Spot Weld Attachment of Thermocouples to a Fuel Rod Cladding Interior Surface

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August 1984

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**Pacific Northwest Laboratory
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ABSTRACT

Research was conducted by Pacific Northwest Laboratory to weld 0.020-inch-diameter thermocouples to the interior surface of Zircaloy 4 light-water reactor fuel cladding. Inconel sheathed Type K thermocouples were attached to fuel cladding to register cladding temperatures during loss-of-coolant accident testing. This report describes the development of welding parameters and the effects of thermocouple attachment on the burst strength and integrity of the cladding at temperatures up to 1550°F.

SUMMARY

A number of tests have been conducted in the last decade to determine the behavior of light-water reactor cores during loss-of-coolant accidents (LOCAs). In the tests, fuel rods have been intentionally deformed or failed. For a given prefill pressure, fuel rod cladding deformation is principally dependent on cladding temperature and temperature distribution. To obtain cladding temperature data with minimal external effects that could influence rod-to-rod interactions, thermocouples were attached to the interior surface of the fuel rod cladding. The purpose of this study was threefold: 1) to develop thermocouple attachment welding parameters, 2) to evaluate the weld quality, and 3) to evaluate the effects of the weld on cladding integrity.

This development effort was performed using 0.020-inch-diameter Inconel 600 sheathed thermocouples and 0.379-inch-outside diameter x 0.022-inch-wall Zircaloy 4 cladding. Thermocouples designed for weld attachment were fabricated with solid tip extensions of sheath material for attachment welding.

The weld quality was determined by weld pull-strength testing and torque strength testing. Weld quality was assessed before and after thermal cycling. Weld attachment effects on cladding integrity were determined by metallurgical examination and pressure burst testing at both room temperature and 1550°F.

It was determined that thermocouples can be attached internally to fuel rod cladding with welds of considerable strength and durability. Metallurgical examination also confirmed high-quality attachments. Burst testing demonstrated that thermocouple weld attachments do not adversely affect cladding integrity at temperatures from ambient to 1550°F.

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INTRODUCTION

A number of tests have been conducted in the last decade to determine thermal hydraulic and materials behavior in light-water reactor (LWR) cores under reactor loss-of-coolant accident (LOCA) conditions. Much of this testing, particularly cases in which fuel rods have been intentionally failed, has been performed with single rods or with sub-bundle groupings of rods. There is considerable interest among the nuclear community in testing a full cross-section fuel bundle under LOCA conditions which will produce balloon and burst failure in most of the fuel rods. The loss-of-fluid test (LOFT) L2-6 with the F-2 fuel bundle offers a unique opportunity to examine deformation and burst behavior of fuel cladding, and to assess the extent of rod-to-rod interaction in a full fuel bundle (15 x 15) cross section under LOCA transient conditions.

For a given prefill pressure, fuel rod cladding deformation is principally dependent on cladding temperature and temperature distribution. Both axial and azimuthal temperature distributions need to be evaluated. To obtain good cladding temperature data and minimize external effects that might influence rod-to-rod interaction, thermocouples welded to the interior of the fuel rod cladding were specified for 42 of the F-2 bundle fuel rods. Twelve of the fuel rods contained three thermocouples at the same axial plane spaced at 120° intervals around the interior circumference of the cladding. The remainder of the rods contained a single internal cladding thermocouple. Axial distribution of thermocouples located the hot junctions at three elevations.

EG&G Idaho requested Pacific Northwest Laboratory (PNL)^(a) to weld thermocouples into LOFT fuel rod cladding in accordance with drawings furnished by Exxon Nuclear Corporation (ENC). The document describes the thermocouple attachment weld development and evaluation. This development effort was performed using 0.020-in.-diameter Inconel 600 wire, 0.020-in.-diameter Inconel 600 sheathed thermocouples, and 0.379-in.-OD (outside diameter) x 0.022-in.-wall Zircaloy 4 cladding. An independent weld assessment effort was performed by ENC and is included as Appendix A of this document.

(a) Operated for the U.S. Department of Energy by Battelle Memorial Institute.

CONCLUSIONS AND RECOMMENDATIONS

Inconel sheath Type K thermocouples can be resistance spot welded to the interior surface of Zircaloy 4 fuel rod cladding. The welded attachments are of high quality and are suitable for short-term tests where cladding temperatures do not exceed the Zr-Ni eutectic temperature (1762°F). Tensile tests of resistance spot welded attachments indicate that thermocouples preferentially fail by sheath breakage rather than by attachment weld failure. The thermocouple attachment weld does not degrade the integrity of the Zircaloy 4 fuel rod cladding.

Resistance spot welding is therefore a recommended method for attaching Inconel sheath thermocouples to Zircaloy 4 fuel rod cladding.

APPROACH

Many factors influence selection of a method for attaching thermocouples to the interior of fuel rod cladding. The attachment method must securely anchor the thermocouple tip to the cladding surface and maintain this contact under all anticipated cladding thermal conditions. The attachment also must not degrade either the thermocouple or the cladding integrity. The welding process must not damage the thermocouple sheath because the sheath is part of the fuel rod pressure boundary. Welding also must not deform the thermocouple so that fuel pellets cannot slide past the weld or damage the thermocouple junction. Since the thermocouple locations are relatively inaccessible, the attachment process must be adaptable to remote application.

Resistance spot welding was selected as the attachment process that meets the above criteria. In this type of welding, the thermocouple-to-cladding interface is bonded at a spot through heat generated by resistance to electric current flow. The thermocouple and cladding are held together by electrodes. The interface in the contact region is heated by a short-time pulse of low-voltage, high-amperage current to form a fused region of weld metal. When the flow of current ceases, the electrode force is maintained until the metal cools, completing the weld in a fraction of a second.

Sheaths on 0.020-in.-diameter thermocouples are approximately 0.003 in. thick. The high electrical current required to produce resistance welds combined with a very limited conductor cross section of the sheath produces high current densities that severely degrade the thermocouple sheath. In order to eliminate sheath degradation, a solid tip extension for welding was added to the thermocouple. Increased conductor cross section provided by the solid extension tip reduces current density to acceptable levels and produces good welds at the extension tip/cladding interface.

PNL has successfully resistance spot welded Inconel 600 and Zircaloy 4 sheath thermocouples to the interior of Zircaloy 4 fuel rod cladding used in instrumented-rod LOCA simulation testing. This expertise was applied to develop and document the resistance weld attachment of thermocouples to cladding interior surfaces for the LOFT F-2 fuel.

Due to time constraints, this development study was carried out with existing thermocouple weld tooling, and proceeded concurrently with fixture design and fabrication required for thermocoupling the L2-6 (F-2 bundle) fuel rods. The study results were applied to and aided the qualification of fixturing and techniques used for the F-2 bundle fuel rod cladding thermocouple welding.

An AC resistance weld control/power supply, built by Unitek Corporation, was selected for this work. The system has a transformer with a higher-than-normal secondary voltage to compensate for voltage drop in cabling and fixturing.

Thermocouple resistance spot weld variables are:

- time
 - the duration of current flow through the thermocouple/cladding interface
- current
 - magnitude of the flowing current
- electrode
 - contact shape
 - contact length
- force
 - the force transmitted by the electrodes to hold the thermocouple to the cladding.

Thermocouple-to-cladding resistance spot welds can be satisfactorily produced using a range of time, current, and electrode force values. Limitations in power supply, fixturing, or control variables can be partly compensated for by adjusting the other variables.

The purpose of this development study is to determine current, time, and force values that yield welds meeting attachment criteria. A graphic technique for evaluating and ranking weld variables versus results is a weld lobe. A weld lobe is a region of acceptable welds, determined by plotting a weld characteristic on a graph of weld time versus weld current. As seen in Figure 1,

FIGURE 1. Weld Lobe; Resistance Welded Variables Versus Performance

the lobe has four boundaries. The two horizontal lines are determined from power supply/control limitations. The right boundary separates acceptable welds from a region where excessive welding heat causes thermocouple deformation and fixture damage. The left boundary separates acceptable welds of adequate pull strength from poor welds of inadequate pull strength.

Adequate weld characteristics are determined by either visual and/or destructive examination of test welds. Tensile-shear property, a weld characteristic, best relates weld quality to weld parameter variation. A tensile-shear test applied to wire welding is commonly referred to as a pull test. The transverse tensile-shear property, another characteristic, is determined by torsional testing and can also be graphically presented as a weld lobe. Torsional testing of the welds was proposed by ENC to simulate the side thrust a fuel pellet could exert on a thermocouple attachment weld. Metallography of the spot weld cross sections gives an in-depth look at weld characteristics such as weld length, penetration of the thermocouple into the cladding, and

quality of the welded interface. Therefore, pull strength, torsional strength, metallography results, or any quantifiable weld characteristic can be plotted as a weld lobe.

It is difficult to determine acceptable values for weld characteristics in terms of suitability for reactor service. Pull strength has been used as the dominant weld characteristic to determine which weld parameters provide adequate thermocouple attachment for reactor service.

A thermocouple attachment weld should be at least as strong as the thermocouple. Sample thermocouples were pull tested to failure at room temperature, so that this pull-test load value could then be used as a minimum criterion for pull strength of thermocouple attachment welds. This value would be the left lobe boundary in Figure 1.

THERMOCOUPLE ATTACHMENT

WELD PULL-STRENGTH CRITERIA

The pull strength (tensile-shear property) of a thermocouple attachment weld has been found to relate to the quality of the attachment weld. A weld pull-strength standard was established by determining the physical limitations of the thermocouples, the established goal being that the attachment weld must exceed the thermocouple limitations. Thermocouples were tested to determine failure strength in two areas, the 0.020-inch-diameter sheath and the fusion weld joint between the thermocouple sheath and the solid tip.

A thermocouple designed for resistance spot welding to fuel rod cladding is illustrated in Figure 2. The solid tip extension is provided for welded attachment to the cladding.

The thermocouples were cut into two sections. The first section contained the fusion-welded tip and a short length of 0.020-in.-diameter sheath. The second section contained a length of 0.020-in.-diameter sheath, the swaged reduction area, and a length of 0.040-in.-diameter sheath. The sections with the fusion-welded tip were placed in the pull tester with the jaws holding the first 0.040-in. length of the tip. All failures of the tip joint occurred within 0.020 in. of the tip fusion weld on the sheath side. In the cases of straight sheath testing, the jaws were placed on the sheath. All failures of the sheath occurred in the 0.020-in.-diameter sections, and sheath elongation was determined from only the 0.020-in.-diameter length. Percent elongation in the test sections varied from 1.3% to 25.2%. Evaluation of the two tested sections indicates that maximum combined strength (both the tip fusion weld and the sheath) is 18 lb and the minimum is 12 lb. Yield of the thermocouple sheaths began in most cases at approximately 12 to 14 lb. Thermocouples obtained from EG&G tended to have higher strength in the sheath sections, while thermocouples from Idaho Laboratories Corporation (ILC) had higher-strength tip fusion welds. The data obtained are summarized in Table 1. Based on these tests, a weld pull strength of 20 lb was established as the minimum standard for a successful thermocouple attachment weld.

FIGURE 2. Thermocouple Designed for Resistance Spot Weld Attachment

TABLE 1. Thermocouple Pull Strength

<u>Thermocouple</u>	<u>Pull Strength, lb</u>			<u>% Elongation</u>
	<u>Vendor</u>	<u>Sheath</u>	<u>Tip</u>	
119	ILC	19	16	7.4
124	ILC	20	16	1.3
163	ILC	16	16(a)	24.2
165	ILC	16	16(a)	25.2
172	ILC	16	15	16.9
174	ILC	16	16(a)	20.7
2	ILC	18	19(a)	
36	ILC	18	15	
64	ILC	18	18(a)	
W-1	EG&G	19	15	
W-36	EG&G	24	14	
W-37	EG&G	18	12	

(a) Failed in sheath behind weld zone.

WELD LOBE

Once a minimum pull-strength criterion for attachment welds has been established, parameters must be developed that will consistently produce welds that meet or exceed this criterion. The two primary and machine-controlled welding parameters are welding current and welding time (weld count). Welds were made using a matrix of weld currents and weld counts. Weld performance was evaluated by plotting weld pull strengths on a graph showing weld current versus weld count. When the data are presented in this format (see Figure 1), a region of acceptable welds, or lobe, develops on the graph. This lobe is defined by eliminating those regions in which the welds exhibit excessive deformation, expulsion, and low and inconsistent pull strengths, and in which excessive electrode damage occurs.

Weld pull strengths were evaluated by welding 0.020-in.-diameter Inconel 600 wire into sections of cladding per LOFT-2 welding procedure (Appendix B). The cladding section was then clamped into a pull tester and the wire was pulled until failure occurred. Pull strengths were then plotted to produce a weld lobe. If the wire failed, rather than the weld, the wire was broken out of the cladding section for weld region examination. In all cases the weld

region of the wires was examined at up to 40X and evaluated for wire deformation, expulsion, and/or melting. In addition, the welding electrode was examined for possible damage or deformation.

Electrode slot width is fixed by the thermocouple tip diameter and is a close-fitting saddle to ensure uniformity of current density. Length is the parameter of weld shape that is variable. The maximum electrode length was limited by the solid thermocouple tip length (0.150 + 0.02 in.). The 0.065-in. length was chosen because of experience in previous successful programs and existence of available tooling. The 0.042-in. and 0.095-in. electrodes were chosen to establish limits on either side of the 0.065-in. electrode.

Weld lobes were developed for these three electrode contact lengths, as shown in Figures 3 through 5. Each plotted number represents a pull strength in pounds of one of more sample welds. A bar over a number (e.g., $\overline{30}$) indicates that the wire failed rather than the weld. Because LOFT 0.020-in.-diameter thermocouple failure strengths are under 20 lb, welds with pull strengths of 20 lb or greater were acceptable. LOFT thermocouples will start to yield at 12 to 14 lb load. Welds in the lower and left regions of the graph were disqualified due to low and inconsistent pull strengths. Welds in the upper and right region of the graphs were unacceptable due to expulsion, wire deformation, and/or melting. Weld counts (one count equals 1/60 of a second) up to 15 were tested, with no significant change in the weld performance above a weld count of 7. An increase of weld count did shift the weld lobe down very slightly. Increasing discoloration with a greater probability of electrode damage were reasons for limiting the weld counts to below 9. A weld count of less than 2 produced unreliable, inconsistent welds.

Electrode length has considerable impact on the weld lobe, as can be seen by comparing Figures 3 through 5. As the electrode contact length increases, the weld lobe area becomes larger and is shifted upward (increasing amperage). The lobe for the longer electrode, 0.095 in., has a greater parameter/domain with the significant advantage of reducing weld parameter sensitivity. The large weld lobe also makes the welding process less sensitive to fabrication variables. The shorter electrode, 0.042 in., would not produce welds strong enough to break the wire in pull tests.

FIGURE 3. Weld Lobe for 0.042-in. Electrode. Pull strengths are in lb.
 xx indicates fail of wire, not weld.

Optimal weld settings were determined to be at a current of 300 to 350 amps with a weld count of 5 to 7. This weld setting is marked on Figure 5.

ELECTRODE FORCE TEST

In resistance welding, the condition of the interfaces between the electrode and the two welding surfaces is very important. When thermocouples are welded into fuel cladding, a push rod is placed within the welding mandrel to contact the electrode. This push rod serves as the current lead to the electrode and applies upward force to ensure contact of the thermocouple with the electrode and the cladding (Figure 6).

In this test a 0.095-in. electrode was used and the force on the electrode was varied for three different sets of weld parameters. Force was measured using a force gauge applied to the end of the push rod. The force recorded is the force applied to the end of the push rod and not the force of the electrode or cladding on the thermocouples. Data obtained are shown in Figure 7. Weld counts of 2 and 5 show force on the electrode to be a factor. As force on the electrode is increased, weld pull-strength values increase and show reduced scatter. Because weld reliability is so important, welds in production will be made at push rod forces of 7 lb and with weld counts greater than 5.

TORQUE TEST

Circumferential shear forces may be produced when slotted pellets are rotated against welded thermocouples. A torque test was conducted to assess the circumferential shear strength of thermocouple attachment welds. The torque test also provides a cross check to ensure the validity of the pull-strength evaluations. The torque test was conducted by inserting a free-turning slotted mandrel to engage the thermocouple at the weld joint. A 5-in.-long moment arm was mounted on the mandrel as shown in Figure 8. The arm was then pulled with a force gauge until the weld failed.

Circumferential shear values for the same weld parameters varied a great deal. This variability was due to small particles of weld expulsion wedging

FIGURE 6. Thermocouple Welding Mandrel Assembly

FIGURE 7. Electrode Force Versus Weld Pull Strength Using a 0.095-in. Electrode

FIGURE 8. Free-Turning Slotted Mandrel Used in Torque Test

between the wire and the cladding, binding the tool and causing high torque loads. Although there is great scatter in the data, some trends can be seen (Figure 9). The higher the amperage and/or the weld count, the higher the torque loads. This trend can also be seen in the weld lobe pull test data.

THERMAL CYCLING

Weld samples were thermal cycled to simulate the effects of reactor power ramping on the weld attachment. Thermal cycling temperatures were kept below the eutectic temperature of Zr and Ni (1762°F). The test samples were evaluated by room temperature pull testing and metallography. Thermal cycling tests were conducted at 1000°F, 1400°F, and 1550°F.

Samples were prepared by welding LOFT weld evaluation thermocouples into 4-in. cladding sections using the 0.095-in. electrode. Sample welds were made

FIGURE 9. Torque Test Data for 0.095-in. Electrode. All values in lb. The 0.095-in. weld lobe is superimposed.

from weld parameters at the upper and lower boundaries of the weld lobe (see Figure 10). This sample selection enables evaluation of the effects of thermal cycling on hot welds as well as on the cooler welds. Four samples were made at each weld parameter set for each test temperature, three were pull tested and one prepared for metallography. The samples were placed in a fused quartz tube centered within an induction coil. An argon atmosphere was provided during thermal cycling; the argon also aided in cooling between cycles. Each test consisted of 10 cycles to temperature, with the temperature lowered to less than 500°F between cycles. Ramping rates were approximately 6°F/s, with the time at maximum temperature being 1 min. After cycling, the samples were pull tested or sectioned for metallography.

Pull test data are summarized in Table 2 and in Figures 11 through 13. Weld strengths are affected by thermal cycling. Although the data are based on a limited number of samples, the higher cycling temperatures tend to reduce weld pull strengths. As thermal cycling temperature is increased and weld pull strengths decrease, a crossover in failure mode from thermocouple failure to weld failure occurs. Table 3 illustrates the influence of thermal cycle temperature on the mode of failure.

FIGURE 10. Weld Power Supply Settings Used in Fabrication of Test Samples with 0.095-in. Electrodes. 1/5/35:1 = tap, 5 = weld count, 35 = % current.

TABLE 2. Pull Test Data at Three Thermal Cycle Conditions^(a)

Temperature	Weld Parameters ^(b)				
	1/5/25	1/2/35	1/5/35	1/7/35	1/5/42
1000°F	18	21BS	19BT	21BS	21BS
	17	19BS	18BT	19BS	17BT
	11BT	17BT	16BT	18BT	16
	12	17	13BT	17BT	15BT
			12	16BT	
1400°F	15	16BT	19BS	18BT	19
	14	16BT	16	15BT	16BT
	13BT	12	15		15BT
	4	11	12		13
			10		
1550°F			10		
	14	17	19BS	19	19BT
	12	16BT	15	14	16BT
		8	14	14	15BT

(a) 10 cycles. Pull-strength values are in lb.

(b) 1/5/25 power supply setting: 1 = tap, 5 = weld count; 25 = % current. See Figure 10.

Note: 18 indicates attachment weld failure; 18BS indicates failure of thermocouple sheath; 18BT indicates failure of thermocouple tip fusion weld.

FIGURE 11. Thermal Cycled Weld Pull-Strength Data; 10 Cycles to 1000°F

FIGURE 12. Thermal Cycled Weld Pull-Strength Data; 10 Cycles to 1400°F

FIGURE 13. Thermal Cycled Weld Pull-Strength Data; 10 Cycles to 1550°F

TABLE 3. Influence of Thermal Cycle Temperature on Failure Mode

<u>Temperature, °F</u>	<u>Weld Failure, %</u>	<u>Thermocouple Failure, %</u>
1000	19	81
1400	50	50
1550	61	39

CLADDING INTEGRITY TESTS

The LOFT L-26 test is a fuel rod cladding deformation and rupture test. If the welding of thermocouples inside the cladding influences the mode of failure, the reactor test data may be suspect. To evaluate the effects of thermocouple welds on cladding integrity, attachment cross sections were metallographically examined and burst tests were conducted at room temperature and at 1550°F.

Because the hottest welds would have the greatest effect on cladding integrity, welds from the upper and right areas of the weld lobe (Figure 10) were tested. Samples of cladding without thermocouple welds were tested for baseline data.

METALLURGICAL EVALUATION

Samples of Inconel 600 wire welded into lengths of Zr cladding were sectioned transversely in the middle of the weld length. These cross sections were then polished, photographed, etched, and photographed again.

Figure 14 shows a typical weld section. The bond interface widths varied from 0.006 to 0.014 in., with the mean at 0.011 in. The penetration of the wire into the cladding varied from 0.0004 in. in the coldest weld to 0.0016 in. in the hottest. In each weld a reaction zone with good metallurgical bonding was observed. The weld exhibited a reaction zone with two phases of weld material between the Inconel 600 and the Zr, a lighter phase next to the Inconel 600 and a darker phase next to the Zr. This zone varied from 0.0001 to 0.0004 in. in width. The hotter welds had a wider reaction zone.

Photomicrographs from ENC and PNL, including scanning electron microscope examination, showed essentially no alloy mixing. Lack of mixing, along with metallurgical bonding, is necessary for sound weld joints. Metallographic examination showed little or no observable changes from the non-thermal-cycled samples at any of the three cycling temperatures.

FIGURE 14. Typical Weld Cross Section. Weld fabricated with a 0.095-in. electrode at 1/5/35 power supply setting.

ROOM TEMPERATURE BURST TEST

Room temperature burst tests were conducted using 10-in. lengths of cladding (Figure 15). A commercial cap fitting was placed on one end of the cladding, and a commercial tubing adapter fitting on the opposite end was connected to the pressurizing equipment. The samples were hydraulically pressurized at 50 psig/s until burst occurred. Due to operator error, some of the samples were pressurized until yield was detected, then allowed to burst without additional increase in pressure.

Data obtained from these tests are summarized in Table 4. No ruptures occurred at or near the thermocouple weld. The burst pressures averaged 18000 psig with yield detected from 16750 to 17200 psig. In some cases the thermocouple was expelled through the rupture, but attachment was generally maintained. Room temperature burst strengths are unaffected by the thermocouple attachment.

ELEVATED TEMPERATURE BURST TEST

Elevated temperature burst test samples consisted of 18-in. lengths of cladding with a commercial cap fitting on one end, and a commercial tubing adapter fitting on the opposite end connected to the pressurization system (Figure 15). The samples were placed in a tube furnace with a steel liner. Two furnace control thermocouples were placed within the liner in close proximity to the cladding. The liner ends were sealed with insulation. The samples were flushed with argon, pressurized to approximately 50 psig, heated in air to 1550°F, and allowed to soak for 5 minutes. Samples were then pressurized with argon to a fixed pressure and allowed to burst or were pressurized as instructed at a rate of 50 psig/s until failure occurred.

Data obtained are summarized in Table 5. It can be seen that given enough time, failure occurred as low as 400 psig. At pressurization rates of 50 psig/s, burst pressures ranged from 950 to 1050 psig. No observable difference in burst pressure could be seen between samples with or without thermocouples. Of the 14 samples with thermocouples, only one weld was near a rupture. In Sample 12 it appears that the weld did not initiate the rupture but was crossed as the failure occurred. The burst pressure of Sample 12 is

FIGURE 15. Typical Room and Elevated Temperature (1550°F) Burst Test Samples

TABLE 4. Room Temperature Burst Test Data

<u>Sample</u>	<u>Weld Parameters^(a)</u>	<u>Yield, psig</u>	<u>Burst, psig</u>
1	1/5/35	17150	18250
2	1/5/35	17750	17800
3	1/5/35	17200	17800
4	1/5/35	17750	18050
5	1/5/35	N/A	18050
6	1/5/35	17750	18100
7	1/5/42	17450	18250
8	1/5/42	17400	17700
9	1/5/42	16800	18100
10	1/7/35	17000	18100
11(b)	1/7/35	18000	17750
12(b)	1/7/35	17900	17300
13(b)	1/7/42	18000	17250
14(b)	1/7/42	17750	17200
15(b)	1/7/42	17250	17900
16	N/A	17000	18000
17	N/A	17100	18275
18	N/A	N/A	18150
19	N/A	16750	18100

(a) 1/5/35 - power supply settings: 1 = tap, 5 = weld count, 35 = % current. (see Figure 10).

(b) These samples were pressurized until yield was seen, then allowed to burst without increasing pressure.

one of the higher burst pressures recorded. The thermocouple weld attachment does not adversely affect the cladding burst strength or integrity at temperatures up to 1550°F.

TABLE 5. Elevated Temperature (1550°F) Burst Test Data

<u>Sample</u>	<u>Weld Parameters(a)</u>	<u>High, psig</u>	<u>Burst, psig</u>	<u>Time, s</u>
1	1/5/35	750	750	9
4	1/5/42	450	440	90
6	1/5/42	650	640	10
8	1/7/35	650	650	7
9	1/7/35	500	500	40
10	1/7/35	500	480	73
15	None	500	470	52
18	None	400	400	155

The following samples were pressurized at a rate of 50 psig until failure occurred:

2	1/5/35	1100	1050	1
3	1/5/35	1050	1050	0
5	1/5/42	950	950	0
7	1/7/35	900	850	2
11	1/7/42	1000	1000	0
12	1/7/42	1050	1045	0.5
13	None	940	940	0
17	None	1025	1025	0

(a) 1/5/35 - power setting: 1 = tap, 5 = weld count, 35 = % current. See Figure 10.

APPENDIX A

LOFT F₂ THERMOCOUPLE TO CLADDING STUDY

LOFT F₂ THERMOCOUPLE TO CLADDING STUDY

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Date

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LOFT F₂ THERMOCOUPLE TO CLADDING STUDY

1.0 INTRODUCTION

The LOFT Experiment L2-6B incorporates thermocouples welded to the zircaloy cladding to monitor cladding I.D. temperatures during "worst case" ballooning conditions of the fuel rod cladding. The cladding is expected to reach temperatures of 1000 to 1050°K, 727 to 777°C, during the test and thermocouple integrity during the ramping conditions is critical in obtaining accurate and reliable thermal response data. Inconel sheathed thermocouples were selected for their high temperature strength but their welding to zircaloy requires exacting procedures to achieve metallurgical bonding without the formation of intermetallics which degrade the weld ductility and strength. The Pacific Northwest Laboratories of Battelle Memorial Institute developed the welding procedures for the Inconel to zircaloy thermocouple weld and the ENC study was conducted to ensure that the cladding burst strength was not affected by the welds and that the welds would withstand thermal cycling tests similar to those proposed for the L2-6B experiment.

2.0 SUMMARY AND CONCLUSIONS

Based on ambient temperature burst tests the welding of the thermocouples to the cladding I.D. does not affect cladding strength. None of the failures occurred at or near the thermocouple welds.

Thermal cycling tests to 1000 to 1050°K, 727 to 777°C, indicated a slight decrease in subsequent room temperature shear strength of less than thirteen percent. The shear strengths of the welds were higher than the yield strength of the cladding indicating that thermal cycling to the L2-6B experiment temperatures would not adversely affect the thermocouple to cladding weld.

Diffusion tests run for one hour at 650 to 760°C indicated that the joint ductility was reduced by prolonged time at temperature.

3.0 MECHANICAL AND THERMAL TESTING

A series of mechanical and thermal tests were conducted to characterize the thermocouple to cladding joints welded by Battelle. Typical joints were sectioned transversely, etched and polished to evaluate the welds prior to testing to serve as metallurgical controls.

3.1 Metallurgical Evaluation

Two samples of 0.020 Inconel wire welded to zircaloy cladding were sectioned transversely, etched and polished, and evaluated. The bonded interface was approximately 0.025 inch long with a reaction zone width of less than 0.0001 inch.

Optical photomicrographs were made at 50, 200, 500 and 1000X. Scanning electron microscope photomicrographs were also made at 420X and 2000X. All of the photomicrographs indicated good metallurgical bonding with essentially no alloy mixing, conditions which are necessary for structurally sound joints between Inconel and zircaloy. Figures 1 through 6 show typical bond lines.

3.2 Burst Test Evaluation

Three tubular samples with thermocouple welds were burst tested at room temperature. One sample was lost in testing with a hoop stress of 123,900 psi at the time of expulsion from the test fixture. The remaining two samples burst at pressures of 18,600 and 18,700 psi with hoop stresses of 137,600 psi and 138,300 psi, respectively. The failure locations were not at the weld locations indicating that interior welds do not affect the burst strength of the cladding.

The following data was generated during burst testing activities.

Sample No. 4 - Thermocouple No. 139

Average Cladding Wall Thickness	0.024 inch
Average Cladding O.D.	0.3790 inch
Burst Pressure	16,750 psi
ULT Hoop Strength	123,900 psi

Remarks: Sample was expelled from clamping fixture during pressurization (16,750 psi). No indication of cladding rupture.

Sample No. 6 - Thermocouple No. 20

Average Cladding Wall Thickness	0.024 inch
Average Cladding O.D.	0.3790 inch
Burst Pressure	18,700 psi
ULT Hoop Strength	138,300 psi

Remarks: Cladding failed at a point approximately two inches below the attachment and at approximately 180° radially from the attachment. T/C was expelled through break opening. However, attachment was maintained.

Sample No. 7 - Thermocouple No. 132

Average Cladding Wall Thickness	0.024 inch
Average Cladding O.D.	0.3790 inch
Burst Pressure	18,600 psi
ULT Hoop Strength	137,600 psi

Remarks: Cladding failed at a point approximately two inches below the attachment and at approximately 180° radially from the attachment. T/C was expelled through break opening. However, the attachment was lost.

Figures 7 and 8 show the nature and locations of the failures in test samples No. 6 and No. 7.

3.3 Torque Test Evaluation

Rotational loads can be applied to the thermocouple to cladding welds by either twisting the sheath or by rotational movement of the slotted fuel pellets. A series of four welds were torque tested by applying a rotational force and measuring the fracture loads. The fracture loads ranged from 3 to 8.5 inch pounds with an average fracture load of 6.0 inch pounds. All failures occurred at the zircaloy-Inconel bond line leaving elongated depressions in the cladding approximately 0.002 inch deep, 0.006 inch wide and 0.015 inch long. Figures 9 and 10 show the cladding depression and thermocouple tip respectively from sample No. 2 which had a fracture load of 3.0 inch pounds while Figures 11 and 12 show the cladding depression and thermocouple tip respectively from sample No. 4 which had a fracture load of 8.5 inch pounds. The thermocouple tip from sample No. 4 had a significantly rougher fracture surface indicating better metallurgical bonding during welding. Figure 13 is a schematic of the testing arrangements.

3.4 Diffusion Testing Evaluation

Many research studies have demonstrated that dissimilar metals in contact with each other will diffuse into each other when held at temperatures which permit lattice vacancies to move and in the case of Inconel-zircaloy brittle inter-metallics can develop.

Three welded joints were heated for one hour at temperatures of 1200, 1400 and 1600°F to determine if diffusion would degrade the bond line in one hour at these temperatures. All three samples fractured during handling or mounting operations indicating prolonged exposure at these temperatures is detrimental.

Since the reactor start-up conditions for the rods were subsequently determined to be 72 hours at 400°C no further diffusion testing and evaluation studies were conducted.

3.5 Thermal Cycling Evaluation

Four welded joints were thermal cycled ten times to temperatures of 315, 540, 760, and 980°C at ramping rates of 3 to 4°C per second to determine if multiple thermal shocks would degrade the bond line. After thermal cycling the joints were sectioned transversely, polished and etched for metallurgical evaluation. The samples thermal cycled to 315 and 540°C showed no degradation or change in the bond line.

The sample thermal cycled to 760°C showed an increase in bond line alloying from less than 0.0001 inch to 0.0002 inch and displayed local areas of bond line fractures up to 0.003 inch long. The sample thermal cycled to 980°C showed extensive alloying and intermetallic formation. Figures 14 and 15 show the bond line of sample No. 8 thermal cycled to 540°C with no visible degradation. Figures 16 and 17 show the bond line from sample No. 10 thermal cycled to 760°C and show areas of bond line fracturing. Figure 18 shows the extensive alloying and intermetallic formation in sample No. 11 thermal cycled to 980°C.

3.6 Single and Double Pulse Thermal Cycle Tests

After discussions with EG&G to determine preconditioning temperatures, a final series of single and double pulse thermal cycle tests were run at 690°C, 732°C and 777°C with ramping rates of 3 to 4°C. The samples were held for 72 hours at 400°C (670°K) to simulate conditions of the L2-6B experiment prior to ramping. After ramping the samples were shear tested rather than metal sectioned to provide mechanical data of weld strength and integrity. The results of the tests are listed in Table I. Sample No. 29 showed a reduction in shear strength of 4 pounds or 13 percent after preconditioning at 450°C and one thermal cycle to 777°C. Sample No. 27 showed no reduction in shear strength after preconditioning at 450°C and two thermal cycles at 777°C. These shear test data indicate that the thermocouple sheath strength is the limiting factor in the welded assemblies.

TABLE I - SHEAR TEST DATA

<u>Joint</u> <u>Number</u>	<u>Thermal</u> <u>Treatment</u>	<u>Fracture</u> <u>Load Lbs.</u>	<u>Elongated</u> <u>Inch</u>	<u>Fracture</u> <u>Location</u>
28	As Received	27.0	0.87	* Weld
30	As Received	30.5	1.56	* Weld
36	As Received	31.0	1.56	Wire
21	72 Hrs at 450° + 1 cycle to 677°C	31.5	1.75	Wire
23	72 Hrs at 450°C + 1 cycle to 727°C	31.5	1.75	Wire
29	72 Hrs at 450°C + 1 cycle to 777°C	27.0	0.93	* Weld
22	72 Hrs at 450°C + 2 cycles at 677°C	31.0	1.70	* Weld
26	72 Hrs at 450°C + 2 cycles to 727°C	23.0	0.55	* Weld
27	72 Hrs at 450°C + 2 cycles to 777°C	31.0	1.70	* Weld

Figure 1 50x

Figure 2 200x

Figure 3 500x "As Polished"

Figure 4 1000x "Etched"

Figure 5 SEM Photomicrograph 419x "Etched"

Figure 6 SEM Photomicrograph 2000x "Etched"

Figure 7 Burst Sample No. 6 Enlargement

Figure 8 Burst Sample No. 7 Enlargement

Figure 9 Sample No. 2 Cladding Depression @ 50x.

Figure 10 Sample No. 2 Thermocouple @ 50x

Figure 11 Sample No. 4 8.5 in/lb.

Figure 12 Sample No. 4 Thermocouple @ 50x

FIGURE 13

Figure 14 200x 540°C

Figure 15 500x 540°C

Figure 16 Sample No. 10 @ 200x.

Figure 17 Sample No. 10 @ 1000x

Figure 18

50x

APPENDIX B

LOFT F-2 INSTRUMENTED CLADDING ASSEMBLY
AND WELDING PROCEDURE

LOFT F-2 INSTRUMENTED CLADDING ASSEMBLY AND WELDING PROCEDURE

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LOFT F-2 INSTRUMENTED CLADDING ASSEMBLY AND WELDING PROCEDURE

1.0 PURPOSE: The purpose of this procedure is to provide instructions for assembling the LOFT F-2 instrumented cladding assemblies.

2.0 APPLICABLE DOCUMENTS

2.1 Design Drawings

- 2.1.1 XN-NF-303,510, Rev 2, Cladding-Fuel Rod, Pt 4
- 2.1.2 XN-NF-303,515, Rev 1, Transition Piece (Zirc to SST)
- 2.1.3 XN-NF-303,788, Rev 0, Plenum Spring
- 2.1.4 XN-NF-304,684, Rev 1, Cladding Subassy (1 TC @ 21")
- 2.1.5 XN-NF-304,685, Rev 1, Cladding Subassy (1 TC @ 26")
- 2.1.6 XN-NF-304,686, Rev 1, Cladding Subassy (1 TC @ 39")
- 2.1.7 XN-NF-304,687, Rev 1, Cladding Subassy (3 TC @ 26")
- 2.1.8 XN-NF-304,689, Rev 0, Volume Spacer
- 2.1.9 XN-NF-304,691, Rev 0, Connector (With 1 Penetration)
- 2.1.10 XN-NF-304,692, Rev 0, Connector (With 3 Penetrations)
- 2.1.11 XN-NF-304,693, Rev 0, Routing Extension
- 2.1.12 XN-NF-304,694, Rev 0, Routing Housing
- 2.1.13 EG&G Dwg 212755, Rev 0, Loft Internal Cladding TCs, F-2 Bundle

2.2 Tools, Fixtures, and Gage Drawings

- 2.2.1 H-3-52087, Rev 0, Welding Mandrel Type I
- 2.2.2 H-3-52091, Rev 0, Welding Mandrel Type II
- 2.2.3 SK-3-22849, Rev 0, Shipping Mandrels
- 2.2.4 SK-3-22749, Rev 0, Shipping Fixture
- 2.2.5 SK-3-22707, Rev 0, V Trough Support
- 2.2.6 SK-3-22750, Rev 1, Mandrel Clamp and TC Depth Gauge

2.3 Procedures and Specifications

- 2.3.1 XN-NF-P66,694, Rev 0, Care and Handling of LOFT Fuel Rod Components
- 2.3.2 QCP-LOFT-1 Rev 0, Procedure for Receiving Inspection, Handling, and Associated Documentation Flow for LOFT F-2 Cladding Assembly Fabrication

- 2.3.3 QCP-LOFT-5 Rev 0, Cleaning and Cleanliness Control Requirements
- 2.3.4 QCP-LOFT-3 Rev 2, LOFT T/C to CLAD Welding Procedure and Qualification
- 2.3.5 QCP-LOFT-4 Rev 0, LOFT Packing and Shipping Procedure
- 2.3.6 QAP 10.1, issue date 2/20/81, M&TE Calibration

3.0 EQUIPMENT AND TOOLS

- 3.1 Cladding Assembly Data Log (attachment on this procedure).
- 3.2 Acetone, ACS reagent grade or better.
- 3.3 Ethyl alcohol, USP Grade ACS/reagent grade or equivalent non-denatured Ethyl alcohol. Composition shall be Ethanol 93-96% - water 7-4%. Ethyl alcohol shall contain less than 40 ppm non-volatile residue upon evaporation.
- 3.4 Lint-free white cloth gloves, manufactured for clean room application from virgin natural or synthetic materials. Gloves shall be lint-free such that glove particles will not deposit on components during use.
- 3.5 Virgin polyethylene gloves, manufactured from pure virgin polyethylene and shall not contain powder lubricants.
- 3.6 Ultrasonic cleaner.
- 3.7 Forceps or tweezers (300 Series SST, chrome plated or plastic).
- 3.8 T/C Welder I and II; H-3-52087, and H-3-52091.
- 3.9 Shipping mandrels, SK-3-22849
- 3.10 Shipping fixture SK-3-22749
- 3.11 Work tables.
- 3.12 Calibrated volt-ohmmeter (10 Vdc max)
- 3.13 Certified marking pen (Marks-A-Lot).
- 3.14 Certified polyethylene sheeting

- 3.15 0.020 dia. Inconel 600 wire (for process sample welds).
- 3.16 6" long sections of fuel rod cladding (for process sample welds).
- 3.17 Amatech pull tester.
- 3.18 Wire brush, 300 Series SST (to polish cladding I.D.).
- 3.19 White lint free cloth.
- 3.20 400 Grit silicon carbide wet and dry sandpaper.
- 3.21 Unitek power supply
- 3.22 Inspection M&TE (Measuring and test equipment).
- 3.23 Calibrated scale - 12 feet long.
- 3.24 Mandrel clamp and TC depth gauge SK-3-22750
- 3.25 Grooved dolphin nose pliers.
- 3.26 Electric drill.
- 3.27 Canned air (oil free).
- 3.28 Misc. hand tools (300 Series SST, chrome plated or plastic).

4.0 GENERAL REQUIREMENTS

- 4.1 Procedure steps requiring inspection hold points or logging of assembly data will be flagged with an "*" in the left hand column of this procedure.
- 4.2 All flagged steps requiring data reporting shall be logged using the Cladding Assembly Data Log.
- 4.3 M&TE used for taking data shall be calibrated in accordance with QAP 10.1.
- 4.4 All fuel rod components shall have been inspected in accordance with QCP-LOFT-1, have material certification, inspection data logs, and an acceptance tag. All BPNL generated documentation shall be added to the Cladding Assembly Data Log for the total cladding assembly data package.

- 4.5 The thermocouple cable ends must remain sealed at all times. Thermocouples must be carefully handled to prevent kinks or mechanical deformation from occurring in the sheaths. The leads must be routed through other fuel assembly components. Thus, the extra length of instrument leads extending beyond the cladding assembly must be protected at all times. The minimum inside bend radius of the cable shall be four cable diameters. All bends shall be made at room temperature and any bend with an inside radius of less than 10 cable diameters shall be formed using tools that have a smooth continuous forming surface. Care shall be taken to prevent occurrence of bends, kinks, flat spots, nicks, scrapes, or other physical alteration. Nicks, scrapes, scratches, etc. shall be assessed under 10X magnification, and rejection shall be determined by the BPNL project engineer. Bend radii greater than four but less than ten cable diameters shall only be straightened with prior approval of the customer (EG&G). Bend radii greater than ten cable diameters shall be straightened as deemed necessary. The cables shall not be twisted. Loading the cable in tension shall not be allowed except during bending, straightening, cleaning, and weld checking. Minimum cable coil diameter shall be 20 inches. Cable lengths shall be properly supported during storage, transfer, and assembly. The cable ends shall be sealed at all times except when operations are being performed that require access to cable conductors. Cable resealing, if necessary, shall be performed per Section 6.1.3 of QCP-LOFT-1.
- 4.6 Process samples of the welding process shall be performed before each cladding assembly welding using the same operator, weld tooling, and weld parameters as for the production weld.
- 4.7 The length of the 0.020 dia. portion plus the transition area of the Inconel TC is critical. Extreme care must be taken to avoid lengthening the TC during handling, cleaning, and assembly activities. Stretch straightening of the 0.020 dia. portion is permitted, providing the "A" length shown on EG&G

Drawing 212755 is not violated. If the TC is stretch straightened, this length must be re-verified by QA prior to assembly of the TC into the fuel rod cladding, and the pin vise must be greater than 0.200 inch away from the TC tip to prevent damage to the tip attachment. If the TC has been stretch straightened, re-read and record resistance values.

- 4.8 Prior to assembly, QC shall verify each fuel rod component and all tooling and fixtures that will contact the fuel rod components meet Class A cleanliness as described in QCP-LOFT-5. The inspector shall monitor activities during cladding assembly to assure Class A cleanliness conditions are maintained. The inspector shall verify final assembly cleanliness prior to and following packaging.
- 4.9 Components, tools, and fixtures shall be maintained in an orderly way for easy identification.
- 4.10 Clean, lint-free gloves shall be used to handle clean components and thermocouples.
- 4.11 Materials such as acetone, alcohol, cotton gloves, polyethylene gloves, and sheeting shall be in accordance with QCP-LOFT-V, Rev. 0. Alternately, a user analysis or independent analysis may be performed to assure conformance to QCP-LOFT-V.
- 4.12 When cleaning, and cleanliness is called for in this procedure, the cleaning and cleanliness controls as defined in QCP-LOFT-5 shall apply.
- 4.13 When taking continuity and resistance measurements of the TCs, a 10 Vdc max volt-ohmmeter shall be used. The resistance values shall be within 10% of the TC manufacturer's reported values.
- 4.14 A separate "Cladding Assembly Data Log" will be prepared for each subassembly.
- 4.15 BPNL shall assign a serial number to each cladding subassembly. This number shall include information easily identifying the subassembly as to its type.

EXAMPLES

<u>S/N</u>	<u>Definition</u>
3-26-4	Means it has 3 TCs at 26" from bottom and it is the fourth of this type fabricated by BPNL.
1-39-6	Means it has 1 TC at 39" from bottom and it is the sixth of this type fabricated by BPNL.

5.0 ASSEMBLY PROCEDURE

- 5.1 All components and thermocouples shall have an acceptance tag per QCP-LOFT-1. All documentation shall be attached to the Cladding Assembly Data Log as part of the assembly's data package. Project Quality Control Representative (PQCR) to verify.
- 5.2 Enter the appropriate information on the Cladding Assembly Data Log.
- 5.3 Clean the certified stainless steel brush to Class A levels per QCP-LOFT-5.
- 5.4 Insert the certified rotary stainless steel brush into the cladding to the point of the thermocouple weld area. Rotate the brush with a drill motor using a push-pull action for 10 seconds maximum to prepare an area of about 1 inch in length.
- 5.5 Using a ramrod cleaned to Class A level per QCP-LOFT-5, run through a lint-free patch with acetone and then alcohol until the bore is clean as indicated by a clean patch.
- * 5.6 Wipe down the outside of the cladding with acetone, flush the cladding ID with alcohol, wipe down the cladding OD with alcohol, and then canned-air dry. QC to verify cleanliness of cladding.
- 5.7 Select the thermocouple(s) for the cladding assembly, and read and record the resistance between leads, and between each lead and the sheath.

- * 5.8 Handle the thermocouple(s) per the precautions of Sections 4.5 and 4.7. The .020 diameter should be straight and not require straightening. If thermocouple(s) need stretch straightening, comply with 4.7.
- 5.9 Determine the necessary straight section of thermocouple(s) required for this cladding assembly and unroll the coil to this length per the precautions of Section 4.5.
- 5.10 Lightly sand the top 1/2-inch of the thermocouple with No. 400 grit wet-dry paper to remove the oxides from the thermocouple tip.
- * 5.11 Clean the thermocouple(s) by wiping with an acetone-saturated lint-free cloth until no evidence of dirt or soil shows on the cloth. Follow this with an alcohol-saturated lint-free cloth until no soil shows on the cloth. QC to verify cleanliness.
- * 5.12 Clean the remaining components in an ultrasonic acetone bath for 5 minutes minimum followed by an ultrasonic ethanol bath for 5 minutes minimum. QC to verify component cleanliness.
- * 5.13 Insert the thermocouple(s) through the appropriate holes in the connector, transition piece, volume spacer, plenum spring, routing extension, and routing housing as shown on the appropriate assembly drawing. Move this string of components up the thermocouple(s) so that there is enough room for welding. Verify the orientation of each thermocouple in the connector. QC to verify proper component sequence.
- 5.14 Place the cladding in the clean V-trough support (SK-3-22707, Part 2) and orient the cladding such that the scribe mark is at the 12 o'clock position.
- 5.15 Select the proper welding mandrel H-3-52087 for single thermocouples or H-3-52091 for triple thermocouples.
- 5.16 Wipe down the mandrel and depth gage with alcohol. Polish the internal electrode(s) with a wire brush and blow off with canned air away from the assembly area.

- 5.17 Wire brush sample cladding, sand weld qualification sample wire, and clean both in preparation for pre-process sample weld.
- * 5.18 Using QCP-LOFT-3, make a check weld using 0.020 Inconel wire to a short piece of cladding. Use weld parameters qualified by QCP-LOFT-3. Record weld parameters, wire certification, and pull tests results on the Cladding Assembly Data Log.
- The weld shall fail at a load greater than 20 pounds. QC to verify welder qualifications and welding parameters per QCP-LOFT-3 and that pull test results are acceptable. This shall be done within four hours of making the production weld. Mark process sample with same serial number as cladding assembly.
- 5.19 Place mandrel clamp loosely on mandrel.
- * 5.20 Position TC depth gauge on the mandrel with the 0.020 Inconel wire portion pushed into the blind groove in the electrode.
- 5.21 Bring the mandrel clamp firmly against the depth gauge, holding the mandrel and depth gauge together, tighten down the screws in the mandrel clamp. Check the depth gauge for minimum end play. Repeat the above step if end play is seen. Now the proper thermocouple/cladding position is established.
- 5.22 Insert TC(s) into mandrel groove(s) under the mandrel clamp stopping with the junction end of the TC(s) against the blind end of the electrode groove.
- 5.23 Lay sections of half cladding (split longitudinally) over the TC and mandrel. This holds the TC in the mandrel groove. With the TC in proper position in the electrode and the TC held in the groove, lock the TC in position with the set screw in the mandrel clamp.
- * 5.24 Check to ensure the TC(s) are against the end of the electrode(s) groove. QC to verify.
- 5.25 Place cladding over the mandrel, TC tip(s), and electrode.

- 5.26 Slowly bring the cladding up the mandrel removing the half cladding pieces until the cladding is firmly against the mandrel clamp.
- 5.27 Check that the cladding and mandrel clamp are parallel.
- 5.28 Align the cladding index mark with the TC in the mandrel groove.
- 5.29 Clamp the external electrode over the cladding at the weld location.
- 5.30 Insert the push electrode into the mandrel's I.D. using a push force to expand the electrode(s), thereby forcing the TC tip against the cladding's internal surface.
- * 5.31 Using the same welding operator and the weld parameters of the test weld of Step 5.18, weld the thermocouple(s) to the cladding in accordance with QCP-LOFT-3. Record the weld parameters on the Cladding Assembly Data Log. Measure and record thermocouple resistances. QC to verify radial and axial locations, ie., marks on thermocouple(s).
- 5.32 Not moving the weld mandrel, remove the external electrode, push rod, and mandrel clamps.
- * 5.33 Gently pull on each thermocouple by hand (approximately 3 to 5 pounds) to ensure the thermocouple is welded to the cladding. QC to verify this test was performed.
- 5.34 Wipe down shipping mandrel and shipping fixture with lint-free cloth saturated in acetone until no soil is detected. Follow this with an alcohol saturated lint-free cloth until no soil is detected on lint-free cloth.
- 5.35 Holding the thermocouple(s) taut, push the shipping mandrels, with the female groove up, (SK-3-22849) into the cladding, displacing the weld mandrel.
- * 5.36 Remove ink marks on cladding using an alcohol soaked lint-free cloth. Air dry. QC verify marking is removed.
- * 5.37 Rotate cladding assembly to position the etch mark on the cladding in the down position and install shipping fixture

SK-3-22749. QC verify cleanliness of assembly and fixture, and verify proper fixture attachment to assembly.

5.38 Place assembly and shipping fixture in a polyethylene tube and the thermocouple coil in a polyethylene bag.

* 5.39 Repeat thermocouple resistance measurements, recording on Data Log as usual. QC verify resistance measurement values are within 10% of the TC manufacturer's reported values.

* 5.40 Have the QA review all fabrication data in this procedure. If data is complete and acceptable, initiate accept tag and attach to assembly. (Sign-off required by QC on Data Log.)

5.41 Refer to Procedure QCP-LOFT-4 for packaging and shipping.

Step 5.6 QC to verify cladding cleanliness _____

Step 5.8 Verify Dim A of Dwg 213755 if stretch straightened _____

Step 5.11 QC to verify thermocouple(s) cleanliness _____

Step 5.12 QC to verify component cleanliness _____

Step 5.13 QC to verify component sequence _____

Step 5.18 QC to verify operator certified by QCP-LOFT-3 _____

QC to record weld operator's names _____

QC to verify weld parameters qualified by QCP-LOFT-3 _____

QC to record weld parameters

Tap _____ Broken _____ Time(Date/Hour) _____

Weld Count _____ Pulled Loose _____

% Current _____

Step 5.20 QC to verify .020 Inconel wire portion of depth gauge is pushed into blind groove in the electrode _____

Step 5.24 QC to verify TCs are against the end of the electrode groove(s) _____

Step 5.31 QC to verify same operator as in 5.19 above certified by QCP-LOFT-3 _____

QC to verify same weld parameters as in 5.19 above _____

QC to record weld parameters Tap _____ Time(Day/Hour) _____

Weld Count _____

% Current _____

QC to verify axial and radial locations _____

Step 5.33 QC to verify this test was performed _____

Step 5.36 QC to verify ink mark removed _____

Step 5.37 QC to verify assembly cleanliness and shipping fixture
attachment _____

Step 5.39 QC to verify resistance measurements recorded on Data Log _____.

Step 5.40 QC to certify cladding assembly built in accordance with
QCP-LOFT 2 _____

THERMOCOUPLE RESISTANCE HISTORY

				INSPECTOR VERIFIED
MFG. SERIAL NO.				
EXXON SERIAL NO.				
ORIENTATION (RADIAL)				
RESISTANCE (OHMS) ($\pm$ 1 ohm)				
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