IN-REACTOR FUEL TRANSIENT BEHAVIOUR EXPERIMENTS AT CRNL

by

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A. INTRODUCTION

Fuel performance during postulated reactor accidents is usually assessed by computer codes. The irradiation program at the Chalk River Nuclear Laboratories (CRNL) includes generic tests of fuel elements to verify particular aspects of these codes and to confirm that no unmodelled phenomenon is significantly affecting fuel performance. The specific objectives of the irradiation program are outlined in Figure 1.

Currently at CRNL we have two vertical, in-reactor loops suitable for transient tests; one to investigate loss of coolant accidents (LOCA) and the other to investigate loss of regulation accidents (LORA). In each we can test either single elements or trefoil clusters (an assembly of 3 fuel elements) as required by the program. Later we plan to investigate larger clusters in an in-reactor horizontal loop.

B. THE LOCA TEST FACILITY AND FUEL ELEMENT ASSEMBLY

The LOCA test facility is a pressurized light water loop with an in-reactor test section 3 m long by 38 mm inside diameter. This test section can be isolated from the main loop circuit and the coolant blown down; see Figure 2. Blowdown rates can be varied and the blowdown can be initiated immediately after or coincident with a reactor shutdown. The test section can be reflooded with cold water to simulate emergency core cooling. The loop piping is heavily shielded and the loop coolant is filtered to remove any fuel debris.

Test assemblies can be either a single instrumented element (19 mm diameter by 500 mm length) or a cluster of three elements each 13 mm diameter. The elements are fuelled with sintered high density (>10.60 Mg/m^3) UO_2 pellets inside a Zircaloy-4 or stainless steel sheath. A typical single element with thermocouples both in the fuel and semi-buried in the 0.8 mm thick sheath is mounted inside a longitudinally split Zircaloy flow tube (Figure 3). This flow tube is also used to mount several other instruments. The flow tube and element assembly are suspended from a stainless steel hanger bar which is attached at its top end to a closure fitting (Figure 4). The closure which can accommodate up to 24 instrument lead wires is the pressure boundary between the loop coolant and the reactor hall.

C. INSTRUMENTATION

Much of our effort has gone into the development, procurement and testing of instrumentation to measure fuel element parameters in-reactor. These measurements fall into four categories: temperature, pressure, displacement (axial to detect dryout and diametral to measure strain) and fission gas release. A brief description of the instruments we have chosen follows:

1. Temperatures

Metal-clad ceramic-insulated thermocouples will be used to measure temperatures of the fuel, sheath, flow-tube and coolant. Fuel thermocouples, three at the pellet periphery and one at the centre are sheathed with either molybdenum or a Mo-Re alloy. Four sheath thermocouples are clad in either stainless steel or Zircaloy. In early tests thermocouples have been attached to the sheath by brazing but are now laser welded; see Figure 5.

2. Pressures

We record both the coolant pressure and the pressure of the gas inside the fuel element during a blowdown. Both pressures are measured with balanced-bridge eddy current pressure transducers purchased from Kaman Sciences (Figure 6). These transducers have been modified to improve their stability during rapid changes in coolant temperature.

3. Displacement

Sheath dryout is detected by measuring the length change of the fuel element with a balanced-bridge eddy-current displacement transducer again supplied by Kaman Sciences (Figure 7). To follow sheath ballooning during a transient we are developing in co-operation with Kaman Sciences a constant-current send-and-receive eddy current sensor for non-contact diameter measurements.

4. Fission Gas Release

The amount and species of gaseous fission products released from the fuel during a blowdown will be determined by using the CRNL sweep gas system (Figure 8) in a test planned for 1982. This system continually sweeps a helium carrier gas over the fuel pellets and past an on-line gamma-ray spectrometer where the quantity of individual isotopes can be measured.

D. IN-REACTOR TESTS

We have completed irradiations with assemblies similar to those described in Section B both to study instrument performance and to commission the loop blowdown circuit.

In the instrument development tests Zircaloy clad elements were cycled in and out of dryout at linear powers of 45 and 55 kW/m. The elements were cooled with a mixture of water and steam; sheath dryout was achieved by cutting off the water flow and cooling only with superheated steam. Dryout sheath temperatures up to 650°C were measured for periods between 2 and 5 minutes; see Figure 9. The eddy current displacement transducers successfully recorded the change from a wet to a dry sheath. However, these tests have shown that the stability of eddy current sensors to rapid changes in neutron flux and coolant temperature must be improved.

The loop blowdown circuit has been commissioned with instrumented fuel elements operated at linear powers of 45 kW/m. Stainless steel sheaths were used both because they are rugged and because our supply of Zircaloy sheathed thermocouples has not as yet been assured. Instrumentation consisted of fuel, sheath, flow tube and coolant thermocouples. All our blowdown tests to date have been done with the coolant depressurization taking place after the reactor has shutdown and blowing down from the top and bottom of the test section simultaneously. We have investigated the blowdown rate, the delay time between the reactor shutdown and blowdown and the time the element resides in near stagnant coolant. Increases in sheath temperature of 350°C have been measured. A plot of element temperatures and how they interact with coolant pressure is given in Figure 10. The elements were rewet with cold pressurized water when the test section pressure dropped below 2.9 MPa.

E. FUTURE LOCA EXPERIMENTS

The blowdown program is projected to last well into 1985 (Figure 11). The instrumented single element experiments are detailed in Figure 12. The B series of tests which are now underway are confined to commissioning the loop and establishing the blowdown parameters with stainless steel clad elements. The next series, C, will be used for code verification studies on Zircaloy sheathed elements with the reactor shutdown preceding the blowdown. Test series D and E will also be verification experiments but with the blowdown before shutdown. The last scheduled tests will investigate the behaviour, particularly element interaction, of three element assemblies during coolant transients.

F. THE LORA PROGRAM

A complementary in-reactor program will investigate the in-reactor behaviour of fuel elements in a postulated loss of regulation accident; see Figure 13. This program, which is similar to the American power coolant mismatch series, will concentrate on fuel and sheath behaviour when the cladding is forced into dryout at high values of surface heat flux, conditions that may result in central UO_2 melting. Instruments for this program will be developed in the blowdown LOCA test series. The program will start with single instrumented elements and then move to three-element assembl..es. Experimental parameters will include heat flux, differen' coolant flow regimes, time in dryout and the effect of fuel burnup. The test series will also look at the effect of 'fuel element - pressure tube' contact at high fuel element powers.

G. HORIZONTAL TEST FACILITY

A horizontal loop in the NRU reactor at CRNL, if it is approved by management, should be available for experiments starting in 1984. This loop will allow us to investigate the effect of gravity on element interaction in a 7 element assembly. Both LOCA and LORA conditions will be studied in this facility. The program for the horizontal loop is not yet well defined.

FIGURE 1

OBJECTIVES OF THE IRRADIATION PROGRAM

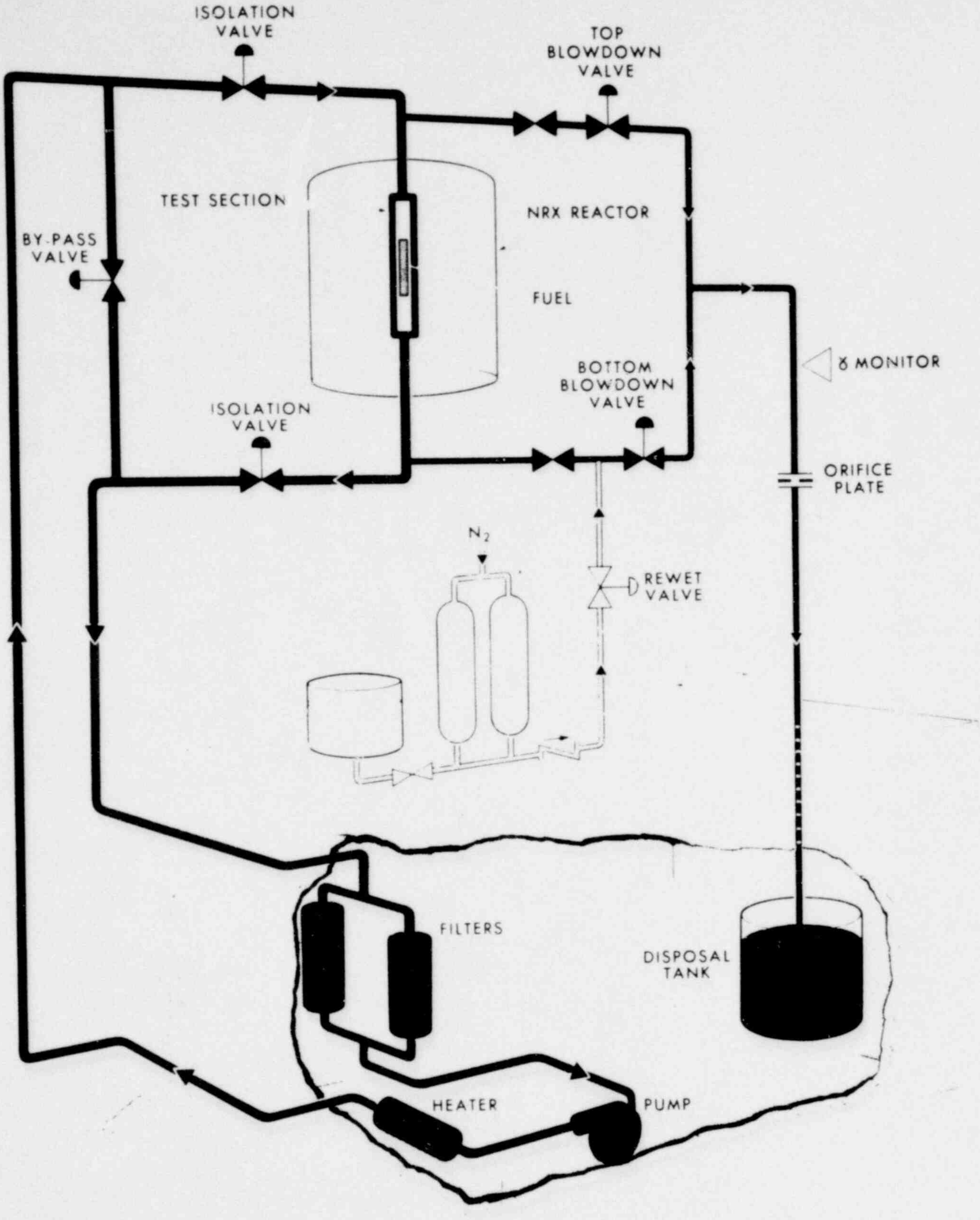
1. COMPARE FUEL AND SHEATH TEMPERATURES CALCULATED BY "ELOCA" WITH MEASUREMENTS.

2. INTERNALLY PRESSURIZE ELEMENTS AND SEE IF SHEATH BALLOONING DURING A TRANSIENT IS PREDICTED BY "ELOCA".

3. PERFORM COMBINED TESTS TO DETERMINE IF AN UNSUSPECTED MECHANISM CAN SIGNIFICANTLY INFLUENCE FUEL BEHAVIOUR.

4. STUDY ELEMENT FAILURE MECHANISMS DURING TRANSIENTS.

5. MEASURE THE FISSION PRODUCT RELEASE FROM THE FUEL DURING A TRANSIENT.



BLOWDOWN CIRCUIT FOR X-2 LOOP

FIGURE 2

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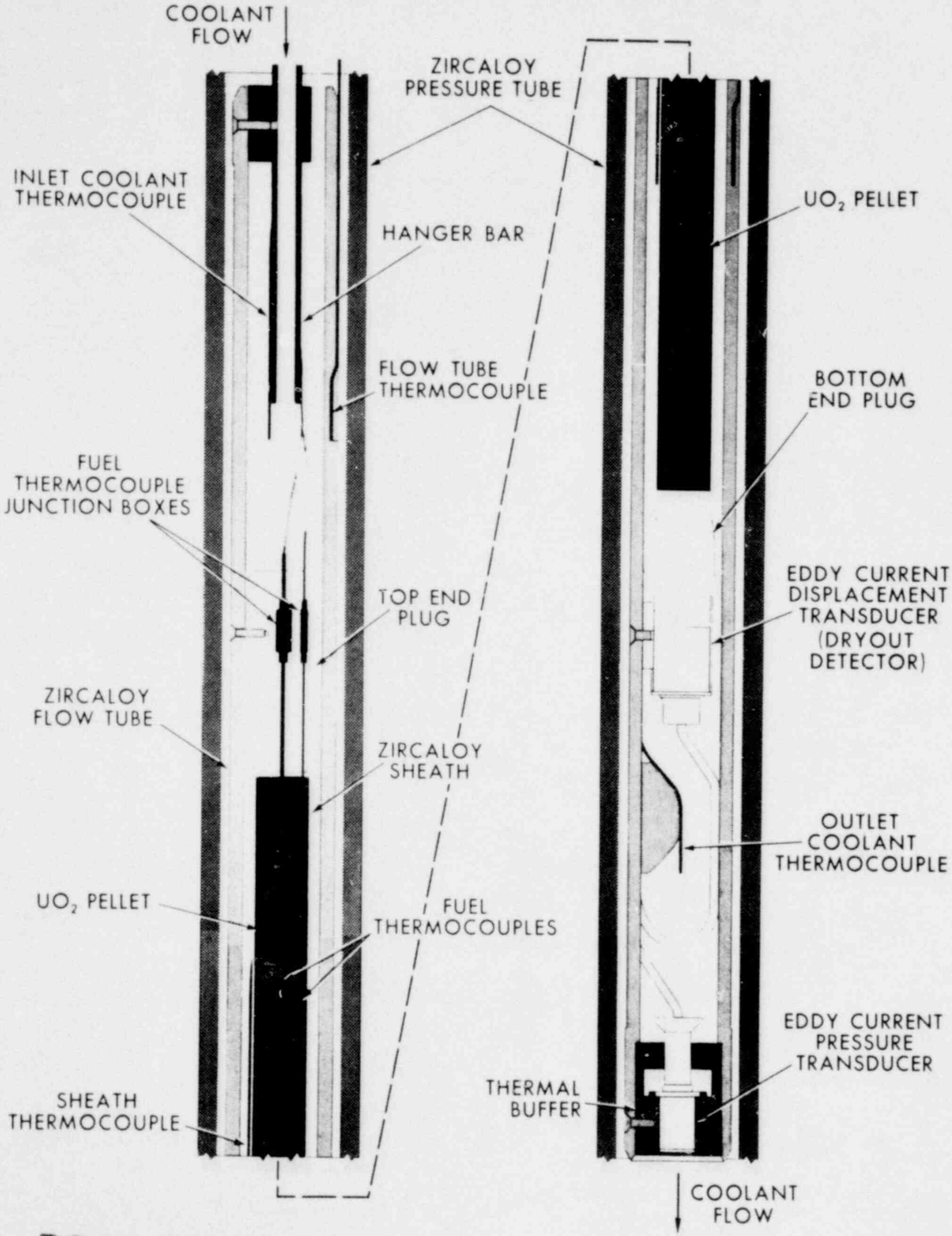
FIGURE 3

FUEL ELEMENT AND FLOW TUBE ASSEMBLY FOR COOLANT TRANSIENT TESTS



POOR ORIGINAL

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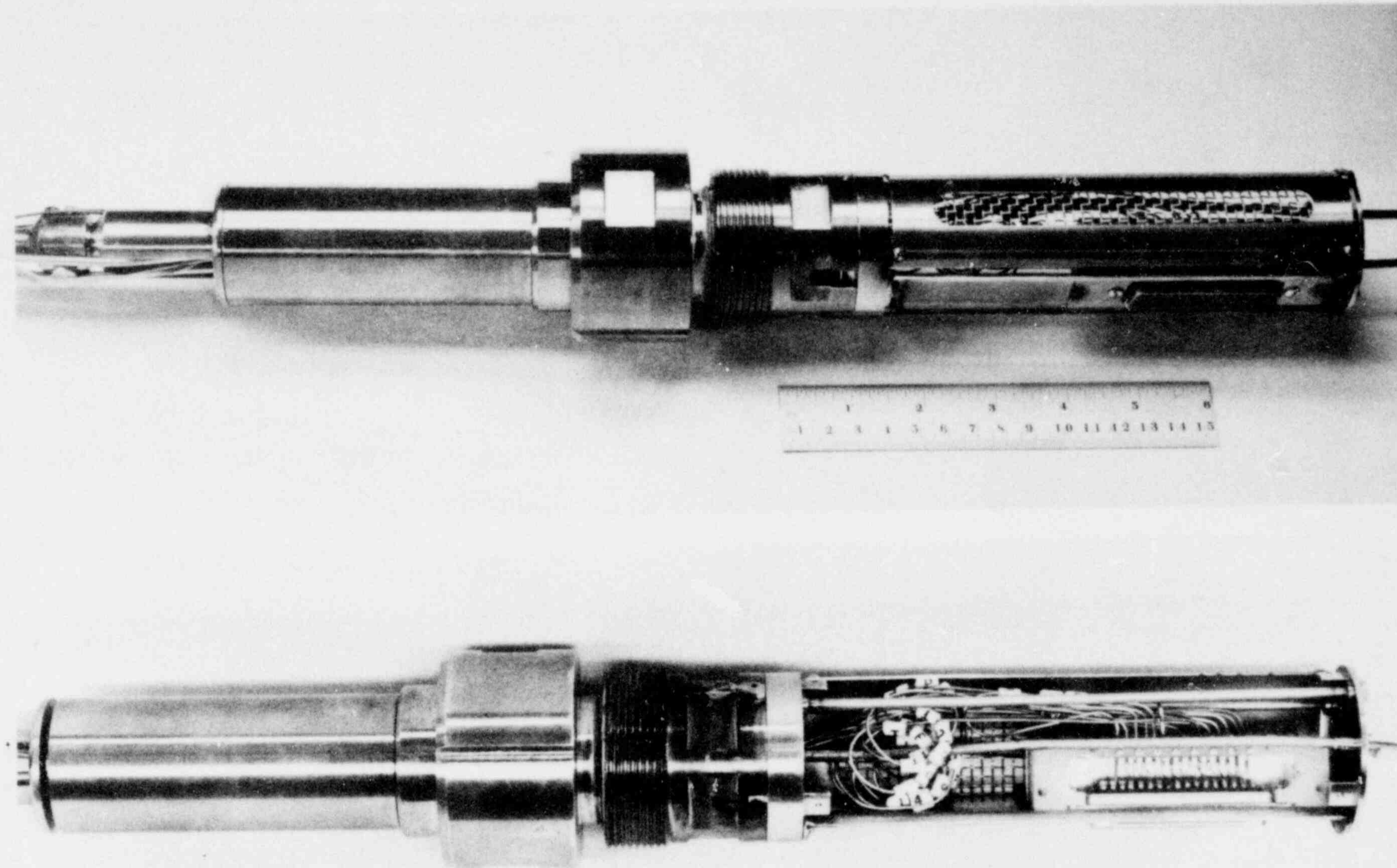

Figure 4 Top closure of the fuel assembly. The instrument lead wires are sealed in a graphite packed Conax fitting inside the stainless steel cylinder. The thermocouple wires are attached to a quick disconnect plug shown on the bottom photograph. The lead wires for the eddy current sensors are terminated on the top plate. The top photograph shows the closure with the cover plates installed.

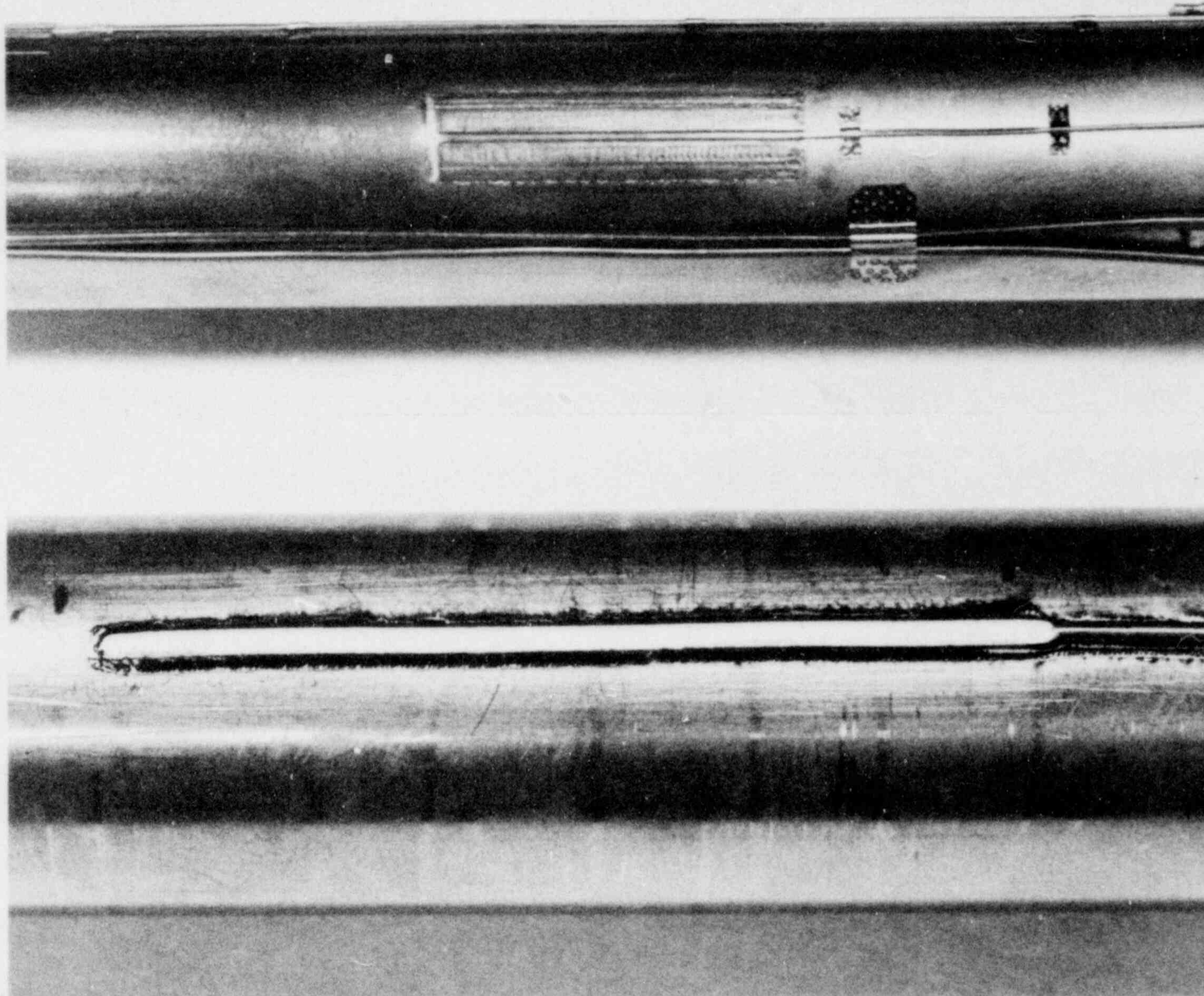

Figure 5 Two types of hot junctions of a chromel/alumel, stainless steel thermocouple used to measure sheath temperature. The top thermocouple is semi-buried in the Zircaloy sheath wall with a Zircaloy cover plate brazed over the flattened tip. The flattened tip of the bottom thermocouple is laser welded in a shallow groove machined in a stainless steel sheath.

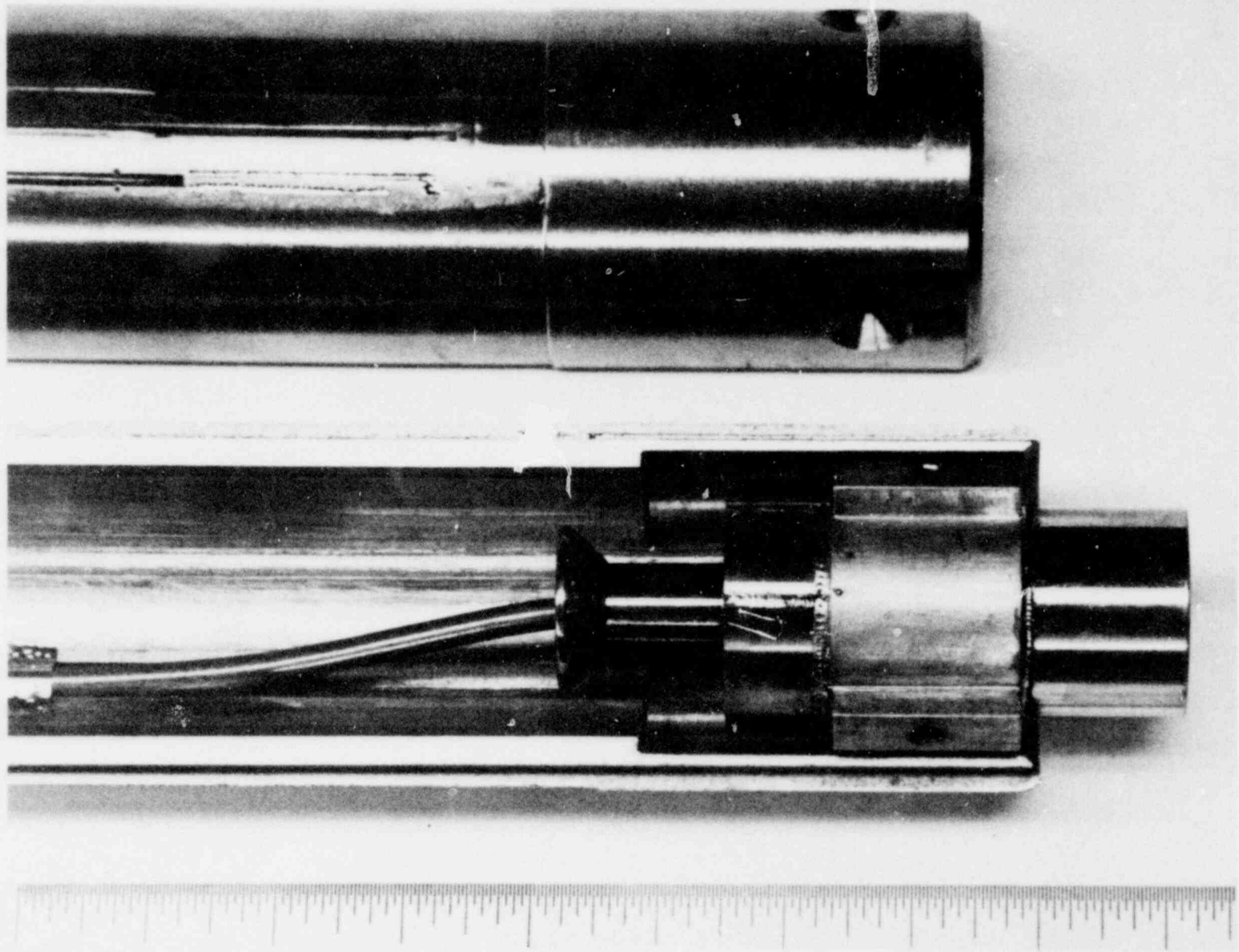

Figure 6 The eddy current pressure transducer mounted in one half of the split flow tube. This transducer is equipped with an early type thermal buffer. Note the thermocouple embedded in the mating half of the flow tube used to measure flow tube temperature.

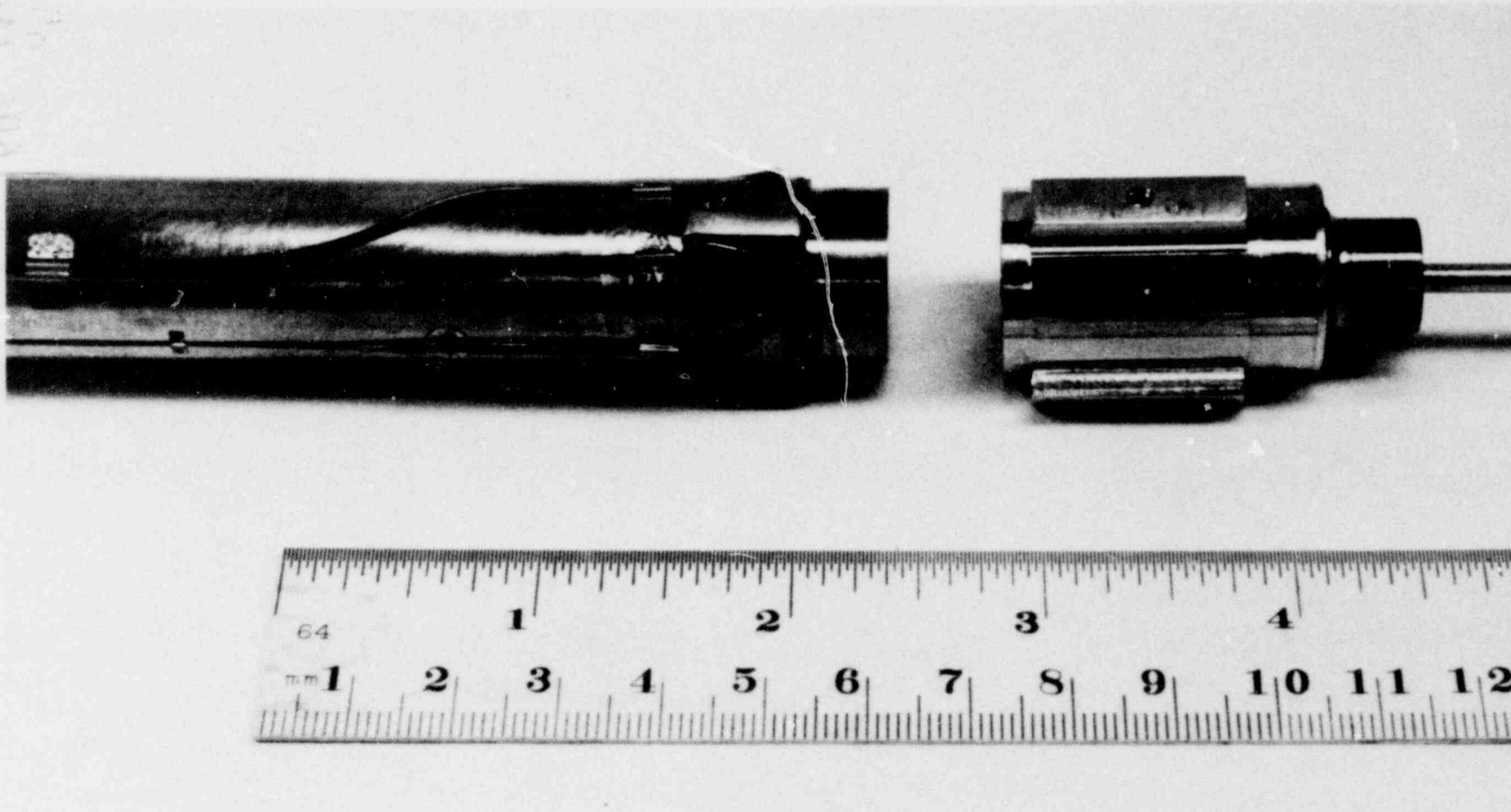

Figure 7 The eddy current displacement transducer (a dryout detector) is shown on the right of the photograph. The bottom end plug of the fuel element on the left fits inside a recess on the end of the transducer.

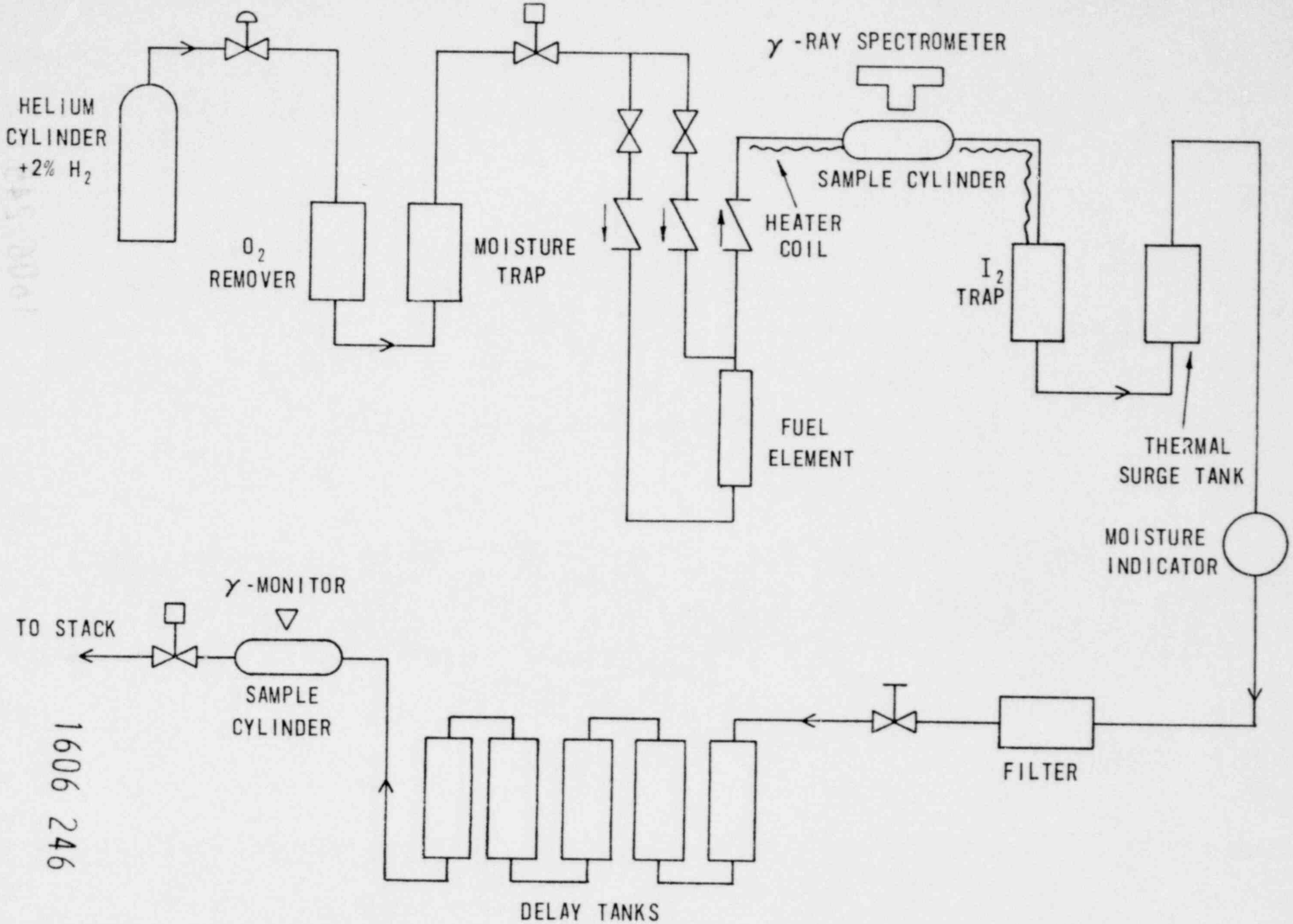

FIGURE 8 FLOW SHEET OF SWEEP GAS SYSTEM AS ADAPTED FOR COOLANT TRANSIENT IRRADIATIONS

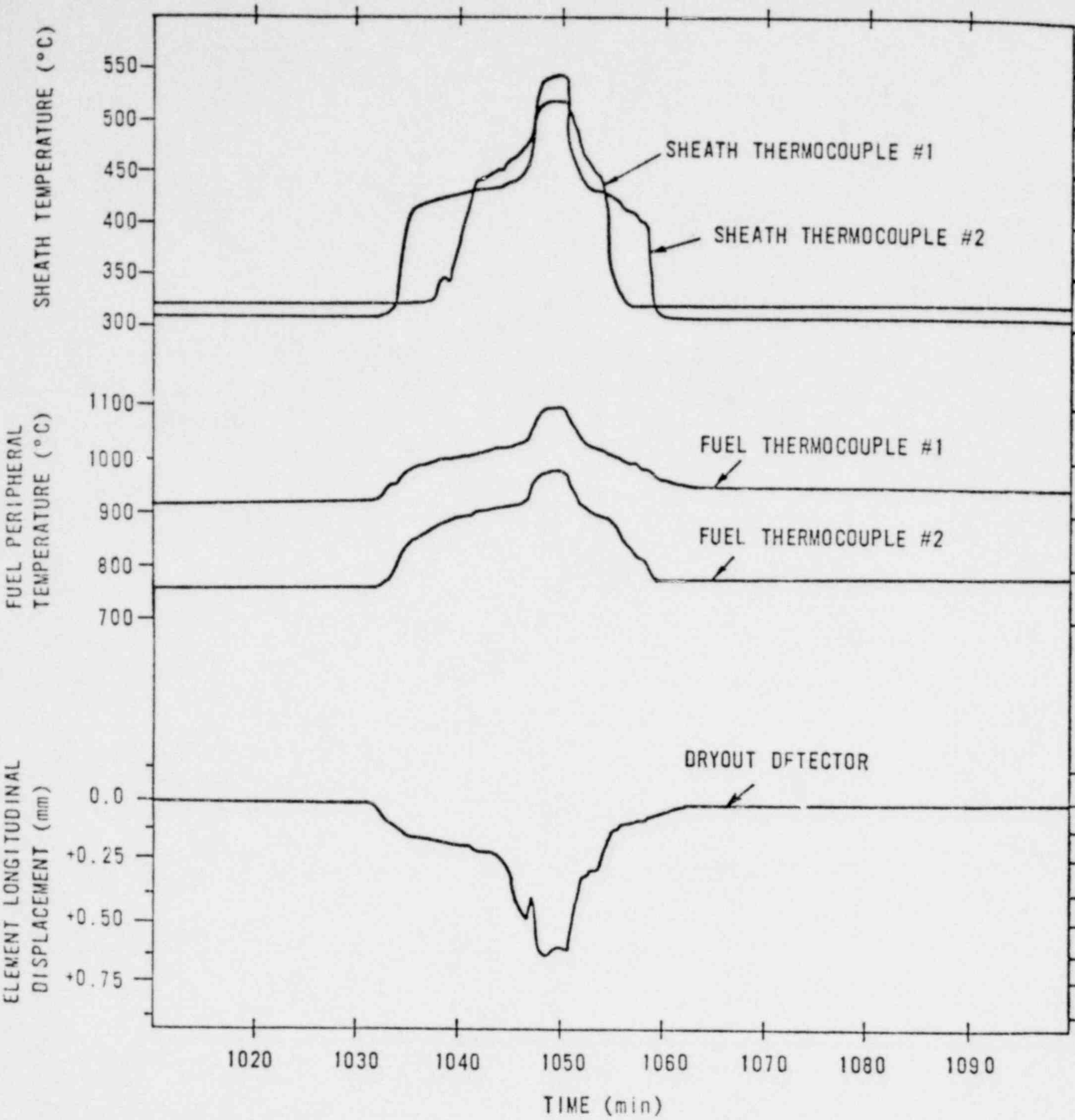

FIGURE 9 COMPARISON OF FUEL AND SHEATH TEMPERATURES AND ELEMENT LONGITUDINAL DISPLACEMENT DURING SHEATH DRYOUT OF AN INSTRUMENTED FUEL ELEMENT

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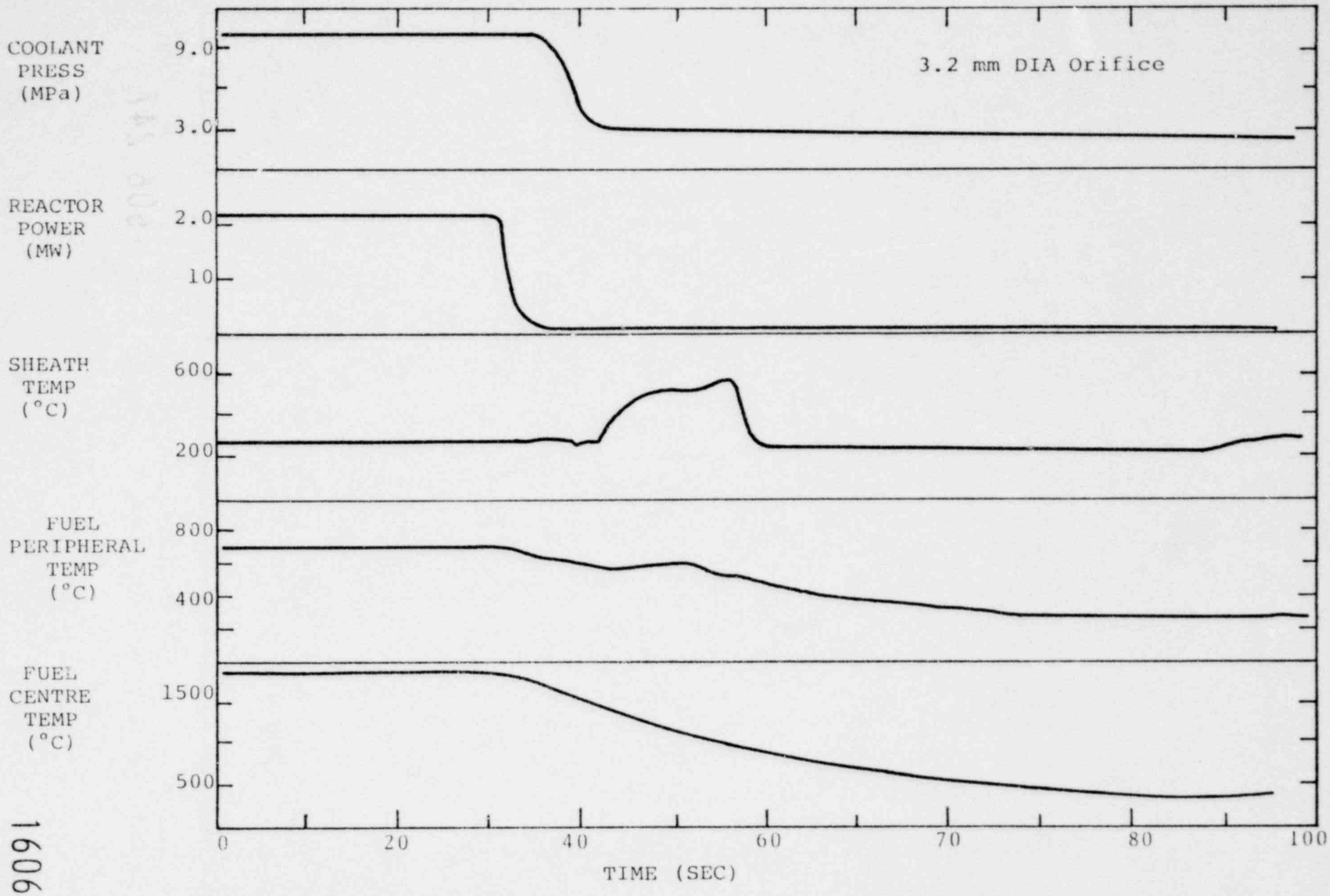

FIGURE 10 COMPARISON OF FUEL AND SHEATH TEMPERATURES FOR X-2 LOOP BLOWDOWN 4 SEC AFTER A REACTOR TRIP.

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FIGURE 11

IN-REACTOR BLOWDOWN PROGRAM

FACILITY	YEARS	NO. OF ELEMENTS	PURPOSE
NRX VERTICAL LOOP	1979 - 1984	SINGLE	FUEL ELEMENT PARAMETERS FOR CODE VERIFICATION
		3 ELEMENT ASSEMBLY	INTERACTION BETWEEN ELEMENTS DURING BLOWDOWN
NRU HORIZONTAL LOOP	1984?	7 ELEMENT ASSEMBLY	ELEMENT INTERACTION DURING BLOWDOWN AND LOSS OF REGULATION TO INCLUDE THE EFFECT OF GRAVITY

FIGURE 12

SCHEDULE FOR IN-REACTOR BLOWDOWN EXPERIMENTS

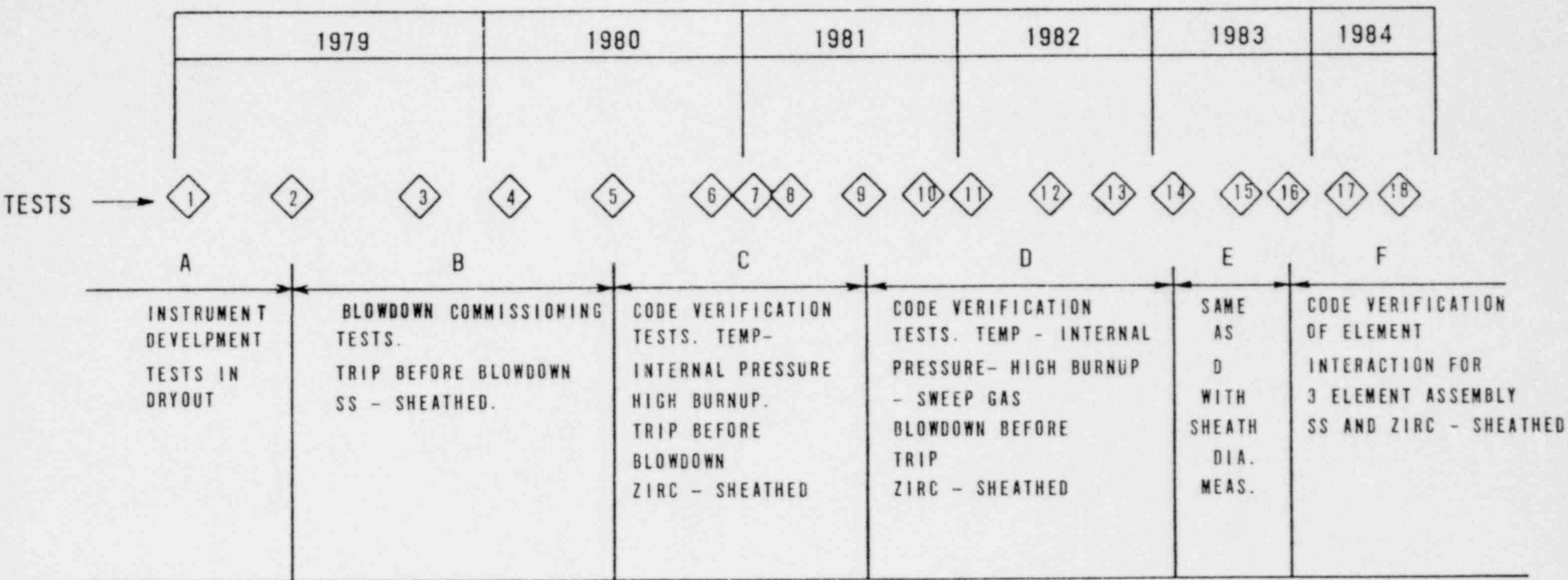

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FIGURE 13

FUEL BEHAVIOUR IN A LOSS OF REGULATION ACCIDENT

FACILITY	TIME PERIOD	TEST ASSEMBLY	TEST OBJECTIVE	TEST VARIABLES
X-4 LOOP IN THE NRX REACTOR	1979 - 1980	SINGLE ELEMENT STAINLESS STEEL SHEATH INST.	CALIBRATE SURFACE VS EMBEDDED T/C	HEAT FLUX FLOW REGIME
		3 ELEMENT ASSEMBLY ZIRC SHEATHS INST.	CALIBRATE SURFACE T/C VS LOOP PARAMETERS	
PRESSURIZED LIGHT WATER, FOG, SUPERHEATED STEAM	1981 - 1983	3 ELEMENT ASSEMBLY ZIRC SHEATHS INST.	FUEL ELEMENT BEHAVIOUR IN DRYOUT	HEAT FLUX FUEL BURNUP RATE OF SHEATH TEMP. RISE REWET TIME AT TEMPERATURE FLOW REGIME
^3H_e COIL AND VENTILATION/ CHARCOAL FILTERS				
	1983 - 1984	SINGLE ELEMENT ECCENTRIC IN FLOW TUBE LINER ZIRC SHEATH INST.	BEHAVIOUR OF FUEL ELEMENT IN CONTACT WITH PRESSURE TUBE	HEAT FLUX CONTACT PRESS. FLOW REGIME

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