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QUICK LOOK REPORT FOR
SEMISCALE MOD-3 TESTS S-07-8 AND S-07-9
BASELINE TEST SERIES

SEMISCALE PROGRAM

May 1979

Prepared for the
U. S. Nuclear Regulatory Commission

EG&G Idaho, Inc.

IDAHO NATIONAL ENGINEERING LABORATORY

DEPARTMENT OF ENERGY

IDAHO OPERATIONS OFFICE UNDER CONTRACT DE-AC07-76IDO1570

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INTERIM REPORT

PRELIMINARY

QUICK LOOK REPORT FOR

SEMISCALE MOD-3 TESTS S-07-8 AND S-07-9

BASELINE TEST SERIES

by

R. G. Hanson

SEMISCALE PROGRAM

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The information contained in this summary report is preliminary and incomplete. Selected pertinent data are presented in order to draw preliminary conclusions and to expedite the reporting of research results.

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Credit is due to those members of the Semiscale Program and its support organizations who contributed to this report. Efforts extended in data reduction and processing, production of data plots, and typing of the document are greatly appreciated. A portion of the analysis in this document was performed by J. E. Blakeley.

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Summary

This report presents the results of a preliminary analysis of the data from Semiscale Mod-3 Tests S-07-8 and S-07-9. Tests S-07-8 and S-07-9 were the first integral blowdown reflood experiments utilizing lower plenum injection conducted in the Mod-3 facility.

Tests S-07-8 and S-07-9 were conducted from an initial system pressure of 15.6 MPa, a core inlet temperature of 557 K, and a core temperature rise of 37 K. The steady state core power was 2 MW. Twenty-three (23) of the 25 rods in the core were powered, one was unpowered, and one rod location contained a liquid level probe. To simulate radial power peaking, the 9 center rods were powered 13% higher than the remaining 14 rods resulting in high and low power rod peak power densities of 39.7 and 35.0 KW/m, respectively. The transient normalized power applied to the core following rupture in Tests S-07-8 and S-07-9 was identical to the normalized power used in Semiscale Mod-1 Test S-05-1 and Semiscale Mod-3 Test S-07-6. For Tests S-07-8 and S-07-9, ambient temperature emergency core coolant (ECC) fluid was injected into the lower plenum through use of the high and low pressure pumped injection systems and the accumulator system. The initial accumulator pressure was 4.14 and 6.89 MPa for Tests S-07-8 and S-07-9, respectively. In general, the initial conditions for Test S-07-8 were selected (where possible) to be similar to the initial conditions for Semiscale Mod-1 Test S-05-1 (a lower plenum injection experiment) to facilitate data comparisons between the Mod-3 and Mod-1 systems.

Tests S-07-8 and S-07-9 were conducted to provide reference data which would permit an evaluation of the effectiveness of lower plenum ECC injection in the Mod-3 system during a 200% cold leg break loss-of-coolant experiment, and determine the effect the accumulator injection pressure has on the core thermal response. In both Tests S-07-8 and S-07-9 the accumulator was isolated prior to the depletion of water to ensure no nitrogen injection into the system. An additional test (Test S-07-8A) in which nitrogen was allowed to enter the system following accumulator liquid depletion was conducted in order to determine the influence of nitrogen injection on core thermal response. Results from these three tests, in addition to comparison of the results to previous Mod-1 and Mod-3 experiments, are addressed in this report.

An evaluation of the results from Test S-07-8 indicates that injection of ECC liquid into the lower plenum resulted in earlier reflood initiation than has been observed in previous Mod-3 tests. A steady increase of the core liquid level following the initiation of reflood at about 32 s resulted in complete quenching of the core by 155 s after rupture. Evaluation of the data from Test S-07-9, in which the

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initial accumulator pressure was increased from 4.14 MPa to 6.89 MPa, indicated that the performance of lower plenum injection was adversely affected by initiation of accumulator injection earlier in the transient. Following the termination of accumulator injection the core heater rod cladding temperatures in Test S-07-9 were typically 50 K higher than they were in S-07-8. As a result of the higher core temperatures following the termination of accumulator injection, and also due partly to an LPIS flowrate 15% lower in Test S-07-9 relative to Test S-07-8, the core was not completely quenched until about 230 s.

The data from Test S-07-8A, in which nitrogen was allowed to enter the system following depletion of the accumulator liquid, indicated that accumulator injection of nitrogen caused depletion of the core and downcomer liquid. Since the core was not completely quenched at the point in time when nitrogen injection began, a gradual increase of the rod cladding temperatures occurred until the termination of nitrogen injection. Due to the observed depletion of the core and downcomer liquid inventory, continuous reflooding did not occur in Test S-07-8A as it did in Test S-07-8. Complete core quenching was not observed until about 300 s.

Comparison of data from Test S-07-8 with data from the Mod-1 Test S-05-1 indicates that lower plenum injection was extremely effective in both systems. Complete quenching of the core was observed to occur later in time in the Mod-3 transient relative to the Mod-1 transient due to the differences in core length between the Mod-1 (1.68 m) and Mod-3 (3.66 m) systems. Also, in the Mod-1 core, since complete quenching occurred prior to the depletion of accumulator ECC, the effect of nitrogen injection was insignificant. However, in the Mod-3 system, since the core was not completely quenched when the accumulator liquid was depleted, the depletion of the core and downcomer liquid by the nitrogen injection (Test S-07-8A) had a pronounced effect on the core thermal response. This nitrogen injection induced depletion delayed the core quenching until the liquid inventory in the core could be replaced by the lower pressure injection system (LPIS) and high pressure injection system (HPIS).

A comparison of the Mod-3 data to the RELAP4/MODF pretest calculation for Tests S-07-8 and S-07-9 indicates that the peak cladding temperature was generally underpredicted in both tests. In Test S-07-8 the heater rod quench times were calculated to occur later in time relative to the measured data throughout the core. This difference between calculated and measured quench times was thought to be primarily related to differences in the mass inventory in the system at the beginning of reflood in the prediction and a lower LPIS flow rate in the calculation than occurred in the test. The difference in mass inventory in Test S-07-8 relative to the pretest calculation was largely due to difficulties encountered in transferring initial conditions from the blowdown to the reflood calculations (due to schedule constraints, the reflood calculation was initialized with the system full of saturated steam). However, a posttest calculation using measured conditions from Test S-07-8 indicated a thermal response similar to the pretest prediction. The reflood calculation for Test S-07-9 did not have the difficulties associated with initial mass inventories as did the calculation for Test S-07-8. The calculated quench time for Test S-07-9 was in good agreement with the test results throughout the core except in the region above the core hot spot where quenching was predicted to occur earlier than at the hot spot. The test data indicated later quenches above the hot spot than occurred in the high power region.

In the reflood calculations for both Tests S-07-8 and S-07-9, the core mixture level behaved in a manner unlike that noted in the experimental data. In the pretest calculations, the mixture level indicated that the core was essentially liquid full at about 40 s. As a consequence, the calculated rod cooling trend prior to quenching does not show the distinct dependence on injection flow rate that was evident in the measured heater rod temperature when the accumulator injection terminated. This phenomena is presently being investigated in greater detail.

Introduction

This document presents a preliminary analysis of data obtained from the Semiscale lower plenum ECC injection Tests S-07-8*, S-07-9*, and S-07-8A** performed in compliance with a request from the Nuclear Regulatory Commission (NRC) (Reference (1)). These tests are part of the first series of experiments to be conducted in the Semiscale Mod-3 facility.

The Semiscale Mod-3 system is the current facility operated by the Semiscale Program. The system design differs significantly from the previous Semiscale systems in several respects including the design of the vessel and broken loop regions. The Mod-3 system has a new vessel which contains a 25-rod, full length (3.66-m) electrically heated core simulator, a full length upper head and upper plenum, and an external single pipe downcomer. The broken loop differs from previous systems in that an active pump and steam generator have replaced the hydraulic resistance simulators used in the Mod-1 system. Unlike previous

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* Accumulator nitrogen injection was not allowed.

** Accumulator nitrogen injection occurred following depletion of the accumulator water.

Semiscale systems, the Mod-3 facility was designed with the capability to investigate the influence of upper head ECC injection on the core thermal hydraulics. However, this capability was not used during the lower plenum injection tests.

The primary objectives of the lower plenum injection tests as outlined in Reference (1) were: (1) to determine the effectiveness of injecting ECC into the lower plenum in the Mod-3 system, (2) to investigate the effect of varying the initial ECC accumulator pressure on system thermal-hydraulic response, and (3) to acquire data for predictive code assessment. Additional objectives of the lower plenum injection tests included a determination of the effect on the Mod-3 system thermal-hydraulic behavior when nitrogen injection is allowed following the depletion of water from the ECC accumulator, and an assessment of the effectiveness of lower plenum injection as a function of the core length.

Tests S-07-8 and S-07-9 were the first integral blowdown-reflood experiments utilizing lower plenum ECC injection to be conducted in the Semiscale Mod-3 system. Comparison of data from the two lower plenum tests with data from Test S-07-6, a cold leg injection test, (Reference (2)) provided an indication of the effectiveness of lower plenum ECC injection in the Semiscale Mod-3 system during a 200% cold leg break experiment. The effect of the ECC accumulator pressure on system thermal-hydraulic response was determined by comparing the data from Tests S-07-8 and S-07-9. The effect of injecting nitrogen into the system after depleting the water in the ECC accumulator was investigated by considering data from Test S-07-8A which was conducted in the same manner as Test S-07-8 with the exception that nitrogen was allowed to enter the system following depletion of the liquid from the accumulator. In addition, comparison of data from Test S-07-8 and Mod-1 Test S-05-1 (Reference (3)) allowed an estimation of the effectiveness of lower plenum injection as a function of core length differences between the Mod-1 and Mod-3 systems.

Tests S-07-8 and S-07-9 were conducted from an initial pressure of about 15.6 MPa, a core inlet temperature of 557 K, and a core temperature rise of about 37 K. The total initial core power was about 2 MW. The core power transient was controlled by a power decay curve that was the same as that used in Test S-05-1 of the Mod-1 baseline test series. Twenty-three (23) of the 25 rods in the core were powered (one rod was unpowered and one rod location contained a liquid level probe). To simulate radial power peaking, the 9 center rods in both lower plenum tests were powered 13% higher than the remaining 14 low powered rods resulting in high and low power rod peak power densities of 39.7 kW/m and 35.10 kW/m, respectively. The system pressurizer discharged into the intact loop hot leg. Ambient temperature ECC fluid was injected into the vessel lower plenum using accumulator, low pressure injection, and high pressure injection systems.

The RELAP4/MODF[4] (Update 55)* computer code was used to perform pretest predictions for Tests S-07-8 and S-07-9. A detailed description of the model nodalization and input selection, and a summary of the predicted results for the lower plenum injection Tests S-07-8 and S-07-9 are contained in Reference (4).

This document contains a summary of the results from the lower plenum injection Tests S-07-8 and S-07-9, in which nitrogen injection was not allowed, and Test S-07-8A in which nitrogen injection followed the depletion of accumulator liquid. The actual test conditions and test procedures are described initially. A discussion of the experimental results and comparisons of the test data to previous Semiscale Mod-3 and Mod-1 data are then presented. Finally, comparisons of the data to the RELAP4/MODF pretest calculation are presented and discussed.

Test Procedure and Test Conditions

This section describes the test procedure and test conditions for the Semiscale Mod-3 lower plenum ECC injection tests.

Test Procedure. Prior to the initiation of testing, the Mod-3 system (shown in an isometric view in Figure 1) was filled with demineralized water and vented to ensure a liquid-full system. Water in the steam generator feedwater tanks was heated to the desired temperature and the required levels were established in the steam generator secondary sides. The lower plenum accumulator water level was established and the accumulator was pressurized with nitrogen gas to 4.14 MPa in Test S-07-8 and 6.89 MPa in Test S-07-9. The instruments were then calibrated and zeroed as required and the system was leak checked and hydro checked. After the necessary protective trip controls and peripheral hardware controls (pumps, valves, etc.) had been set, the system was brought to initial conditions and allowed to equilibrate. When system equilibrium was reached and the initial conditions were within the specified tolerances, the test was initiated by rupturing discs in the broken loop to break the system pressure boundary. The transient core power control and broken and intact loop pump speed controls were initiated coincident with the rupturing of the system pressure boundary. The tests were terminated at about 450 s after rupture after determining that the core had completely quenched.

* Idaho National Engineering Laboratory Configuration Control Number H00358IB.

Test Conditions and Hardware. A plan view of the Semiscale Mod-3 heated core showing the heater rod cladding thermocouple locations recorded during the lower plenum injection experiments is shown in Figure 2. The azimuthal location (referenced to the intact loop cold leg) and elevations above the bottom of the heated core of the thermocouples on each heater rod are shown in the figure. The thermocouples are located approximately 0.095 cm beneath the cladding surface. The axial power profile for the Semiscale Mod-3 3.66-m rods is shown in Figure 3. As illustrated in the figure, the axial power profile has a step cosine shape and has a peaking factor of about 1.55. The locations of the in-core instrumentation (gamma densitometers and core inlet drag screen) relative to the core axial power profile are shown in Figure 4. The general instrumentation locations for the Mod-3 system are shown in Figure 5. Details of the instrumentation specifications can be found in Reference (5). The transient normalized power curve used for the lower plenum injection tests is shown in Figure 6.

The specified and actual test conditions for the lower plenum injection tests are compared in Table I. In general the initial conditions and test parameters were judged as satisfactory to meet the test objectives. However, the LPIS flow rate was about 15% lower in Test S-07-9 relative to Test S-07-8. This may have exaggerated the differences in observed thermal-hydraulic response in the two tests. However, analysis conducted to date indicates that the same conclusions would have resulted even if the LPIS rates would have been the same in the two tests.

Test Results

To ensure a complete discussion of the Mod-3 system response to lower plenum ECC injection and to evaluate the effect on system response of accumulator pressure, accumulator nitrogen injection, and core length, the test results section is divided into five subsections. The first subsection deals with the overall system thermal-hydraulic response observed in Test S-07-8. This subsection includes comparisons of data from Test S-07-8 and Test S-07-6 in order to determine the effectiveness of lower plenum ECC injection. The second subsection addresses the effect of accumulator pressure on system response. The third subsection evaluates the response differences observed when nitrogen injection was allowed in the system. The fourth subsection deals with core length effects on the effectiveness of lower plenum injection. Comparisons of data from Tests S-07-8 and S-07-8A to data from Mod-1 Test S-05-1 (Reference (3)) are made in this section. The final subsection presents a comparison of experimental results for Tests S-07-8 and S-07-9 with RELAP4 pretest predictions.

TABLE I

INITIAL AND OPERATING CONDITIONS FOR TESTS S-07-8 AND S-07-9

	Specified	Actual (Test S-07-8)	Actual (Test S-07-9)
System Pressure	15.51 MPa ± 0.172 Mpa	15.72 MPa	15.89 MPa
Hot Leg Fluid Temperature	594 K ± 1 K	594.2 K	594.2 K
Cold Leg Fluid Temperature	557 K ± 1 K	555.7 K	555.7 K
Core Temperature Differential	37 K ± 1 K	38.5 K	38.5 K
Core Inlet Flow Rate	as required to establish core ΔT	8.80 Kg/s	8.85 Kg/s
Total Core Power	2 MW + 0.05 MW	2.02 MW	2.01 MW
Core Radial Power Profile	13% Peaked	11.8%	12.5%
Pressure Suppression System Pressure	0.241 MPa	0.244 MPa	0.242 MPa
ECC Injection			
Intact Loop Accumulator			
Actuation Pressure	4.14 MPa (Test S-07-8) 6.89 MPa (Test S-07-9)	4.15 MPa	6.89 MPa
Temperature	300 K	300 K	300 K
Injection Rate	1.25 l/s	1.10 l/s	1.18 l/s
Intact Loop HPIS			
Actuation Pressure	12.41 MPa	13.0 MPa	12.[illegible] MPa
Temperature	300 K	300 K	300 K
Injection Rate	0.062 l/s	0.063 l/s	0.065 l/s
Intact Loop LPIS			
Actuation Pressure	1.03 MPa	1.17 MPa	1.13 MPa
Temperature	300 K	300 K	300 K
Injection Rate	0.[illegible]6 l/s	0.189 l/s	0.162 l/s

General Thermal-Hydraulic Response to Lower Plenum Injection. The overall system and core thermal-hydraulic response from the time of rupture to the initiation of accumulator injection was essentially the same as the response observed in previous blowdown-refill and integral blowdown-reflood tests performed in the Mod-3 system. Since the early blowdown response is discussed in detail in References (6) and (7), only a brief summary of this portion of the transient will be presented in this section.

The core thermal response early in blowdown for Test S-07-8 was characterized by early departures from nucleate boiling (DNB) in the higher powered regions of the core (below the 291-cm elevation) followed by a rapid increase in core heater rod temperature. Peak cladding temperatures experienced in the test occurred during blowdown (between 8 and 15 s after rupture). The peak cladding temperature observed was about 1131 K, measured on Rod A4 at the 191-cm elevation. Table II presents a summary of initial heater rod cladding temperatures, the peak cladding temperature measured during blowdown, and the time of DNB for each thermocouple. As shown in Table II, temperature measurements above 291-cm did not experience DNB. These thermocouple readings essentially followed system saturation temperature after rupture.

Between 10 and 25 s after rupture, rod cladding temperature measurements indicated that relatively good cooling existed in the core as shown in Figure 7, which compares the cladding temperatures at different elevations in the core for Test S-07-8. The cooling trend, which began at about 10 s, was due to flashing of the fluid in the upper head which in turn forced fluid down through the core via the guide tube and support columns. This is evidenced in Figure 8 by an increase in fluid density measured in the upper core region. The cladding temperatures began to rise after 25 s. This temperature rise was due to the depletion of the upper head liquid inventory and the resultant decrease in the core heat transfer due to the core density decrease. The density decrease at 22 s is illustrated in Figure 8. The cladding temperatures continued to rise until accumulator ECC fluid was injected into the lower plenum and caused initiation of reflood at about 32 s after rupture.

The initial portion of reflood was characterized by average cladding cooldown rates of about 7 K/s due to the continued accumulator injection. Following the termination of accumulator injection at 58 s, the average cooldown rate of the cladding decreased to about 2.2 K/s. Figure 7 shows the change in cooling rate by a distinct change in the slope of the temperature curves throughout the core at 58 s. The core and downcomer collapsed liquid levels shown in Figure 9, illustrate that accumulator injection in the lower plenum resulted in

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CORE ROD TEMPERATURE RESPONSE FOR TEST S-07-8

Measurement (cm)	T initial (K)	T peak (K)	t DNB (s)
C2-08	571	662	0.19
D2-10	580	662	0.20
A4-40	585	693	0.33
C3-49	585	730	0.15
D3-71	618	868	0.27
A4-108	647	942	0.62
E2-109	646	942	0.74
C3-115	674	1040	0.62
D3-132	662	1063	0.71
D2-134	684	1082	0.59
E3-134	672	1020	0.60
D5-137	666	997	0.76
C2-164	678	1088	0.59
A5-164	674	1011	0.45
D2-166	675	1086	0.66
D1-178	679	1037	0.50
A5-179	731	1126	0.57
D2-179	688	1110	0.64
D5-179	685	1025	0.50
B3-180	703	1115	0.64
E4-180	674	1020	0.66
C2-180	679	1110	0.53
A4-181	666	1031	0.71
C3-184	690	1120	0.64
E2-190	674	1021	0.45
A4-191	693	1131	0.60
C3-194	688	1101	0.64
D3-206	686	1096	0.50
E3-207	678	1017	0.53
A3-208	675	1035	0.55
E3-223	675	1016	0.59
B3-226	693	1120	0.53
D3-226	674	1077	0.60
A3-229	681	1051	0.67
C3-230	684	1085	0.53
D1-251	671	940	0.57
A5-252	670	946	0.62
E1-252	669	919	0.67
D5-254	674	970	0.71
D2-254	679	1003	0.55
C2-277	681	1011	0.55
E3-290	656	697	0.59
A3-291	657	748	*
B1-321	628	628	*
C2-321	637	646	*
E1-321	632	636	*
D5-322	663	664	*
B3-353	643	702	*
E2-353	619	623	*
E4-354	618	618	*

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* DNB did not occur.

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filling of the downcomer early in time and a collapsed liquid level of about 2.25 m in the core. This large core liquid inventory resulted in the observed high cooling rate during the period between 32 and 58 s. The cooling during the 32 to 58 s period reduced rod cladding temperatures above and below the high power zone such that quenching occurred within about 90 s after the termination of accumulator injection as indicated in Figure 10. Figure 10 presents the quench time for each thermocouple heater rod used in Test S-07-8 and the core collapsed liquid level. The figure shows many thermocouple locations quenched due to entrainment of ECC from lower in the core, as indicated by quench points lying well above the core collapsed liquid level curve. Increased cooling was observed prior to quenching in the hot spot region as shown in Figure 11, a comparison of a core heater rod temperature response and the measured void fraction at the core high power location. As shown, the approach of the liquid front is indicated by a decreasing void fraction. Quenching of the hot spot occurred when the void fraction decreased to about 0.7.

The observed hydraulic response in Test S-07-8 was substantially different than the response observed in Mod-3 Test S-07-6 (Reference (8)) in which cold leg ECC injection was used. The cyclic mass depletion from the core and downcomer during the reflood portion of Test S-07-6 was not observed in Test S-07-8. The injection of ECC into the lower plenum in Test S-07-8 maintained subcooled fluid conditions in the downcomer throughout the reflooding of the system. The downcomer fluid conditions are shown in Figure 12, which compares the fluid temperature in the lower downcomer for Tests S-07-6 and S-07-8. In Test S-07-6 the fluid temperature is near saturation temperature whereas in Test S-70-8, the fluid temperature is between 25 and 35 K subcooled. As discussed in Reference (8), the downcomer fluid in Test S-07-6 began to boil and caused the downcomer liquid to deplete. The subcooled downcomer liquid in Test S-07-8 could not boil and therefore mass depletion did not occur resulting in a continual large downcomer driving head for reflooding the core.

A preliminary analysis of data from Test S-07-8 revealed that lower plenum ECC injection was extremely effective in causing relatively early quenching in the Mod-3 core. The accumulator was activated at about 18.5 s (4.14 MPa) in Test S-07-8 and reflooding was initiated at about 32 s. Prior to the initiation of reflood a second cladding temperature increase was observed following flashing of the upper head mass. Test S-07-9 was run identical to Test S-07-8 except the ECC accumulator was pressurized to 6.89 MPa in an effort to extend the highly efficient cooling observed during the 10 to 25 s period of blowdown and perhaps eliminate the second short temperature rise observed in Test S-07-8 following upper head liquid depletion. The following subsection discusses the effect the accumulator pressure change had on the core thermal response.

Effect of Accumulator Pressure on Lower Plenum ECC Effectiveness. The axial variation in core thermal response for Test S-07-9 is compared to the response for Test S-07-8 in Figures 13, 14, and 15, and indicates that the core behavior was affected by the change in accumulator pressure. Figure 13 shows the thermal response at the 71-cm elevation and illustrates a later quench was observed in Test S-07-9. Comparison of the thermal response at the hot spot in Figure 14 shows that at the time accumulator injection ended, the Test S-07-9 hot spot temperature was about 50 K higher. This higher temperature in Test S-07-9 relative to Test S-07-9 appears to be a factor resulting in later quenching. Figure 15 shows an analogous trend occurring at the 230-cm elevation in Test S-07-9. High in the core the cladding temperature dropped steadily upon initiation of the transient in Test S-07-9 as was observed in Tests S-07-8. Generally Test S-07-9 was characterized by a bottom-up quench with the exception of early quenches high in the core (above 291-cm elevation) whereas in Test S-07-8 quenching above and below the hot spot occurred earlier than at the hot spot. In Test S-07-9 the core was completely quenched by about 230 s after rupture. The predominantly later quenches observed in Test S-07-9 were due to the 50 K higher surface temperature following accumulator injection and also to a 15% lower LPIS flowrate which slightly affected the cooldown rate after the accumulator shut off.

Comparison of the core hydraulic response for Tests S-07-8 and S-07-9 show a considerable difference during the period of lower plenum accumulator injection. Activation of the accumulator in Test S-07-9 occurred at about 8 s compared to 18.5 s in Test S-07-8. Figure 16 compares the lower plenum average density and indicates that in Test S-07-9 the earlier activation of the accumulator resulted in maintaining the liquid inventory whereas in Test S-07-8 the lower plenum average density decreased as the blowdown continued prior to the beginning of accumulator injection at 18.5 s. The figure indicates, however, that in Test S-07-8 the lower plenum refilled within about 15 s after the accumulator was activated. During the blowdown period, from about 14 s to about 25 s in Test S-07-9, a considerable amount of the accumulator injected ECC fluid was carried out of the system through the vessel side break since at this time the blowdown induced break flow was still high. Figure 17 shows the volumetric flow at the vessel side break location indicating a lower flow in Test S-07-9. The presence of the ECC water at the break location resulted in a higher density and therefore lower volumetric flow beginning at about 14 s in Test S-07-9 relative to Test S-07-8.

Comparison of the core collapsed liquid levels for Tests S-07-8 and S-07-9 indicate that reflood began at about 28 s in Test S-07-9 and 32 s in Test S-07-8. As shown in Figure 18, the core collapsed liquid levels increased at about the same rate and reached the 2.5 m elevation at about the same time. However, on Test S-07-9 only 4 s of accumulator injection remained once this level was attained whereas, in Test S-07-8, 16 s of accumulator injection occurred after the 2.5 m elevation was reached. As a result of the shorter period of accumulator injection after initiation of reflood in Test S-07-9, the cladding temperatures were about 50 K higher throughout the core when accumulator injection terminated. Following the termination of accumulator injection the cooldown rates were only slightly different due to a slightly lower LPIS flow rate in Test S-07-9 mentioned earlier.

Effect of Nitrogen Injection on Thermal-Hydraulic Response. To investigate the effect of allowing nitrogen to enter the system after the depletion of accumulator water, Test S-07-8A was run with conditions similar to Test S-07-8 with the exception of allowing nitrogen to enter the system.

The accumulator flow rate for Test S-07-8A, shown in Figure 19, illustrates that nitrogen injection began 43 s after rupture in Test S-07-8A* and continued until about 93 s. Figure 20 presents the cladding temperature response at the 71-cm elevation, and shows similar behavior for the two tests. Since quenching low in the core occurred before nitrogen injection began, the nitrogen had no effect on the cladding temperatures. A different response was observed prior to 43 s at the 71-cm elevation as a result of the differences in accumulator mass inventories. However, the nitrogen injection had a significant influence on the cladding temperatures in the core between the 71- and 290-cm elevations. Figure 21 shows the response at the hot spot was the same for Tests S-07-8A and S-07-8 until nitrogen injection began at 43 s. During the period of nitrogen injection, the rod cladding temperature in Test S-07-8A increased at about 1.65 K/s and continued until about 120 s when reflood was reinitiated. The cooldown rate noted once reflood was restarted in Test S-07-8A was similar to that observed in Test S-07-8 after accumulator injection since reflood during this period is driven by the LPIS and HPIS rates. Figure 22 compares the cladding temperature response high in the core (above 290 cm) and indicates identical early cooldown behavior in both Test S-07-8A and Test S-07-8. However, when nitrogen injection began in Test S-07-8A, several of these locations experienced dryout since the liquid was removed from the system by the nitrogen injection. Requenching of the 290-cm and above elevations occurred at about [illegible] s.

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* The accumulator liquid inventory was low in Test S-07-8A relative to Tests S-07-8 and S-07-9. This does not however invalidate the conclusions concerning accumulator nitrogen injection.

A comparison of the core collapsed liquid levels for Tests S-07-8A and S-07-8 is shown in Figure 23. In both tests the core liquid level is increasing in a similar manner prior to the initiation of nitrogen injection in Test S-07-8A. At about 43 s nitrogen entered the system in Test S-07-8A which caused the fluid to be blown out of the core, and resulted in reducing the collapsed liquid level to about 25-cm. A similar response was observed in the downcomer as shown in Figure 24. In both tests, the downcomer was filled by the accumulator injection, but when nitrogen entered the system at 43 s in Test S-07-8A, the downcomer head was nearly depleted. After nitrogen injection ceased at about 93 s in Test S-07-8 the downcomer began refilling as did the core. Reflooding of the core resumed at about 120 s. Reflooding was accompanied by rod temperature turnover, increased cooling, and finally by total core quenching at 300 s.

Comparison of Lower Plenum ECC Injection Effectiveness in the Mod-1 and Mod-3 Systems. To establish the effect of core length on the effectiveness of lower plenum ECC injection, the results of the preliminary analysis of Test S-07-8 were compared to the results of Mod-1 Test S-05-1. Conditions for the two tests were similar except for design differences between the Mod-1 and Mod-3 systems, especially the 1.68-m core in the Mod-1 system and the 3.66-m core in the Mod-3 system.

Comparison of data from Mod-3 Test S-07-8 and Mod-1 Test S-05-1 indicate that the core quenched earlier in the Mod-1 system than in the Mod-3 system. Figure 25 presents the heater rod thermocouple quench times versus elevation throughout the core for Mod-1 Test S-05-1 and Mod-3 Test S-07-8. The data show that complete quenching of the Mod-1 core occurred prior to 60 s compared with 155 s in the Mod-3 core. The ratio of time required to quench the core in the Mod-3 system and the Mod-1 system is about the same as the ratio of the core lengths in the Mod-3 and Mod-1 systems.

As indicated in the previous subsection, the effectiveness of lower plenum injection in the Mod-3 system was adversely affected by the injection of nitrogen since at the time nitrogen came into the system the core was not completely quenched. The depletion of the liquid head in the Mod-3 core resulted in a loss of cooling and the rod temperatures increased until nitrogen injection terminated and LPIS flow was able to once again initiate reflood. However, in the Mod-1 system with the 1.68 m core, complete quenching occurred prior to nitrogen injection and no adverse effects due to nitrogen injection were observed.

Comparison of Mod-3 Data and RELAP4 Results. The pretest calculations for the lower plenum injection Tests S-07-8 and S-07-9 were performed using the RELAP4/MODF (Update 55) computer code. The RELAP4 code was used to calculate the system response during both the blowdown and reflood periods. This section presents comparisons between the calculated results and the data for Tests S-07-8 and S-07-9. Since Test S-07-8A which included injection was not among the planned lower pelnum injection tests a pretest calculation was not made. Since the blowdown portion is the same as in previous Mod-3 blowdown calculations, the major emphasis of this section is placed on the reflood portion of the calculation.

The pretest calculations were made in two parts. The blowdown portion of the calculations, initialized to the specified conditions for Tests S-07-8 and S-07-9, were run to the point in time (after rupture) when the lower plenum was calculated to be full of water. At this time in the transient the system conditions from the blowdown model were used to initialize the reflood calculation which in turn was run until the core was quenched. However, in the lower plenum injection calculation, the transition from the blowdown to the reflood portion of the calculation was made while the system was still in the blowdown transient. The transition was therefore quite difficult to make computationally and in some cases minor compromises on the reflood initial conditions had to be made in order to complete the prediction. Because of computation problems and time constraints, the reflood calculations for Test S-07-8 was started with saturated steam throughout the system and, as a result, reflooding of the core began only after the lower plenum was filled. This short delay in the initiation of reflooding was expected to influence the reflood results. To investigate this, a posttest calculation which had the correct lower plenum mass inventory at the initiation of reflood was performed. This calculation yielded results similar to the pretest calculation and therefore indicates that the two models were not extremely sensitive to the mass inventory. Because of this similarity, only the pretest calculation results will be presented in this report (the calculation for Test S-07-9 was conducted with the correct mass inventory). A problem observed in both calculations was the underprediction of the system pressure after the initiation of ECC injection. Figure 26 compares the predicted and measured system pressure responses for Test S-07-8. The addition of subcooled liquid into the lower plenum of the model caused the calculated pressure to decrease more rapidly than test data indicated. This drop is due to the instantaneous condensation assumed by the RELAP4 equilibrium calculation. A similar depressurization was observed in the prediction of Test S-07-9 and in the posttest calculation for Test S-07-8. It appears that the lower calculated pressure had minimal impact on the overall core thermal response.

The results of the calculation for Test S-07-8 will be discussed first since the two tests are similar in nature. The general calculated blowdown response was characterized by a rapid temperature rise immediately following rupture, followed by a temperature turnover similar to the response observed in Test S-07-8. Following the turnover a gradual heatup was calculated to occur prior to the initiation of reflood. The rod cladding quench was predicted to occur later than observed throughout the core. Figure 27 shows the calculated and measured heater rod cladding temperature response at the core hot spot for Test S-07-8. The predicted blowdown peak temperature of the cladding was underpredicted by about 40 K. The rod cladding temperatures turned over at about 8 s and were followed by a temperature decrease. The rate of the temperature decrease was the same as that observed in Test S-07-8 due to the draining of upper head fluid which began at about 8 s. At 27 s the reflood calculation began and a gradual heatup of the cladding temperatures was calculated until the lower plenum was refilled with ECC water. The heatup rate was similar to the rate observed in the test following the upper head drain and prior to the initiation of reflood. Flooding of the core was predicted to begin at about 37 s evidenced in Figure 27 by the initiation of a heater rod temperature cooldown. The initial calculated cooldown rate associated with reflood was similar to that in Test S-07-8. However, the calculated rate was unaffected by the termination of accumulator injection. The insensitivity of the calculation to the termination of accumulator injection (which occurred at about 50 s) was due to the core filling prior to 50 s and remaining full throughout the remainder of the calculation. In contrast, the results of Tests S-07-8 indicated a slow flooding of the core. Figure 27 shows quenching at the core hot spot was predicted to occur later in time than observed in the test. A similar comparison of the quenching behavior was observed above and below the hot spot location. As mentioned previously, a post-test calculation with the correct mass inventory and LPIS flow rate showed similar results as the pretest calculation.

The predicted heater rod cladding temperature at the hot spot for Test S-07-9 is compared to test data in Figure 28. As in Test S-07-8, the peak cladding temperature was underpredicted by about 40 K. Following the temperature turnover during blowdown, a similar cooldown rate was observed in the prediction and test data. As in Test S-07-8, the prediction for Test S-07-9 showed an early filling of the core (about 40 s) which essentially resulted in a rod environment that was insensitive to ECC flow changes incurred when the accumulator shut off. The test data showed a definite change of slope in the heater rod temperature response when the accumulator was shut off at about 58 s. The predicted quench time in Test S-07-9 at the hot spot was in good agreement with the test data. Similar agreement was observed below the hot spot; however, above the high power region the quench was predicted to occur much earlier in the transient than was observed. In the calculation the rod surfaces were exposed to a water full core whereas in the test a slow flooding of the core was observed. As a result, a different heat transfer environment was calculated to exist relative to that observed in both Tests S-07-8 and S-07-9.

Further investigation of the predicted results is needed to determine the cause of the early filling of the core. One possible cause may be related to modeling of core internal structures. It has been noted previously that the structures can add considerable energy to the core fluid and thereby induce frothing and entrainment out of the core region. It appears that if a better prediction of the core mass inventory in Tests S-07-8 and S-07-9 were obtained, the core heater rod cladding temperature predictions would follow test data better since the heat transfer conditions in the core would th be properly represented.

Conclusions

Results of the preliminary data analysis for Test S-07-8 indicate that lower plenum injection in the Semiscale Mod-3 system is extremely effective in inducing relatively early reflood and, as a result, early heater rod quenching in a 200% cold leg break experiment.

Comparison of the data from Test S-07-9 with the data from Test S-07-8 indicate that injection of ECC into the lower plenum at an accumulator pressure of 6.89 MPa rather than 4.14 MPa resulted in degraded ECC cooling performance. Quench times occurred later in Tests S-07-9 than in Test S-07-8. The later quenching was due to considerable spillover of ECC liquid to the cold leg break since accumulator initiation occurred while blowdown induced reverse core flow and break flow were strong. Therefore, less ECC was injected into the core in Test S-07-9 and about 50 K higher cladding temperatures were observed following accumulator injection.

The results of Test S-07-8A, in which nitrogen was allowed to enter the system, indicated adverse effects on the core thermal-hydraulic response resulted. Initiation of nitrogen injection into the lower plenum following depletion of the accumulator liquid resulted in sweeping out the liquid inventory in the core and downcomer. For the duration of nitrogen injection, the cladding temperatures rose gradually and dryouts were obseved high in the core. Reflood of the unquenched region in the core began at about 120 s following the depletion of nitrogen. These results suggest that a lower plenum ECC injection system should either provide a large enough volume of water for injection to quench the core before the water is depleted or the accumulator injection system should be isolated prior to the depletion of liquid.

In both the Mod-1 and Mod-3 systems lower plenum injection was very effective. An evaluation of lower plenum ECC injection in the Mod-1 system indicated that the shorter core was completely quenched prior to depletion of the accumulator liquid. Nitrogen injection therefore had no influence on the core response. However, in the Mod-3 system, the core liquid inventory was depleted when nitrogen was allowed to enter the system which resulted in a gradual heat-up of the heater rod cladding until the LPIS reinstated reflood.

Comparison of Test S-07-8 to the pretest calculation indicated calculated peak cladding temperatures were about 40 K low and quench times were observed to occur somewhat earlier than calculated. A discrepancy in mass inventory at the beginning of reflood and the LPIS flow rate were corrected in a posttest calculation. However, similar results were observed in the posttest calculation indicating that the calculation may be more sensitive to computational problems incurred when the transition from the blowdown to reflood portions of the calculation occurs prior to the end of blowdown. The calculated peak clad temperature response for Test S-07-9 was also about 40 K low, however quench times were generally in good agreement. The calculated pressure response for both Tests S-07-8 and S-07-9 was strongly affected by condensation introduced by the injection of ECC into the lower plenum.

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3. E. M. Feldman et al, Experiment Data Report for Semiscale Mod-1 Test S-05-1 (Alternate ECC Injection Test), TREE-NUREG-1050, EG&G Idaho, Inc. (February 1977).

4. C. P. Fineman et al, Pretest Analysis for Semiscale Mod-3 Test Series, Semiscale Mod-3 Baseline Test Series Tests S-07-8 and S-07-9, SEMI-TR-001, EG&G Idaho, Inc. (January 1979).

5. Semiscale Program, Semiscale EOS Appendix 7, WR-S-78-002, EG&G Idaho, Inc. (March 1978).

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7. E. A. Harvego and R. G. Hanson, Quick Look Report for Semiscale Mod-3 Test S-07-2 Baseline Test Series, WR-S-78-014, EG&G Idaho, Inc. (August 1978).

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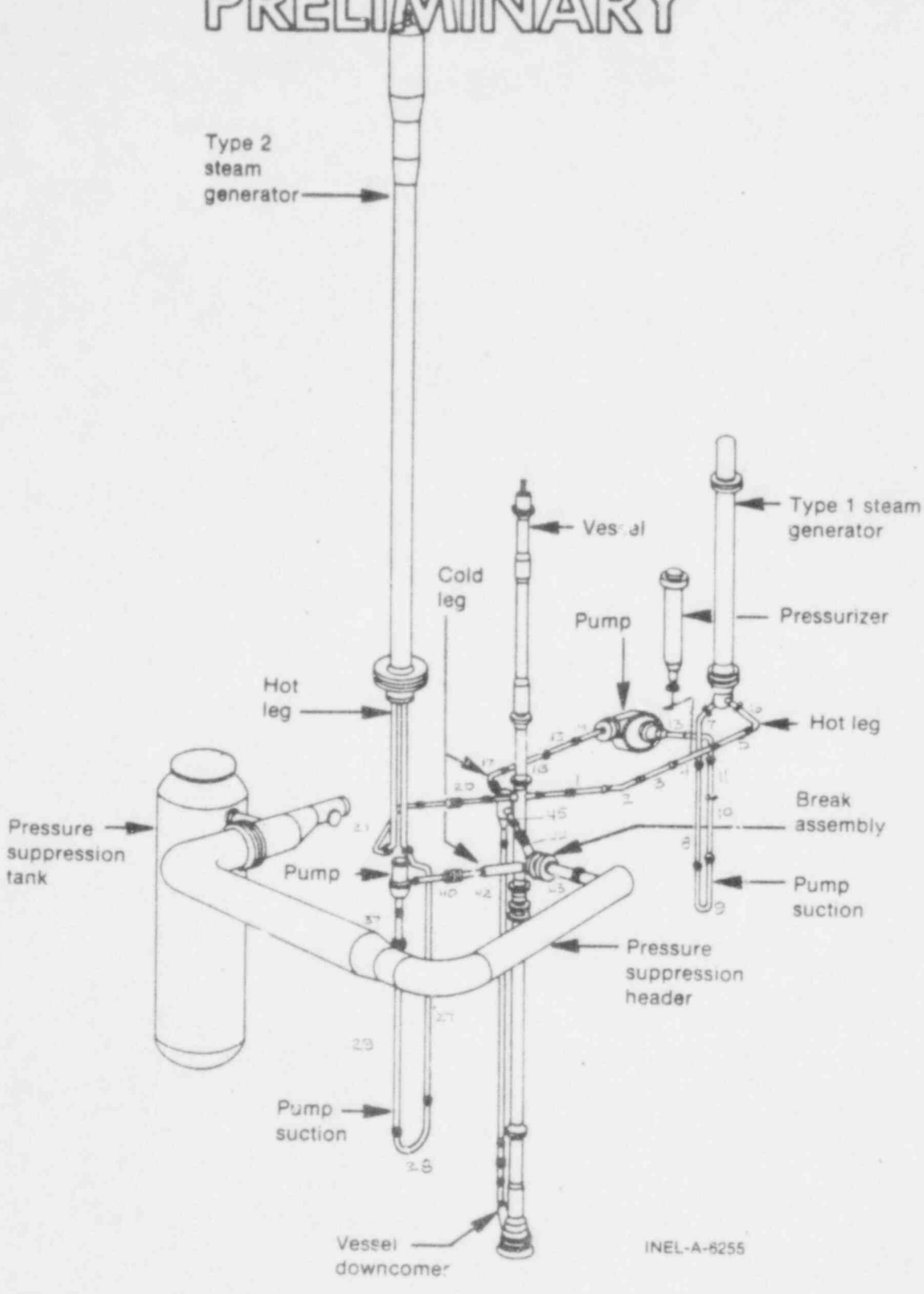

Fig. 1 Semiscale Mod-3 system cold leg noncommunicative break configuration isometric.

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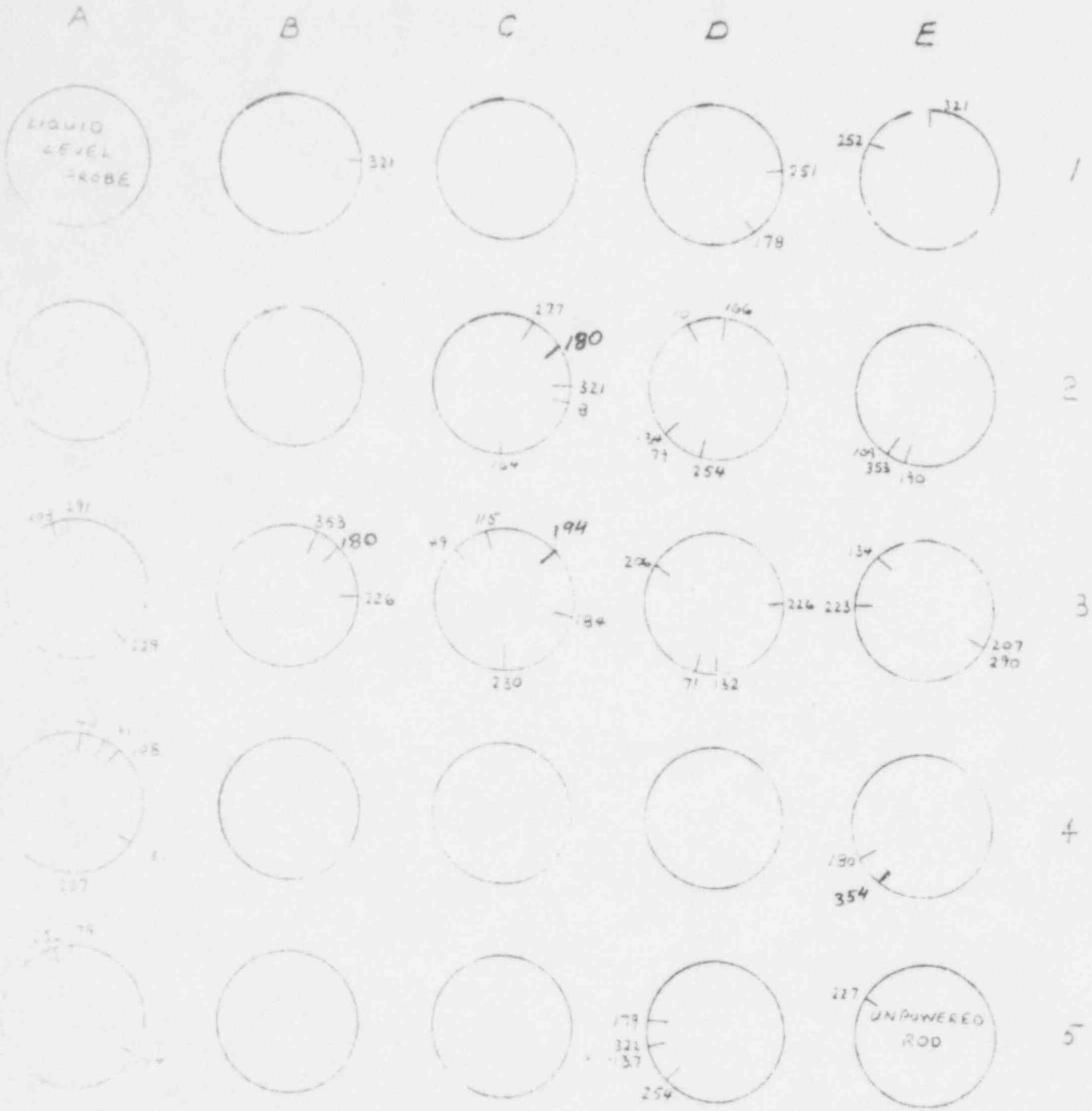

Fig. 2 Location of core heater rod thermocouples for Tests S-07-8 and S-07-9. (Note: Numbers indicate thermocouple axial location in centimeters.)

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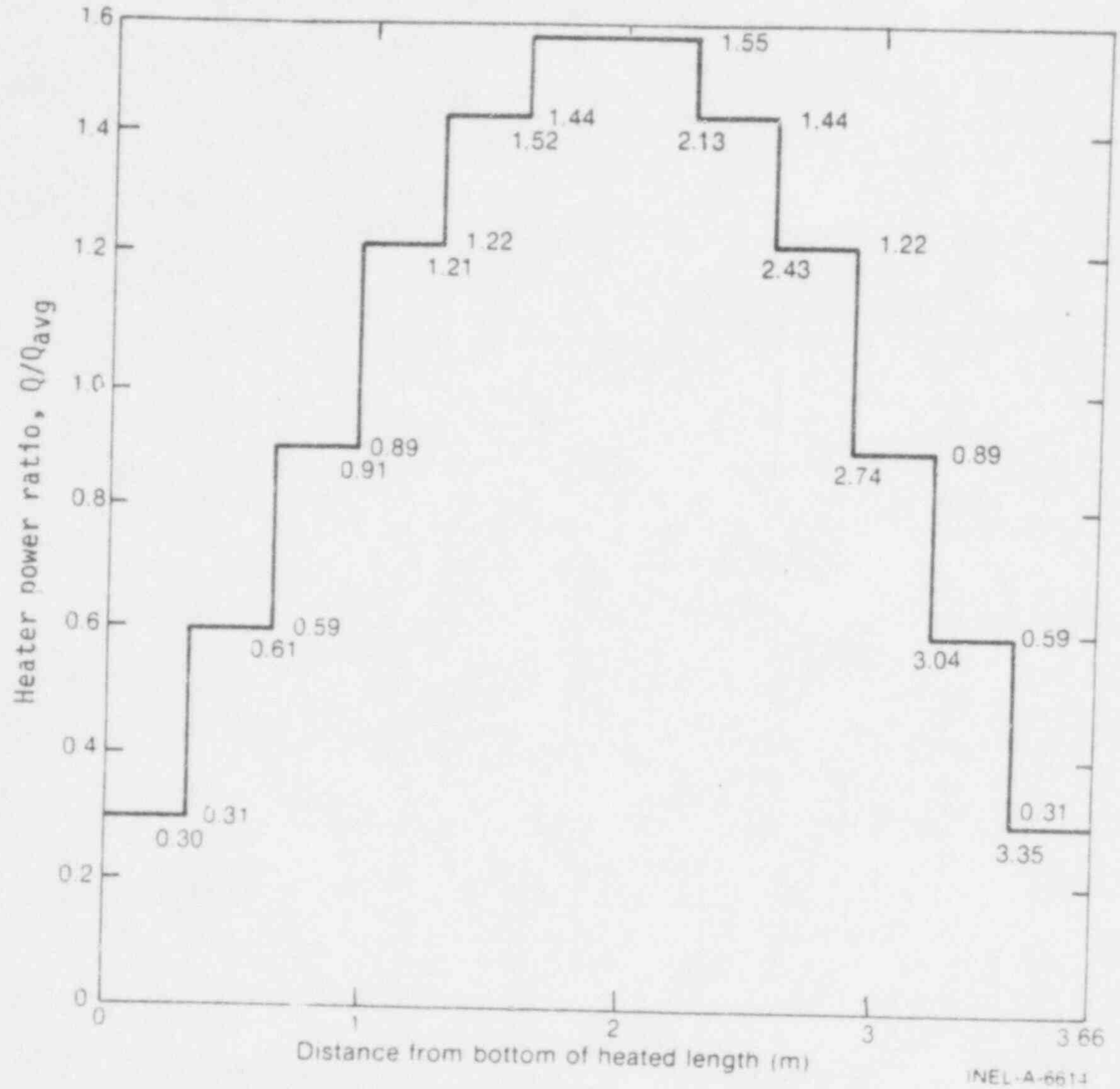

Fig. 3 Semiscale Mod-3 heater rod axial power distribution.

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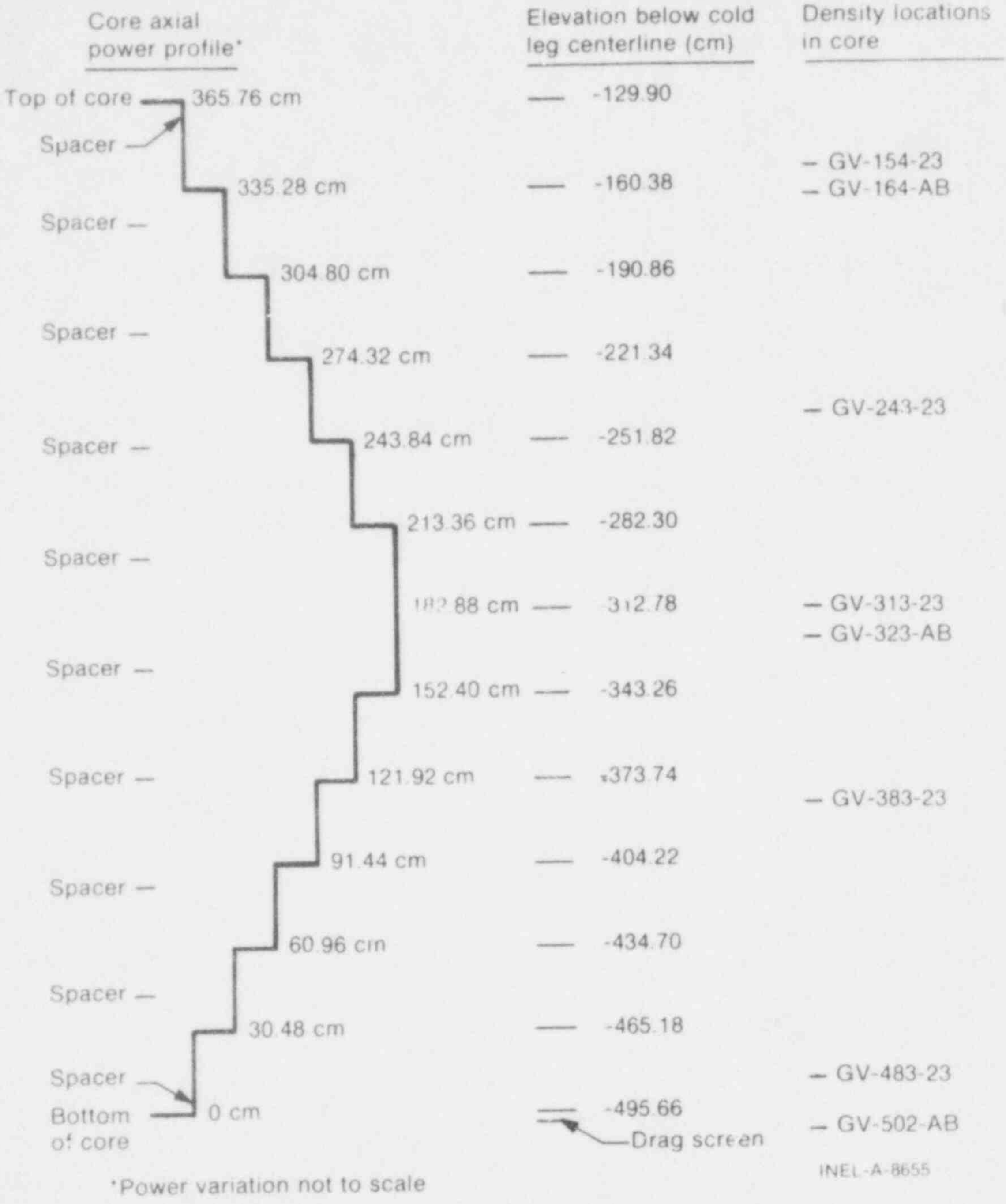

Fig. 4 Axial power profile in relation to vessel instrumentation.

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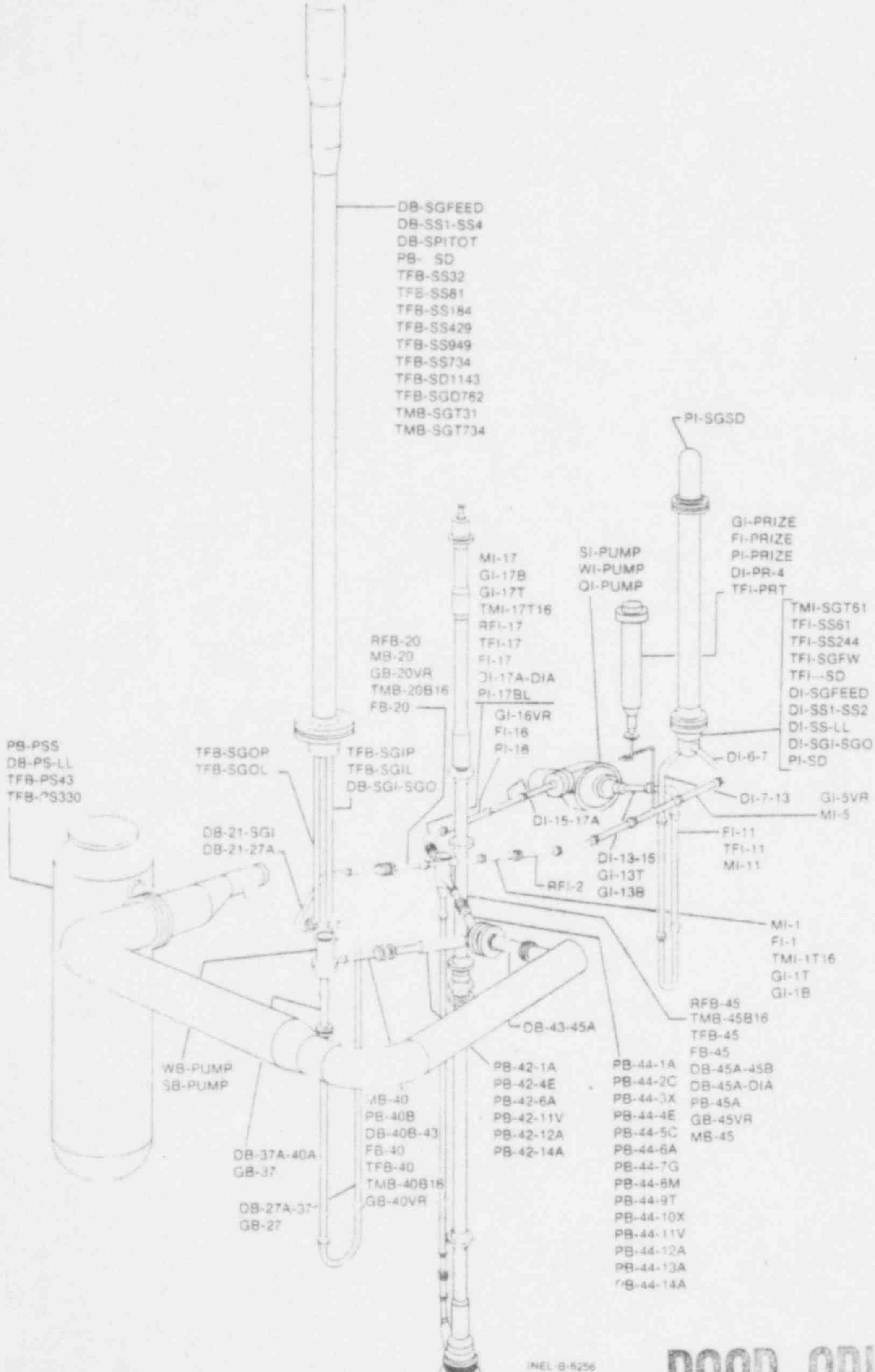

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Fig. 5 Semiscale Mod-3 system cold leg noncommunicative break configuration - isometric with available instrumentation locations.

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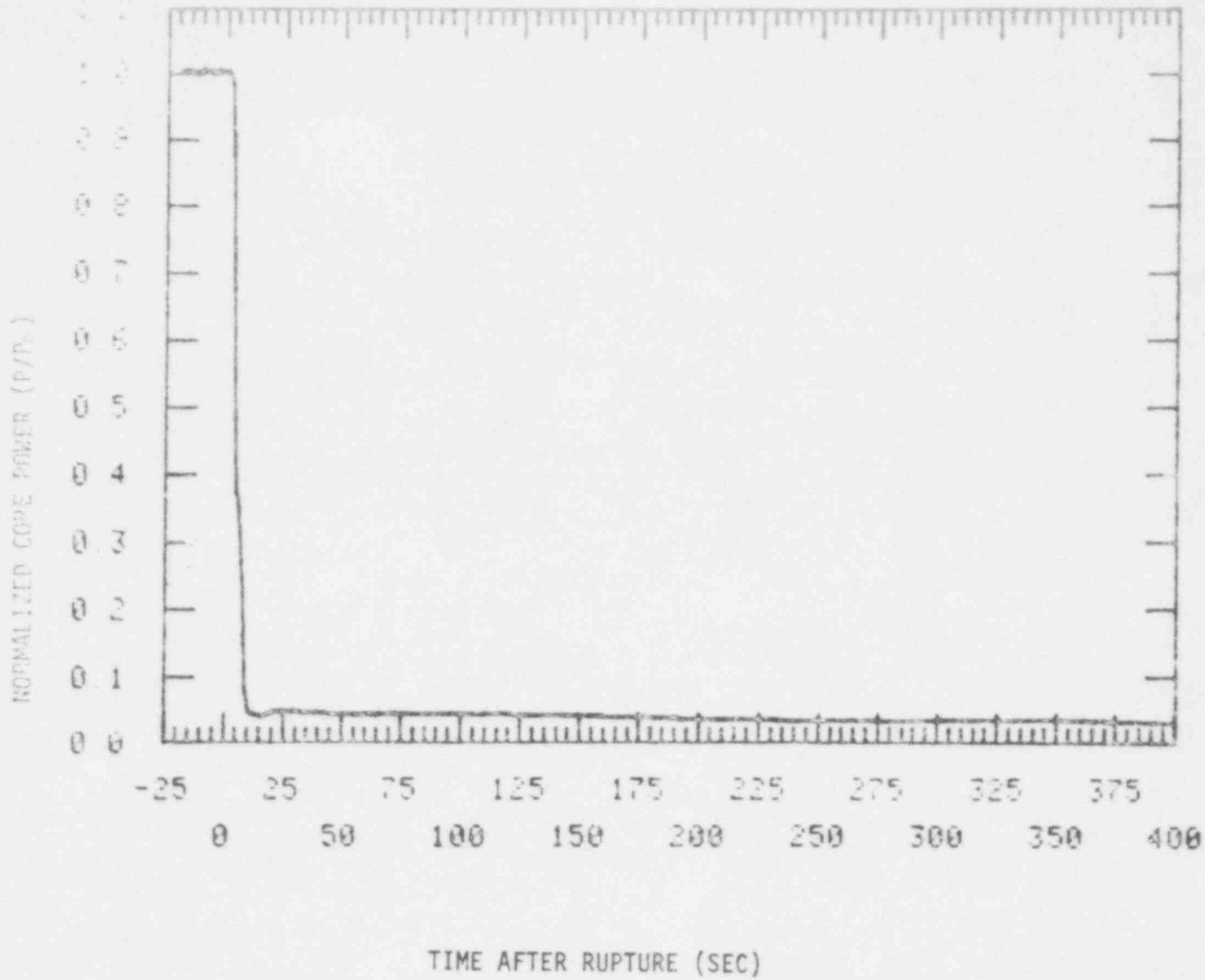

Fig. 6 Normalized core power for Tests S-07-8 and S-07-9.

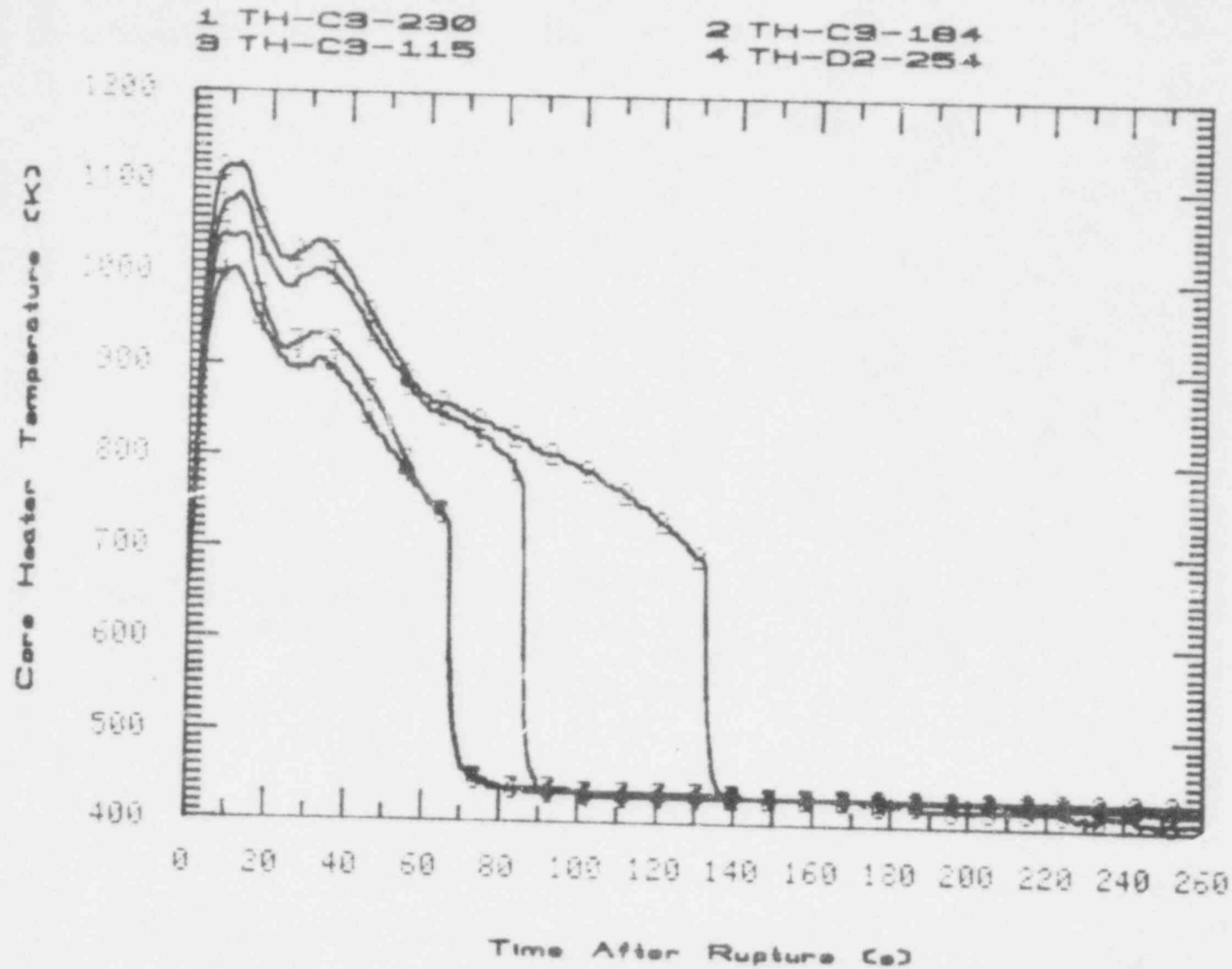

Fig. 7 Core thermal response at the 115, 184, 230, and 254-cm elevations for Test S-07-8.

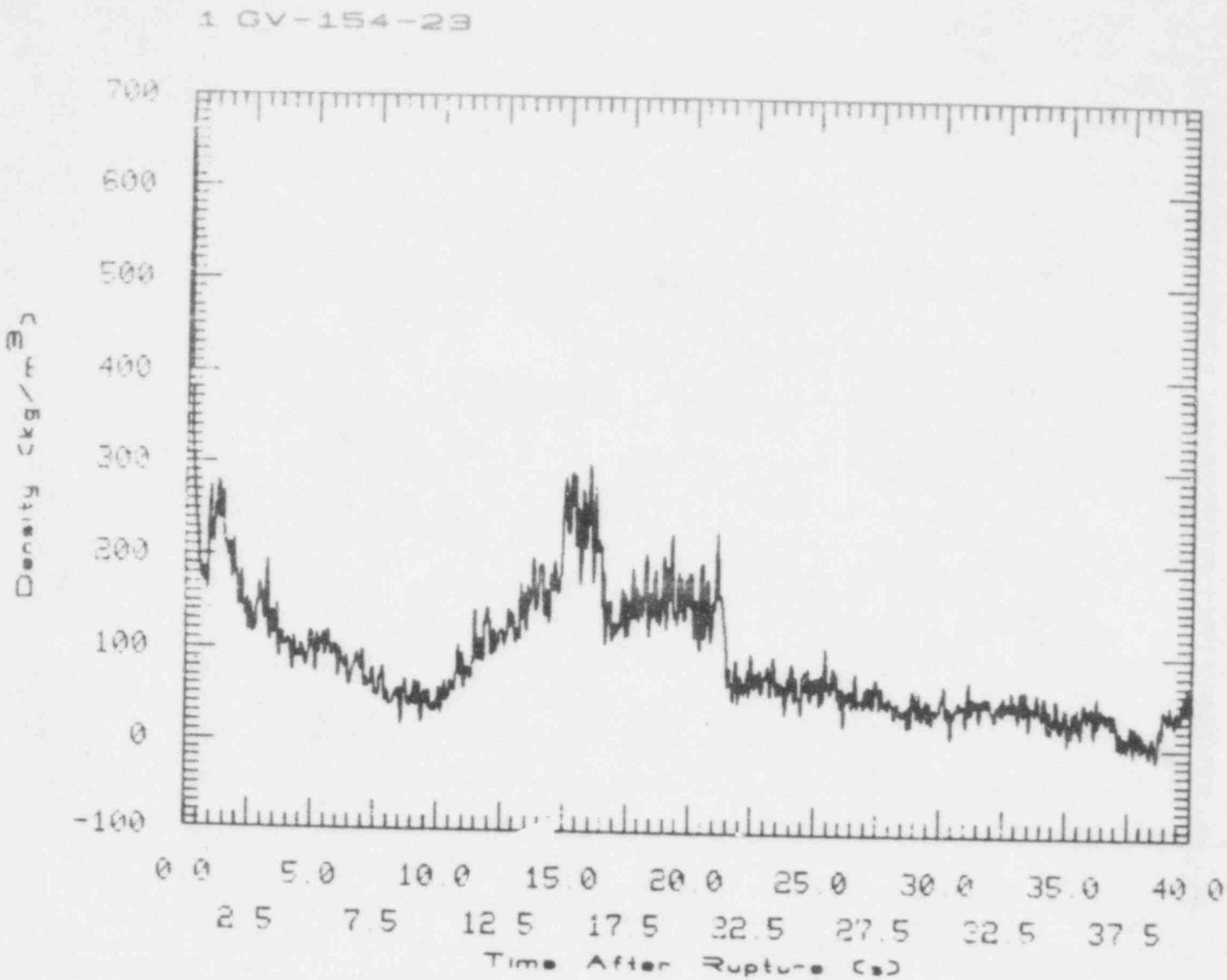

Fig. 8 Fluid density in the upper core region in Test S-07-8.

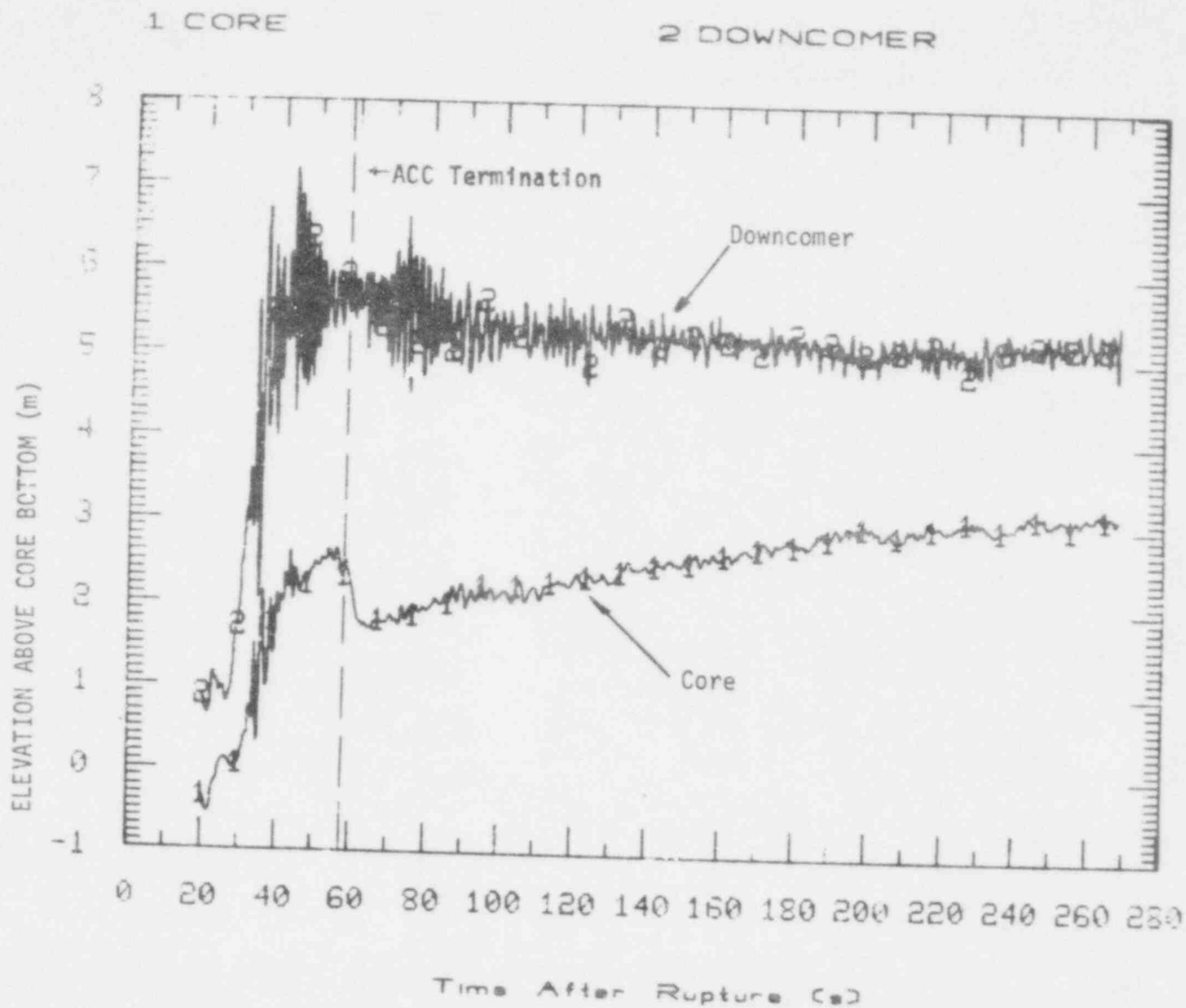

Fig. 9 Core and downcomer collapsed liquid levels for Test S-07-8.

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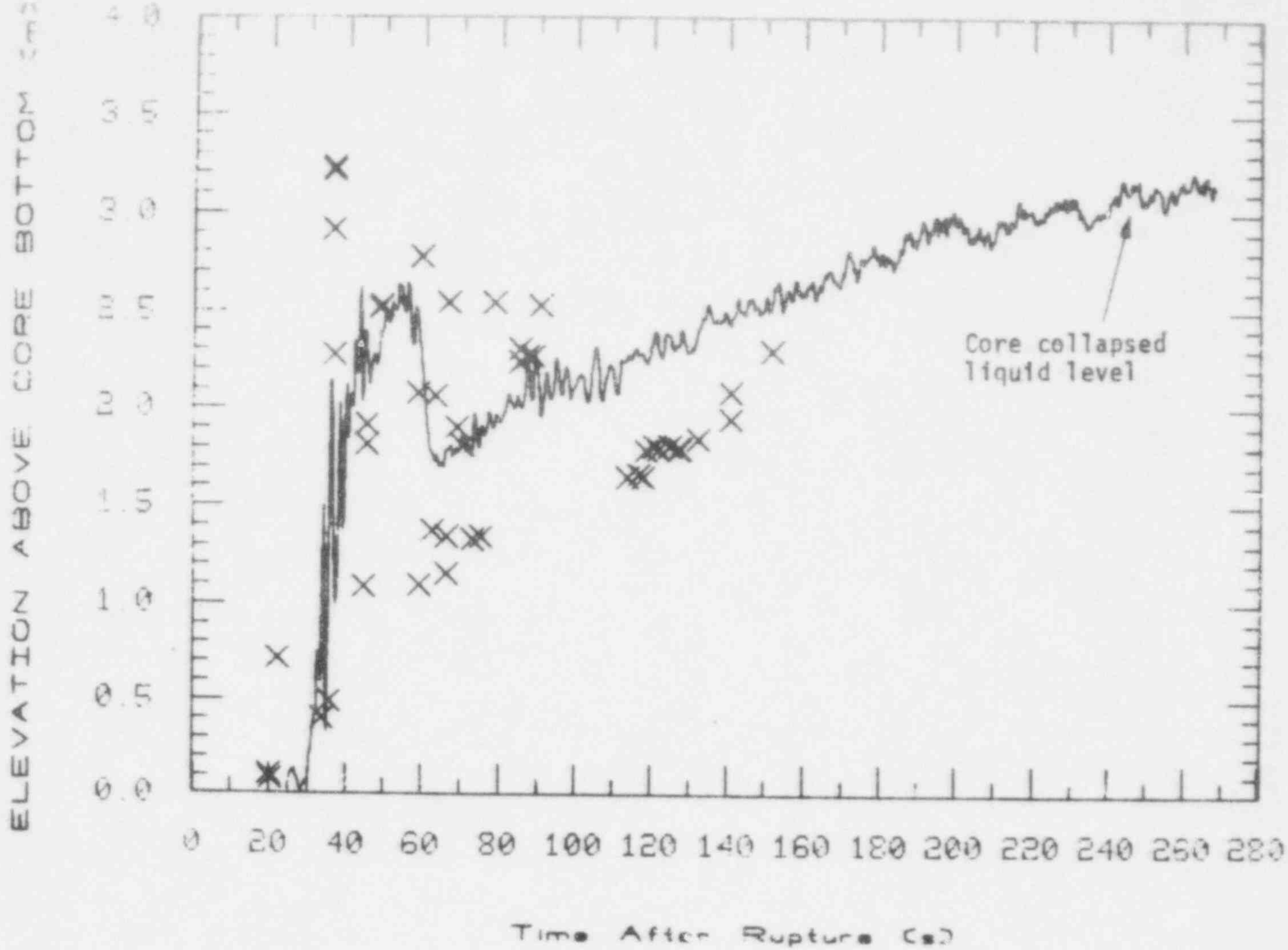

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Fig. 10 Quench time for each thermocouple and core collapsed liquid level for Test S-07-8.

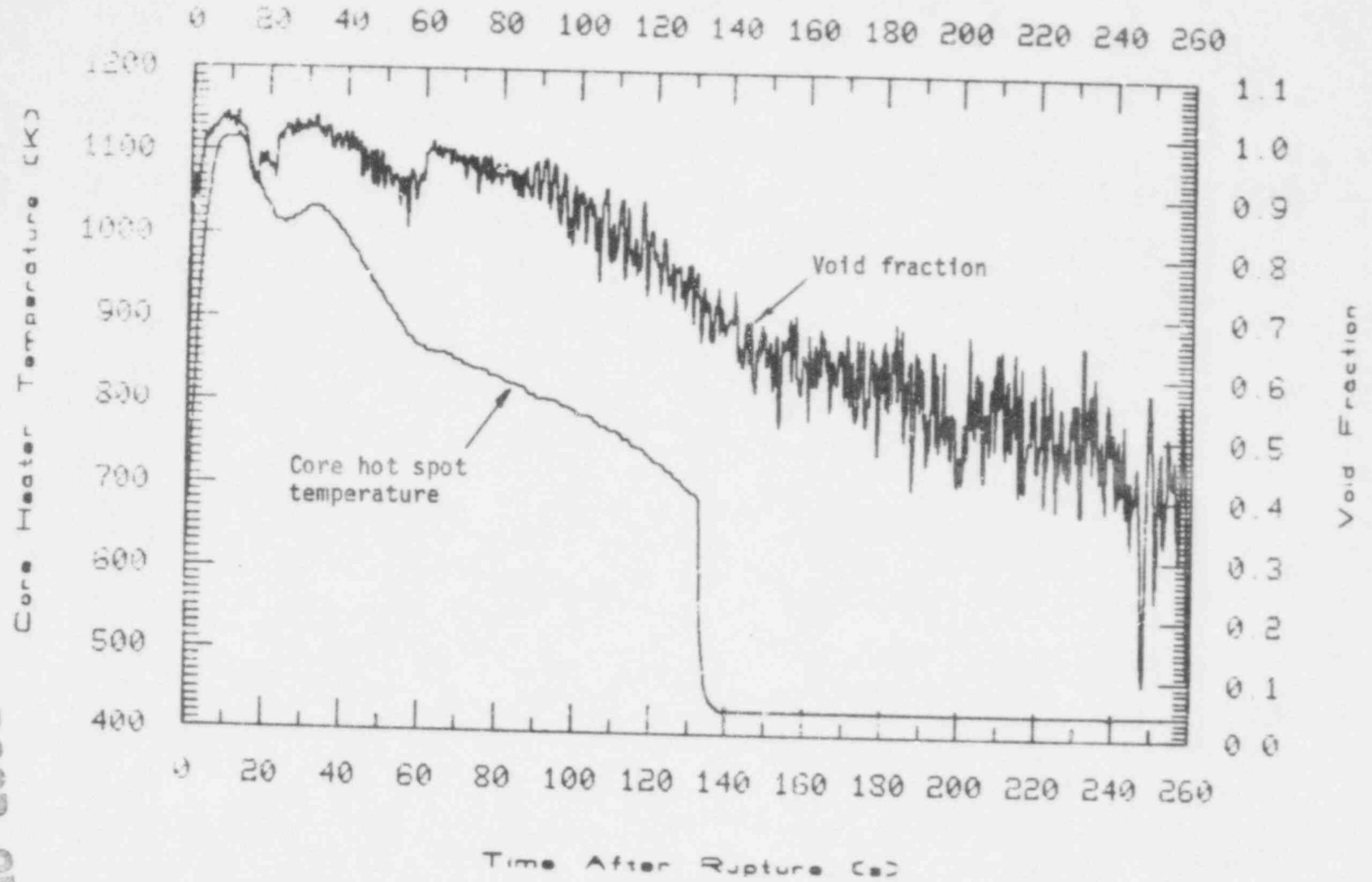

Fig. 11 Temperature and void fraction response at the core hot spot for Test S-07-8.

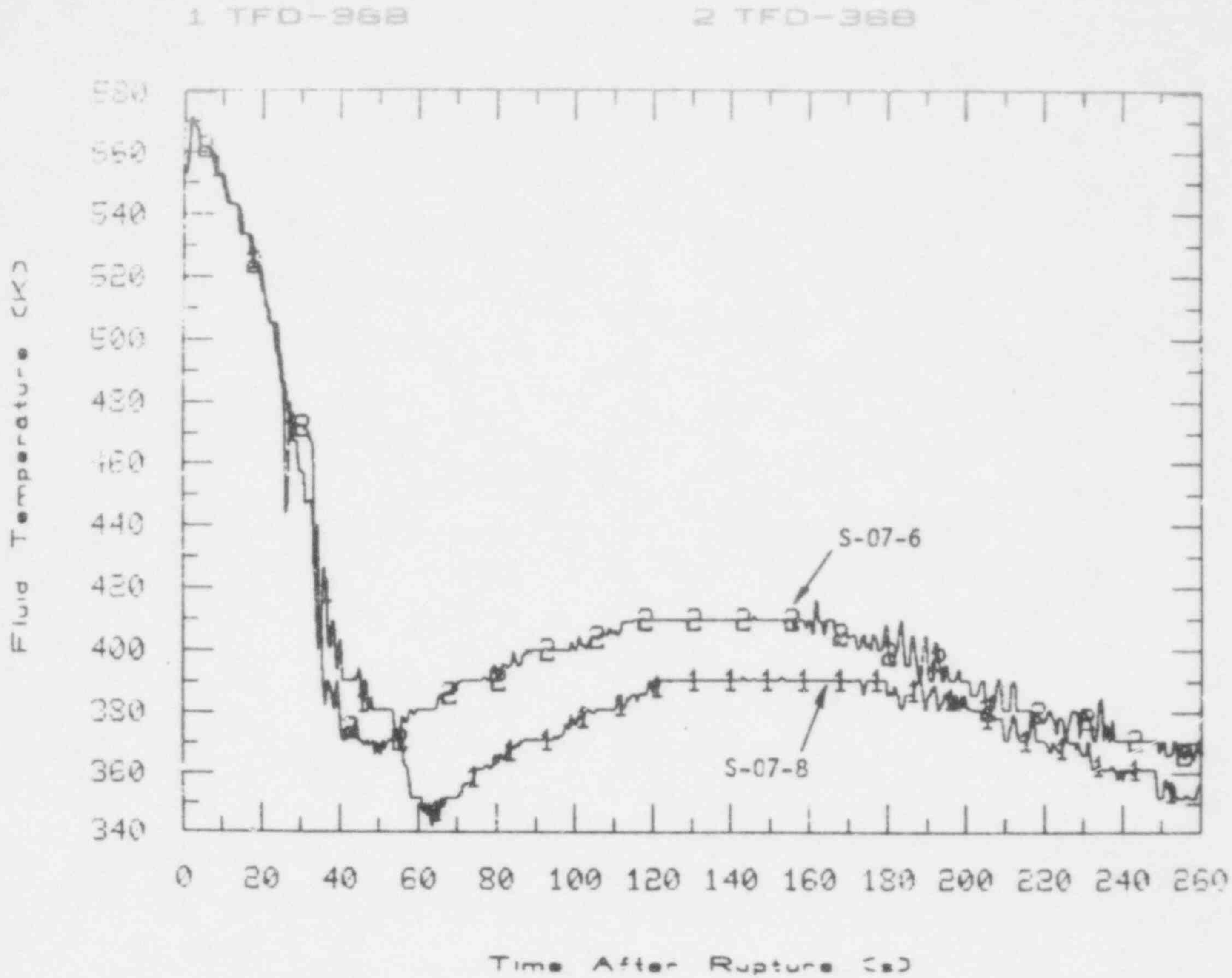

Fig. 12 Comparison of fluid temperature in the downcomer for Tests S-07-8 and Test S-07-9.

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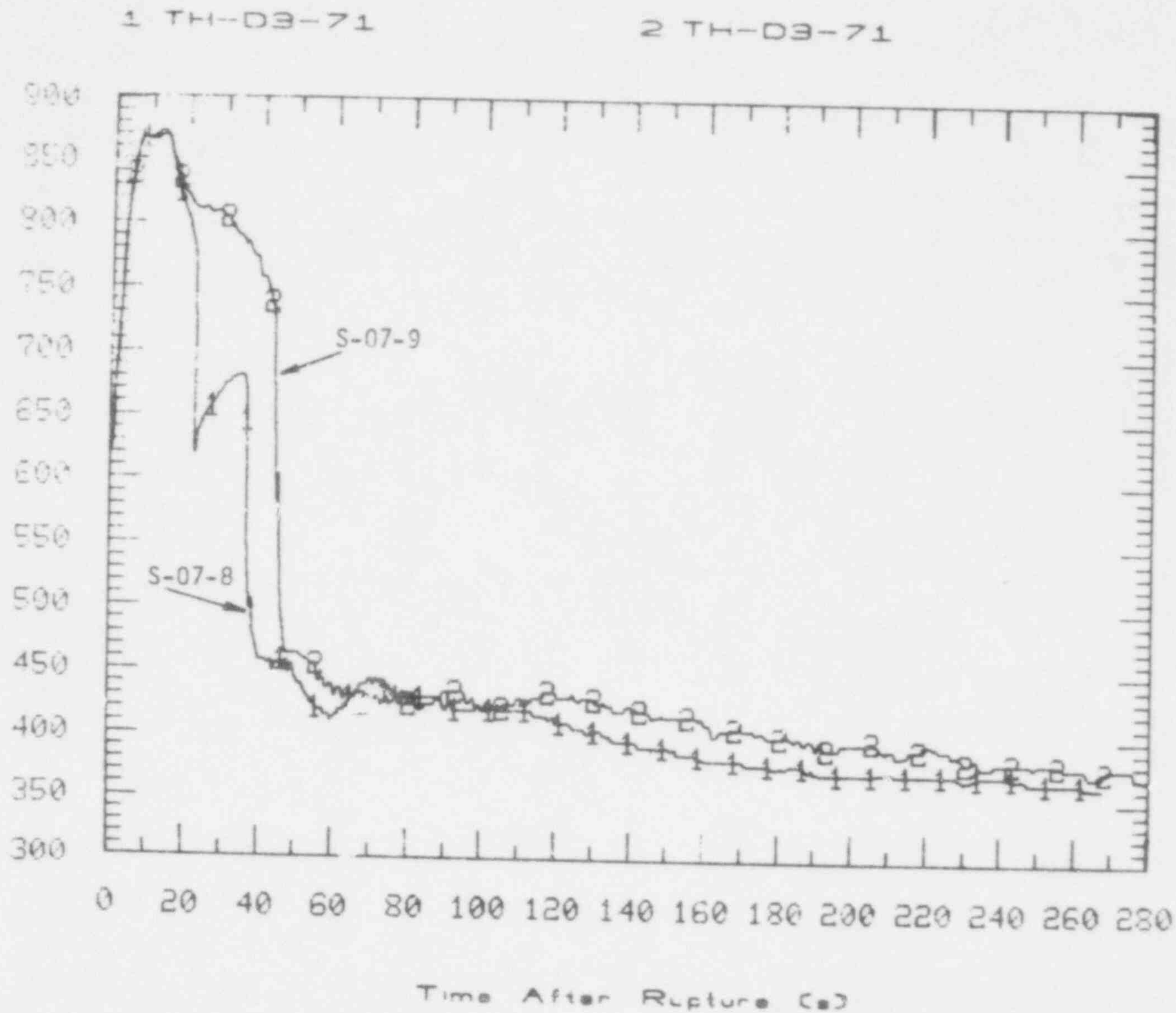

Fig. 13 Comparison of core thermal response at the 71-cm elevation for Tests S-07-8 and S-07-9.

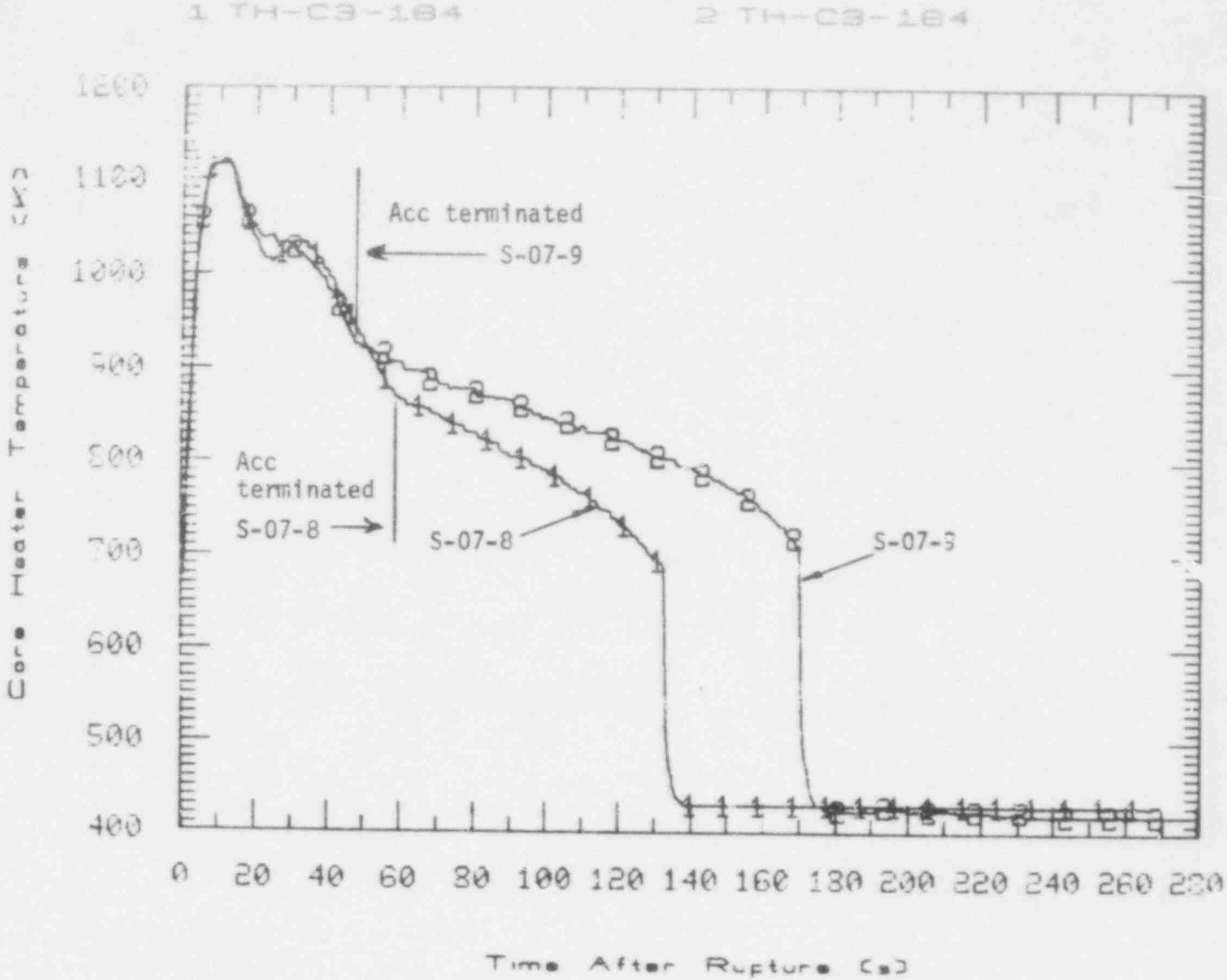

Fig. 14 Comparison of core thermal response at the hot spot for Tests S-07-8 and S-07-9.

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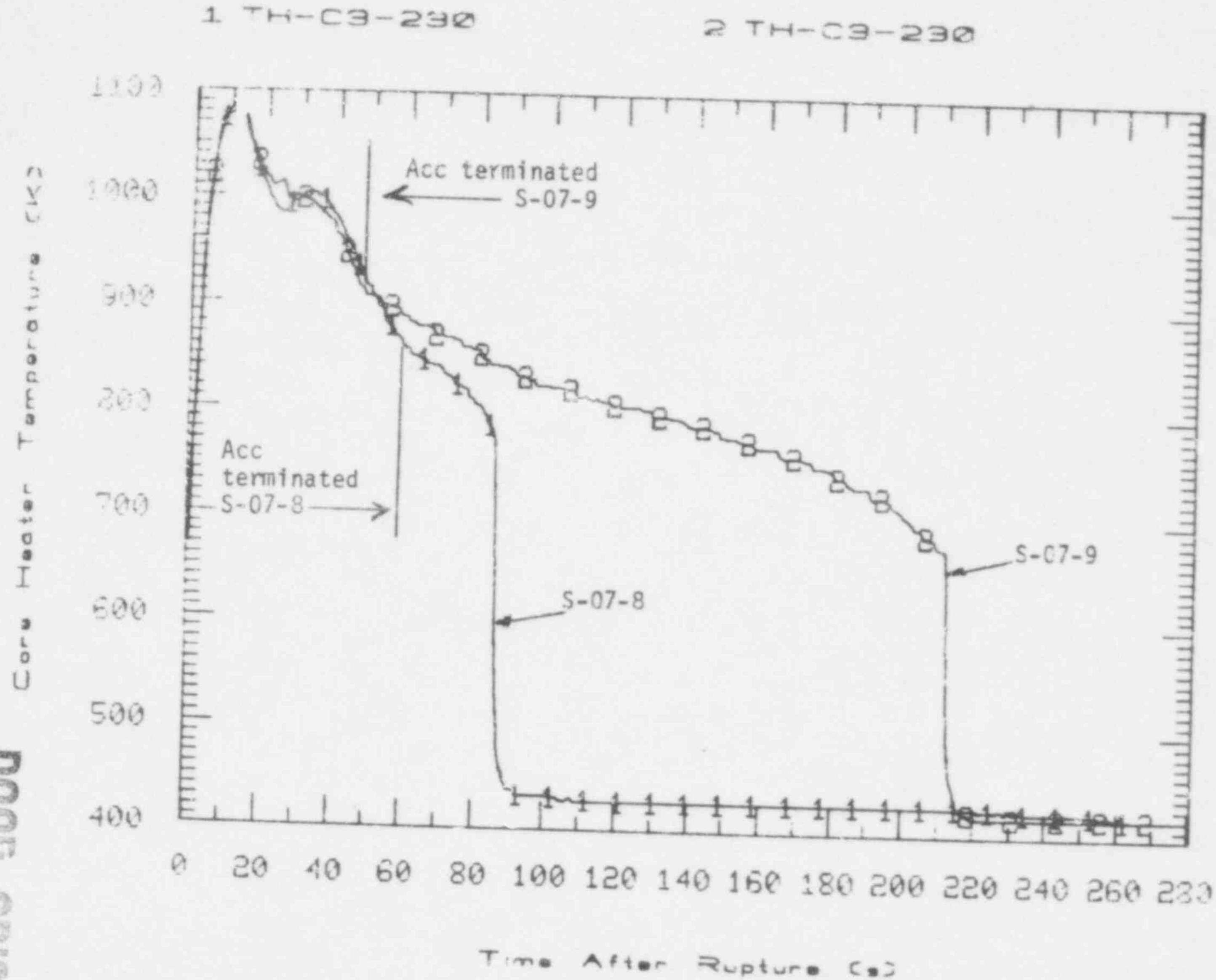

Fig. 15 Comparison of core thermal response at the 230-cm elevation for Tests S-07-8 and S-07-9.

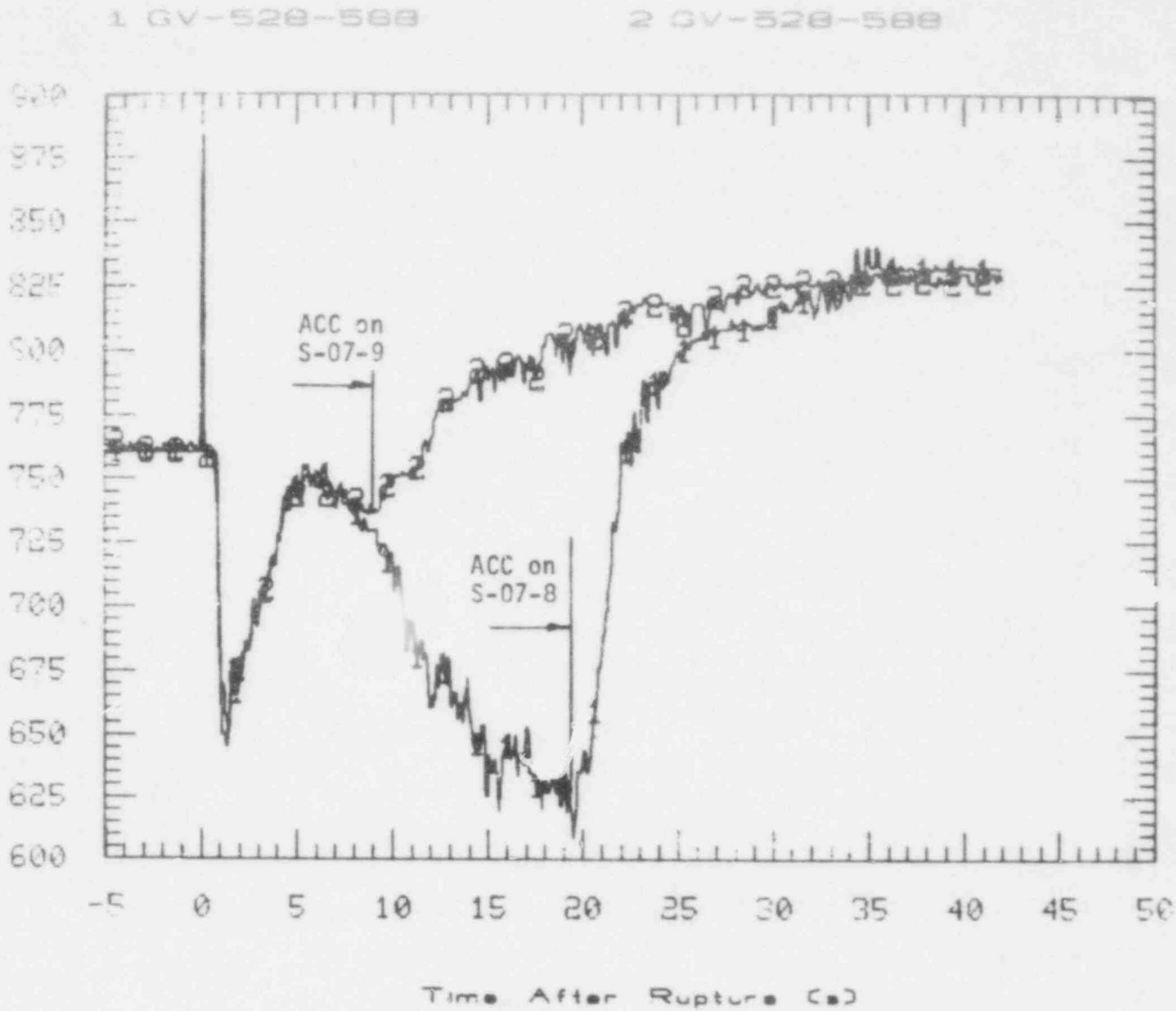

Fig. 16 Comparison of the average density in the lower plenum for Tests S-07-8 and S-07-9.

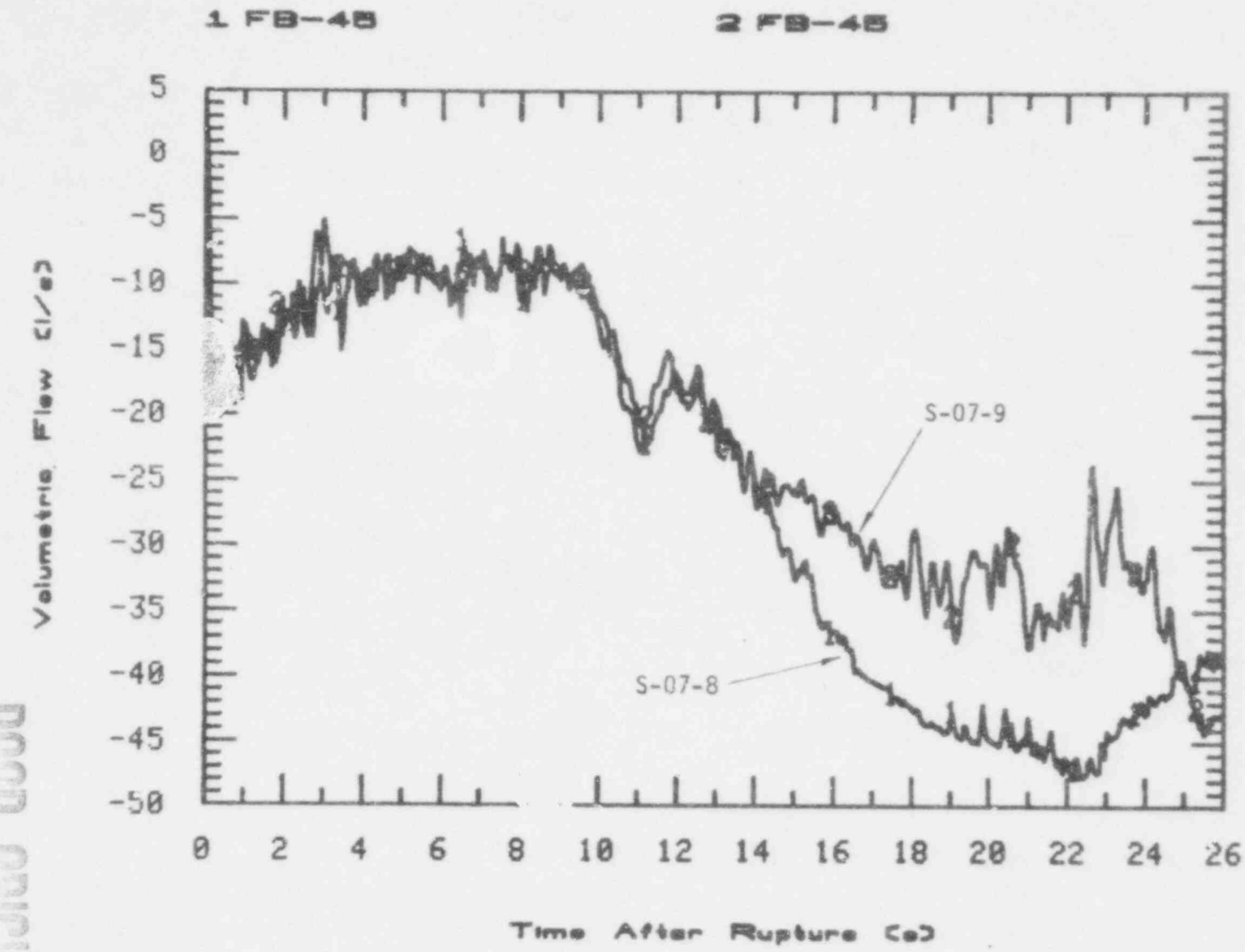

Fig. 17 Comparison of the volumetric flow rate at the vessel side break location for Tests S-07-8 and S-07-9.

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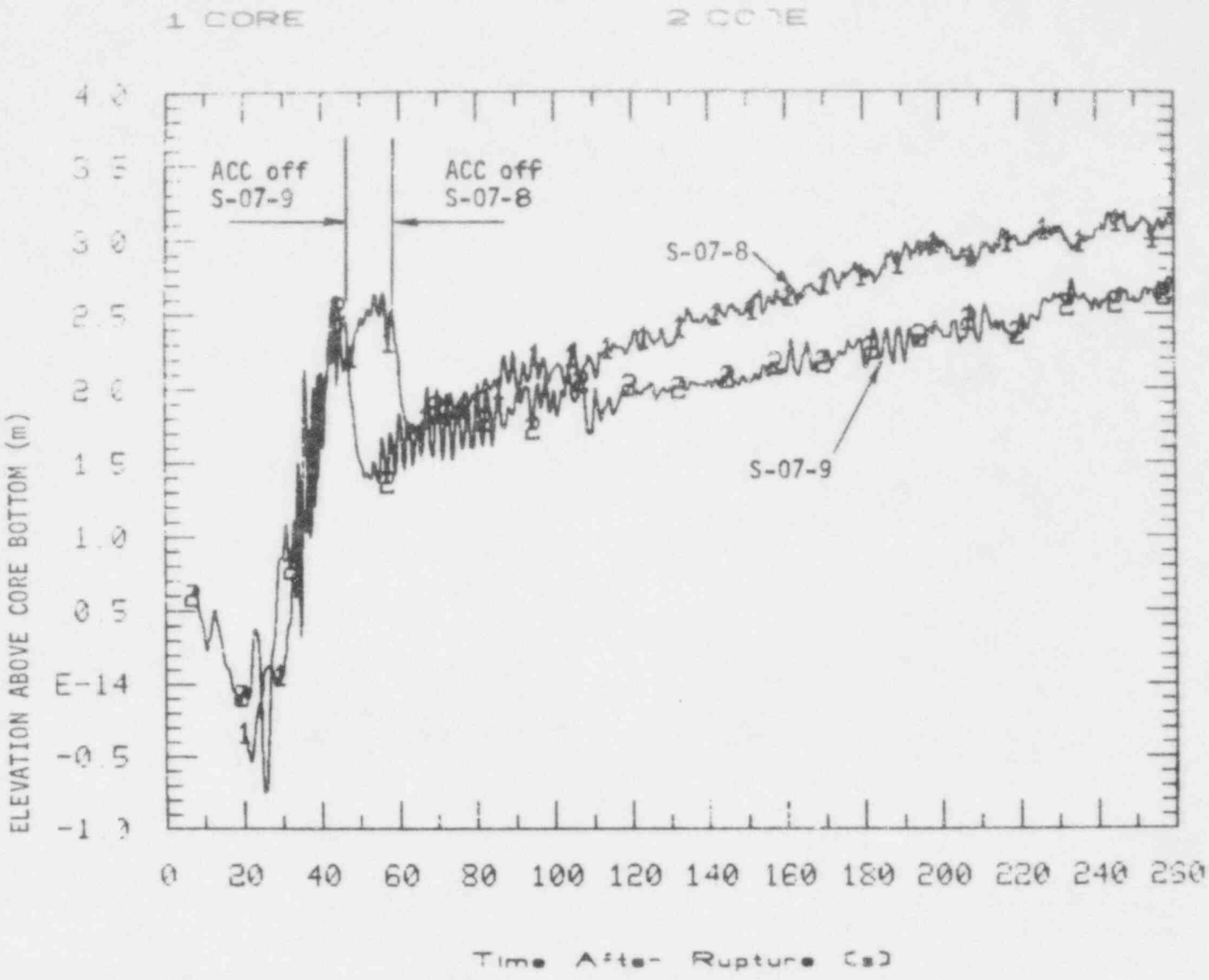

Fig. 18 Comparison of core collapsed liquid level for Tests S-07-8 and S-07-9.

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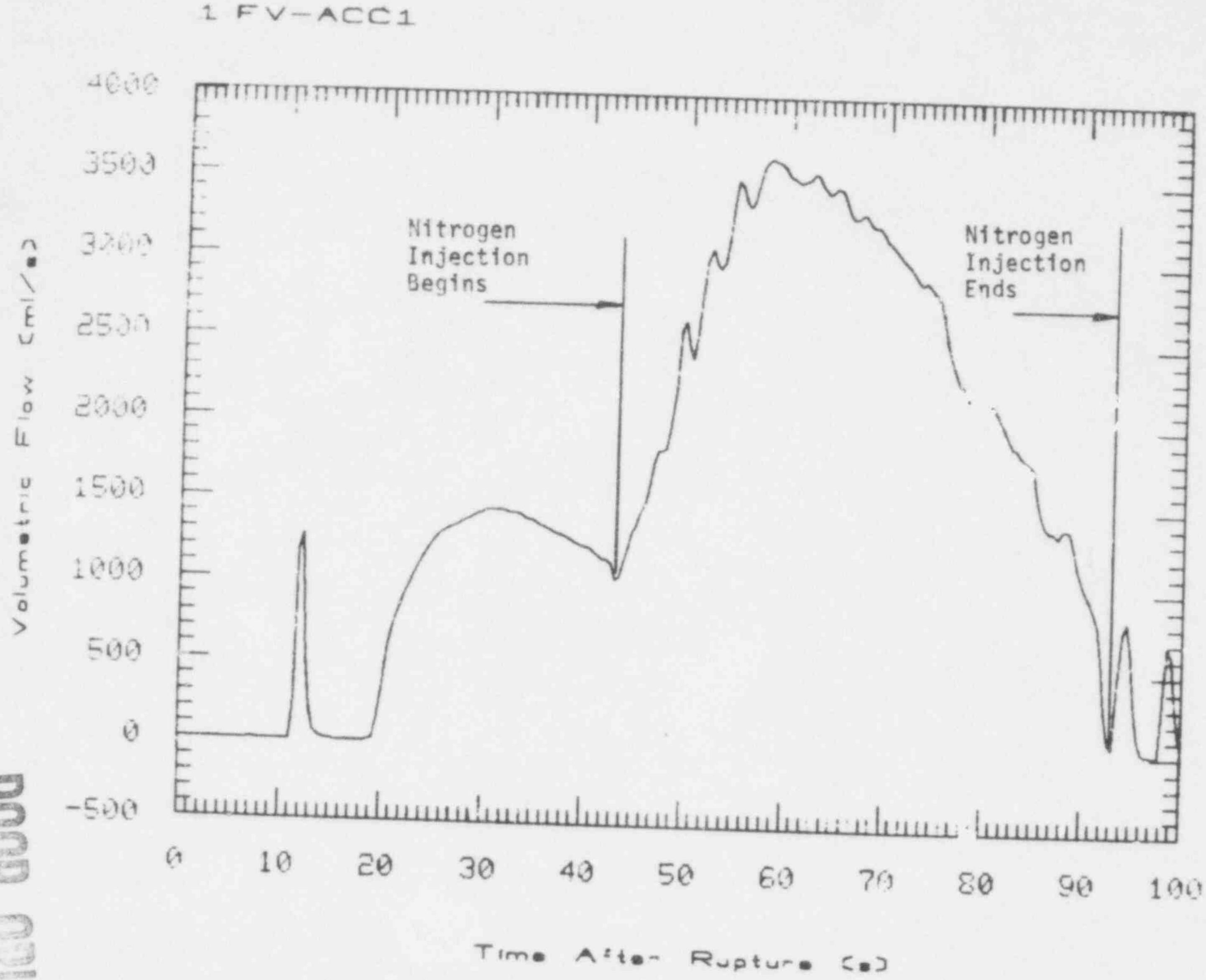

Fig. 19 Accumulator flow rate for Test S-07-1.

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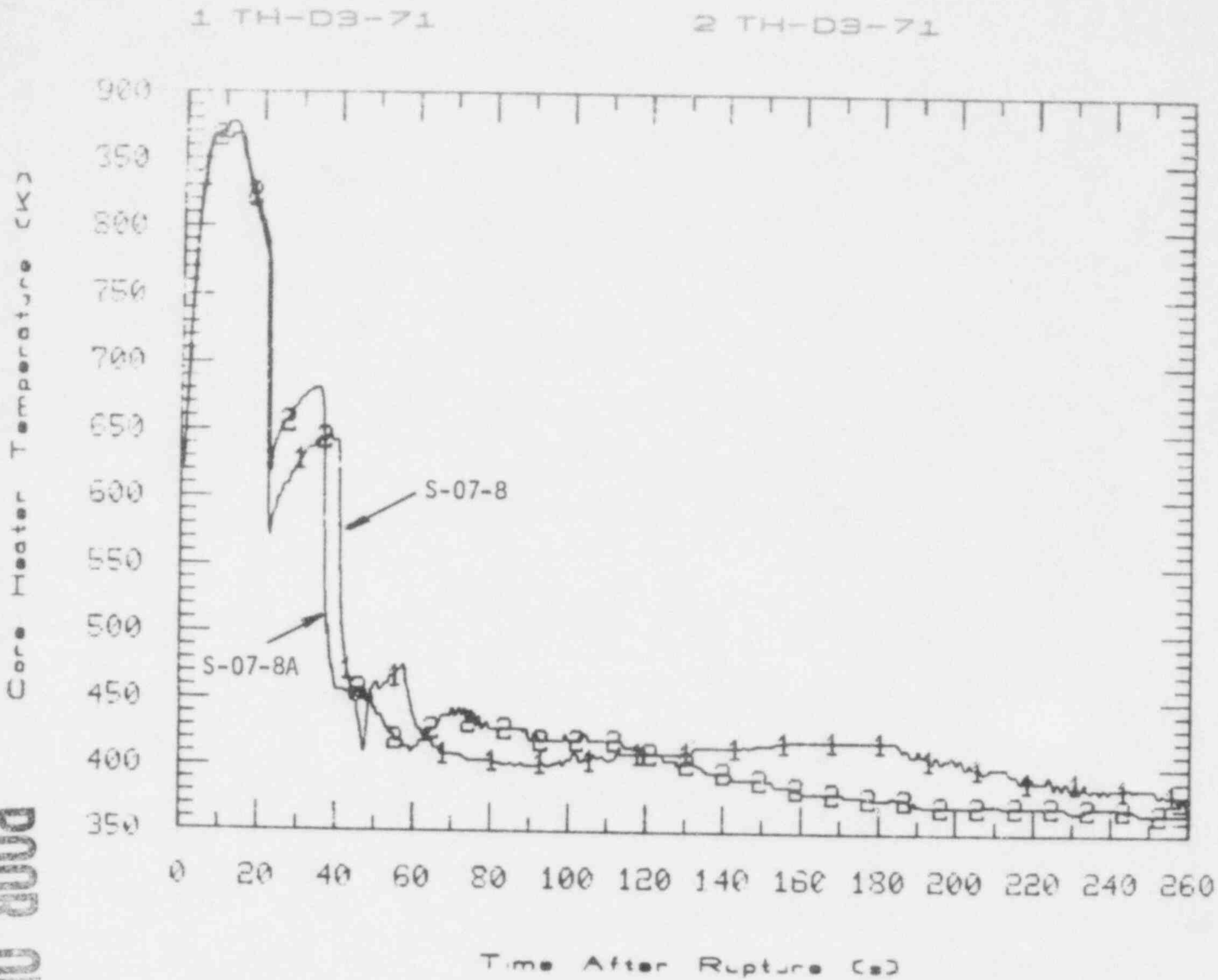

Fig. 20 Comparison of core thermal response at the 71-cm elevation for Tests S-07-8 and S-07-8A.

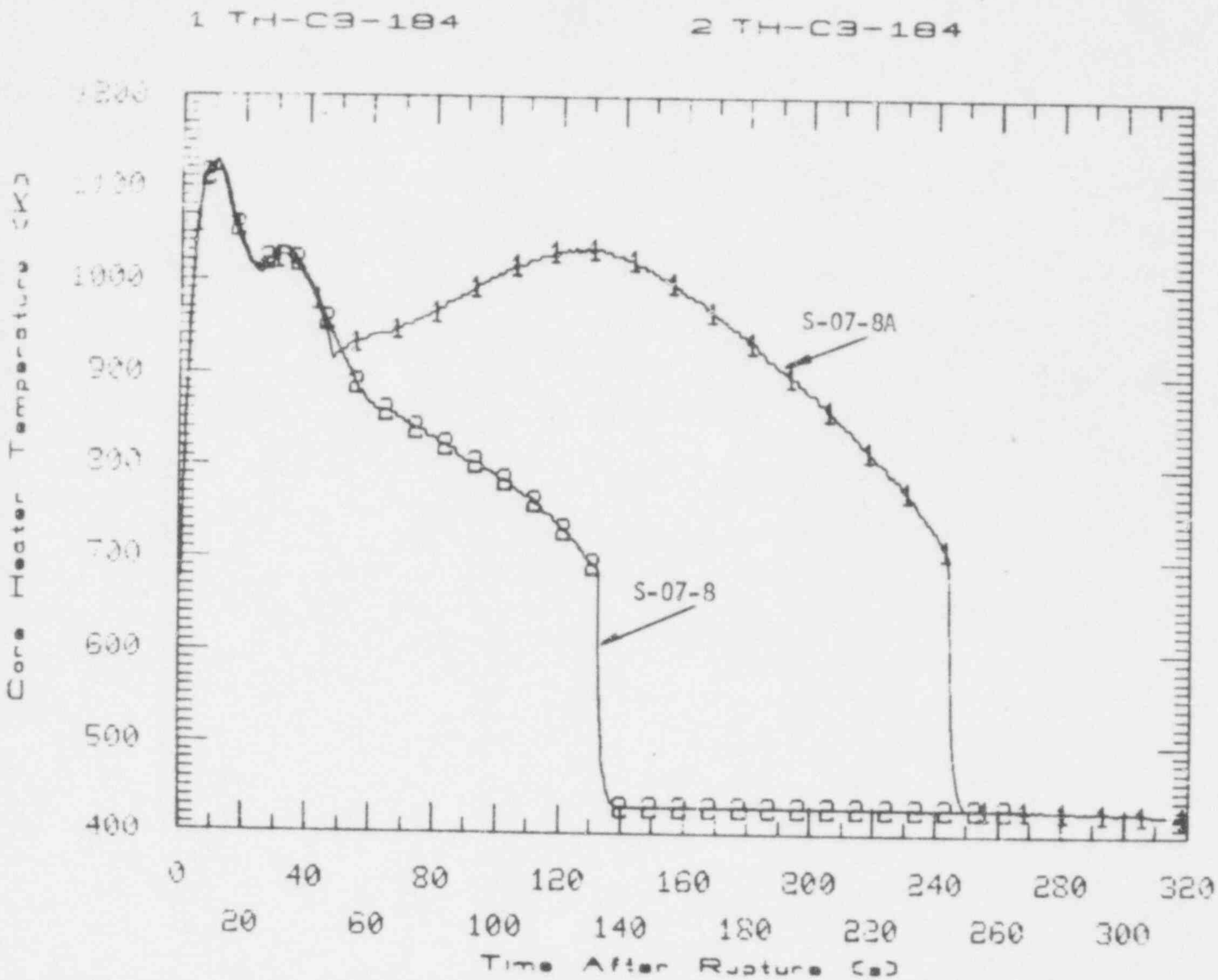

Fig. 21 Comparison of the core hot spot thermal response for Tests S-07-8 and S-07-8A.

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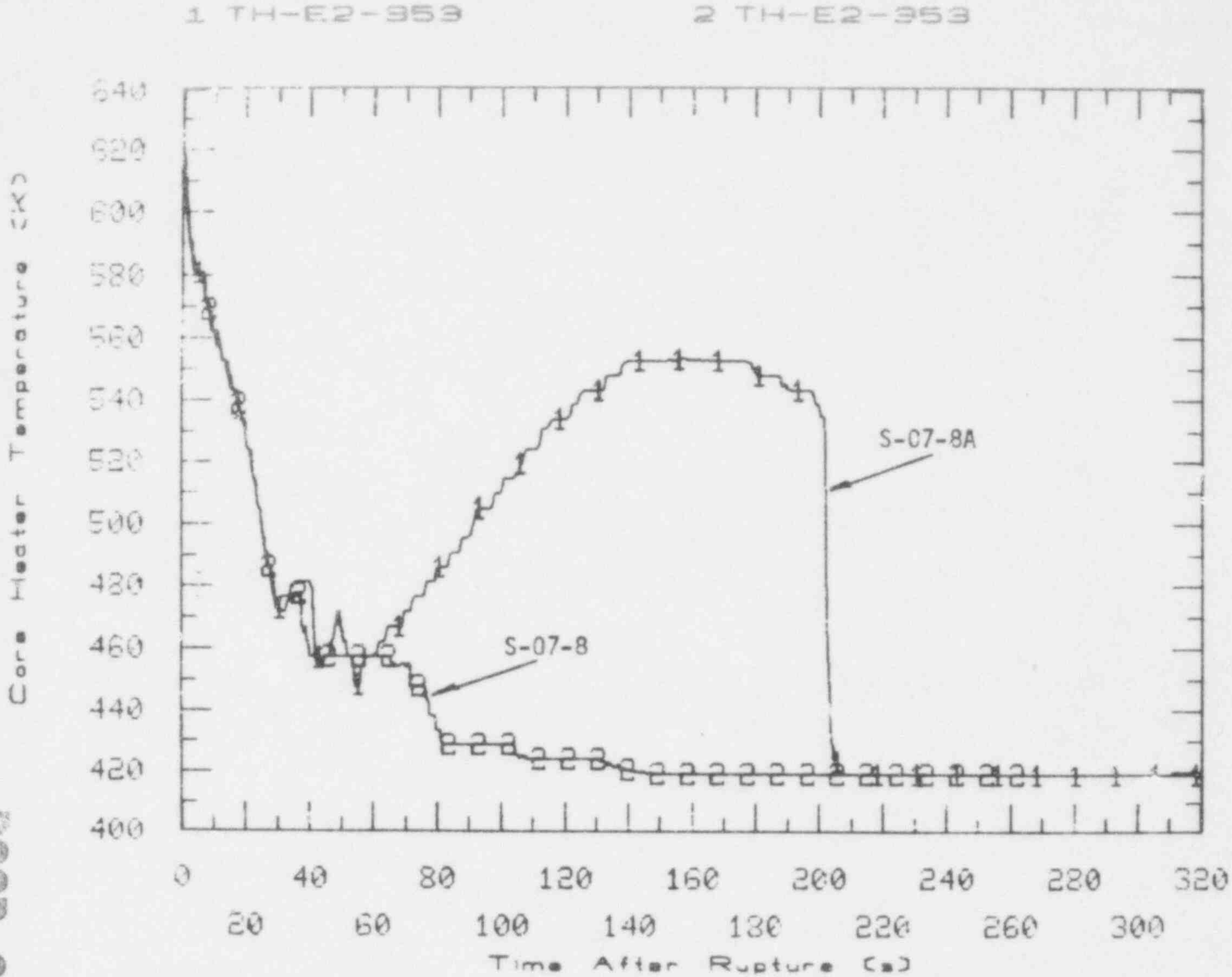

Fig. 22 Comparison of the thermal response high in the core for Tests S-07-8 and S-07-8A.

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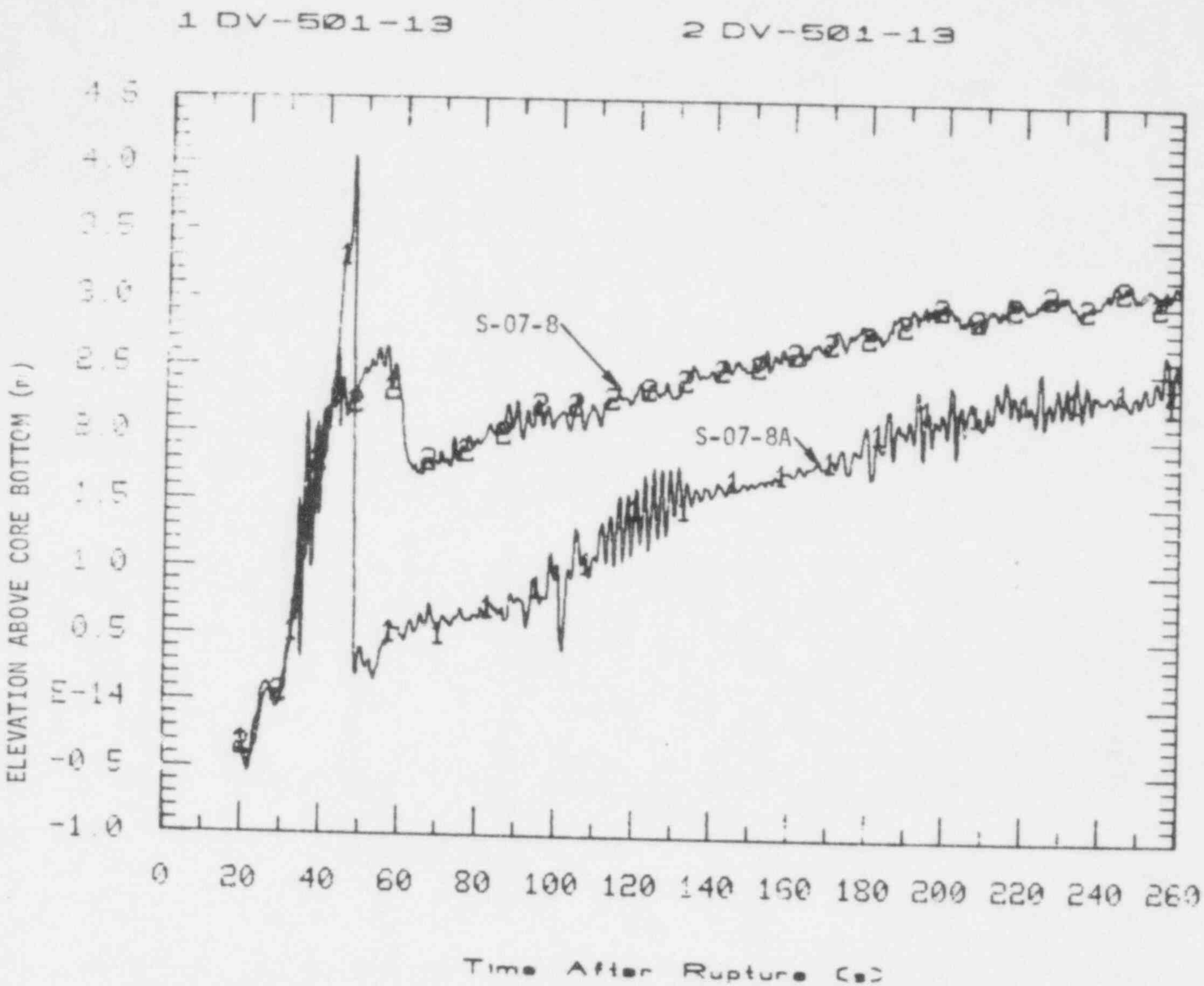

Fig. 23 Comparison of the core collapsed liquid level for Tests S-07-8 and S-07-8A.

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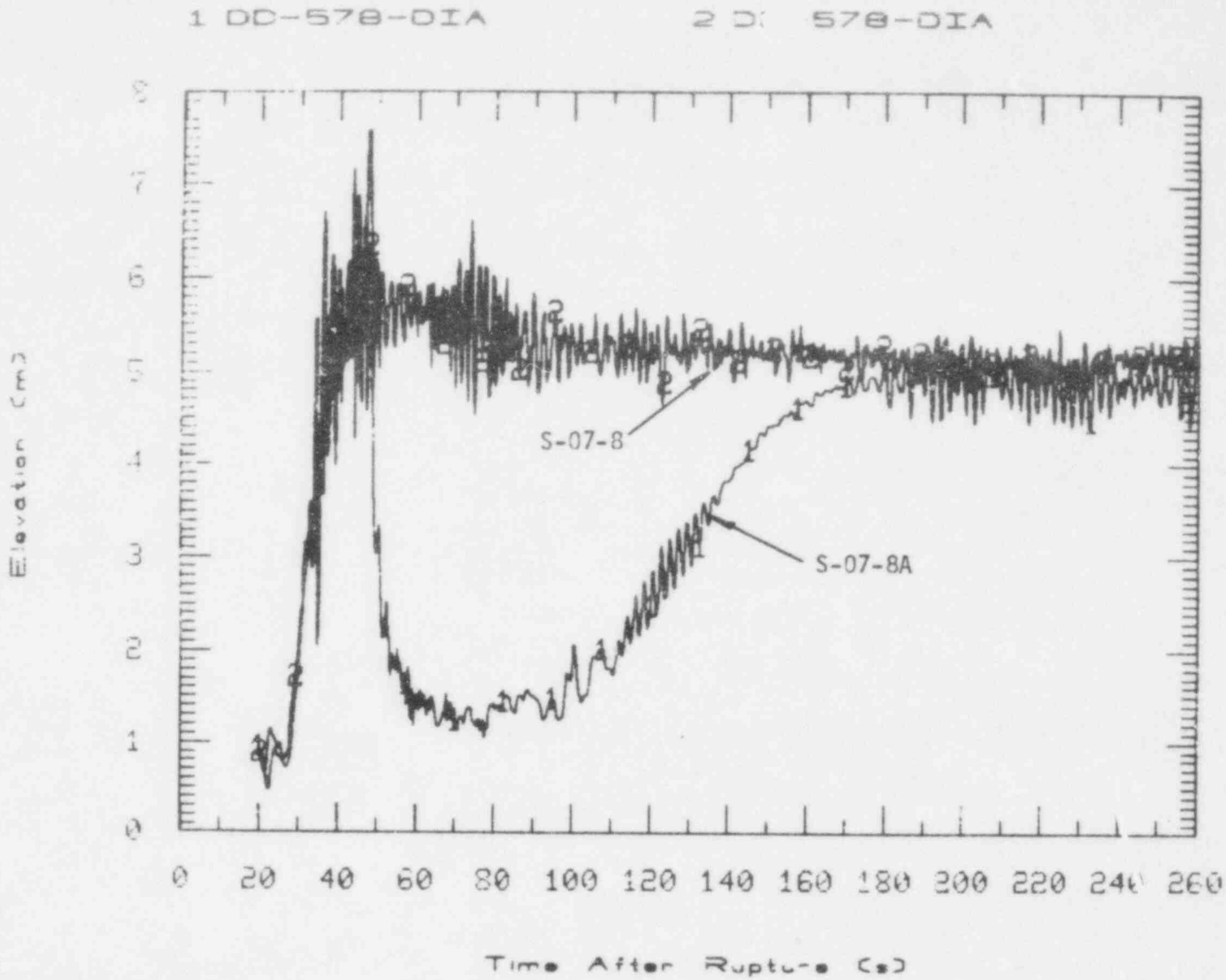

Fig. 24 Comparison of the downcomer collapsed liquid level for Tests S-07-8 and S-07-8A.

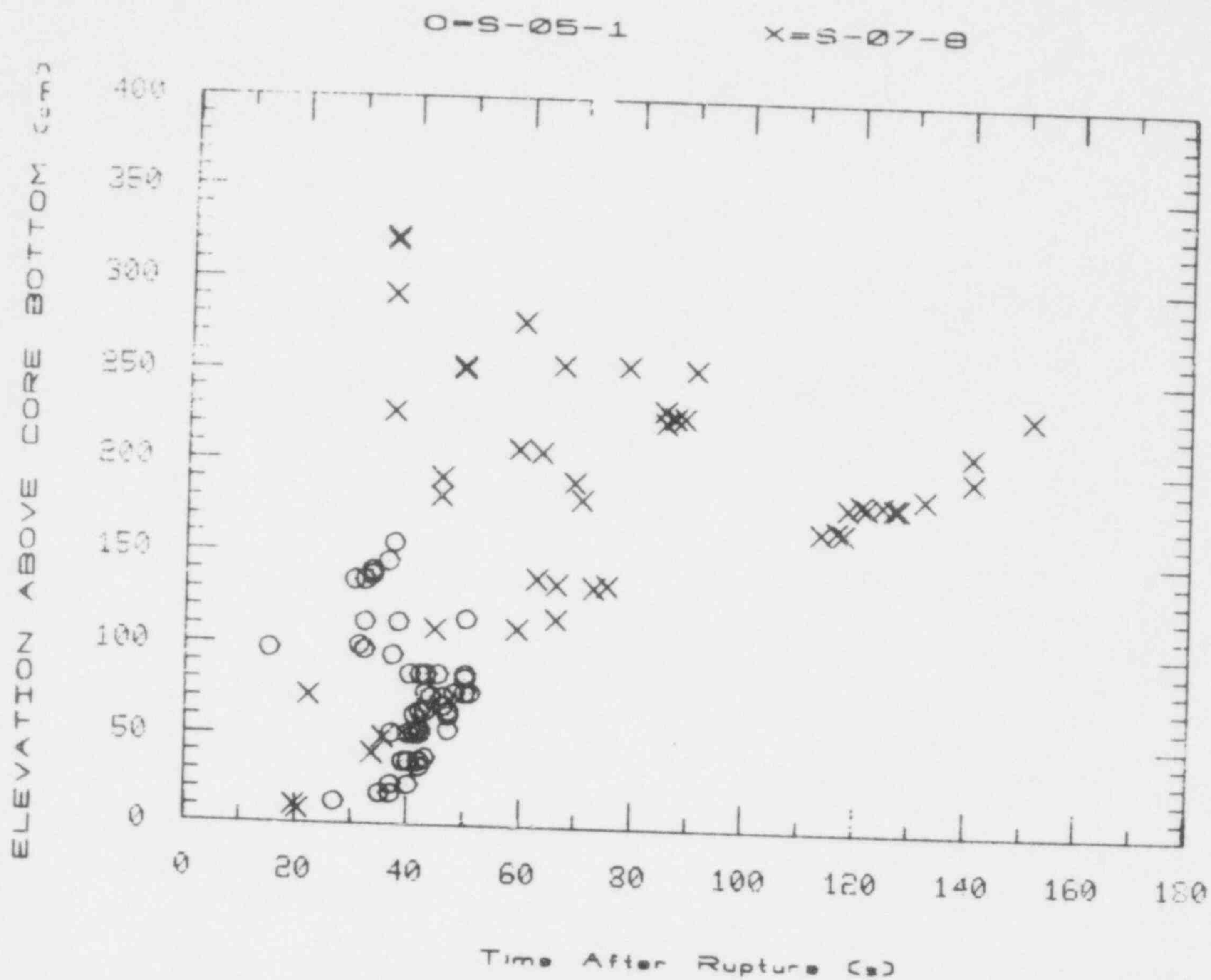

Fig. 25 Comparison of quench times for Mod-3 Test S-07-8 and Mod-1 Test S-05-1.

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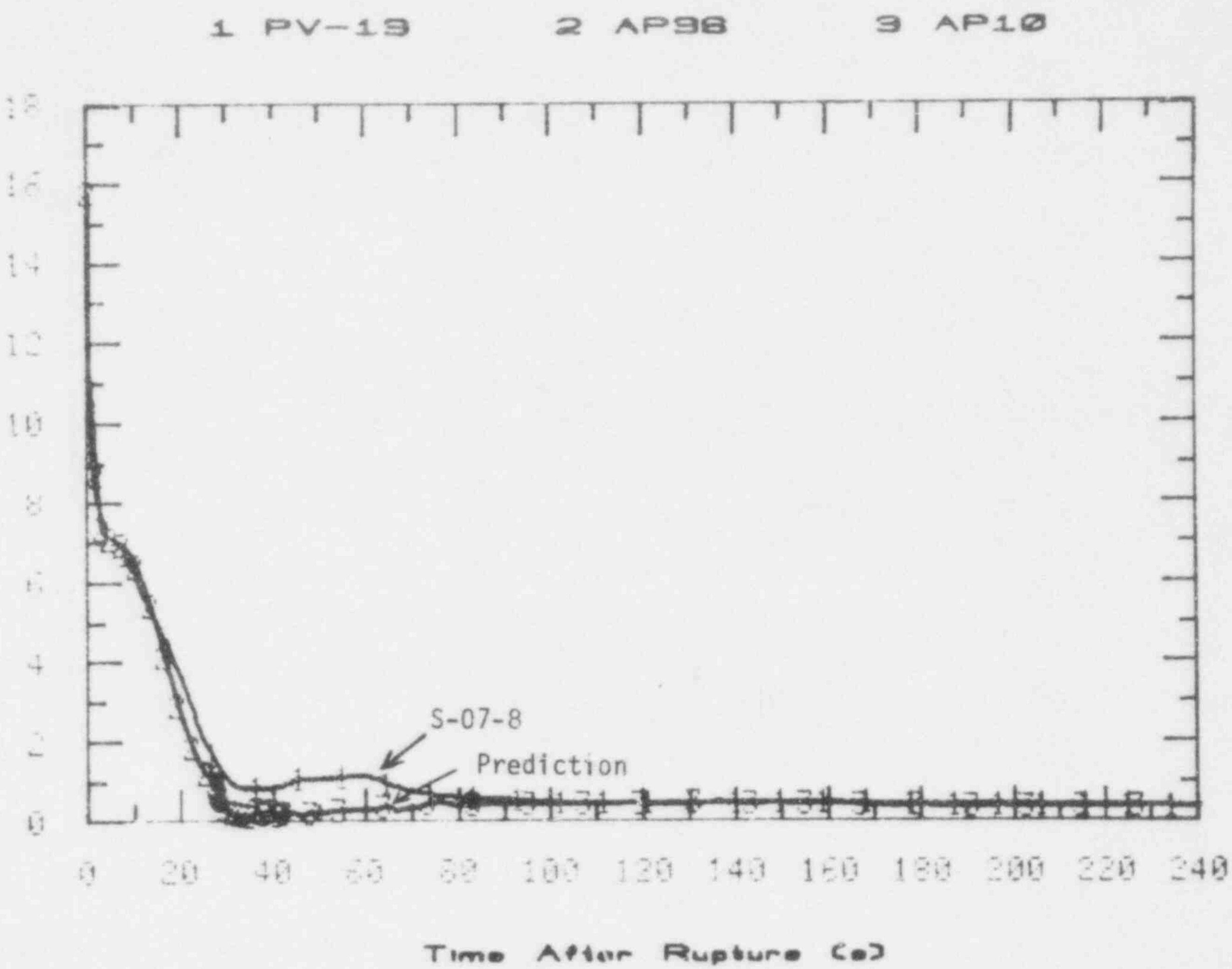

Fig. 26 Comparison of predicted system depressurization and data for Test S-07-8.

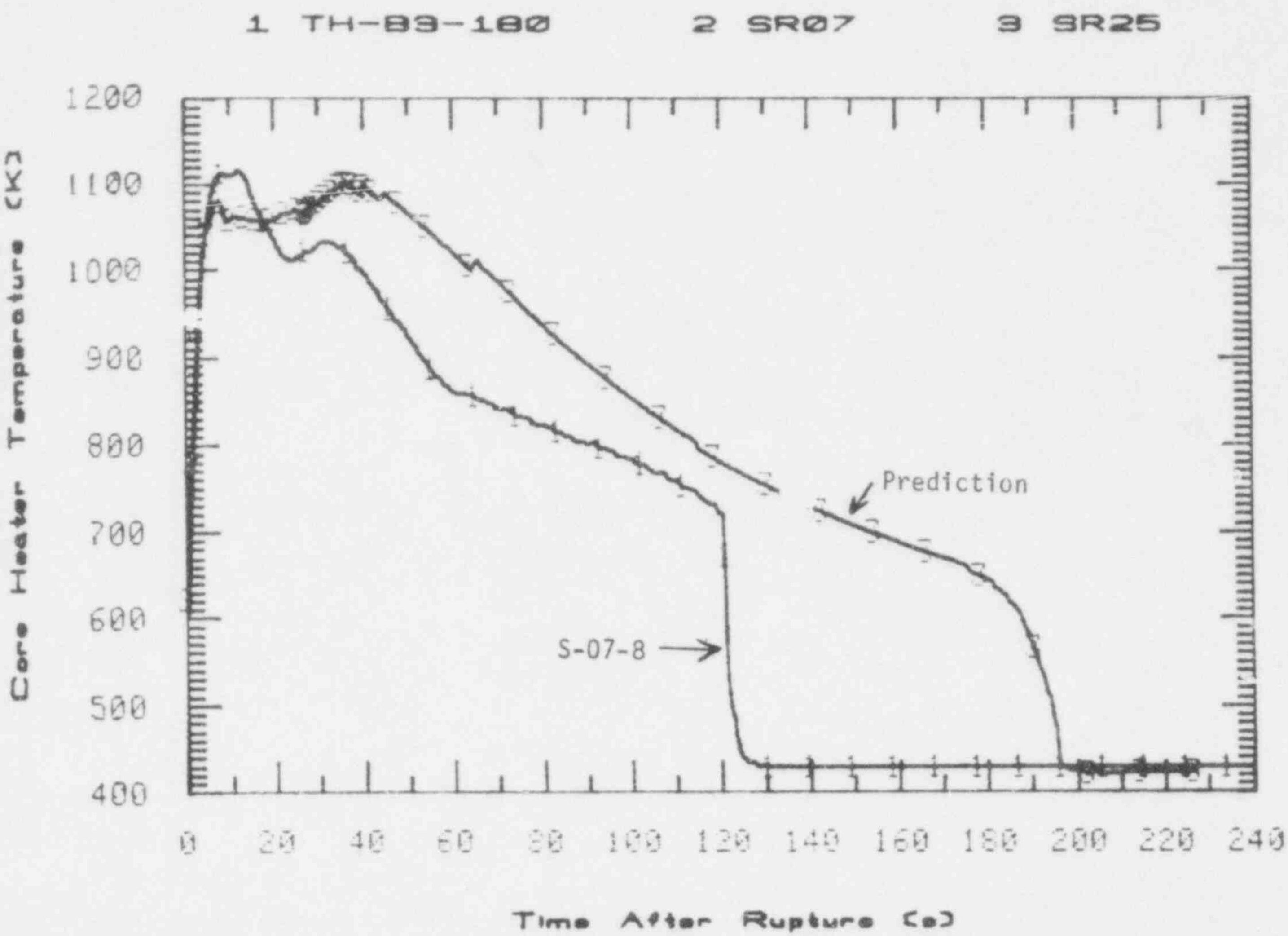

Fig. 27 Thermal response comparison of the pretest prediction and test data at the core hot spot for Test S-07-8.

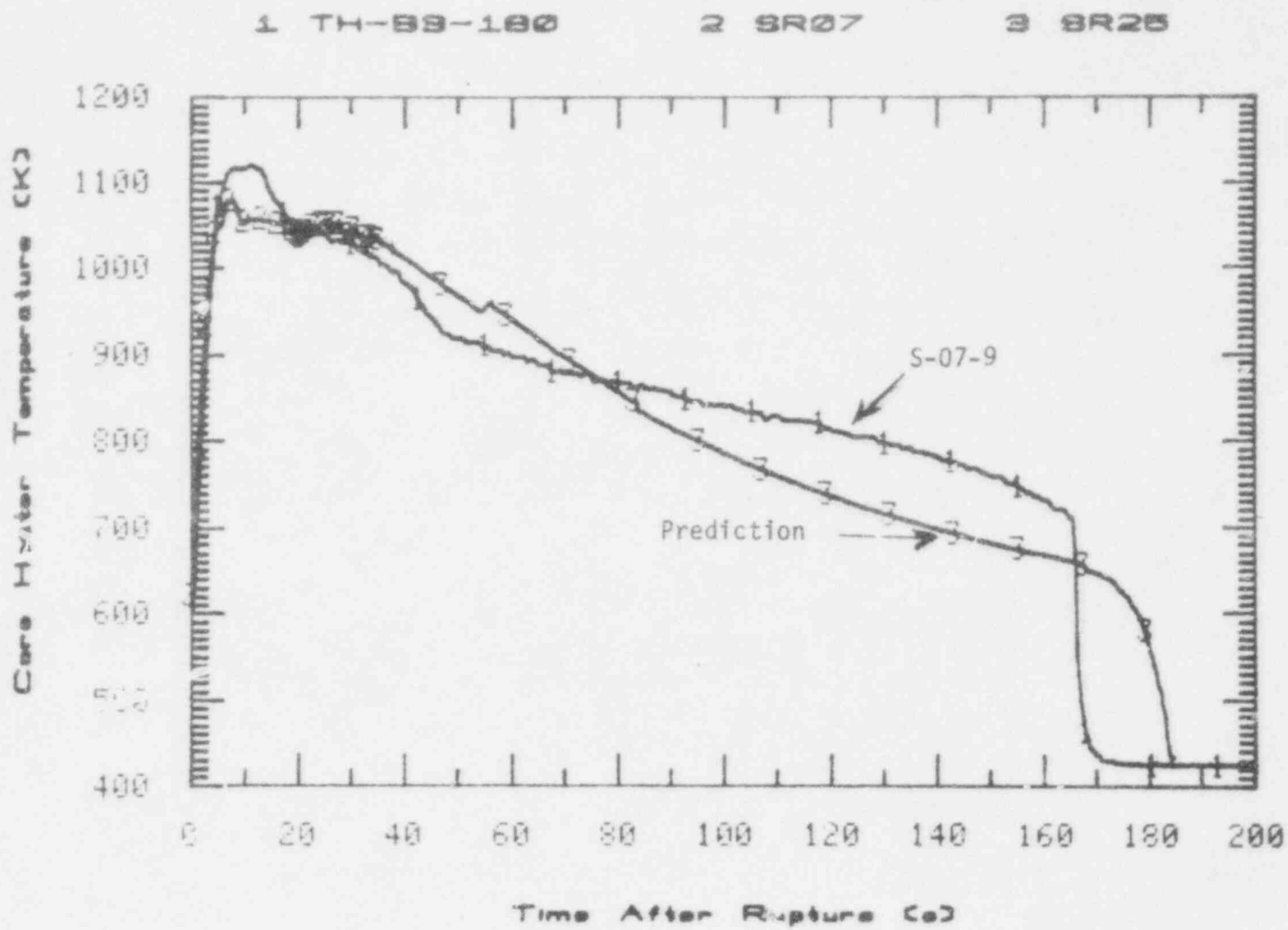

Fig. 28 Thermal response comparison of the pretest prediction and test data the core hot spot for Test S-07-9.