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thermal stress testing of type 1 fuel plates

Contract No. AT[30-1]-2639
with U. S. Atomic Energy Commission
New York Operations Office

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AEC Research and
Development Report
UC-81 Reactors, Power
(Special Distribution)

THERMAL STRESS TESTING
OF TYPE 1 FUEL PLATES

By
F. G. Gebhardt

Approved by:
E. W. Schrader, Acting Project Engineer

Issued: June 27, 1962

Contract No. AT(30-1)-2639
with U. S. Atomic Energy Commission
New York Operations Office

ALCO PRODUCTS, INC.
Nuclear Power Engineering Department
Post Office Box 414
Schenectady 1, N.Y.

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ABSTRACT

Thermal stress tests on Type 1, SM-1A. Core II fuel element sections were performed to study plate distortion and determine its dependency on temperature distribution, temperature differential, initial flatness, and ripple length. Test results will be correlated with the analytical model and used to predict ripple growth in other plate-type fuel elements. The tests showed:

1. Ripple growth is dependent on initial flatness of the plate.
2. The characteristic shape of ripples is maintained at all temperature differentials.
3. The ripple growth rate for a ripple of 5 mil initial magnitude is approximately 0.12 mils/°F for a peak temperature differential of 103°F.
4. The apparent relationship between ripple net growth and length is 1.3 mil/in. of ripple for a peak temperature differential of 103°F.
5. The permanent distortion is 2 mils for a complete temperature cycle from 0°F to 103°F to 0° differential.
6. The temperature profile across the plate width affects the magnitude of ripple growth.

ACKNOWLEDGEMENT

The author is indebted to E. A. Bemis and J. V. Miller for their aid in preparing the analysis and figures appearing in Section 3.0 "Thermal Analysis."

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1.0 SUMMARY

Thermal stress testing was performed on Type 1 fuel plates as part of the Engineering Support and Development of the Army Pressurized Water Reactor Power Plant program as presented in AP Note 378 Subtask 3.9.(2). Test specimens consisted of a single fuel plate containing a stainless steel -UO_2 core and its proportionate share of element side plates, machined from a rejected SM-1A Core II fuel section. Three such plates were tested.

The test method consisted of applying various transverse temperature profiles to the test plates at temperature differences up to 116°F and measuring the distortion at each differential increment. Test results in the areas investigated are considered conclusive because not only were the findings of these tests similar, but these findings were compared to those of the tests previously conducted.

Conclusions are as follows:

1. The characteristic shape of the flatness curve of the test plate does not change as a result of varying the temperature profile or the temperature differential.
2. The increase in ripple amplitude is a linear function of increasing temperature differential within the differential range of the test (116°F max)). The slight change in ripple growth at the higher differentials is attributed to normal plastic deformation characteristic of austenitic stainless steels.
3. The growth rate of a ripple with an initial amplitude of 7.5 mils is approximately $0.12 \text{ mils}/^\circ\text{F}$ for a temperature differential range $0\text{--}103^\circ\text{F}$.
4. The permanent distortion measured for one complete temperature cycle (0°F to 103°F to 0°F differential) is 2.0 mils. (Note: It is expected that the permanent distortion in reactor fuel plates will be greater than that indicated in the test data because of the higher absolute temperatures encountered.)
5. A definite relation exists between ripple growth (δ) and ripple length (L). The approximate ratio is 1.3 mils/in. of ripple at 103°F temperature differential. A similar relationship exists between initial distortion and ripple length, the ratio of which is approximately 1.15 mils/in. of ripple.

6. The temperature profile across the plate width affects the magnitude of ripple growth. It appears that the nearer to the center of the plate the peak temperature occurs, the greater the distortion for a given temperature differential.

2.0 INTRODUCTION

2.1 GENERAL

As part of the Engineering Support and Development of Army Pressurized Water Reactor Power Plants, AP Note-378, Subtask 3.9, (2) an investigation is being conducted for accurate prediction of fuel plate ripple growth and its effects on core performance. This investigation is primarily concerned with establishing the mathematical analysis required to achieve this end. Concurrent with the mathematical analysis, a laboratory test program was carried out to determine experimentally the effect on rippling growth of initial amplitude, the number of ripples, and applied temperature differential. The results of this test program will be used to verify the mathematical approach to the problem.

This report presents the test program undertaken and its results. Actual fabrication of the test equipment and performance of the test work was done by, or under the supervision of, Alco General Engineering Laboratory personnel. The mathematical analysis will be covered in a separate report.

2.2 APPROACH

When a multi-plate fuel element assembly is producing power within a reactor, thermal stresses are produced which tend to distort the element structurally. These stresses can, in extreme cases, lead to fuel element failure. Thermal stresses are produced by the temperature difference between the fuel portion of the fuel plate and the inert edges of the plate and side plates where the relatively cool inert sections restrain the normal thermal expansion.

The requirements of the mathematical analysis dictated that certain basic fuel plate structural and thermal conditions be met in the experimental phase of the program if the test results were to be of any value in verifying the analysis.

Structural limitations imposed were as follows:

1. The test specimen was to be preferably a fuel plate containing a stainless- UO_2 core, machined with its proportionate share of side plate from a brazed Type 1 fuel section.
2. The test specimen selected was to be as free as possible from any warpage, bowing, or other distortion which might arise from the machining process.
3. The test apparatus was to be designed in such a manner as to minimize any restraining forces which would restrict the normal thermal expansion of the test specimen.

Thermal limitations imposed were as follows:

1. The test apparatus was to be designed in such a manner as to provide a temperature differential across the width of the plate corresponding as closely as possible to the temperature differential experienced by a fuel plate in the SM-1A Reactor when operating at design conditions.
2. If the exact temperature profile could not be obtained, the nearest possible simulation would be acceptable with emphasis on knowing as precisely as possible the temperature profile obtained.

2.3 TEST SPECIMEN

A rejected Type 1, (SM-1A Core II) brazed, stationary, fuel section, (No. 3-25) was acquired. Test specimens were machined from this section. Table 2-1 gives the reference dimensional and physical characteristics of the test specimens. Figure 9-1 and associated Table 9-7 gives dimensional data concerning fuel plate width, thickness, thermocouple, seal strip locations and so forth taken by actual measurement.

Three test specimens were machined from the fuel section; Plate No. 3-29-7, hereafter called Test Plate No. 1, Plate No. 3-29-5, hereafter called Test Plate No. 2, and Plate No. 3-89-6, hereafter called Test Plate No. 3. Figure 2-1 shows an un-instrumented test plate.

TABLE 2-1
REFERENCE DIMENSIONAL AND PHYSICAL CHARACTERISTICS OF
TYPE I (SM-1A CORE II) TEST PLATES - 1, 2, AND 3

Material

Side Plate	-	304 SS
Cladding and Frame	-	304 SS
Core	-	34.9245 gm of UO ₂ dispersed in SS
		U _{Total} - 30.734 gm
		U ₂₃₅ - 28.62 gm
Braze Metal	-	Coast Metals NP

Dimensions

Test Specimen Length	-	23-1/2 in.
Test Specimen Width	-	2.844 in.
Test Specimen Thickness		
(at side plate section)	-	.163 in.
Fuel Plate Length	-	23 in.
Fuel Plate Width	-	2.780 in.
Fuel Plate Thickness	-	.031 in.
Side Plate Thickness	-	.050 in.

Figure 2.1. Uninstrumented Test Plate

3.0 THERMAL ANALYSIS

3.1 TEMPERATURE PROFILE

The temperature distribution for the hottest fuel plate in the SM-1A Core II was obtained by using a two dimensional IBM-704 digital heat transfer program (HOC-01). (3)

Since the fuel plate is very long with respect to the width and thickness of the plate, heat flow in the axial (length) direction is assumed to be negligible. From peak axial nuclear flux distributions associated with the hottest fuel plate, volumetric heat generation rates were assigned to regions along the width of the plate. By a process of finite differencing, the two-dimensional steady state heat conduction equation

$$\frac{d^2T}{dx^2} + \frac{d^2T}{dy^2} = -Q_m/K_m$$

is solved subject to the appropriate boundary conditions. Figure 3.1 is a schematic representation of the input used. It shows boundary conditions, volumetric heat generation rates, and other thermal parameters required for the problem.

The output of the digital code consists of temperatures at each mesh point described by the geometry of the plate. Utilizing these values, isotherms can be constructed showing the temperature distribution throughout the plate. Figure 3.2 is an isotherm plot that gives the results for the hottest SM-1A plate and shows the temperature profile from the centerline of the fuel plate to the center of the coolant channel.

At any point along the width of the plate, the average temperature can be found by the integration:

$$T_{avg} = \frac{\int_0^+ T_m dx}{\int_0^+ dx}$$

where + is the distance from the centerline of the plate to the surface. This value, the surface temperature, and the plate centerline temperature are shown on Fig.

3.3. The average temperature distribution was used as the basic profile in establishing the simulated temperature distribution in the tests.

Region No. 1 is insulation. $K_1 = 0$, $h_1 = 0$, $Q_1 = 0$, $T_1 = 0$.

Regions No. 2 through No. 9 are water. $K_n = 0$, $h_2 = h_9 = 3150.$,
 $h_3 = h_5 = 1890.$, $h_4 = 825.$, $h_6 = 2510.$, $h_7 = 2940.$, $h_8 = 3116.$,
 $Q_n = 0$, $T_n = 425.$

Regions No. 10 through No. 35 are stainless steel cladding and side plate.
 $K_n = 10.85$, $h_n = 0$, $Q_n = 18.89 \times 10^6$, $T_n = \text{variable}$.

Regions No. 36 through No. 48 are fuel. $K_n = 9.46$, $h_n = 0$, $Q_{36} = Q_{37} = 362.0 \times 10^6$,
 $Q_{38} = Q_{39} = 357.1 \times 10^6$, $Q_{40} = Q_{41} = 353.0 \times 10^6$, $Q_{42} = 348.3 \times 10^6$, $Q_{43} = 343.4 \times 10^6$,
 $Q_{44} = 339.7 \times 10^6$, $Q_{45} = 336.6 \times 10^6$, $Q_{46} = 334.4 \times 10^6$, $Q_{47} = 332.8 \times 10^6$,
 $Q_{48} = 331.6 \times 10^6$, $T_n = \text{variable}$.

where: $K_n = \text{Thermal Conductivity} \sim \frac{\text{Btu-Ft}}{\text{Hr-Ft}^2-\text{°F}}$

$h_n = \text{Film Coefficient} \sim \frac{\text{Btu}}{\text{Hr-Ft}^2-\text{°F}}$

$Q_n = \text{Volumetric Heat Generation Rate} \sim \frac{\text{Btu}}{\text{Hr-Ft}^3}$

$T_n = \text{Fixed Temperature} \sim \text{°F}$

Figure 3.1. HOC-01 Input for SM-1A Core II, Quarter Section of Fuel Plate in Position 44

Figure 3.2. Isotherm Plot, One Quater Fuel Plate, Plan View of SM-1A Core II, Position 44

Figure 3.3. Fuel-Plate Temperature Profile, SM-1A, Core II, Position 44

4.0 DESCRIPTION OF TEST RIG

An assembly drawing of the thermal stress test rig is given in Fig. 4.1. A schematic drawing of the rig and its various components is given in Fig. 4.2. Photographs of the rig and its components are shown in Figs. 4.3 and 4.4.

4.1 TEST REQUIREMENTS

To design the test apparatus adequately, certain designs and test specifications were first established. They were as follows:

4.1.1 Structural Support

The test specimen will be simply supported at the side plate section with a minimum of restraint opposing normal thermal expansion. A rigid support on one edge of the side plate with a pin-type pressure member on the opposite edge is acceptable.

The test specimen may be suspended from an upper support member, so that rippling caused by gravitational forces may be reduced to a minimum.

4.1.2 Thermal Characteristics

A temperature profile simulating the gradient in an SM-1A Core II Type 1 fuel plate was attempted. Specifically, this simulation required that a symmetrical temperature pattern about the plate axial centerline would be as follows: starting at the side plate section and extending towards the center of the specimen for a width of 0.125 in., a datum temperature will be maintained; a section starting 0.125 in. from the side plate section and extending towards the center of the specimen for a width of 0.250 in. will be heated to a maximum of approximately 103°F above the datum temperature; the remaining section of the test specimen to the axial centerline will be heated to a maximum of approximately 72°F above datum.

The method used to create and maintain the desired temperature distribution must not impose significant restraint to the test specimen.

4.1.3 Measurements Required

It was required that the test specimen be brought to the maximum temperature differential in several steps. Axial centerline plate deflections (distortion) would be measured, preferably in a continuous plot, at each of the several temperature plateaus. Readings would also be taken at 0°F temperature differential before and after the heat cycle.

41	4	BRASS	#4-40 UNC -E6 HEX NUT
40	2	A9-50-2525	SPRAY TUBE HOLDER
39	2	A9-50-2526	SPRAY TUBE
38	1	CARB. STL.	3/4 DIA. x 27 (Oven 200)
37	1	A9-50-2527	SPRAY PIPE TEMPLATE
36	1	B9-50-1297	FUEL PLATE SUPPLY ASSY
35	8	ELASTIC STOPBUT WASH. STL. STL. A15-170 1/8 170	ROLL PIN 1/8 DIA x 3/16 LG. 79-02R-176-1717
34	4	BRASS	MACH. SCREW. RD. HD. #4-50 UNC 2A x 1/8 LG.
33	8	SYN. STL. TYPE 304	PIN .125 DIA x 2 3/8 LG
32	8	STN. STL. TYPE 304	PIN .125 DIA x 1 1/2 LG.
31	2	STN. STL. TYPE 304	SHOULDER SCREW-HEX. SOC. HD. #10-24 UNC-2A x 1 LG. LOTH SHOULDER x 1/8 LG. SHOULDER
30	8	B9-50-1294-2	REFLECTOR - L.H.
29	8	B9-50-1294-1	REFLECTOR - R.H.
28	1	C9-50-2226	BASE
27	8	B9-50-1295	SPRAY PIPE
26	8	C9-50-2233 MAKES - 2	HEATER SUPPORT
25	1	C9-50-2232 MAKES - 2	HEATER SUPPORT
24	1	B9-50-1296	FUEL PLATE SUPPLY ASSY
23	1	A9-50-2522	SPRING
22	1	A9-50-2515	PROBE
21	2	CARB. STL	MACH. SCREW. RD. HD. #4-48 UNC-2A x 1 LG.
20	8	CARB. STL	SPRING LOCKWASHER #10
19	1	C9-50-1291	INSTRUMENT/WIRING
18	8	CARB. STL	MACH. SCREW. RD. HD. #10-24 UNC-2A x 3/8 LG.
17	1	B9-50-1285	BOTTOM SPROCKET ASSEM
16	1	B9-50-1286	MACH. SPROCKET ASSEM.
15	2	CARB. STL	SET SCREW-HEX. SOC. HD. #10-24 UNC-2A x 1/8 LG.
14	8	CARB. STL.	NUT-HEX. #8-16 UNC-2B
13	8	CARB. STL.	LOCKWASHER 3/8
12	8	CARB. STL.	SHOULDER SCREW-HEX. SOC. HD. #8-16 UNC-3A x 1 1/8 LG
11	8	CARB. STL.	CAPSCREW-HEX. HD. #8-20 UNC-2A x 1 1/8 LG.
10	8	D9-50-1059	ASSY-THERMAL STRESS TEST
9	8	CARB. STL	SHOULDER SCREW-HEX. SOC. HD. #8-16 UNC-2A x 1 LG. LOTH #8-16 UNC-2A x 1 LG.
8	5	CARB. STL.	SET SCREW-HEX. SOC. HD. #10-24 UNC-2A x 1 LG.
7	60	BOSTON GEAR CAT. #1A	STEEL LADDER CHAIN
6	8	CARB. STL	CAPSCREW. HEX. HD. #8-16 UNC-2A x 1 1/8 LG.
5	1	B9-50-1284	TRAVERSE ASSEM.
4	1	THOMSON IND. 50 CASE-CL.	GUIDE ROD, 3.00 DIA 26 1/8 LG
3	4	A9-50-1289	SUPPORT BRACKET
2	1	B9-50-1287	TOP PLATE
1	1	B9-50-1288	BASE PLATE
PC. QTY.		DWG. NO.	DESCRIPTION

PART NO. 09:50-1283

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

✓ FINISH AS INDICATED
IN MICROINCHES.

(/1) MACHINE FINISH-ROUGH

(/10) FLAME CUT OR SAW

ALCO PRODUCTS, INC. NUCLEAR POWER ENGINEERING DEPT. SCHENECTADY, N. Y., U. S. A.	
SCALE	NALF	REV.	
MATERIAL SPEC.		DR.	E. Parnes 11-13-61
		TR.	
		CHK.	Deak 12-1-61
		APPR.	F32 12-1-61
		APPR.	
		WET.	Wetzel 12-1-61
NAME		THERMAL STRESS TEST RIG - ASSEM.	
PART NO.		D9-50-1283	

Figure 4.1, Thermal Stress Test Rig - Assembly
Drawing D9-50-1283 Rev. B

Figure 4.2. Schematic Plan View of Thermal Stress Test Assembly

Figure 4.3. Thermal Stress Rig (Complete Assembly)

Figure 4.4. Thermal Stress Rig (Test Plate Removed)

Various temperature profiles would be imposed on the test plate with center-line deflection measurements taken for each profile. In addition, test plate deflection measurements would be taken along the axis of one of the peak temperature regions for several temperature differentials.

4.2 THERMAL STRESS TEST RIG (REFERENCE FIG. 4.1)

4.2.1 Top and Bottom Plates

The top and bottom plates (Piece No. 1 and 2) were separated by, and rigidly bolted to, the support brackets (Piece No. 3). This box-like structure provided a foundation for support of the fuel plate, deflection measuring instrumentation, and heat transfer mechanism.

4.2.2 Test Plate Support

Support of the test plate was provided by two vertical bars (Piece No. 24), one on each side of the test plate, extending from the base plate to the top plate. Shoulder bolts rigidly fixed each support to the base plate. Dowel pins extended through accurately machined holes in the top plate and engaged the upper edge of the supports. This method of attachment allowed the supports to expand axially in relation to the test rig without changing the test plate position. Five pins extending laterally from each of the supports provided rigid bearing surfaces for the test plate. Setscrews directly opposed to each pin applied slight pressure against the test plate, thus holding the test plate against the dowels.

4.2.3 Temperature Control

Two methods of temperature control were experimented with: (1) combination of electric heaters, reflectors, and variable temperature water and (2) variable temperature water. Preliminary tests indicated that a suitable temperature profile could be obtained using the combination of heaters and water. The small increase in temperature differential (5-10°F) obtained, using radiant heat, was not justified, however, because the heater and reflectors required careful alignment to prevent electrical shorts, and installation time was extremely long. Testing with water of various temperature provided a slightly lower peak temperature differential, but the advantage gained in test time and assembly of this system justified its use.

The variable temperature water system was comprised of three independently controlled groups of water pipes.

The first group consisted of four spray pipes, (Piece No. 27) two on each side of the plate, located at the outer edge of the test plate. Cold water spray at approximately 60°F provided cooling for the side plate section and dead edge area of the test plate and established the reference temperature.

The second group, also consisting of four spray pipes, two on each side of the plate, were located about one-half inch on either side of the axial centerline of the test plate. These pipes provided a spray of water to the center region of the test plate varying in temperature from the reference temperature to a maximum of about 150°F, depending on test requirements.

The third group of water pipes, (Piece No. 39) consisting of four tubes, two on each side of the plate, were located about one inch on either side of the axial centerline of the plate. These tubes provided a constant stream of water to the peak temperature region of the test plate varying in temperature from the reference temperature to a maximum of about 170-180°F, depending on test requirements.

Two, double-coil, heat exchangers, utilizing steam as the heat source, were piped independently to each of the two groups of water pipes requiring hot water. Water temperature at the test plate was controlled by one or all of three methods: (1) change of flow rate at the test plate, (2) change of steam rate to heat exchanger and (3) change of water flow rate through the heat exchanger independent of flow rate at the test plate by a bleed line.

No attempt was made to provide a plate axial temperature profile similar to that existing in an SM-1A fuel plate. (Note: The temperature differential along the plate axial center during the tests was determined to be 0.3°F/in. at a plate temperature differential of 107°F.)

4.2.4 Water Seals

In order to maintain the water films of various temperature within specified boundaries on the test plate, water seals were molded to the test plate surface. These seals were accomplished by potting silicone rubber (General Electric RTV No. 11) to each side of the test plate surface in strips 1/16 in. wide x 3/8 in. high x 23 in. long. Each side of the test plate had four of these seal strips, two on each side of the axial centerline. Each pair of seal strips was separated by a gap approximately 1/4 in. wide. The outermost seal strip was located approximately 1/8 in. from the outer surface of the side plate section. This seal strip arrangement thus provided five separate channels down the length of each side of the test plate: two heated channels; two channels for side plate and dead edge cooling; and one channel in the center for temperature depression. This method of sealing the alternately heated and cooled sections of the test plate provided virtually no restraint on the plate. There was, however, some stiffness added to the plate along the dead edge region, but it was felt that the effect on the test data from this condition was extremely small because of the flexibility of the rubber (approximate Durometer 40 to 50) and the proximity of the seal strips to the restrained edge of the fuel plate. Figure 4.5 shows a test plate with seal strips applied.

4.2.5 Traverse Assembly

Plate flatness was measured by a linear motion potentiometer mounted on a traverse assembly (Piece No. 5). Two guide rods (Piece Nos. 4 and 38) mounted parallel to the test plate supports, extended between the top and bottom plate. Three ball bushings mounted in a triangular pattern on the traverse support allowed unrestrained movement of the traverse assembly up and down the guide rods while maintaining a fixed lateral relationship to the test plate supports.

4.3 INSTRUMENTATION

4.3.1 Temperature Measurements

To determine the temperature profile existing on the test plate, thermocouples were installed on the test plate at locations shown on Fig. 4.6. Thermocouples were made of B & S gauge 30 iron-constantan wires electrically insulated by silicone - resin impregnated double glass wrap. Attachment of the thermocouples to the test plate was by capacitance discharge welding. Overall dimensions of the thermocouples was .040 in. x .045 in. x 72 in. long.

Thermocouple measurements were taken on a Minneapolis Honeywell Multi-Point Indicator Model 156 x 16 - P485. Figure 4.7 shows a test plate with thermocouple attached.

4.3.2 Deflection Measurement

The instrumentation system to measure ripple growth (deflection) was designed to give a continuous measurement of test plate deflection versus position along the axial centerline of the test plate. The equipment selected to perform this function includes a linear motion potentiometer, multi-turn potentiometer, and an X-Y recorder.

A Computer Instruments Corporation carbon film linear motion potentiometer, Model 111 was mounted on the traverse assembly as mentioned in Section 4.2.5. This instrument sensed the change in flatness of the test plate surface and converted the translational motion of the probe to an electrical signal. The electrical signal provided, thus became the input signal for the Y axis of the X-Y recorder.

A Computer Instruments Corporation carbon film multi-turn potentiometer, Model 7810, was coupled to a sprocket assembly (Piece No. 17) mounted on the base plate. A chain drive (Piece No. 7) coupled between the bottom sprocket assembly and top sprocket assembly (Piece No. 16) and directly connected to the traverse assembly provided positive positioning of the potentiometer rotor for any axial displacement of the traverse assembly. The rotational motion of potentiometer rotor was thus converted to an electrical input signal for the X axis of the X-Y recorder.

The X-Y recorder used was a Pace Variplotter Model 1100E with a plotting surface 11 x 15 in. A schematic diagram of the instrumentation circuit is shown as Fig. 4.8. Table 4-1 gives the electrical and mechanical characteristics of the potentiometers and X-Y recorder.

Figure 4.5. Un-instrumented Test Plate with Rubber Seal Strips Applied

Key to Thermocouple Locations

<u>No.</u>	<u>Side</u>	<u>Front</u>	<u>Back</u>
1	x		
2	x		
3	x		
4	x		
5		x	
6			x
7		x	
8			x
9			x
10		x	
11		x	
12		x	
13			x
14		x	
15			x
16		x	
17		x	
18			x
19		x	
20		x	

Figure 4.6. Thermocouple Locations on Test Plate

Figure 4.7. Instrumented Test Plate

TABLE 4-1
ELECTRICAL AND MECHANICAL CHARACTERISTICS OF DEFLECTION
MEASURING EQUIPMENT

Computer Instruments Corporation Linear Motion
Carbon Film Potentiometer Model 111

Resistance	- 10k ohms per inch of stroke
Linearity	- 1 percent
Virtual Resolution	- 1/35,000 per inch of stroke
Wattage	- 1 watt per inch of stroke
Temperature Range	- -55°C to 85°C
Starting Force	- .5 lb. max. at 25°C
Life	- To 30 x 10 ⁶ strokes depending on circuitry
Excitation Voltage	- 6 volts
Sensitivity	- 8.15 inch output per inch input per volt

Computer Instruments Corporation Multi-Turn
Carbon Film Potentiometer Model 7810

Mechanical Rotation	- 3700° minimum
Electrical Function Angle	- 3600° ± 10°
Resistance	- 10k ohms
Linearity	- 0.5 percent
Virtual Resolution	- 1/40,000
Wattage	- 1 watt
Temperature Range	- -55°C to +150°C
Starting Torque	- .35 in.-oz
Life	- 10 million revolutions
Excitation Voltage	- 1.9 volts
Sensitivity	- 2.63 inch output per inch input per volt

Pace Variplotter Model 1100E

Input Voltage	- 115 volts, single phase, 60 cycle
Input Power	- 150 watts
Input Impedance	- 10k ohms per volt
Full Scale Deflection	
ARM	- 15 inch
PEN	- 10 inch
Static Accuracy of PEN and ARM	- 0.075%
ARM	- 0.1% for plotting speeds up to 10 in/sec.
PEN	- 0.1% for plotting speeds up to 10 in/sec
Acceleration	
ARM	- 250 in/sec ² max
PEN	- 750 in/sec ² max

DATE	LET.	REVISION RECORD	AUTH.	DR.	CHK.
4-18-62	R	R 4 WAS "67-01C12-60P			
	Q	R 9 WAS 250 OHM			
		ECO-0405	JLH	LSJ	EW

18	1	B9-50-2513	PANEL MODIFICATION
17	50	BELDEN TYPE 8443 APPROV. OR EQUAL	3-COND. CABLE-VINYL COVERED PLASTIC INSULAT.
16	6	EVEREADY NO. 6 APPROV. OR EQUAL	1-1/2 VOLT- STANDARD IGNITION DRY CELL
15	REF	B9-50-1284-3	POTENTIOMETER
14	REF	B9-50-1285-5	POTENTIOMETER
13	10	BELDEN TYPE 8529 APPROV. OR EQUAL	20 GA. SOLID HOOK-UP WIRE
12	1	BUD METAL PROD. TYPE AC-1613 APPROV. OR EQUAL	UNIVERSAL SLOPING PANEL CABINET 4x4 1/4 x 7

PART NO.
1621-05-60

11	1	OHMITE NO. 1MM730 APPROV. OR EQUAL	5-WATT, 400-OHM RESISTOR
10	1	OHMITE NO. 1MM730 APPROV. OR EQUAL	5-WATT, 100-OHM RESISTOR
9	2	OHMITE NO. 1MM730 APPROV. OR EQUAL	5-WATT, 5K-OHM RESISTOR
8	2	MALLORY TYPE 151L APPROV. OR EQUAL	TWO SECTION-5 POSITION SELECTOR SWITCH
7	1	CENTRALAB TYPE 1461 APPROV. OR EQUAL	SP-3- POSITION SELECTOR SWITCH
6	1	SIMPSON MODEL 127 APPROV. OR EQUAL	0-10 D.C. VOLTMETER
5	2	OHMITE TYPE CU 5001 APPROV. OR EQUAL	2-WATT, 50-OHM POTENTIOMETER
4	4	AMPHENOL 67-06C12-60P APPROV. OR EQUAL	3-PIN PLUG
3	4	AMPHENOL 67-01C12-60S APPROV. OR EQUAL	3-PIN PANEL MOUNTING RECEPTACLE
2	4	H.H. SMITH TYPE 205 APPROV. OR EQUAL	BANANA JACK-1-EACH OF RED, YELLOW, GREEN & BLUE
1	4	H.H. SMITH TYPE 204 APPROV. OR EQUAL	BANANA PLUG-1-EACH OF RED, YELLOW, GREEN & BLUE
Pc	2	DWG NO. OR MAT'L *	DESCRIPTION

ALCO		ALCO PRODUCTS, INC.	
NUCLEAR POWER ENGINEERING DEPT.		SCHENECTADY, N. Y., U. S. A.	
SCALE	REF.	DR.	B PARKER 11-15-61
D9-50-1283		TR.	
MATERIAL SPEC.		CHK.	Decker 12-1-61
		APPR.	JLH 12-1-61
		APPR.	
		MET.	12-1-61
NAME INSTRUMENT WIRING			
THERMAL STRESS TEST RIG			
PART NO. C9-50-1291			

Figure 4.8. Instrument Wiring, Thermal Stress Test Rig, Drawing C9-50-1291 Rev. A

5.0 CALIBRATION

Calibration was performed to determine consistent errors peculiar to the test rig, random errors, and overall error of the test rig and associated instrumentation.

5.1 RIG CALIBRATION

Calibration was initiated using a flat glass plate 1/8 in. thick to determine the degree of parallelism between the plane of the support pins in the fuel plate supports and that of the traverse assembly. Calibration points were taken progressively as the traverse assembly was raised until the linear motion potentiometer probe was opposite each support pin location. The location of the X-Y plotter pen was then indicated on the graph paper. The points were connected by a straight line to determine the rig calibration curve.

Initial testing with three support pins spaced at approximately equal intervals along the fuel plate supports indicated unsatisfactory results, caused by excessive bowing of the glass plate between pins. The fuel plate supports were modified, increasing the number of support pins from three to five. These five pins were also spaced at approximately equal intervals.

The slope of the rig calibration curve, with five support pins in use, with respect to the axis of travel of the traverse assembly was 0.0004 in./in. Maximum deviation of any single calibration point from the straight line calibration curve was 0.001 inch. The maximum deviation between any two points was 0.002 inch.

NOTE: All curves presented in this report have been corrected for rig non-parallelism.

5.2 CALIBRATION FOR SENSITIVITY

Test plate No. 1 was installed in the test rig. The linear motion potentiometer was removed from the traverse assembly and replaced by a magnetic base dial indicator. Indicator readings were taken at 1/2-in. intervals starting at a point 4 in. above the potentiometer probe starting point and extending along the plate centerline for a distance of 16 in. The linear motion potentiometer was then returned to the traverse assembly, and a trace was made along the fuel plate centerline. Figure 5.1A shows this trace with dial indicator readings superposed as points "X". The maximum error between the potentiometer trace and dial indicator readings is 0.001 in.

5.3 CALIBRATION FOR REPEATABILITY

With test plate No. 1 installed in the test rig, the plate flatness was repetitively measured for a total of five cycles, superposing one trace on the other. Figure 5.1B illustrates the repeatability of the measuring instrumentation. These traces repeat themselves to 0.0005 in.

5.4 CALIBRATION FOR RANDOM EFFECTS

A further check on the test rig and measuring equipment was made by tracing the flatness of each side of test plate No. 1. No changes were made to any of the equipment at this time other than reversing the test plate. Figure 5.1C illustrates the mirror image resulting from this phase of the calibration. It will be noted that there appear to be slight inconsistencies in what should theoretically be a mirror image.

The effects causing these inconsistencies which are applicable to the testing and accuracy of results are as follows:

1. A slight amount of force is required to maintain the potentiometer probe in contact with the plate surface. As the probe approaches the leading or trailing edge of the plate, one degree of restraint providing support to the probe is reduced. Thus for a constant probe force a greater amount of plate deflection caused by this force is expected at the ends. Experimenting with different probe forces had little effect on this condition, and a probe starting force of approximately 5 oz was found to be satisfactory.
2. The difference in stiffness between concave and convex ripples creates a small error originating from the probe force. In addition, a convex ripple as measured from the probe side of the plate tends to be pushed along by the probe. This, in turn, changes the length of the ripples slightly.
3. The thickness of the test plates is not consistent, as shown in Table 9-7. The variation is small, but the effect in some cases may result in the appearance of ripples on the trace which do not occur on the plate.

Other effects which distort the mirror image but which do not affect the results of the test are as follows:

1. Deviation of the fuel-plate support pins from a straight line. This deviation causes the plate to bow slightly.
2. Fabrication and machining tolerances which displace the fuel plate from the center of the side plate section.

5.5 CALIBRATION FOR EFFECT OF RUBBER SEALS

Silicone rubber seals were applied to Test Plate No. 1 as described in 4.2.4; and the test plate was installed in the test rig. Figure 5.1D is a potentiometer trace of the plate flatness with the rubber seals applied. Comparison of this trace with the trace of the front side of the test plate shown in Fig. 5.1C illustrates that little or no effect results from application of the seal strips when measurements are taken with 0°F temperature differential. Some change in plate stiffness may occur with increasing temperature differential. Although no attempt was made to determine the magnitude of this effect it would be expected to be negligible because of the very low modulus of the rubber.

5.6 THERMOCOUPLE SYSTEM CALIBRATION

All thermocouples were calibrated to determine the range of thermocouple readings at a given temperature and the accuracy of plate surface temperature measurements.

5.6.1 Table 9-6 shows data collected during the thermocouple system calibration. The range of thermocouple readings at a given temperature are given as Run No. 1 of the data. Absolute values of the temperatures have no major significance in this test, except as noted in Section 1.0 and 8.0; the concern is primarily with temperature differentials. The span of the thermocouple readings indicate a range of 2.5°F for a total of 24 thermocouples. All but two of the thermocouples are separated by a span of only 1.5°F.

5.6.2 Table 9-6, Runs 2 through 8 shows data collected to determine accuracy of plate surface temperatures. The test plate was installed in the test rig with water sprays to one side of the plate shut off. All thermocouples were insulated with a thin coating of silicone rubber to reduce the fin effect. Thermocouples on the "wet" side of the plate were immersed in a film of water; but they were, nevertheless, protected from direct contact with the water. The water spray pipes for the "dry" side of the plate were eliminated; therefore, the thermocouples on that side of the plate were completely "dry." Thermocouples 7, 8, 14, and 15 provide significant data in determining accuracy of plate surface temperature. Thermocouples 7 and 14 were on one side of the plate; and thermocouples 8 and 15, on the opposite side. The differences in reading between the thermocouples in each pair was 1°F maximum at equilibrium conditions.

5.7 CONCLUSIONS ON THERMAL STRESS TEST CALIBRATIONS

5.7.1 Deflection Measurements

The calibration data presented in Fig. 5.1 and the subsequent analysis of all test data indicate that deflection measurements are accurate to ± 0.002 in.

5.7.2 Temperature Measurements

The error in temperature differentials obtained from thermocouple measurements is based on the premise that regardless of the actual reading of any one thermocouple at a given temperature, the error of that reading does not change in the span 50°F to 200°F.

The maximum error in determining temperature differentials is $\pm 2-1/2^\circ\text{F}$.

Figure 5.1. Cold Calibration Curves, Test Plate No.1

6.0 TEST PROGRAM

The test program was divided into two categories.

The objective of the first category of tests was to determine the effect on ripple growth of a specific temperature distribution similar to that generated by a fuel plate of SM-1A Core II when at power and to determine the effect of initial ripple length and magnitude.

A temperature profile similar to that of the average temperature curve shown in Fig. 3.3 was imposed on each test plate, and plate centerline deflection measurements were taken for increasing and decreasing temperature differentials. In addition, deflection measurements were taken in the peak temperature region of one plate for this type of temperature profile at various temperature differentials.

The objective of the second category of tests was to determine the relationship and effect of various temperature profiles on ripple growth. This was to be done by reducing all temperature distribution data to an average temperature differential. The desired temperature distribution was such that the center portion of the plate would be maintained at a temperature equal to or higher than that of the area previously assigned the peak temperature. Test plates No. 2 and 3 were subjected to this desired temperature profile, and plate centerline deflection measurements were taken for various temperature differentials.

7.0 TEST RESULTS

Test results have been very informative in certain areas pertaining to plate ripple growth. Sufficient data has been collected to establish that (1) there is a relationship between ripple growth, length, and initial magnitude and (2) that there exists a definite dependency of these characteristics on one another and on a temperature distribution.

When comparing traces of test plate distortion, one must keep in mind the fact that there is a dimensional magnification of 100 between the Y and X axes. If the X-axis were in the same proportion to the Y-axis, the trace would be nearly 100 feet long.

7.1 DATA REDUCTION

Although a large portion of the data collected appears as curves for temperature profiles and fuel plate distortion, certain areas of investigation require that the data be further reduced for subsequent analysis and discussion.

With regard to temperature data, this reduction must necessarily occur in terms of maximum temperature differential and average temperature differential. The basis of this reduction stems from the test program requirements in that the temperature distribution or profile was changed for various portions of the test.

The definition of terms used in the subsequent analysis is as follows:

Temperature Profile - The distribution of plate surface temperature across the plate width.

Specific Temperature Profile - The distribution of plate surface temperature across the plate width whereby the temperature differences between the heated and cooled regions are maintained in the approximate proportions as shown in Fig. 3.3.

Varying Temperature Profile - The distribution of plate surface temperature whereby the temperature differences between the heated and cooled regions are not maintained in the proportions shown in Fig. 3.3. For the purposes of the tests conducted, the relationship of side plate-to-plate centerline temperature differential was maintained at a greater value than the differential of corresponding areas shown in Fig. 3.3.

Temperature Differential - The difference in temperature between any two specific areas on the plate surface.

$T_{\max} - T_{\min}$ Differential - The temperature difference between the hottest and coldest area of the plate surface, regardless of location.

Region Averaged Temperature Differential - The difference between the average temperature of the test plate hot region and the average temperature of the test plate cold region.

The temperature data presented in Table 7-1 shows the relationship for each run between $T_{\max} - T_{\min}$ and region averaged temperature differential.

Values of $T_{\max} - T_{\min}$ were selected directly from the temperature distribution curves; values of region averaged temperature differential were determined by measuring the area of the hot and cold regions under each curve with a planimeter, then subtracting the two values.

Reduction of the plate distortion curves to data applicable for determining ripple length, initial distortion, and net distortion was a difficult task because of the complexity of the curves and unknown factors such as bowing the plate. The method used to determine ripple length was one of super-imposing curves for progressive temperature differential on top of each other and mating points of inflection for individual ripples. When necessary, the plate distortion curve base line was adjusted to compensate for bowing of the test plate. This compensation was generally required for data taken at elevated temperature differentials. The definitions of terms used in the analysis are as follows:

Ripple Length - Distance between points of inflection for any given ripple.

Initial Distortion - The amplitude of a ripple when measured at 0°F temperature differential, to a line passing through the points of inflection for that ripple.

Total Distortion - The amplitude of a ripple when measured at any temperature differential, referenced to a line passing through the points of inflection for that ripple.

Net Distortion - The difference between total and initial distortion for a given ripple.

7.2 EFFECT OF INITIAL FLATNESS ON RIPPLE GROWTH

As can be seen in the traces of fuel plate distortion for all three plates tested, Fig. 7.1, 7.3, 7.5, 7.10, and 7.14, the characteristic shape of the fuel plate does not change with application of temperature differentials. It is clearly evident that the initial shape of the fuel plate is a dominant factor in determining the distortion resulting from thermal stress at any temperature differential or profile.

TABLE 7-1
TEMPERATURE DISTRIBUTION DATA REDUCED TO AVERAGE TEMPERATURE DIFFERENTIAL

<u>TEST PLATE NO.1</u> <u>FRONT SIDE (REF.FIG.7.2)</u>			<u>TEST PLATE NO.2</u> <u>FRONT SIDE (REF.FIG.7.4)</u>		
<u>Run No.</u>	<u>T_{max}-T_{min} °F</u>	<u>Avg Δ T °F</u>	<u>Run No.</u>	<u>T_{max}-T_{min} °F</u>	<u>Avg Δ T °F</u>
1	0	0	1	0	0
2	67	54	2	63	53
3	107	76	3	86	67
4	81	61	4	95	72
5	60	40	5	38	29
6	0	0	6	0	0
7	45	32	7	0	0
8	65	51	8	33	27
9	0	0	9	42	29
			10	59	47
			11	68	56
			12	77	62
			13	85	69
			14	103	86
			15	0	0
<u>TEST PLATE NO.3</u> <u>FRONT SIDE (REF.FIG.7.6)</u>			<u>TEST PLATE NO.2</u> <u>BACK SIDE (REF.FIG.7.10)</u>		
<u>Run No.</u>	<u>T_{max}-T_{min} °F</u>	<u>Avg Δ T °F</u>	<u>Run No.</u>	<u>T_{max}-T_{min} °F</u>	<u>Avg Δ T °F</u>
1	0	0	1	0	0
2	35	31	2	30	25
3	49	41	3	68	53
4	68	57	4	85	69
5	77	65	5	103	84
6	85	74	6	116	95
7	95	78	7	100	91
8	102	85	8	103	93
9	77	65	9	101	88
10	57	47	10	83	76
11	39	31	11	78	70
12	0	0	12	79	72
13	0	0	13	78	68
14	78	71	14	55	52
15	71	66	15	57	52
16	80	70	16	56	48
17	46	43	17	60	49
18	49	43	18	0	0
19	47	40			
20	46	37			
21	0	0			
<u>TEST PLATE NO.3</u> <u>FRONT SIDE, PEAK TEMPERATURE</u> <u>REGION (REF.FIG.7.14)</u>					
<u>Run No.</u>	<u>T_{max}-T_{min} °F</u>	<u>Avg Δ T °F</u>			
1	0	0			
2	45	36			
3	70	57			
4	79	62			
5	0	0			

7.3 ANALYSIS OF TEST RESULTS AS AFFECTED BY A SPECIFIC TEMPERATURE PROFILE

Figures 7.2 runs 2 through 5, 7, and 8; 7.4 runs 2 through 5, 8 through 14; 7.6 runs 2 through 11; and 7.11 runs 2 through 6 are temperature distribution profiles generated from data appearing in Tables 9-1 through 9-4 and are noted to be similar to Fig. 3.3 in that the characteristic profile has been duplicated.

Figures 7.1 runs 1 through 9; 7.3 runs 1 through 15; 7.5 runs 1-12 and 7.10 runs 1-6 are traces of fuel plate distortion resulting from thermal stresses introduced by the corresponding temperature differential seen in Fig. 7.2, 7.4, 7.6, and 7.11 as noted above.

7.3.1 Effect of Temperature Differential on Ripple Growth

Figure 7.7 is a curve of distortion versus $T_{\max}-T_{\min}$ generated from the data shown in Fig. 7.5 runs 1 through 12 and 7.6 runs 2-11. The lower curve is for an increasing differential while the upper curve represents a decreasing differential. Results indicate that the ripple growth or distortion is a linear function of temperature differential. The slight increase in distortion at 0°F temperature differential between the starting and completion of the thermal cycle is the amount of plastic deformation resulting from the thermal stress cycle. This permanent distortion varies with the initial magnitude of the ripple. In this case, the distortion is approximately 2 mils.

7.3.2 Effect of Ripple Length on Test Plate Distortion

It has been shown in Fig. 7.7 that fuel plate distortion is a linear function of the temperature differential between the cold side plate region and the heated region of the plate. Furthermore, the results indicate that the initial plate distortion is a predominant factor in the subsequent magnitude of the ripple growth. Based on these observations, it follows that the length of each half wave has a significant influence on the magnitude of net distortion. If a simple geometrical analysis were made to determine the effect of ripple length on distortion (considering simply the change in length of the plate due to thermal expansion, that is: $\Delta L = L_0 \alpha \Delta T$), it would be found that the calculated net distortion would be considerably greater than the net distortion observed from the test results. This difference may be expected because the geometrical analysis applies to a plate restrained at the extreme ends and does not consider edge restraint or the stiffness of the side plates.

Figure 7.8 shows the relationship of net distortion as a function of ripple length for a $T_{\max}-T_{\min}$ of 102°F. The approximate ratio of ripple length to ripple growth is determined to be 1.3 mils/in. of ripple.

Figure 7.9 illustrates the relationship between ripple length and initial distortion: This relationship is approximately 1.15 mils/in. of ripple. This relationship is not clearly understood, although there is evidence that the

Figure 7.1. Fuel Plate Distortion Resulting from Thermal Stresses, Front Side, Vertical Centerline, Test Plate No. 1

Figure 7.1 (Cont'd)

Figure 7.2. Test Temperature Distribution Across Width of Test Plate No. 1, Refer to Fig. 7.1 (Axial Location: 7-1/2 In. from Top of Plate)

Figure 7.2 (Cont'd)

Figure 7.3. Fuel Plate Distortion Resulting from Thermal Stresses, Front Side, Vertical Centerline, Test Plate No. 2

Figure 7.3 (Cont'd)

Figure 7.3 (Cont'd)

Figure 7.4. Test Temperature Distribution Across Width of Test Plate No. 2, Refer to Fig. 7.3 (Axial Location: 7-1/2 In. from Top of Plate)

Figure 7.4 (Cont'd)

Figure 7.4 (Cont'd)

Figure 7.5. Fuel Plate Distortion Resulting from Thermal Stresses, Front Side, Vertical Centerline, Test Plate No. 3

Figure 7.5 (Cont'd)

Figure 7.5 (Cont'd)

Figure 7.5 (Cont'd)

Figure 7.6. Test Temperature Distribution Across Width of Test Plate No. 3, Refer to Fig. 7.5 (Axial Location: 7-1/2 In. from Top of Plate)

Figure 7.6 (Cont'd)

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Figure 7.6 (Cont'd)

Figure 7.7. Total Test Plate Distortion as a Function of $T_{\max} - T_{\min}$
Temperature Differential

Figure 7-8. Net Test Plate Distortion as a Function of Ripple Length

Figure 7-9. Initial Plate Distortion as a Function of Ripple Length

assembly and fabricating techniques of fuel element sections may influence the initial length and magnitude of ripples in individual plates.

It is important to point out that Fig.7.8 and 7.9 merely indicate the trend in dependency of distortion on ripple length. The reasons for this are as follows:

1. Plastic deformation of an unknown magnitude occurs with increasing temperature differential (increasing stress) in the austenitic stainless steels. Half waves of greatest length may therefore be expected to incur a more measurable proportion of the plastic deformation.
2. The temperature differential along the axial length of the test plate was not necessarily constant due to the method of creating the temperature differential. The measured change in plate axial centerline temperature was 0.3°F per inch at a $T_{\text{max}} - T_{\text{min}}$ of 107°F .
3. As previously described, the length of each ripple must be determined by reducing the test plate distortion data. The method used to select the ripple length has an inherent error that may be significant for short ripple lengths.
4. There is some indication in the traces of test plate distortion that bowing of the test plate occurred between support pins. As a result, stresses which would normally be transferred to the plate, causing distortion, were relieved by the bowing action.

7.4 ANALYSIS OF TEST RESULTS FOR DISTORTION IN PEAK TEMPERATURE REGION

Figure 7.14 runs 1-5 are fuel plate distortion traces for the temperature differentials shown in Fig.7.15 run 2 through 4. For this test, the ripple measuring probe was moved to the left side of the traverse assembly, and measurements were taken in the center of the peak temperature region of Test Plate No.3. Although the measurements were taken in an area subjected to the maximum temperature differential, the traces indicate small ripple growth rates for an initial distortion similar to that measured along the plate centerline. This condition may be expected due to the restraint provided by the I-beam shape of the side plate and fuel plate intersection.

7.5 ANALYSIS OF TEST RESULTS AS AFFECTED BY AVERAGE TEMPERATURE DISTRIBUTION

For the purposes of this analysis, results obtained from applying differentials of specific and varying temperature distributions on Test Plate No.3 will be used. Figure 7.5, runs 8 through 12 are fuel plate distortion traces for the descending temperature differentials shown in Fig.7.6, runs 8 through 11. Figure 7.5

Figure 7.10. Sheet 1, Fuel Plate Distortion Resulting from Thermal Stresses, Back Side, Vertical Centerline, Test Plate No. 2

Figure 7.10. Sheet 2

Figure 7.10. Sheet 3

Figure 7.11. Test Temperature Distribution Across Width of Test Plate No. 2, Refer to Fig. 7.10 (Axial Location: 7-1/2 In. from Top Of Plate)

runs 14 through 21 are fuel plate distortion traces for the descending temperature differentials shown in Fig.7.6, runs 14 through 20. Temperature differential data was selected from the compilation presented in Table 7-1. Figure 7.12 is a comparison of test plate distortion as a function of $T_{\max}-T_{\min}$ differential and Fig.7.13 is a comparison of test plate distortion as a function of averaged temperature differential.

In each figure, the upper curve shows the change in distortion for the varying temperature profile and the lower curve shows the change in distortion for the specific temperature distribution. Examination of Fig.7.12 and 7.13 indicates that there is a decided difference in distortion growth rate. This difference is attributed to the change in location of the maximum compressive stress area. On Fig.7.12 and 7.13 a comparison is shown of typical temperature profiles across the plate width at an equivalent, averaged, temperature difference in one case and an equivalent, $T_{\max}-T_{\min}$, temperature difference in the other case. As can be seen in both figures, the peak temperature region for the varying temperature profile has been shifted inward toward the plate centerline as compared to the peak temperature region for the specific temperature profile.

This factor appears to be the dominant influence on the change in distortion growth rate. Carefully comparing the temperature differentials between thermocouples 5, 6, 7, 8 and 1, and 3 against the fuel plate distortion traces for Fig.7.5 runs 14 through 20, it will be seen that for any given temperature differential between peak- and side-plate temperature the smaller the differential between 5, 6, 7, 8 and 1 and 3, the smaller the distortion. This conclusion will also result by comparing similar data for Fig.7.10. In addition the differential between peak temperature and centerline temperature has been reduced for the varying temperature profile.

These two factors have resulted in a shift of the maximum compressive stress area toward the less rigidly supported center area of the plate, and a decrease in the magnitude of tensile stress in the depressed temperature region of the plate. Therefore, the net effect is to increase the distortion growth rate for comparable temperature differentials of specific and varying temperature distributions.

7.6 COMPARISON OF TEST RESULTS WITH PREVIOUSLY REPORTED RESULTS⁽¹⁾

Because of the differences of test specimen support structure, method and control of plate surface temperatures, and physical characteristics of test specimens, precise comparisons between test results presented in this report against the results previously reported in APAE Memo 239 are not practical. There are, however, several observations which may be made indicating areas of agreement:

1. All test data to date indicate that the characteristic shape of the test plate does not change with applied temperature differentials.

2. All test data to date indicate that ripple growth rate is nearly constant with an increase in temperature differential for the range experienced in the tests.
3. All test data to date indicate a linear relationship between ripple growth and ripple length.
4. All test data to date indicate a basic relationship, not completely understood between initial ripple magnitude and ripple length.

One area of basic disagreement between the test results is the function of temperature profile in relation to fuel plate distortion. Previous tests ⁽¹⁾ were conducted with primary emphasis on duplicating average temperature differences and assumed that the effects of a specific temperature profile occurring in the fuel plates were negligible.

The emphasis of the current test program has been to duplicate the actual reactor fuel plate temperature profile as accurately as possible. The results of this testing has indicated that a change in profile from the conventional peaked profile to any other profile (previously defined as varying temperature profile) may result in distortions 25 percent or more greater than actually occurs in a reactor fuel plate. As a further consequence, comparison of distortion data as a function of length or initial distortion will indicate this same conservatism.

- x Figure 7-5 Runs 8-12
 ● Figure 7-5 Runs 14-21

Figure 7.12 Total Test Plate Distortion as a Function of $T_{\max} - T_{\min}$ Temperature Differential

- x Figure 7-5 Runs 8-12
- o Figure 7-5 Runs 14-21

Figure 7.13 Total Test Plate Distortion as a Function of Average Temperature Differential

Figure 7.14. Fuel Plate Distortion Resulting from Thermal Stresses, Front Side, Peak Temperature Region, Left Side Test Plate No. 3

Figure 7.15. Test Temperature Distribution Across Width of Test Plate No. 3, Refer to Fig. 7.14 (Axial Location: 7-1/2 In. from Top of Plate)

8.0 CONCLUSIONS AND RECOMMENDATIONS

The conclusions reached from the analysis of the data collected during thermal stress testing of test plates augment the conclusions presented in APAE Memo No. 239(1) and in general add to their validity because the results of all tests to date are similar. The conclusions are as follows:

1. Varying the temperature profile or the temperature differential does not change the characteristic shape of the flatness curve of the test plate.
2. The increase in ripple growth is a linear function of increasing temperature differential within the differential range of the test (116°F max). The slight change in ripple growth at the higher differential may be attributed to normal plastic deformation characteristic of austenitic stainless steels.
3. The growth rate of a ripple with an initial amplitude of 7.5 mils is approximately 0.12 mils/°F for a temperature differential range of 0 to 103°F.
4. The permanent distortion measured for one complete temperature cycle (0°F to 103°F to 0°F differential) is 2.0 mils. (Note: Because the absolute test temperatures are significantly less than reactor operating temperatures, this conclusion may not be applicable to fuel plates in the reactor.)
5. A definite relation exists between ripple growth (δ) and ripple length (L). The approximate ratio is 1.3 mils/in. of ripple, at 103°F temperature differential. A similar relationship exists between initial distortion and ripple length, the ratio of which is approximately 1.15 mils/in. of ripple.
6. The temperature profile across the plate width affects the magnitude of ripple growth. It appears that the nearer to the center of the plate the peak temperature occurs, the greater the distortion for a given temperature differential.

Although significant information has been collected on a single test plate, simply supported in the test rig, several areas of ripple growth warrant further investigation:

1. There is some question as to the effect of temperature profile on ripple growth. Indications are that shifting the peak temperature region nearer the center of the plate results in greater ripple growth for a given temperature differential. Further testing of single test plates

should be considered with a wider latitude of temperature profiles consistent with those of a reactor fuel plate during various phases of burn-up. Information of this nature may prove invaluable in understanding the overall ripple growth problem during the lifetime of a reactor fuel plate.

2. The effect of side plate restraint on ripple growth for a single plate is unknown. Further testing of single test plates without the side plate section attached would provide the basic data required to evaluate this effect.
3. The total effect of collective plates attached to common side plate sections is unknown. Further testing with a multi-plate section, preferably investigating the outer fuel plate of a fuel element section would yield the required data needed to evaluate this effect.

As outlined in AP Note 378⁽²⁾, testing of a multi-plate section is scheduled for the second half of fiscal year 1962.

9.0 DATA SHEETS

TABLE 9-1
DATA SHEET NO. 1, TEST PLATE NO. 1, FRONT SIDE, VERTICAL CENTERLINE DEFLECTION MEASUREMENTS
(Refer To Figs. 7.1, 7.2)

Thermocouple No.	Temperature - °F																	
	Run 1	Run 2	Run 3	Run 4	Run 5	Run 6	Run 7	Run 8	Run 9	Run 10	Run 11	Run 12	Run 13	Run 14	Run 15	Run 16	Run 17	Run 18
1	49	53	56	55	53	50	62	65	60									
2	49	53	56	55	53	50	62	65	60									
3	49	53	56	54	53	50	62	65	60									
4	49	53	56	54	53	50	62	65	60									
5	53	120	162	136	113	52	107	130	60									
6	53	120	163	136	113	52	107	130	60									
7	-	-	-	-	-	-	-	-	-									
8	53	118	160	133	112	52	107	129	60									
9	53	118	160	133	112	52	107	129	60									
10	-	-	-	-	-	-	-	-	-									
11	52	118	161	134	112	52	107	129	60									
12	51	113	146	121	98	52	98	120	60									
13	52	110	138	118	95	52	96	119	60									
14	51	109	136	117	93	52	96	119	60									
15	51	109	136	117	94	52	96	119	60									
16	51	109	139	118	96	52	96	120	60									
17	51	110	143	117	94	52	97	118	60									
18	51	108	135	117	93	52	95	118	60									
19	51	104	128	112	90	52	95	112	60									
20	51	107	132	114	90	52	93	114	60									
37 Hot Water Front	52	122	167	138	117	-	109	130	60									
38 Cold Water	49	149	49	49	49	50	58	60	60									
39 Hot Water Back	52	122	167	138	117	-	109	130	60									
40 Warm Water	51	106	133	117	92	52	97	117	60									

TABLE 9-2
DATA SHEET NO. 2, TEST PLATE NO. 2, FRONT SIDE, VERTICAL CENTERLINE DEFLECTION MEASUREMENTS
 (Refer To Figs. 7.3, 7.4)

Thermocouple No.	Temperature - °F																	
	Run 1	Run 2	Run 3	Run 4	Run 5	Run 6	Run 7	Run 8	Run 9	Run 10	Run 11	Run 12	Run 13	Run 14	Run 15	Run 16	Run 17	Run 18
1	68	64	59	66	62	59	74	57	62	63	64	65	66	56	50			
2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-			
3	68	64	59	66	62	59	74	57	62	63	65	66	67	57	50			
4	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-			
5	68	127	145	161	100	50	74	90	104	122	132	142	151	159	51			
6	68	127	145	161	100	50	74	90	104	122	132	142	151	159	51			
7	68	127	145	161	100	50	74	90	104	122	132	142	151	159	51			
8	68	127	145	161	100	50	74	90	104	122	132	142	151	159	51			
9	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-			
10	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-			
11	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-			
12	68	120	130	140	92	50	74	85	92	113	124	132	138	149	51			
13	68	120	130	140	92	50	74	85	92	113	124	132	138	149	51			
14	68	120	130	140	92	50	74	85	92	113	124	132	138	149	51			
15	68	120	130	141	92	60	74	85	92	113	124	132	138	149	51			
16	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-			
17	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-			
18	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-			
19	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-			
20	68	114	125	134	91	61	74	83	90	110	120	126	133	143	52			
37 Hot Water Front	68	127	148	165	101	60	-	91	106	124	134	145	154	163	52			
38 Cold Water	68	58	50	58	58	59	-	53	57	59	60	60	60	50	50			
39 Hot Water Back	68	127	148	165	101	60	-	91	106	124	134	145	154	163	52			
40 Warm Water	68	122	130	141	90	60	-	84	91	114	125	133	140	151	151			

TABLE 9-3
DATA SHEET NO. 3, TEST PLATE NO. 3, FRONT SIDE, VERTICAL CENTERLINE DEFLECTION MEASUREMENTS
(Refer To Figs. 7.5, 7.6)

Thermocouple No.	Temperature - °F																				
	Run 1	Run 2	Run 3	Run 4	Run 5	Run 6	Run 7	Run 8	Run 9	Run 10	Run 11	Run 12	Run 13	Run 14	Run 15	Run 16	Run 17	Run 18	Run 19	Run 20	Run 21
1	65	53	54	55	56	57	57	58	56	55	53	50	60	60	55	53	60	60	60	60	60
2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	60	-	60	-
3	65	53	54	55	56	57	57	58	56	55	53	50	60	62	56	55	62	61	60	60	60
4	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
5	65	88	103	123	133	142	152	160	133	112	92	50	60	136	122	98	107	99	88	81	60
6	65	88	103	123	133	142	152	160	133	112	92	50	60	136	122	98	107	99	88	81	60
7	65	88	103	123	133	142	152	160	133	112	92	50	60	136	122	100	107	99	88	83	60
8	65	88	103	123	133	142	152	160	133	112	92	50	60	136	122	98	107	99	88	81	60
9	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
10	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
11	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
12	65	85	97	115	125	134	140	149	126	105	86	50	60	137	136	133	109	108	106	105	60
13	65	85	97	115	125	134	140	149	126	105	86	50	60	137	136	133	109	108	106	105	60
14	65	85	97	115	124	134	138	149	126	105	86	50	60	137	136	135	109	108	108	106	60
15	65	85	97	115	125	135	140	150	127	105	86	50	60	137	136	131	109	108	106	104	60
16	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
17	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
18	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
19	65	82	91	112	120	130	134	144	122	102	84	52	60	128	128	127	105	104	104	103	60
20	65	85	94	112	120	130	134	144	122	102	84	52	60	132	133	132	107	106	106	105	60
37 Hot Water Front	65	90	105	126	136	145	156	165	136	114	95	50	60	140	124	100	110	100	88	58	60
38 Cold Water	65	50	50	50	50	50	50	50	50	50	50	50	60	55	50	50	57	57	57	81	60
39 Hot Water Back	65	90	105	126	136	145	156	165	136	114	95	50	60	140	124	100	110	100	88	81	60
40 Warm Water	65	85	96	115	125	135	139	150	126	104	85	50	60	140	140	140	110	110	111	110	60

TABLE 9-4
DATA SHEET NO. 4, TEST PLATE NO. 2, BACK SIDE, VERTICAL CENTERLINE DEFLECTION MEASUREMENTS
(Refer to Figs. 7.10, 7.11)

Thermocouple No.	Temperature - °F																	
	Run 1	Run 2	Run 3	Run 4	Run 5	Run 6	Run 7	Run 8	Run 9	Run 10	Run 11	Run 12	Run 13	Run 14	Run 15	Run 16	Run 17	Run 18
1	74	57	56	57	57	58	56	55	55	55	55	54	53	54	53	52	51	50
2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
3	74	57	63	57	57	58	56	55	55	55	55	54	53	54	53	52	51	50
4	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
5	74	87	124	141	160	172	146	137	125	136	123	116	99	107	97	81	67	50
6	74	87	124	141	160	172	146	137	125	136	123	116	99	107	97	81	67	50
7	74	85	118	142	161	174	147	138	125	137	124	116	99	108	97	81	67	50
8	74	85	118	142	160	174	146	137	125	136	124	116	99	107	97	81	67	50
9	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
10	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
11	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
12	74	84	112	130	146	153	156	158	156	137	133	133	130	109	109	106	108	50
13	74	84	112	130	146	153	156	158	156	137	133	133	130	109	109	106	108	50
14	74	84	112	131	147	153	156	158	156	137	133	133	130	109	109	106	108	50
15	74	84	112	131	147	160	156	158	156	137	133	133	130	109	109	106	108	50
16	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
17	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
18	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
19	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
20	74*	83*	105*	124*	142*	153*	150*	152*	151*	132*	129*	130*	129*	107*	109*	107*	110*	50
37 Hot Water Front	-	88	128	145	164	173	149	140	127	139	125	118	99	110	99	82	67	50
38 Cold Water	-	53	50	51	50	48	48	48	48	49	49	49	49	50	50	50	49	50
39 Hot Water Back	-	88	128	145	164	178	149	140	127	139	125	118	99	110	99	82	67	50
40 Warm Water	-	84	112	131	149	162	162	164	163	140	136	137	136	110	112	109	113	50

* Extrapolated from previous data.

TABLE 9-5
DATA SHEET NO. 5, TEST PLATE NO. 3
FRONT SIDE, DEFLECTION MEASUREMENTS TAKEN VERTICALLY
DOWN PEAK TEMPERATURE REGION,
LEFT SIDE OF PLATE
(Refer To Fig. 7.14, 7.15)

Thermocouple No.	Temperature - °F				
	Run 1	Run 2	Run 3	Run 4	Run 5
1	68	61	60	68	64
2	-	-	-	-	-
3	68	61	61	68	64
4	-	-	-	-	-
5	68	106	130	147	64
6	-	-	-	-	-
7	68	106	130	145	64
8	68	106	129	145	64
9	-	-	-	-	-
10	-	-	-	-	-
11	-	-	-	-	-
12	68	100	119	135	64
13	68	100	119	135	64
14	68	100	118	133	64
15	68	100	119	134	64
16	-	-	-	-	-
17	-	-	-	-	-
18	-	-	-	-	-
19	68	95	113	124	64
20	68	96	115	128	64
37 Hot Water Front	68	108	133	149	64
38 Cold Water	68	59	54	61	64
39 Hot Water Back	68	108	133	149	64
40 Warm Water	68	100	120	134	64

TABLE 9-6
DATA SHEET NO. 6
TEMPERATURE CALIBRATION DATA

Thermocouple No.	Temperature - °F							
	Run 1	Run 2	Run 3	Run 4	Run 5	Run 6	Run 7	Run 8
1	61.5	55	55	64	65	66	67	68
2	62	-	-	-	-	-	-	-
3	62	56	56	65	66	67	68	69
4	62	-	-	-	-	-	-	-
5	62	87	97	117	126	135	145	150
6	62	-	-	-	-	-	-	-
7	-	87	97	116	126	135	146	151
8	62	87	97	116	125	134	145	150
9	62	-	-	-	-	-	-	-
10	-	-	-	-	-	-	-	-
11	62	-	-	-	-	-	-	-
12	62.5	86	96	112	121	130	144	149
13	63	-	-	-	-	-	-	-
14	63	85	95	111	120	129	135	140
15	63	85	95	112	121	130	137	142
16	63	-	-	-	-	-	-	-
17	63	-	-	-	-	-	-	-
18	63	-	-	-	-	-	-	-
19	64	81	89	102	109	116	122	127
20	64	82	92	116	114	122	130	136
37 Hot Water Front	61.5	90	99	120	130	139	150	155
38 Cold Water	63	53	52	59	59	60	60	61
39 Hot Water Back	62	-	-	-	-	-	-	-
40 Warm Water	62	85	94	111	120	129	135	140

TABLE 9-7
DATA SHEET NO.7
DIMENSIONS OF TEST PLATES (REFER TO FIGURE 9.1)

Test Plate No.1

Posit. on Plate	Location (Dimensions in Inches)											
	A	B	C	D	E	F	H		L	W	Z	
							Left	Right				
Top	Average Thickness .052	2.741	5/32	15/32	3/8	1/16	.158	.164	23	2.845	.0289	
1"		2.748					.157	.165		2.852	.0298	
2"							.156	.163		2.852	.0301	
3"							.156	.164		2.846	.0301	
4"							.157	.163		2.838	.0302	
5"							.157	.163		2.835	.0301	
6"							.157	.162		2.837	.0301	
7"							.156	.164		2.841	.0300	
8"							.157	.163		2.846	.0300	
9"			2.741					.157	.165		2.845	.0300
10"								.156	.161		2.843	.0301
11"								.156	.161		2.841	.0300
12"								.156	.161		2.839	.0303
13"								.157	.161		2.839	.0301
14"								.157	.161		2.840	.0301
15"								.157	.161		2.839	.0301
16"								.156	.161		2.838	.0302
17"								.156	.161		2.836	.0302
18"								.156	.161		2.836	.0301
19"								.156	.161		2.842	.0302
20"								.156	.161		2.849	.0302
21"			2.752					.155	.160		2.856	.0302
22"								.155	.161		2.858	.0293
Bottom		2.745					.154	.160		2.847	.0294	

TABLE 9-7 (CONT'D)

Test Plate No.2

Posit. on Plate	Location (Dimensions in Inches)										
	A	B	C	D	E	F	H		L	W	Z
							Left	Right			
Top	Average Thickness .053	2.734	5/32	15/32	3/8	1/16	.161	.162	23	2.848	.0285
1"							.161	.161		2.850	.0296
2"							.161	.161		2.848	.0299
3"							.160	.161		2.842	.0299
4"							.161	.161		2.836	.0299
5"							.161	.162		2.835	.0299
6"							.161	.161		2.836	.0301
7"							.162	.161		2.839	.0298
8"							.162	.161		2.842	.0298
9"							.162	.161		2.842	.0299
10"							.162	.161		2.841	.0299
11"							.161	.161		2.840	.0298
12"							.162	.161		2.839	.0299
13"							.162	.161		2.839	.0300
14"							.162	.162		2.839	.0300
15"							.161	.163		2.838	.0300
16"							.161	.161		2.836	.0299
17"							.162	.162		2.835	.0303
18"							.162	.161		2.836	.0302
19"							.163	.161		2.840	.0302
20"							.163	.161		2.848	.0301
21"							.163	.161		2.856	.0301
22"							.164	.161		2.856	.0299
Bottom								.165	.160		2.848

TABLE 9-7 (CONT'D)

Test Plate No.3.

Posit. on Plate	Location (Dimensions in Inches)										
	A	B	C	D	E	F	H		L	W	Z
							Left	Right			
Top	.0532	2.734	5/32	15/32	3/8	1/16	.166	.166	23	2.843	.0289
1"	Average Thickness .053	↓	↓	↓	↓	↓	.164	.164	↓	2.845	.0300
2"							.163	.162		2.844	.0303
3"							.163	.162		2.838	.0302
4"							.163	.162		2.833	.0304
5"							.163	.162		2.832	.0304
6"							.163	.162		2.834	.0303
7"							.163	.162		2.837	.0304
8"							.163	.162		2.837	.0303
9"							.163	.162		2.838	.0304
10"							.163	.162		2.838	.0303
11"							.164	.164		2.838	.0302
12"							.164	.163		2.838	.0303
13"							.163	.163		2.837	.0302
14"							↓	.163		2.837	.0303
15"								.163		2.834	.0303
16"								.163		2.833	.0303
17"								.163		2.833	.0302
18"								.163		2.834	.0303
19"								.163		2.837	.0302
20"								.162		2.845	.0303
21"								.161		2.851	.0303
22"								.161		2.853	.0299
Bottom	↓	↓	↓	↓	↓	.161	↓	2.848	.0322

Figure 9.1. Key for Locating Test Plate Dimensions
(Refer to Table 9-7)

10.0 REFERENCES

1. Christenson, J.A., "Thermal Stress Testing of SM-2 Fuel Elements, Interim Report, January 1, 1959 to January 1, 1960," APAE Memo No. 239, February 9, 1960.
2. Brown, W.S., Dixon, M.H., "Fiscal Year 1962 Program Plan for Engineering Support and Development of Army Pressurized Water Reactor Power Plants," AP Note 378, September 6, 1961.
3. Meyer, J.E., "The HOC Code," CPM-M-105, March 17, 1958.

APPENDIX A - PROPOSED MULTI-PLATE TESTING OF TYPE 1 FUEL PLATES

APPENDIX A

1.0 TEST REQUIREMENTS FOR MULTI-PLATE RIPPLE GROWTH MEASUREMENTS

1.1 Objective

The objective of the multi-plate test will be to obtain ripple measurements on the outer fuel plate to determine the effect of the restraints imposed by the side plate and internal fuel plates. This effect can then be determined by comparing the data with the previous single plate test results.

To obtain the desired restraint, a minimum of four fuel plates will be required to simulate a fuel element. (Measurements will be made on the outer plates only.) A full section of a rejected SM-1A Core II brazed element is available for the test, including an outer (27 in.) plate.

1.2 Structural Support

Since the side plate and internal fuel plates are to provide the restraint for the outer plate, it is only necessary to clamp the element in a manner to assure firm support. Figure A.1 is a schematic representation of the test rig.

1.3 Thermal Characteristics

As in the single plate test, a temperature profile simulating the SM-1A gradient (Fig. A.1) will be imposed on the element. In the event that technical difficulties make it impossible to provide such a distribution on the internal plates, the necessary distribution will be imposed on the outer plates and a nominal distribution with approximately the same average value will be maintained on the inner plates.

Water seals between heated and cooled portions of the plate will be maintained with silicon rubber strips of minimal dimensions. Figure A.1 schematically shows the method which will be used to obtain the desired flow channels in the assembly.

1.4 Measurements Required

Basic. Continuous plate ripple measurements should be made along the centerline of the outer plate for temperature differentials similar to those obtained on the single plate test. Temperature differentials of from zero to 125°F will be used in the test. (Heating to be done over the 22 in. fuel length only.)

Additional. If time is available at the completion of test, a measurement of the lateral profile should be attempted at the point of maximum deflection so that the variation in deflection across the plate can be determined. These measurements should be made at similar temperature differentials.

C = Cold Water Channel
H = Hot Water Channel
W = Warm Water Channel

Figure A.1. Cross Section of Multi-Plate Test Assembly (Subtask 3.9)

A cold measurement should be taken at the beginning and end of each series of tests to assure support stability has been maintained.

1.5 Data Presentation

For comparison purposes, results of the test should be presented in the same form as in the single plate test. This will include

1. Continuous centerline measurements at each temperature differential.*
2. Graphs showing deflection as a function of temperature differentials (max and average values).
3. Deflections as a function of initial imperfection and temperature differentials.

2.0 RECOMMENDATION FOR TESTING

2.1 General Test Method

It is recommended that the basic thermal stress test rig, as designed for subtask 3.9, be used to accomplish the test with appropriate modifications. An assembly drawing of this rig appears in the main body of this report as Fig. 4.1.

The method of measuring ripple growth should be with the existing equipment, consisting of C1C potentiometers, Models 111 and 7810 and with a Pace Variplotter Model 1100E. By using this equipment, inherent instrument errors will be duplicated in the multi-plate test, making evaluation of test results compatible with the results of this report.

The general method of imposing the temperature profile across the plates should be with varying temperature water films.

2.2 Specific Recommendations for Rig Modifications

Due to the increased length (22 in. to 27 in.) of the test section, the test rig must be increased in height. In order to do this, it is recommended that the four corner posts or supports, appearing as pc. no. 3 of Dwg.D9-50-1283 Rev. B (Fig.4.1), be replaced by 4 metal tubes of the correct increased length, with threaded draw bolts extending through the upper and lower plates and tubes. In addition, the two guide rods pc. nos. 4 and 38 of Dwg.D9-50-1283 Rev. B, should be replaced by Thomson Industry 60 Case - Class L guide rods 3/4 diam x correct length of about 30-32 in.

* Measurements to be made over the 22 in. fuel length only.

Changes recommended for the fuel plate support assemblies pc. nos. 24 and 36 and top plate pc. no. 2 of Dwg. D9-50-1283 are shown in Fig. A.2. It is recommended that only three support pins be used in each fuel plate support assembly.

It is also recommended that the drain for the rig be placed through the base plate.

2.3 Specific Recommendations for Multi-Plate Test Specimen

The Alco General Laboratory has developed what appears to be a satisfactory method of baffling the channels in the multi-plate test specimen. This method involves molding silicone rubber strips approximately $1/8 \times 1/8 \times 23$ in. long with a string potted through the center of the strip. These strips can be drawn through the channel and become snug against opposing plates. Four strips in each channel will provide the required paths for supplying the heated water to the fuel plates. Silicone rubber strips should be molded to the outer fuel plates to provide seals for the cold water. This is shown in Fig. A.2. It is not recommended that the channels be filled with water due to the hydrostatic forces which will occur at the base of the test section.

Figure A.2. Modification to Top Plate (Scale 2X)