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Uranium and Sodium Oxide Aerosol Experiments: NSPP Tests 201-203 and Tests 301-302, Data Record Report

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SUMMARY

This data record report summarizes three uranium oxide aerosol behavior tests and two preliminary uranium oxide–sodium oxide mixed aerosol behavior tests in the Nuclear Safety Pilot Plant (NSPP) project, which is part of the Aerosol Release and Transport (ART) Program at Oak Ridge National Laboratory (ORNL), sponsored by the Nuclear Regulatory Commission Advanced Reactor Safety Research (NRC-ARSR). The uranium oxide aerosol tests constituted the initial shakedown runs to investigate the performance of an untried consumable-electrode aerosol generator. These also serve as low concentration level single-component U_3O_8 aerosol behavior tests. The objective of the mixed aerosol tests was to obtain a preliminary observation of the behavior of a mixture of the two aerosols. These data will be used along with future NSPP data to provide experimental validation to aerosol behavioral models also being developed by NRC-ARSR.

The three uranium oxide aerosol tests, in which the aerosol was produced by the dc-arc consumable-electrode generator, achieved maximum U_3O_8 aerosol concentrations ranging from 0.04 to 0.20 g/m^3. The two mixed-oxide aerosol tests, in which the uranium oxide aerosol was generated first and followed at a later time by a sodium pool fire, achieved uranium oxide:sodium oxide mass concentration levels of 0.1:3 and 0.5:2 g/m^3, respectively, at the time of mixing.

In this data record report, a brief description is given of each test, followed by test results in the form of tables and graphs. Included are data on aerosol mass concentration, aerosol fallout rate, aerosol plateout rate, cumulative mass fallout and plateout, aerosol particle size, vessel atmosphere pressure, vessel atmosphere temperatures, thermal gradients near the vessel wall, and final aerosol distribution at the termination of the test.

URANIUM AND SODIUM OXIDE AEROSOL EXPERIMENTS: NSPP TESTS 201–203 AND TESTS 301–302, DATA RECORD REPORT

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ABSTRACT

This data record report summarizes the first three uranium oxide aerosol tests and two preliminary mixed uranium oxide–sodium oxide aerosol tests conducted in the Nuclear Safety Pilot Plant project at Oak Ridge National Laboratory. The goal of the project is to establish the validity (or level of conservatism) of the aerosol behavioral code, HAARM-3, and follow-on codes under development at the Battelle Columbus Laboratories for the U.S. Nuclear Regulatory Commission. Included in the report are descriptions of the five tests, together with tables and graphs summarizi g the results.

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1. INTRODUCTION

The Nuclear Safety Pilot Plant (NSPP) Project is part of the Aerosol Release and Transport (ART) Program at Oak Ridge National Laboratory (ORNL), sponsored by the Nuclear Regulatory Commission Advanced Reactor Safety Research (NRC-ARSR). The NSPP project is studying the behavior in secondary containment environments of aerosols released under liquid-metal fast breeder reactor (LMFBR) accident conditions which involve mixtures of aerosols containing both fuel and sodium oxides, relatively high aerosol concentration, temperature and pressure transients due to sodium burning, possible presence of moisture in the secondary containment air atmosphere, and continuous as well as instantaneous sources.

The NSPP program presently focuses on establishing the validity (or level of conservatism) of the aerosol behavioral code, HAARM-3,[1] and follow-on codes under development for NRC at Battelle Columbus Laboratories (BCL). Special emphasis is placed on the applicability of the codes for describing the behavior of mixtures of aerosols and on the model features related to the effects of vessel size.

The test program provides for single-component aerosol tests using either sodium or uranium oxides (to simulate fuel oxide aerosols) followed by two-component aerosol tests where sodium and uranium oxides will be mixed in varying proportions and time sequences to study the interaction of the two individual aerosols as well as the composite behavior of the aerosol mixture. A previous report[2] covered the first five sodium oxide aerosol tests. This report covers the first three uranium oxide aerosol tests and two preliminary mixed-oxide aerosol tests where sodium oxide aerosols were mixed with an existing uranium oxide aerosol. Future reports in this series will cover single-component sodium oxide and uranium oxide aerosol tests conducted at higher aerosol concentrations and the two-component mixed aerosol tests.

2. NUCLEAR SAFETY PILOT PLANT (NSPP)

2.1 NSPP System

The NSPP is composed of a test vessel, aerosol generating equipment, analytical sampling and system parameter measuring equipment, and a water spray decontaminating system. A schematic representation of the system appears as Fig. 1. The NSPP vessel is a stainless steel cylinder with dished ends having an inside diameter of 3.05 m (10 ft), a total height of 5.49 m (18 ft), and a volume of 38.3 m^3 (1350 ft^3). The wall thickness of the vessel is 9.53 mm (0.375 in.). The floor area is 7.7 m^2 (82.9 ft^2), and the internal surface area (including top and floor) is 68.9 m^2 (741.6 ft^2). The design temperature limitation is 150°C (300°F), and the design pressure limitation is 0.414 MPa (60 psia).

2.1.1 Equipment for measurement of aerosol parameters

Aerosol mass concentration. Aerosol mass concentrations are obtained with two types of filter samplers. The in-vessel sampler is a self-contained unit with 12 filter tubes, a sequential valve, and a stepping motor; mechanical operation is remote from the control room. The other type, the wall aerosol sampler (named because the sampler penetrates the vessel wall through a ball valve and flange arrangement), is inserted and retrieved manually. The sampling procedure for either type of sampler requires drawing a measured volume of containment vessel atmosphere through a sampling pack that contains four membrane filters in series. The filter material is Millipore Fluoropore with a 0.5-μm pore size. The quantity of uranium on each filter paper and associated metal parts is determined by a fluorometric technique. In tests where sodium is present, the quantity of sodium is determined by atomic absorption spectroscopy.

The locations of the four in-vessel samplers and the three wall aerosol samplers are noted in Table 1.

Aerosol fallout rate. Aerosol fallout rate is measured with an incremental retrievable coupon sampler. This system also penetrates the

Table 1. Locations of aerosol mass concentration samplers

Sampler	Radial direction	Distance from bottom [m (ft)]	Radial distance from centerline [m (ft)]
In-vessel 151	East	4.15 (13.6)	0.58 (1.90)
In-vessel 152	East	4.15 (13.6)	1.06 (3.48)
In-vessel 153	East	2.80 (9.2)	1.09 (3.58)
In-vessel 154	East	1.34 (4.4)	1.11 (3.64)
Wall 155	South	4.15 (13.6)	0.61 (2.0)
Wall 156	Southeast	2.80 (9.2)	[a]
Wall 157	Southwest	2.80 (9.2)	1.06 (3.48)

[a] 25 mm (1 in.) from wall.

vessel wall through a ball valve and flange arrangement. The sampler is located in the southwest quadrant at 51 mm (2 in.) from the vessel wall and is ~0.56 m (1.83 ft) above the low point of the vessel floor.

Aerosol plateout rate. Aerosol plateout rate is measured with an incremental retrievable coupon sampler; the coupon is in the form of a disk and fits flush with the vessel wall. This system penetrates the vessel wall through a ball valve and flange arrangement and is located in the northeast quadrant ~2.92 m (9.6 ft) above the low point of the vessel floor.

Total fallout collectors. Total fallout is measured with six shallow dishes, 65 mm (2.56 in.) in diameter, placed along a vessel radius near the bottom of the vessel within the northwest quadrant. Each dish is placed ~30 mm (1.2 in.) apart; the edge of the first dish is 13 mm (0.5 in.) from the wall. The exposed collectors are retrieved with remote tools at the end of sampling operations and before liquid spray decontamination of the interior of the vessel.

Total plateout collectors. Total plateout is measured with three flat disks, 61 mm (2.38 in.) in diameter, mounted flat on the vessel wall. One disk is mounted on the east side of the vessel at an elevation of 0.76 m (2.5 ft) from the low point of the vessel bottom. Two disks are mounted on the west side of the vessel, 0.76 and 2.67 m (2.5 and 8.75 ft), respectively, from the bottom of the vessel. The exposed

disks and the total fallout collectors are also retrieved with remote tools.

Aerosol particle size. Aerodynamic particle size is measured with a cascade impactor (Andersen Mark III Particle Sizing Stack Sampler). This is an eight-stage impactor, operating at a gas flow of 2.36×10^{-4} m^3/sec (0.5 cfm), which covers the aerodynamic particle diameter of 0.54 to 13.6 μm. The sampling location is in the southwest quadrant at 0.457 m (1.5 ft) from the vessel wall and ~2.9 m (9.6 ft) from the low point of the vessel floor.

During the uranium oxide aerosol tests, samples are taken at the same location for electron microscopy. The aerosol is deposited onto carbon-coated copper grids using a Model 3100 Electrostatic Aerosol Sampler (Thermo-Systems, Inc.).

2.1.2 Equipment for measurement of system parameters

Temperature of the vessel atmosphere. Twelve Chromel-Alumel thermocouples are used for the measurement of the vessel atmospheric temperatures. At each of three elevations in the vessel, there are four thermocouples, one in each quadrant. The elevations are 1.22, 2.74, and 4.27 m (4, 9, and 14 ft). Thermocouple responses are recorded with strip-chart recorders and with a Digitrend data logger.

Wall temperature gradients. Two thermocouple arrays (rakes), each having five thermocouples, are mounted near the wall, one at a 2.7-m (9-ft) elevation on the east radius and the other at a 1.2-m (4-ft) elevation on the north radius. The thermocouples in each array are located at 10, 5, 2.5, and 1.25 mm (0.39, 0.2, 0.1, and 0.05 in.) from the wall and on the wall surface; a sixth thermocouple is located on the outer surface of the vessel at approximately the same location. Thermocouple responses are recorded with strip-chart recorders and with the Digitrend data logger.

Vessel gas pressure. Vessel gas pressure is measured with a pressure cell, and the pneumatic signal is converted to an equivalent electrical signal and recorded on a strip-chart recorder and with the Digitrend data logger.

2.1.3 Aerosol generating equipment

Uranium oxide aerosols. The uranium oxide aerosol is generated by consuming a uranium metal electrode in a dc arc. As the uranium metal vapor leaves the arc, it combines with the oxygen in the vessel atmosphere to become airborne U_3O_8 aerosol particles.

The system consists primarily of a fixed-position tungsten metal electrode, argon shield gas supply for the tungsten electrode, a movable holder containing the uranium electrode, a drive unit for moving the uranium electrode holder, a dc power supply, and a remote TV camera and monitor for viewing the two electrodes. A schematic of the primary system appears as Fig. 2.

The procedure for aerosol generation is as follows. The two electrodes are positioned a short distance apart by using the uranium electrode drive unit while viewing the electrodes with the remote TV camera. A light transmission filter is placed over the lens of the camera. The dc arc is then initiated and viewed on the TV monitor in the control room. As the tip of the uranium electrode is consumed, the electrode is moved upward to maintain the proper spacing for arc stability. Uranium vapor is moved from the vicinity of the arc by the argon shield gas flowing downward around the tungsten electrode. When the desired amount of the uranium electrode has been consumed, the dc arc is terminated; the argon gas flow is continued for a short time as the electrodes cool.

Sodium oxide aerosols. For the two mixed-oxide aerosol tests (301 and 302), the sodium oxide aerosol was generated by a sodium pool fire. The sodium inventory, contained in the sodium transfer tank, was heated to about 773 K (500°C) and then transferred to the heated sodium burn pan [0.50 m^2 (5.34 ft^2)] within the vessel where rapid oxidation of the heated liquid sodium produced the sodium oxide aerosol.

2.2 NSPP Test Procedures

2.2.1 Uranium oxide aerosol tests

Each of the uranium oxide aerosol tests has followed essentially the same procedure. Uranium oxide aerosol (U_3O_8) is produced with the dc-arc

consumable electrode generator, and the behavior of the aerosol within the containment vessel is monitored for 24 hr (test 201) or 48 hr (tests 202 and 203). At the conclusion of the test, the vessel interior is purged with dry filtered air, with all gases being discharged into the off-gas disposal stack. During this step, a gas sample is taken through a filter pack to determine the amount of uranium oxide contained in these gases. Next, the top flange of the vessel is opened and photographs are taken of the interior; the in-vessel samplers, the total fallout samplers, and the total plateout samplers are recovered before the flange cover is replaced. The interior surfaces of the vessel are then remotely decontaminated with a heated solution that is a mixture of oxalic acid, hydrogen peroxide, ammonium citrate, ammonium hydroxide, and water. The spray decontamination proceeds sequentially from the vessel floor to the walls and then to the top of the vessel. Each batch of decontamination solution and rinse water is weighed and sampled for analysis prior to disposal. From these data, a uranium material balance is obtained.

Aerosol parameters measured during the test are mass concentration, aerodynamic particle size, plateout, and fallout. System parameters measured are gas temperature, pressure, and thermal gradient at the vessel wall.

At the conclusion of these steps, all of the sampling devices (filter packs, impactors, coupons, etc.) are submitted to the analytical chemistry laboratory for uranium analysis by a fluorometric technique.

2.2.2 Mixed uranium oxide–sodium oxide aerosol tests

The two preliminary mixed-oxide aerosol tests followed the same procedure. The test plan was to generate the uranium oxide aerosol first, allow time for it to agglomerate, and then introduce sodium oxide aerosol and observe the behavior of the resulting mixed-oxide aerosol over the duration of the test. Aerosol and system parameters measured were the same as for the uranium oxide tests described in Sect. 2.2.1. One modification was made in the preparations for vessel decontamination: subsequent to the recovery of the in-vessel samplers and prior to initiation of the decontamination sprays, the vessel atmosphere was replaced with

nitrogen. This step was taken to reduce the oxygen concentration to less than 4% to ensure against an energetic hydrogen-oxygen recombination if unoxidized sodium metal remained in the sodium burn pan.

All of the aerosol sampling devices were disassembled, packaged, and again submitted for analysis. In samples where sodium oxide was present, the sodium content was determined by atomic absorption spectroscopy.

3. DESCRIPTION OF AEROSOL TESTS 201–203 AND 301–302

3.1 Uranium Oxide Test 201

The primary purpose of this experiment was to provide a full-scale operational performance of the uranium oxide aerosol generating system. The NSPP vessel atmosphere was dry air (initial relative humidity of around 8%), and the vessel pressure was ambient. A small resistance heater rod in the bottom of the vessel maintained convection currents to provide mixing of the aerosol.

Approximately 89 mm (3.5 in.) of the 25.4-mm-diam (1.0-in.) uranium electrode was removed by the arc over the 7-min duration of aerosol generation. The major portion of this material fell into the catch pan below the electrode as a fine granular black residue, which was identified as being predominately U_3O_8. Aerosol parameters measured were mass concentration, particle size, and fallout and plateout rates. The temperature and pressure rises within the vessel atmosphere were small and attributable to the heat generated by the resistance heater rod in the bottom of the vessel. The test duration was 24 hr.

3.2 Uranium Oxide Test 202

This second test of the series was similar to test 201, with the exception that the aerosol generator was operated at a higher dc-arc current in an attempt to increase the uranium oxide aerosol concentration. The vessel atmosphere was dry air (initial relative humidity of less than 3%), and the pressure was atmospheric. The test duration was extended to 48 hr.

Approximately 0.1 m (4 in.) of the uranium metal electrode was removed by the arc over 5 min of aerosol generation. Almost all of the uranium removed from the electrode appeared in the catch pan below the electrode as fine granular U_3O_8. The maximum uranium oxide aerosol concentration achieved was only 35% of that concentration noted in test 201.

3.3 Uranium Oxide Test 203

This was the third and last of the planned series to establish the performance characteristics of the consumable-electrode generator. The test differed slightly from tests 201 and 202 in that the dc-arc current and the argon shield gas flow rate were decreased in an effort to achieve a larger aerosol concentration within the vessel. The vessel contained relatively dry air (initial relative humidity of about 10%) at ambient temperature and pressure. The test duration was 24 hr.

Approximately 0.15 m (6 in.) of the uranium metal electrode was removed by the arc over 18.5 min of aerosol generation. As before, the major portion of the uranium fell into the catch pan as a granular residue of U_3O_8. An increase in aerosol concentration relative to test 201 was noted, but the level was still below the desired range.

3.4 Mixed Uranium Oxide–Sodium Oxide Test 301

This was the first of two preliminary mixed-oxide aerosol tests. The U_3O_8 aerosol was produced with the consumable-electrode aerosol generator, and the Na_2O was produced by a pool fire. The vessel atmosphere was dry air (initial relative humidity of ~7%), and the initial pressure and temperature were ambient. The test plan was to generate U_3O_8 aerosol first, allow time for it to agglomerate, and then generate Na_2O aerosol and observe the behavior of the resultant mixed-oxide aerosol. The U_3O_8 was generated over 19.5 min, with a maximum concentration achieved of about 0.3 g/m^3. At 103 min after the start of U_3O_8 aerosol generation, the Na_2O aerosol was generated by introducing 1 kg of heated sodium into the preheated burn pan. At the time of mixing, the U_3O_8 aerosol concentration was estimated to be 0.1 g/m^3, and the Na_2O aerosol concentration was about 3 g/m^3, producing an Na_2O:U_3O_8 mass ratio of 30:1. The behavior of the resultant mixed-oxide aerosol was monitored for an additional 46.3 hr. Over the first 100 min, the mass concentration of the U_3O_8 aerosol slowly decreased. At the time of Na_2O aerosol generation, the rate of removal of the U_3O_8 aerosol increased and was similar to that for the Na_2O aerosol. This behavior suggests that the two aerosols were coagglomerating.

3.5 Mixed Uranium Oxide–Sodium Oxide Test 302

This experiment was similar to that for test 301, but it was designed to produce an $Na_2O:U_3O_8$ mass ratio of 10:1 or less. The uranium oxide aerosol was produced with the consumable-electrode generator, and the sodium oxide was produced by a sodium pool fire. The vessel atmosphere was dry air (initial relative humidity of 4%), and the initial temperature and pressure were ambient. The U_3O_8 aerosol was generated over 44 min, with a maximum concentration achieved of about 1 g/m^3; at 93 min after start of U_3O_8 aerosol generation, the Na_2O aerosol was generated by introducing 0.5 kg of heated sodium into the preheated burn pan. At the time of mixing, the U_3O_8 aerosol concentration was about 0.5 g/m^3, and the Na_2O aerosol concentration was about 2 g/m^3, producing an $Na_2O:U_3O_8$ mass ratio of 4:1. The behavior of the resultant mixed-oxide aerosol was monitored for an additional 46.5 hr. The mass concentration of U_3O_8 aerosol slowly decreased over the first 93 min. At the time of Na_2O introduction, the rate of removal of U_3O_8 aerosol increased and became similar to that for the Na_2O aerosol. This behavior duplicates the behavior noted during test 301 and supports the observation that the two aerosols are coagglomerating.

4. RESULTS OF URANIUM OXIDE TESTS 201–203 AND MIXED-OXIDE TESTS 301–302

The results from each test are summarized in this section in the form of tables and graphs. At the beginning of each section, tabular material is presented list ng test parameters, parameters measured, and a summary of test results. Following this are graphs and tables report ing aerosol mass concentrations, fallout and plateout rates, aerosol particle size data, vessel pressure, vessel atmosphere temperature, and temperature gradients near the vessel wall as functions of time. Time is measured from the start of uranium oxide aerosol generation. To aid in interpreting these graphs, the following comments are offered.

Mass concentration. Results for all seven mass concentration filter samplers are presented in one graph for tests 201 through 203. Values of mass concentration are for U_3O_8 (and Na_2O in the case of tests 301 and 302) within the vessel atmosphere computed under vessel atmospheric conditions existing at the sample time. The legend on the graph lists the elevation and radial distance from centerline for all samplers. The radial direction of each sampler may be found in Table 1.

Aerosol fallout and plateout rates; cumulative values for fallout and plateout. The data reported in these graphs were obtained from the coupon samplers. An average fallout or plateout rate was computed from the mass of aerosol deposited on the coupon over the time interval of exposure. The sample time is taken as one-half the time interval of exposure added to the time at the start of the sample.

Values for cumulative mass fallout or plateout were computed by multiplying the fallout and plateout rates by the time of exposure of the coupon and the appropriate area within the vessel.

Aerosol particle size. The data presented are derived with an Andersen Mark III Particle Sizing Stack Sampler (cascade impactor). The raw data were processed to the extent necessary to produce the tables included in this report.

Vessel gas pressure rise. For all the tests included in this report, the vessel gas pressure was initially atmospheric (0 psig). During tests 201 through 203, a slight pressure rise was produced by the heating

of the vessel atmosphere from two sources: the dc arc of the generator and the resistance heater used to produce convection currents. During tests 301 and 302, additional heating of the vessel atmosphere occurred when the sodium pool fire was initiated. The graphs included depict vessel gas pressure as a function of time after start of uranium oxide aerosol generation. A graph for test 202 is not included because of failure of the data logging equipment; however, vessel gas pressure rise was very similar to that observed during tests 201 and 203.

Vessel gas temperatures. Three graphs are presented displaying the temperatures within each of the four quadrants at three elevations. The legend on each graph gives the elevation measured from the vessel midplane and the radial distance from the centerline of the vessel. An elevation of +1.5 m from midplane is 4.27 m (14 ft) from the bottom of the vessel, the elevation at midplane is 2.74 m (9 ft), and the elevation at -1.5 m is 1.22 m (4 ft) from the bottom of the vessel. Graphs for test 202 are not included because of failure of the data logging equipment; the temperatures observed were very similar to those in tests 201 and 203.

Temperature gradient at vessel wall. Two graphs are presented to illustrate the temperature gradients near the vessel wall on the north radius (-1.5 m from midplane of the vessel) and on the east radius at the centerline. Two thermocouples measure the temperature on the outside and inside vessel walls; four other thermocouples measure temperatures at varying distances from the inside wall.

Three additional graphs are also presented. Two of these graphs display the temperatures at various distances from the wall at selected values of time from start of aerosol generation. A third graph illustrates the magnitude of the temperature gradient (degrees centigrade per centimeter) at the two thermocouple rake locations as a function of time. For the same reason given earlier, no graphs are presented for test 202.

4.1 Summary and Data Graphs for Test 201

Aerosol source	
Test aerosol	U_3O_8
Aerosol generator	dc-arc consumable electrode
Duration of aerosol generation	7 min
Vessel atmosphere prior to aerosol generation	
Oxygen level	21%
Relative humidity	~8%
Temperature	Ambient
Pressure	Ambient
Duration of test	24 hr
Aerosol parameters measured and figure number	
Mass concentration of aerosol	Fig. 3
Aerosol fallout rate	Fig. 4
Aerosol plateout rate	Fig. 5
Cumulative mass fallout and plateout	Fig. 6
Aerosol particle size	Table 2
System parameters measured and figure number	
Vessel atmosphere pressure	Fig. 7
Vessel atmopshere temperatures	Figs. 8–10
Thermal gradients at vessel wall	Figs. 11–15
Posttest results	
Maximum aerosol concentration achieved	0.12 g/m^3
Uranium oxide aerosol distribution at end of test	
Still suspended in vessel atmosphere	7%
Plated onto internal surfaces	39%
Settled onto vessel floor	54%

Table 2. Andersen impactor data — test 201

Aerodynamic mass mean diameter (μm)	Sample No.[a]						
	1 (17 min)	2 (32 min)	3 (59 min)	4 (107 min)	5 (175 min)	6 (290 min)	7 (414 min)
13.7	99.3	99.7	99.5	99.3	98.7	98.0	98.0
8.5	99.0	99.5	99.0	98.7	97.5	96.9	96.6
5.8	98.5	99.0	97.8	97.9	95.0	95.3	93.3
4.0	97.8	97.8	94.6	94.1	85.8	90.9	85.0
2.5	95.5	90.9	85.4	87.1	65.8	73.4	62.2
1.3	85.1	71.9	60.4	57.2	45.0	47.8	34.4
0.78	66.4	50.3	34.3	26.3	21.8	20.1	14.7
0.53	35.5	18.2	9.1	5.2	2.9	4.5	2.2

[a] Percent smaller than indicated size.

4.2 Summary and Data Graphs for Test 202

Aerosol source	
Test aerosol	U_3O_8
Aerosol generator	dc-arc consumable electrode
Duration of aerosol generation	5 min
Vessel atmosphere prior to aerosol generation	
Oxygen level	21%
Relative humidity	<3%
Temperature	Ambient
Pressure	Ambient
Duration of test	48 hr
Aerosol parameters measured and figure number	
Mass concentration of aerosol	Fig. 16
Aerosol fallout rate	Fig. 17
Aerosol plateout rate	Fig. 18
Cumulative mass fallout and plateout	Fig. 19
Aerosol particle size	Table 3
System parameters measured and figure number	
Vessel atmosphere pressure	Not available
Vessel atmopshere temperatures	Not available
Thermal gradients at vessel wall	Not available
Posttest results	
Maximum aerosol concentration achieved	0.04 g/m^3
Uranium oxide aerosol distribution at end of test	
Still suspended in vessel atmosphere	6%
Plated onto internal surfaces	43%
Settled onto vessel floor	51%

Table 3. Andersen impactor data — test 202

Aerodynamic mass mean diameter (μm)	Sample No.[a]						
	1 (11 min)	2 (41 min)	3 (103 min)	4 (203 min)	5 (328 min)	6 (752 min)	7 (1475 min)
13.7	99.6	97.3	99.5	98.7	98.8	97.9	98.8
8.5	99.5	95.6	99.2	98.1	98.1	96.6	97.9
5.8	99.1	94.6	98.6	97.2	97.3	95.5	97.0
4.0	98.8	93.6	97.8	96.6	96.0	93.2	95.5
2.5	97.8	92.3	94.3	81.0	64.3	61.3	66.3
1.3	95.9	90.9	75.4	61.3	43.1	36.7	42.8
0.78	88.1	88.4	47.9	36.7	20.3	18.7	23.5
0.53	70.5	83.6	17.4	12.2	6.3	5.1	5.8

[a]Percent smaller than indicated size.

4.3 Summary and Data Graphs for Test 203

Aerosol source	
Test aerosol	U_3O_8
Aerosol generator	dc-arc consumable electrode
Duration of aerosol generation	18.5 min
Vessel atmosphere prior to aerosol generation	
Oxygen level	21%
Relative humidity	~10%
Temperature	Ambient
Pressure	Ambient
Duration of test	48 hr
Aerosol parameters measured and figure number	
Mass concentration of aerosol	Fig. 20
Aerosol fallout rate	Fig. 21
Aerosol plateout rate	Fig. 22
Cumulative mass fallout and plateout	Fig. 23
Aerosol particle size	Table 4
System parameters measured and figure number	
Vessel atmosphere pressure	Fig. 24
Vessel atmosphere temperatures	Figs. 25–27
Thermal gradients at vessel wall	Figs. 28–32
Posttest results	
Maximum aerosol concentration achieved	0.20 g/m^3
Uranium oxide aerosol distribution at end of test	
Still suspended in vessel atmosphere	0.7%
Plated onto internal surfaces	17.7%
Settled onto vessel floor	81.6%

Table 4. Andersen impactor data — test 203

Aerodynamic mass mean diameter (μm)	Sample No.[a]						
	1 (28 min)	2 (54 min)	3 (118 min)	4 (221 min)	5 (335 min)	6 (585 min)	7 (1487 min)
13.7	99.6	97.9	91.7	91.5	96.0	95.7	98.9
8.5	99.2	96.8	86.9	88.0	94.5	94.9	98.5
5.8	98.7	95.0	69.8	75.4	91.0	93.4	97.6
4.0	97.2	86.6	52.7	61.5	82.0	88.7	94.7
2.5	93.6	68.9	35.0	43.3	66.8	73.5	88.8
1.3	70.0	34.3	16.9	26.8	43.5	53.5	73.2
0.78	36.7	17.1	7.7	12.7	21.9	26.1	40.9
0.53	15.6	5.9	2.4	3.8	8.1	7.6	7.2

[a]Percent smaller than indicated size.

4.4 Summary and Data Graphs for Test 301

Aerosol source	
Test aerosols	U_3O_8 and Na_2O
Aerosol generators	dc-arc consumable electrode and sodium pool fire
Duration of U_3O_8 aerosol generation	19.5 min
Time of initiation of sodium pool fire	103 min
Mass of sodium introduced	1.0 kg (2.2 lb)
Vessel atmosphere prior to aerosol generation	
Oxygen level	21%
Relative humidity	7%
Temperature	Ambient
Pressure	Ambient
Duration of test	48 hr
Aerosol parameters measured and figure number	
Mass concentration of aerosol	Fig. 33
Aerosol fallout rate	Figs. 34–35
Aerosol plateout rate	Figs. 34–35
Cumulative mass fallout and plateout	Figs. 36–37
Aerosol particle size	Table 5
System parameters measured and figure number	
Vessel atmosphere pressure	Fig. 38
Vessel atmopshere temperatures	Figs. 39–41
Thermal gradients at vessel wall	Figs. 42–46
Posttest results	
Maximum aerosol concentration achieved	0.3 g/m^3 U_3O_8 and 3 g/m^3 Na_2O
Mass ratio at time of mixing of the aerosols	30:1 (Na_2O:U_3O_8)
Mixed-oxide aerosol distribution at end of test	
Still suspended in vessel atmosphere	<0.03%
Plated onto internal surfaces	29.8%
Settled onto vessel floor	70.2%

Table 5. Andersen impactor data — test 301

Aerodynamic mass mean diameter (μm)	Sample No.[a]						
	1 (49 min)	2 (150 min)	3 (259 min)	4 (420 min)	5 (585 min)	6 (1468 min)	7 (2906 min)
13.7	86.4	86.0	91.4	96.8	97.7	96.6	98.9
8.5	81.1	80.6	89.6	96.1	96.8	95.3	98.6
5.8	66.8	56.6	76.4	92.2	95.3	95.2	98.4
4.0	47.3	34.0	57.8	84.4	90.6	95.0	98.2
2.5	30.6	19.5	34.3	62.0	71.6	94.2	98.0
1.3	13.6	10.9	20.2	40.7	53.9	84.8	96.4
0.78	3.9	8.8	18.3	37.3	49.2	76.1	92.9
0.53	1.3	6.0	17.9	36.3	47.7	73.1	91.4

[a]Percent smaller than indicated size.

4.5 Summary and Data Graphs for Test 302

Aerosol source	
Test aerosols	U_3O_8 and Na_2O
Aerosol generators	dc-arc consumable electrode and sodium pool fire
Duration of U_3O_8 aerosol generation	44 min
Time of initiation of sodium pool fire	93 min
Mass of sodium introduced	0.5 kg (1.1 lb)
Vessel atmosphere prior to aerosol generation	
Oxygen level	21%
Relative humidity	4%
Temperature	Ambient
Pressure	Ambient
Duration of test	48 hr
Aerosol parameters measured and figure number	
Mass concentration of aerosol	Fig. 47
Aerosol fallout rate	Figs. 48–49
Aerosol plateout rate	Figs. 48–49
Cumulative mass fallout and plateout	Figs. 50–51
Aerosol particle size	Table 6
System parameters measured and figure number	
Vessel atmosphere pressure	Fig. 52
Vessel atmopshere temperatures	Figs. 53–55
Thermal gradients at vessel wall	Figs. 56–60
Posttest results	
Maximum aerosol concentration achieved	1.0 g/m^3 U_3O_8 and 2.0 g/m^3 Na_2O
Mass ratio at time of mixing of the aerosols	4:1 (Na_2O:U_3O_8)
Mixed-oxide aerosol distribution at end of test	
Still suspended in vessel atmosphere	<0.02%
Plated onto internal surfaces	49.1%
Settled onto vessel floor	50.9%

Table 6. Andersen impactor data — test 302

Aerodynamic mass mean diameter (μm)	Sample No.[a]						
	1 (62 min)	2 (140 min)	3 (252 min)	4 (415 min)	5 (572 min)	6 (1460 min)	7 (2903 min)
13.7	97.2	88.2	95.6	97.7	96.5	98.3	94.0
8.5	94.6	80.8	93.0	96.9	95.6	97.6	92.4
5.8	88.1	71.3	86.1	94.0	93.7	97.0	91.2
4.0	75.4	58.1	73.3	88.0	91.2	96.4	90.3
2.5	56.9	45.4	54.8	75.0	83.7	95.3	89.5
1.3	40.0	24.6	30.2	50.9	64.3	85.2	86.7
0.78	14.8	13.3	21.6	41.1	56.5	77.3	82.7
0.53	1.5	11.1	19.4	39.8	53.1	75.6	81.3

[a]Percent smaller than indicated size.

REFERENCES

1. J. A. Gieseke, K. W. Lee, and L. D. Reed, *HAARM-3 User's Manual*, BMI-NUREG-1991 (January 1978).

2. R. E. Adams, T. S. Kress, and L. F. Parsly, Jr., *Sodium Oxide Aerosol Study: NSPP Runs 101–105, Data Record Report*, ORNL/NUREG/TM-179 (April 1978).

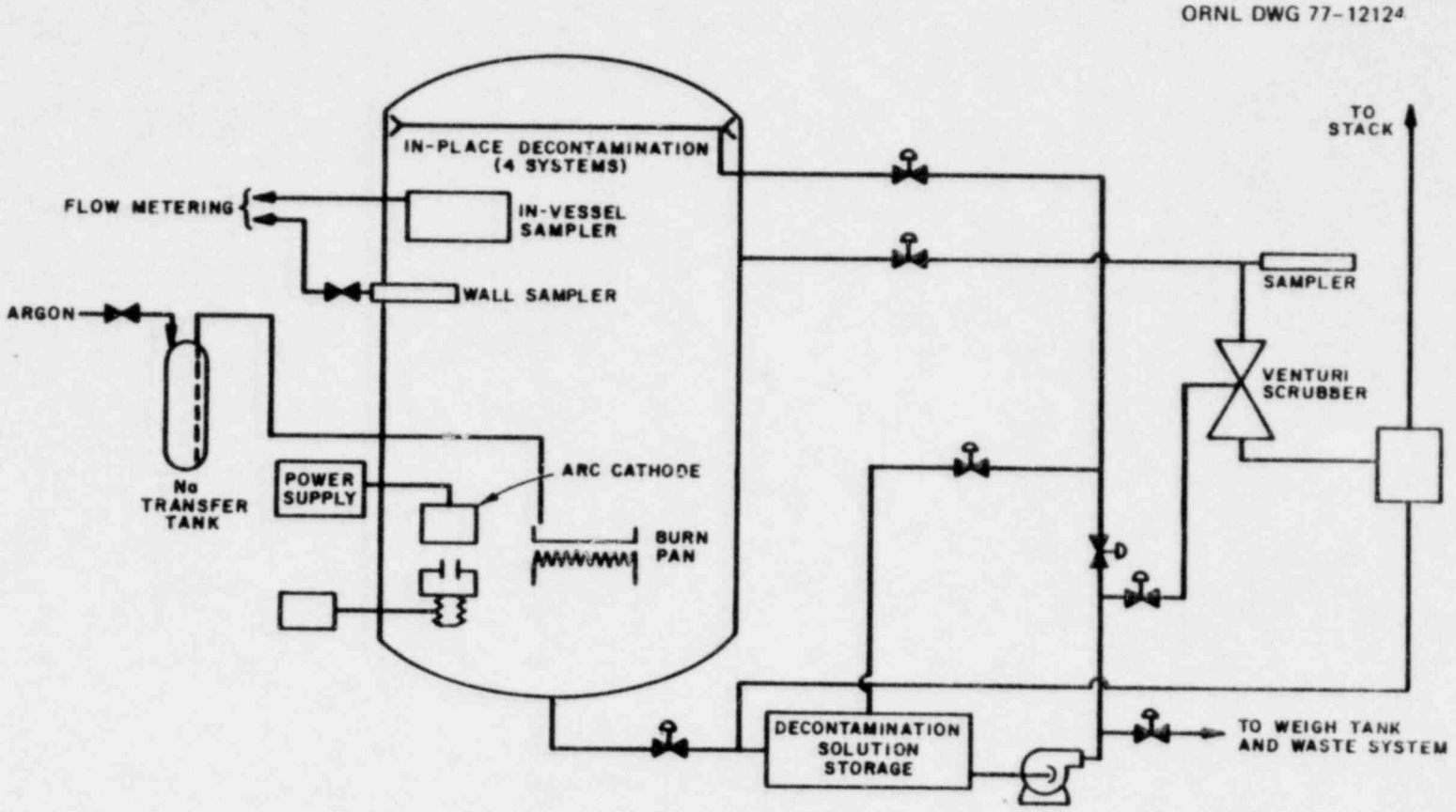

Fig. 1. Nuclear Safety Pilot Plant (NSPP) flow sheet.

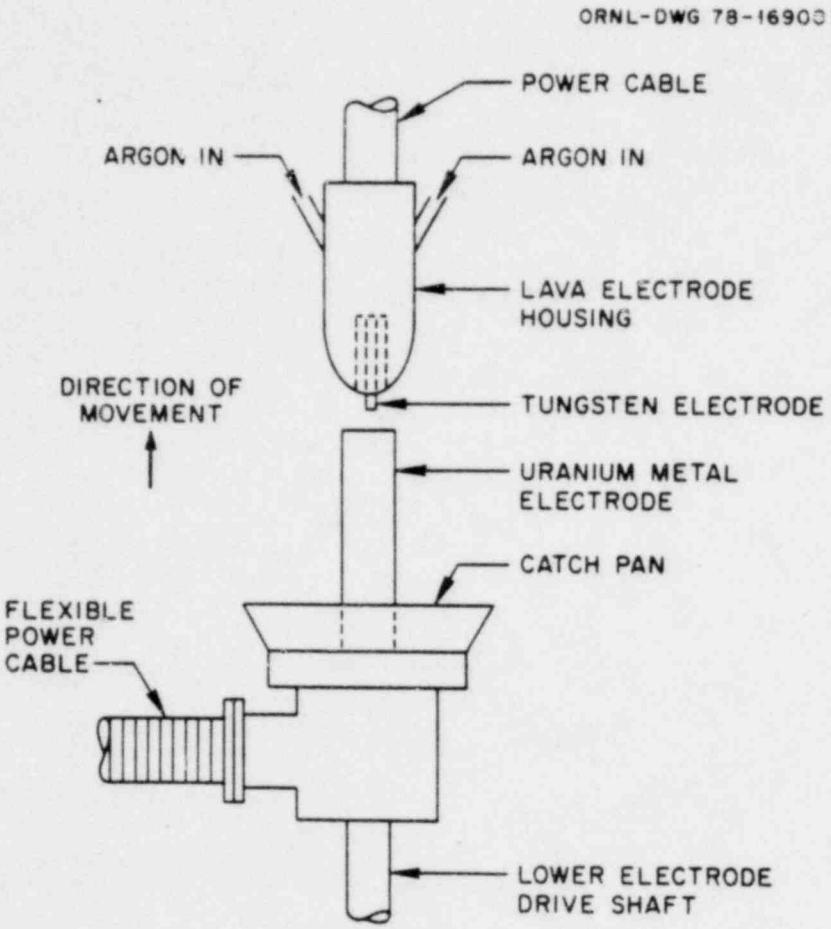

Fig. 2. dc-arc uranium oxide aerosol generating system.

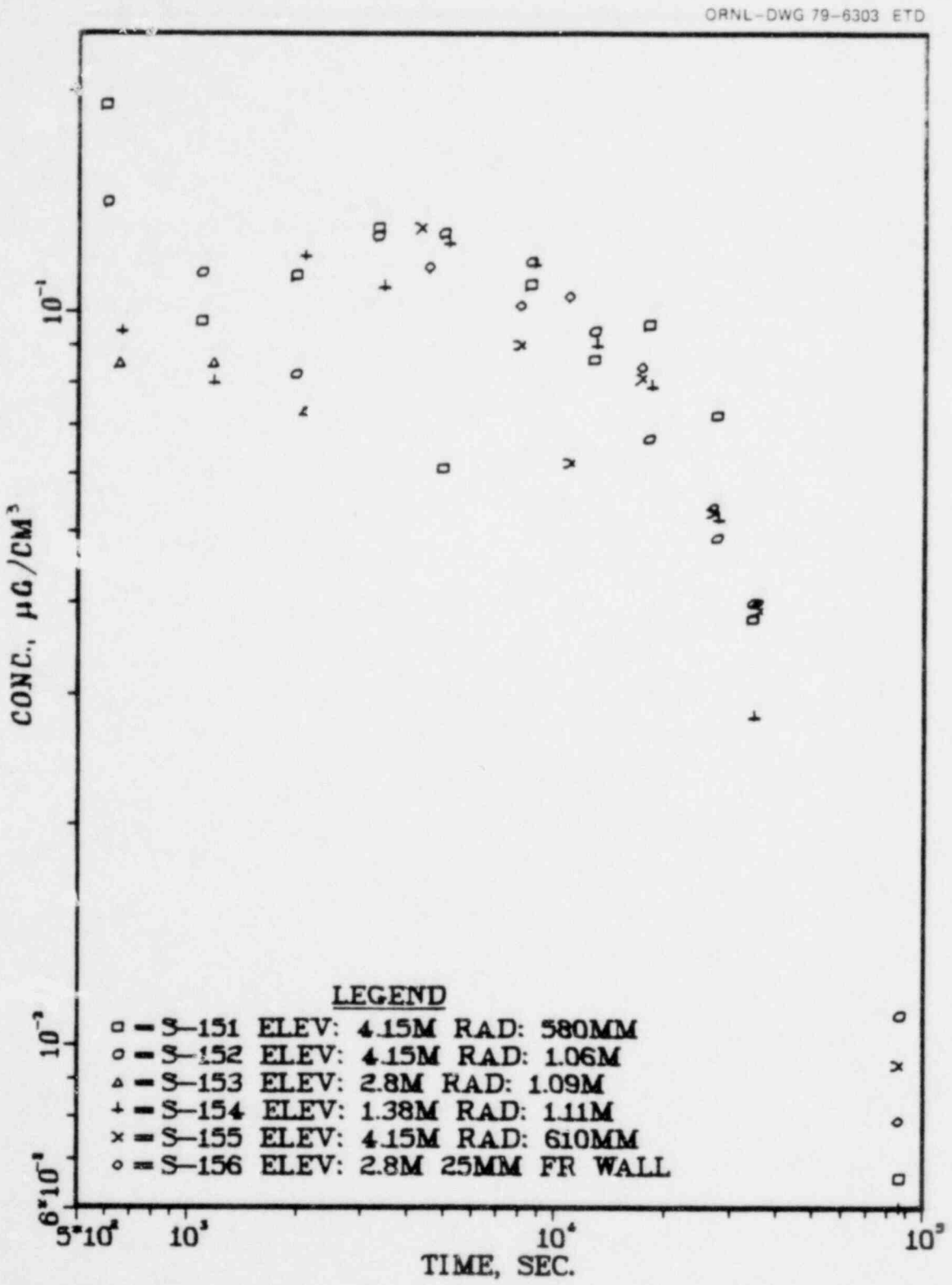

Fig. 3. Aerosol mass concentrations (measured with six samplers) vs time for NSPP test 201.

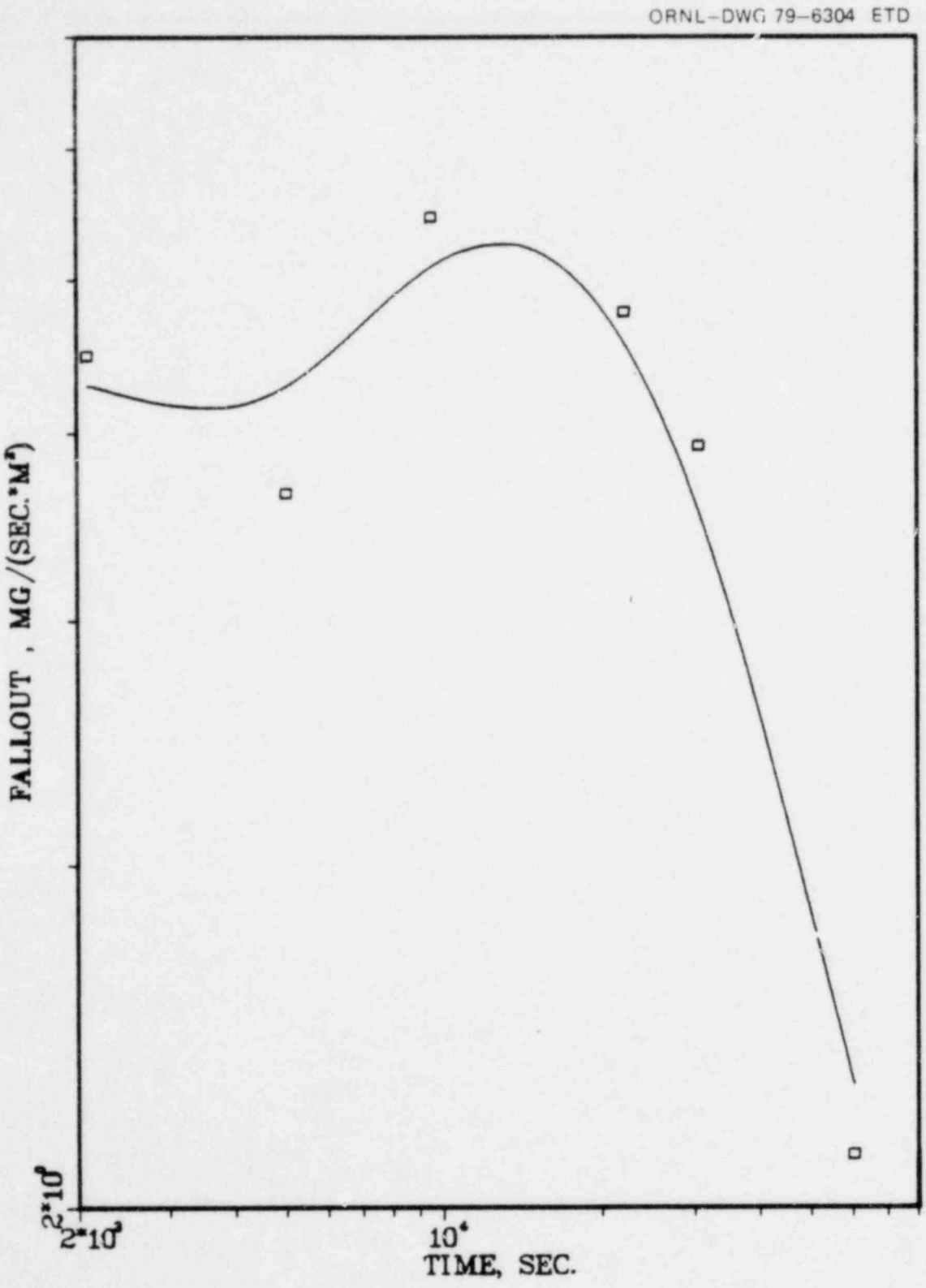

Fig. 4. Fallout rate vs time for NSPP test 201.

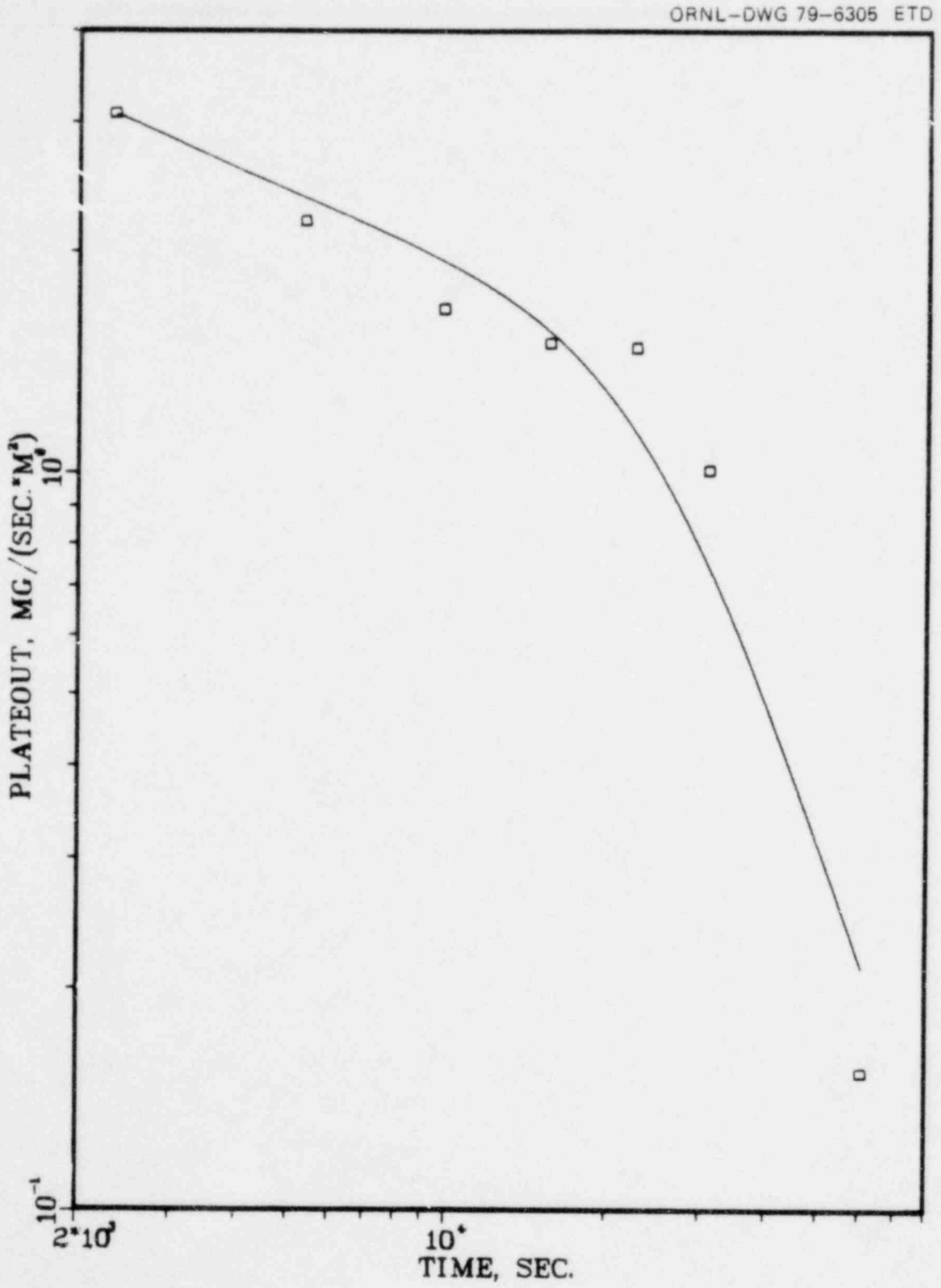

Fig. 5. Plateout rate vs time for NSPP test 201.

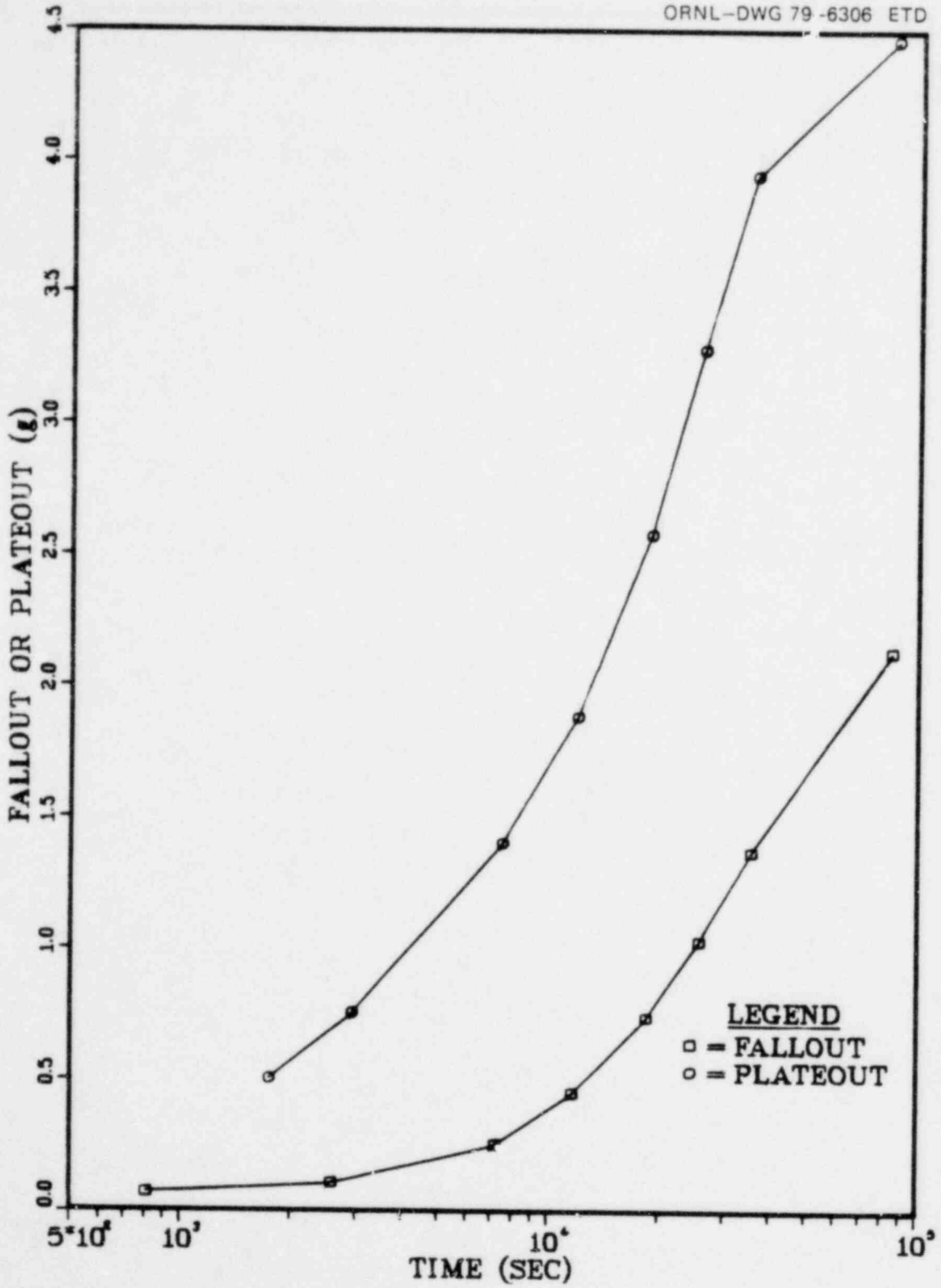

Fig. 6. Cumulative fallout and plateout vs time for NSPP test 201.

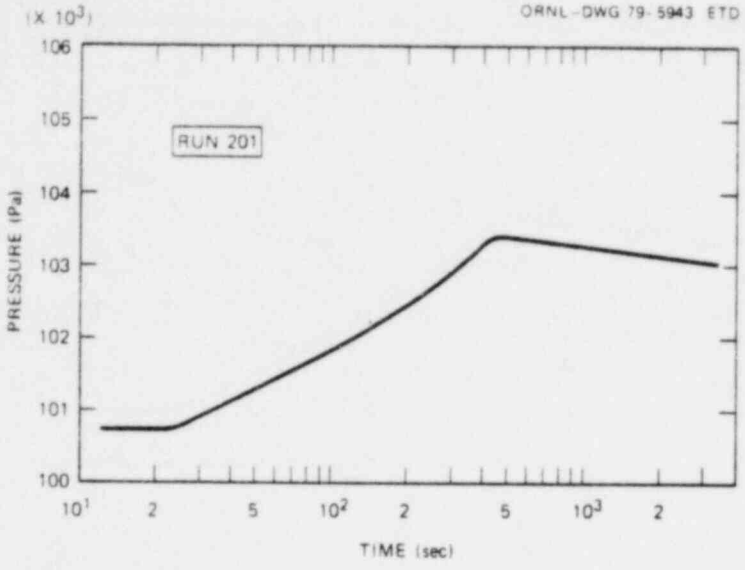

Fig. 7. In-vessel pressure vs time for NSPP test 201.

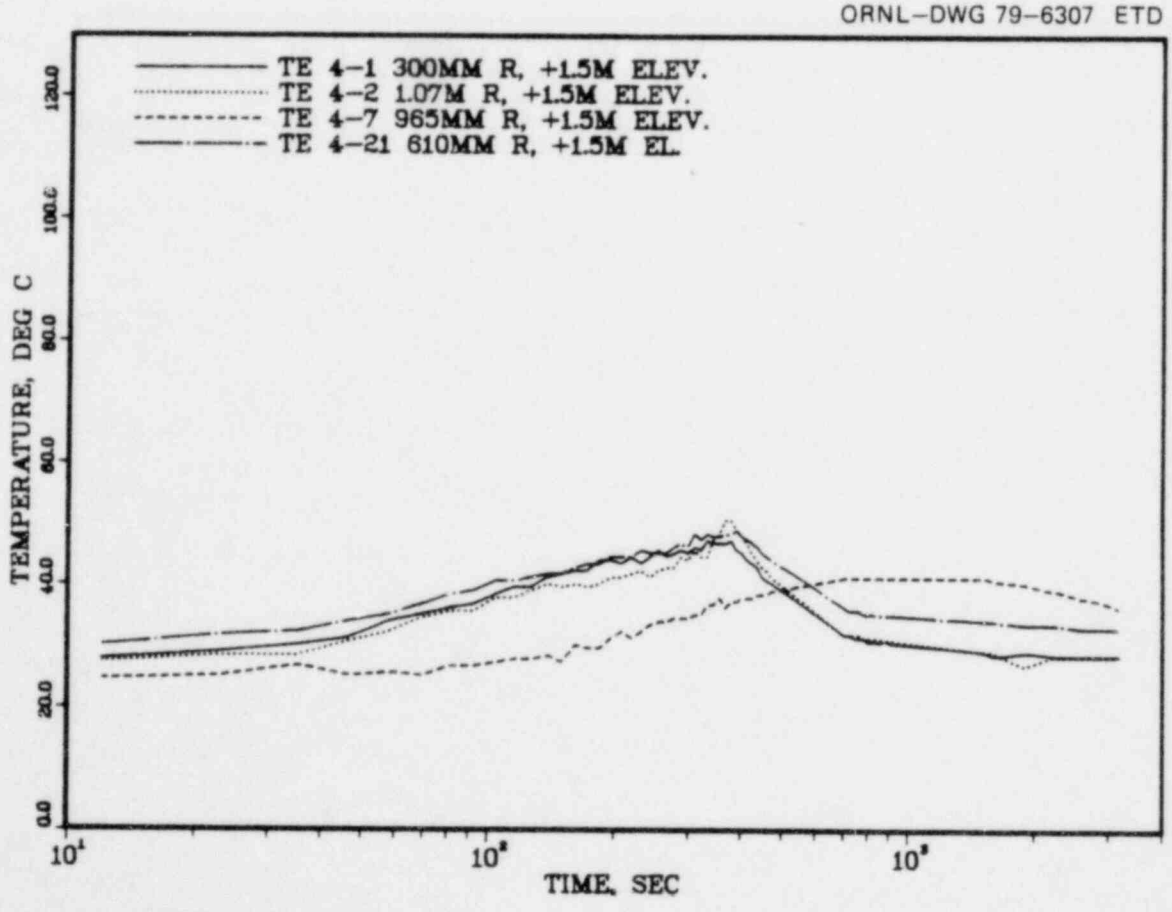

Fig. 8. Temperature measurements at 1.5 m above the vessel midplane for NSPP test 201.

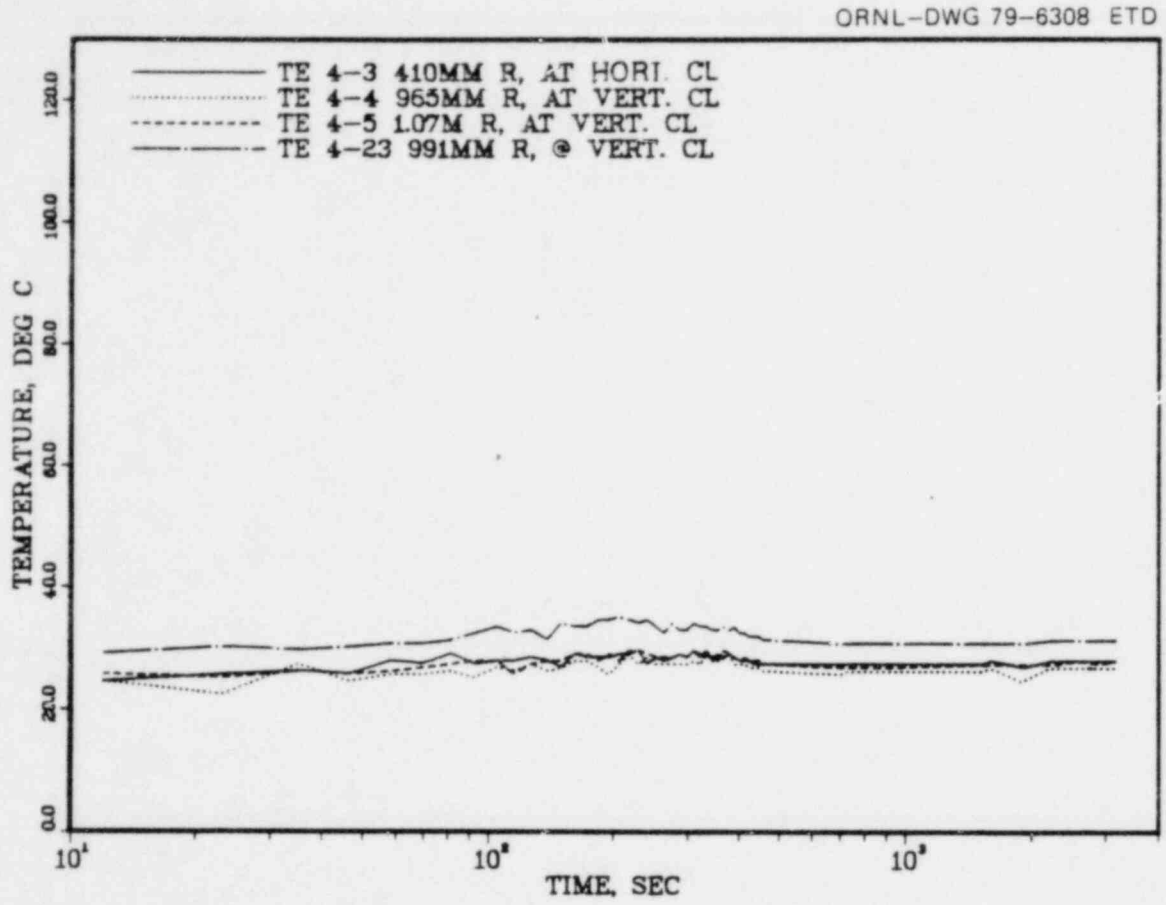

Fig. 9. Temperature measurements at the midplane of the NSPP vessel for NSPP test 201.

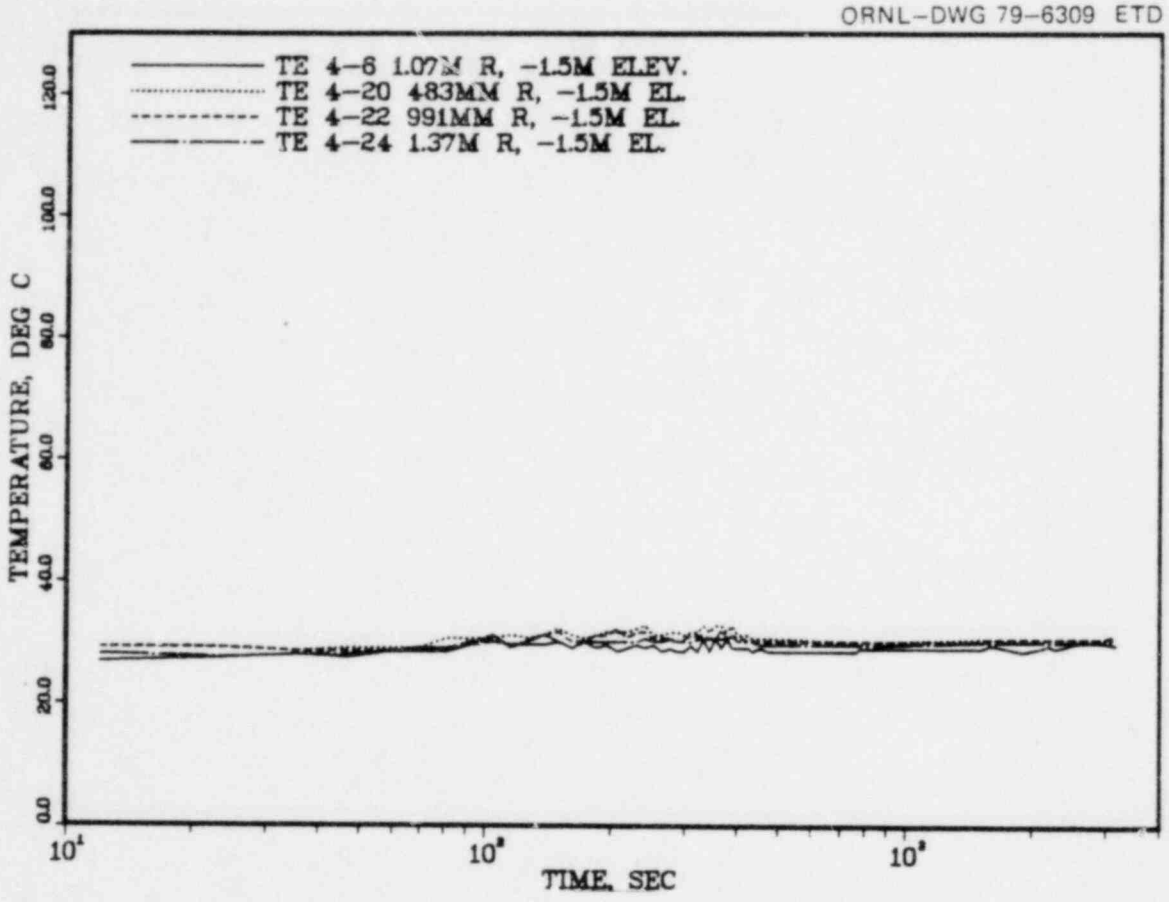

Fig. 10. Temperature measurements at 1.5 m below the vessel midplane for NSPP test 201.

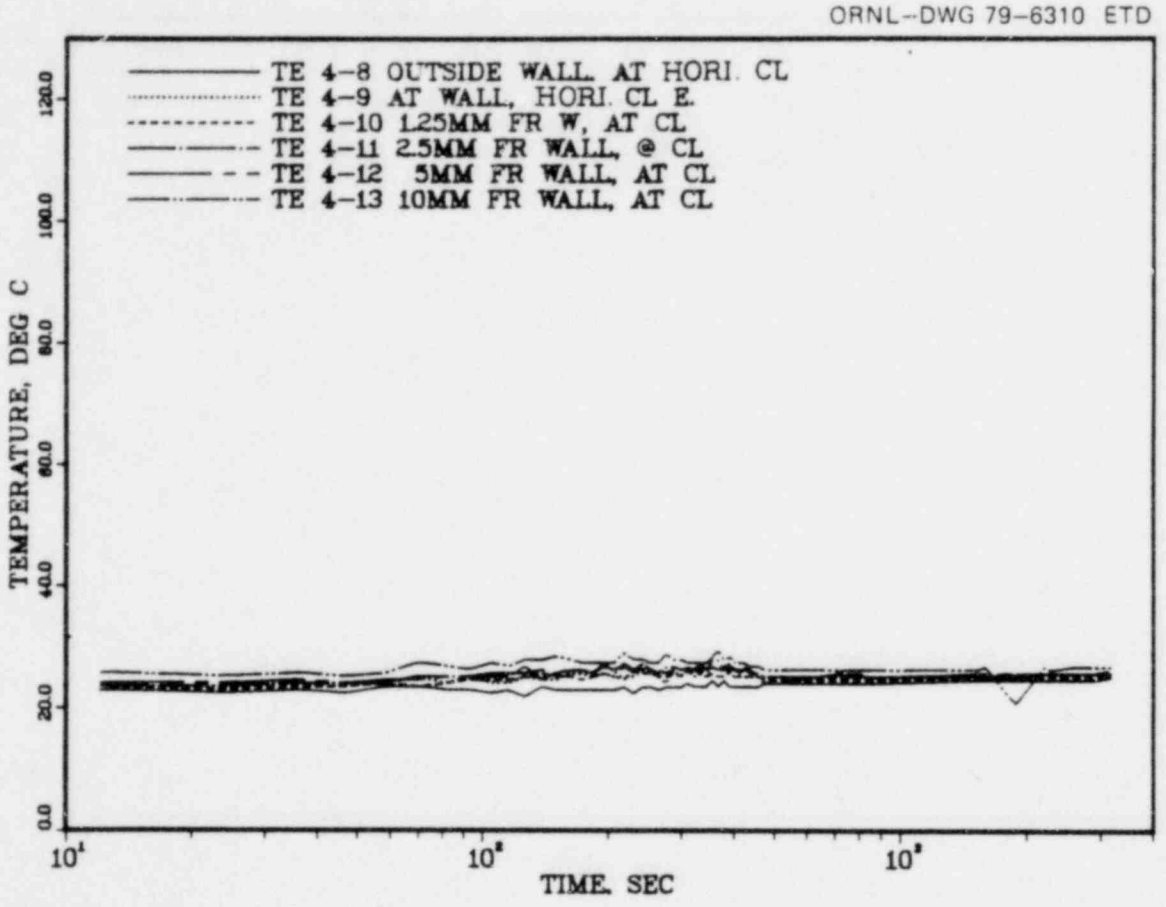

Fig. 11. Temperature measurements along the vessel midplane.

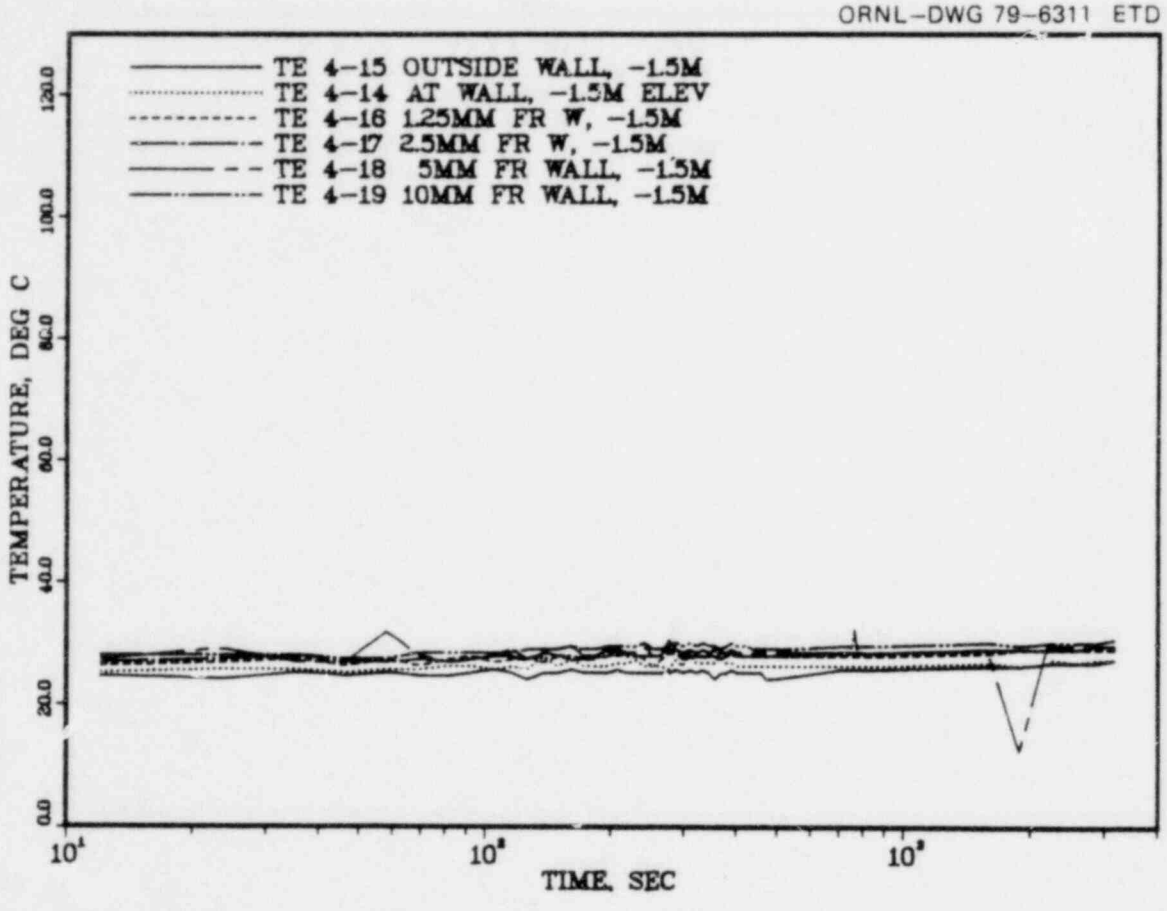

Fig. 12. Temperature measurements near the wall at 1.5 m below the vessel midplane.

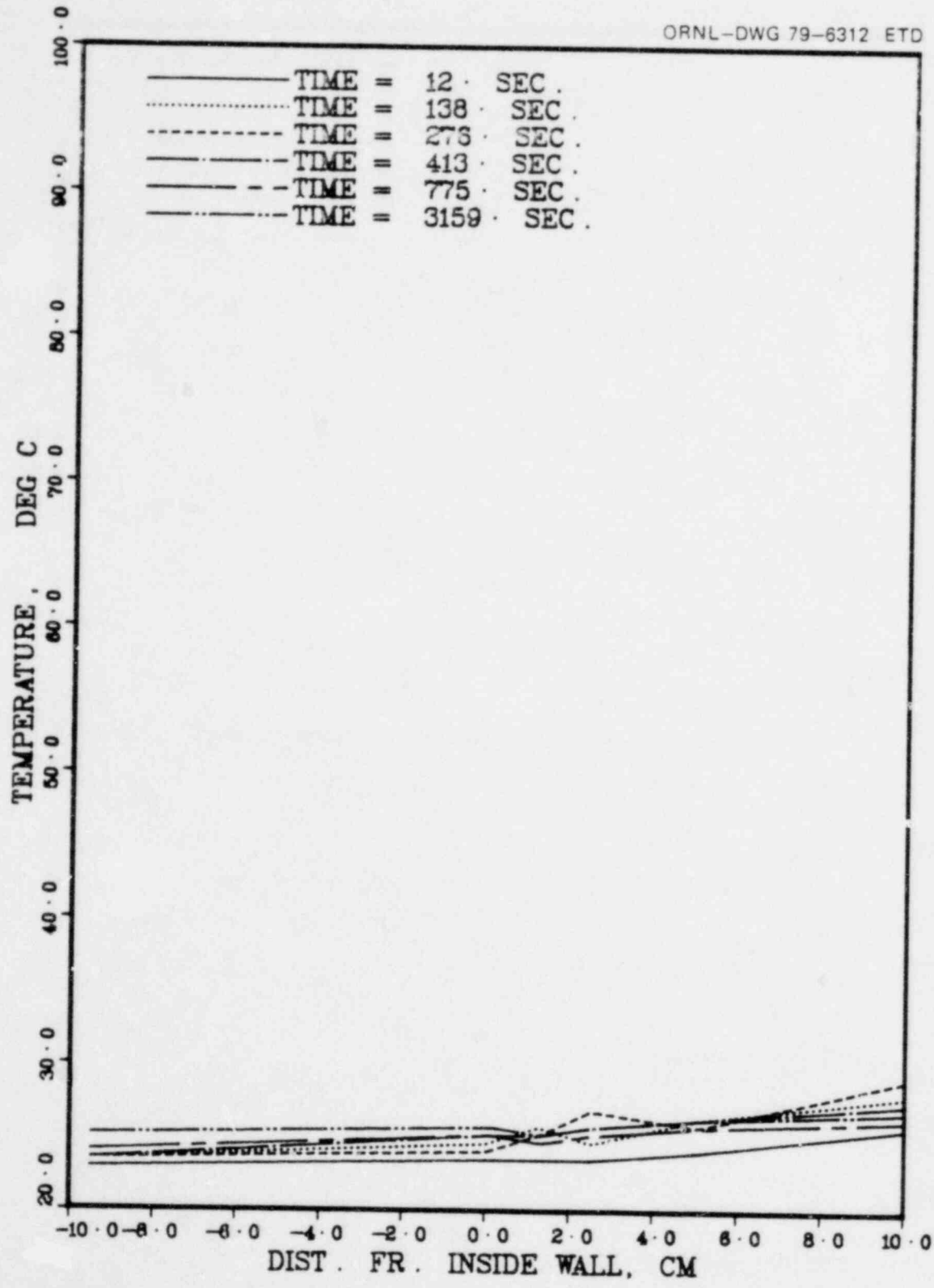

Fig. 13. Temperature measurements at the vessel midplane for NSPP test 201. (Note that the distance is measured from the inside wall toward the vessel centerline.)

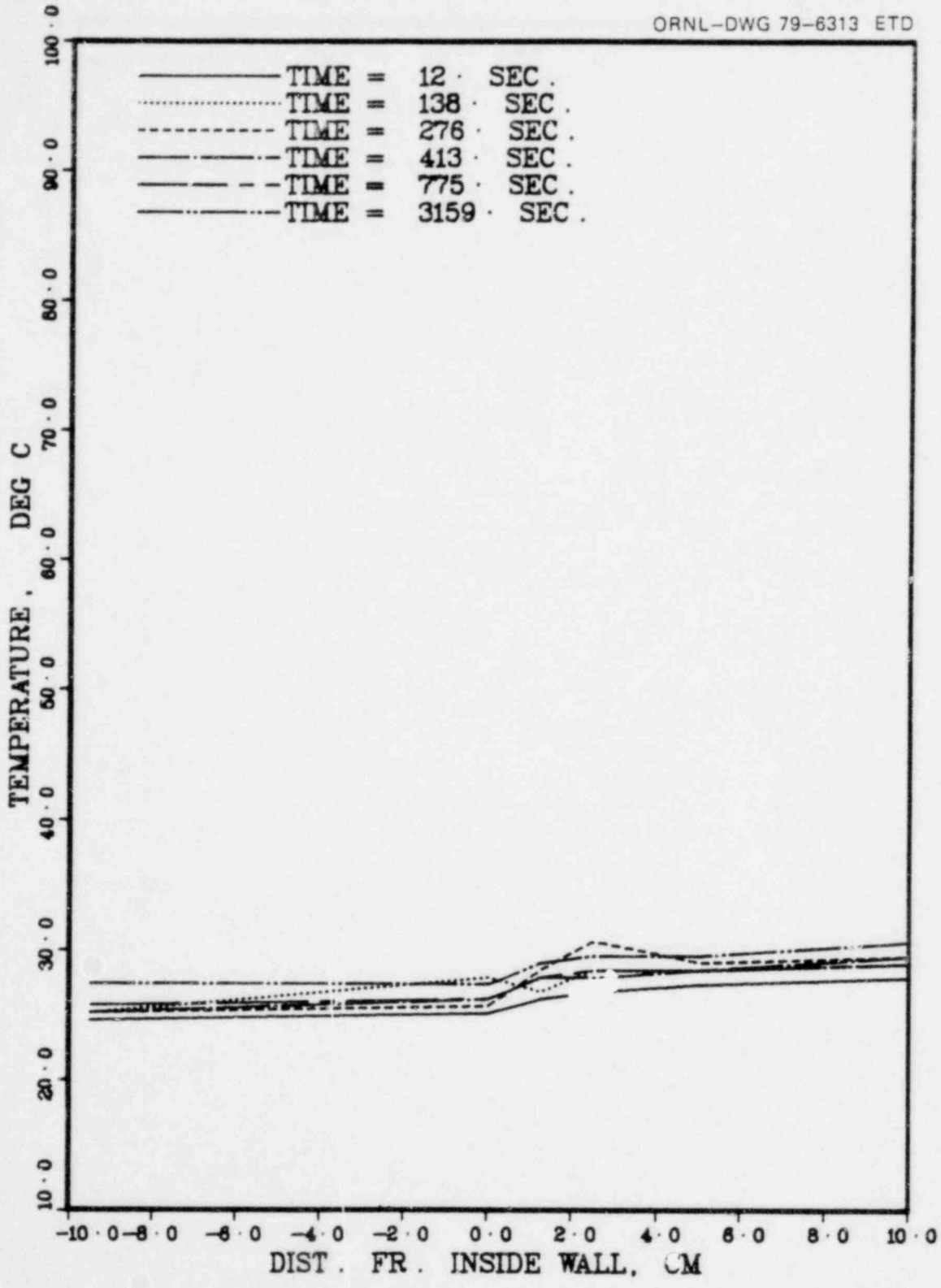

Fig. 14. Temperature measurements at 1.5 m below the vessel midplane for NSPP test 201.

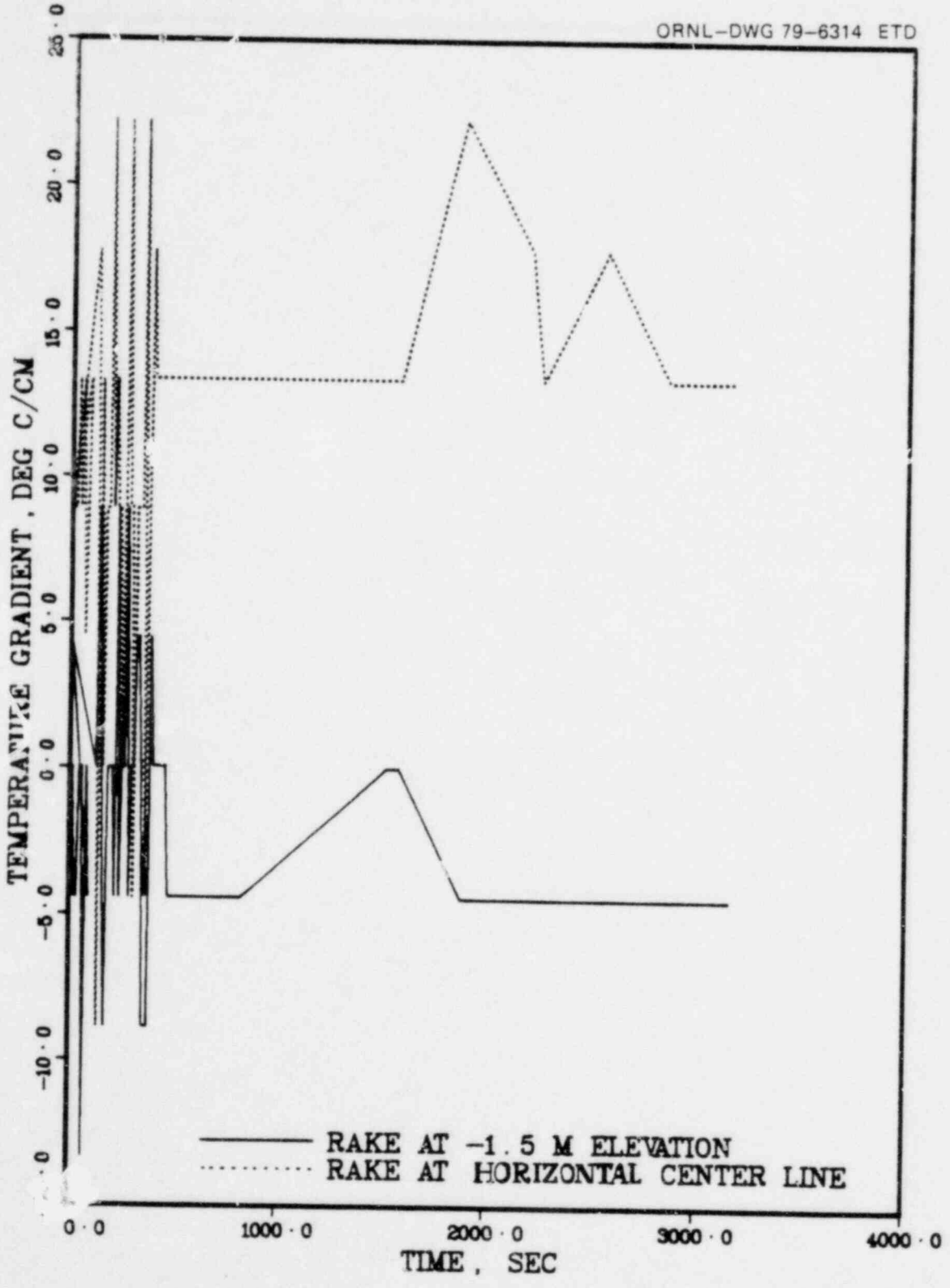

Fig. 15. Temperature gradients at the wall for NSPP test 201.

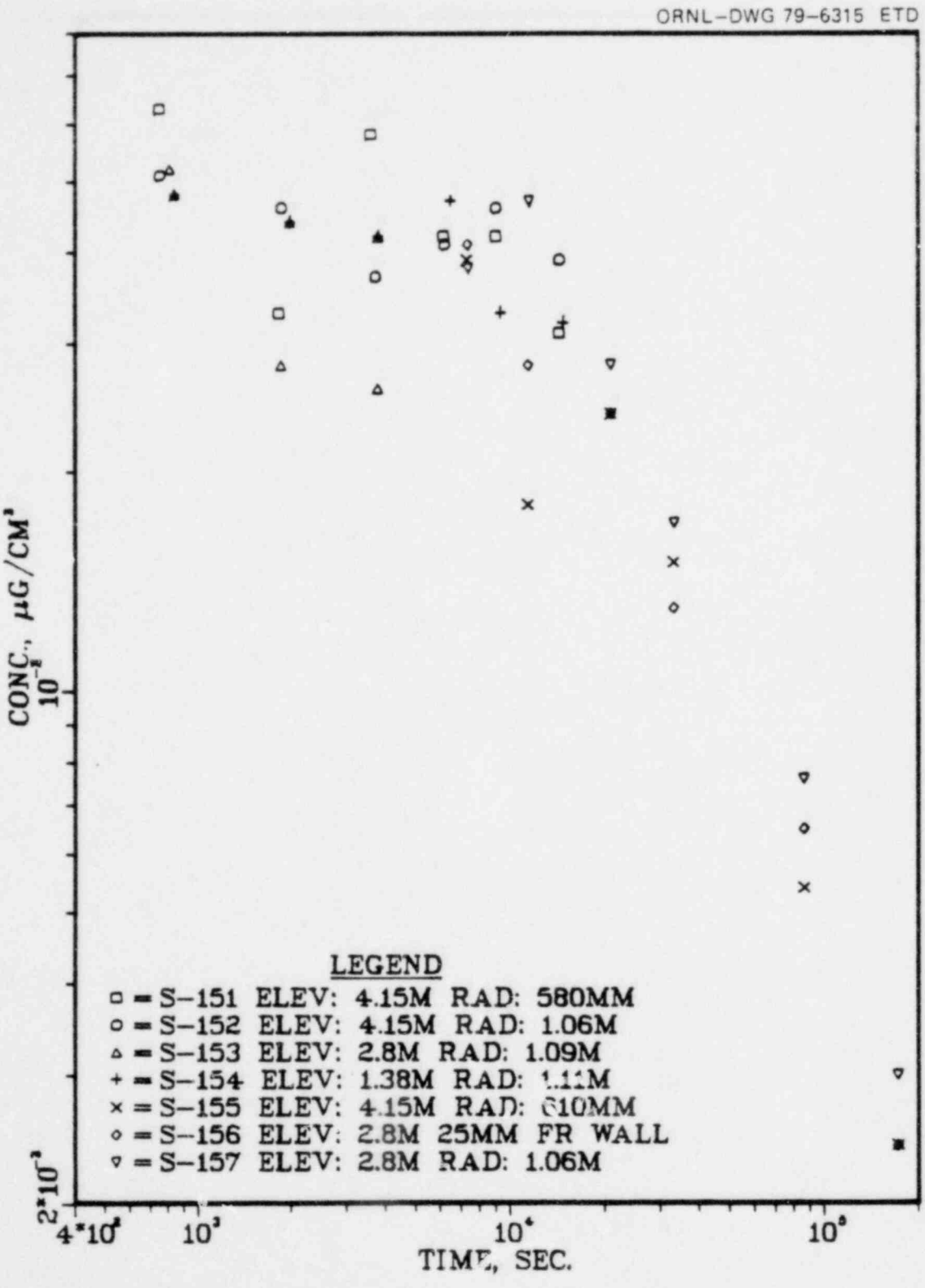

Fig. 16. Aerosol mass concentrations (measured witn seven samplers) vs time for NSPP test 202.

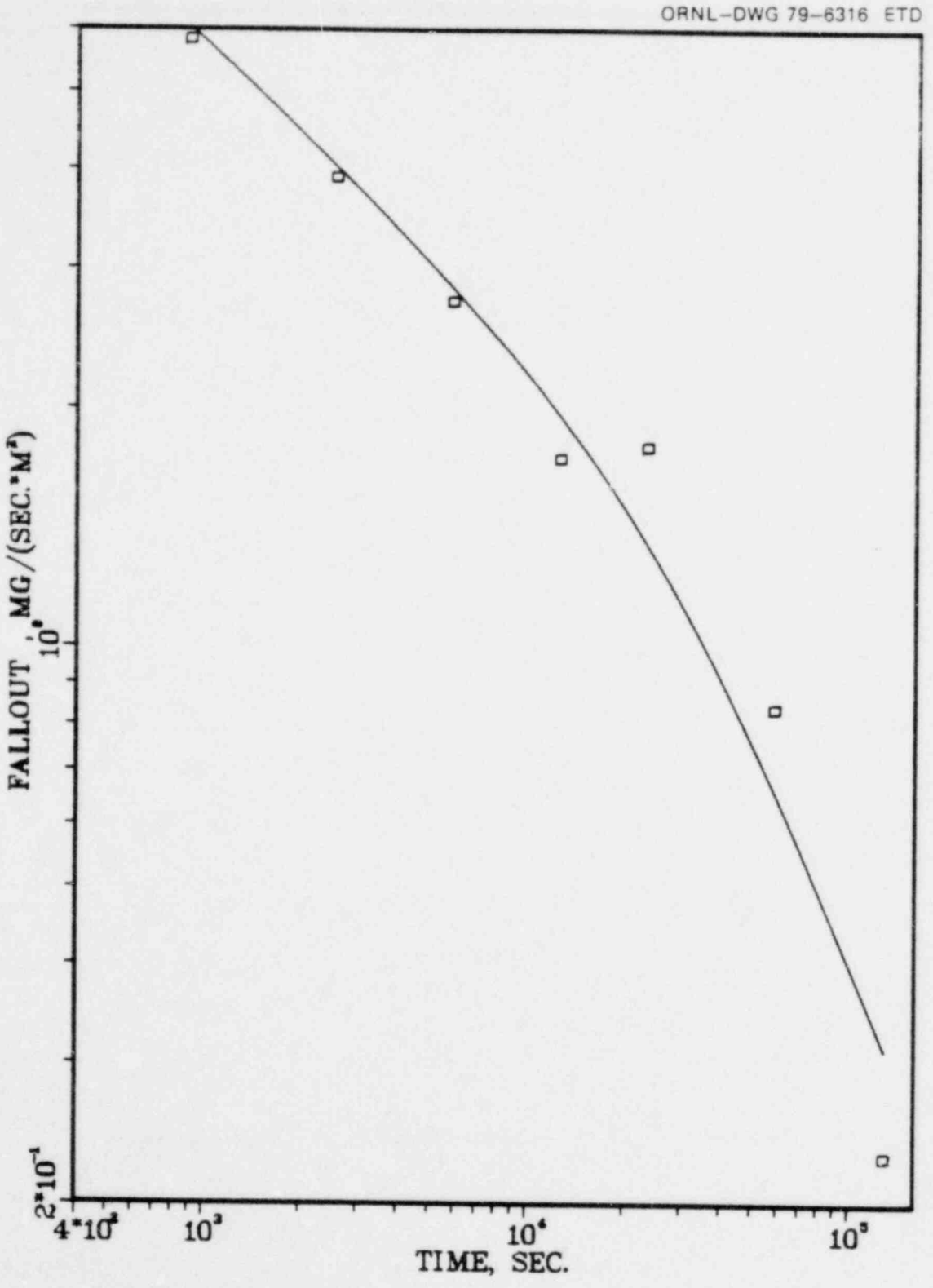

Fig. 17. Fallout rate vs time for NSPP test 202.

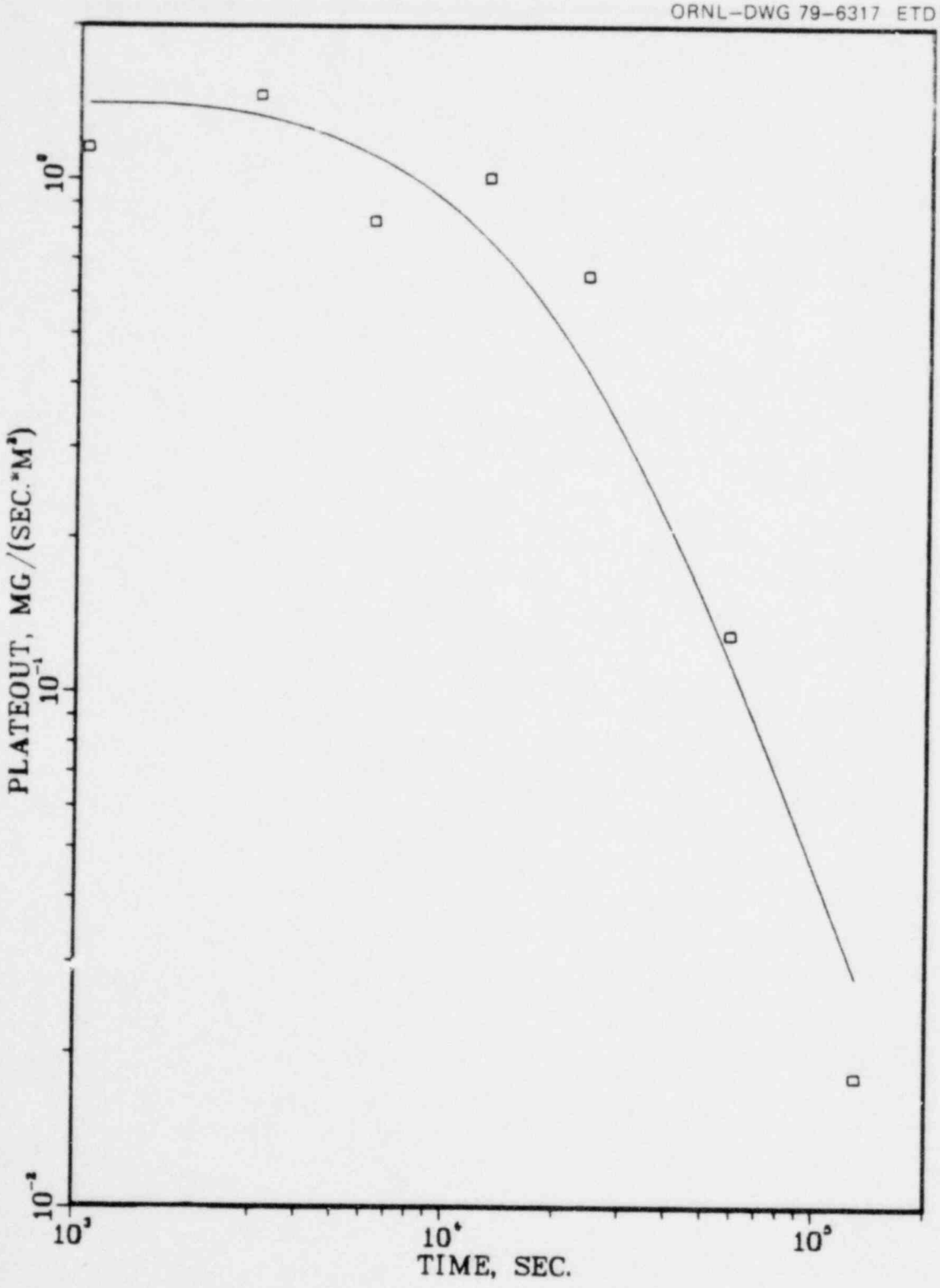

Fig. 18. Plateout rate vs time for NSPP test 202.

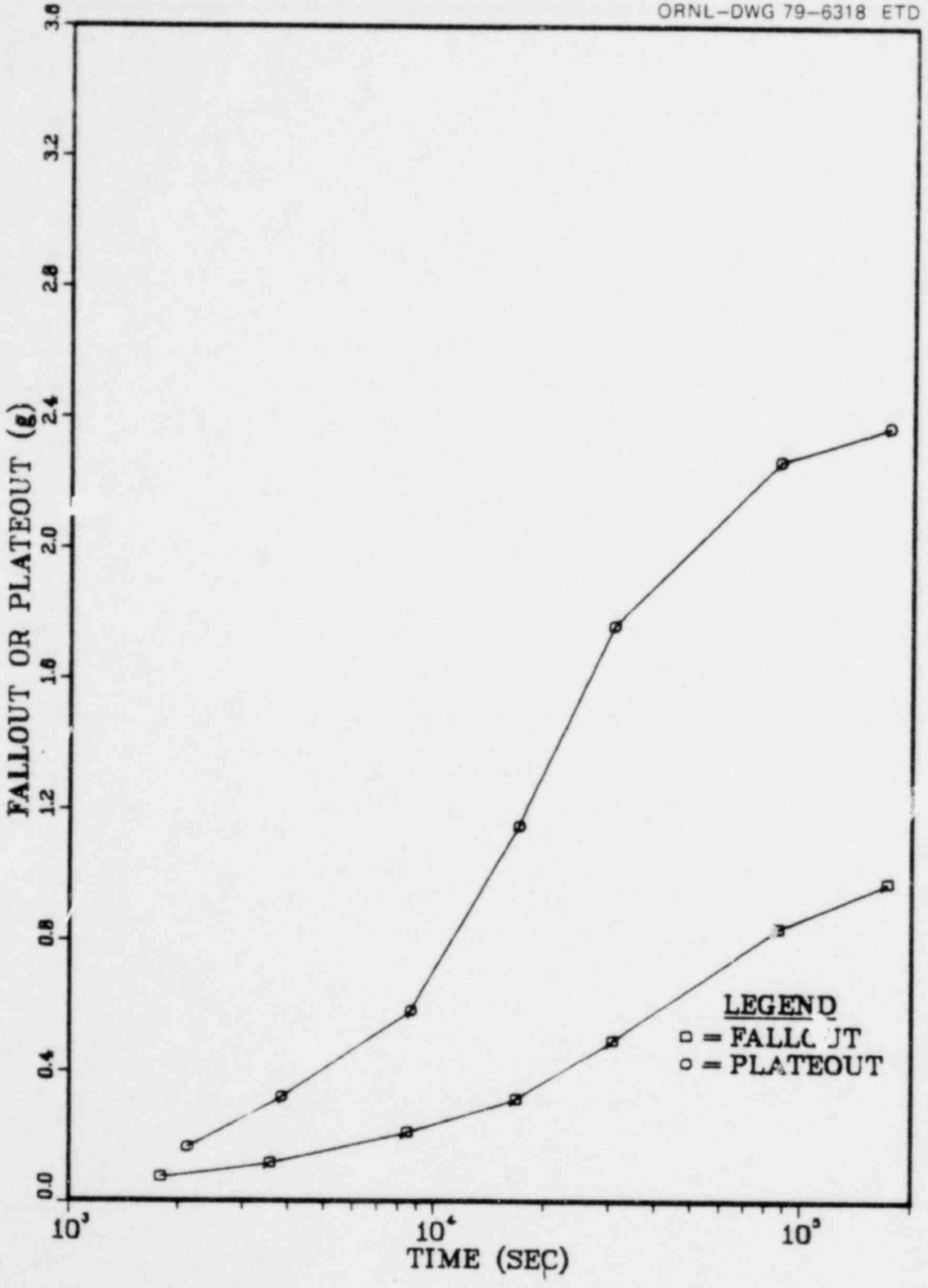

Fig. 19. Cumulative fallout and plateout vs time for NSPP test 202.

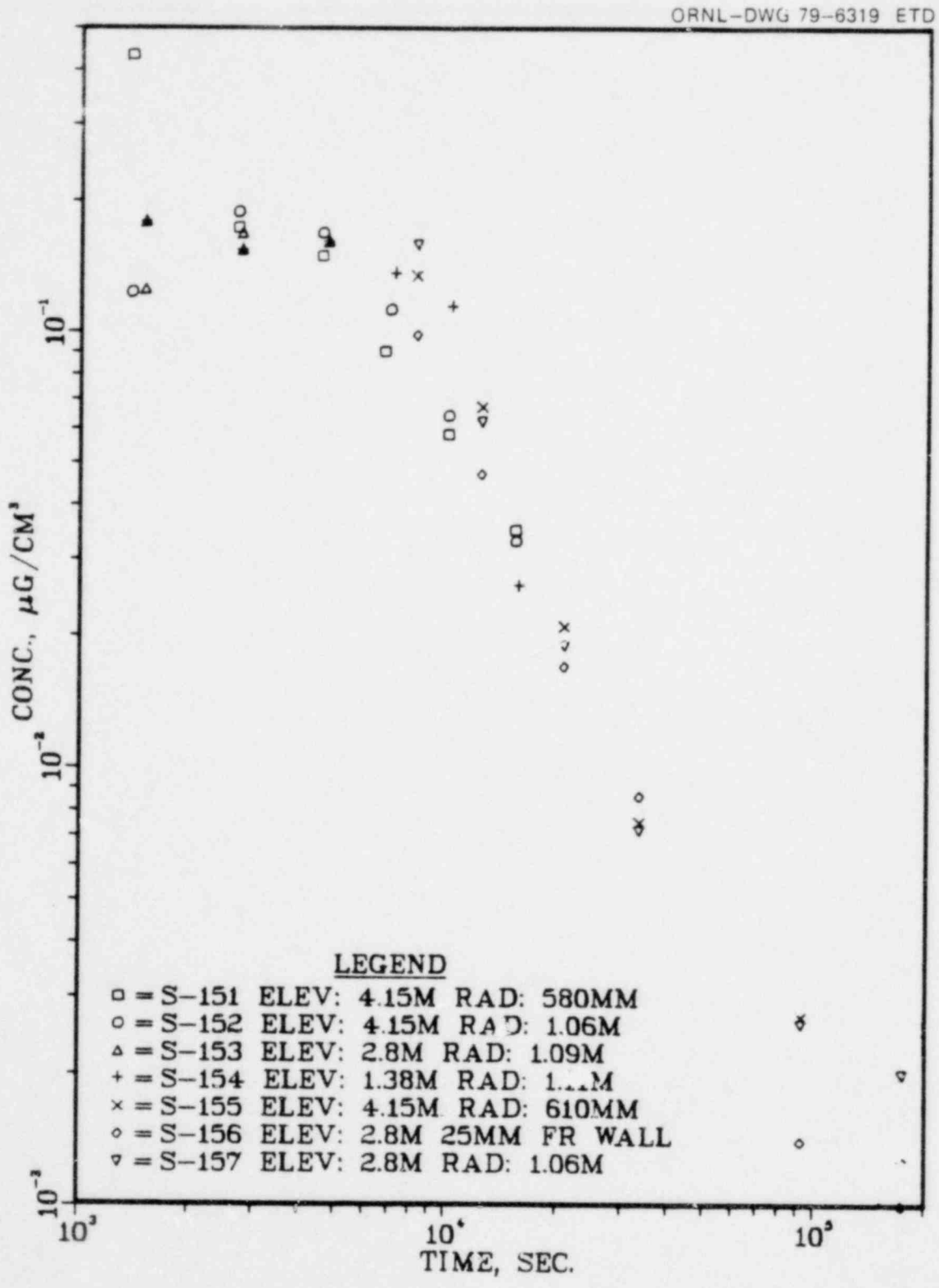

Fig. 20. Aerosol mass concentrations (measured with seven samplers) vs time for NSPP test 203.

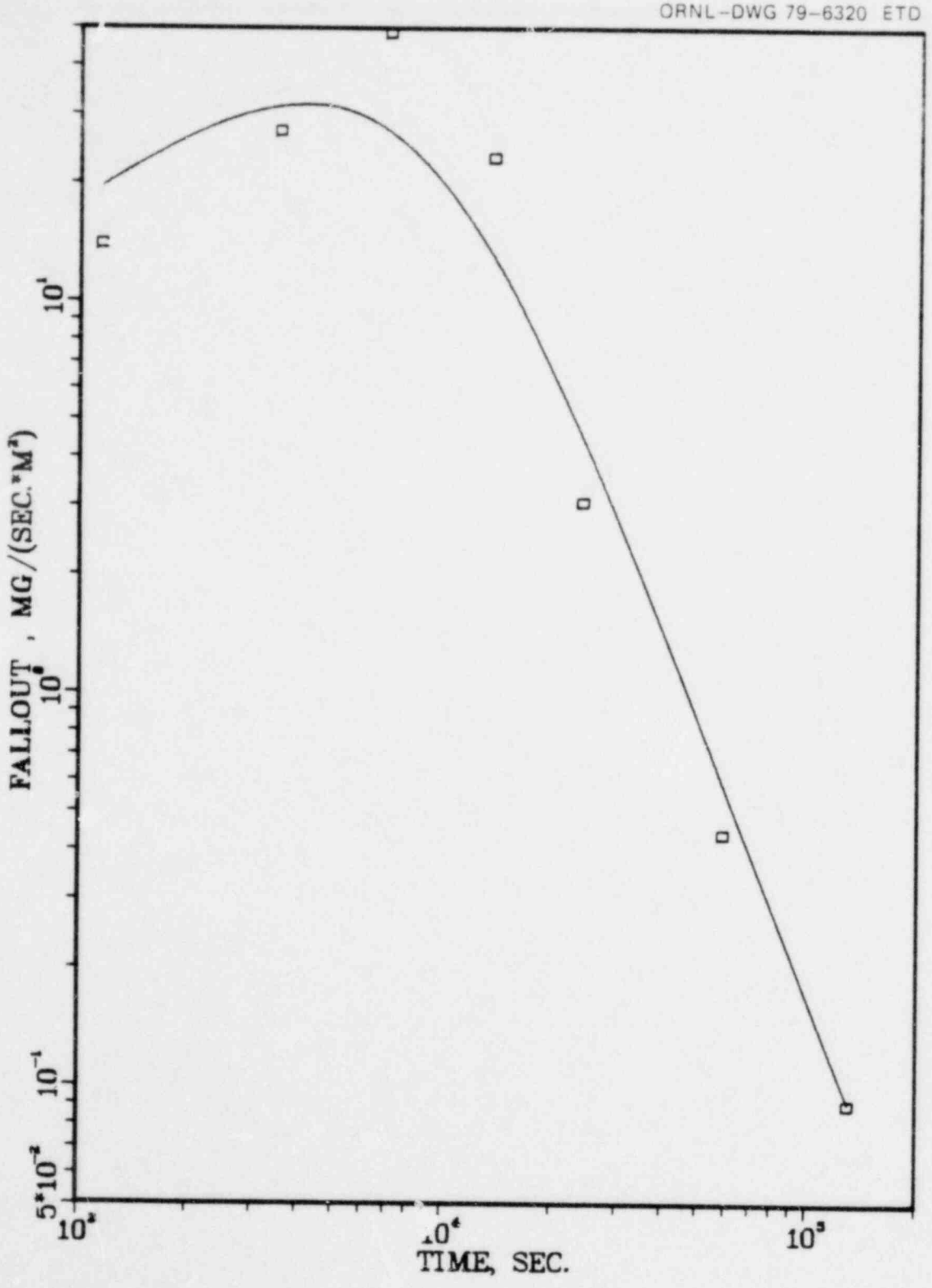

Fig. 21. Fallout rate vs time for NSPP test 203.

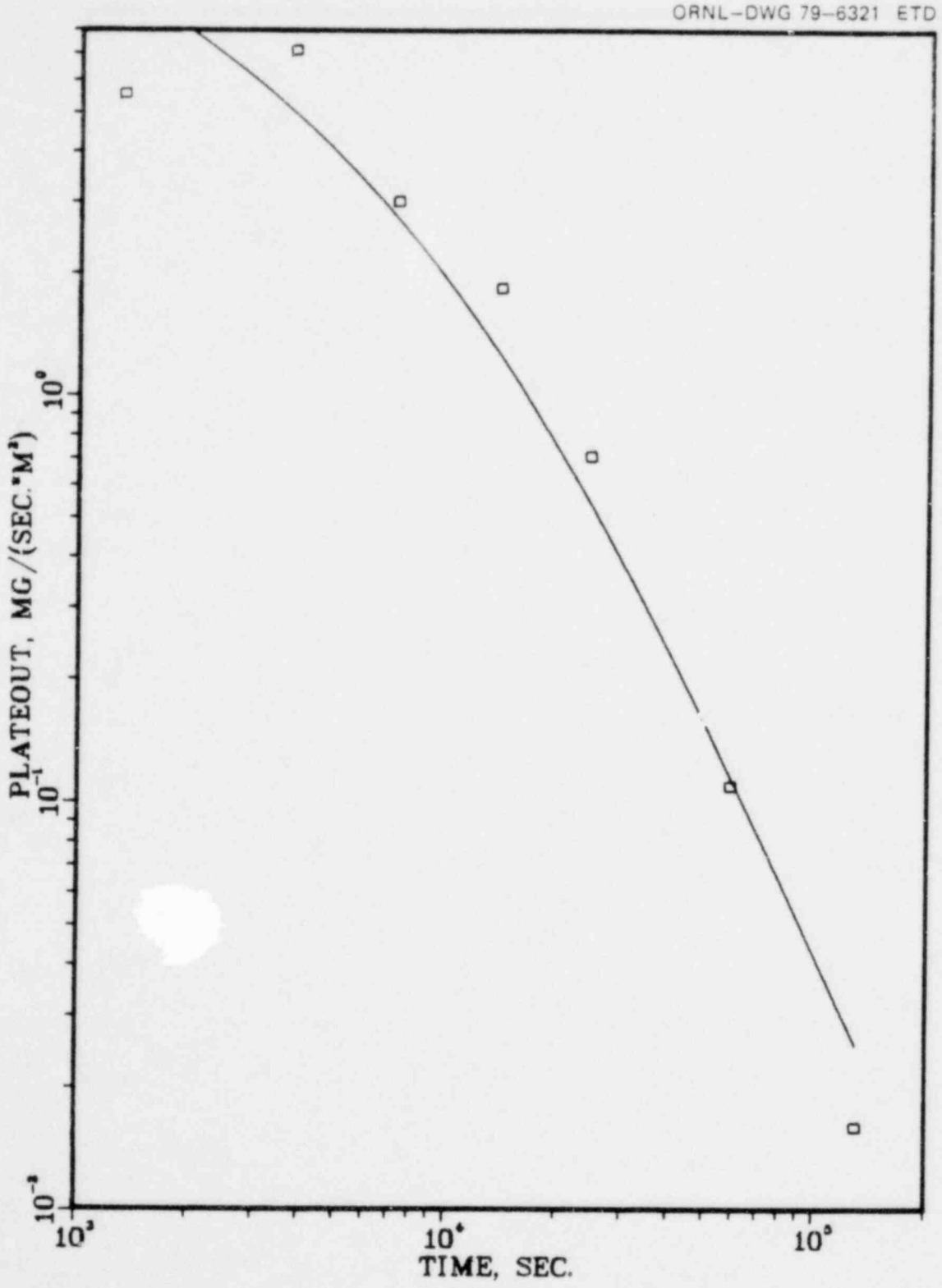

Fig. 22. Plateout rate vs time for NSPP test 203.

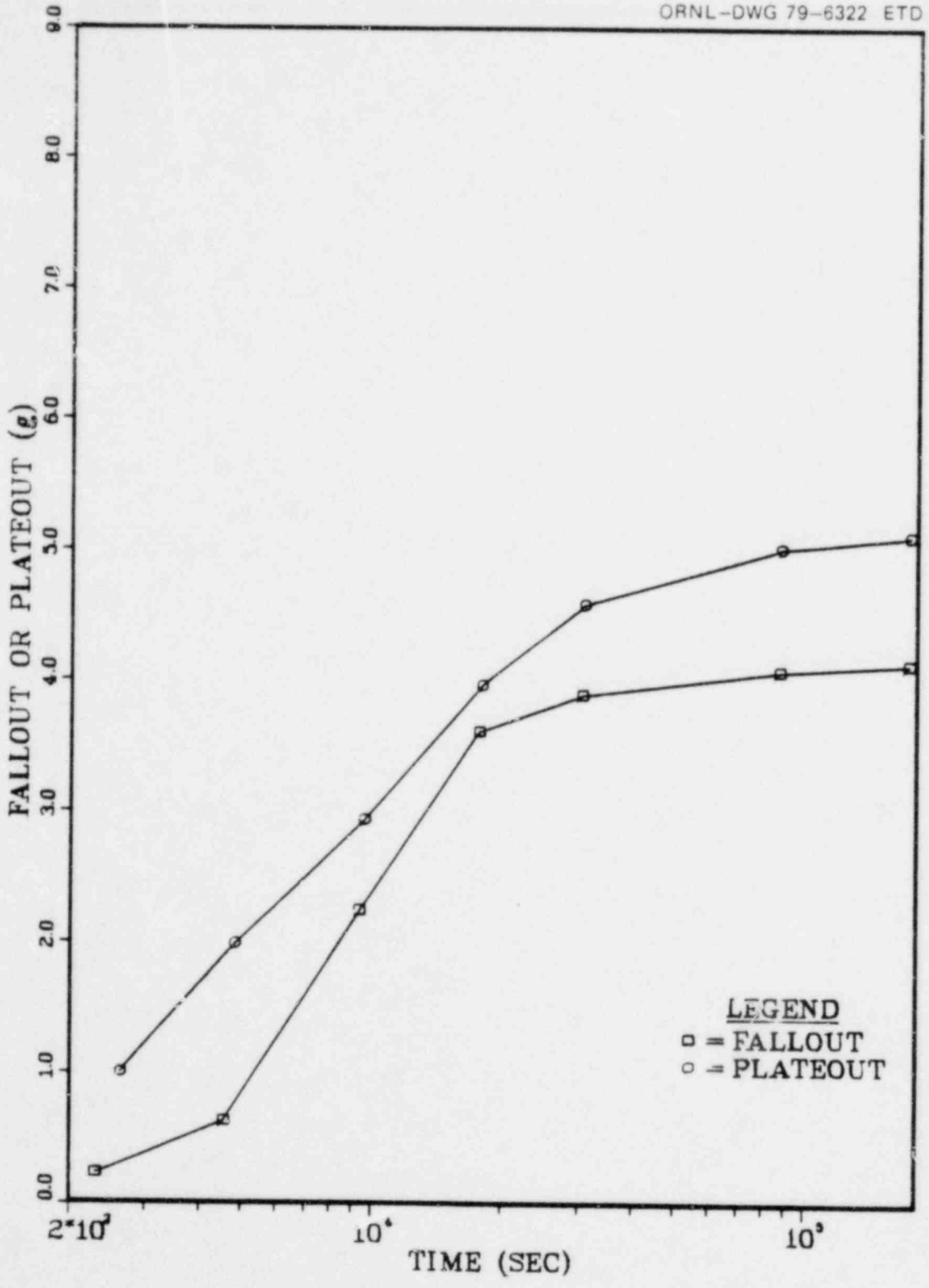

Fig. 23. Cumulative fallout and plateout vs time for NSPP test 203.

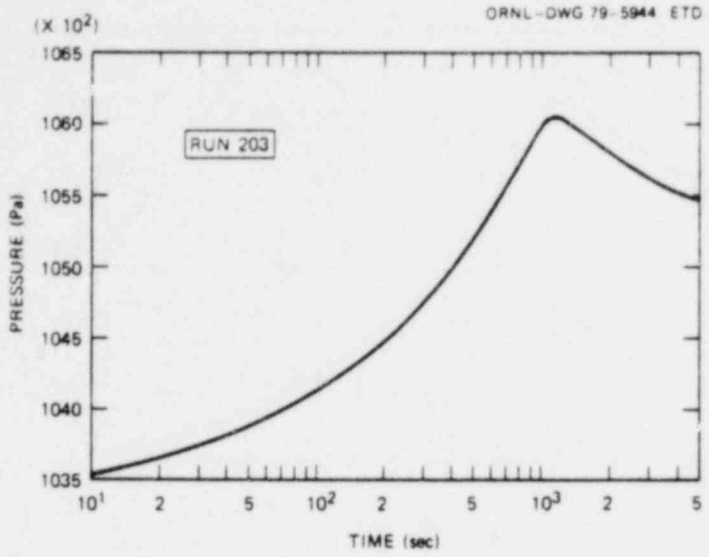

Fig. 24. In-vessel pressure vs time for NSPP test 203.

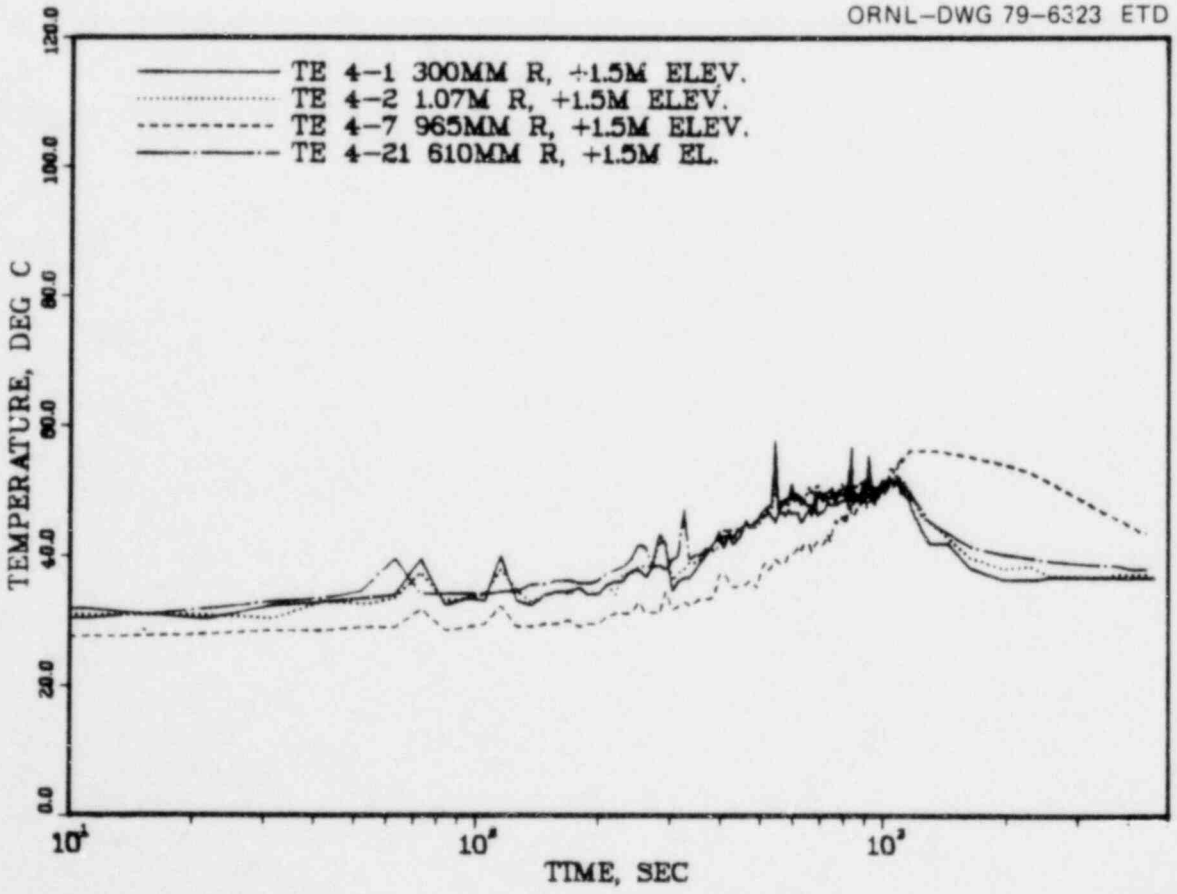

Fig. 25. Temperature measurements at 1.5 m above the vessel midplane for NSPP test 203.

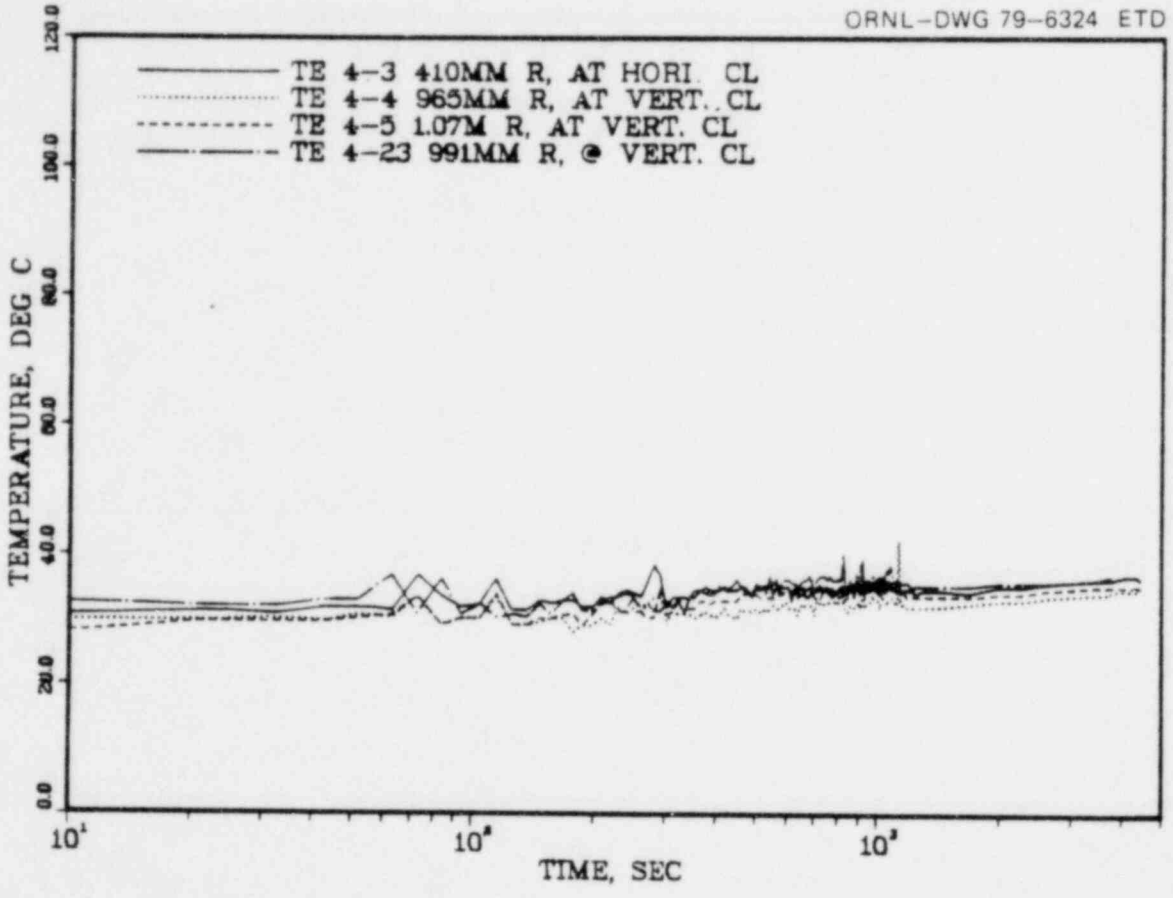

Fig. 26. Temperature measurements at the midplane of the NSPP vessel for NSPP test 203.

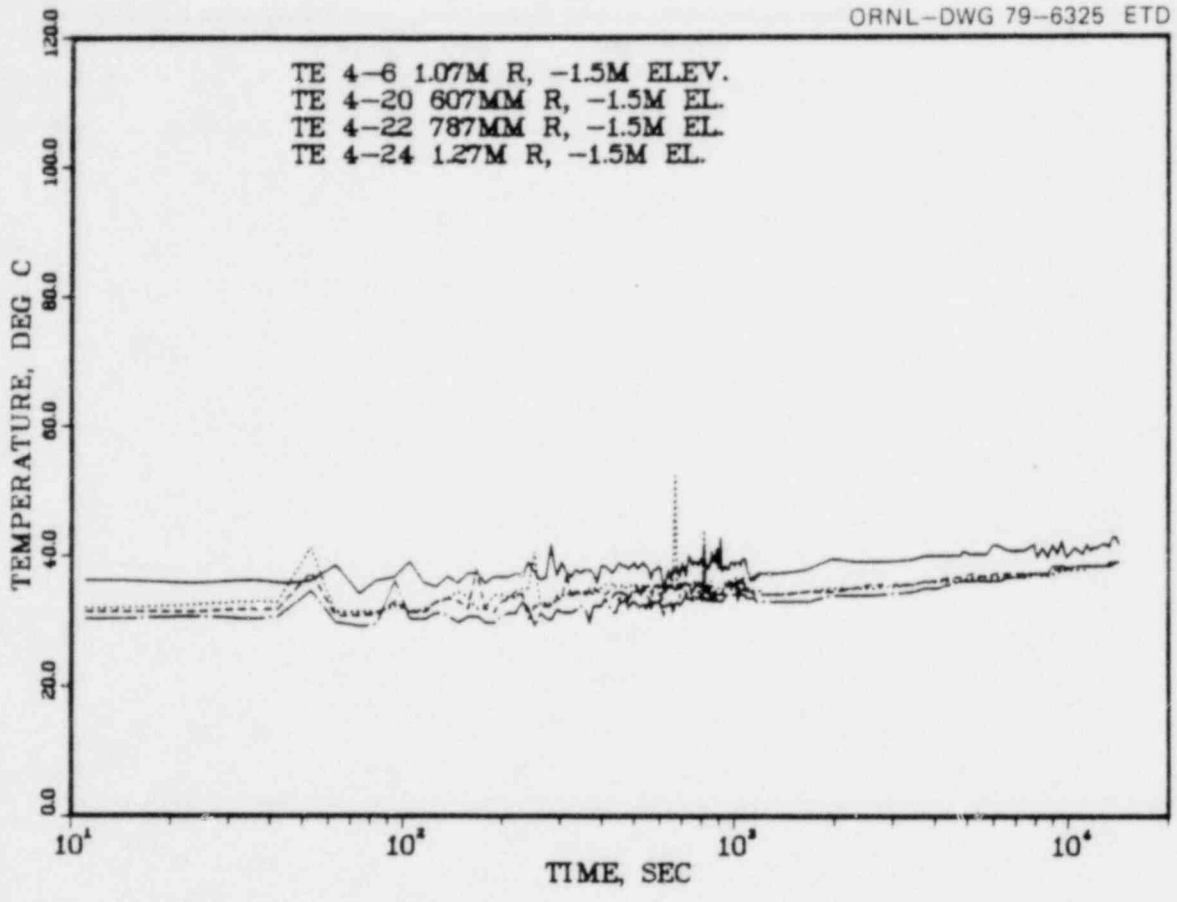

Fig. 27. Temperature measurements at 1.5 m below the vessel midplane for NSPP test 203.

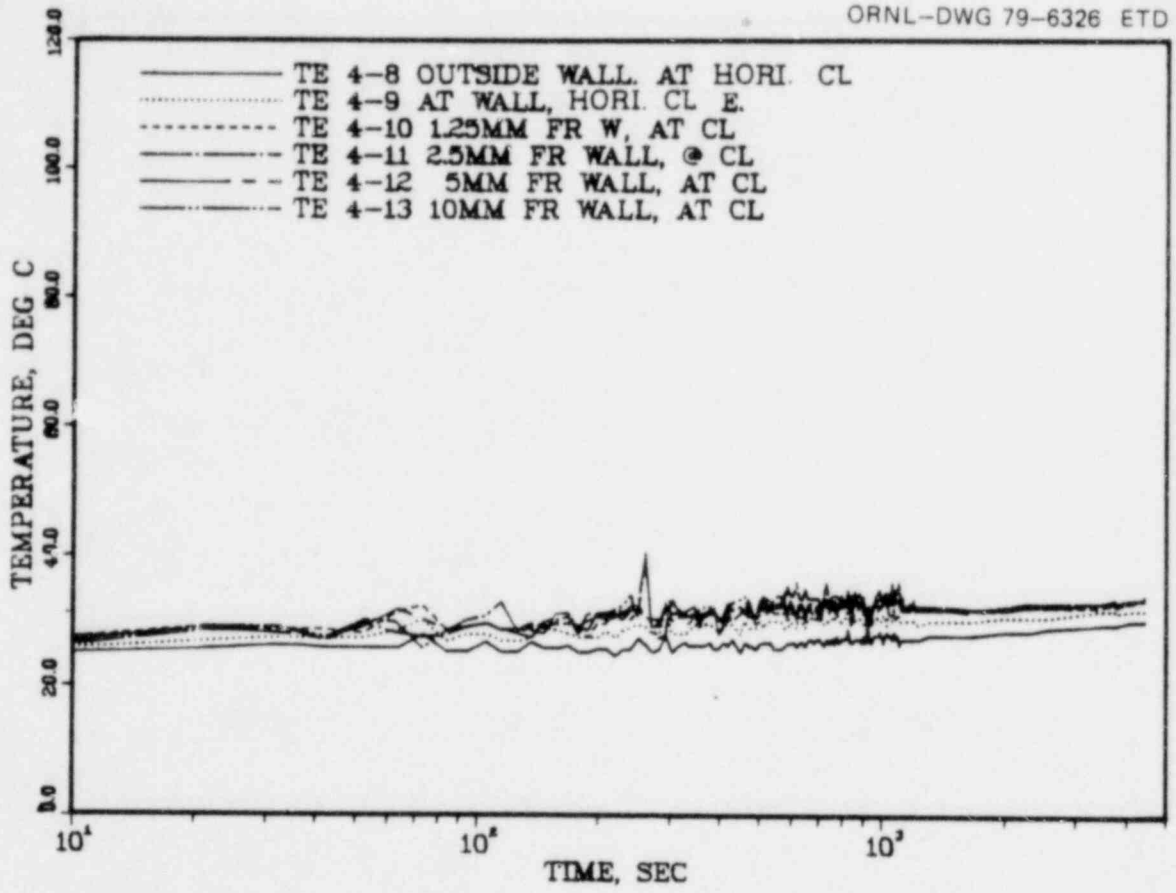

Fig. 28. Temperature measurements near the wall at the vessel midplane for NSPP test 203.

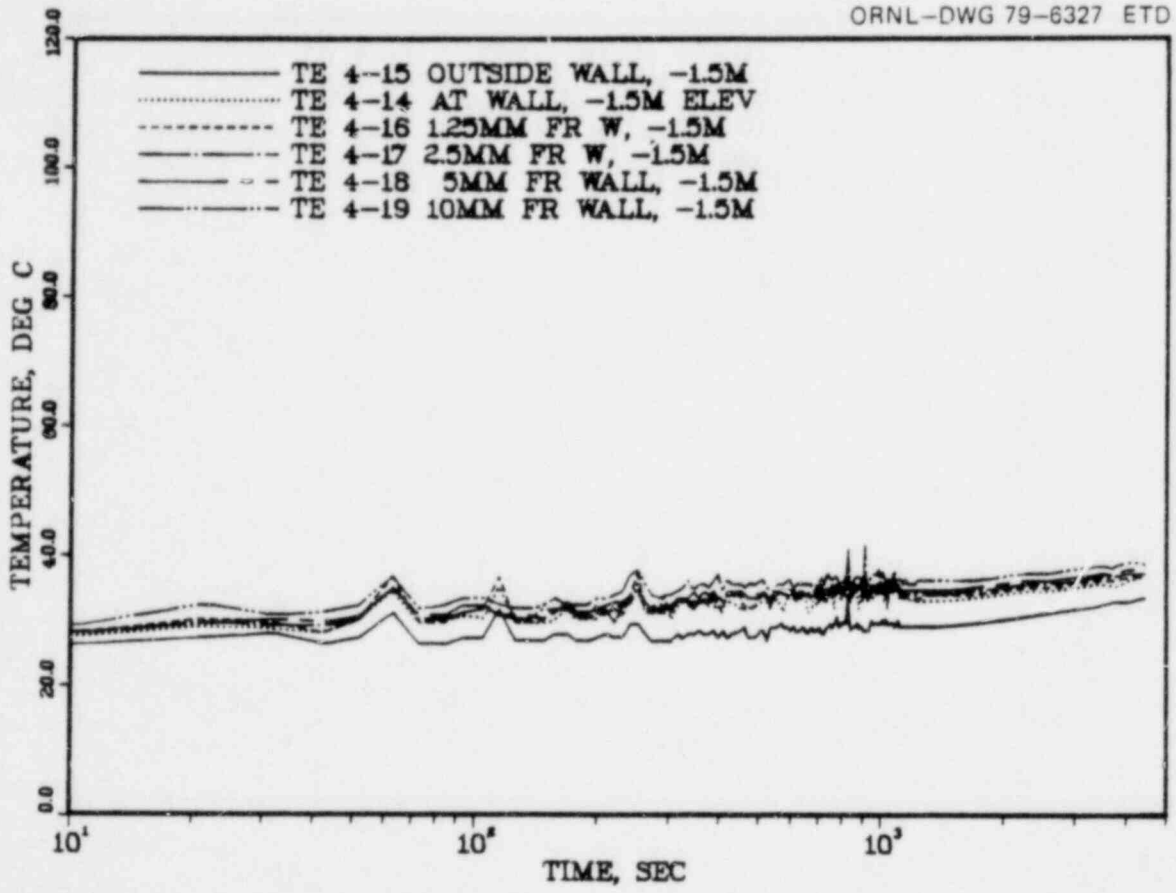

Fig. 29. Temperature measurements near the wall at 1.5 m below the vessel midplane for NSPP test 203.

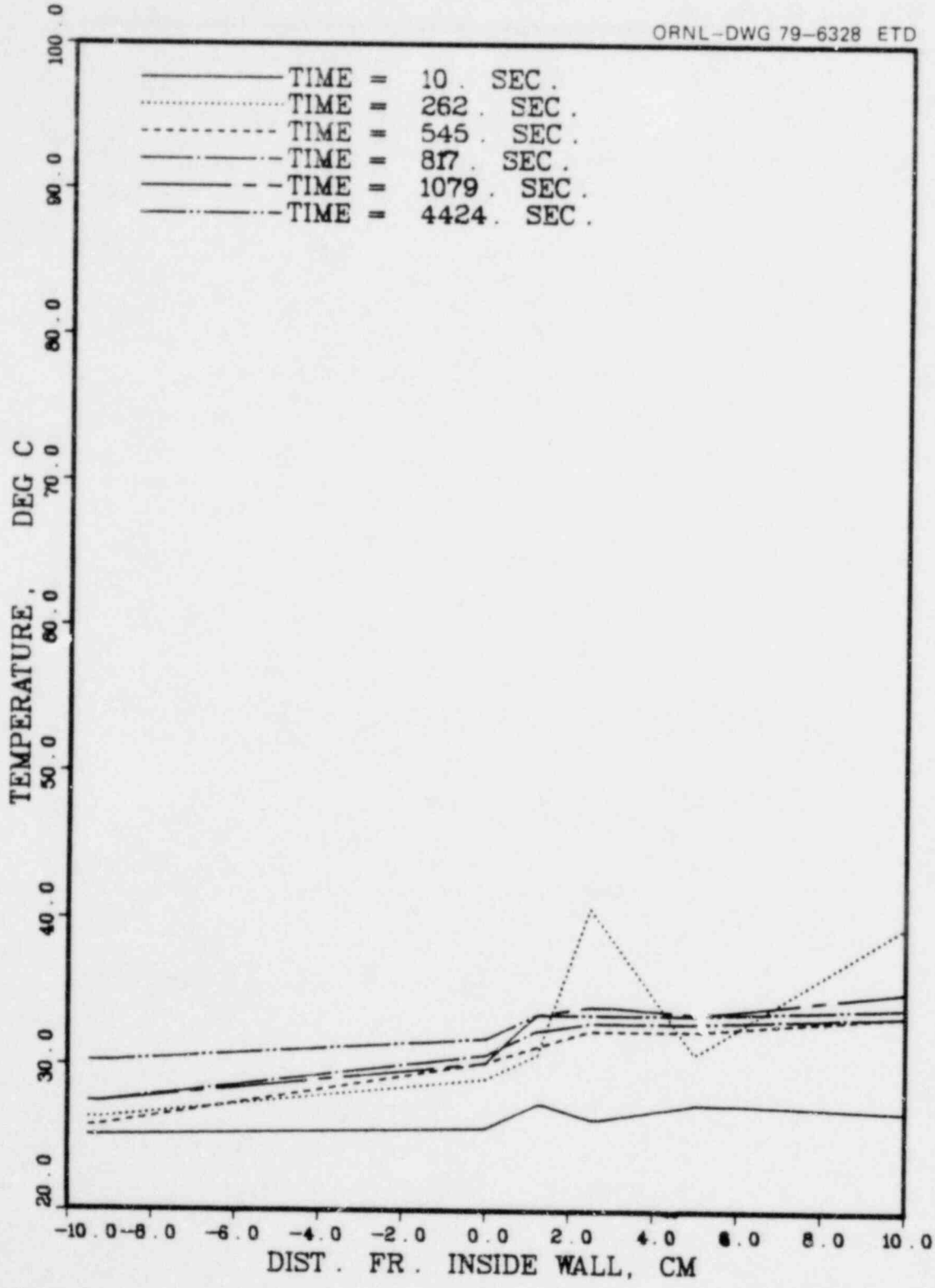

Fig. 30. Temperature measurements along the vessel midplane for NSPP test 203.

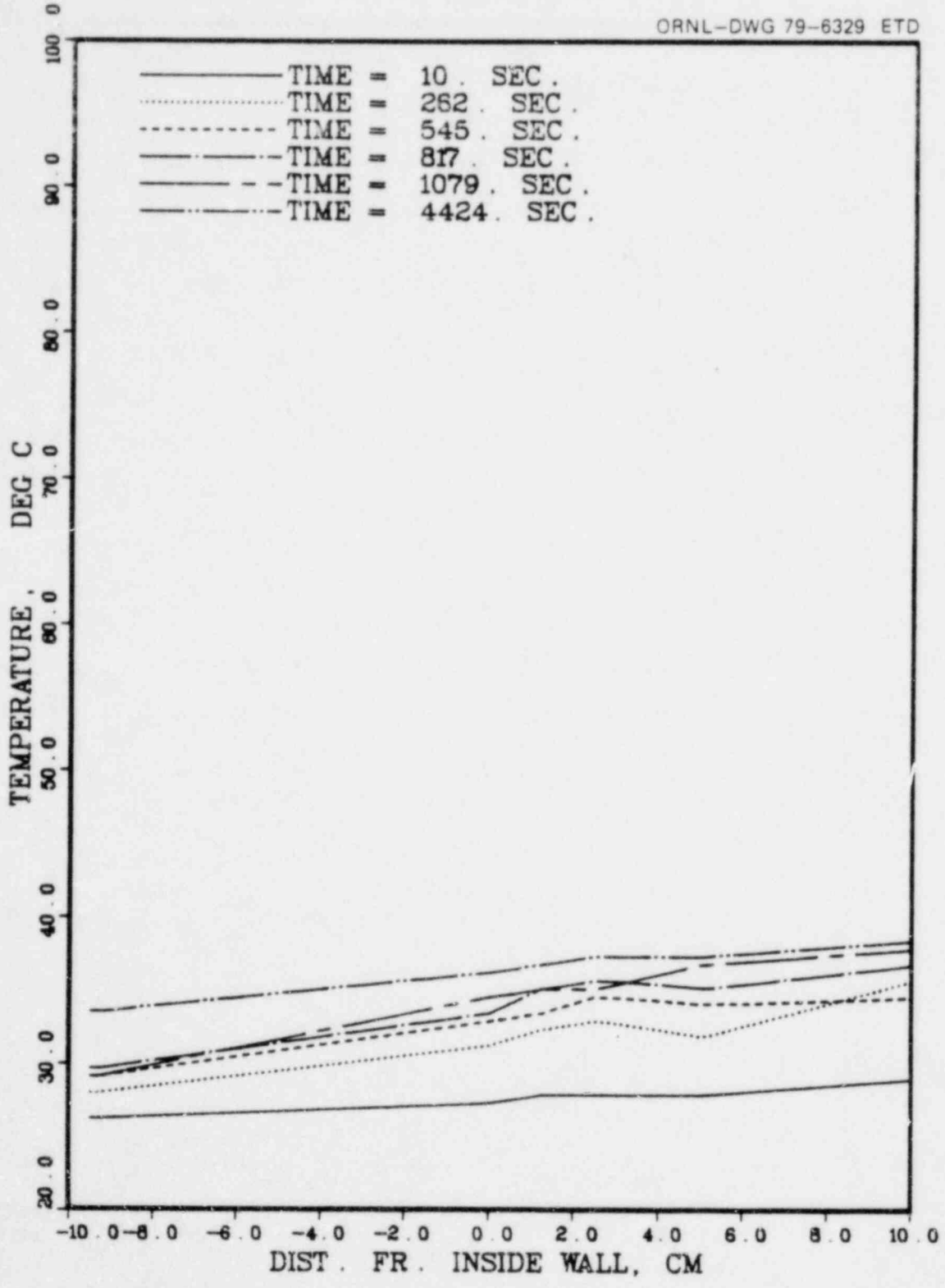

Fig. 31. Temperature measurements at 1.5 m below the vessel midplane for NSPP test 203.

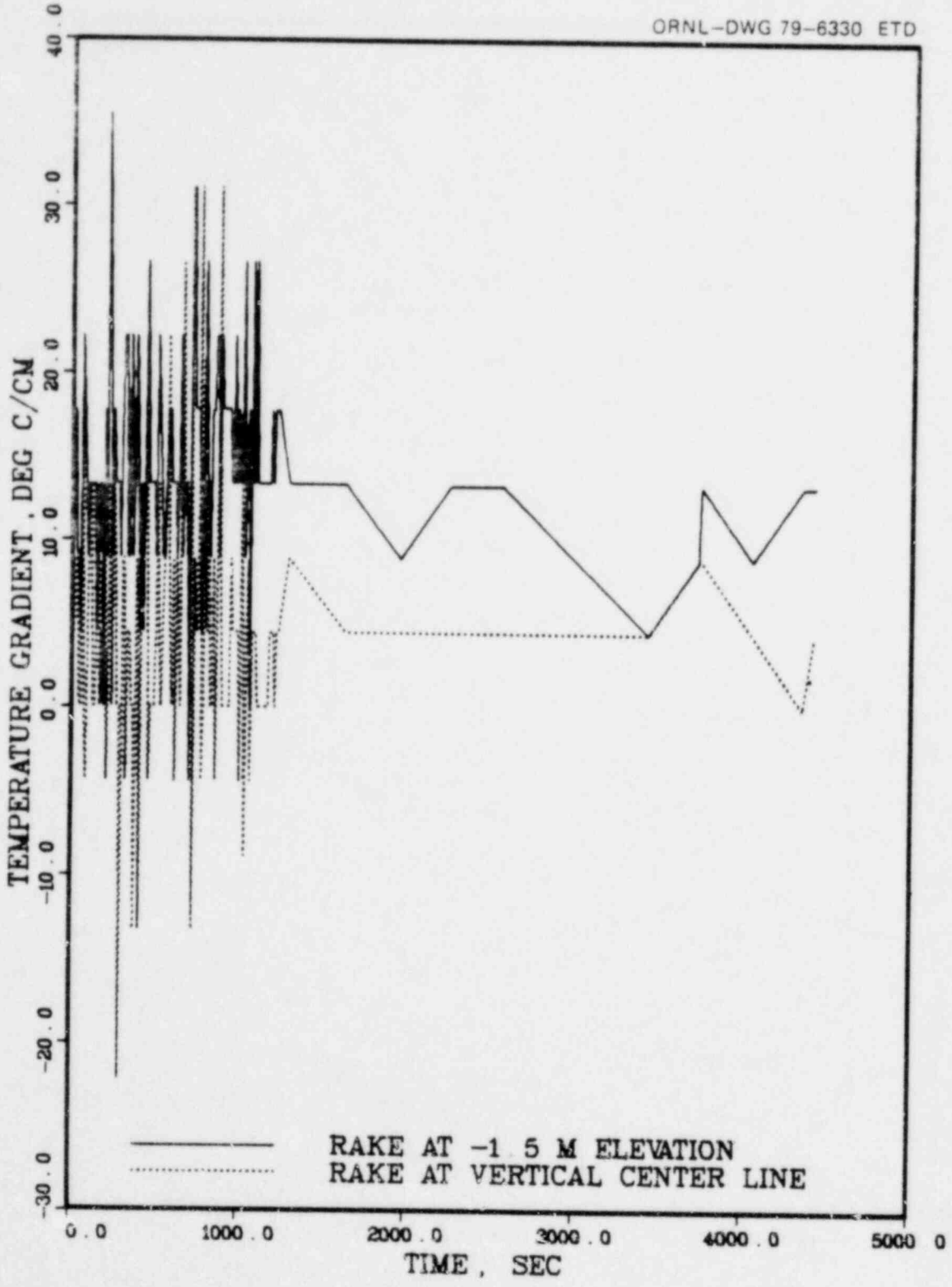

Fig. 32. Temperature gradients at the wall for NSPP test 203.

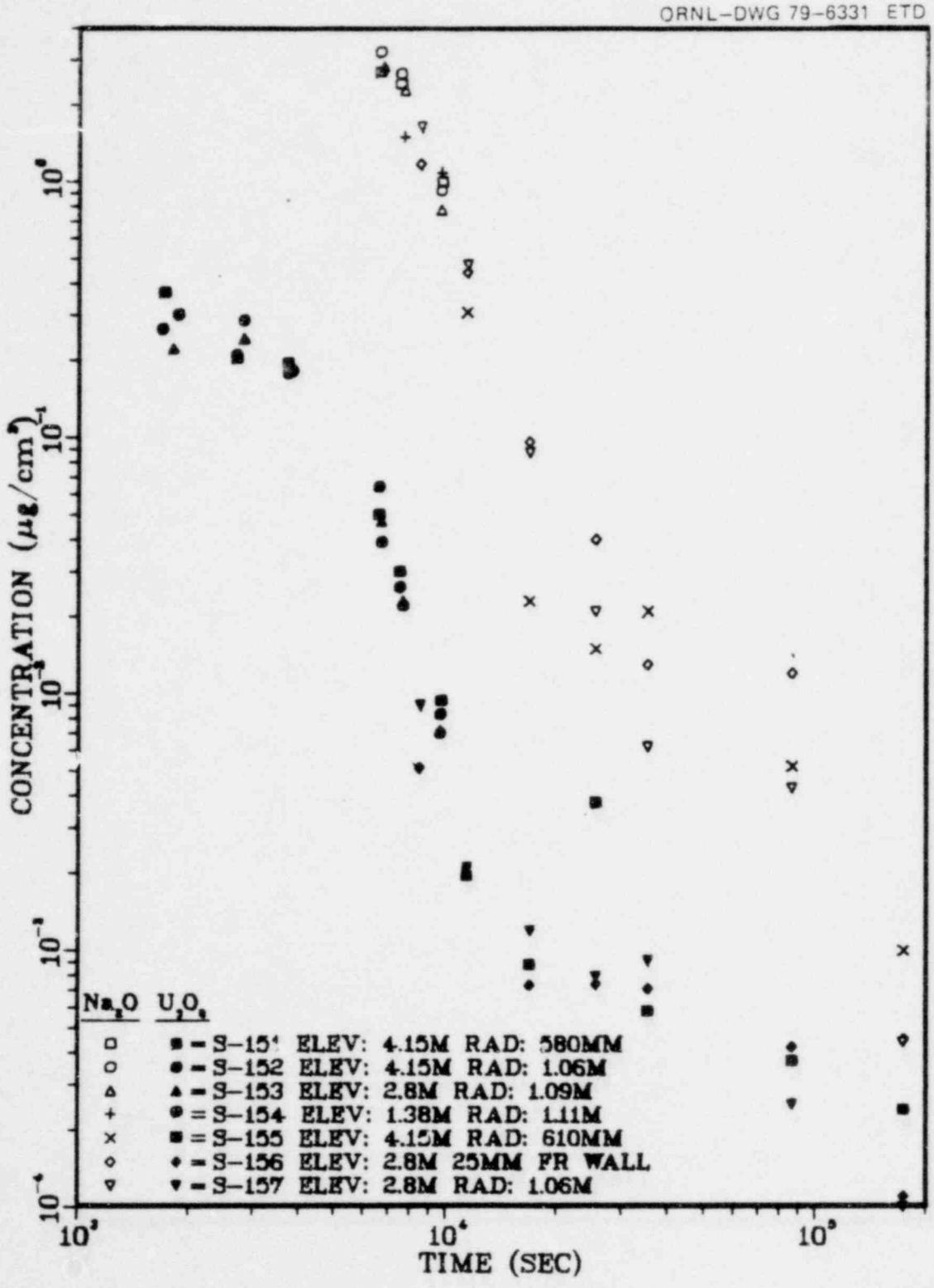

Fig. 33. Mass concentrations vs time for sodium oxide and uranium oxide aerosols for NSPP test 301.

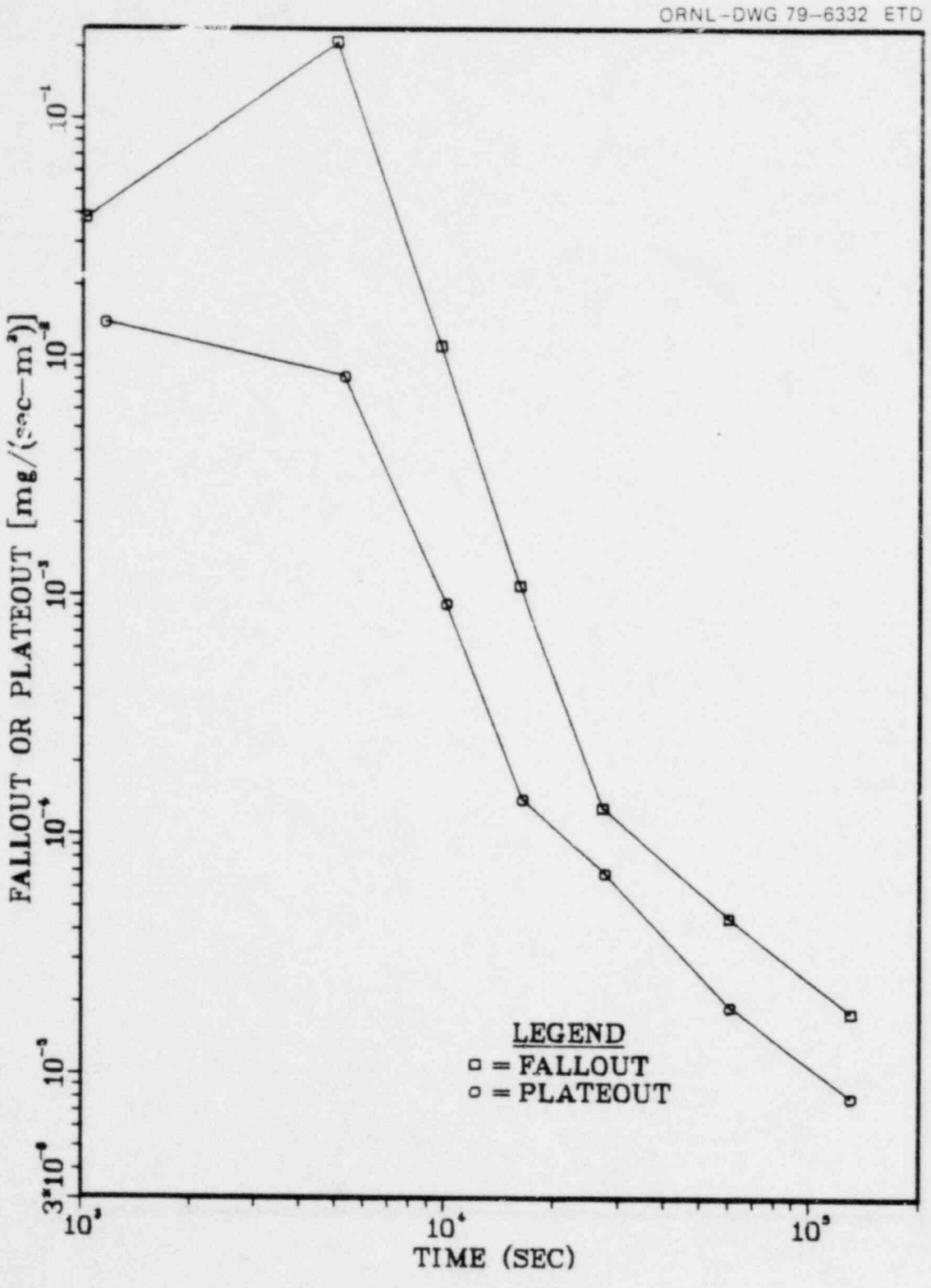

Fig. 34. Fallout and plateout rates vs time for U_3O_8 aerosol for NSPP test 301.

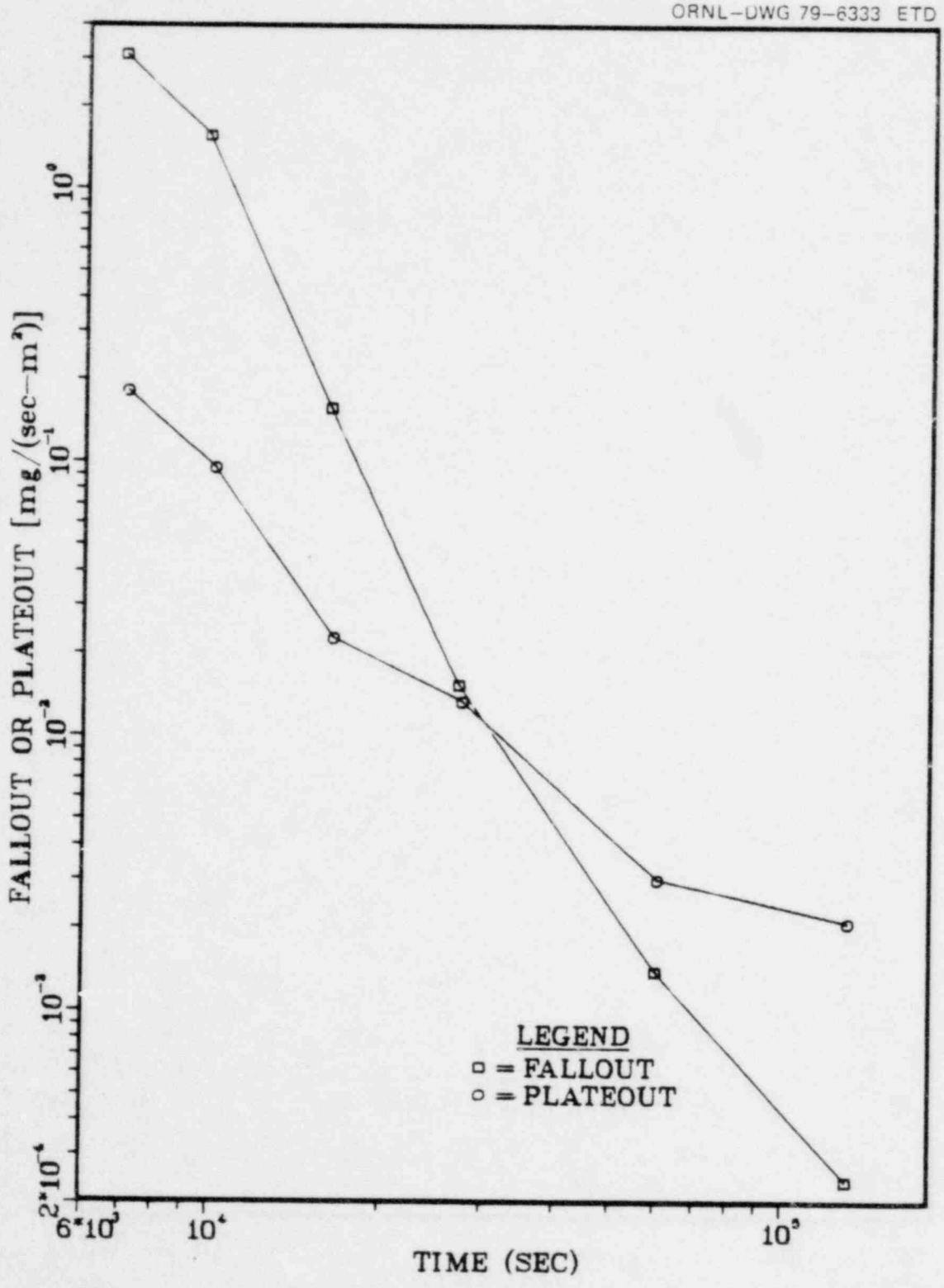

Fig. 35. Fallout and plateout rates vs time for Na_2O aerosol for NSPP test 301.

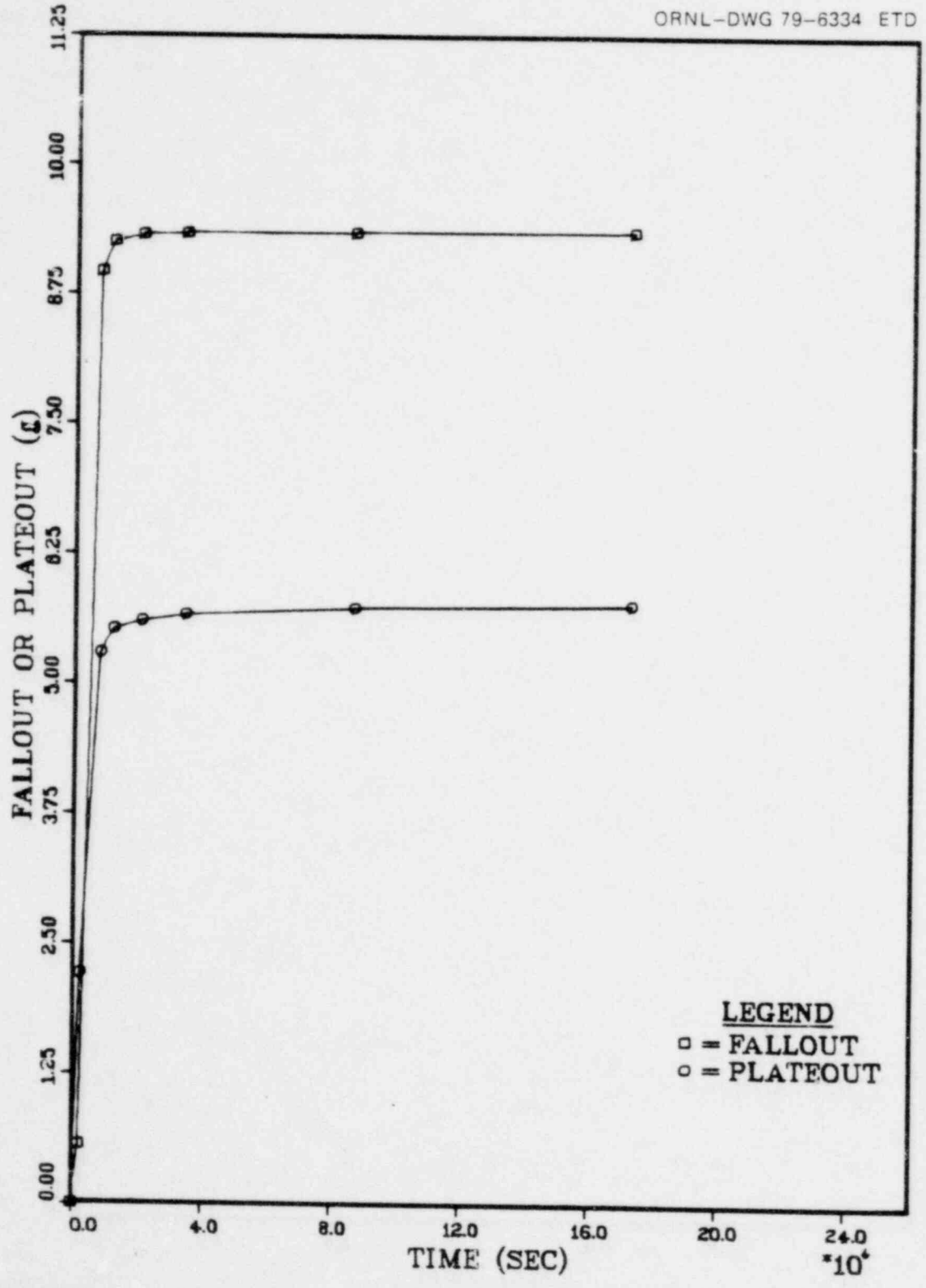

Fig. 36. Cumulative fallout and plateout vs time for U_3O_8 aerosol for NSPP test 301.

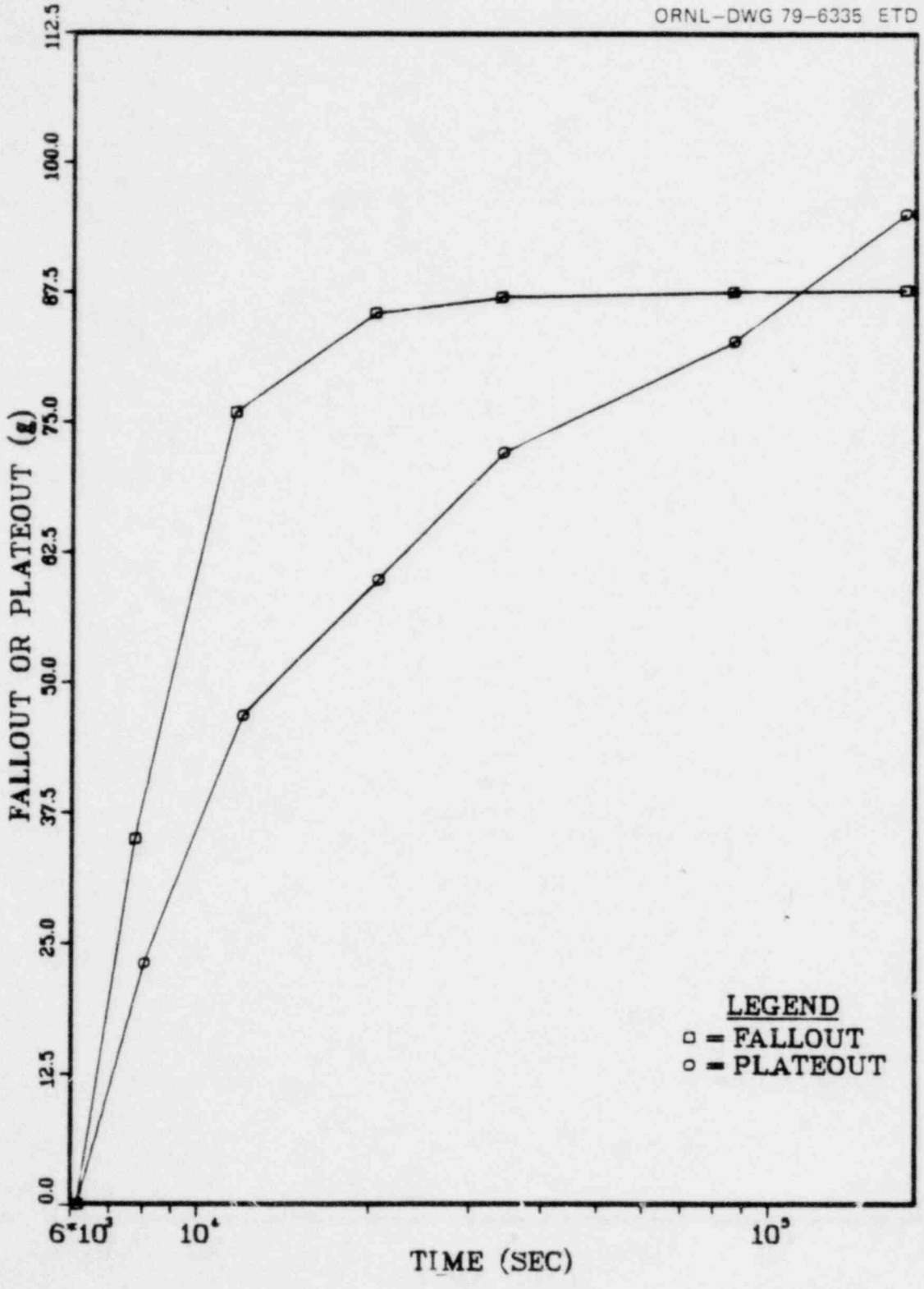

Fig. 37. Cumulative fallout and plateout vs time for Na_2O aerosol for NSPP test 301.

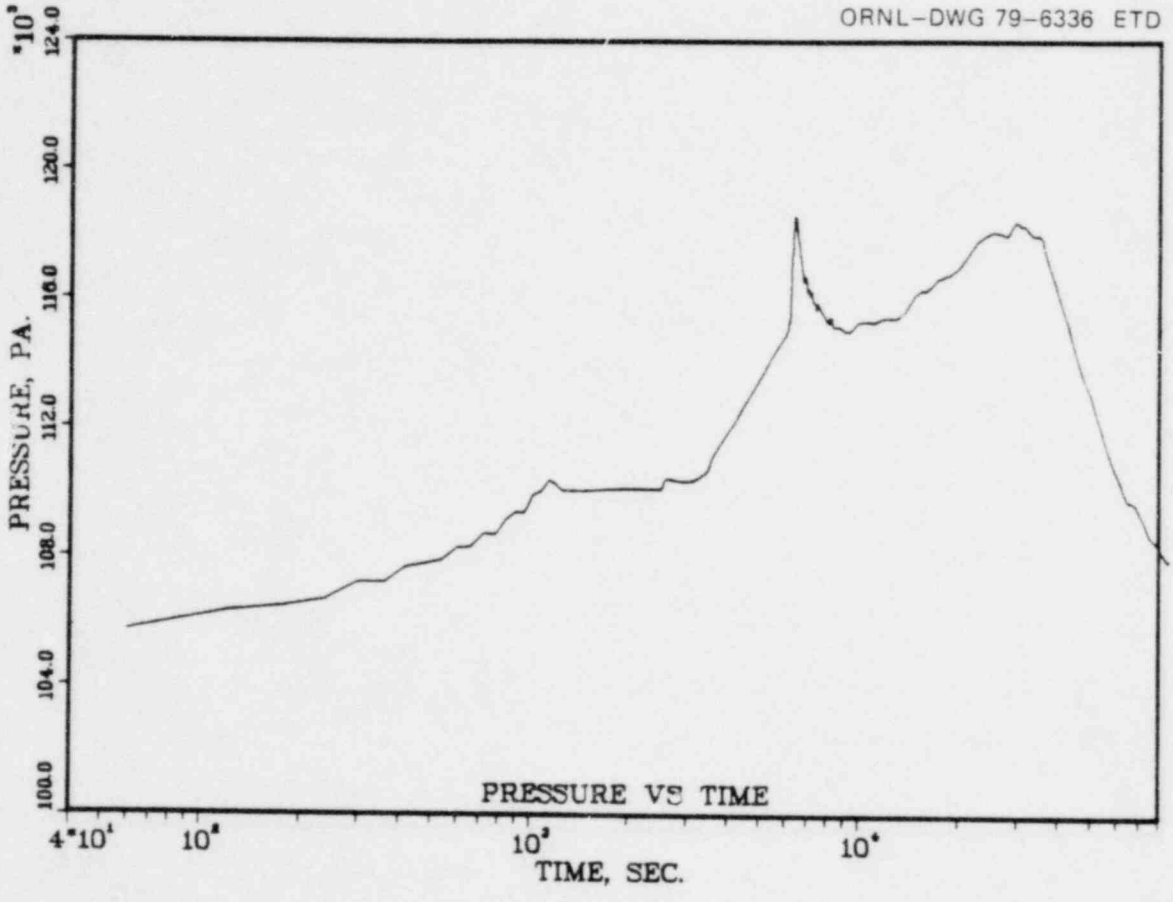

Fig. 38. In-vessel pressure vs time for NSPP test 301.

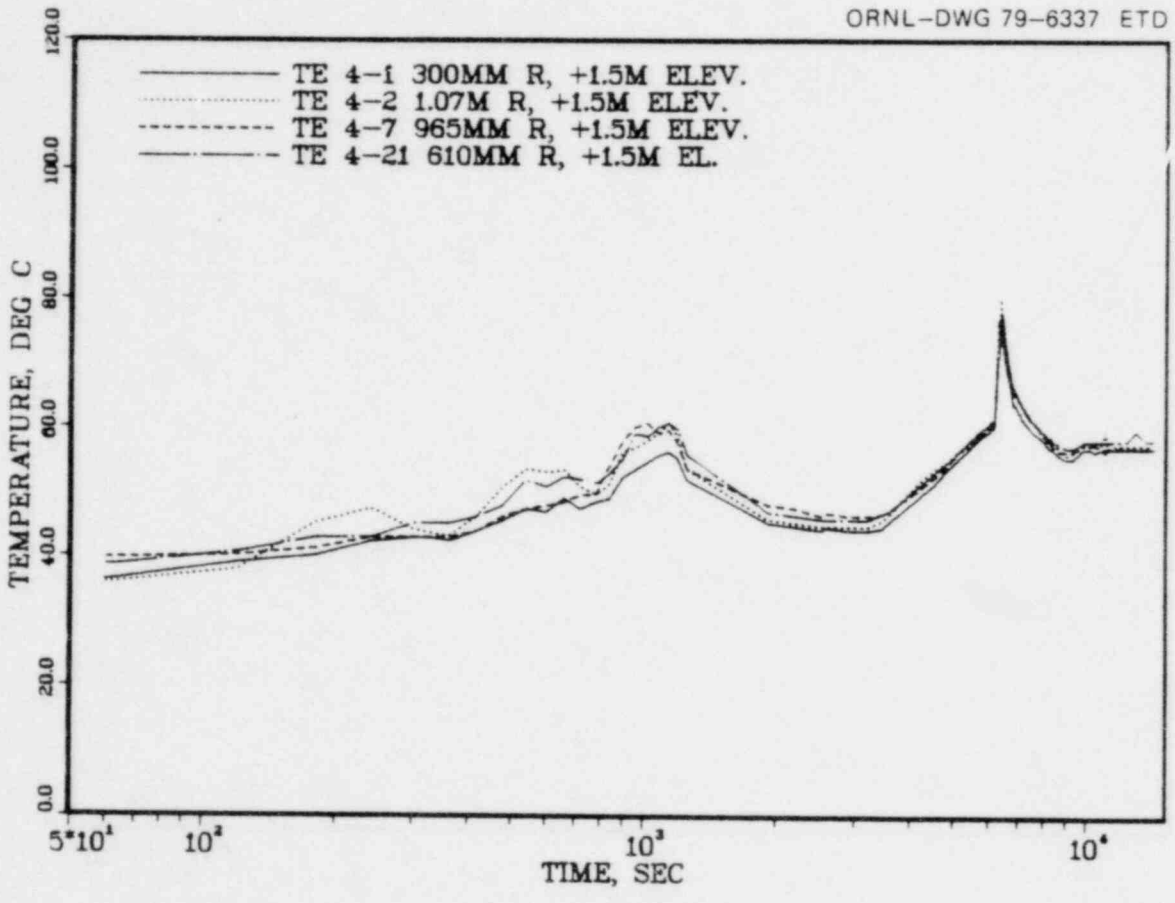

Fig. 39. Temperature measurements at 1.5 m above the vessel midplane for NSPP test 301.

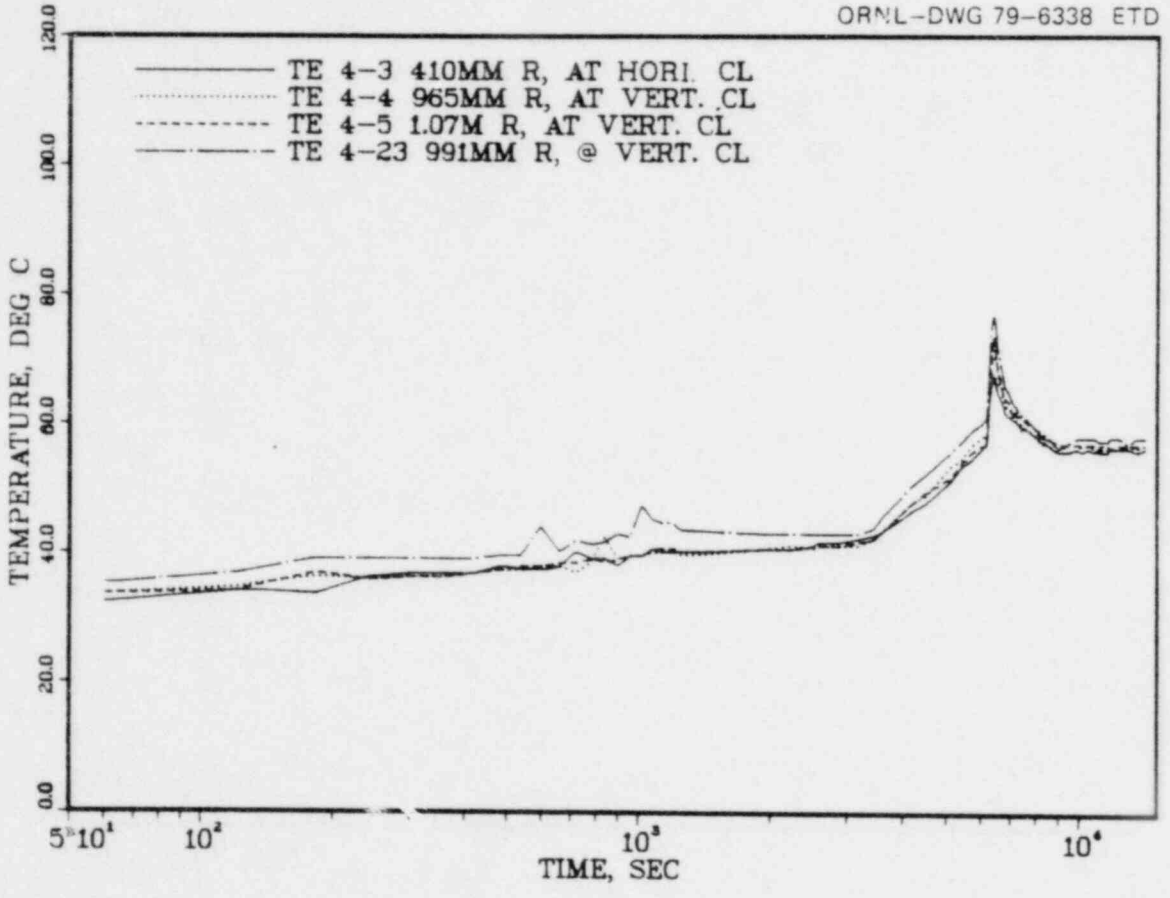

Fig. 40. Temperature measurements at the vessel midplane for NSPP test 301.

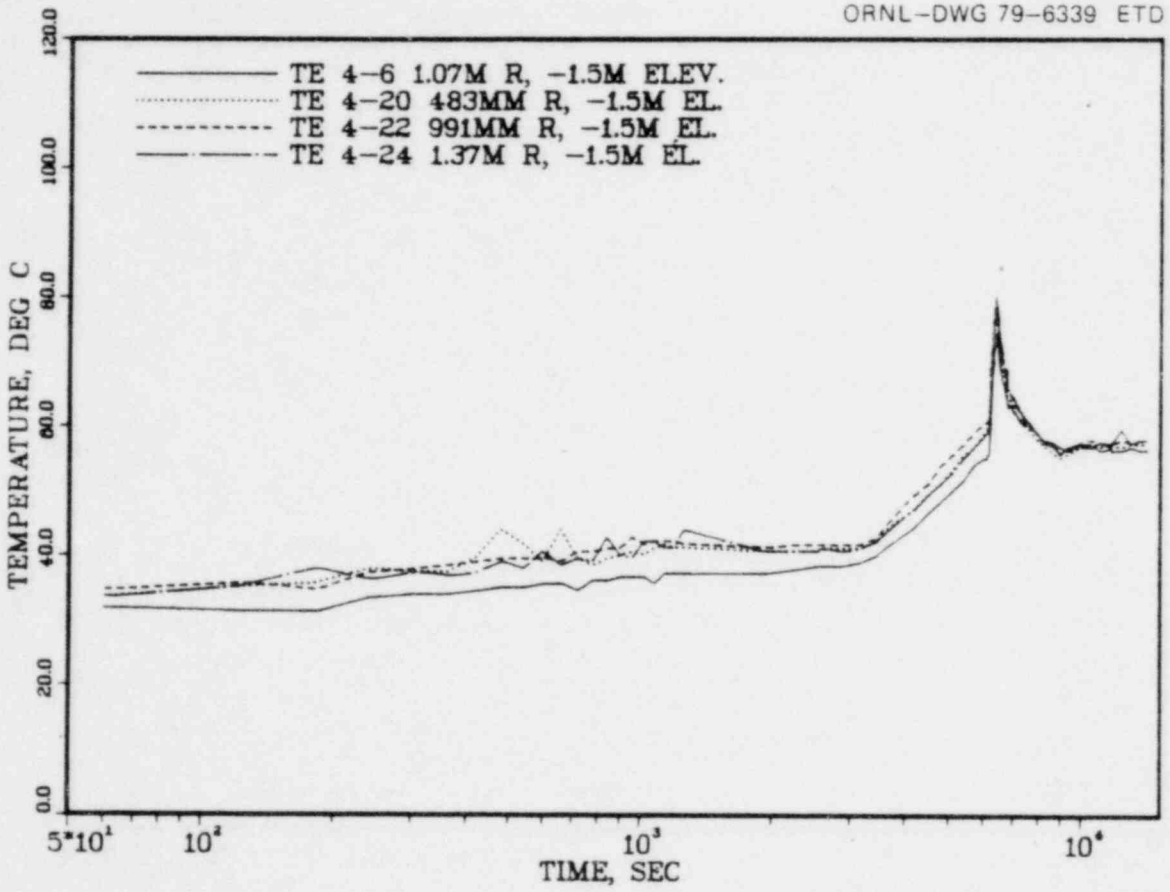

Fig. 41. Temperature measurements at 1.5 m below the vessel midlane for NSPP test 301.

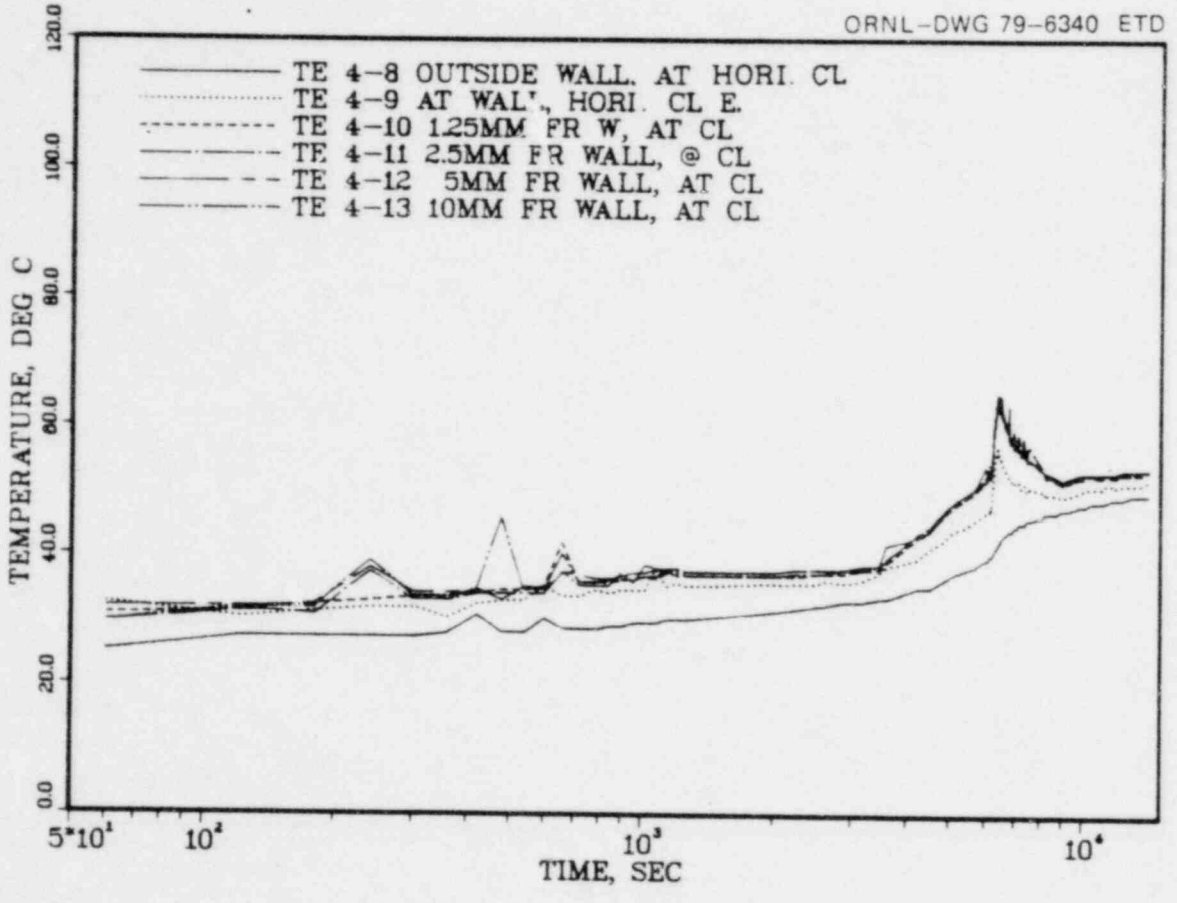

Fig. 42. Temperature measurements at the vessel midplane for NSPP test 301.

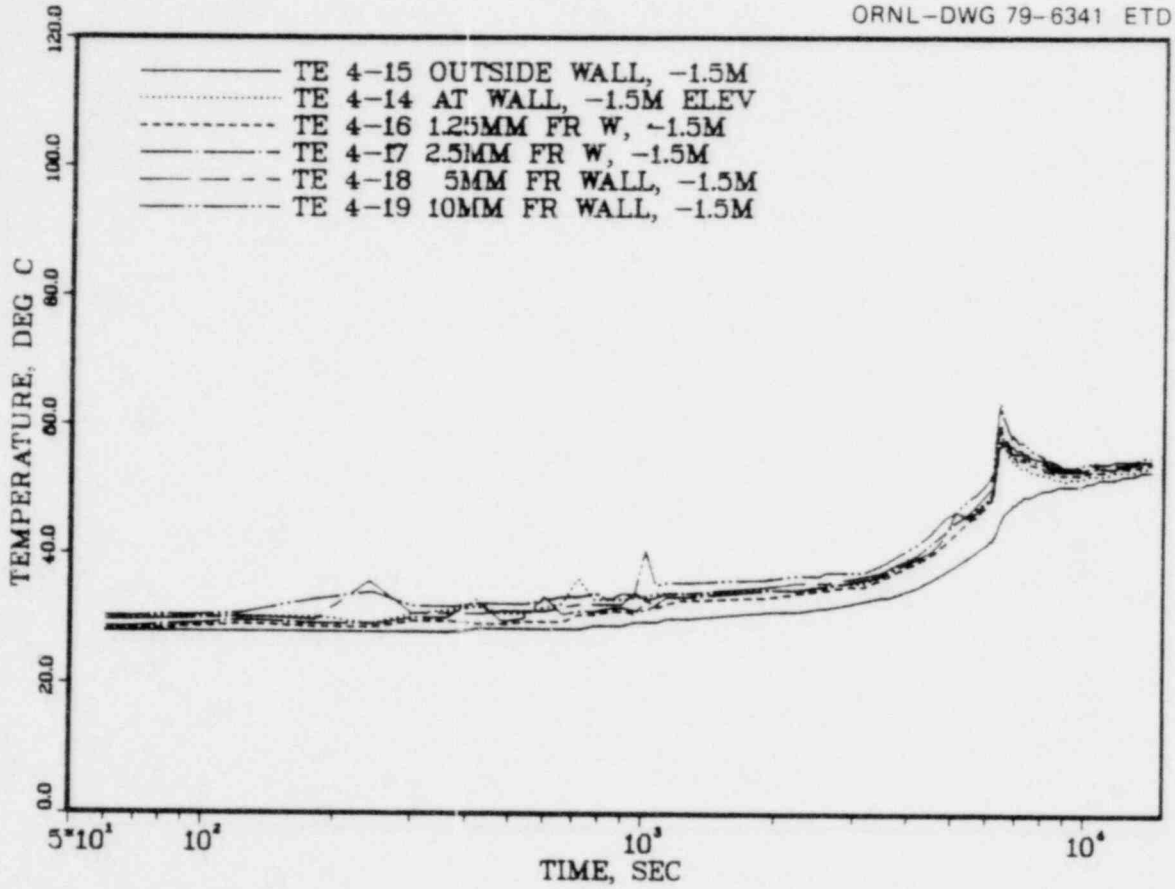

Fig. 43. Temperature measurements near the wall at 1.5 m below the vessel midplane for NSPP test 301.

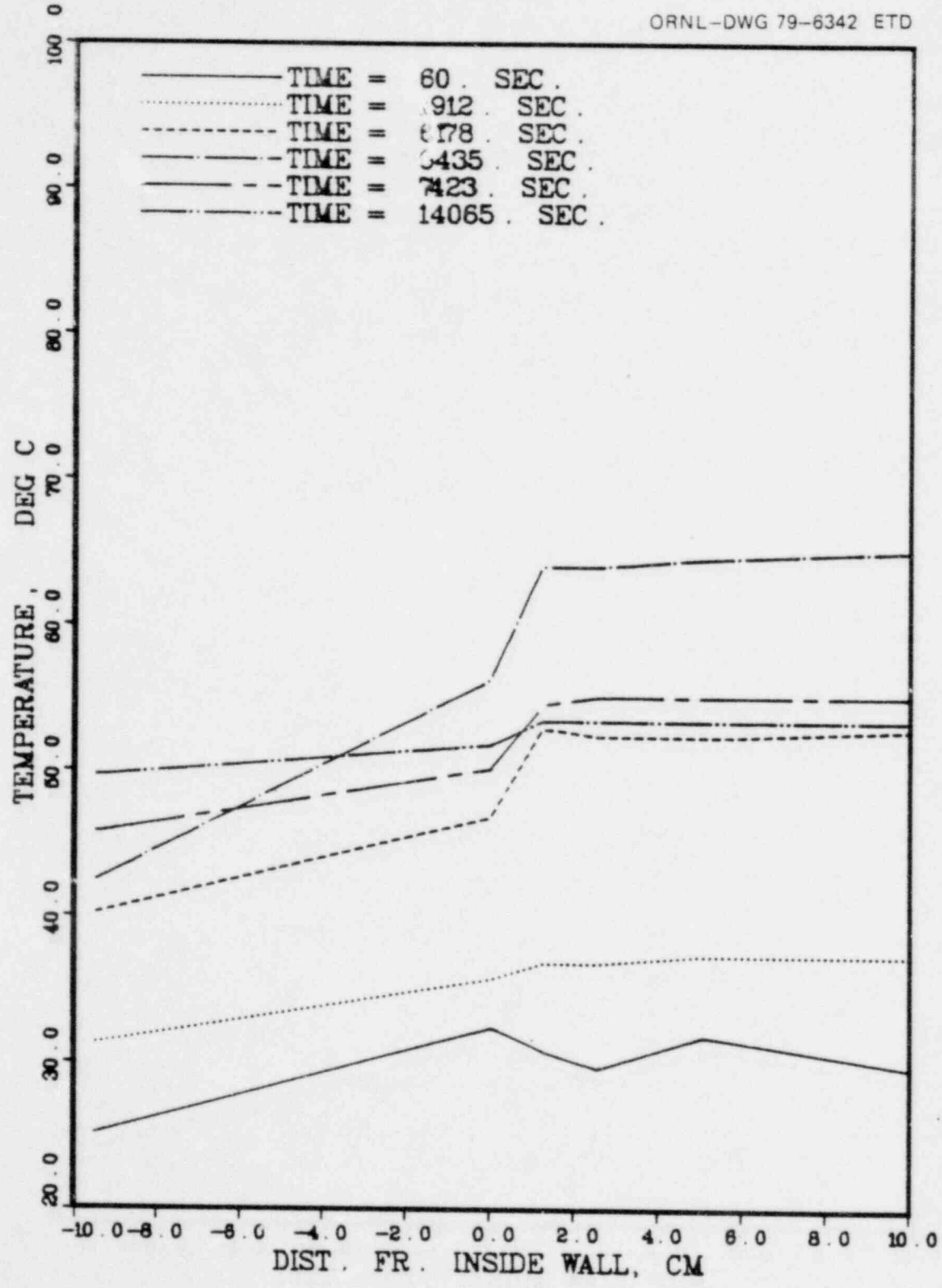

Fig. 44. Temperature measurements along the midplane of the NSPP vessel for NSPP test 301.

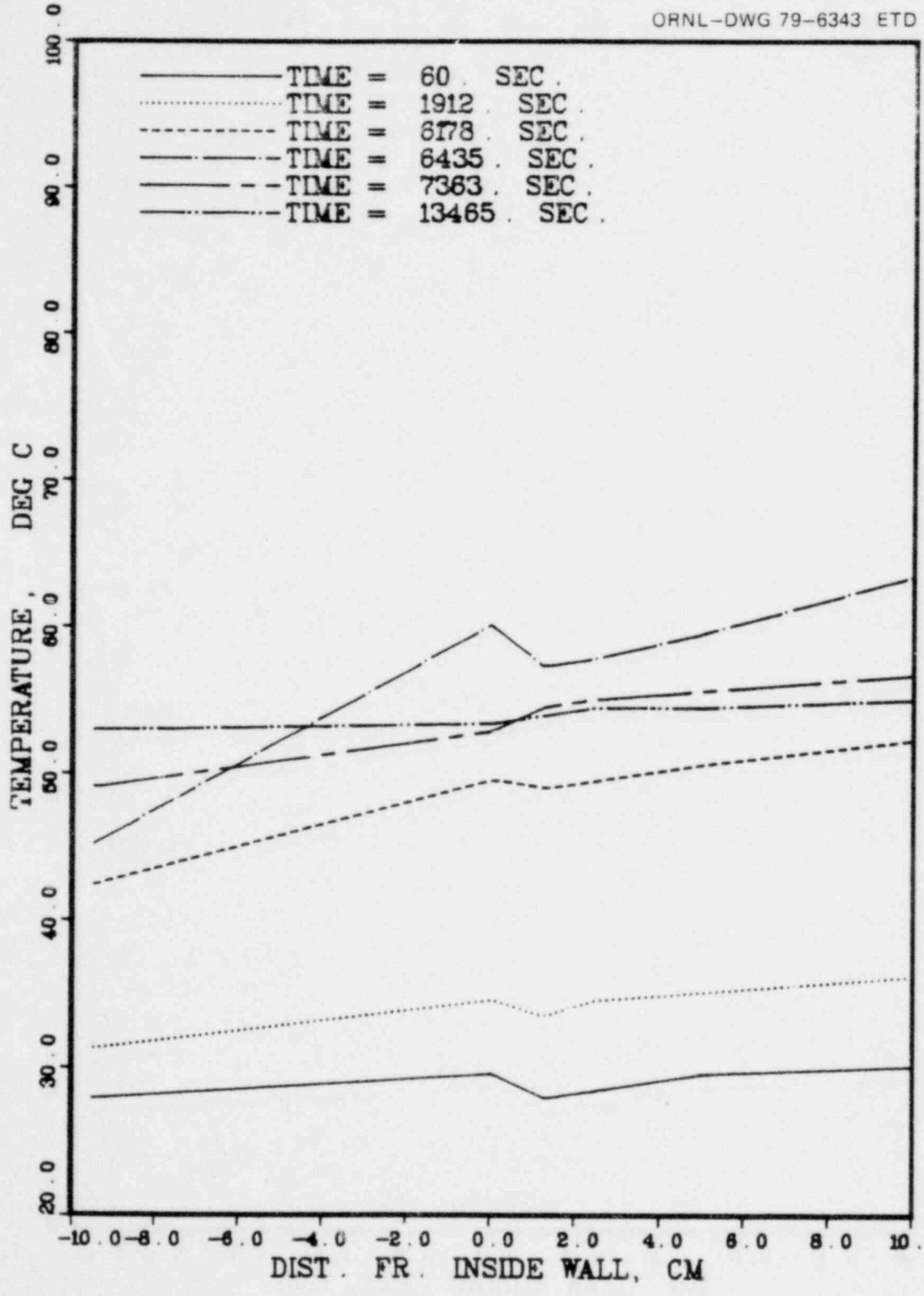

Fig. 45. Temperature measurements at 1.5 m below the vessel midplane for NSPP test 301.

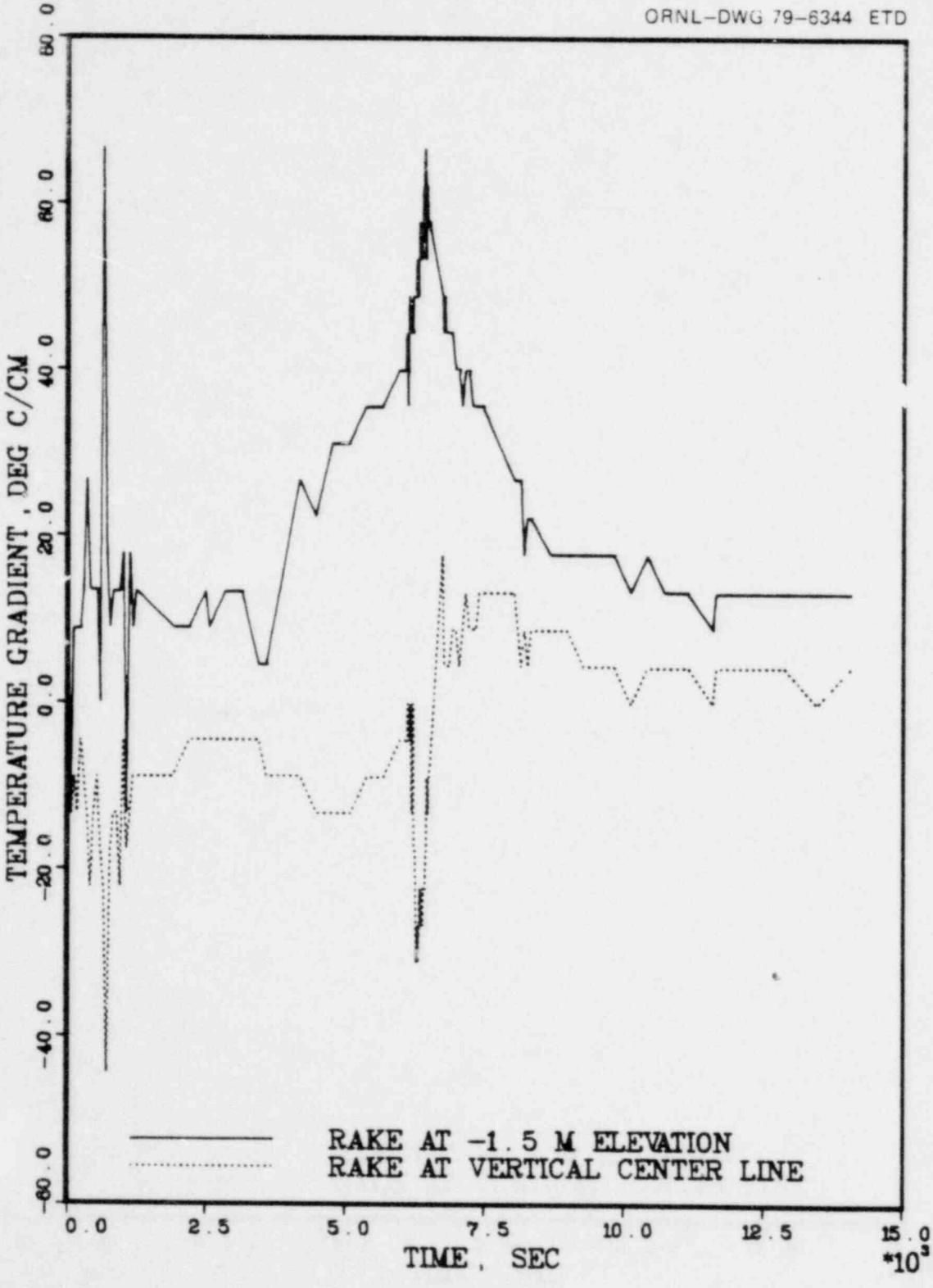

Fig. 46. Temperature gradients at the wall for NSPP test 301.

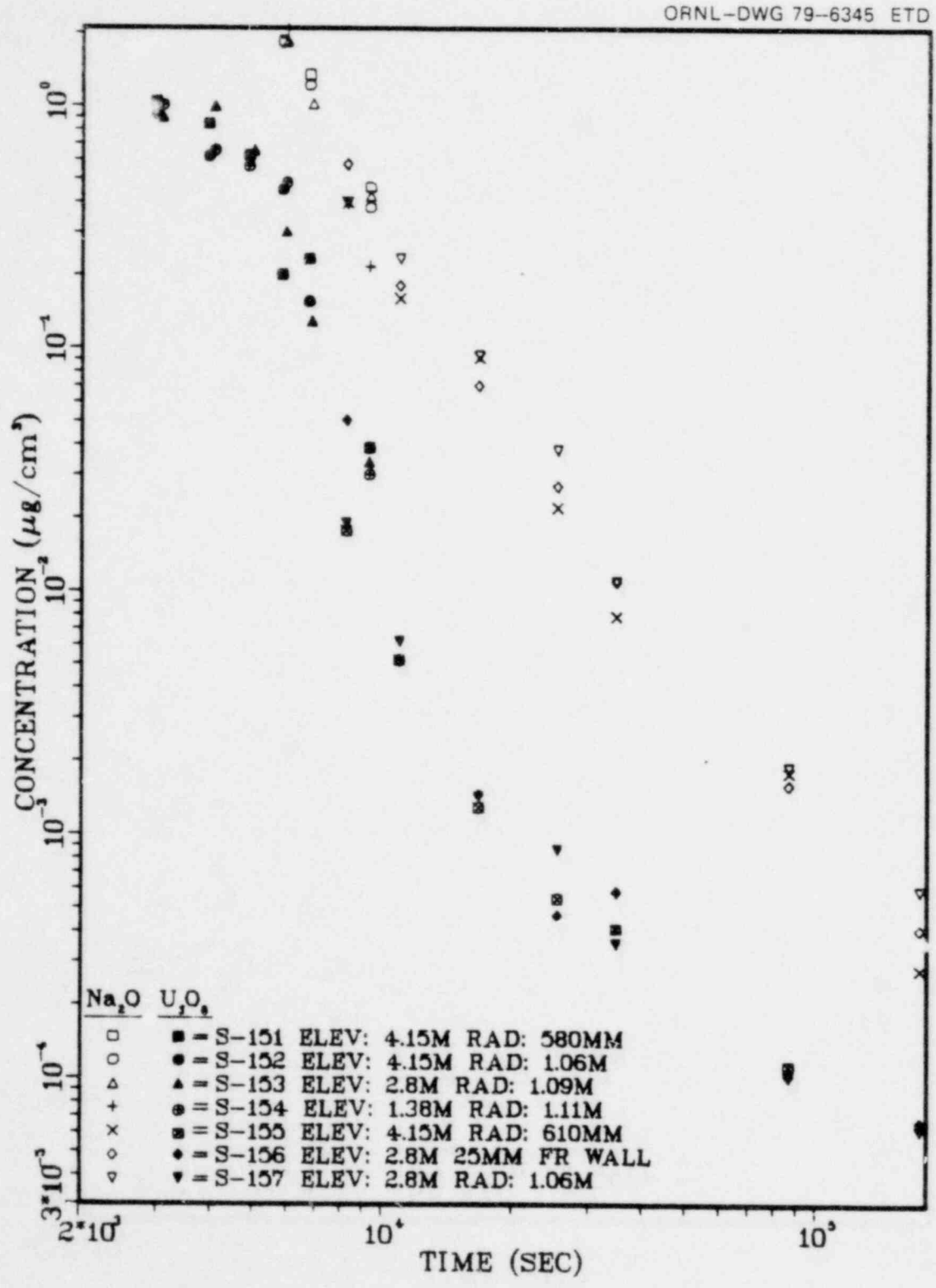

Fig. 47. Mass concentrations vs time for sodium oxide and uranium oxide aerosols for NSPP test 302.

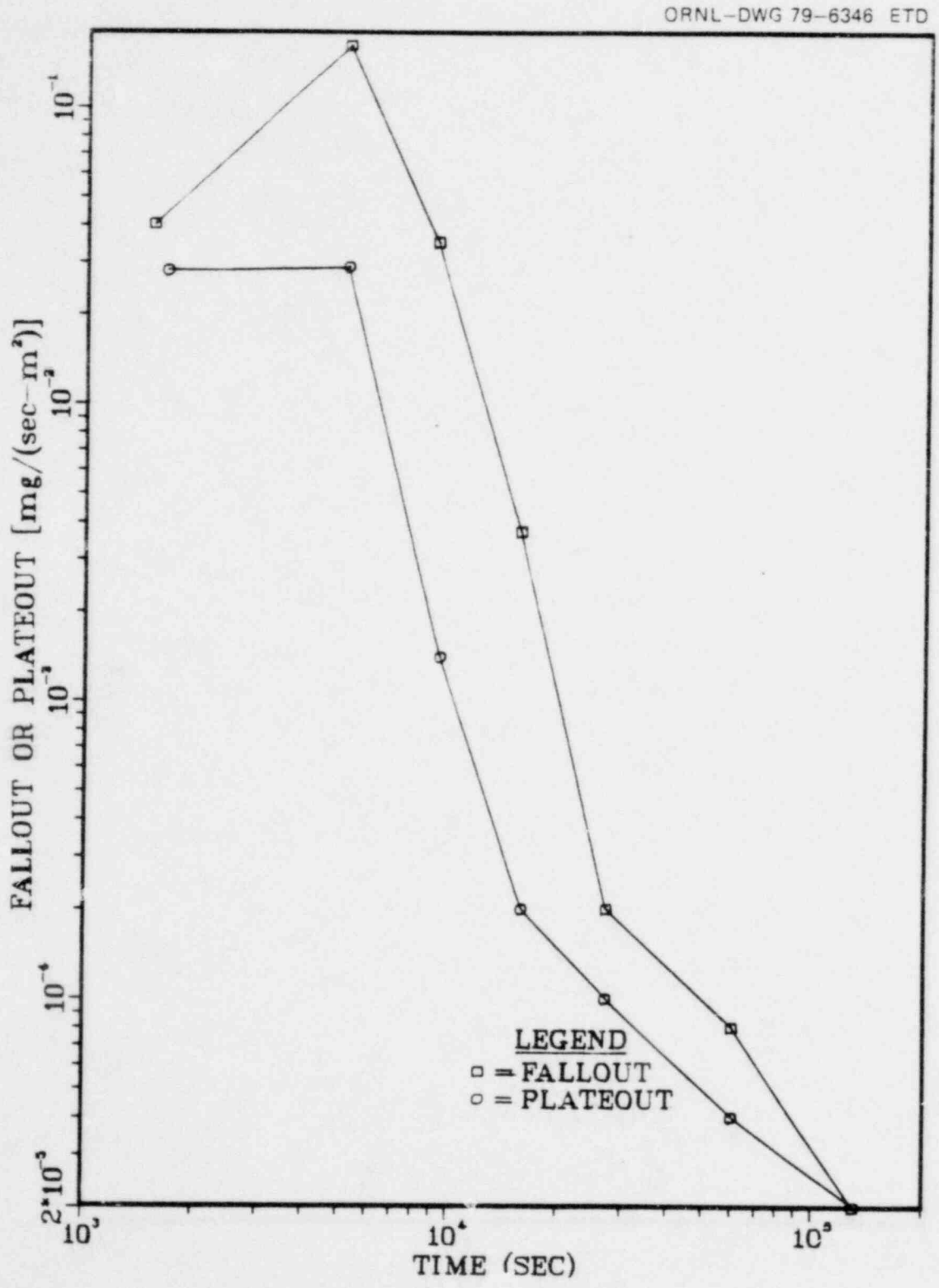

Fig. 48. Fallout and plateout rates vs time for U_3O_8 aerosol for NSPP test 302.

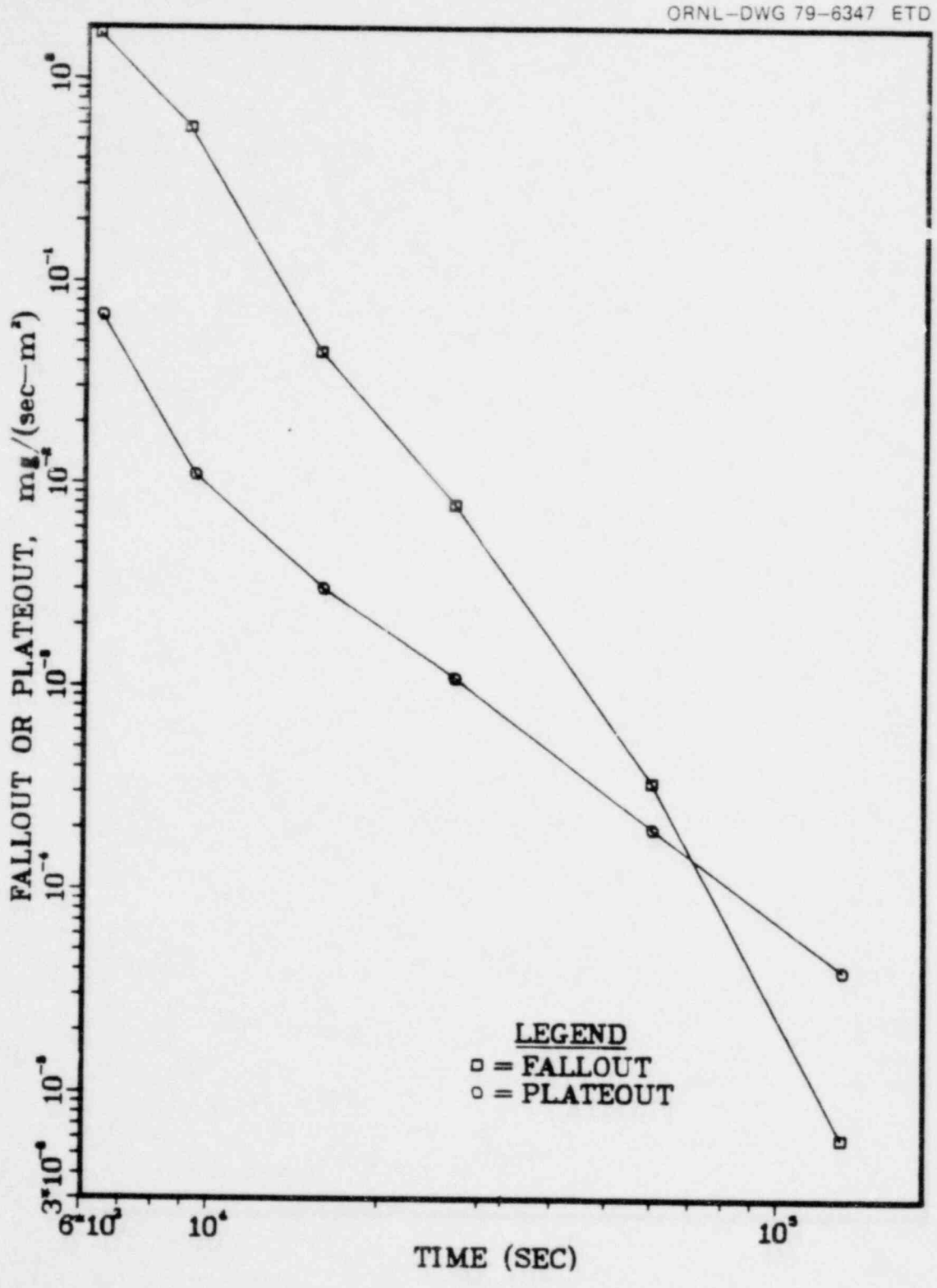

Fig. 49. Fallout and plateout rates vs time for Na_2O aerosol for NSPP test 302.

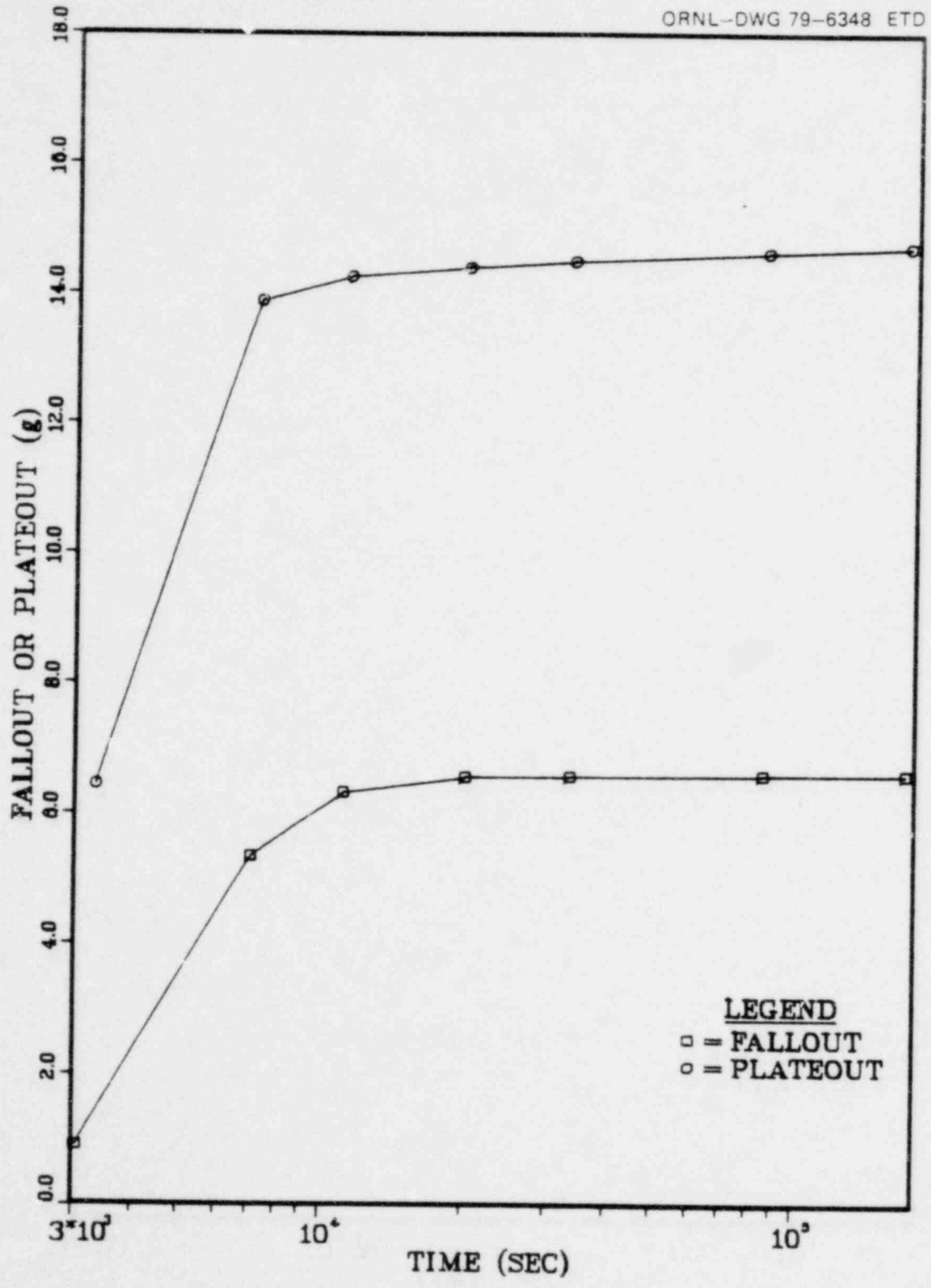

Fig. 50. Cumulative fallout and plateout vs time for U_3O_8 aerosol for NSPP test 302.

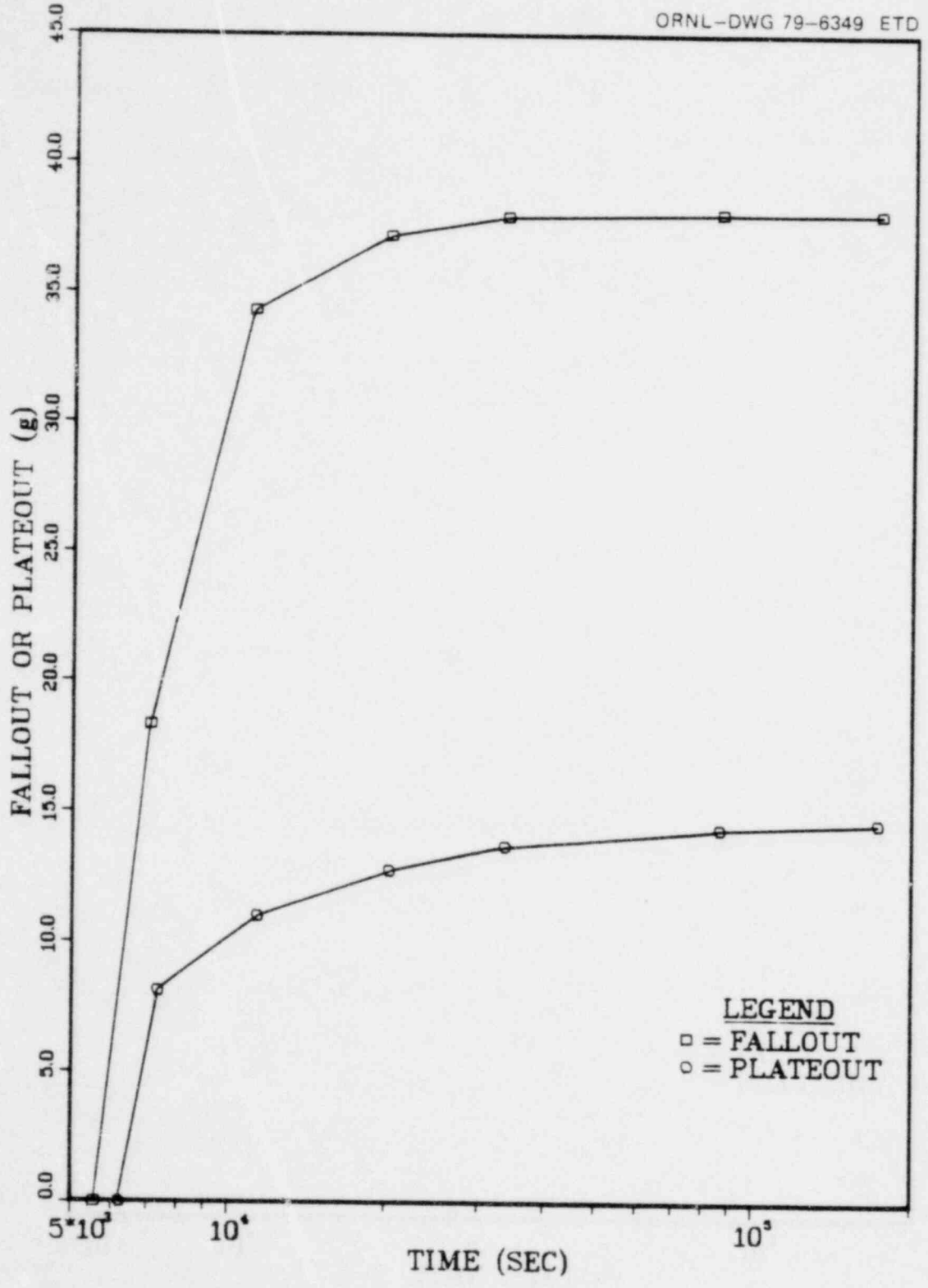

Fig. 51. Cumulative fallout and plateout vs time for Na_2O aerosol for NSPP test 302.

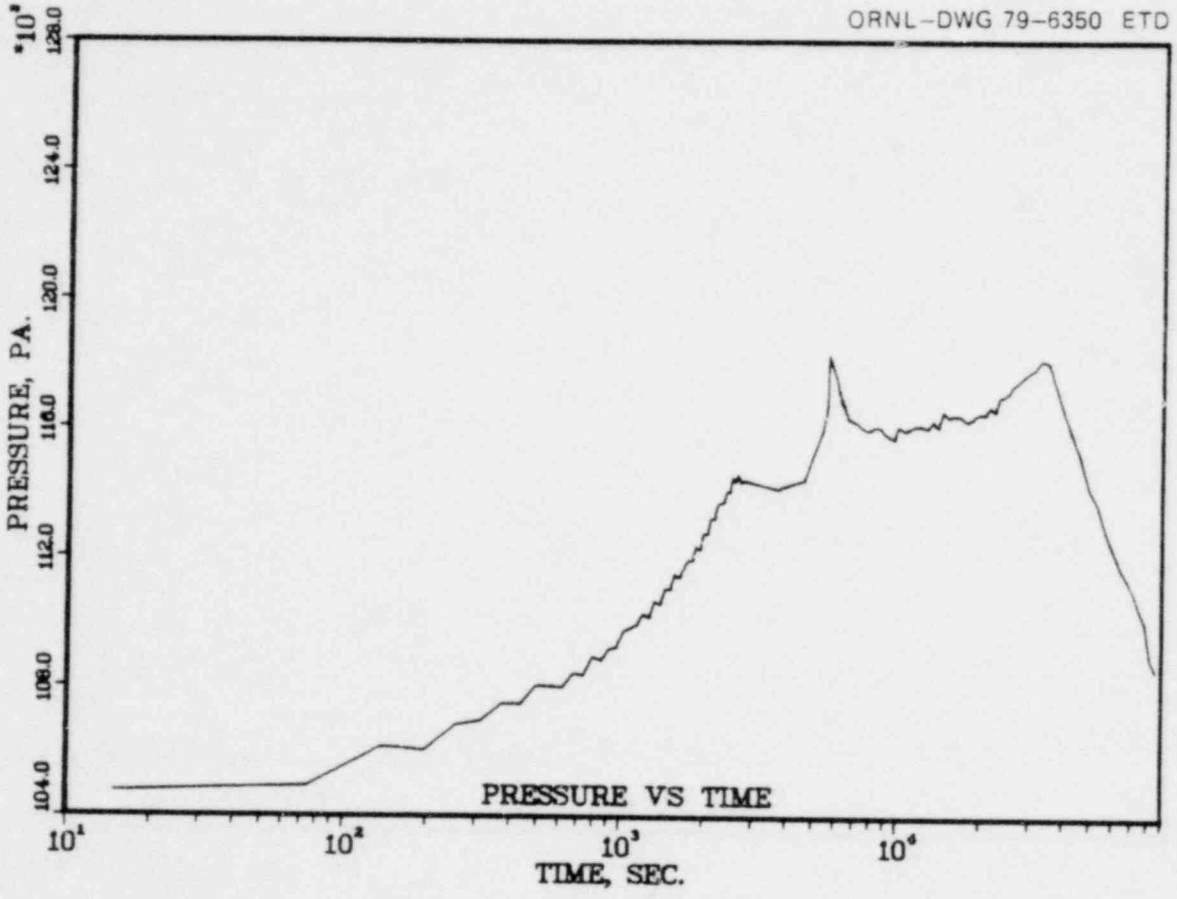

Fig. 52. In-vessel pressure vs time for NSPP test 302.

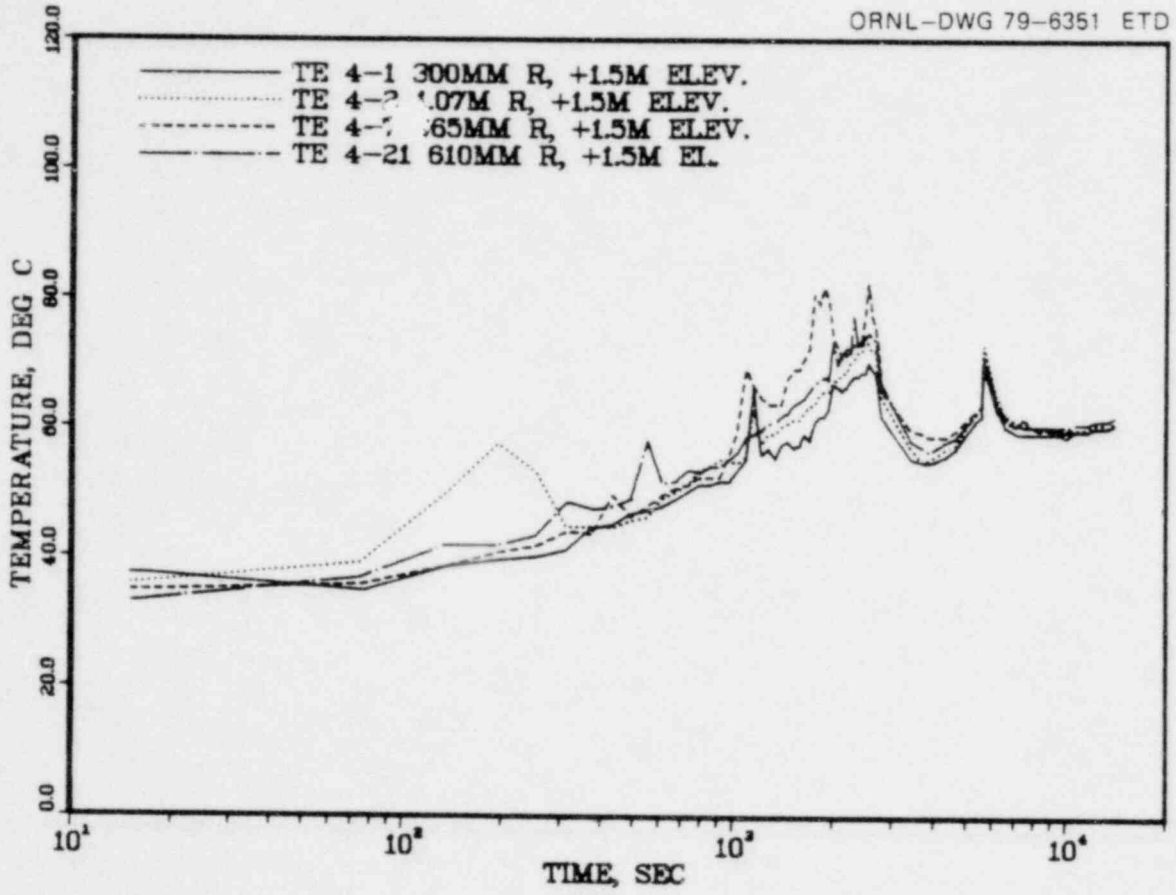

Fig. 53. Temperature measurements at 1.5 m above the vessel midplane for NSPP test 302.

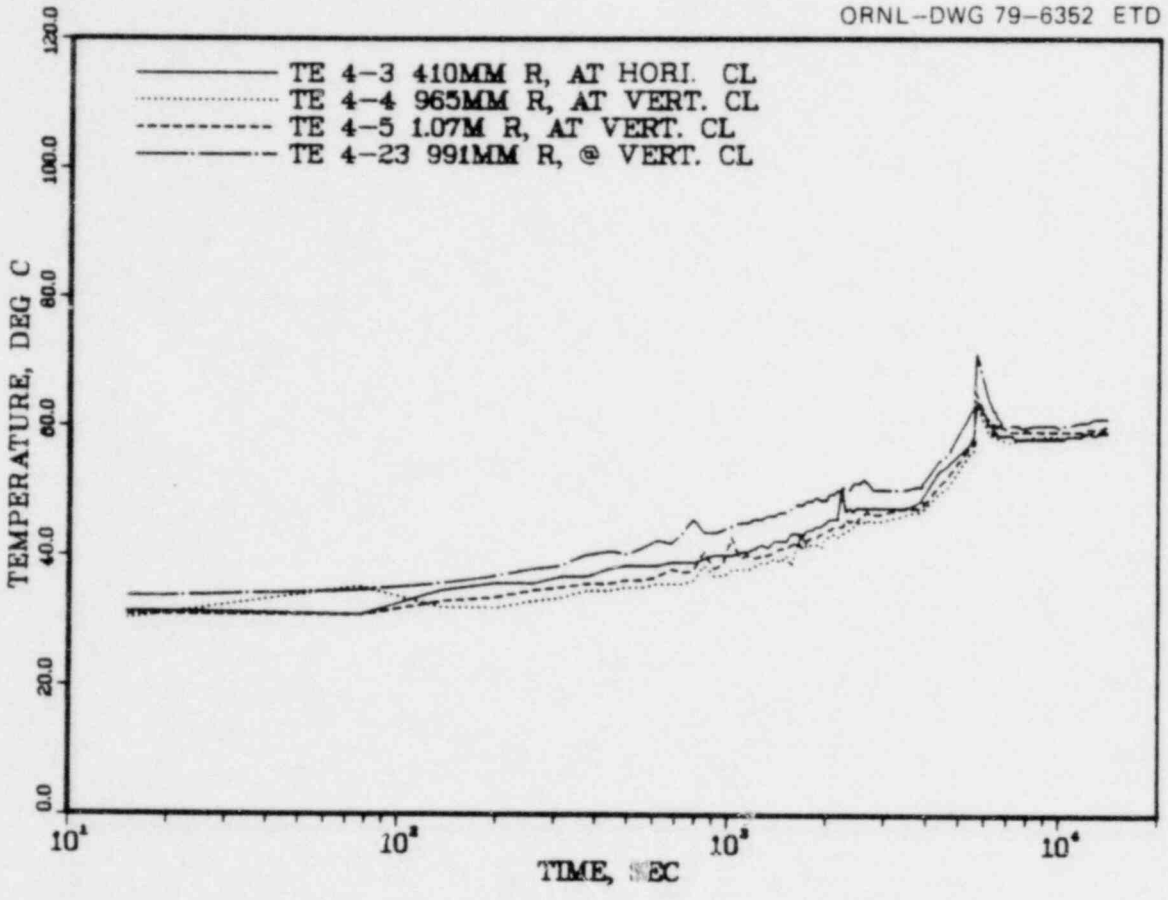

Fig. 54. Temperature measurements at the vessel midplane for NSPP test 302.

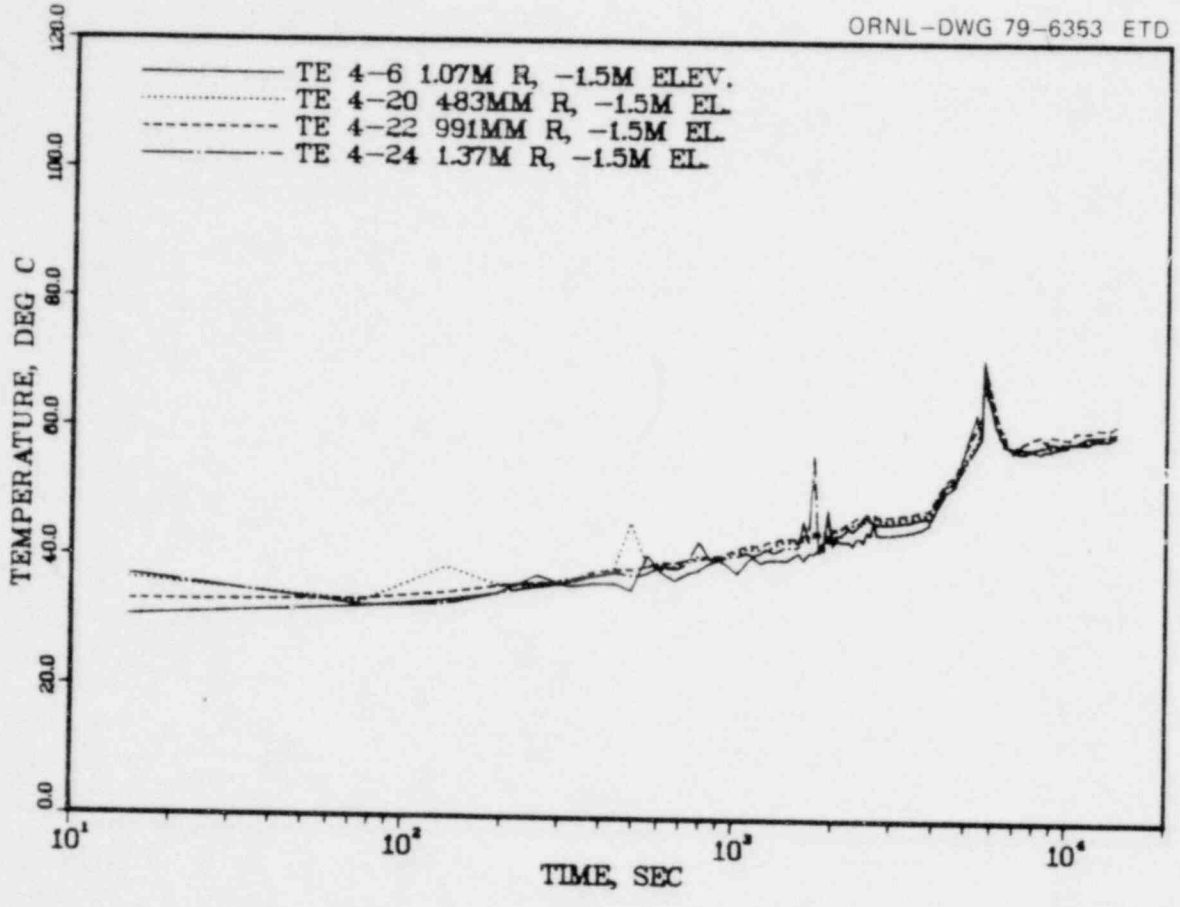

Fig. 55. Temperature measurements at 1.5 m below the vessel midlane for NSPP test 302.

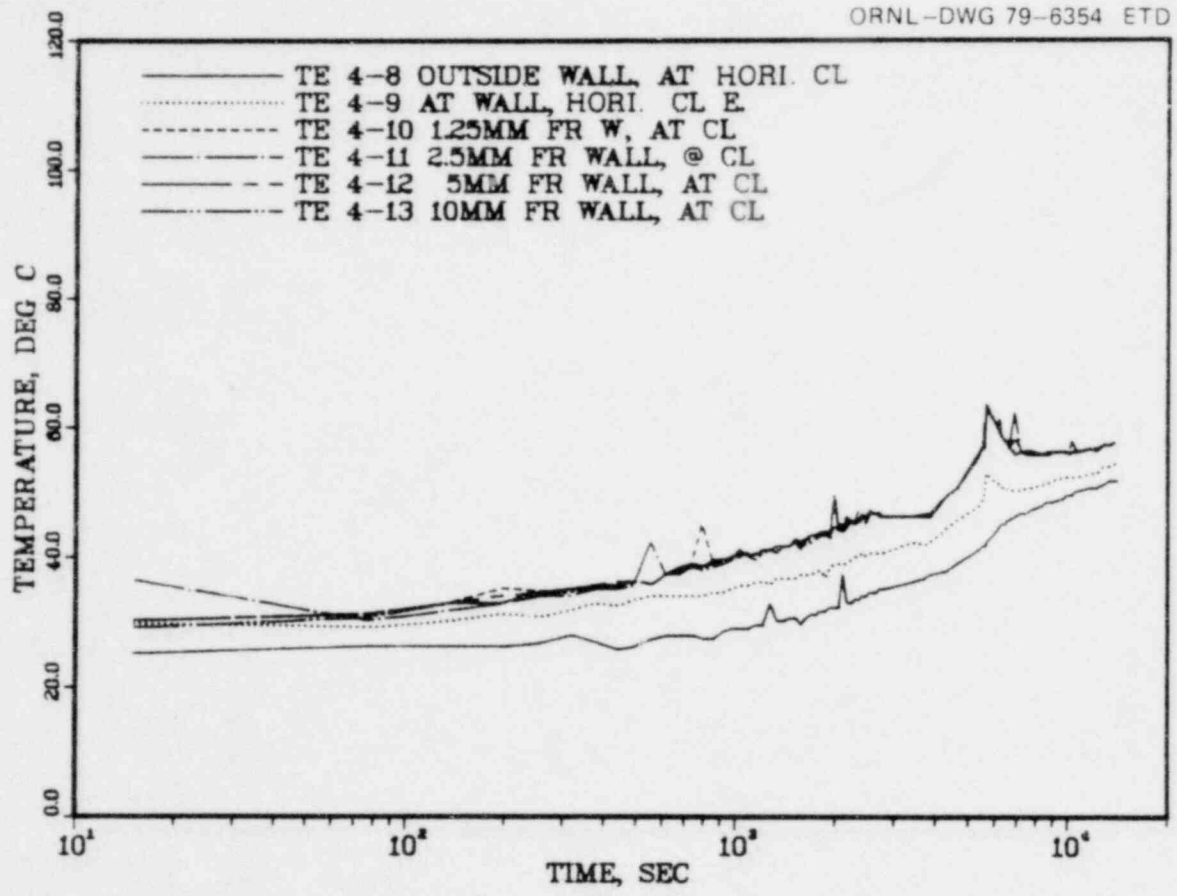

Fig. 56. Temperature measurements near the wall at the vessel midplane for NSPP test 302.

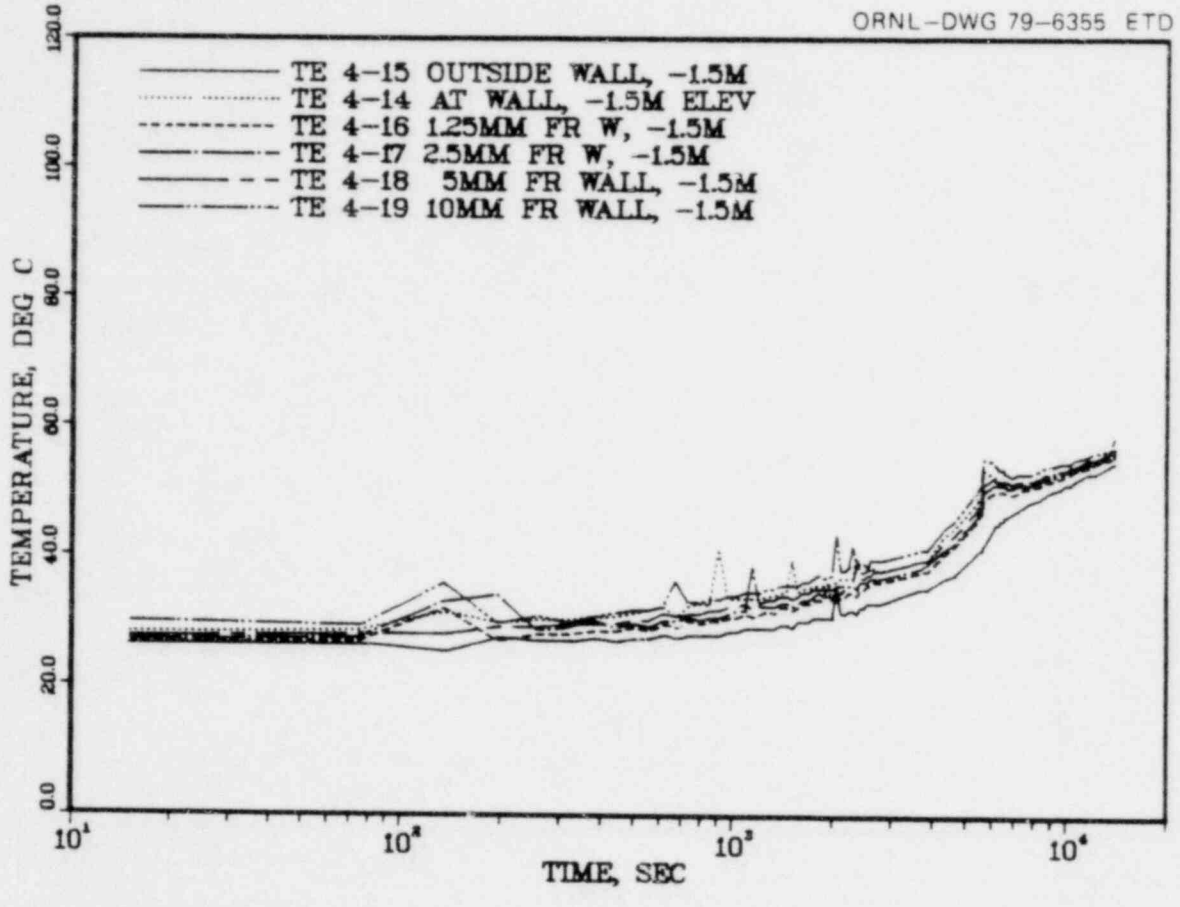

Fig. 57. Temperature measurements near the wall at 1.5 m below the vessel midplane for NSPP test 302.

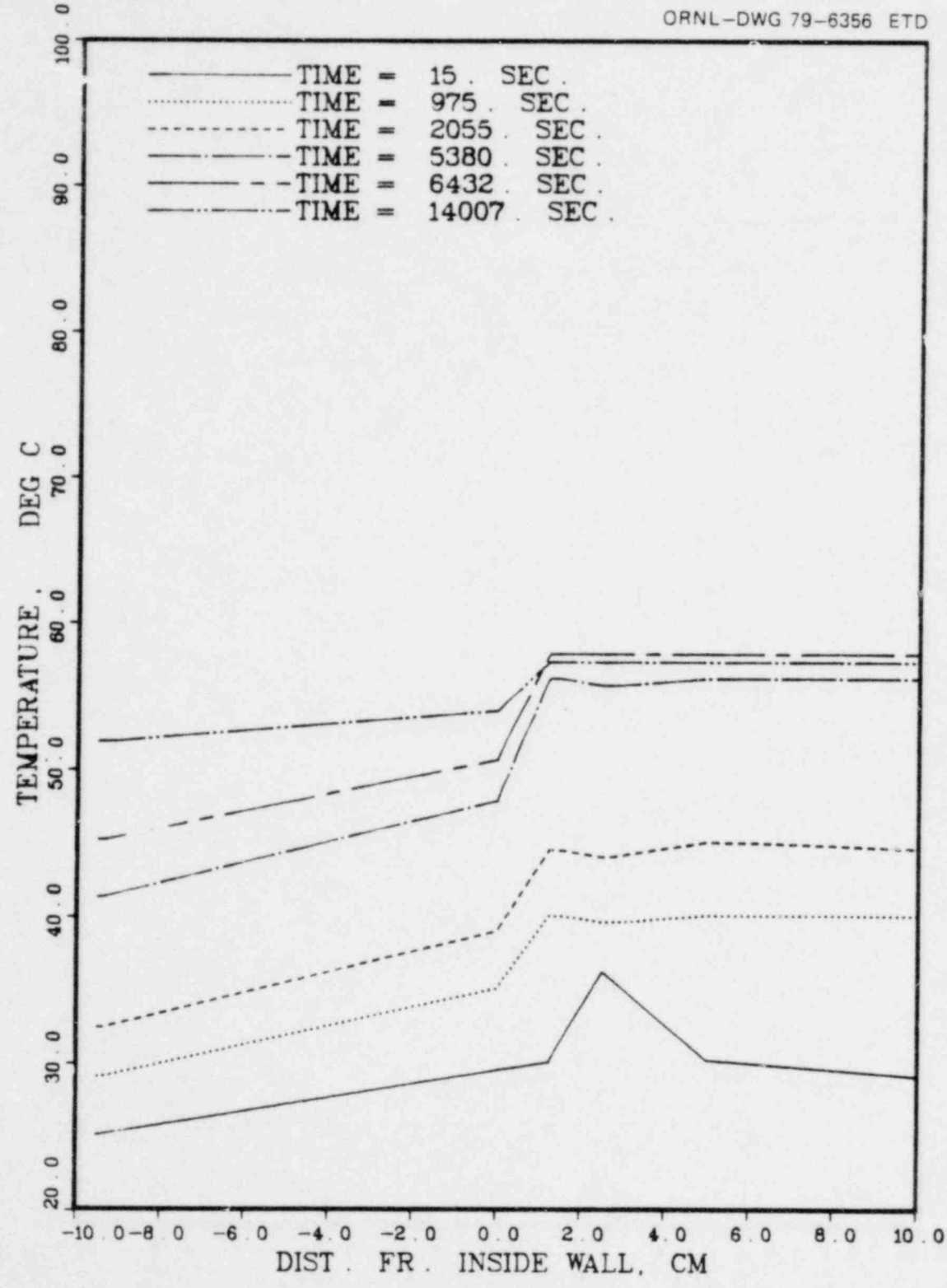

Fig. 58. Temperature measurements along the vessel midplane for NSPP test 302.

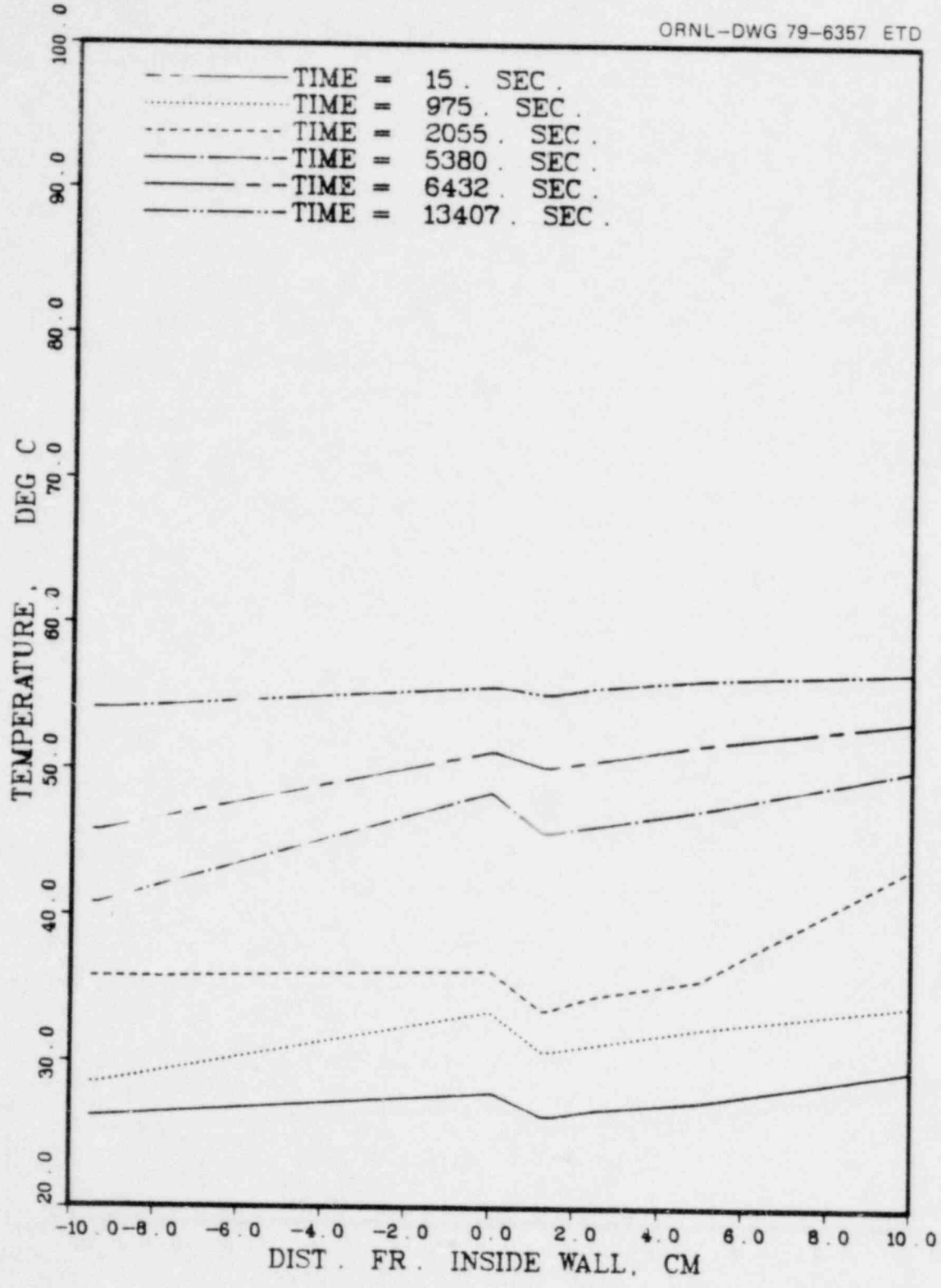

Fig. 59. Temperature measurements at 1.5 m below the vessel midplane for NSPP test 302.

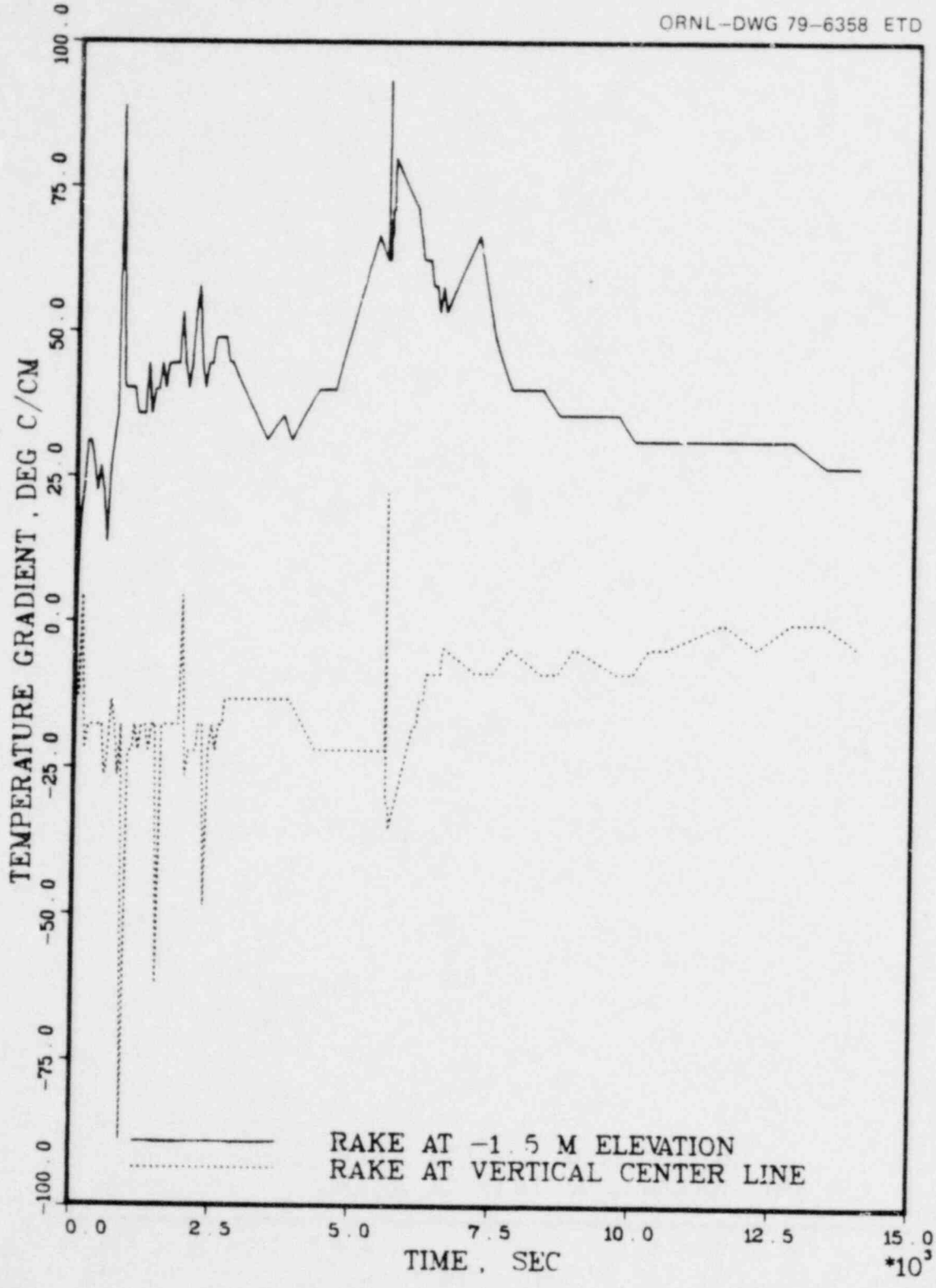

Fig. 60. Temperature gradients at the wall for NSPP test 302.

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