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A CORROSION STUDY OF WELDED STAINLESS STEEL FUEL ELEMENTS

By

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ABSTRACT

This report covers fuel element corrosion studies conducted from April, 1959 through July, 1960, designed to aid in selecting and evaluating SM-2 fuel element welding techniques. Tests on type 347 ss plate type fuel elements welded by the selected tungsten inert gas technique showed good corrosion integrity of specimens under a variety of conditions including a 500-hr test under simulated SM-2 conditions of flow and coolant chemistry.

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TABLE OF CONTENTS

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LIST OF ILLUSTRATIONS

LIST OF ILLUSTRATIONS (CONT'D)

LIST OF TABLES

1.0 SUMMARY

This report covers fuel element corrosion testing performed in conjunction with SM-2 Task 5, Fuel Element Welding Development.

Corrosion tests of tungsten inert gas (TIG) and resistance welded Type 347 ss plate type fuel elements were conducted in degassed neutral water under saturated steam conditions at 635°F. Both types of welds appeared to have adequate resistance to general surface attack.

In testing of sound TIG welds, cracking was not produced by submerged thermal cycling, 635°F aqueous corrosion, boiling 40% Mg Cl_2 or boiling 65% nitric acid. No evidence of crevice corrosion was found in TIG welds.

A dynamic corrosion test was performed on a TIG welded element made with annealed fuel plates containing depleted uranium. Adequate corrosion resistance was maintained during a 500-hr exposure to simulated SM-2 coolant.

2.0 INTRODUCTION

This study was undertaken to determine the resistance of welded fuel elements to corrosive attack under SM-2 operating conditions in order that operational corrosion integrity could be established. Work under Phase 1 consisted of static autoclave testing, to aid in selection of the best welding technique. Phase 2 work, utilizing the selected welding technique, involved several types of corrosion tests including a dynamic test under simulated SM-2 temperature, flow, and water chemistry conditions.

The SM-2 coolant will be high purity deaerated water of nominally neutral pH. Hydrogen will be added primarily to control the dissociation of water under flux (1) as shown by the following equation:

$$H_2O \underset{\gamma}{\overset{n^\circ}{\rightleftharpoons}} H_2 + 1/2\ O_2$$

Hydrogen also prevents an acid pH occurring in the event that nitrogen (air) is accidentally introduced into the primary system. In the absence of radiation and where oxygen is maintained at low levels, hydrogen probably has no appreciable inhibiting effect on corrosion of stainless steel. (1) Therefore, because of the difficulty in maintaining hydrogen in a static autoclave no hydrogen was added to the water during the corrosion tests described herein.

Coolant flow in the SM-2 varies from element to element. The maximum flow rate was selected for the dynamic study since it is probably the more severe from a corrosion standpoint. (2)

2.1 CORROSION OF TYPE 347 STAINLESS STEEL

Type 347 ss is a corrosion resistant alloy (See Appendix I) stabilized with Cb to inhibit sensitization. Stainless steel (Type 347) corrodes uniformly at a maximum rate of 0.4 mils/yr in high purity water at temperatures up to 600°F. (3) Slight pitting of Type 347 ss at 650°F under dynamic (flowing) conditions is reported. (4) Crevice corrosion is probably not a problem (in non-moving parts) if oxygen is kept below 0.15 ppm. (5) The effect of nascent oxygen in flux zones is not known. Type 347 ss may be more susceptible to stress corrosion than type 304 ss. (6) The above statements apply generally to rolled sheet in either the cold-worked or annealed condition.

The severe local heating of the weld zone may affect the local corrosion resistance. The high residual stresses present due to welding may make the material subject to stress corrosion.

The corrosion study herein described used the above information as a guide in design of tests and in analysis of the test results.

2.2 WELDING TECHNIQUES

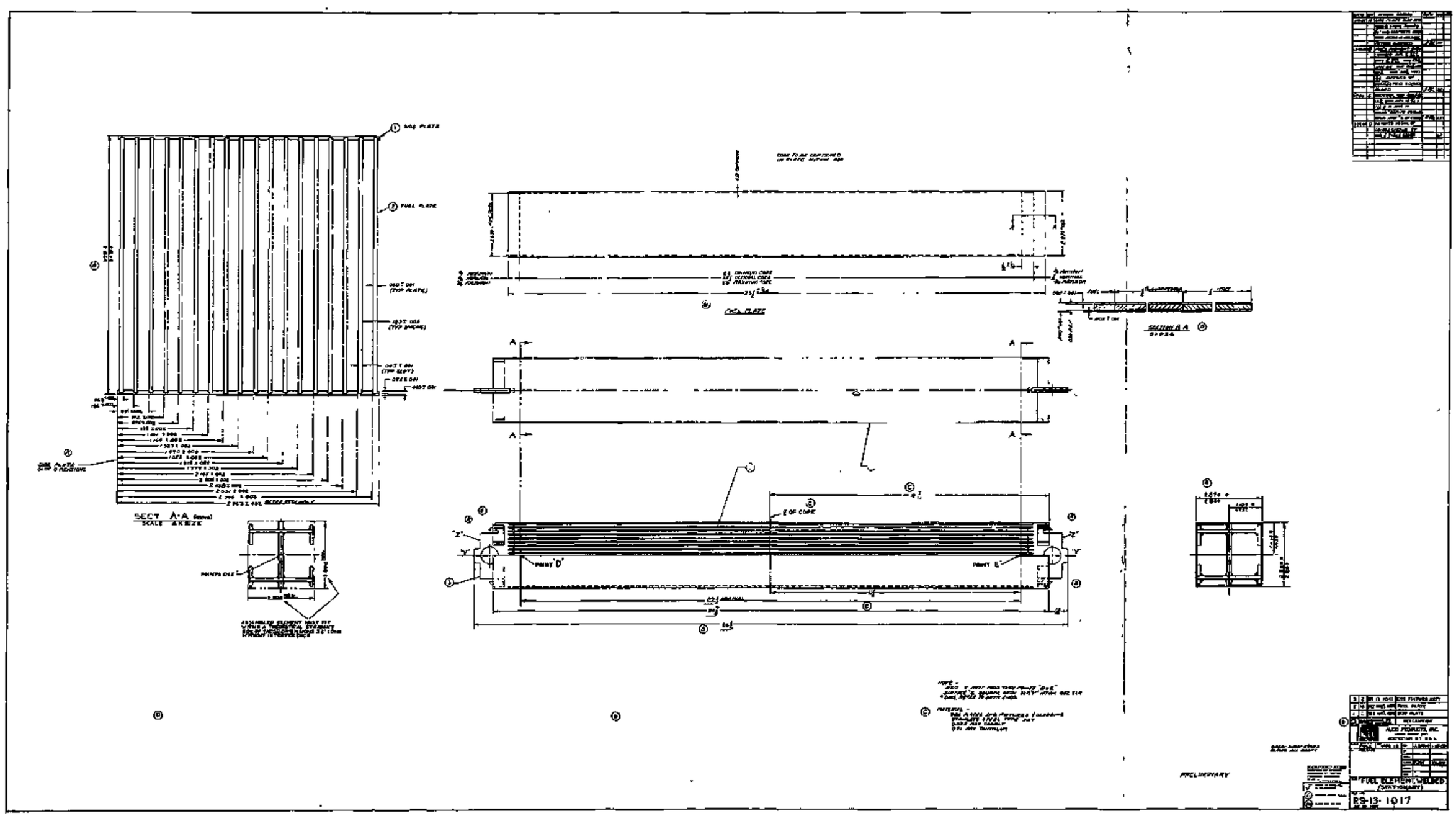
The technique of welding offers the following advantages over brazing of fuel elements:

1. Lower manufacturing equipment costs.
2. Fewer fabrication steps, also resulting in lower costs.
3. Faster production.
4. Improved tolerances in the finished element.
5. More control during production because each weld is individually done.
6. Dead edge width requirement is reduced, providing better heat and flux distribution.

A preliminary drawing of the SM-2 fuel element design is shown in Fig. 2.1 (Dwg. R9-13-1017). Eighteen fuel plates are joined by welding to two side plates. Two welding techniques were investigated, resistance welding and tungsten inert gas (TIG) welding. Fuel element design differed in certain minor aspects, depending on the intended welding technique.

With the resistance welding process, the side plates were given a series of transverse crimps and the welding took place at the junction of the edges of the fuel plates and the apex of the crimps (Fig. 2.2). The weld itself was generally a small spot with a heat affected area of up to 1/8-in. With the TIG welding process, the side plates were slotted longitudinally. The fuel plate was fitted into the slots and a series of equally spaced welds, formed by fusing thru the side plate at the bottom of of the slots, joined the fuel plates to the side plates (Fig. 2.3). One-half inch long welds have been used to date. The heat affected area was as wide as 1/8 in.

This sideplates used in Phase 1 testing were 0.030 in. thick; those during Phase 2 were 0.040 in. thick. All elements were constructed entirely of solid type 347 ss (except for the dynamic test in which type 347 ss clad fuel plates contained depleted uranium oxide dispersion).


SECT A-A
SCALE 4X SIZE
SECTION A-A
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PRELIMINARY
FUEL ELEMENT, WELDED
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RS-13-1017

Fig. 2.1

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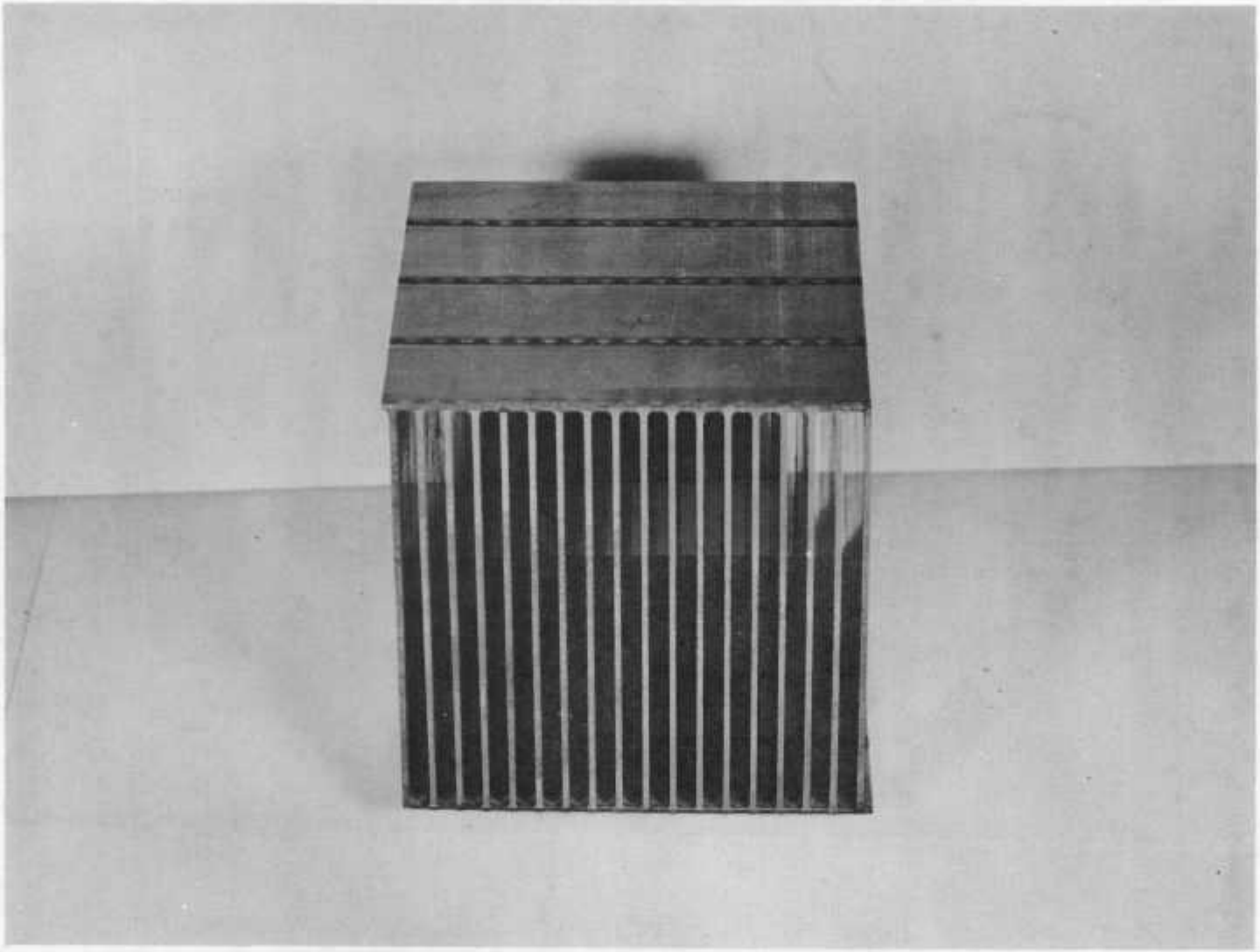

Fig. 2. 2 - Segment of Resistance Welded Element

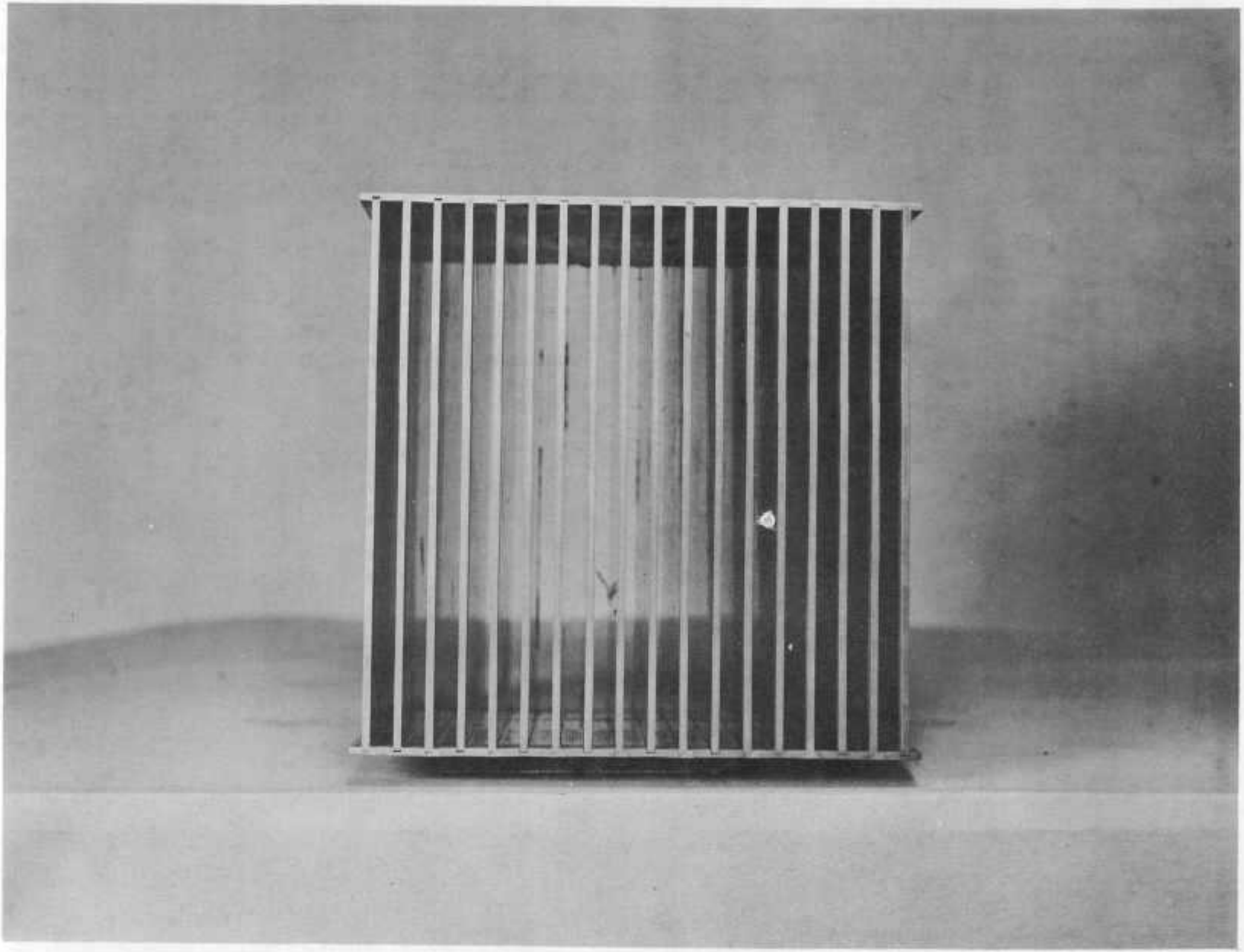

Fig. 2. 3 - Segment of T. I. G. Welded Element

3.0 EXPERIMENTAL WORK

Corrosion testing of the welded fuel elements was designed to determine susceptibility to the various types of corrosion discussed in Section 2.1. During Phase I, general corrosion integrity of the welds was investigated in static autoclaves. Phase 2 involved more detailed investigations of several types of corrosive effects on the elements welded by the selected technique.

3.1 TEST EQUIPMENT

Initial tests were conducted in stainless steel autoclaves equipped with strap-on external heaters. Figure 3.1 is a view of a 5 in. by 40 in. autoclave with its control panel. This autoclave could accommodate a full length element. A temperature gradient was found to exist in this autoclave. The bottom operated approximately 80°F cooler than the set point while 8 in. from the bottom the temperature equalled that of the control point. It is believed that convection currents were adequate to maintain an even temperature except for the cold pocket extending about 8 in. upward from the bottom. A smaller 5 by 12 in. autoclave of similar construction and with similar auxiliary equipment was also used. No significant thermal gradient existed in this smaller autoclave but only half length elements could be accommodated in it.

A high pressure loop capable of maintaining 550°F and 2000 psi was used for the dynamic test (Fig. 3.2). The loop was equipped with a bypass purification system for maintaining water purity. The mixed bed resin also served as a filter for removing suspended crud. The loop water was degassed by boiling before start of testing. It was possible by this method to reduce oxygen to less than 70 parts per billion (ppb). Makeup water was passed through a copper deoxygenating resin. During the actual test, oxygen levels could be held below 5 ppb.

The dynamic corrosion test was conducted simultaneously with a rod drop life test. The flow requirements for the two tests differed in that a constant flow was desired in the corrosion test section while the rod drive section required various flows. By suitable manipulation of valves, both flow requirements could be satisfied except for brief fluctuations while adjusting the valves.

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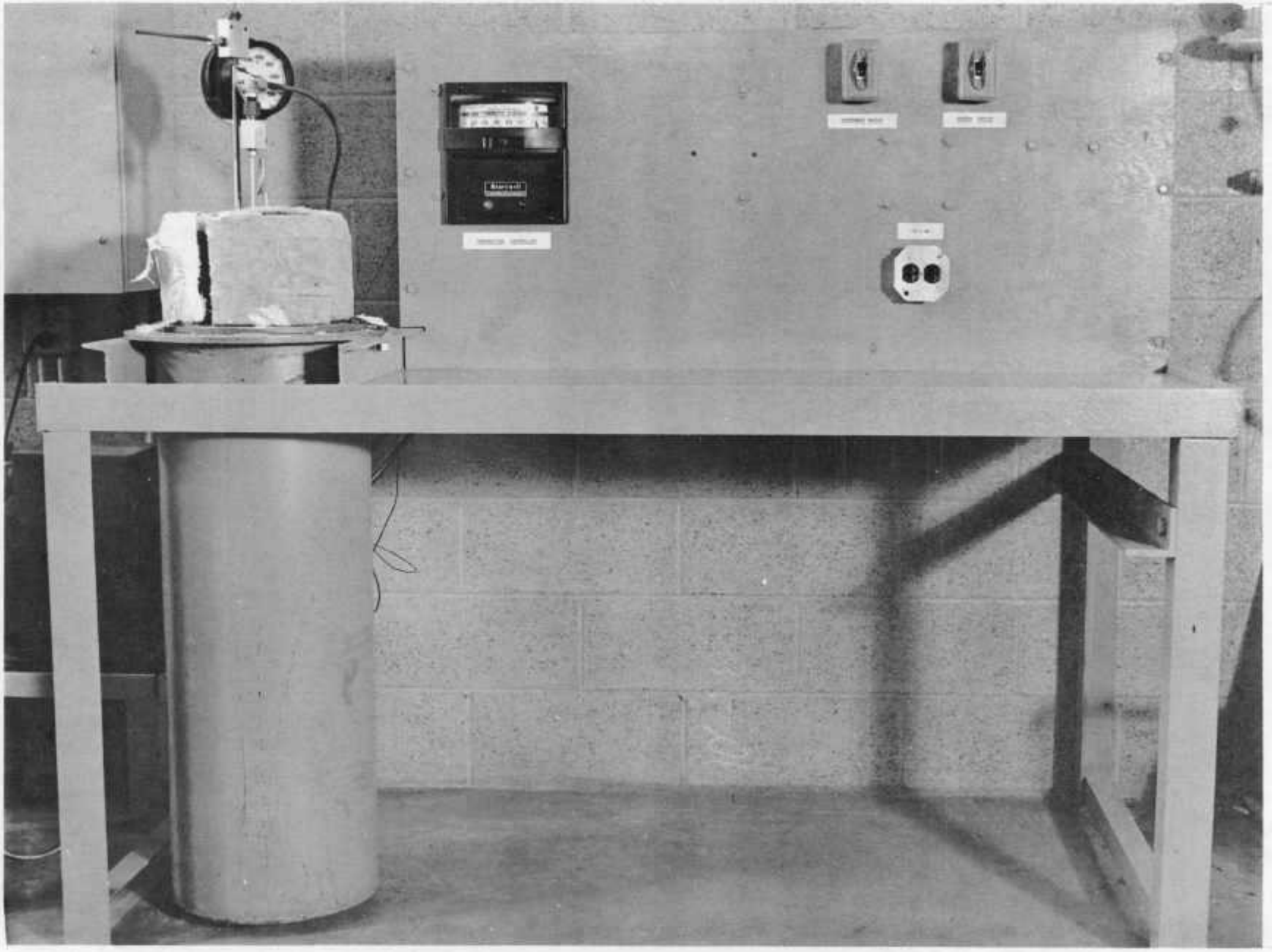

Fig. 3.1 - Large Autoclave and Associated Equipment

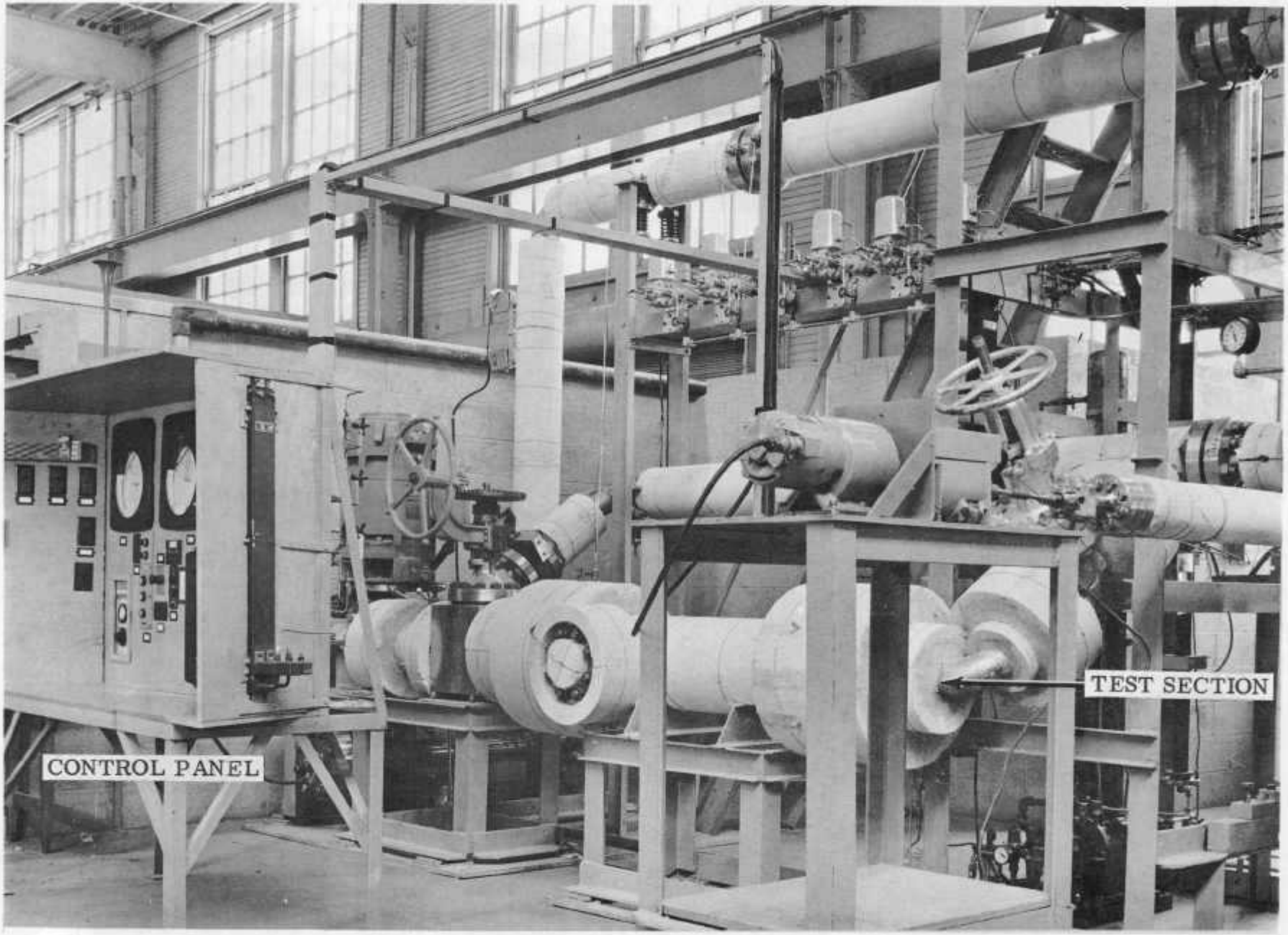

Fig. 3. 2 - High Pressure Corrosion Test Loop

The desired flow through the test section was set by the maximum fuel element flow of 320 gpm in the SM-2 core. There was 5% leakage around the corrosion test element. The total flow required through the test section, therefore, was the sum of the 320 gpm internal flow plus the 5% (16 gpm) external flow, or a total of 336 gpm. The flow was measured by pressure drop across the entire test section including the losses due to the specimen mounting brackets and flow directing baffles. The pressure sensing points were located at the inlet and outlet flanges to the section. The flow was calibrated against the main flow orifice meter at 250°F. The actual test temperature was 550°F. This temperature difference may have resulted in a slight error in the reported flow.

3.2 PREPARATION OF FUEL ELEMENTS FOR TEST

The fuel elements were welded for corrosion testing by either the resistance or TIG technique. Because the welding techniques themselves were continually being improved, the quality of welds varied somewhat from element to element. The later elements were characterized by fewer defective welds. In some cases there was a variation in the welding parameters so that weld quality possibly varied from joint to joint.

The elements were carefully inspected and plate spacings were measured by the Welding Laboratory before receipt by the Corrosion Laboratory. Table 3.1 lists and describes the fuel elements tested. Elements 2, 4, and 8 were tested as welded. The balance were given special treatments or handling.

TABLE 3.1

DESCRIPTION OF FUEL ELEMENTS

Element No.	Type of Weld Joints	Form in Which Tested
Phase 1		
1	Resistance Welded	Full Length Element
2	Resistance Welded	Half Length
3	T.I.G. Welded	Full Length
4	T.I.G. Welded	Full Length
5	T.I.G. Welded	Cut in 1 in. Sections

Phase 2	Type of Weld Joints	Form in Which Tested
6	T.I.G. Welded Miniature SM-2 (see text)	See Sec. 3.4
7	T.I.G. Welded (Depleted Plates)	Full Length Dynamic
8	T.I.G. Welded	Cut in 1 in. Sections

Elements 1 and 3 were given chemical cleaning to remove oxide films caused by welding and to determine the effects of such surface treatment on corrosion. Element 1 was given two descaling treatments. On one end (upper when under test) the weld areas were acid cleaned using a proprietary commercial treatment. On the other end, the cleaning treatment consisted of a 30-min soak in 20% sodium hydroxide, and 5% potassium permanganate at 180°F followed by a dip in 5% oxalic acid. The surface was then passivated in nitric acid at 120°F for 20 min. Element 3 was also chemically cleaned over two weld zones on one end (upper end when in autoclave). This cleaning consisted of a 30 min soak at 180°F in a solution of 10% sodium hydroxide and 5% potassium permanganate. This was followed by a dip in 5% oxalic acid, in turn followed by water and acetone rinsing.

Element 6 (Fig. 3.3) was a small version of the SM-2 fuel element and was the pilot model of an active element designed for in-pile studies of burnup, etc. It was cut into two parts for corrosion testing. It had only one defect as shown by dye penetrant.

Element 7 was fabricated from annealed depleted fuel plates. The width of these plates (2.664 in.) did not correspond to SM-2 standard size. This necessitated shimming of the assembly in the welding fixture and resulted in scratching of the outer fuel plates. Also because of the unusual shimming, the first and last rows of welds were not representative of good welding technique.

3.3 WATER CHMISTRY

One of the main characteristics of pressurized water reactor coolant is the extreme purity requirement. For this reason the fuel elements were carefully cleaned just before inserting in test. The procedure used is given below. Slight modifications were made depending on the extent and nature of the fuel element contamination.

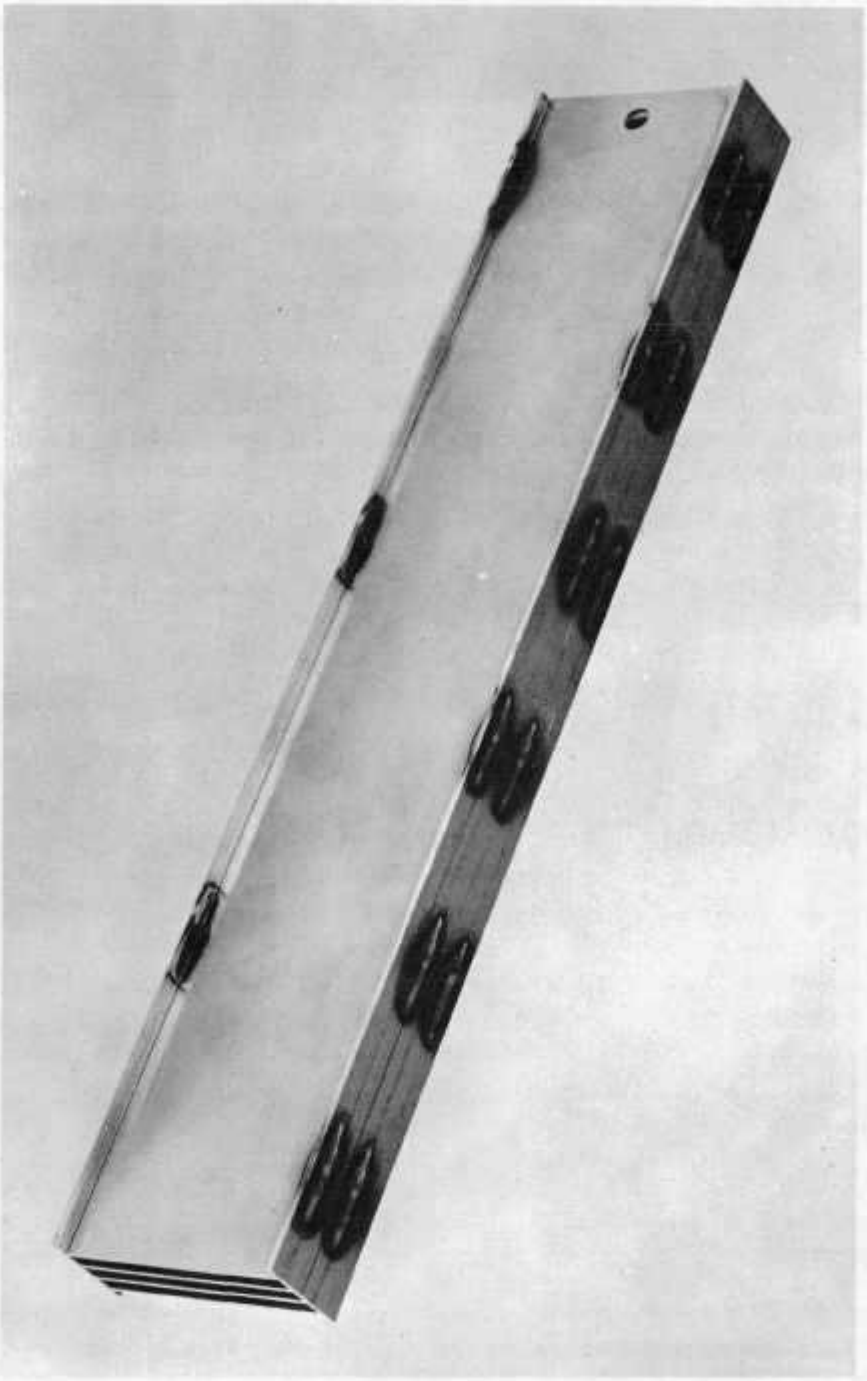

Fig. 3. 3 - Miniature SM-2 (WTR) Element

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First rinse	1% Sparkleen in 180°F water
Second rinse	Demineralized water
Third rinse	Acetone
Fourth rinse	Carbon tetrachloride
Fifth rinse	Acetone
Sixth rinse	Demineralized water

After cleansing, the test elements were handled only with clean cotton gloves or clean shop towels.

Before each test the autoclave was washed out with demineralized water and wiped with paper toweling to remove loose crud. The fuel element was set on the bottom of the autoclave and sufficient water charged to the autoclave to insure that the element remained submerged at all times. The test water was demineralized by passage through a mixed bed ion exchange resin. In all cases the water purity as charged was above 0.7 megohm-cm resistivity, and had a pH of 6.5 to 7.5. Table 3.2 shows the chemistry of the static autoclave water before and after testing. After adding water the autoclave was closed and evacuated for 30 min to remove air (oxygen) before sealing. The degassing was completed by venting briefly (30 sec) at 250°F. The temperature of 635°F was then obtained as rapidly as possible and held for duration of test.

TABLE 3.2

STATIC AUTOCLAVE WATER CHEMISTRY

Test No.	Test Duration, Hours	Before Test			After Test		
		Resistivity ohm-cm	pH	Oxygen	Resistivity ohm-cm	pH	Cl
1	497	800,000	6.8	degassed	45,000	8.2	-
2*	549	700,000	-	degassed	-	8.4	-
3	501	900,000	6.5	degassed	80,000	7.4	-
4	484	1,400,000	7.3	degassed	85,000	7.6	-
5**	1,336 (a)	1,500,000		degassed	-	-	-
	(b)	<1,000,000		not degassed	105,000	7.8	0.2
6	1,386	1,000,000		same as test 5	-	7.2	0.5

Slightly different chemistry conditions prevailed when testing elements 5 and 6. As previously mentioned these elements were sectioned before testing. The individual sections were placed in the 1 gal autoclave with the fuel plates vertical and the welded edges downward. The autoclave was charged with water as outlined above. During the first exposure period the autoclave operated with degassed water. During the final 500 hr* the autoclave was not degassed and operated with the water saturated with air plus the air present in the overhead space. The high oxygen level was used in an effort to determine if stress corrosion cracking could occur. The dissolved oxygen concentration was estimated at about 270 ppm at start of this test. The concentration would decrease during the course of the test as oxygen was consumed by the corrosion reaction.

TABLE 3.3

LOOP TEST CONDITIONS

	Nominal	Low	High
Pressure (psi)	1900	-	-
Flow (gpm) Total	380	344	407
Test Section	336		-
Resistivity (ohm-cm)	500,000	380,000**	3,000,000
Oxygen (ppb)	10	0	10***†
pH	7	6.6	7.6
Temperature (^{o}F)	550	535	
Duration (hr)	486	-	

The dynamic loop was carefully washed with commercial "All" detergent solution before assembly. After rinsing and inserting of the depleted test element, the loop was sealed and filled with demineralized water.

The loop water was degassed by venting the loop from the highest point for 15 min. Alternating with the venting was a 5-min period during which the pump and loop heaters were turned on. This cycle was repeated until oxygen concentration was less than 0.7 ppm. A temperature between 230 and 250^{o}F was maintained during degassing of the loop. Loop water conditions are shown in Table 3.3

*Test 5, final 493 hr; test 6, final 500 hr.
** Total time below 500,000 ohm-cm was less than 2 hr.
*** One recorded reading of 25 is believed to be in error.

3.4 TEST PROCEDURES

Channel spacing was measured prior to each test to insure that the elements were within specifications. Close visual inspection of all welds was also made. The specimens were then exposed in the static autoclave for 500 hr at 635°F. The exposure was timed from the completion of degassing to heater shutoff. After the 1 month exposures, elements were usually examined to determine the general resistance to corrosion. Weld areas were examined for local attack, pitting or cracking. Metallographic specimens were prepared of questionable welds and examined for cracking, knife line attack, crevice corrosion etc. Certain welds, containing defects in the form of small cracks associated with weld craters, were checked for propagation of cracks (Tests 5 and 6).

Following selection of the T.I.G. welding technique for use with 0.040 in. side plates, more detailed studies were conducted. A submerged thermal cycling test was carried out on the half length (element 6) specimen previously described. Six cycles to 635°F were made with a heating and cooling rate of 200°F/hr and 100°F/hr respectively. This specimen was visually examined for surface cracking then etched* to remove surface scale and checked for surface cracks both microscopically (45X) and by flourescent dye penetration.

To determine the resistance of the welds to stress corrosion cracking and intergranular attack, element 7 was cut into five weld segments. One of these was immersed in boiling 40% $MgCl_2$ [7] for two 72-hr periods. A second was boiled in 65% nitric acid, (the Huey test). [8]

The dynamic test element was measured for plate spacing before testing and immediately after conclusion of the test. It was inspected visually and under 30X magnification. Since the element contained depleted uranium, it was sent to an outside laboratory for metallographic sectioning. Twenty-five weld sections of selected welds were taken both longitudinally and transversely. The sections were viewed at magnifications up to 500X.

* Etch was 20% HNO_3 - 5% HF for 2 minutes at 180°F

4.0 TEST RESULTS AND CONCLUSIONS

The elements tested during Phase 1 of this study were welded during various stages of the development of welding techniques. Because the welding techniques had not yet been optimized, some welds were not of satisfactory quality. Some resistance welded joints exhibited lack of bonding while other welds exhibited overheating and excessive amount of extruded metal. Similarly, cracking defects existed in some earlier TIG welds. The elements welded by the TIG technique with 0.040-in. side plates have been practically free of weld defects (Phase 2 elements).

In early development elements where defects were common, it was difficult to determine whether a post-test defect was caused by corrosion or had been present in the weld prior to testing. Every effort was made to take this into account when evaluating the test results.

4.1 RESISTANCE WELDED ELEMENTS

During the subject study, resistance welding development was discontinued (because of inability to produce consistent welds of satisfactory quality) in favor of the tungsten inert gas technique. Figures 4.1 and 4.2 show respectively a typical resistance weld section as it appeared before corrosion and a similar weld after corrosive exposure for 1 month.

Metallographic examination of the surface of the corroded specimens showed only the normal slight general surface attack expected on type 347 ss under the test conditions. Figure 4.3 shows a close-up of the upset zone of a resistance weld. The cracking illustrated could be a result of corrosion, interdendritic cracking during welding, or the latter followed by crack extension by corrosion. Because the development of the resistance welding technique was terminated, corrosion studies were not continued to a point where more definite conclusions could be drawn. The major accomplishment of this part of the corrosion study was determination of possible problem areas if resistance welding should be reconsidered in the future.

4.2 TIG WELDED ELEMENTS

4.2.1 Phase 1 Studies

Because there was little difference between results on the first two TIG welded elements (#3 and #4) exposed in Phase 1 testing, the results will be discussed together.

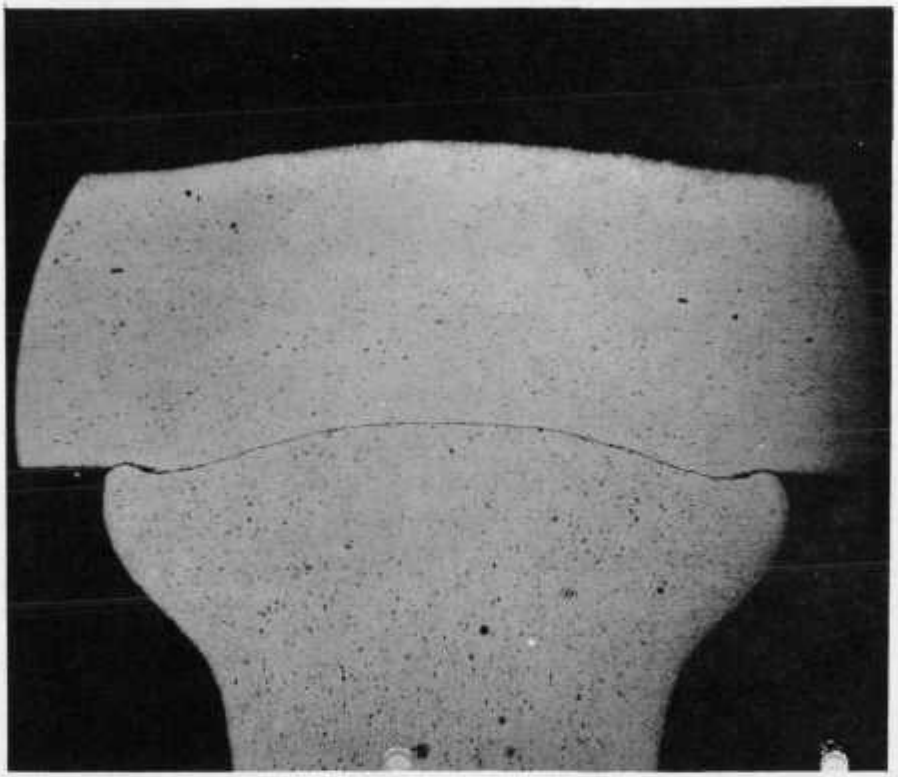

Fig. 4. 2 - Resistance Welded Element after 635°F Exposure for 500 Hrs.

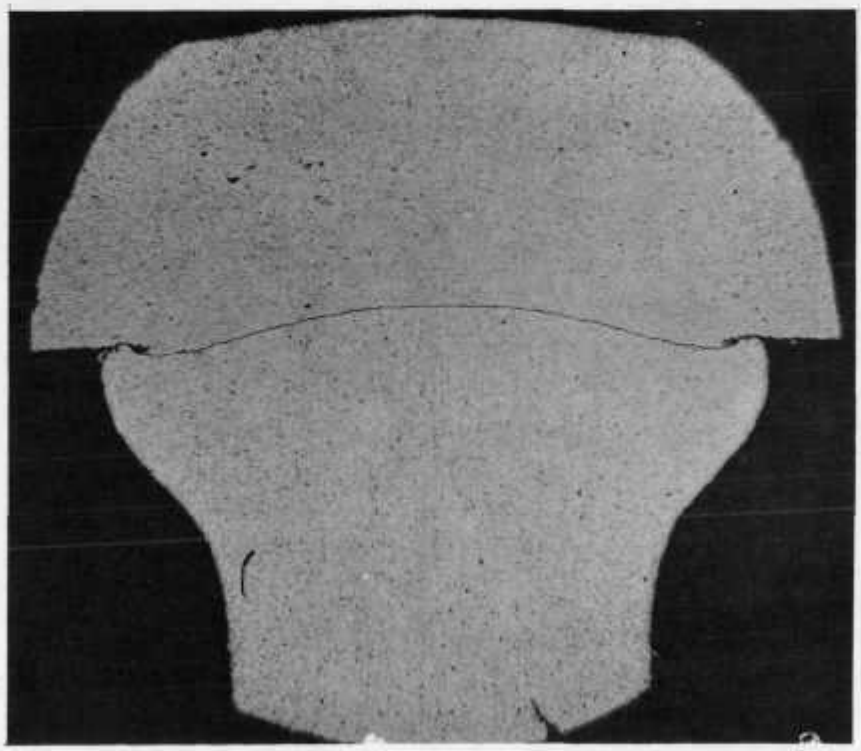

Fig. 4. 1 - Resistance Welded Element before Corrosion

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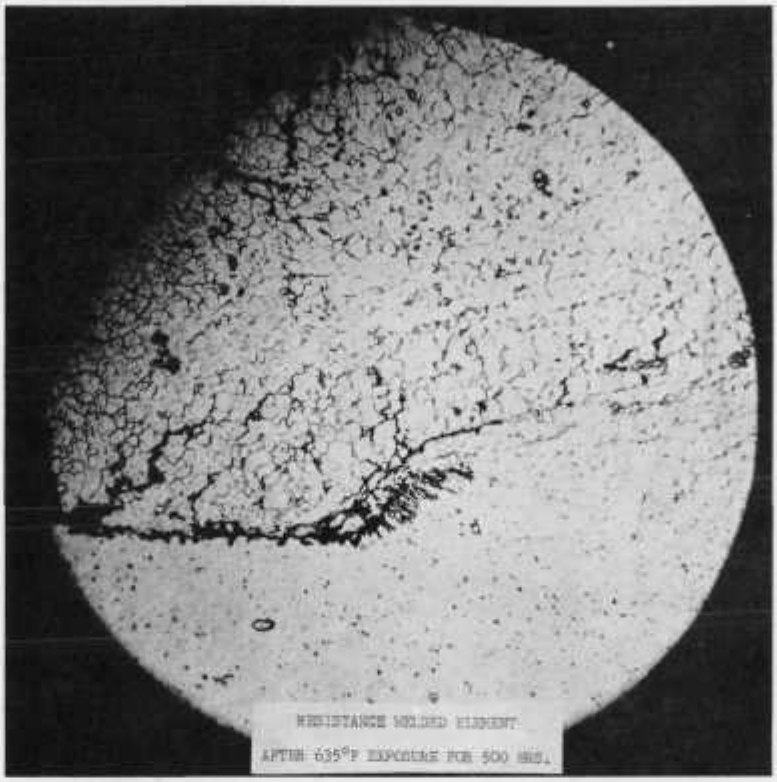

Fig. 4. 3 - Upset Zone at Side of Resistance Weld (500X)

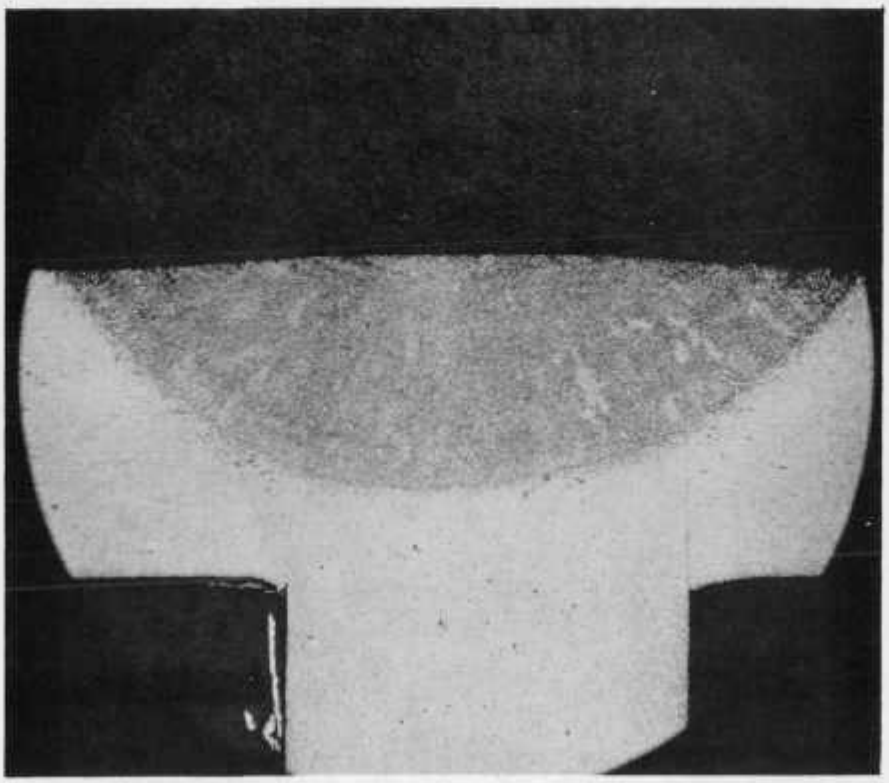

Fig. 4. 4 - Section of Good T. I. G. Weld after Corrosion (100X)

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Figure 4.4 shows a cross section of a typical good weld after exposure. Only insignificant general surface corrosion is visible and there is no specific attack on the weld surface. Figure 4.5 is a cross section along the length of a weld showing essentially the same good integrity as the transverse view.

Cracking, if found in early welds, was always associated with weld cratering. In some few instances, cracking extended from the crater area at the trailing end of the weld into the fuel plate-side plate fusion as shown in Fig. 4.6. The weld shown in Fig. 4.6 was in an element not exposed to corrosion testing.

Cracking of this type is of interest because propagation into the dead edge of the fuel plate is conceivable. Welds in which propagation might have occurred were found in elements 3 and 4. A more intensive study was therefore undertaken to determine if propagation of cracks could occur in welds in which crater cracks existed.

Elements 5 and 6 were utilized in this test for crack propagation. The behavior of an element with numerous defects (#5) was compared with that of an element with no defects (#6) exposed under similar corrosive exposure. In addition a portion of each element was retained for comparison of before and after appearance.

In element 5, 21 of 27 welds placed in test had cracks prior to testing. Following exposure, cracks were found on four of the six original non-cracked welds (based on dye penetrant examination) by examination at 25 diameters magnification. Figure 4.7 shows a cross section of one of the welds which had no visible external cracking before testing. The area shown in Fig. 4.7 represents the trailing end of the weld in which fusion of the side plate to the fuel plate is not expected. It is probable that in each of the four cases a crack was present in the body of the weld on the fuel plate side before testing. It is not known whether their detection after corrosion is due to improved sensitivity of crack detection or to crack propagation by mechanical causes or stress corrosion.

Element 6 showed no cracks of any kind after exposure. It is concluded therefore, based on the studies to date, that occurrence of cracks in properly welded elements is not expected. Occasional defects not detected by inspection would not be expected to propagate or to cause deterioration of welds to a point which could affect operation of the core. In addition, continued development of welding techniques has improved the quality of welds to the point where no weld cracks are expected.

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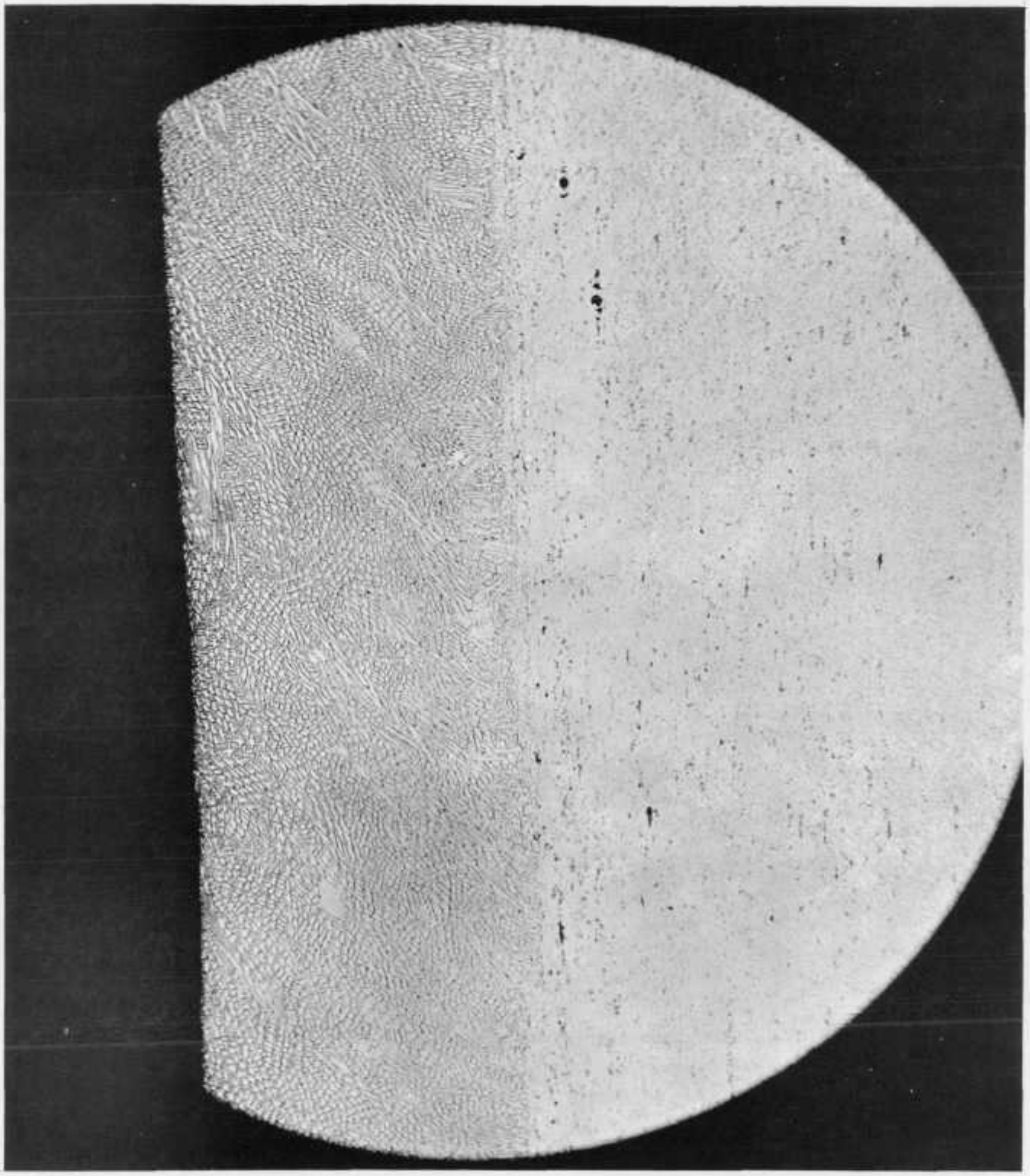

Fig. 4. 5 - Longitudinal Section of a Good T. I. G. Weld after Corrosion (100X)

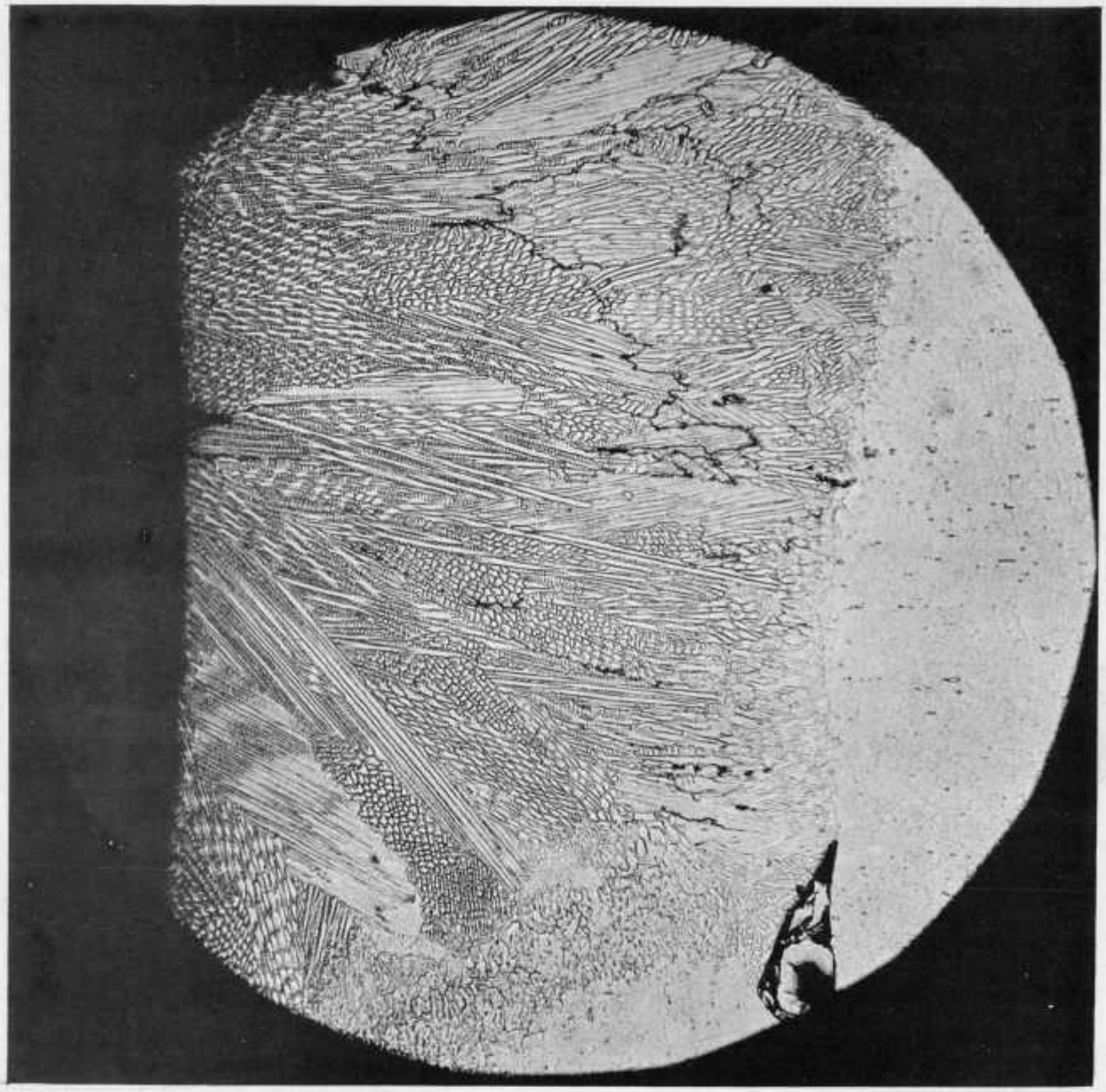

Fig. 4. 6 - Pre-Test Cracking Extending Within 0. 002 Inch of Fuel Plate (250X)

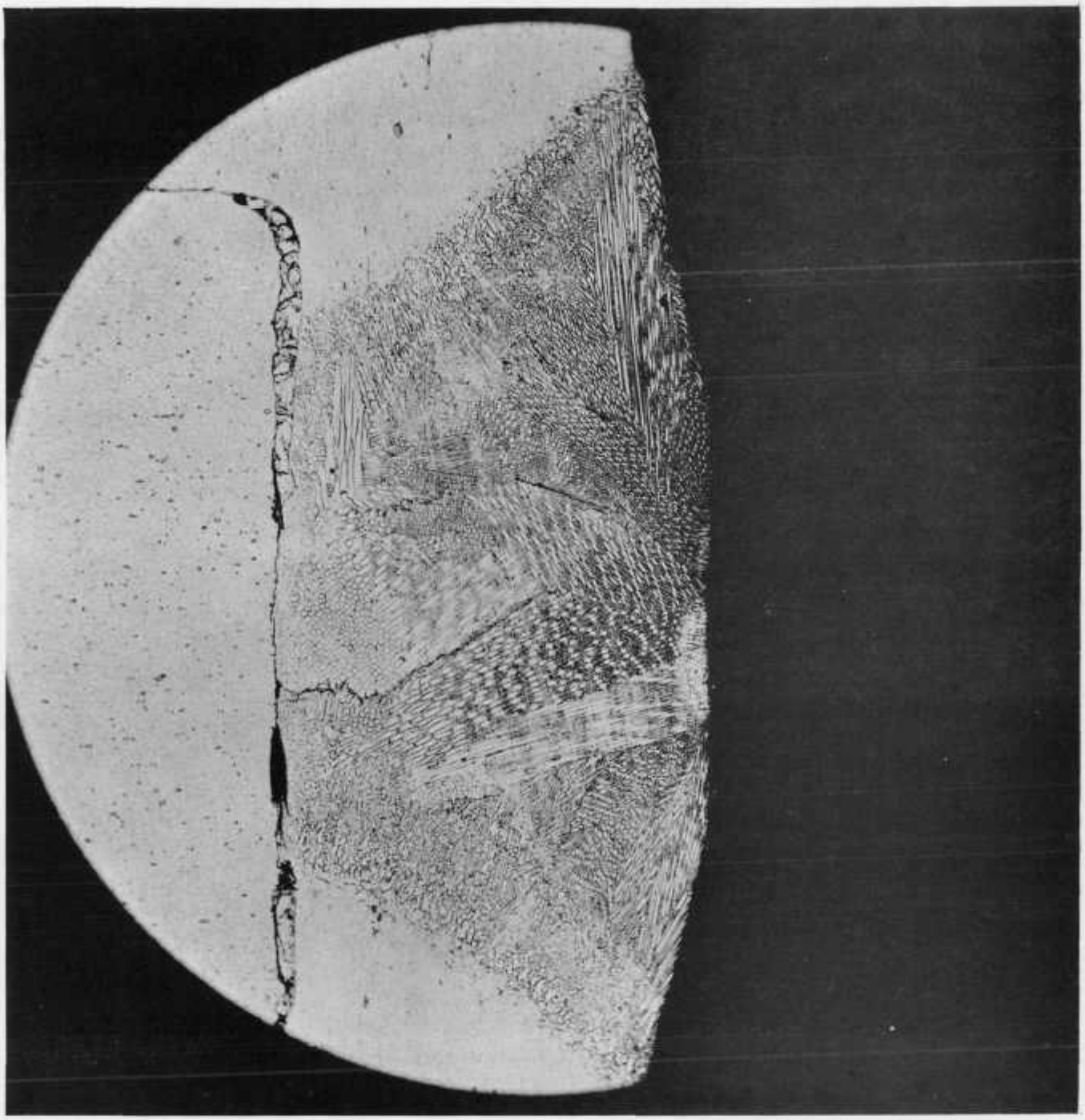

Fig. 4.7 - Cross Section of Weld Which Developed Surface Crack Only after Exposure (100X)

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The oxidizing conditions of the test (element 6) did produce slight pitting at the edges of the heat affected zone around the welds. Maximum pit depth was measured as 0.0075 in., with an average pit depth of about 0.0035 in. In view of the rather severe conditions of the test, this pitting is not considered significant. If necessary in the future to make significant changes in welding conditions, these areas should be re-examined.

4.2.2 Phase 2 Studies

The several miscellaneous cracking studies (elements 6 and 8) did not produce evidence of cracking, either by submerged thermal cycling, stress corrosion or by boiling in 65% nitric acid. Figure 4.8 shows the surface of a portion of a five weld segment after two consecutive 72-hr exposures to fresh 65% nitric acid. Some pitting attack was observed in the weld zone boundary discussed above. Inasmuch as exposure to degassed water does not produce this type of attack, it is believed of no serious consequence.

4.3 DYNAMIC CORROSION TEST

Figure 4.9 shows the dynamic test specimen before and after the test. After test the element had a slight blue tarnish but showed no other evidence of general corrosive attack.

Measurements of plate spacing changes resulting from the test revealed an average decrease of about 0.00054 in. Table 4.1 shows a comparison between the plate spacing change during the dynamic test (element D) and that observed during thermal cycling in a dry air atmosphere. The change is roughly comparable to that due to thermal cycling.

Examination of the weld areas at 30X magnification showed good corrosion resistance (Fig. 4.10). The middle third of the welds had a slight etching, sufficient to show some dendritic pattern. Some indication appeared of erosion of deeply cupped welds in the form of slight scouring at the downstream end of the depression.

Only one definite defect due to corrosion was found, a deep pit roughly in the center of weld 10-3. This surface pit unfortunately was lost in polishing the mounted specimen and no information was gained as to contributing causes. Otherwise the metallographic specimens showed no significant corrosion effects.

At conclusion of the test a large sample of water was drawn and analyzed for total solids. The solids concentration in the coolant was 5 ppm. An approximate solids analysis is shown in Table 4.2.

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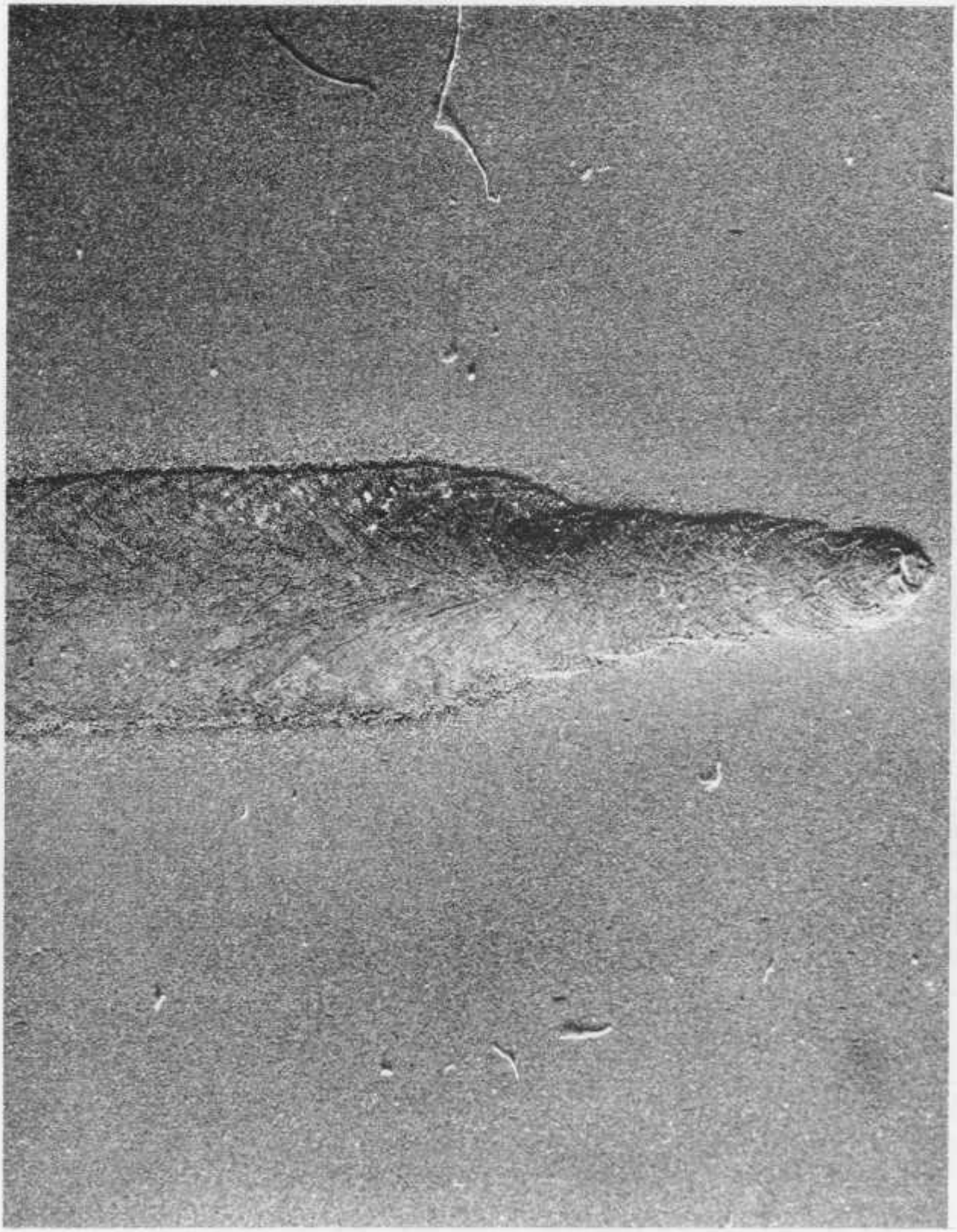

Fig. 4.8 - Pitting at Edge of Weld after Huey Test (15X)

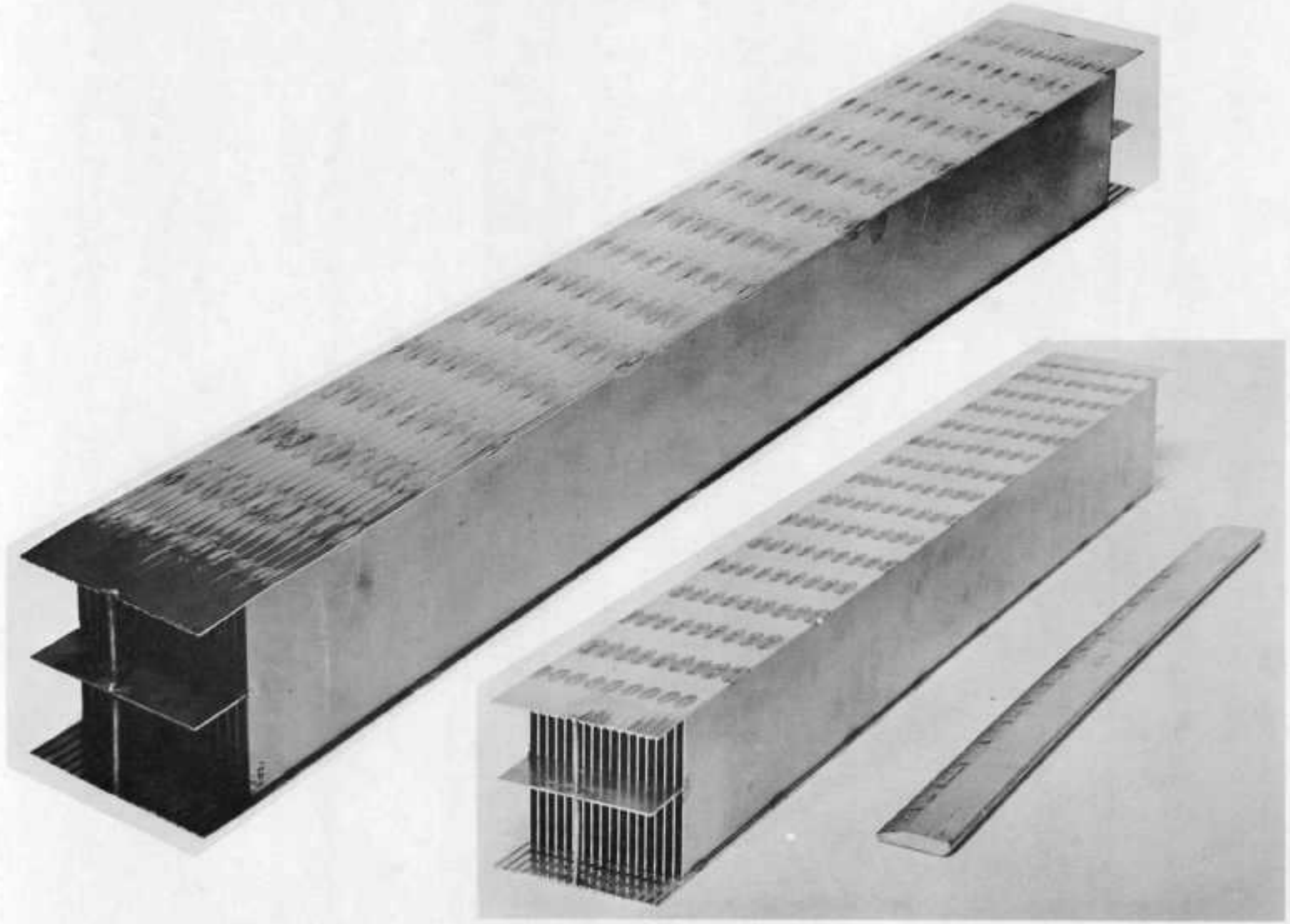

Fig. 4.9 - Before (Insert) and after Appearance of Dynamic Test Specimen

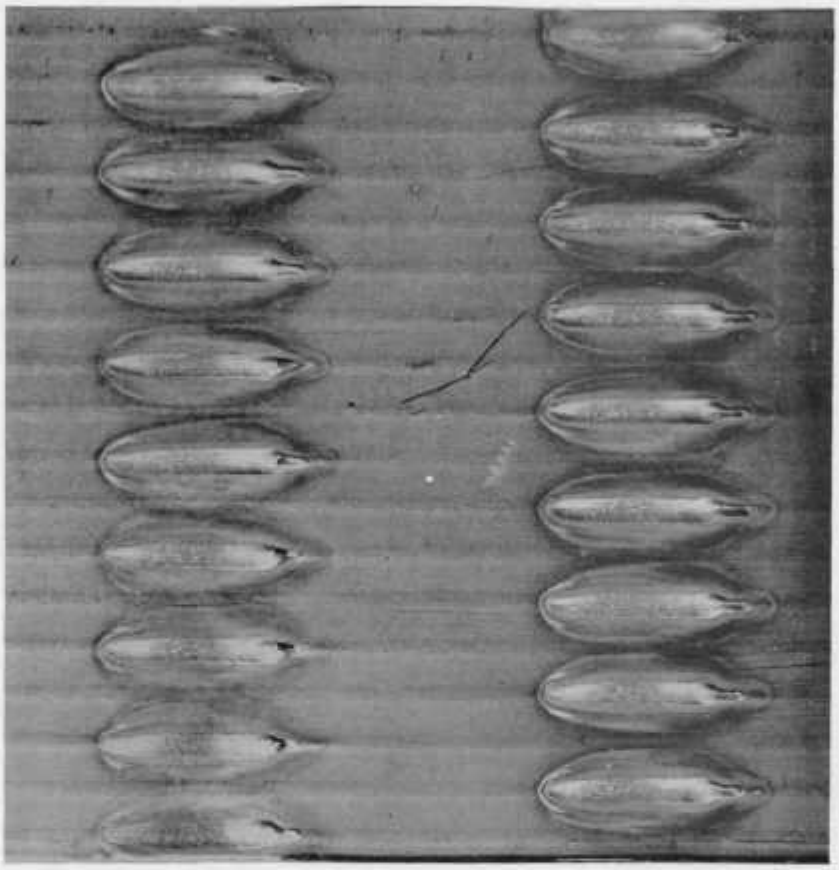

Fig. 4.10 - Post-Test of Welds showing Slight Etching of Middle Third of Weld (2X)

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TABLE 4.1

ANALYSES OF SPACING MEASUREMENT AFTER THREE THERMAL CYCLES*

Fuel Elements
A Solid C Cold rolled
B Annealed D Corrosion specimen

Subscripts show position 1-1" 2-8" 3-15" 4-22" Location

Measurements in thousandths of an inch

Space Between Plate No.	A_1	A_2	A_3	A_4	B_1	B_2	B_3	B_4	C_1	C_2	C_3	C_4	D_1	D_2	D_3	D_4
1-2	0	0	0	-2	-1	1	0	-1	-1	0	1	-1	-3	-1	0	-3
2-3	.5	1	.5	-1	.5	0	0	1.5	0	-1	-1	0	-1	-1	-1	2
3-4	0	0	-.5	1.5	-1	-.5	0	1	1	0	-1	-1	0	-1	0	-1
4-5	.5	0	-1	-1.5	-1.5	-.5	0	.5	0	-1	0	-1	-1	0	-1	1
5-6	0	0	-.5	0	-.5	0	-1	.5	0	0	0	-1	-1	0	0	2
6-7	-1	-1.0	-.5	-1	3.5	-1.5	1.5	2.5	0	0	-1	-1	-1	-1	0	-2
7-8	-.5	-0.5	-1	-1	-3	0	0	1.5	0	-1	-1	-1	-2	-.5	-1	2
8-9	0	-1	-.5	-1	1.5	0	0	-1	1	0	-1	0	-1	-1	-1	0
9-10	-.5	-1	-1.5	-1	1.5	0	0	0	1	-1	0	0				
10-11	-.5	-2	-1	-1	-1	0	0	-1.5	0	-1	0	-1	-1	-.5	0	0
11-12	-1	-1	-1	-2	0	1	.5	2	0	-1	-1	-1	-1	0	-1	2
12-13	-1	-1	-1.5	-1	1	1	0	-1	0	-1	0	0	.5	0	-1	1
13-14	-1.5	-.5	-1	-1	0	0	0	.5	-1	-1	0	-1	1	-1	-.5	1
14-15	-.5	-.5	-.5	-1	-1	0	0	0	0	0	0	-1	0	-1	0	-1.5
15-16	0	-1	-.5	-.5	-.5	0	0	0	0	-.5	-.5	0	-3	-1	0	0
16-17	1	0	0	-1	-.5	-.5	0	1	0	0	0	0	-1	-1	-1.5	0
17-18	-1.5	-1	-1	0	.5	-2	.5	-1	0	0	-1	0	0	-1	-2	0
Σd	-8	-9.5	-11.5	-14.5	1.5	-2	1.5	2.5	1	-5.5	-6.5	-10	-14.5	-11	-10	3.5
$\bar{d}$	-0.35	-.58	-.675	-.85	.1	-.12	.1	.15	.06	-.5	-.38	-.6	-.9	-.7	-.6	.22
R (d)	2.5	3.0	2.0	3.5	4.5	3.0	2.5	4.0	2	1	2	1	3.5	1	2	5
$P = \frac{\bar{d}}{\sigma_d}$	.141	.187	.338	.243	.022	.04	.04	.038	.030	.5	.190	.300	.257	.7	.3	.0404
Probability that $\bar{d}$ is real	low	low	99%	95%	low	low	low	low	low	99%	90%	98	95	99	98	low

* $\bar{d}$ represents average change, R(d) = range.
- 100°F per hour, except element D which was 20°/ hour.

A, B and C to 650°F - D only to 540 F.

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TABLE 4.2 SPECTROSCOPIC ANALYSIS OF LOOP SOLIDS

Elemental Constituent	as	W/O
Co	-	none detected
Ni	Ni 0	2.9
Cr	Cr. 0_3	0.9
Cu	-	trace
Si	Si 0_2	51.4
Mn	Mn_3 0_4	6.7
Fe	Fe_2 0_3	31.2
B	B_2 0_3	6.4
Na	-	trace

The relatively large boron concentration led to an investigation of possible sources. Its presence in the detergent used to clean the test loop should not have caused so high a level because the bypass purification loop was operating during the entire test. Nevertheless, the detergent was analyzed and found boron free. An analysis of the side plate, cladding and core gave the following results:

Sample	Area	% Boron
side plate	-	0.011
11-D-19	dead end	0.005
11-D-19	core	0.005
9-D-2	core	0.007
Commercial 347		up to 0.014%

The actual source of the boron was not found, but it is doubtful that the boron came from corrosion of the fuel plates. For this reason it is not believed to be of significance for the purpose of this corrosion study.

4.4 CONCLUSIONS

1. The expected resistance of type 347 ss to general surface corrosion in the SM-2 coolant was confirmed.

2. No evidence of crevice corrosion was found in TIG welds.

3. Sound TIG welds are resistant to cracking by stress corrosion or submerged thermal cycling. Sound welds do not show significant corrosion under static or dynamic exposure to simulated SM-2 coolant.

4. The chemical cleaning methods given elements 1 and 3 had no detectable effects on corrosion of welds.

4.5 RECOMMENDATIONS

1. Welds repaired by rewelding have not received study and should be corrosion tested although increased susceptibility to corrosion is not expected.

2. Should significant changes in welding conditions become desirable, additional corrosion testing should be undertaken. Emphasis should be placed on post-test examination to determine if pitting attack possibly occurs at the weld zone boundary.

3. A long term (1500-hr) dynamic corrosion test with periodic thermal cycling is desirable to confirm the corrosion resistance found during the relatively short 500-hr test reported herein.

APPENDIX I

Typical Composition of Type 347 Stainless Steel Utilized in This Study.

	W/O
Chromium	18.2
Nickel	10.5
Columbium*	0.56
Carbon	0.04
Manganese	1.55
Silicon	0.4
Phosphorus	0.025
Sulphur	0.009

* Ta may be substituted for part of the Cb.

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