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Evaluation of Seals for Mechanical Penetrations of Containment Buildings

Prepared by D. A. Brinson, G. H. Graves

ERC International

Sandia National Laboratories

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ABSTRACT

This report describes tests of elastomeric seals that are used in the mechanical penetrations of nuclear power plant containments. These tests assessed the effects of thermal aging, radiation and thermal aging, sealing surface separation, and squeeze on the performance of several gasket designs: O-ring, gum drop, double dog ear, and tongue and groove. Both ethylene propylene rubber and silicone rubber gaskets were tested. The environment for testing enveloped a hypothetical severe accident: 143 psig and up to 700°F. The performance of the seals is quantified in terms of the leakage onset point on the time-temperature curve.

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ACKNOWLEDGEMENTS

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EXECUTIVE SUMMARY

These tests were conducted at Sandia National Laboratories as part of the Integrity of Containment Penetrations Under Severe Accident Loads Program, which is sponsored by the U.S. Nuclear Regulatory Commission and managed by Sandia National Laboratories. The tests were designed to measure leak rates from seals that are typically used in the mechanical penetrations of nuclear power plant containments. Gasket cross sections were actual size, but gasket circumferences were much smaller than actual size in order to reduce the cost of testing.

A total of 22 tests were performed. Eighteen tested 1/4-inch O-rings. One test each was run on the following designs: 1/2 inch O-ring, gum drop, double dog ear, and tongue and groove. Gaskets tested were of two elastomers: silicone (SI) rubber and ethylene propylene (EP) rubber. Some gaskets were tested in the unaged condition; others were given one of the following aging histories:

1. 300°F for 168 hours

2. 300°F for 168 hours and 200 Mrad at 1 Mrad/hour

Gaskets were aged in a fixture that provided the same squeeze as the leak test fixture.

Steam was the environment for 20 of the tests; hot air for 2 of the tests. Leakage was measured in each test; however, several experimental deficiencies made it impossible to have confidence in the leak rate data.

The results reported are the leakage onset points as indicated on the temperature vs. time plots, and the posttest photographs, which indicate the extent of the gaskets' degradation at the end of the test.

Some of the observations derived from the test results are as follows:

1. The thermal and radiation aging that was specified in these tests had a negligible deleterious effect on leakage onset temperature.

2. Metal-to-metal contact at the sealing surfaces virtually prevented significant leakage.

3. Leakage onset temperature did not appear to be significantly affected by increasing squeeze* from 9% to 17%. This may suggest that the seals prevent leakage as long as positive compression exists.

4. Leakage onset temperatures ranged from 626°F to 669°F for the five steam tests of EP rubber 1/4-inch O-rings with a gap between the sealing surfaces.

5. Leakage onset temperatures ranged from 486°F to 592°F for the eight steam tests of SI rubber 1/4-inch O-rings with a gap between the sealing surfaces.

6. Posttest visual inspection indicated that all gaskets experienced severe degradation, including those that were tested without a gap between the sealing surfaces.

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* Squeeze = $\frac{U-C}{U} \times 100$

where: U = uncompressed seal dimension
C = compressed seal dimension
(both dimensions measured normal to the sealing surface)

1. INTRODUCTION

Since the accident at Three Mile Island, a major effort in safety studies has been directed toward understanding the risks and consequences of severe accidents. Knowledge concerning the leakage behavior of nuclear plant containments is important input to accident mitigation strategies, risk studies, and emergency preparedness planning. Five NRC programs are concerned with containment integrity and leakage behavior under severe accident conditions: the Containment Safety Margins Program, the Valve Isolation Program, the Integrity of Containment Penetrations Under Severe Accident Conditions Program, the Electrical Penetrations Assemblies Program, and the Containment Integrity Under Extreme Loads Program.

1.1 Loss of Penetration Integrity

Calculations made under the Severe Accident Sequence Analysis Program indicate that pressures and temperatures significantly above the design basis levels are likely to occur during a severe accident. Loss of penetration integrity could occur as a result of (a) excessive pressure differentials across the penetrations, (b) degradation of seal materials resulting from exposure to high temperatures, (c) distortion of sealing surfaces as a result of containment deformation, and (d) enlargement of pre-existing leakage paths or creation of new leakage paths as a result of stress-induced cracks in liners, hatches, and flanges.* The probability of these failure modes is unknown, and the magnitude of any particular failure is difficult to predict.[1]

1.2 Failure of Seals in Penetrations

Containments subjected to severe accidents (static pressure conditions) have the potential to leak as a result of seal failure in a penetration rather than by failure of the containment shell. Some of the reasons for this are as follows:

1. Elastomers used in seals are generally not qualified for the severe accident environment.

2. Deformation at the penetration/containment interface is detrimental to seal integrity; this is especially significant when an equipment hatch sleeve deforms relative to the hatch cover and tensioning ring.

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* The inflatable seals that are used in some penetrations (e.g., personnel airlocks) are not discussed in this report.

3. The sealing surfaces of pressure unseating hatches will begin to separate when the bolt preload is nullified by the internal pressure.

   Note: Clauss [2] discusses the leakage potential of pressure unseating hatches. He gives a formula for the separation between the sealing surfaces and a formula for the pressure at which leaking begins in terms of the applicable stiffnesses, thermal strains, and bolt preloads. Clauss tabulates some of these numbers for existing containments. For one type of equipment hatch in BWR Mk IIIs, he calculates that separation would begin at 2X design pressure, and that at 3X design pressure the separation would be approximately 0.003 inch.

1.3 Application Caveats

The following caveats should be considered before applying the test results given in this report to full-sized penetrations:

1. The test fixture, with its reduced circumference, has relatively rigid surfaces; the gap between the flanges is nearly uniform around the perimeter. The full-sized penetration, on the other hand, might exhibit a varying gap around the perimeter.

2. In the event of a severe accident, sealing surfaces might move relative to each other. In these tests, such movement was not modeled; the test fixture's sealing surfaces were fixed.

3. Radiolytic damage to elastomers may depend not only on the absorbed dose, but also on the length of time that the elastomer is subject to radiation and hence on the dose rate. The damage caused by low dose rate exposure for a long time may be more severe than the damage resulting from high dose rate (but identical total dose) exposure over a short time. Thermal damage exhibits a similar phenomenon. These effects were not considered in the tests.

1.4 Previous Work

This section briefly mentions some of the previous work in elastomeric seal testing.

Argonne National Laboratory (ANL) produced a study [3] of existing penetrations that were believed to have a high probability of leaking when subjected to temperatures and pressures exceeding design values. They concentrated on large, operating type penetrations such as personnel airlocks, equipment hatches, and bellows seals. The ANL study is an extensive collection of text and drawings for the penetrations in 48 nuclear plants.

Welch and Kurzeka [4] investigated the effects of temperature, gland* surface finish, and squeeze** on leakage behavior. They also investigated the effects of temperature on the permeability and the compression set of elastomeric gaskets. They concluded that compression set is virtually independent of the amount of squeeze.

Welch and Kurzeka chose a compression set of 90% to represent end of useful life. Employing this number, they created some Arrhenius plots to show maximum allowable operating temperature for a given life.

Chivers and Hunt [5] offer a concise explanation of the issues in elastomeric seal performance. They include plots of compression set versus time and expected life versus temperature; end of life is defined to be when compression set reaches 100%.

Blakeston, Tomblin, and Ward [6] plotted percentage loss of standoff*** versus time and compression set versus time for selected temperatures and elastomers. They also studied the effects of oxygen on polymer degradation.

Wensel [7] reports that the change in sealing force is the best indicator of seal performance, and that it correlates well with compression set, which is easier to measure. He suggests compression set equal to 75% as a conservative estimate for the end of a gasket's useful life.

Wensel and Cotnam [8] subjected elastomeric gaskets to 350°F and 450°F water for up to one year. They concluded that compression set is an effective indicator for the extent of degradation, and that changes in hardness and weight <u>are not</u> effective indicators of degradation. All of the leakage in their experiments occurred at compression sets exceeding 75%.

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*gland -- the cavity into which an O-ring is installed. Includes the groove and the mating surface of the second part that together confine the O-ring.

**Squeeze $= \frac{U-C}{U} \times 100$

where: U = uncompressed seal dimension
C = compressed seal dimension
(both dimensions measured normal to the sealing surface)

***standoff -- the amount by which the gasket projects from the groove.

There seems to be a strong consensus that compression set is an effective indicator of degradation in an elastomeric gasket and that the end of a gasket's useful life occurs at a compression set ranging from 75% to 100%.

Thomas Bridges [9], at Idaho National Engineering Laboratory, tested elastomeric gaskets (under contract to Sandia National Laboratories) at 160 psig and temperatures up to 700°F, unaged and thermally aged. Flange rotation was simulated by machining one flange at an angle (up to 12°) relative to the mating flange. The pressurized fluid was dry nitrogen. Some of his conclusions:

1. Flange rotation had little effect on failure temperature.

2. Thermal aging had little effect on failure temperature.*

3. Seepage leak rate** increased as flange rotation increased.

4. Seepage leak rate increased as squeeze decreased.

5. Seepage leak rate was not affected by thermal aging.

6. Leak rates after gasket failure increased as flange separation increased.

7. Failure temperatures increased as squeeze increased.

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* Thermal aging probably does affect <u>leak rates</u> in pressure-unseating hatches, however, because it changes compression set retention.

** Seepage leak rates are those leak rates occurring prior to failure of the gasket.

2. DESCRIPTION OF TESTS

Tests were performed on five seal designs: double 1/4-inch O-ring, double 1/2-inch O-ring, double tongue and groove, double gumdrop, and double dog ear. A study by Argonne National Laboratory [3] determined that these seal designs are among the most commonly used in nuclear containment penetrations.

The test matrix is given in Table 1. The gaskets tested were of silicon (SI) rubber and ethylene propylene (EP) rubber.* The compound numbers are given in Table 2.

2.1 Leak Rates

A total of 20 tests were performed in a steam environment; 2 were performed in a hot air environment. The leak rate for the steam tests was measured by condensing the steam and then weighing the water collected during a given time. Leak rates associated with dry air tests were measured with flowmeters.

2.2 Temperature Profile

The temperatures and pressures chosen for testing enveloped the predicted severe accident conditions for the following types of nuclear containments: PWR, BWR Mk I, and BWR Mk III. The predicted worst-case temperature and pressure profiles are shown in Figures 1 through 3. The typical test temperature profile is shown in Figure 4. (This temperature profile was chosen so that failures would probably occur during regular working hours.) The temperature was first held at 360°F then increased up to 500°F, 600°F, and 700°F on successive days. The pressure was maintained at 143 psig throughout the tests.

2.3 Aging

Aging of the elastomers was in three categories: no aging, thermal aging only, and radiation followed by thermal aging. All aging was performed with the gaskets installed in the test fixture. Thermal aging was at 300°F for 168 hours. Radiation aging consisted of a 200 Mrad dose of gamma radiation applied at 1 Mrad/hour.

2.4 Flange Separation

Sealing surface separation was simulated by placing shims between the flanges of the test fixture. Tests were run with gaps of 0.006, 0.012, 0.024, and 0.048 inches as well as with metal-to-metal contact.

Note: Flange separation was fixed (constant) during the tests.

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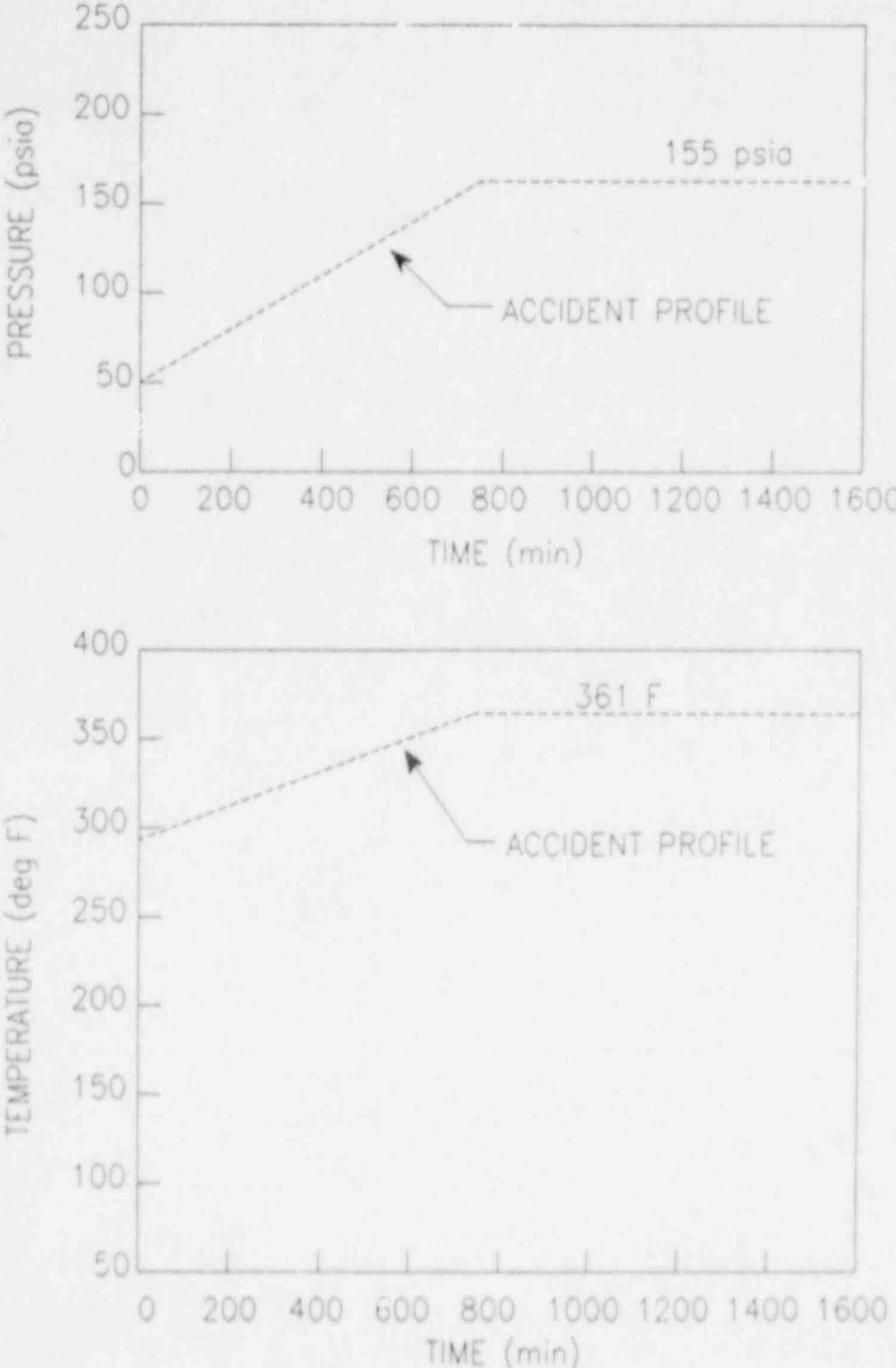
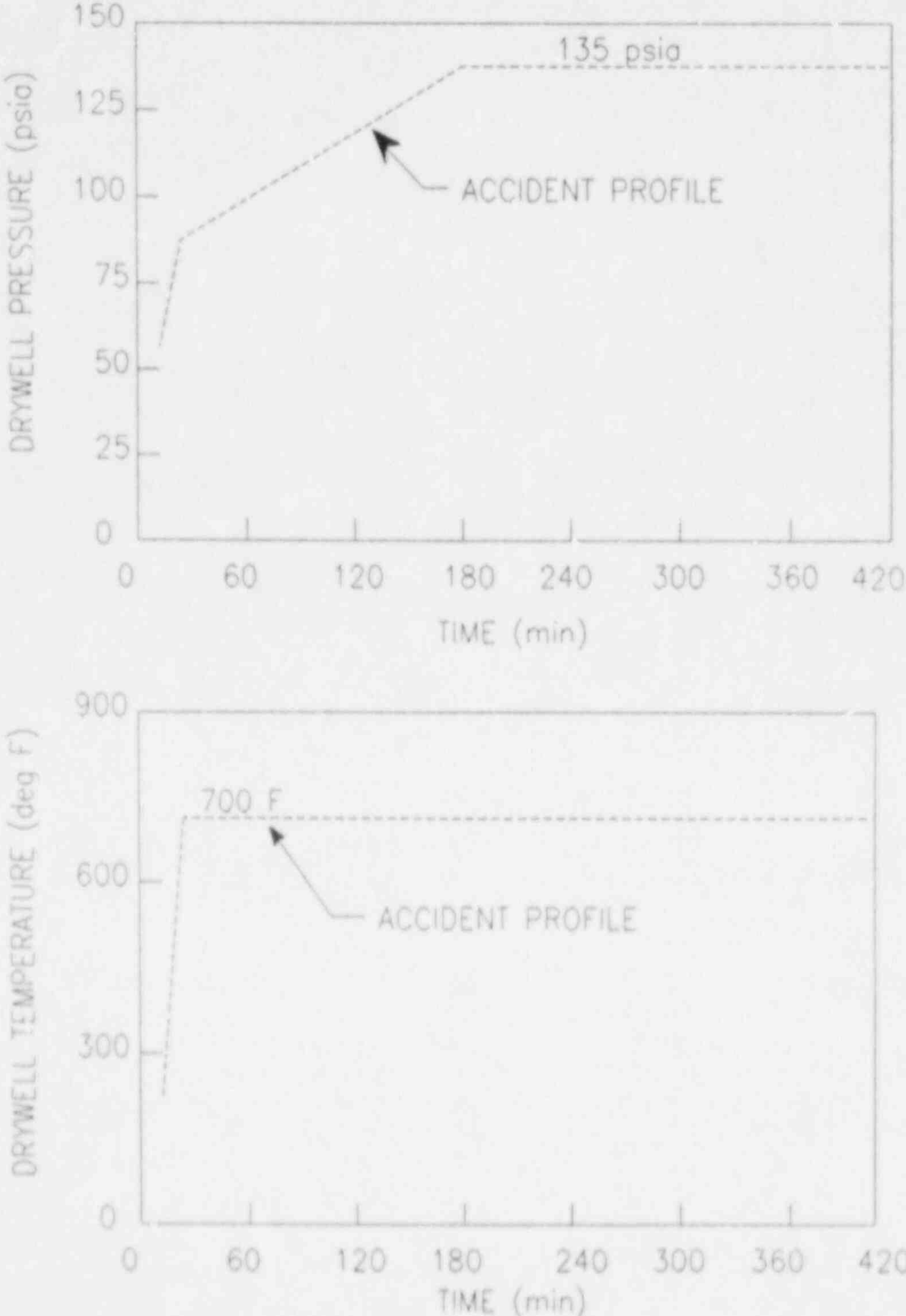
*One test was attempted with gaskets of fluorocarbon rubber; this elastomer deteriorated the fixture so severely that the test was aborted.



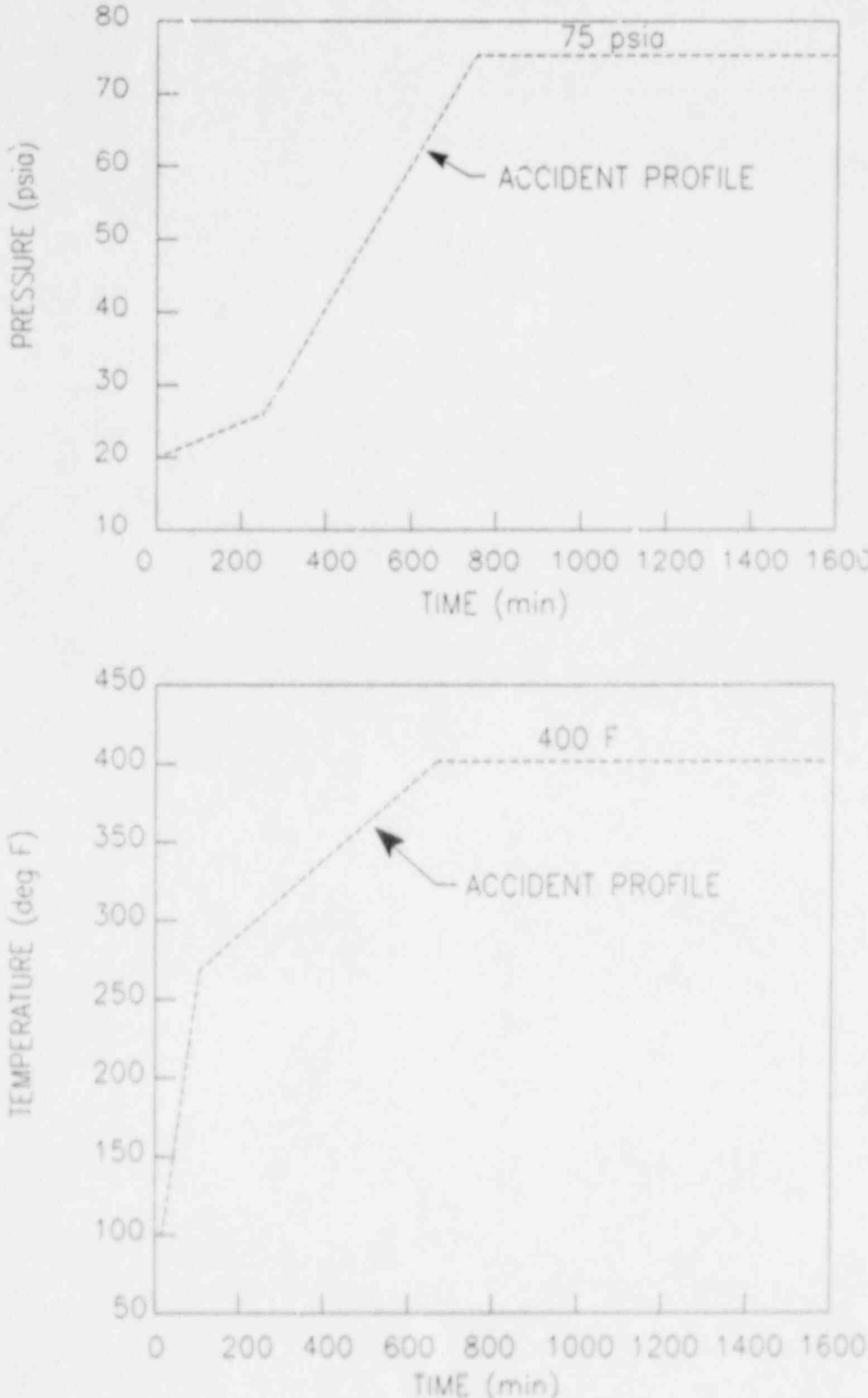
Reactor Accident Conditions for PWRs
(Containment Atmosphere)

Figure 1

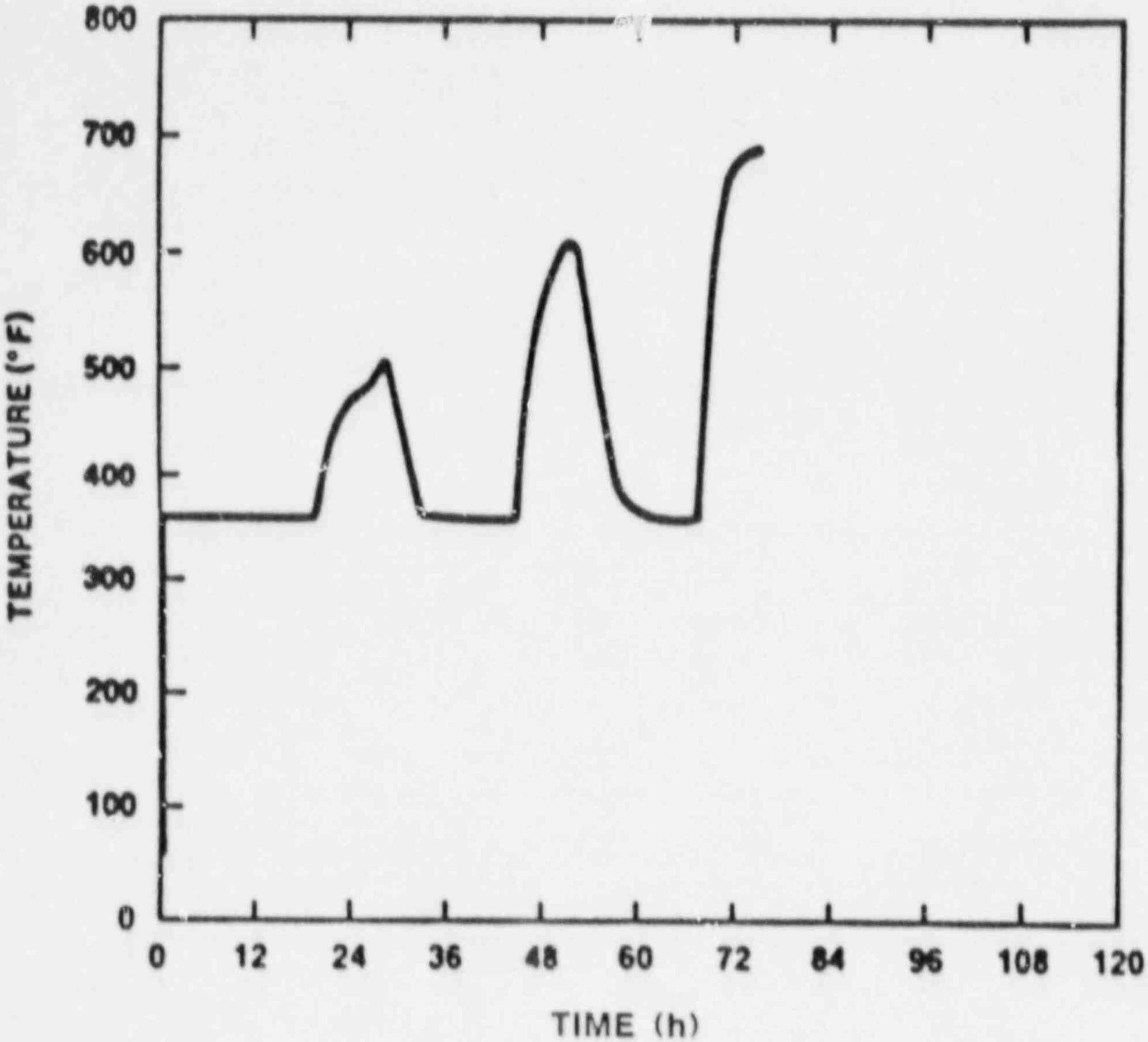


Reactor Accident Conditions for BWR Mark I
(Drywell Atmosphere)

Figure 2



Reactor Accident Conditions for BWR Mark III
(Wetwell Atmosphere)
Figure 3



Test Temperature Profile (Typical)

Figure 4

TABLE 1

Test Matrix

TEST NO.	SEAL DESIGN	ELASTOMER	AGING	ATMOSPHERE	GAP (in)	SQUEEZE (%)	FIXTURE[f]	LEAKAGE ONSET TEMP. (°F)
E1	0.275" DOR	EP	None	Steam	.000	26	A	692[a]
E2	0.275" DOR	EP	None	Steam	.024	17	A	626
E3	0.275" DOR	EP	None	Steam	.048	9	B	669[a]
E4	0.275" DOR	EP	R & T	Steam	.000	26	B	DNL
E5	0.275" DOR	EP	None	Hot Air	.024	17	B	651
E6	0.275" DOR	EP	R & T	Steam	.024	17	B	657
E7	0.275" DOR	EP	R & T	Steam	.048	9	B	637
E8	0.275" DOR	SI	R & T	Steam	.024	17	B	524[b]
E9	0.275" DOR	SI	R & T	Steam	.048	9	B	508[b]
E10	0.275" DOR	EP	T	Steam	.024	17	B	648
E11	0.275" DOR	SI	T	Steam	.024	17	B	497
E12	0.275" DOR	SI	R & T	Steam	.024	17	B	592
E13	0.275" DOR	SI	None	Steam	.012	22	B	506
E14	0.275" DOR	SI	None	Steam	.006	24	B	486
S1	0.275" DOR	SI	None	Steam	.000	26	A	DNL
S2	0.275" DOR	SI	None	Steam	.024	17	B	493
S3	0.275" DOR	SI	None	Steam	.048	9	B	493
S4	0.275" DOR	SI	None	Hot Air	.024	17	B	681
DGD	DGD[c]	EP	None	Steam	.012	22	DGD	g
DDE	DDE[d]	EP	None	Steam	.012	26	DDE	617
DTG	DTG[e]	EP	None	Steam	.012	N/A	DTG	609
DOR	0.500" DOR	EP	None	Steam	.012	23	O-ring	590

DOR = Double O-ring
DGD = Double Gum Drop
DDE = Double Dog Ear (one gasket)
DTG = Double Tongue and Groove
None = No Aging

R & T = Radiation and Thermal Aging
T = Thermal Aging Only
EP = Ethylene Propylene Rubber
SI = Silicone Rubber
DNL = Did Not Leak During Test

a The thermocouple used to determine the fixture temperature is not in the typical location as shown in Figure 9 on page 19. Instead, the temperature was measured by a thermocouple attached to the outside of the test fixture. Therefore, the reported temperature may vary slightly from that of the interior cavity of the fixture.

b See Note 2, page 23.

c See Figure 5.

d See Figure 6.

e See Figure 7.

f Two fixtures were used to test 1/4-inch O-rings; they are designated "A" and "B" (see Appendix B).

g See Appendix A, p. A-46.

TABLE 2

Gaskets Tested

GASKET TYPE	CROSS-SECTION	PERIMETER*	ELASTOMER	COMPOUND NUMBER	DUROMETER	MANUFACTURER
O-ring	0.275" dia	3-11**	EP	E603-70	70	Parker Hannifin
O-ring	0.275" dia	3-11**	SI	S604-70	70	Parker Hannifin
O-ring	0.5" dia	23-25	EP	E603-60	60	Presray
Gum Drop	Fig. 5	18-20	EP	E603-60	60	Presray
Double Dog Ear	Fig. 6	13-15	EP	E603-60	60	Presray
Tongue & Groove	Fig. 7	28-30	EP	E603-60	60	Presray

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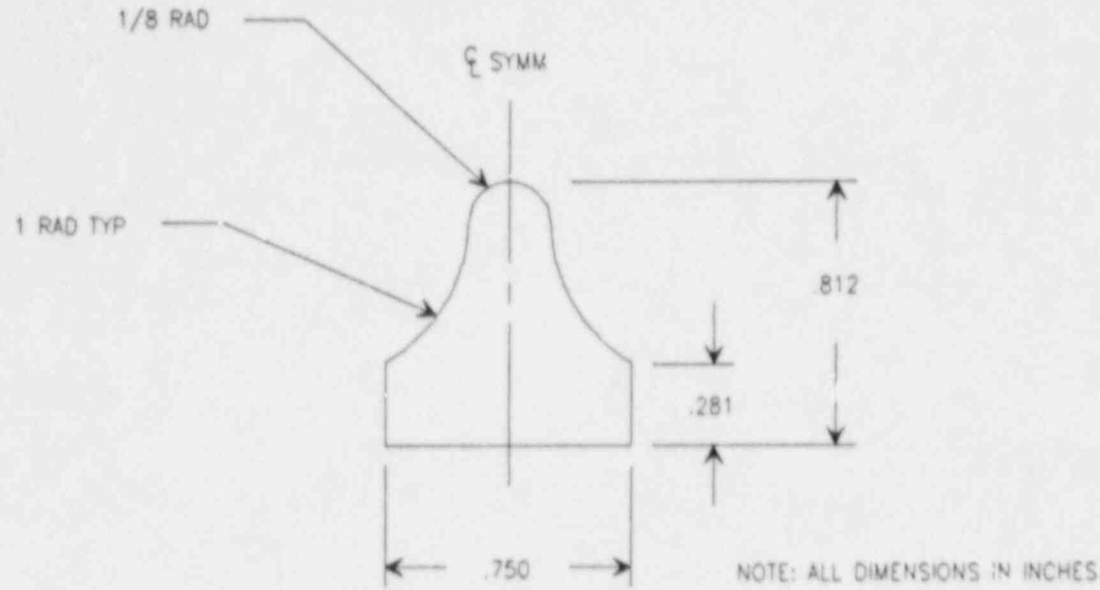
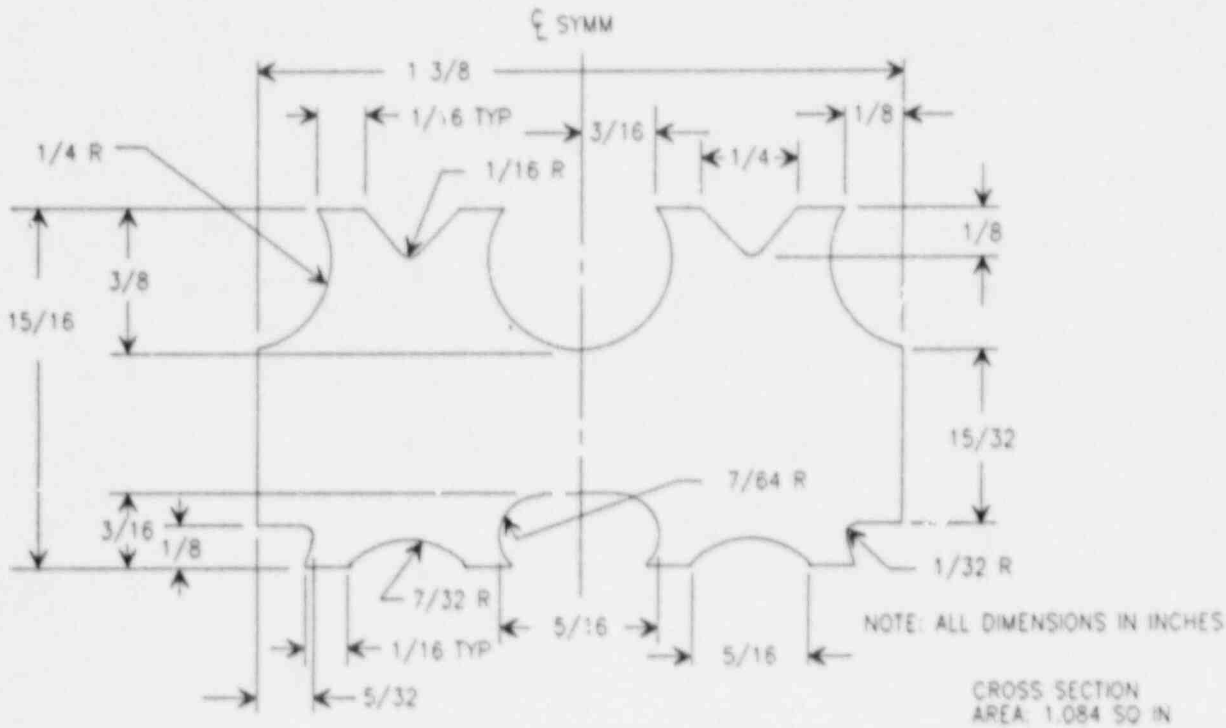
* This column gives page numbers in Appendix B.

** The largest diameter groove on the "B" Fixture was not used.



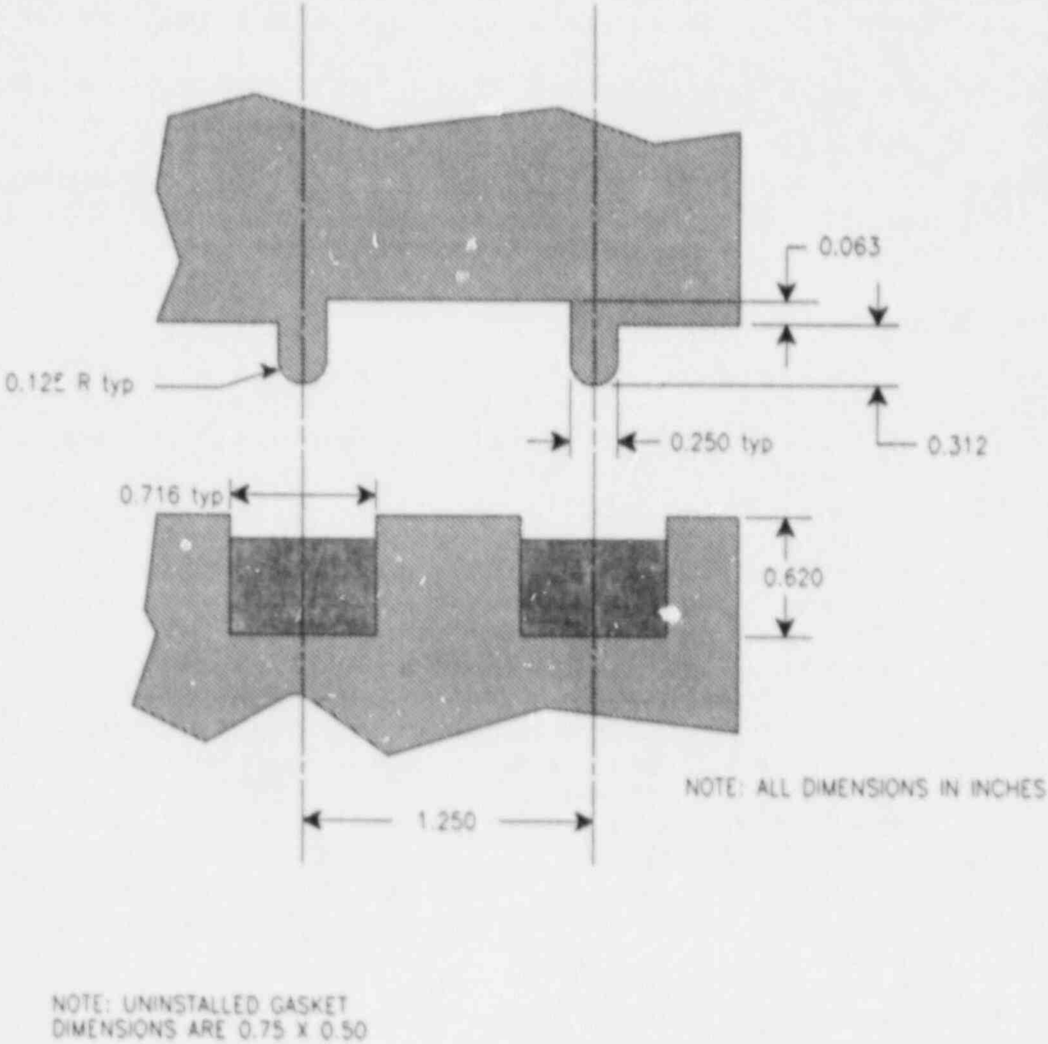
Cross Section of Gum Drop Gasket

Figure 5



Cross Section of Double Dog Ear Gasket

Figure 6



Double Tongue-and-Groove Seal Design

Figure 7

3. TEST PROCEDURE

3.1 Equipment

The steam system used for these tests has two boilers (3 hp and 6 hp), a 16-cubic-foot accumulator with 8-cubic-feet of water, and a 20-kW superheater. The system can deliver superheated steam at up to 750°F and 200 psig.

The environmental chamber is shown in Figure 8. The test environment fills the chamber and surrounds the test fixture.

Schematics of a typical test apparatus are given in Figures 9 and 10.

Test fixture drawings are in Appendix B. Test fixtures were fabricated for each gasket design. Two different 1/4-inch O-ring fixtures were used in the tests (see Table 1).

3.2 Testing Sequence*

The typical procedure for testing a gasket is as follows:

1) Measure compression set, hardness, and diameter of virgin gaskets.
2) Irradiate gaskets (in test fixture) to 200 Mrad at 1 Mrad/hour.
3) Measure diameter and hardness of gasket.
4) Thermally age gaskets (in test fixture) for 168 hours at 300°F.
5) Measure diameter and hardness of gaskets.
6) Install gaskets in test fixture.
7) Install shims to achieve desired gap setting.
   Note: Squeeze was constant throughout the test.
8) Torque assembly bolts to 100 lb-in.
9) Place fixture in environmental chamber.
10) Apply steam at 143 psig and 360°F; hold overnight.
   Note: Pressure was held constant throughout the tests.
11) Next day increase temperature to 500°F and hold for 2 hours.
12) Return to 360° for evening.
13) Next day increase temperature to 600°F and hold for 2 hours.
14) Return to 360° for evening.

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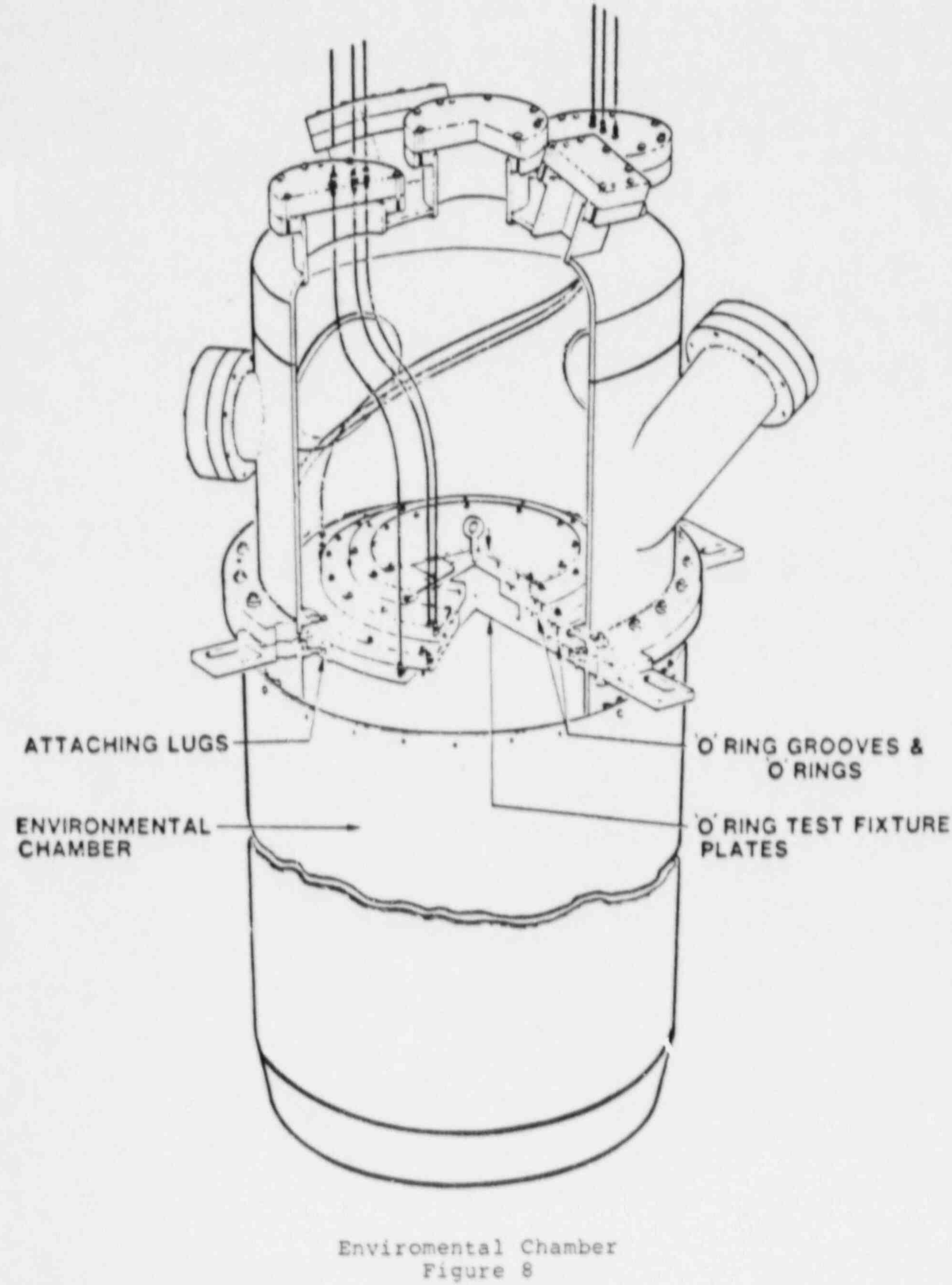
*For a gasket that was only thermally aged, steps 2 and 3 were deleted. For a gasket that was to have no aging, steps 2,3,4 and 5 were deleted.

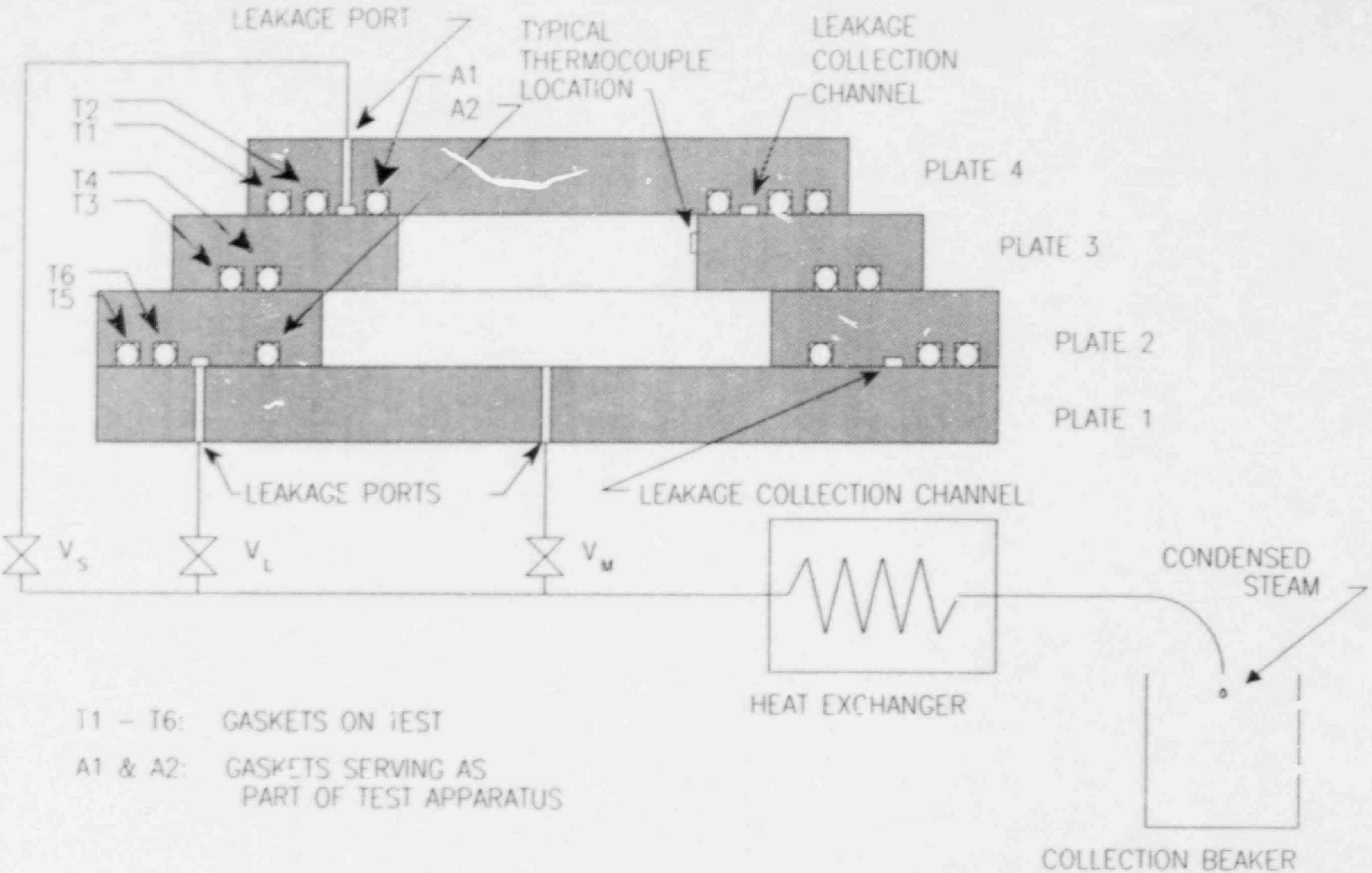
15) Next day increase temperature to 700°F and hold for 2 hours.

    Note: A typical temperature profile is shown in Figure 4.

16) Return fixture to room temperature.
17) Disassemble.
18) Photograph gaskets and sealing surfaces.

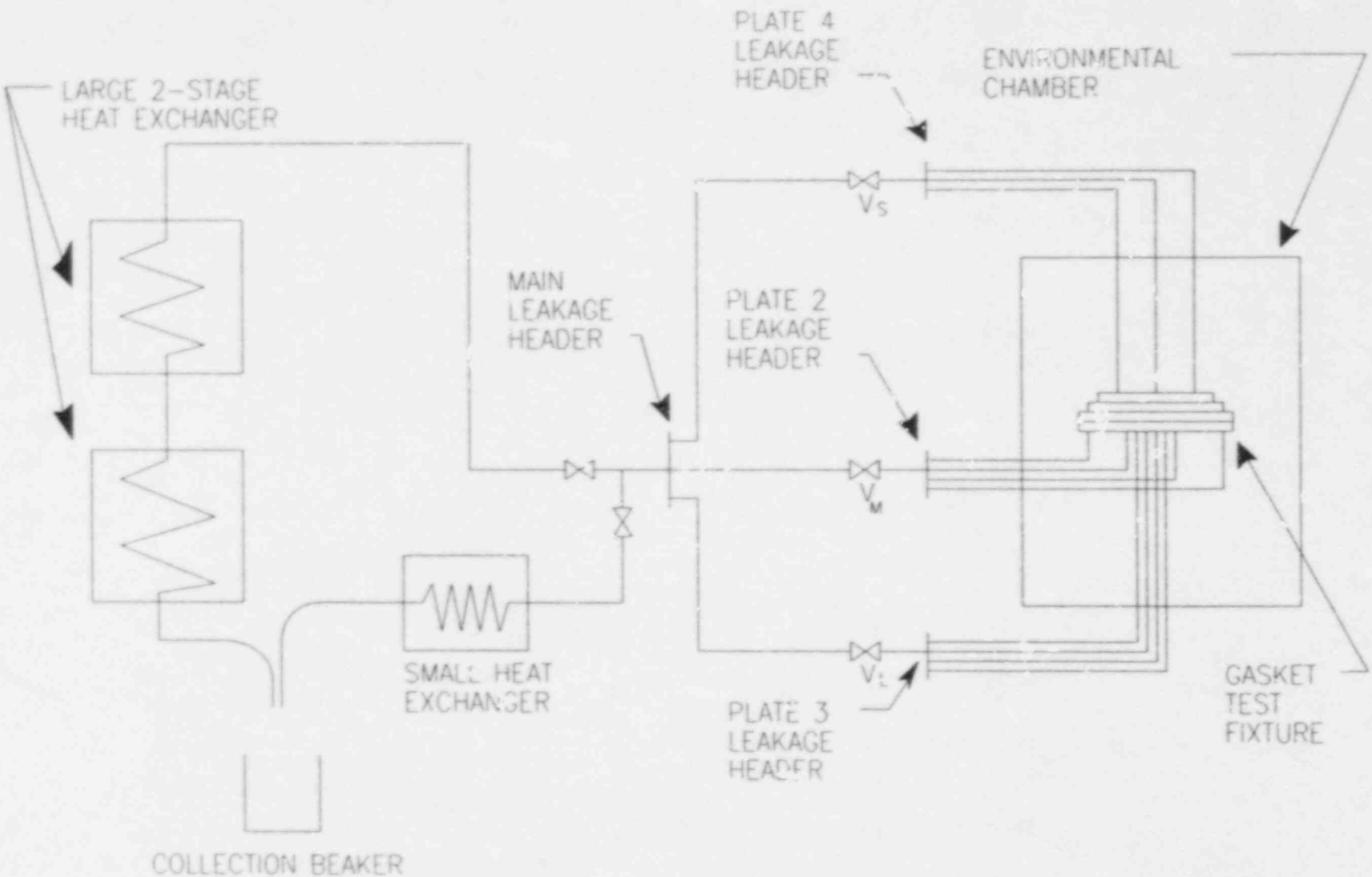


Enviromental Chamber
Figure 8



Cross Sectional View of a Typical Test Fixture with Simplified Piping Schematic

Figure 9



Piping Schematic
Figure 10

4. LEAK RATE DATA EVALUATION

One of the original goals of this test program was to measure leakage rates for several different seal and gasket materials and cross-sectional shapes. However, for the reasons described below, only the onset of leakage was determined. It was impossible to accurately measure the leak rate past a single set of gaskets during these tests. The difficulty arose because of breakup of the seal material, which then caused clogging of the leakage detection lines. Another problem was in the design of the test fixture, which was meant to measure leakage past several different seals during a single test.

4.1 Failure Characteristics of the Elastomers

During some of the tests, the gaskets melted, allowing molten elastomer to move and clog the leakage collection ports.* Clogging occurred to such an extent during several tests that the ports were completely obstructed and leaking stopped. In other tests, the data suggests that ports were obstructed and then reopened; these tests exhibited leak rate variations that are otherwise inexplicable. The leak rates would decrease and then increase again as the material plugged the ports and then later blew through the system. Clearly, such leak rates do not represent an accurate picture of gasket performance.

4.2 Apparatus Design Deficiencies

The apparatus was designed so that three sets of two seals each could be tested simultaneously, thus tripling the amount of data generated by each test. A schematic of the test apparatus and associated leakage detection piping is shown in Figure 9. Valves V_S, V_L, V_M were all open at the beginning of the test and remained open until leakage was first detected. At this point the valves were all closed and then reopened one at a time until the location of the leak was determined. As can be seen in Figure 9, when valves V_S, V_L, V_M were closed and gaskets T_1/T_2 or T_5/T_6 began to leak, the apparatus gaskets (A_1 or A_2) may have been subjected to the full test pressure. Because the apparatus gaskets were made of the same material as the gaskets under test, they would be expected to leak under approximately the same pressure and temperature conditions. Leakage past the apparatus gaskets would have <u>appeared</u> to result from failure of T_3/T_4. The degraded condition of the apparatus gaskets after the tests indicates

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*For example, see the photographs in Appendix A for tests E1 and E8.

that such spurious leakage probably did occur. (See posttest photos, Appendix A). Obviously, leakage past the apparatus gaskets could cause serious errors in the measured leak rates, which were originally thought to be solely a result of test gasket failure.

The pressure and temperature conditions at the point of leakage onset for the first set of gaskets to begin leaking were not affected by this problem. Thus, the measured pressure and temperature at onset of leakage for these seals are considered correct.

5. RESULTS

5.1 Leakage Onset Point

The leakage onset point is indicated on the temperature profiles shown in Appendix A.* A summary of the leakage onset temperatures for all the tests is provided in Table 1. For 1/4-inch O-rings, these data are displayed in Figures 11 and 12.

For purposes of these tests, leakage onset point was defined to be when the leakage rate reached 1.0 ml/min of condensate.

Note:

1. The time required for the steam to pass through the leakage piping and be condensed in the heat exchanger caused some imprecision in the leakage onset temperatures; therefore, the data should be considered approximate.

2. For tests E8 and E9, one of the three sets of gaskets that had been radiation and thermally aged failed to provide a seal when the leak test was begun. This one set was replaced by a set of unaged gaskets. During the tests, the unaged gaskets were the first to fail. After the first failure occurred, leakage onset point for the remaining gaskets was undetectable (see Section 4.2), so these data are not available for E8 and E9. Since the radiation and thermally aged gaskets were still providing an effective seal when the unaged gaskets failed, they performed at least as well as the unaged gaskets. Therefore, the temperatures reported for E8 (524°F) and E9 (508°F) are lower bounds of the leakage onset point for the radiation and thermally aged gaskets.

5.2 Posttest Photographs

Posttest photographs of the gaskets are displayed in Appendix A.

5.3 Typical Temperature Distribution

A typical temperature distribution on the 1/4-inch O-ring test fixture is shown in Appendix C.

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*The typical location of the thermocouple used to determine fixture temperature is shown in Figure 9.

5.4 Observations

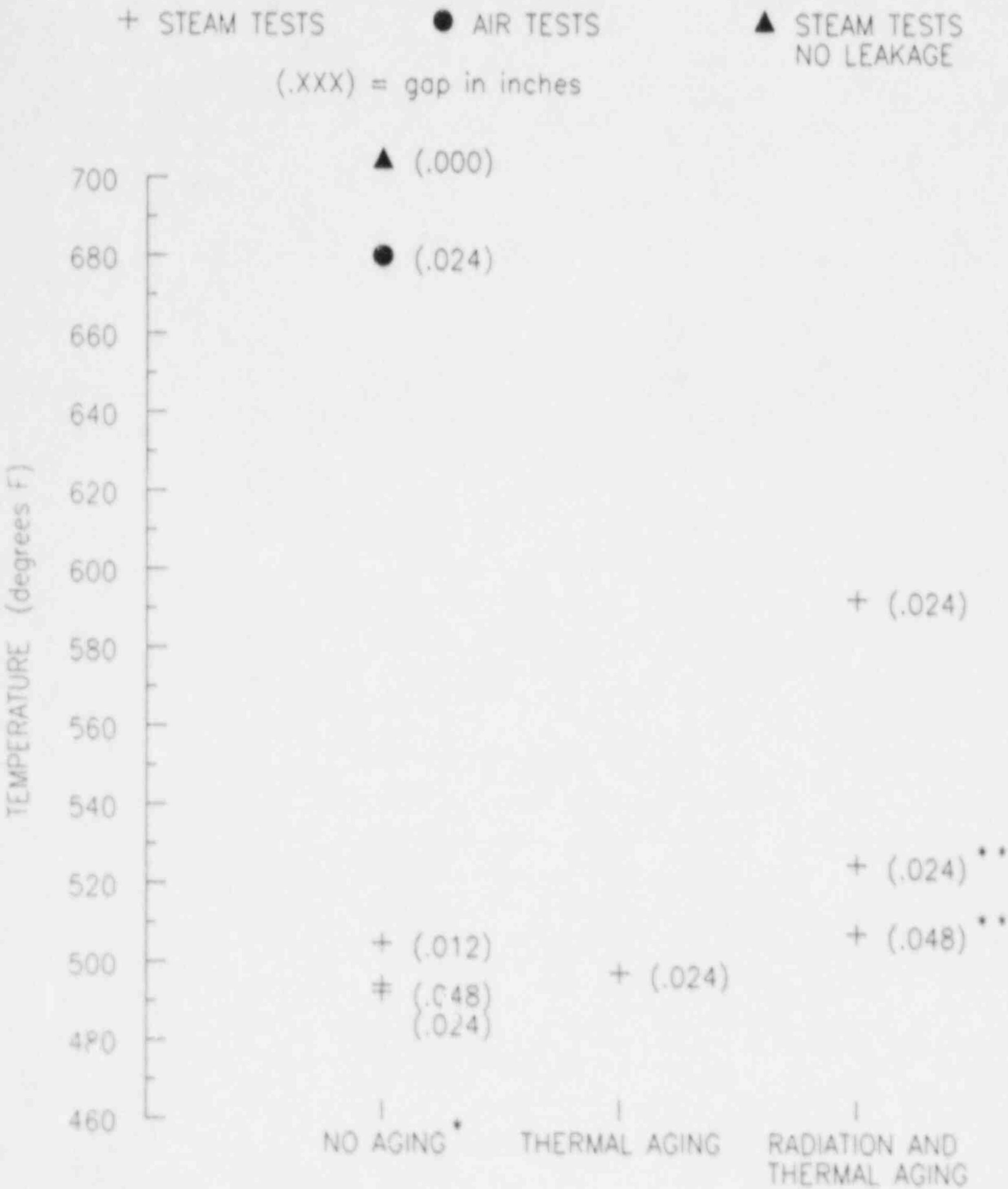
Note: Keep in mind that relatively few data points are reported from these tests. The observations are significant as indicative of trends only, not as proof of gasket performance under particular conditions.

1. Table 3 gives the leakage onset temperatures in each aging category for the tests with gaps of 0.024 and 0.048 inch. The data indicate that the aging specified in these tests had no deleterious effect on the leakage onset temperatures.

2. The highest leakage onset temperatures for steam environment tests occurred with no gap between the sealing surfaces (see Figures 11 and 12). Visual inspection indicates, however, that degradation of gaskets from these tests was similar to that for gaskets tested with a gap. (See posttest photos of tests E1, E4, and S1 to note gasket degradation for the tests with no gap.) It appears likely that the metal-to-metal contact delayed leakage; gasket condition apparently had little effect on the seal's performance when metal-to-metal contact was present.

3. Leakage onset temperature does not appear to be significantly affected by the amount of squeeze. Refer to Table 4. Note that of the four comparisons in the table, one shows no change in performance, and one shows deteriorated performance as squeeze increases from 9% to 17%.

4. Posttest visual inspection indicated that all gaskets experienced severe degradation, including those that were tested without a gap between the sealing surfaces.



LEAKAGE ONSET TEMPERATURES
1/4 - inch SI rubber O-rings

* Test E-14, which is in this category, is not included on this plot due to a test system failure.

** See note 2 in section 5.1.

Figure 11

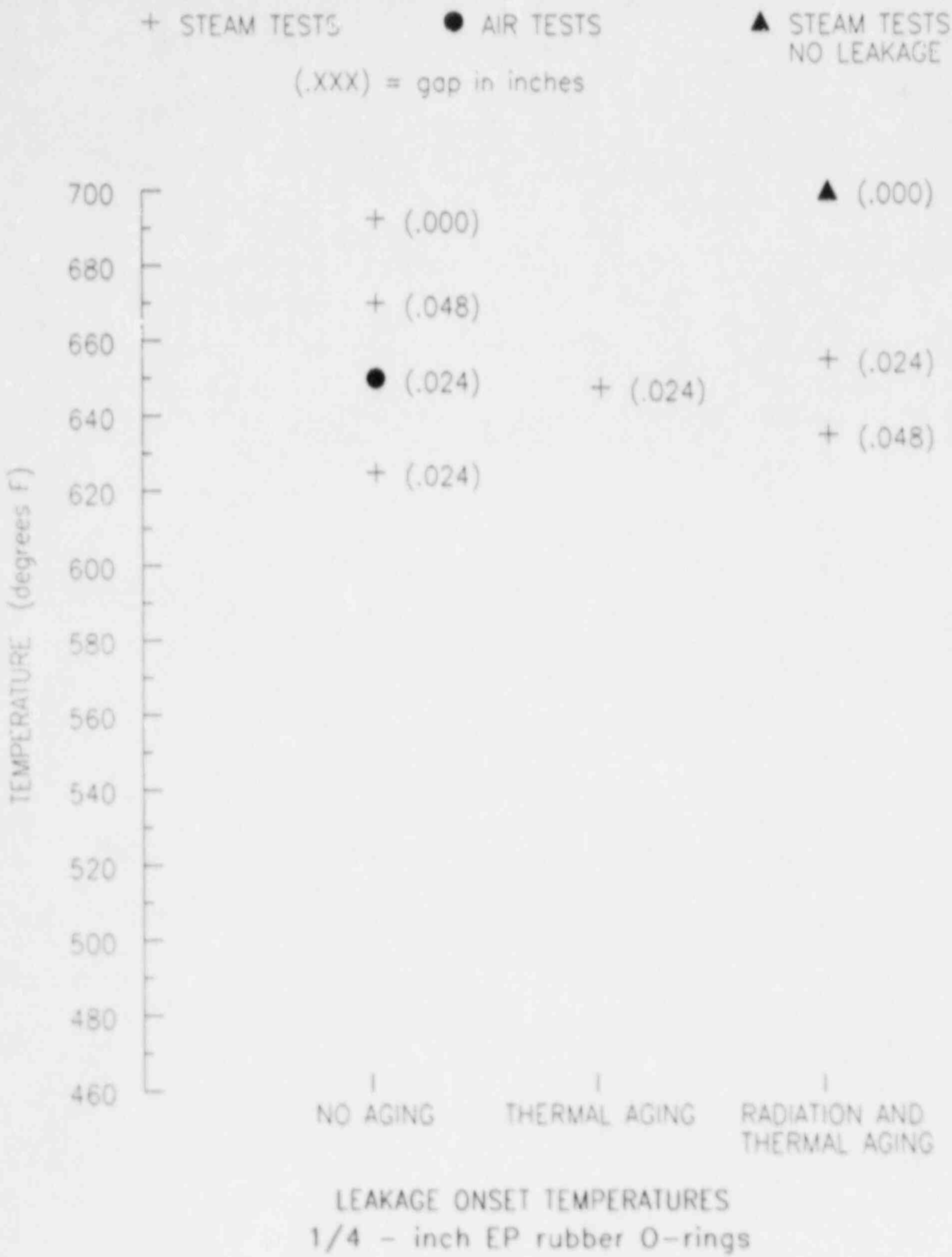

+ STEAM TESTS
● AIR TESTS
▲ STEAM TESTS NO LEAKAGE
(.XXX) = gap in inches
TEMPERATURE (degrees F)
700
680
660
640
620
600
580
560
540
520
500
480
460
(.000)
(.048)
(.024)
(.024)
(.024)
(.000)
(.024)
(.048)
NO AGING
THERMAL AGING
RADIATION AND THERMAL AGING
LEAKAGE ONSET TEMPERATURES
1/4 - inch EP rubber O-rings

Figure 12

TABLE 3

Performance of Aged Gaskets Compared to
Performance of Unaged Gaskets
(1/4-inch O-rings, steam environment)

ELASTOMER	GAP (in)	SQUEEZE (%)	LEAKAGE ONSET TEMP. (°F)		
			UNAGED	THERMAL	RAD. & THERMAL
EP	.024	17	626	648	657
EP	.048	9	669	-	637
SI	.024	17	493	497	524*/592
SI	.048	9	493	-	508*

* See note 2, page 23

TABLE 4

Performance of 17% Squeeze Compared to Performance of 9% Squeeze
(1/4-inch O-rings, steam environment)

ELASTOMER	AGING	LEAKAGE ONSET TEMP. (°F)		PERFORMANCE OF 17% COMPARED TO 9%
		AT 9%** SQUEEZE	AT 17%*** SQUEEZE	
EP	None	669	626	Worse
EP	Rad & Thermal	637	657	Better
SI	None	493	493	Same
SI	Rad & Thermal	508*	524*/592	Better

* See note 2, page 23
** Gap = 0.048 inch
*** Gap = 0.024 inch

6. SUMMARY

The observations resulting from this test program may be summarized as follows:

1. The thermal and radiation aging that was specified in these tests (300°F for 168 h and 200 Mrad at 1 Mrad/h) had a negligible deleterious effect on leakage onset temperature.

2. Metal-to-metal contact at the sealing surfaces virtually prevented significant leakage.

3. Leakage onset temperature did not appear to be significantly affected by increasing squeeze from 9% to 17%.

4. Leakage onset temperatures ranged from 626°F to 669°F for steam tests of <u>EP rubber</u> 1/4-inch O-rings with a gap between the sealing surfaces.

5. Leakage onset temperatures ranged from 486°F to 592°F for steam tests of <u>SI rubber</u> 1/4-inch O-rings with a gap between the sealing surfaces.

6. Posttest visual inspection indicated that all gaskets experienced severe degradation, including those that were tested without a gap between the sealing surfaces.

REFERENCES

1. C. V. Subramanian, "Test Plan for Evaluating Leakage Behavior of Seals and Gaskets under Severe Accident Conditions," Sandia National Laboratories, Albuquerque, NM, August 1984.

2. D. B. Clauss, "Failure Mechanisms of LWR Steel Containment Buildings Subject to Severe Accident Loadings," Proceedings of the Third Workshop on Containment Integrity, NUREG/CP-0076, SAND86-0618, Sandia National Laboratories, Albuquerque, NM, August 1986, pp. 498-504.

3. M. H. Shackelford, et al., Characteristics of Nuclear Reactor Containment Penetrations, NUREG/CR-3855, SAND84-7180, Sandia National Laboratories, Albuquerque, NM, 1985.

4. F. H. Welch and W. J. Kurzeka, "Testing and Evaluation of Elastomeric Seals for Sodium-Cooled Fast Reactor Systems," presented at meeting of Nuclear Engineering Division of ASME, 1975.

5. T. C. Chivers and R. P. Hunt, "Problems, Properties, and Performance of Static Seals," CEGB Research, January 1978, pp. 26-35.

6. M. L. Blakeston, et al., "The Testing of Elastomers for Channel Seal Plugs in a Steam Generating Heavy Water Nuclear Reactor," 8th International Conference on Fluid Sealing, 1978.

7. R. G. Wensel, Resistance of O-Ring Seal Compounds to Heat and Ionizing Radiation in Air and in Water, Atomic Energy of Canada Limited, AECL-5697, 1977.

8. R. G. Wensel and B. M. Cotnam, Evaluation of O-Rings of Various Elastomer Compounds for Service in Hot Water, Atomic Energy of Canada Limited, AECL-6214, 1978.

9. T. L. Bridges, Containment Penetration Elastomer Seal Leak Rate Tests, NUREG/CR-4944, SAND87-7118, Sandia National Laboratories, Albuquerque, NM, July 1987.

BIBLIOGRAPHY

Barnes, B. L., "Containment Penetration Elastomer Seal Test," Proceedings of the Second Workshop on Containment Integrity, NUREG/CP-0056, SAND84-1514, Sandia National Laboratories, Albuquerque, NM, August 1984.

Beynel, P., et al., Compilation of Radiation Damage Test Data, European Organization for Nuclear Research, CERN 82-10, November 4, 1982.

Blakeston, M. L., et al., "The Testing of Elastomers for Channel Seal Plugs in a Steam Generating Heavy Water Nuclear Reactor," 8th International Conference on Fluid Sealing, 1978.

Bonzon, L. L., et al., Status Report on Equipment Qualification Issues, NUREG/CR-4301, SAND85-1309, Sandia National Laboratories, Albuquerque, NM, November 1986.

Bridges, T. L., Containment Penetration Elastomer Seal Leak Rate Tests, NUREG/CR-4944, SAND87-7118, Sandia National Laboratories, Albuquerque, NM, July 1987.

Chivers, T. C. and R. P. Hunt, "Problems, Properties, and Performance of Static Seals," CEGB Research, January 1978.

Clauss, D. B., Comparison of Analytical Predictions and Experimental Results for a 1:8-Scale Steel Containment Model Pressurized to Failure, NUREG/CR-4209, SAND85-0679, Sandia National Laboratories, Albuquerque, NM, July 1985.

--------, "Failure Mechanisms of LWR Steel Containment Buildings Subject to Severe Accident Loadings," Proceedings of the Third Workshop on Containment Integrity, NUREG/CP-0076, SAND86-0618, Sandia National Laboratories, Albuquerque, NM, August 1986.

Horschel, D. S., Experimental Results of High Pressure Testing a 1:6 Scale Nuclear Power Plant Containment, NUREG/CR-5121, SAND88-0906, Sandia National Laboratories, Albuquerque, NM, 1988.

Koenig, L. N., Experimental Results for a 1:8-Scale Steel Model Nuclear Power Plant Containment Pressurized to Failure, NUREG/CR-4216, SAND85-0790, Sandia National Laboratories, Albuquerque, NM, December 1986.

--------, "Leakage Potential Through Mechanical Penetrations in a Severe Accident Environment," Proceedings of the Third Workshop on Containment Integrity, NUREG/CP-0076, SAND86-0618, Sandia National Laboratories, Albuquerque, NM, August 1986.

Raut, H. D., et al., "Gasket Leakage Behavior Trends," Welding Research Council Bulletin, Bulletin 271, October 1981.

Shackelford, M. H., et al., Characteristics of Nuclear Reactor Containment Penetrations, NUREG/CR-3855, SAND84-7180, Sandia National Laboratories, 1985.

Subramanian, C. V., "Test Plan for Evaluating Leakage Behavior of Seals and Gaskets Under Severe Accident Conditions," Sandia National Laboratories, August 1984.

Welch, F. H., and W. J. Kurzeka, "Testing and Evaluation of Elastomeric Seals for Sodium-Cooled Fast Reactor Systems," presented at meeting of Nuclear Engineering Division of ASME, 1975.

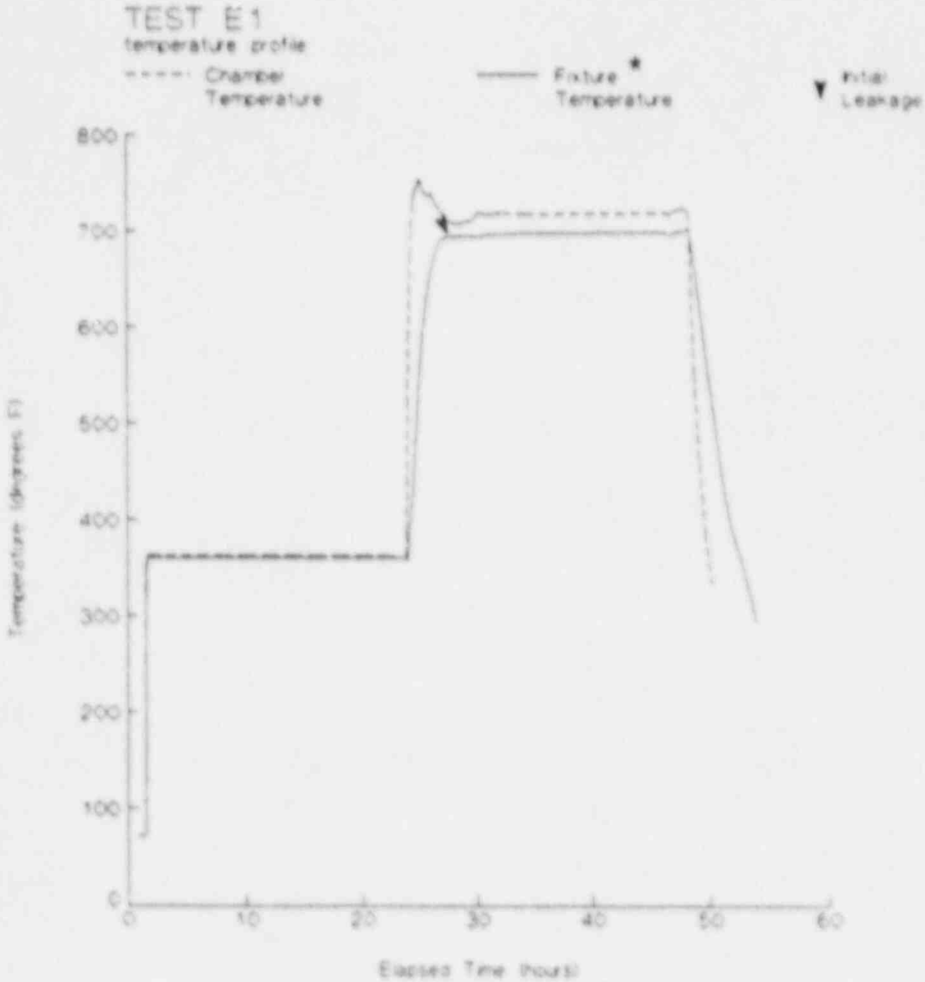
Wensel, R. G., Resistance of O-Ring Seal Compounds to Heat and Ionizing Radiation in Air and in Water, Atomic Energy of Canada Limited, AECL-5697, 1977.

Wensel, R. G., and B. M. Cotnam, Evaluation of O-Rings of Various Elastomer Compounds for Service in Hot Water, Atomic Energy of Canada Limited, AECL-6214, 1978.

APPENDIX A

TEST TEMPERATURE PROFILES AND TEST PHOTOGRAPHS

APPENDIX A TABLE OF CONTENTS



TEST NO. E1

Seal:	1/4" Double O-Ring
Elastomer:	EP Rubber
Compound:	Parker E603-70
Aging:	None
Atmosphere:	Steam
GAP (in):	0.000
Leakage Onset Temp (^{o}F):	692

*The thermocouple used to determine the fixture temperature is not in the typical location as shown in Figure 9 on page 19. Instead, the fixture temperature is based on the output of a thermocouple attached to the outside of the test fixture. Therefore, the reported temperature may vary slightly from that of the interior cavity of the fixture.

Figure A-E1.1
Test E-1
Posttest photo of leakage collection beaker
Note: Gasket material in leakage

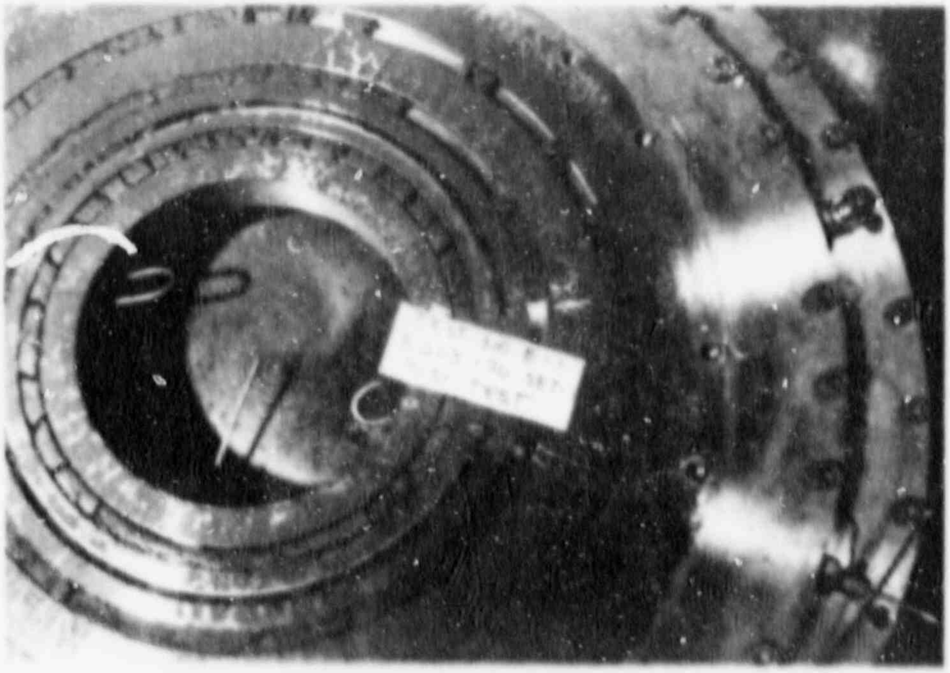
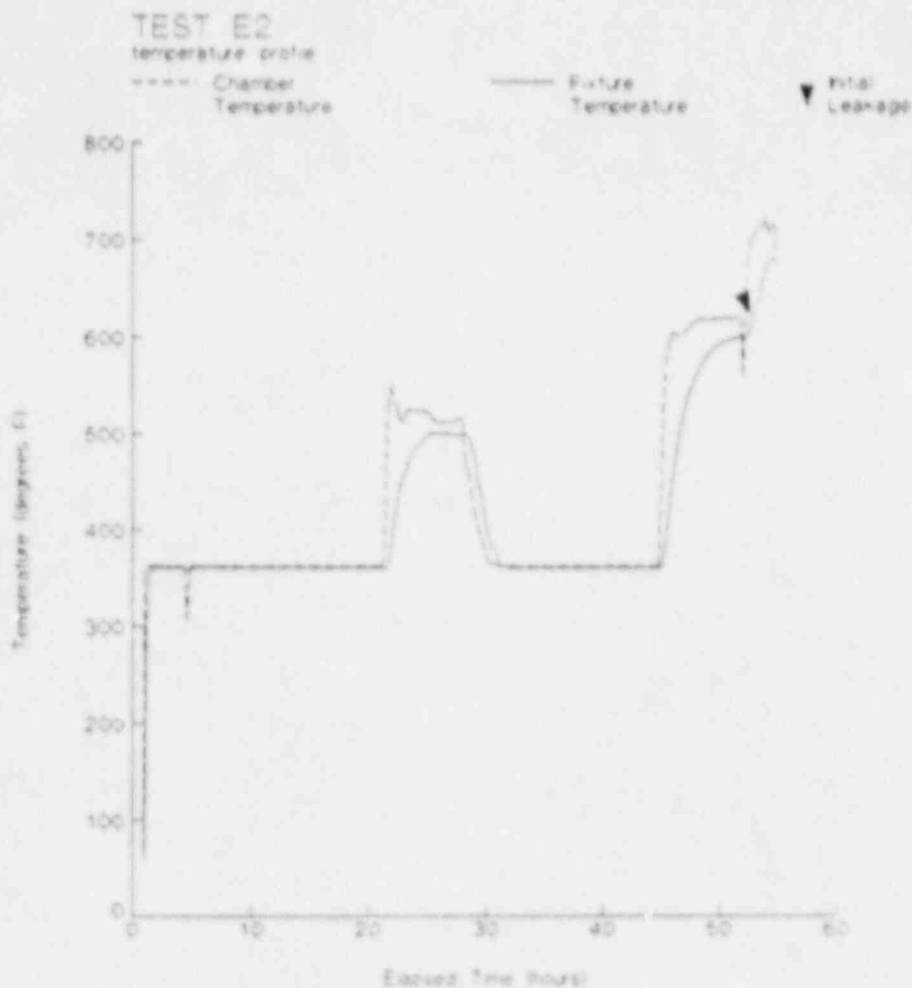


Figure A-E1.2
Test E-1
Posttest photo of plate 3
Note: Gasket degradation



TEST NO. E2

Seal:	1/4" Double O-Ring
Elastomer:	EP Rubber
Compound:	Parker E603-70
Aging:	None
Atmosphere:	Steam
GAP (in):	0.024
Leakage Onset Temp (^{o}F):	626

Figure A-E2.1
Test E-2
Posttest photo of plate 1
Note: Gasket degradation

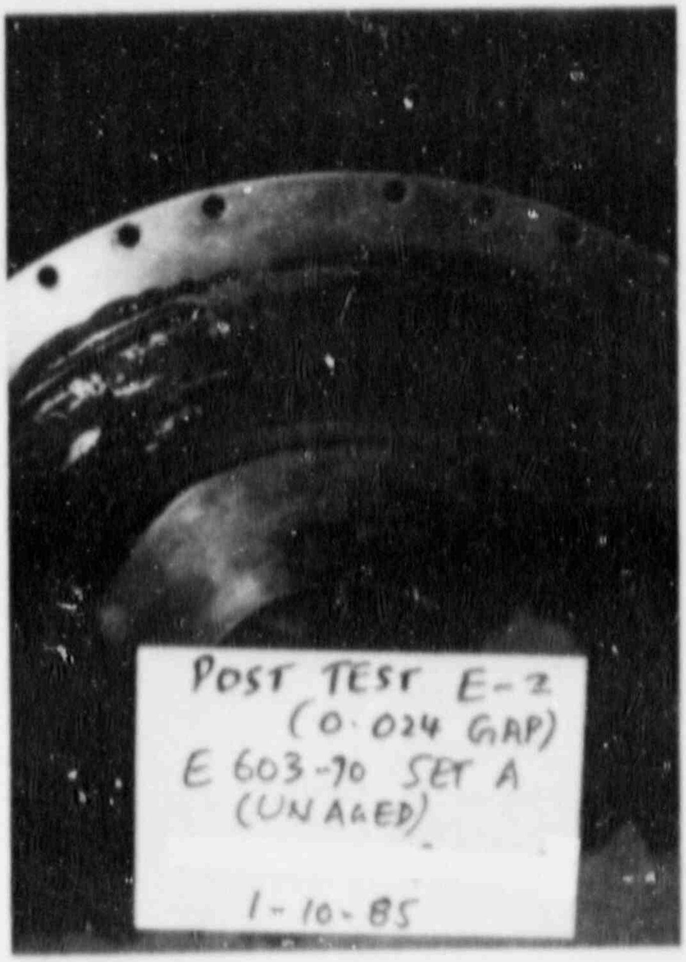
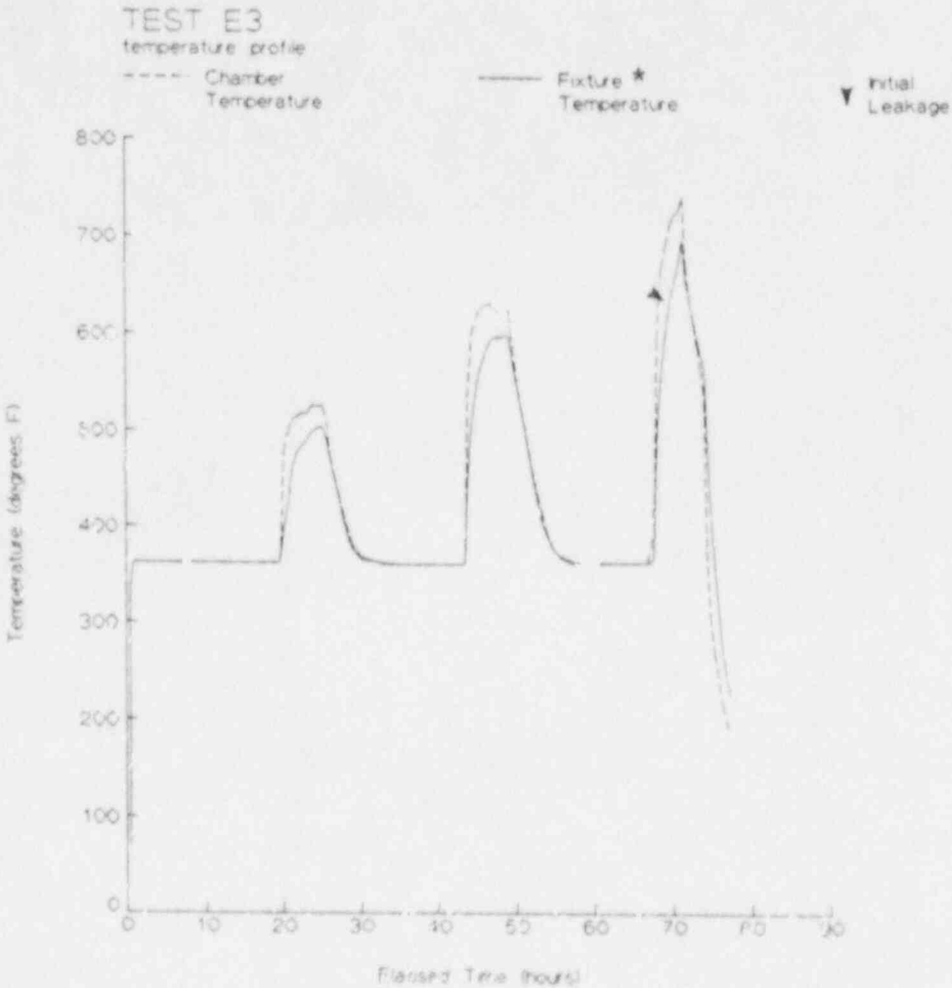


Figure A-E2.2
Test E-2
Posttest photo of plate 3
Note: Gasket degradation



TEST NO. E3

Seal:	1/4" Double O-Ring
Elastomer:	EP Rubber
Compound:	Parker E603-70
Aging:	None
Atmosphere:	Steam
GAP (in):	0.048
Leakage Onset Temp (^{o}F):	669

*The thermocouple used to determine the fixture temperature is not in the typical location as shown in Figure 9 on page 19. Instead, the fixture temperature is based on the output of a thermocouple attached to the outside of the test fixture. Therefore, the reported temperature may vary slightly from that of the interior cavity of the fixture.

Figure A-E3.1
Test E-3
Posttest photo of plate 4
Note: Gasket degradation

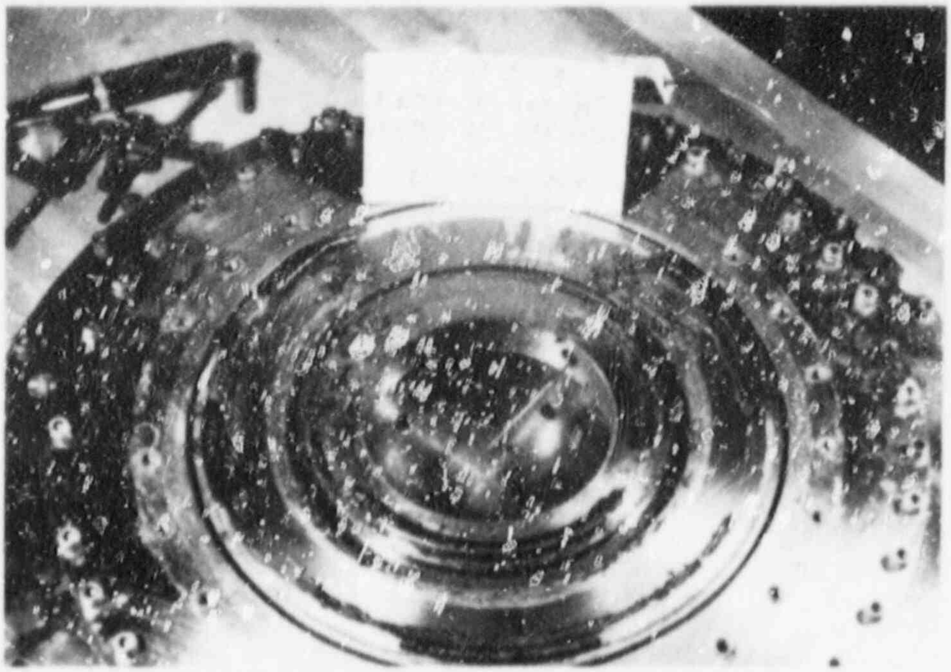
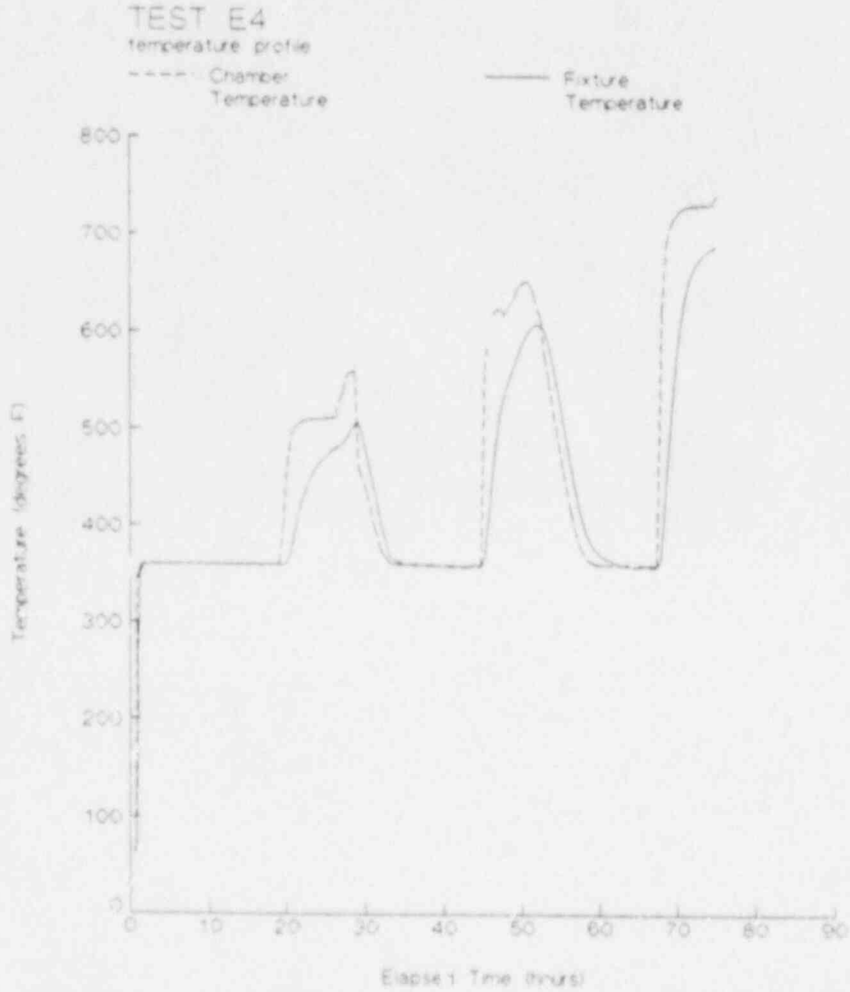


Figure A-E3.2
Test E-3
Posttest photo of plate 3
Note: Gasket blow-out



TEST NO. E4

Seal:	1/4" Double O-Ring
Elastomer:	EP Rubber
Compound:	Parker E603-70
Aging:	Radiation and Thermal
Atmosphere:	Steam
GAP (in):	0.000
Leakage Onset Temp (^{O}F):	Did Not Leak

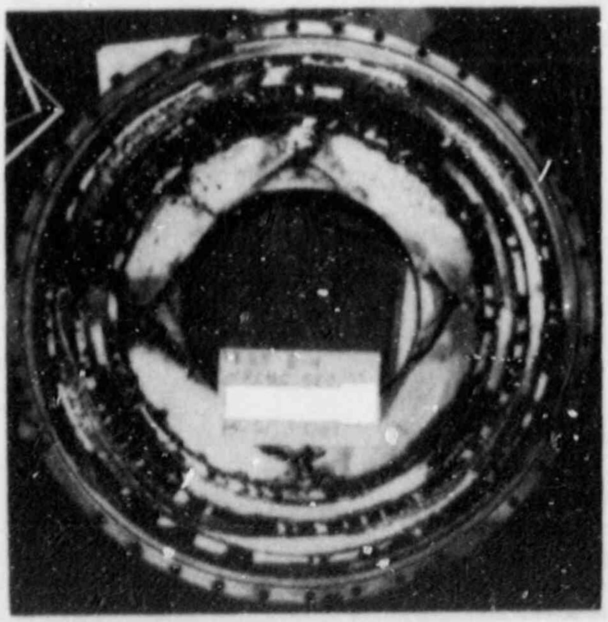
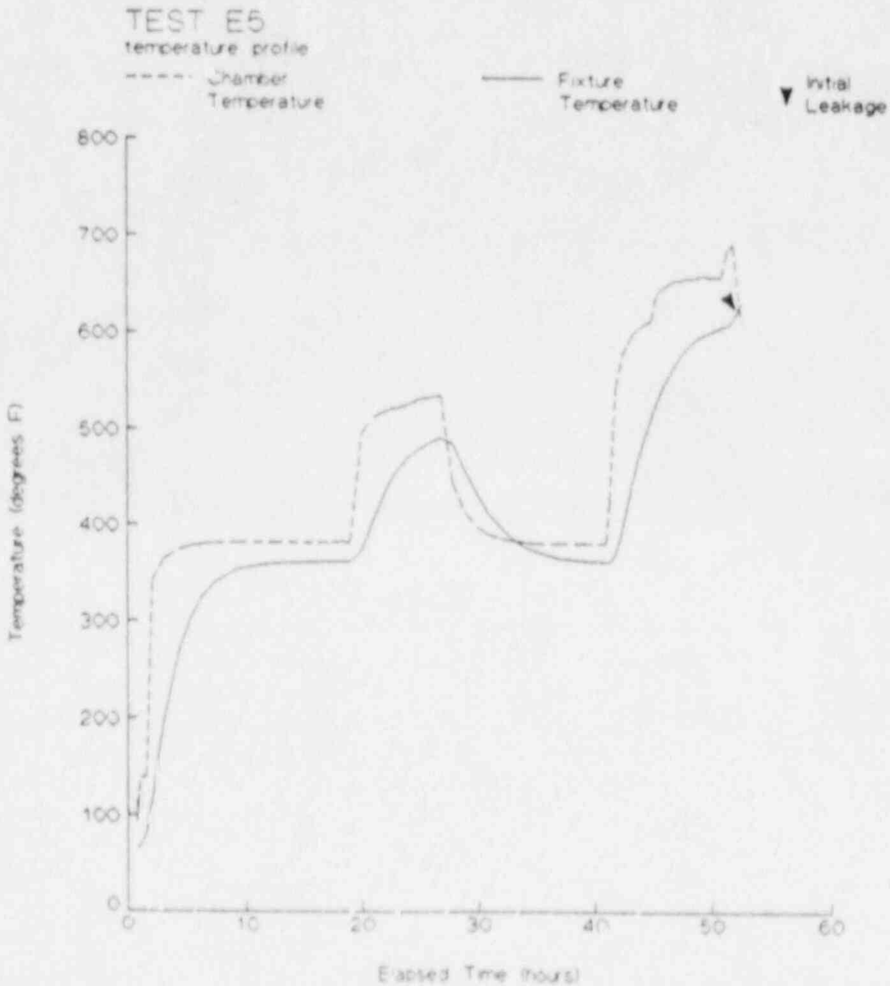


Figure A-E4.1
Test E-4
Posttest photo of plate 2
Note: Gasket degradation



TEST NO. E5

Seal:	1/4" Double O-Ring
Elastomer:	EP Rubber
Compound:	Parker E603-70
Aging:	None
Atmosphere:	Dry Air
GAP (in):	0.024
Leakage Onset Temp (^{O}F):	651

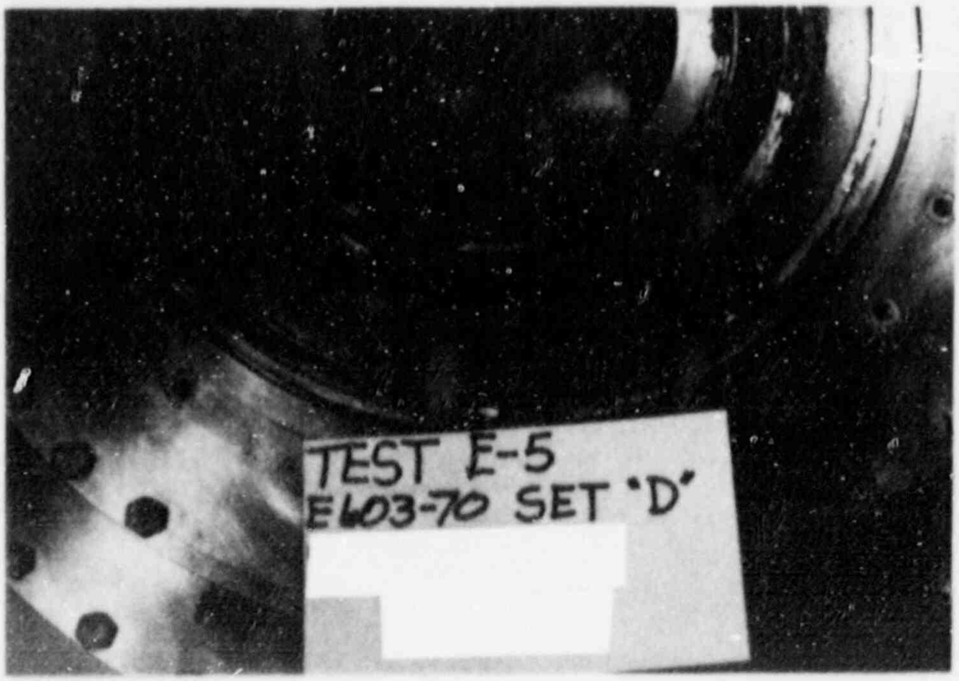
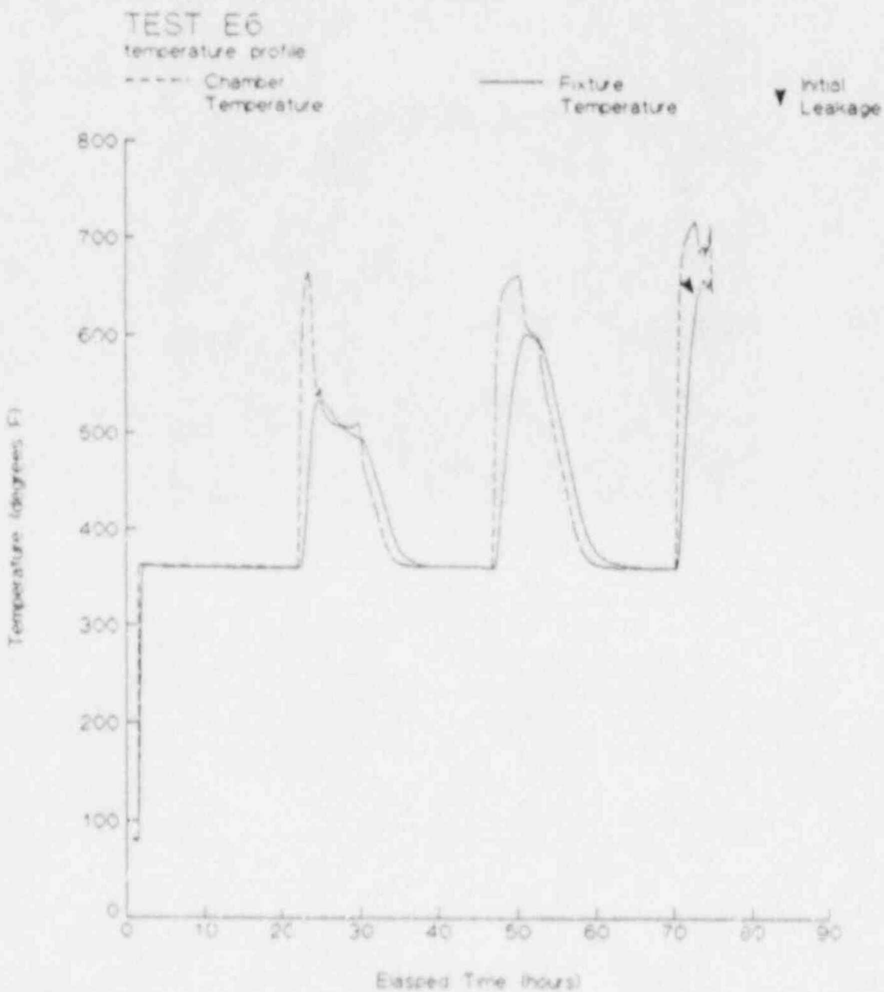


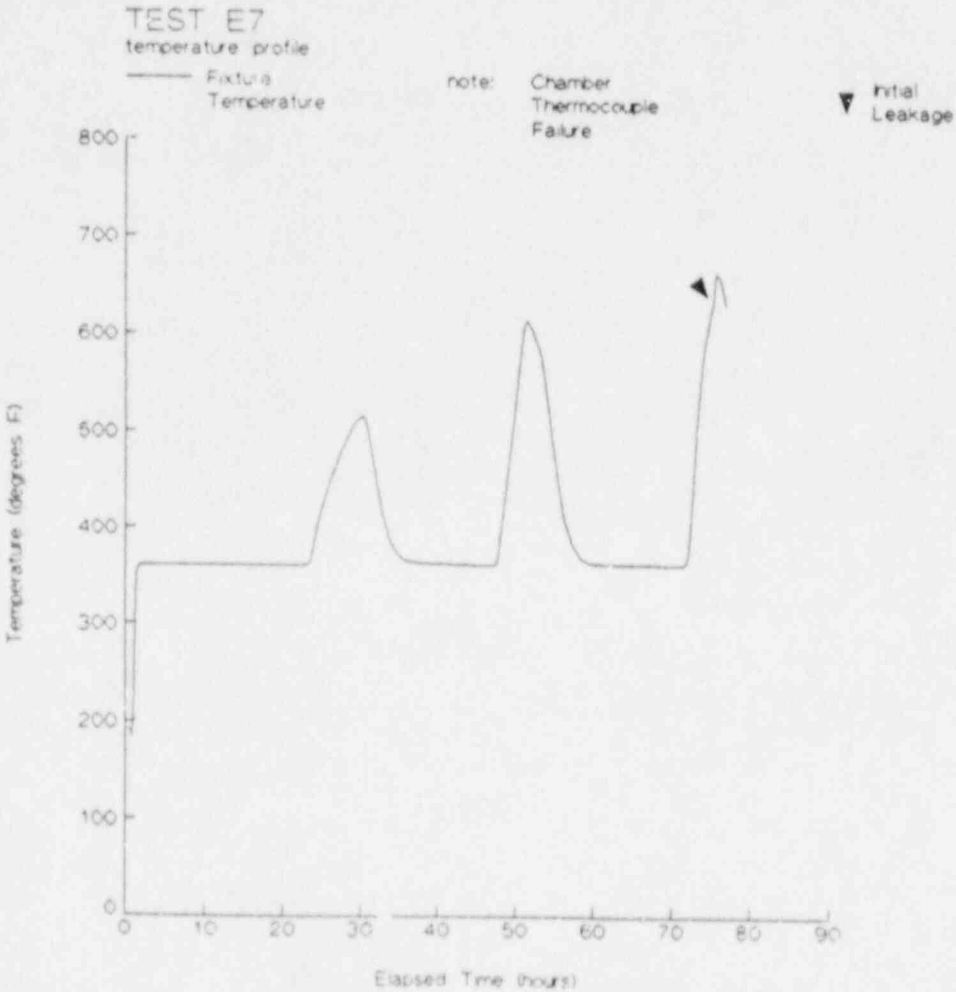
Figure A-E5.1
Test E-5
Posttest photo of plate 3



TEST NO. E6

Seal:	1/4" Double O-Ring
Elastomer:	EP Rubber
Compound:	Parker E603-70
Aging:	Radiation and Thermal
Atmosphere:	Steam
GAP (in):	0.024
Leakage Onset Temp (^oF):	657

Figure A-E6.1
Test E-6
Posttest photo of plate 4
Note: Gasket degradation



TEST NO. E7

Seal:	1/4" Double O-Ring
Elastomer:	EP Rubber
Compound:	Parker E603-70
Aging:	Radiation and Thermal
Atmosphere:	Steam
GAP (in):	0.048
Leakage Onset Temp (°F):	637

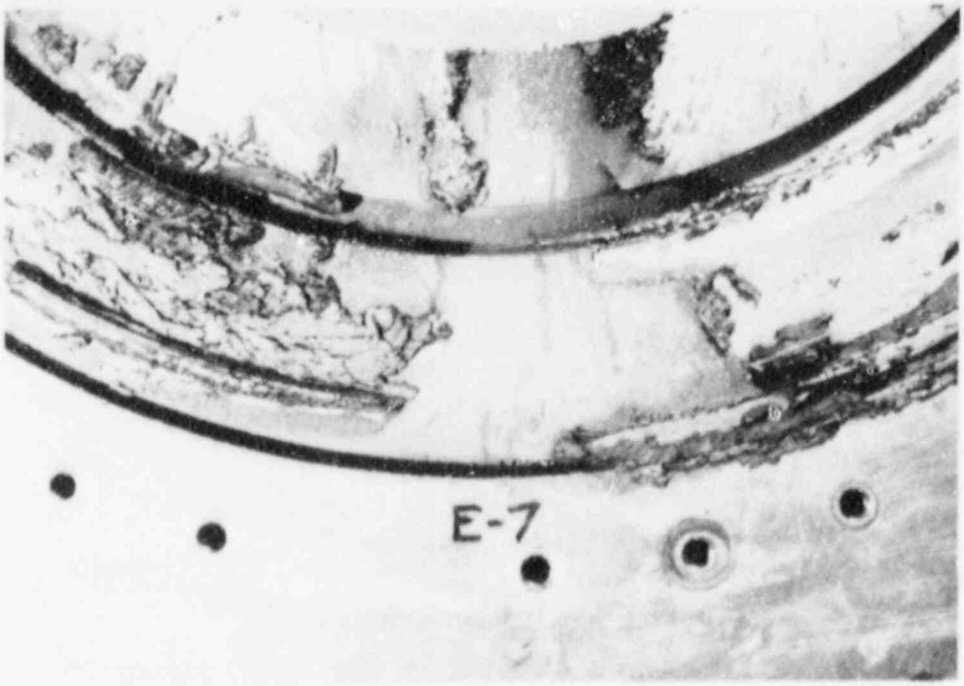


Figure A-E7.1
Test E-7
Posttest photo of plate 2
Note: Gasket material missing or blown-out

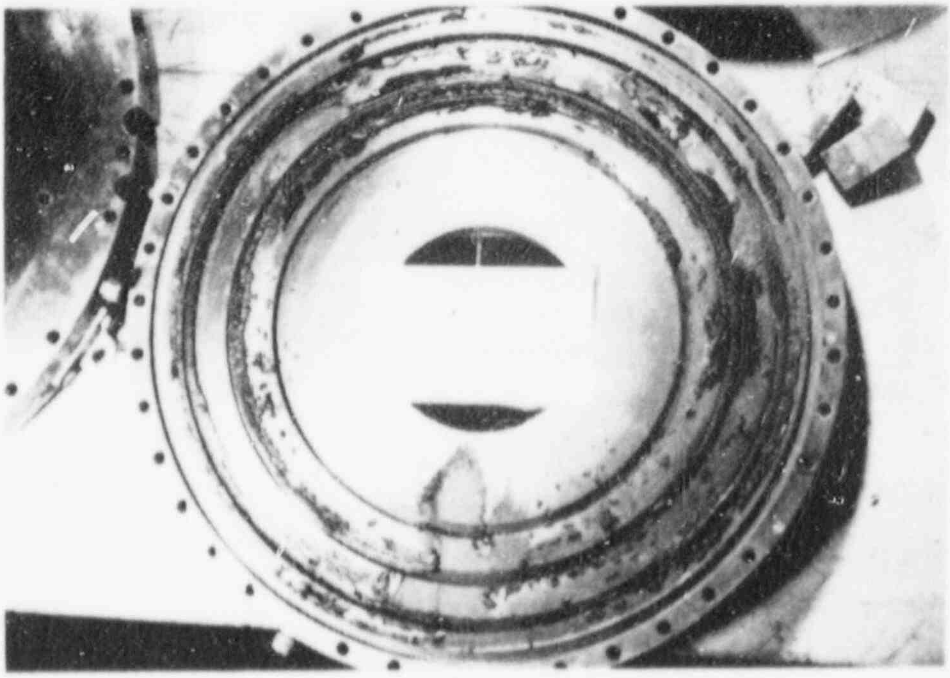
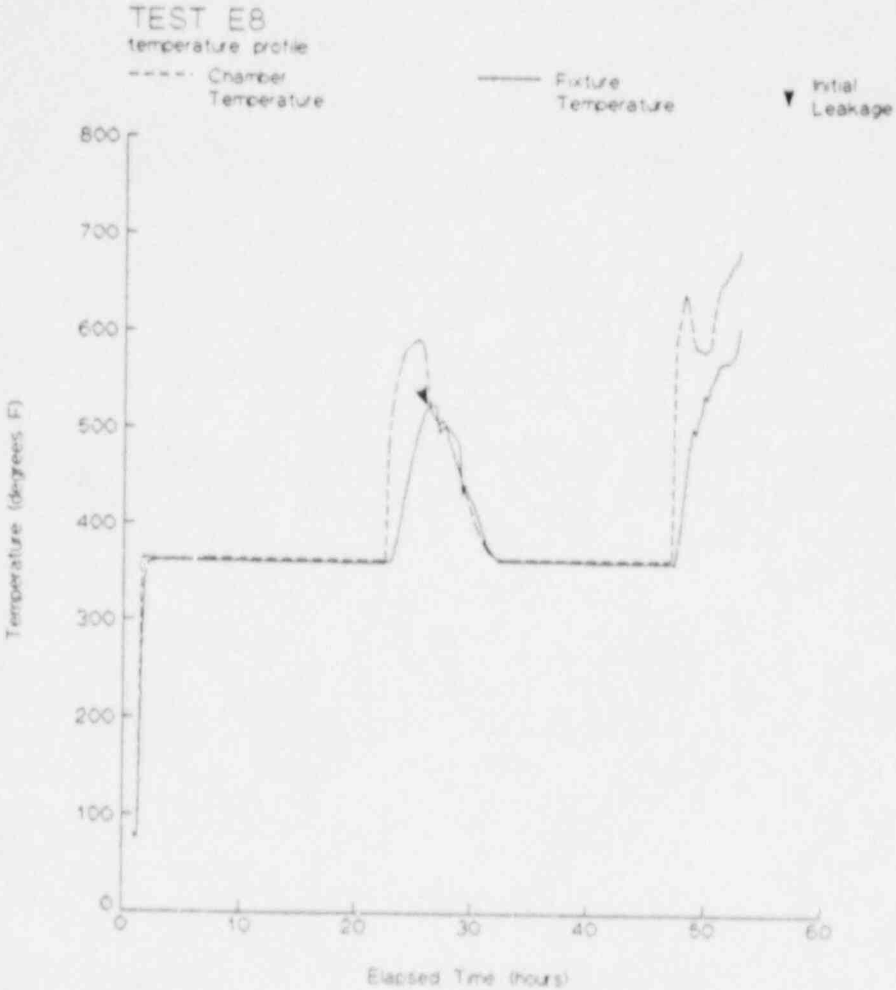


Figure A-E7.2
Test E-7
Posttest photo of plate 3
Note: Gasket degradation



TEST NO. E8

Seal:	1/4" Double O-Ring
Elastomer:	SI Rubber
Compound:	Parker S604-70
Aging:	None
Atmosphere:	Steam
GAP (in):	0.024
Leakage Onset Temp (^{o}F):	524 (See note 3, page 23)

Figure A-E8.1
Test E-8
Posttest photo of plate 3
Note: Gasket break-up

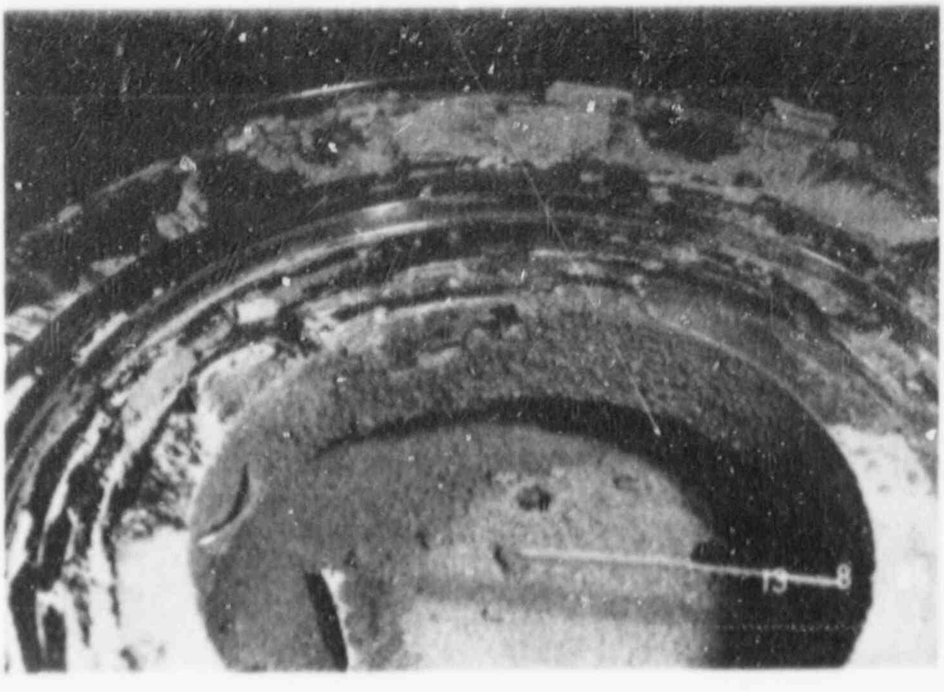
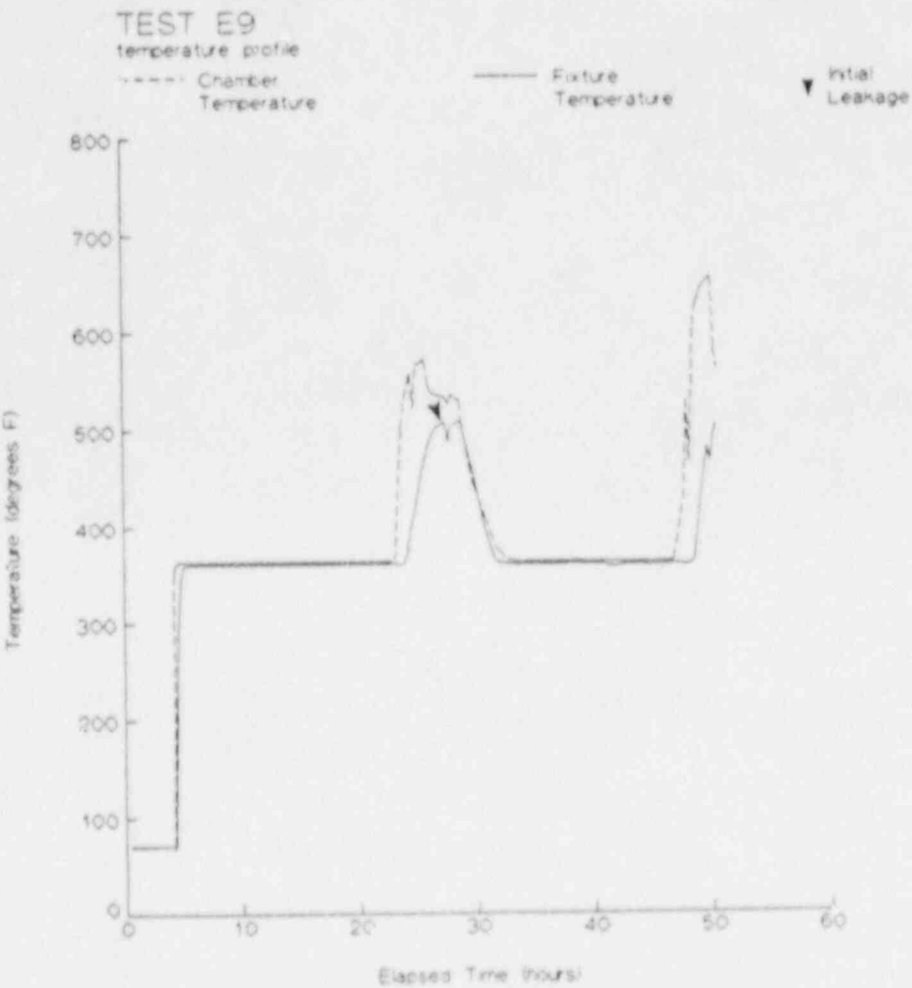


Figure A-E8.2
Test E-8
Posttest photo of plate 3
Note: Powdered gasket material

Figure A-E8.3
Test E-8
Posttest photo of plate 2
Note: Gasket blow-out



TEST NO. E9

Seal:	1/4" Double O-Ring
Elastomer:	SI Rubber
Compound:	Parker S604-70
Aging:	Radiation and Thermal
Atmosphere:	Steam
GAP (in):	0.048
Leakage Onset Temp (^{o}F):	508 (See note 2, page 23)

Figure A-E9.1
Test E-9
Posttest photo of plate 4
Note: Gasket flow and blow-out

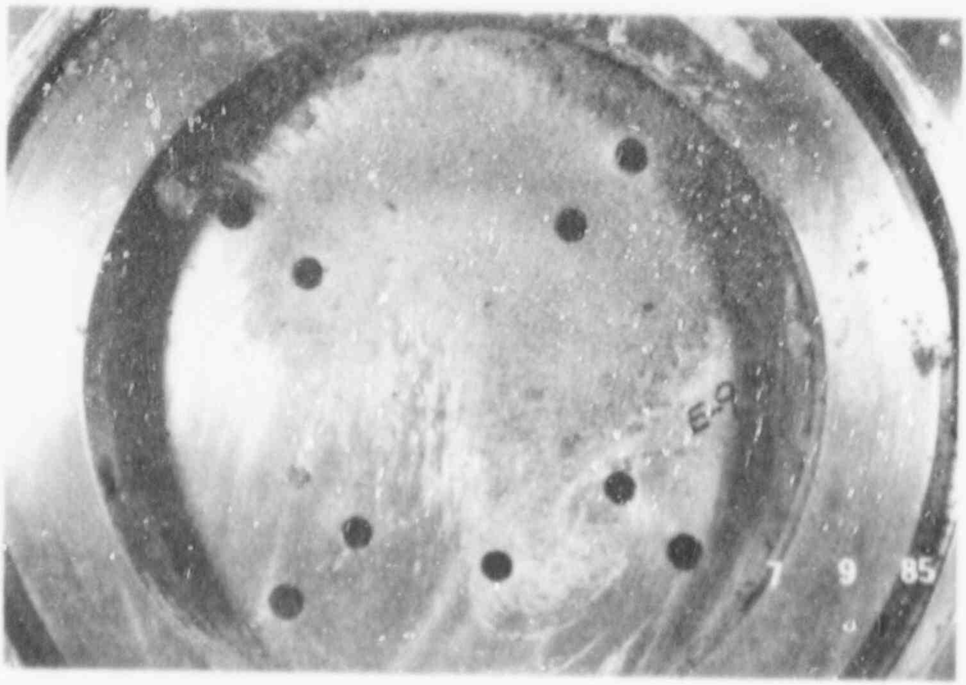
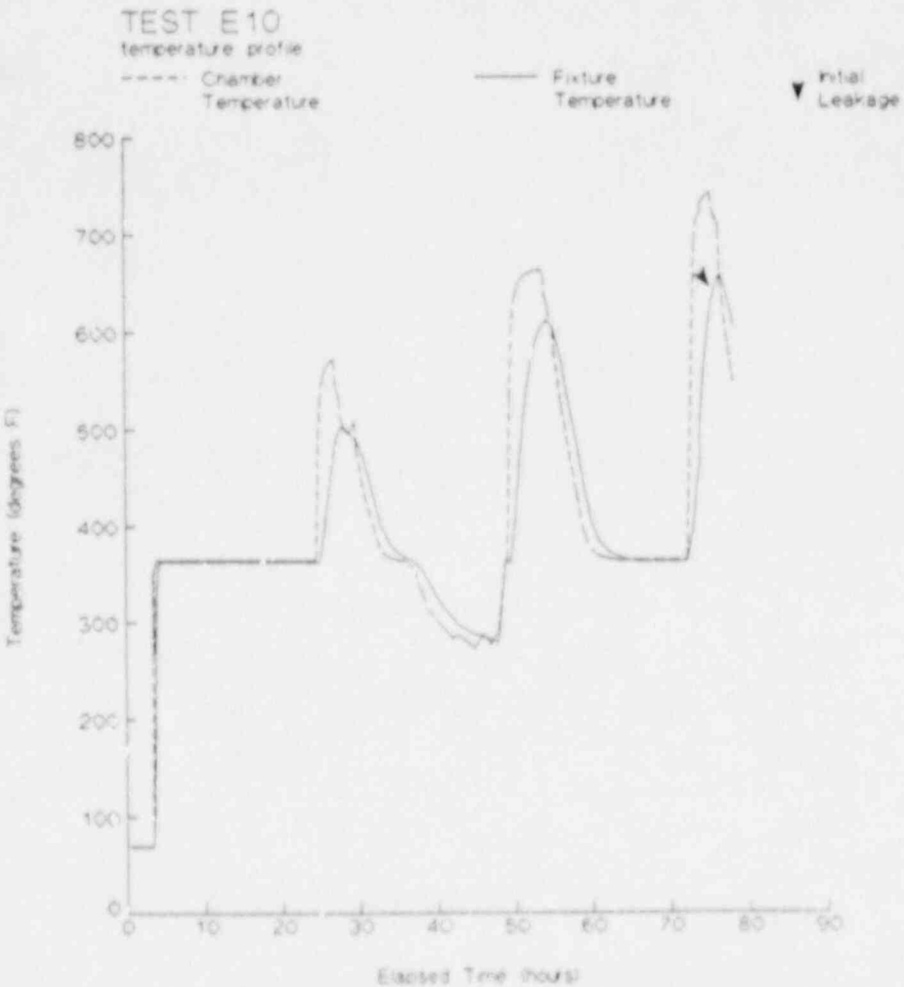


Figure A-E9.2
Test E-9
Posttest photo of plate 2 on plate 1
Note: Powdered gasket material



TEST NO. E10

Seal:	1/4" Double O-Ring
Elastomer:	EP Rubber
Compound:	Parker E603-70
Aging:	Thermal Only
Atmosphere:	Steam
GAP (in):	0.024
Leakage Onset Temp (°F):	648

Figure A-E10.1
Test E-10
Posttest photo of plate 1
Note: Leakage channel clogging

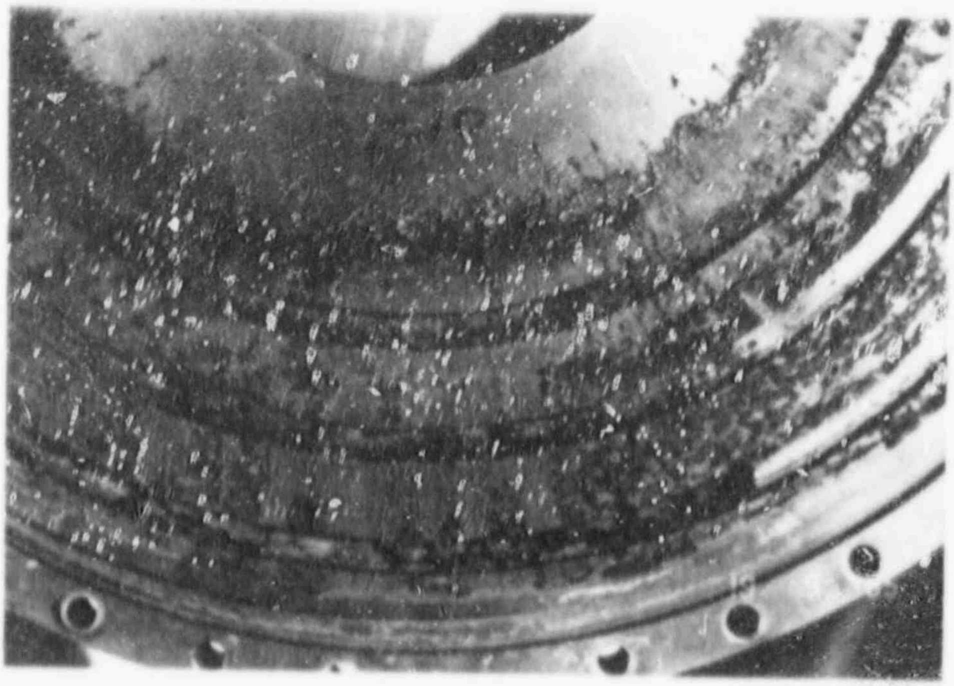
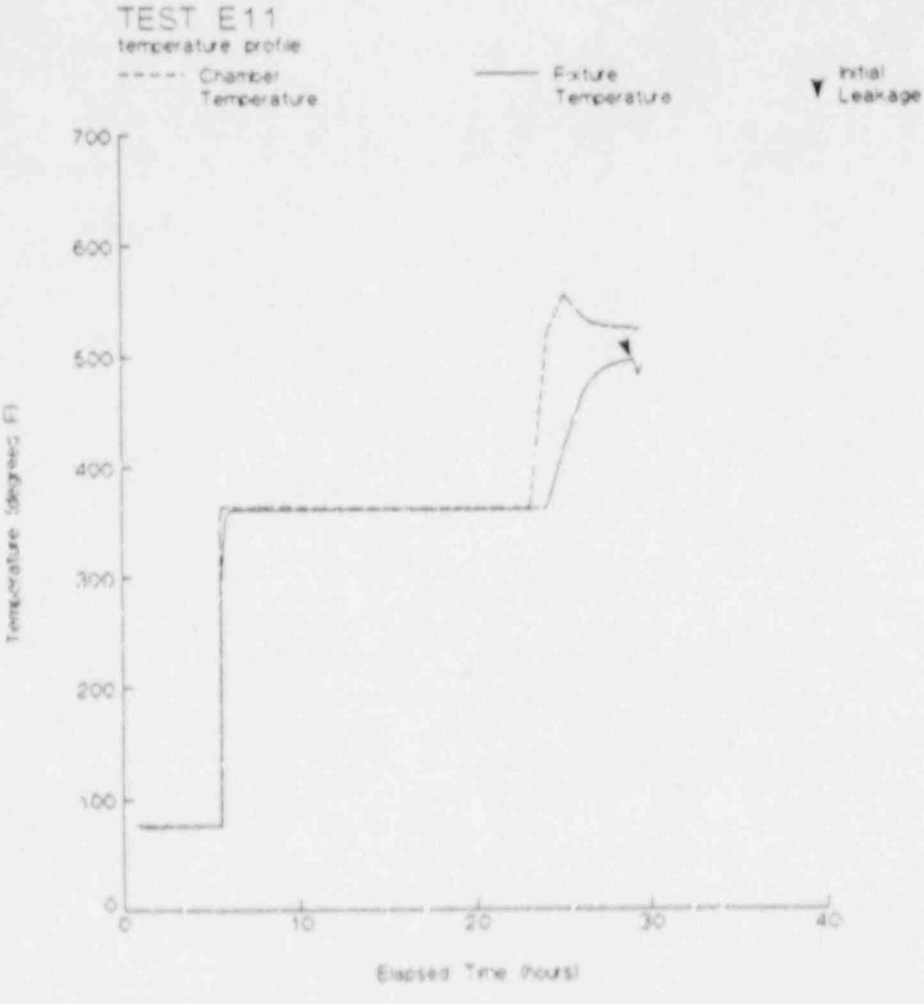


Figure A-E10.2
Test E-10
Posttest photo of plate 2
Note: Gasket material flow



TEST NO. E11

Seal:	1/4" Double O-Ring
Elastomer:	SI Rubber
Compound:	Parker S604-70
Aging:	Thermal Only
Atmosphere:	Steam
GAP (in):	0.024
Leakage Onset Temp (^{o}F):	497

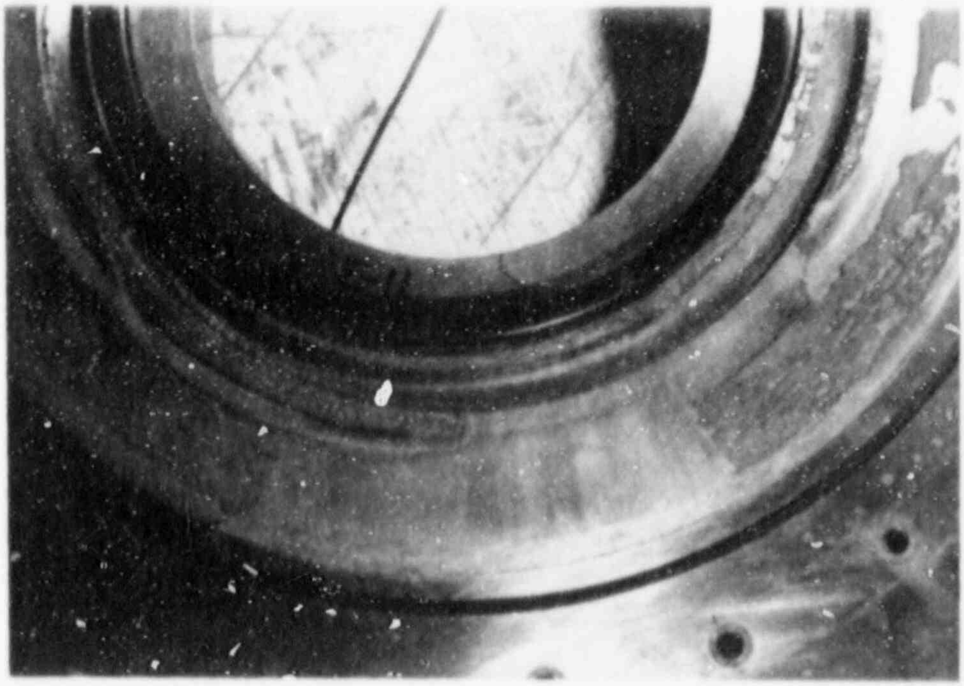


Figure A-E11.1
Test E-11
Posttest photo of plate 3
Note: Use of an EP rubber apparatus gasket

Figure A-E11.2
Test E-11
Posttest photo of plate 2
Note: Use of an EP rubber apparatus gasket

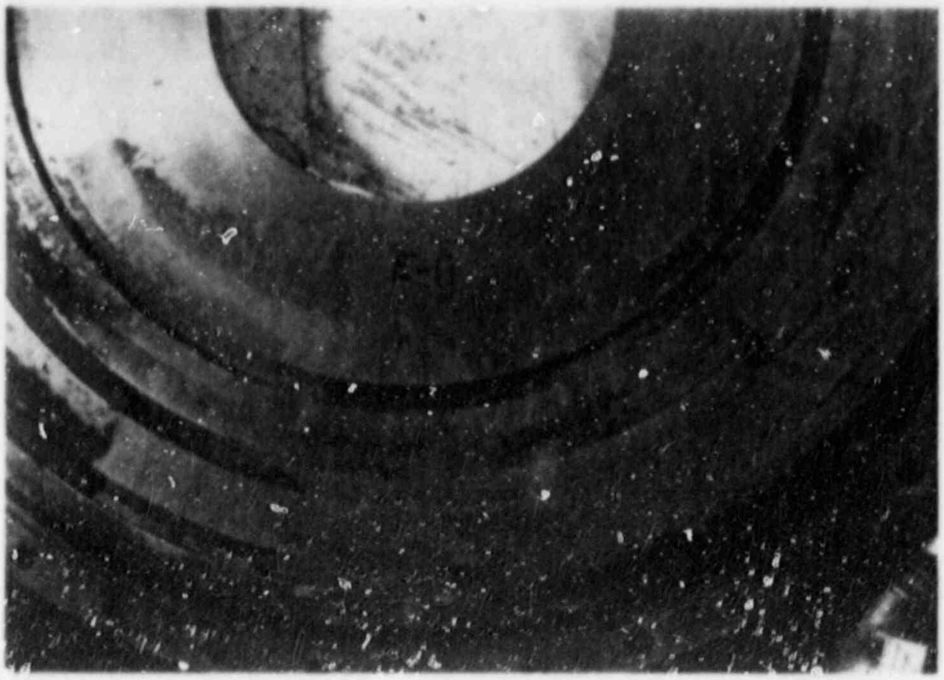
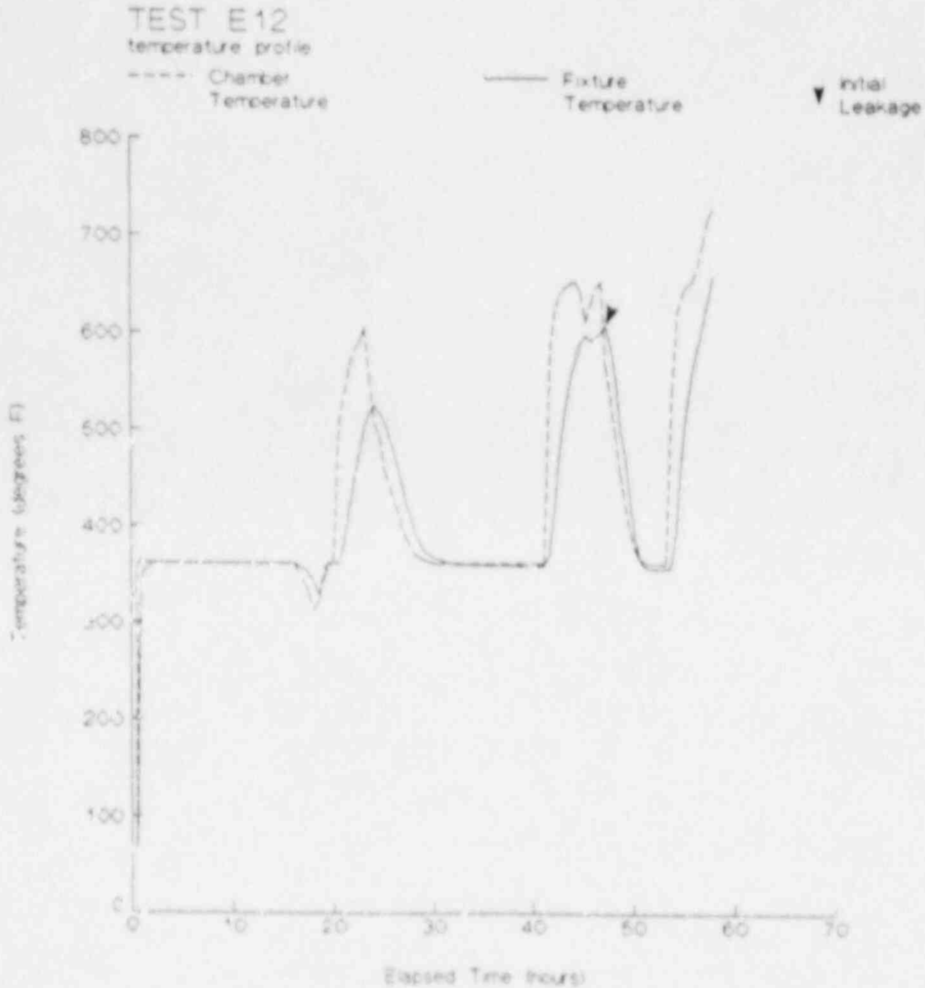


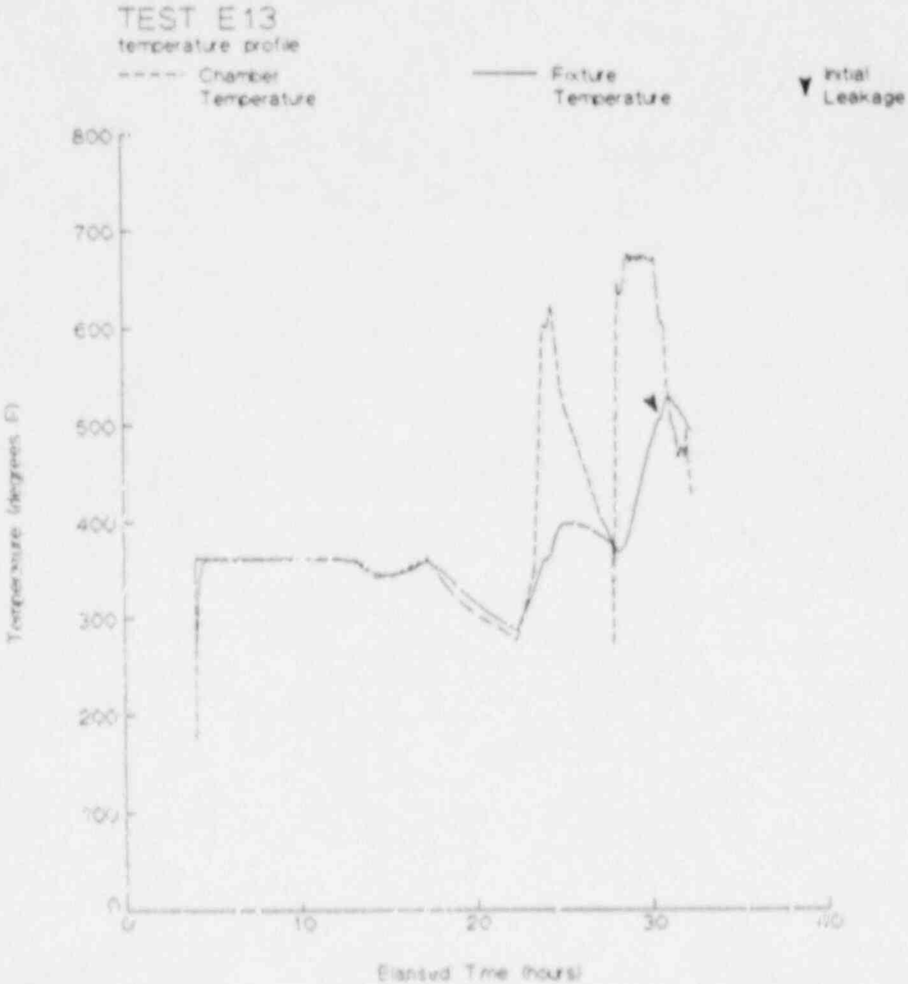
Figure A-E11.3
Test E-11
Posttest photo of plate 3
Note: Gasket deyradation



TEST NO. E12

Seal:	1/4" Double O-Ring
Elastomer:	SI Rubber
Compound:	Parker S604-70
Aging:	Radiation and Thermal
Atmosphere:	Steam
GAP (in):	0.024
Leakage Onset Temp (°F):	592

Figure A-E12.1
Test E-12
Posttest photo of plate 1
Note: Gasket degradation



TEST NO. E13

Seal:	1/4" Double O-Ring
Elastomer:	SI Rubber
Compound:	Parker S604-70
Aging:	None
Atmosphere:	Steam
GAP (in):	0.012
Leakage Onset Temp (^{o}F):	506

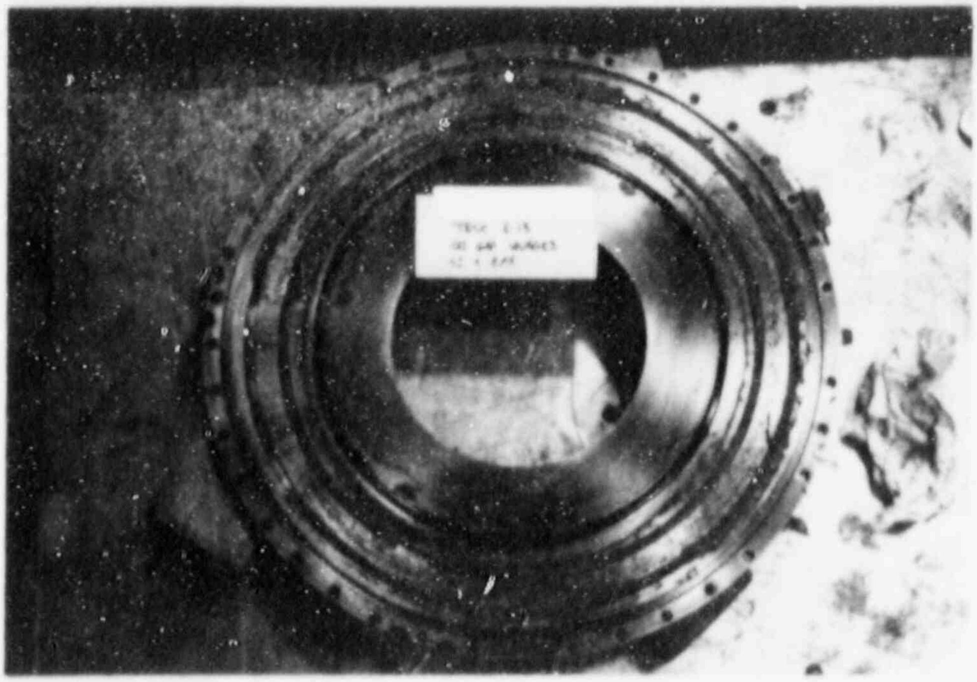
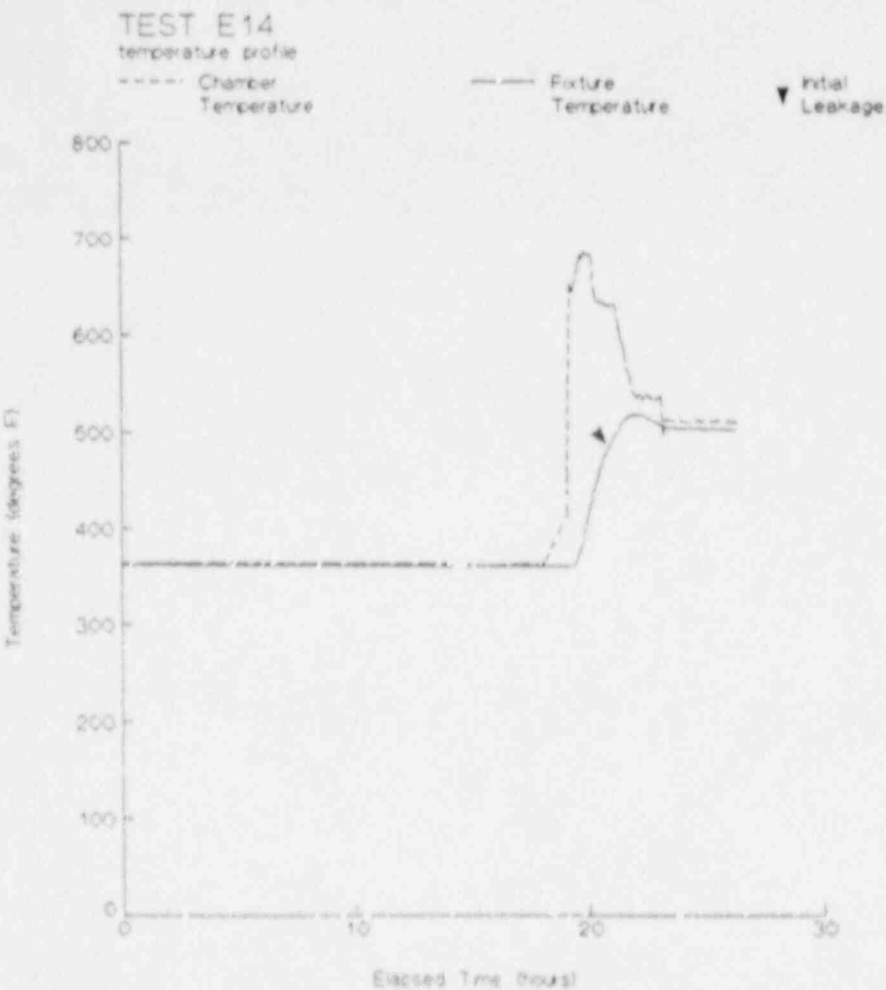


Figure A-E13.1
Test E-13
Posttest photo of plate 2
Note: Use of EP rubber apparatus gasket

Figure A-E13.2
Test E-13
Posttest photo of plate 2
Note: SI rubber gasket degradation



TEST NO. E14

Seal:	1/4" Double O-Ring
Elastomer:	SI Rubber
Compound:	Parker S604-70
Aging:	None
Atmosphere:	Steam
GAP (in):	0.006
Leakage Onset Temp (°F):	486

Figure A-E14.1
Test E-14
Posttest photo of plate 4
Note: Gasket degradation

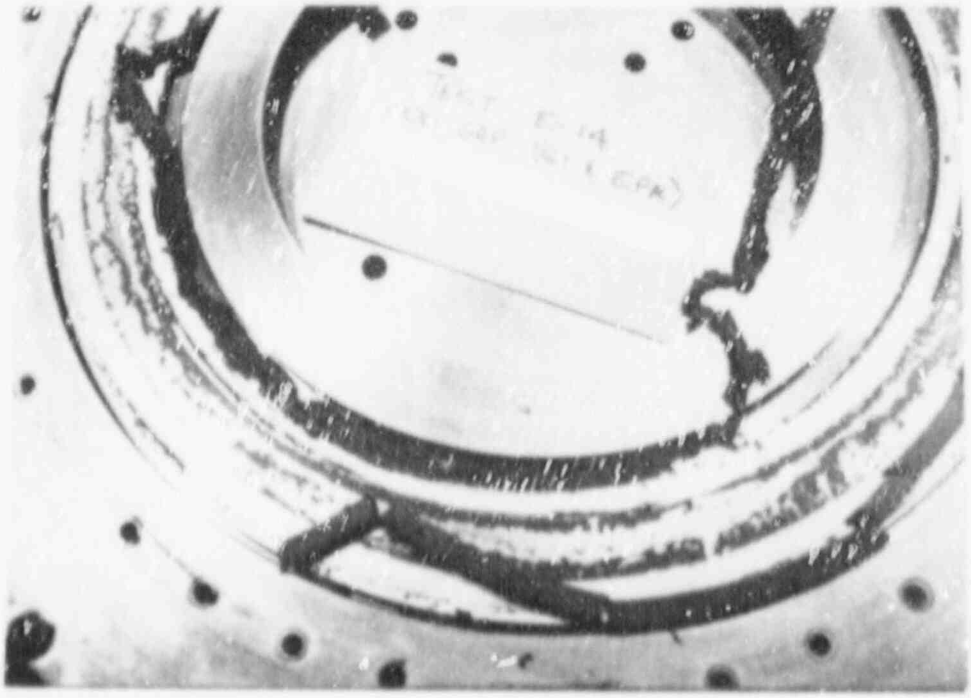


Figure A-E14.2
Test E-14
Posttest photo of plate 2 on plate 1
Note: Gasket degradation

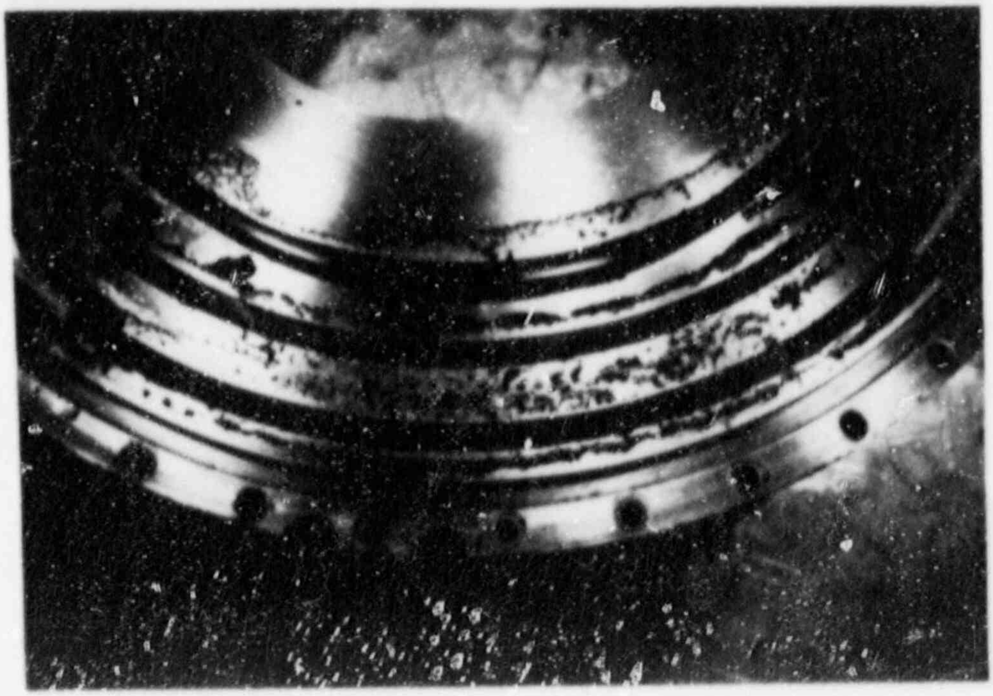
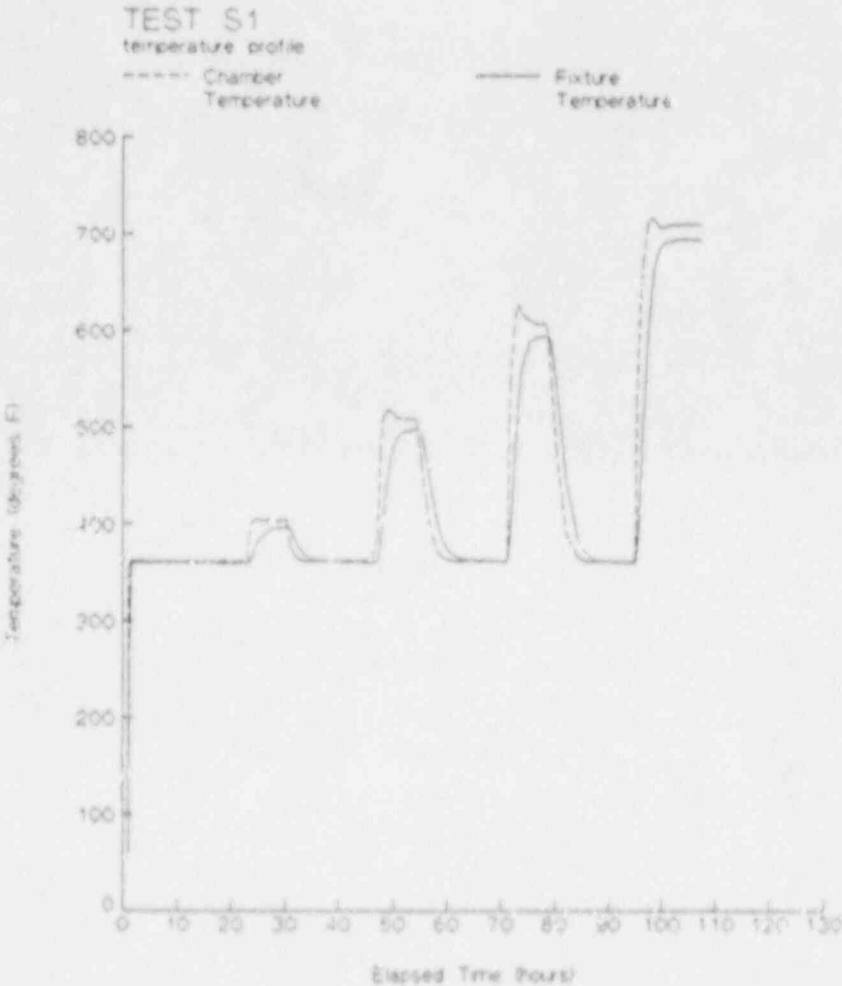


Figure A-E14.3
Test E-14
Posttest photo of plate 2
Note: Use of EP rubber apparatus gasket



TEST NO. S1

Seal:	1/4" Double O-ring
Elastomer:	SI Rubber
Compound:	Parker S604-70
Aging:	None
Atmosphere:	Steam
Gap (in):	0.000
Leakage Onset Temperature:	Did Not Leak

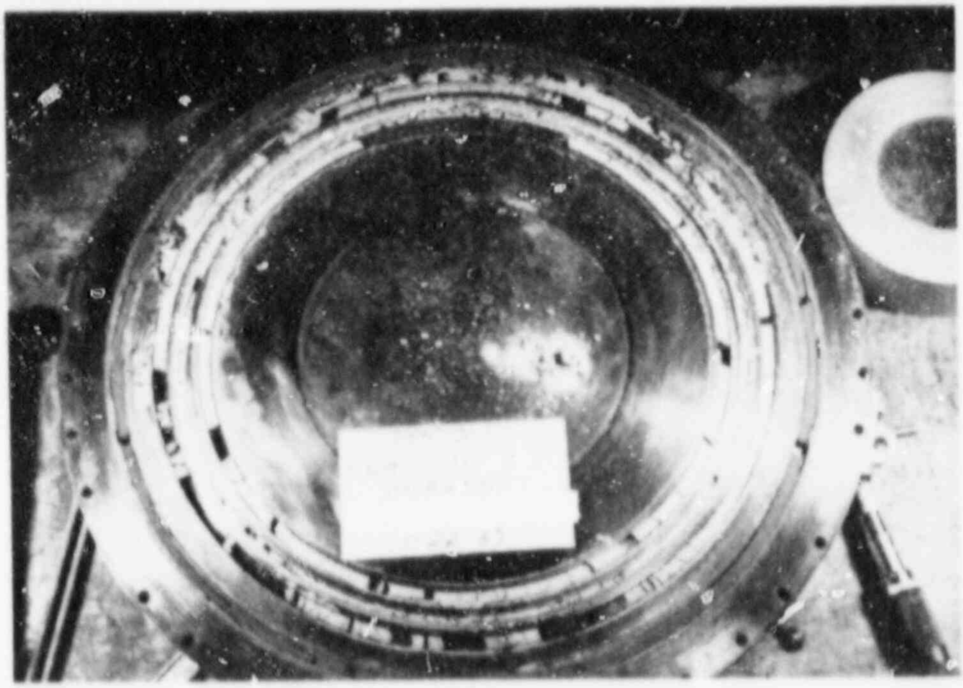
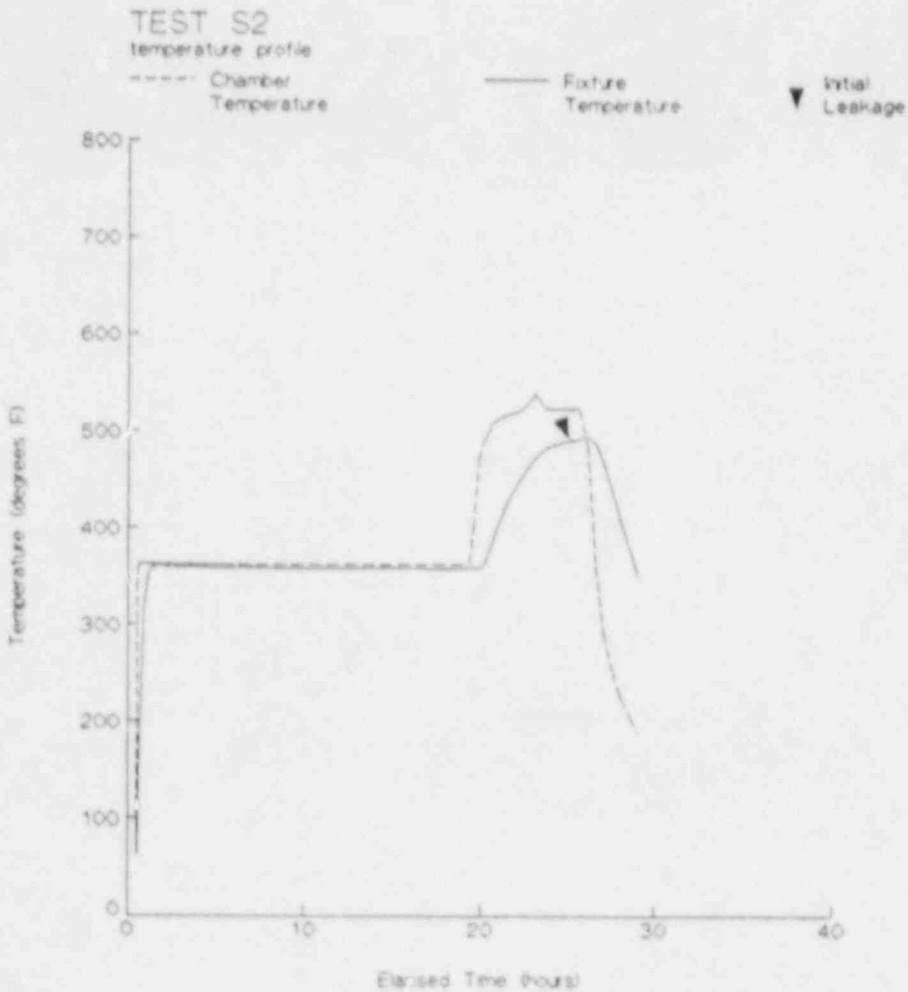


Figure A-S1.1
Test S-1
Posttest photo of plate 1
Note: Gasket degradation

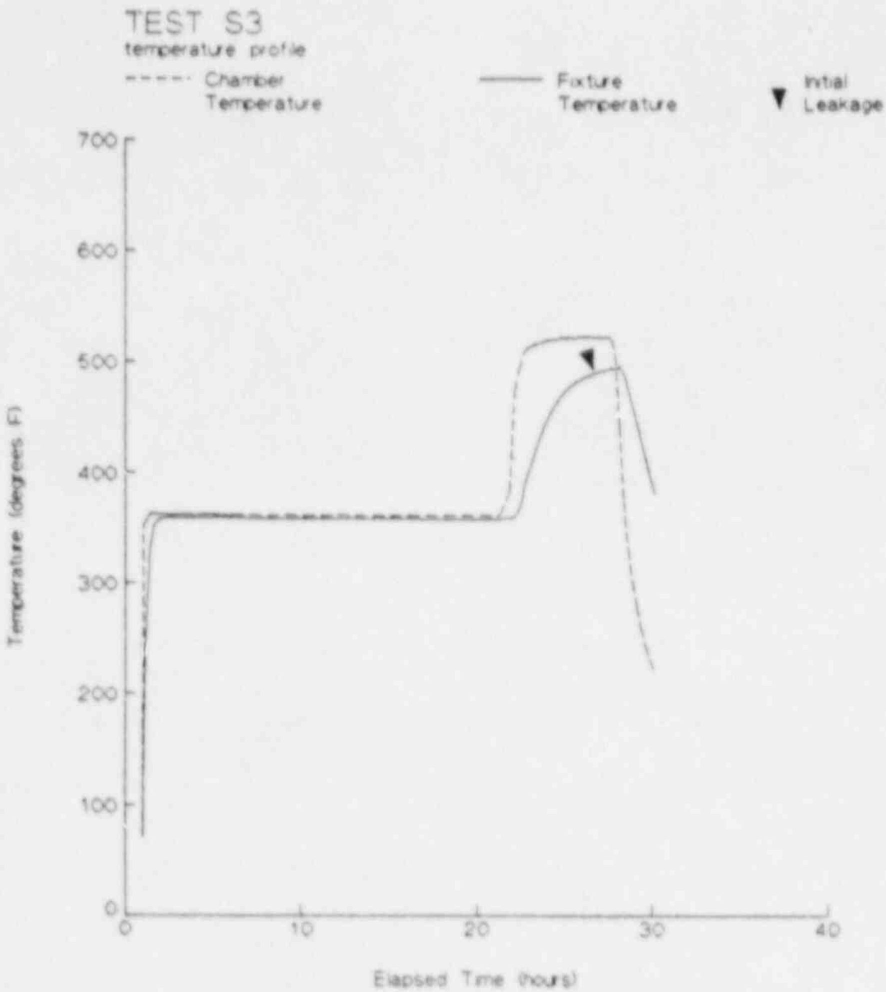
Figure A-S1.2
Test S-1
Posttest photo of plate 1
Note: Gasket degradation



TEST NO. S2

Seal:	1/4" Double O-Ring
Elastomer:	SI Rubber
Compound:	Parker S604-70
Aging:	None
Atmosphere:	Steam
GAP (in):	0.024
Leakage Onset Temp (°F):	493

Figure A-S2.1
Test S-2
Posttest photo of plate 2
Note: Gasket blow-out



TEST NO. S3

Seal:	1/4" Double O-Ring
Elastomer:	SI Rubber
Compound:	Parker S604-70
Aging:	None
Atmosphere:	Steam
GAP (in):	0.048
Leakage Onset Temp (°F):	493

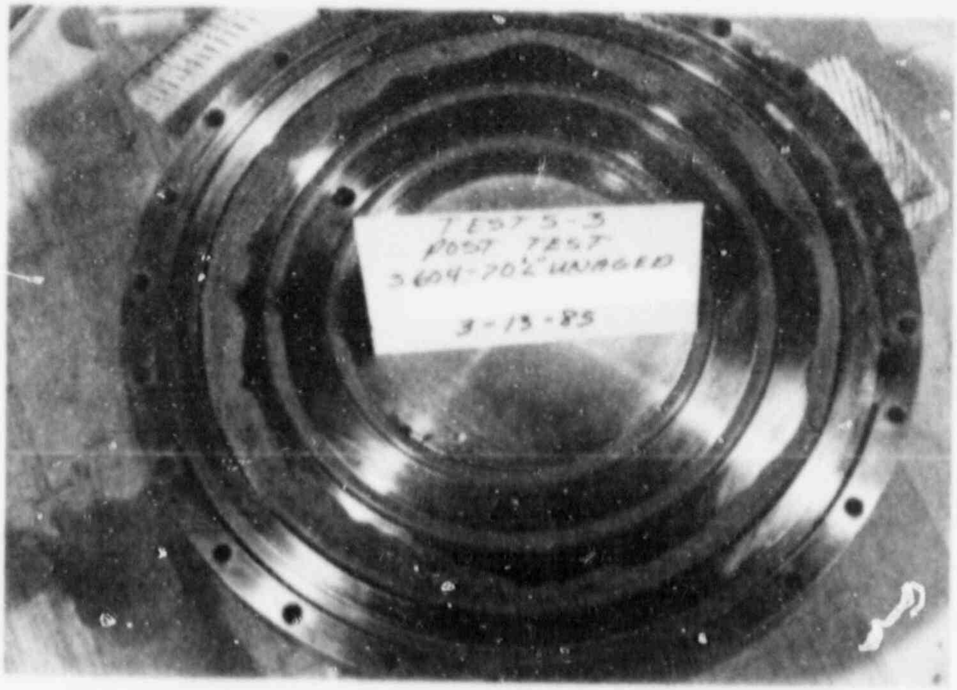


Figure A-S3.1
Test S-3
Posttest photo of plate 4
Note: Gasket flow

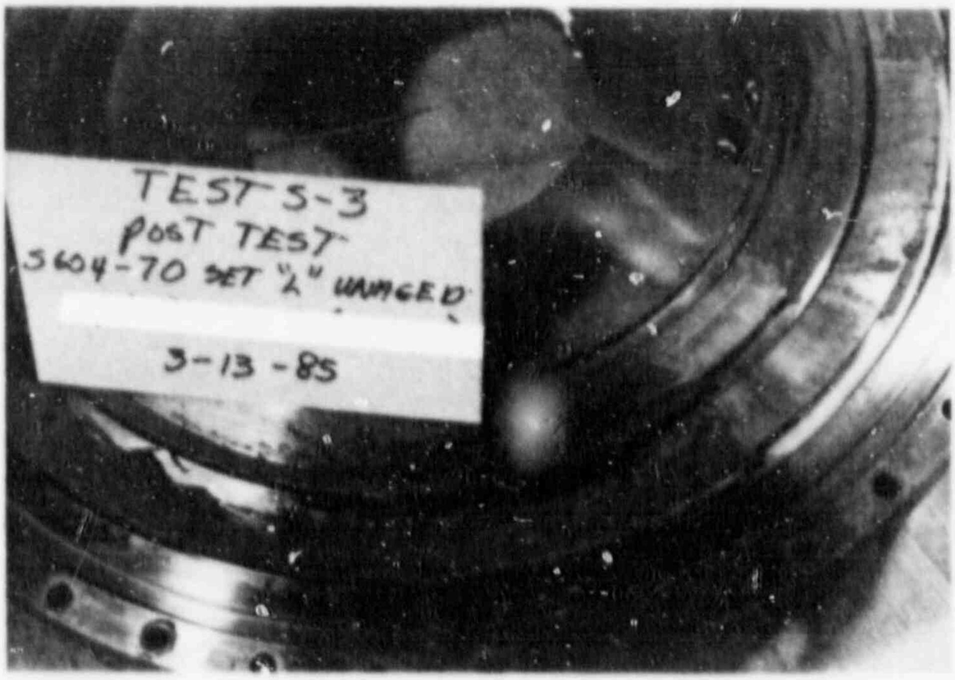
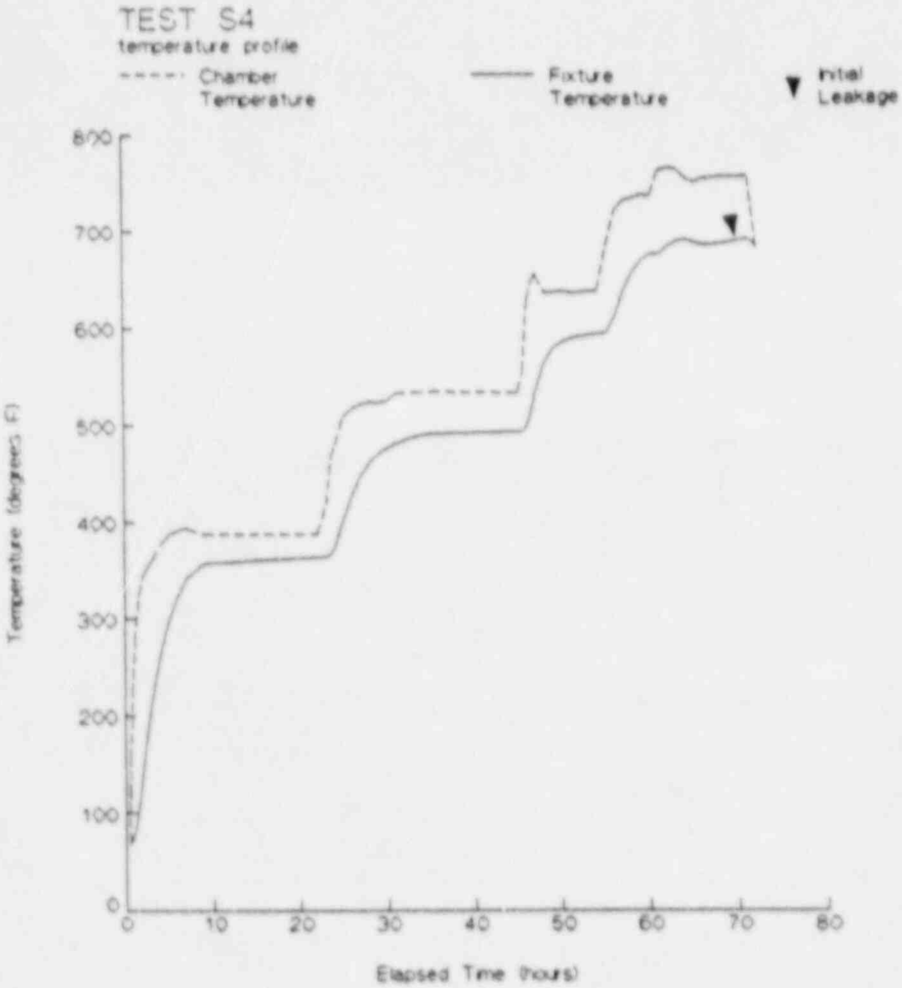


Figure A-S3.2
Test S-3
Posttest photo of plate 3
Note: Gasket blow-out

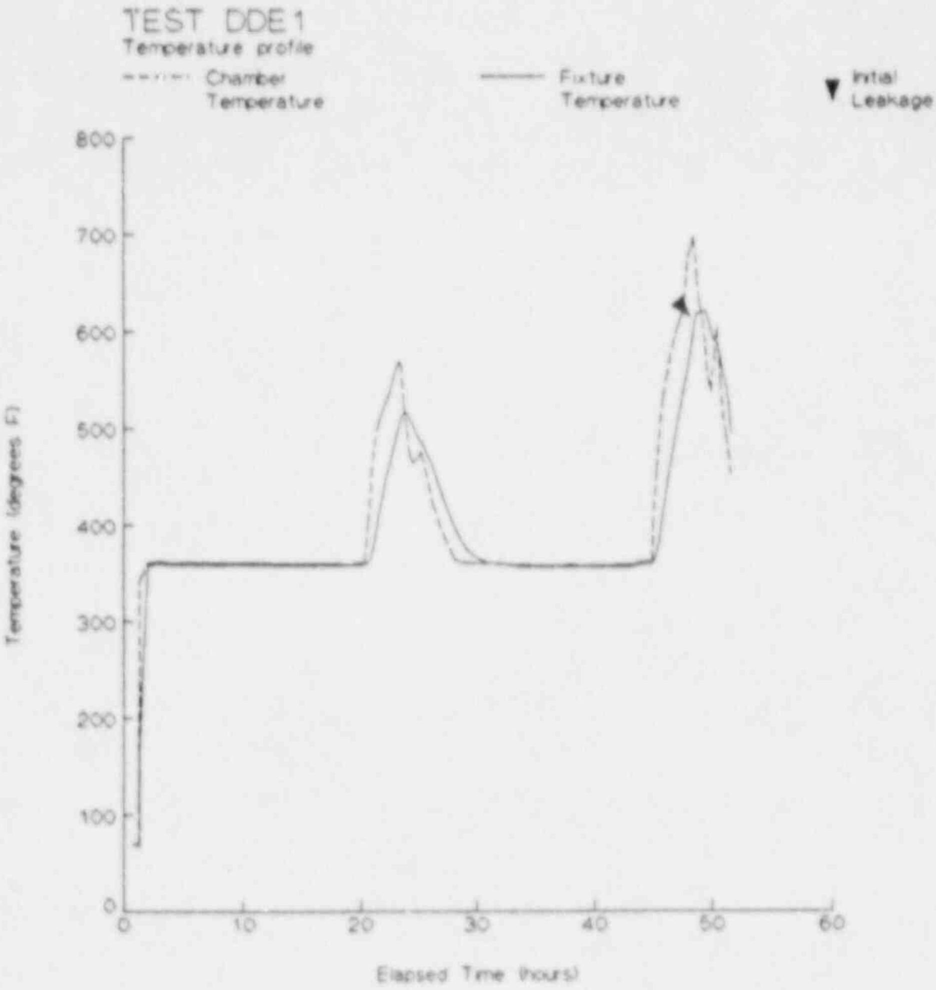


TEST NO. S4

Seal:	1/4" Double O-Ring
Elastomer:	SI Rubber
Compound:	Parker S604-70
Aging:	None
Atmosphere:	Dry Air
GAP (in):	0.024
Leakage Onset Temp (^{o}F):	681

Figure A-S4.1
Test S-4
Posttest photo of plate 3
Note: Gasket degradation

Figure A-S4.2
Test S-4
Posttest photo of plate 2
Note: Gasket degradation



TEST NO. DDE

Seal:	Double Dog Ear
Elastomer:	EP Rubber
Compound:	Presray E603-60
Aging:	None
Atmosphere:	Steam
GAP (in):	0.012
Leakage Onset Temp (°F):	617

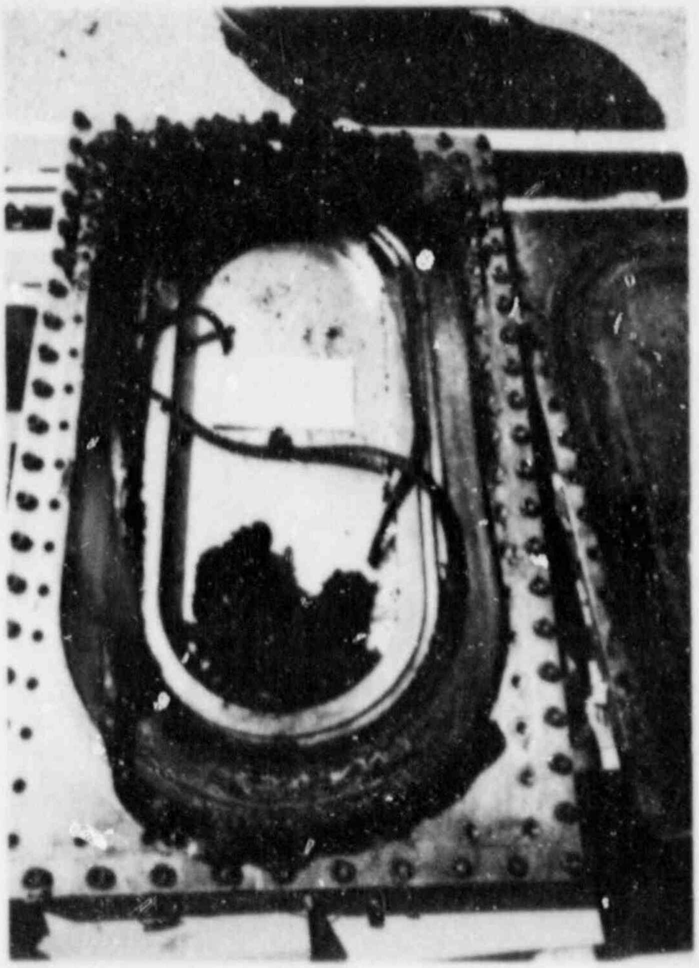


Figure A-DDE1.1
Test DDE 1
Posttest photo of plate 2
Note: Gasket degradation

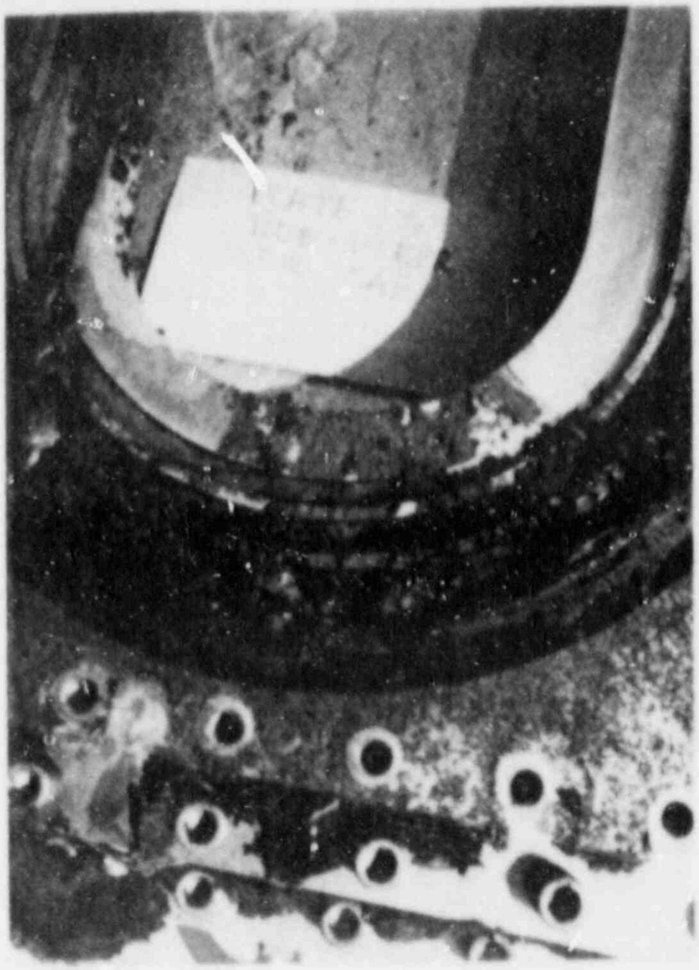


Figure A-DDE1.2
Test DDE 1
Posttest photo of plate 3
Note: Gasket blow-out

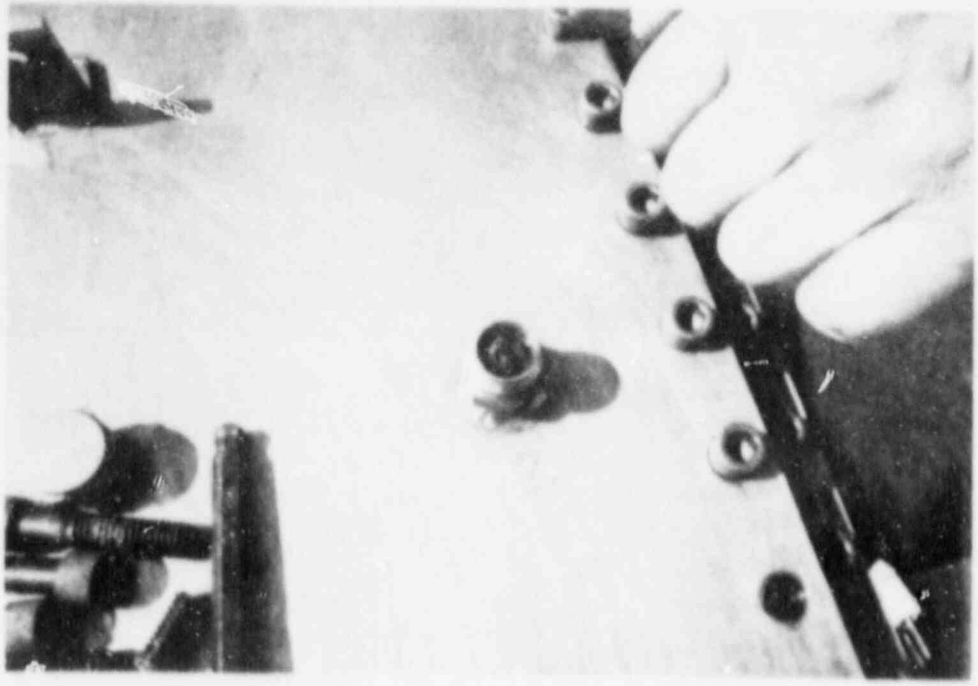


Figure A-DDE1.3
Test DDE 1
Posttest photo of plate 4 leakage port
Note: Leakage port clogging

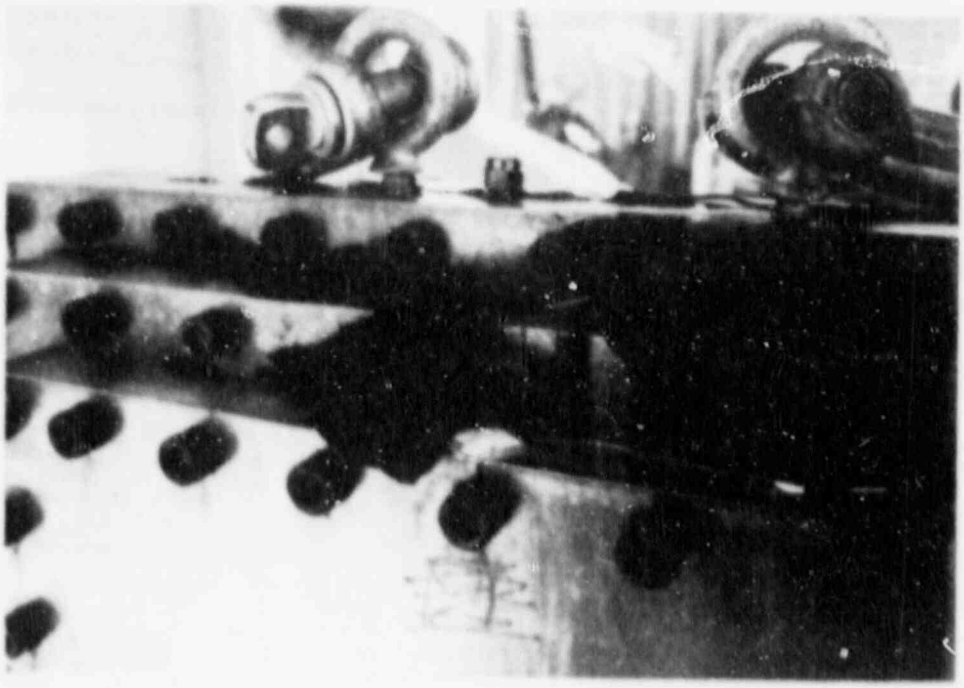
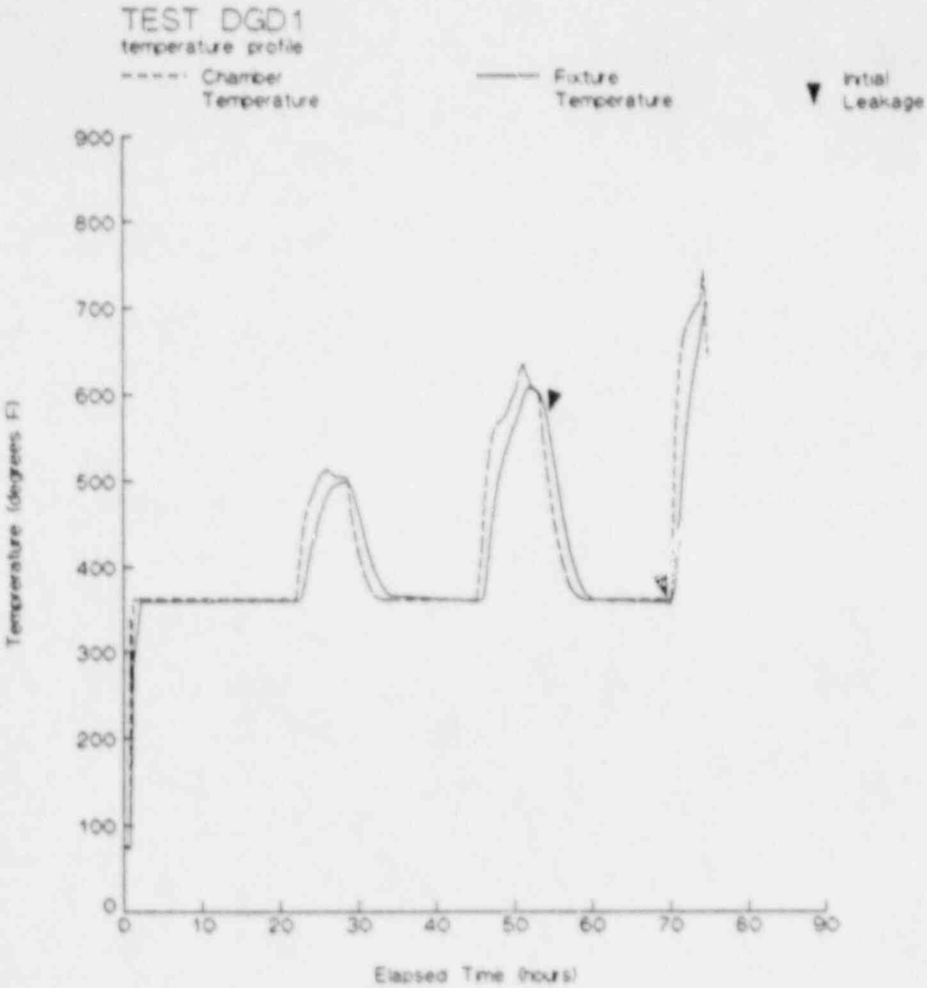


Figure A-DDE1.4
Test DDE 1
Posttest photo of assembled test fixture
Note: Extruded gasket material



TEST NO. DGD

Seal:	Double Gum Drop
Elastomer:	EP Rubber
Compound:	Presray E603-60
Aging:	None
Atmosphere:	Steam
GAP (in):	0.012
Leakage Onset Temp (^{o}F):	Onset occurred overnight between points indicated

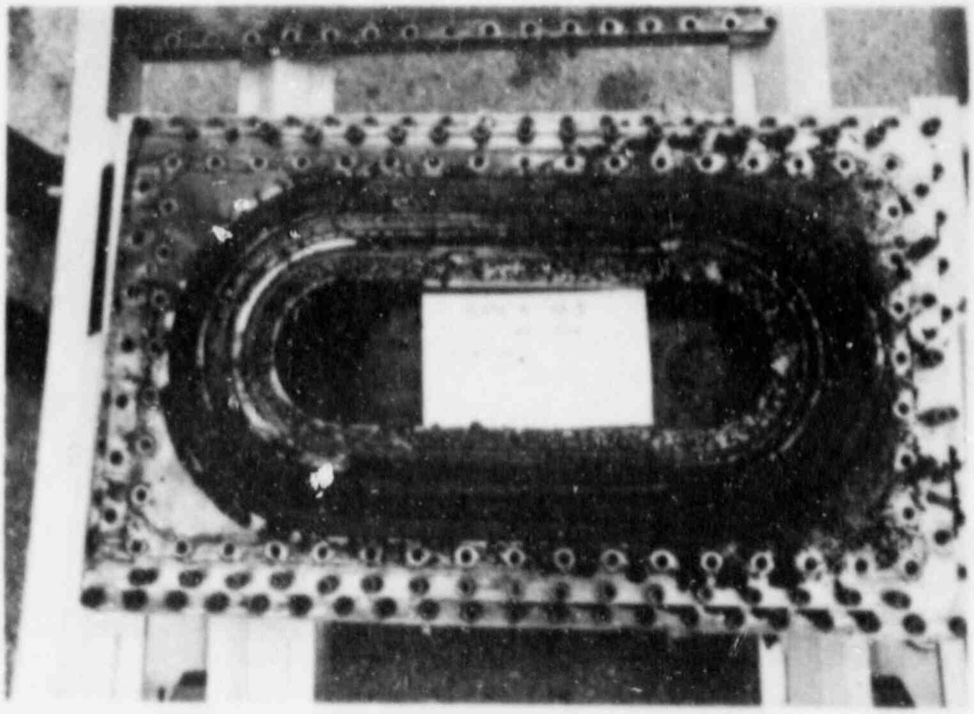


Figure A-DGD1.1
Test DGD 1
Posttest photo of plate 3
Note: Gasket degradation

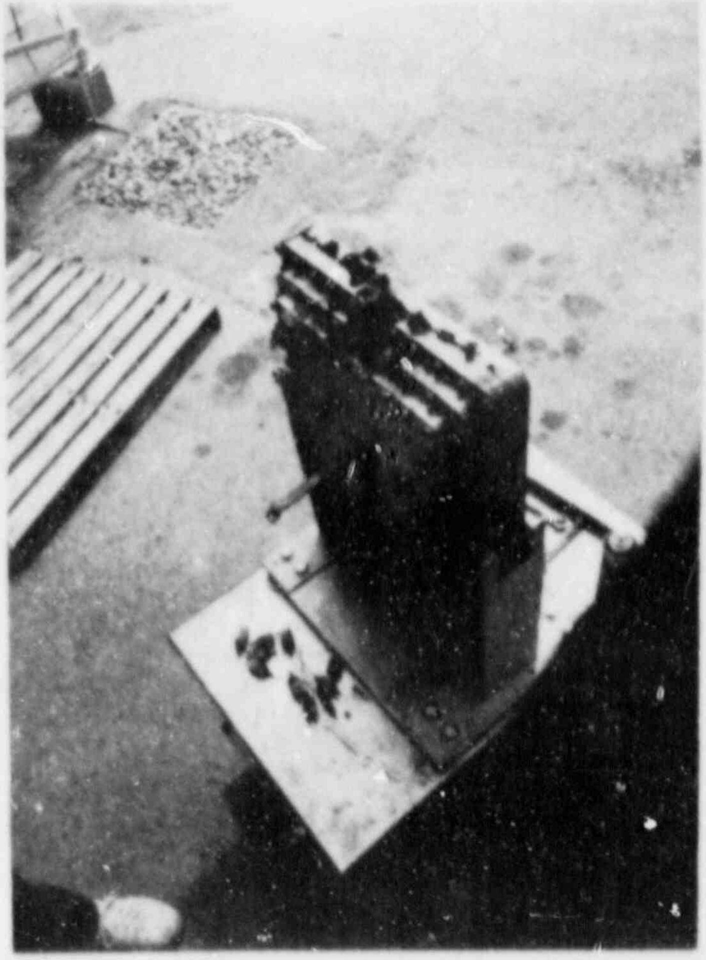
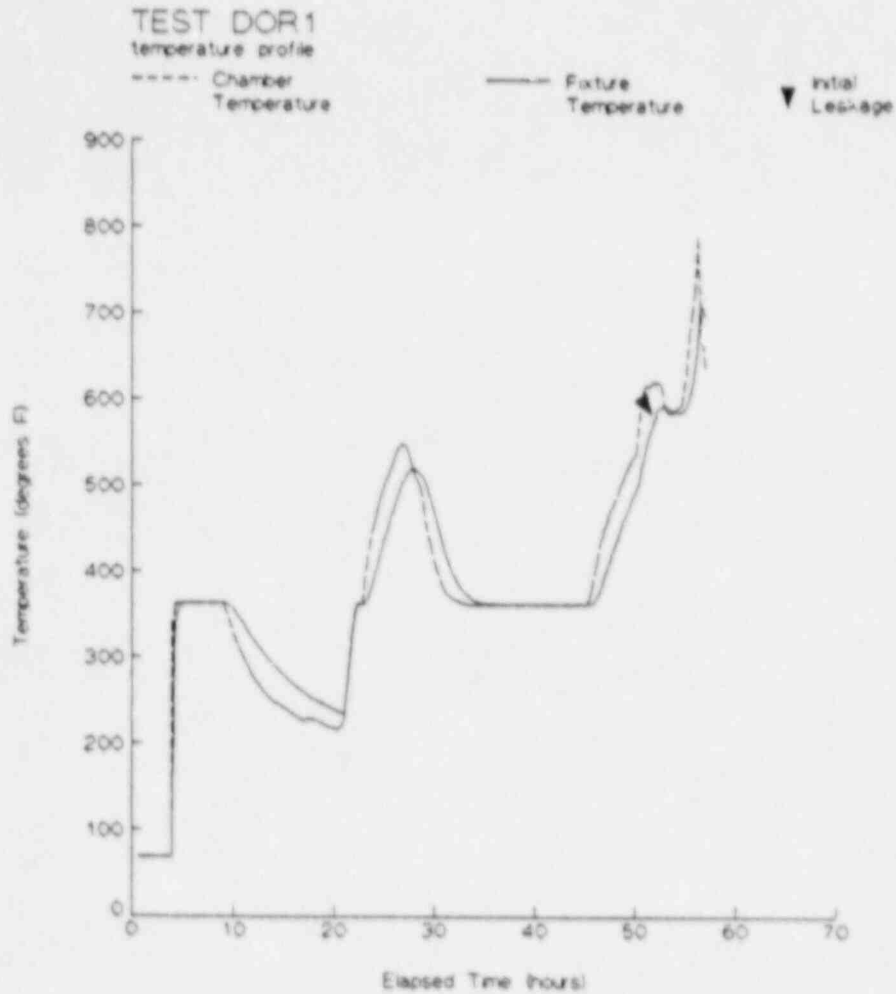


Figure A-DGD1.2
Test DGD 1
Posttest photo of assembled test fixture
Note: Extruded gasket material



TEST NO. DOR

Seal:	1/2" Double O-Ring
Elastomer:	EP Rubber
Compound:	Presray E603-60
Aging:	None
Atmosphere:	Steam
GAP (in):	0.012
Leakage Onset Temp (°F):	590

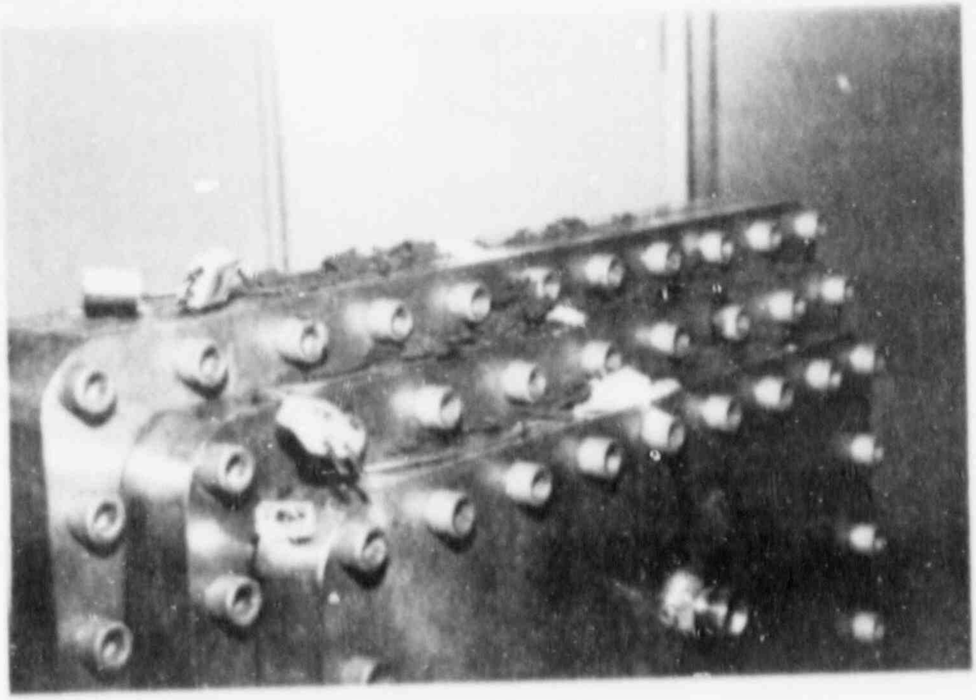


Figure A-DOR1.1
Test DOR 1
Posttest photo of assembled test fixture
Note: Extruded gasket material

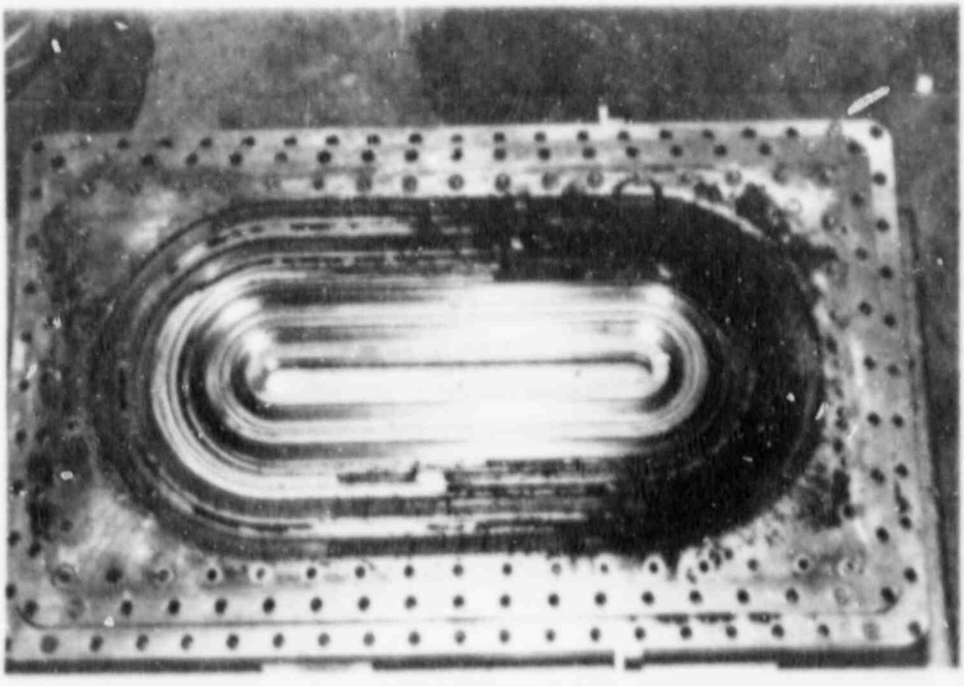


Figure A-DOR1.2
·st DOR 1
Postte photo of plate 3
Note: Powdered gasket material

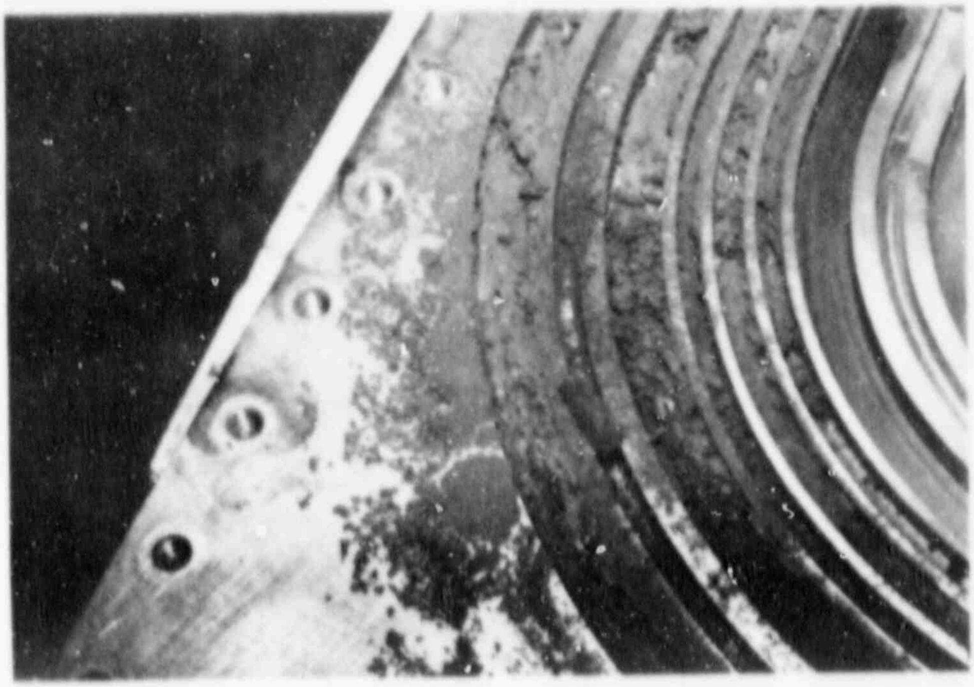


Figure A-DOR1.3
Test DOR 1
Posttest photo of plate 1
Note: Gasket degradation

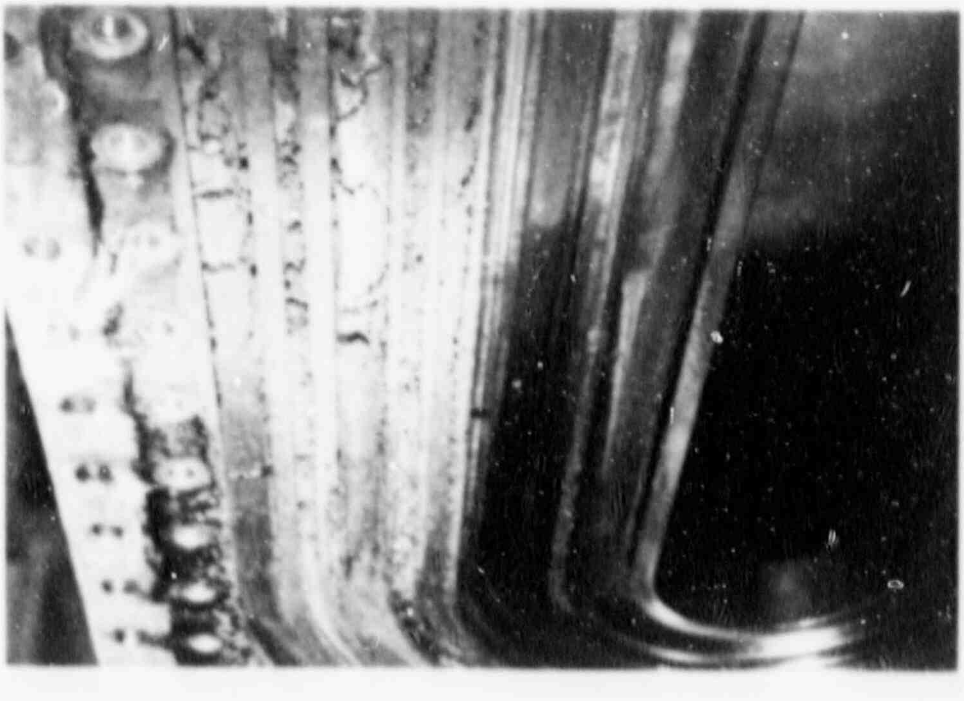
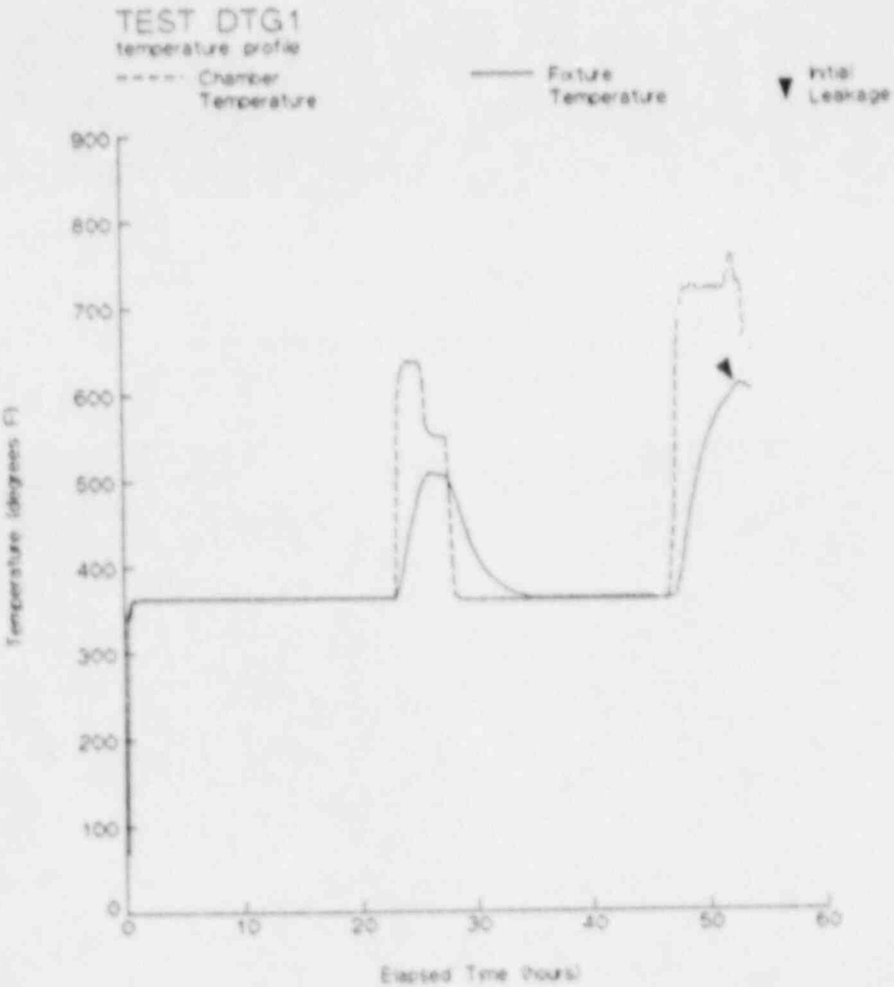


Figure A-DOR1.4
Test DOR 1
Posttest photo of plate 2
Note: Leakage channel clogging



TEST NO. DTG

Seal:	Double Tongue and Groove
Elastomer:	FP Rubber
Compound:	Presray E603-60
Aging:	None
Atmosphere:	Steam
GAP (in):	0.012
Leakage Onset Temp (°F):	609

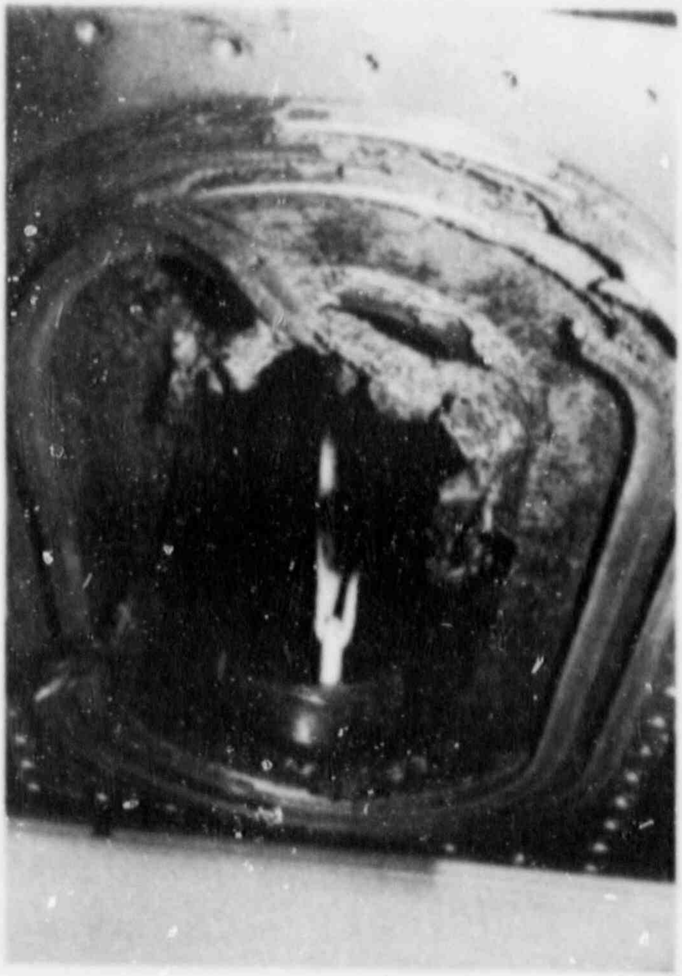


Figure A-DTG1.1
Test DTG 1
Posttest photo of plate 3
Note: Gasket degradation

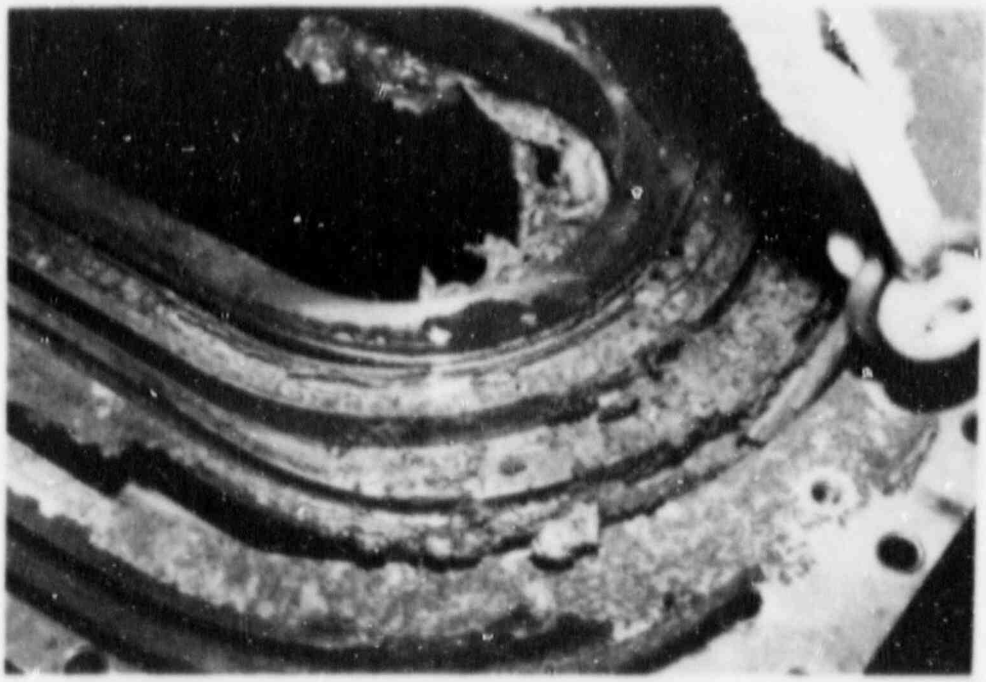


Figure A-DTG1.2
Test DTG 1
Posttest photo of plate 3
Note: Leakage channel clogging

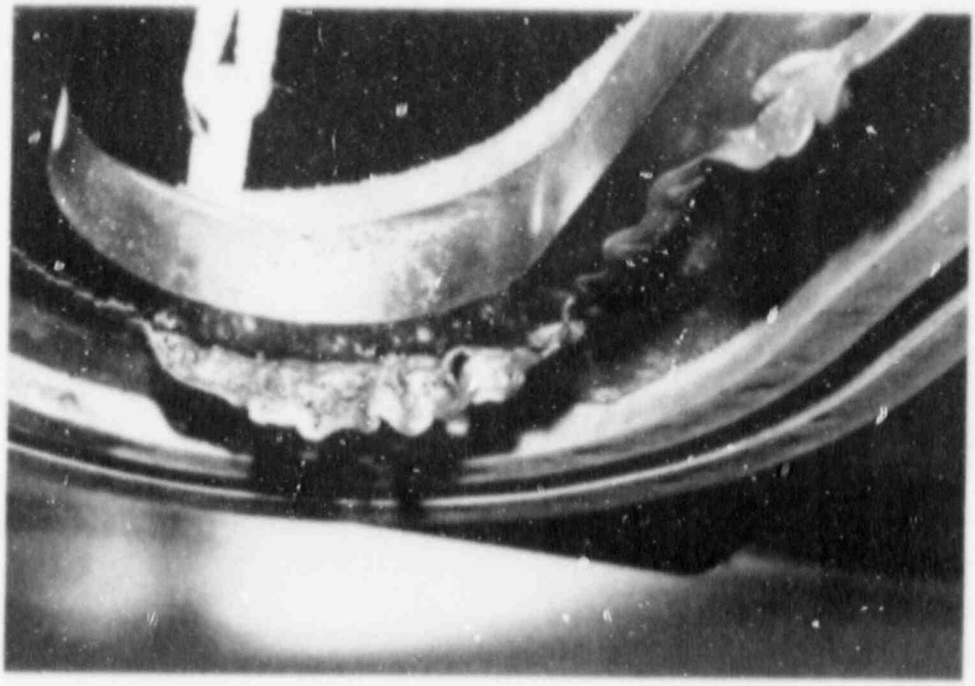


Figure A-DTG1.3
Test DTG 1
Posttest photo of plate 3
Note: Gasket degradation

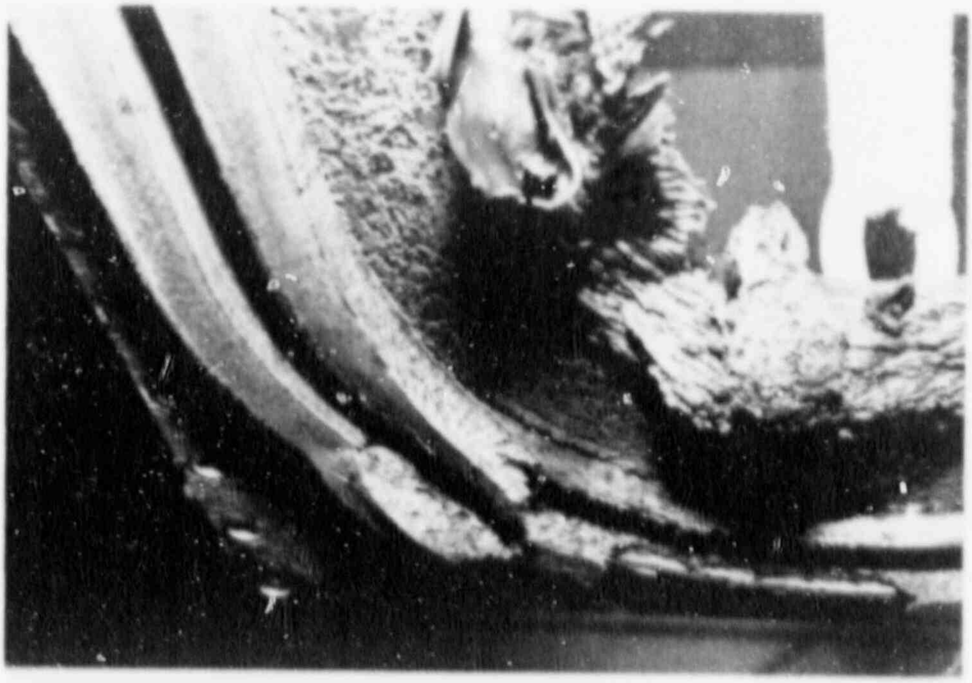


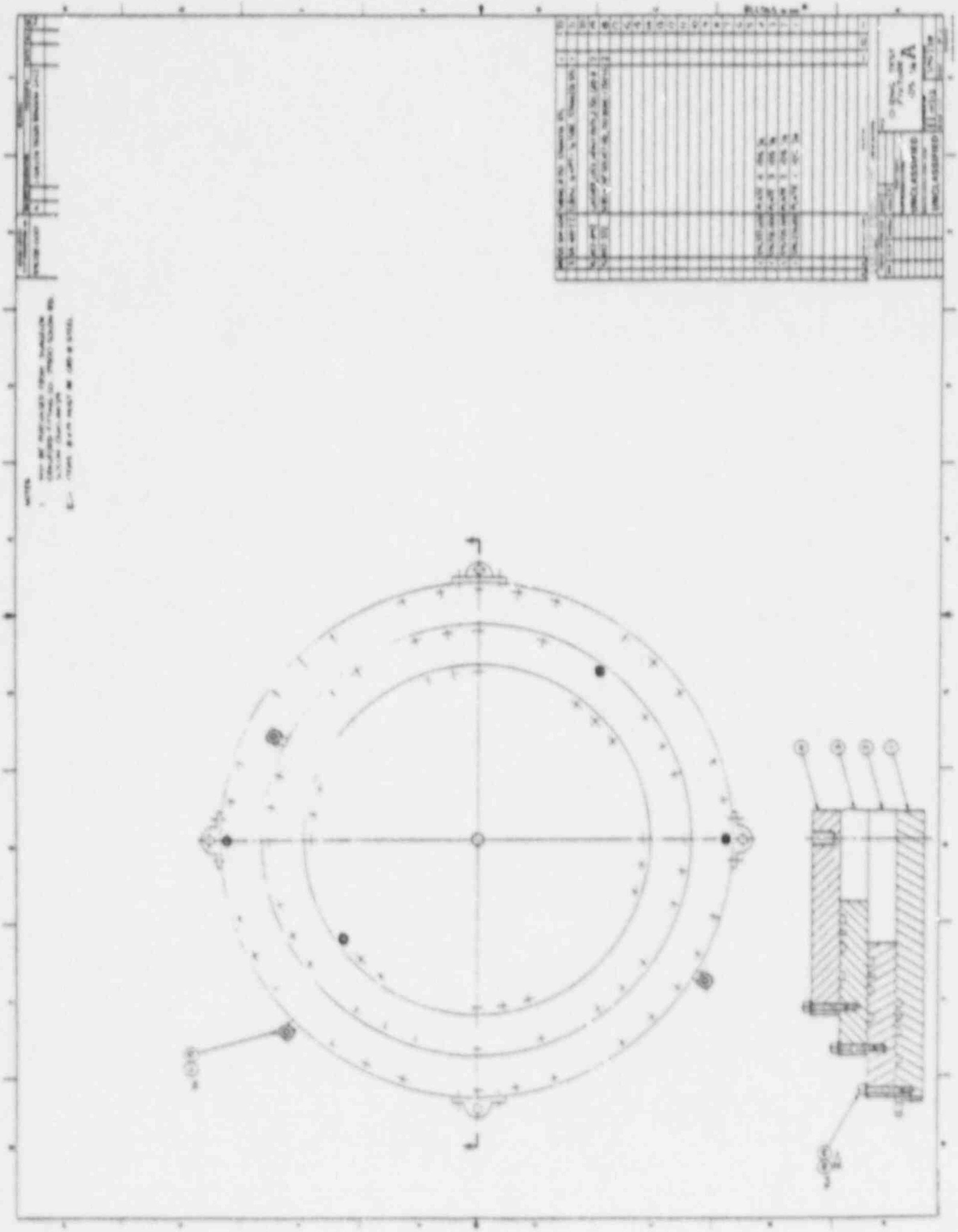
Figure A-DTG1.4
Test DTG 1
Posttest photo of plate 3
Note: Gasket degradation

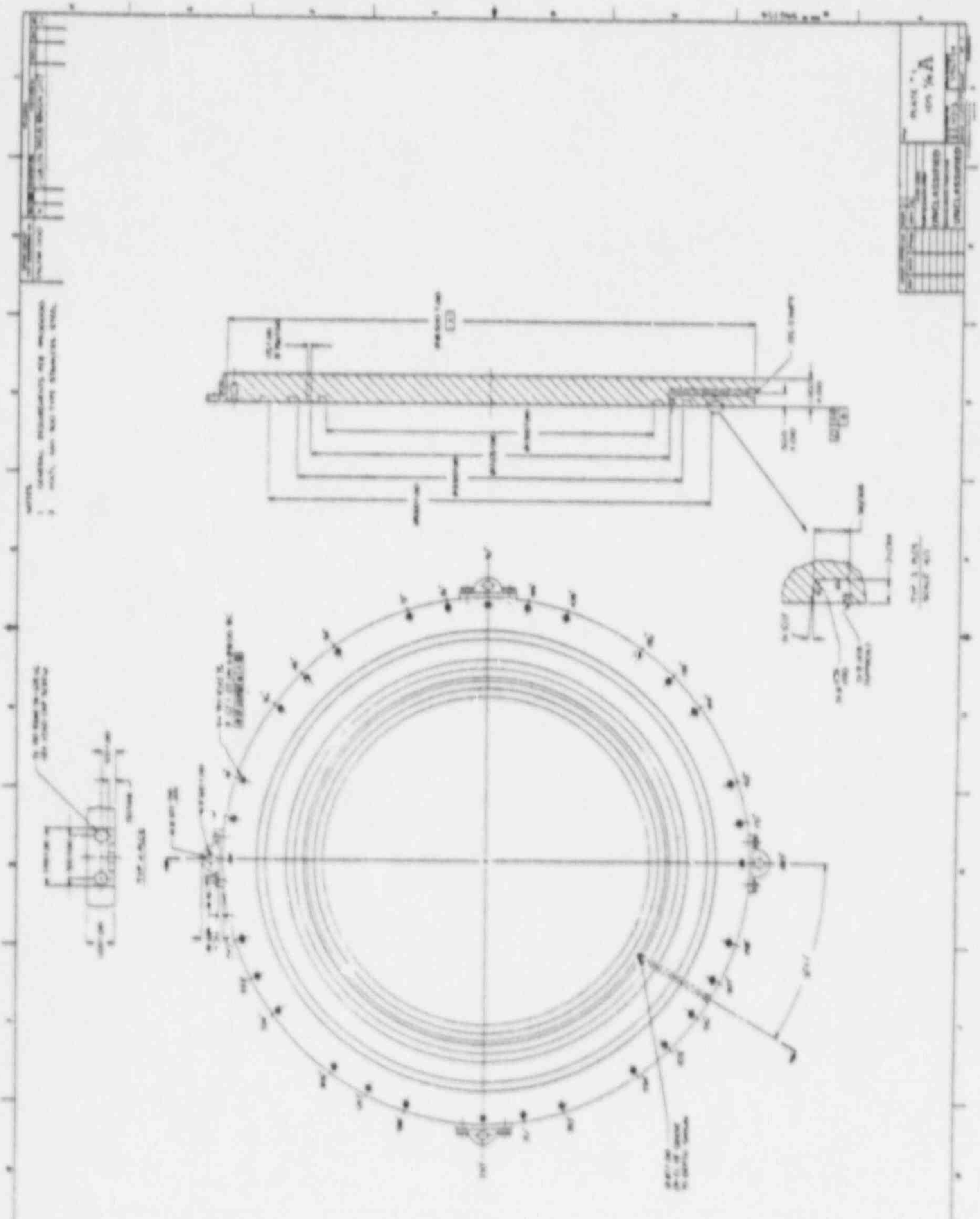
APPENDIX B

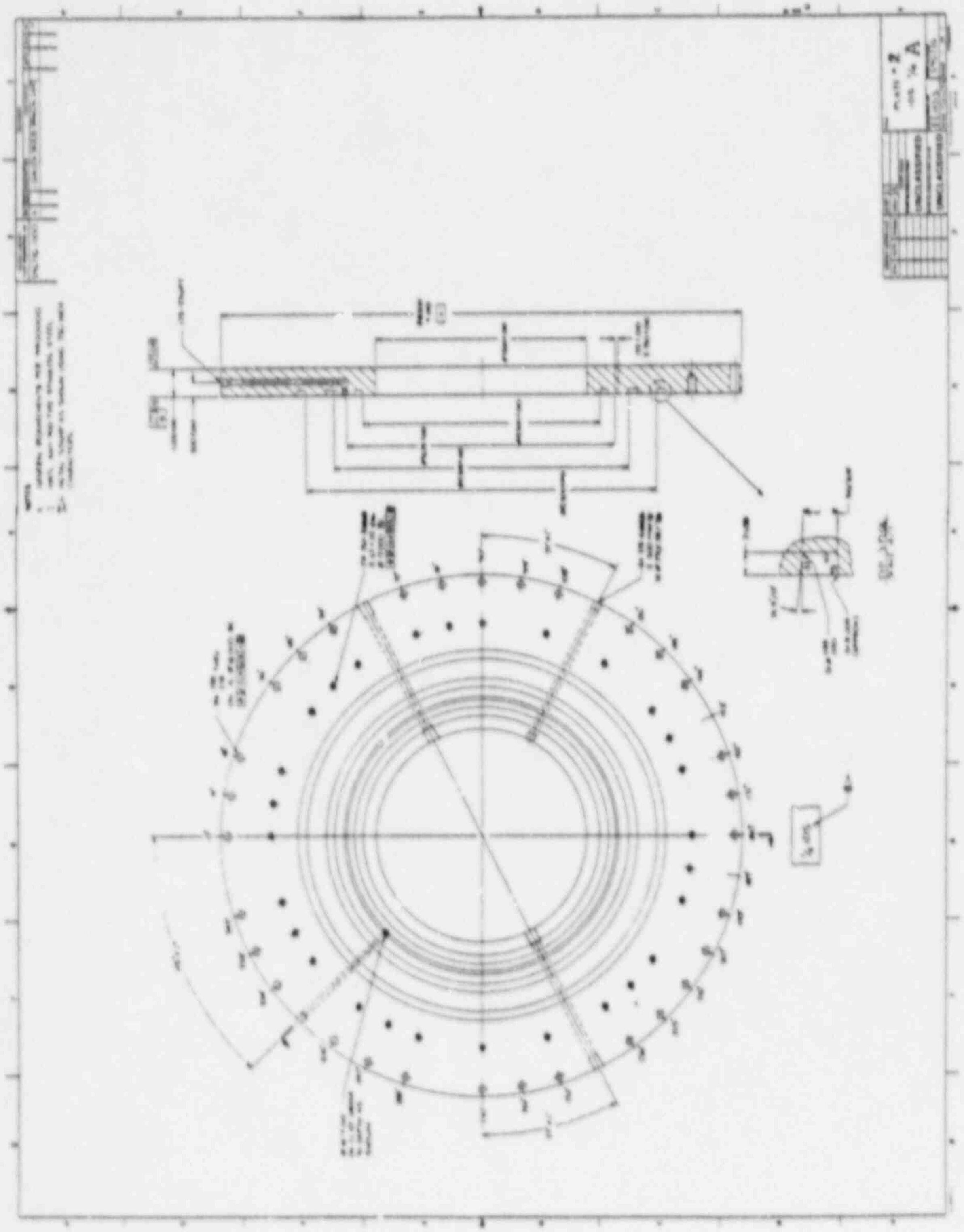
TEXT FIXTURE DRAWINGS

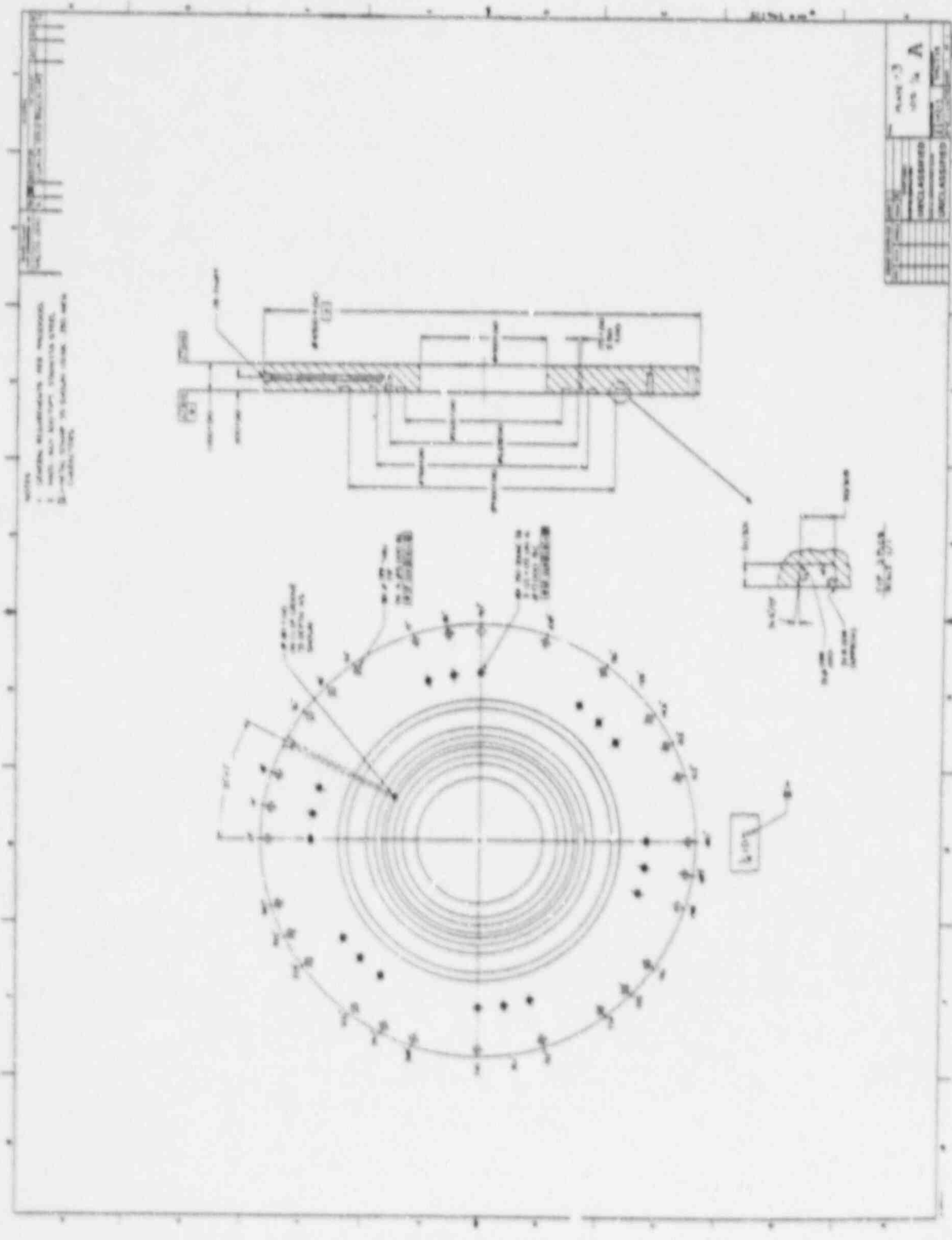
APPENDIX B

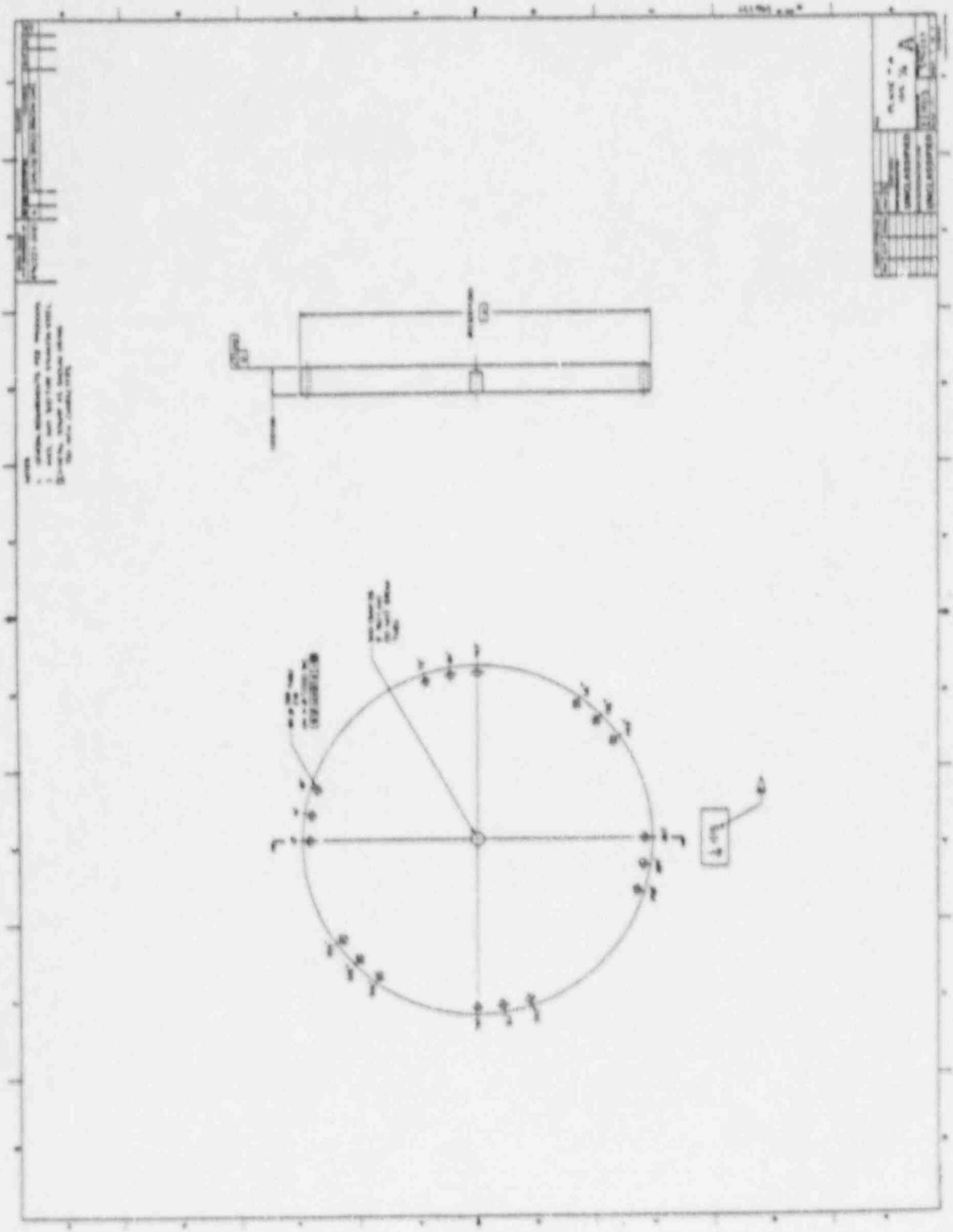
TEST FIXTURE DRAWINGS

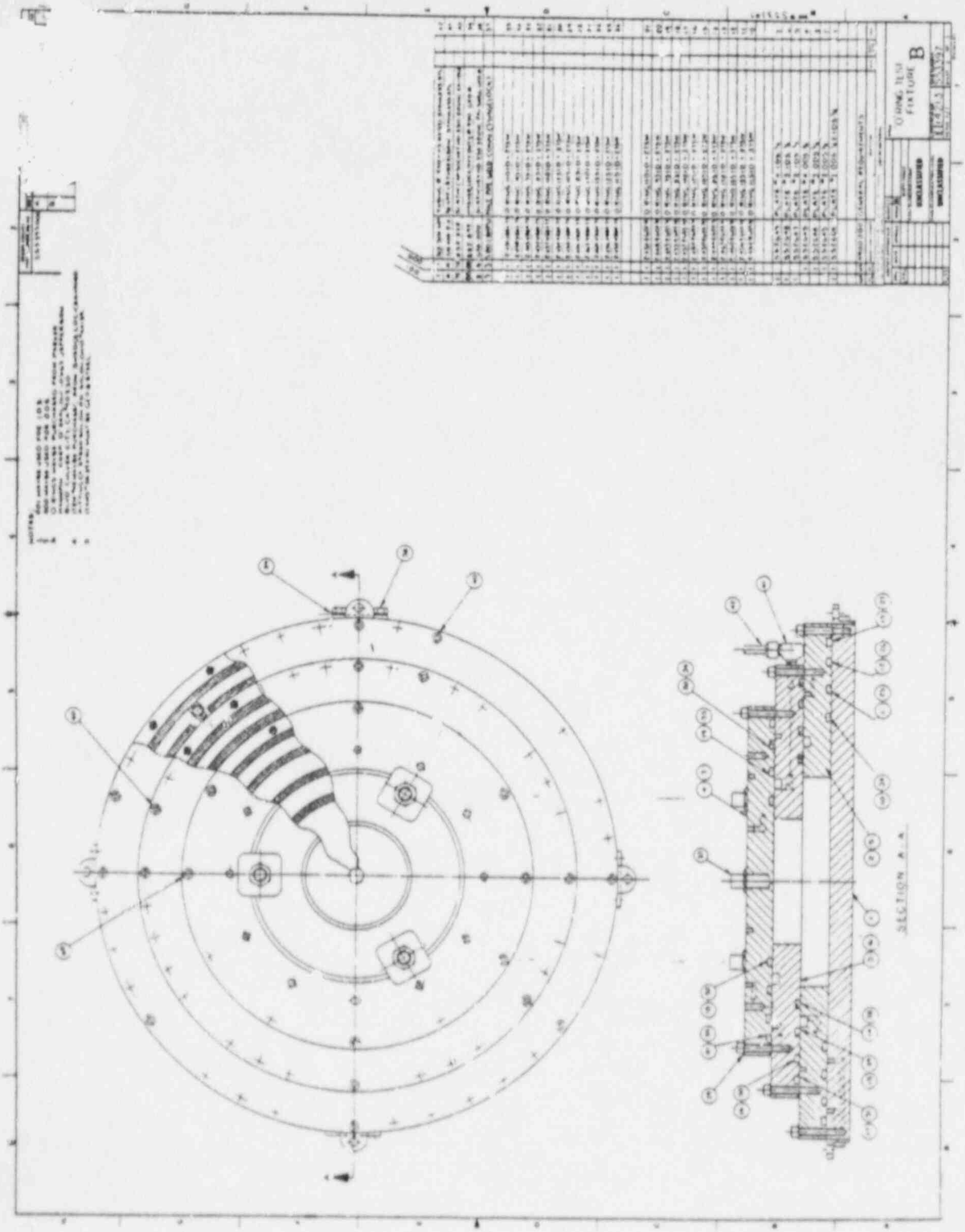


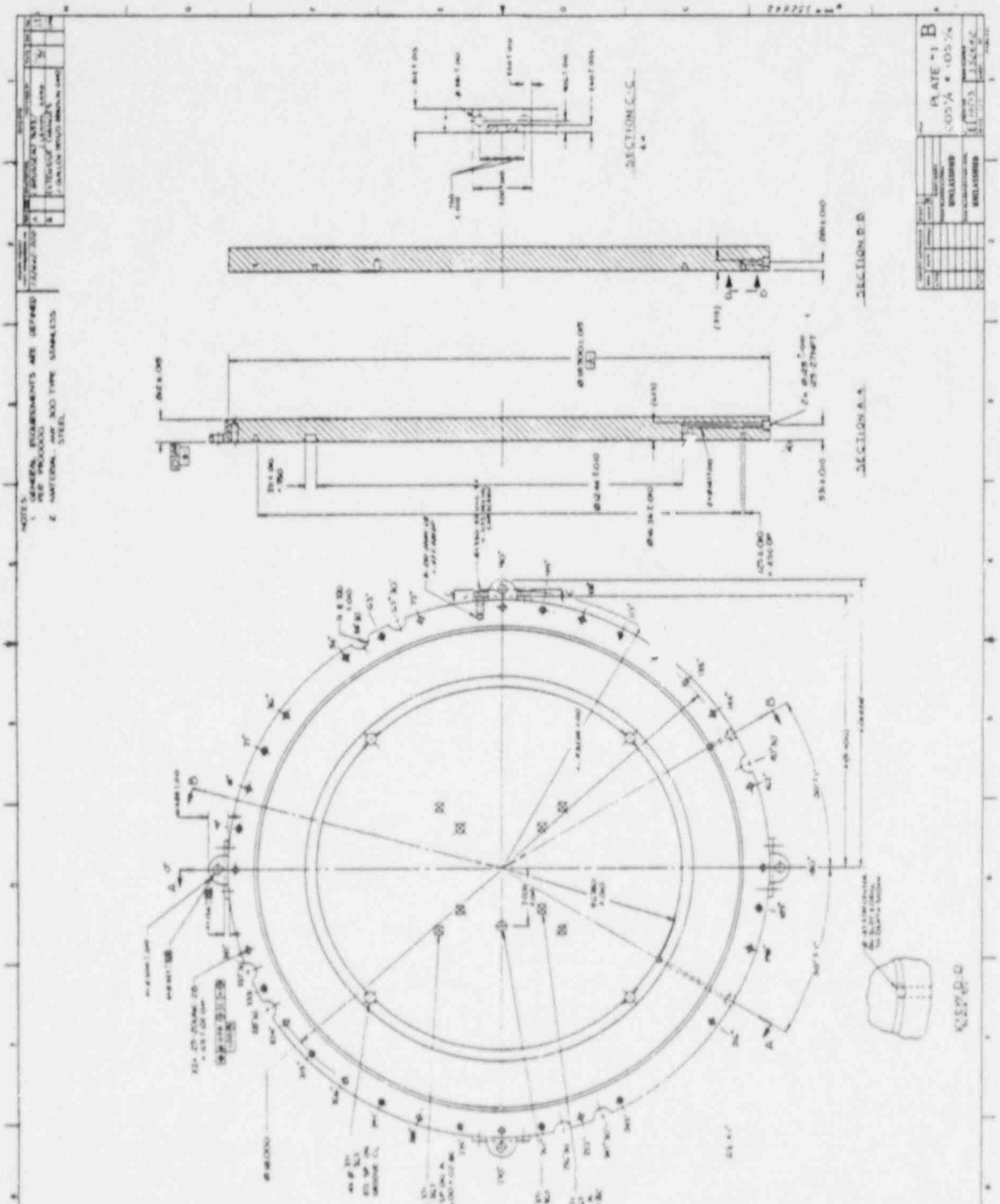


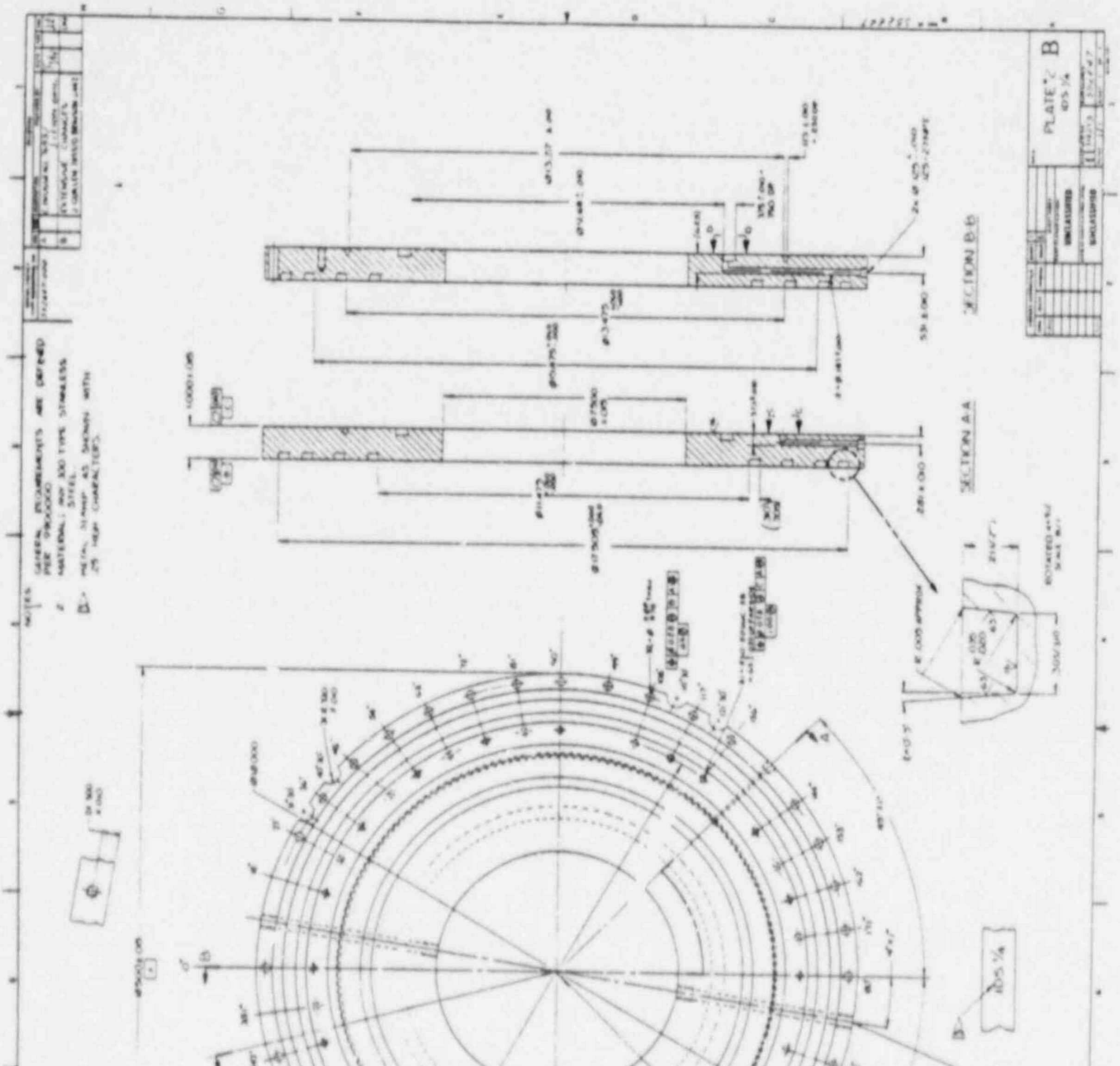


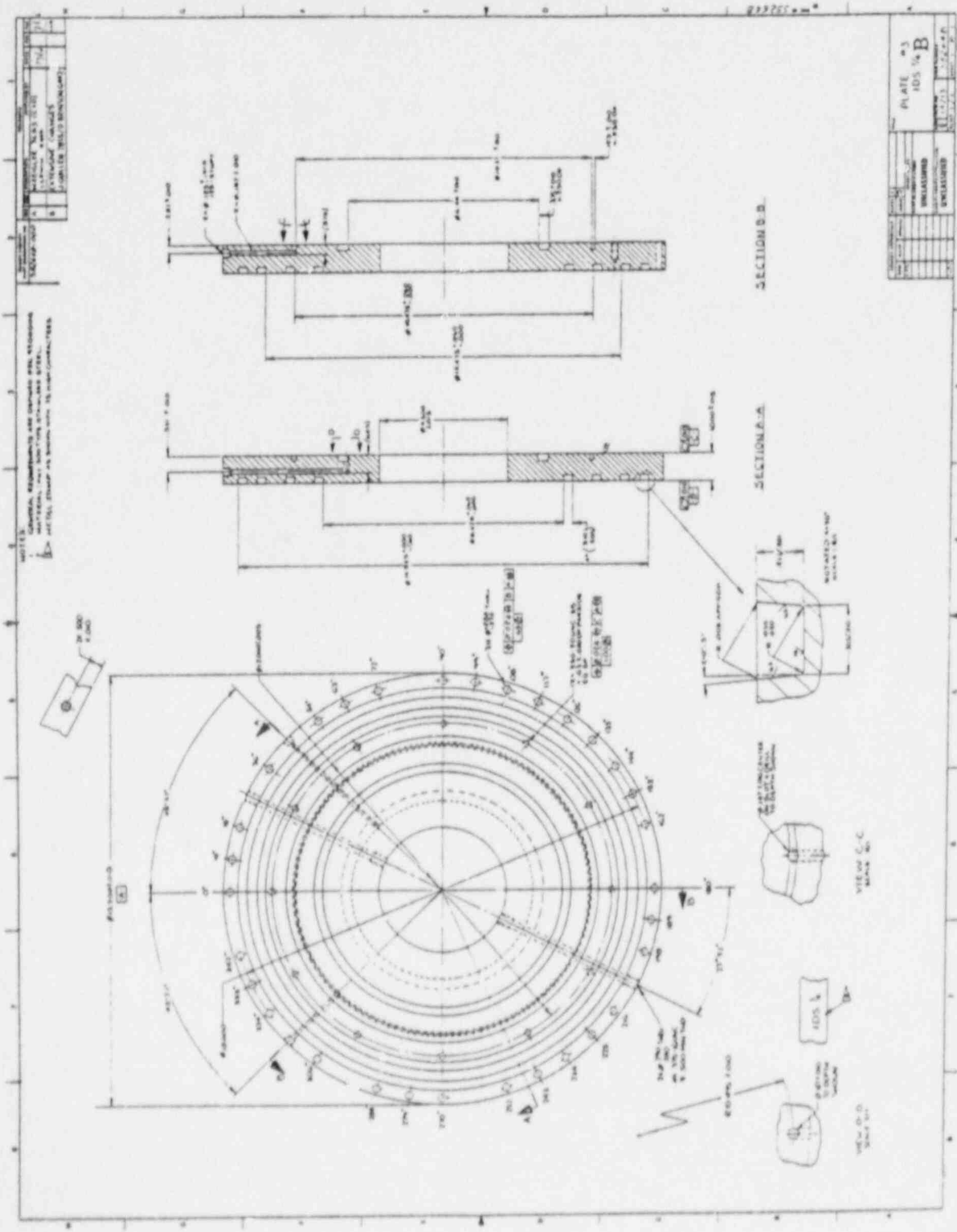


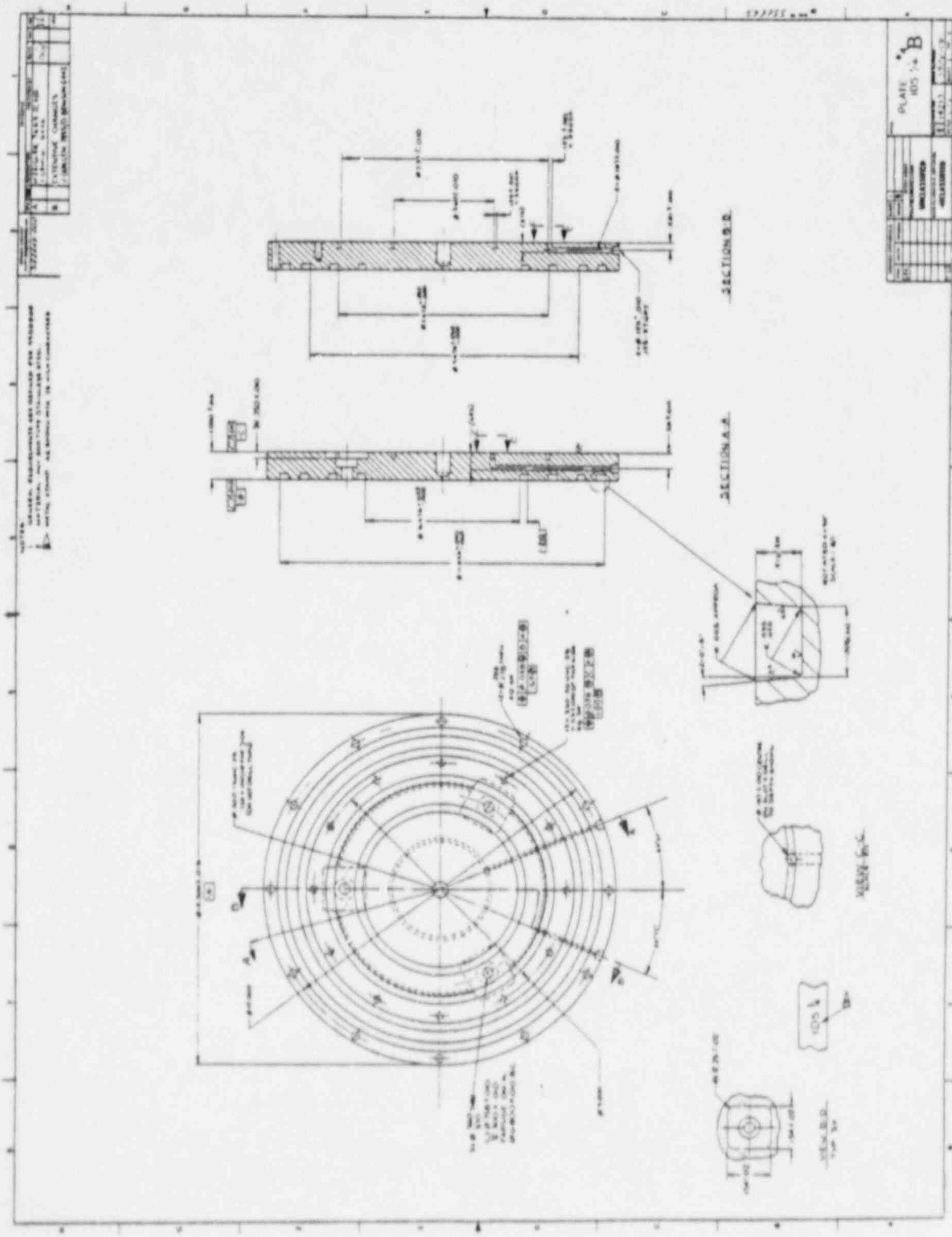


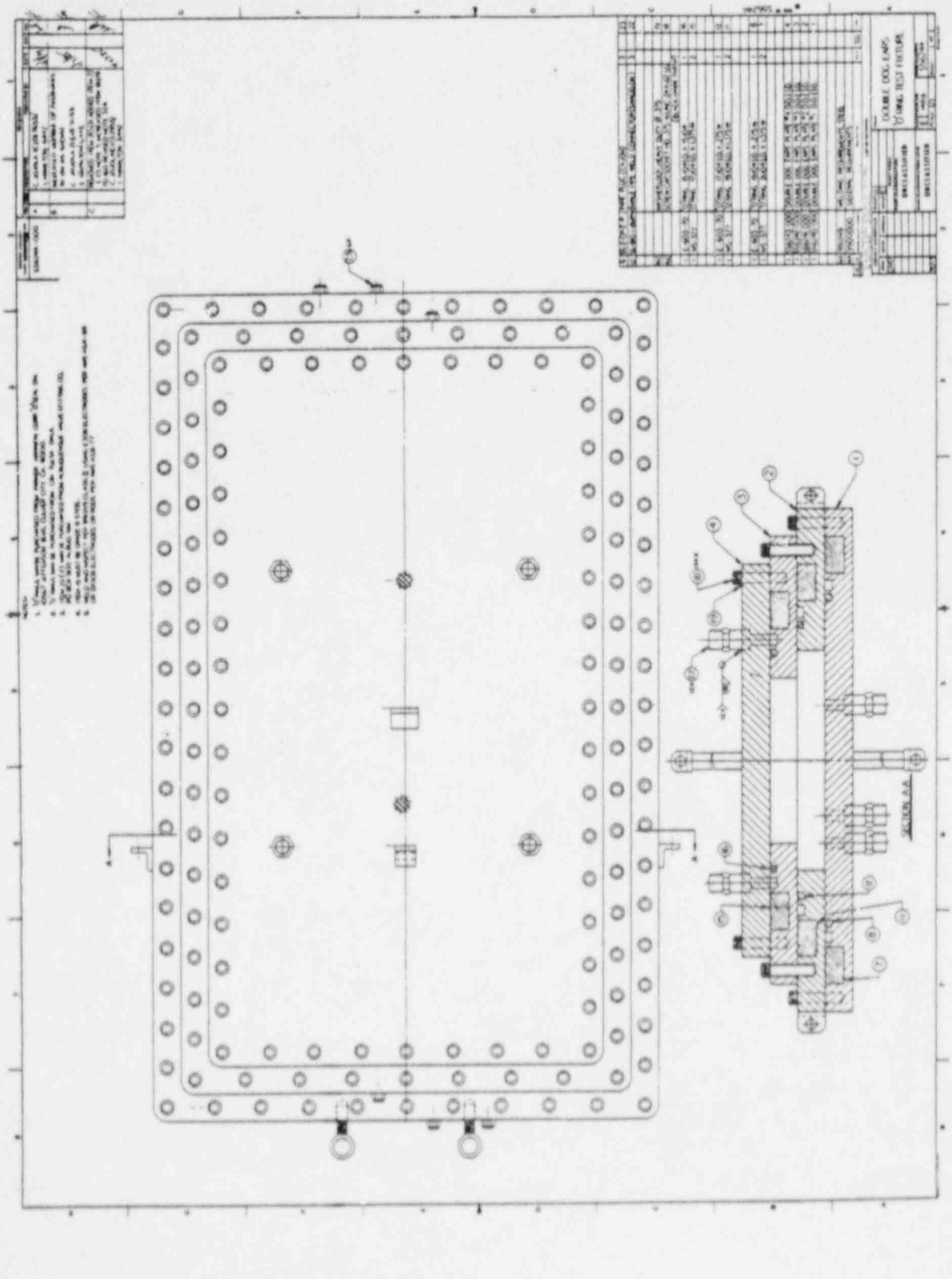

O'RING TEST FIXTURE B
UNCLASSIFIED
UNCLASSIFIED
SECTION A-A

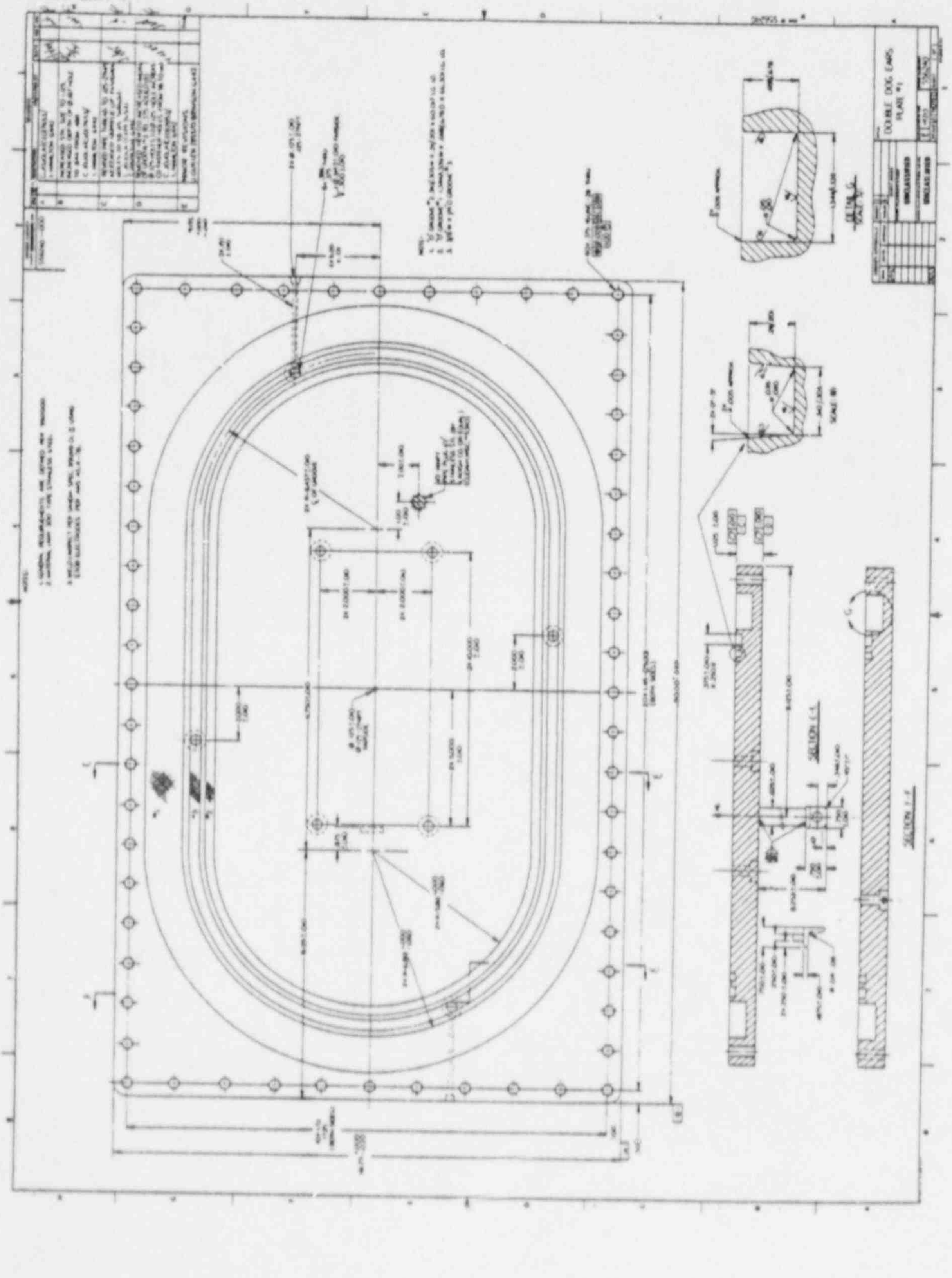

SECTION A-A
SECTION B-B
SECTION C-C

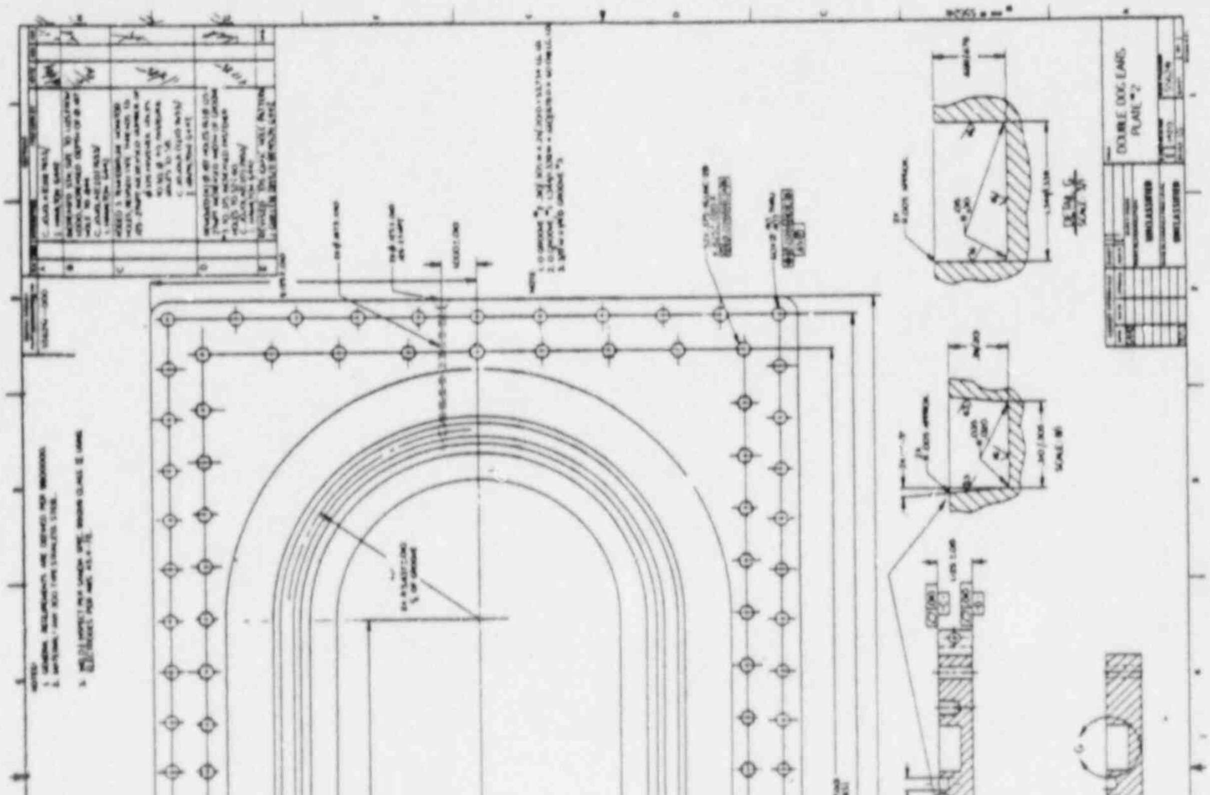

SECTION A-A
SECTION B-B

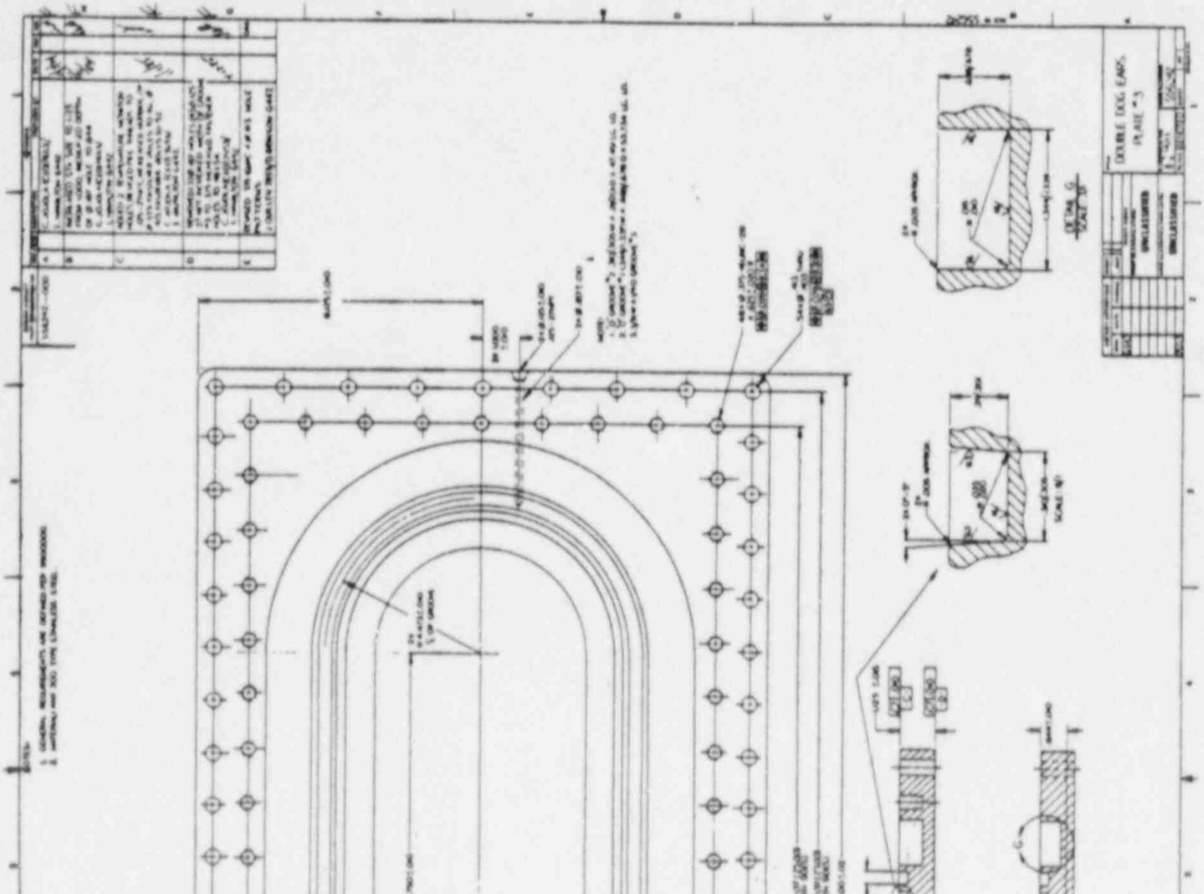

SECTION A-A
SECTION B-B
PLATE #3

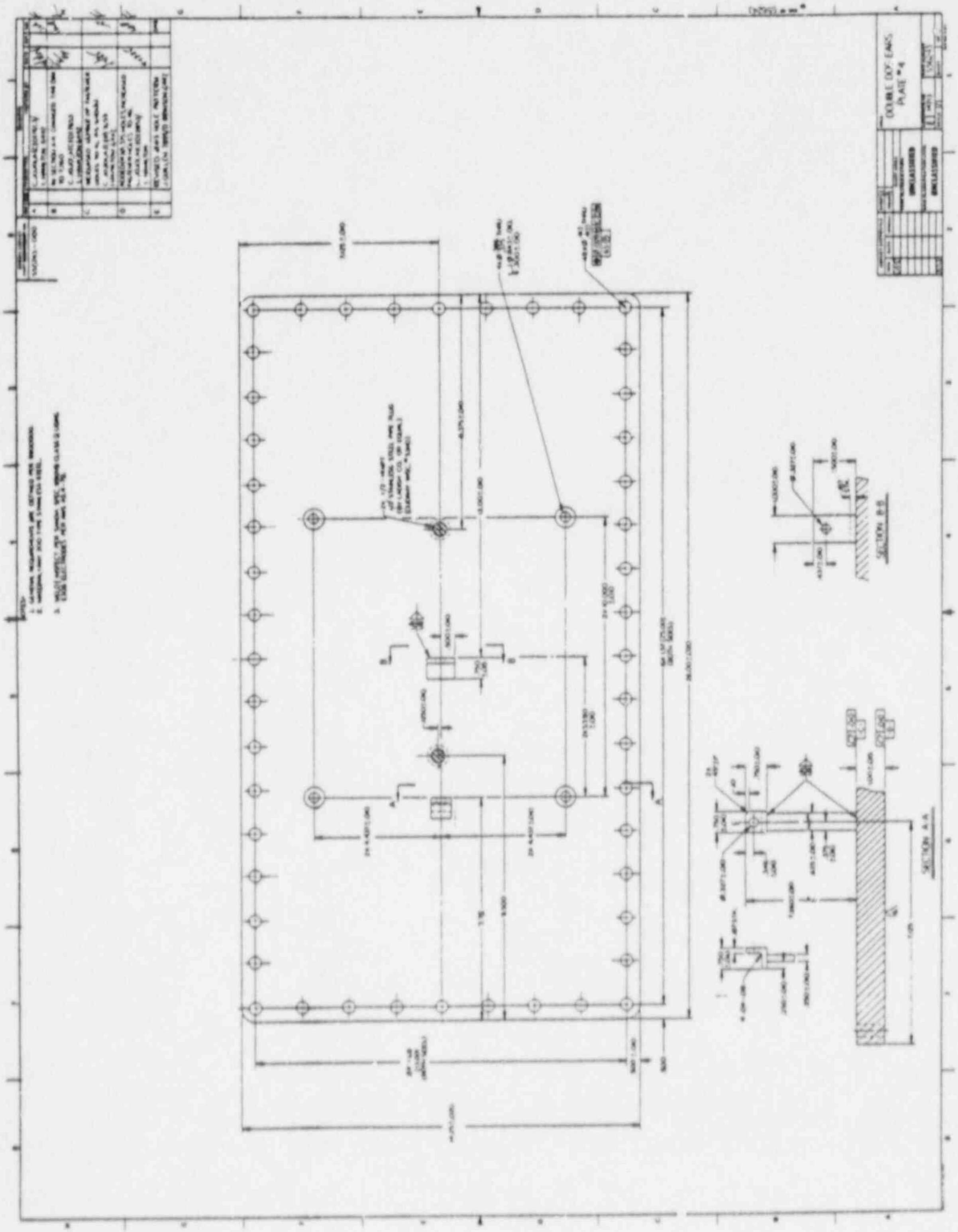


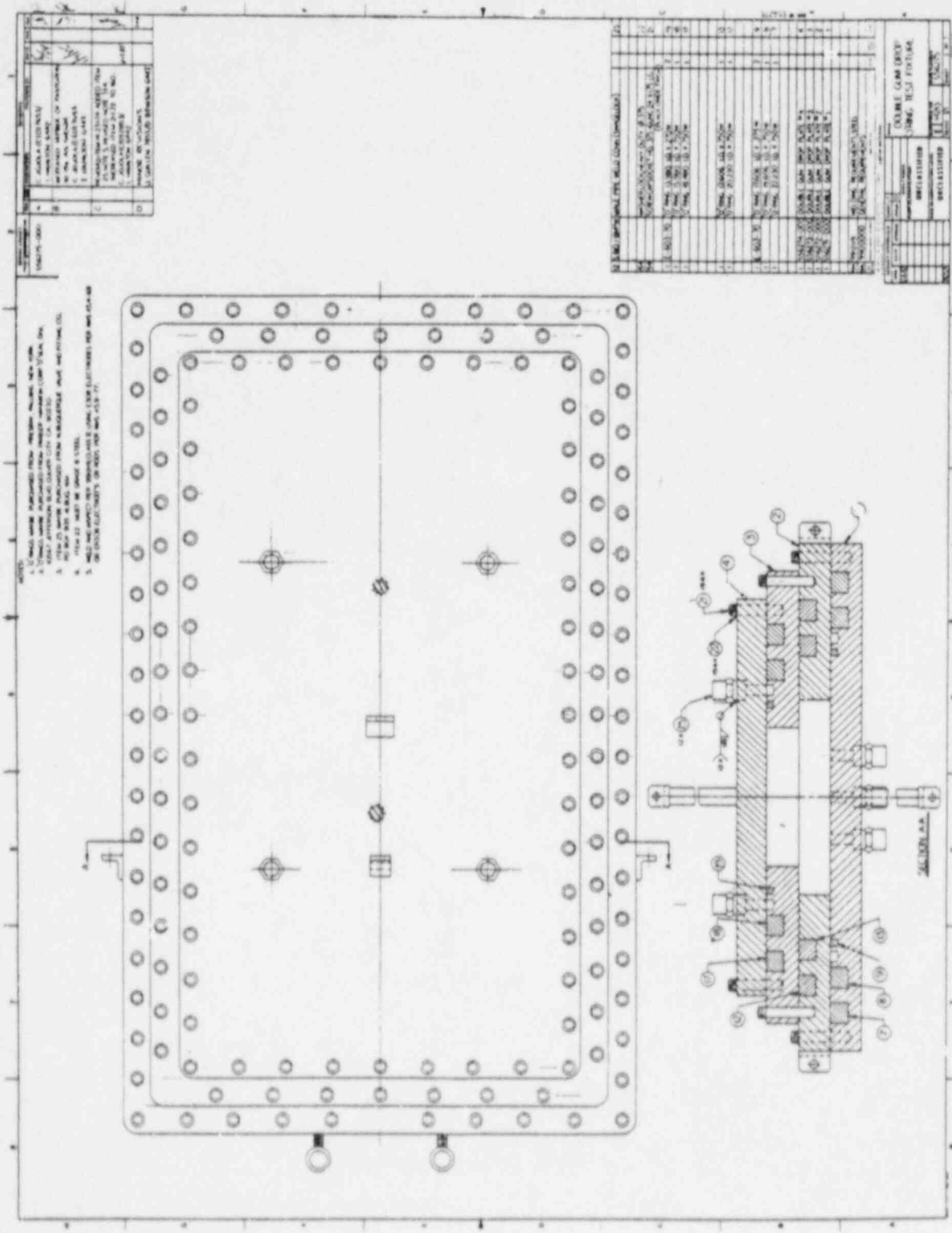


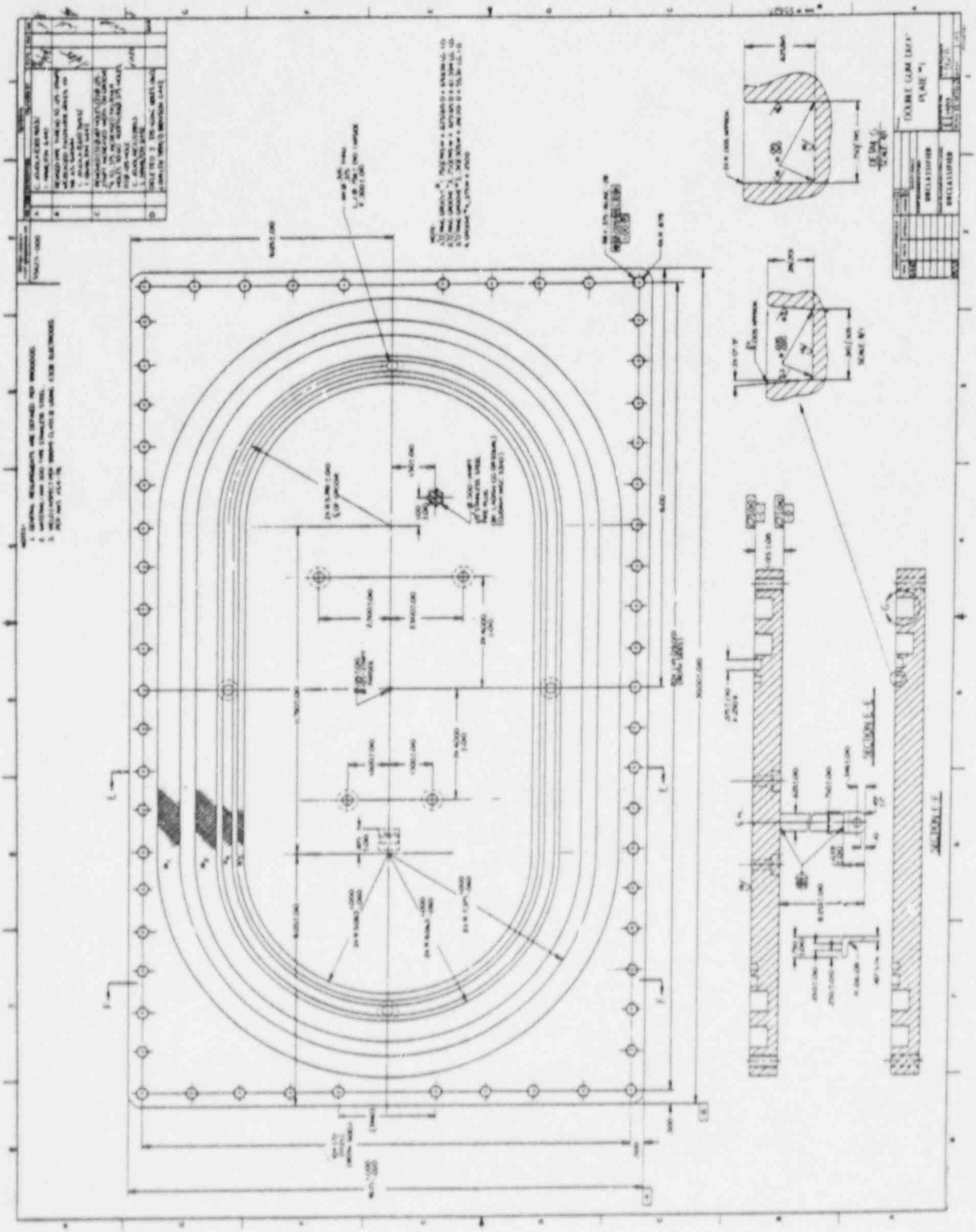


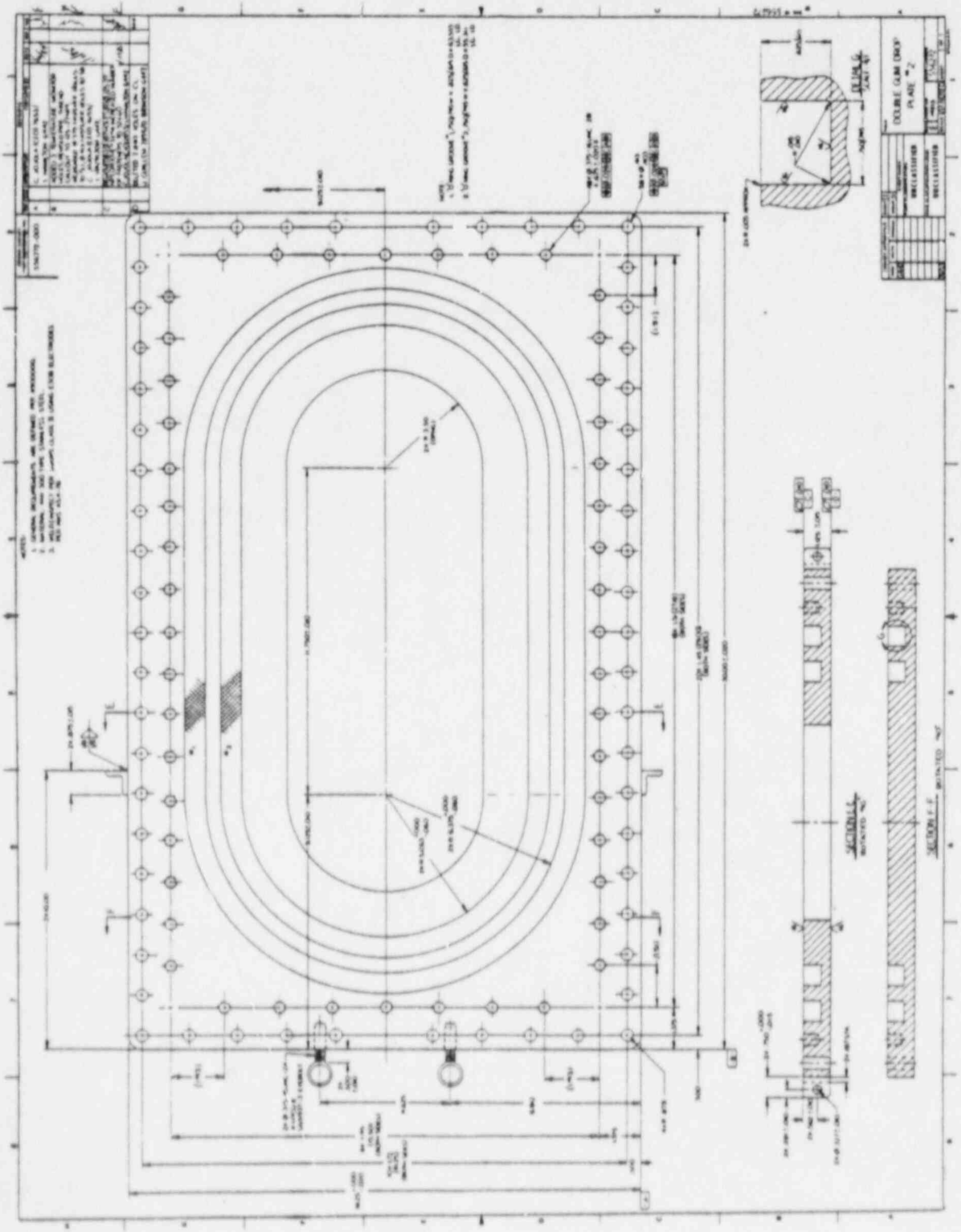

DOUBLE DOG EARS,
PLATE #2
SECTION E-E
SECTION F-F

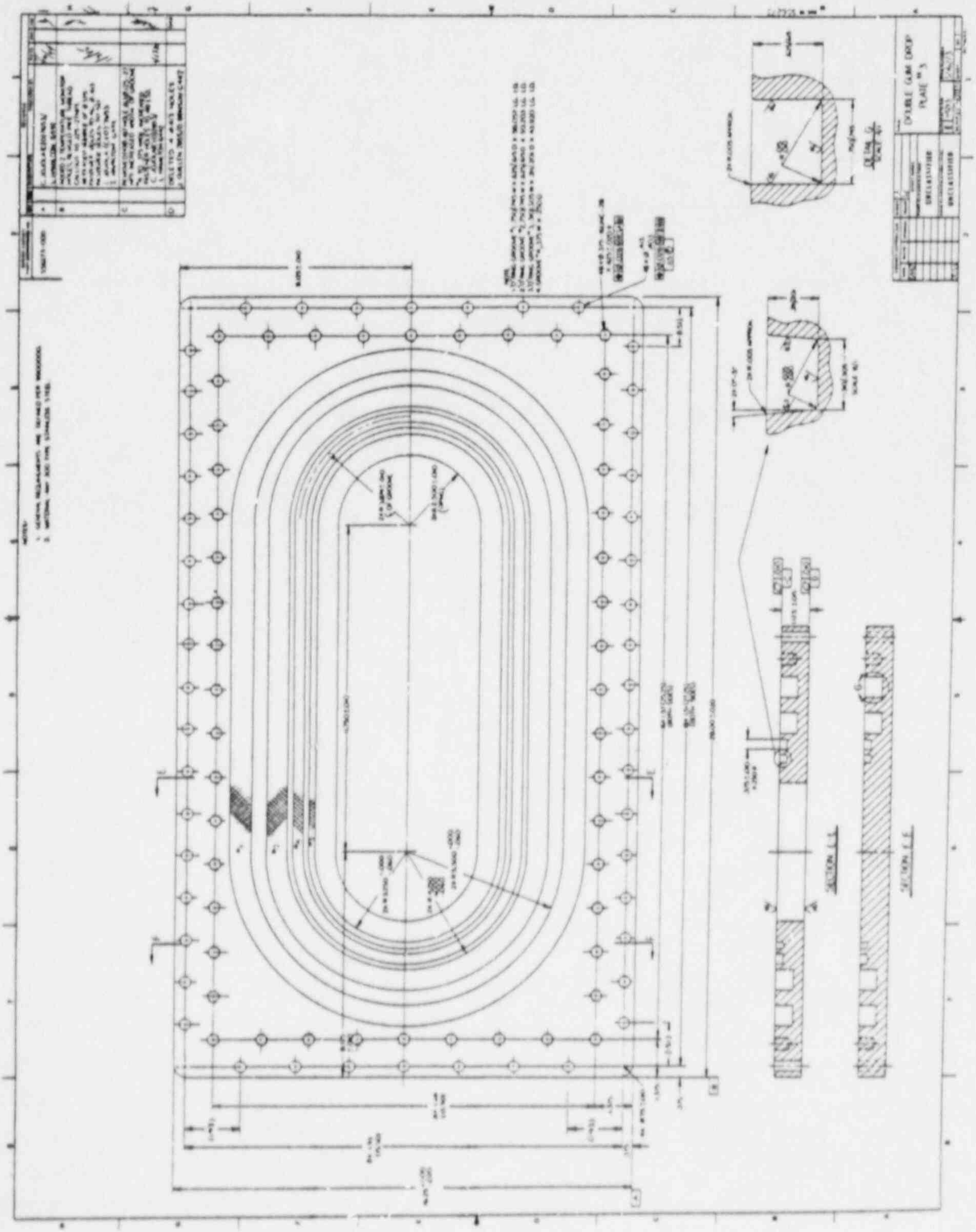


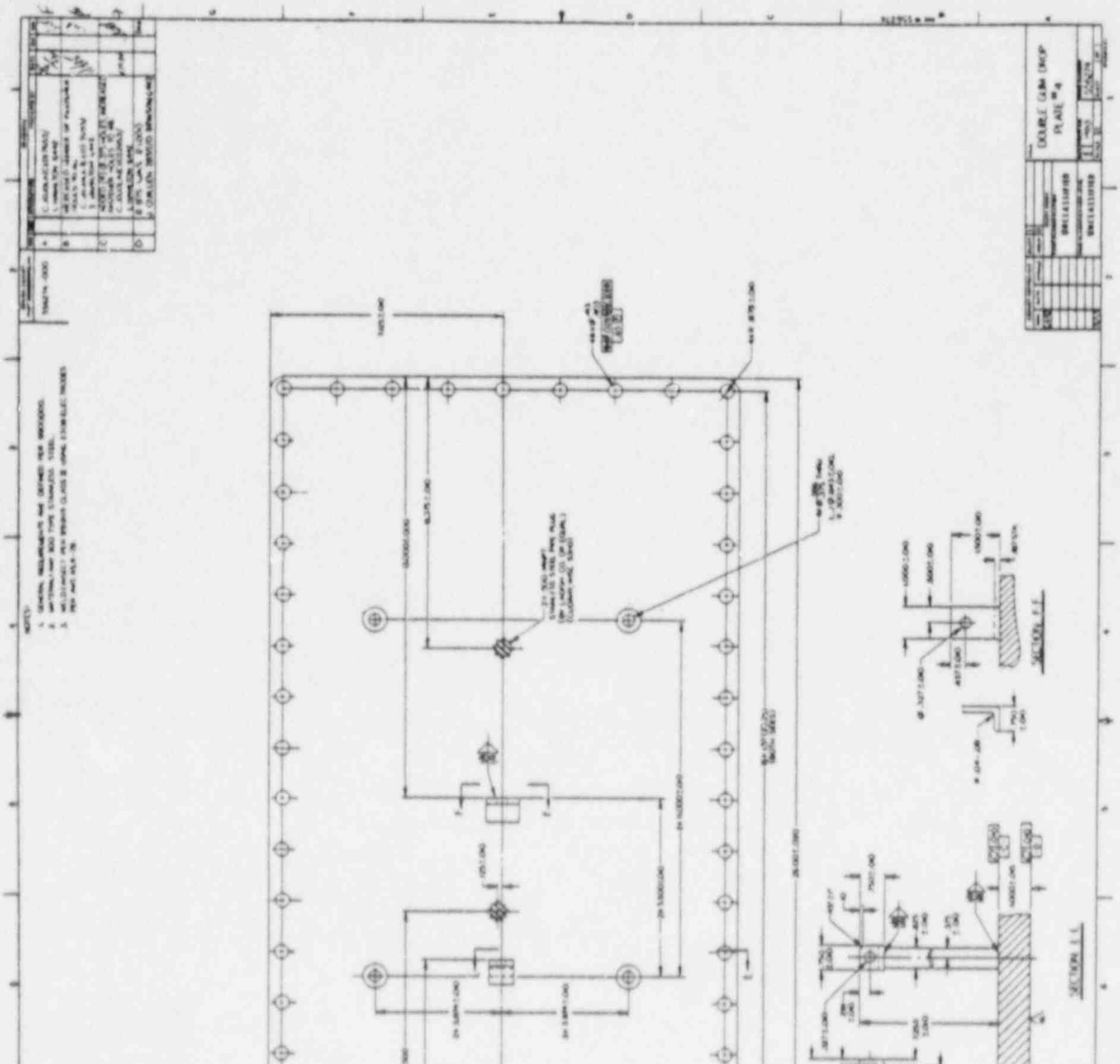

SECTION A-A
SECTION B-B
UNCLASSIFIED
UNCLASSIFIED

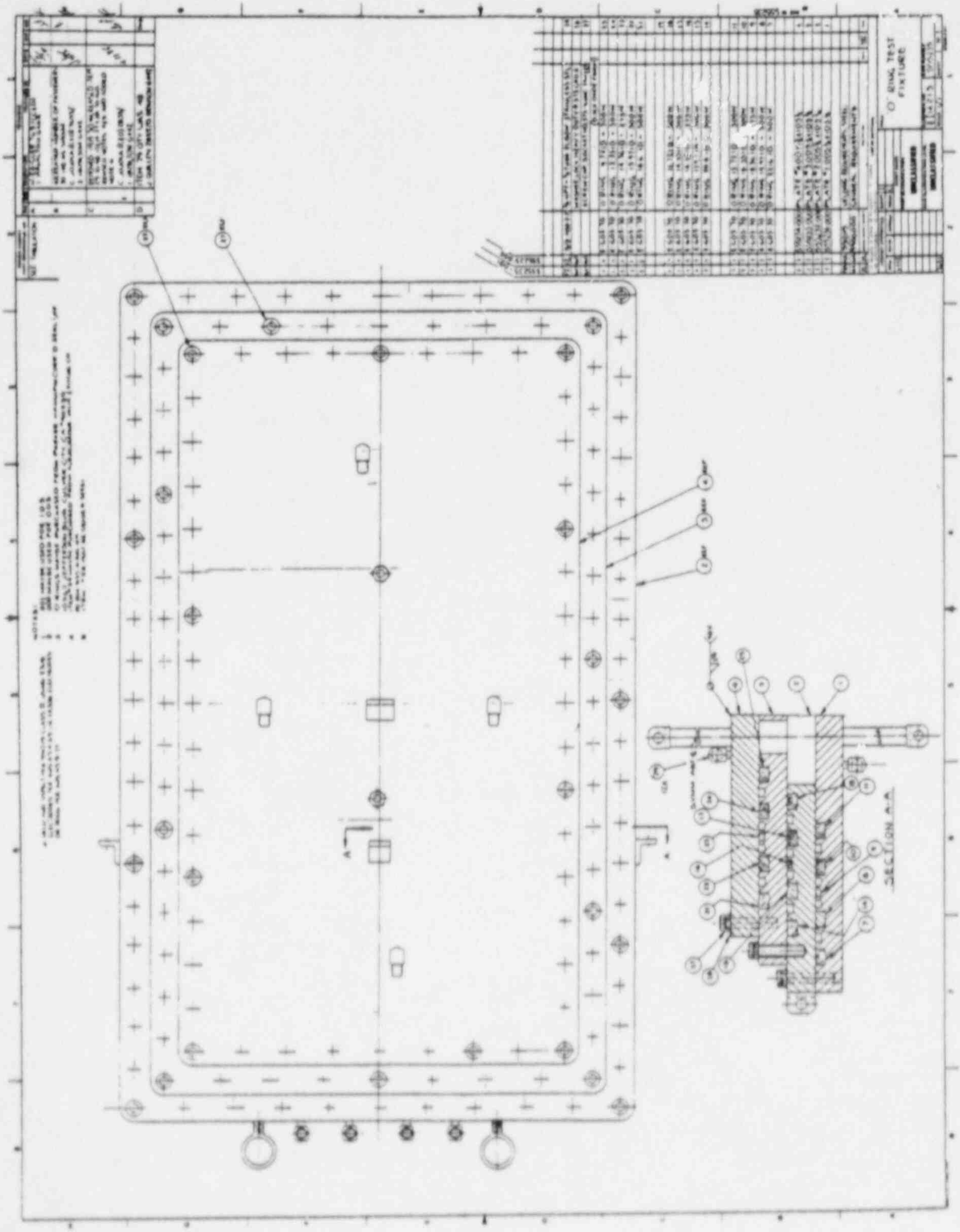


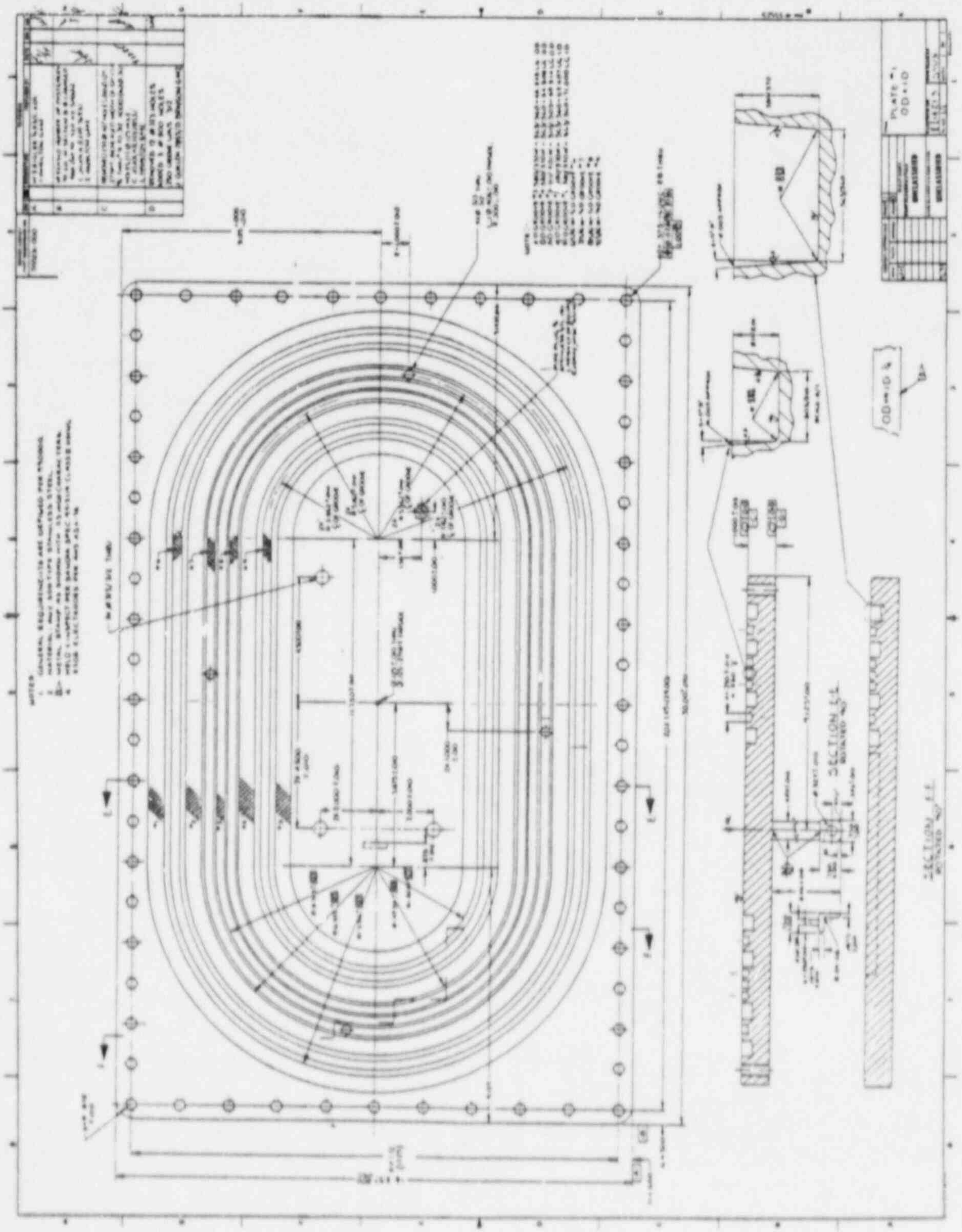


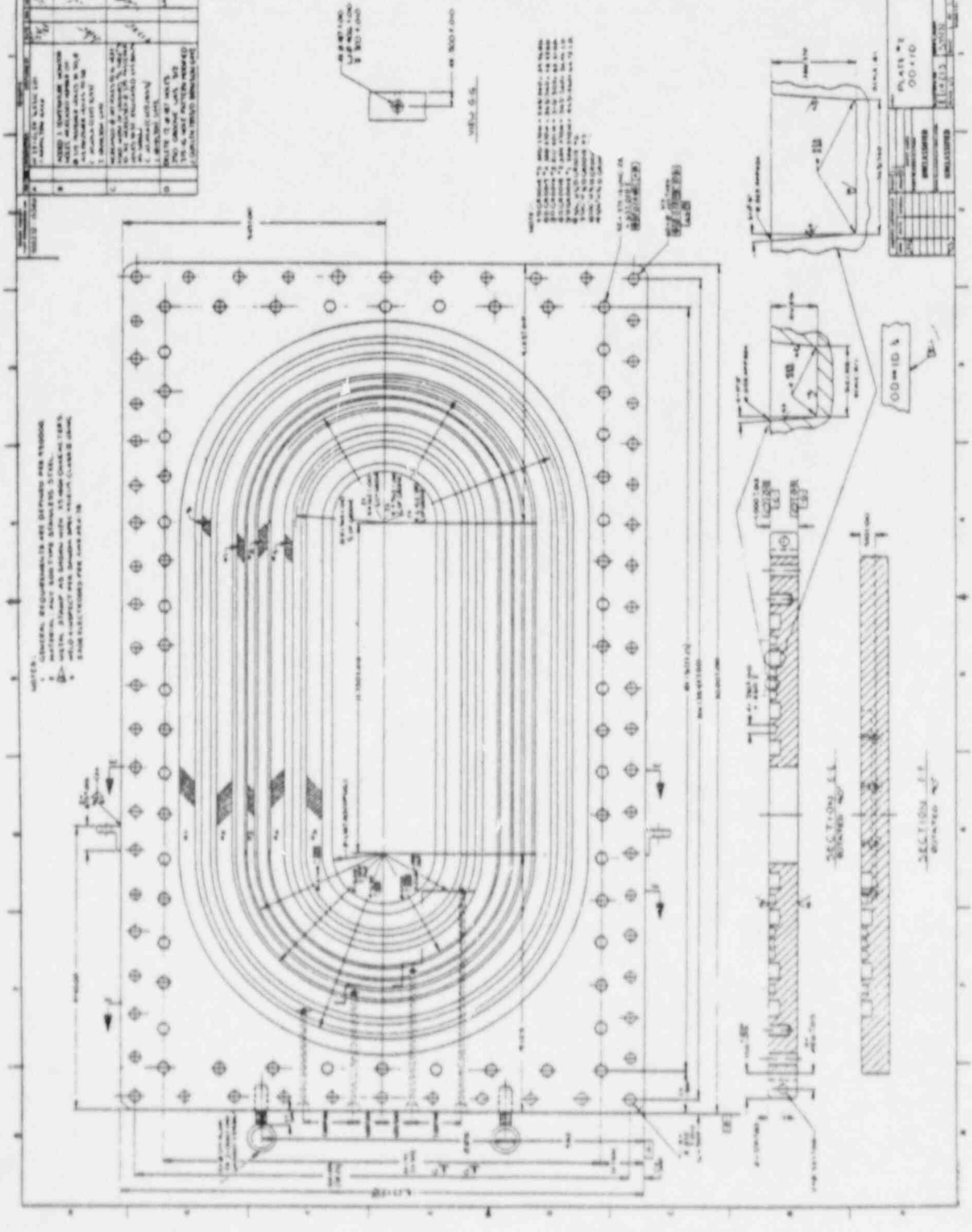

DOUBLE GUM DROP
PLATE #2
UNCLASSIFIED
UNCLASSIFIED

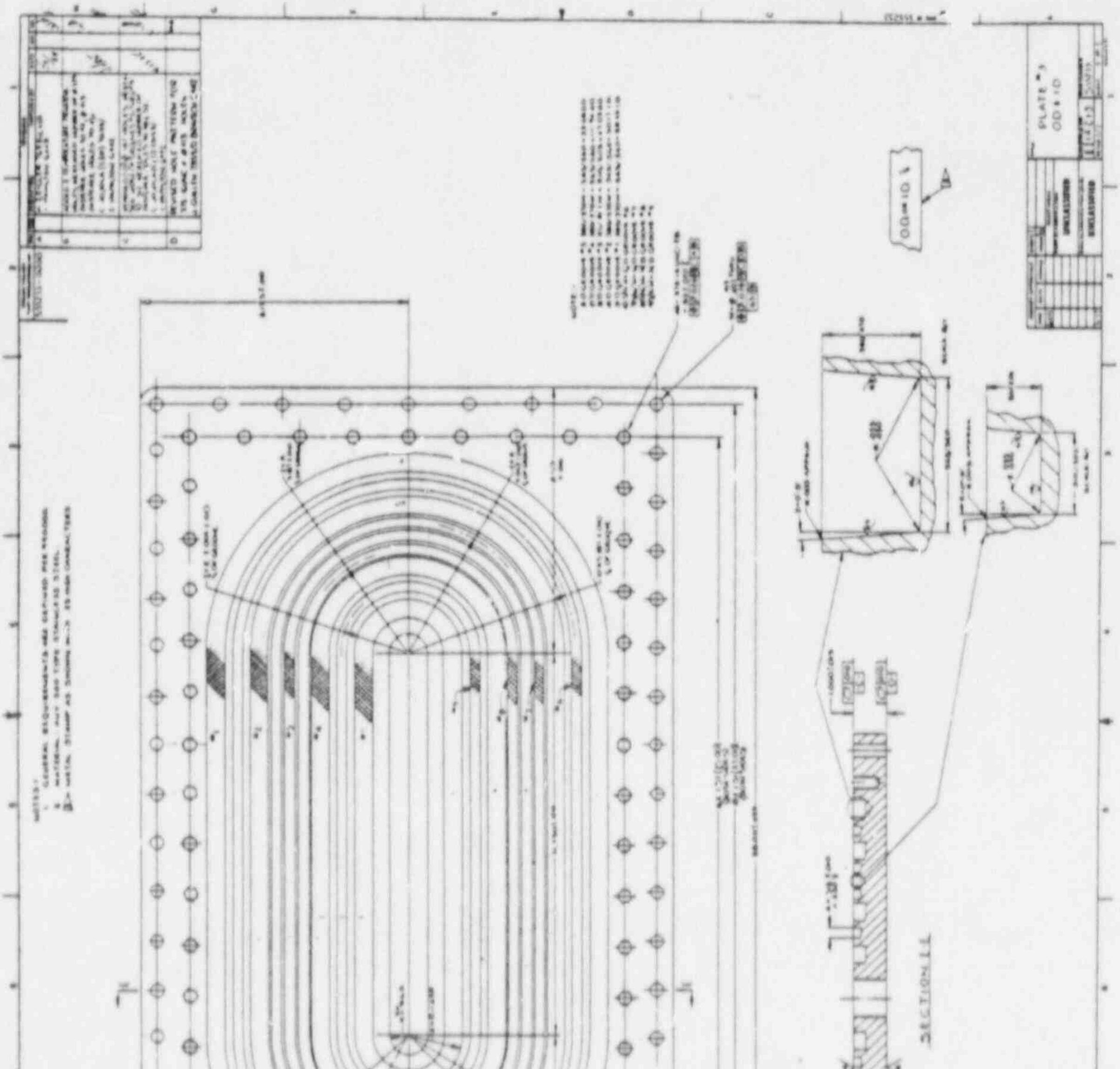





O' RING TEST FIXTURE
SECTION A-A







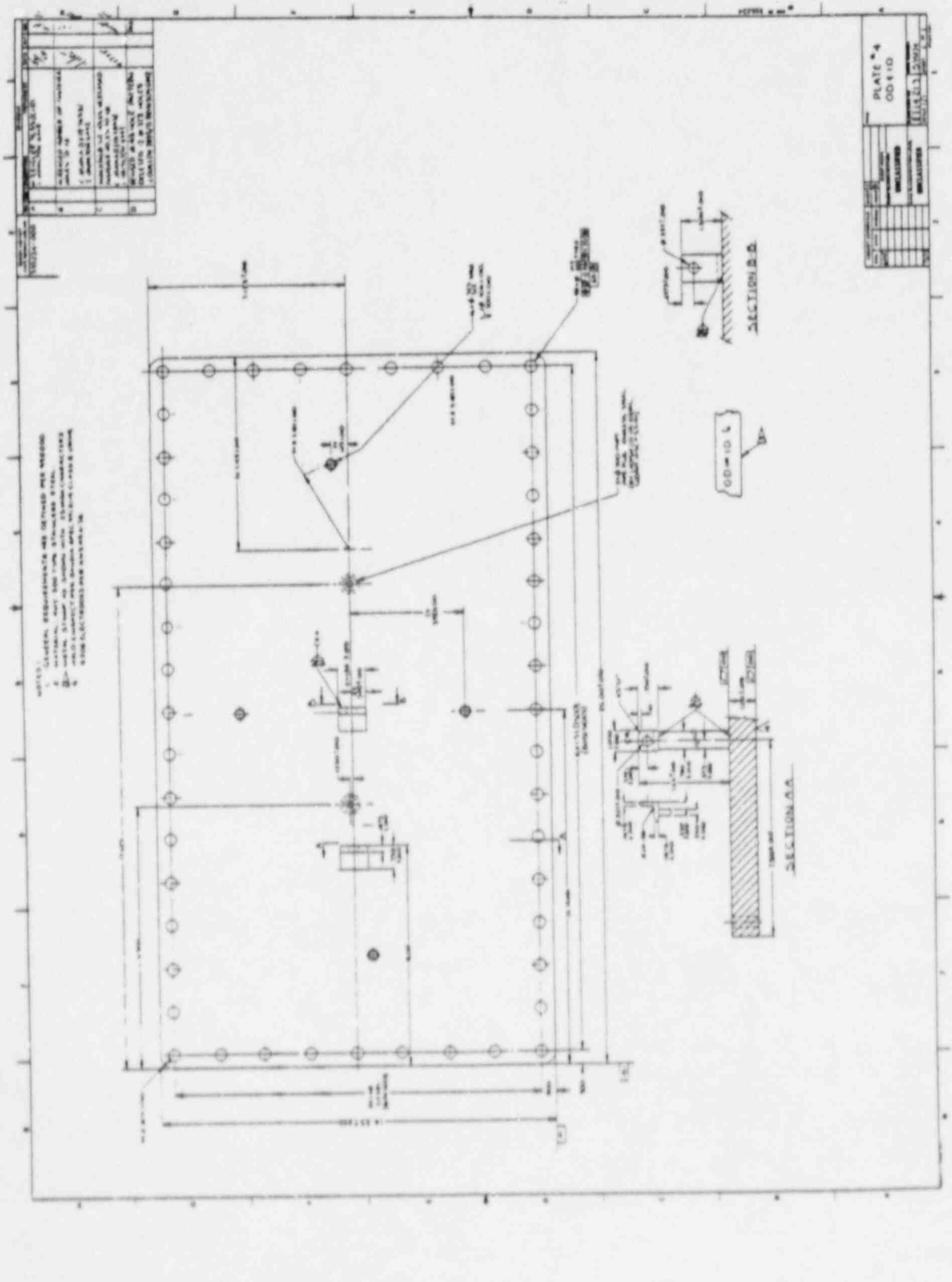
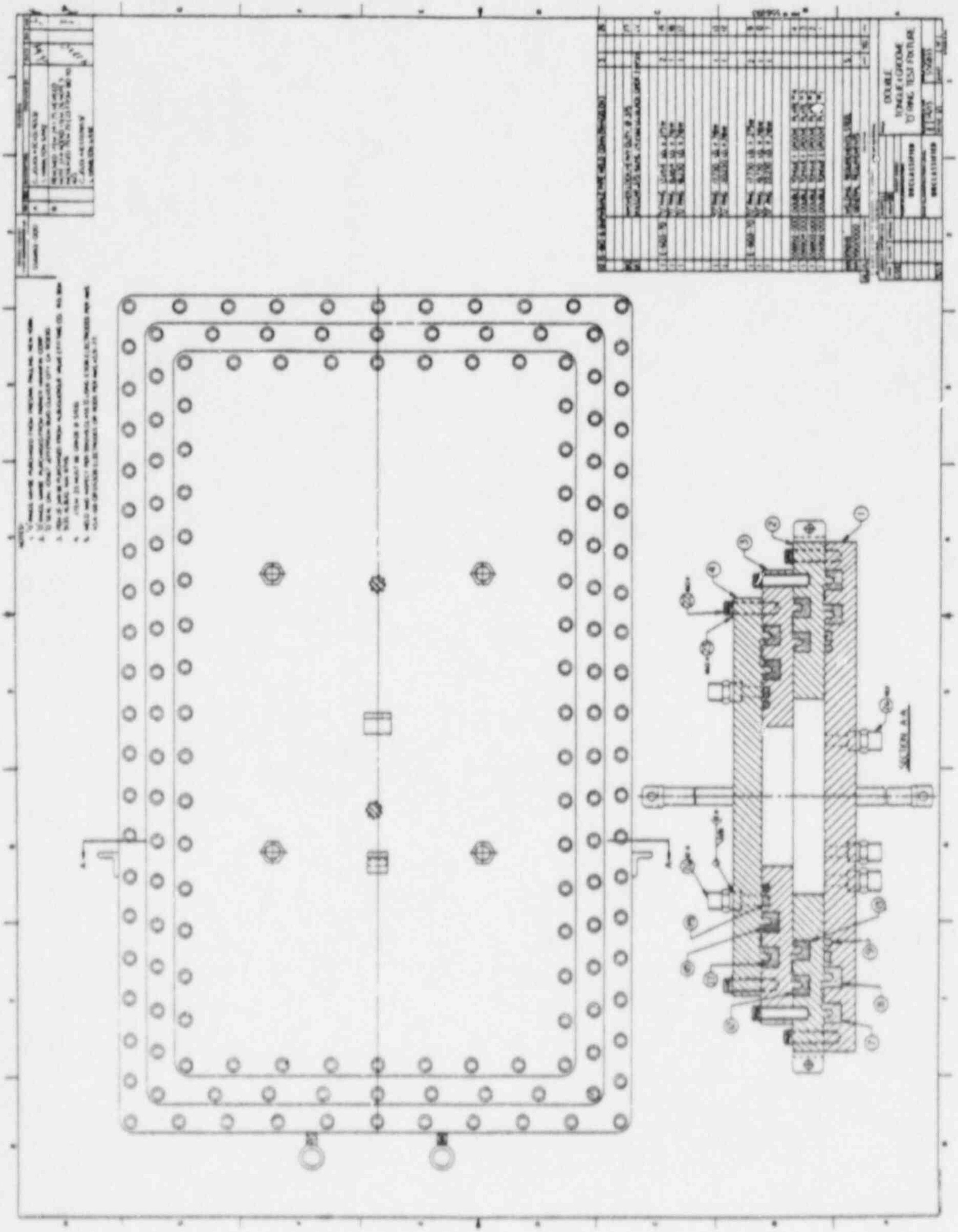
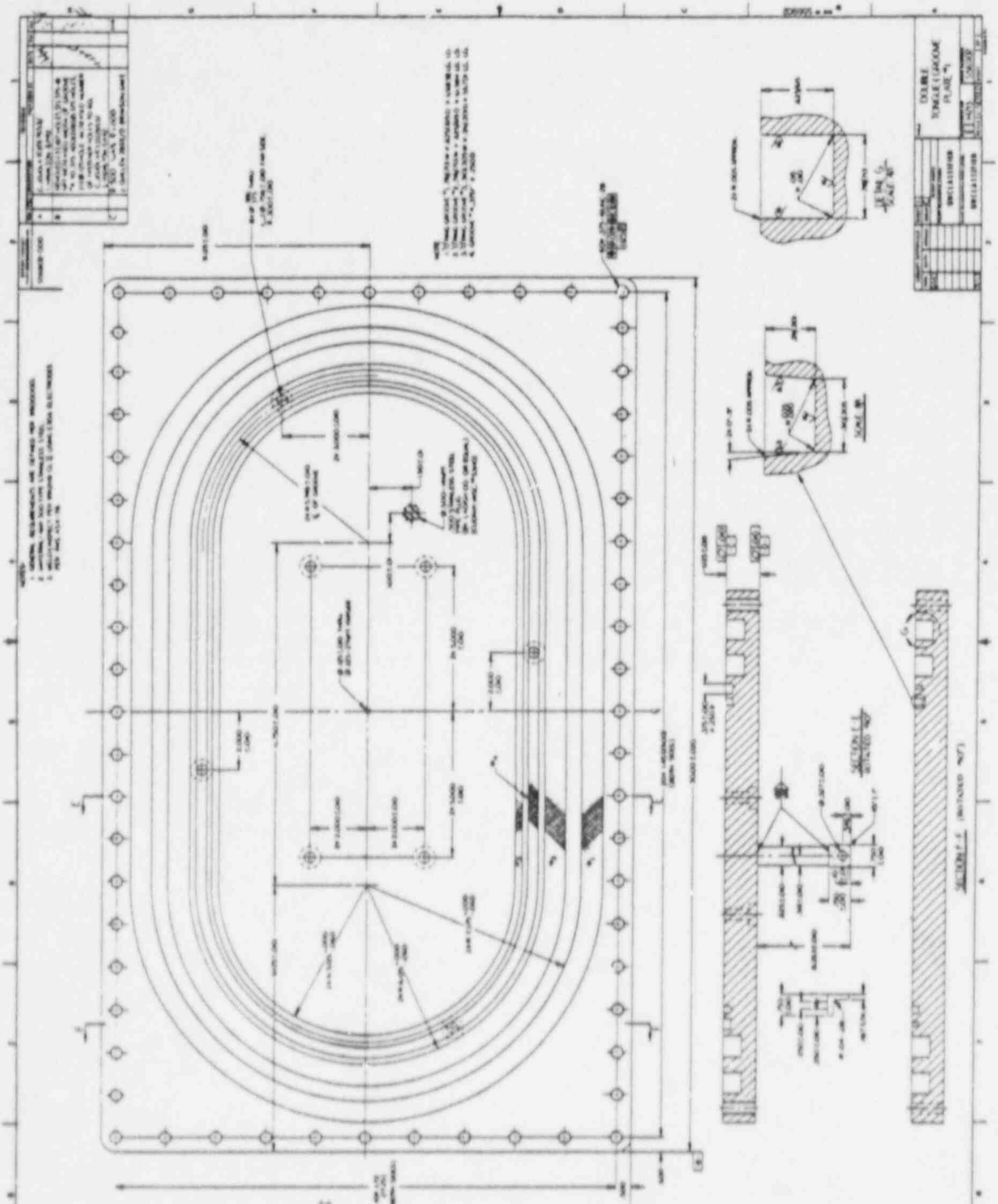
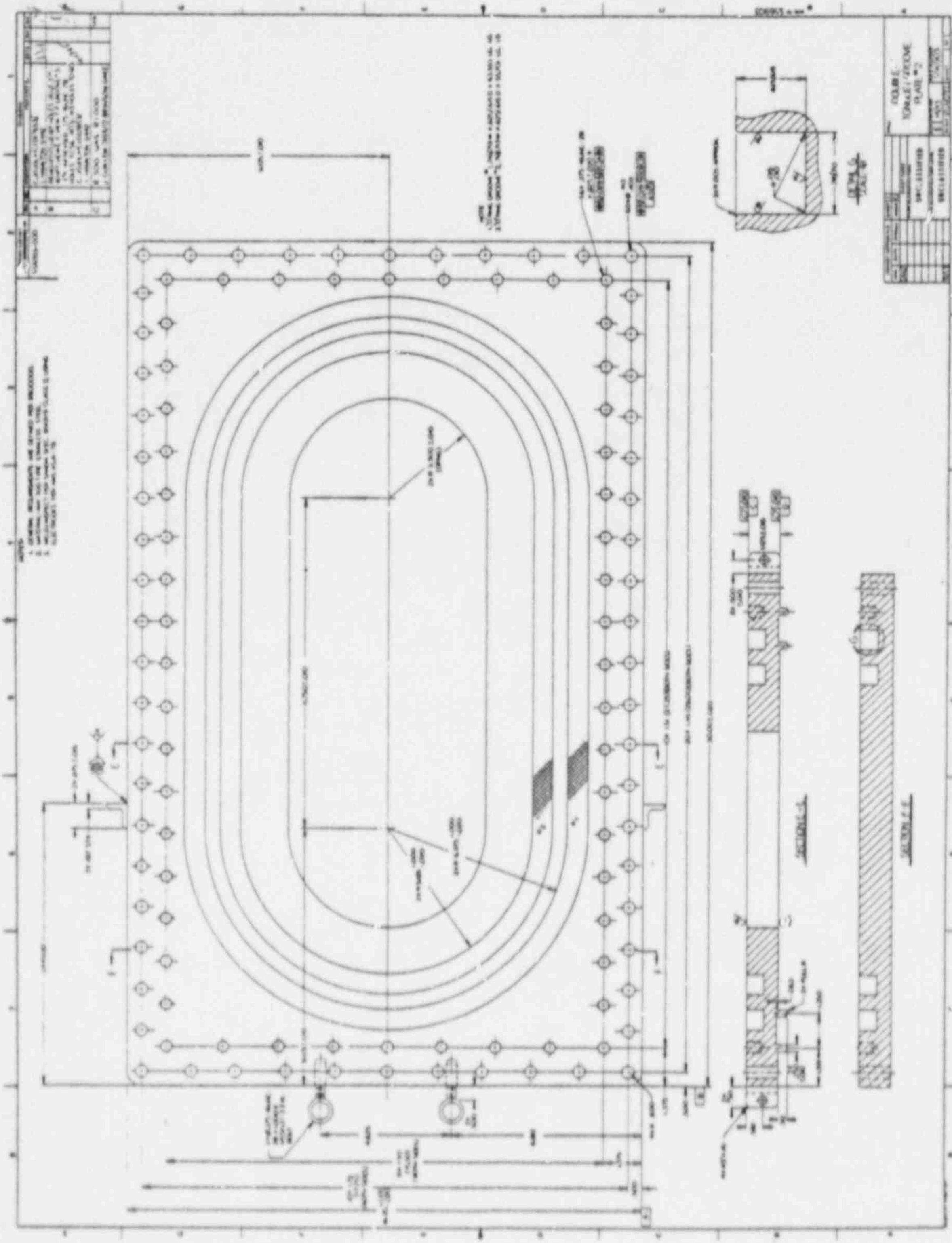
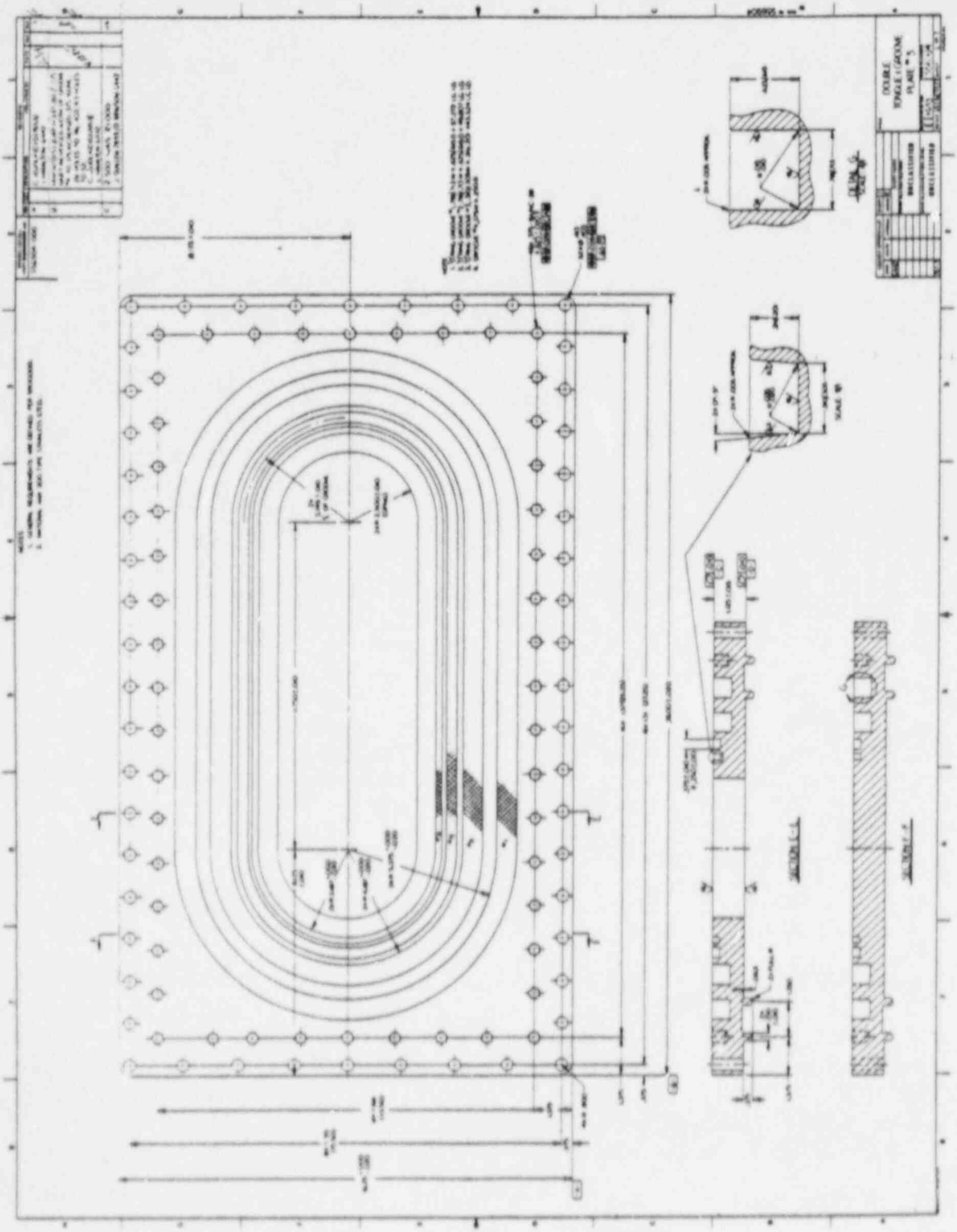


PLATE #4
OD-410
SECTION B-B
SECTION A-A

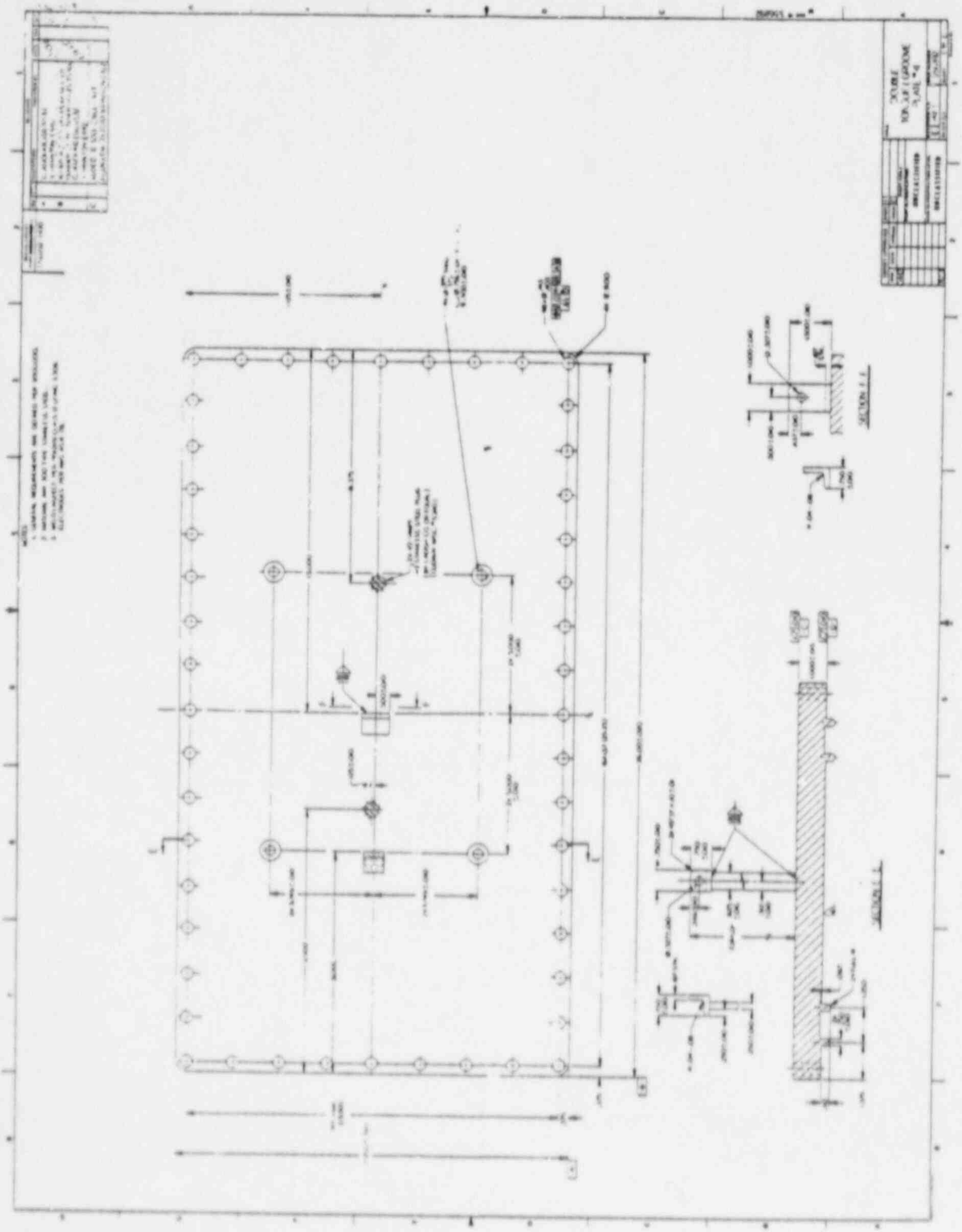

DOUBLE
TONGUE & GROOVE
O-RING TEST FIXTURE
SECTION A-A







DOUBLE
TONGUE & GROOVE
PLATE # 3

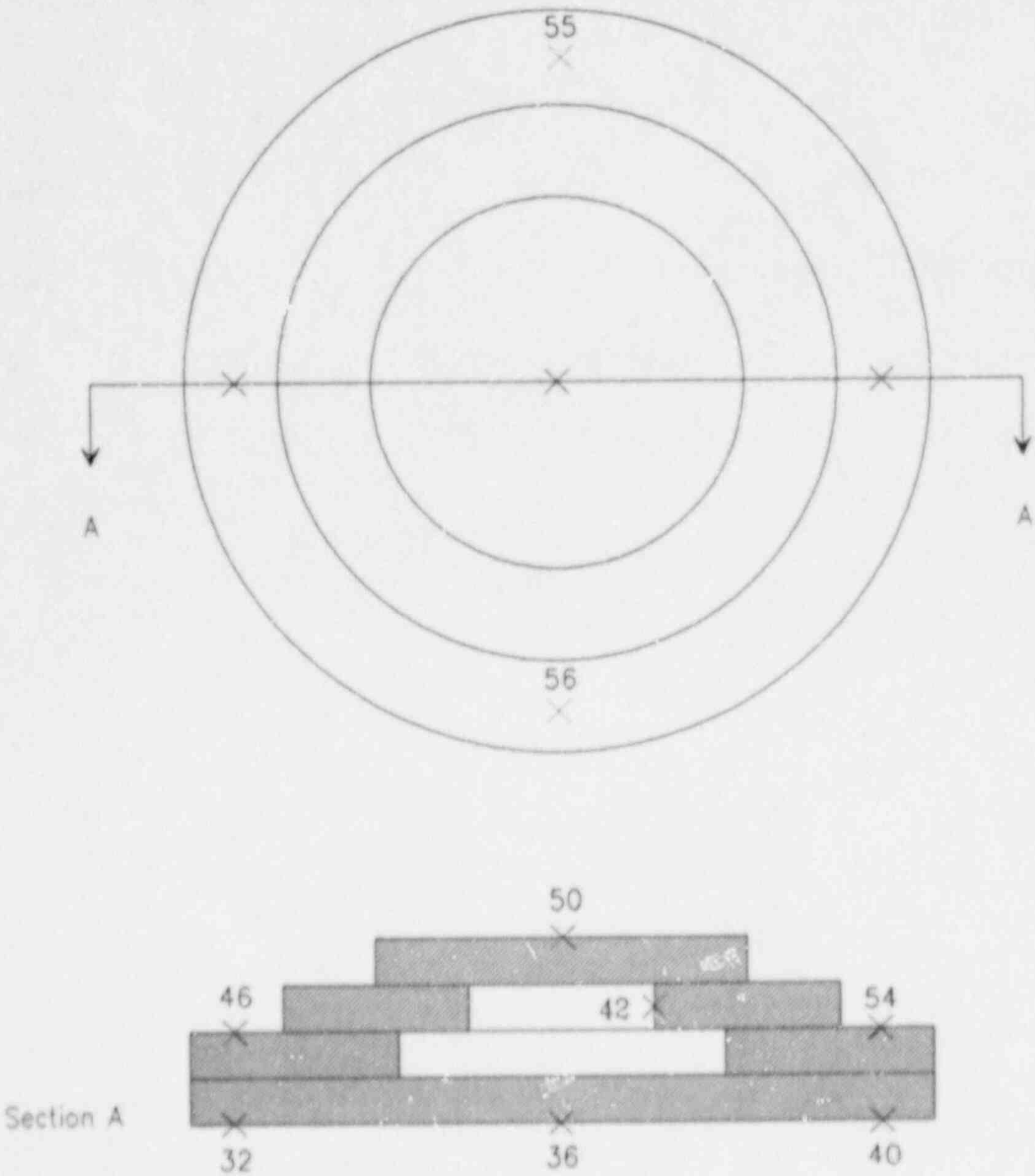


APPENDIX C

TEMPERATURE DISTRIBUTIONS ON THE TEST FIXTURE FOR TEST E-4

APPENDIX C

TEMPERATURE DISTRIBUTIONS ON THE TEST FIXTURE FOR TEST E-4



Thermocouple locations for Test E-4

Figure C-1

THERMOCOUPLE RECORDINGS FOR TEST E-4 (degrees F)

TIME	CH 32	CH 36	CH 40	CH 42	CH 46	CH 50	CH 54	CH 55	CH 56
11:30:07	64.9	64.9	65.0	64.7	65.1	66.0	64.2	64.2	64.1
11:44:01	64.9	65.0	65.1	64.9	65.1	66.0	64.1	64.1	64.1
11:44:30	64.9	64.9	65.0	64.9	65.0	65.9	64.1	64.1	64.0
11:45:00	294.2	293.9	292.2	62.2	274.8	272.1	249.0	304.1	305.7
11:45:30	350.6	347.6	349.7	68.0	346.1	346.6	340.8	348.2	347.7
11:46:00	348.9	345.9	347.7	66.4	345.4	347.2	344.2	346.5	346.2
11:46:30	347.8	344.7	346.8	67.9	344.3	346.1	344.5	345.4	345.4
11:47:00	347.1	344.1	346.2	70.9	343.9	345.8	343.5	344.8	345.0
11:47:30	346.6	343.6	345.8	77.8	343.4	345.5	343.1	344.2	344.7
11:48:00	346.3	343.3	345.3	86.5	343.1	345.3	343.0	343.8	344.5
11:48:30	345.9	343.0	345.1	97.7	342.6	344.8	342.6	343.4	344.3
11:49:00	345.8	342.7	344.8	110.9	342.5	345.1	342.5	343.3	344.2
11:49:30	345.8	342.8	344.9	125.3	342.6	345.2	342.5	343.2	344.2
11:50:00	345.7	342.7	344.8	139.9	342.5	345.1	342.5	343.1	344.[illegible]
11:55:01	346.6	343.7	345.8	262.4	343.4	346.6	343.5	344.1	[illegible]
12:10:30	358.7	355.8	358.1	349.3	355.6	358.9	355.6	356.3	[illegible]
12:25:00	362.1	359.2	361.6	359.7	359.0	362.2	358.9	359.4	360.8
12:40:00	362.0	359.1	361.5	360.5	359.0	362.2	358.8	359.2	360.6
12:55:00	361.9	359.0	361.4	360.5	359.0	362.2	358.7	359.2	360.6
13:10:00	360.8	357.8	360.3	359.4	357.9	361.0	357.6	358.0	359.5
13:25:00	361.3	358.4	360.8	359.7	358.4	361.6	358.1	358.6	360.0
13:40:00	361.6	358.6	361.0	359.8	358.6	361.9	358.3	358.8	360.3
13:55:00	361.8	358.8	361.2	359.9	358.7	362.1	358.6	359.0	360.5
14:10:00	361.7	358.8	361.3	360.3	358.8	362.1	358.6	359.0	360.5
14:25:00	361.3	358.4	360.9	359.2	358.4	361.8	358.2	358.6	360.0
14:40:00	362.0	359.1	361.6	360.2	359.1	362.5	358.8	359.3	360.7
14:55:00	361.9	359.0	361.4	360.2	358.9	362.3	358.8	359.1	360.6
15:10:00	362.0	359.1	361.6	360.2	359.1	362.4	358.9	359.3	360.8
15:25:00	361.8	358.9	361.3	360.1	358.9	362.3	358.6	359.1	360.5
15:40:00	361.9	359.0	361.4	360.1	359.0	362.3	358.8	359.2	360.7
15:41:00	361.9	359.0	361.4	360.1	359.0	362.4	358.8	359.2	360.6
16:00:00	362.0	359.1	361.5	360.2	359.0	362.5	358.8	359.1	360.6
17:00:00	361.7	358.9	361.3	360.1	358.9	362.1	358.7	358.9	360.4
18:00:00	361.7	358.8	361.2	360.0	358.8	362.0	358.5	358.9	360.4
19:00:00	361.7	358.8	361.2	360.0	358.8	362.2	358.6	358.9	360.5
20:00:00	361.7	358.8	361.1	360.0	358.8	362.1	358.6	358.8	360.5
21:00:00	361.8	359.0	361.3	360.1	359.0	362.3	358.8	358.9	360.8
22:00:00	361.8	358.9	361.2	360.1	358.8	362.3	358.6	358.8	360.6
23:00:00	362.1	359.3	361.5	360.3	359.2	362.7	358.9	359.2	360.9
0:00:00	362.0	359.0	361.4	360.2	359.0	362.6	358.9	359.2	360.9
1:00:00	362.0	359.1	361.5	360.2	359.1	362.6	358.8	359.1	360.9
2:00:00	362.0	359.0	361.4	360.2	358.9	362.5	358.8	359.1	360.8
3:00:00	361.9	358.8	361.2	360.1	358.8	362.3	358.7	358.9	360.7
4:00:00	361.8	358.7	361.2	360.0	358.7	362.3	358.6	358.9	360.6
5:00:00	361.7	358.7	361.1	360.0	358.6	362.1	358.4	358.7	360.5
6:00:00	361.7	358.7	361.1	359.9	358.6	362.1	358.4	358.8	360.4
6:15:01	361.7	358.8	361.2	359.9	358.7	362.1	358.6	358.8	360.6

THERMOCOUPLE RECORDINGS FOR TEST E-4 (degrees F)

TIME	CH 32	CH 36	CH 40	CH 42	CH 46	CH 50	CH 54	CH 55	CH 56
6:30:00	366.8	367.9	368.8	360.6	359.6	367.3	359.4	370.0	370.0
6:45:00	380.3	[illegible]	386.9	360.4	372.9	372.3	361.1	379.7	388.8
7:00:00	404.0	403.6	409.6	360.9	390.2	380.9	387.9	403.4	411.9
7:15:00	424.4	423.9	430.4	366.3	407.6	395.3	403.8	423.4	434.3
7:30:00	438.3	438.0	445.6	376.4	420.5	406.7	417.9	438.0	450.1
7:45:00	447.6	447.1	454.8	386.9	430.4	416.4	427.0	447.2	458.8
8:00:00	454.6	453.4	461.8	396.9	436.9	424.6	434.1	453.9	467.4
8:15:00	460.2	458.7	466.6	406.5	442.6	432.8	440.1	459.8	471.5
8:30:00	464.4	462.4	470.6	415.0	446.2	437.4	445.6	463.4	476.3
8:45:00	467.3	[illegible]	473.1	422.6	450.0	442.9	449.4	466.9	478.7
9:00:00	470.4	468.3	475.9	429.5	453.9	447.6	452.8	470.0	480.6
9:15:00	473.1	470.5	477.9	435.5	456.8	451.4	456.5	472.0	482.0
9:30:00	474.9	472.5	479.5	440.8	459.5	454.7	458.7	473.7	483.7
9:45:00	478.1	475.4	482.1	445.6	462.8	460.2	462.6	477.0	485.9
10:00:00	480.3	477.5	484.3	450.2	465.2	464.6	466.3	479.1	487.8
10:15:00	481.8	479.1	486.0	454.6	467.9	468.5	469.4	480.9	489.0
10:30:01	483.1	480.6	487.4	458.5	470.2	471.8	471.6	482.4	489.7
10:45:00	484.4	481.8	488.1	462.0	471.8	473.5	473.6	483.6	490.1
11:00:00	486.2	483.0	489.6	465.1	473.9	476.1	475.6	484.4	490.8
11:15:00	487.1	484.3	490.4	468.0	474.6	477.8	477.2	485.7	492.1
11:30:00	487.6	485.2	490.9	470.3	476.1	478.8	478.4	486.3	491.9
11:45:00	489.0	485.3	491.3	472.4	476.7	480.6	479.6	486.5	492.4
12:00:00	489.3	486.0	492.3	474.4	477.8	481.3	480.7	[illegible]	493.0
12:15:00	490.1	486.5	492.6	476.0	478.5	482.2	481.6	488.5	493.3
12:30:00	490.6	487.3	493.1	477.5	479.4	483.2	482.1	488.3	493.4
12:45:00	491.1	487.6	493.5	478.7	479.8	483.9	483.0	489.3	494.2
13:00:00	491.6	488.2	493.8	479.8	480.5	484.3	483.6	489.6	494.1
13:15:00	491.6	487.9	493.4	480.9	480.6	484.7	483.9	489.6	493.6
13:30:00	498.1	494.8	501.3	481.7	485.5	488.0	488.3	496.0	502.8
13:45:00	502.7	499.0	506.2	483.3	489.1	491.7	491.6	500.7	507.8
14:00:00	505.8	502.1	509.4	485.4	492.2	494.8	494.9	503.8	510.7
14:15:00	512.3	508.7	516.5	487.9	497.2	498.3	499.2	510.9	519.1
14:30:00	516.8	514.0	521.9	491.0	502.6	502.9	504.3	516.6	525.4
14:45:00	520.7	518.0	525.5	494.4	505.7	506.9	508.0	520.0	528.9
15:00:00	524.3	521.2	529.0	498.3	509.2	510.1	512.0	523.6	531.5
15:15:00	526.7	523.4	530.8	501.8	512.2	513.4	513.9	525.8	533.4
15:30:00	529.4	525.8	532.9	505.4	513.9	516.8	517.2	527.5	535.4
15:45:00	498.7	496.1	498.1	508.2	501.6	504.5	504.1	495.9	500.5
16:00:01	467.9	455.2	452.1	506.8	475.5	482.5	484.3	458.0	465.4
17:00:00	437.4	431.5	438.1	474.5	440.1	444.1	441.2	[illegible]	424.3
18:00:00	398.1	397.2	403.7	438.6	402.7	406.7	408.3	397.7	393.8
19:00:00	373.9	369.8	377.9	398.7	374.0	378.9	379.9	375.7	370.4
20:00:00	363.4	361.0	365.9	368.5	362.0	367.1	366.7	360.3	362.2
21:00:00	362.4	359.7	362.4	362.7	359.7	364.3	361.7	359.6	361.1
22:00:00	362.2	359.4	361.7	361.1	359.6	363.3	359.9	359.5	361.1
23:00:00	362.1	359.3	361.6	360.5	359.4	362.8	359.2	359.3	361.1
0:00:00	362.2	359.4	361.7	360.5	359.4	362.7	359.2	359.4	361.1

THERMOCOUPLE RECORDINGS FOR TEST E-4 (degrees F)

TIME	CH 32	CH 36	CH 40	CH 42	CH 46	CH 50	CH 54	CH 55	CH 56
1:00:00	362.3	359.4	361.6	360.4	359.3	362.7	359.2	359.4	361.2
2:00:00	362.2	359.3	361.6	360.5	359.2	362.7	359.1	359.3	361.1
3:00:00	362.0	359.1	361.4	360.4	359.1	362.5	358.9	359.1	360.9
4:00:00	361.6	358.7	361.0	360.0	358.6	362.2	358.6	358.7	360.5
5:00:00	360.9	358.0	360.2	359.4	357.9	361.5	358.0	358.0	359.9
6:00:00	359.4	356.5	358.9	358.5	356.5	360.3	356.9	356.5	358.4
6:23:59	361.8	358.9	361.3	359.9	358.9	362.3	358.8	358.9	360.7
6:30:01	361.7	358.8	361.2	360.0	358.9	362.2	358.6	358.8	360.5
6:45:00	361.9	359.0	361.3	359.8	359.0	362.3	358.8	359.0	360.7
7:00:00	361.8	358.9	361.3	360.1	358.8	362.2	358.6	358.9	360.5
7:15:00	361.3	358.4	360.8	359.7	358.4	361.7	358.2	358.5	360.0
7:30:00	359.8	356.9	359.4	358.9	357.0	360.3	356.8	357.1	358.6
7:45:00	386.3	365.9	399.7	360.2	380.0	377.3	[illegible].5	390.3	390.9
8:00:00	466.1	469.0	481.0	366.1	439.6	419.7	436.5	469.1	482.4
8:15:00	501.0	501.8	516.6	383.9	465.9	447.5	465.3	504.4	521.9
8:30:00	518.9	519.4	534.5	405.6	489.1	466.9	482.0	523.2	539.6
8:45:00	541.8	540.4	555.1	428.2	507.6	491.4	507.6	544.2	561.0
9:00:00	555.7	554.0	566.0	451.2	523.5	512.4	522.4	557.8	574.8
9:15:00	562.4	559.6	572.8	472.0	533.4	521.8	533.5	565.4	578.8
9:30:00	568.5	567.0	578.7	489.8	542.6	532.2	540.8	571.4	582.9
9:45:00	574.4	570.7	581.3	505.3	547.0	542.7	549.1	575.2	587.7
10:00:00	576.1	573.7	583.5	518.1	552.9	549.7	555.6	577.5	588.8
10:15:00	577.2	574.0	583.9	528.7	556.5	554.4	558.9	578.2	589.0
10:16:35	576.9	574.4	584.0	529.7	557.2	553.2	559.1	577.9	588.7
10:17:34	577.6	574.7	583.3	530.4	556.1	554.3	559.0	578.1	588.9
10:32:34	575.7	573.3	582.3	538.4	557.1	556.2	559.5	576.5	586.2
10:47:34	584.8	581.7	588.9	54[illegible].7	563.8	567.3	567.7	586.9	594.4
11:02:34	589.2	586.6	593.5	551.3	569.9	572.3	572.9	589.6	597.9
11:17:34	592.0	589.1	596.1	557.5	573.9	577.0	577.6	593.0	600.7
11:32:34	595.1	592.5	600.2	563.1	577.3	580.9	581.8	596.0	603.6
11:47:34	601.0	598.0	605.9	568.4	583.0	585.0	586.8	600.9	608.6
12:02:34	607.3	604.6	611.9	57[illegible].5	588.6	592.2	592.7	609.2	615.1
12:17:34	612.3	608.6	616.2	579.1	593.2	596.8	598.1	614.1	620.3
12:32:34	615.2	611.3	618.8	584.3	597.0	600.5	601.3	617.2	622.1
12:47:34	617.7	613.7	621.3	589.3	599.8	604.7	605.2	619.2	624.1
13:02:34	619.3	615.7	623.0	593.8	602.2	607.2	607.2	621.6	625.5
13:17:34	621.0	617.5	624.6	597.8	603.8	609.0	609.8	623.9	626.2
13:32:34	621.9	618.2	626.3	601.2	606.1	611.0	610.7	625.3	627.7
13:47:34	623.2	619.0	627.1	604.1	607.7	612.6	612.6	626.0	628.2
14:02:34	620.5	617.0	623.2	606.5	606.6	612.5	611.1	621.4	623.0
14:17:34	617.9	614.9	620.3	608.3	606.4	611.5	610.0	619.4	619.0
14:32:34	612.4	609.8	615.0	608.9	603.4	608.9	607.5	611.2	611.0
14:47:34	607.5	606.5	612.1	608.6	600.9	606.0	605.3	606.4	605.7
15:02:34	603.1	601.3	606.9	607.5	598.3	602.8	602.3	601.5	600.9
15:03:15	603.0	600.8	606.1	607.4	598.1	602.8	602.2	601.8	600.9
15:18:14	589.5	588.4	592.1	605.5	589.6	595.0	594.2	588.1	585.4
15:33:14	576.1	576.6	578.9	601.8	580.6	585.1	583.8	573.4	572.7

THERMOCOUPLE RECORDINGS FOR TEST E-4 (degrees F)

TIME	CH 32	CH 36	CH 40	CH 42	CH 46	CH 50	CH 54	CH 55	CH 56
15:33:48	575.2	575.8	581.2	601.6	580.0	584.6	583.4	572.9	572.2
16:00:01	554.5	548.8	557.1	590.2	563.1	566.7	564.5	561.5	547.0
17:00:00	505.4	497.3	505.2	551.1	514.0	518.5	514.7	510.4	493.1
18:00:00	460.[illegible]	452.7	460.4	505.9	467.6	468.8	466.2	465.8	443.9
19:00:00	412.9	411.2	417.3	463.3	417.3	420.1	421.3	420.4	404.6
20:00:00	381.3	381.0	384.0	419.2	382.5	386.4	386.0	380.8	378.2
21:00:00	370.6	367.3	368.3	391.7	367.5	373.1	371.3	369.7	366.8
22:00:00	365.3	361.6	362.7	376.8	363.2	367.9	365.8	364.4	362.6
23:00:00	362.2	360.0	361.6	368.7	361.1	365.3	362.4	361.1	361.9
0:00:00	361.4	359.0	361.1	363.6	358.4	363.7	360.3	359.8	360.9
1:00:00	361.2	358.3	360.8	360.8	358.2	362.5	359.2	358.7	360.3
2:00:00	360.7	357.9	360.4	359.8	357.8	361.7	358.3	358.0	359.7
3:00:00	360.4	357.5	359.9	359.1	357.4	361.1	357.8	357.5	359.4
4:00:00	360.2	357.3	359.5	358.6	357.2	360.8	357.3	357.2	359.1
5:00:00	360.1	357.2	359.5	358.4	357.2	360.7	357.2	357.2	359.0
6:00:00	360.8	357.9	360.2	359.7	357.8	361.3	357.7	357.9	359.8
6:15:01	388.7	396.0	402.6	359.5	382.0	378.3	382.0	398.8	403.4
6:30:00	493.4	496.3	509.3	365.2	452.7	430.3	453.8	495.5	511.2
6:45:00	545.3	547.1	566.4	387.3	503.5	472.7	499.2	550.0	571.9
7:00:00	579.4	579.5	598.6	419.0	537.4	505.2	532.9	585.0	605.3
7:15:00	603.0	602.0	622.2	452.9	559.4	534.1	558.2	608.0	628.9
7:30:00	619.7	617.5	635.3	485.3	579.8	556.7	579.5	623.9	643.5
7:45:00	633.6	630.4	647.0	514.6	593.3	577.1	593.8	637.9	655.9
8:00:00	645.2	641.5	655.8	540.4	608.6	594.1	610.4	648.3	664.0
8:15:00	654.5	650.2	665.1	562.8	620.1	608.9	624.8	657.8	673.1
8:30:00	662.3	658.8	670.0	582.1	631.4	623.3	633.1	664.7	679.6
8:45:00	669.1	665.1	676.2	598.9	640.4	634.1	642.7	670.6	684.4
9:00:00	674.4	670.4	681.0	613.4	647.9	644.8	650.5	675.3	689.4
9:15:00	679.0	674.6	684.0	625.7	653.3	653.3	658.0	679.9	691.4
9:30:00	682.4	679.3	687.6	636.2	657.7	661.1	662.7	684.1	694.4
9:45:00	684.9	681.4	690.9	645.0	661.9	665.4	667.9	686.3	695.7
10:00:00	687.3	683.8	692.6	652.5	665.2	670.0	672.0	689.7	697.1
10:15:00	689.3	685.8	694.7	658.8	668.9	673.7	675.2	690.9	698.2
10:30:00	691.1	687.6	695.6	664.2	671.4	676.0	678.4	692.5	699.1
10:45:00	692.5	688.7	697.8	668.6	673.4	678.4	679.7	693.3	700.1
11:00:00	693.5	689.6	698.3	672.3	674.7	680.6	681.7	694.9	700.8
11:15:00	694.1	690.6	698.8	675.4	676.5	682.3	682.4	695.9	700.7
11:30:00	695.4	691.3	699.2	678.0	678.1	683.7	684.1	697.3	701.3
11:45:00	696.4	692.5	700.3	680.2	679.0	684.8	685.2	697.8	701.9
12:00:00	697.3	693.0	701.2	682.0	680.1	686.1	686.6	698.2	702.3
12:15:00	697.4	693.7	701.8	683.5	680.9	686.9	687.3	698.5	702.8
12:30:00	697.8	693.9	701.9	684.9	681.3	687.5	687.8	699.2	703.1
12:45:00	698.6	694.5	701.7	685.9	682.0	688.6	688.1	700.0	703.2
13:00:00	698.9	695.0	702.6	686.7	682.6	689.1	689.2	700.7	703.7
13:15:00	701.5	697.9	705.7	687.6	684.2	690.8	691.2	702.7	707.4
13:30:00	703.3	699.7	708.1	688.6	686.1	692.3	693.1	704.0	708.9

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13. ABSTRACT (200 words or less)

This report describes tests of elastomeric seals that are used in the mechanical penetrations of nuclear power plant containments. These tests assessed the effects of thermal aging, radiation and thermal aging, sealing surface separation, and squeeze on the performance of several gasket designs: O-ring, gum drop, double dog ear, and tongue and groove. Both ethylene propylene rubber and silicone rubber gaskets were tested. The environment for testing enveloped a hypothetical severe accident: 143 psig and up to 700°F. The seal's performance is quantified in terms of the leakage onset point on the time-temperature curve.

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