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**SM-1 REACTOR VESSEL PENETRATED GASKET
DESIGN AND TEST REPORT**

By
F. G. Gebhardt

Approved by: **J. O. Brondel, Task Engineer**
R. E. Williams, Leader, Mechanical Test Unit

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ABSTRACT

Mechanical compression tests were performed on gasket test specimens machined to the cross-sectional dimensions of a stainless steel ring type gasket to be installed in the SM-1 reactor pressure vessel. Testing the mechanical properties of the gasket specimens under varying loads, and subsequent sectioning and inspection of specimens for adequacy of welded and brazed joints, gave the following results: (1) a penetration scheme involving five 0.070 in. diam. holes, spaced 1/4 in. center to center for each 6-1/2 in. bolt-circle span, may be made in a gasket ring without materially increasing the gasket stresses, (2) a lug may be welded to the gasket face to provide a brazed sealing support for 0.0625 in. diam. tubes and thermocouples, and (3) excellent attachments can be made by tungsten-inert gas welding of the lug to the gasket face and induction brazing of the tubes and T/c's to the lug using Nicrobraz alloy.

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1.0 SUMMARY

As part of the SM-1 Temperature and Flow Measurement Program (Task XIV), mechanical compression testing was performed on facsimile specimens of a Type 304 stainless steel ring-joint gasket. The specimens were machined to required cross-sectional dimensions of a gasket ring to be installed in the SM-1 reactor pressure vessel. Two specimen gasket sections were drilled for pressure tube and thermocouple penetration; a third section remained unpenetrated for use as reference.

Test procedure consisted of subjecting each section to various loads, measuring by strain gauge instrumentation the strain at various loads, and then sectioning the penetrated specimens for inspection of welded and brazed joints.

Test results indicated;

1. Penetrating the SM-1 reactor pressure vessel solid stainless steel octagonal gasket with the hole size, number and space used in Styles A and B will not impose objectionable stresses on the gaskets.
2. The compression stresses that are imposed on a penetrated gasket section with a welded attachment are, as expected, proportional to the amount of material removed for a unit length of gasket surface.
3. The strain gauge rosette indicated that the penetrations did not impose objectionable multi-planar stresses.
4. From the point of view of gasket stress, Style B would be a more satisfactory method of penetration than Style A due to the decreased area of gasket metal removed for a unit length of gasket surface, and the resulting lower stresses.
5. Microbraz alloy is a more satisfactory brazing material than the 85 Silver 15 Manganese material for the brazed joints involved.
6. Tungsten-inert gas welding is a satisfactory method of welding the lug to the gasket face.
7. Repeated loading and unloading the gasket section, as shown by the results of the five testing cycles imposed, do not affect the integrity of the welded and brazed joints.

8. Permanent deformation of the cycled unpenetrated section was slightly greater than that of a cycled penetrated section, and is attributed to variations within design tolerances of the gasket section wedge angles, causing slightly greater plastic flow upon seating of the unpenetrated specimen.
9. On the basis of the testing performed a recommended design for penetration of a stainless steel ring type gasket was prepared and is included in the report as Fig. 6-1 and 6-2.

2.0. INTRODUCTION

2.1 GENERAL

Shortly after the SM-1 Nuclear Power Plant became operative, a Research and Development program was initiated to internally instrument the reactor core. The problem of conducting the impulses from the instrumentation within the vessel to recorders outside the vessel became apparent, and severe schemes of instrumentation lead penetration were suggested. Two of these schemes were selected for further study:

(1) penetration of the vessel cover, and (2) penetration of the gasket ring. In September 1958, this investigation¹ was completed and showed that the most advantageous and feasible method to penetrate the vessel was through the gasket ring.

In August 1959 a Developmental Test Program was inaugurated to develop the actual penetration scheme as suggested by the previous study¹. This scheme was one whereby the instrument leads would be brazed to a welding lug and the lug welded to the outer face of the gasket, with the leads extending through clearance holes in the gasket. The problem was not simply solved, because the ASME Pressure Vessel Code made no provision for this type of penetration although the SM-1 pressure vessel is a coded vessel. Efforts were made to design a pressure test vessel of reduced dimensions which would adequately simulate the gasket load. The design proved unsatisfactory since secondary stresses could not be duplicated although primary stress simulation was adequate. The problem was presented for review to an expert in the field of mechanical stress analysis, Mr. M. F. Sayre, consulting engineer for Alco Products, Inc. It was Mr. Sayre's opinion that the only areas requiring experimental verification were concerned with: (1) determining the hole size, (2) number of holes per unit length of gasket surface, and (3) the structural integrity of the joints involved. Further Mr. Sayre stated that answers to these questions can best be obtained by tests made on short lengths of gasket, drilled and undrilled, supported to simulate conditions in the reactor, and loaded in a standard compression testing machine, by steps up to the maximum loading to be expected in the reactor itself. To obtain structural similarity, since the dimensions of the gasket and the load on the gasket could not well be reduced, this would have to be done in a full scale rather than a part scale unit. Loads on the gasket would be less accurately measured and strain gauge measurements on the inside of the gasket would be more difficult to obtain.

2.2 APPROACH

The general approach to the problem was to subject three gasket specimens to a load per linear inch of gasket surface equivalent to that of the SM-1 (APPR-1) reactor vessel gasket. Of these three specimens, one would be unpenetrated and two penetrated.

Each specimen would be similarly instrumented with strain gauges, and readings taken at pre-determined loads.

Upon completion of the testing the results would be compiled, and a critical survey would be made of the data.

The final step would be to section the gasket specimens and observe by metallurgical inspection, the effect, if any, that loading had on the welded and brazed joints.

3.0 DESCRIPTION OF TEST APPARATUS

3.1 DESIGN CONSIDERATIONS

In order to achieve the least amount of obstruction in routing the instrument leads from the vessel, the welding lugs would have to be placed between reactor vessel cover studs.

The space between the studs is about 6-1/2 in. with respect to the gasket, which is on a smaller pitch diameter. Sections with equivalent gasket length were made up for the tests.

From APAE-10 (Vol. 1)⁽²⁾, it is found that the load per linear inch of gasket surface is 14,200 lb/in for initial bolt loading. The equivalent loading on a 6-1/2 in. section of gasket is 92,000 lb.

Since the capacity of the compression testing machine is 100,000 lb, a maximum load of 90,000 lb was selected on the advice of the strength of materials laboratory supervisor.

3.2 TEST SPECIMENS

Drawings of individual components are shown in Fig. 3-1 thru 3-5, and photographs of the units are shown in Fig. 3-6 thru 3-12. Each gasket section was machined from stainless steel type 304, annealed dead soft (150 BHN max.) to the dimensions of the gasket ring in the SM-1 (APPR-1) reactor vessel. (Material specifications for the specimens are found in Table 3-1.) The only deviations from these dimensions were as follows:

1. The specimens were straight.
2. The specimens were approximately 6-1/2 in. in length.
3. The height of the specimen was increased by 3/8 in. to give adequate clearance for the welding lug between vessel flange and vessel cover.

Selection of hole size, spacing and number was based on the following criteria:

1. A maximum of 8 penetrations in the horizontal plane per bolt space.
2. Thermocouple sheathing size of 0.040 in. OD.
3. Pressure tube size of 0.065 in. OD.

4. Diametral clearance of leads in gasket of 0.005 in. min.
5. Diametral clearance of leads in the welding lug of 0.005 in. for ideal braze penetration.

Drilling the 0.045 in. holes through the 3/4-in. thick stainless steel section proved difficult and the electroless weld process was employed using a 0.040 in. weld tip. The resulting holes were 0.050 in. diam. and not altogether satisfactory. (This procedure was used on gasket specimen Style B as shown in Fig. 3-9.)

A different approach was selected in making penetrations in the second penetrated section. This approach was to drill 0.070 in. holes through the gasket, using only 7 holes per bolt spacing. The smaller leads, 0.040 in. OD thermocouple sheathing, would then be brazed into 0.065 in. OD tubes, and the tubes brazed into the welding lug.

In effect this would give a 0.065 in. OD tube "floating" in a 0.070 in. hole through the gasket. This method is shown in Fig. 3-5 and 3-8.

Another approach considered involved drilling the gasket to have two rows of holes with 7 holes per row. Figure 3-12 shows a photomicrograph made on a section taken through the welding lug of such an arrangement. Difficulties in drilling the holes through the gasket led to abandonment of this scheme.

Brazing the leads onto the welding lugs was accomplished by the induction heat method. Gasket specimen Style A used Microbraz 50 braze material, and gasket specimen Style B used Silver 85% - Manganese 15% braze material.

The welding lugs were welded to the gasket specimens by the tungsten-inert gas electroless process.

3.3 COMPRESSION BLOCKS

The upper and lower compression blocks were machined from stainless steel type 410 (180 BHN min). (Material specifications for the blocks are found in Table 3-1. The groove in each block was machined identical to the vessel cover and flange groove, except the groove was straight.

3.4 INSTRUMENTATION

Each specimen was instrumented with Baldwin-Lima-Hamilton Type SR-4 strain gauges. (Specifications for the gauges are shown in Table 3-2. Gauges #1 and 2 were cemented to the ends of the specimen and the other gauges cemented to the face of the gasket opposite the welding lug. Locations of the strain gauges are shown in Fig. 3-13.

The gauges numbered 3, 4, and 7 comprised a strain gauge rosette which was used to determine the principal stresses and direction of the principal axis.

TABLE 3-1
MATERIAL SPECIFICATIONS FOR GASKET SPECIMENS AND
COMPRESSION BLOCKS

Gasket Specimen
Unpenetrated - Penetrated Style B

<u>Chemical Analysis</u>									
<u>Heat No.</u>	<u>Carbon</u>	<u>Mang</u>	<u>Phos</u>	<u>Sulphur</u>	<u>Si</u>	<u>Ni</u>	<u>Cr</u>	<u>Moly</u>	<u>Cu</u>
68664	.052	.68	.023	.028	.45	9.23	18.66	.28	.19
<u>Mechanical Properties</u>									
<u>Tensile lbs/in²</u>	<u>Yield lbs/in²</u>		<u>Elongation %</u>		<u>Reduction %</u>		<u>Hardness</u>		
80,000	31,000		56.0		68.0		143		

No data available for Penetrated Gasket Style A.

Compression Blocks

<u>Chemical Analysis</u>									
<u>Heat No.</u>	<u>Carbon</u>	<u>Mang</u>	<u>Phos</u>	<u>Sulphur</u>	<u>Si</u>	<u>Ni</u>	<u>Cr</u>	<u>Moly</u>	<u>Cu</u>
19473									
Lower Block	.11	.71	.02	.011	.31	.17	12.25	.08	-
37682									
Upper Block	.10	.45	.015	.023	.23	.42	12.24	.50	-
<u>Mechanical Properties</u>									
<u>Heat No.</u>	<u>Tensile lbs/in²</u>	<u>Yield lb/in²</u>	<u>Elongation %</u>	<u>Reduction %</u>	<u>Hardness</u>				
19473									
Lower Block	90,000	46,000	48	62	230-234				
37682									
Upper Block	98,000	48,000	30	42	265				

TABLE 3-2
SPECIFICATION OF B-L-H STRAIN GAUGES USED FOR
GASKET MECHANICAL TEST

<u>Location</u>	<u>1 & 2</u>	<u>3 & 8</u>	<u>5 & 6</u>	<u>4 & 7</u>
Gauge Code No.	A-12	A-5	A-7	A-18
Gauge Length	1"	1/2"	1/4"	1/8"
Gauge Factor	2.05	1.96	1.96	1.78
Gauge Resistance	120 ohms	120 ohms	120 ohms	119.5 ohms

PART NO.
AES - 412 Sht. 1

DATE	LET.	REVISION RECORD	AUTH.	DR.	CHK.

BREAK SHARP EDGES
REMOVE ALL BURRS

UNLESS OTHERWISE SPECIFIED
DIMENSIONS ARE IN INCHES.
TOLERANCES ON FINISHED
FRACTIONAL DIMENSIONS
TO BE ± 1/64

- ✓ FINISH AS INDICATED
IN MICRONS.
- (f1) MACHINE FINISH - ROUGH
- (f10) FLAME CUT OR SAW

All surfaces finished to 63 rms
or better

		ALCO PRODUCTS, INC.	
		NUCLEAR POWER ENGINEERING DEPT. SCHENECTADY, N. Y., U. S. A.	
SCALE	1 = 1	DR.	FJH
MATERIAL SPEC.	304 Stainless Steel Annealed Dead Soft BHN 150 max.	TR.	12/2/59
		CHK.	
		APPR.	
		APPR.	
		NET.	
NAME GASKET SPECIMEN			
PART NO. AES - 412 Sht. 2			

Figure 3-1
Gasket Specimen

Figure 3-2 Compression Blocks

Figure 3-3 Penetrated Gasket (Style A)

Figure 3-4 Penetrated Gasket (Style B)

Figure 3-5

Details of Penetrations for Penetrated Gasket (Style A)

PART NO.	DATE	LET.	REVISION RECORD	AUTH.	DR.	CHK.
AES-412 Sht. 6						

PRESSURE TUBE PENETRATION

T/C PENETRATION

**BREAK SHARP EDGES
REMOVE ALL BURRS**

**UNLESS OTHERWISE SPECIFIED
DIMENSIONS ARE IN INCHES.
TOLERANCES ON FINISHED
FRACTIONAL DIMENSIONS
TO BE ±**

✓ FINISH AS INDICATED
IN MICROINCHES.

(f1) MACHINE FINISH - ROUGH

(f10) FLAME CUT OR SAW

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MATERIAL SPEC.		TR.	
		CHK.	
		APPR.	
		APPR.	
		MET.	

NAME *DETAIL of PENETRATIONS for*
'PENETRATED GASKET STYLE A

PART NO.
AES-412 Sht. 6

Figure 3-6

Penetrated Gasket Specimen (Style B)

Figure 3-7

**Unpenetrated Gasket Specimen with Strain Gauges
Applied: Also Upper and Lower Compression Blocks**

Figure 3-8

Penetrated Gasket Specimen (Style A)

Figure 3-9

Penetrated Gasket Specimen (Style B)
With Strain Gauges Applied

Figure 3-10

Penetrated Gasket Section (Style A)
Macro-Etch Section through Pressure Tube

Figure 3-11 **Penetrated Gasket Section(Style B)**
Macro-Etch Section through Pressure Tube

Figure 3-12

**Penetrated Welding Lug Macro-Etch
Section through Pressure Tube & Thermocouple**

UNPENETRATED SPECIMEN

PENETRATED SPECIMEN (STYLE A)

PENETRATED SPECIMEN (STYLE B)

Figure 3-13

Location of Strain Gages

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4.0 TEST PROCEDURE

4.1 COMPRESSION TESTING

4.1.1 Unpenetrated Gasket Section

An initial load of 55,000 lb was applied to the gasket to pre-stress the strain gauges. The load was released then re-applied in the increments specified in Tables 3-1, 3-2 and 3-3. At each change of load, the strain gauge measurements, distance between compression blocks, and overall length and thickness of the specimen were recorded. The load was then released to 0 lb and another set of readings was taken. Five successive cycles applying 90,000 lb load and releasing the load to 0 lb were then made with strain gauge readings taken at 0 lbs and 90,000 lb on the third and fifth cycles.

4.1.2 Penetrated Gasket Section Style A

The same procedure was followed for this specimen as for the unpenetrated section, except that the five successive cycles were omitted.

4.1.3 Penetrated Gasket Section Style B

The same procedure was followed for this section as for the unpenetrated section, including the five load cyclings.

Explanatory Note:

During the initial loading of the test specimens, it was noted that the strain gauge readings rose slightly from the 0 load reading. As the load was applied, readings began to decrease in the manner expected. This was presumably due to the gasket being seated as the load was applied. Therefore the differences between readings were taken from the maximum reading obtained to the lowest reading obtained.

In the test data for penetrated gasket section Style B, the maximum gauge readings in compression, and minimum gauge readings in tension were found to be at a load of 6500 lb. This loading was therefore recorded as the no load reading.

4.2 INSPECTION OF JOINTS

Upon completion of the tests, the specimens were examined by microscope for cracks in the welds and brazed joints, clearance between tubes and gasket, and depth of penetration.

Macro-etches were made on each of the penetrated sections; photographs of these etches are shown as Fig. 3-10 and 3-11.

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5.0 TEST RESULTS

5.1 COMPRESSION TESTING

No attempt was made to simulate all the conditions to which a gasket is subjected to in a pressure vessel of the SM-1 (APPR-1) type. It was decided to subject various test specimens to a compressive loading over the approximate working range of the SM-1 (APPR-1) pressure vessel gasket. The load limits were 0-90,000 lbs, 2000 lbs less than that of the SM-1 gasket for an equivalent length.

Therefore, in order to present results with any significance, it was necessary to have a standard for purposes of comparison, and the unpenetrated section was used as the standard.

Compiled data is presented in Tables 5-1, 5-2, and 5-3. Graphic presentation of this data is shown in Fig. 5-1, 5-2, 5-3, 5-4, 5-5 and 5-6.

TABLE 5-1
DATA SHEET - UNPENETRATED GASKET SPECIMEN

Load lbs	End to End of Spec. in.	Face to Face of Spec. in.	Strain Gauge Readings (Corrected)							
			$\times 10^{-6}$ in/in							
			1	2	3	4	5	6	7	8
0	6.497	.7475	11100	9399	11414	12602	11484	11630	10634	10020
15,500	6.497	.7475	11100	9399	11350	12578	11408	11580	10649	9956
25,500	6.4975	.7475	11086	9379	11323	12568	11384	11557	10667	9928
35,500	6.4975	.7475	11048	9340	11295	12567	11364	11533	10689	9902
45,500	6.4977	.7475	10978	9262	11260	12566	11333	11507	10709	9865
55,600	6.4979	.7475	10892	9185	11228	12556	11302	11474	10723	9825
65,500	6.4980	.7475	10802	9107	11184	12536	11263	11439	10737	9773
75,500	6.4981	.7475	10694	9025	11130	12516	11220	11390	10757	9735
85,500	6.4985	.7475	10618	8951	11077	12484	11164	11337	10774	9678
90,000	6.4990	.7475	10530	8872	11000	12463	11097	11275	10802	9598
0	6.4975	.7475	10941	9235	11360	12607	11434	11598	10678	9950
90,000	-	-	10149	8599	10485	12083	10730	10914	10751	9251
0	-	-	10628	9029	11000	12385	11205	11373	10588	9710
90,000	-	-	10033	8497	10455	12089	10071	10894	10802	9236
0	-	-	10545	8955	10955	12347	11071	11302	10639	9675

TABLE 5-2
DATA SHEET - PENETRATED GASKET SPECIMEN STYLE A

Load lbs	End to End of Spec. in.	Face to Face of Spec. in.	Strain Gauge Readings (Corrected)							
			x 10 ⁻⁶ in/in							
			1	2	3	4	5	6	7	8
0	6.5106	.7571	10674	11000	11373	17782	11769	11905	11982	10147
15,500	6.5118	.7571	10676	11007	11439	17579	11914	12056	11178	10189
25,500	6.5120	.7571	10662	10978	11393	17557	11883	12005	11195	10129
35,500	6.5112	.7571	10632	10944	11342	17546	11842	11965	11218	10057
45,500	6.5122	.7571	10593	10900	11266	17506	11776	11898	11229	9976
55,500	6.5125	.7571	10564	10866	11072	17444	11618	11756	11262	9761
65,500	6.5132	.7571	10515	10798	10827	17355	11434	11567	11313	9522
75,500	6.5135	.7571	10403	10647	10562	17265	11205	11358	11369	9262
85,500	6.5145	.7571	10238	10394	10338	17186	10965	11133	11437	9037
90,000	6.5135	.7571	10101	10233	10220	17119	10832	11000	11465	8945
0	6.5110	.7571	10384	10569	10700	17534	11240	11424	12016	9506

TABLE 5-3
DATA SHEET - PENETRATED GASKET SPECIMEN STYLE B

Load lbs	End to End of Spec. in.	Face to Face of Spec. in.	Strain Gauge Readings (Corrected)							
			$\times 10^{-6}$ in/in							
			1	2	3	4	5	6	7	8
0	6.4950	.7464	9882	11237	10649	16191	11531	12229	15972	10705
15,500	6.4950	.7464	9877	11183	10613	16129	11480	12174	15966	10618
25,500	6.4956	.7464	9838	11105	10572	16118	11449	12138	15972	10557
35,500	6.4955	.7464	9784	10988	10516	16084	11398	12072	16017	10490
45,500	6.4955	.7464	9711	10881	10445	16034	11307	11979	16039	10409
55,500	6.4958	.7464	9633	10798	10373	15989	11220	11893	16062	10317
65,500	6.4960	.7464	9545	10667	10230	15905	11087	11760	16107	10175
75,500	6.4961	.7464	9448	10491	10083	15815	10945	11608	16163	10037
85,500	6.4961	.7464	9321	10247	9929	15736	10812	11465	16247	9878
90,000	6.4973	.7464	9253	10091	9843	15691	10725	11378	16304	9802
0	6.4967	.7464	9653	10549	10353	16118	11220	11985	16179	10399
90,000	-	-	9092	9891	9619	15511	10654	10980	16332	9716
0	-	-	9555	10398	10328	16062	11296	11898	16214	10373
90,000	-	-	9087	9857	9772	15668	10689	11342	16411	9751
0	-	-	9575	10418	10343	16062	11322	11985	16231	10343

An extract of the compiled data is presented in Tables 5-4 and 5-5 to show comparison of sections. The strains recorded are not actual readings, but merely differences between initial and final readings.

TABLE 5-4
STRESS-STRAIN DATA, LOAD RANGE 0-90,000 LB

Strains at 90,000 lb Determined by Extending the Curves

<u>Gage No.</u>	<u>Unpenetrated Section</u>		<u>Penetrated Section Style A</u>		<u>Penetrated Section Style B</u>	
	<u>E in/in</u>	<u>S psi</u>	<u>E in/in</u>	<u>S psi</u>	<u>E in/in</u>	<u>S psi</u>
1	570	15,720	575	15,870	625	17,220
2	530	14,600	765	21,100	1145	31,600
3	420	11,600	1260	34,800	805	22,200
5	370	10,200	1085	30,000	805	22,200
6	405	11,200	1055	29,100	850	23,400
8	420	11,600	1300	35,900	905	25,000

TABLE 5-5
PERMANENT DEFORMATION, LOAD CHANGE 90,000 - 0 LB

E in/in Permanent Deformation

<u>Gage No.</u>	<u>Unpenetrated Section</u>	<u>Penetrated Section Style A</u>	<u>Penetrated Section Style B</u>
1	159	282	229
2	164	438	688
3	54	627	286
5	30	465	230
6	32	443	244
8	62	632	306

Results above indicate that the penetrated gasket sections yield higher stress values than the unpenetrated section over the same load range. Various factors contribute to the interpretation of these data, as given below:

1. Accuracy of the data is dependent upon tester, inherent error in instrumentation method, and acquired error in placing the gauges. Since the same tester performed all the tests, instrumentation was the same for all specimens, and specimens were instrumented by the same individual, it is quite possible that the expected error for all specimens should be essentially the same.
2. Loading stainless steel Type 304 tends to work-harden the material and the amount of hardening depends on the rate at which the load is applied. Therefore if the loading rate between any incremental change is varied from specimen to specimen, the strain readings may be influenced by the varying rates in hardening of the material. Every precaution was taken to assure consistency.
3. Optimum results would be expected if each specimen was taken from the same heat. For this test, as shown in Table 3-1, material was from two different heats. The unpenetrated specimen and penetrated specimen style B were from one heat; penetrated specimen style A was from a different heat. The effects that may result from this inconsistency are variations in strain measurements due to properties of the material such as hardness, tensile strength and chemical composition.
4. Size and number of penetrations differ, and one specimen was undrilled. Specimen Style A had a total of seven 0.070 in. diam. holes drilled through; specimen Style B had a total of ten 0.0635 in. diam. holes and six 0.045 in. diam. holes drilled through. Since the area of metal removed over a given length in a given plane is proportional to the number times the diameter of the holes, the ratio of metal removed per 1 in. length of specimen is:

Specimen Style A

Specimen Style B

$$\frac{0.490}{1.1950} = 0.41$$

$$\frac{0.397}{1.360} = 0.288$$

Indication that the observed stress values are influenced by the amount of metal removed is exhibited by comparing the ratio of metal removed for each section with the average stress values over the specimen surface covered and included by strain gauges 3 and 8. The ratio of metal removed for the specimens is:

$$\frac{\text{Specimen Style A}}{\text{Specimen Style B}} = \frac{0.41}{0.288} = 1.42$$

The ratio of average stress values is:

$$\frac{\text{Specimen Style A}}{\text{Specimen Style B}} = \frac{1175 \times 27.6 \times 10^6}{841 \times 27.6 \times 10^6} = 1.39$$

Figures 5-1, 5-2, 5-3, 5-4, 5-5 and 5-6 are graphic presentations of strain vs. load for each gasket specimen tested at strain gauge locations 1, 2, 3, 5, 6, and 8 respectively.

Results of cycling the unpenetrated gasket section and gasket section Style B yielded the following permanent deformations:

TABLE 5-6
PERMANENT DEFORMATION (CYCLE), LOAD RANGE 0-90,000-0 LB

<u>Unpenetrated Section</u>		<u>Penetrated Section Style B</u>	
<u>Gauge No.</u>	<u>E in/in Permanent Deformation</u>	<u>Gauge No.</u>	<u>E in/in Permanent Deformation</u>
1	555	1	307
2	444	2	819
3	459	3	306
5	387	5	209
6	328	6	244
8	345	8	362

This data indicates that the penetrated gasket section may have work-hardened at a more rapid rate than the unpenetrated section.

Results obtained from the strain gauge rosette configuration comprised of gauges 3, 4 and 7 show the following:

TABLE 5-7
STRAIN GAUGE ROSETTE RESULTS

	<u>Principal Stresses</u>		<u>Direction of Principal Axis</u>
	<u>Tension</u>	<u>Compression</u>	
Unpenetrated Specimen	930 psi	13,370 psi	- .68°
Penetrated Specimen Style A	2,600 psi	37,000 psi	6.3°
Penetrated Specimen Style B	10,750 psi	30,050 psi	12.1°

The method for computing the strain gauge rosette is contained in the Appendix.

5.2 INSPECTION OF GASKET SECTION

A visual inspection of the penetrated gasket specimens was made upon completion of compression testing. The external inspection revealed no cracks or imperfections in either the welded or brazed joints.

Macro-etches were made of both penetrated sections and these were inspected under the microscope by a welding engineer. The engineer's opinion was that the welds of both specimens were satisfactory in penetration and revealed no flaws or cracks. Upon inspection of the brazed joints, it was noted that the joints made with 85 Silver 15 Manganese alloy did not completely fill the cavity between tube and lug. The joints made with the Nicroba alloy showed satisfactory penetration. Photographs of these sections appear as Figs. 3-10, 3-11 and 3-12.

Figure 5-1

Comparison of Load Vs. Strain at Gauge Location #1

Figure 5-2

Comparison of Load Vs. Strain at Gauge Location #2

Figure 5-3

Comparison of Load Vs. Strain at Gauge Location #3

Figure 5-4

Comparison of Load Vs. Strain at Gauge Location #5

Figure 5-5

Comparison of Load Vs. Strain at Gauge Location #6

10/10/60

10/10/60

Figure 5-6

Comparison of Load Vs. Strain at Gauge Location #8

6.0 CONCLUSIONS AND RECOMMENDATIONS

6.1 CONCLUSIONS

1. Penetrating the SM-1 reactor pressure vessel solid stainless steel octagonal gasket with the hole size, number and spacing used in specimen Styles A and B does not impose objectionable stresses on the gasket.
2. The stresses that are imposed on the gasket section with a welded attachment are, as expected, proportional to the area of metal removed for a unit length of gasket surface.
3. The strain gauge rosette indicated that the penetrations did not impose objectionable multi-planar stresses on the gasket.
4. From the point of view of gasket stresses, Style B would be a more satisfactory method of penetration than Style A due to the decreased area of gasket metal removed for a unit length of gasket surface and the resulting lower stresses.
5. Microbraz brazing alloy is a more satisfactory brazing material than the 85 Silver 15 Manganese material for the brazed joints of the penetrated SM-1 reactor pressure vessel gasket.
6. Tungsten-inert gas welding is a satisfactory method of welding the lug to the face of the penetrated SM-1 reactor pressure vessel gasket.
7. Repeated loading and unloading the gasket specimen as shown by the results of the five testing cycles imposed do not affect the integrity of the welded and brazed joints.
8. Permanent deformation of the cycled unpenetrated gasket specimen was slightly greater than that of a cycled penetrated section, and is attributed to variations within design tolerances of the gasket section wedge angles, causing slightly greater plastic flow upon seating of the unpenetrated section.

6.2 RECOMMENDATIONS

1. The total number of penetrations required for the penetrated SM-1 reactor pressure vessel gasket is 71. Thus with a total of 16 bolts, a total of five penetrations per bolt space will give an adequate number of penetrations. Although results of the

compression testing did not yield excessive stress values, a more conservative design will be utilized on the basis of total number of penetrations required.

The following design is presented as the optimum condition for the Task XIV penetrated gasket:

Hole Size - 0.070 in. diam.

No. of holes/bolt space - 5 holes

Space between holes - 0.25 in. center to center

2. Penetration points should be midway between reactor vessel cover studs.
3. Microbraz brazing alloy should be used to connect the leads to the welding lug.
4. Tungsten-inert gas weld process should be used to weld the lug to the outer face of the SM-1 reactor pressure vessel gasket.
5. The overall recommended design for a penetration scheme of this type should conform to the design shown on Alco Dwgs. R9-50-1111 and A9-50-2407. (Fig. 6-1 and 6-2.)

Figure 6-1 Dwg. R9-50-1111- Instrumented Table Ass'y.

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PART NO.
A9-50-2407

ALL SURFACES FINISH TO 63 RMS

BREAK SHARP EDGES
REMOVE ALL BURRS

UNLESS OTHERWISE SPECIFIED
DIMENSIONS ARE IN INCHES.
TOLERANCES ON FINISHED
FRACTIONAL DIMENSIONS
TO BE $\pm .010$

- ✓ FINISH AS INDICATED
IN MICROINCHES.
- (f1) MACHINE FINISH - ROUGH
- (f10) FLAME CUT OR SAW

DATE	LET.	REVISION RECORD	AUTH.	DR.	CHK.

ALCO PRODUCTS, INC.
NUCLEAR POWER ENGINEERING DEPT.
SCHENECTADY, N. Y., U. S. A.

SCALE	FULL	REF.	R9-50-1111	DR.	E. Bayer	4-14-60
MATERIAL SPEC.	STAINLESS STEEL TYPE 304			TR.		
				CHK.		
				APPR.	H. H. H. H.	4/20/60
				APPR.		
				MET.	ALCO	7/20/60

NAME **BLOCK- GASKET
PENETRATIONS**

PART NO.
A9-50-2407

Figure 6-2

Dwg. A9-50-2407 - Block (Gasket Penetrations)

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7.0 APPENDIX

7.1 COMPARISON OF STANDARD 1500 LB-24 IN. PIPE FLANGE OCTAGONAL RING GASKET STRESS VS. GASKET SPECIMEN STRESS

Nomenclature:

- P = Load per linear inch of gasket surface, lbs/in
 W = Total applied load, lb
 L = Length of gasket surface, in.
 A_B = Actual bolt area, square in.
 S_B = Allowable bolt stress, psi
 G = Ring diameter, in.
 N = Load normal to gasket seating surface, lb
 F_U = Total vertical forces, lb
 F_N = Frictional force, lbs- where $F_N = .3N$

Standard 1500 lb, 24 in. Pipe Flange Octagonal Ring Gasket Stress:

- Pitch Diam = 27.25 in.
No. Bolts = 16
Size of Bolts = 3-1/2 in.

$$W = A_B \times S_B \times \text{No. of Bolts}$$

$$= (5.81) (20,000) (16)$$

$$W = 2,820,000 \text{ lb}$$

$$P = \frac{W}{\pi G} = \frac{2,820,000}{\pi (27.25)}$$

$$P = 32,900 \text{ lbs/in.}$$

$$F_U = 0$$

$$0 = P - 2 FN \cos 23^\circ - 2N \sin 23^\circ$$

$$= 32,900 - 2(.3N \times .920) - 2N (.391)$$

$$N = \frac{32,900}{1.334}$$

$$= 24,700 \text{ lb}$$

Stress on Face of Gasket:

$$S = \frac{N}{A}$$

$$= \frac{24,700}{.51}$$

$$S = 48,400 \text{ psi}$$

Stress on Cross Section of Gasket:

$$S = \frac{P}{A}$$

$$= \frac{32,900}{1.375}$$

$$= 23,900 \text{ psi}$$

Gasket Test Specimen Stress:

$$W = 90,000 \text{ lb (actual loading)}$$

$$P = \frac{W}{L} = \frac{90,000}{6.5} = 13,840 \text{ lbs/in}$$

$$FV = 0$$

$$0 = P - 2 FN \cos 23^\circ - 2N \sin 23^\circ$$

$$= 13,840 - 2(.3N \times .920) - 2N (.391)$$

$$N = \frac{13,840}{1.334}$$

$$= 10,370 \text{ lb}$$

Stress on Face of Gasket:

$$S = \frac{N}{A} = \frac{10,320}{.339}$$

$$= 30,600 \text{ psi}$$

Stress on Cross Section of Gasket (Max. from Test Data):

<u>Style A</u>	<u>Style B</u>
35,900	31,600

It should be noted that stress values obtained from the test data are highly localized stresses and are maximum stresses noted. Average stress values for each penetrated section are listed below.

<u>Style A</u>	<u>Style B</u>
27,778	23,603

7.2 ROSETTE ANALYSIS

At any point on a free surface of a solid it is necessary to know three independent quantities in order to specify the state of stress completely.

A strain gauge grid was incorporated in the instrumentation to resemble a 45° rectangular rosette.

For purposes of this analysis, gauges 3, 4 and 7 were used.

The unpenetrated gasket specimen rosette computations are presented as typical for all of the specimens.

Stresses at 90,000 lb Load

Nomenclature:

δ_1	=	Stress intensity, tension, psi
δ_2	=	Stress intensity, compression, psi
E	=	Modulus of elasticity = 27.6×10^6 psi
μ	=	Poisson's Ratio = 0.305
ϵ	=	Strain in/in (+ tension, - compression)
A	=	Hydrostatic component of strain, in/in
B	=	Shear component of strain, in/in
A''	=	Hydrostatic component of stress, psi
B''	=	Shear component of stress, psi
ϕ	=	Direction of principal axis, degrees

Principal Stresses:

$$\begin{aligned}\epsilon_3 &= 490 \text{ in/in} \times 10^{-6} \\ \epsilon_4 &= 145 \text{ in/in} \times 10^{-6} \\ \epsilon_7 &= 185 \text{ in/in} \times 10^{-6}\end{aligned}$$

$$= -153 \text{ in/in} \times 10^{-6}$$

$$B = \frac{\sqrt{2}}{2} \sqrt{(\epsilon_3 - \epsilon_4)^2 + (\epsilon_4 - \epsilon_7)^2}$$

$$= 338 \text{ in/in} \times 10^{-6}$$

$$A'' = A \frac{E}{1 - \mu}$$

$$= 6,220 \text{ psi}$$

$$B'' = B \frac{E}{1-\mu}$$

= 7,150 psi

$$\delta_1 = A'' = B''$$

= 930 psi tension

$$\delta_2 = A'' = B''$$

$\sigma = 13,370$ psi compression

Direction of Principal Axis

$$\tan 2\phi = \frac{E_4 - A}{E_3 - A}$$

$$2\phi = -1.36^\circ$$

$$\phi = -.68^\circ$$

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8.0 REFERENCES

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2. Alco Products, Inc., "Phase III Design Analysis for the Army Package Power Reactor," APAE 10, Vol. 1, August 15, 1956.