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# INSTRUMENTED FUELS TEST FOR FFTF


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## INTRODUCTION

In support of the LMFBR Fuels Development Program, Hanford Engineering Development Laboratory (HEDL) has designed the Fuels Open Test Assembly (FOTA) for fuels testing at the Fast Flux Test Facility (FFTF). The FOTA is a test vehicle designed to contain and support instrumented fuel experiments in the Fast Test Reactor (FTR) at FFTF. The initial two FOTA experiments will characterize the reference Driver Fuel Assembly performance in the FTR and provide experimental data to evaluate thermohydraulic models used to predict assembly performance. Instrumentation data from these experiments will also be used in the evaluation of the natural circulation cooling capabilities and core characterization of the Fast Test Reactor.

This paper describes the design features and fabrication of the first two FOTA instrumented fuel experiments, which have been fabricated and are now in the FTR, and presents a brief description of the FOTA test vehicle.

## FOTA TEST VEHICLE

The FOTA (illustrated in Figure 1) is a 12.2 meter assembly consisting of a 3.7 meter hexagonal in-core assembly that contains the fuel experiment and an 8.5 meter tubular stalk. The interface between the stalk and in-core assembly is a slip-joint held together by tie rods. The stalk, which is supported by the reactor head, suspends the in-core assembly within the core, routes the instrumentation leads from the experiment through the reactor head,

# FUELS OPEN TEST ASSEMBLY (FOTA) PRIMARY FEATURES

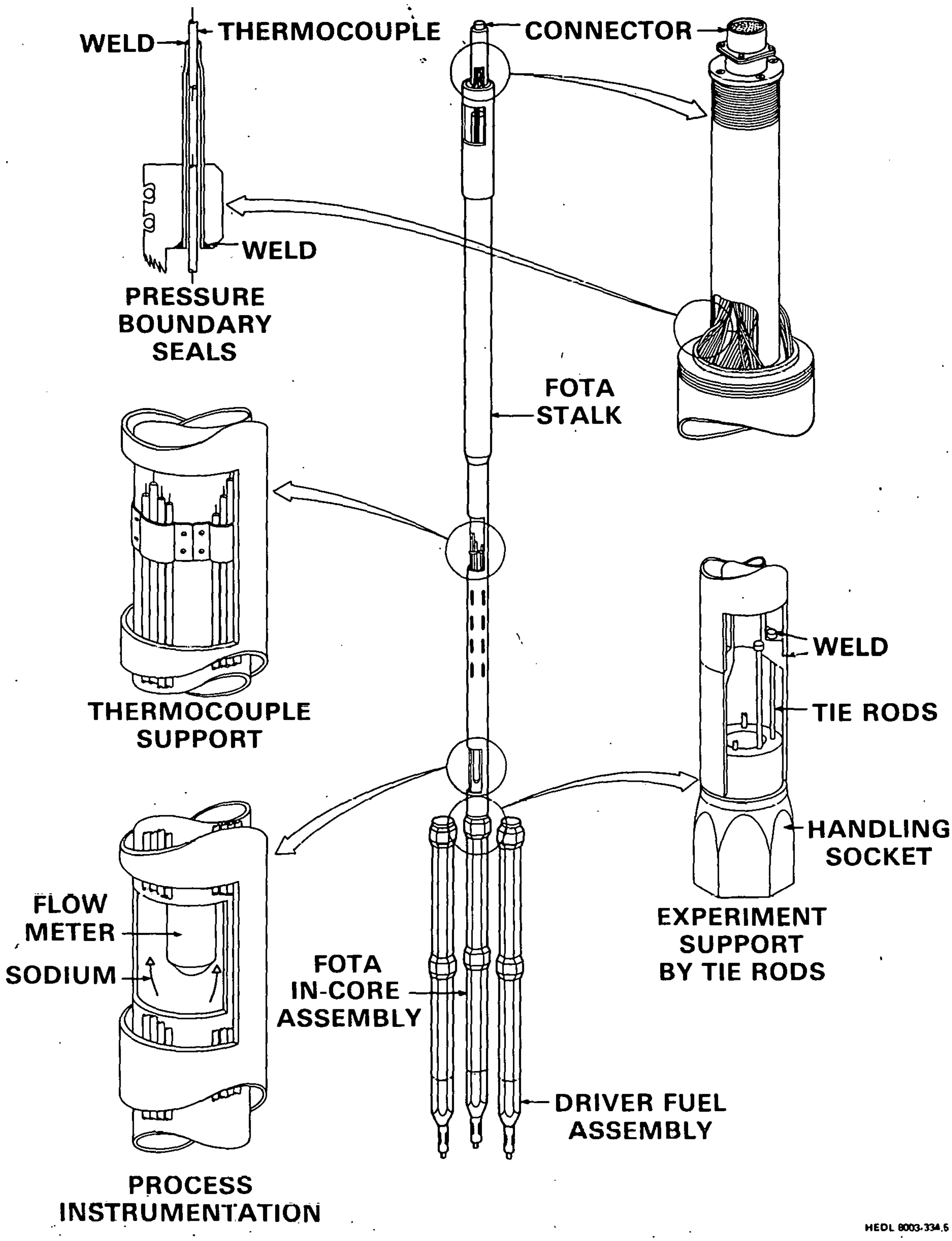



FIGURE 1

and provides process instrumentation to measure the sodium outlet conditions. In addition, after irradiation testing the stalk provides a path for inserting a cutter used to sever the tie rods and instrumentation leads in order to separate the in-core assembly from the stalk. This separation allows the irradiated fuel to be removed from the reactor by standard refueling operations using the In-Vessel Handling Machine and the stalk using the Closed Loop Ex-vessel Machine (see Figure 2).

PROCESS INSTRUMENTATION

Each FOTA stalk contains instrumentation to measure the sodium flow rate and outlet temperature which is monitored by operations and the plant protection system and is available to the experimenter. This instrumentation is located within a thimble in the stalk 1/2 meter above the experiment (see Figure 1).

The sodium flow rate is measured with an Eddy-Current Flowmeter calibrated to an accuracy to ± 5% over a flow range from 200 to 2000 liters/minute which corresponds to pump pony motor flow to reactor full power flow. In addition, the flowmeters in the two FOTA's were especially selected and calibrated to measure low flow rates during natural circulation tests. These flowmeters are accurate to ± 4 liters/minute in a range from 7 to 60 liters/minute.

The sodium outlet temperature is measured by three type K thermocouples located within the thimble above the flowmeter.

FOTA EXPERIMENT GENERAL DESCRIPTION

The initial two FOTA experiments are instrumented FFTF reference Driver Fuel Assemblies with some minor modifications to accommodate instrumentation. One experiment is located in the inner row of the core and the other in the

# FUELS OPEN TEST ASSEMBLY (FOTA) INSTALLED IN THE FTR

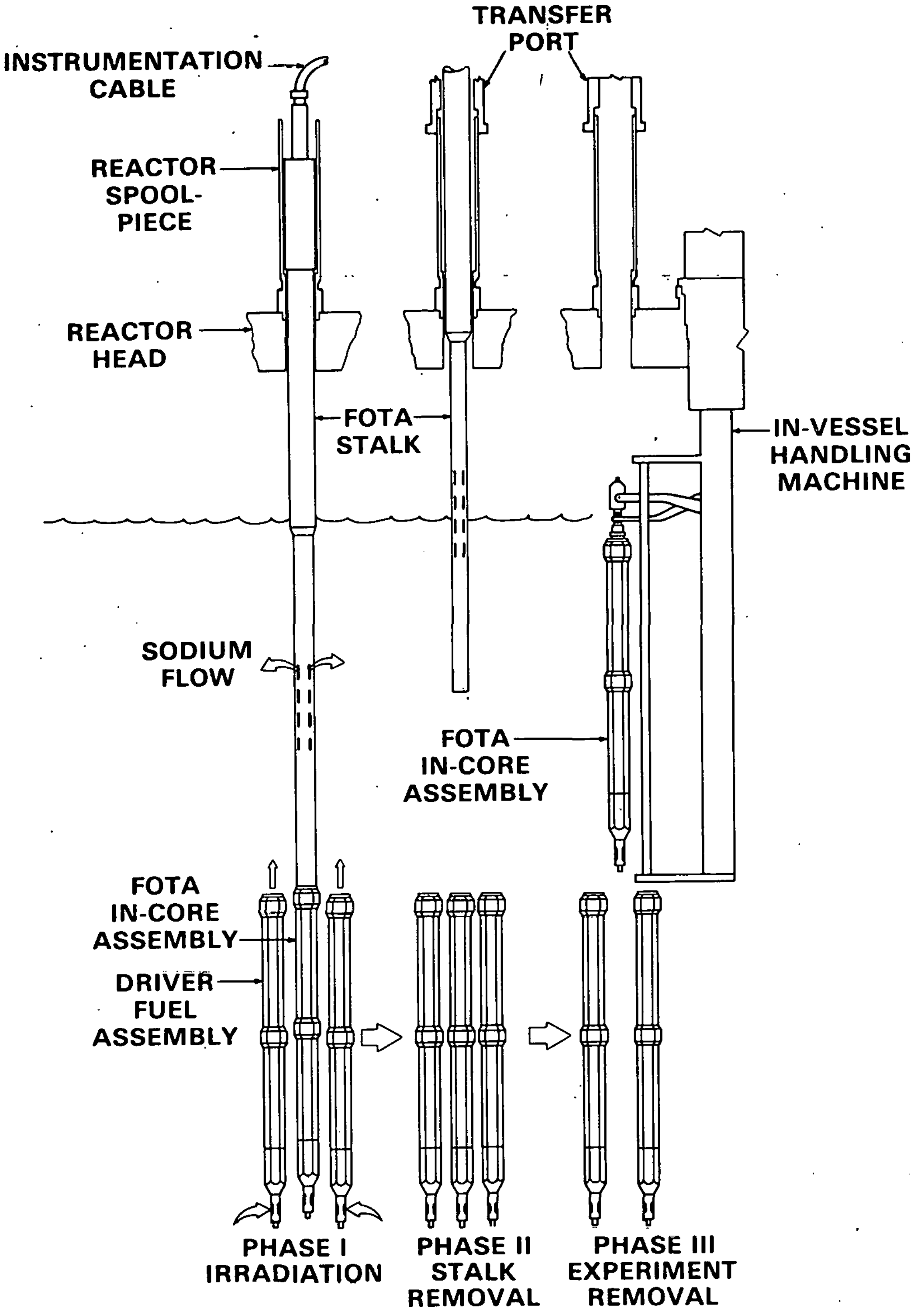



FIGURE 2

outer row; they differ only in fuel composition, sodium flow rate, and location of instrumentation within the fuel pin bundle.

Both experiments consist of 217 standard FFTF driver fuel pins enclosed in a modified driver duct tube (see Figure 3). In each experiment, 39 fuel pins are instrumented with thermocouple assemblies and the duct tube has one thermocouple junction embedded in each of its six surfaces just above the fuel column. These 45 thermocouples are used to measure the subchannel coolant temperatures.

Together the experiments have a total of 25 fuel pins instrumented with passive dosimetry assemblies which will be used to determine neutron exposure distribution (i.e. flux fluence spectra and displaced atoms) within the fuel column of the core.

The thermocouple and dosimetry assemblies were especially designed, fabricated and assembled into the driver assembly with extreme care to minimize the change in the thermal hydraulic performance from that of a reference driver assembly. This objective was achieved by replacing the standard wire wrap spacer on selected fuel pins with a thermocouple or dosimeter assembly of equal diameter as the solid wire spacer (as shown in Figure 4). This produced a bundle of fuel pins spaced identically as is a drive bundle with no additional obstructions to the sodium flow due to instrumentation.

The routing of the thermocouple leads from the top of the fuel pins to the stalk required a flexible bend (as shown in Figure 3) to accomoodate the differential growth between the fuel pins and the duct tube due to thermal expansion and irradiation swelling. The routing of the leads through the top of the stalk to the electrical connector required a closure weld (as shown in Figure 1) to form an ASME reactor vessel pressure boundary.

# FOTA INSTRUMENTED FUEL ASSEMBLY HF - 011

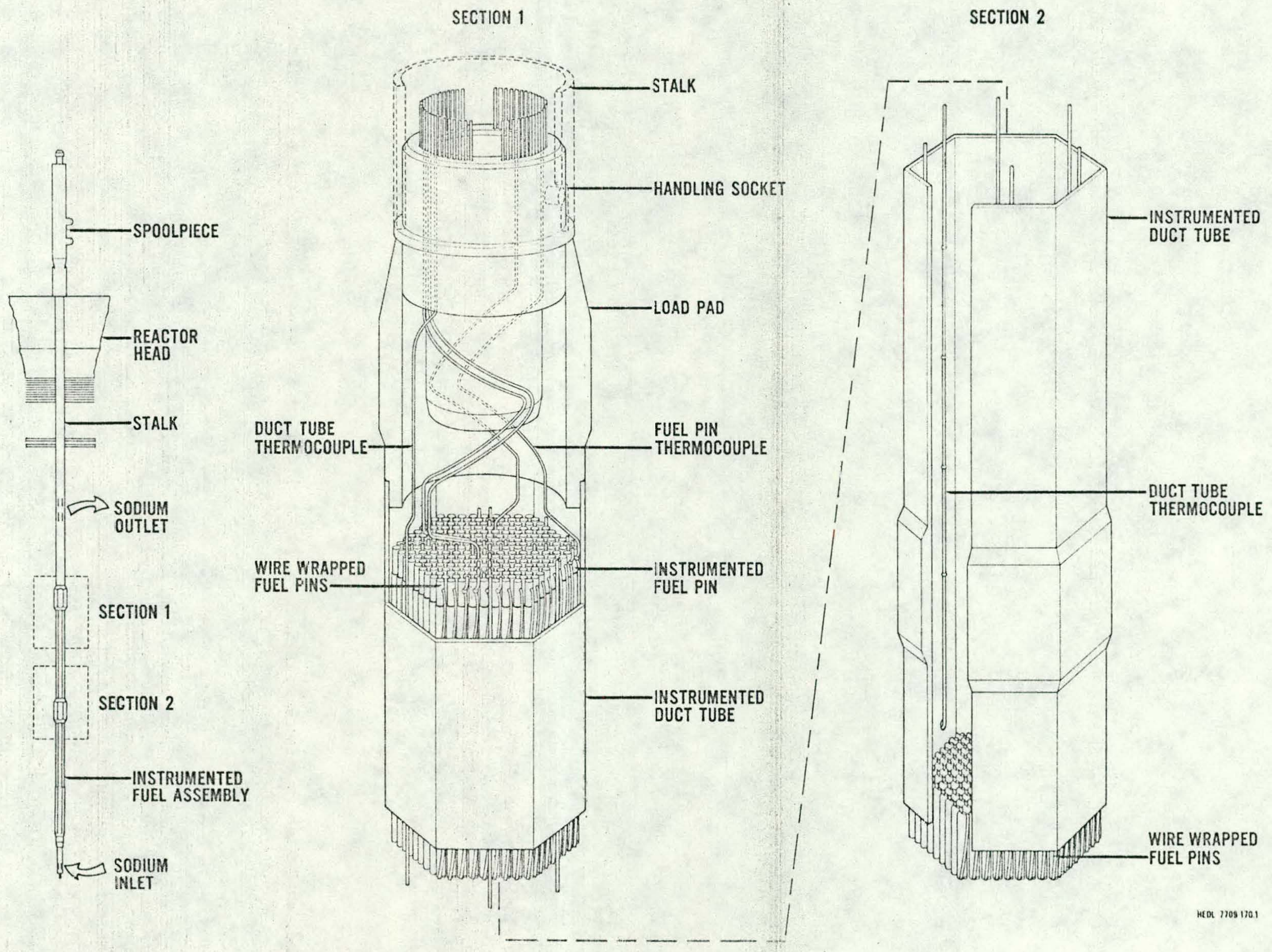



FIGURE 3

# FOTA EXPERIMENT HF-011 INSTRUMENTATION

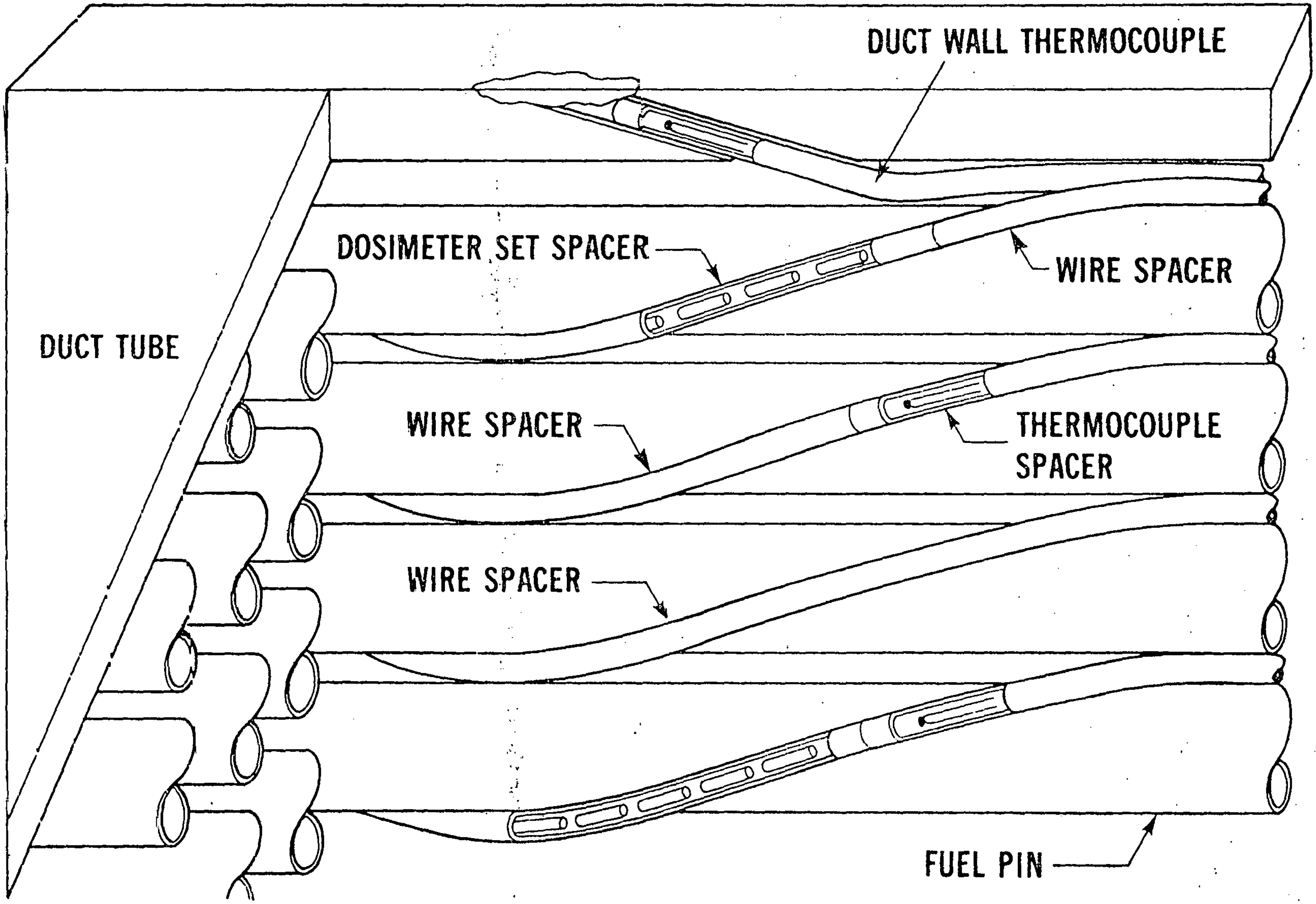



FIGURE 4

THERMOCOUPLE ASSEMBLIES

Thirty-nine fuel pins in each experiment were wrapped with ungrounded chromel/alumel thermocouple assemblies. The thermocouples used in the assemblies were fabricated by a vendor to RDT C7-6T standards in continuous seamless sheaths 13 meters long made from 316 stainless steel and Inconel 600. Each thermocouple (as shown in Figure 5) was fabricated to HEDL specifications requiring two diameters formed by first making a 2.36mm diameter thermocouple by swaging and then centerless grinding the junction end down to 1.42mm diameter. The smaller diameter was required to form the wire wrap on the pin and the thick wall, larger diameter was required to form an ASME pressure boundary weld to the stalk bulkhead.

The vendor supplied thermocouples were used at HEDL to fabricate three types of wire wrap assemblies, types A, B, and C as shown in Figure 5. The designs of these assemblies were carefully studied with the objective to improve the probability that all 90 thermocouples will survive the one year test in the FTR. The most significant factors that influenced the designs were: 1) the location of the thermocouple junction on the fuel pin; 2) the fact that the thermocouple assemblies are attached at both ends of the fuel pins which could produce axial loading due to differential expansion between the two; and 3) the results of similar tests conducted by Argonne and Oak Ridge National Laboratory using 1.42mm diameter stainless steel sheathed chromel/alumel thermocouples.

The design of Assembly A, which locates the thermocouple junction at the top of the fuel pin 113cm above the fuel, incorporates a stainless steel tube in the stainless steel attachment wire to reduce the axial strain on the short thermocouple sheath. The design was recommended by ANL to avoid the high

# FOTA HF-011
# THERMOCOUPLE ASSEMBLIES

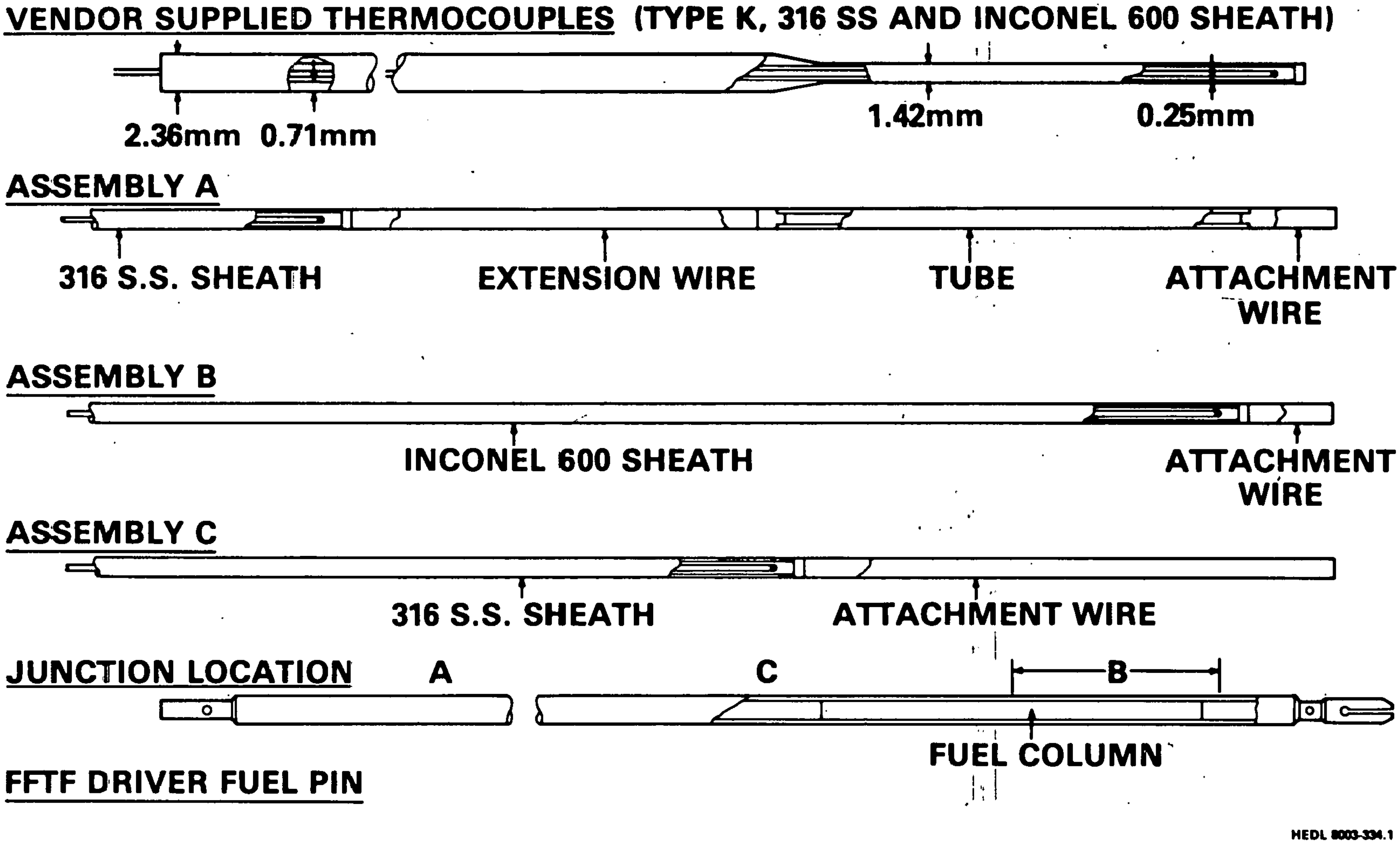



FIGURE 5

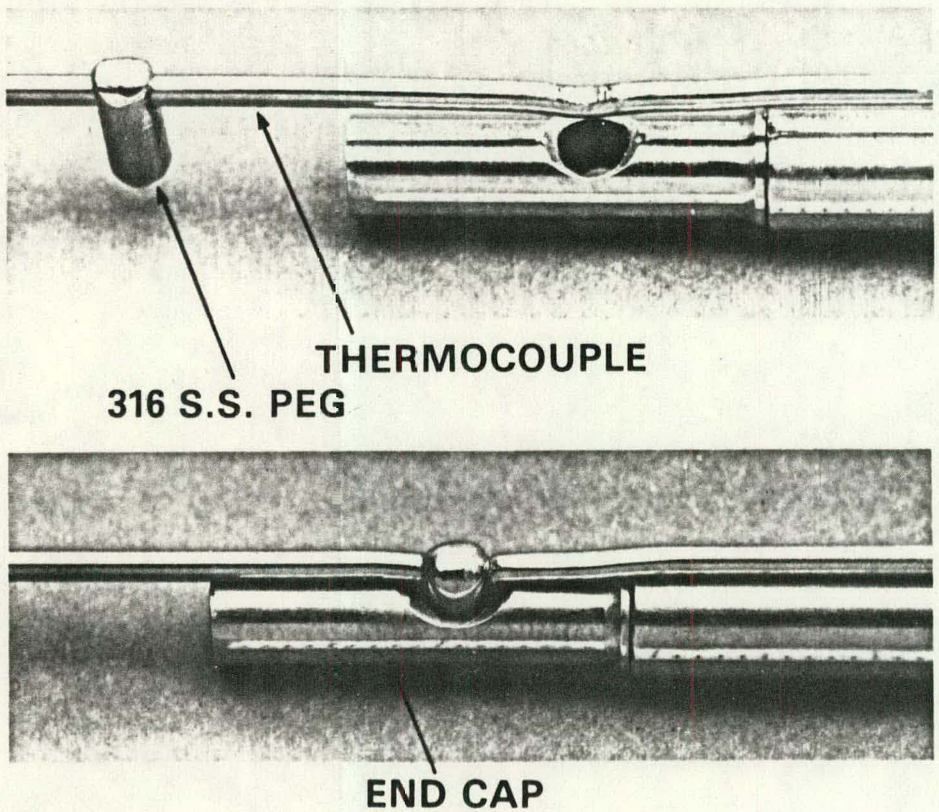
thermocouple failure rates they experienced in their P-2 Sodium Loop Safety Facility experiment in which the thermocouples located at the top of the pins were attached to a solid extension wire. ANL felt that the differential expansion was accommodated by the short, thin wall of the thermocouple rather than the solid wire extension.

Assembly B, which locates the thermocouple junction at the middle of the fuel column on some pins and 15cm below the fuel on others, places the thermocouple within the peak neutron flux region of the core. Therefore, to further improve the chances of survival in this environment, Assembly B was fabricated using an Inconel sheath and attachment wire to take advantage of Inconel's greater strength and reduced irradiation swelling over that of stainless steel; also taken into account is the fact that Atomics International had excellent performance with Inconel sheathed, small diameter thermocouples which they attributed to the fact that the thermal expansion coefficient of Inconel was between that of chromel and alumel thus reducing wire failure.

Assembly C, which located the thermocouple junction 2.5cm above the fuel, was fabricated using a stainless steel sheath and a solid stainless steel attachment wire. The selection of this design was based on the fact that the thermocouple is located in a reduced neutron flux and the length of the thermocouple below the upper attachment point is 120cm. Therefore, it was considered not necessary to use a tube extension in the attachment wire nor an Inconel sheath.

The end of the thermocouple assemblies were attached to the fuel pins identically as the wire wrap on reference driver fuel pins by welding the attachment wire to the bottom end cap. Each assembly was attached to the top of the fuel pins by using a peg welded to the top end cap as shown in Figure 6.

## FOTA HF-011 EXPERIMENT THERMOCOUPLE ATTACHMENT TO FUEL PIN END CAP




HEDL 8003-334.6

FIGURE 6

DOSIMETER ASSEMBLIES

The two experiments contain dosimeter assemblies wrapped around selected fuel pins to measure radial and axial neutron spectral information and fuel burnup. The experiment near the center of the core, where the radial variation in neutron flux is small, contains 10 dosimeter assemblies and the experiment located at the edge of the core, where the neutron flux gradient is greatest, contains 15 assemblies. The dosimetry is a mix of spectral sets and gradient sets wherein a spectral set containing 15 monitors is designed to respond to neutrons of various energies to define neutron fluence-spectrum, and a gradient set consisting of $^{239}Pu$ serves to define burnup.

Each dosimeter assembly was fabricated at HEDL as shown in Figure 7, and attached to a fuel pin identically as a solid wire spacer by welding the attachment wires to the end caps. The assembly tube which is placed adjacent to the fuel column contains vanadium encapsulated monitors and stainless steel wire spacers. The vanadium capsules, which measured 0.89mm in diameter by 4.8 to 8.6mm long, were fabricated at HEDL and were loaded with monitors and sealed at Oak Ridge. In order to provide a helium atmosphere around the vanadium capsules, the assembly tube was welded closed in a glove box which was evacuated and back filled with helium.

DUCT TUBE INSTRUMENTATION

The temperature of the duct tube wall is measured at the center of each face just above the fuel column. To accomplish this, a thermocouple was welded in a hole (as shown in Figure 4) in each face which locates the junction in the middle of the 3mm wall just 25mm above the fuel. The thermocouples extend upward from these holes along the inside of the tube in a triangular space between two pins and the wall.

# FOTA HF-011 DOSIMETER ASSEMBLIES

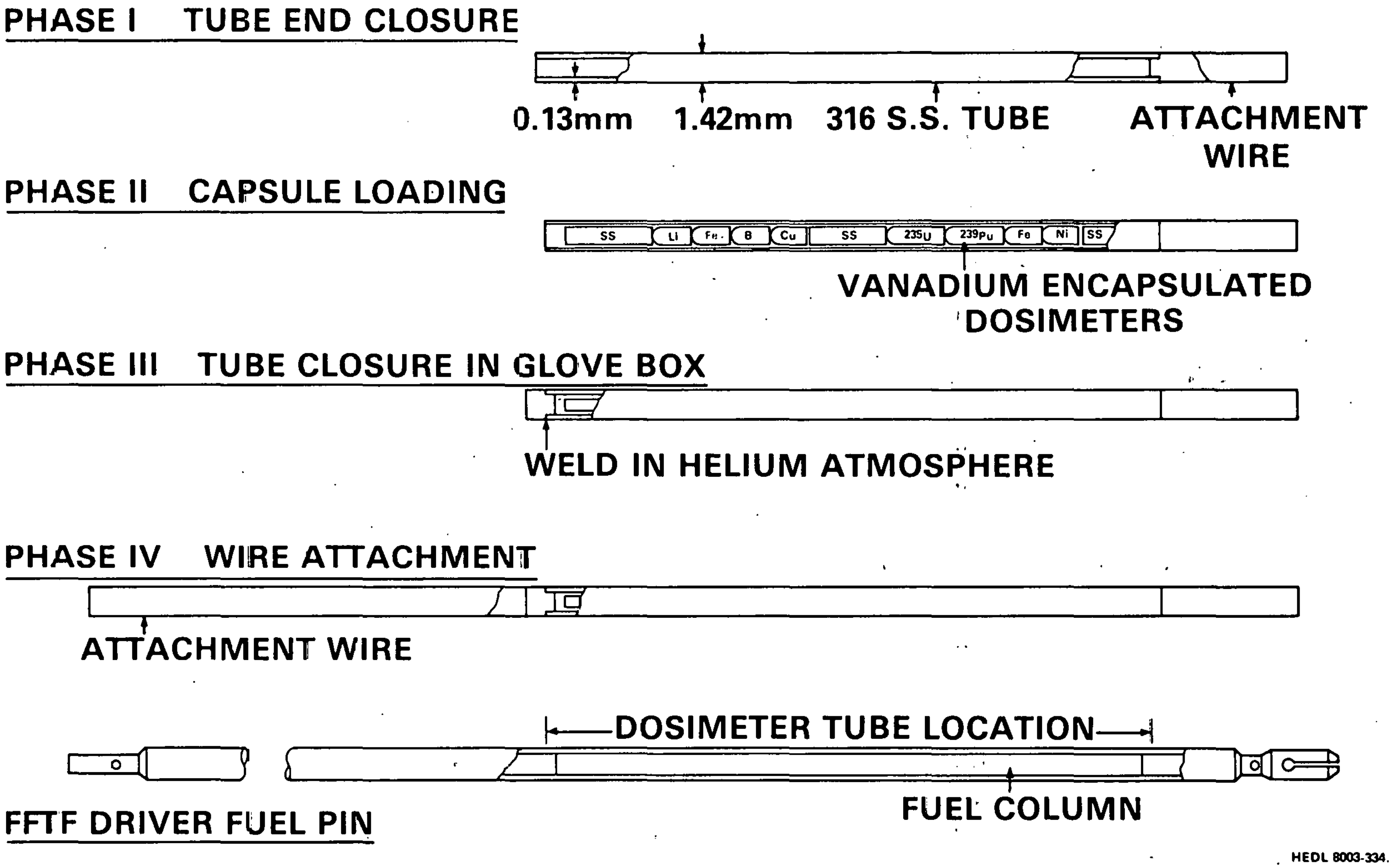



FIGURE 7

To retain the reference driver duct tube to fuel bundle clearance at 0.5mm meant that the thermocouples would fit tightly within these spaces and that it would be difficult to assemble a preinstrumented duct tube over the bundle. This problem was resolved by developing a special assembly technique in which the tube was lowered over the bundle first, and then the six thermocouples were pulled, one at a time, into position in the tube. This technique, which is illustrated in Figure 8, involved preassembling the tube with small diameter wires cinched against the inner wall using shim stock straps. After the tube was assembled over the bundle, each wire was welded to a thermocouple and used to pull the thermocouple into the tube, between the pins, and guide it through the straps and into the hole. The nose piece on the thermocouples and the straps cinched against the thermocouples were then welded to the duct tube (as shown in Figure 9).

THERMOCOUPLE EXPANSION BENDS

During the time the FOTA is in the reactor, a considerable amount of difference expansion will occur between the fuel pins and duct tube due to thermal expansion early in the test and then to irradiation swelling near the end of the test. To accommodate this pin growth, flexible expansion bends had to be accurately formed in each thermocouple at the top of the fuel bundle as shown in Figure 10. Precise bends and accurate placement of the bends were required to assure that the thermocouples would not interfere with each other and bind-up the pins.

The bends were manually formed in a special fixture designed for these two experiments (shown in Figure 11 and 12). The procedure for forming the bends required wrapping the fuel pin with the thermocouple first, and then making the bend prior to assembling the pin into the bundle. The formation

# FOTA HF-011 DUCT TUBE INSTRUMENTATION

## PHASE I DUCT TUBE ASSEMBLY OVER PIN BUNDLE

## PHASE II THERMOCOUPLE ASSEMBLY

## PHASE III ATTACHMENT WELDS

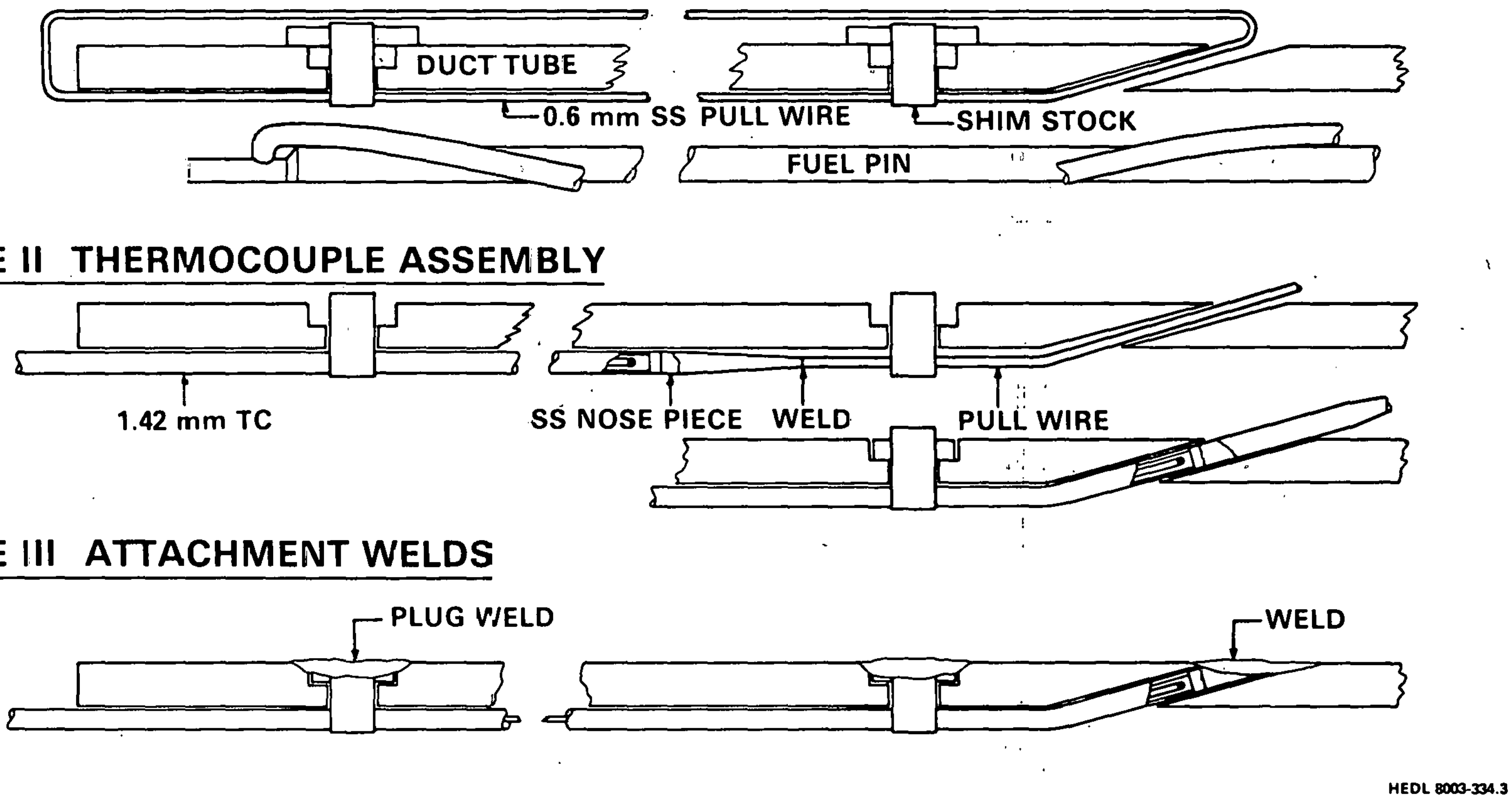



FIGURE 8

## FOTA HF-011 EXPERIMENT THERMOCOUPLE ATTACHMENT TO DUCT TUBE WALL

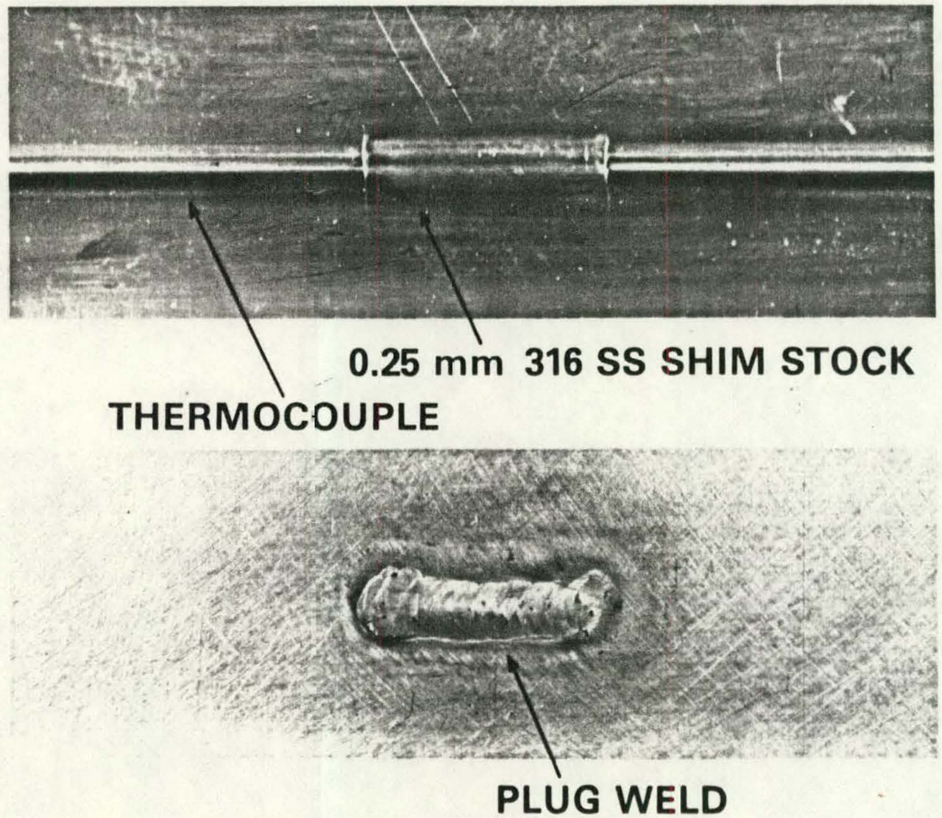



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FIGURE 9

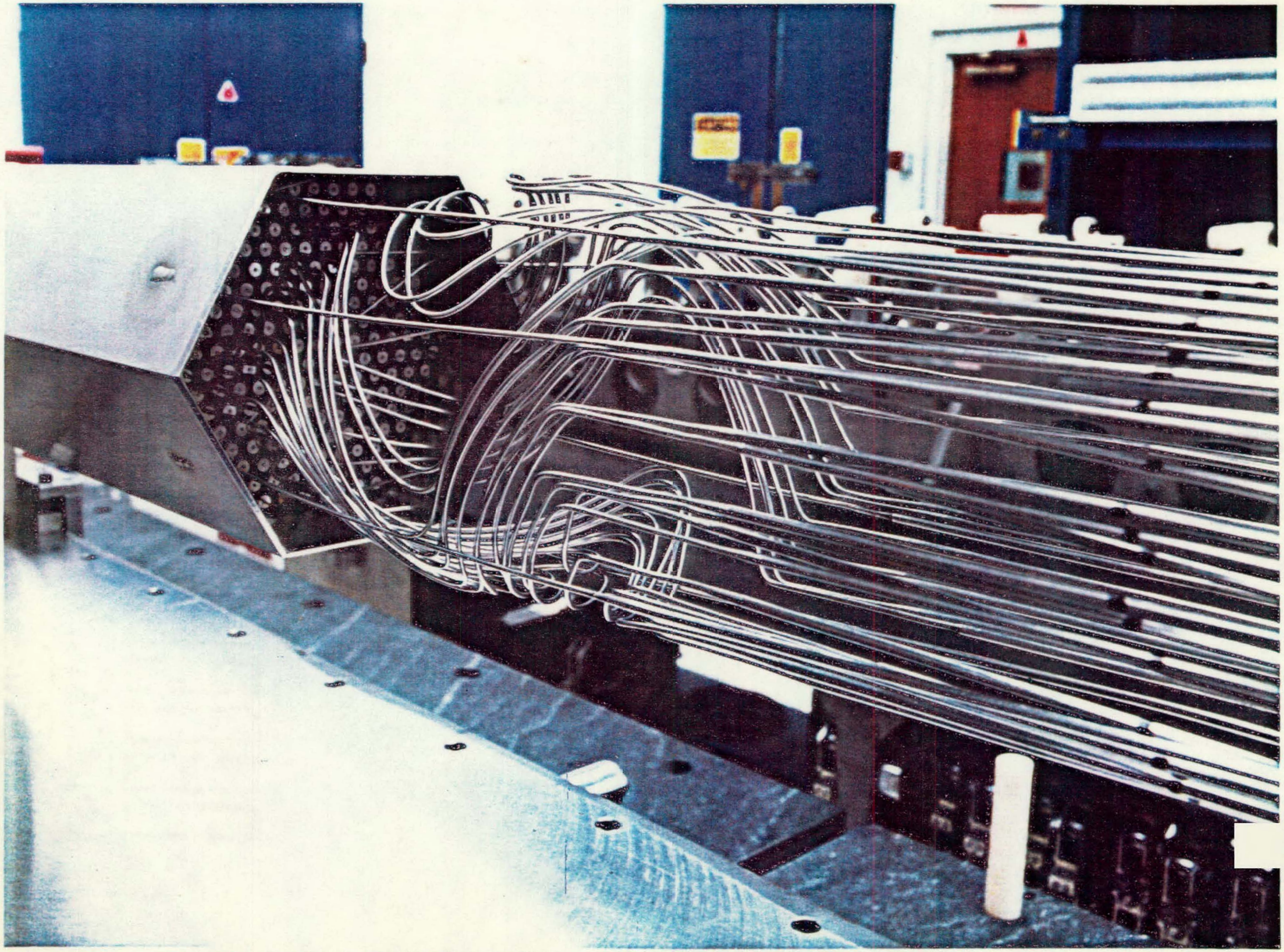

FIGURE 10 THERMOCOUPLE EXPANSION BENDS

FIGURE 11 BEND FIXTURE SET UP FOR INITIAL BENDS IN FLAT PLANE

FIGURE 12 BEND FIXTURE SET UP FOR FINAL 3-DIMENSIONAL BEND

of the bundle one pin at a time was required because those thermocouples emerging from the center of the bundle had to be precisely crossed over each other to extend them to the periphery of the bundle to remove them from the main sodium flow.

A full scale mock-up of the bundle and expansion bends in a duct tube was used in water flow tests to evaluate the extent of flow induced vibration to the thermocouples at the top of the bundle. The tests confirmed that vibration and thermocouple sheath wear were not excessive.

INSTRUMENTATION WELDS

To assure the success of these two experiments, HEDL conducted an extensive weld development and qualification program. Ninety special 15cm Inconel and stainless steel thermocouple samples (with junctions and end closure) and dosimeter tubing were procured in advance from the vendor's production lot. These samples and additional long lengths of production development thermocouples were used to qualify the thermocouple and dosimeter assembly welds, and the thermocouple to stalk pressure boundary welds.

The experiment welds in the in-core assembly were qualified and examined in accordance with RDT F6-2T. The thermocouple pressure boundary welds were qualified in accordance with ASME Pressure Vessel Code, section 3 and 9, and examined to section 5.

All the thermocouple and dosimeter assembly welds were visually examined, dye penetrant tested and radiographed. In addition, the dosimeter tube end closures were helium leak tested. The attachment welds to the fuel pin end caps were visually examined and dye penetrant tested.

The thermocouple to stalk pressure boundary welds are illustrated in Figure 1 and the actual welds are shown in Figure 13. The welds were formed

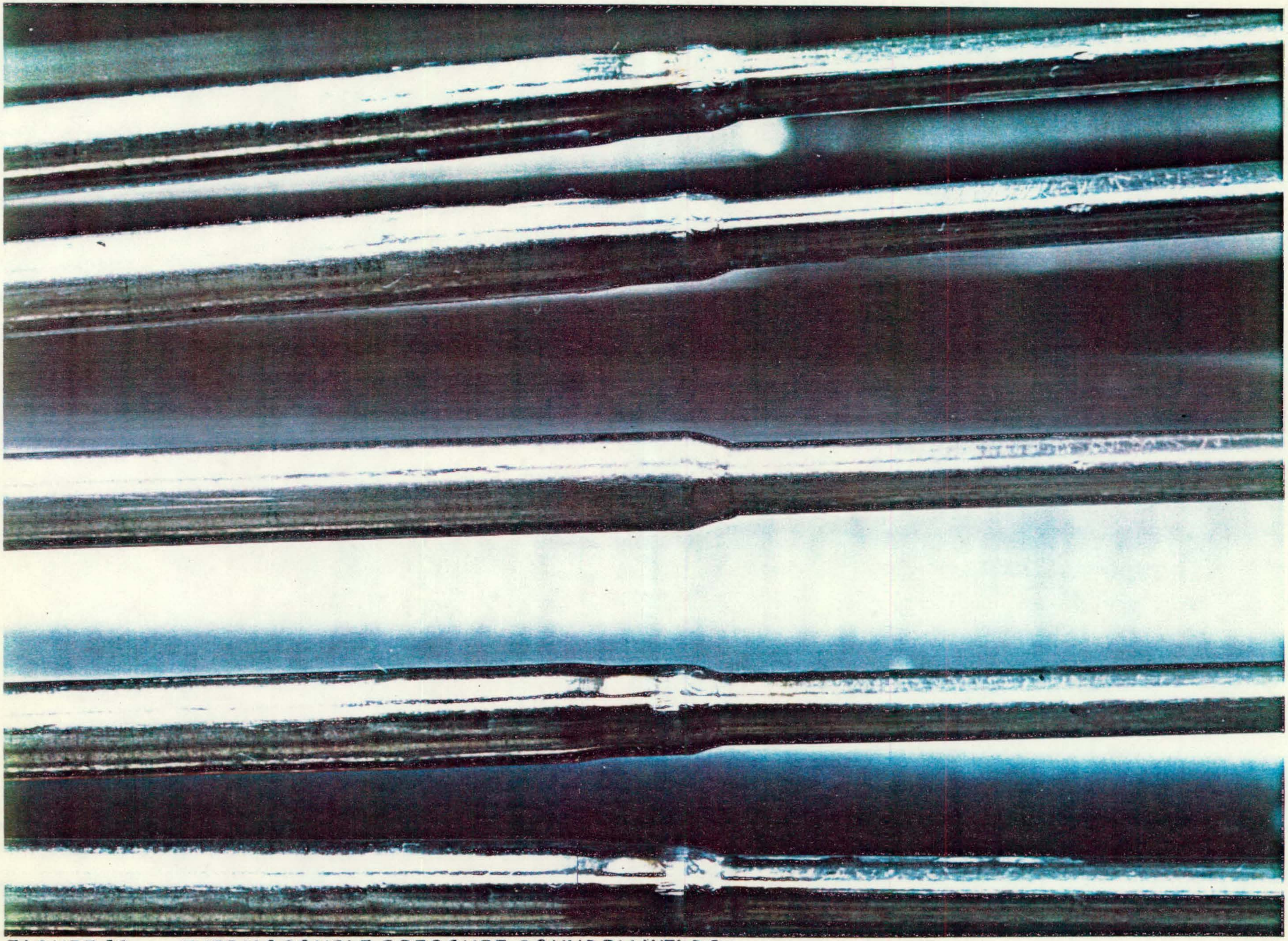

FIGURE 13 THERMOCOUPLE PRESSURE BOUNDRY WELDS

between the thermocouple sheath and a 0.25mm wall sleeve tube which is itself welded to the stalk bulkhead. All 45 sleeve tubes were 316 stainless steel, which required the qualification of two types of welds: stainless steel (S.S.) sheath to sleeve tube, and Inconel sheath to sleeve tube. The S.S. to S.S. weld was formed without a filler by first swaging the tip of the sleeve tube to the sheath and then welding. The Inconel to S.S. weld required a thin Inconel 82 ring to be inserted between the two which required no swaging. The two types of welds can be seen in Figure 13 in which the middle tube is not swaged. These welds were automatically formed using a small GTAW shown in Figure 14.

Each thermocouple pressure boundary weld was visually examined and dye penetrant tested. All 45 welds were helium leak tested at the same time by sealing the entire FOTA vehicle in a 13 meter chamber. The FOTA bulkhead o-rings partition the chamber into two sections; a lower section below the welds which was evacuated and pressurized with helium, and an upper section which was evacuated to the mass spectrometer. The tests showed that not one of the 90 welds in the two experiments had a recordable leak when using a mass spectrometer and system sensitivity of $8 \times 10^{-10}$ atm cc/sec per full scale division.

CONCLUSION

The two experiments, FOTA HF-011 and HF-012, were assembled simultaneously and given certification of conformance in June 1979. The FFTF Project gave reactor insertion approval in July 1979, and both FOTA test articles were inserted into the FTR in December 1979.

In the six months that the FOTA's have been in the reactor, the experiments have been a part of the FTR acceptance test program. During this period, the sodium flow rate through the experiments has varied from pony motor flow to

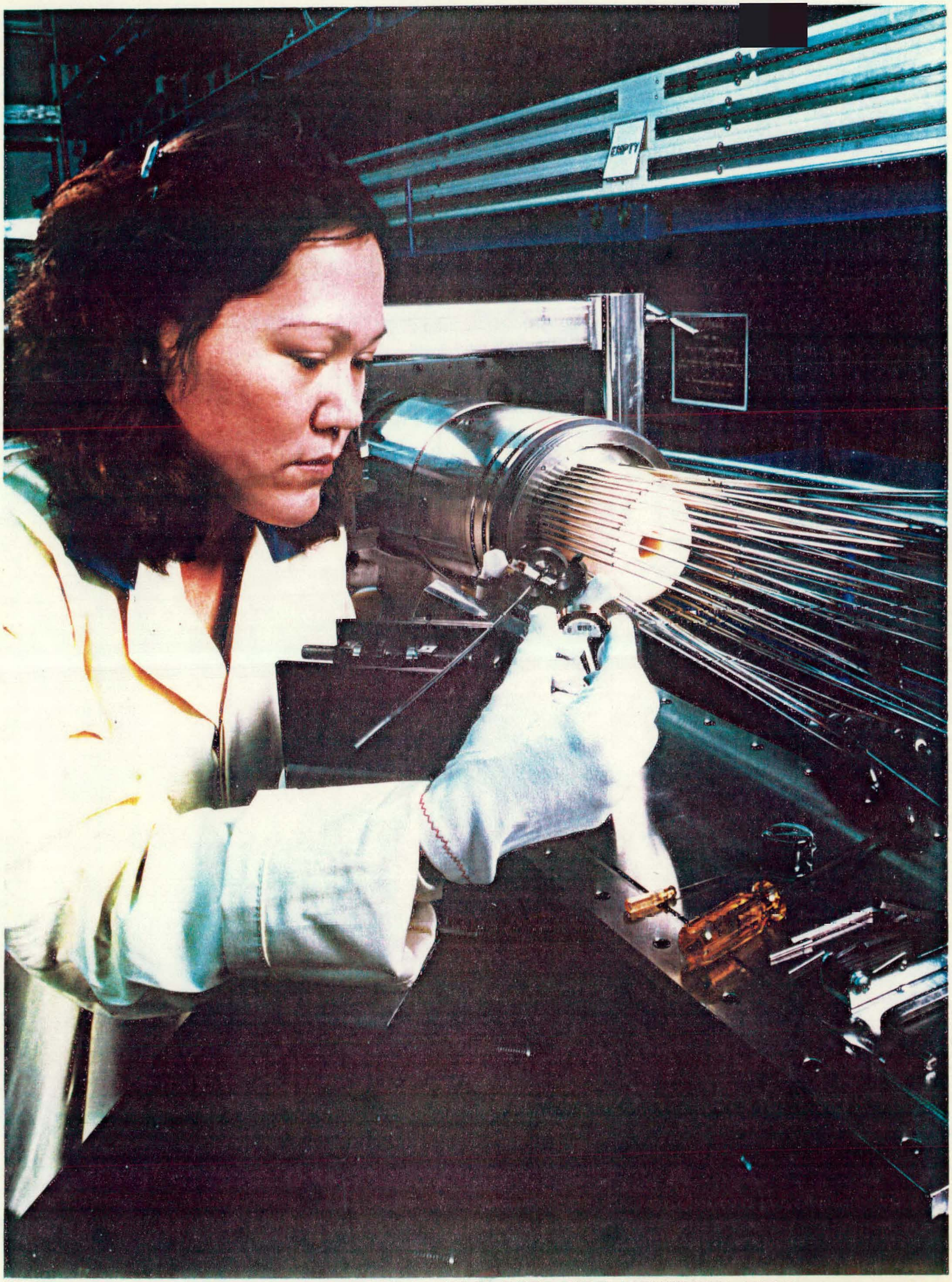


FIGURE 14 PERFORMING THERMOCOUPLE PRESSURE BOUNDARY WELD

100% flow at a sodium temperature of 400 ± 15°F. Since initial criticality, the experiments have experienced a maximum reactor power of approximately 20 kilowatts. At this time, all 90 thermocouples are still functioning correctly and during the latest extended period of isothermal flow all thermocouples read the sodium temperature to within ± 2°F.