

POOR ORIGINAL

**PWR Blowdown Heat Transfer
Separate-Effects Program—
Thermal-Hydraulic Test Facility
Experimental Data Report for Test 157**

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Prepared for the U.S. Nuclear Regulatory Commission
Office of Nuclear Regulatory Research
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OAK RIDGE NATIONAL LABORATORY
OPERATED BY UNION CARBIDE CORPORATION • FOR THE DEPARTMENT OF ENERGY

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PWR BLOWDOWN HEAT TRANSFER SEPARATE-EFFECTS PROGRAM --
THERMAL-HYDRAULIC TEST FACILITY EXPERIMENTAL
DATA REPORT FOR TEST 157

G. S. Massengill R. A. Hedrick M. D. White

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PWR BLOWDOWN HEAT TRANSFER SEPARATE-EFFECTS PROGRAM —
THERMAL-HYDRAULIC TEST FACILITY EXPERIMENTAL
DATA REPORT FOR TEST 157

G. S. Massengill R. A. Hedrick M. D. White

ABSTRACT

Reduced instrument responses are presented for Thermal-Hydraulic Test Facility (THTF) test 157, which is part of the ORNL Pressurized-Water Reactor (PWR) Blowdown Heat Transfer Separate-Effects Program. The objective of the program is to investigate the thermal-hydraulic phenomenon governing the energy transfer and transport processes that occur during a loss-of-coolant accident in a PWR system.

Test 157 was conducted to obtain thermal-hydraulic and CHF information in the THTF bundle 1 operating at nominal power with significant outlet subcooling and containing four unpowered rods.

The primary purpose of this report is to make the reduced instrument responses during test 157 available. The responses are presented in graphical form in engineering units and have been analyzed only to the extent necessary to assure reasonableness and consistency.

I. INTRODUCTION

The Oak Ridge National Laboratory Pressurized-Water Reactor (ORNL-PWR) Blowdown Heat Transfer Program is a separate-effects study of the relations among the principal variables that can alter the rate of blowdown, the presence of flow reversal and rereversal, time delay to critical heat flux (CHF), the rate at which dryout progresses, and similar time- and space-related functions that are important in loss-of-coolant accident (LOCA) analyses. Primary test results are obtained from the Thermal-Hydraulic Test Facility (THTF), a large nonnuclear pressurized-water loop incorporating a 49-rod electrically heated bundle in a 7×7 geometry.

THTF test 157 (conducted March 24, 1977) was the 14th test conducted in the facility with bundle 1 in place. This test was performed to obtain thermal-hydraulic and CHF information in a bundle operating at nominal power with significant outlet subcooling and containing four unpowered rods.

The purpose of this report is to provide the reduced instrument responses during test 157 in a readily usable form to the nuclear community in advance of detailed analyses and interpretations. These data are presented on microfiche attached to the back cover of the report. Final analyses and interpretations are scheduled for publication six months after the completion of the test series. The program and the experimental facilities are described in Ref. 1.

II. SYSTEM, PROCEDURES, CONDITIONS, AND EVENTS FOR TEST 157

1. System Configuration and Test Procedure

The Thermal-Hydraulic Test Facility (THTF), shown in Fig. 1, consists of a test section with a 49-rod, 3.66-m-long (12-ft) electrically heated core; a circulation loop comprised of three parallel heat exchangers with bypass, a pressurizer, a pump with bypass, and associated control valves; two rupture assemblies; and a pressure-suppression system. For test 157 the break configuration was a 40% inlet-60% outlet break with a total break area of 12.54 cm^2 (0.0135 ft^2). The THTF experimental system is described further in Ref. 1.

The electric core was taken to the preblowdown power (100 kW/rod) in ~ 20 -kW/rod steps to provide steady-state calibration information. The main heat exchangers were operated to match the core power input. The primary coolant pump was tripped coincident with break initiation, but the electric core was operated at the preblowdown power for ~ 2 sec into the transient. The power was then decayed with a time constant of ~ 0.45 sec. Rods 19, 24, 39, and 47 were unpowered. Closure of the secondary side main heat exchanger valves was initiated at the trip from 100 kW/rod.

In preparation for the test, the loop was filled with demineralized water and the system pressure checked. Instrumentation and data acquisition checks were performed. During the warmup, data were taken for use in flow and pressure calibrations.

1. *Project Description: ORNL-PWR Blowdown Heat Transfer Separate-Effects Program - Thermal-Hydraulic Test Facility (THTF)*, ORNL/NUREG/TM-2 (February 1976).

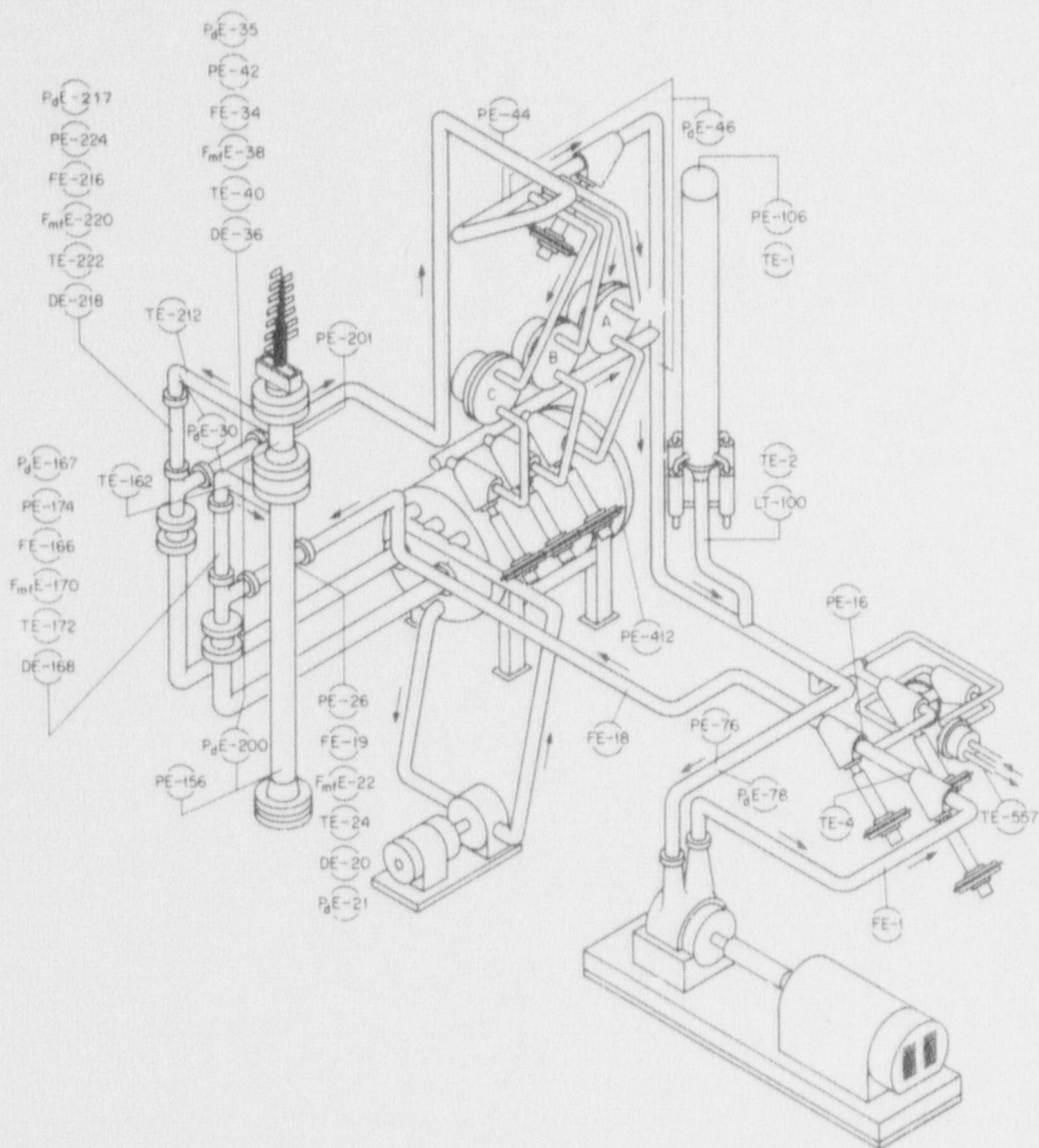


Fig. 1. Thermal-Hydraulic Test Facility (THTF).

During the test, the THTF was successfully subjected to a double-ended pipe break through the rupture assemblies containing the orifice plates. The effluent from the primary system was injected into the pressure-suppression system, which was maintained at atmospheric pressure.

2. Initial Test Conditions and Sequence of Events

The THTF conditions immediately preceding rupture are given in Tables 1 and 2. The sequence of events relative to the rupture is given in Table 3.

Table 1. Desired vs actual prerupture conditions

Parameters	Instrument	Desired ^a	Actual ^b
System pressure	PE-201		
MN/m ²		15.858	16.061
psig		2300	2329
Core power	EIE-9, EIE-10, EIE-11, EIE-12		
MW	EEE-9, EEE-10, EEE-11, EEE-12	4.500	4.493
Number of unpowered rods		4	4
Core volumetric flow rate	FE-19		
m ³ /s		0.0331	0.0335
gpm		525	531
Test section inlet temperature	TE-162		
K		558.2	557.3
°F		545	544
Test section outlet temperature	TE-212		
K		588.7	587.9
°F		600	599
Pressurizer pressure	PE-106		
MN/m ²		15.444	15.499
psig		2240	2248
Mass liquid water			
kg		54.88	78.42
lb _m		121	173
Coolant pump speed	SE-72		
rps		60.33	60.04
rpm		3620	3602
Pressure differential	P _d E-78		
MN/m ²		4.509	4.573
psid		654	663
Pressure between HCV-2 and FCV-18	PE-16		
MN/m ²		16.761	17.679
psig		2431	2564
Pressure differential across main heat exchangers	P _d E-46		
MN/m ²		0.331	0.340
psid		48	49.3

^aDesired prerupture conditions are based on programmatic requirements.

^bActual prerupture conditions are based on instrument signals recorded within 10 sec of primary system rupture.

Table 2. Prerupture primary-coolant temperature and pressure distribution^a test 157

Location	Instrument	Temperature [K (°F)]	Pressure [MN/m ² (psig)]
Vertical inlet spool piece	TE-172	557.3 (544)	
Vertical inlet spool piece	PE-174		16.396 (2378)
Test section inlet	TE-162	557.3 (544)	
Lower plenum	TE-150	558.3 (545)	
Lower plenum	PE-156		16.344 (2371)
Upper plenum	PE-201		16.061 (2329)
Test section outlet	TE-212	587.9 (599)	
Vertical outlet spool piece	TE-222	587.9 (599)	
Vertical outlet spool piece	PE-224		15.924 (2310)
Heat exchanger inlet header	PE-44		15.759 (2286)
Mixed mean temperature downstream heat exchangers	TE-28B	564.4 (556)	
Pressurizer surge line	TE-2	599.2 (619)	
Pressurizer	PE-106		15.499 (2248)
Primary pump suction	PE-76		15.381 (2231)
Between main control valves HCV-2, FCV-18	TE-4B	555.4 (540)	
Between main control valves HCV-2, FCV-18	PE-16		17.679 (2564)

^aPrerupture distribution is based on instrument signals recorded within 10 sec of primary system rupture.

Table 3. Sequence of events during test 157

Event	Time relative to rupture (sec)
Core power level established	-3195
Core temperature rise established	-3015
Analog tapes and CCDAS fast scan started	-15
Blowdown initiated	0
Pump power tripped	0
Heat exchanger secondary valves closure initiated	+2
Core power tripped to decay	+2
Core power tripped	+3.5

III. DATA PRESENTATION

The recorded instrument responses for THTF test 157 have been processed only to the extent necessary to obtain appropriate engineering units and to ensure reasonableness and consistency. In converting the instrument responses to engineering units, a homogeneous fluid has been assumed. Therefore, interpretation or analysis of the data must account for the fact that the instruments may have been subjected to nonhomogeneous fluid conditions during the transient.

The reduced instrument responses presented in this report were recorded by a computer-controlled digital data acquisition system (CCDAS). Further information on this system may be found in Ref. 1.

Figures 2 through 4 provide supportive information for the instrument responses and indicate the relative locations of the detectors in the THTF.

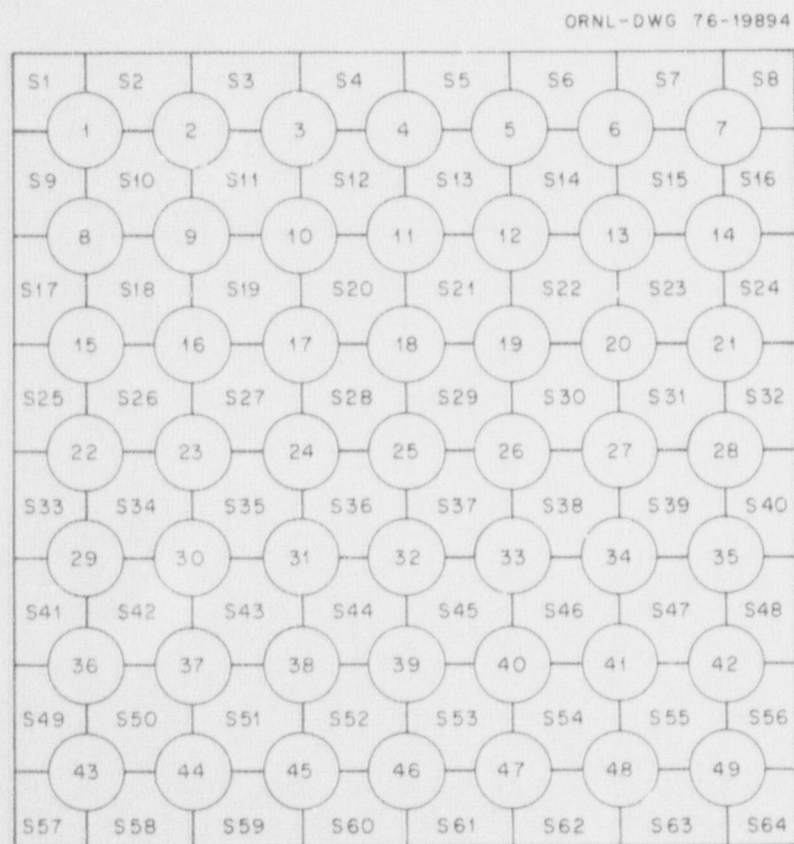
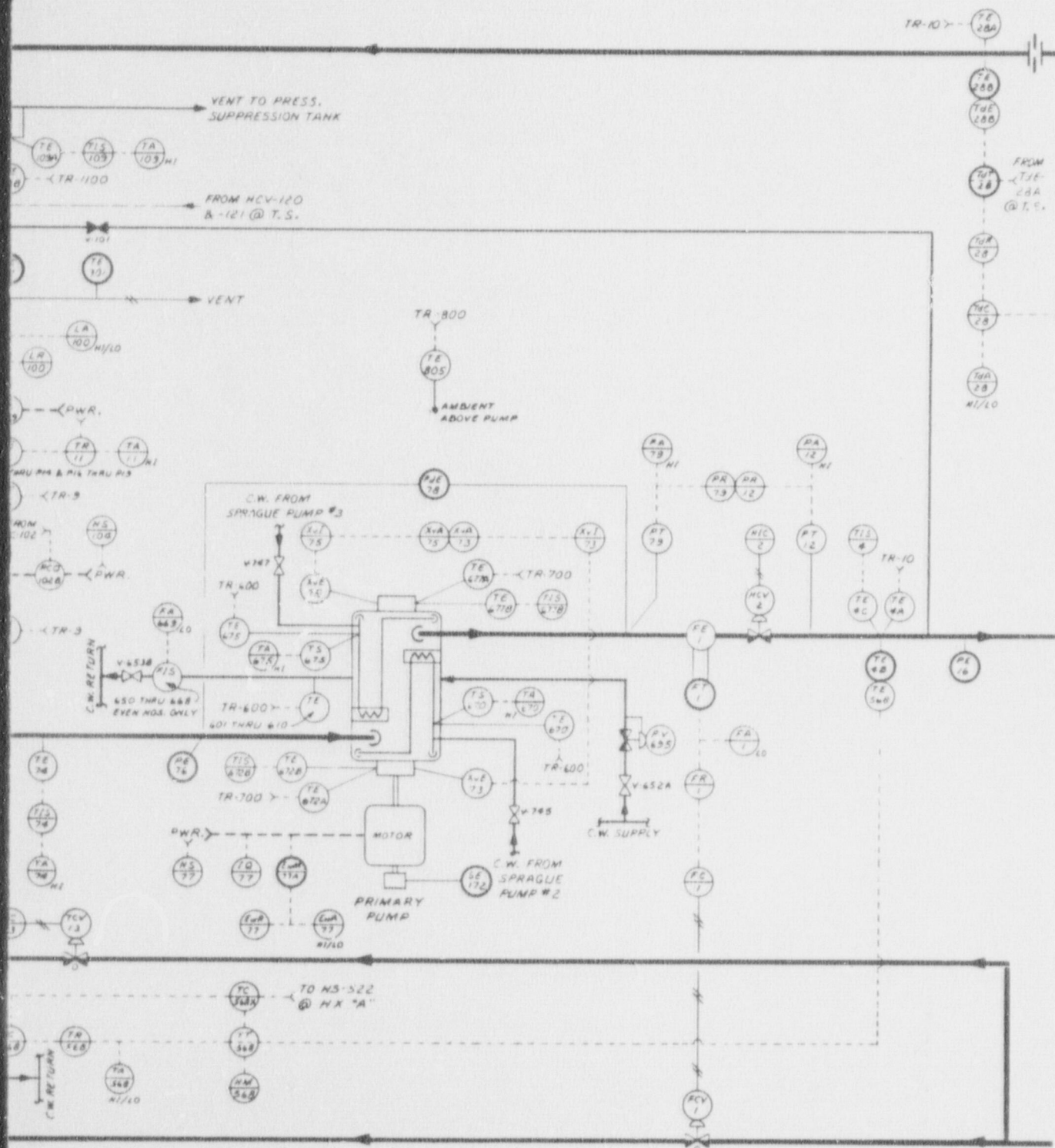


Fig. 2. Identification of THTF heater rod and subchannel locations in bundles 1 and 2.





4. THTF instrument identification and location.

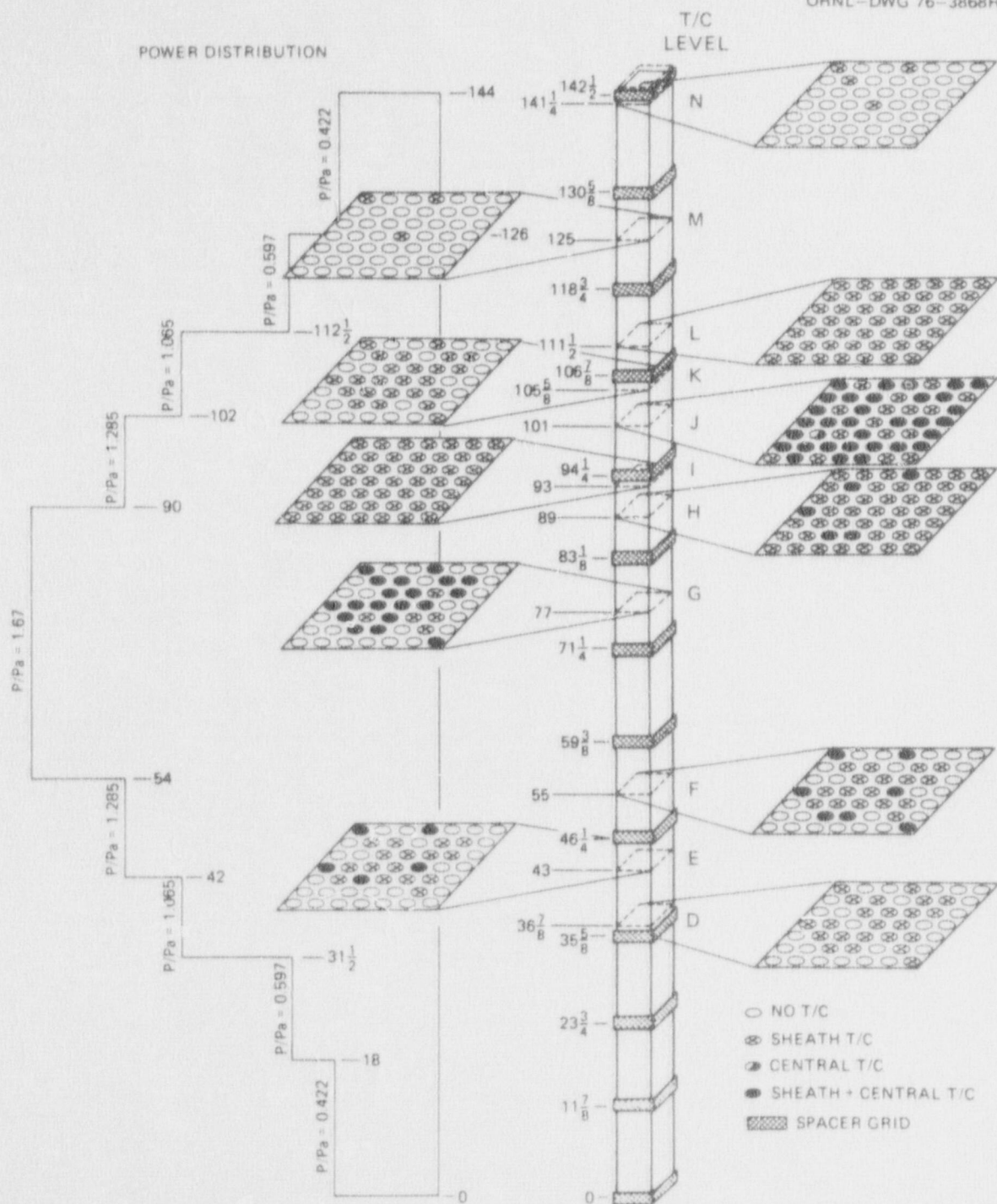


Fig. 3. Location of thermocouples in THTF bundle 1.

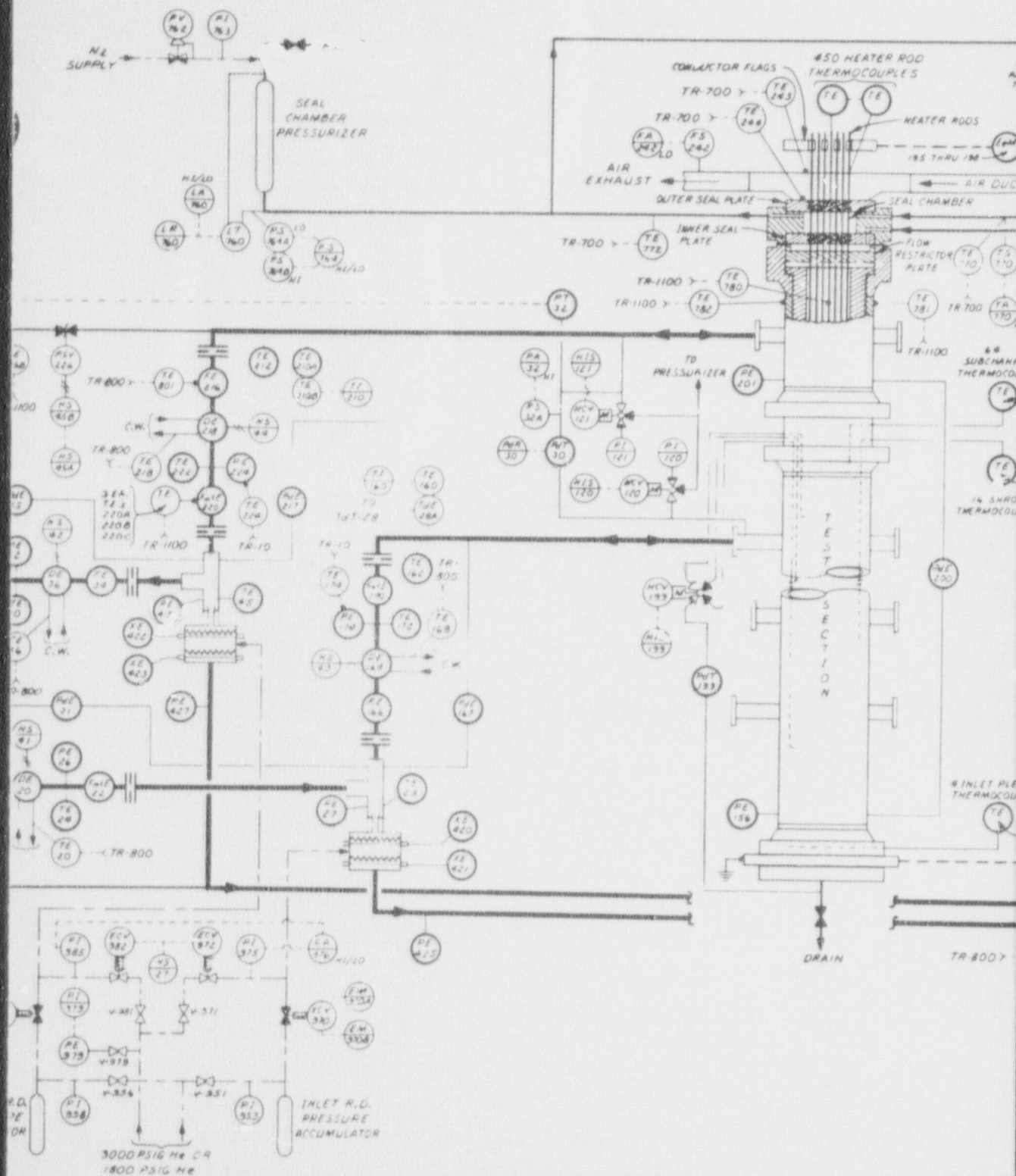


Fig. 4 (continued)

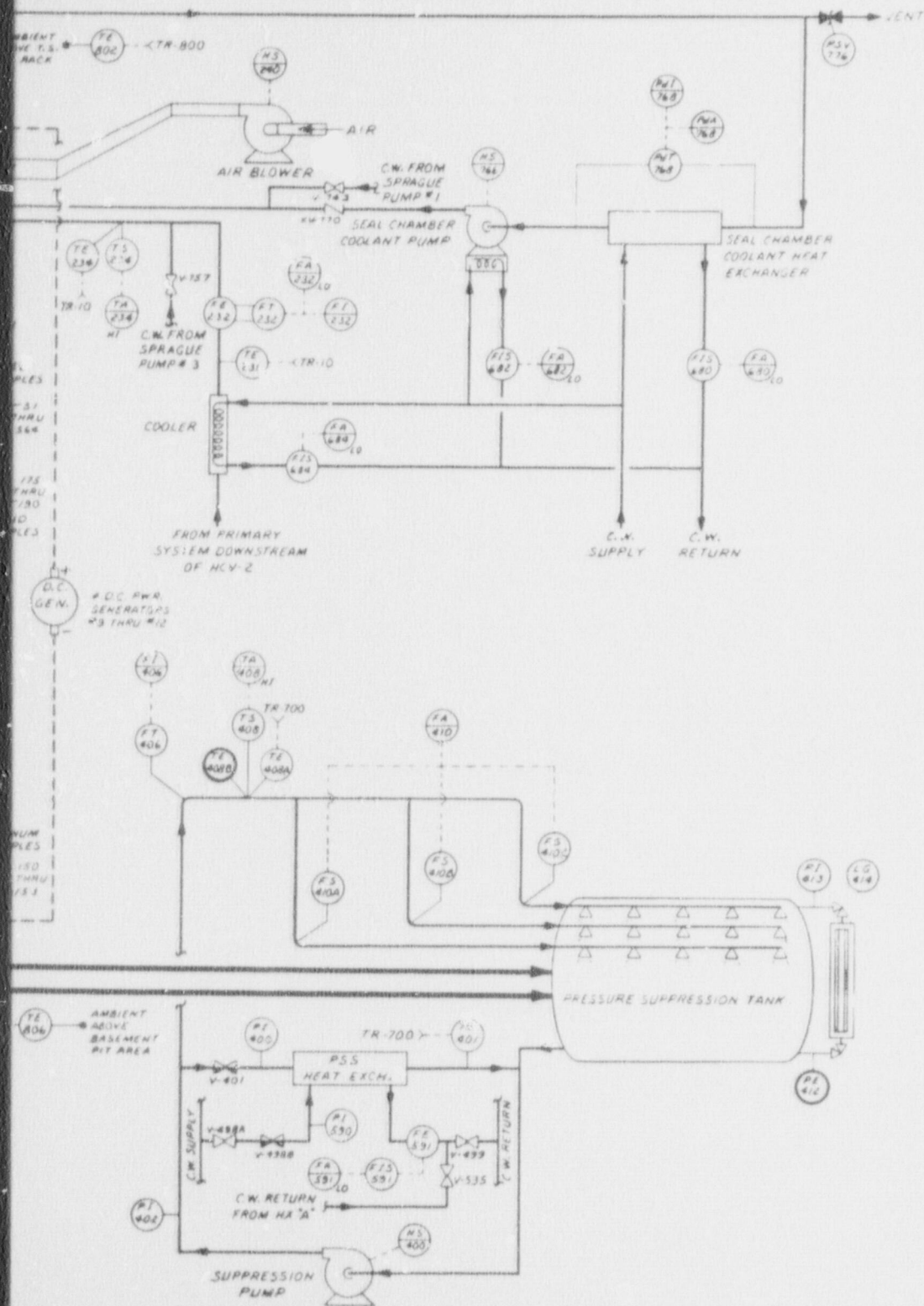


Table 4 gives the precision of the recorded instrument responses, and Table 5 groups the measurements by location and provides brief comments regarding the detectors and the recorded responses. Time zero on all graphs is the time of break initiation.

Table 4. Precision of experimental measurements for test 157

System	Standard deviation
Pressure measurement, MN/m ² (psig)	
CCDAS	0.185 (26.8)
Analog tape system	0.197 (28.5)
Pressure difference measurement, MN/m ² (psid)	
CCDAS	
6.89-MN/m ² (1000-psid) span	0.025 (3.6)
1.38-MN/m ² (200-psid) span	0.005 (0.72)
0.34-MN/m ² (50-psid) span	0.001 (0.18)
Analog tape system	
6.89-MN/m ² (1000-psid) span	0.033 (4.8)
1.38-MN/m ² (200-psid) span	0.007 (0.95)
0.34-MN/m ² (50-psid) span	0.002 (0.24)
Temperature measurement, K (°F)	2.4 (4.3)
Electric core power measurement	
Rod current, A	0.877
Rod voltage, V	0.304
Flow measurement, m ³ /sec (gpm)	
FE-19	
Forward	+0.0009 -0.0002 (+13.97) (-2.90)
Reverse	+0.0011 -0.0004 (+16.77) (-5.70)
FE-166	
Forward	+0.0011 -0.0004 (+17.49) (-6.43)
Reverse	+0.0009 -0.0002 (+14.14) (-3.07)
FE-216	
Forward	+0.0008 -0.0001 (+12.88) (-1.81)
Reverse	+0.0009 -0.0002 (+14.46) (-3.39)
FE-34	
Forward	+0.0019 -0.0005 (+30.71) (-8.58)
Reverse	+0.0019 -0.0005 (+29.54) (-7.41)
Momentum flux measurement, kg/m-sec ² (lb _m /ft-sec ²)	
CCDAS	2264 (1522)
Analog tape system	2554 (1716)
Density measurement @ 961 kg/m ³ (60 lb _m /ft ³), kg/m ³ (lb _m /ft ³)	12.9 (0.81)

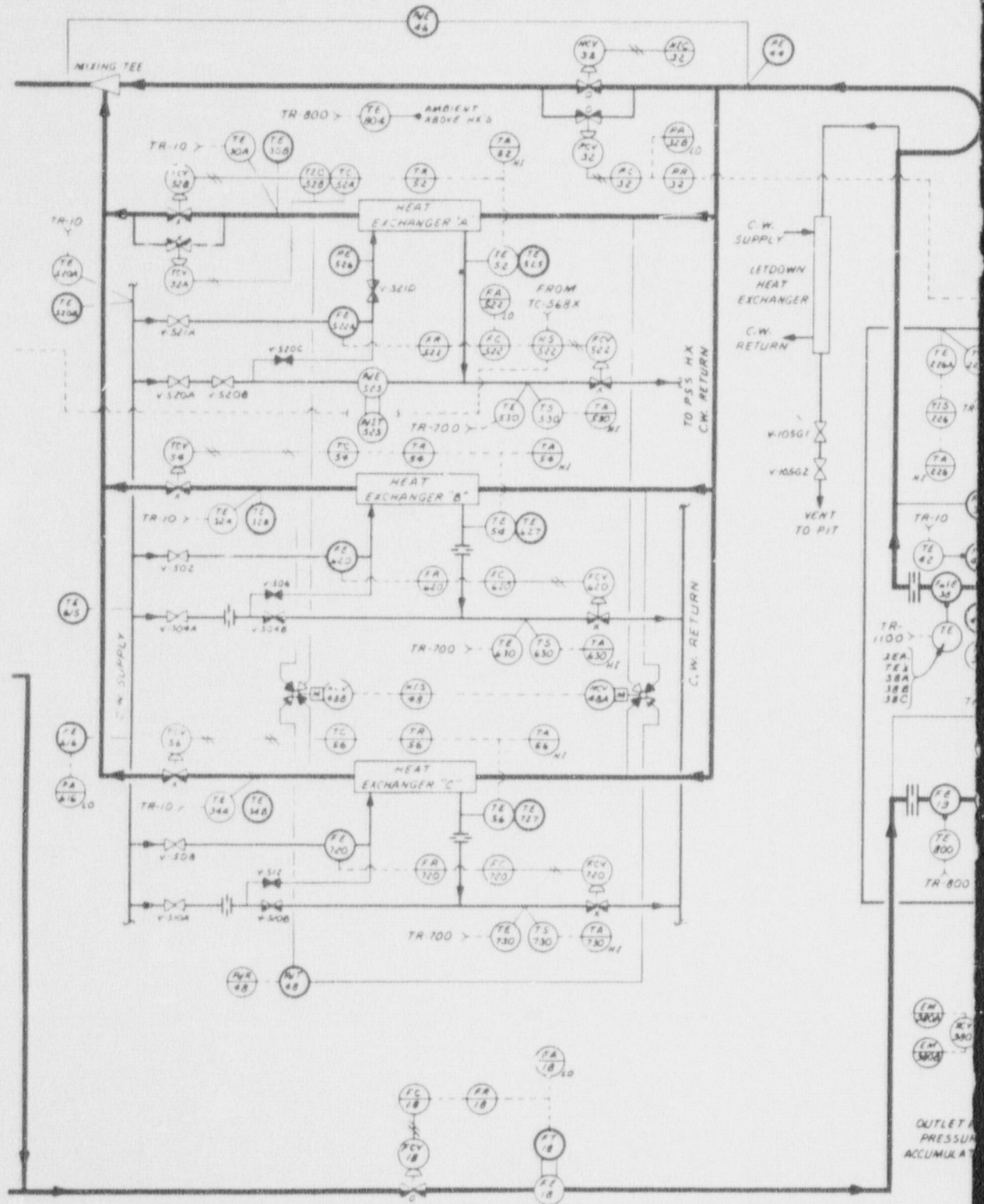


Table 5. Data presentation for test 157

Measurement	Location and comments	Range		Figure	Measurement comments
		Detector	Data acquisition system		
BUNDLE TEMPERATURE	Chromel-Alumel thermocouples	+32 to +1897°F (all)	-0.0027 to +0.0500 V (all)		
<u>Heater Rod Sheath</u>					
	LEVEL D				
TE-301AD	Rod 1			5	Erratic prior to BD
TE-304AD	Rod 4			6	
TE-309AD	Rod 9			7	
TE-310AD	Rod 10			8	Small spike
TE-312AD	Rod 12			9	
TE-313AD	Rod 13			10	
TE-317AD	Rod 17			11	
TE-318AD	Rod 18			12	
TE-320AD	Rod 20			13	
TE-322AD	Rod 22			14	
TE-323AD	Rod 23			15	
TE-325AD	Rod 25			16	
TE-326AD	Rod 26			17	
TE-331AD	Rod 31			18	
TE-338AD	Rod 38			19	
TE-339AD	Rod 39			20	Unpowered rod
TE-341AD	Rod 41			21	Noisy
TE-349AD	Rod 49			22	
	LEVEL E				
TE-301AE	Rod 1			23	Instrument failed
TE-304AE	Rod 4			24	
TE-309AE	Rod 9			25	
TE-312AE	Rod 12			26	
TE-313AE	Rod 13			27	
TE-317AE	Rod 17			28	
TE-318AE	Rod 18			29	
TE-320AE	Rod 20			30	
TE-322AE	Rod 22			31	
TE-323AE	Rod 23			32	
TE-324AE	Rod 24			33	Unpowered rod
TE-325AE	Rod 25			34	
TE-326AE	Rod 26			35	
TE-331AE	Rod 31			36	
TE-333AE	Rod 33			37	
TE-338AE	Rod 38			38	
TE-339AE	Rod 39			39	Unpowered rod
TE-341AE	Rod 41			40	
TE-349AE	Rod 49			41	

Table 5 (continued)

Measurement	Location and comments	Range		Figure	Measurement comments
		Detector	Data acquisition system		
BUNDLE TEMPERATURE (continued)					
	LEVEL 1				
TE-301CI	Rod 1			119	
TE-302AI	Rod 2			120	
TE-303AI	Rod 3			121	
TE-304CI	Rod 4			122	
TE-305AI	Rod 5			123	
TE-306AI	Rod 6			124	
TE-307AI	Rod 7			125	
TE-308AI	Rod 8			126	Spike
TE-309CI	Rod 9			127	
TE-310CI	Rod 10			128	Small spike
TE-311AI	Rod 11			129	
TE-312CI	Rod 12			130	
TE-313CI	Rod 13			131	
TE-314AI	Rod 14			132	Small spike
TE-315AI	Rod 15			133	Spike
TE-316AI	Rod 16			134	Spike
TE-317CI	Rod 17			135	
TE-318CI	Rod 18			136	
TE-320CI	Rod 20			137	
TE-321AI	Rod 21			138	
TE-322CI	Rod 22			139	
TE-323CI	Rod 23			140	
TE-324CI	Rod 24			141	Unpowered rod
TE-325CI	Rod 25			142	
TE-326CI	Rod 26			143	
TE-327AI	Rod 27			144	
TE-328AI	Rod 28			145	
TE-331CI	Rod 31			146	
TE-333CI	Rod 33			147	Small spikes
TE-336AI	Rod 36			148	
TE-337AI	Rod 37			149	
TE-338CI	Rod 38			150	
TE-339CI	Rod 39			151	Unpowered rod
TE-341CI	Rod 41			152	
TE-342AI	Rod 42			153	
TE-343AI	Rod 43			154	
TE-344AI	Rod 44			155	Small spike
TE-345AI	Rod 45			156	Small spikes
TE-346AI	Rod 46			157	Small spike
TE-348AI	Rod 48			158	
TE-349CI	Rod 49			159	Small spikes

Table 5 (continued)

Measurement	Location and comments	Range		Figure	Measurement comments
		Detector	Data acquisition system		
BUNDLE TEMPERATURE (continued)					
	LEVEL J				
TE-301DJ	Rod 1			160	Small spikes
TE-302CJ	Rod 2			161	
TE-304DJ	Rod 4			162	
TE-305CJ	Rod 5			163	
TE-306CJ	Rod 6			164	
TE-307CJ	Rod 7			165	
TE-308CJ	Rod 8			166	
TE-309DJ	Rod 9			167	
TE-310DJ	Rod 10			168	
TE-312DJ	Rod 12			169	
TE-313DJ	Rod 13			170	Unpowered rod
TE-314DJ	Rod 14			171	
TE-316CJ	Rod 16			172	
TE-317DJ	Rod 17			173	
TE-318DJ	Rod 18			174	
TE-320DJ	Rod 20			175	
TE-321CJ	Rod 21			176	
TE-322DJ	Rod 22			177	
TE-323DJ	Rod 23			178	
TE-324DJ	Rod 24			179	
TE-325DJ	Rod 25			180	Unpowered rod
TE-326DJ	Rod 26			181	
TE-327CJ	Rod 27			182	
TE-328CJ	Rod 28			183	
TE-331DJ	Rod 31			184	
TE-333DJ	Rod 33			185	
TE-336CJ	Rod 36			186	
TE-337CJ	Rod 37			187	
TE-338DJ	Rod 38			188	
TE-339DJ	Rod 39			189	
TE-340CJ	Rod 40			190	Unpowered rod
TE-341DJ	Rod 41			191	
TE-342CJ	Rod 42			192	
TE-343CJ	Rod 43			193	
TE-344CJ	Rod 44			194	
TE-345CJ	Rod 45			195	
TE-346CJ	Rod 46			196	
TE-349DJ	Rod 49			197	

Table 5 (continued)

Measurement	Location and comments	Range		Figure	Measurement comments
		Detector	Data acquisition system		
BUNDLE TEMPERATURE (continued)					
LEVEL K					
TE-301DK	Rod 1			198	
TE-304DK	Rod 4			199	
TE-309DK	Rod 9			200	
TE-310DK	Rod 10			201	Slightly noisy
TE-312DK	Rod 12			202	
TE-313DK	Rod 13			203	
TE-317DK	Rod 17			204	
TE-318DK	Rod 18			205	
TE-320DK	Rod 20			206	
TE-322DK	Rod 22			207	
TE-323DK	Rod 23			208	
TE-324DK	Rod 24			209	Unpowered rod
TE-325DK	Rod 25			210	
TE-326DK	Rod 26			211	
TE-331DK	Rod 31			212	
TE-333DK	Rod 33			213	
TE-338DK	Rod 38			214	
TE-339DK	Rod 39			215	Unpowered rod
TE-341DK	Rod 41			216	
TE-349DK	Rod 49			217	
LEVEL L					
TE-301EL	Rod 1			218	
TE-302CL	Rod 2			219	
TE-303CL	Rod 3			220	
TE-304EL	Rod 4			221	
TE-305CL	Rod 5			222	
TE-306CL	Rod 6			223	
TE-307CL	Rod 7			224	Instrument failed
TE-308CL	Rod 8			225	
TE-309EL	Rod 9			226	Reads low
TE-310EL	Rod 10			227	
TE-311CL	Rod 11			228	
TE-312EL	Rod 12			229	
TE-313EL	Rod 13			230	
TE-316CL	Rod 16			231	
TE-317EL	Rod 17			232	
TE-318EL	Rod 18			233	
TE-320EL	Rod 20			234	
TE-321CL	Rod 21			235	
TE-322EL	Rod 22			236	

Table 5 (continued)

Measurement	Location and comments	Range		Figure	Measurement comments
		Detector	Data acquisition system		
BUNDLE TEMPERATURE (continued)					
LEVEL O (continued)					
TE-317EO	Rod 17			269	Noisy
TE-318EO	Rod 18			270	
TE-320EO	Rod 20			271	
TE-322EO	Rod 22			272	
TE-323EO	Rod 23			273	
TE-324EO	Rod 24			274	Unpowered rod
TE-325FO	Rod 25			275	
TE-326EO	Rod 26			276	
TE-331EO	Rod 31			277	Noisy
TE-333EO	Rod 33			278	
TE-338EO	Rod 38			279	
TE-339EO	Rod 39			280	Unpowered rod
TE-341EO	Rod 41			281	
TE-349EO	Rod 49			282	
Heater Rod Center					
LEVEL E					
TE-301ME	Rod 1			283	
TE-304ME	Rod 4			284	Small spike
TE-318ME	Rod 18			285	Spike
TE-322ME	Rod 22			286	Small spike
TE-326ME	Rod 26			287	Small spike
TE-331ME	Rod 31			288	Instrument failed
TE-338ME	Rod 33			289	
TE-349ME	Rod 49			290	
LEVEL F					
TE-301MF	Rod 1			291	
TE-304MF	Rod 4			292	
TE-322MF	Rod 22			293	
TE-326MF	Rod 26			294	
TE-338MF	Rod 38			295	
TE-349MF	Rod 49			296	
LEVEL G					
TE-301MG	Rod 1			297	Small spike
TE-310MG	Rod 10			298	

Table 5 (continued)

Measurement	Location and comments	Range		Figure	Measurement comments
		Detector	Data acquisition system		
BUNDLE TEMPERATURE (continued)					
<u>Heater Rod Center</u> (continued)					
LEVEL G (continued)					
TE-313MG	Rod 13			299	
TE-317MG	Rod 17			300	
TE-318MG	Rod 18			301	
TE-322MG	Rod 22			302	
TE-323MG	Rod 23			303	
TE-325MG	Rod 25			304	
TE-326MG	Rod 26			305	
TE-338MG	Rod 38			306	
TE-349MG	Rod 49			307	
LEVEL H					
TE-304MH	Rod 4			308	
TE-309MH	Rod 9			309	
TE-318MH	Rod 18			310	
TE-322MH	Rod 22			311	
TE-338MH	Rod 38			312	
LEVEL J					
TE-301MJ	Rod 1			313	
TE-310MJ	Rod 10			314	
TE-317MJ	Rod 17			315	
TE-323MJ	Rod 23			316	
TE-324MJ	Rod 24			317	Unpowered rod
TE-326MJ	Rod 26			318	
TE-338MJ	Rod 38			319	
SPOOL PIECE INSTRUMENTS					
<u>Temperature</u>	Chromel-Alumel thermocouples	+32 to +1897°F	-0.0027 to +0.0400 V		
TE-24	Horizontal inlet			360	
TE-172	Vertical inlet			366	
TE-222	Vertical outlet			372	
TE-40	Horizontal outlet			378	

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