1.2 Background

This research program was a follow-on to an earlier program conducted by Franklin Research Center (FRC) for the Nuclear Regulatory Commission (NRC) on SOVs, the results of which are documented in Reference 1. The earlier test program included thermal, operational, radiation, and vibration aging as well as seismic testing, design basis event radiation, and an exposure to a simulated main-stream-line-break/loss-of-coolant accident (MSLB/LOCA) SOVs aged by accelerated techniques and others that were aged in real time by the manufacturer were included in the program. A failure analysis was conducted at the conclusion of the test program to identify the types of degradation that had occurred.

The main observation of the earlier program was that, sooner or later during the testing sequence, degradation resulted in high leakage. In spite of evidence that the coils became flooded during the MSLB/LOCA simulation, their performance was essentially satisfactory except when failure of other parts of an SOV led to coil burnout. The types of degradation observed could not be correlated conclusively with the effects of the several segments of the test program, because disassembly and examination of the specimens were performed only after the entire test program had been completed (i.e., not after each test segment). The comparison of accelerated and real-time thermal aging was limited by differences in the process medium (air and nitrogen) used during the aging simulation and differences in the model lines of the two sets of specimens.

Certain elements of the earlier test program, particularly valve cycling at the accelerated aging temperature, were judged to be excessively severe; therefore, SOV failure during the research program did not necessarily imply unacceptability for use in safety systems.* However, the picture was clouded

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*The cycling at accelerated aging temperature had been included in the program in accordance with its initial objective, which was to verify the manufacturer's qualification program. Consequently, the program raised a question concerning the reasonableness of the requirement for such cycling in IEEE Std 382, which the manufacturer had followed in its qualification program.

by the fact that a naturally aged specimen, which had not been subjected to cycling at high temperatures, also failed during the program.

The program documented in this report was developed to apply the lessons learned during the earlier program and meet the objectives listed in Section 1.1. The test plan is provided in Appendix A.

The project was performed under contract to Martin Marietta Energy Systems, Inc., operator of Oak Ridge National Laboratory (ORNL), for the Nuclear Plant Aging Research (NPAR) Program, which is sponsored by the Office of Nuclear Regulatory Research (RES) of the U.S. Nuclear Regulatory Commission (NRC). The NPAR program plan is detailed in NUREG-1144 [2].*

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*Numbers in brackets refer to citations listed in Section 9.

2. SUMMARY OF TEST PROGRAM

The specimens consisted of three-way, direct acting SOVs manufactured by ASCO and Valcor. Some specimens of both manufacturers had been removed from service in nuclear power plants, and others were new specimens.

The basic elements of the test program consisted of accelerated aging (thermal aging and operational cycling), gamma irradiation, and simulation of a main-steam-line-break/loss-of-coolant-accident (MSLB/LOCA). The specimens that were removed from service were not subjected to thermal aging. In separate sets of specimens, the accelerated thermal aging of the new ASCO SOVs was conducted using air and nitrogen as the process gas. Accelerated thermal aging of the new Valcor SOVs was conducted only with air as the process medium; however, as explained in Section 6, all Valcor SOVs subjected to accelerated thermal aging failed.

The specimens were divided into four groups (see Section 3.4) to permit functional testing, disassembly, and testing of parts after each major element of the test program. The following table defines the groups:

Group I:	reference specimens
Group II:	aging - natural (in-service) or - accelerated, thermal aging plus operational cycling
Group III:	aging (as in Group II) plus gamma irradiation
Group IV:	aging and gamma irradiation (as in Group III) plus MSLB/LOCA simulation.

The aging of ASCO SOVs was equivalent to 4 y* of service life, and that of the Valcor SOVs was intended to be equivalent to 5 y of service life. The 2000 operational cycles were conducted on ASCO SOVs, at 140°F (60°C), in increments of 500 cycles at the end of each 1/4-y equivalent of thermal aging. Because of the failure of Valcor SOVs during the thermal aging, there was no cycling of the Valcor SOVs. The naturally aged SOVs were not subjected to any additional accelerated aging or cycling.

Radiation aging was omitted as a separate step because it was considered to have negligible effect. The largest radiation dose that had been received by any of the naturally aged valves was only 1.5×10^6 rd, over a 5-year service life, and this dose was considered negligible when compared to the DBE dose. Therefore, no radiation aging of the SOVs was performed. Radiation aging may be regarded as having been combined with the much larger DBE

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*As discussed in Section 6.4, the equivalent service life simulated by the accelerated aging program depends on the ambient air temperature and flow rate in the vicinity of the installed SOVs. Four years applies to a location (such as the pipe tunnel) where air flow produces convective heat transfer from an energized SOV. Where the ambient air is stagnant and the air temperature is 140°F (60°C), the accelerated thermal aging was equivalent to 1 y of service life.

irradiation, but there was no functional testing following what would have been the aging dose.

No vibration aging or seismic testing was conducted, because no effect of such testing could be discerned in the predecessor research program [1].

The DBE simulation included exposure to 200 Mrd of gamma radiation, which enveloped the calculated DBE dose of all the plants included in a survey of nuclear plant service conditions. The MSLB/LOCA simulation was of 30-d duration. The initial, high-temperature portion of the profile, which was of 5-h duration and included a peak temperature of 420°F (216°C), was conducted twice. A chemical solution was sprayed onto the specimens, beginning 6 h after the start of the second transient to peak temperature and lasting for 1 d. The SOVs were deenergized throughout the MSLB/LOCA simulation, except at intervals when they were cycled for operational testing.

Specimens in Groups II, III, and IV were subjected to functional tests after completion of the test sequences listed above; they were then disassembled and inspected, and measurements of several physical properties were made on O-rings and core discs. The functional tests consisted of operational testing, leakage testing, insulation resistance measurement, and a high-potential-withstand test, as described in Section 8 of Appendix A. Physical property measurements made on the elastomeric parts of the SOVs, after they were disassembled and inspected, consisted of Shore durometer measurements and tensile testing of O-rings and compression testing of the ASCO core discs and the lower seats of the Valcor SOVs.

3. DESCRIPTION OF TEST SPECIMENS

3.1 Selection of Test Specimens

The selection of specimens to be included in the research program was determined by the prevalence of Automatic Switch Company (ASCO) and Valcor Engineering Corporation SOVs in safety-related applications at operating nuclear power plants. The choice of particular models was dictated primarily by the requirement they be of the same type as the naturally aged SOVs made available by utilities that had removed them from service at the end of their qualified life.

To obtain naturally aged SOVs, approximately 25 nuclear power plants were contacted, two of which were able to provide SOVs for the program. Descriptions of the naturally aged SOVs and their service histories are discussed in the paragraphs that follow. A summary description of all the test specimens is provided in Table 1, and the service history of the naturally aged SOVs is summarized in Table 2.

3.2 ASCO Solenoid Operated Valves

Two types of ASCO SOVs were obtained from Omaha Public Power District's Ft. Calhoun Station. Ten ASCO SOVs that are not environmentally qualified for Class 1E service were received. These ten SOVs were three-way, direct-acting SOVs, ASCO Model No. HXT831429. They were removed from the Ft. Calhoun plant after approximately 8 years of continuously energized service, due to lack of qualification documentation.

The Ft. Calhoun plant also provided an additional ten ASCO SOVs, which were environmentally qualified for Class 1E service. These SOVs are Model No. NP8314C29E and are also three-way, direct-acting SOVs. The NP8314 SOVs were used to replace the HTX8314 SOVs discussed previously. The NP8314 SOVs had been in continuously energized service approximately 18 months and were removed from service as a result of failures of similar ASCO SOVs. The failures were caused by sticking of the SOV core assembly to its plug nut.

FRC procured nine new NP8314C29E SOVs from ASCO, one to use as a reference and the others for accelerated aging. An exploded view of the NP8314 SOV is shown in Figure 1.*

A description of each of the ASCO SOVs is included in Table 1, and the service history of the naturally aged SOVs is summarized in Table 2.

3.3 Valcor Solenoid Operated Valves

Duke Power Company supplied seven Valcor three-way, direct-acting, Model No. V-70900-21-3 SOVs removed from the McGuire Nuclear Station at the end of their 5-year qualified life. The service life of these SOVs consisted of 2 years of preoperational testing and 3 years of continuously energized service during power plant operation.

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*A similar view of the ASCO SOV Model No. HXT831429 was not available.

Table 1. Description of Test Specimens and Related Data

				Solenoid Description		Valve Description				
FRC Ident. Number	Manufacturer	Model Number	Serial Number	Normal Voltage (Vdc)	Enclosure (NEMA Type)	Application and Operation	Valve Seating Material	Pipe Size (in)	Maximum Pressure (lb/in^2)	Test Pressure (lb/in^2)
6096-1	ASCO	HTX831429	52758T	125	4,7	Normally closed, 3-way construction	Buna "N" and Nylon	1/4	60	60
6096-2	ASCO	HTX831429	53290T	125	4,7	Normally closed, 3-way construction	Buna "N" and Nylon	1/4	60	60
6093-3	ASCO	HTX831429	53291T	125	4,7	Normally closed, 3-way construction	Buna "N" and Nylon	1/4	60	60
6096-4	ASCO	HTX831429	53291T	125	4,7	Normally closed, 3-way construction	Buna "N" and Nylon	1/4	60	60
6096-5	ASCO	NP8314C29E	05467K-36	125	3,4,7,9	Normally closed, 3-way construction	Combination metal and ethylene propylene	1/4	60	60
6096-6	ASCO	NP8314C29E	05467K-32	125	3,4,7,9	Normally closed, 3-way construction	Combination metal and ethylene propylene	1/4	60	60
6096-7	ASCO	NP8314C29E	05467K-37	125	3,4,7,9	Normally closed, 3-way construction	Combination metal and ethylene propylene	1/4	60	60
6096-8	ASCO	NP8314C29E	05467K-44	125	3,4,7,9	Normally closed, 3-way construction	Combination metal and ethylene propylene	1/4	60	60
6096-9	ASCO	NP8314C29E	20884(R-8)	125	3,4,7,9	Normally closed, 3-way construction	Combination metal and ethylene propylene	1/4	60	60
6096-10	ASCO	NP8314C29E	20884R(4)	125	3,4,7,9	Normally closed, 3-way construction	Combination metal and ethylene propylene	1/4	60	60
6096-11	ASCO	NP8314C29E	20884R(7)	125	3,4,7,9	Normally closed, 3-way construction	Combination metal and ethylene propylene	1/4	60	60
6096-12	ASCO	NP8314C29E	20884R(5)	125	3,4,7,9	Normally closed, 3-way construction	Combination metal and ethylene propylene	1/4	60	60
6096-13	ASCO	NP8314C29E	20884R(6)	125	3,4,7,9	Normally closed, 3-way construction	Combination metal and ethylene propylene	1/4	60	60

Table 1. Description of Test Specimens and Related Data (Cont.)

				Solenoid Description		Valve Description				
FRC Ident. Number	Manufacturer	Model Number	Serial Number	Normal Voltage (Vdc)	Enclosure (NEMA Type)	Application and Operation	Valve Seating Material	Pipe Size (in)	Maximum Pressure (lb/in^2)	Test Pressure (lb/in^2)
6096-14	ASCO	NP8314C29E	20884R(2)	125	3,4,7,9	Normally closed, 3-way construction	Combination metal and ethylene propylene	1/4	60	60
6096-15	ASCO	NP8314C29E	20884R(1)	125	3,4,7,9	Normally closed, 3-way construction	Combination metal and ethylene propylene	1/4	60	60
6096-16	ASCO	NP8314C29E	20884R(3)	125	3,4,7,9	Normally closed, 3-way construction	Combination metal and ethylene propylene	1/4	60	60
6096-17	ASCO	NP8314C29E	20884R(9)	125	3,4,7,9	Normally closed, 3-way construction	Combination metal and ethylene propylene	1/4	60	60
6096-18	Valcor	V07900-21-3	258	125	4	Normally closed, 3-way construction	EPR	1/2	150	100
6096-19	Valcor	V07900-21-3	45	125	4	Normally closed, 3-way construction	EPR	1/2	150	100
6096-20	Valcor	V07900-21-3	128	125	4	Normally closed, 3-way construction	EPR	1/2	150	100
6096-21	Valcor	V07900-21-3	201	125	4	Normally closed, 3-way construction	EPR	1/2	150	100
6096-22	Valcor	V07900-21-3	1596	125	4	Normally closed, 3-way construction	EPR	1/2	150	100
6096-23	Valcor	V07900-21-3	1597	125	4	Normally closed, 3-way construction	EPR	1/2	150	100
6096-24	Valcor	V07900-21-3	1598	125	4	Normally closed, 3-way construction	EPR	1/2	150	100
6096-25	Valcor	V07900-21-3	1599	125	4	Normally closed, 3-way construction	EPR	1/2	150	100
6096-26	Valcor	V07900-21-3	1600	125	4	Normally closed 3-way construction	EPR	1/2	150	100
6096-27	Valcor	V07900-21-3	1601	125	4	Normally closed, 3-way construction	EPR	1/2	150	100

Table 2. Service History of Naturally Aged Valves

FRC Ident. Number	Manu- facturer	Model Number	Serial Number	Years of Service	Normal Ambient Temperature (°F)	Radiation Dose (rad/h)	Calculated Total Integrated Dose (rad)
6096-1	ASCO	HTX831429	52758T	8[a]	107	--	7.0×10^4
6096-2	ASCO	HTX831429	53290T	8[a]	90	--	7.0×10^4
6096-3	ASCO	HTX831429	53291T	8[a]	Unknown	Unknown	Unknown
6096-4	ASCO	HTX831429	53291T	8[a]	Unknown	Unknown	Unknown
6096-5	ASCO	NP8314C29E	05467K-36	1.25	107	--	1.1×10^4
6096-6	ASCO	NP8314C29E	05467K-32	1.25	107	--	1.1×10^4
6096-7	ASCO	NP8314C29E	05467K-37	1.25	107	--	1.1×10^4
6096-8	ASCO	NP8314C29E	05467K-44	1.25	107	--	1.1×10^4
6096-18	Valcor	V-70900-21-3	258	5	100-120	2.9	7.6×10^4 (b)
6096-19	Valcor	V-70900-21-3	45	5	100-120	2.9	7.6×10^5 (b)
6096-20	Valcor	V-70900-21-3	128	5	100-120	57	1.5×10^6 (b)
6096-21	Valcor	V-70900-21-3	201	5	100-120	57	1.5×10^6 (b)

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a. Approximate age; exact age not known.

b. The valve experienced the listed radiation levels in approximately 3 years, as 2 of the 5 years of service were during preoperational testing.

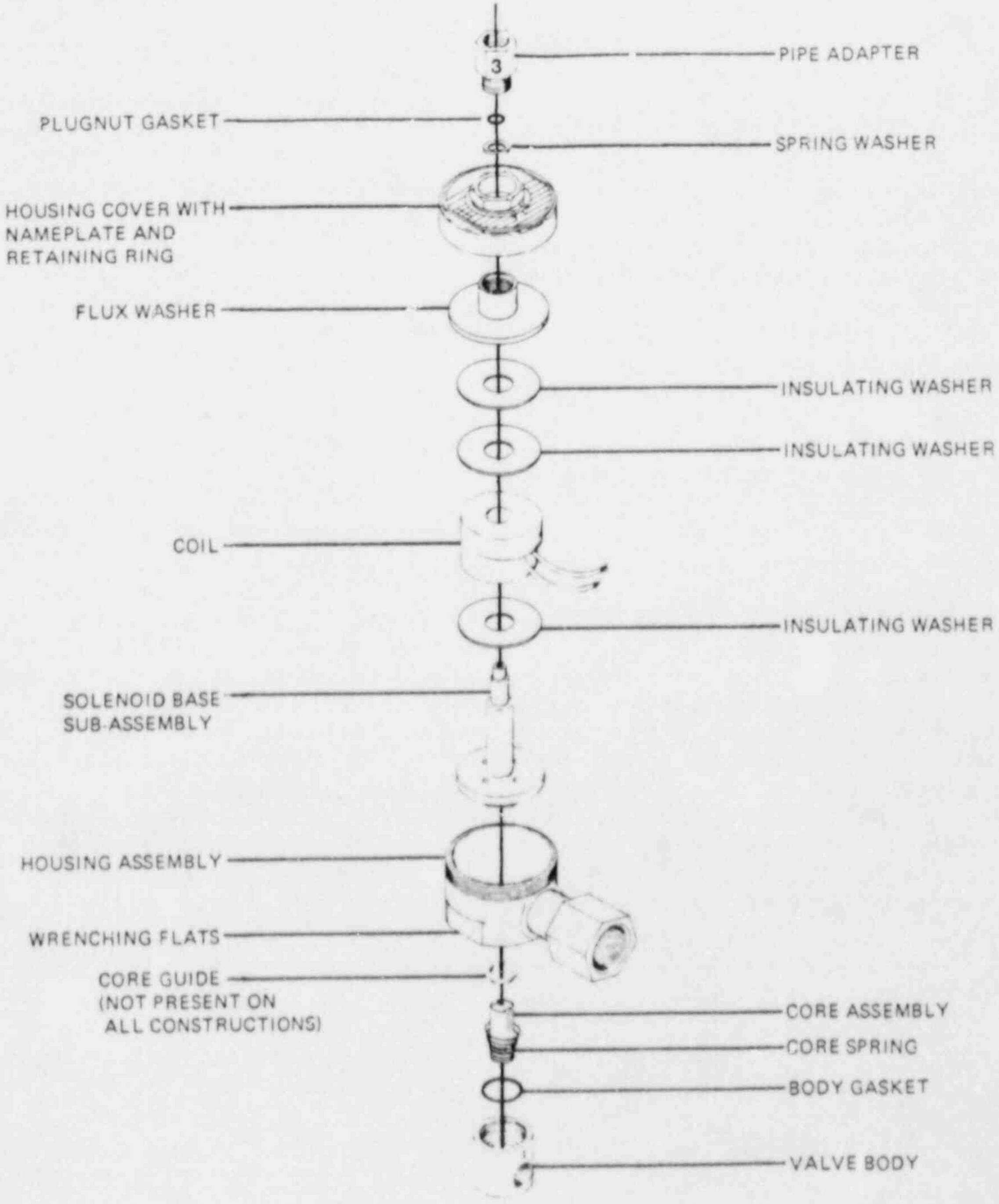

Figure 1. Exploded View of ASCO NP8314 SOV

FRC procured six new Valcor Model No. V-70900-21-3 SOVs, one to use as a reference and the others for accelerated aging. A section view of the Valcor SOV is shown in Figure 2.

A description of each of the Valcor SOVs is included in Table 1, and Table 2 provides the service history of the naturally aged SOVs.

3.4 Description of SOV Groups

To meet program objectives, the test specimens were divided into four groups. Each of the four groups was exposed to specific segments of the test program to allow comparison of the effects of the environmental exposures on the SOVs. Group I SOVs were subjected to functional testing prior to disassembly, inspection, and material testing to provide baseline data on the SOV and material performance. The testing of each of the other three groups was terminated at different stages of the program. Group I consisted of one new ASCO Model No. NP8314C29E SOV (6096-15) and one new Valcor Model No. V-70900-21 SOV (6096-27). Groups II, III, and IV consisted of the samples identified in Table 3. The naturally aged SOVs in Group II, (both ASCO and Valcor), were examined as received from the plants.

The new ASCO SOVs put into Group II were subjected to accelerated aging (thermal and operational) prior to disassembly and material testing. Comparison of data for SOVs in Groups I and II was intended to reveal the change in SOV performance and material properties caused by aging. The SOVs in Group III were subjected to 200 Mrd of gamma radiation after completion of the aging simulation. The disassembly and material testing that followed was intended to provide information on the incremental effect of the irradiation. The final group of SOVs, Group IV, was subjected to a 30-day MSLB/LOCA simulation in addition to the aging and radiation exposures. The functional test data from Group IV, together with the post-LOCA material testing, provided the final set of data. One set of ASCO SOVs, Model No. NP8314C29E, was supplied with nitrogen as the process medium throughout the test so that the effects of the nitrogen environment on the internal organic materials could be compared with the effects of air, which is normally used as the process medium.

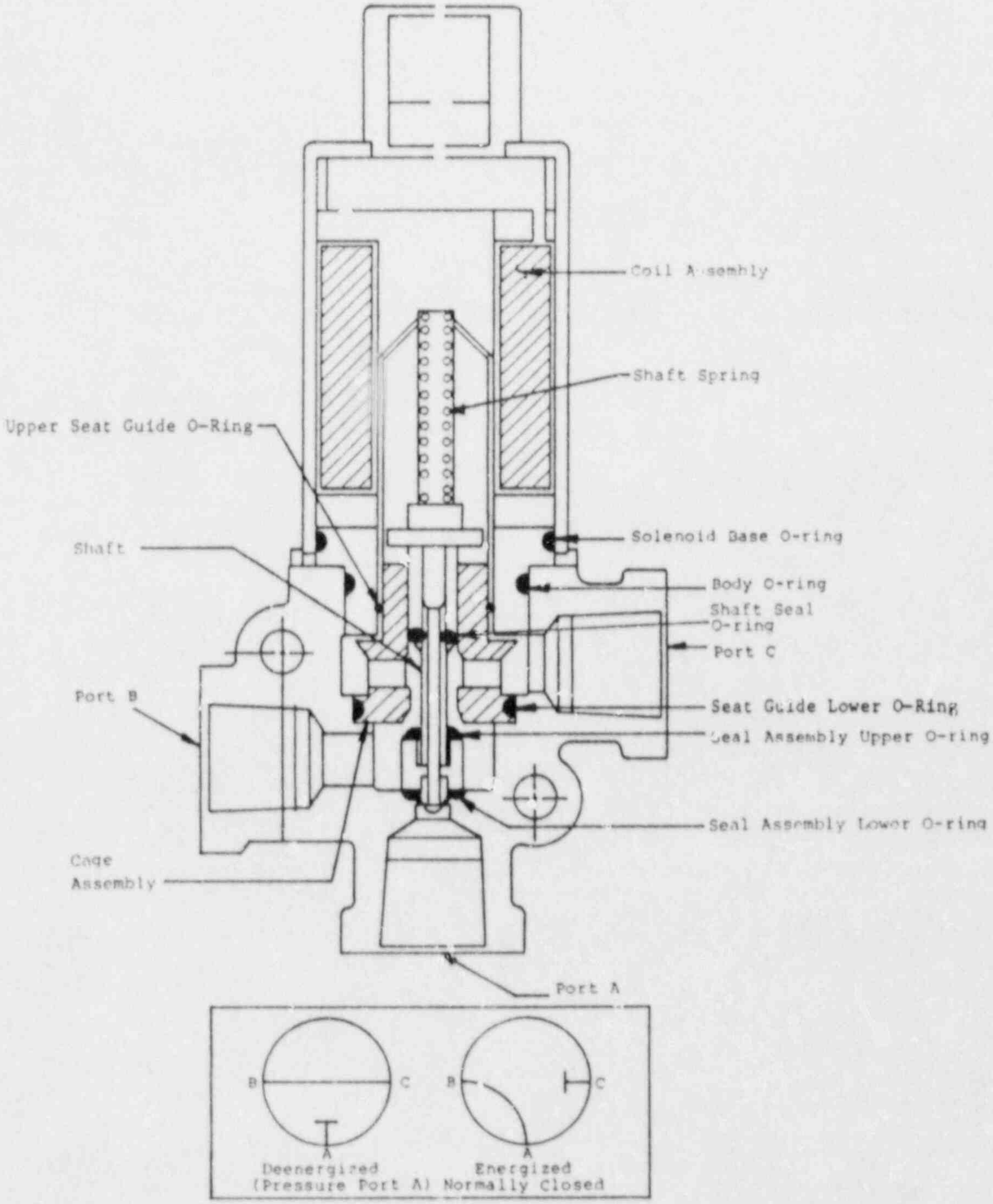

Figure 2. Section View of Valcor V-70900-21 SOV

Table 3. Test Specimen Groups

Group (a)/Specimen No.							
I	II	III	IV				
Reference	Aging	Aging and Irradiation	Aging and Irradiation and MSLB/LOCA	Mfr.	Model No.	Aging	Process Medium
6096-16				ASCO	NF8314C29E	None	--
6096-25				Valcor	V-70900-21	None	--
	6096-9	6096-10	6096-15	ASCO	NP8314C29E	Accelerated	Air
	6096-12	6096-13	6096-14	ASCO	NP8314C29E	Accelerated	Nitrogen
	6096-6	6096-7	6096-8	ASCO	NP8314C29E	Natural	Air
	6096-1(e)	6096-2	6096-3(e)	ASCO	HTX831429	Natural	Air
	(d)	6096-27(c)	6096-26(c)	Valcor	V-70900-21	Accelerated(b)	Air
	6096-19	6096-20	6096-21	Valcor	V-70900-21	Natural	Air

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a. Test sequences:
Group II = aging
Group III = aging + irradiation
Group IV = aging + irradiation + MSLB/LOCA simulation.

b. Accelerated thermal aging of the Valcor SOVs was not successful. (See Section 6.)

c. Valcor valves 6096-27 and 6096-26 had neither thermal aging nor the 2500 operational cycles: SOV 6096-27 was subjected to irradiation only and SOV 6096-26 was subjected to irradiation and the MSLB/LOCA simulation.

d. Three efforts to conduct accelerated thermal aging on Valcor SOVs all resulted in valve failure. The SOVs used were numbers 6096-22, -23, and -24.

e. Initially, SOV 6096-1 was placed in Group IV and SOV 6096-3 in Group II. However, they were interchanged because SOV 6096-1 was found to be leaking after accelerated aging.

4. TEST FACILITIES

4.1 Thermal Aging

Accelerated thermal aging was conducted in a forced-circulation air oven with internal dimensions of 4 ft by 4 ft by 5 ft high (1.2 m by 1.2 m by 1.5 m). Temperature uniformity throughout the volume occupied by test speci- mens was within the range of ±5°F (±3°C) relative to the average oven tempera- ture. The approximate velocity of recirculated air through the oven was 250 ft/min (76 m/min). An air-intake/air-exhaust system introduced fresh air continuously into the recirculating air stream.

Figure 3 shows all the specimens mounted on the test rack, which was placed inside the aging oven. All specimens were mounted with the solenoids at the top of the SOVs. Some specimens were removed after thermal aging and some specimens were removed after irradiation, leaving the specimens that were exposed to the MSLB/LOCA simulation.

4.2 Nuclear Irradiation

The basic element of the nuclear radiation facility was a cobalt-60 source which provided gamma radiation in an air environment. The specimens were irradiated while mounted on the test rack shown in Figures 3 and 4. The specimens that had been scheduled for thermal aging only were removed; and other specimens that were to be irradiated, but had not been on the rack for accelerated thermal aging, were added.

The gamma irradiation was conducted by Isomedix, Inc., Parsippany, NJ. Additional information is presented in Appendix B.

4.3 Simulated MSLB/LOCA Exposure

The test vessel used for the steam, chemical-spray, and high-humidity exposure was a 24-in-diam by 48-in-high (0.61-m-diam by 1.2-m-high) stainless steel vessel illustrated schematically in Figure 5. After removal of specimens that had not been scheduled for the MSLB/LOCA simulation and detachment of the legs and upper extensions of the test rack, it was attached to the vessel head; and the assembly was lowered onto the test vessel, with the rack going inside the vessel.

Steam was admitted into the vessel through a central tube of stainless steel shown in Figure 5. Superheated steam was obtained by passing utility-supplied saturated steam through a moisture separator and a stored-energy heat exchanger. The system was capable of delivering steam at a gage pressure of approximately 100 lb/in^2 (689 kPa) and a temperature of 600°F (316°C). Saturated steam was available at a gage pressure of approximately 150 lb/in^2 (1034 kPa) and a temperature of 365°F (185°C). Superheated-steam temperatures in the test vessel were controlled by mixing the 600°F (316°C) steam with small amounts of saturated steam prior to injection into the test vessel.

Chemical spray war provided by use of a high-pressure turbine pump and six wide-angle, full-cone spray nozzles. The nozzles were distributed in the test vessel to spray the SOV specimens as uniformly as possible.

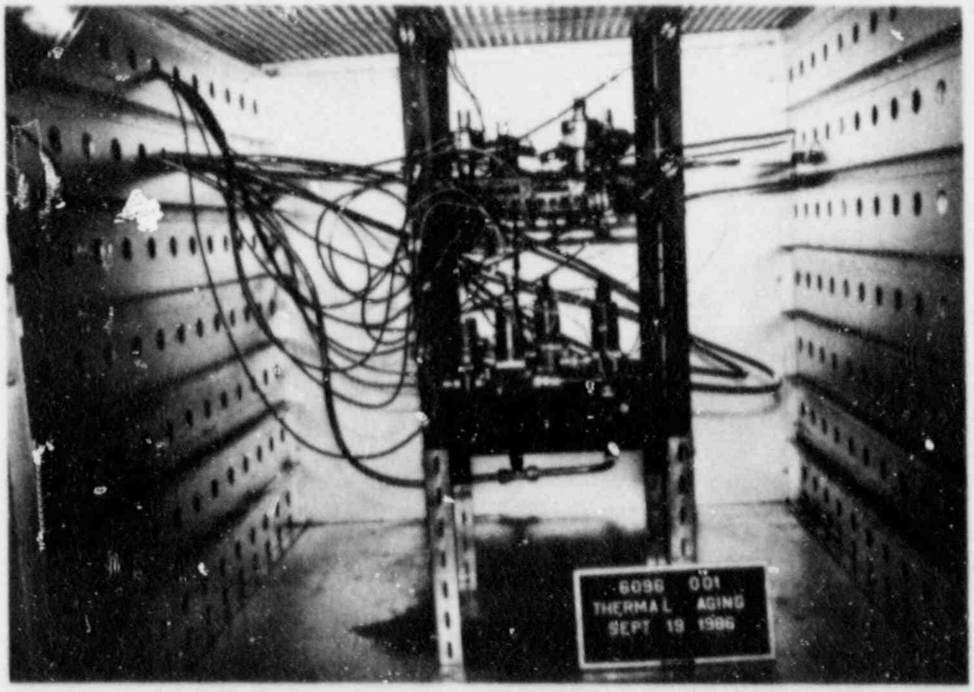


Figure 3. View of Solenoid Operated Valves in Thermal Aging Oven

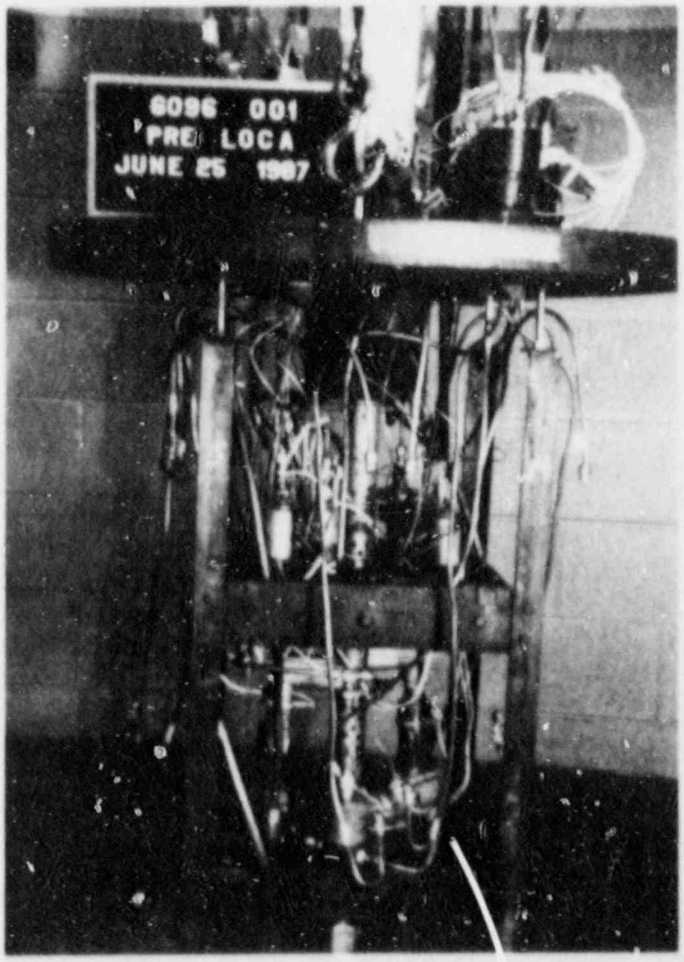
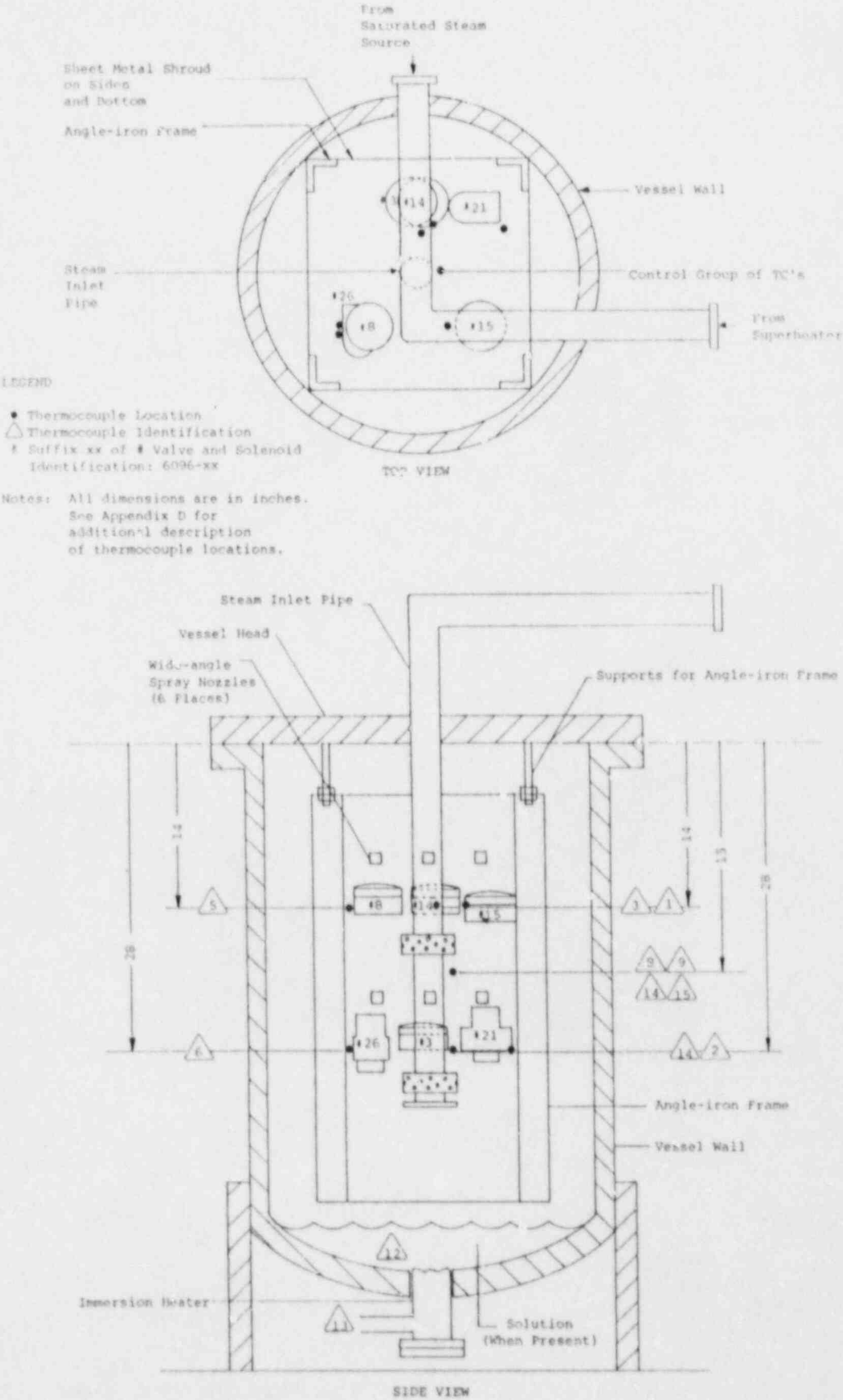


Figure 4. View of Solenoid Operated Valves Prior to MSLB/LOCA Exposure



Notes: All dimensions are in inches.
See Appendix D for additional description of thermocouple locations.

Figure 5. Salient Features of Test Arrangements for Simulated MSLB/LOCA Exposure Including Thermocouple Locations

Electric strip heaters external to the vessel and a three-element immersion heater within the vessel provided temperature control when vessel temperatures of 200°F (93°C) were required.

The facility included instrumentation for measuring and recording temperature, pressure, and flow rate.

4.4 Data Acquisition Instruments

A list of data acquisition instruments is provided as Appendix C.

5. ELECTRICAL CONNECTIONS

Electrical connections and interfaces to the specimens varied somewhat throughout the program. A chronological description is provided as follows:

- Thermal Aging with Cycling

  The inlet/outlet ports of the SOV bodies were equipped with appropriately sized NPT bushings and adapters to connect with copper tubing. The exhaust ports of the ASCO SOVs were provided with a copper tube having a 180° bend so that the exhaust was directed downward and no foreign particles could enter the SOV body through the exhaust port. The Valcor SOV exhaust ports were fitted with a 90° street elbow so that the SOV exhaust was directed downward.

  During the thermal aging simulation, the wires for the Valcor SOVs were routed through a 3/4-in NPT 90° street elbow so that the lead wires were in a horizontal plane. The lead wires for the ASCO SOVs were routed in a similar manner; however, the construction of the ASCO SOVs results in the open ends of the 90° street elbows facing downward.

  The lead wires for the SOVs were terminated with crimped spade lugs of appropriate size and connected to terminal strips which were fastened to the test fixture.

- Gamma Irradiation Exposure

  Prior to the gamma irradiation, the electrical connections for the six SOVs that were to be exposed to the MSLB/LOCA exposure were removed, and threaded condulet boxes were connected to the SOV conduit connection. The specimen lead wires were laid in the condulet box with any excess length protruding through the condulet box conduit connection.

- MSLB/LOCA Exposure

  Prior to the MLSB/LOCA exposure, the solenoid leads were butt-spliced to Teflon-insulated solid conductor extension wires. The spliced sections were covered with Raychem Thermofit WCSF-N heat-shrinkable splices. A threaded condulet box was connected to the solenoid housing and the leads were routed through the condulet box. The condulet box cover was removed and a General Electric RTV silicone compound was poured into the condulet box, filling the condulet box from the solenoid housing (see Figure 6) to the condulet outlet. The removable cover was then replaced.

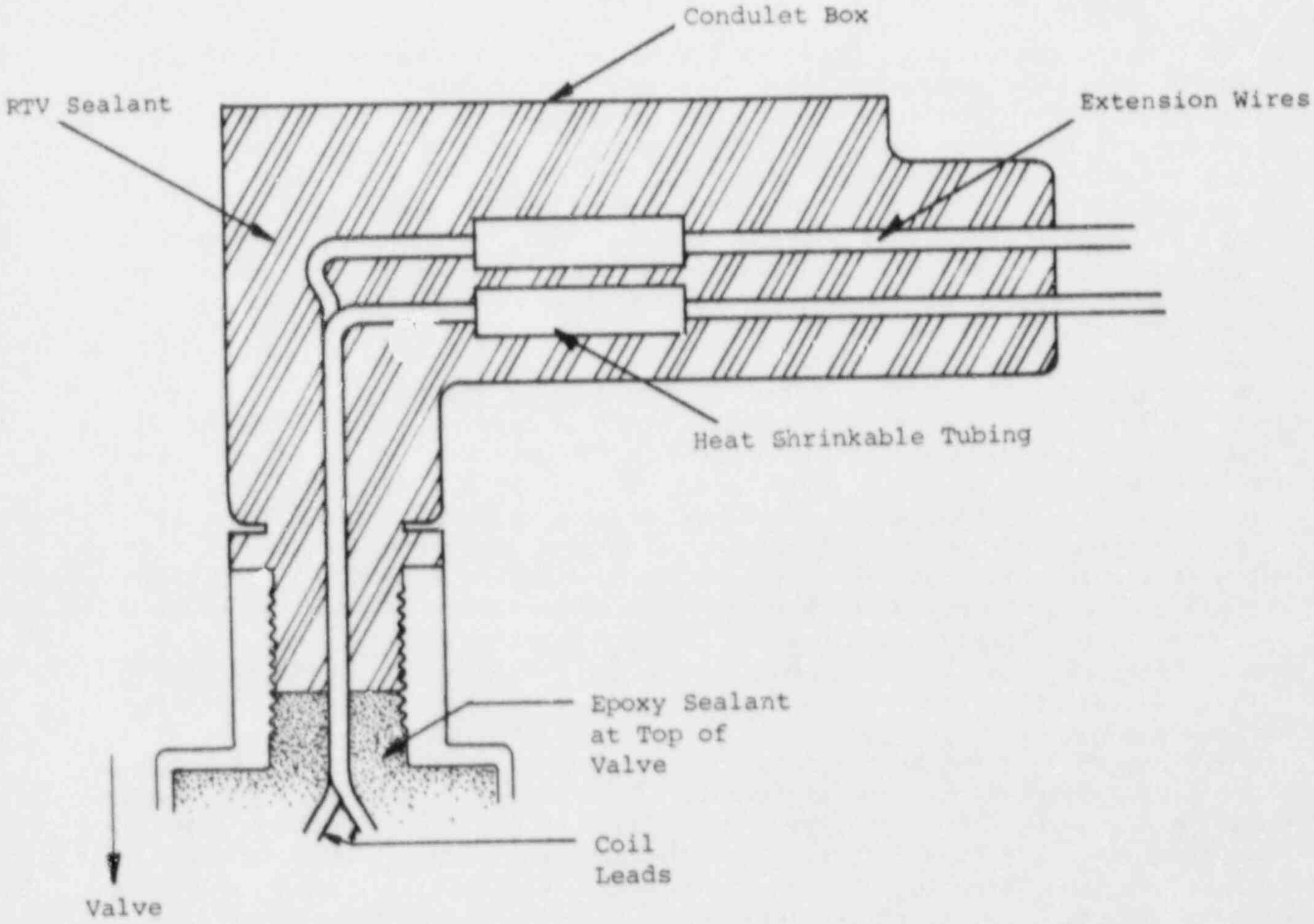


Figure 6. Electrical Interface Sealing Configuration

6. THERMAL AGING

6.1 Introduction

The thermal aging of the SOV assemblies was based on the aging required for the weak link, i.e., the part most likely to cause SOV failure in a common-cause mode. For the ASCO SOVs, the weak link was identified as the core disc; and for the Valcor SOVs the weak link was initially identified as the lower O-ring on the seal assembly. Analysis of Valcor SOV failures during the first attempt at thermal aging led to the conclusion that the shaft seal O-ring is the critical component; and subsequent thermal aging calculations for Valcor SOVs were based on this conclusion.

Thermal aging calculations based on the Arrhenius equation are summarized in Table 4. The plan was to age ASCO SOVs to the equivalent of 4 y of continuously energized service and the Valcor SOVs to the equivalent of 5 y of continuously energized service. In all cases the environmental temperature in the plant was assumed to be 140°F (60°C). Since the SOVs were assumed to be continuously energized, it was necessary to measure experimentally the temperature of the critical parts (coils and seals) at both the environmental temperature, which yielded the service temperature T_s of the critical parts, and the oven temperature, which yielded the aging temperature T_a of the critical parts.

The temperature measurements and accelerated aging were conducted in ovens with circulating air; therefore, the service temperature of the critical parts applies to a location where the ambient air temperature is 140°F (60°C) and the air velocity near the SOVs is comparable to the air velocity in the oven. The critical part temperature measurements were conducted in an oven with an interior cross section of 3 ft x 3 ft and a height of 4 ft. There was a cross flow of air in this oven, in one direction across the lower half and in the opposite direction in the upper half. The air velocity depended somewhat on position within the oven and the settings of inlet and outlet dampers. At most locations, the air motion was approximately horizontal, from side to side. At the centerline of the oven, one-third up from the bottom the air velocity ranged between approximately 50 and 80 ft/min; and at a point two-thirds up from the bottom (again at the centerline) the velocity ranged approximately between 30 and 60 ft/min. After the specimens were mounted on a test rack, the thermal aging was conducted in a larger oven with an interior cross section of 4 ft x 4 ft and a height of 5 ft. In this oven, the air flow was in the same direction at all levels. On the centerline, one-third up from the bottom the velocity ranged approximately between 60 and 70 ft/min, and two-thirds up from the bottom it ranged approximately between 100 and 120 ft/min. The air velocity was not measured at the specific locations of the SOV specimens. In summary, the critical part temperature measurements were made in air moving horizontally at a speed between 30 and 80 ft/min; and the accelerated thermal aging was conducted in a similar environment with the air speed between 60 and 120 ft/min. Since the air speed and rate of convective heat loss from the energized SOVs were higher in the aging oven than in the oven used for temperature measurements, the actual critical part aging temperatures (T_a) were probably somewhat lower than the values listed in Table 4; however, no correction was made for the difference in air flow rates in the two ovens. Although the ratio of air speeds in the two ovens was about

Table 4. Thermal Aging Calculations

Formula: $t_a/t_s = \exp(\phi/k)[(1/T_a) - (1/T_s)]$

where:

ϕ = activation energy (eV)
k = Boltzmann's constant = 8.617×10^{-5} (eV/K)
t_a = accelerated aging time)any convenient unit of time, provided
t_s = simulated time in service)it is same for t_a and t_s
T_a = aging temperature (K)
T_s = service temperature (K)

Environmental temperature (in plant) = 140°F (60°C), except for calculation No. 14.

Elastomeric parts aged in energized SOVs.

Coils aged separately, not energized.

Calc. No.	Part	ϕ	T_{oven}		T_s +		T_a +		t_s	t_a	
		(eV)	(°F)	(°C)	(°F)	(°C)	(°F)	(°C)	(y)	(h)	(d)
	Calculations for Valcor SOVs										
1.	Lower seal O-ring	0.94	230	110	190	88	275	135	5	1302	54.3
2.	Coil	1.0	350	177	223	106	350	177	5	360	15.0
3.	Shaft seal O-ring	0.94	210	99	190	88	257	125	5	2568	107.0
4.	Shaft seal O-ring	0.94	215	102	190	88	262	128	5	2144	89.3
	Calculations for ASCO SOVs										
5.	Core disc	0.94	230	110	181	83	270	132	4	846	35.2
6.	Coil	1.0	350	177	215	102	350	177	4	200	8.3
7.	Core disc	0.94	230	110	181	83	270	132	0.146 (1285h)	31	1.29
8.	Core disc	0.94	215	102	181	83	255	124	3.85	1424	59.3
9.	Core disc	0.94	215	102	181	83	255	124	4.0	1478	61.6
10.	Core disc	0.94	215	102	212*	100*	255	124	4	6031	251.3
11.	Core disc	0.94			212*	100*	255	124	0.98	1478	61.6
12.	Coil	1.0	350	177	324*	162*	350	177	4	14889 (1.69y)	620.4
13.	Coil	1.0	350	177	324*	162*	350	177	0.0538 (471 h)	200	8.34
14.**	Core disc	0.94	215	102	178*	81*	255	124	4.7	1478	61.6
15.**	Coil	1.0	350	177	293*	145*	350	177	0.16	200	83

+Values of T_s and T_a apply to "Part" listed in second column.
*Based on ASCO data.
**For environmental temperature of 100°F (38°C)

2, the heat transfer rate is proportional to the square root of speed for the laminar flow conditions in the ovens; therefore, the effect of speed differences was to produce heat transfer rates that differed by about 40%. Since the coils used in the test specimens for radiation and MSLB/LOCA testing were not energized during accelerated thermal aging, the oven air speed did not affect the aging temperature.

Thermal aging was conducted on all except the naturally aged specimens in Groups II, III, and IV, Table 3. As a consequence of problems encountered during thermal aging, three different methods were tried on the Valcor SOVs. However, in each case, the thermal aging produced seal degradation that prevented satisfactory operation of the valves. After the third trial, thermal aging of the Valcor SOVs was abandoned due to program cost and schedule concerns.

During thermal aging of the ASCO valves, sticking was observed (see Section 6.3.2) that required cleaning the vicinity of the metal-to-metal interface (at the top of the core assembly) prior to resumption of the thermal aging program. Ultimately, thermal aging was completed on the ASCO SOVs.

During the preparation of plans for thermal aging the ASCO and Valcor valves, both companies were kept fully informed and agreed that the elevated temperatures being used to accelerate the aging were within their prescribed material limitations. Information provided by ASCO during final report preparation included seat and coil temperature measurements it had recently performed on ASCO valves in essentially stagnant air as contrasted with measurements in this program with air circulation through the aging ovens. ASCO measured significantly higher temperatures for the seat and coil when energized. Using temperatures measured by ASCO in the Arrhenius equation gave the equivalent of 1 y of thermal aging of the critical elastomeric components and 0.05 y aging of the coils.

In a plant, there are large variations in temperature and air flow rate depending on location; and the actual equivalent age is dependent not only on the service temperature but the air flow rate as well. Section 6.4 includes a discussion of the interpretation of the accelerated aging for various service conditions.

6.2 Aging of Valcor SOVs*

6.2.1 Initial Procedure

The accelerated thermal aging exposure was initiated as specified in the initial test plan [Ref. 3, p 22] in accordance with calculations 1 and 2 of Table 4. At the selected oven temperature, the temperature of the lower seal assembly O-ring was 275°F (135°C), which is below the limit of 300°F (149°C) recommended by the manufacturer [5].

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*All accelerated thermal aging calculations for Valcor SOVs apply to a service location where the ambient air temperature is 140°F (60°C) and the air is moving at a velocity comparable to the air velocity in the aging oven.

At an elapsed time of 31 h, the oven was turned off to allow determination of the cause of high leakage in the air line connected to the SOVs. The elastomeric components within the SOVs were allowed to cool in their energized position until 51 h elapsed time, when the SOVs were deenergized.

Two of the three Valcor SOVs (6096-22 and -23) failed to return to their deenergized position upon deenergization of their coils. A failure analysis showed that the failure to transfer was caused by sticking of the shaft seal O-ring to its guide tube. Using a spare Valcor* SOV, the temperature of the shaft seal O-ring was measured as 278°F (137°C) at the thermal aging temperature of 230°F (110°C). The temperature measurement confirmed that the temperature at the shaft seal O-ring had not exceeded the manufacturer's suggested limit of 300°F (149°C).

Further evaluation of the failure indicated that the observed failure could have been the result of peculiarities of the accelerated thermal aging procedure which would not occur in a plant environment. Two possible causes were hypothesized.** The first hypothesis was that the physical and chemical changes of the EPDM O-ring that occurred at the elevated aging temperature and caused it to adhere to the guide tube, rather than slide in it, are different from the changes that occur under service conditions. The second hypothesis was that creep of the O-ring at the aging temperature under the stress of the process pressure far exceeded the creep that could occur under the same pressure at service temperatures. At the aging temperature (278°C [137°C]), the O-ring tends to soften; therefore, the 150-psig process pressure would tend to compress the O-ring between the shaft it rides on and the shaft guide tube (see Figure 7). When the oven temperature was reduced to room temperature with the SOV energized, the O-ring returned to a less pliable state and prevented movement of the shaft.

6.2.2 Review of Stresses on the Shaft Seal O-Ring

Two significant stresses were identified for the shaft seal O-ring: thermal and mechanical.

The thermal stress acting on the shaft seal O-ring during the normal service life of the SOV is caused by the temperature of the environment in which the SOV is located as well as the temperature rise caused by continuous energization of the solenoid coil. Based on temperature-rise measurements, the temperature of the shaft seal O-ring was estimated to be 190°F (88°C) at a service temperature of 140°F (60°C).

Because the shaft seal O-ring provides a dynamic seal during normal operation, it has several mechanical stresses acting on it. The shaft seal O-ring is under compression where it contacts the guide tube on its outer diameter and the shaft on its inside diameter. Another mechanical stress acting on the O-ring is caused by the pressure from the process medium acting downward on the upper surface of the O-ring when the solenoid coil is energized (Figure 7).

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*Valcor type V70900-21-3 (Ser. 120), Duke Power Co., Item No. 1210.04-00-0022; not among SOVs listed in Table 1.

**Further discussion of the possible causes of failure is included in Section 6.2.2.

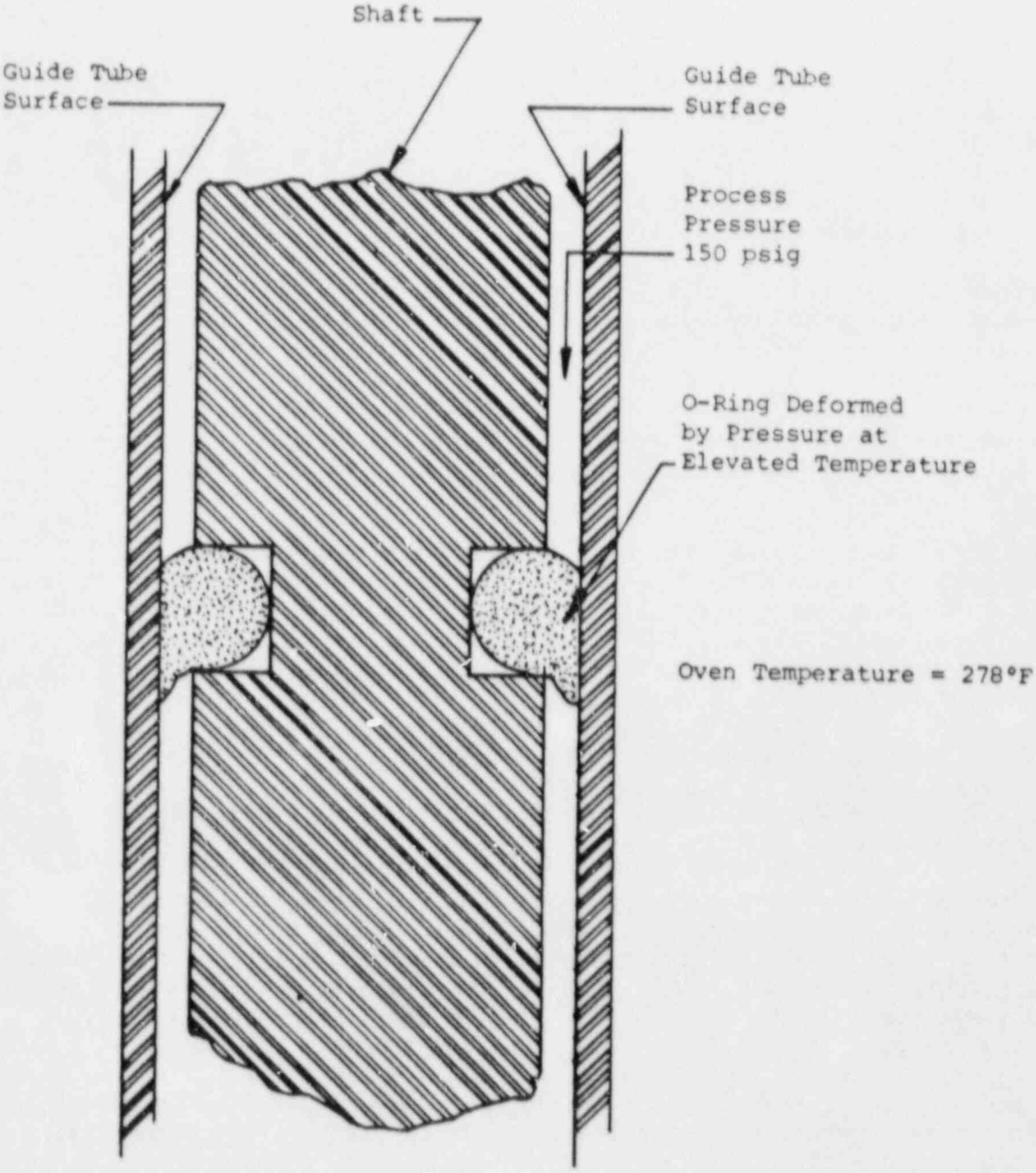

Figure 7. Hypothesized Deformation of Valcor Shaft Seal O-Ring During Accelerated Thermal Aging

The pressure normally assists in unseating the SOV seats and starts the shaft in its downward direction when the SOV is deenergized. The second stress acting on the O-ring is related to a combination of mechanical and thermal stresses acting on it and is a possible explanation of the observed failure. At elevated temperatures, such as those used during the thermal aging simulation, the EDPM O-ring material has a tendency to soften and become more pliable, as with most rubber products. The differential pressure across the O-ring (150 psig) causes the O-ring to deform by wedging between the shaft and guide tube, such that a larger portion of the O-ring is in contact with the guide tube. If the SOV is cooled while remaining in the energized state, the deformed O-ring becomes harder and binds the shaft in its energized position.

6.2.3 First Revision of the Valcor Aging Simulation

To allow completion of the thermal aging simulation and continuation of the research program, the accelerated thermal aging analysis was revised in an attempt to preclude further Valcor SOV failures that appeared to be nonrepresentative of normal aging. The objective was to reduce the accelerated aging temperature and correspondingly increase the aging time. As a result of the observed failure mode, the shaft seal O-ring was chosen to be the critical component, since its failure could prevent the seats from transferring from the energized position to the deenergized position. Previously, failure of the lower seal assembly O-ring with subsequent high leakage had been considered the critical failure mode.

In view of the new failure mode observed, the critical component was identified as the shaft seal O-ring. With the knowledge that 300°F (149°C) was considered a limiting temperature for the O-ring material, and that the failure of the lower O-ring seal had occurred at 278°F (137°C) during the thermal aging simulation, the O-ring was examined for evidence of stickiness on its surface. Since no stickiness was observed on the lower O-ring seal, it was concluded that by keeping the temperature of the shaft seal O-ring at or below 278°F (137°C), the tendency for the EPDM O-ring to become sticky would be reduced.

The temperature of the Valcor shaft seal O-ring was measured (in a forced circulation oven) at the four ambient temperatures listed in the following table:

Ambient Temperature		Shaft Seal O-Ring Temperature	
(°F)	(°C)	(°F)	(°C)
125	52	175	79
140	60	190	88
210	99	257	125
230	110	278	137
230	110 (repeated)	276	136
215	102 (interpolated)	262	128 (interpolated)

The plot of O-ring temperature vs. ambient temperature was a straight line, which made it easy to interpolate within the range of measurements.

At a thermal aging temperature of 210°F (99°C), the temperature of the shaft seal O-ring would be 257°F (125°C). However, a recalculation (No. 3, Table 4) of thermal aging assuming an oven temperature of 210°F (99°C) resulted in approximately doubling the duration of the aging time, which was considered too long. A second recalculation (No. 4, Table 4) assuming an oven temperature of 215°F (102°C) yielded acceptable results. Interpolation yielded a temperature at the shaft seal O-ring of 262°F (128°C) at an oven temperature of 215°F (102°C). The lowering of the shaft seal O-ring temperature to 262°F (128°C) would also reduce the tendency for creeping, because there would be less softening of the material at the reduced temperature. Using a service temperature of 140°F (60°C), which gives a temperature of 190°F (88°C) at the shaft seal O-ring, the activation energy value (0.94 eV) identified in the test plan [3], and a service life of 5 years (43,800 h), the calculated thermal aging duration was 2144 h (89.3 days).

To minimize the potential for recurrence of the failure should the failure have been caused by the creep of the shaft seal O-ring due to pressurization of one side of the shaft seal O-ring, the supply pressure to the Valcor SOVs was reduced from 150 psig to 100 psig. Although the SOV is rated for 150 psig, the decreased process pressure of 100 psig is consistent with pressures used in actual applications. In addition, it was decided that, whenever the thermal aging was to be interrupted for cycling, analysis, or functional tests, the Valcor SOV was to be deenergized at the thermal aging temperature. The intent was to eliminate the potential for binding of the shaft due to setting of the O-ring as it cooled if the oven temperature were reduced.

It was also decided that, as there is no normal service condition that requires the Valcor SOVs to be exposed to temperatures equivalent to the thermal aging temperatures during normal service, any hesitation of the Valcor SOVs during the initial deenergization following a thermal aging segment would not be considered improper operation. However, if hesitation occurred during the MSLB/LOCA simulation, it would be considered an abnormal condition, because the valves must remain operable during a DBE.

As in the initial plan, replacement coils for the Valcor SOVs were to be aged separately for a period of 360 h at a temperature of 350°F (177°C).

6.2.4 Second Revision of the Valcor Aging Simulation

The Valcor specimens were refurbished by replacement of the elastomeric parts. On December 10, 1986, the aging simulation for the Valcor SOVs was started anew, and the ASCO simulation was continued. The aging oven temperature was 215°F (102°C), and the SOVs were energized. Seven days into the exposure, the air bottle for the Valcor SOVs began experiencing rapid depletion. Valcor Specimen 6096-22 was found to be leaking from its exhaust port. The air supply bottle was replaced with a full bottle, but it was depleted overnight. The test was stopped on the eighth day (December 18, 1986) and the valves were deenergized. During functional testing at this time, two of the three Valcor SOVs (6096-23 and -24) failed to transfer.

The problem was evaluated and again traced to sticking of the shaft seal O-ring to the guide tube. It was again hypothesized that the failure was caused by deformation of the shaft seal O-ring from pressure against its top side while at the thermal aging temperature. To eliminate the deforming pressure on the O-ring without removing the process pressure during accelerated aging, it was decided to apply the process pressure to the exhaust port of the

SOV (as well as the inlet port) during the next attempt at thermal aging. This procedure exposed both sides of the O-ring to 100 psig and eliminated the differential pressure that tended to deform the O-ring. The Valcor valves were again rebuilt with new elastomers prior to restarting the accelerated aging.

The oven temperature was again 215°F (102°C). The only difference was that both sides of the shaft seal O-rings on the Valcor valves were pres- surized to 100 psig to eliminate the differential pressure on the O-rings.

Thirteen days after the restart of the aging, the oven temperature was reduced to 140°F (60°C) to allow an increment of cycling of the SOVs to be performed. However, the Valcor SOVs (Specimens 6096-22, -23, and -24) had still not transferred as late as one hour after deenergization.

Due to the additional costs associated with multiple failure evaluations, rebuilding of the valves, and the delays in completion of the program, the attempts to age the Valcor SOVs were discontinued. New Valcor valves were used to complete the program with no accelerated thermal aging.

6.2.5 Evaluation of Valcor SOVs after Final Failure

The first failures of the Valcor valves occurred after approximately 2 days of thermal aging. The shaft seal temperature during this aging was 278°F (137°C) and the process air pressure was 150 psig. The second set of failures occurred after 7 days with the process air pressure at 100 psig and the shaft seal O-ring temperature at 262°F (128°C). The third set of failures was observed after 13 days of exposure at 262°F (128°C) with 100 psig of process air pressure on both sides of the seal, i.e., with no pressure differential across the shaft seal O-ring. The first and second failures appeared to be similar in nature. The shaft seal O-ring had swollen and adhered to the guide assembly. In the third set of failures, the deterioration of the shaft seal O-ring was much worse; the O-ring had started to powder and disintegrate. The upper O-ring on the seal assembly had also severely deteriorated and adhered to the seat, which did not occur on the first and second failures.

Detailed observations from examination of the disassembled SOVs are given below. (See Figure 2 for parts nomenclature.)

Valcor SOV Specimen 6096-22

The shaft seal O-ring was severely deteriorated with indications that it had stuck to the seat guide tube. The O-ring was decomposed, had a circumferential crack, and was severely embrittled. Portions of the O-ring material were missing. The seal assembly upper O-ring was completely flattened and also appeared to have adhered to the upper seat. The upper O-ring on the seat guide was embrittled and cracked, and loose particulate matter was present. The lower seal assembly O-ring was hardened, but was intact and had retained its shape. The lower guide assembly O-ring was deteriorated to a lesser degree than the upper O-ring. The solenoid base and body O-rings were slightly hardened, but appeared to be functional.

Valcor SOV Specimen 6096-23

The shaft seal O-ring was very hard and the upper edge was eroded and powdery. The edge appeared to have adhered to the guide tube. The seal assembly upper O-ring was completely flattened and appeared to have adhered to the seat. The lower seal assembly O-ring was similar to that of Valve 6096-22 in that it was hardened but had retained its shape. The lower and upper seat guide O-rings were deteriorated but appeared to be functional. The solenoid base and body O-rings had taken a slight set, but remained pliable.

Valcor SOV Specimen 6096-24

The shaft seal O-ring was distorted and hardened. Some separation of particles had occurred on the upper surface of the O-ring. The O-ring was deteriorated less than the O-ring in SOV 6096-22. The upper seal assembly O-ring was fully flattened and appeared to have adhered to the seat. The upper seat guide O-ring was slightly deteriorated, but appeared to be functional. The lower seat guide O-ring had a compressive set, but appeared to be relatively undamaged. The solenoid base and body O-ring seemed to be undamaged and functional.

6.3 Aging of ASCO SOVs

6.3.1 Initial Procedure and Its Revision

The initial thermal aging calculations for ASCO SOVs were made assuming that the core disc temperature is approximately the same as the seat temperatures reported in the Test Plan (Appendix A). As discussed in Section 6.4, below, the core disc temperature was probably significantly higher than the seat temperature; nonetheless, the discussion in this section is based on that approximation.

As with the Valcor aging calculations, the calculations discussed in this section apply to applications in which the ambient air temperature is 140°F (60°C) and it is moving at a velocity comparable to the air velocity in the aging oven. Interpretation of the thermal aging used in this program for other service conditions is discussed in Section 6.4.

The accelerated thermal aging exposure specified in the initial test plan (Ref. 3, p. 22) was in accordance with calculations 5 and 6 in Table 4. During performance of a previous test program [4], ASCO had indicated that thermal aging of the SOVs at an oven temperature of 268°F (131°C) while energized was acceptable. Therefore, the choice of an oven temperature of 230°F (110°C) was considered well within the acceptable range for ASCO SOVs. Although thermal aging was initiated as planned, the modification of the oven temperature as a consequence of Valcor SOV failures required that the aging time be recalculated for the ASCO valves.

The initial period of aging to which the ASCO valves had been exposed (31 h with a critical component temperature of 270°F [132°C]) equated to a service life of 1285 h (Calculation 7, Table 4). This left 33,759 h (3.853 y) of service life to be simulated to attain a 4-year service life. At an oven temperature of 215°F (102°C), the valve seat temperature was 255°F (124°C);

and calculation 8, Table 4, shows that the remaining exposure was 1424 h, or 59.3 d. Calculation 9, Table 4, shows that the ASCO thermal aging was equivalent to 1478 h (61.6 d) in an oven at 215°F (102°C).

Since the ASCO SOV coils would be overaged during the valve aging program, replacement solenoid coils for the ASCO SOVs were aged separately for a period of 200 h (8.3 d) at a temperature of 350°F (177°C), in accordance with calculation 6, Table 4, to provide solenoid coils aged to the same equivalent service life as the remainder of the SOV assembly. (The coils were actually aged for 202 h.)

6.3.2 Discovery of Deposits in ASCO SOVs

After 8 d of accelerated thermal aging (on December 18, 1986), the ASCO specimens were deenergized. At this time, ASCO Specimen 6096-13 (with nitrogen as the process medium) failed to transfer to the deenergized state until the process medium pressure was removed. Examination of SOV 6096-13 and the other five ASCO specimens revealed a lacquer-like, organic deposit on the top of the core assembly where it mated with the solenoid base subassembly when the SOV was energized. This interface is a metal-to-metal interface. On SOV 6096-13, the patterns in the deposit on the core assembly matched the markings in the solenoid base assembly, indicating that the deposit was the probable cause of the SOV sticking.

The test setup was evaluated to determine if it was the source of the deposit. The process gases consisted of bottled breathing air and bottled nitrogen. These are high quality gas sources and not prone to oil or water contamination as could occur in a compressor supplied system. Furthermore, the contamination occurred in valves connected to both gas sources, and it is unlikely that both the air and nitrogen sources had the same contaminant. Accordingly, it was concluded that the process medium supplies were probably not the source of contamination. The piping setup for the thermal aging was assembled with clean, new materials and therefore was also not a likely source of contamination. The exhaust ports through which contaminants could have entered the area had 180° elbows that piped the outlets downward. This prevented contaminants from falling into the exhausts. No spray painting of any sort occurred in the vicinity of the SOVs during any of the program, and they had not been disassembled by FRC prior to the failure of SOV 6096-13.

These valves are of the same model that failed at the Ft. Calhoun plant in the same manner; and Ft. Calhoun personnel could likewise not identify an external source for the lacquer-like deposit. (Note: Some of these valves were donated to this program and, after being cleaned of the residue from the metal-to-metal interface area, were used as Specimens 6096-6, -7, and -8.) The problem could not be investigated further within the constraints of the program; and it could be concluded only that the deposit was apparently an organic material, but of unknown composition or origin.

To allow the program to continue, the deposit was cleaned from ASCO Specimens 6096-9, -10, -15, -12, -13, and -14, and the valves were reassembled. Thermal aging was then resumed from the point where it had been interrupted. The ASCO valves completed the thermal aging to the equivalent of a thermal life of 4 years at an ambient temperature of 140°F (60°C), with 2000 operational cycles.

6.4 Interpretation of Accelerated Thermal Aging for Various Service Conditions

The accelerated thermal aging conducted in this program is equivalent to different service times depending on the air temperature and velocity at the location of the installed SOV. As stated in the two preceding sections, the basic calculations (to produce aging equivalent to 4 y for continuously energized ASCO SOVs and 5 y for continuously energized Valcor SOVs) apply to locations where the ambient temperature is 140°F (60°C) and the air velocity is comparable to the air velocity in the aging oven, which was of the order of 100 ft/min. To be precise, the calculations apply to any location where the service conditions produce critical part temperatures equal to the temperatures used in this program. Wherever service conditions cause the critical part temperatures to be higher or lower than the values used in this program, the equivalent service lives will be shorter or longer, respectively, than the equivalent values of 4 y for ASCO SOVs and 5 y for Valcor SOVs that apply to the basic calculations of this program (calculations 1 through 9 in Table 4).

The following discussion shows how the equivalent service life is affected by a few service conditions different from those assumed in this program. Because the data that became available applies to ASCO SOVs, the discussion is limited to that type of SOV.

Subsequent to the completion of the thermal aging of the ASCO SOVs, the manufacturer communicated core disc temperature measurements (with the SOV energized) higher than the values obtained in this program. The difference is attributed primarily to the fact that FRC measured the temperature rise above ambient temperature in an oven with forced air circulation, while ASCO made its measurements with minimal air flow (reported as "no flow"). Consequently, the SOVs were losing heat to the environment at a faster rate, via forced convection, in the FRC measurements than was the case in the ASCO measurements, in which the SOVs lost heat primarily via natural convection. The effect is illustrated by the table of temperature measurements at the bottom of page 33 of Appendix A, where the ASCO core seat temperature measured in essentially quiescent air is 93°F (51°C), above the ambient (room) temperature of 77°F(25°C), while the seat temperatures measured under the condition of forced air circulation, in an oven, are only 40°F (22°C) above the oven temperature.

Another factor contributing to the difference between ASCO and FRC temperature rise measurements is that, to avoid destroying the SOVs, FRC fed a thermocouple through a valve port to a point as close as possible to the core disc. Thus, the measurement actually applied to the core seat area, but, as explained in Section 6.3.1, it was assigned to the core disc. On the other hand, ASCO was able to sacrifice its specimens, and fed its thermocouple through a hole in the SOV body and embedded the junction in the core disc.

Using the data provided by ASCO, Calculation 10, Table 4, shows that simulation of 4 y of service would have required 6031 h at an oven temperature of 215°F (102°C). FRC's aging (Calculation 11, Table 4) was equivalent to only 1 year of aging at a core disc service temperature of 100°C, which applies to an SOV in a stagnant air environment at 140°F (60°C). This result illustrates the dramatic effect of air velocity at the installed SOV, if the SOV is energized.

In the case of the coils, there was a similar effect due to air circulation. Both ASCO and FRC used the change in coil resistance with temperature as the basis for obtaining the 'average' temperature rise of the coil. In addition, ASCO has performed experiments showing that the 'hot spot' of the coil is 3°C to 4°C higher than the temperature deduced from resistance measurements. ASCO used 5°C as a conservative estimate of the hot spot increment.

At an environmental temperature of 140°F (60°C), ASCO's measurements in an oven with minimal air circulation yielded a hot spot temperature of 324°F (162°C) compared to FRC's value of 102°C. At an oven temperature of 350°F (177°C), with the coils not energized (in which case air circulation does not affect the coil temperature), Calculation 12, Table 4, shows that 1.7 y of oven aging would be required to simulate 4 y of service. Consequently, in accordance with this analysis, aging for 200 h at 350°F (177°C) produces the equivalent of 0.05 y of coil aging (Calculation 13, Table 4) for an SOV in stagnant air at 140°F (60°C).

Actual plant service conditions vary over a wide range. Although the ambient temperature of 140°F (60°C) was intended to encompass most plant applications, there are some in which the ambient temperature exceeds 140°F (60°C). For example, one utility that has measured temperatures in a steam tunnel has evidence that the ambient temperature in the vicinity of SOVs mounted on steam pipe valve actuators is about 155°F (68°C). On the other hand ambient temperatures as low as 100°F are probably more common. At this service temperature, Calculations 14 and 15, Table 4, show that the thermal aging conducted in this program was equivalent to 4.7 y of service for the core disc and 0.2 y for the coil of the ASCO SOVs.

Finally, it is necessary to recall that the use of temperature rises measured in a stagnant air environment, as done by ASCO, is strictly applicable only to stagnant plant environments. But air in a plant is rarely stagnant, although its flow rate may be much lower than the air circulation rate in the ovens used for thermal aging in this program. However, any air flow in the vicinity of energized SOVs will tend to lower their temperature rise compared to the rise in stagnant air.

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*Extrapolated from ASCO data for ambient temperatures between 25°C and 131°C.

7. TEST RESULTS

7.1 Gamma Irradiation

To simulate DBE irradiation, specimens of groups III and IV (see Table 3) were exposed to a DBE minimum air equivalent dose of 200.4 Mrd (2004 kGy) of gamma radiation from a cobalt-60 source at an average dose rate of 0.61 Mrd/h (6.1 kGy/h). A discussion of dosimetry and dose uniformity is provided in Appendix B together with the report of the radiation laboratory.

7.2 Description of Actual MSLB/LOCA Simulation

The MSLB/LOCA exposure was performed in accordance with the specified temperature/pressure profile illustrated in the test plan of FRC Report No. P-C6096 attached as Appendix A. The experimental configuration, including specimen arrangement and thermocouple location, is discussed in Section 4.

There were three minor deviations which occurred.

1. During the drop in temperature/pressure from 420°F (216°C)/ 68 lbf/in^2 (469 kPa) to 365°F (185°C)/68 lbf/in^2 (469 kPa) of the first transient, the temperature inadvertently decreased to a minimum of 335°F, as shown in Figure 8. The total period of this deviation was less than 2 minutes and is not considered to have a significant effect on the program. The temperature deviation is shown on an expanded time scale in Figure 9.

2. Pressure during the specified dwells of 365°F (185°C)/68 lbf/in^2 (469 kPa) was 72 psig instead of 68 psig due to control problems associated with the back pressure regulator station. This pressure deviation is of a conservative nature and is also considered insignificant.

3. Pressure during the period of 4 d to 30 d ET was approximately 3 psig, not 0 psig as specified. This deviation was incurred because a slight pressure was necessary to control the 200°F vessel temperature.

The actual temperature/pressures recorded throughout the first and second transients to the peak temperatures are shown in an expanded time scale in Figures 10 and 11, respectively. Aside from the minor deviation mentioned in Item 1 above, the actual temperature profile (Figure 8) was practically identical to the specified profile (Figure 6, Appendix A).

7.3 Operation of SOVs During the MSLB/LOCA Simulation

Prior to the first environmental transient, with the vessel at 140°F (60°C), each valve was cycled 10 times; no problems were noted. Each valve functioned and pressurized the cylinder that simulated a process device. To simulate normal nuclear plant service, the SOVs were energized just prior to starting the MSLB/LOCA simulation; and they were de-energized during the transient to

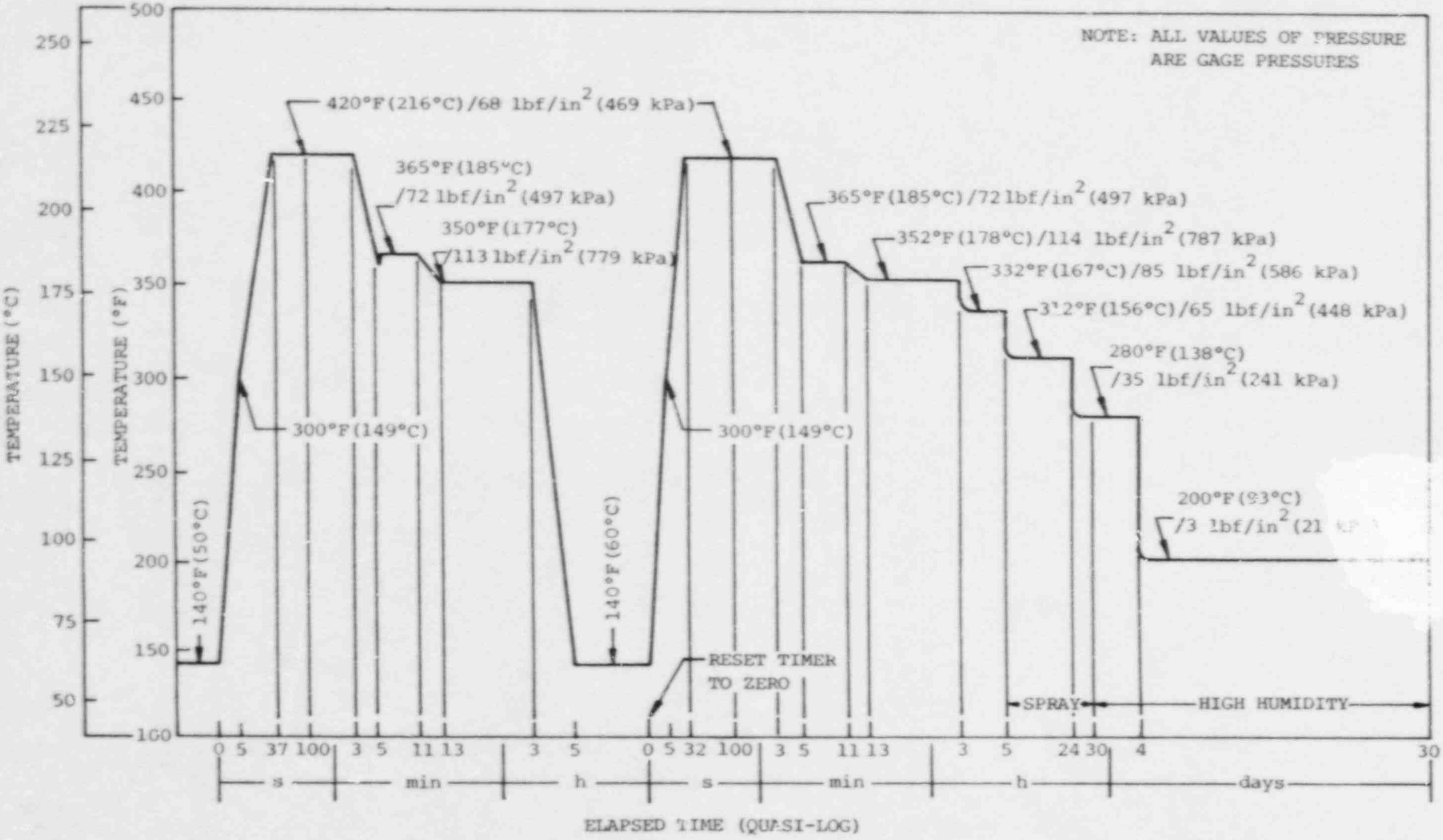

Figure 8. Actual Temperature and Pressure Profile of Simulated MSLB/LOCA Exposure

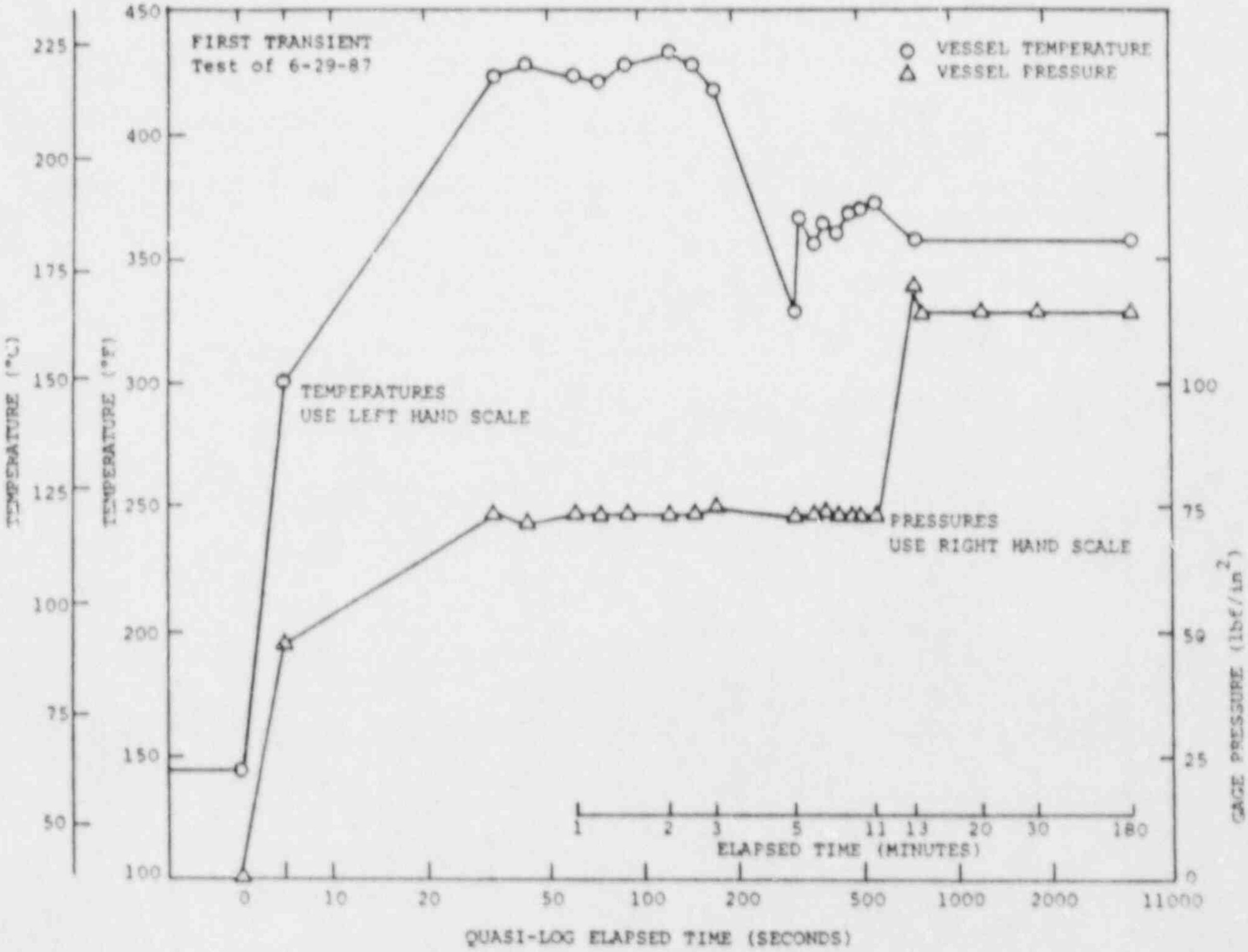

Figure 9. Actual Temperature and Pressure Profile of First MSLB/LOCA Transient

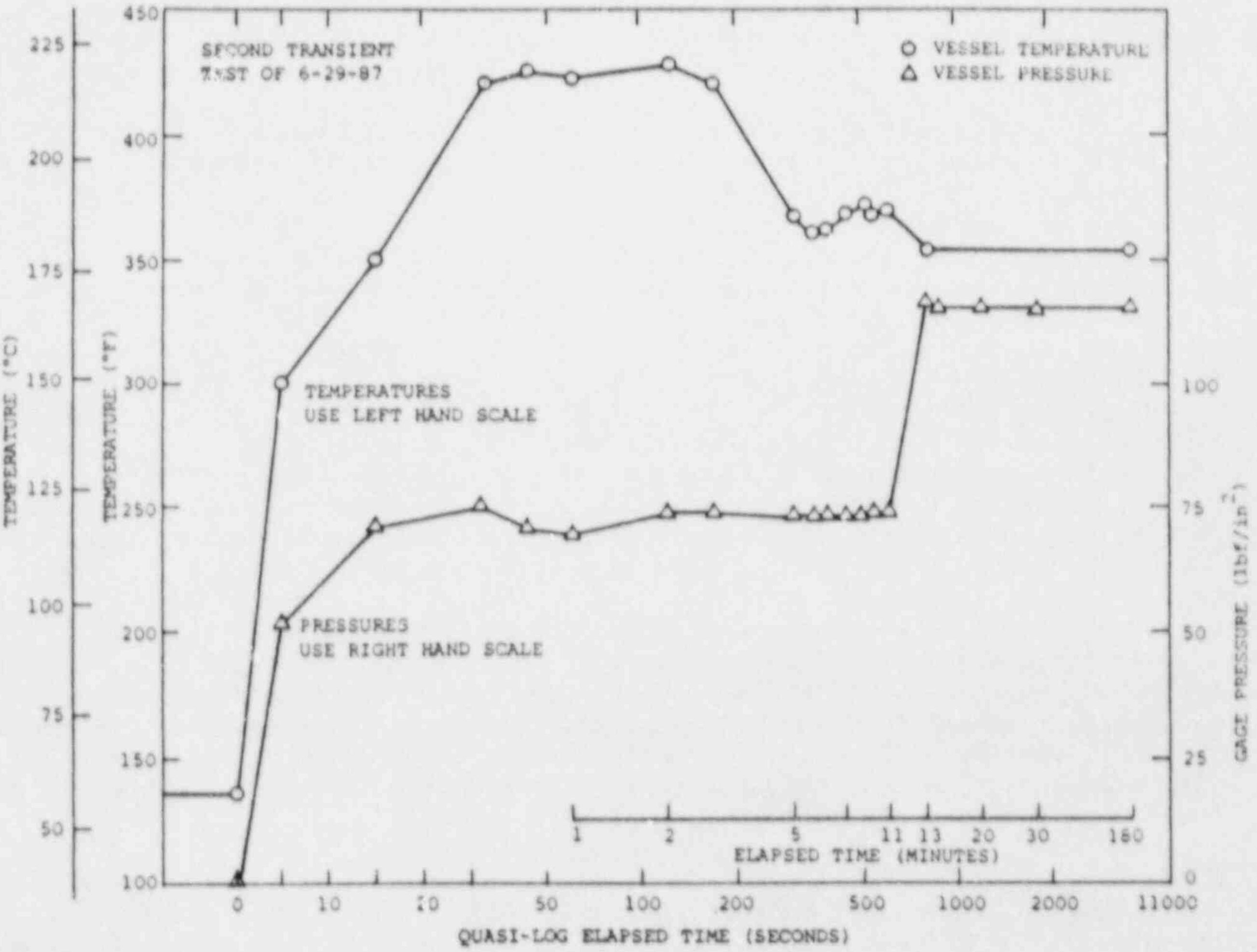

Figure 10. Actual Temperature and Pressure Profile of Second MSLB/LOCA Transient

the peak temperature of 420°F (216°C). Thereafter, the valves were deenergized throughout the MSLB/LOCA simulation except when cycled for operational testing and a 2-h period of continuous energization to simulate sampling system service.* The SOVs operated properly at reduced and normal voltage when cycled during the dwell at 420°F (216°C).

During the ten-cycle operation that occurred at 140°F (60°C) between the first and second transient, Specimen 6096-21 (Valcor: naturally aged, irradiated) drew normal current on the first three attempts to operate, but did not transfer and pressurize the process cylinder. Thereafter, it operated properly seven times. At the same time, Specimen 6096-26 (Valcor: new, no thermal aging, irradiated) was observed to be leaking heavily when energized.

At 2 h 40 min elapsed time from the start of the second transient, all of the valves were cycled. Valve 6096-26 continued to have heavy leakage when energized.

At 4 h elapsed time, Valve 6096-21 failed to transfer on the first attempt. After four further attempts, the valve transferred, but was determined to be leaking in the energized state.

At 7 h 40 min elapsed time from the start of the second transient, following the drop from 325°F (163°C) to 312°F (155°V) and the start of the chemical spray, the valves were energized for a period of 2 h. This period of energization was performed to simulate SOV applications where the valve is used in containment environment sampling systems.* Twenty-five minutes later, the leakage on Valve 6096-26 was so severe that it had to be deenergized. The valve was causing a 100 psi/min drop in bottled air supply pressure.

Thirty minutes into the 2-h energization period, Specimen 6096-15 (ASCO: accelerated aging, irradiated) was noted to be drawing no current. The fuse to the SOV had blown. Investigation revealed that the coil was open-circuited, with one lead shorted to ground. Attempts to re-energize the coil to see if voltage would bridge the open circuit resulted in failures of 0.5-A, slow-blow fuses and no valve operation. The remainder of the valves completed the 2-h period of operation without malfunctioning.

Subsequent to the 2-h period of energization, throughout the remainder of the MSLB/LOCA simulation, SOV 6096-26 continued to leak excessively whenever energized. The current drawn by SOV 6096-21 was noted to have increased from a range between 70 and 120 mA to 410 mA, but it was still functioning. At 21 h, the current was greater than 500 mA, but the SOV had transferred. At 29 h, SOV 6096-21 blew its fuse and did not transfer. At 47 h and 99 h, it drew greater than 500 mA, but did not transfer. During each energization after 118 h, it blew its fuse without transferring with the exception of the energization at 405 h, during which it momentarily transferred before blowing the fuse.

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*A request to energize the SOVs for a 2-h period to simulate service in containment atmosphere sampling systems resulted from a discussion of this program before the Electric Power Research Institute's Environmental Qualification Advisory Group on June 9, 1987 in Palo Alto.

At 25 h elapsed time, the coil resistance and resistance to ground of each lead were recorded for each SOV. The results are contained in Table 4. These results indicate that the coils of Specimens 6096-3 and -26 were behaving essentially as expected, but that the coils of SOVs 6096-8, -14, -15, and -21 had experienced degradation.

At 47 h elapsed time, SOV 6096-15 (ASCO: accelerated aging, irradiated, 1E) blew its fuse after 15 s of energization. With a 0.5-A, slow-blow fuse in the circuit, the coil drew more than 0.5 A without blowing the fuse, but the valve did not transfer. SOV 6096-21 also did not blow the fuse with a 0.5-A, slow-blow fuse and did not transfer.

Starting with the energization at 99 h, SOV 6096-15 would draw more than 0.5 A and would transfer when energized, except at 118 h elapsed time, when it also blew its fuse. However, it should be noted that the SOV was energized only long enough to determine if it would transfer. No energizations for significant periods were performed.

At 21 h elapsed time, SOV 6096-8 (ASCO: naturally aged, irradiated) drew only 75 mA instead of 150 mA, as it had on previous readings, and the current continued to drop. However, the valve appeared to be functioning. During energizations at 29, 47, 99, and 118 h, the SOV drew little or no current (0 to 30 mA) and failed to transfer. At 174 h, the coil resistance of SOV 6096-8 was measured and found to be 33 kΩ. At 257 h and each energiza- tion thereafter, the SOV drew 170 to 200 mA, which slowly decreased; and it transferred properly.

Throughout the test, SOV 6096-3 (ASCO: naturally aged, irradiated) drew between 60 and 85 mA when energized, and it functioned properly. SOV 6096-14 initially drew between 80 and 140 mA until the energization at 21 h from the start of the second transient. It then drew 180 mA and thereafter it drew between 150 and 300 mA. It transferred properly at each energization and never blew the 0.5-A fuse.

SOV 6096-26, while having very high leakage when energized, transferred at each energization and drew between 180 and 250 mA.

Table 5 summarizes the functional results of the MSLB/LOCA exposure for the valves.

7.4 Results of Functional Tests

The coil resistance and coil insulation resistance were measured for each valve in the as-received state (i.e., new or naturally aged) and after each segment of the program to which the valve was exposed (thermal aging, irradiation, MSLB/LOCA simulation). Coil insulation resistance measurements were performed at 500 Vdc, held for 1 min. Each SOV was also operationally checked to verify transfer at normal and design limit voltages (125, 100, 142 Vdc). During these operational checks, the SOVs, were observed for signs of sluggish operation, failure to transfer, and noisiness.

Table 5. Coil and Insulation Resistances for SOVs Under Test at 25 Hours Elapsed Time

Identification	Condition at Start of MSLB/LOCA	Coil Resistance(Ω)	Lead 1* Insulation Resistance(Ω)	Lead 2* Insulation Resistance(Ω)
ASCO 6096-3	Naturally Aged, Irradiated to Accident Dose	1.9×10^{3}	∞	∞
ASCO 6096-8	Naturally Aged, Irradiated to Accident Dose	2.5×10^3	282×10^3	203×10^3
ASCO 6096-14	Accelerated Aging with Nitrogen as Process Medium, Irradiated to Accident Dose	84.8×10^3	503×10^3	586×10^3
ASCO 6096-15	Accelerated Aging with Air as Process Medium, Irradiated to Accident Dose	165×10^3	4.2×10^3	164×10^3
Valcor 6096-21	Naturally Aged, Irradiated to Accident Dose	133	42×10^3	383×10^3
Valcor 6096-26	New, Irradiated	592	∞	∞

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*The difference between the IR measurements of leads 1 and 2 could be a consequence of wetting of the coils, which can cause battery action with respect to ground and affect the insulation resistance readings.

Table 6. Summary of MSLB/LOCA Functional Results

Identification	Condition at Start of MSLB/LOCA	Summary of Functional Results During MSLB/LOCA Exposure
ASCO 6096-3	Naturally Aged, Irradiated to Accident Dose	No failures to transfer; no significant coil problems.
ASCO 6096-	Naturally Aged, Irradiated to Accident Dose	Operated properly until 29 h elasped time (ET) of second transient. Then failed to transfer until the cycling on the 10th day of the test, when it began transferring properly again. Coil apparently open circuited and later bridged when energized. Failed to transfer after test, apparently due to coil failure.
ASCO 6096-14	Accelerated Aging with Nitrogen as Process Medium, Irradiated to Accident Dose	Transferred properly at each energization. However, it experienced some non-debilitating coil damage after 21 h ET after start of the second transient, when coil currents increased. Slight leakage in deenergized position after test.
ASCO 6096-15	Accelerated Aging with Air as Process Medium, Irradiated to Accident Dose	Transferred properly until approximately 8 h after start of second transient, when it drew more than 0.5 A. At this point, it had been energized and exposed to chemical spray for 30 min. Measurements indicated the coil was open-circuited, and one lead was shorted to ground. It blew 0.5-A, slow-blow fuses at each energization until 29 h ET, when it transferred momentarily. At 99 h ET and thereafter, it transferred at each energization except at 118 h, when it again blew the 0.5-A, slow-blow fuse. Transferred properly and no leakage observed at conclusion of test.
Valcor 6096-21	Naturally Aged, Irradiated to Accident Dose	Transferred properly during first transient and high-temperature dwell, but failed to transfer during first 3 attempts between first and second transient. At 4 h ET from start of second transient, the SOV did not transfer until the fourth attempt. Current increased to 410 mA at the end of the 2-h energization. At 29 h ET, the valve blew its 0.5-A fuse without transferring. Thereafter, it trans-

Table 6. Summary of MSLB/LOCA Functional Results (Cont.)

Identification	Condition at Start of MSLB/LOCA	Summary of Functional Results During MSLB/LOCA Exposure
Valcor 6096-21 (Cont.)		ferred only once momentarily at 405 h. At each other attempt to transfer, it did not transfer or blew its fuse before transferring. Replacement of failed coil after test allowed transfer, but only after repeated attempts and with significant delays.
Valcor 6096-26	New, Irradiated to Accident Dose	Transferred properly throughout test, but had high leakage when energized before second transient and thereafter. Had extremely high leakage when energized at ET of 8 h 10 min from start of second transient (after 1/2 h of con- tinuous energization during exposure to spray and 310°F/65 psig steam). It had high leakage during the balance of the test and after the test, particularly in the energized position.

Leakage testing was performed using the test system shown in Figure 11. The SOVs were mounted on the test stand, and the appropriate process and electrical connections made. The valve inlets were pressurized at the SOV operational pressure (60 psig for ASCO SOVs, 150 psig for Valcor SOVs) while deenergized. After pressurization, the flow meter was observed for any indication of flow that would indicate either seat or body leakage through the valve. The flow meter was capable of detecting leakage in the range from 0.37 scfm (19 L/min) to 4.2 scfm (118 L/min). The SOVs were then energized, and the accumulator was allowed to stabilize at the supply pressure. The flow meter was then observed to detect any indication of leakage.

The following subsections describe the results for each type of valve and cross-comparisons for appropriate groups of valves.

7.4.1 Naturally Aged ASCO SOVs

There were two sets of naturally aged ASCO SOVs. One set had been in service for 1 5 y, and the other set had been in service for about 8 y.

Three 1.5-year-old naturally aged NP8314 ASOC SOVs (6096-6, 7, 8) were functionally tested in the as-received state. SOV 6096-7 and -8 were then irradiated and functionally tested. Specimen 6096-8 was then subjected to a simulated MSLB/LOCA exposure and was functionally tested. The results of these tests are shown in Table 6. All three valves did not leak when received, and their coils were acceptable. After irradiation, SOV 6096-7 and 6096-8 showed little change in coil resistance and exhibited lower but adequate coil insulation resistances. During the MSLB/LOCA exposure, the coil of Specimen 6096-8 open circuited, and its insulation resistance dropped to an unacceptable level. It should be noted that even after the coil open circuited, the SOV did transfer later in the test when the applied voltage bridged the open circuit (see Section 7.1). However, it did not operate every time and did not operate when placed on the test stand for functional tests following the MSLB/LOCA simulation. Observation of the seats following the MSLB/LOCA test indicated no severe damage, and proper operation would have been expected if coil failure had not occurred.

The results for the HTX8314 SOVs (6096-1, 2, 3) that had been in service about 8 y, are also listed in Table 6. These valves had not been qualified by the manufacturer and had been removed from service so that qualified valves could be installed. SOV 6096-1 was only naturally aged; Valve 6096-2 was naturally aged and irradiated; Valve 6096-3 was naturally aged, irradiated, and exposed to the simulated MSLB/LOCA environment. During functional testing of 6096-2 following irradiation, some leakage was noted during the first energization. However, on subsequent energizations, the leakage returned to zero. Following the MSLB/LOCA exposure, the coil of SOV 6096-3 had low insulation resistance (60 k$^{\Omega}$) but was functioning properly. These valves functioned properly through all elements of the test program.

7.4.2 ASCO Valves with Accelerated Aging

Table 7 shows the functional test results for the ASCO NP8314 valves that were subjected to accelerated aging with air and nitrogen as the process media. SOV 6096-16 was not exposed to test conditions and was used for comparison with those that were exposed to test conditions. Valve 6096-9 was exposed to

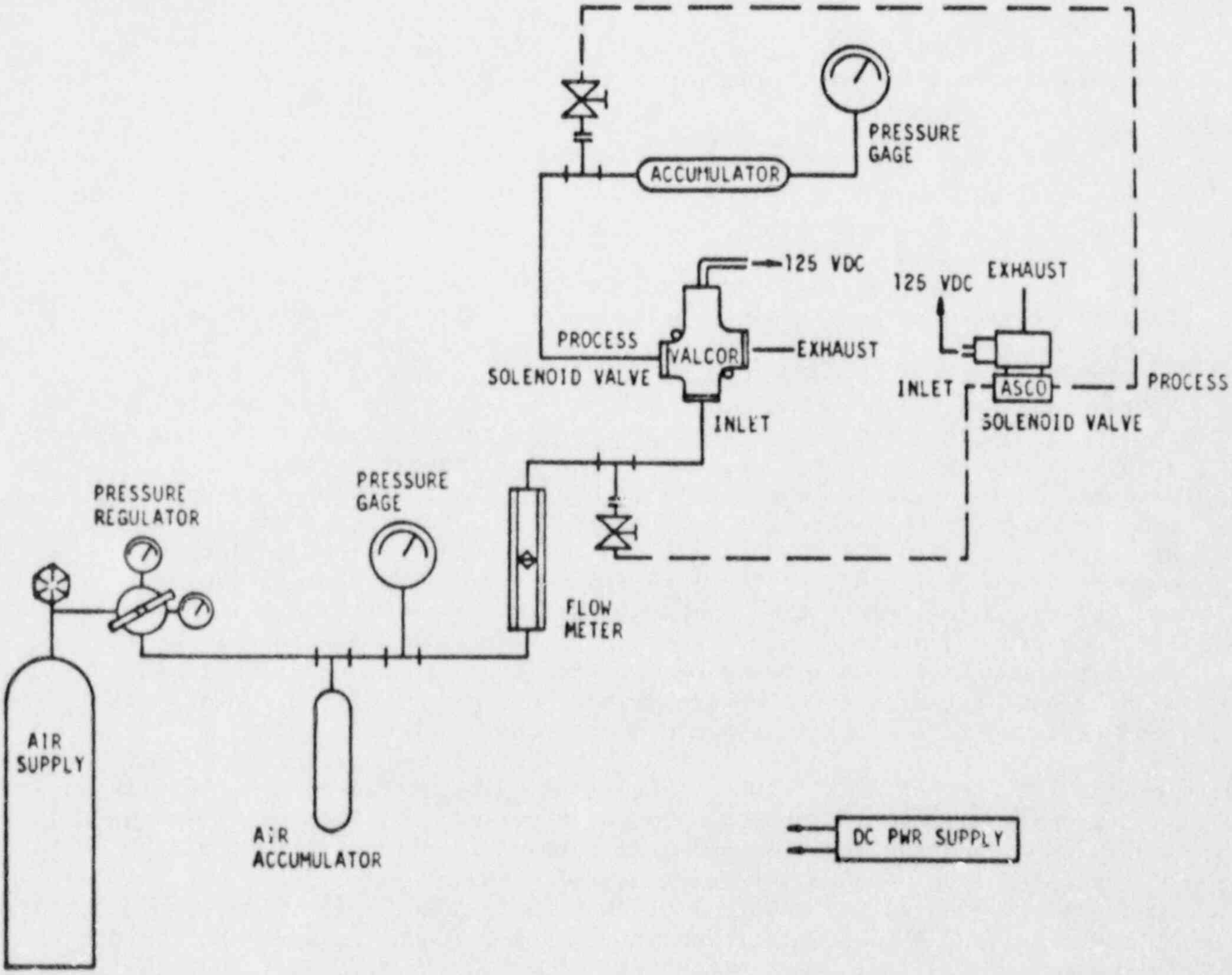

Figure 11. Schematic Diagram of SOV Leakage Test Stand

Table 7. Functional Test Results for Naturally Aged ASCO SOVs

	NP8314 (1.5 years)			HTX8314 (8 years)		
Specimen No.	6096-6	6096-7	6096-8	6096-1	6096-2	6096-3
Pre-Irradiation						
Coil Resistance ( )	799	790	789	1399	1375	1336
Coil Insulation Res ( )	36×10^6	1.[illegible] × 10^{12}	1.5×10^{12}	3×10^{12}	1.3×10^{12}	5.4×10^{12}
Leakage Energized (scfm)(a)	0	0	0	25	0	0
Leakage Deenergized (scfm)(a)	0	0	0	0	0	0
Post-Irradiation						
Coil Resistance ( )	NA	789	784	NA	1370	1330
Coil Insulation Res ( )	NA	0.010×10^{12}	0.24×10^{12}	NA	0.80×10^{12}	1.5×10^{12}
Leakage Energized (scfm)(a)	NA	0	0	NA	47/0(c)	0
Leakage Deenergized (scfm)(a)	NA	0	0	NA	0	0
Post-MSLB/LOCA Simulation						
Coil Resistance ( )	NA	NA	95×10^3	NA	NA	1340
Coil Insulation Res ( )	NA	NA	$<500 \times 10^3$	NA	NA	60×10^3(d)
Leakage Energized (scfm)(a)	NA	NA	(b)	NA	NA	0
Leakage Deenergized (scfm)(a)	NA	NA	(b)	NA	NA	0

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a. Pressurized to 60 psig.

b. Coil failed; SOV did not transfer.

c. On first energization during functional tests, 47 scfm leakage was noted; upon subsequent energization, there was essentially no leakage.

d. Using multimeter.

NA = Not applicable.

Table 8. Functional Test Results for ASCO NP8314 Valves with Accelerated Aging

	Specimen No.						
Process Medium	6096-16 Control Specimen	6096-9 (Air)	6096-10 (Air)	6096-15 (Air)	6096-12 (Nitrogen)	6096-13 (Nitrogen)	6096-14 (Nitrogen)
Pre-Thermal Aging							
Coil Resistance ( )	769	766	780	777	797	774	782
Coil Insulation Res ( )(a)	0.60×10^{12}	0.54×10^{12}	0.70×10^{12}	0.30×10^{12}	0.68×10^{12}	0.60×10^{12}	0.50×10^{12}
Leakage Energized (scfm)(b,c)	0	0	0	0	0	0	0
Leakage Deenergized (scfm)	0	0	0	0	0	0	0
Post-Thermal Aging							
Coil Resistance ( )	NA	770	815 (d)	804 (d)	800	804 (d)	808 (d)
Coil Insulation Res ( )	NA	50×10^{12}	5×10^{12}	1.5×10^{12}	100×10^{12}	45×10^{12}	1.8×10^{12}
Leakage Energized (scfm)	NA	0	0	0	0	0	0
Leakage Deenergized (scfm)	NA	0	<23.2 (e)	0	0	0	0
Post-Irradiation							
Coil Resistance ( )	NA	NA	807	795	NA	801	800
Coil Insulation Res ( )	NA	NA	0.56×10^{12}	0.30×10^{12}	NA	1.5×10^{12}	0.30×10^{12}
Leakage Energized (scfm)	NA	NA	<23.2 (e)	0	NA	0	0
Leakage Deenergized (scfm)	NA	NA	<23.2 (e)	0	NA	0	0
Post-MSLB/LOCA Simulation							
Coil Resistance ( )	NA	NA	NA	727	NA	NA	1060
Coil Insulation Res ( )	NA	NA	NA	12.5 (f)	NA	NA	$<1.1 \times 10^{3}$(f)
Leakage Energized (scfm)	NA	NA	NA	0(g)	NA	NA	0(g)
Leakage Deenergized (scfm)	NA	NA	NA	0	NA	NA	<23.2

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a. Using 500 Vdc megger.
b. Pressurized to 60 psig.
c. 125 Vdc.
d. Original coil replaced with separately aged coil (see thermal aging plan).
e. Leakages were slight; they were greater than zero but much less than 23.2 scfm, which was the lowest marking on the flow meter.
f. Insulation resistance measured with multimeter; value too low to measure with megger.
g. Valve transferred properly when energized at 100, 125, and 142 Vdc.
NA = Not applicable.

accelerated aging with air as the process medium. Valve 6096-10 was exposed to accelerated aging and irradiation with air as the processmedium; and Valve 6096-15 was exposed to accelerated aging, irradiation, and the simulated MSLB/LOCA environment. Valves 6096-12, -13, and 14 were exposed similarly to valves 6096-9, -10, and -15, respectively, but with nitrogen as the process medium.

All the valves had comparable coil and leakage data when new. Following irradiation, Valve 6096-10, which had air as the process medium, began to experience slight leakage (i.e., significantly less than 23.2 scfm, the lowest marking on the flow meter) in the deenergized state. In the deenergized state, the EPDM covers the process source orifice; therefore, some minor degradation of the EPDM core disc of the valve may have occurred as a consequence of the combination of thermal aging and irradiation. After disassembly, a small split was found in the core disc where it mated with the orifice. Valve 6096-15 did not experience such damage. Valve 6096-14 experienced similar leakage, but only after the MSLB/LOCA exposure; again, the leakage was not excessive. No obvious cause for the leakage of SOV 6096-14 was found on disassembly.

Both SOV 6096-15 and 6096-14 experienced coil deterioration during the MSLB/LOCA exposure. The coil resistance of SOV 6096-15 did not change appreciably following the MSLB/LOCA exposure when compared to previous readings. However, the coil was practically shorted to ground, with a resistance to ground of 12.5 Ω. The fuse for this SOV did blow once during the MSLB/LOCA, but the SOV operated most of the time. The coil resistance of SOV 6096-14 increased by approximately 40%, indicating that an open circuit was developing during the MSLB/LOCA exposure. The SOV coil also had a low insulation resistance (<1.1 kΩ). However, the SOV transferred properly at all times before, during, and after the MSLB/LOCA exposure. The process medium (air vs nitrogen) had no effect on coil deterioration, because the coils are not bathed in the process medium.

7.4.3 Functional Tests of Valcor Valves

Table 8 presents the functional test results for new and naturally aged Valcor SOVs. Specimen 6096-25 was a new SOV used for comparison to the remaining Valcor SOVs in the program. SOV 6096-19 was naturally aged only. SOV 6096-20 was naturally aged and irradiated, and 6096-21 was naturally aged, irradiated, and subjected to the MSLB/LOCA simulation.

The reference SOV (6096-25), in the as-new state, exhibited a 5-s delay on the transfer during the first deenergization of the functional testing.

SOV 6096-21 failed to transfer on its first energization in the as-received state when energized for 10 s. It was then energized again and transferred properly. During the first transfer after irradiation, it hesitated slightly. During the MSLB/LOCA simulation, the coil of SOV 6096-21 failed; subsequent to the MSLB/LOCA simulation, it had readings between 16 and 44 Ω. Following the MSLB/LOCA simulation, the coil was replaced with a new coil to determine if the valve was still operating. When energized, it took numerous attempts to get the valve to transfer; when it did transfer, it operated very slowly. Even with a new coil, the valve did not operate properly. Further discussion of the condition of this valve is contained in the disassembly teardown description in Section 7.5.

Table 9. Functional Test Results for New and Naturally Aged Valcor SOVs

Specimen No.	6096-25
New, As-Received From Manufacturer	
Coil Resistance (Ω)	415
Coil Insulation Resistence (Ω)	2×10^{12}
Leakage Energized(a)	0
Leakage Deenergized(a)	0(b)

Naturally Aged SOVs (Approximately 5 Years of Service)

Specimen No.	6096-19	6096-20	6096-21
Coil Resistance (Ω)	409	405	403
Coil Insulation Resistance (Ω)	1.5×10^{12}	3.5×10^{12}	1.1×10^{12}
Leakage Energized(a)	0	0	0(c)
Leakage Deenergized(a)	0	0	0
Post-Irradiation			
Coil Resistance (Ω)	NA	402	401
Coil Insulation (Ω)	NA	0.004×10^{12}	1.2×10^{12}
Leakage Energized(a)	NA	0	0(d)
Leakage Deenergized(a)	NA	0	0
Post MSLB/LOCA Exposure			
Coil Resistance (Ω)	NA	NA	16 to 44
Coil Insulation Resistance (Ω)	NA	NA	(e)
Leakage Energized(a)	NA	NA	(e)
Leakage Deenergized(a)	NA	NA	(e)

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a. Pressurized to 150 psig.

b. Approximately 5-s delay was noted on deenergization, subsequent attempts to transfer to deenergized position were also delayed.

c. First transfer upon initial energization at 125 Vdc did not occur within 10 s. Transferred properly on second energization.

d. Slight hesitation noted on first transfer upon energization.

e. Coil failed, replacement of coil allowed determination that valve would transfer, but only after repeated attempts and significant delays.

NA = Not applicable.

7.4.4 Valcor SOVs with Irradiation and MSLB/LOCA Exposure

Table 9 provides the functional results for the new Valcor valves and those subjected to irradiation and the MSLB/LOCA simulation. None of the Valcor valves was thermally aged by accelerated means due to failures that occurred during the thermal aging attempts. Therefore, Table 9 provides data on a new Valcor SOV (6096-25), an irradiated SOV (6096-27), and one (6096-26) that was irradiated and subjected to a MSLB/LOCA simulation. It should be noted again that SOV 6096-25 experienced a 5-s delay upon initial deenergization and that subsequent transfers also had delays. SOV 6096-26, when new, also experienced transfer delays of 2 to 8 s, during which heavy leakage was noted. Following irradiation, SOV 6096-27 also experienced transfer delays, but no leakage before or after transfer. SOV 6096-26 appeared to have increasing delay periods following irradiation, during which transfers took 7 to 40 s, with leakage during the period of transfer.

The coil of SOV 6096-26 did not deteriorate significantly during the accident simulation. However, excessive leakage was noted during and after the MSLB/LOCA simulation, while the SOV was energized. Following the accident simulation, it was also noted that leakage was occurring in the deenergized position.

7.4.5 Cross-Comparison of Valcor SOVs

Both the naturally aged SOV 6096-21, which was put through irradiation and simulated accident exposure, and the new SOV 6096-26, which was put through accident exposure and irradiation, experienced failures, but of different types. The failure of SOV 6096-21 involved the coil and internal mechanism; however, the seats appeared to be working properly. SOV 6096-26 experienced failure of the seats but not of the coil, and the valve continued to transfer properly. A number of specimens exhibited slowness to transfer, some when new and some later in the program. SOV 6096-21 was slow in transferring after natural aging, and again slow following irradiation. SOV 6096-25, which was a new valve, experienced slowness on its first test. SOV 6096-26 experienced slowness when new and continued to do so until following irradiation; then it experienced high leakage during and after the MSLB/LOCA simulation.

7.4.6 Cross-Comparison of Results for ASCO SOVs

It is interesting that SOV 6096-3, with Buna N seats and 8 y of service, had the best performance among the SOVs put through the MSLB/LOCA simulation. No coil failure and no leakage occurred. Coil failure occurred on SOV 6096-8, which had EPDM seats and 1.5 y of service; however, the internal portions of the valve appeared to be in proper working order.

With respect to air and nitrogen as a process medium, the air-supplied SOV 6096-10 suffered slight leakage following irradiation. The nitrogen-supplied valve in similar condition, SOV 6096-13, did not leak. With respect to accident simulation, the nitrogen-supplied SOV had slight leakage and the air-supplied valve had none following a MSLB/LOCA. The coils of these two SOVs experienced deterioration; however, they did function periodically during the MSLB/LOCA simulation. It appears that coil problems could be significant for any valve that must operate well into the MSLB/LOCA condition.

Table 10. Functional Test Results for New and Irradiated Valcor SOVs [a]

Specimen No.	6096-25	6096-27	6096-26
New, As Received from Manufacturer			
Coil Resistance (Ω)	415	413	416
Coil Insulation (Ω)	2×10^{12}	2.8×10^{12}	2.6×10^{12}
Leakage Energized[b]	0	0	0
Leakage Deenergized[b]	0[c]	0	0[d]
Post-Irradiation (No Thermal Aging)			
Coil Resistance (Ω)	NA	410	413
Coil Insulation (Ω)	NA	2.6×10^{12}	3.5×10^{12}
Leakage Energized[b]	NA	0	0
Leakage Deenergized[b]	NA	0[e]	0[f]
Post MSLB/LOCA Exposure			
Coil Resistance (Ω)	NA	NA	418
Coil Insulation (Ω)	NA	NA	2.6×10^{11}
Leakage Energized[b]	NA	NA	>350 scfh[g]
Leakage Deenergized[b]	NA	NA	95 scfh

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a. Due to repeated valve failures, thermal aging was not completed on these valves. Valves with no thermal aging were used for irradiation and accident simulation.

b. Pressurized to 150 psig.

c. Delay of approximately 5 s was noted on deenergization; subsequent transfers to the deenergized position were also delayed.

d. Transfers to the deenergized position took 2 to 8 s during which heavy leakage was noted.

e. Transfers after deenergization took 9 to 10 s.

f. Transfers after deenergization took 7 to 40 s, during which leakage increased until transfer was completed.

g. Transfers occurred properly, but high seat leakage occurred.

NA = Not applicable.

7.5 Final Inspection of SOVs

Upon the completion of the MSLB/LOCA simulation, the valves were disassembled to determine the condition of their internal components. The subsections are ordered by valve type, type of aging, type of process medium, and increment of exposure to program conditions.

7.5.1 ASCO SOV 6096-16 (NP8314) Unaged

No significant damage or deterioration was noted upon disassembly of the new valve that was used as a basis for comparison with other valves.

7.5.2 ASCO SOV 6096-6 (NP8315) Naturally Aged

Visual examination of the internal components of this valve revealed little observable damage. The plugnut O-ring appeared to be in an as-new state and still had signs of silicone grease from its initial assembly. The body gasket O-ring was slightly squared and had taken a minor compressive set.
The core seat appeared like new. The area around the metal-to-metal seat had a very light lacquer-like film similar to that found in the valves that had stuck during accelerated aging. No physical deterioration of the coil was noted.

7.5.3 ASCO SOV 6096-7 (NP8314) Naturally Aged, Irradiated

No observable deterioration was noted in the coil or coil housing. The body gasket (see Figure 2) O-ring had taken a compression set, but had remained pliable and, based on the results of the functional test, was performing its function. A thin film of the material found in the ASCO NP8314 valves that stuck during aging was observed on the top of the core assembly where it meets the top of the solenoid base subassembly.

7.5.4 ASCO SOV 6096-8 (NP8314) Naturally Aged, Irradiated, and Exposed to MSLB/LOCA

The outside of the valve body was covered by corrosion products from the chemical spray and steam exposure. The top of the solenoid coil enclosure had extensive corrosion products and was heavily rusted. The upper coil insulating washers were moist. The plugnut O-ring was hard and brittle but intact. The solenoid coil was very wet, and the housing had allowed significant moisture intrusion. The inside of the coil housing also exhibited corrosion products. There was no observable water line; however, it appeared that water had filled the housing at least to the level of the bottom of the conduit connection. The core disc had a heavy compression set. There was no lacquer-like film in the area of the exhaust port as was observed on SOV 6096-7. The body gasket had taken a compression set, but was intact and pliable. There was a black carbon-like deposit on the valve body at the seat.

7.5.5 ASCO SOV 6096-1 (HTX8314)* Naturally Aged

The coil housing was dry and clean. No observable damage had occurred to the coil. The body gasket O-ring was intact but extremely hard. The upper Buna-N core seat had a deposit of dirt on it. Both the upper and lower Buna-N seats appeared to be in good condition. The plugnut gasket was extremely hard and could not be removed. A flat circular gasket was found on this type of SOV between the solenoid base assembly and the upper flange of the valve body. The gasket was extremely brittle.

7.5.6 ASCO SOV 6096-2 (HTX8314) Naturally Aged and Irradiated

Upon disassembly, the plugnut O-ring was found to be missing. (It is not known whether this condition existed from the time of manufacture or occurred during in-plant maintenance.) The upper and lower core discs had very little compression set and appeared to be in good condition. The body gasket O-ring was extremely hard and had a compression set. No damage or deterioration was observed on the coil and leads. The flat circular gasket between the solenoid base assembly and the valve body was intact, but very hard and brittle.

7.5.7 ASCO SOV 6096-3 (HTX8313) Naturally Aged, Irradiated, and Exposed to MSLB/LOCA

The housing for the coil had some corrosion products on it. The coil housing was corroded shut and had to be cut open. There was evidence that internal surfaces had become damp, but no indication of a water line. The seal style for this housing appeared to be much more effective than the one for the NP8314 SOVs. At the interface of the solenoid base subassembly to the coil housing, the solenoid base subassembly was rusted. The upper Buna-N seat had not taken a significant compression set at the location of the valve seat. However, the core disc assembly had taken a severe compression set where it rested on the lower valve seat. While there were corrosion products within the valve body, the area was dry. The body gasket O-ring had only slight compression set and was intact; however, it was very hard and brittle and could not be removed.

While the O-rings on SOVs 6096-1, -2, and -3 were hard and brittle, they all were performing their function prior to valve disassembly. The body gaskets prevented body leakage during the test program; and, because of the configuration and application of the valve, the plugnut gasket was not under pressure. A flat circular gasket was not found on this SOV between the solenoid base assembly and its valve body.

7.5.8 ASCO SOV 6096-9 (NP8314) Accelerated Aging with Air Process Medium

The coil housing and coil showed no signs of deterioration. The plugnut O-ring was firm but pliable. There was very little compression set on the EPDM core disc where it met the valve seat. The body gasket O-ring was

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*See Figure 1 for HTX8314 parts nomenclature.

extremely compressed because the solenoid base had been very tightly applied to the solenoid base assembly on this valve. The body gasket O-ring was very brittle and was damaged in an attempt to remove it.

7.5.9 ASCO SOV 6096-10 (NP8314) Accelerated Aging with Air Process Medium, Irradiated

There was no observable damage to the coil or leads. The plugnut O-ring was no longer pliable. The core disc was hard, but exhibited only minor compression set in the vicinity of the valve seat interface. The body O-ring was no longer pliable and failed during removal.

7.5.10 ASCO SOV 6096-15 (NP8314) Accelerated Aging with Air Process Medium, Irradiated, and Exposed to MSLB/LOCA

The coil housing was damp when opened, and the coil lead wires were slightly damp when touched. The inside surface of the housing was rusted on the bottom half. The plugnut O-ring was very hard. The body gasket O-ring was severely compressed, hard, and fragmented, and could not be removed for further testing. The EPDM core disc had taken a severe compression set where it met with the valve seat. The core disc was also scarred in areas around the valve seat interface, the cause of which is not known.

7.5.11 ASCO SOV 6096-12 (NP8314) Accelerated Aging with Nitrogen Process Medium

The plugnut and body O-rings were pliable and had only minor compression set. The core disc also had minor compression set in the vicinity of the valve seat interface. No observable coil or lead damage was noted.

7.5.12 ASCO SOV 6096-13 (NP8314) Accelerated Aging with Nitrogen Process Medium, Irradiated

Corrosion products were observed on the outside of the valve body. The body gasket O-ring had taken a significant compression set but was very pliable. The EPDM core disc had taken a compression set where it met with the valve seal; however, it was reasonably soft. There was evidence of a lacquer-like film on the top of the core assembly in the vicinity of the upper valve seat where it met with the solenoid base assembly. No deterioration or damage was observed in the coil housing or the coil.

7.5.13 ASCO SOV 6096-14 (NP8314) Accelerated Aging with Nitrogen Process Medium, Irradiated, Exposed to MSLB/LOCA

The coil housing was rusted. There was evidence of moisture intrusion inside the housing. The silicone grease that was used to coat the interfaces between the upper flux washer and the housing cover and between the bottom of the solenoid base and the housing assembly had congealed into a gasket-like configuration. The plugnut O-ring was intact. The RTV used to seal the electrical lead penetration to the housing was intact up to the entrance of the coil area and appeared to have sealed properly, indicating that the moisture which entered the housing had done so by way of the solenoid base or plugnut penetrations. The upper fiber washer on the coil had obviously been wet and the coil was still moist. The solenoid base subassembly was corroded in the vicinity of the coil. Some moisture was found in the base of the coil housing.

The valve body was heavily blackened on the inside and outside. The inside of this valve body had signs of moisture intrusion. The EPDM core disc had a very slight compression set in the vicinity of the valve seat. The top of the core assembly had signs of the film that had previously caused sticking during aging. The body gasket O-ring was intact, but had taken a compression set. It remained somewhat pliable.

7.5.14 Valcor SOV 6096-25 New

The elastomeric materials of this SOV were all pliable. The body and solenoid base gaskets had all taken the shapes of their cavities, but were resilient. No coil damage was noted.

7.5.15 Valcor SOV 6096-27 New, Irradiated

The solenoid base O-ring (see Figure 3) was pliable, but was flattened at the interface with the solenoid housing. The body O-ring was also reasonably pliable, but was squared as a consequence of a compression set where it met the body. Throughout the internal portions of the valve there was evidence of a white powder, which may have been from the silicone grease used to lubricate the O-rings. The upper and lower seat-guide O-rings were squared as a consequence of compression set where they met with the solenoid base and valve body. Both were reasonably soft and pliable. The shaft seal O-ring was pliable; however, it split during removal. The seal assembly upper O-ring had taken a compression set but was soft and pliable. The lower seal assembly O-ring had flared to take the shape of the lower valve seat; it remained soft and pliable. Heavy deposits of silicone grease were evident on all of the internal O-rings.

7.5.16 Valcor SOV 6096-26 New, Irradiated, Exposed to MSLB/LOCA

This valve was disassembled in the presence of NRC, Valcor, and Equipment Qualification Advisory Group representatives. The solenoid base O-ring was squared where it met with the solenoid housing as a consequence of compression set; it remained slightly pliable. The body O-ring was slightly pliable, but some shreading was noted where it passed the threads of the base. The shaft seal O-ring broke during removal; it was soft but not pliable. The upper seat guide O-ring had deteriorated, was not pliable, and broke during removal. The lower seat guide O-ring had fine cracks around its entire circumference and was not pliable. Portions of the upper and lower seal assembly O-rings (the valve seats) were missing. The remainder of these O-ring segments were severely compressed. The portions of the O-rings between the brass portions of the assembly were somewhat pliable.

The coils of the Valcor valves were potted to the coil housing at the time of manufacture and were not removable. Therefore, complete visual inspection was not possible. No significant problems were noted on the areas that could be observed.

7.5.17 Valcor SOV 6096-19 Naturally Aged

The body O-ring was intact and pliable. The solenoid base O-ring was pliable and soft. The upper seal assembly O-ring was pliable and soft, but had taken a slight compression set with respect to its seat. The lower seal assembly O-ring had become extremely flattened in its seat. The cage assembly had deposits of dirt or carbon on the cage assembly and upper seat. The seat guide upper and lower O-ring were pliable and soft and had some residual silicone grease on them. The area where the shaft seal O-ring rides in the seat guide was coated with carbon-like material that most likely came from the shaft seal O-ring. The stainless steel shaft was also coated with the material. The shaft seal O-ring was squared but was soft and pliable and could be removed.

7.5.18 Valcor SOV 6096-20 Naturally Aged, Irradiated

The body O-ring had squared where it met the body, but was pliable. The solenoid base O-ring had squared with a compression set where it fits with the housing, but was reasonably pliable. The upper seat guide O-ring had taken and retained a shape square where it met with the solenoid base assembly. However, it was soft and pliable. The lower seat guide O-ring was in the same condition. The lower seal assembly O-ring was flared and flattened with heavy deposits of material on the seat assembly. The upper seal assembly O-ring had also become significantly flattened as a consequence of compression in its seat but was reasonably pliable. The upper seal assembly O-ring was much harder than the lower assembly O-ring. No unusual conditions were observed on the coil.

7.5.19 Valcor SOV 6096-21 Naturally Aged, Irradiated, Exposed to MSLB/LOCA

The cross section of the body O-ring had become square where it mates with the valve body, but was still pliable. The solenoid base O-ring was in a similar condition, but the surface material had smeared onto the solenoid housing surface. The upper and lower seat guide O-rings were squared and no longer pliable. The shaft seal O-ring had completely deteriorated and only residual material was observed to be on the shaft surrounding the slot and on the inner surface of the seat guide of the cage assembly. This material caused the shaft to be partially bound and required considerable force to cause it to move.

The upper and lower seal assembly O-rings were highly compressed and no longer pliable. The upper and lower seat guide O-rings were deteriorated and crumbling, and were not pliable.

The lead penetrations for the coils of the naturally aged Valcor SOVs had been potted with a Scotchcast material. This material had totally deterio- rated on Valve 6096-21 and only blackened, crumbly residue remained.

Upon removal of this valve from the MSLB/LOCA test chamber, it was noted that the cover on the condulet that formed the penetration seal for test purposes had popped off.* This most probably was caused by expansion of the RTV sealing compound contained in the condulet. It was also noted that red material had wept from the side of the condulet. The material was determined to be sealant from the Raychem heat shrink tubing used to cover the test lead splices. Apparently, during the MSLB/LOCA exposure, the Raychem sealant material tried to expand but was restrained at the ends of the tube by the RTV, causing the side of the seat shrink tube to burst and, in turn, split open. Because there was an electrical short with a resistance of 16 to 44 Ω in the circuit of this SOV, the RTV was removed from the lead penetrations. No shorts were found in the leads, and the Raychem cover splices were found to have good insulation resistance, even though split. The short was verified as being within the coil.

7.5.20 Overall Results of Teardown Evaluations

Based on the visual examinations, the effects of natural and accelerated thermal aging were relatively minor compared to the effects of the MSLB/LOCA exposure. For the ASCO NP8314 valves, the coil housing admitted water even though the electrical penetration was well sealed. The entry of water apparently led to coil deterioration on SOVs 6096-8, -14, and -15. Some moisture entered the housing of SOV 6096-3 (type HTX8314) but did not result in failure of the coil. While there was deterioration of the elastomeric parts of the ASCO SOVs that were exposed to the MSLB/LOCA simulation, the deterioration did not appear to be sufficient to prevent functioning, no matter which process medium or material was involved. The problems encountered with ASCO SOVs during the MSLB/LOCA simulation were probably attributable to coil deterioration.

The internal condition of the Valcor valves that were exposed to the MSLB/LOCA provided insight with regard to functional failure during the MSLB/LOCA and post-LOCA testing. The coil of Valve 6096-21 definitely had shorted. The fact that the shaft seal O-ring had deteriorated and coated the shaft and guide tube, causing them to bind, explained why changing the coil during post-LOCA functional testing did not restore valve operability. The loss of fragments of the seal assembly O-ring on Valve 6096-26 explains the excessive leakage: the remaining hardened seal assembly O-ring material prevented closure of the parts.

7.6 Discussion of Material Test Results

The organic materials of the SOVs were tested to determine their mechanical properties so that the extent of deterioration of specimens exposed to different segments of testing could be compared. The tests were: Shore "A" durometry for evaluation of hardness; tensile testing of O-rings to determine elongation at break; and controlled rate compression of ASCO core discs to evaluate modulus of elasticity and relaxation properties. The data that follow should be evaluated in conjunction with functional test results. Although the

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*The condulet covers had popped off of all the SOVs subjected to the MSLB/LOCA simulation except the ASCO SOV with 8 y of in-plant service (SOV 6096-3).

materials data makes it appear that some components of the specimens failed, the SOVs may have nonetheless performed adequately during the MSLB/LOCA simulation.

7.6.1 Shore "A" Durometry Test Results

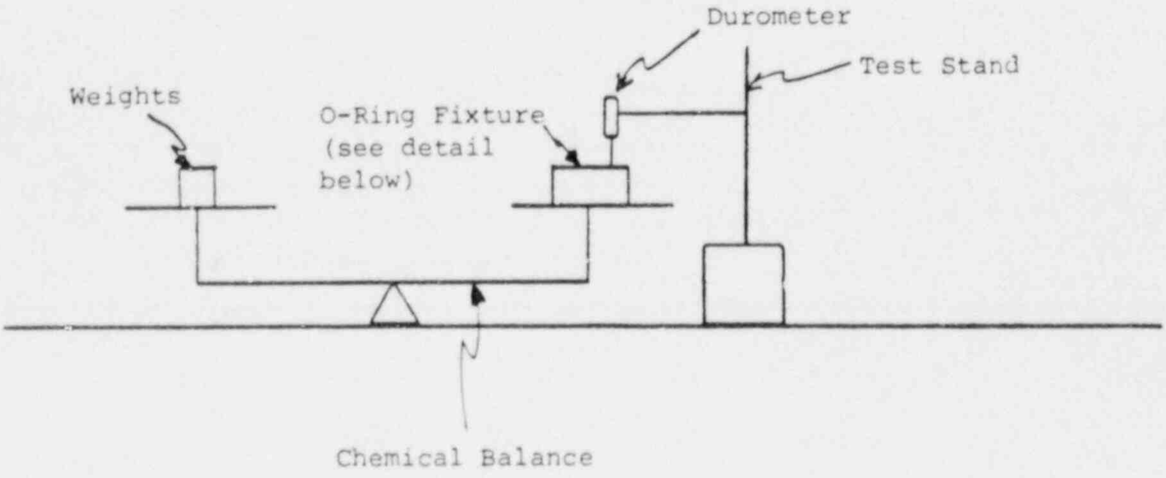
A Shore "A" durometer was mounted on a laboratory test stand so that it was fixed in position as shown in Figure 12. A set of laboratory weights was then used to calibrate the durometer in accordance with paragraph 23.1.4 of ASTM D2240-75. Following calibration, the durometer was placed over one pan of a double pan chemical balance, and an O-ring fixture was placed on the pan. The indentation point of the durometer was positioned to touch the surface of the test fixture while being balanced with weights on the opposite pan. After positioning the elastomeric test material (O-ring or core disc) on the fixture and allowing the indentation point to touch the elastomer, a 1-kg weight was placed on the opposite pan and the durometer was read immediately.

7.6.1.1 ASCO SOV Durometry

Durometry measurements were performed on the plugnut gasket O-rings, body gasket O-rings, and the core discs of each of the ASCO SOVs. Tables 10 and 11 provide the results for body and plugnut gasket O-rings. Tables 12 and 13 provide the results for the core discs. The data in these tables probably reflect some variability in the durometry of new O-rings or discs. Not all of a particular type of O-ring were identical at the start of the test, and base data could not be taken without disturbing the condition of the valves.

Because of their location in the valve, the plugnut O-rings are not affected by differences in the process medium. They are directly at the top of the coil housing and do experience much of the coil temperature rise. The plugnut O-ring of SOV 6096-6 (NP8314) that was in service for 1.5 years was somewhat harder than the unaged SOV 6096-16 (NP8314) (durometer 80 vs 75). Durometer readings for the plugnut O-rings with accelerated aging equivalent to 1 year (6096-9 and 6096-17) were slightly lower than the values for the unaged O-ring (6096-16) (72 and 74 vs 75). These differences may be attributable to differences in O-ring materials or to the possibility that the accelerated aging is not fully representative of natural aging. Both of the plugnut O-rings that were irradiated and had accelerated aging (6096-15 and -13) were significantly harder than either the SOVs with accelerated aging or new SOVs; they had durometer readings of 89 and 90. In all of the SOVs exposed to the MSLB/LOCA (6096-8, -14, and -15), plugnuts were hard, but not necessarily significantly harder than the irradiated O-rings, indicating that irradiation caused most of the hardening.

The body gasket measurements for the HTX8314 SOVs that were naturally aged for 8 years with air as the process medium showed little change in hardness, with readings of 98, 96, and 97. It appears that 8 years of service caused the hardening, and the irradiation and MSLB/LOCA exposure had little additional effect. The 1.5-year natural aging of the body gasket O-ring from SOV 6096-6 caused little change from the new specimen. However, 1.5 years of natural aging followed by irradiation (SOV 6096-7) did cause hardening.



O-Ring Fixture Detail
(approximately full size)

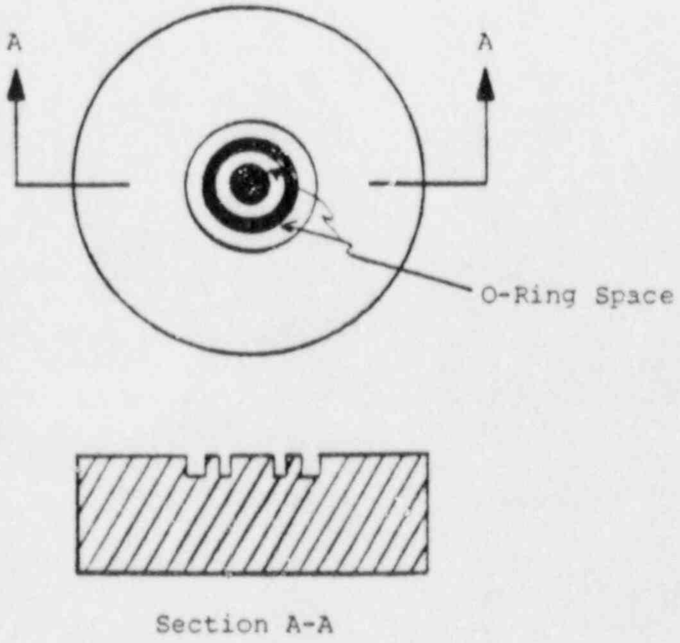


Figure 12. Schematic of Durometer Test Setup and O-Ring Fixture Details

Table 11. Shore "A" Durometer Measurements on O-rings of Naturally Aged ASCO SOVs

Specimen	Model	Condition	Durometer Reading*	
			Body O-Ring	Plugnut O-Ring
6096-16	NP8314	Unaged	76	75
6096-6	NP8314	Naturally Aged (1.5 y)	73	80
6096-7	NP8314	Naturally Aged (1.5 y), Irradiated to Accident Dose	82	Too damaged to test
6096-8	NP8314	Naturally Aged (1.5 y), Irradiated to Accident Dose, Exposed to MSLB/LOCA	82	96
6096-1	HTX8314	Naturally Aged (8 y)	98	Too damaged to test
6096-2	HTX8314	Naturally Aged (8 y), Irradiated to Accident Dose	96	Too damaged to test
6096-3	HTX8314	Naturally Aged (8 y), Irradiated to Accident Dose, Exposed to MSLB/LOCA	97	Too damaged to test

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*Each reading is an average of three measurements.

Table 12. Shore "A" Durometer Measurements on O-rings of ASCO SOVs with Accelerated Aging

Specimen	Model	Condition	Durometer Reading*	
			Body O-Ring	Plugnut O-Ring
6096-16	NP8314	Unaged	76	75
6096-9	NP8314	Thermally Aged in Air	Too damaged to test	72
6096-10	NP8314	Thermally Aged in Air, Irradiated to Accident Dose	Too damaged to test	89
6096-15	NP8314	Thermally Aged in Air, Irradiated to Accident Dose, Exposed to MSLB/LOCA	Too damaged to test	94
6096-12	NP8314	Thermally Aged in Nitrogen	85	74
6096-13	NP8314	Thermally Aged in Nitrogen, Irradiated to Accident Dose	83	90
6096-14	NP8314	Thermally Aged in Nitrogen, Irradiated to Accident Dose, Exposed to MSLB/LOCA	85	91

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*Each reading is an average of three measurements.

Table 13. Shore "A" Durometer Measurements on Core Discs of Naturally Aged ASCO SOVs

Specimen	Model	Condition	Durometer Reading*
6096-16	NP8314	Unaged	82
6096-6	NP8314	Naturally Aged (1.5 y)	83
6096-7	NP8314	Naturally Aged (1.5 y), Irradiated to Accident Dose	87
6096-8	NP83141	Naturally Aged (1.5 y), Irradiated to Accident Dose, Exposed to MSLB/LOCA	86
6096-1	HTX8314	Naturally Aged (8 y)	90 (Buna N)
6096-2	HTX8314	Naturally Aged (8 y), Irradiated to Accident Dose	92 (Buna N)
6096-3	HTX8314	Naturally Aged (8 y), Irradiated to Accident Dose, Exposed to MSLB/LOCA	93 (Buna N)

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*Each reading is an average of three measurements.

Table 14. Shore "A" Durometer Measurements on Core Discs of ASCO SOVs with Accelerated Aging

Specimen	Model	Condition	Durometer Reading*
66096-16	NP8314	Unaged	82
6096-9	NP8314	Thermally Aged in Air	90
6096-10	NP8314	Thermally Aged in Air, Irradiated to Accident Dose	92
6096-15	NP8314	Thermally Aged in Air, Irradiated to Accident Dose, Exposed to MSLB/LOCA	89
6096-12	NP8314	Thermal Aged in Nitrogen	82
6096-13	NP8314	Thermally Aged in Nitrogen, Irradiated to Accident Dose	88
6096-14	NP8314	Thermally Aged in Nitrogen, Irradiated to Accident Dose, Exposed to MSLB/LOCA	88

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*Each reading is an average of three measurements.

Again, little further hardening occurred when the MSLB/LOCA exposure was added. The 1-year thermal aging with air as the process medium for the ASCO NP8314 SOVs caused sufficient damage to all of the body gasket O-rings (SOVs 6096-9, -10, and -15) that they could not be removed from the SOV for testing. However, it should be remembered that body leakage was not observed on any of these SOVs during functional tests.

The 1-year accelerated thermal aging of the NP8314s (SOVs 6096-12, -13, and -14), with nitrogen as a process medium, caused uniform hardening of the body O-rings, which did not change significantly with the addition of irradiation or MSLB/LOCA exposure. The comparison of the results of accelerated thermal aging with air and nitrogen as the process medium indicates that air caused more hardening than nitrogen. However, both sets of valves performed properly under functional testing.

The core disc results (Tables 12 and 13) indicate that natural thermal aging for 1.5 years caused little hardening of the core disc, that irradiation caused significantly more hardening, and that MSLB/LOCA exposure caused little additional hardening. It is interesting to note that the results for the SOVs with nitrogen as the process gas and 1 year of accelerated aging were very similar to the results for SOVs with 1.5 years of natural aging. However, the results for the SOVs with 1 year of accelerated aging and air as the process medium (SOVs 6096-9, -10, and -15) show that the bulk of the hardening is associated with the thermal aging and that there is little change from the addition of irradiation and MSLB/LOCA exposure. The naturally aged HTX8314 SOVs behaved similarly, with the hardening remaining constant following natural aging. However, cross-comparison with other valves should be limited because these valves have Buna-N core discs, whereas all of the others have EPDM core discs.

Overall, the hardness measurements indicate that the accelerated aging of the core disc and body O-ring with air as the process medium causes more hardening than the use of nitrogen as the process medium, but not enough to affect functional capability.

7.6.1.2 Valcor Durometry

Tables 14 and 15 provide the durometry measurements for the Valcor SOVs. The seal assembly O-rings mate with the seats to stop process flow during operation. The shaft seal O-ring is a dynamic seal that moves with the solenoid core. The seat guide assembly O-rings are static seals that prevent process medium flow from cavity to cavity within the valve body. The body O-ring prevents body leakage of the process medium. The solenoid base O-ring provides a lower seal for the coil housing from the outside environment. The O-rings of highest importance to operation are the seal assembly O-rings and the shaft seal O-ring. The next highest in importance are the static seals that prevent internal and external leakage.

Table 14 compares results from the naturally aged SOV with those of the unaged specimen. According to discussions with Valcor, it is possible that the O-rings in the unaged and naturally aged SOVs were produced by different manufacturers and may have had somewhat different properties. As a minimum,

Table 15. Shore "A" Durometer Measurements for Naturally Aged Valcor Valves

		Durometer Reading(a)						
		Seat Guide				Seal Assembly		
Specimen	Condition	Upper O-Ring	Lower O-Ring	Solenoid Base O-Ring	Body O-Ring	Upper O-Ring (Seat)	Lower O-Ring (Seat)	Shaft Seal O-Ring
6096-25(b)	Unaged	77	73	75	78	71	73	72
6096-19	Naturally Aged (5 y)	70	74	60	75	76	79	69
6096-20	Naturally Aged (5 y), Irradiated to Accident Dose	75	74	(d)	75	80	93	71
6096-21	Naturally Aged (5 y), Irradiated to Accident Dose, Exposed to MSLB/LOCA	(c)	(c)	(c)	(c)	89	89	(e)

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a. Each reading is an average of three measurements.

b. This SOV was manufactured in 1986; data are provided for comparison to naturally aged SOVs that were manufactured in the 1980 time frame.

c. Too deteriorated to test.

d. No data available.

e. O-ring deteriorated completely.

Table 16. Shore "A" Durometer Measurements for Initially New Valcor Valves

		Durometer Reading(a)						
		Seat Guide				Seal Assembly		
Specimen	Condition	Upper O-Ring	Lower O-Ring	Solenoid Base O-Ring	Body O-Ring	Upper O-Ring (Seat)	Lower O-Ring (Seat)	Shaft Seal O-Ring
6096-25	Unaged	77	73	75	78	71	73	72
6096-27	Unaged, Irradiated to Accident Dose	80	78	80	79	81	81	77
6096-26	Unaged, Irradiated to Accident Dose, Exposed to MSLB/LOCA	Broken and deteriorated	Cracked and deteriorated	74	72	83	85	Broken and deteriorated

---

a. Each reading is an average of three measurements.

they are from different manufacturing batches. The shaft seal O-rings show little difference among a new SOV (6096-25), one naturally aged for 5 years (6096-19), and one thermally aged and irradiated (6096-20). However, the MSLB/LOCA exposure caused sufficient damage that the shaft seal O-ring on SOV 6096-21 became totally deteriorated and fragmented. Curiously, the lower seal assembly O-ring on the naturally aged and irradiated SOV (6096-20) had hardened significantly when compared to the naturally aged SOV (6096-19) and unaged SOV, but similar hardening did not occur until after the MSLB/LOCA exposure on the upper seal assembly O-ring of SOV 6096-21.

The shaft seal O-ring on the new, irradiated SOV (6096-27) was slightly harder than that on the new SOV. The shaft seal O-ring on the SOV exposed to a MSLB/LOCA simulation was too fractured and deteriorated to test. The hardening of the upper and lower seal assembly O-rings occurred in an orderly fashion on the new SOV (6096-25), irradiated SOV (6096-27), and new SOV that was irradiated and exposed to a MSLB/LOCA simulation (6096-26). The hardening of this O-ring caused by the MSLB/LOCA was less than the effect on the naturally aged O-rings, as judged by the amount of hardness change from the unaged to naturally aged condition.

Some hardening of the remaining O-rings occurred during aging and irradiation, but the most significant damage appeared to occur from MSLB/LOCA exposure, when most O-rings deteriorated to the point at which they could not be removed for testing.

7.6.2 Tensile Test Results

ASTM D1414-78 guidelines were followed in conducting the tensile tests. The tests were performed using an Instron Model 1125 Universal testing machine operated at a crosshead speed of 20 in/min. Each O-ring was positioned on appropriately sized hooks and stretched until broken. The tensile force was plotted continuously as a function of elongation by a recorder which was wired to the testing machine's load cell.

7.6.2.1 Tensile Test Results for ASCO SOV O-Rings

Tables 17 and 18 provide the results of the tensile tests of the ASCO valve O-ring. The ultimate elongation at break is given in percent for each O-ring. Only the body gasket O-ring was exposed to the process medium.

For the NP8314 SOVs naturally aged for 1.5 years, a small loss of elongation at break occurred from thermal aging. A significantly larger loss occurred from irradiation (see Table 16). For the plugnut O-ring, the damage was sufficient to cause failure during removal from the SOV. For the body O-ring, only a small additional loss of elongation occurred from the MSLB/LOCA exposure. The combination of exposures to the plugnut O-ring on SOV 6096-8 caused it to lose pliability to the extent that it cracked on the testing rig prior to extension.

All of the O-rings on the HTX8314 SOVs naturally aged for 8 y failed either during removal or prior to extension on the test rig. However, all were intact and performing their function in the SOVs.

Table 17. Ultimate Elongation-at-Break Measurements for ASCO Naturally Aged SOVs

Specimen	Model	Condition	Ultimate Elongation at Break (%)	
			Body O-Ring	Plugnut O-Ring
6096-16	NP8314	Unaged	246	224
6096-6	NP8314	In Service 1.5 y Plus 2000 Cycles	226	189
6096-7	NP8314	In Service 1.5 y, 2000 Cycles, Irradiated to Accident Dose	65	(a)
6096-8	NP8313	In Service 1.5 y, 2000 Cycles, Irradiated to Accident Dose, Exposed to MSLB/LOCA	50	(b)
6096-1 (c)	HTX8314	In Service 8 y Plus 2000 Cycles	(b)	(a)
6096-2 (c)	HTX8314	In Service 8 y, 2000 Cycles, Irradiated to Accident Dose	(b)	(a)
6096-3 (c)	HTX8314	In Service 8 y, 2000 Cycles, Irradiated to Accident Dose, Exposed to MSLB/LOCA	(b)	(a)

---

a. Failed during removal from SOV.

b. Failed on test rig prior to elongation.

c. Buna-N seals.

Table 18. Ultimate Elongation-at-Break Measurements for ASCO NP8314 SOVs with Accelerated Aging

Specimen	Condition	Ultimate Elongation at Break (%) Body O-Ring	 Plugnut O-Ring (b)
6096-16	Unaged	246	224
6096-9	Thermally Aged with Air as Process Medium	(a)	203
6096-10	Thermally Aged with Air as Process Medium, Irradiated to Accident Dose	(a)	16
6096-15	Thermally Aged with Air as Process Medium, Irradiated to Accident Dose, Exposed to MSLB/LOCA	(a)	3
6096-12	Thermally Aged with Nitrogen as Process Medium,	168	181
6096-13	Thermally Aged with Nitrogen as Process Medium, Irradiated to Accident Dose	47	(a)
6096-14	Thermally Aged with Nitrogen as Process Medium, Irradiated to Accident Dose, Exposed to MSLB/LOCA	22	(a)

---

a. Failed during removal from SOV.

b. Not exposed to process medium.

The accelerated thermal aging of the NP8314 SOVs with air as the process medium caused a condition similar to that of the O-rings in the HTX8314 SOVs;all of the body O-rings failed during removal from the SOVs but were performing their function while in the SOVs. The plugnut O-rings of these SOVs experienced a small loss of elongation from thermal aging, a large loss due to irradiation, and a small loss from the MSLB/LOCA exposure.

The thermal aging with nitrogen as the process medium was much less damaging than that of air for the body O-ring (6096-12). A large change again occurred during irradiation (6096-13), with a smaller change from the MSLB/ LOCA simulation. For SOVs 6096-12, -13, and -14 (nitrogen as process medium), the deterioration of the plugnut O-rings from the various segments of the test was very similar to that of the set (6096-9, -10, and -15) with air as the process medium (i.e., the elongation of O-rings that failed during removal was probably not significantly different from the values of 3 and 16% obtained for those that did not fail during removal).

The results of the tensile tests for the body O-rings of the ASCO SOVs with air as the process medium and accelerated aging were similar to those of the HTX9314 SOVs that were 8 years old. The results for the SOVs with nitrogen as the process medium were similar to those for the SOVs with 1.5 years of natural aging. This shows that accelerated aging with air is more severe than with nitrogen. However, there was no effect on the functional capability of the SOVs. All of the organic materials performed their required function during the MSLB/LOCA simulation.

7.6.2.2 Tensile Test Results for Valcor SOV O-Rings

Tables 19 and 20 provide the elongation-at-break data for the Valcor SOVs. The shaft seal O-ring on the naturally aged SOV (6096-19) actually had somewhat greater elongation than the new SOV (6096-25) (i.e., 268% vs 253%). Irradiation of the naturally aged SOV (6096-20) caused a sharp loss in elongation capability, and the addition of MSLB/LOCA exposure caused total deterioration of the O-ring. Irradiation of a new SOV without thermal aging caused deterioration to the point where the O-ring was intact in the SOV, causing no functional problems, but could not be rolled out of its slot without being split. MSLB/LOCA exposure coupled with irradiation caused some further deterioration that did not affect the O-ring's function, but again prevented removal for testing.

The upper and lower assembly O-rings on the naturally aged SOVs (6096-19, -20, and -21) reacted quite differently until the MSLB/LOCA exposure. The natural aging had little effect on the upper seal assembly O-ring, but seems to have had a larger effect on the lower O-ring. (The lower O-ring may have been cut or damaged at some time, which would greatly affect the elongation measurements.) Irradiation of the naturally aged SOVs caused a large change in both the upper and lower seal assembly O-rings, with the lower O-ring having practically zero elongation. The addition of the MSLB/LOCA exposure essentially eliminated the remaining elongation of the upper O-ring, so that after all exposures the upper and lower O-rings had nearly zero elongation capability left.

Table 19. Elongation-at-Break Measurements for Initially New Valcor Valves

		Ultimate Elongation-at-Break (%)						
		Seat Guide		Solenoid		Seal Assembly		
Specimen	Condition	Upper O-Ring	Lower O-Ring	Base O-Ring	Body O-Ring	Upper O-Ring (Seat)	Lower O-Ring (Seat)	Shaft Seal O-Ring
6096-25	Unaged	201	220	152	205	223	252	253
6096-27	Unaged, Irradiated to Accident Dose	56	52	27	56	69	81	Split during removal
6096-26	Unaged, Irradiated to Accident Dose, Exposed to MSLB/LOCA	Too deteriorated to test	0(b)	27	38	61	71	Too deteriorated to test

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a. This SOV was manufactured in 1986; data are provided for comparison to naturally aged devices that were manufactured in the 1980 time frame.

b. Fractured on testing machine prior to elongation.

Table 20. Elongation-at-Break Measurements for Naturally Aged Valcor Valves

		Ultimate Elongation-at-Break (%)						
		Seat Guide		Solenoid		Seal Assembly		
Specimen	Condition	Upper O-Ring	Lower O-Ring	Base O-Ring	Body O-Ring	Upper O-Ring (Seat)	Lower O-Ring (Seat)	Shaft Seal O-Ring
6096-25(a)	Unaged	201	220	152	205	223	252	253
6096-19	Naturally Aged (5 y)	191	166	191	190	226	132	268
6096-20	Naturally Aged (5 y), Irradiated to Accident Dose	58	15	43	55	83	0(b)	70
6096-21	Naturally Aged (5 y), Irradiated to Accident Dose, Exposed to MSLB/LOCA	Too deteriorated to test	4	0(b)	36	16	17	Too deteriorated to test

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a. This SOV was manufactured in 1986; data are provided for comparison to naturally aged devices that were manufactured in the 1980 time frame.

b. Fractured on testing machine before elongation.

The upper and lower seal assembly O-rings of the initially new SOVs (6096-27 and -26) behaved similarly: irradiation caused a large loss in elongation. However, there was no marked change in elongation from addition of the MSLB/LOCA exposure.

The remaining O-rings in the Valcor SOVs, i.e., those that provide static seals, behaved similarly to each other. Irradiation caused the largest loss of elongation, whether the SOVs were naturally aged or unaged. Following accident exposure, all had either totally lost their elongation capability or retained only a small fraction of it. It should be noted that the body O-ring, which seems to have retained its elongation best, is the best shield from air and the environment.

7.6.3 ASCO Core Disc Compression Tests

Table 20 summarizes the compression test results for the core disc assemblies of all of the ASCO valves in the program. The core discs were removed from the core assemblies by cutting through the core metal just above the disc so that the discs could be removed without damaging them. Each disc was then placed on an Instron tester and compressed between two flat plates at a rate of 0.1 in/min until a force of 500 lb was reached. The compression was then stopped, and the Instron plates were held at that position and the drop in force was measured as the disc material relaxed. The diameter of the discs was 0.37 in; the height was 0.28 in. The peak compression stress was approximately 4500 lb/in^2. The test was performed in an attempt to gain further insight with respect to the compressibility and stress relaxation of the disc material as a consequence of compressive loads (i.e., seating on the valve). The travel of the moving plate required to reach the 500-lb force load was recorded for each specimen. As stress relaxation occurred, the force was measured at 15 s, 30 s, 60 s, and 7 min, at which time the force had become reasonably stable.

For the unaged SOV (6096-16), the disc had to be compressed to less than half its thickness (0.17 in of compression) to reach the 500-lb force. The rate of relaxation was rather fast, with the force dropping to 405 lb within 15 s. Natural aging caused an apparent hardening of the disc of SOV 6096-6, but its relaxation was similar to that of the unaged disc. With irradiation added, the naturally aged disc of SOV 6096-7 hardened further and less stress relaxation occurred. The addition of MSLB/LOCA exposure caused little additional change in compressibility or relaxation.

The results of the compression tests for the SOVs with nitrogen as a process medium (6096-12, -13, and -14), in which 1 year of accelerated aging was simulated, were very similar to those for the SOVs with 1.5 years of natural aging.

The results of the compression tests for the SOVs with air as the process medium indicated that more deterioration occurred with air (instead of nitrogen) as the process medium during accelerated aging and MSLB/LOCA exposure.

7.6.4 Summary of Physical Property Measurements

Analysis of the effect of real or simulated service and accident simulation on the properties of the elastomeric parts of the SOVs was subject to the

Table 21. Depth of Compression and Relaxation Data for ASCO Core Discs

Code: Specimen No.
Depth of compression (in) at peak force of 500 lb.
Relaxation force (lb) at 15 s, 30 s, 60 s and 7 min.

	Naturally Aged, 1.5 y (NP8314)	Naturally Aged, 8 y (HTX8314)	Accelerated Aging, 4 y Air Process Medium	Accelerated Aging, 4 y Nitrogen Process Medium
Unaged	6096-16 0.17 405, 385, 370, 340			
Aged only	6096-6 0.14 405, 395, 380, 350	6096-1 0.10 410, 395, 380, 340	6096-9 0.13 390, 370, 350, 305	6096-12 0.14 400, 380, 365, 335
Aged and Irradiated to Accident Dose	6096-7 0.10 430, 420, 405, 380	6096-2 0.12 420, 410, 400, 370	6096-10 0.08 430, 420, 410, 380	6096-13 0.11 420, 410, 395, 365
Aged, Irradiated to Accident Dose, and Exposed to MSLB/LOCA	6096-8 0.11 435, 420, 410, 380	6096-3 0.05 365, 345, 325, 275	6096-15 0.08 420, 400, 385, 350	6096-14 0.10 425, 410, 395, 365

following limitations: for a particular part, the progressively increased severity of stressing was applied not to the same part but to equivalent parts in different SOVs, and for each combination of part and stress history there was only one specimen. Consequently, the data were subject not only to measurement errors but also the scatter caused by intrinsic differences among the SOVs and their parts.

7.6.4.1 Hardness of ASCO SOV Parts

On ASCO SOVs, 1.5 y of service appeared to cause little hardening of the body O-ring; irradiation increased the hardness, but the MSLB/LOCA exposure had little further effect. Eight years of service did produce noticeable hardening of the body O-ring; but in this case neither irradiation and the MSLB/LOCA exposure had significant effect on hardness. Most of the plugnut O-rings from the naturally aged SOVs were too damaged to be tested.

Hardness measurements on the body O-rings from the ASCO SOVs showed an increase in hardness due to accelerated thermal aging with nitrogen as the process medium, but no further effect due to irradiation or the MSLB/LOCA exposure. The body O-rings from the SOVs that had been tested with air as the process medium were too damaged to permit hardness measurements. In the case of the plugnut O-rings, thermal aging appeared to have little effect on hardness, independently of whether air or nitrogen was the process medium. This observation is consistent with the fact these O-rings are not exposed to the process medium and their position makes them less sensitive to heat from the coil. However, irradiation did cause a significant increase in hardness.

The effect of natural aging on the ASCO core discs was similar to the effect on the body O-rings, i.e., little effect after 1.5 y of service but noticeable hardening after 8 y of service. Irradiation appeared to produce a small increase in hardness of the core disc from the SOV with 1.5 y of natural aging, and an even smaller hardness increase (comparable to the experimental accuracy) in the case of the SOV with 8 y of natural aging. In both cases, the MSLB/LOCA exposure appeared to have negligible effect.

With accelerated thermal aging, there was no noticeable change in the ASCO core disc hardness with nitrogen as the process medium, but there was a significant increase with air as the process medium. In the latter case, irradiation and the MSLB/LOCA exposure did not have significant additional effect, but in the former case (i.e., nitrogen process medium) irradiation caused an increase in hardness and the MSLB/LOCA exposure had no noticeable effect.

Irradiation of the Valcor SOVs produced negligible to substantial increase in hardness, the largest increase (from a Shore "A" durometer of 79 to 93) occurred in the naturally aged SOVs.

Most of the O-rings deteriorated during the MSLB/LOCA exposure to the point that post-MSLB/LOCA measurements were impossible. The seal assembly O-rings retained their integrity through the MSLB/LOCA exposure, with the hardness increasing as much as 10%; but the pattern of increasing hardness was clouded by the observation of lower hardness, after the MSLB/LOCA exposure, in the case of the lower seal assembly O-ring of the naturally aged SOV. The solenoid base and body O-rings of the initially new SOVs also retained their integrity; but these likewise exhibited a reduction of hardness by about 10% during the MSLB/LOCA exposure.

Although the hardness of elastomeric parts in the ASCO SOVs was affected in various ways by years of service, thermal aging, process medium, and irradiation, there was usually no significant effect due to the MSLB/LOCA exposure. The hardness changes did not affect the functional capability.

7.6.4.2 Elongation of ASCO SOV Parts

The effect of service and test stresses on the ultimate elongation at break was much greater than the effect on hardness. For ASCO SOVs, either accelerated thermal aging in air or 1.5 y of service reduced the elongation of the EPDM O-rings by 10% to 15%; however, one O-ring failed during removal from the SOV. After thermal aging with nitrogen as the process medium, the elongation of the EPDM O-rings was 20% to 30% less than the elongation of the O-rings in the new SOVs. The elongation of the body O-ring exposed to air during accelerated aging was essentially zero, the O-ring being too fragile to be removed from the specimen without destroying it. After irradiation and exposure to the MSLB/LOCA simulation the elongation was greatly reduced, the highest value being about 1/4th the original value and essentially zero (i.e., too deteriorated to measure) in several cases. For the SOVs with Buna-N, seals, 8 y of service plus 2000 cycles caused the O-rings to become too fragile for measurement.

7.6.4.3 Elongation of Valcor SOV Parts

Evaluation of the data for ultimate elongation at Break for Valcor SOVs was complicated by the fact that the O-rings of naturally-aged SOVs and the other SOVs came from different batches, and possibly from different manufacturers. In some cases the elongation of O-rings from naturally-aged SOVs was as much as 50% lower than the elongation of O-rings from new SOVs; but in other cases there was either no significant difference or the difference was in the opposite direction. Irradiation caused large decreases in elongation, whether applied to new SOVs or the naturally-aged SOVs. In practically all cases, the MSLB/LOCA exposure caused further decrease in elongation; in a few cases the O-rings were too deteriorated for elongation measurements following the MSLB/LOCA exposure.

7.6.4.4 Compression/Relaxation of ASCO Core Discs

The compression/relaxation measurements indicated that the ASCO core discs became less compressible after various environmental exosures; however, they retained their ability to flow under load and take the shape of the valve seat.

After thermal aging, SOV 6096-9 had greater stress relaxation than the naturally aged SOVs or the SOVs with nitrogen as the process medium. A more drastic hardening occurred during irradiation (SOV 6096-10). The hardening did not change due to the MSLB/LOCA exposure. Stress relaxation decreased after irradiation, then increased somewhat after the MSLB/LOCA simulation.

The Buna-N core discs of the HTX8314 SOVs (6096-1, -2, and -3) responded differently from the EPDM seats of the NP8314 SOVs (6096-6, 7, 8).

Irradiation of the SOVs softened the Buna-N disc seats, but decreased the relaxation slightly. The MSLB/LOCA exposure caused significant hardening, and the stress relaxation increased substantially.

The results of these tests are not highly definitive. However, they indicate that, while the materials become less compressible (i.e., deform less when loaded) after the various environmental exposures, they retain their ability to adjust their shape. That is, they flow under load, and are thereby able to take the shape of the valve seat, which is one requirement to provide a seal.

7.6.5 Properties of Critical Parts

The somewhat complex account of the effect of plant service and test stresses on physical properties of the elastomeric parts can be simplified by focusing on the critical parts. In Table 22, the hardness measurements are summarized for the critical parts: the ASCO core discs and the Valcor shaft seal O-rings. A similar summary of elongation data is given in Table 23; however, since elongation measurements could not be made on the ASCO core discs, data are given for the ASCO body O-rings instead.

The core disc data show that accelerated thermal aging with air as the process medium caused an increase in hardness to the level observed in SOVs that had been in service for 8 y. With nitrogen as the process medium, there was no noticeable hardening due to thermal aging. Irradiation caused hardness to increase slightly, except that a larger increase occurred in the SOVs aged with nitrogen as the process medium. It appears that radiation has less effect if hardness has already been increased by the prior stress history. The MSLB/LOCA exposure had no significant effect on hardness.

The pattern of hardness changes caused by service stresses and radiation in the Valcor shaft seal O-rings is similar to the ASCO pattern. However, the MSLB/LOCA exposure caused deterioration that prevented subsequent hardness measurements.

Table 23 reveals the general loss of elongation with increasing stress history. Accelerated thermal aging in air and 8 y of service caused complete loss of elongation in the ASCO body O-rings. Unlike the effect on hardness, radiation caused significant decrease in elongation independently of the prior history; and the MSLB/LOCA also caused significant further reduction in elongation. (Of course, once the elongation was lost altogether, further stressing had no effect.)

Table 22. Shore "A" Durometer Measurements for Critical Elastomeric Parts (a)

ASCO Core Discs (EPDM, except as marked)

Condition	In service	In service	Accelerated Aging	
	1.5 y	8 y	Air Medium	Nitrogen Medium
As received from mfr.	-	-	82	82
After thermal and cyclic aging	-	-	90	82
After service	83	90 (Buna-N)	-	-
Plus 200 Mrd	87	92 (Buna-N)	92	88
Plus MSLB/LOCA	86	93 (Buna-N)	89	88

Valcor Shaft Seal O-rings (EPR)

Condition	In Service 5 y	Initially New
As received from mfr.	-	72
After service	69	-
Plus 200 Mrd	71	77
Plus MSLB/LOCA	(b)	(b)

(a) Each number is an average of three measurements.

(b) Too damaged to test.

Table 23. Elongation at Break for Critical O-rings
(all values in %)

ASCO Body O-rings (EPDM, except as marked)

Condition	In service	In service	Accelerated Aging	
	1.5 y	8 y	Air Medium	Nitrogen Medium
As received from mfr.	-	-	246	246
After thermal and cyclic aging	-	-	0	168
After service	226	0 (Buna-N)	-	-
Plus 200 Mrd	65	0 (Buna-N)	0	47
Plus MSLB/LOCA	50	0 (Buna-N)	0	22

Valcor Shaft Seal O-rings (EPR)

Condition	In Service 5 y	Initially New
As received from mfr.	-	253
After service	191	-
Plus 200 Mrd	58	0
Plus MSLB/LOCA	0	0

8. CONCLUSIONS

It was difficult to draw quantitative general conclusions from the program because each specimen differed from the others in type of specimen, or test sequence, or both. Nonetheless, differences among the test results for different combinations of specimen type and test sequence did permit qualitative observations.

An organic deposit of undetermined origin discovered during an early stage of thermal aging in the area surrounding the metal-to-metal seat of the ASCO NP8314 SOVs caused failure to transfer. Similar failures have been observed at the Ft. Calhoun plant, which supplied some naturally aged NP8314 SOVs for the program, and at other plants. Transfer occurred properly after the deposit was cleaned from the SOVs. Once the organic deposit was removed, accelerated thermal aging of the ASCO SOVs was completed successfully.

The equivalence of the accelerated thermal aging to years of plant service depends on ambient air velocity as well as temperature. For stagnant air at an ambient temperature of 100°F (38°C), the accelerated thermal aging of ASCO SOVs was equivalent to 4.7 y of continuously energized service. For the same application, the accelerated thermal aging of the coils was equivalent to 0.2 y of continuously energized service.

Attempts at aging the Valcor SOVs were terminated because of repeated failures during accelerated thermal aging. Two types of failures occurred: the shaft seal O-ring adhered to the guide tube, and the upper seal assembly O-ring adhered to its seat.

Measurement of the physical properties (hardness, elongation, and compressibility) of the elastomeric parts indicated progressive deterioration as a consequence of stresses due to service, thermal aging, process medium, irradiation, and the MSLB/LOCA exposure.

In the ASCO SOVs, the elastomeric parts wet by the process medium experienced greater degradation with air than with nitrogen as the process medium. (As all of the Valcor SOVs were tested using air as the process medium, they did not contribute to information on the relative effects of air and nitrogen.)

For the naturally aged SOVs there was significantly more hardening, as expected, after 8 y of service than after 1.5 y of service. Accelerated thermal aging with air as the process medium caused an increase in hardness of the ASCO core disc comparable to the level observed in SOVs that had been in service for 8 y. With nitrogen as the process medium, there was no noticeable hardening of the core disc due to thermal aging.

When added to natural aging or thermal aging in air, irradiation tended to increase hardness, brittleness, and compression set. A greater increase in hardness occurred in the SOVs aged with nitrogen as the process medium. It appeared that radiation has less effect if hardness has already been increased by the prior stress history (e.g., by 8 y of service or accelerated thermal aging in air). The combined effect of thermal aging and irradiation appeared to be nearly independent of the process medium. However, elastomeric parts tended to remain more pliable after irradiation if nitrogen had been used during thermal aging or if there had been no thermal aging prior to irradiation. The MSLB/LOCA exposure had no significant effect on hardness.

The effect of service and test stresses on the ultimate elongation at break was much greater than the effect on hardness.

Complete loss of elongation occurred in ASCO body O-rings subjected either to accelerated thermal aging in air or 8 y of service. On those parts that retained elongation due to a less severe stress history (e.g., shorter service time or thermal aging with nitrogen) irradiation produced a major decrease in elongation. Accelerated thermal aging with nitrogen as the process medium caused elongation to be reduced to about two-thirds of the initial value and subsequent irradiation reduced the elongation to a level less than one-third the value after thermal aging. Irradiation caused a reduction of body O-ring elongation in the SOV with 1.5 y of service to less than one-third its value when removed from service. Elongation was further decreased or destroyed altogether by exposure to the MSLB/LOCA environment.

As seen from the foregoing statements, the degrading effect of radiation on hardness and elongation depended in part on the degradation already present due to prior stressing. The greater the existing degradation, the less the additional degradation caused by radiation.

The compression/relaxation measurements indicated that the ASCO core discs became less compressible after various environmental exposures; however, they retained their ability to flow under load and take the shape of the valve seat. The core discs retained adequate sealing capability, leakage being minor when it did occur.

The deterioration of the elastomeric parts of the ASCO SOVs appeared to have a secondary effect on their functional capability. There was no influence at the upper seat, where there is a metal-to-metal interface; and, at the lower seat, sealing took place even with a degraded core disc.

Deterioration of the Valcor O-rings did interfere with the functional capability of the SOVs. Fragmentation of the O-ring prevented sealing, and deterioration of the shaft seal O-ring caused the shaft to stick inside its guide tube.

The elastomeric parts of ASCO SOVs appeared to retain adequate integrity during all test exposures (aging, gamma irradiation, and MSLB/LOCA simulation). This was true independently of which process medium (air or nitrogen) or material (EPDM or Buna N) was used. However, the ASCO coil housings permitted entry of moisture during the MSLB/LOCA simulation, and this caused significant coil deterioration. Two of four ASCO SOVs failed as a consequence of coil problems during the MSLB/LOCA simulation. This contrasts with the findings of an earlier research program [1], in which coils of ASCO valves functioned satisfactorily even when subjected to wetting during a LOCA simulation.

During the MSLB/LOCA test, the SOVs began to experience severe difficulty when they were energized for 2 h to simulate the operation of SOVs used in sampling systems. Moisture had probably already penetrated the coil housings at this time. Evidently, the metal-to-metal seals with silicone grease were not able to prevent moisture intrusion during MSLB/LOCA conditions.

Of the two naturally-aged ASCO SOVs put through the MSLB/LOCA simulation, one (with Buna-N seats and 8 y of service) functioned satisfactorily throughout the test, while another (with EPDM seats and 1.5 y of service) failed to operate 29 h after the start of the second MSLB/LOCA transient. Of the two ASCO SOVs with accelerated aging, the one with nitrogen as the process medium transferred properly at all times (in spite of minor coil damage at one point) and the one with air as the process medium failed to operate 8 h after the start of the second transient of the MSLB/LOCA simulation.

In the predecessor research program [1], body leakage was observed; but no body leakage was detected with the configuration of ASCO SOVs tested in this program.

A 5-y old, naturally aged Valcor SOV experienced some transfer delays as received and after irradiation, but it functioned satisfactorily during the first high temperature profile of the MSLB/LOCA simulation. However, it failed to transfer before the start of the second MSLB/LOCA transient; it experienced difficulty 4 h later, and essentially failed altogether about a day later. Both coil failure and elastomer deterioration contributed to the problem, with elastomer deterioration possibly aggravating the coil problem. The shaft seal O-ring had deteriorated totally; and the residual materials had become redistributed between the shaft and its guide tube, causing them to adhere to one another. The deterioration of the shaft seal O-ring and binding of the shaft were similar to, but less severe than, the deterioration observed during thermal aging.

Except for some transfer delays, a Valcor SOV that had no thermal or operational aging transferred properly throughout the test, but it had excessive leakage beginning about 8 h after the start of the second MSLB/LOCA transient. Leakage was caused by hardening and partial fragmentation of the O-ring seals, with the remaining seat material preventing closure of the valve ports. This type of failure was observed following the completion of the first MSLB/LOCA transient, and it worsened significantly after a half-hour of continuous energization 8 h after the start of the second transient.

Partly because of the dominance of problems with coils, which are not exposed to the process medium, there was no clear evidence that the process medium had a significant influence under accident conditions. More importantly, the effects of natural and accelerated aging were relatively minor compared to the effects of the MSLB/LOCA exposure on functional capability.

In summary, the ASCO SOVs experienced a transfer problem early in the program due to an internal deposit of undetermined origin; removal of the deposit eliminated the problem. During the MSLB/LOCA simulation, entry of water into the coil housings caused coil problems that resulted in transfer failure in two of the ASCO SOVs. The earliest ASCO failure occurred 8 h after the start of the second MSLB/LOCA transient with an SOV that had been subjected to accelerated thermal aging using air as the process medium. The next failure occurred with an SOV that had been in service 1.5 y. The SOV with Buna-N parts and 8 y of service, as well as the SOV with accelerated thermal aging of the core disc using nitrogen as the process medium, performed satisfactorily throughout the program.

The ASCO SOVs tested in this program, after cleaning of any internal deposits, were capable of short term operation following the start of an accident. However, it should be noted that an early failure occurred with an SOV that had had relatively short (1.5 y) natural aging.

The Valcor SOV that had been in service for 5 y was also able to perform satisfactorily for a short term after initiation of the accident simulation. On the other hand, the initially new Valcor SOV, that was not subjected to thermal aging, exhibited transfer delays and excessive leakage even before the start of the MSLB/LOCA exposure.

9. REFERENCES

1. D. V. Paulson, T. A. Shook, V. P. Bacanskas, S. P. Carfagno, "Environmental Qualification Research - Test Program and Failure Analysis of Class 1E Solenoid Valves," NUREG/CR-3424, USNRC, Washington, DC, November 1983

2. "Nuclear Plant Aging Research (NPAR) Program Plan," NUREG-1144, USNRC, Washington, DC, July 1985

3. FRC Report No. P-C6096, "Test Plan and General Procedures for Aging and Qualification Research on Solenoid Operated Valves," September 9, 1986. (Revision 1 of the test plan is included as Appendix A of this report.)

4. U.S. Nuclear Regulatory Commission, NUREG/CR-3424, "Equipment Qualification Research - Test Program and Failure Analysis of Class 1E Solenoid Valves," Washington, DC, November 1983, prepared by Franklin Research Center.

5. Letter, R. Heilman (Valcor Engineering Corporation) to V. P. Bacanskas (FRC), July 14, 1986.

6. "Ethylene Propylene Elastomer Technology for Improved High Temperature Serviceability," R. S. Auda and D. R. Hazelton, Exxon Chemical Co., presented at the Society of Automotive Engineers - Automobile Engineering Meeting, Detroit, MI, October 1975.

APPENDIX A

COMPLETE TEST PLAN

NOTE: Because of the specimen failure during accelerated thermal aging, the procedures were modified as discussed in Section 6 of the report.

Test Plan and General Procedures for Aging and Qualification Research on Solenoid Operated Valves

FRC Report No. P-C6096
Revision 1

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1. INTRODUCTION

1.1 TEST PROGRAM OBJECTIVES

The purpose of the test program is to evaluate and compare the condition of solenoid operated valves (SOVs) that have been subjected to natural and artificial aging, different process media (air and nitrogen), and the incremental changes in deterioration from aging, accident irradiation, and loss-of-coolant-accident (LOCA) tests.

1.2 REQUIREMENTS AND GUIDANCE

The elements of the test program are based on the requirements and guidelines of the following references:

- Martin Marietta Subcontract No. 41Y-19760-C [1]*
- IEEE Std 323-1983 [2]
- IEEE Std 382-1980 [3]
- UL-429 [4]
- ASTM D2240-81 [5]
- ASTM D1414-78 [6]

Additional guidance was provided by review of the following documents:

- FRC Report No. P-C5569-9 [7]
- NUREG/CR-3424 [8].

1.3 DISCUSSION OF TEST PLAN OBJECTIVES

This research program has been designed to provide quantifiable data for the degradation of SOV elastomers resulting from normal service and accident simulation in nuclear power plants. To accomplish this objective, several Valcor[1] and ASCO[2] SOVs have been obtained from operating nuclear power plants. The Valcor SOVs were replaced because they had reached the end of their qualified life, whereas the ASCO SOVs were replaced due to a plant-specific sticking problem. New SOVs of the same model number and having the same elastomer compounds were procured to provide a basis for comparison.

The test program is designed to provide a direct comparison between valves aged in nuclear power plant service and valves aged by accelerated methods. The number of test specimens will be sufficient to allow removal of one valve from each manufacturer from each state (naturally or artificially aged) after each environmental exposure to determine the contribution of that exposure to the degradation of the valve. In addition, two sets of new ASCO solenoid valves will be included in the test program to determine the difference in aging effects on valves using nitrogen as a process fluid as opposed to valves using instrument quality air as a process fluid. The use of different process media will provide data on the aging of the elastomers in both oxygen and inert (nitrogen) environments.

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*Numbers in brackets refer to citations in Section 18.

[1] Valcor Engineering Corp., Springfield, NJ 07081.

[2] Automatic Switch Company, Florham Park, NJ 07932.

The current research program is a sequel to an earlier program conducted by Franklin Research Center (FRC) for the Nuclear Regulatory Commission (NRC) on SOVs manufactured by the Automatic Switch Company (ASCO). The results of the research program are documented in Reference 8. The test program steps included thermal, operational, radiation, and vibration aging as well as seismic testing, design basis event radiation, and an exposure to LOCA steam and pressure conditions. A failure analysis was conducted at the conclusion of the test program. One of the goals of the failure analysis was to identify the portion of the environmental simulation (e.g., thermal aging, radiation) that was most responsible for the significant elastomer deterioration that occurred. A comparison between valves aged by accelerated techniques and valves that were aged in real time at the manufacturer's facilities was also included in the program.

The portion of the environmental simulation during which the valve degradation occurred could not be specifically identified from the failure analysis, because disassembly and testing of specimens was performed only after the entire test program had been completed (i.e., not after each step of the environmental simulation). The comparison between the SOVs aged in real time by the manufacturer and the artificially aged SOVs was limited by differences in the process medium (air and nitrogen) used during the aging simulation and by dissimilar equivalent lives of the two sets of specimens.

2. DESCRIPTION OF TEST SPECIMENS

2.1 OVERVIEW

To obtain naturally aged SOVs, approximately 25 nuclear power plants were contacted by FRC in an effort to obtain ASCO and Valcor SOVs that were being replaced because they had reached the end of their qualified life in the plants. The contacts resulted in FRC obtaining three sets of test specimens from two operating power plants. The naturally aged test specimens are described in the paragraphs that follow. A summary description of all the test specimens is provided in Table 1.

2.2 ASCO SOLENOID OPERATED VALVES

Two types of ASCO SOVs were obtained from Omaha Public Power District's Fort Calhoun Station. Ten ASCO SOVs that are not environmentally qualified for Class 1E service were received. These ten SOVs are three-way, direct acting SOVs, ASCO Model No. HTX831429. They were removed from service at the Fort Calhoun plant after approximately 8 years of service, since the function that they performed was safety-related and the SOVs were not environmentally qualified.

The Fort Calhoun plant also provided an additional ten ASCO SOVs; these ten were environmentally qualified for Class 1E service. These SOVs are ASCO Model No. NP8314C29E and are three-way, direct acting SOVs as well. The NP8314 SOVs were used to replace the HTX8314 SOVs discussed previously. The NP8314 SOVs had been in service approximately 18 months and were removed from service as a result of failures of similar ASCO SOVs. The failures were caused by sticking of the SOV core assembly to its plug nut.

FRC has procured nine new NP8314C29E SOVs from ASCO to be used as the artificially aged specimens for the test.

2.3 VALCOR SOLENOID OPERATED VALVES

Seven Valcor SOVs were supplied for the program by the Duke Power Company. The SOVs are three-way, direct acting SOVs removed from the McGuire Nuclear Station at the end of their 5-year qualified life. The Valcor SOVs are Model No. V-70900-21-3 and are environmentally qualified for Class 1E service. The service life of these SOVs consisted of 2 years of preoperational testing and 3 years of power plant operation.

FRC has procured six new Valcor Model No. V-70900-21-3 SOVs to be used as the artificially aged specimens for the test.

A description of each of the Valcor SOVs is included in Table 1. Table 2 provides the service history of all of the SOVs to be used in the program.

FRC has procured six new Valcor Model No. V-70900-21-3 SOVs to be used as the artificially aged specimens for the test.

A description of each of the Valcor SOVs is included in Table 1. Table 2 provides the service history of all of the SOVs to be used in the program.

Table 1. Description of Test Specimens and Related Data

FRC Ident. Number	Catalog No. and Type	Serial Number	Solenoid Description		Valve Description		Pipe Size (in)	Maximum Pressure (lb/in^2)	Test Pressure (lb/in^2)
			Normal Voltage	Enclosure (NEMA Type)	Application and Operation	Valve Seating Material			
6096-1	HTX831429	52758T	125 Vdc	4,7	Normally closed, 3-way construction	Buna "N" and Nylon	1/4	60	60
6096-2	HTX831429	53290T	125 Vdc	4,7	Normally closed, 3-way construction	Buna "N" and Nylon	1/4	60	60
6093-3	HTX831429	53291T	125 Vdc	4,7	Normally closed, 3-way construction	Buna "N" and Nylon	1/4	60	60
6096-4	HTX831429	53291T	125 Vdc	4,7	Normally closed, 3-way construction	Buna "N" and Nylon	1/4	60	60
6096-5	NP8314C29E	05467K-36	125 Vdc	3,4,7,9	Normally closed, 3-way construction	Combination metal and ethylene propylene	1/4	60	60
6096-6	NP8314C29E	05467K-32	125 Vdc	3,4,7,9	Normally closed, 3-way construction	Combination metal and ethylene propylene	1/4	60	60
6096-7	NP8314C29E	05467K-37	125 Vdc	3,4,7,9	Normally closed, 3-way construction	Combination metal and ethylene propylene	1/4	60	60
6096-8	NP8314C29E	05467K-44	125 Vdc	3,4,7,9	Normally closed, 3-way construction	Combination metal and ethylene propylene	1/4	60	60
6096-9	NP8314C29E	20884(R-8)	125 Vdc	3,4,7,9	Normally closed, 3-way construction	Combination metal and ethylene propylene	1/4	60	60
6096-10	NP8314C29E	20884R(4)	125 Vdc	3,4,7,9	Normally closed, 3-way construction	Combination metal and ethylene propylene	1/4	60	60
6096-11	NP8314C29E	20884R(7)	125 Vdc	3,4,7,9	Normally closed, 3-way construction	Combination metal and ethylene propylene	1/4	60	60
6096-12	NP8314C29E	20884R(5)	125 Vdc	3,4,7,9	Normally closed, 3-way construction	Combination metal and ethylene propylene	1/4	60	60

Table 1. Description of Test Specimens and Related Data (Cont.)

FRC Ident. Number	Catalog No. and Type	Serial Number	Solenoid Description		Valve Description		Pipe Size (in)	Maximum Pressure (lb/in^2)	Test Pressure (lb/in^2)
			Normal Voltage	Enclosure (NEMA Type)	Application and Operation	Valve Seating Material			
6096-13	NP8314C29E	20884R(6)	125 Vdc	3,4,7,9	Normally closed, 3-way construction	Combination metal and ethylene propylene	1/4	60	60
6096-14	NP8314C29E	20884R(2)	125 Vdc	3,4,7,9	Normally closed, 3-way construction	Combination metal and ethylene propylene	1/4	60	60
6096-15	NP8314C29E	20884R(1)	125 Vdc	3,4,7,9	Normally closed, 3-way construction	Combination metal and ethylene propylene	1/4	60	60
6096-16	NP8314C29E	20884R(3)	125 Vdc	3,4,7,9	Normally closed, 3-way construction	Combination metal and ethylene propylene	1/4	60	60
6096-17	NP8314C29E	20884R(9)	125 Vdc	3,4,7,9	Normally closed, 3-way construction	Combination metal and ethylene propylene	1/4	60	60
6096-18	V07900-21-3	258	125 Vdc	4	Normally closed, 3-way construction	EPR	1/2	150	100
6096-19	V07900-21-3	45	125 Vdc	4	Normally closed, 3-way construction	EPR	1/2	150	100
6096-20	V07900-21-3	128	125 Vdc	4	Normally closed, 3-way construction	EPR	1/2	150	100
6096-21	V07900-21-3	201	125 Vdc	4	Normally closed, 3-way construction	EPR	1/2	150	100
6096-22	V07900-21-3	1596	125 Vdc	4	Normally closed, 3-way construction	EPR	1/2	150	100
6096-23	V07900-21-3	1597	125 Vdc	4	Normally closed, 3-way construction	EPR	1/2	150	100
6096-24	V07900-21-3	1598	125 Vdc	4	Normally closed, 3-way construction	EPR	1/2	150	100
6096-25	V07900-21-3	1599	125 Vdc	4	Normally closed, 3-way construction	EPR	1/2	150	100
6096-26	V07900-21-3	1600	125 Vdc	4	Normally closed 3-way construction	EPR	1/2	150	100
6096-27	V07900-21-3	1601	125 Vdc	4	Normally closed, 3-way construction	EPR	1/2	150	100

Table 2. Naturally Aged Valves Service History

FRC Ident. Number	Serial Number	Manufacturer	Model Number	Years of Service	Normal Ambient Temperature (°F)	Radiation Dose (R/h)	Calculated Total Integrated Dose
6096-1	52758T	ASCO	HTX831429	8*	107	--	7.0×10^4
6096-2	53290T	ASCO	HTX831429	8*	90	--	7.0×10^4
6096-3	53291T	ASCO	HTX831429	8*	Unknown	Unknown	Unknown
6096-4	53291T	ASCO	HTX831429	8*	Unknown	Unknown	Unknown
6096-5	05467K-36	ASCO	NP8314C29E	1.25	107	--	1.1×10^4
6096-6	05467K-32	ASCO	NP8314C29E	1.25	107	--	1.1×10^4
6096-7	05467K-37	ASCO	NP8314C29E	1.25	107	--	1.1×10^4
6096-8	05467K-44	ASCO	NP8314C29E	1.25	107	--	1.1×10^4
6096-18	258	Valcor	V-70900-21-3	5	100-120	2.9	7.6×10^4**
6096-19	45	Valcor	V-70900-21-3	5	100-120	2.9	7.6×10^5**
6096-20	128	Valcor	V-70900-21-3	5	100-120	57	1.5×10^6**
6096-21	201	Valcor	V-70900-21-3	5	100-120	57	1.5×10^6**

---

*Approximate age; exact age is unknown.

**The valve experienced the listed radiation levels in approximately 3 years. Two of the 5 years of service were during preoperational testing.

2.4 RATIONALE FOR SELECTION OF TEST SPECIMENS

Selection of the test specimens was limited by the availability of naturally aged SOVs. The new SOVs procured for the program have identical model numbers and elastomers to the SOVs obtained from the nuclear power plants.

3. ACCEPTANCE CRITERIA

The SOVs will be considered to have met the acceptance criteria for this program if, during and after the test program, upon application (or removal) of rated voltages and supply pressures, the SOVs respond promptly to pressurize or exhaust sealed volumes (e.g., cylinders) as required by their mode of operation. Although no acceptance criteria for leakage were established, SOV leakage will be measured during functional testing throughout the test program.

Rationale

The types of SOVs being tested are normally used as pilot devices to actuate pneumatically actuated operators that move larger valves or dampers. They are used in a normally energized state so that upon loss of electrical power or pneumatic supply to the SOV, the pneumatically actuated device will transfer to its fail-safe condition. For these reasons, the safety function of the SOVs is defined as responding to the removal of nominal voltage from the solenoid coil to cause a closed volume in the pneumatically actuated device to be promptly exhausted.

Although the SOV manufacturers usually have an acceptance criterion for response time of SOV actuation, the response time is generally in the millisecond range and could not be accurately measured without use of test equipment that is precluded by the budget for the project. The qualitative term "responds promptly" has been used to define acceptable operability of the SOVs. During previous testing of SOVs at FRC, visual observation of the pressure gage connected to the process port of the SOV has been used to determine operability. Since slow or sluggish operation (i.e., response time observed to be seconds or longer) has been readily apparent, this method will satisfy the test criteria.

With respect to SOV leakage (combined body and seat leakage), no specific acceptance criteria for nuclear power plant applications could be identified. Although it is known that there are applications in nuclear power plants where small accumulators are used to provide supply pressure to SOVs under loss of pneumatic supply and under post-accident conditions, leakage acceptance criteria could not be identified on a generic basis since the criteria depend on the specific application. As a result, no acceptance criteria will be stated for this test program, but measured leakages will be reported.

4. MOUNTING, CONNECTION, AND INTERFACE REQUIREMENTS

The specimens will be mounted with solenoids vertical and upright throughout the test program. The SOVs will be fastened to test fixtures using brackets and the integral mounting holes on each style of SOV.

As a test convenience, all specimens will be mounted onto a support fixture in a tree-like arrangement for compactness during exposures to thermal aging, gamma irradiation, and simulated LOCA/MSLB conditions. The specimens will remain on the test fixture for functional testing.

The inlet/outlet ports of the valve bodies will be equipped with appropriately sized NPT bushings and adapters to connect [illegible] copper tubing. Supports will be provided for the tubing as requi[illegible] [illegible]-based lubricant will be applied to the pipe thread interface betw[illegible] valve body port and piped connections. The exhaust port of the ASCO [illegible] will be provided with a series of two 90° elbows prior to [illegible]/MSLB exposure so that the open end faces down precluding direct ent[illegible] the valve body of steam or chemical spray.

During thermal aging and the DBE radiation exposure, the lead wires for the artificially aged Valcor SOVs will be routed through the 3/4-in NPT electrical conduit connections and through 90° street elbows so that the lead wires are in a horizontal plane. The lead wires for the artificially aged ASCO SOVs will be routed in a similar manner; however, the construction of the ASCO SOVs results in the open ends of the 90° street elbows facing downward.

The lead wires for the artificially aged SOVs will be terminated with crimped spade lugs of appropriate size which will be connected to terminal strips fastened to the support fixture. The naturally aged SOVs will be provided with crimped spade lugs of appropriate size for use during functional testing.

After the DBE radiation exposure, the six SOVs (four ASCO, two Valcor) to be subjected to the LOCA/MSLB exposure will have their electrical connections prepared in the following manner (see Figure 1).

Prior to the LOCA/MSLB exposure, the solenoid leads will be butt-spliced with crimped connections to Teflon-insulated solid conductor extension wires. The spliced sections will be covered with Raychem Thermofit WCSF-N heat-shrinkable tubing. The splices will be physically separated from each other and from exposed conductive materials (e.g., solenoid housing). A threaded condolet box (with removable cover) will be connected to the solenoid housing and the leads routed through the condolet box. The condolet box cover will be removed, and a GE RTV silicone compound will be poured into the condolet box, filling the condolet box from the solenoid housing (see Figure 1) to the condolet outlet. The sealing method will provide reasonable assurance that moisture will not enter the solenoid housing during the LOCA/MSLB exposure through the electrical interface.

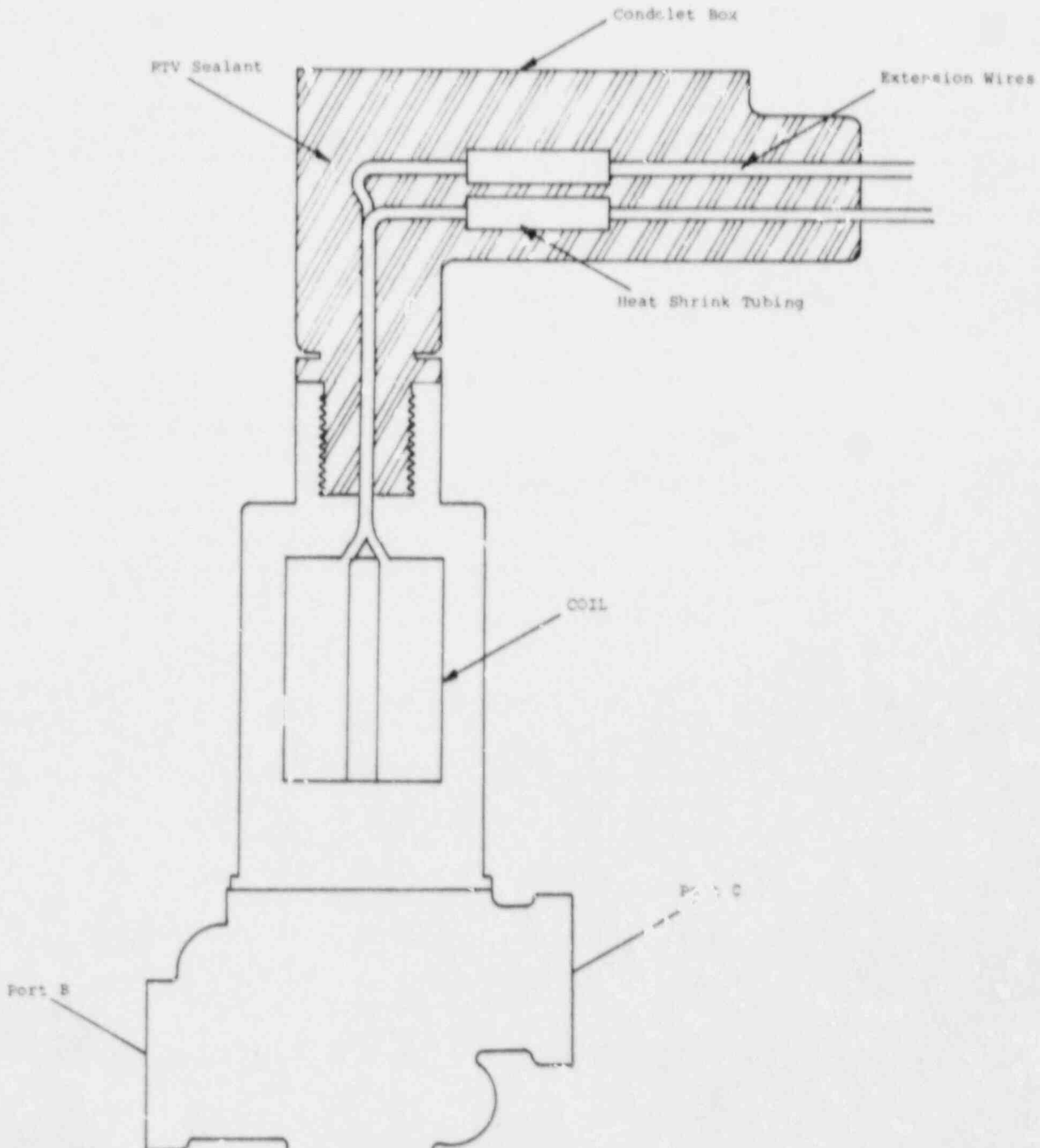

Figure 1. Electrical Interface Sealing Method

5. DESCRIPTION OF SOV FUNCTIONAL GROUPS

To be responsive to the program objectives, the test specimens were divided into four groups. Each of the four groups will be exposed to portions of the test program to allow comparison of the effects of the environmental exposures on the SOVs. Group I SOVs will be subjected to functional testing prior to disassembly, inspection, and material testing to provide baseline data on the SOV and material performance. Group I consists of one new ASCO Model No. NP8314C29E SOV (6096-15) and one Valcor Model No. V-70900-21 SOV (6096-27). Groups II, III, and IV consist of multiple samples and are identified in Table 3. The naturally aged ASCO and Valcor SOVs will not be subjected to any additional aging prior to other test steps.

The SOVs from Group II will be subjected to accelerated aging (thermal and operational) prior to disassembly and material testing. The data obtained from the Group II values will be compared with the data from the Group I valves to determine the change in SOV performance and material degradation resulting from the aging. The SOVs from Group III will be subjected to a DBE radiation exposure (200 Mrd gamma) after completion of the aging simulation. The disassembly and material testing that follows will provide information on the effects of the sequential exposures on the SOV materials. The final group of SOVs, Group IV will be subjected to a 30-day LOCA/MSLB simulation in addition to the aging and radiation exposures. The functional test data from Group IV, as well as the post-DBE exposure material testing will provide the final set of data on the effects of the environmental simulation on the SOVs. In addition, one ASCO Model No. NP8314C29E will be supplied with nitrogen as the process medium throughout the test so that the effects of the nitrogen environment on the internal organic materials can be compared with the air environment that is normally used with SOVs.

Table 3. SOV Functional Groups

Mfr.	Model No.	Aging	Process Medium	Functional Group II	Functional Group III	Functional Group IV
ASCO	NP8314C29E	Accelerated	Air	6096-9	6096-10	6096-11
ASCO	NP8314C29E	Accelerated	Nitrogen	6096-12	6096-13	6096-14
ASCO	NP8314C29E	Natural	Air	6096-6	6096-7	6096-8
ASCO	HTX831429	Natural	Air	6096-3	6096-2	6096-1
Valcor	V-70900-21	Accelerated	Air	6096-22	6096-23	6096-24
Valcor	V-70900-21	Natural	Air	6096-19	6096-20	6096-21

6. SURVEY OF ENVIRONMENTAL CONDITIONS

To identify environmental and operational conditions for actual SOV service in operating nuclear power plants, a short engineering survey questionnaire was prepared, and several utilities were asked to complete it. The utilities were selected on the basis of plant nuclear steam supplier, electrical output, and age. Table 4 shows the environmental survey form. Six utilities representing 11 stations with one or more pressurized water reactors (PWR) and 6 stations with one or more boiling water reactors (BWR) were polled. Four of the six utilities provided responses that represented 9 PWR stations and 5 BWR stations. The environmental information provided by the utilities is summarized in Table 5.

The profiles contained in Appendix represent all of the design basis accident profiles supplied by the utilities in response to the survey (i.e., BWR-1 provided only plant LOCA curves, BWR-2 provided only MSLB profiles, etc.).

Table 4. Environmental Survey Form

FRANKLIN RESEARCH CENTER

PLANT ____________ NSSS ____________ MWe ____________

1. ENVIRONMENTAL CONDITIONS

A. Please complete the following items. Actual recorded data are preferable.

Containment Conditions: (Source: Recorded ( ) Design Document ( ))

Normal Temperature ______ °F; Normal Pressure __________ __ psig

Normal Relative Humidity _______ % RH, Radiation __________ R/h

B. Please complete or attach the following information:

LOCA Temperature Profile:
LOCA Pressure Profile:
LOCA Integrated Dose: ______ Rads Gamma; ______ Rads Beta

MSLB Temperature Profile:
MSLB Pressure Profile:
MSLB Integrated Dose: ______ Rads Gamma; ______ Rads Beta

2. MAINTENANCE QUESTIONS

A. Please describe any periodic maintenance or surveillance performed on SOVs in service:

____
____
____

B. Do any criteria for requiring initiation of maintenance/repair exist other than end of qualified life or valve failure?

____
____
____

C. Are solenoid valves used in any applications other than air service? If so, please describe process fluid and process conditions.

____
____
____

Table 5. Plant Environmental Conditions Noted in Environmental Survey

Plant	Normal Temp. (°F)	Normal Pressure (psig)	Normal Relative Humidity (%)	Normal Radiation (rad)*	DBE Radiation (rad)
PWR-1	130	0 to 5	2 to 100	3×10^7	6.1×10^7
PWR-2	130	0	65	--	2×10^7
PWR-3	120	0	50	5×10^4	1.3×10^7
PWR-4	120	-0.3 to 0.3	20 to 90	2×10^7	1.0×10^8
PWR-5	120	-1 to 1	35	1.1×10^6	2×10^8
PWR-6	65-120	-0.1 to 0.3	10 to 50		2×10^8**
PWR-7	120	-0.1 to 0.3	20 to 50	3.5×10^6	2×10^8
PWR-8	120	-0.3 to 0.3	20 to 90	2×10^7	1.0×10^8
PWR-9	120	-0.1 to 0.3	20 to 50	3.5×10^6	2×10^8
BWR-1	135	-0.5 to 0.2	40 to 55	6×10^7	5×10^7
BWR-2	150	1.2	20 to 30	3.5×10^7	3×10^7
BWR-3	135-150	-0.5 to 2	40 to 55	2×10^7	--
BWR-4	150	-0.5 to 2	20 to 90	1.8×10^7	1.0×10^8
BWR-5	150	-0.5 to 2	20 to 90	1.8×10^7	1.0×10^8

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*40-year integrated dose.

**DBE plus normal radiation.

7. TEST SEQUENCE

The test sequence summarized below was developed on the basis of the program objectives (Section 1.1), the guidance provided by the previous research program [8], and the applicable environmental qualification standards [2, 3].

A completed description of each test step is provided in the referenced section along with the supporting rationale for selection of the test levels and durations.

Step No.	Test Title	Level and Duration	Valve Group
1	Inspection and Baseline Tests	See Section 8	I, II, III, IV
2	Disassembly and Material Testing	See Section 16	I
3	Thermal Aging*	4 years equivalent life ASCO, 5 years equivalent life Valcor	II, III, IV
4	Operational Cycling	2000 cycles, ASCO 2500 cycles, Valcor See Section 10	II, III, IV
5	Functional Tests	See Section 8	II, III, IV
6	Disassembly and Material Tests	See Section 16	II
7	DBE Radiation Exposure	200 Mrd gamma See Section 13	III, IV
8	Functional Tests	See Section 8	III, IV
9	Disassembly and Material Testing	See Section 16	III
10	LOCA/MSLB Exposure	30 days, 420°F peak temperature (see Section 14)	IV
11	Functional Tests	See Section 8	IV
12	Disassembly and Material Testing	See Section 16	IV

---

*Naturally aged SOVs from Groups II, III, and IV will not be included in the thermal aging simulation.

8. FUNCTIONAL TESTS

Prior to the start of the aging program, functional tests a, b, and c (identified below) will be performed as a baseline for comparison with subsequent functional tests. The functional tests will be repeated as indicated in Section 7 after each segment of the test.

Functional testing will consist of the following:

a. Operational Test

Complete operation, i.e., cycling of the SOV at normal and design limit conditions of voltage and nominal air pressure while determining the presence of appropriate air flows or pressures at the ports of the SOV. This testing will be referred to as operational testing. Operational testing will include observation for evidence of abnormal operation such as sluggish operation of the SOV or failure to transfer, or noise such as solenoid chattering. In addition, the SOVs will be operated under degraded voltage conditions.

b. Leakage Testing

Leakage testing will be conducted on the test stand shown in Figure 2. The SOV will be mounted to the test stand and the appropriate process and electrical connections made. The valve inlet will be pressurized at the SOV operational pressure (60 psig for ASCO SOVs, 150 psig for Valcor SOVs) while deenergized. The flow meter will be observed for any indication of flow after pressurization, which would indicate either seat or body leakage of the valve. The flow meter will detect leakage through the valve in the range from 0.37 scfm (10 L/m) to 4.2 scfm (118 L/m). The SOV will then be energized and the accumulator allowed to stabilize at the supply pressure. The flow meter will again be observed to detect any flow which would provide evidence of leakage. The leakage testing follows the method prescribed in Sections 28 and 29 of UL 429 [4].

c. Insulation Resistance

Measurement of insulation resistance (IR) between the conductor of the solenoid coil and the housing (enclosure) of the coil will be made at a dc potential of 500 V held for 1 minute.

d. Potential-Withstand Test

A high-potential withstand test of the coil conductor will be performed. An ac potential of twice the rated potential plus 1000 V will be applied between the coil conductor and the coil enclosure. The potential-withstand test will be conducted prior to disassembly of the SOV only.

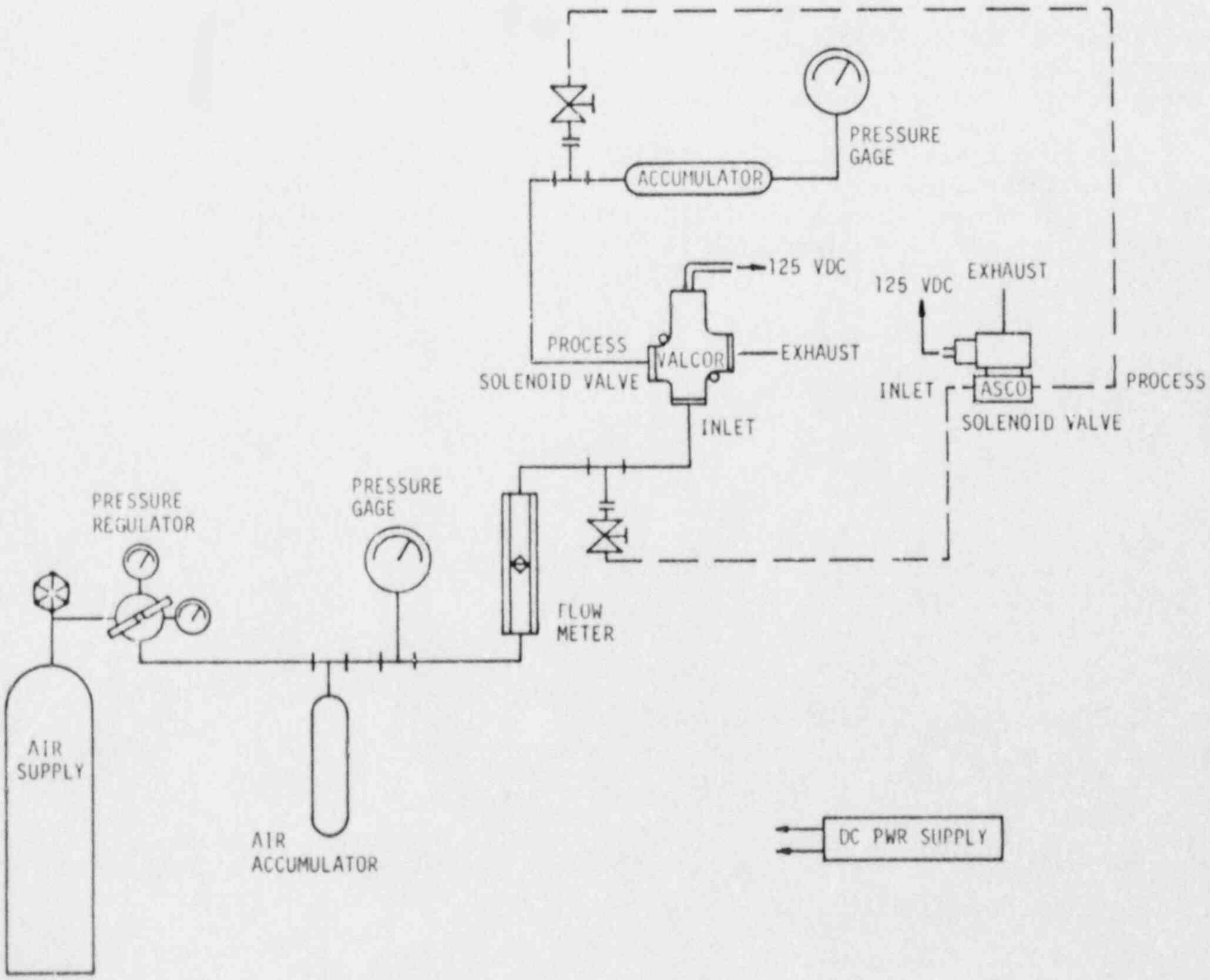

Figure 2. Schematic Diagram of SOV Leakage Test Stand

Rationale

Selection of the functional testing was based on the following sources of guidance:

- IEEE Std 382-1980 [3]
- UL 429 [4]
- Catalog descriptions and technical bulletins by the SOV manufacturers.

While other testing could be performed (e.g., pull-in-voltage: the potential supply is slowly increased until the SOV changes position, and the voltage level at the change is recorded), the functional testing selected provides an indication of SOV operability with measurements that could be performed in a plant service enviroment.

During performance of the operability tests, the SOVs will be checked for operation under degraded voltage conditions, i.e., 80% of nominal voltage. This test has been included to address plant conditions where the SOVs would be powered by station batteries while they are discharging.

9. RADIATION AGING

No radiation aging of the SOVs will be performed.

Rationale

The largest radiation dose received by any of the naturally aged valves was 1.5×10^6 rd gamma for a 5-year service life. This dose represents less than 2% of the DBE dose and is considered negligible by comparison. The elastomers used in the SOVs experience negligible deterioration from a 1.5×10^6 rd exposure to the body of the SOV.

10. THERMAL AGING EXPOSURE

10.1 THERMAL AGING SUMMARY

The Group II, III, and IV SOVs will be subjected to accelerated thermal aging to place the SOVs in their end-of-service life state, i.e., 4 years for ASCO SOVs and 5 years for Valcor SOVs. A service temperature of 140°F (60°C) was selected to represent in-containment applications. The SOVs will be aged to simulate a continuously energized operating mode; therefore, the aging analysis accounts for the effects of ohmic heating on the critical components due to continuous energization of the solenoid coil. Process connections will be provided so that the SOVs can be pressurized and energized during the thermal aging exposure. The naturally aged SOVs in Groups II, III, and IV will not be subjected to artificial aging.

The ASCO SOVs will be aged in an energized state at an oven temperature of 215°F (102°C) for a period of 1467 hours (61.1 days) to simulate a service life of 4 years in an operating environment of 140°F (60°C) for the elastomeric components within the SOV. Since this aging simulation would overage the ASCO solenoid coils, a replacement set of solenoid coils will be thermally aged for a period of 202 hours at 350°F (177°C) and placed in the SOV so that the entire SOV assembly has been aged to an equivalent 4-year service life.

The Valcor SOVs will be aged in an energized state at an oven temperature of 215°F (102°C) for a period of 2232 hours (93 days) to simulate a 5-year life in an operating environment of 140°F (60°C) while continuously energized for the elastomeric components within the SOV. The Valcor SOV will also be provided with a 100-psig air source at the exhaust port during the themal aging simulation to provide a 0-psig differential pressure across the shaft seal O-ring to preclude damage from a high differential pressure (100 psig) and the high temperature at the O-ring. Since this aging simulation would overage the Valcor solenoid coils, a replacement set of solenoid coils will be thermally aged for a period of 350 hours at 350°F (177°C) and placed in the SOV so that the entire SOV assembly has been aged to an equivalent 5-year service life.

Rationale

The aging analysis for the SOVs was conducted in the following steps:

- o Determination of weak-link components
- o Identification of component materials and activation energies
- o Measurement of temperature rise at weak-link components and solenoid coils due to continuous energization
- o Calculation of thermal aging parameters.

Each of these activities is documented in the paragraphs that follow.

10.2 DETERMINATION OF WEAK-LINK COMPONENTS

The weak-link components for the SOVs are determined primarily by component function with respect to the required safety function of the device. Components are first identified as critical components (i.e., the component can act to defeat the safety function) and then identified as a weak-link component by analyzing the effect of the component's normal environment on the component's functional capability. Since a weak-link component must degrade substantially in the environment to which it will be exposed, metallic components are essentially excluded from being weak-link components.

10.2.1 ASCO SOV Weak-Link Component Analysis

An exploded view of the ASCO NP8314 SOV is shown in Figure 3. From review of this figure, the only nonmetallic components contained in the SOV are the body gasket, the core disc (not shown), the solenoid coil, and the plugnut gasket. The plugnut gasket and body gasket are used as static seals to prevent inleakage of contaminants to the solenoid coil housing and minimize body leakage, respectively. From previous testing [8], it has been found that even with gross failures of the body gasket, the SOV is able to perform its function. The core disc, however, is used as a dynamic seal to control the flow of the process medium to an operated device and align the exhaust path. Failure of the core disc could result in leakage past the SOV seat and may defeat the SOV safety function. Therefore, the core disc is considered the weak-link component.

Although the coil of the ASCO solenoid valve has been previously shown to be less susceptible to degradation from environmental effects than the EPDM core disc, it is nonetheless critical to the proper operation of the SOV. Therefore, the solenoid coil will be aged to an equivalent life equal to the core disc.

10.2.2 Valcor SOV Weak-Link Component Analysis

The internal components of the Valcor V-70900-21 SOV are shown in Figure 4. In addition to the solenoid coil, the Valcor SOV contains seven elastomeric components, all O-rings used as either static or dynamic seals. The function of each of the O-rings and the effect of its failure on operability of the SOV are discussed in the following paragraphs.

- Solenoid Base O-Ring

  The solenoid base O-ring provides a static seal to preclude the entrance of moisture into the solenoid coil enclosure. Complete failure of the O-ring due to thermal aging might allow entrance of moisture into the coil area during a high pressure steam exposure. Failure of the O-ring due the thermal aging is considered a low probability occurence. Intrusion of water into the coil area could result in the electrical failure of the coil; however, the fail-safe position of the SOV is normally the deenergized position. Since failure of the solenoid base O-ring coupled with subsequent coil failure would cause the SOV to go to its fail-safe position, the solenoid base O-ring is not considered the weak-link component.

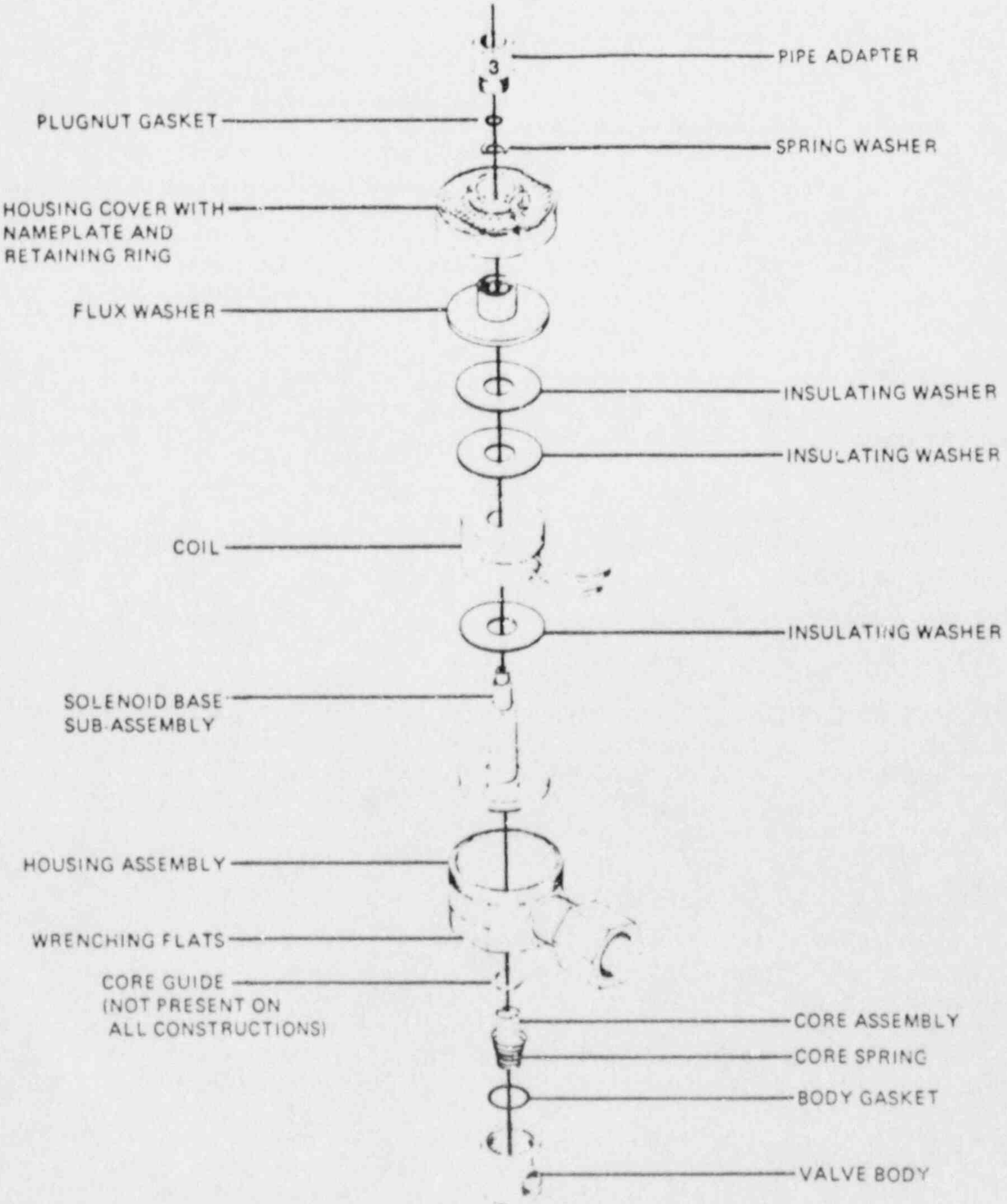

Figure 3. Exploded View of ASCO NP8314 SOV

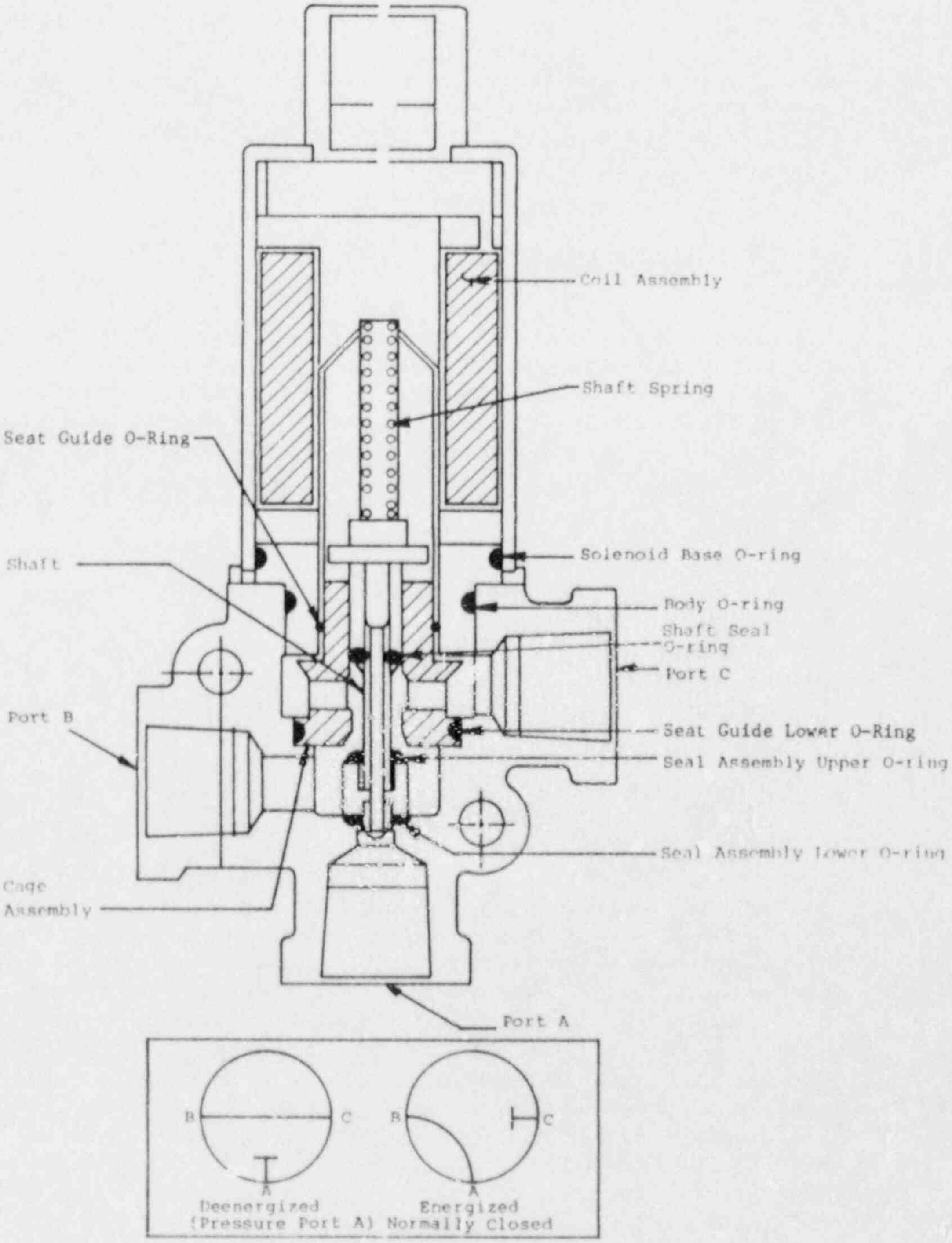

Figure 4. Section View of Valcor V70900-21 SOV

- Body O-Ring

  The body O-ring provides a static seal between the solenoid base and the SOV body. Failure of the body O-ring could result in a entrance of moisure into the exhaust port area (port C) of the body during a high pressure steam exposure. Moisture leakage into this area would have no effect on the operability of the SOV, since leakage through the vented exhaust port would normally be expected.

- Seat Guide O-Ring

  The seat guide O-ring provides a static seal between the seat guide and the solenoid base. Failure of the seat guide O-ring would allow leakage of the process fluid, which is used to assist SOV transfer at the pilot mechanism (shaft seal O-ring) through the exhaust port (port C). Although the process leakage might cause a longer transfer time for the SOV when it becomes deenergized, the force generated by the shaft spring is adequate to effect transfer of the SOV to the deenergized position without the assistance of the pilot pressure.

- Cage O-Ring

  The cage O-ring provides a static seal between the SOV body and the exhaust port (port C) when the SOV is in the energized state. Failure of the O-ring would allow some leakage of the process fluid from the supply (port A) to the exhaust port when the SOV is in the energized position. Although the potential for leakage exists, the leakage rate would not be sufficient to defeat the safety function of the SOV.

- Shaft Seal O-Ring

  The shaft seal O-ring provides a dynamic seal which performs two basic functions. With the SOV deenergized, the process fluid passes through the center of the shaft and exerts a force on the shaft seal O-ring helping to seat the lower O-ring seat. A differential pressure equal to the supply pressure exists across the O-ring when the exhaust is not pressurized. Upon energization of the coil, the differential pressure across the O-ring is instanteneously reduced since the process pressure is applied to both sides of the O-ring and the magnetic circuit is able to move the shaft to its energized position. Once the SOV is at its energized position, the differential pressure across the O-ring is again equal to the differnence between the process pressure and the pressure at the exhaust port (normally 0 psig). Upon deenergization of the solenoid coil, the pressure above the shaft seal O-ring assists the spring in moving the shaft to the deenergized position.

  Failure of the shaft seal O-ring could result in several types of SOV failure. Shrinkage due to hardening could allow leakage of the process fluid past the shaft seal O-ring and reduce the force used to start the travel of the shaft upon deenergization of the SOV. Embrittlement and breakdown of the shaft seal O-ring could result in pieces of the O-ring becomming trapped between the shaft and the cage assembly and prevent shaft travel. Creep of the O-ring due to softening from heating and the differential pressure across the O-ring could cause flow of the shaft seal O-ring between the shaft and the cage assembly, causing the shaft to bind. The three potential failures of the SOV discussed would all prevent the SOV from performing its safety functions.

- Upper O-Ring Seat

  The upper O-ring seat seals the SOV body cavity between the process and the exhaust (Port C) in the energized state. In the deenergized position, the upper O-ring seat serves no purpose. Deterioration of the upper O-ring seat would allow leakage of the process fluid through the exhaust port in the energized position. Because the Valcor SOV is designed to provide principally metal-to-metal seating, the anticipated leakage rate would be small. Failure of the upper O-ring seat due to high temperature may cause adherence of the O-ring to the cage assembly and defeat the SOV's safety function.

- Lower O-Ring Seat

  The lower O-ring seat isolates the process supply from the process (Port B) and exhaust (Port C) ports in the deenergized state. In the energized state, the lower O-ring seat provides no function. Failure of the lower O-ring seat would permit leakage of the process fluid to the process and exhaust ports. As with the upper O-ring seat, because the seating is primarily metal-to-metal on this SOV, the anticipated leakage rate would be small. It is anticipated, however, that during normal service, the lower O-ring seat would exhibit the highest level of degradation since the seat is blanketed in air in its energized position, resulting in hardening of the seat. Sticking of the lower O-ring seat is not expected due to the high force exerted by the magnetic circuit of the SOV upon energization.

  Analysis of the nonmetallic components in the Valcor SOV and their function indicate that the shaft seal O-ring and the upper O-ring seat may fail in a manner that would impair performance of the SOV safety function. The shaft seal O-ring and upper O-ring are made of the same elastomeric materials. Because the shaft seal O-ring can fail in three different ways that would impair perfomance of the SOV safety functin and because the shaft seal O-ring is located in a closer promixity to the solenoid coil and would be exposed to a higher temperature and greater thermal stress during normal service than the upper O-ring, the shaft seal O-ring will be used as the weak-line component.

10.3 IDENTIFICATION OF COMPONENT MATERIALS AND THE ASSOCIATED ACTIVATION ENERGY VALUES

The materials of construction for the SOVs were detemined from the ASCO [9] and Valcor [10] environmental qualification test reports. The elastomers used in both SOVs were identified as being constructed of ethylene propylene diene monomers (EPDM), which are also referred to as ethylene propylene terpolymer, and ethylene propylene rubber (EPR). Each manufacturer's solenoid coil is made of various materials listed in the respective qualification reports. The materials were reviewed by FRC but, since they are considered proprietary by the manufacturers, they will not be identified here.

A literature search was conducted to identify sources of activation energies for the various materials used in construction of the ASCO and Valcor SOVs. References 12 through 14 provided information on activation energies for materials similar to those used in the SOVs, but no direct correlation to the compounds identified by the SOV manufacturers could be made.

A study conducted by the U.S. Navy [12] on solenoid coil insulation systems identified activation energy values in the range of 0.42 eV to 1.09 eV. Reference 13 identified activation energy values for a compression set of EPDM in the range of 0.73 eV to 1.05 eV. Reference 14 did not provide any information relevant to the materials and properties of interest.

ASCO has identified a range of activation energies for the EPDM, with 0.94 eV used for their thermal aging program. Valcor has identified a somewhat higher activation energy for the EPDM compound used for their seats based on thermogravimetric analysis (TGA) of the material. ASCO and Valcor also listed activation energy values for the materials making up the solenoid coil. ASCO identified a limiting activation energy of 1.0 eV, whereas Valcor identified an activation energy of 1.47 eV based upon TGA measurements.

Since acceptance of TGA data for development of activation energy values has been limited, information on TGA was reviewed to determine the applicability of TGA for determining activation energies for thermal aging. ASTM Standard D3850-84, "Rapid Thermal Degradation of Solid Electrical Insulating Materials by Thermogravimetric Method," states: "This method is not intended to directly establish thermal life comparison on insulating materials. The relationship between TG data and long-term thermal capabilities of a material, if it exists, needs to be developed and demonstrated by the experimenter, preferably by comparing data for known materials possessing similar failure modes." The review of published literature did not provide any firm basis for selection of activation energy values for the SOV elastomers and solenoid coil materials. The activation energies reported by ASCO in its qualification test report [9], 0.94 eV for the EPDM elastomers and 1.0 eV for the solenoid coils, were chosen for the accelerated aging calculations for the ASCO and Valcor SOVs since they represent conservative values for the materials to be tested.

10.4 MEASUREMENT OF TEMPERATURE RISE AT WEAK-LINK COMPONENTS AND SOLENOID COILS DUE TO CONTINUOUS ENERGIZATION

The operating temperature of the weak-link components due to normal ambient temperature surrounding the SOV and the internal heat generated by continuous energization of the solenoid coil was determined by direct measurement at several temperatures. In order to minimize the experimental error, a least squares fit for the data was performed and the temperatures determined through the mathematical analysis were used as the service and the thermal aging temperatures. In addition, the temperature of the solenoid coils at the service temperature and at the thermal aging temperature was calculated using the resistance method discussed below.

The service and aging temperatures of the ASCO SOV core seat were determined by placing a 0.005-in (0.1-mm) thermocouple within the core seat material. A 0.005-in diameter hole approximately 0.03125-in (0.8 mm) deep was drilled in the center of the core seat, and the thermocouple was placed in the hole and potted in place using a small amount of RTV material. The SOV was then fitted with 6-in-long stainless steel tubes and applicable fittings in the process and supply ports to simulate the tubing connected to the SOVs in service. The open ends of the tubes were fitted with insulating material to block any air flow into the SOV body. The ASCO SOV was mounted on a metal laboratory stand and placed in a circulating air oven for temperature tests.

The service and aging temperatures of the Valcor SOV shaft seal O-ring were determined by placing a 0.005-in (0.1-mm) thermocouple between the SOV shaft and the shaft seal O-ring. Since the Valcor SOV had previously been supplied with fittings and tubing to allow pressurization of the SOV, these connections were used for the temperature measurements. The Valcor SOV was mounted on a metal laboratory test stand and placed in the circulating air oven with the ASCO SOV. Both SOVs were connected to a 125 Vdc power supply for energization of the solenoid coils and the thermocouples were connected to a data logger. A thermocouple to measure the oven temperature was located in a central portion of the oven and connected to the data logger. The SOVs were energized and the oven controls manipulated to provide the temperatures shown below. The oven was allowed to remain at the selected temperature for approximately 2 hours at each temperature, which was sufficient duration to allow stabilization of the critical components. The solenoid coil resistance was also measured at each temperature. It should be noted that the circulating air oven was not turned on to measure the weak-link component temperatures at room ambient (77°F) and these temperatures were recorded under still air conditions.

The recorded data were then fed into a computer program which analyzes the data to provide least squares fit of the curve that best represents the data. The circulation air oven temperature, the recorded weak-link component temperature and the mathematically derived temperatures for the weak-link components are provided below.

Oven Temp.	ASCO Core Seat		Valcor Lower Seat Assembly O-Ring	
(°F)/(°C)	Measured (°F/°C)	Best Fit (°F/°C)	Measured (°F/°C)	Best Fit (°F/°C)
77.1/25.0	169.8/ 76.6	--	173.5/ 78.6	--
140.0/60.0	181.1/ 82.8	181.2/ 82.9	190.0/ 87.8	189.8/ 87.7
210.0/99.0	250.0/121.1	250.1/121.1	257.0/125	156.2/124.6
215.0/102.0	256.0/124.4	255.0/123.9	259.0/126.1	261.0/127.2
230.0/110.0	269.1/131.7	269.8/132.1	276.2/	275.2/135.1

The temperature of the solenoid coils was calculated using the temperature coefficient of resistance method from Reference 15, which states:

$$R_{T2} = R_{T1} \left[1 + \alpha_{T1} \left(T_2 - T_1\right)\right] \qquad (1)$$

where:
R_{T2} = resistance at the evaluated temperature in ohms
R_{T1} = resistance at the reference temperature in ohms
α_{T1} = temperature-resistance coefficient at the reference temperature
T_2 = evaluated temperature in °C
T_1 = reference temperature (21°C)

Rearranging the equation to solve for the elevated temperature yields:

$$T_2 = \frac{\left({}^{R}T2/{}^{R}T1\right) - 1}{\alpha T_1} + T_1 \qquad (2)$$

The temperature-resistance coefficient for copper (assuming 100% conductivity) is 0.00393 (from Table 4-3 of Reference 15). The resistance of each of the SOV coils was measured at the elevated temperatures listed for the critical components and at the reference temperature (72°F/21°C). The temperature of the SOV coils at each elevated temperature is tabulated below.

Oven Temp. (°F/°C)	ASCO Solenoid Coil Resistance (ohms)	ASCO Solenoid Coil Temp. (°F/°C)	Valcor Solenoid Coil Resistance (ohms)	Valcor Solenoid Coil Temp. (°F/°C)
72/21	796	--	401	--
140/60	1050	215/102	535	223/106
210/99	1200	302/150	600	297/147
215/102	1225	316/158	615	315/157
230/110	1280	347/175	650	354/179

10.5 CALCULATION OF THERMAL AGING PARAMETERS

The thermal aging parameters were calculated using the Arrhenius equation:

$$t_a = t_s \exp[(\Phi/k)(1/T_a - 1/T_s)] \qquad (3)$$

where:

t_a = thermal aging period (h)
t_s = equivalent service life (h)
exp = e = 2.7183
Φ = activation energy in eV
k = Boltzmann's constant, 0.8617×10^{-4} eV/K
T_a = accelerated thermal aging temperature in degrees Kelvin
T_s = normal operating service temperature in degrees Kelvin

The Arrhenius model assumes that, within a limited temperature range, the rate of thermal aging is governed by a single degradation mechanism (related to the material's activation energy) and the absolute temperature. The rate of thermal degradation increases exponentially as the activation energy is decreased and the absolute temperature is increased. In applying the Arrhenius model, care must be taken to ensure that the activation energy used applies to both the specific material in use and to the deterioration of the physical property of interest for that material. The identification of an activation energy should also be conservative enough to provide realistic results while avoiding overaging that would exceed a desired endpoint condition. The accelerated thermal aging of a device is complicated by the fact that parts of the device generally degrade at different rates, partly because of differences in activation energy and partly because internal heating may cause different parts to operate at different temperatures. A conservative approach is to base the accelerated aging on the device's weakest link, i.e., that part (among those that contribute to functional capability) which, because of its activation energy and operating temperature, has the highest rate of degradation. The disadvantage of this approach is that when the device is aged so that the weak-link component is aged to the equivalent of a specific life, some parts will be overaged and others will be underaged. Since other aging models have similar disadvantages, the aging parameters were determined on a weak-link approach.

The weak-link component identified for the ASCO SOV is the core seat disc, and for the Valcor SOV, it is the shaft seal O-ring. Both components are constructed of EPDM with an activation energy of 0.94 eV.

The maximum normal operating service temperature for SOVs is 140°F (60°C). The service life for purposes of this test is 4 years (35,040 hours) for the ASCO SOV and 5 years (43,800 hours) for the Valcor SOV.

Two methods for simulation of the internal heat rise generated by ohmic heating of the coil were considered. The first method would consist of adding the temperature rise to the temperature of the service environment and aging the SOVs in the deenergized state. While the thermal aging temperature could be raised to simulate the internal heat rise of the critical components, the valve configuration would be directly opposite its normally energized state (i.e., where the upper O-ring is compressed in the energized state, the lower O-ring is compressed in the deenergized state). The potential for degradation modes not representative of normal service exists if the valve is aged in this manner.

The second method, consisting of energizing the coil during thermal aging, is the preferred method since the SOV is placed in its normal operating configuration during thermal aging. For the ASCO SOV, the temperature of the core seat with the coil energized and an ambient temperature of 140°F (60°C) was 181.2°F (82.9°C). With the coil energized, the temperature of the core seat at the thermal aging temperature (215°F/102°C) was 255°F (123.9°C). Using these core seat temperatures for service and thermal aging conditions, an activation energy of 0.94 eV for the EPDM core seat, and a service life of 4 years (35,040 hours), Equation 3 yields a thermal aging period for the ASCO 261.0°F (127.2°C) SOV of 1467 hours (61.1 days) at an oven temperature of 215°F (102°C) with the coil continuously energized.

With the coil energized, the temperature for the Valcor lower O-ring at an ambient temperature of 140°F (60°C) was 190°F (87.8°C). The temperature for the Valcor O-ring at the thermal aging temperature of 215°F (102°C) was 261.0°F (127.2°C) with the coil energized. Using an activation energy of 0.94 eV, a service life of 5 years (43,800 hours), Equation 3 yields an aging time for the Valcor SOV of 2232 hours (93 days) at an oven temperature of 215°F (102°C) with the coil continuously energized.

The equivalent service life of the Valcor solenoid coil exposed to the accelerated aging described above is approximately 9 years. To avoid excessive overaging of the solenoid coils, a duplicate set of ASCO and Valcor solenoid coils will be aged separately from the SOV assemblies. The duplicate set of solenoid coils will be aged to an equivalent of 4 years for the ASCO coils and 5 years for the Valcor coils. The solenoid coils will be aged in a deenergized state. Using the parameters listed below for calculation of the required thermal aging, a thermal aging period of 202 hours (8 1/2 days) is required for the ASCO solenoid coil, and a thermal aging period of 350 hours (14.58 days) is required for the Valcor solenoid coil.

Solenoid Coil Aging

Manufacturer	Service Temperature (°F/°C)	Activation Energy (eV)	Aging Temperature (°F/°C)	Aging Time (h)
ASCO	215/102	1.0	350/177	202
Valcor	223/106	1.0	350/177	350

11. OPERATIONAL AGING

The SOVs to be thermally aged will be cycled at their normal operating temperature during the thermal aging portion of the test program to simulate the degradation resulting from operation during plant service. The environmental survey did not reveal any uniformity for the number of cycles expected during plant service, primarily because of the application-specific nature of cycling. Two thousand cycles for a 4-year life were selected based upon knowledge of SOV use and engineering judgment. The SOVs will be cycled during the thermal aging exposure while they are pressurized with the appropriate process medium. The operational cycling will be integrated into the thermal aging program so that, at the completion of the equivalent thermal aging period simulating approximately one year, the thermal aging oven temperature will be reduced to the plant service temperature (140°F, 60°C) and allowed to stabilize at that temperature for a period of 2 to 3 hours. A total of 500 operational cycles will be performed at the service temperature. The thermal aging oven will then be returned to the thermal aging temperature and the equivalent of one year's aging will be performed. This process will be repeated until the ASCO SOVs are aged to an equivalent of 4 years' life and 2000 operational cycles, and the Valcor SOVs are aged to 5 years' life and 2500 cycles.

Rationale

The number of cycles that an SOV will see in service depends on the specific application of the device as well as the operational history of the plant in which it is installed. Specific guidelines for operational aging of two-position valves were identified in IEEE Std 382-1980 [3], which requires 2000 cycles for a 40-year valve life. Many of the SOVs used in nuclear plant systems experience much more than 2000 cycles during a 40-year period; however, it is unlikely that any would experience more than 20,000 cycles in 40 years. Consequently, 2000 cycles corresponds to 4 years of service under conditions requiring the most frequent cycling expected. Since this value is well within the capability of the valves in the program, it was chosen for the operational aging element.

IEEE Std 382-1980, paragraph 5.5.4 requires that 10% of the operational aging be performed during the thermal aging simulation. In the previous research program on SOVs [8], cycling at the thermal aging temperature was found to be inappropriate since the elevated temperature of the seating material and SOV body during cycling results in degradation not representative of plant service. Therefore, the cycling will be performed at the peak normal ambient service temperature (60°C) so that wear from cycling is more representative. The operational aging will, therefore, be performed at the plant service temperature on an incremental basis. Each increment will equate to one year's thermal aging combined with one year's equivalent operational aging. The incremental cycling and thermal aging should be more representative of real time aging in that the cyclic wear would be imposed over the period of thermal deterioration rather than at the end of it.

12. VIBRATION AGING AND SEISMIC TESTING

No vibration aging or seismic testing will be performed.

Rationale

During performance of a previous qualification research program [8], FRC subjected one naturally aged, one artificially aged, and one unaged SOV to the complete seismic and vibration testing specified by IEEE Std 382-1980 [3]. In these tests and subsequent functional testing, no discernible differences in the performance of the three SOVs was observed. Furthermore, there was no evidence that the seismic simulation tests had caused any degradation. Consequently, seismic and vibration testing were omitted.

13. DBE RADIATION EXPOSURE

The Group III and IV SOVs will be exposed to a minimum air-equivalent dose of 200 Mrd of gamma radiation from a cobalt-60 source at an average dose rate of 0.5 to 0.9 Mrd/h. The SOVs will be passive during this exposure.

At the conclusion of the DBE radiation exposure, the SOVs will be subjected to the functional tests described in Section 8. The Group IV SOVs will then be prepared for the LOCA/MSLB exposure as described in Section 14, and the Group III SOVs will be disassembled and subjected to material testing described in Section 15.

Rationale

The results of the environmental survey indicated that a DBE radiation dose of 200 Mrd gamma would envelope the DBE radiation exposure calculated for all of the plants responding to the survey.

The disassembly, internal inspection, and material testing of the Group III SOVs will provide data on the degradation of the SOV elastomeric components resulting from the aging simulation and the DBE radiation exposure for the artificially aged SOVs. Evaluation of the data from the naturally aged Group III SOVs will provide a basis for comparison of the effects of natural aging and DBE radiation exposure on the elastomeric components with the data recorded for the artificially aged SOVs. In addition, comparison of the data from the Group III SOVs with the data recorded for the Group II SOVs will identify the degradation resulting from the DBE radiation exposure.

14. SIMULATED LOCA/MSLB EXPOSURE

The Group IV SOVs will be installed in the LOCA/MSLB test vessel, as schematically illustrated in Figure 5, and exposed to the steam, chemical-spray, and high-humidity conditions resulting from a postulated LOCA/MSLB event, as shown in Figure 6. During the LOCA/MSLB exposure, the SOVs will be pressurized and cycled to simulate their in-plant usage.

The ASCO SOVs will be supplied with a pressure source (bottled air or nitrogen) with a cylinder connected to the SOV process connection simulating a device operated by the SOV. This arrangement is schematically depicted in Figure 7. The ASCO SOVs will be pressurized (see Table 3 for the type of process medium to be used) at a gage pressure of 60 lbf/in^2 during the test. A 125-Vdc power supply and appropriate control switches will be supplied to energize and deenergize the SOVs. Current meters will be used to measure the current drawn by the solenoids.

The Valcor SOVs will be supplied with a pressure source of oil-free instrument quality air at a gage pressure of 100 lbf/in^2. The SOV will be piped as shown in Figure 8. A 125-Vdc power supply and control switches will be used to energize and deenergize the SOVs. The current drawn by the solenoid coil will be measured using dial indicator type current meters.

The SOVs will be continuously pressurized with the bottled gas until 3 h elapsed time (ET) of the second transient. At that time, the SOVs will be isolated from the pressure source until 10 min prior to the next cycling period in order to avoid loss of bottled gas due to leakage. At each subsequent cycling period, the SOVs will be pressurized 10 min before cycling, cycled, and left in the pressurized state for 10 min following cycling to allow observation of any leakage.

The pressure/temperature profile of Figure 6 will be attained through the use of utility-supplied process steam passed through a superheater to obtain superheat conditions. Flow of the superheated steam into the test vessel will be manually controlled through observation of thermocouple signals on a stripchart recorder and differential pressure transmitter output to a stripchart recorder.

A minimum of ten thermocouples will be placed in different portions of the test vessel to monitor the temperature throughout the vessel. One thermocouple will be connected to a continuously recording stripchart recorder with the remaining thermocouples connected to data loggers. The thermocouple connected to the stripchart recorder will be used as the control thermocouple for purposes of following the temperature profile and will be centrally located in the test vessel but shielded from direct steam impingement.

A differential pressure transmitter with its output continuously recorded on a stripchart recorder will be used to monitor the test vessel pressure. In addition, a dial-indicating type pressure gage will be available for comparison purposes.

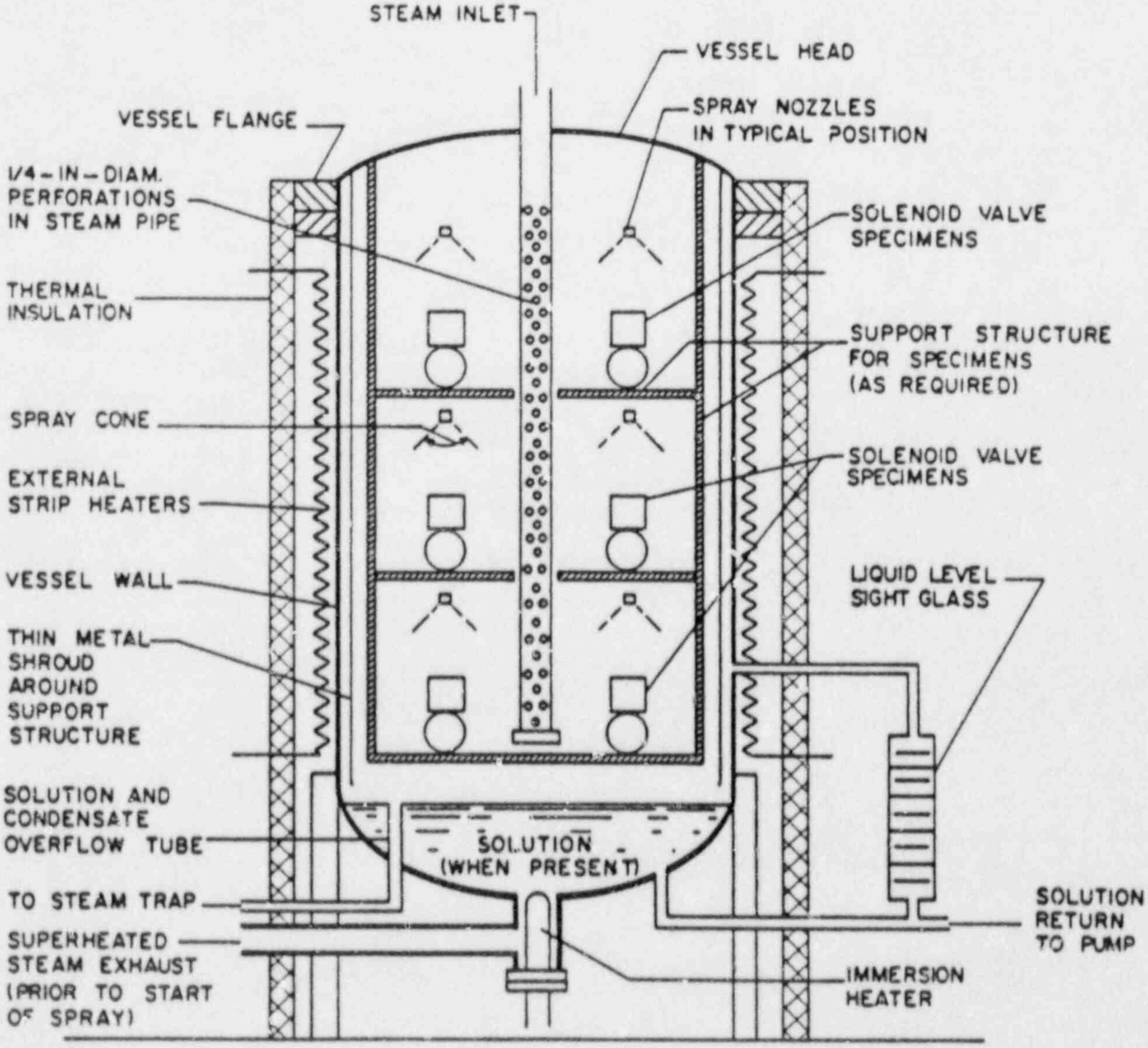

Figure 5. Schematic Illustration of SOVs Installed in Test Vessel for LOCA/MSLB Exposure

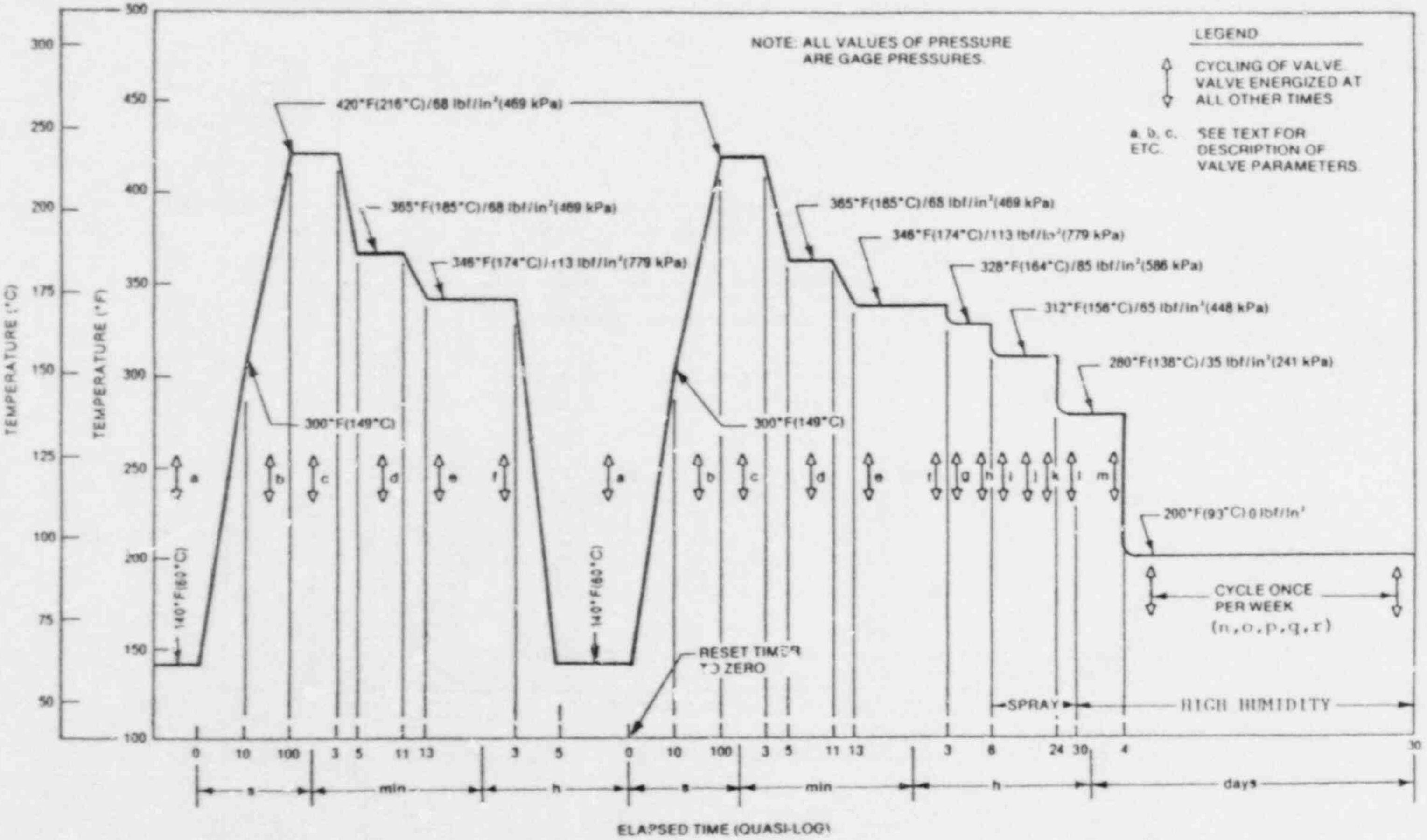

Figure 6. Specified Temperature/Pressure Profile for Simulated LOCA/MLSB Event

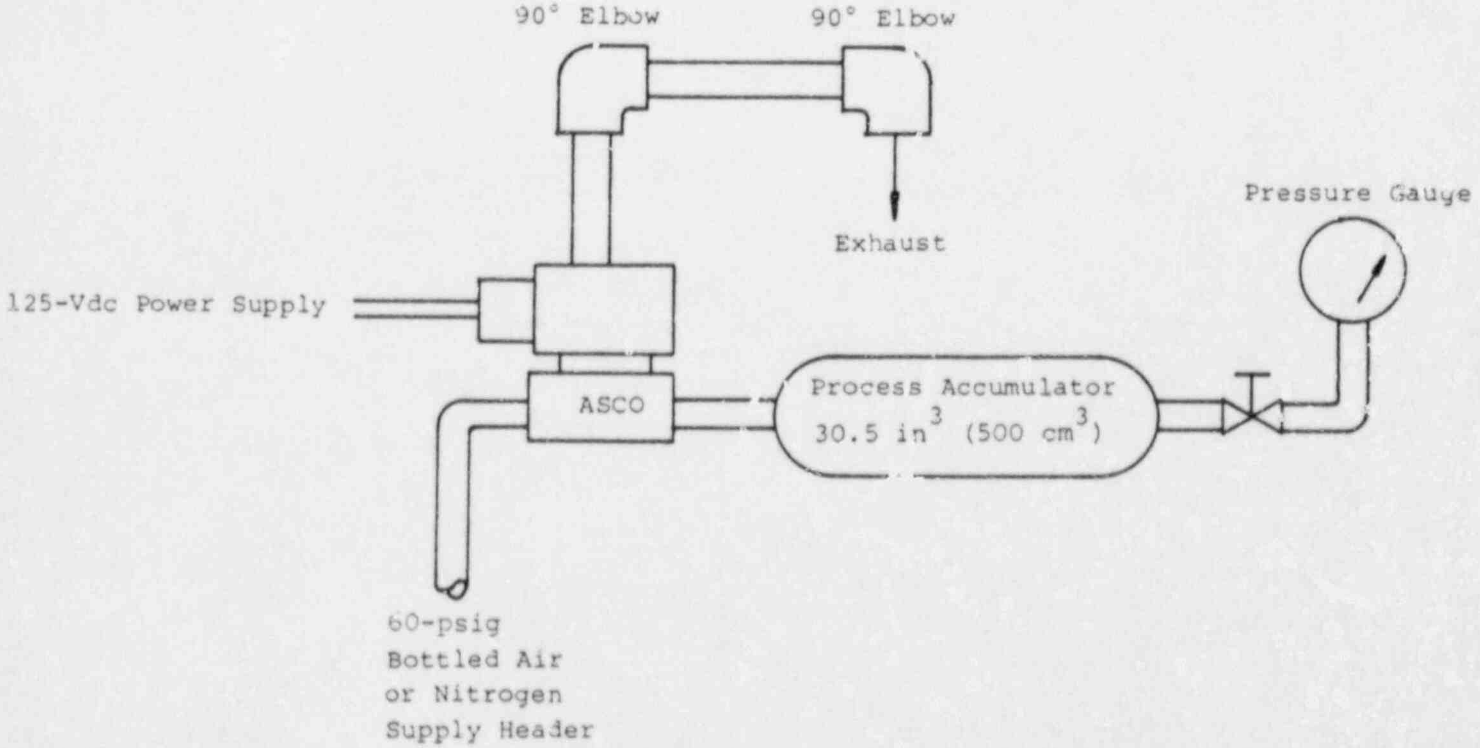

Figure 7. ASCO SOV Process Piping

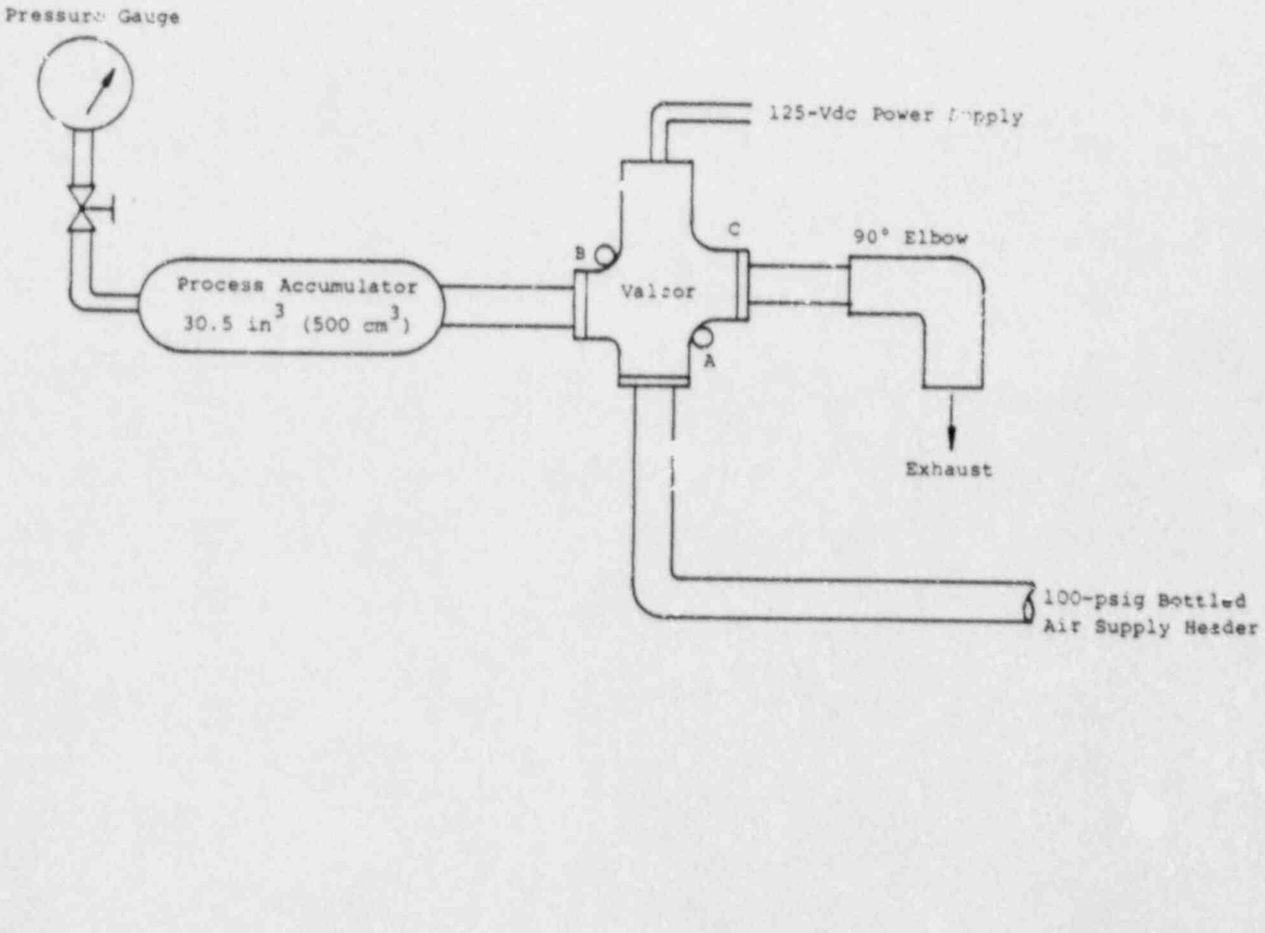

Figure 8. Valcor SOV Process Piping

At 6-h ET from the start of the second transient, a chemical solution will be sprayed into the test vessel. The spray will be applied by positioning nozzles directly above each solenoid housing so as to provide a minimum spray rate of 0.7 gpm/ft^2 of area in a horizontal plane that includes the tops of the solenoid housings. The congested nature of the test arrangement within the test vessel may perturb the spray patterns somewhat, but the tops of the specimens will be covered by direct impingement of sprays and by solution that bounces and flows from nearby structures.

Fresh spray solution will be used during the first hour (minimum) of the spray period; thereafter, the spray solution will be recirculated from a pool of spray solution which collects in the bottom of the test vessel.

The chemical solution will consist of 6200 ppm boron as boric acid, 50 to 100 ppm hydrazine, sufficient trisodium phosphate to obtain a pH of 8.5 (minimum), and sufficient sodium hydroxide to increase the pH to a level of 10.0 to 11.0 at room temperature. The water used to prepare the spray will be dechlorinated by charcoal filtering. The pH of the spray will be measured every hour during application of the chemical spray. If the pH level is less than 9.0, the recirculated solution will be replaced with fresh solution to restore the pH level to a value of 10.0 to 11.0.

After the spray is terminated, a high-humidity condition will be provided by maintaining a pool of solution in the bottom of the vessel at a temperature approximately equal to the temperature of the vessel gases.

The SOVs will be operated at the times shown in Figure 4 and at the voltage and pressure levels specified in Table 6.

The following parameters will be measured and manually recorded on data sheets throughout the exposure:

- Applied voltages
- Steady state dc currents
- Applied inlet pressures
- Cylinder pressures
- Evidence of proper valve functions
- Vessel temperature and pressures
- Chemical spray rate (total flow)
- Measurements of spray solution pH
- Time of the measurements.

Any anomalous behavior of a solenoid valve will be investigated within the limitations of the test arrangements, i.e., the SOVs will not be physically accessible until the simulated LOCA/MSLB exposure is terminated.

Rationale

The Group IV valves were chosen for this exposure in order to provide operability and material capability data for one set of SOVs that had been subjected to natural aging, followed by DBE irradiation exposure and a LOCA/MSLB exposure for comparison with SOVs that had been subjected to accelerated aging followed by the remaining exposures.

Table 6. Operation of Solenoid Valves During Simulated LOCA/MSLB Exposure

Elapsed Time	Code for Figure 4	Vessel Temperature (°F/°C)	Valve Operation[1]	Voltage Levels (Vdc)
Pre-test (approx. 1 h)	a	140/60	Cycle 10 times[2]	125
0.0	a	140/60	Valves energized[1]	125
10 to 30 s	b	300 to 420/ 149 to 216	Deenergize valves	125
100 s to 3 min	c	420/216	Cycle valves	100
5 to 11 min	d	365/185	Cycle valves	100
13 to 15 min	e	346/174	Cycle valves	100
1.0 h (approx.)	f	346/174	Cycle valves	125
2.5 to 3.0 h	f	346/174	Cycle valves	100
5.5 h (approx.)	a	140/60	Energize valves,[1,2] cycle 10 times	125
Reset timer to 0.0	a	140/60	Valves energized[1]	125
10 to 30 s	b	300 to 420 149 to 216	Deenergize valves	125
100 s to 3 min	c	420/216	Cycle valves[3]	125
5 to 11 min	d	365/185	Cycle valves	100
13 to 15 min	e	346/174	Cycle valves	100
2.5 to 3.0 h	f	346/174	Cycle valves	142
3.5 to 4.0 h	g	328/164	Cycle valves	142
5.5 to 6.0 h	h	328/164	Cycle valves	125

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1. Valves are continuously energized prior to each transient, then deenergized at approximately 10 s elapsed time, and remained deenergized unless otherwise indicated.
2. Valves deenergized for 4 to 10 s, then reenergized. Repeat 10 times.
3. After test started, valves are cycled once by being energized for 10 s, or long enough to allow observations, and then deenergized.

Table 6. (Cont.)

Elapsed Time	Code for Figure 4	Vessel Temperature (°F/°C)	Valve Operation[1]	Voltage Levels (Vdc)
6.5 to 7.0 h	i	312/156	Cycle valves	125
16 to 17 h	j	312/156	Cycle valves	125
23 to 24 h	k	312/156	Cycle valves	125
25 to 26 h	l	280/138	Cycle valves	125
46 to 48 h	m	280/138	Cycle valves	125
Once per week starting at 4.1 days	n,o,p q,r	200/93	Cycle valves	125

The SOV test arrangement was selected to provide testing that was representative of the physical connection and process requirements in use in nuclear power plants. Applied voltage levels stated in Table 6 were selected on the basis of electrical margin requirements of Reference 3 and also to account for conditions where the station batteries may be on a float charge during post-accident recovery periods.

The LOCA/MSLB profile was taken from Reference 1. The environmental survey discussed in Section 7 yielded various profiles for LOCA, MSLB, and combined environmental qualification conditions from the surveyed plants. With the diversity in each of the profiles considered, it was deemed that the profile used in the previous FRC research program would provide an adequate envelope for all of the profiles supplied by the utilities responding to the survey. Since each of the utility-supplied profiles returned to lower temperature conditions (120° to 140°F) within a few hours of event initiation, it was decided to lower the last phase of the LOCA/MSLB simulation from 250°F to 200°F. Because the test ends after a 30-day LOCA simulation and some applications may require the SOV to be functionable beyond 30 days post-LOCA, 200°F was chosen for conservatism.

15. MATERIAL TESTS

Material testing will be performed on elastomeric components from each of the SOVs after they have been subjected to all environmental exposures for that SOV and the functional testing has been completed. Three types of material tests will be performed on the components to determine their functional capability at the conclusion of environmental testing. O-rings will be subjected to Shore durometer testing in accordance with ASTM D2240-81 [5] and tensile testing in accordance with ASTM D1414-78 [6]. The core disc from the ASCO SOVs and the lower seats from the Valcor SOVs will also be subjected to compression testing in accordance with ASTM 575-83 [11].

With the functional groups established as they are, data on material properties (and material property changes) will be obtained for:

- o new SOVs
- o SOVs subjected to accelerated aging with air as the process fluid
- o SOVs that were naturally aged
- o SOVs subjected to accelerated aging and DBE radiation
- o naturally aged SOVs that have been exposed to DBE radiation
- o SOVs subjected to accelerated aging, DBE radiation, and a LOCA/MSLB event
- o naturally aged SOVs exposed to DBE radiation and a LOCA/MSLB event
- o ASCO SOVs that were subjected to accelerated aging using nitrogen as the process fluid
- o ASCO SOVs (nitrogen) with accelerated aging and DBE radiation
- o ASCO SOVs (nitrogen) with accelerated aging, DBE radiation, and a LOCA/MSLB event.

The durometer testing will provide data on the relative change in hardness of the components that results from the various environmental exposure; the tensile tests will provide data on the change in percent elongation at break. The compression and relaxation tests to be performed on the SOV seats will show the relative change in the capability of the seats to provide a resilient seating surface throughout the various states of the SOV's life.

To determine the suitability of the test data for relaxation and compression tests, a trial run was made using a core disc seat from a naturally aged ASCO SOV that had been in nuclear power plant service and from a core disc seat that had completed the previous SOV research program performed at FRC. Figure 9 depicts the results of the trial run. The deformation scale at

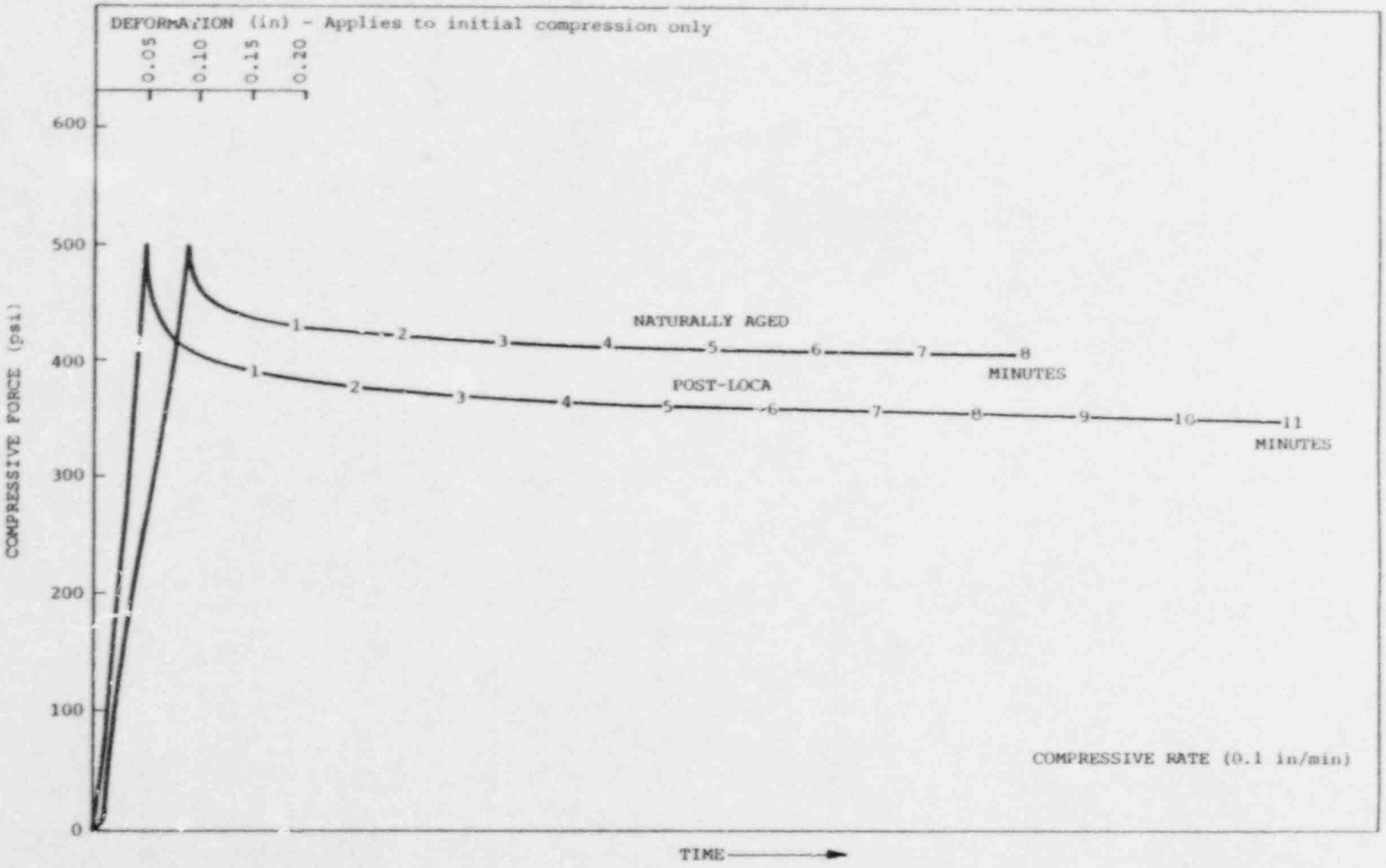

Figure 9. Compression and Relaxation Test Curves for ASCO Core Disc Seats

P-C6096

the upper left corner of the graph shows the total compression of the core disc seat at 500 psi. For the naturally aged core disc, the deformation was 0.10 in, and for the post-LOCA specimen, the deformation was 0.05 in. The difference in the deformation at equal compressive loadings shows a substantial hardening of the post-LOCA core disc resulting from the environmental stresses. During this test program, materials that were exposed to equivalent environmental stresses (e.g., natural vs artificial aging) will be tested and compared.

Rationale

The purpose of the material testing is to quantify the changes in material properties through each successive environmental exposure and to provide a firm basis for comparison of the effects of baseline changes in the test specifications (e.g., natural vs artificial aging). The three test procedures selected follow nationally recognized standards and should, therefore, provide repeatable and accurate results. The three material properties selected for testing (hardness, elongation, and compression) are properties for which there are known specifications for the components in a new state and are reproducible in many laboratories.

16. DESCRIPTION OF TEST FACILITIES

16.1 THERMAL AGING

The thermal aging test facility will consist of a forced-circulation air oven. Temperature uniformity throughout the volume occupied by test specimens is equal to or better than ±5°F (± 3°C) relative to the average oven temperature. Fifty complete changes of air per hour are provided. The approximate velocity of air through the oven is 250 ft/min across the midplane of the oven.

16.2 NUCLEAR RADIATION

The nuclear radiation facility will consist of a cobalt-60 source which provides gamma radiation in an air environment. It is planned to subcontract the radiation services to Isomedix, Inc., Parsippany, NJ.

16.3 SIMULATED LOCA/MSLB EXPOSURE

Steam is admitted into the vessel through a central perforated pipe shown in Figure 5. Superheated steam is obtained by passing utility-supplied satuated steam through a moisture separator and a stored-heat-bed heat exchanger; the heat exchanger delivers steam at approximaely 100 lbf/in^2 gage pressure and 600°F temperature. Saturated steam is available at approximately 150 lbf/in^2 gage pressure (365°F temperature). Superheated steam vessel temperaures are controlled by mixing the 600°F steam with small amounts of saturated steam prior to injection into the test vessel.

Chemical spray is obtained by use of a high-pressure turbine pump and wide-angle, full-flow spray nozzles.

Electric strip heaters external to the vessel and immersion heaters within the vessel provide temperature control at vessel temperature below approximately 250°F.

Appropriate temperature and pressure recording capabilities are provided.

17. DOCUMENTATION

The documentation for the subject test program will include the following:

a. The test plan and general procedures, which provide a general description of the program for development of detailed planning. Any subsequent changes in planning will be documented as in supplements to this test plan; a complete description of the actual program will be included in the comprehensive test report (Item c below).

b. FRC internal test procedures which provide detailed instructions for the execution of the test plan. (The primary purpose of the test procedures is to assure that necessary preparations and tests are conducted with proper data acquisition and documentation.) The test procedures will reference this test plan for guidance.

c. A final report that will be a comprehensive documentation of the program, including description of tests, arrangements, facilities, summarized results, and conclusions. Detailed data and test logs will be available as a separate data package.

The final report will comply with Section 8.3(4) of IEEE Std 323-1974.

18. REFERENCES

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3. IEEE Std 382-1980, "IEEE Standard for Qualification of Safety-Related Valve Actuators," The Institute of Electrical and Electronics Engineers, Inc., New York, NY, 1980

4. UL 429, "Standard for Safety-Electrically Operated Valves," Underwriter Laboratories, Inc., Third Edition, January 21, 1985, Northbook, IL

5. ANSI ASTM D2240-81,"Standard Test Method for Rubber Property-Durometer Hardness," American Society for Testing of Materials, Philadelphia, PA, 1981

6. ASTM D1414-78, "Standard Test Method of Testing O-Rings," American Society for Testing of Materials, Philadelphia, PA, 1978 (Reapproved 1983)

7. FRC Report No. P-C5569-9, "Test Plan - Qualification Test Program of Class 1E Solenoid Valves," Franklin Research Center, Philadelphia, PA, January 24, 1983

8. U.S. Nuclear Regulatory Commission, NUREG/CR-3424, "Equipment Qualification Research - Test Program and Failure Analysis of Class 1E Solenoid Valves," Washington, DC, November 1983, prepared by Franklin Research Center

9. ASCO Test Report No. AQR-67368/Rev. 0, "Report on Qualification of Automatic Switch Company (ASCO) Catalog NP-1 Solenoid Valves for Safety-Related Applications in Nuclear Power Generating Stations," Automatic Switch Company, Florham Park, NJ, March 2, 1982 (proprietary)

10. Valcor Test Report No. QR 70900-21-1 and -3, "Qualification Test Report - Solenoid Valve Assemblies, V70900-21-1/V70900-21-3," Valcor Engineering Corp., Springfield, NJ, April 9, 1984 (proprietary)

11. ASTM 575-83, "Standard Test Method for Rubber Properties in Compression," American Society for Testing of Materials, Philadelphia, PA, 1983

12. MEL R&D Report 13/66, "Thermal Aging Studies of Solenoid Coil Insulation Systems," U.S. Navy Marine Engineering Laboratory, Annapolis, MD, June 1986

13. "Aging Characteristics of Presray Seal and Gasket Material," Presray Corporation, Pawling, NY, March 1986

14. EPRI NP-1558, "A Review of Equipment Aging Theory and Technology," Electric Power Research Institute, Palo Alto, CA, September 1980

15. "Standard Handbook for Electrical Engineers," Tenth Edition, McGraw-Hill Book Company, New York, NY, 1969

APPENDIX

PLANT DBE PROFILES FROM SURVEY

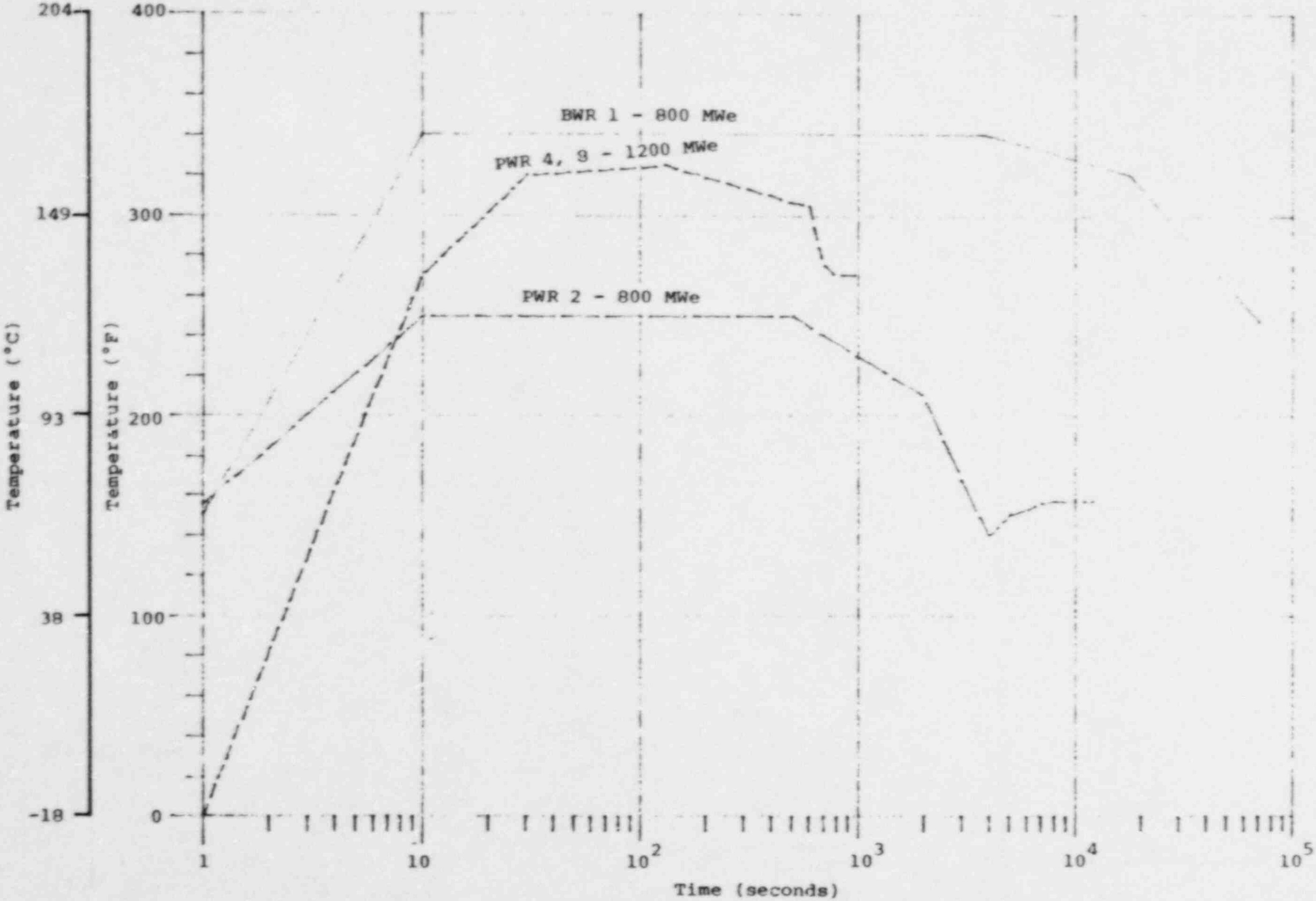


Figure A-1. Plant LOCA Curves (Temperature)

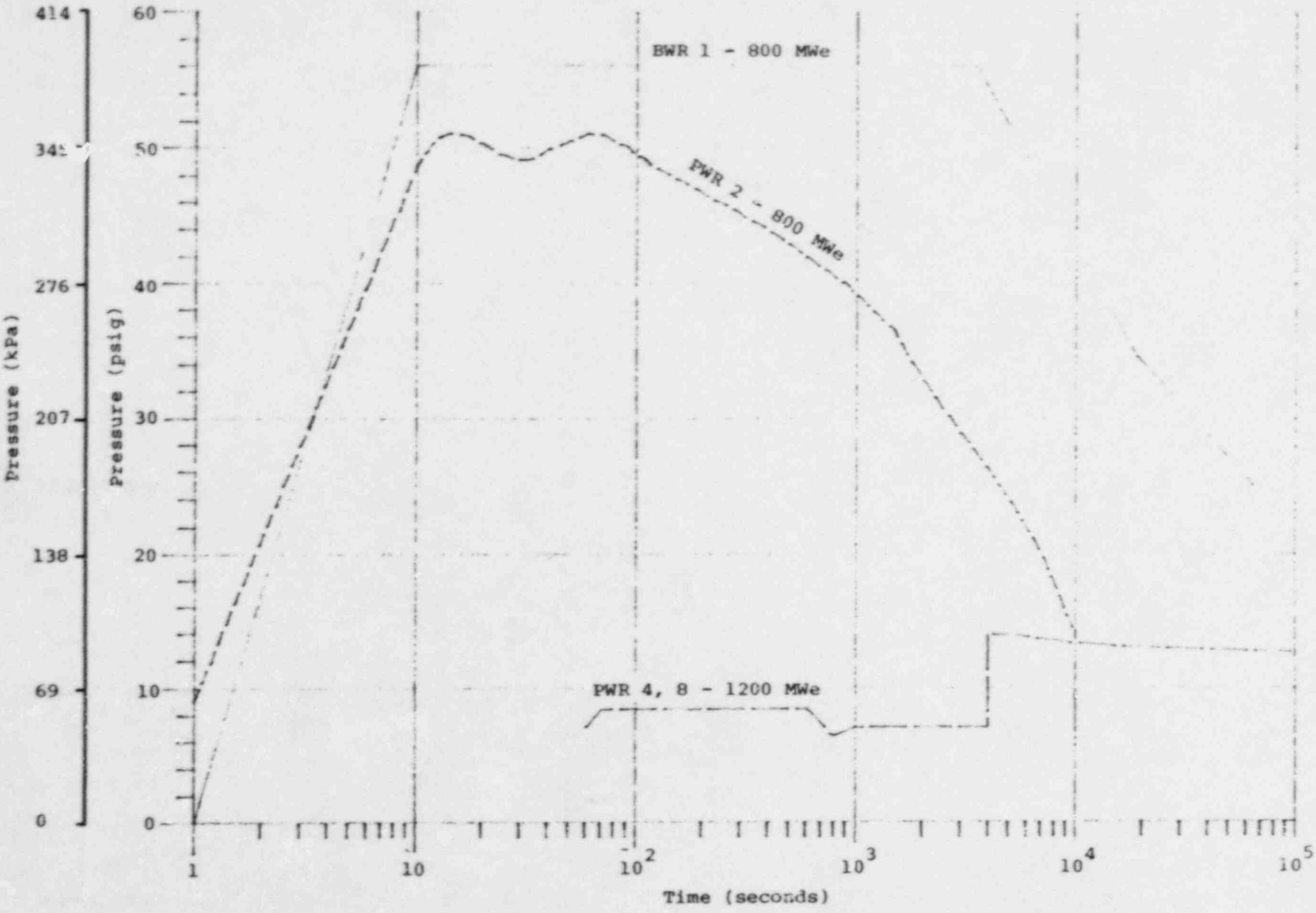


Figure A-2. Plant LOCA Curves (Pressure)

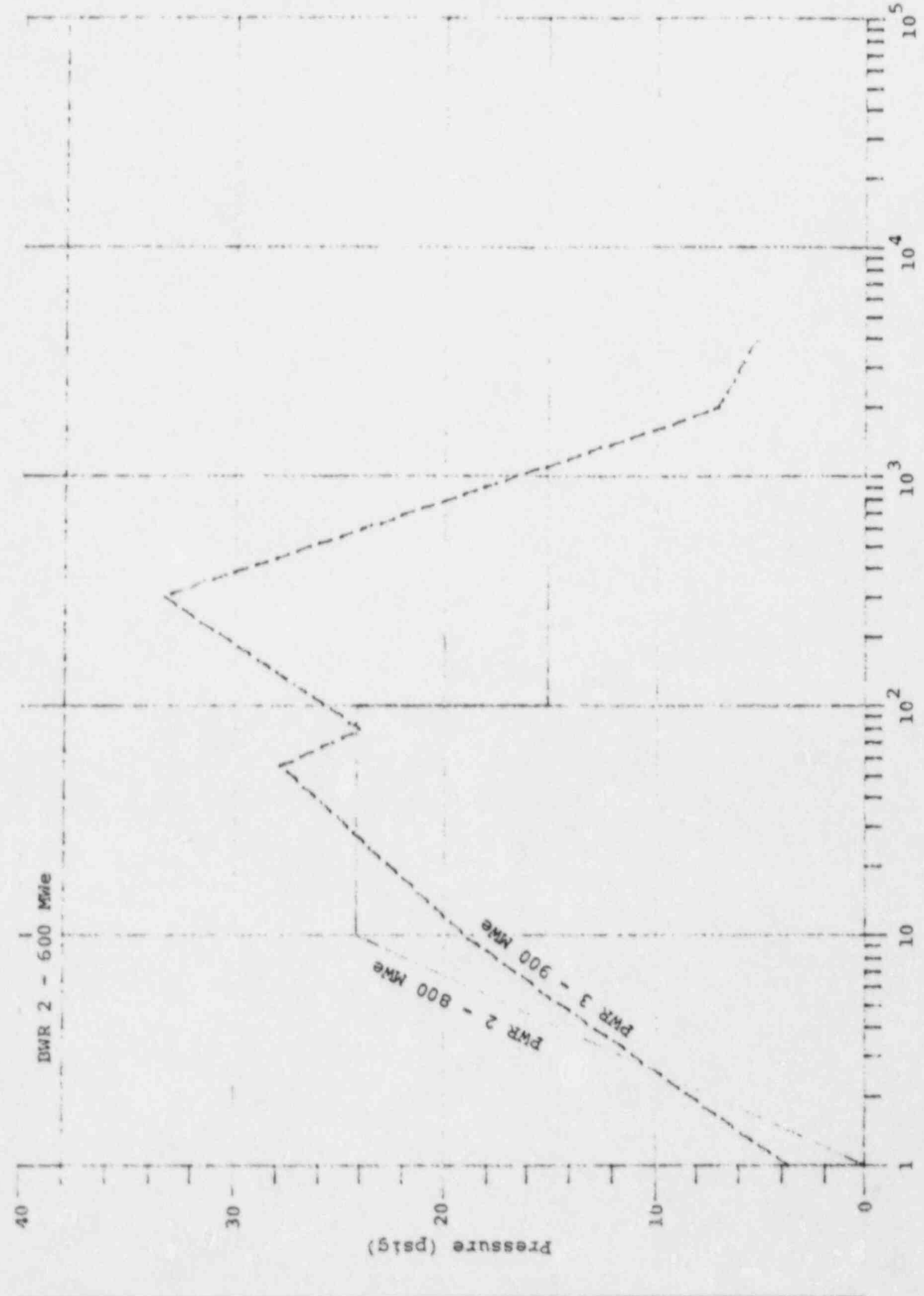


Figure A-3. Plant MSLB Curves (Pressure)

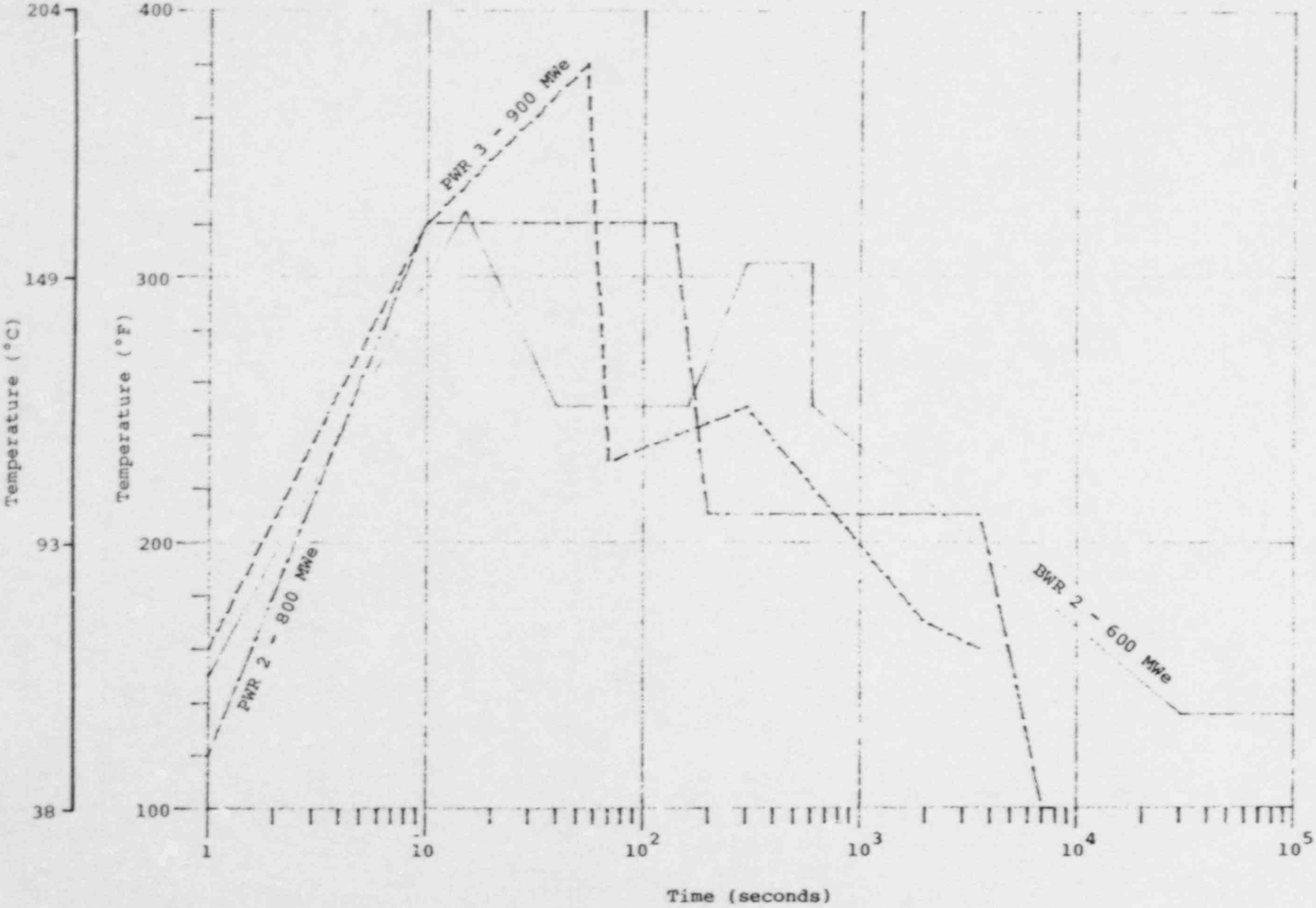


Figure A-4. Plant MSLB Curves (Temperature)

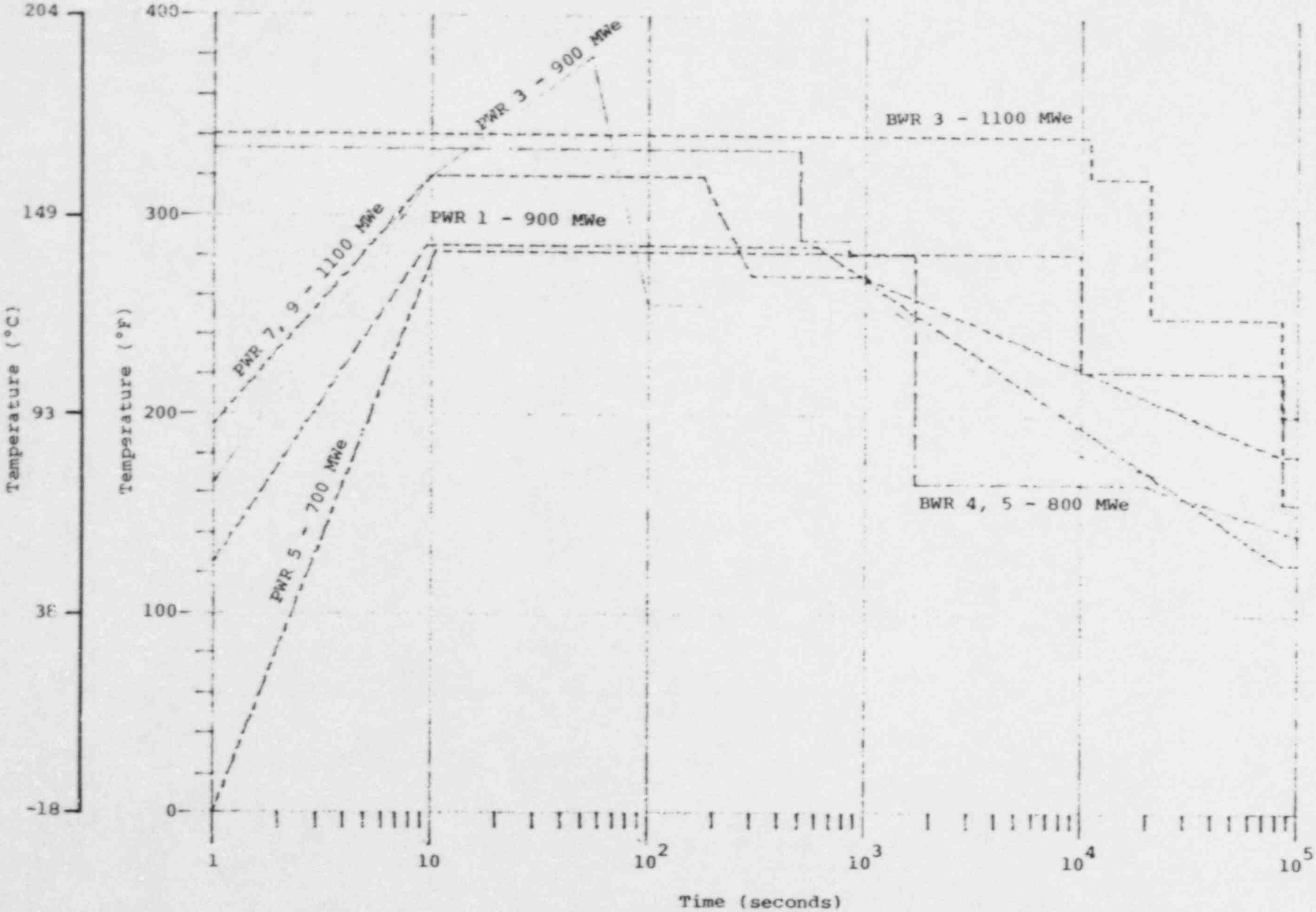


Figure A-5. Plant Equipment Qualification Curves (Temperature)

P-C6096

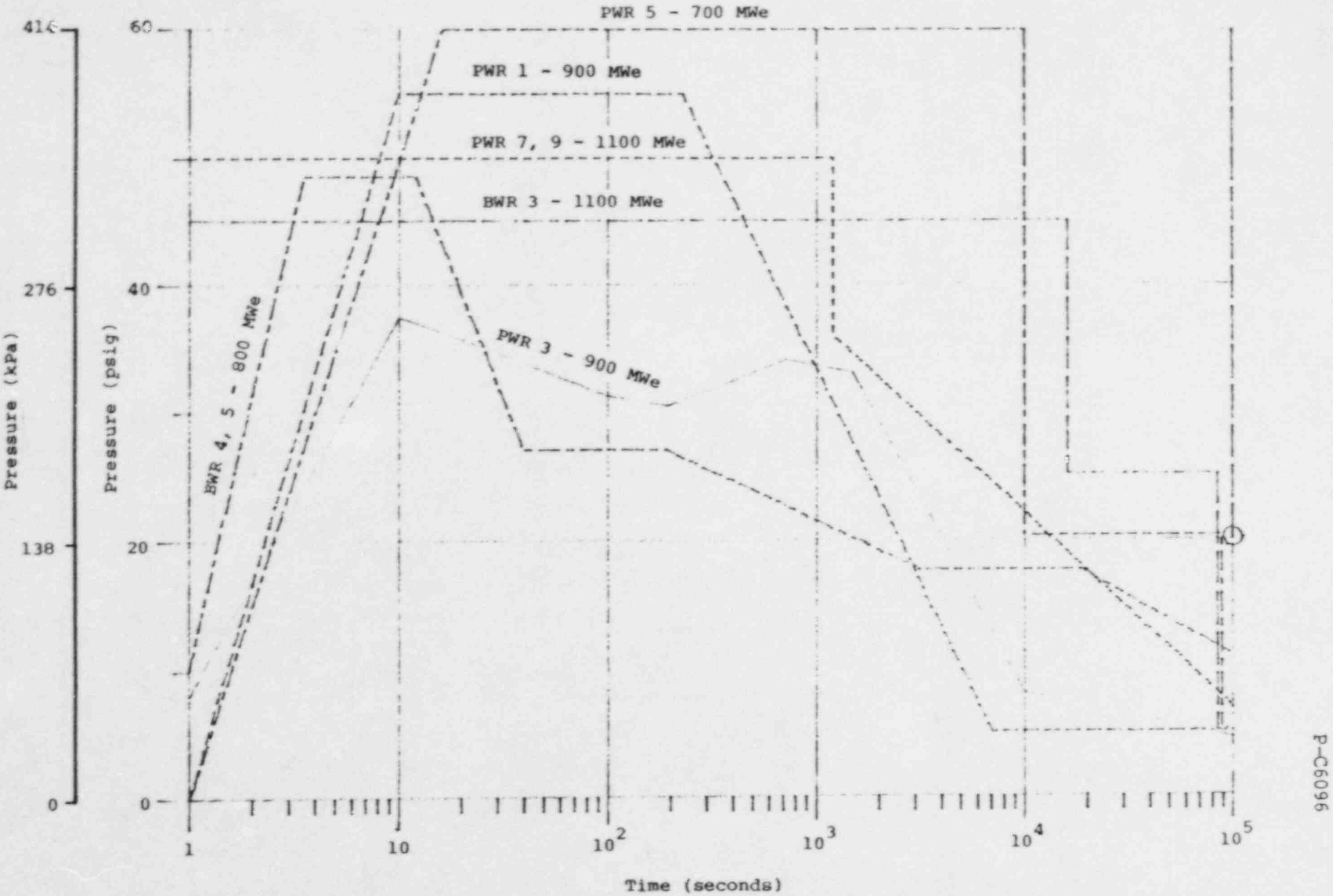


Figure A-6. Plant Qualification Curves (Pressure)

APPENDIX B

NUCLEAR IRRADIATION INFORMATION

July 6, 1987

Mr. Vince Bacanskas
Franklin Research
20th and Race Streets
Philadelphia, PA 19103

Dear Mr. Bacanskas:

This letter will summarize the parameters pertinent to the irradiation of one (1) stand containing twelve (12) valves. Reference your Purchase Order No. 76631 dated April 14, 1987.

A. Description of the Irradiated Material

The irradiated material consisted of one (1) test stand with six (6) valves mounted on each of two levels. The individual specimans were identified by stamped metal tags with the following FIRL serial numbers.

Lower Level Valves		Upper Level Valves	
6096-2	6096-20	6096-3	6096-14
6096-7	6096-21	6096-8	6096-15
6096-13	6096-26	6096-10	6096-27

B. Arrangements for Gamma Irradiation

The mounted valves constituted an exposure area of approximately 15 inches cubed. With the valves oriented around the perimeter of each level, the four way rotation methodology was used for processing. Dosimeters were placed directly on the valves to determine the exposure rate.

Attached is a diagram showing the stand's horizontal and vertical orientation to the source.

C. Procedure for Uniform Gamma Irradiation

For both levels, Lower and Upper, four (4) dosimeter positions, identified as quadrants A, B, C and D, were monitored to determine the average center point dose rate. The stand was rotated in 90 degree intervals four times throughout its exposure. The rotation occurred when the center point dose reached 25% of the required minimum dose. The total length of time between rotation intervals is called an exposure Phase.

D. Calculation of the Dose

The minimum delivered dose to each level was calculated by the summation of the actual dose values obtained in each of the four quadrants for each exposure phase. The minimum reported dose is the lowest totaled value from any of the four quadrants. The maximum reported dose is highest totaled value from any of the four quadrants. The following tables detail the dose verification values for each level.

Lower Level Valves

	Quadrant A			Quadrant B			Quadrant C			Quadrant D		
	Rate	Hrs.	Dose	Rate	Hrs.	Dose	Rate	Hrs.	Dose	Rate	Hrs.	Dose
Phase 1	.81	82.7	67.0	.58	82.7	48.0	.45	82.7	37.2	.61	82.7	50.4
Phase 2	.61	86.8	52.9	.81	86.8	70.3	.58	86.8	50.3	.45	86.8	39.1
Phase 3	.45	79.5	35.8	.61	79.5	48.5	.81	79.5	64.4	.58	79.5	46.1
Phase 4	.58	83.0	48.1	.45	83.0	37.4	.61	83.0	50.6	.81	83.0	67.2
		Total	203.8		Total	204.2		Total	202.5		Total	202.8

Total Exposure Hrs.: 332.0 Minimum Delivered Dose: 202.5 Mrads

Maximum Delivered Dose: 204.2 Mrads

Upper Level Valves

	Quadrant A			Quadrant B			Quadrant C			Quadrant D		
	Rate	Hrs.	Dose	Rate	Hrs.	Dose	Rate	Hrs.	Dose	Rate	Hrs.	Dose
Phase 1	.89	82.7	73.6	.52	82.7	43.0	.49	82.7	40.5	.53	82.7	43.8
Phase 2	.53	86.8	46.0	.89	86.8	77.3	.52	86.8	45.1	.49	86.8	42.5
Phase 3	.49	79.5	39.0	.53	79.5	42.1	.89	79.5	70.8	.52	79.5	41.3
Phase 4	.52	83.0	43.2	.49	83.0	40.7	.53	83.0	44.0	.89	83.0	73.9
		Total	201.8		Total	203.1		Total	200.4		Total	201.5

Total Exposure Hrs.: 332.0 Minimum Delivered Dose: 200.4 Mrads

Maximum Delivered Dose: 203.1 Mrads

Starting Date: 4/17/87
Completion Date: 5/ 7/87

E. Dosimetry

Dosimetry was performed using Harwell 4034 Perspex dosimeters utilizing a Bausch and Lomb Model 1001 spectrophotometer as the readout instrument. The Batch AG dosimeters were calibrated traceable to a recognized standards laboratory with the last calibration date being June 5, 1986. The spectrophotometer used (S/N 1215592F) was last calibrated by Bausch and Lomb personnel on January 15, 1987 using standards traceable to NBS. The measurement tolerance for this dosimetry system is estimated to be ±8.0%.

The dose rate values stated in this report have been calculated by dividing measured dose by exposure time. Combining the estimated uncertainty of the dose measurement (±8.0%) with that of the time measurement (±0.7%) yields an uncertainty of ±8.8% for dose rate measurements.

The total dose values stated in this report are calculated by multiplying measured dose rates by exposure time. Combining the estimated uncertainty of the dose rate measurement (±8.8%) with that of the time measurement (±0.7%) yields an uncertainty of ±9.5% for total dose measurements.

Attached are copies of the calibration records for the instrumentation used with the dosimetry system.

F. Quality Assurance

The processing of this material followed the procedures outlined in the Isomedix Inc. Quality Assurance Manual for Reactor Component Processing, Revision H. The program specified in this manual is designed to comply with the quality assurance requirements of 10-CFR-50, Appendix B and the reporting requirements of 10-CFR-21.

Per your request, copies of all the worksheets generated to monitor the exposure of the test specimans are attached.

Sincerely;

Jonathan C Young
Plant Manager

Steven R. Thompson
Steven R Thompson
Manager Quality Assurance

NOTICE OF ANOMALY

Customer: Franklin Research Institute
Purchase Order No.: 76631
Date of Notice: July 6, 1987

Description of Anomaly:

A. The Purchase Order requests that the monitoring instrumentation for dose and dose rates shall have an accuracy of ±8%. When considering the estimated uncertainty to the time measurement of ±0.7%, the reported dose rate values have an uncertainty level of ±8.8%. The time measurement uncertainty in turn causes the reported dose values to have an uncertainty level of ±9.5%.

Technical Evaluation:

A. The total uncertainty of dose rate and total dose measurements remains below 10%. The 10% margin applied per IEEE-323 should be sufficient to assure that the minimum required dose was achieved. The customer is asked to evaluate the effect of this on the equipment qualification process.

Corrective Action:

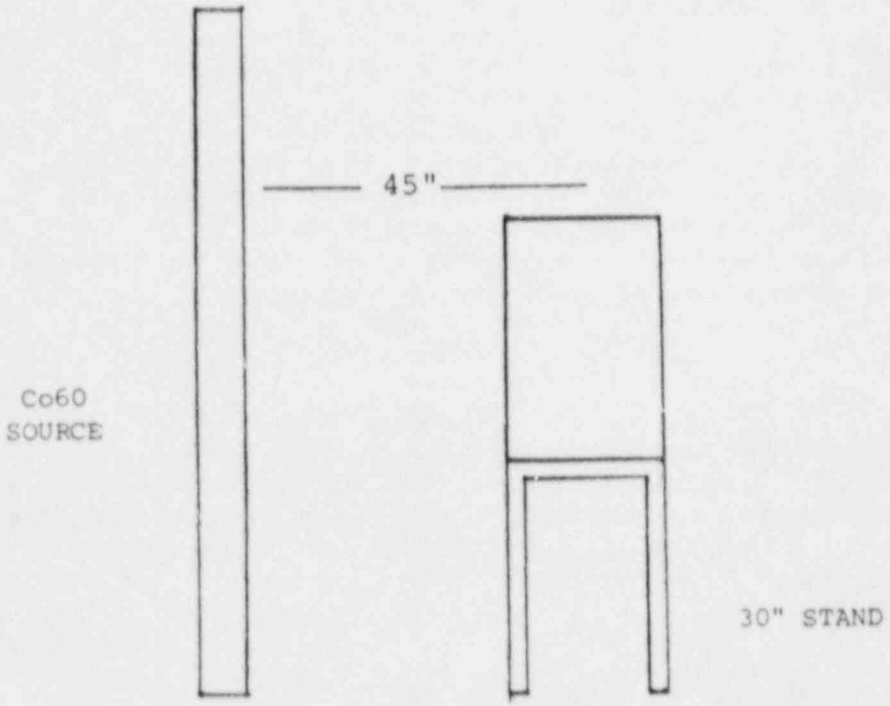
A. By the end of May 1987, a new batch of dosimeters will be in use. Studies will be performed to reevaluate the precision of the components of the system which comprise the ±8%. New timing instrumentation is being evaluated in order to reduce the effect of the time measurement uncertaipty.

Jonathan C Young
Plant Manager

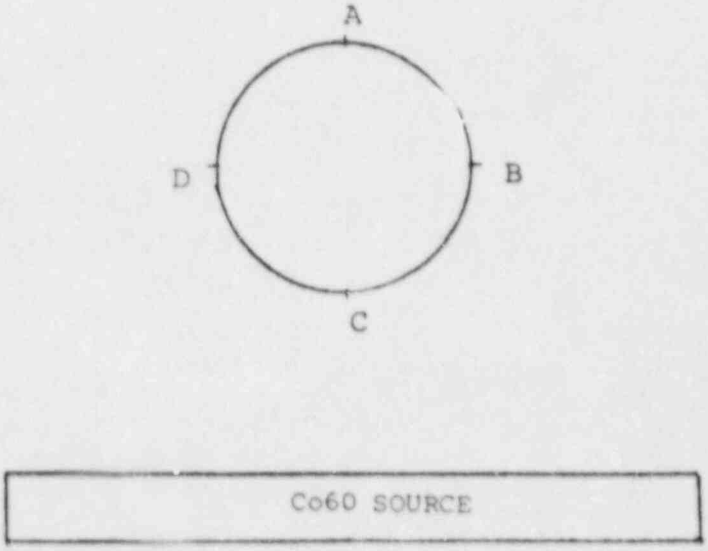
CUSTOMER: Franklin Research

PURCHASE ORDER NO.: 76631

SIDE VIEW



TOP VIEW with DOSIMETER PLACEMENTS

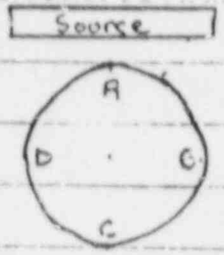


Rate Worksheet - Mandrel ___ of ___

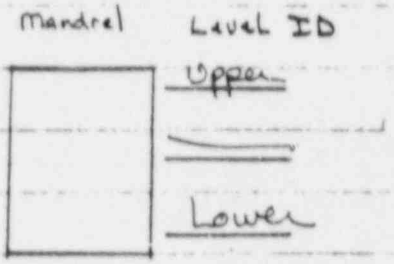
Customer: Franklin Institute Min. Required Dose : 200.00

P.O. No : .76631 Tolerances : —

Sample ID : Value stand Dose Rate Spec. : <.90 mr/hr



Quadrant Orientation To Source



Level Lower	Dose	Exposure Hrs	Rate Mr/hr
Quadrant A	1.94	2.38	.81
B	1.39		.58
C	1.07		.45
D	1.46		.61
		Total	2.45

Average Rate : .61

Level Upper			
Quadrant A	2.11	2.38	.89
B	1.23		.52
C	1.16		.49
D	1.27		.53
		TOTAL	2.43

Average Rate : .61

Min Dose Calculations

1. Min Required Dose : 200.00 ÷ LADR .61 = Total hrs : 327.9

2. Total hrs : 332.0 ÷ 4 = Rotation Interval 83

Source Clock Start :	6697.5
Rotation 1	6780.5
Rotation 2	6863.5
Rotation 3	6946.5
END	7029.5

Operators Sign.

Date 4/17/87

QA Sign. Sandi Tallman

Date 5/7/87

Exposure Hours

* Use punch clock on back for **start and end time for Dosimetry.**

End Clock Reading 932245

minus

Start Clock Reading 932102

= 143 ÷ 60 = 2.38 exposure hours

DOSIMETRY RECORD

Isomedix (New Jersey), Inc. Whippany, NJ 07981

PAGE ___ of ___

CUSTOMER Franklin Institute

IRRADIATION LOT NO. 76631

DOSIMETER BATCH AG

SPECTROPHOTOMETER NO. 1215592F

DOSIMETER LOCATION		ABS.	THK. (cm)	DOSE (Mrad)	REMARKS	TECHNICIAN	DATE
CARRIER	POSITION						
Lower	A	545	298	1.94			4/17/87
	B	419	288	1.39			
	C	370	310	1.07			
	D	448	297	1.46			
Upper	A	578	300	2.11			
	B	397	299	1.23			
	C	390	307	1.16			
	D	406	298	1.27			

APPROVED ______ TITLE Plant Mgr DATE 4/17/87

— of —

Data Work sheet - Mandrel

ustomer : Franklin Institute

Min Required Dose : 200.0

P.O. No. : 76631

Tolerances : —

Sample I.D : Value Stand

Dose Rate Spec : ≤.90 mr/hr

	Quadrant Tested Source	Calc. Clock Reading	Actual Clock Reading	ET hours	Operators Signature / Date	QA Signature / Date
START Time	A		6697.5	82.7	Jonathan C Young 4/17/87	n/A
Rotation 1	B	6780.5	6780.2	86.8	4/23/87	
Rotation 2	C	6863.5	6867.0	79.5	4/28/87	
Rotation 3	D	6946.5	6946.5	83.0	5/1/87	
End		7029.5	7029.5		5/7/87	
TOTAL			.	332.0		

Dose Verification (UPPER)

	Quadrant A			Quadrant B			Quadrant C			Quadrant D		
	Rate	Hrs.	Dose	Rate	Hrs	Dose	Rate	HRS	Dose	Rate	HRS	Dose
ase 1	.89	82.7	73.6	.52	82.7	43.0	.49	82.7	40.5	.53	82.7	43.8
2	.53	86.8	46.0	.89	86.8	77.3	.52	86.8	45.1	.49	86.8	42.5
3	.49	79.5	39.0	.53	79.5	42.1	.89	79.5	70.8	.52	79.5	41.3
4	.52	83.0	43.2	.49	83.0	40.7	.53	83.0	44.0	.89	83.0	73.9
	Total		201.8	TOTAL		203.1	Total		200.4	TOTAL		201.5

Minimum Dose : 200.4

Operators Sign. Jon Young Date 5/7/87

Maximum Dose : 203.1

QA Review Date 5/7/87

— of —

Data Worksheet - Mandrel

Customer : Franklin Institute
min Required Dose : 200.0
P.O. no. : 76631
Tolerances : —
Sample I.D : Value Stand
Dose Rate spec : ≤.90 mr/hr

	Quadrant Targeted Source	Calc. Clock Reading	Actual Clock Reading	Net hours	Operators Signature / Date	QA Signature / Date
START Time	A		6697.5	82.7	Jonathan C Young 4/17/87	n/A
Rotation 1	B	6780.5	6780.2	86.8	4/23/87	
Rotation 2	C	6863.5	6867.0	79.5	4/28/87	
Rotation 3	D	6946.5	6946.5	83.0	5/1/87	
End		7029.5	7029.5		5/7/87	
TOTAL			.	332.0		

Dose Verification (Lower)

	Quadrant A			Quadrant B			Quadrant C			Quadrant D		
	Rate	Hrs.	Dose	Rate	Hrs	Dose	Rate	HRS	Dose	Rate	HRS	Dose
Dose 1	.81	82.7	67.0	.58	82.7	48.0	.45	82.7	37.2	.61	82.7	50.4
2	.61	86.8	52.9	.91	86.8	10.3	.58	86.8	50.3	.45	86.8	39.1
3	.45	[illegible].5	35.8	.61	79.5	48.5	.81	79.5	64.4	.58	79.5	46.1
4	.58	[illegible]	48.1	.45	83.0	37.4	.61	83.0	50.6	.81	83.0	67.2
	Total		203.8	TOTAL		204.2	Total		202.5	TOTAL		202.8

Minimum Dose : 202.5
Operators Sign Jon Young Date 5/7/87
Maximum Dose : 204.2
B-11 QA Review Sandi Tallman Date 5/7/87

ee Attached Test Anomoly sheet Yes ___ N/A ___

MILTON ROY COMPANY/Analytical Products Division
(Formerly a division of BAUSCH & LOMB)

MILTON ROY COMPANY, Analytical Products Division, certifies that the instrument listed below has been repaired, calibrated, aligned, cleaned and operationally checked. This unit meets or exceeds all operating specifications as published by the manufacturer. Further, all parts (excluding expendables) used and labor performed to correct the original malfunction were warranted for 90 days.

SPEC. STANDARDS REGISTRY # 0260239 Y

INSTRUMENT: SPEC. 1001 SERIAL NO.: 1215592F

FIELD SERVICE ENGINEER: Roger A. [illegible] DATE: 1-15-87

TELEPHONE ( ) 1-800-654-9955

ISOMEDIX

THICKNESS GAGE CALIBRATION RECORD

CALIB. DATE: 4/16/87   TECHNICIAN: S. Tallman

THICKNESS GAGE ID: 7301

1.) THICKNESS GAGE EXAMINATION:

a.) Mechanism operates smoothly: Yes ✓ , No ___
b.) Contact points are clean: Yes ✓ , No ___

(If 1a or 1b answered "No", recommend to correct/repair.)

2.) TRANSFER STANDARD GAGE BLOCKS EXAMINATION:

a.) Calibrated within 36 months: Yes ✓ , No ___
b.) Free of corrosion, dirt, & defects: Yes ✓ , No ___

(If 2a or 2b answered "No", replace noncomplying gage blocks)

3.) CALIBRATION DATA (all readings in millimeters):

☑ Gage and standards stabilized ≥2 hr at room conditions.
☑ Gage set to 3.000 mm using 3.0 mm gage block standard.

GAGE BLOCK STANDARD	THICKNESS GAGE READING	DIFFERENCE (LIMIT ± 0.010 mm)	WITHIN LIMITS? (yes or no)
3.000 mm ID# 3127	* 3.000	0	yes
2.500 mm ID# 2114	2.502	.002	yes
3.500 mm ID# 4141	3.502	.002	yes
2.000 mm ID# 4132	2.002	.002	yes

*(If reading is not 3.000, reset gage and repeat measurement)

4.) GAGE ZERO OFFSET VALUE 0.000 millimeters

☑ GAGE IN CALIBRATION. Recalibration due: 5/16/87

☐ GAGE NOT IN CALIBRATION. Remove from service & replace.

Reviewed By: ______________ Date: 4/16/87
Plant Manager

2

THKCAL Rev. 2: 10/85

TIMERCAL 2
Rev. A, 8/86

ISOMEDIX

EXPOSURE TIMER CALIBRATION RECORD

INDIRECT CALIBRATION METHOD

1. Intermediate Clock (stopwatch)

Test Date	(a) Stopwatch ID	(b) NBS Time Signal Start	(c) NBS Time Signal Stop	(d) Elapsed NBS Time (c - b)	(e) Elapsed Stopwatch Time	(f) * Stopwatch Correction Factor (d ÷ e)
4/1/87	A1	8:23:20	9:23:20	60 min.	59.9 min	1.00

B-1A

2. Exposure Timer

Type: ☐ Off-Carrier Punch Clock; ☑ Console Source-Up Timer

Test Date	(g) Timer ID	(h) Initial Timer Reading	(i) Final Timer Reading	(j) Timer Elapsed Time (i - h)	(k) Elapsed Stopwatch Time	(l) Corrected Elapsed Stopwatch Time (k x f)	(m) ** Exposure Timer % Error = [(l ÷ j) - 1] x 100
4/1/87	Cramer BZGc 48	06386.1	06387.1	1.0 hrs 60 min.	1.0 hrs 60 min.	1.0	0

* Limits for 1(f) are: 1.000 ± 0.010 ** Limits for 2(m) are: ± 2.0%

PERFORMED BY: Sandi Tallman 4/1/87
Technician Date

REVIEWED BY: 4/1/87
QA or Plant Manager Date

ISOMEDIX

July 6, 1987

Mr. Vince Bacanskas
Franklin Research Institute
20th and Race Streets
Philadelphia, PA 19103

Re: Franklin Research Purchase Order No. 76631

Dear Mr Bacanskas:

Please find enclosed the entire file pertaining to the radiation exposure as specified in the above Purchase Order.

Isomedix is hereby transferring the record retention responsibilities to Franklin Research. Isomedix will retain a copy of said file for historical purposes only.

Please acknowledge receipt of the above file by signing the acceptance below and returning this release form.

Sincerely,

Jonathan C Young
Plant Manager

Accepted Vincent B Bacanskas

Title Senior Engineer

Date 7/21/87

JUL 1987
RECEIVED
ENGINEERING

DOSIMETRY RECORD

Isomedix (New Jersey), Inc. Whippany, NJ 07981

PAGE ___ of ___

CUSTOMER Franklin Institute
IRRADIATION LOT NO. 76631
DOSIMETER BATCH AG
SPECTROPHOTOMETER NO. 1215592F

DOSIMETER LOCATION		ABS.	THK. (c ,	DOSE (Mrad)	REMARKS	TECHNICIAN	DATE
CARRIER	POSITION						
Lower	A	545	298	1.94			4/17/87
	B	419	288	1.39			
	C	370	310	1.07			
	D	448	297	1.46			
Opper	A	578	300	2.11			
	B	397	299	1.23			
	C	390	307	1.16			
	D	406	298	1.27			

APPROVED Jonathan C
TITLE Plant Mgr
DATE 4/17/87

APPENDIX C

LIST OF DATA ACQUISITION INSTRUMENTS

LIST OF DATA ACQUISITION INSTRUMENTS

PROJECT 6096-002

ITEM NUMBER	EQUIPMENT NOMENCLATURE	MANUFACTURER NAME	MANUF. MODEL NO.	SERIAL NUMBER	RANGE/ FEATURES	ACCURACY TOLERANCE	DATE CALIBRATED	CALIBRATION DUE	RESULTS/ STATUS
5027	DC MILLIAMPERE-METER	KEPCO LABS	NONE	NONE	0-500 MA DC	2%	6/15/87	6/15/88	USED FOR TEST CKT'S
5028	DC MILLIAMPERE	SIMPSON	1227	06290	0-500 MA DC	2%	6/24/87	6/24/88	FOR TEST CKT'S
18175	GAGE PRESSURE	ASHCROFT	NONE	1003	0 TO 160 PSIG	3% OF FULL SCALE	09-12-86	09-12-87	IN TOLERANCE
19183	GAGE PRESSURE	BARTON	227	227-197-14	0-100 IN W.C.	1.0% OF FULL SCALE	04-28-87	04-28-88	IN TOLERANCE TO 50 IN W.C. WITH 3/8 IN ORIFICE
18187	GAGE PRESSURE	NORDEN KETAY	ACRAGAGE AISI 316 TUBE	1005	0 TO 200 PSIG, 1 PSI/DIV	1% OF FULL SCALE	6/25/87	6/25/88	IN TOLERANCE
18221	RECORDER STRIP CHART	ESTERLINE ANGUS	SPEED SERVO II L11025	908001	0.5 MV TO 100 VDC	0.25% OF FULL SCALE	04-29-87	10-29-87	IN TOLERANCE
18340	GAGE PRESSURE	U.S.GAUGE	10242	NONE	0 TO 160 PSIG	1.5% OF FULL SCALE	09-12-86	09-12-87	IN TOLERANCE
18341	GAGE PRESSURE	ASHCROFT	ANC-4289	NONE	0 TO 160 PSIG	1.5% OF FULL SCALE	09-12-86	09-12-87	IN TOLERANCE
18376	GAGE PRESSURE	U.S. GAGE	NONE	NONE	0 TO 160 PSIG	3% OF FULL SCALE	09-12-86	09-12-87	IN TOLERANCE
18382	GAGE PRESSURE	U.S. GAGE	NONE	10242	0 TO 160 PSIG	3% OF FULL SCALE	09-12-86	09-12-87	IN TOLERANCE
18395	GAGE PRESSURE	U.S. GAGE	1902*	NONE	0 TO 200 PSIG	1% OF FULL SCALE	09-15-86	09-15-87	IN TOLERANCE

LIST OF DATA ACQUISITION INSTRUMENTS

PROJECT 6096-002

ITEM NUMBER	EQUIPMENT NOMENCLATURE	MANUFACTURER NAME	MANUF. MODEL NO.	SERIAL NUMBER	RANGE/ FEATURES	ACCURACY TOLERANCE	DATE CALIBRATED	CALIBRATION DUE	RESULTS/ STATUS
18396	GAGE PRESSURE	U.S. GAGE	19028	NONE	0 TO [illegible] PSIG FULL SCALE	1% OF FULL SCALE	09-15-86	09-15-87	IN TOLERANCE
18402	GAGE PRESSURE	U.S. GAGE	19028	NONE	0 TO [illegible] PSIG	1% OF FULL SCALE	09-15-86	09-15-87	IN TOLERANCE
18409	AMMETER, DC	GENERAL ELECTRIC	DW-91	NONE	0 TO 500 MA FULL SCALE	2% OF FULL SCALE	6/15/87	6/15/88	INACTIVE
18410	AMMETER, DC	GENERAL ELECTRIC	DW-91	NONE	0 TO 500 MA FULL SCALE	2% OF FULL SCALE	6/15/87	6/15/88	IN TOLERANCE
18411	AMMETER, DC	GENERAL ELECTRIC	DW-91	NONE	0 TO 500 MA FULL SCALE	2% OF FULL SCALE	6/15/87	6/15/88	IN TOLERANCE
18412	AMMETER, DC	GENERAL ELECTRIC	DW-91	NONE	0 TO 500 MA FULL SCALE	2% OF FULL SCALE	6/15/87	6/15/88	IN TOLERANCE
18420	GAGE PRESSURE	U.S. GAGE	HBA200	NONE	0-200 PSIG	0.5% OF FULL SCALE	09-12-86	09-12-87	IN TOLERANCE
4217927	GAGE PRESSURE	HEISE	CMM	CMM-237-25	0 TO 500 PSIG 0.5 PSI/DIV	0.1% OF FULL SCALE	08-01-86	08-01-87	IN TOLERANCE
4217927	GAGE PRESSURE	HEISE	CMM	CMM-237-25	0 TO 500 PSIG 0.5 PSI/DIV	0.1% OF FULL SCALE	08-01-86	08-01-87	IN TOLERANCE
4218031	VOLTAGE STANDARD, DC	ANALOGIC	AN3100	4460	0-11.1110 MVDC, 0-111 VDC	0.005% OF READING	07-28-86	07-28-87	IN TOLERANCE
4218031	VOLTAGE STANDARD, DC	ANALOGIC	AN3100	4460	0-11.1110 MVDC, 0-111 VDC	0.005% OF READING	07-28-86	07-28-87	IN TOLERANCE
4218031	VOLTAGE STANDARD, DC	ANALOGIC	AN3100	4460	0-11.1110 MVDC, 0-111 VDC	0.005% OF READING	07-28-86	07-28-87	IN TOLERANCE

LIST OF DATA ACQUISITION INSTRUMENTS

PROJECT 6096-002

ITEM NUMBER	EQUIPMENT NOMENCLATURE	MANUFACTURER NAME	MANUF. MODEL NO.	SERIAL NUMBER	RANGE/ FEATURES	ACCURACY TOLERANCE	DATE CALIBRATED	CALIBRATION DUE	RESULTS/ STATUS
218119	RECORDER MULTIPOINT	ESTERLINE ANGUS	L1124S	950436	0 TO 500 DEG F TYPE T T/C 24 POINTS	0.25% OF SPAN	04-29-87	10-29-87	IN TOLERANCE
218202	MULTIMETER DIGITAL	JOHN FLUKE MFG CO	8800A	36076	200MV-1200VDC 2-1200VAC 200-20MOHMS	0.02% OF FULL SCALE	07-31-87	07-31-88	IN TOLERANCE

NRC FORM 335
(2 84)
NRCM 1102
3201, 3202

U.S. NUCLEAR REGULATORY COMMISSION

BIBLIOGRAPHIC DATA SHEET

SEE INSTRUCTIONS ON THE REVERSE

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5 AUTHOR(S)
V. P. Bacanskas, G. J. Toman, S. P. Carfagno

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12 SUPPLEMENTARY NOTES
None

13 ABSTRACT (200 words or less)

A research program was conducted on the aging and qualification of solenoid operated valves (SOVs). Some SOVs had been aged naturally through service in nuclear power plants and others were subjected to accelerated aging. Thermal aging was conducted both with air and nitrogen as the process gas. Operational aging was simulated by putting the specimens through operational cycles. The program included simulation of a design basis event (DBE), that consisted of DBE gamma irradiation and a 30-d main steam line break/loss of coolant accident (MSLB/LOCA) simulation.

A naturally aged ASCO SOV with Buna N seals and a new ASCO SOV, with EPDM seals, subjected to accelerated aging with nitrogen as the process gas, were the only ones to perform satisfactorily throughout the test program. Failures to transfer of other ASCO SOVs appeared to be caused by coil deterioration, not by seal deterioration.

Valcor SOVs suffered from sticking of the shaft seal O-rings, making it impossible to complete accelerated thermal aging. Seal deterioration in the Valcor SOVs caused leakage and delays in transferring following DBE irradiation. Valcor SOVs performed satisfactorily during several hours of the MSLB/LOCA simulation, but malfunctioned during most of the rest of the test.

14 DOCUMENT ANALYSIS – a. KEYWORDS/DESCRIPTORS
equipment qualification, accelerated aging, solenoid-operated valves

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