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W-1 SLSF EXPERIMENT

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MASTER

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W-1 SLSF EXPERIMENT

I. INTRODUCTION

The Sodium Loop Safety Facility (SLSF) is a doubly-contained, closed sodium loop designed to test full length fast breeder reactor (FBR) fuel pins under simulated hypothetical fast reactor accident conditions. The SLSF is located in the Engineering Test Reactor (ETR) at the Idaho National Engineering Laboratory (INEL), and is operated by EG&G Idaho, Inc.

The W-1 SLSF experiment is the fifth in a series of experiments being performed by the Department of Energy (DOE) to resolve technical issues affecting licensing of fast breeder reactors. The experiments are being conducted under the direction of both Argonne National Laboratory (ANL) and the Hanford Engineering Development Laboratory (HEDL). W-1 is the first in the series of HEDL tests, and is being conducted in cooperation with the Advanced Reactor Systems Division of the General Electric Company (GE/ARSD).

II. OBJECTIVES

The W-1 experiment has two distinct and separate objectives. The primary objective is to evaluate fuel pin heat release characteristics during loss-of-piping integrity (LOPI) accident flow and power conditions. The Clinch River Breeder Reactor (CRBR) conditions during this accident are being used as representative of FBR's. A progression of four LOPI tests will be conducted to collect data at different fuel pin conditions. These four tests will be performed on fuel pins with a) fresh, unrestructured fuel, b) fresh, restructured fuel, c) irradiated, uncracked fuel (after steady-state irradiation), and d) irradiated, cracked fuel (after shutdown and startup).

The second objective of the W-1 experiment is to determine stable boiling and recovery limits (boiling window) as a function of fuel pin power. These boiling tests and the W-1 experiment will, by design, culminate with incipient fuel pin failure in order to determine the range of power/flow ratios over which stable sodium boiling exists.

W-1 SLSF EXPERIMENT

OBJECTIVES

- EVALUATE HEAT RELEASE CHARACTERISTICS OF FBR FUEL PINS DURING LOPI TRANSIENT CONDITIONS

- STUDY STABLE BOILING AND RECOVERY LIMITS (BOILING WINDOW)

These objectives are consistent with the resolution of major second level FBR safety assurance (LOA-2) issues identified in the Fuel Pin Failure Mechanisms Program Plan and will provide increased insight and understanding of phenomena that inherently terminate hypothetical accidents with limited core damage (LOA-2) prior to whole core disruption (LOA-3).

III. EXPECTED RESULTS

The combined results from the W-1 SLSF experiment are expected to resolve open questions regarding:

- Heat release characteristics and fuel-cladding gap conductance of FBR fuel pins under transient operating conditions,
- The rate at which sodium boiling develops,
- The formation growth and stability of sodium boiling,
- The early and intermediate sodium boiling regimes with low quality,
- The operating conditions which produce prolonged boiling in a pin array,
- The time required to establish film boiling and dryout in local coolant channels, and
- The time fuel pins can sustain coolant boiling without cladding failure.

The improved knowledge in those areas will permit refinement of the computer models employed in whole-core, loss-of-flow safety analyses. Application of these experimentally supported models or correlations will bear out the fact that many loss-of-cooling accidents will cause only limited core damage rather than carry over to whole-core involvement.

IV. EXPERIMENT DESCRIPTION

A. General Experiment Activities

The W-1 SLSF Experiment involves many activities by the experimenter (HEDL) and facility operators (EG&G and ANL/W). These activities include

W-1 SLSF EXPERIMENT

EXPERIMENT RESULTS

THE COMBINED RESULTS FROM THE W-1 SLSF EXPERIMENT ARE EXPECTED TO RESOLVE OPEN QUESTIONS REGARDING:

- HEAT RELEASE CHARACTERISTICS AND FUEL-CLADDING GAP CONDUCTANCE OF FBR FUEL PINS UNDER TRANSIENT OPERATING CONDITIONS,
- THE RATE AT WHICH SODIUM BOILING DEVELOPS,
- THE FORMATION GROWTH AND STABILITY OF SODIUM BOILING,
- THE EARLY AND INTERMEDIATE SODIUM BOILING REGIMES WITH LOW QUALITY,
- THE OPERATING CONDITIONS WHICH PRODUCE PROLONGED BOILING IN A PIN ARRAY,
- THE TIME REQUIRED TO ESTABLISH FILM BOILING AND DRYOUT IN LOCAL COOLANT CHANNELS, AND
- THE TIME FUEL PINS CAN SUSTAIN COOLANT BOILING WITHOUT CLADDING FAILURE.

test definition, test train (test vehicle) design and fabrication, pretest analysis predictions, detailed test specification (test plan) development, test operations, postirradiation examination (PIE), and preparation of experiment reports. Due to the complexity of each SLSF experiment, these activities span approximately three years for each experiment.

The pretest analysis for the W-1 SLSF experiment was performed for HEDL by GE/ARSD. This in-depth analysis included both steady-state and transient predictions of test train instrumentation response during the entire W-1 experiment.

The HEDL activities include test definition (with assistance from GE/ARSD), test train design and fabrication, test plan preparation, experiment operations, PIE planning, detailed fuel pin PIE, and experiment data reporting.

EG&G activities involve the design and fabrication (in conjunction with ANL) of the many SLSF supporting systems such as the data acquisition system (DAS), On-Line-Cover Gas System (OLCS), and On-Line Sodium Sampling System (OLSS). EG&G is responsible for SLSF loop procurement, outfitting and assembly, sodium fill activities, loop handling, and ETR/SLSF systems operations.

ANL activities for the W-1 Experiment include assistance in the checkout and operation of the OLCS (by ANL/E) and PIE work at the Hot Fuels Examination Facility (HFEF, operated by ANL/W), where the SLSF loop is disassembled and the W-1 fuel pins will be recovered for shipment to HEDL.

B. Facility Description

Following fabrication at HEDL, the W-1 test train was shipped to the Engineering Test Reactor (ETR). The ETR is a 175 MW water cooled reactor. [Also shown in the figure is the Materials Test Reactor (MTR) and the Advance Test Reactor (ATR).]

The SLSF loop is shown here in schematic form.

Shown in black is the primary tube, complete with sodium-to-helium heat exchanger and sodium pump core. The primary tube is made of 1/4" thick stainless steel.

Shown in blue is the pump coil stator which is placed on the primary tube.

Shown in red is the secondary tube. The secondary tube is also 1/4" thick stainless steel and completes the double containment of the loop.

Shown in yellow is the HEDL-designed and -fabricated test train.

Following assembly, the entire loop is lowered into the ETR.

The Removable Top Closure, shown in brown, is attached, linking the loop to the helium system, the pump power system, and the data aquisition system. The loop is approximately 8.2 meters (27 feet) long and wieghs close to 4500 kg (10,000 lbm).

The ETR, loop, and several facility components supporting irradiation testing are shown here. The ETR with SLSF loop in place is shown on the right. The pump power supply is shown in upper level of the reactor building.

The data acquisition system is shown in middle level of the building. The loop heat exchanger system is shown in the lower level [helium-to-water HX].

c) Test Train Description

The HEDL-fabricated test train contains nineteen (19) Fast Flux Test Facility (FFTF)-type fuel pins. Each pin has a wire wrap thermocouple and the inner seven pins of the hexagonal bundle contain in-fuel thermocouples. This is a schematic of the W-1 fuel pins. The W-1 fuel bundle contains pins with graded enrichments from center pin to outer pin to keep the bundle radial power profile flat. This figure shows the pin complete with both in-fuel and wire-wrap thermocouples.

The W-1 test train contains, in total, about eighty (80) thermocouples, sixteen (16) pressure transducers and four (4) sodium flow meters. A detailed vertical schematic of the W-1 SLSF loop and test train is shown in the next two figures.

Shown first is a schematic of the upper section of the SLSF loop and W-1 test train. Shown on the upper right is the W-1 connector assembly which mates with the removable top closure (not shown) for transfer of instrumentation signals to the data acquisition system. Shown on the left are some details of the double-element total flow-sensor.

Shown next is the lower section of the SLSF loop and W-1 test train. Shown on the right is the test section outlet flow sensor, thermocouples and pressure transducers. Shown on the left is the test section inlet flow sensor, thermocouples, and pressure transducer and the test train tungsten meltdown cup.

A horizontal cross-section of the loop in the test section region is shown here.

Shown in gray and pale green are the SLSF secondary and primary tubes respectively. Shown in blue, orange, and yellow are the downcommer, bypass and test section flow streams respectively. Shown in red is the stainless steel hexcan and shown in white are the fuel pins.

D. W-1 Operational Phases

Shown next is the ETR power history for the W-1 SLSF experiment.

The W-1 SLSF experiment is divided into three operational phases, namely:

Phase 1: Calibration, low power, and decay heating tests

Phase 2: Transient heat release during LOPI transients in which the fuel has different combinations of structures, burnups and crack configurations

Phase 3: Boiling stability (Boiling Window) tests which are to be concluded with fuel pin dryout and fuel pin failure.

Phase 1 involves a detailed checkout of the SLSF in-pile loop, all supporting systems, test train instrumentation, and pretest analysis predictions of flows, pressure drops, temperatures, and ETR-to-test section power coupling. The information gathered in this phase of testing will aid the experimenters and facility operators in the successful completion of phases 2 and 3 of the experiment.

Phase 2 of the experiment involves the study of the heat release characteristics of FBR fuel pins under LOPI accident conditions. The W-1 fuel pins will undergo various stages of thermal and structural preconditioning prior to each LOPI transient . These stages are:

LOPI 1: fresh, unrestructured fuel (transient initiated after one hour at full power)

LOPI 2: fresh, restructured fuel (transient initiated after two days at full power)

LOPI 3: irradiated, uncracked fuel (transient initiated after twelve days at full power)

LOPI 4: irradiated, cracked fuel (transient initiated within one hour after startup to full power)

Phase 3 of the experiment is Boiling Window Tests designed to study sodium boiling phenomena at various combinations of pin power and coolant flow. This series of transients will undergo increasingly more severe power-to-flow mismatches (yielding extended periods of coolant boiling), and will culminate with incipient fuel pin failure.

In addition to these in-reactor tests, there was extensive out-of-reactor calibration work done on the flow sensors and in-fuel thermocouples.

E. W-1 SLSF Experiment LOPI Transients

The W-1 SLSF Experiment LOPI transients are conducted from full power conditions (i.e., test pins at 472 W/cm [14.4 kw/ft] peak linear power). The flow undergoes a very rapid reduction in magnitude (starting at zero seconds) down to approximately 20% of steady-state values (modeling CRBR LOPI). The ETR is scrammed 0.65 seconds after the initiation of the LOPI flow transient. The ETR scram was timed to deposit the same amount of integrated energy into the test fuel pins as the target CRBR power decay curve. Approximately one second of mild local coolang boiling is expected to occur during the LOPI transients. Fuel pin failure is not anticipated.

Shown here is the axial temperature distribution for the coolant surrounding the center W-1 fuel pin at 0.9 seconds into the first LOPI transient. Boiling is predicted to start near the top of the active section at this time.

Shown next is the radial coolant temperature profiles as a function of time through the LOPI transient. Channels 1 through 3 correspond to the coolant channels around a pin from each row of the bundle, progressing out to the hexcan. Channel 4 is the fuel pin-hexcan interface channel. Coolant boiling stops around 1.8 seconds.

F. Boiling Window Tests

A schematic of the W-1 Boiling Window flow transient is shown here. The flow is reduced from the steady-state value, F_1, and held there for Δt_2 seconds. Δt_2 ranges from two (2) seconds to seven (7) seconds. Δt_1 and Δt_3 are 0.5 seconds each.

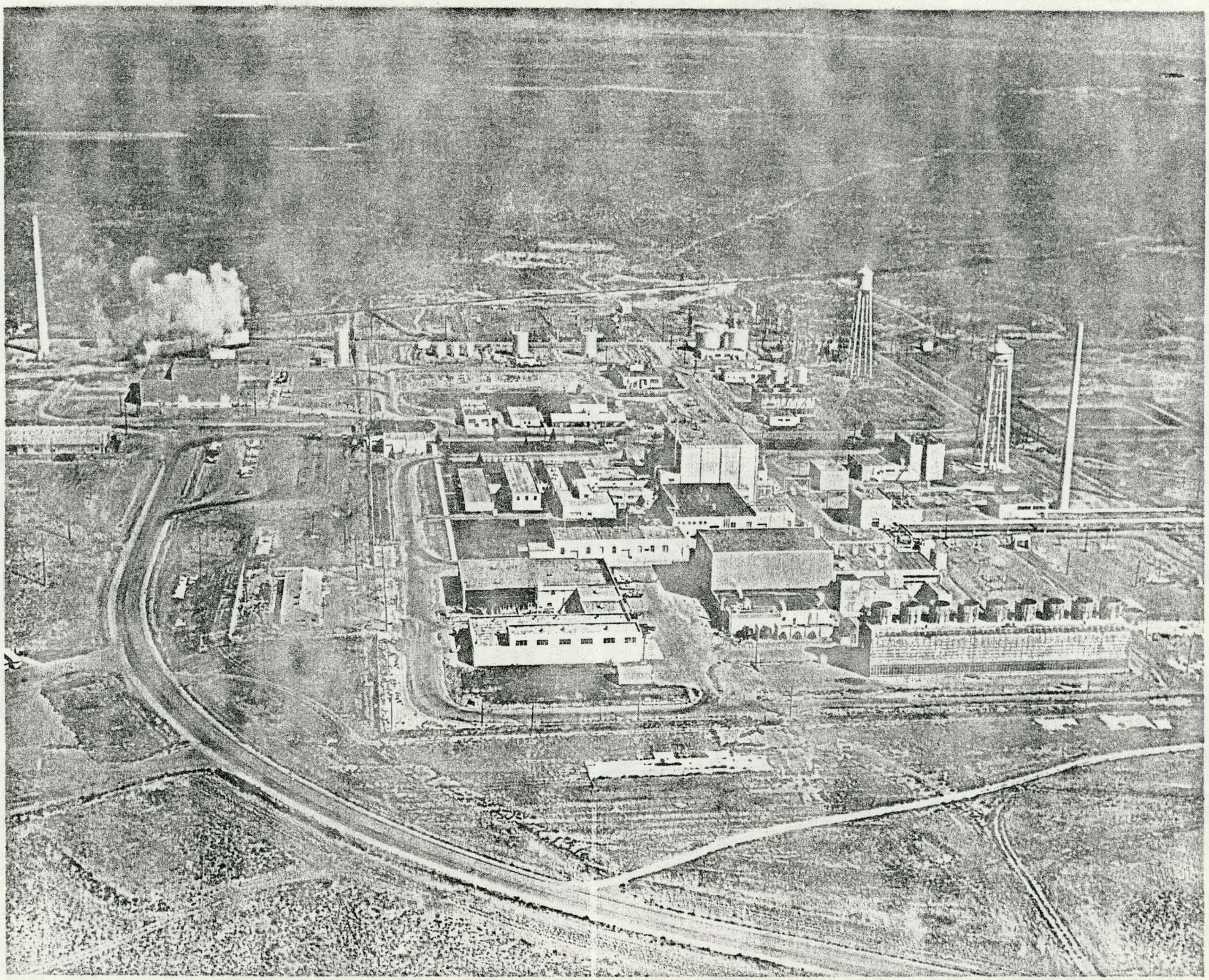
The next two (2) figures show the test matrix for the boiling window test. The tests at each power level include an "approach-to-boiling" test where no boiling is expected to occur and an incipient boiling test where only limited boiling is expected to occur. The
in power to the full power condition and end with the "dry-out" test where pin failure is expected to occur. Also included in the matrix are alternate tests which can be performed if the nominal conditions fail to produce anticipated results.

The next series of figures show the expected coolant temperature profiles during the tests studied for the Boiling Window Test Matrix. As the flow is reduced to the various levels, the coolant temperature reaches various levels of saturation, culminating in dryout conditions during the high power tests. The ETR will remain at design power through all but the final transient. This transient will be terminated by both a return to full flow and an ETR scram.

The next figure shows the expected "Boiling Window" to be generated during the W-1 experiment and how that window relates to other boiling tests being conducted in the United States at the Oak Ridge National Laboratory (ORNL) Thermal Hydraulic Out-of-Reactor Safety (THORS) facility. No boiling is predicted below the dotted line marked T_{sat}. Fuel pin dryout and pin failure are predicted up and to the left of the dashed line marked Test 4. The power/flow conditions between the two curves are postulated to support extended coolant boiling, effectively lengthening the time between the onset of boiling and dryout conditions.

In conclusion, the W-1 SLSF Experiment schedule is shown.

To date, all pre-test preparation has been completed and the HEDL test train has been installed into the SLSF primary vessel. Sodium fill activities are expected to be completed by January 1, 1979. W-1 irradiation will begin by May 1979.



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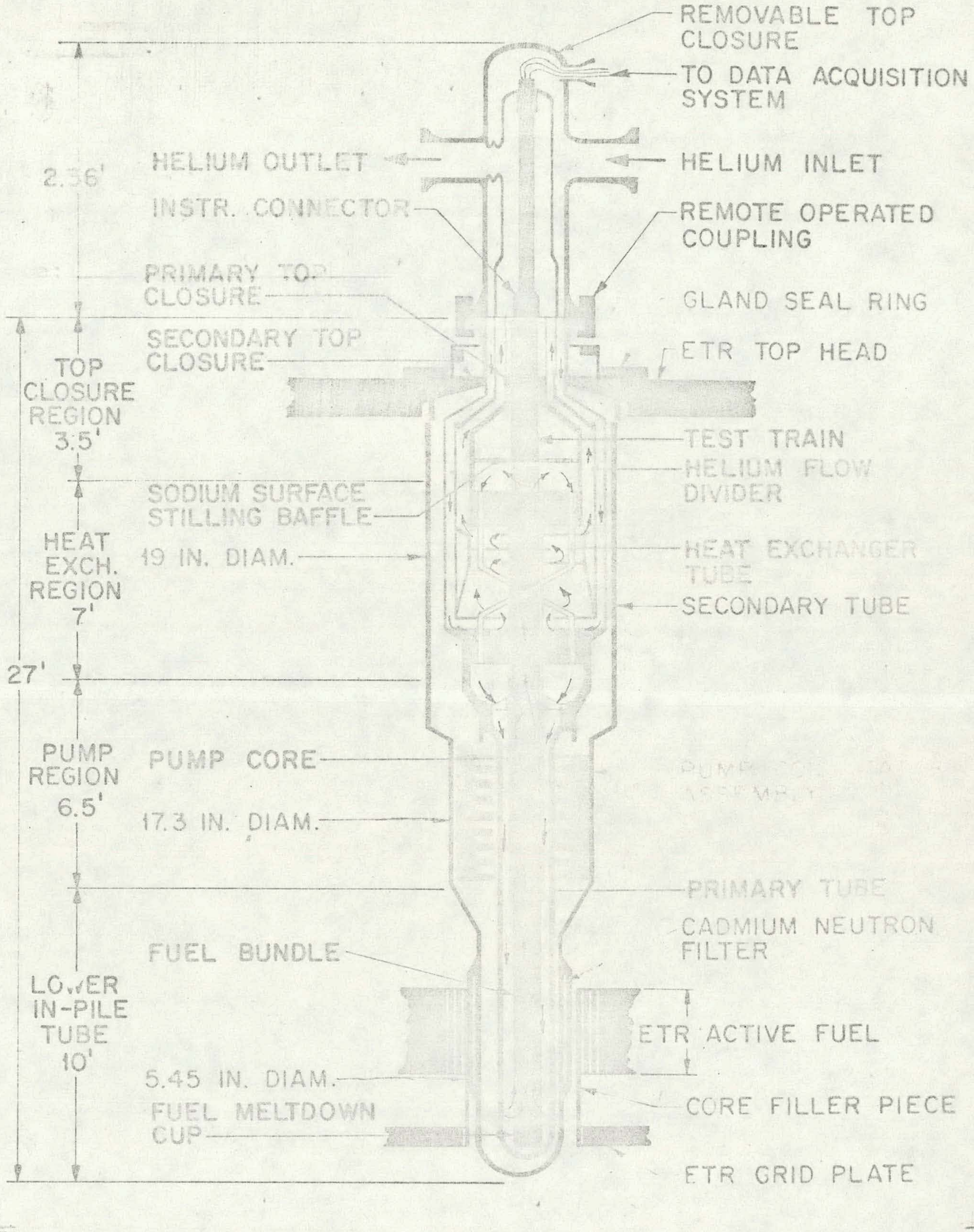
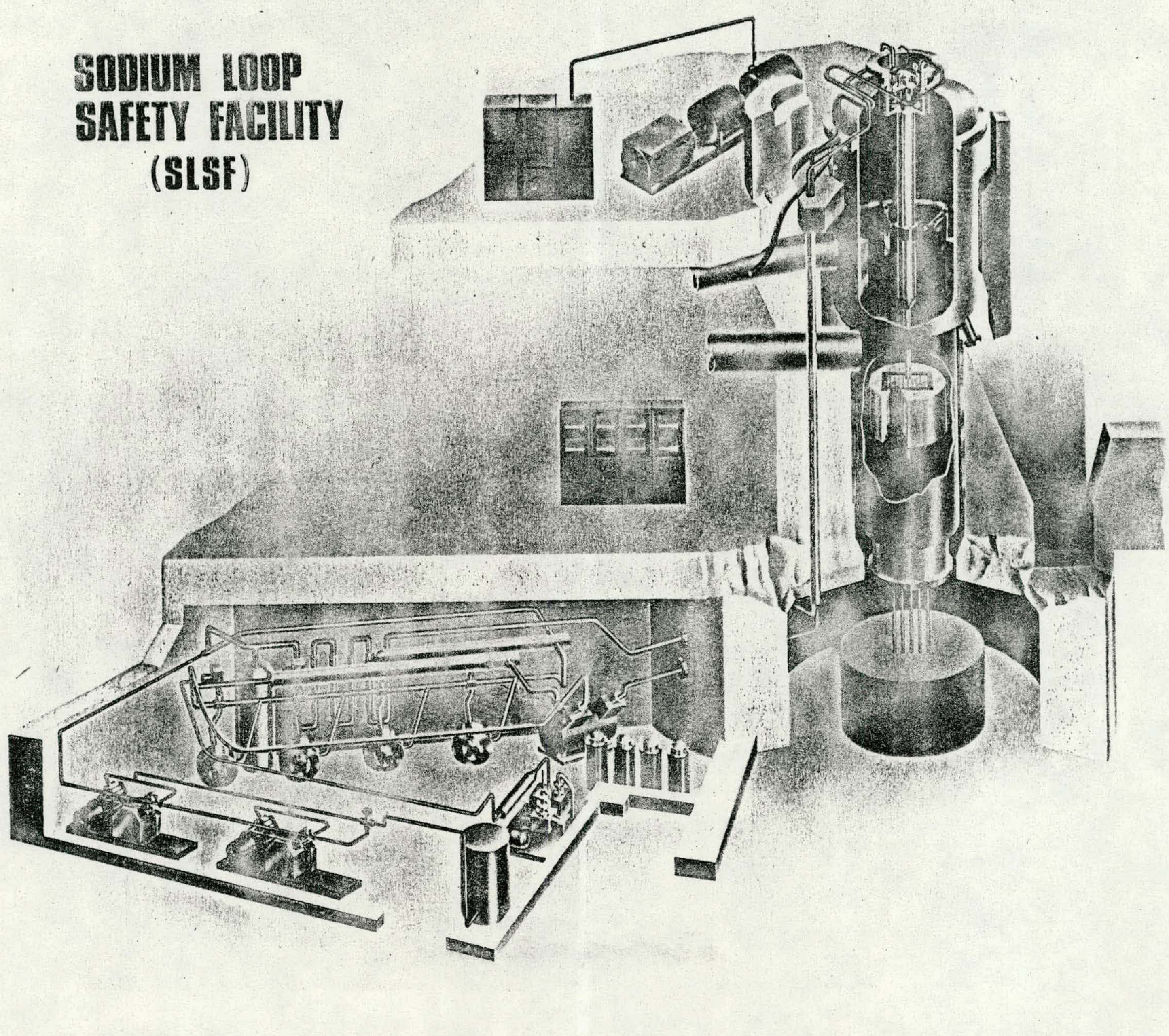
SLSF IN-PILE LOOP CROSS SECTION

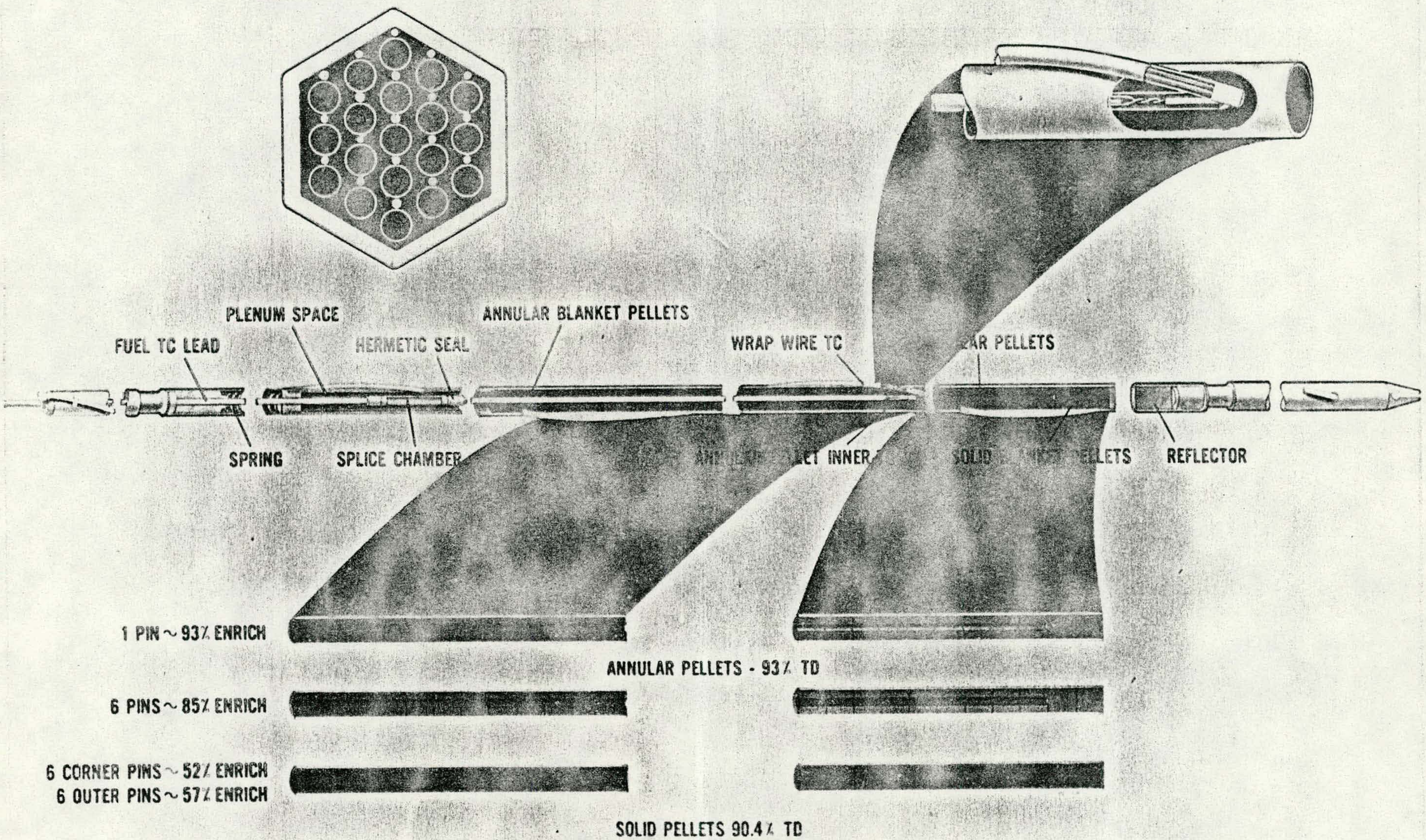


Mount hinged overlay foils on this side.
Mount basic foils on back.

SODIUM LOOP SAFETY FACILITY (SLSF)



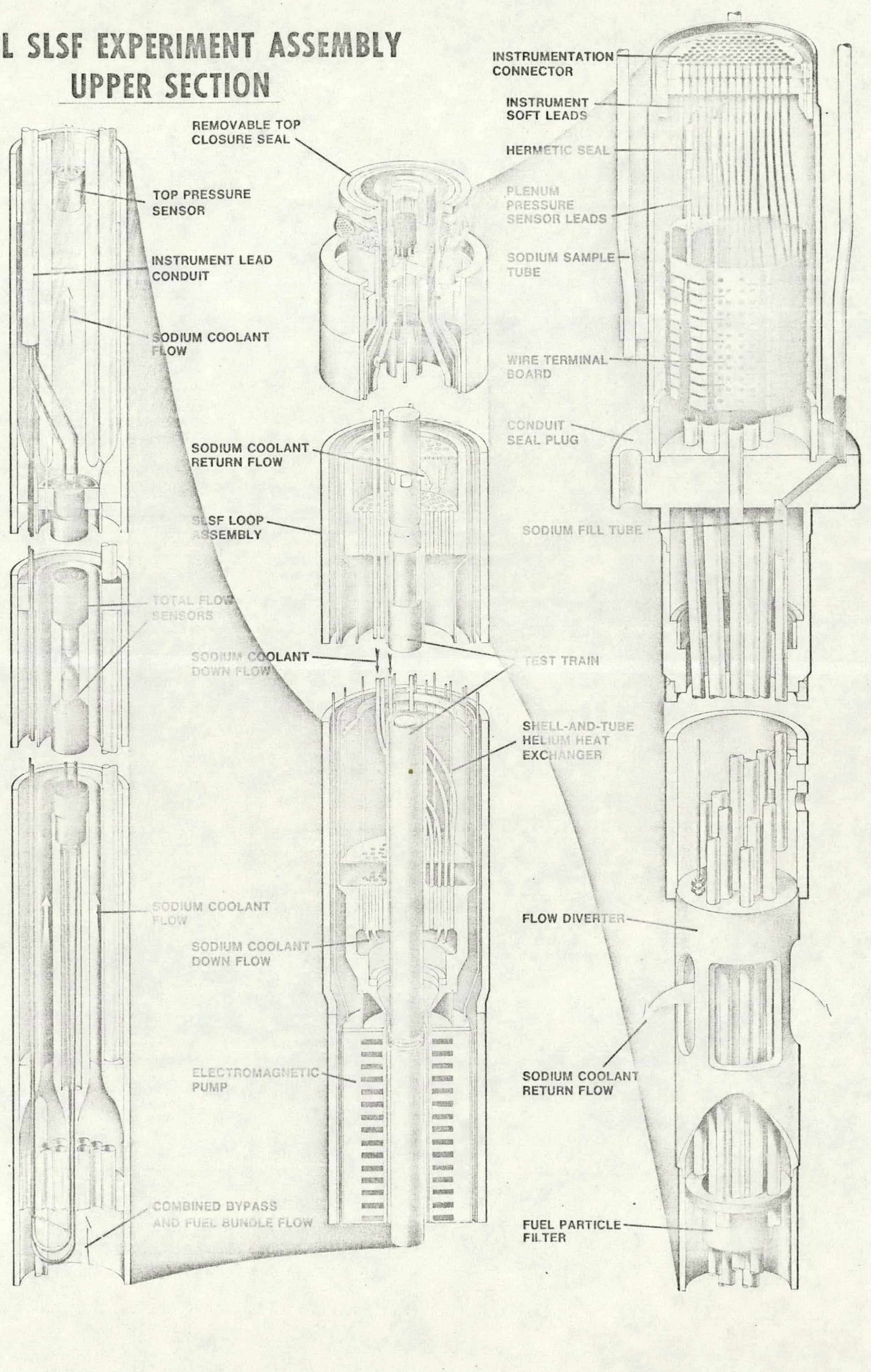
SLSF INSTRUMENTED PINS



HEDL W-1 TEST TRAIN INSTRUMENTATION

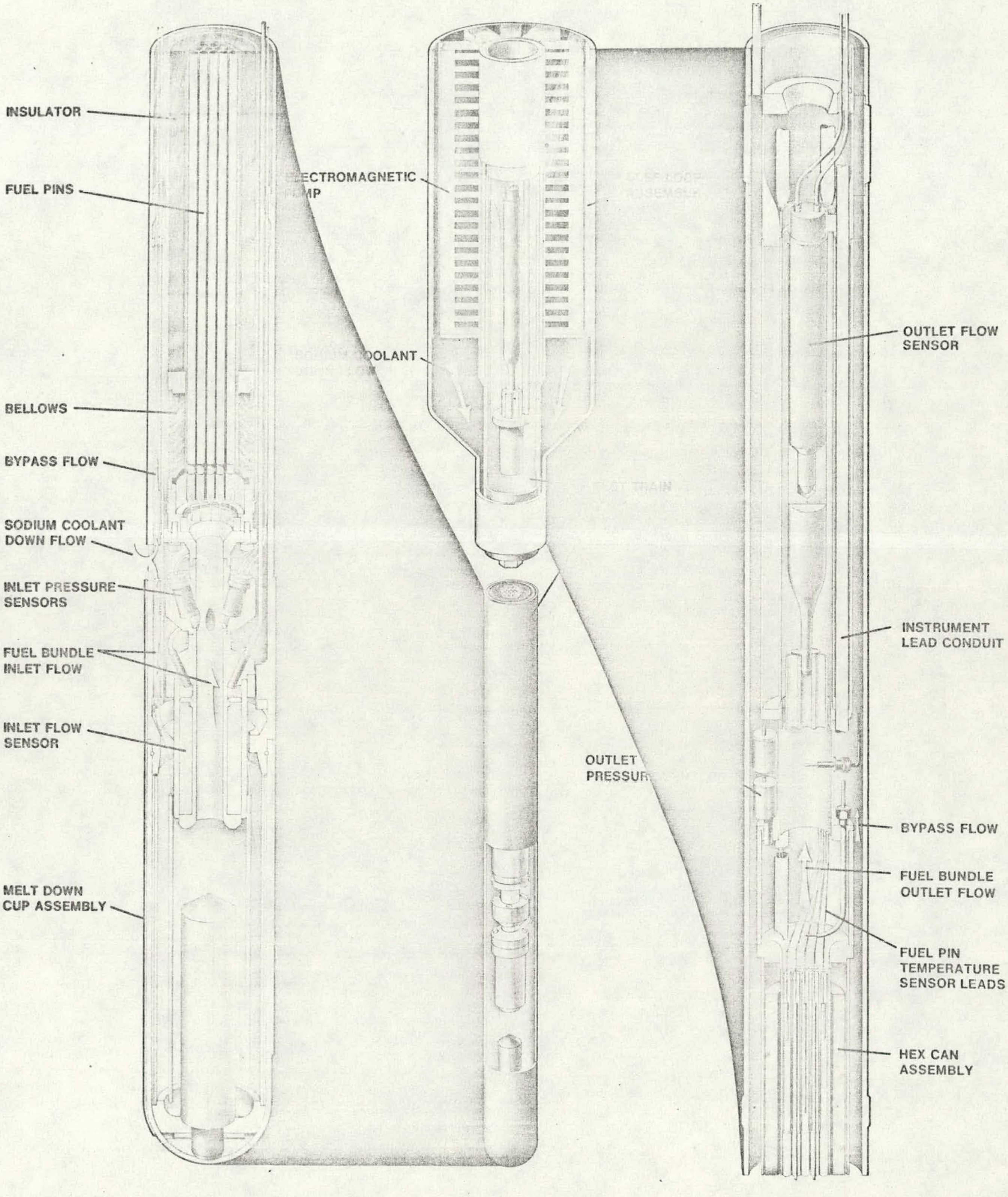
VARIABLE	INSTRUMENT TYPE	MAXIMUM RANGE	NUMBER
Coolant Temperature	Chromel-P vs. Alumel thermocouple	2200°F	72
Fuel Temperature	W3% RE/W25% Re	4200°F	7
Bundle Inlet Coolant Flow	Permanent Magnet Flow Sensor	65 gpm	1
Bundle Outlet Coolant Flow	Eddy Current Flow Sensor	65 gpm	1
Total Coolant Flow	Eddy Current Flow Sensor	130 gpm	2
Static Coolant Pressure	Strain Gauge Pressure Transducer	200 psi	6
	Eddy Current Pressure Transducer	100 psi	4
Dynamic Coolant Pressure	Strain Guage Pressure Transducer	2000 psi	6

HEDL SLSF EXPERIMENT ASSEMBLY
UPPER SECTION

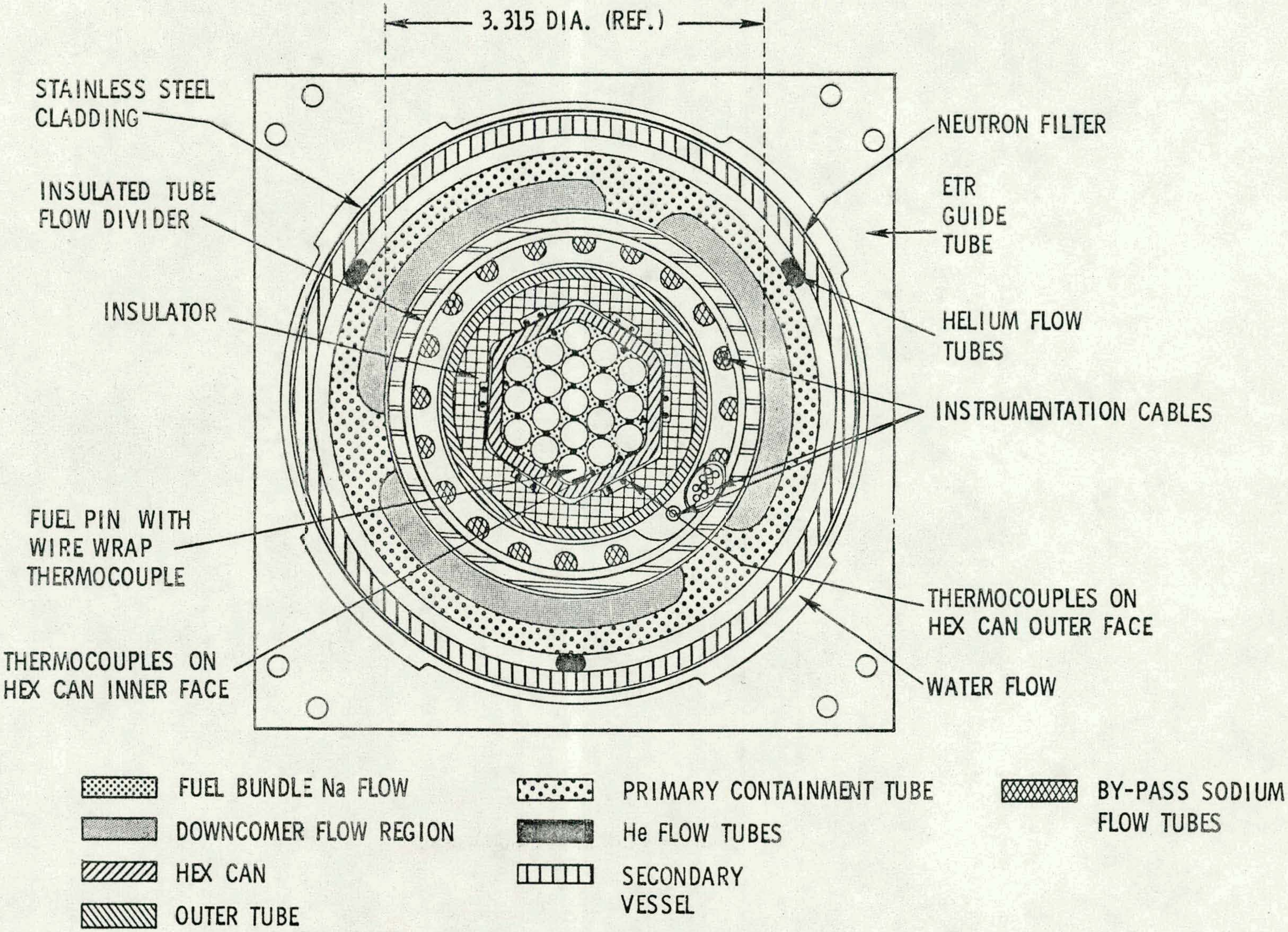


HEDL SLSF EXPERIMENT ASSEMBLY

LOWER SECTION

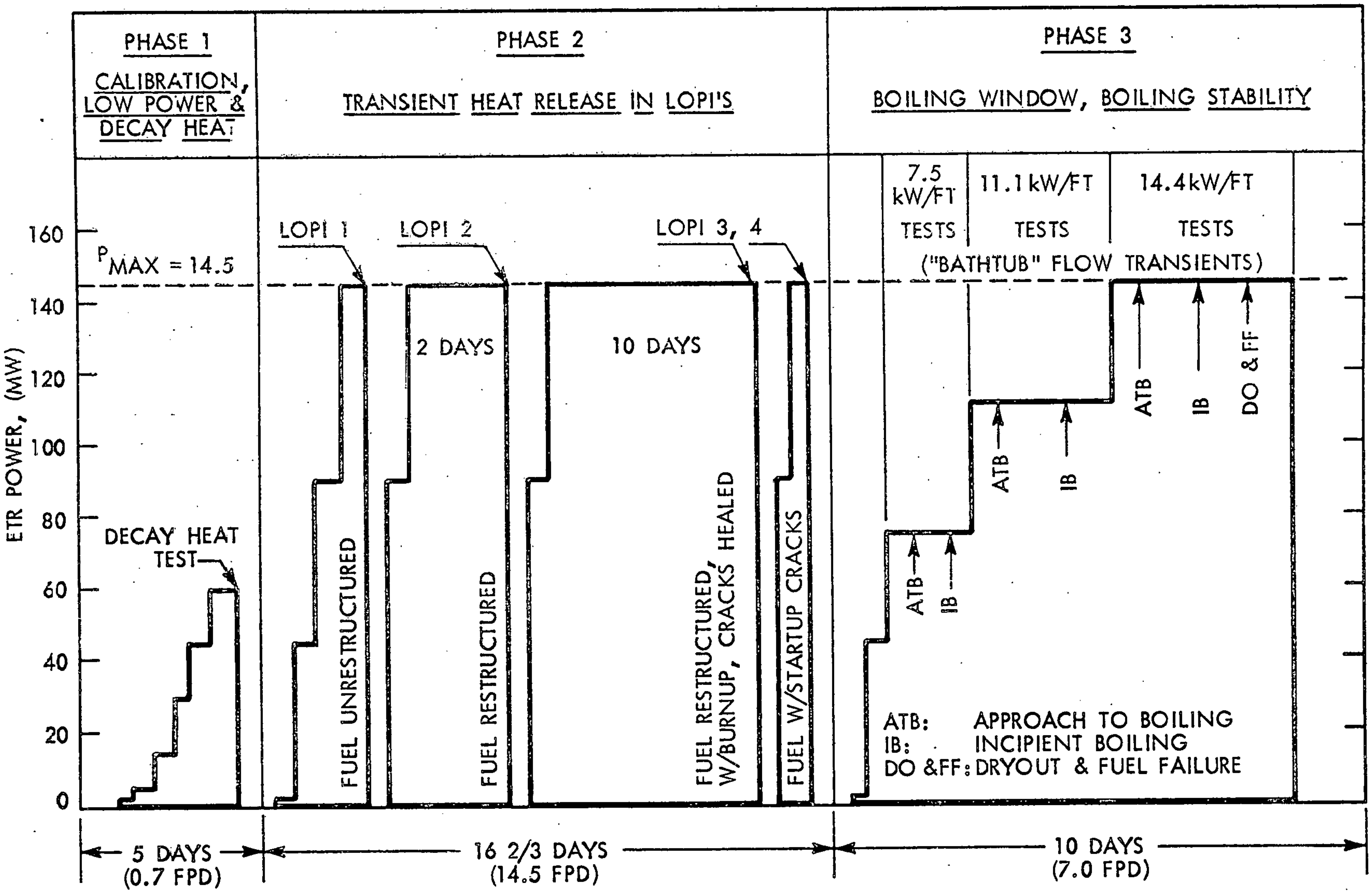


CROSS-SECTION OF THE W-1 SLSF IN THE LOWER TEST SECTION REGION

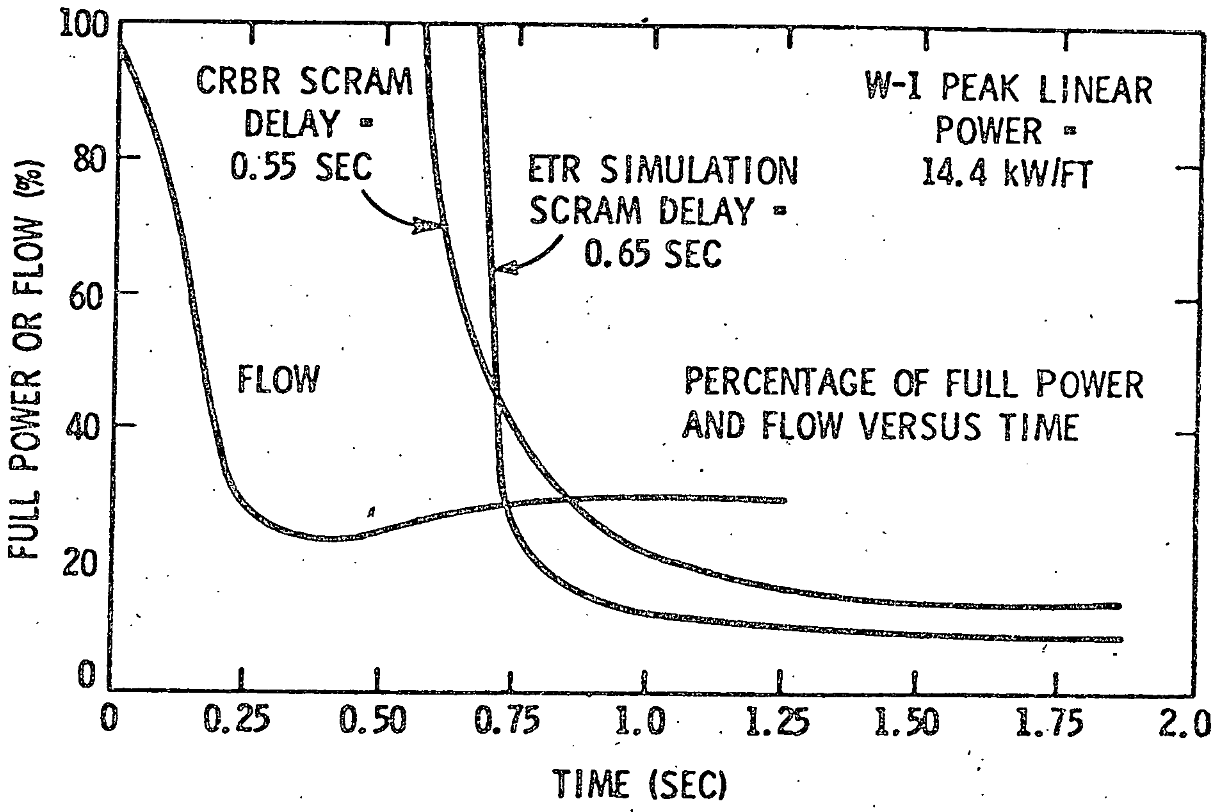


HEDL 7701-62.1

ETR POWER HISTORY FOR SLSF EXPERIMENT W-1

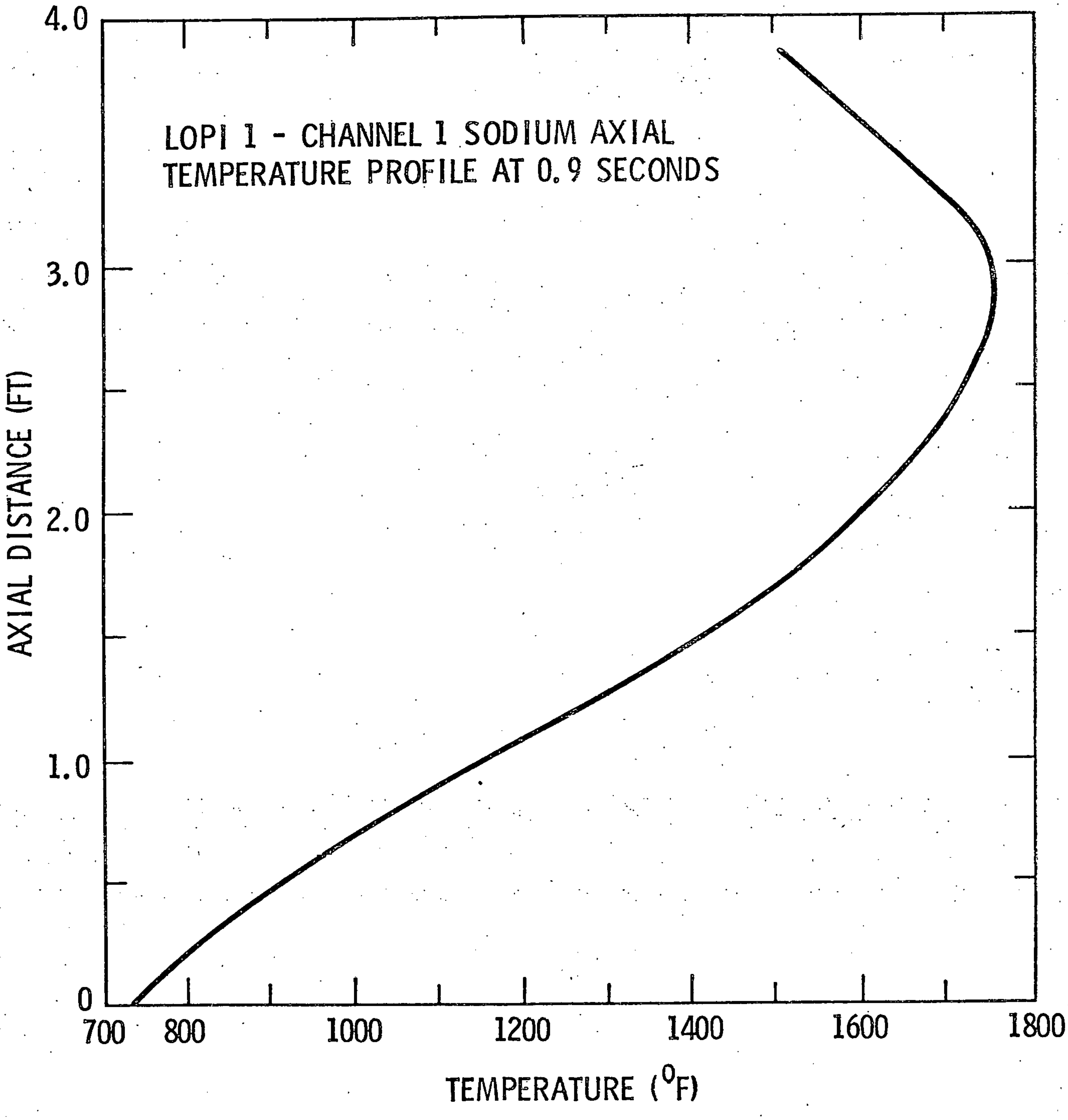


HEDL 7709-13.4

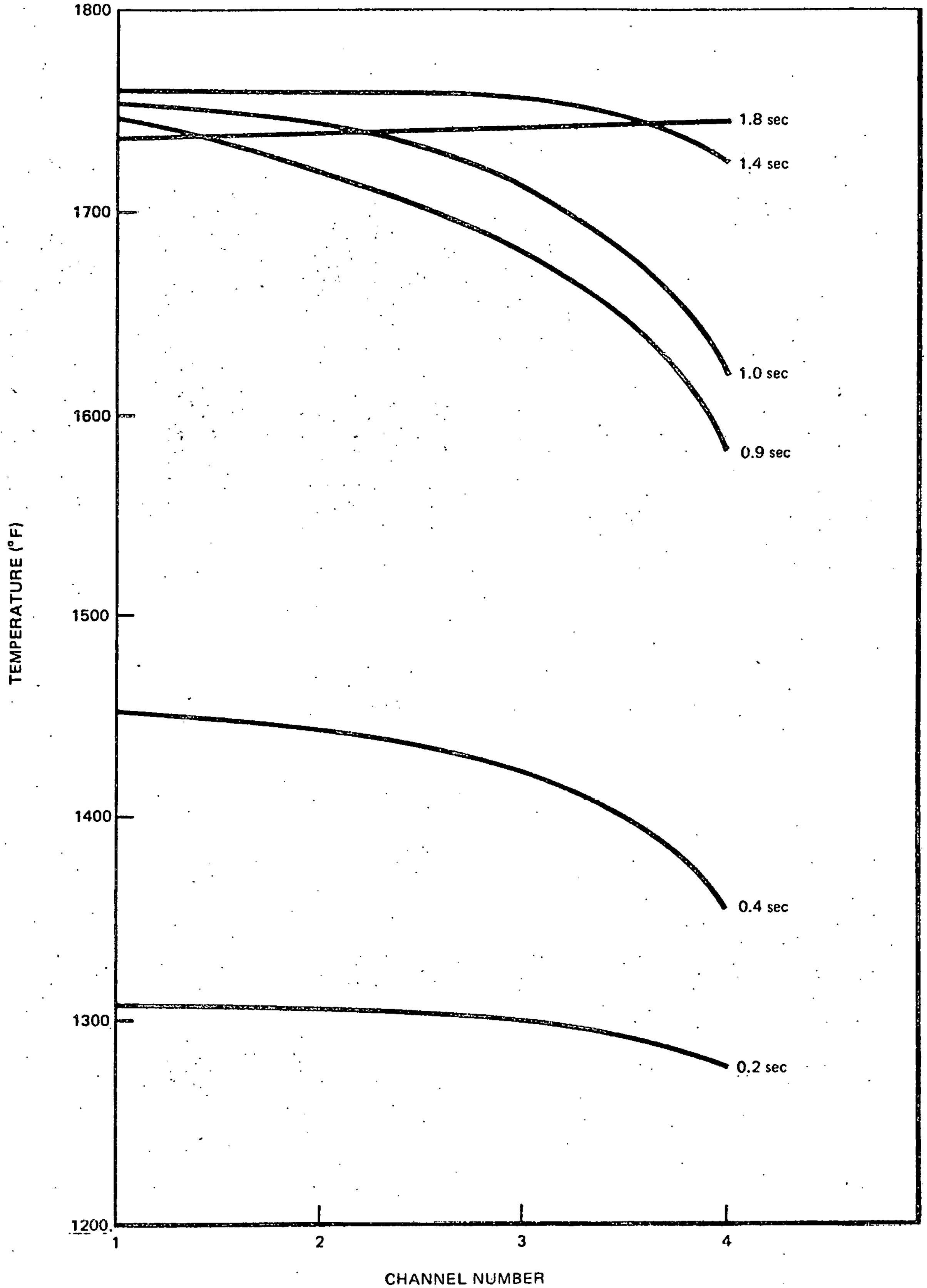


HEDL 7709-13.14

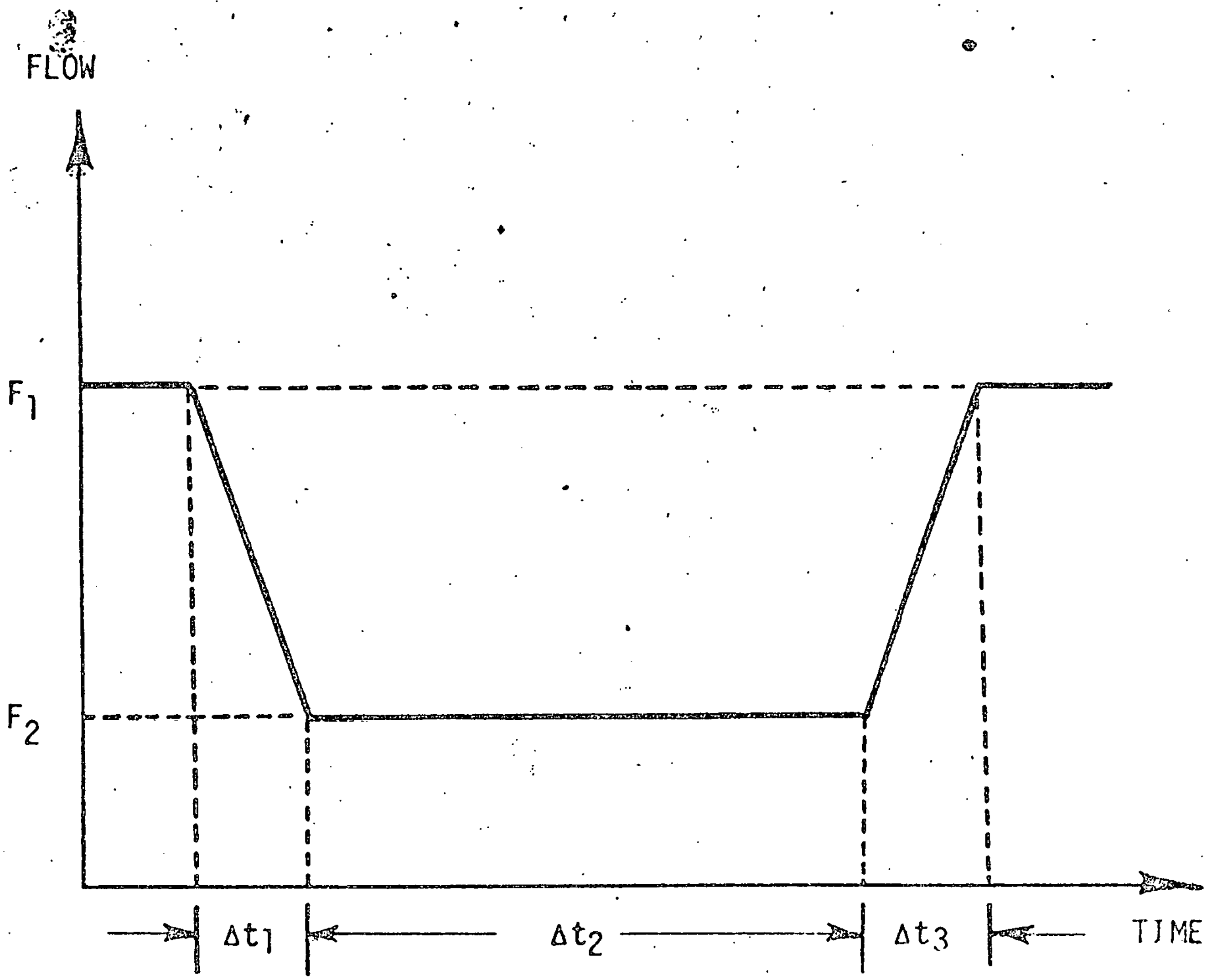
10



HEDL 7709-13.11



Sodium Radial Temperature Profiles at the Fuel/Blanket Interface for Various Times During LOPI 1 (COBRA-3M – Test Section Transient)



FLOW VS. TIME FOR BOILING WINDOW TESTS

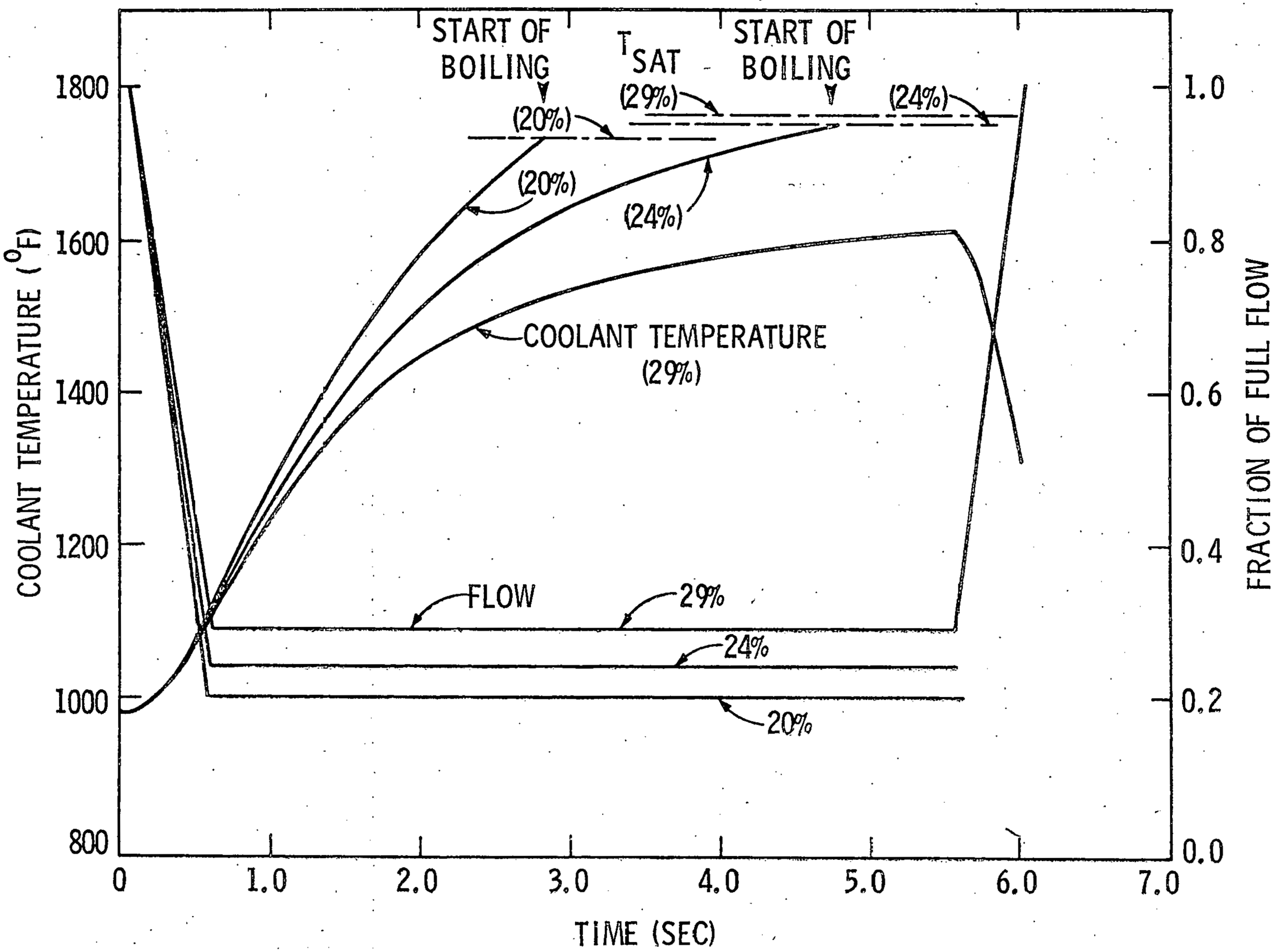
BOILING WINDOW TEST MATRIX

OPERATING PHASE AND PROCEDURES		FUEL BUNDLE POWER (KW) @ PEAK PIN POWER (KW/FT)	348 KW / 7.5 KW/FT	532 KW / 11.1 KW/FT	662 KW / 14.4 KW/FT	
APPROACH TO BOILING	NORMAL PROCEDURE	PERCENTAGE OF FULL FLOW	29	42	53	
		t (SEC.)	5.0	5.0	5.0	
		TEST SEQUENCE	(1)	(3)	(5)	
INCIPIENT-BOILING	NORMAL PROCEDURE	PERCENTAGE OF FULL FLOW	24	35	45	
		t (SEC.)	5.0	4.0	3.0	
		TEST SEQUENCE	(2)	(4)	(6)	
	FALLBACK PROCEDURE A	PERCENTAGE OF FULL FLOW	24	35	45	—
		t (SEC.)	7.0	6.0	5.0	—
		TEST SEQUENCE	(2a)	(4a)	(6a)	—
	FALLBACK PROCEDURE B	PERCENTAGE OF FULL FLOW	22	33	—	43
		t (SEC.)	4.5	3.0	—	2.5
		TEST SEQUENCE	(2b) *	(4b) *		(6b) *

BOILING WINDOW TEST MATRIX

FUEL BUNDLE POWER (KW) @ PEAK PIN POWER (KW/FT) / OPERATING PHASE AND PROCEDURES			348 KW / 7.5 KW/FT	532 KW / 11.1 KW/FT	662 KW / 14.4 KW/FT	
DRYOUT OR FUEL PIN FAILURE	NORMAL PROCEDURE	PERCENTAGE OF FULL FLOW			42	40
		Δt_2 (SEC.)			2.0	2.0
		TEST SEQUENCE			(7)	(7')
	FALLBACK PROCEDURE A	PERCENTAGE OF FULL FLOW			42	40
		Δt_2 (SEC.)			3.0	3.0
		TEST SEQUENCE			(7a)	(7a')
	FALLBACK PROCEDURE B	PERCENTAGE OF FULL FLOW			40	38
		Δt_2 (SEC.)			3.0	3.0
		TEST SEQUENCE			(7b)	(7b')

INFLUENCE OF LOW FLOW ON W-1 COOLANT TEMPERATURE TRANSIENTS WITH PEAK LINEAR POWER 7.5 kW/ft



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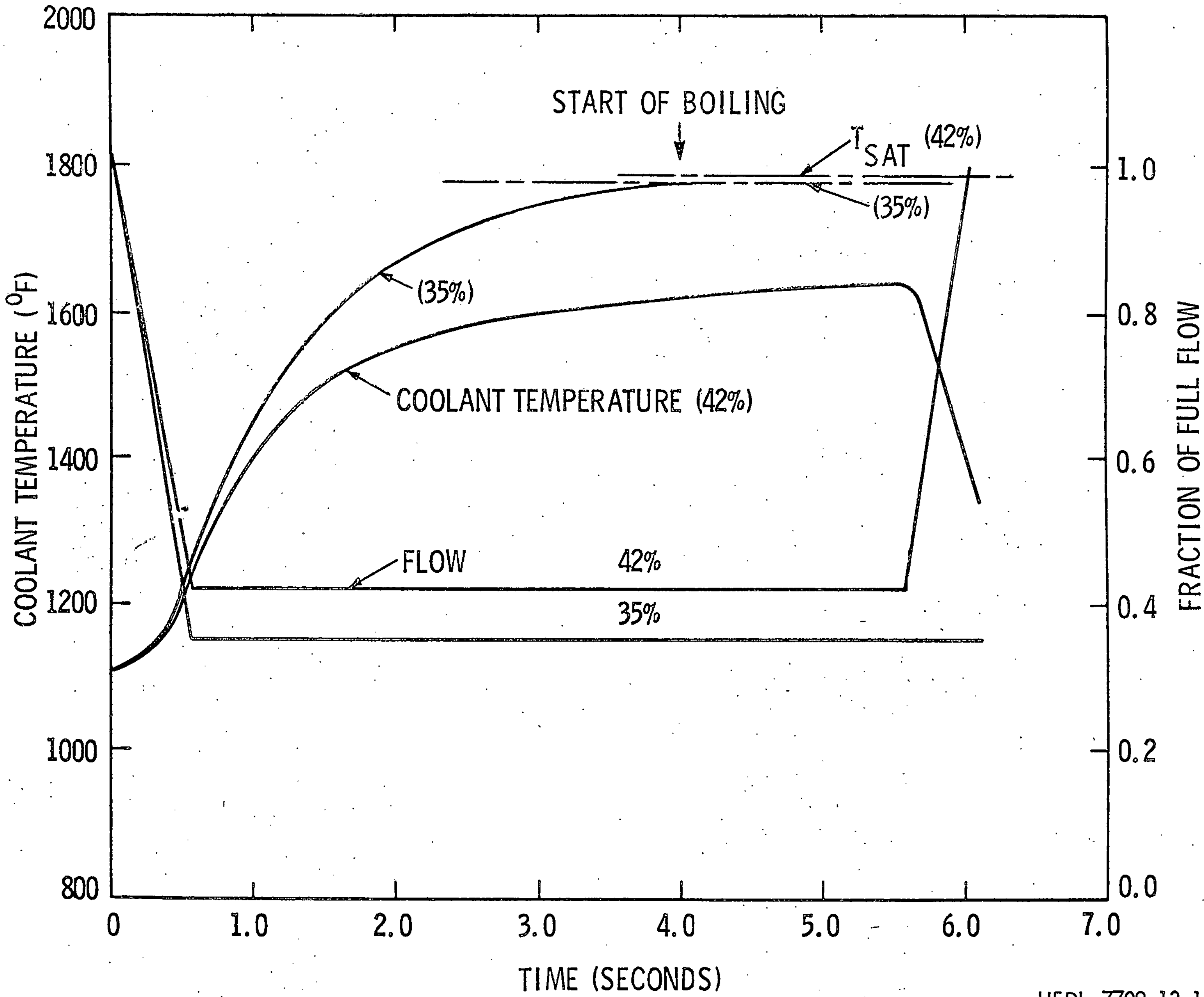
INFLUENCE OF LOW FLOW ON W-1 COOLANT TEMPERATURE TRANSIENTS
WITH PEAK LINEAR POWER 11.1 kW/ft



HEDL 7709-13.1

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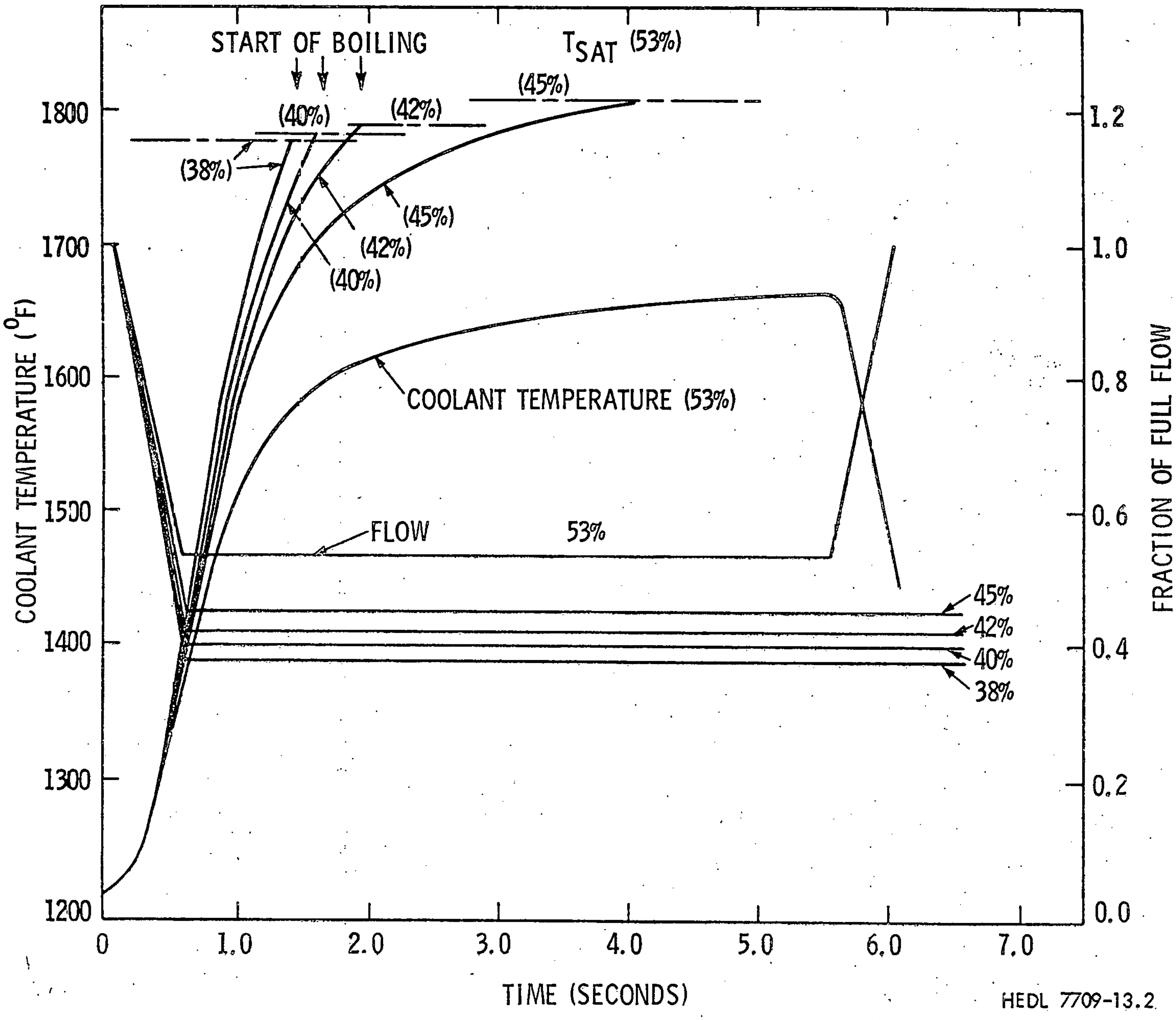
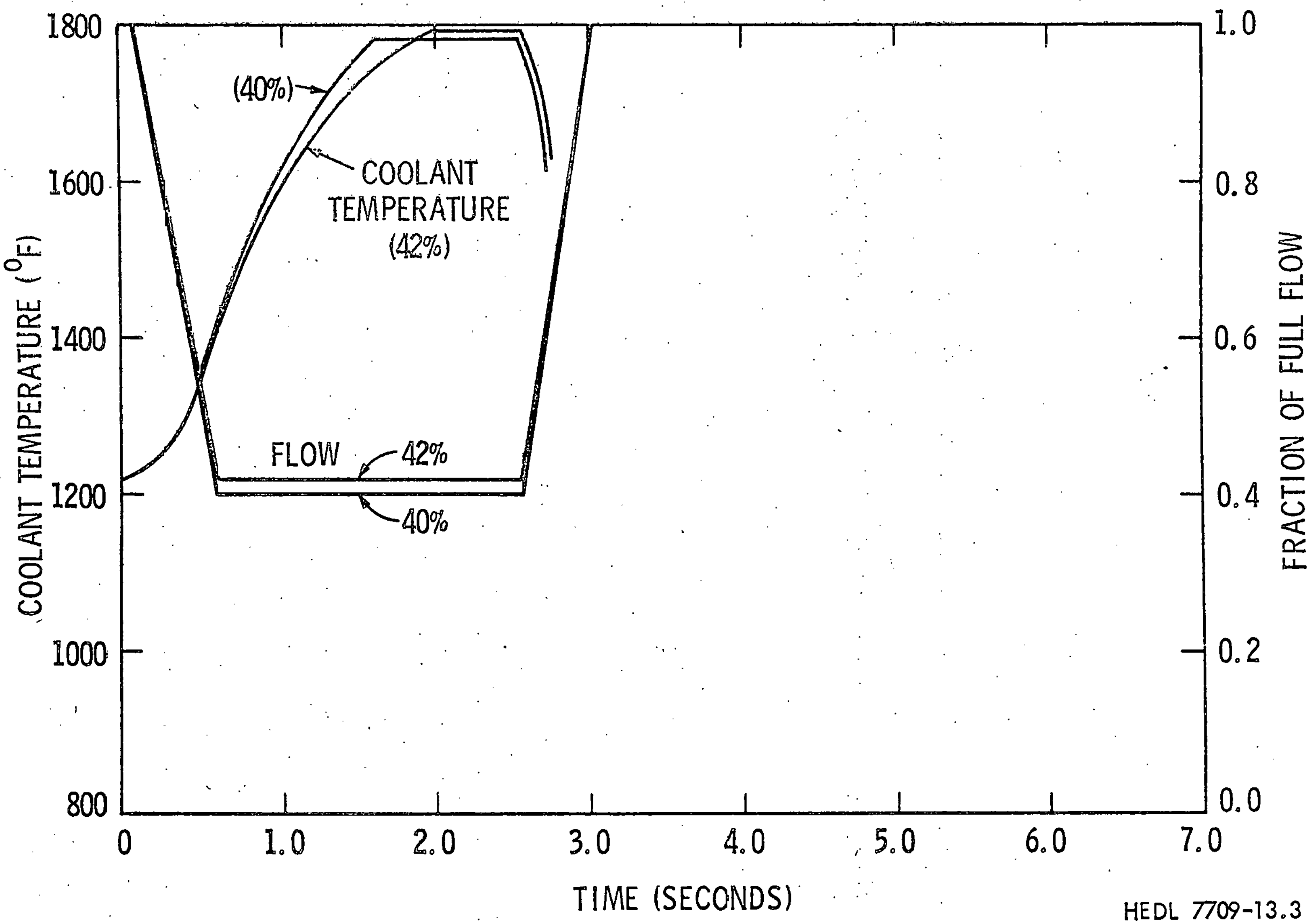
INFLUENCE OF LOW FLOW ON W-1 COOLANT TEMPERATURE TRANSIENTS
WITH PEAK LINEAR POWER 14.4 kW/ft



HEDL 7709-13.2

7710750-7

COBRA-3M PREDICTIONS OF COOLANT BEHAVIOR AT CORE OUTLET
FOR THE DRYOUT TEST 14.4 kW/ft



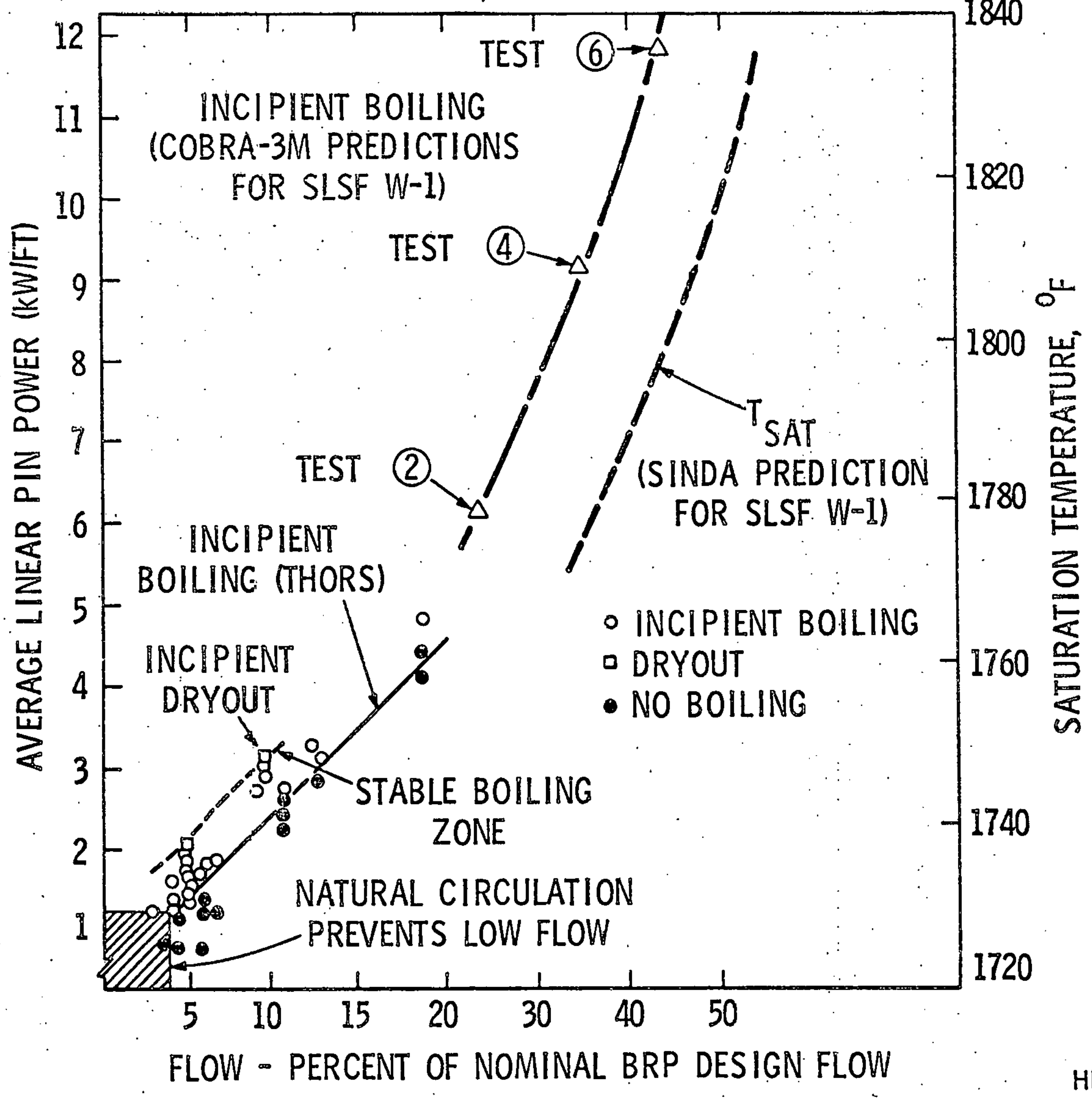
HEDL 7709-13.3

7710750-5

SODIUM BOILING REGIMES

COMPARISON BETWEEN THORS DATA AND W-1 PREDICTIONS ON INCIPIENT BOILING

(DATA FROM THORS MEASUREMENTS, MAY 1977)



HEDL 7709-13.8

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HEDL PROGRAM SCHEDULE FOR THE W-1 SLSF EXPERIMENT - - - MAY 1979 TEST DATE