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Development of an In-Line Grout Meter for Improved Quality Control: January 1990 Progress Report

G. D. Del Cul
T. M. Gilliam

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Chemical Technology Division

DEVELOPMENT OF AN IN-LINE GROUT METER FOR IMPROVED QUALITY CONTROL: JANUARY 1990 PROGRESS REPORT

G. D. Del Cul
T. M. Gilliam

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PREFACE

This report meets requirements for Milestone 3.2, "Report Results of Grout Meter Bench-Top Tests," as described in Statement-of-Work TMG-SOW-90, Revision No. 1, in support of the Westinghouse Hanford Grout Disposal Program.

EXECUTIVE SUMMARY

Stabilization/solidification (S/S) technology is the most widely used technique for the treatment and ultimate disposal of both radioactive and chemically hazardous waste. Cement-based products, commonly referred to as grouts, are the predominate materials of choice due to their associated low processing costs, compatibility with a wide variety of disposal scenarios, and ability to meet stringent processing and performance requirements.

It has long been recognized that there is a need for a monitor to use with freshly prepared grouts that would facilitate improved quality control. In the past, efforts in this area have not proven successful due to the fact that the freshly prepared grout tended to cake on the monitor probe, thus greatly reducing its effectiveness. This report documents progress to date on efforts at Oak Ridge National Laboratory (ORNL) in support of the Westinghouse Hanford Company Grout Technology Program to develop an in-line monitor for mix ratio verification and, hence, improved quality control in the Westinghouse Hanford Grout Treatment Facility (GTF).

Data have been presented which show that the electrical resistance of freshly prepared grouts is linear with respect to grout mix ratio over a wide range of values. The data serve to establish the merits for application to the Westinghouse Hanford GTF. The data further establish that special care must be maintained during design and installation to ensure that the electrodes are properly sealed. The data also indicate that a separate meter will be required in order to assess waste-feed variations.

In addition, the data provide guidance on future efforts to be addressed in subsequent progress reports. In particular, the data suggest that waste-feed variability may be the most important future task. Future efforts will be directed towards assessing the effects of (1) variation in waste solids content and (2) variation in waste dilution.

DEVELOPMENT OF AN IN-LINE GROUT METER FOR IMPROVED QUALITY CONTROL: JANUARY 1990 PROGRESS REPORT

G. D. Del Cul
T. M. Gilliam

ABSTRACT

This report documents progress to date on the development of an in-line grout meter. The grout meter, which is based on measurement of grout electrical resistance/capacitance, is intended to provide real-time measurements of grout mix ratio (ratio of dry-solids-blend materials to waste).

1. INTRODUCTION

Stabilization/solidification (S/S) technology is the most widely used technique for the treatment and ultimate disposal of both radioactive and chemically hazardous waste. Cement-based products, commonly referred to as grouts, are the predominate materials of choice due to their associated low processing costs, compatibility with a wide variety of disposal scenarios, and ability to meet stringent processing and performance requirements.

It has long been recognized that there was a need for a monitor for use with freshly prepared grouts that would facilitate improved quality control. In the past, efforts in this area have not proven successful because the freshly prepared grout tended to cake on the monitor probe, thus greatly reducing its effectiveness. This report documents progress to date on efforts at Oak Ridge National Laboratory (ORNL) in support of the Westinghouse Hanford Company Grout Technology Program to develop an in-line monitor for mix ratio verification and, hence, improved quality control in the Westinghouse Hanford Grout Treatment Facility (GTF).

2. BACKGROUND

This section describes the expected behavior of a freshly prepared grout, hereafter simply referred to as grout, when subjected to an alternating electrical field. As such, it provides the basis for the grout-meter development.

2.1 THEORY

When a dry-solids blend containing cement materials is mixed with an aqueous waste to form a grout, a series of chemical reactions take place. The reactions of the various cementitious phases proceed at different rates and involve both hydrolysis and hydration. All of the physicochemical properties are going to change while the system evolves from the initial plastic state to the hardened state.

When an electrical field is applied to a grout, some ions are free to drift and produce a conduction effect. In addition, other charges that are bound to the solid particles and, hence, not free to drift, can oscillate under the action of an alternating electric field. The electrical behavior of this system can be modeled as a circuit with resistive (R) and capacitive (C) elements in parallel. The impedance (Z) of such a circuit is given by:

$$Z = \frac{R}{\sqrt{(2 \cdot f \cdot C \cdot R)^2 + 1}}, \tag{1}$$

where f is the frequency of the applied electrical field. At a relatively high frequency (on the order of 1 kHz), the electrical measurement on the grout is relatively insensitive to the movement of the grout as a whole (e.g., grout flow through a pipe). In addition, the fast alternating current inhibits the electrolysis of the solution because any reaction induced during the first half of a cycle will be reversed by the second half of the cycle.

2.2 APPLICATION TO GROUT-METER DEVELOPMENT

When the dry-solids-blend materials are mixed with the aqueous waste, there is an initial fast adsorption of the liquid on the surface of the solid particles. Associated with this adsorption are the creation of an electrical double layer along the surface of the solid particles as well as dissolution of soluble components and some hydrolysis. This initial stage, which is virtually instantaneous, is followed by an interval of nearly constant behavior that is often referred to as the dormant period. This dormant period should result in a stable electrical response from an applied electrical field for a period of

several minutes to several hours, depending on the grout composition and meter configuration.

For a given meter geometry, the resistance of the system will increase with increases in mix ratio (i.e., the ratio of dry-solids blend to waste) due to the growing fraction of volume occupied by poorly conducting (as compared with the liquid waste) solids. In addition, the solid particles can affect the movement of some of the free ions in solution. If movement of some of these ions is not parallel to the applied electrical field because of the dispersion of the solid particles in the liquid phase, the resistance of the grout will be increased further.

The capacitance of the system is due to polarization processes following the alternation of the electrical field (i.e., a separation between centers of positive and negative charge). The nature of the different polarization processes will strongly depend on the frequency of the alternating current. At a frequency of 1 kHz, the two main processes are: (1) the orientation of both permanent and induced dipoles in the liquid phase in sympathy with the alternating electrical field, and (2) polarization of the double layer adjacent to the surface of the solid particles. As the mix ratio is increased, the amount of liquid phase present will decrease, and the capacitance due to the first process will diminish. On the other hand, the total solid particle surface area will grow as mix ratio increases, and the capacitance due to the second process will increase. However, the impact of the reduced liquid fraction is believed to be dominant, and the net effect should be a decrease in capacitance with an increase in mix ratio.

3. METER DEVELOPMENT

This section describes the equipment and experimental results to date. Figures and tables are presented in the text where appropriate. Additional figures and tables containing supporting data are located in Appendix A.

All data presented in this section used simulated 101-AW as the reference waste. The composition of simulated 101-AW is shown in Table 1. All grouts were prepared using a dry-solids blend consisting of 47 wt % ASTM Class F fly ash, 47 wt % granulated blast furnace slag, and 6 wt % Type I-II LA Portland cement.

Table 1. Major constituents in 101-AW waste

Component	Molarity (mol/L)
$NaAlO_2$	0.46
NaOH	2.49
$NaNO_2$	0.86
$NaNO_3$	1.86
Na_2CO_3	0.25
$Na_3PO_4 \cdot 12H_2O$	0.10
Na_2SO_4	0.02
NaF	0.08
NaCl	0.16

3.1 EQUIPMENT CONFIGURATION

The configuration of the grout meter was designed using two principal criteria: (1) the meter, which would be considered a prototype, had to be compatible with the GTF (i.e., connectible to a pipeline), and (2) the electrodes had to be as unobtrusive as possible to minimize (and hopefully avoid) grout caking during operation. The first criterion was met quite easily by requiring the monitor to be flanged for installation to an existing pipeline. In order to meet the second criterion, several geometries were considered. The geometry chosen was the use of electrically isolated, stainless steel (SS) rings made with the same materials as the pipeline and configured such that when flanged into the pipeline, the rings would be flush with the pipe. Thus, the electrodes would be completely unobtrusive.

As discussed previously, upon application of an electrical field to the grout, some ions are free to drift through the material producing a conduction effect. The electrical resistivity (the reciprocal of the conductivity) is equal to the material's electrical resistance (to current flow) times the cross-sectional area of current flow per unit length of current path. Thus, the resistivity will be a function of the monitor-configuration dimensions, such as length between electrodes. In order to address this issue, the monitor design also needed to allow for variable electrode spacing, which became the third criterion.

The design chosen to meet all three criteria is shown in Fig. 1. The monitor was made of PVC in the shape of a right circular cylinder with a hole drilled through the center. In the center of the hole is a 1-in. wide lip with a nominal 2-in. I.D. One-third-inch wide rings, either SS or PVC, of nominal 2-in. diam, were placed on either side of the lip to form a nominal 2-in. diam "pipe" through which the fluid of interest (i.e., grout) will flow. The metal rings served as the electrodes, while the PVC rings served as spacers. Changing the dispositions of the metal rings and spacers readily allows the spacing between electrodes to be varied between 1 and 2.33 in. Metal screws contacting the metal rings through the side of the monitor made the connection with the impedance meter. A model IET IMF-600 impedance meter with a frequency of 1 kHz was used to measure the resistance or capacitance between the electrodes. The monitor in combination with the impedence meter is hereafter referred to as the grout meter.

The monitor was connected with flanges (with rubber gaskets between the monitor and flanges) to a nominal 2-in. diam bench-top pumping loop as shown in Figs. 2 and 3. The loop consisted of a plastic 10-gal stirred holding tank, a Warren Rupp Model SB11/2-A Type 4 airpowered diaphragm pump, and sufficient nominal 2-in. diam SS pipe to close the loop. A type K thermocouple was inserted upstream of the monitor to record grout temperature. A data acquisition board Metrabyte model DAS-8 and IBM-AT personal computer were used to continuously record the temperature and the electrical variable of interest (resistance or capacitance).

3.2 CALIBRATION AND TEMPERATURE CORRECTION

Prior to experimental runs, the impedance meter calibration was checked. The resistance range was checked against a 1-Ω resistor and two 1-Ω resistors in series. The capacitance range was tested against a 1-μF and 0.1-μF capacitor.

The ionic conductivity of the grout is known to be a function of temperature. The actual relationship between grout conductivity and temperature is complex but may be approximated by the Nerst-Einstein equation:

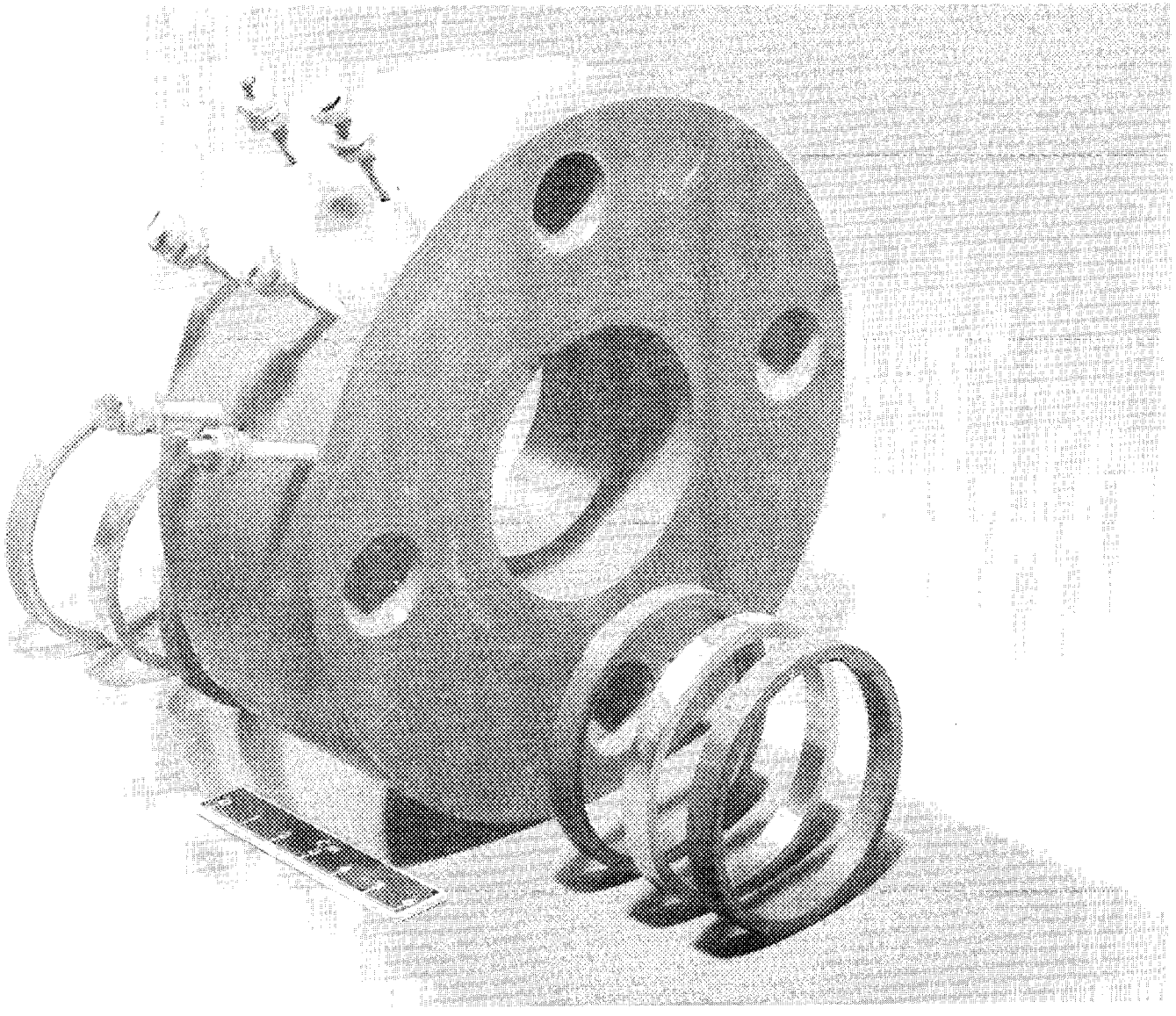

Fig. 1. Disassembled grout monitor (ORNL Photo 10796-88).

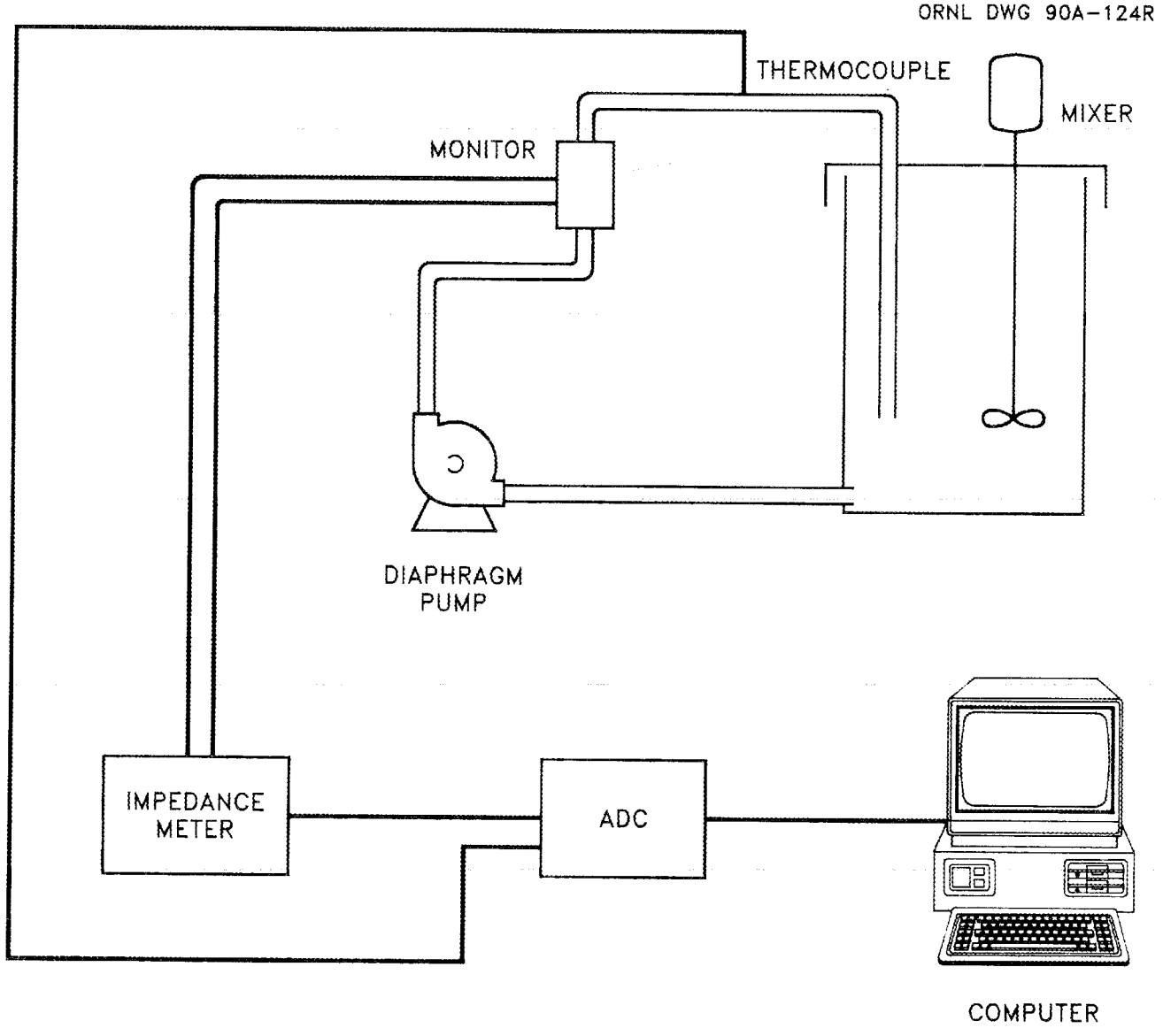

Fig. 2. Schematic of pumping loop.

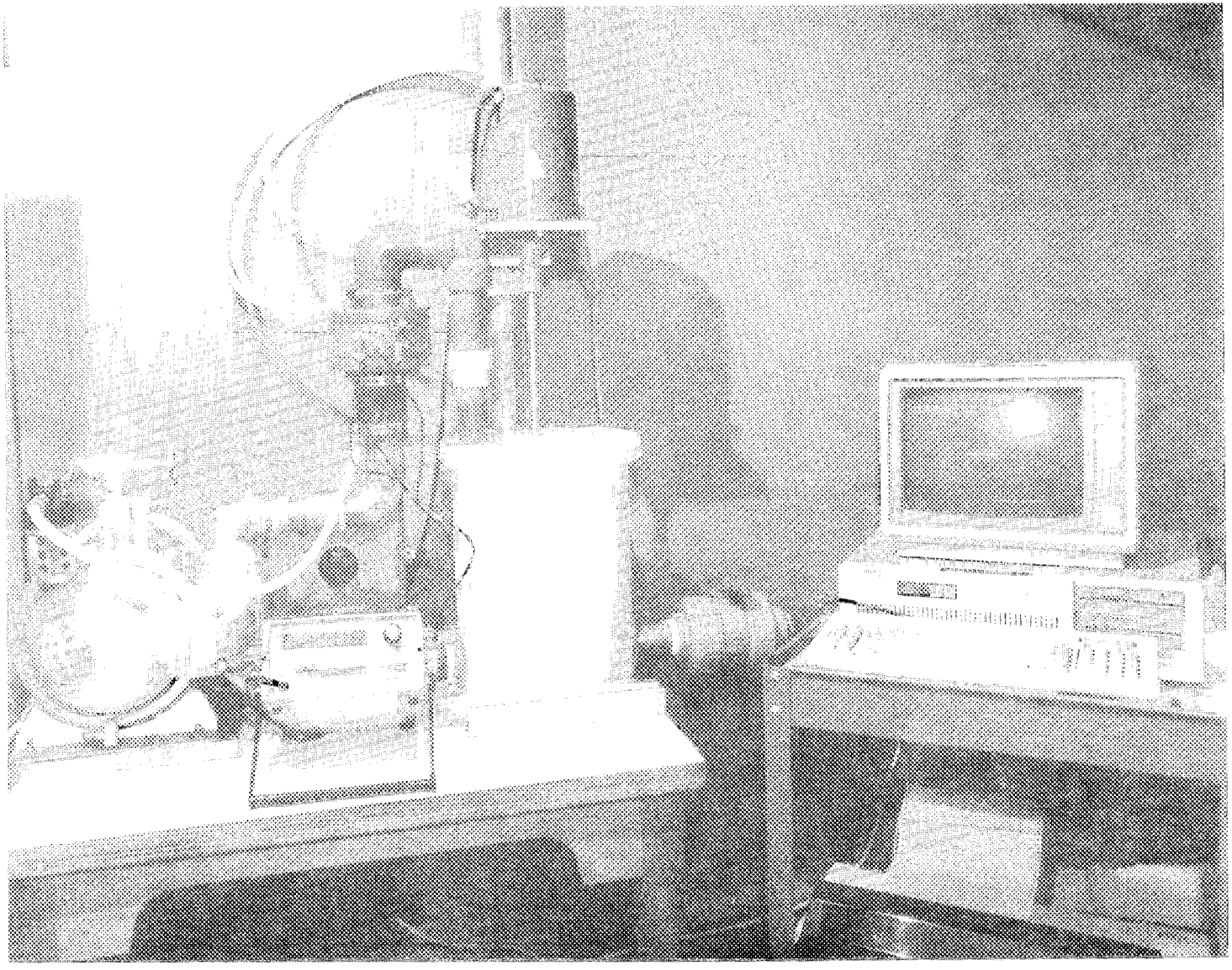

Fig. 3. Pumping loop (ORNL Photo 1152-90).

$$\sigma = \frac{F^2}{RT}(\Sigma C_i Z_i^2 D_i)\epsilon \quad , \tag{2}$$

where

σ	=	ionic conductivity,
F	=	Farraday constant,
k	=	molar gas constant,
T	=	absolute temperature,
C_i	=	ionic concentration of species,
Z_i	=	species valence,
D_i	=	diffusion coefficient of species, and
ϵ	=	volume fraction occupied by liquid.

As an initial approximation, the resistance of the simulated 101-AW liquid waste was measured as a function of temperature for a few degrees (± 5°C) around 20°C. The resulting data was normalized to 20°C by the equation:

$$R_o = R_t + (t-20) \cdot 0.03188, \tag{3}$$

where

R_o = resistance normalized to 20°C,

R_t = resistance measured at temperature, t.

This temperature correction has been applied to all resistance data presented in the text of this report as "normalized to 20°C." One of the future subtasks of this development effort is to quantify the temperature correction over a wider range of temperatures.

3.3 EVALUATION OF ELECTRODE SPACING

For a given waste liquid and variable mix-ratios, the expected range of the capacitance or resistance will vary between the values for the pure liquid and the values for the hypothetical mix-ratio of infinity (pure dry-solids blend). In order to evaluate the sensitivity of electrode spacing to electrical response, capacitance and resistance were measured at three electrode spacings for various dilutions of simulated waste.

The three electrode spacings were obtained by rearranging the spacers and rings as follows:

Configuration	Electrode spacing (in.)	Label
ring-spacer-spacer-lip-spacer-spacer-ring	2.33	O/O
ring-spacer-spacer-lip-spacer-ring-spacer	2.00	O/M
spacer-ring-spacer-lip-spacer-ring-spacer	1.67	M/M

Measurements were taken on various waste dilutions with results shown in Figs. 4 and 5. Additional data are shown in Tables A.1 through A.3. In the figures, a waste concentration of 100 vol % corresponds to a liquid of composition shown in Table 1. A waste concentration of 10 vol % corresponds to a waste consisting of 90 vol % distilled water and 10 vol % liquid of composition shown in Table 1.

As shown in Figs. 4 and 5, at approximately 70 vol % waste concentration, the electrical response reached a maximum for capacitance and a minimum for resistance. At approximately 70 vol % waste concentration, the liquid became saturated and higher waste concentrations resulted in the appearance of undissolved solids. The increasing fraction of undissolved solids in suspension at higher concentrations behaved in a manner similar to that expected by the addition of dry-solids blend (i.e., the electrical response was dominated by the liquid fraction present, which, in turn, is controlled by the mix ratio).

The derivative of the electrical response with respect to waste concentration as a function of waste concentration is shown in Figs. 6 and 7. The derivatives or slopes of the electrical response versus waste concentration can be used to evaluate the sensitivity of the electrical response (i.e., the higher the slope, the greater the sensitivity of the electrical response to changes in waste concentration). Inspection of Figs. 6 and 7 indicate that of the three configurations evaluated: (1) configuration M/M (the shortest distance between electrodes) exhibited the highest sensitivity with respect to capacitance, and (2) configuration O/O (the longest distance between electrodes) exhibited the highest sensitivity with respect to resistance.

Based on the configurations tested, the data would suggest that if both capacitance and resistance were to be measured simultaneously, then a four-electrode probe would be optimum. Two electrodes with spacing O/O for resistance determinations and two with spacing M/M for separate capacitance measurements. The configuration O/M was used for the remainder of this

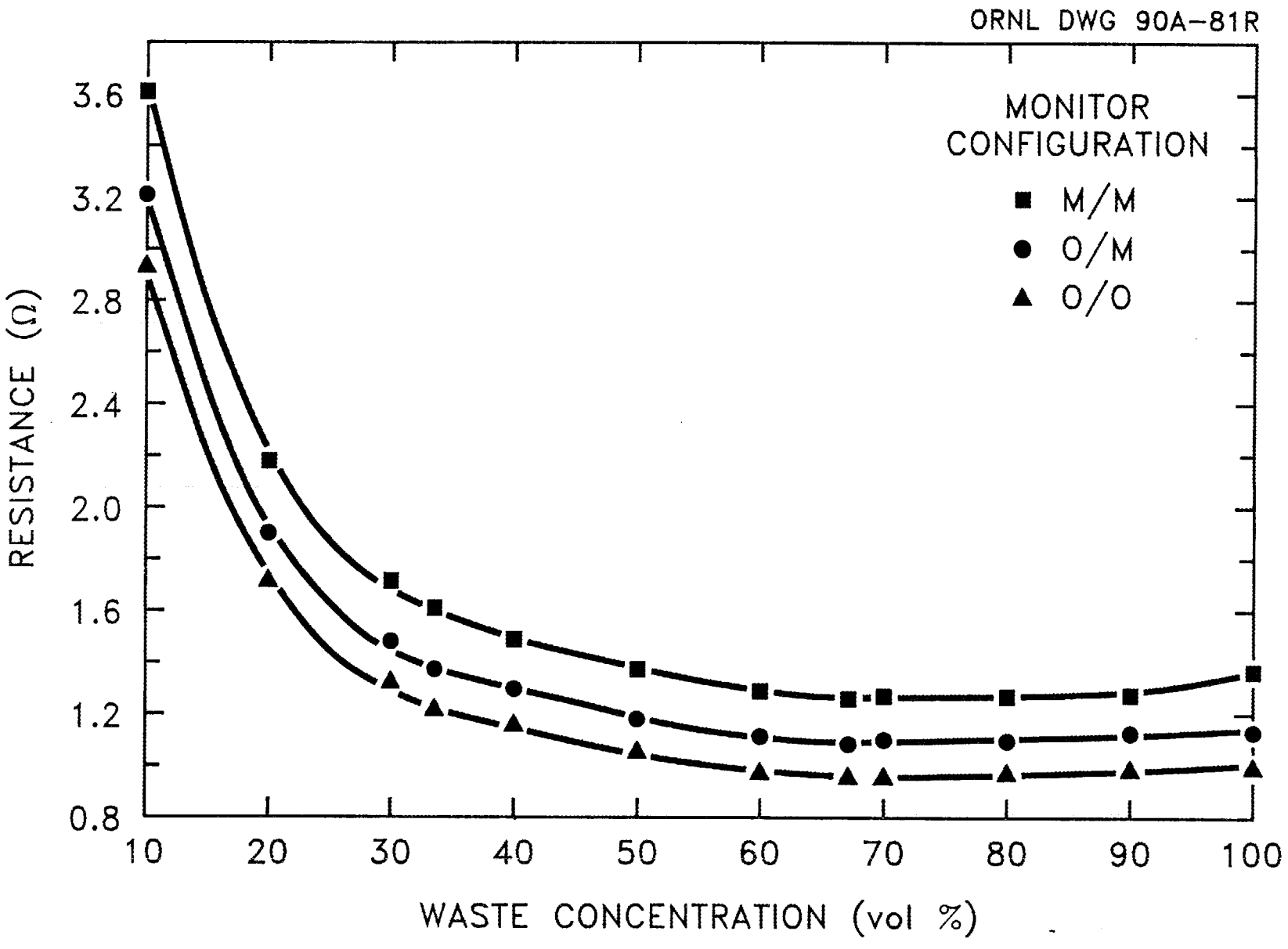

Fig. 4. Electrical response (resistance) normalized to 20°C as a function of time for selected dilutions of reference waste.

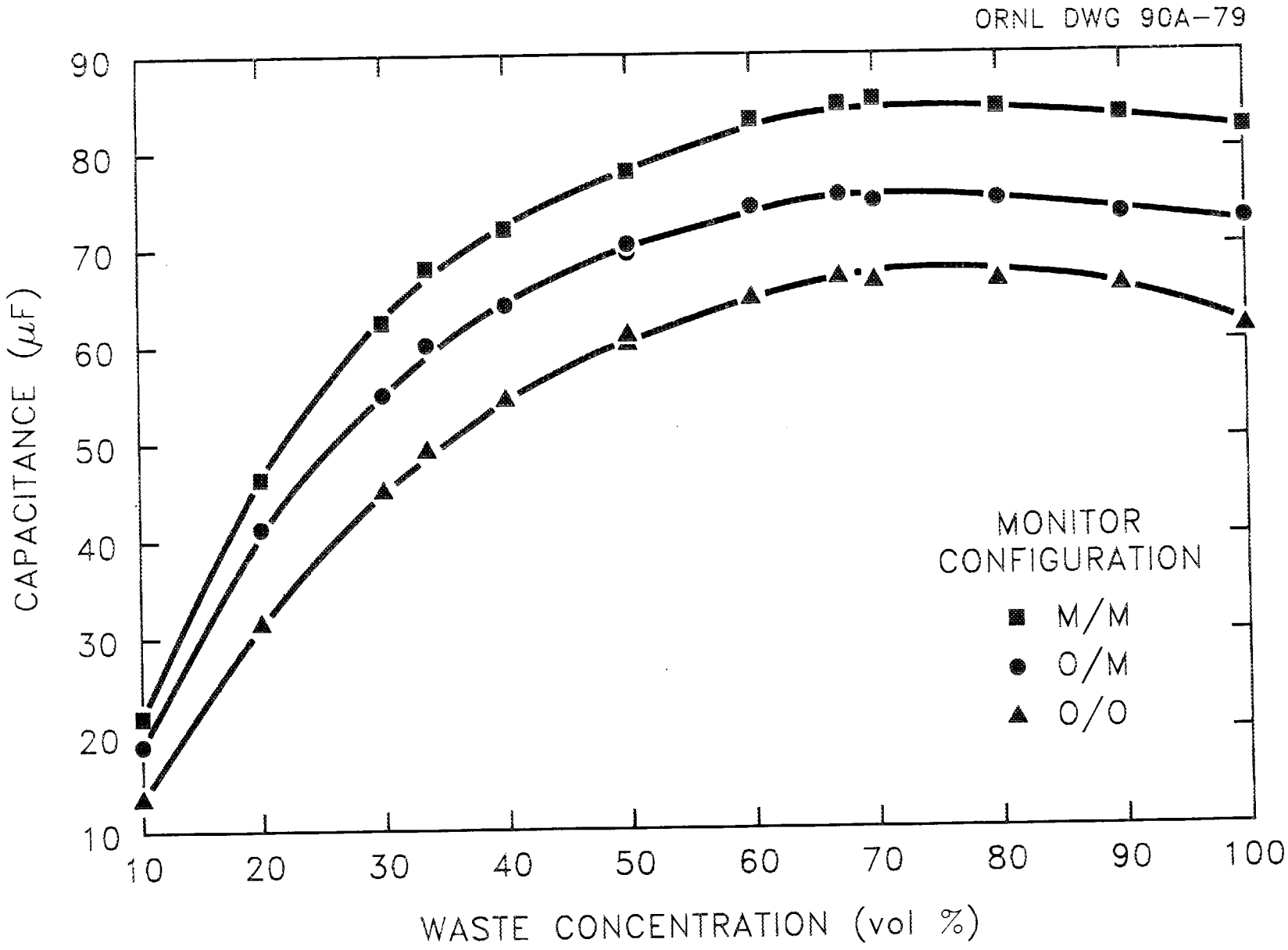

Fig. 5. Electrical response (capacitance) normalized to 20°C as a function of time for selected dilutions of reference waste.

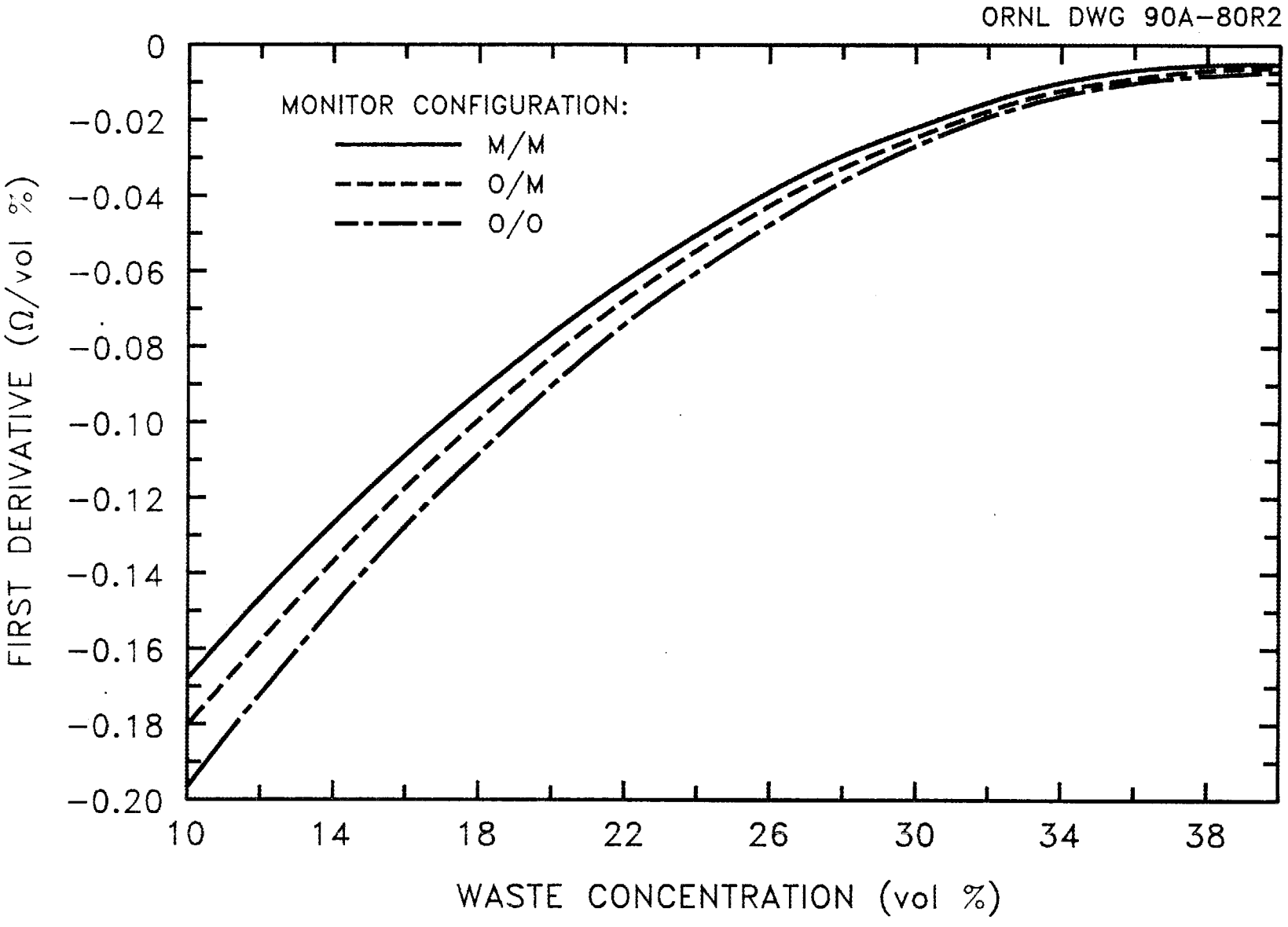

Fig. 6. Sensitivity of resistance measurements normalized to 20°C as a function of selected dilutions of reference waste.

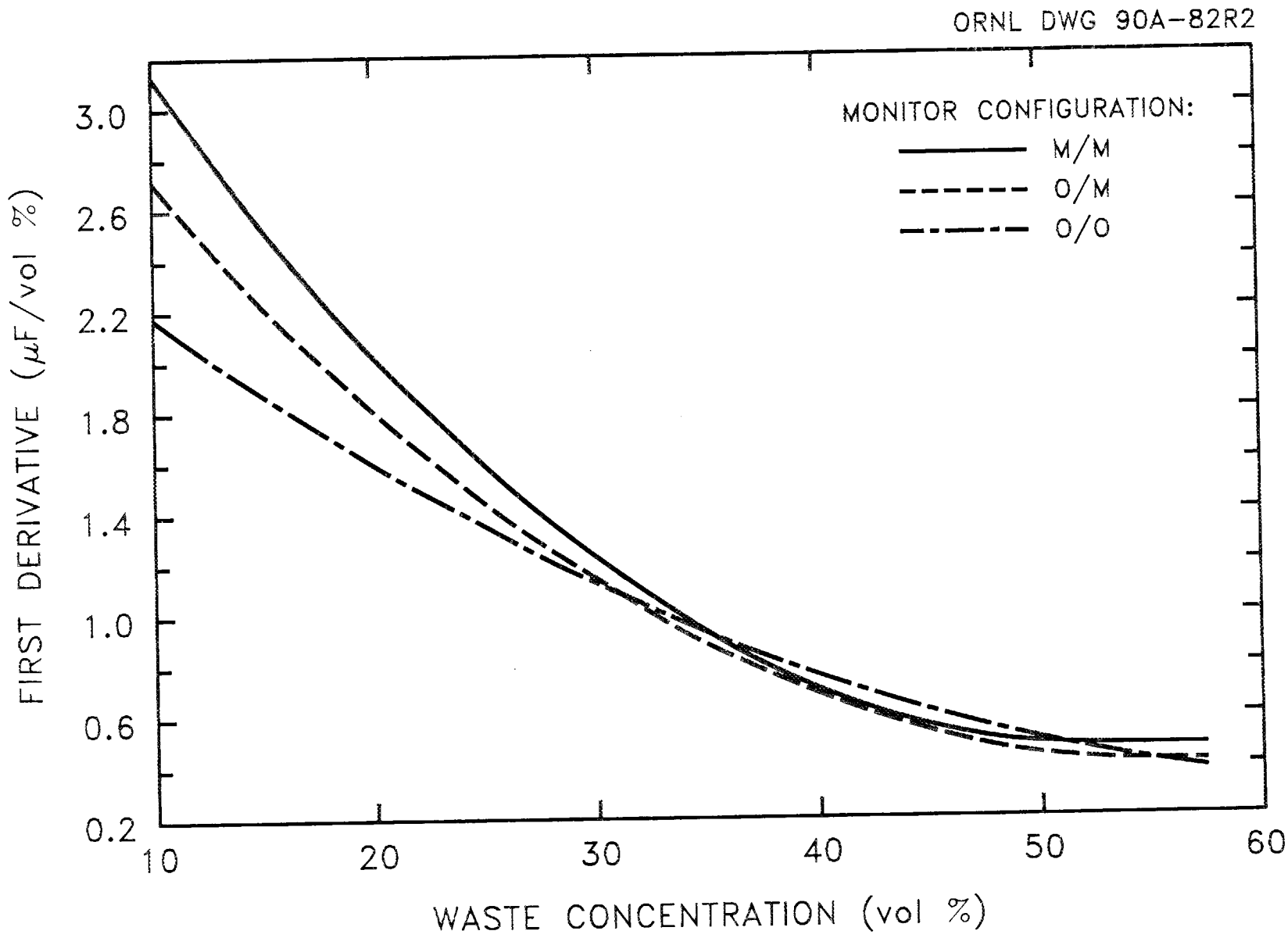

Fig. 7. Sensitivity of capacitance measurements normalized to 20°C as a function of selected dilutions of reference waste.

development effort. As shown in Figs. 6 and 7, this configuration gave the median sensitivity for both capacitance and resistance.

3.4 GROUT PREPARATION

At the beginning of each experiment utilizing grout, 3 gal of reference waste was placed in the stirring tank with the stirrer in operation. The liquid was circulated through the pump loop for about 5 min prior to the addition of dry-solids-blend material. The dry-solids-blend material was added in stages with the resulting grout circulating through the pump loop for approximately 5 min prior to the introduction of additional dry-solids-blend material. The dry-solids blend was blended for 23 h in a 3 ft^3 V-blender prior to addition to the waste.

3.5 MIX RATIO AS A FUNCTION OF RESISTANCE

Grouts were prepared by four sequential additions of dry-solids-blend material to the waste to obtain mix ratios of 2.5, 5.1, 7.8, and 10 lbs/gal designated as Run 1. Resulting resistance data are shown in Fig. 8. Additional data are shown in Figs. A.1 and A.2.

As seen in Fig. 8, the response of the detector was quite rapid. In some instances, there was a sharp initial peak in the response during the addition of the grout. This is due to the fact that the grout materials can enter the pump loop before homogenization takes place. This peak quickly disappeared after mixing took place. This is an important point because it shows that the meter can detect even minor temporary changes in homogeneity.

The mix ratio was plotted against the resistance (from Fig. 8) as shown in Fig. 9. Also shown is a plot of the equation obtained by linear regression of the data pairs:

$$M = 9.96 \cdot R - 11.9, \tag{4}$$

where

M = mix ratio, lb/gal; and

R = resistance, Ω.

Eq. 4 was then used to calculate the mix ratio based on the electrical response. A comparison of the calculated values with actual values of mix ratio is shown in Table 2. The linear equation results in values within ± 0.1 lb/gal of the actual mix ratios.

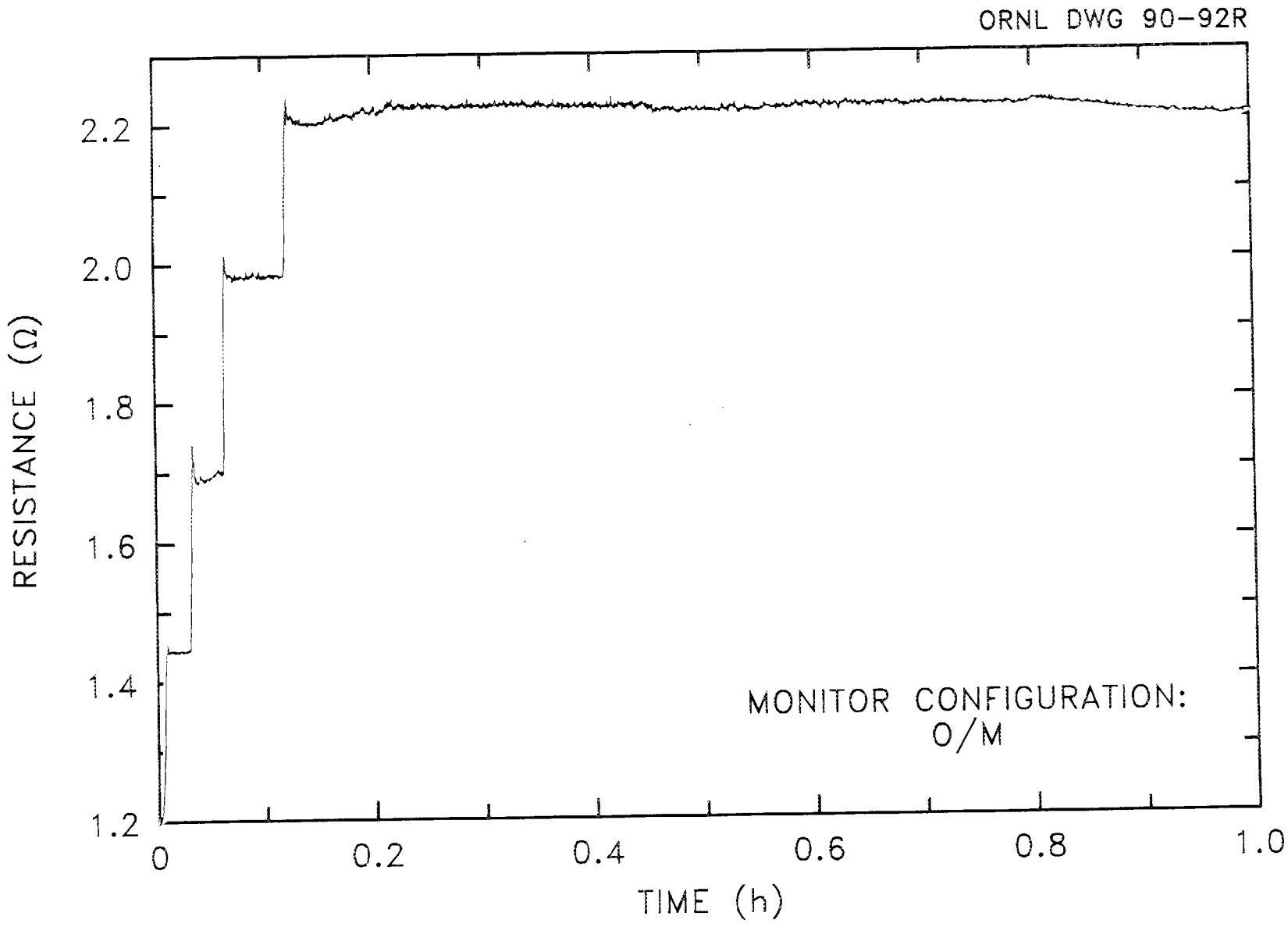

Fig. 8. Electrical response (resistance) normalized to 20°C as a function of time for Run 1.

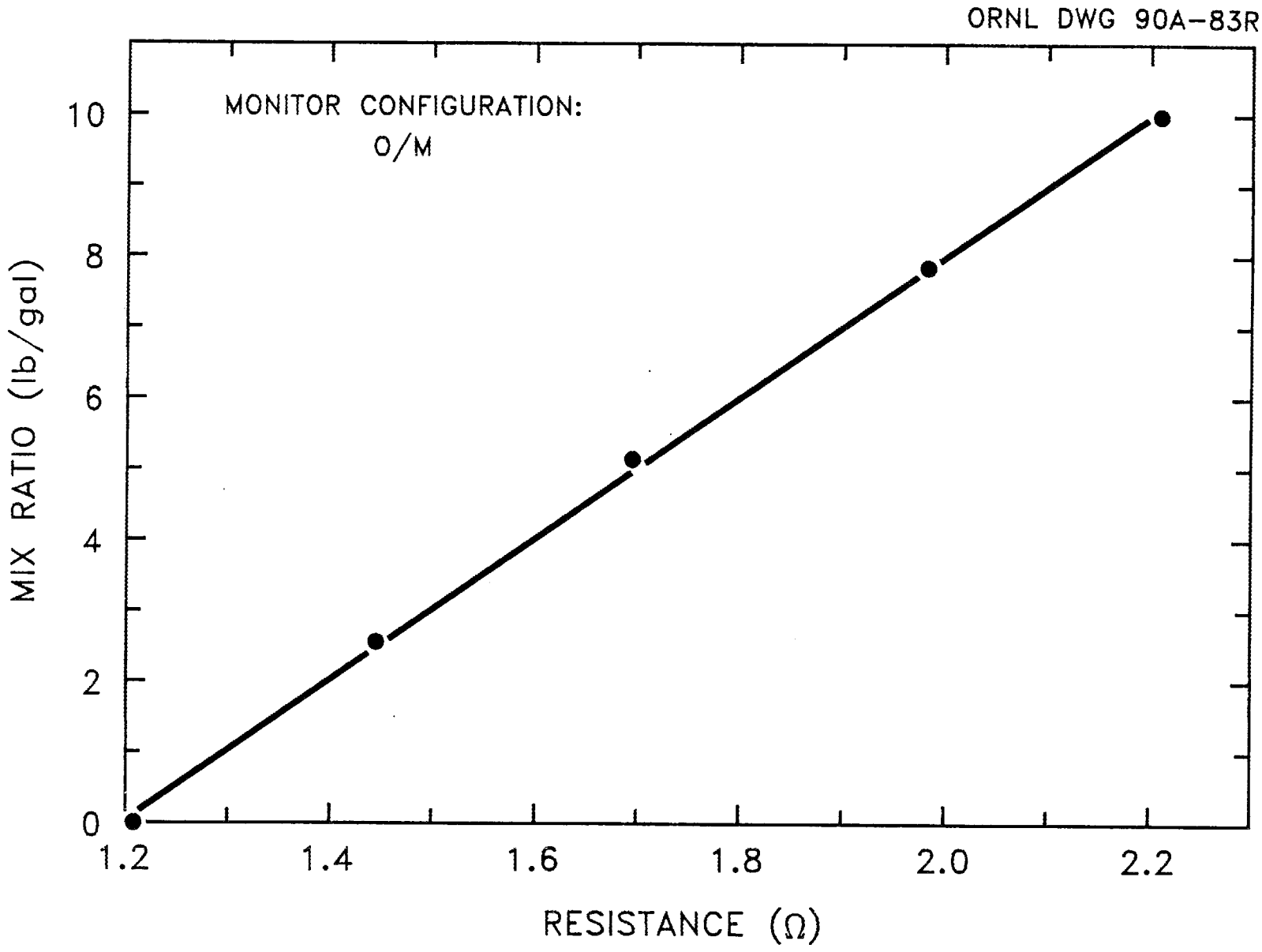

Fig. 9. Grout mix ratio as a function of resistance normalized to 20°C for Run 1.

Table 2. Comparison of calculated and actual mix ratios for Run 1

Resistance[a] (Ω)	Mix ratio (lb/gal)	
	Actual	Calculated
1.206	0.0	0.1
1.445	2.5	2.5
1.695	5.1	5.0
1.982	7.8	7.8
2.207	10.0	10.1

[a]Normalized to 20° C.

As with Run 1, this linear equation results in calculated values within ± 0.1 lb/gal of the actual mix ratios (see Table 3).

Table 3. Comparison of calculated and actual mix ratios for Run 2

Resistance[a] (Ω)	Mix ratio (lb/gal)	
	Actual	Calculated
1.285	0.0	0.1
1.877	6.0	5.8
2.000	7.0	7.0
2.106	8.0	8.0
2.223	9.0	9.1
2.319	10.0	10.0

[a]Normalized to 20° C.

3.6 DATA REPRODUCIBILITY

In an effort to assess the reproducibility of the measurements, the first run was repeated but with five sequential additions of dry-solids-blend materials to obtain mix ratios of 6, 7, 8, 9, and 10 lb/gal designated as Run 2. Additional data are shown in Figs. A.3 through A.5. Mix ratio as a function of resistance is shown in Fig. 10. The equation obtained by linear regression of the data pairs is:

$$M = 9.62 \cdot R - 12.3. \tag{5}$$

The two equations are quite similar, but minor differences do exist. These minor differences are thought to be due to variations in waste composition. The 3-gal simulated waste sample used for each run is taken from a larger 55-gal drum sample. As the simulated waste contains undissolved solids, some composition differences may exist upon subsampling.

3.7 EQUIPMENT MODIFICATION

Several experiments were performed with the monitor being dismantled and cleaned following each run. Reproducibility was poor, and duplicate runs were inconsistent. It was observed that the rubber gasket did not make a proper seal on the outermost electrode. As discussed in Sect. 3.3, the configuration used in this effort had one electrode in the outermost position of the monitor and the other surrounded by two PVC rings. Lack of a proper seal on the outermost ring by the rubber gasket allowed the electrode area to vary slightly during each run which affected the electrical response measurements by altering the electrical field. Consequently, the monitor was modified to improve the seal on the outermost electrode. This modification consisted of reducing the width of one of the PVC spacers between the outermost electrode and lip by 1/16-in. and fabrication of an 1/16-in. PVC spacer to be placed between the outermost electrode and the rubber gasket (i.e., the new monitor configuration is 1/16-in. spacer—ring—spacer with width reduced 1/16-in. spacer—lip—spacer—ring—spacer). This modification ensured that the only area of the electrode rings exposed to the grout would be the internal face that is in contact with the grout. This electrode configuration is referred to as O/M Modified throughout the remainder of this report.

The new configuration was tested by preparing a grout with an initial mix ratio of 6 lb/gal and then sequential additions of dry-solids-blend materials to increase the mix ratio to 10 lb/gal

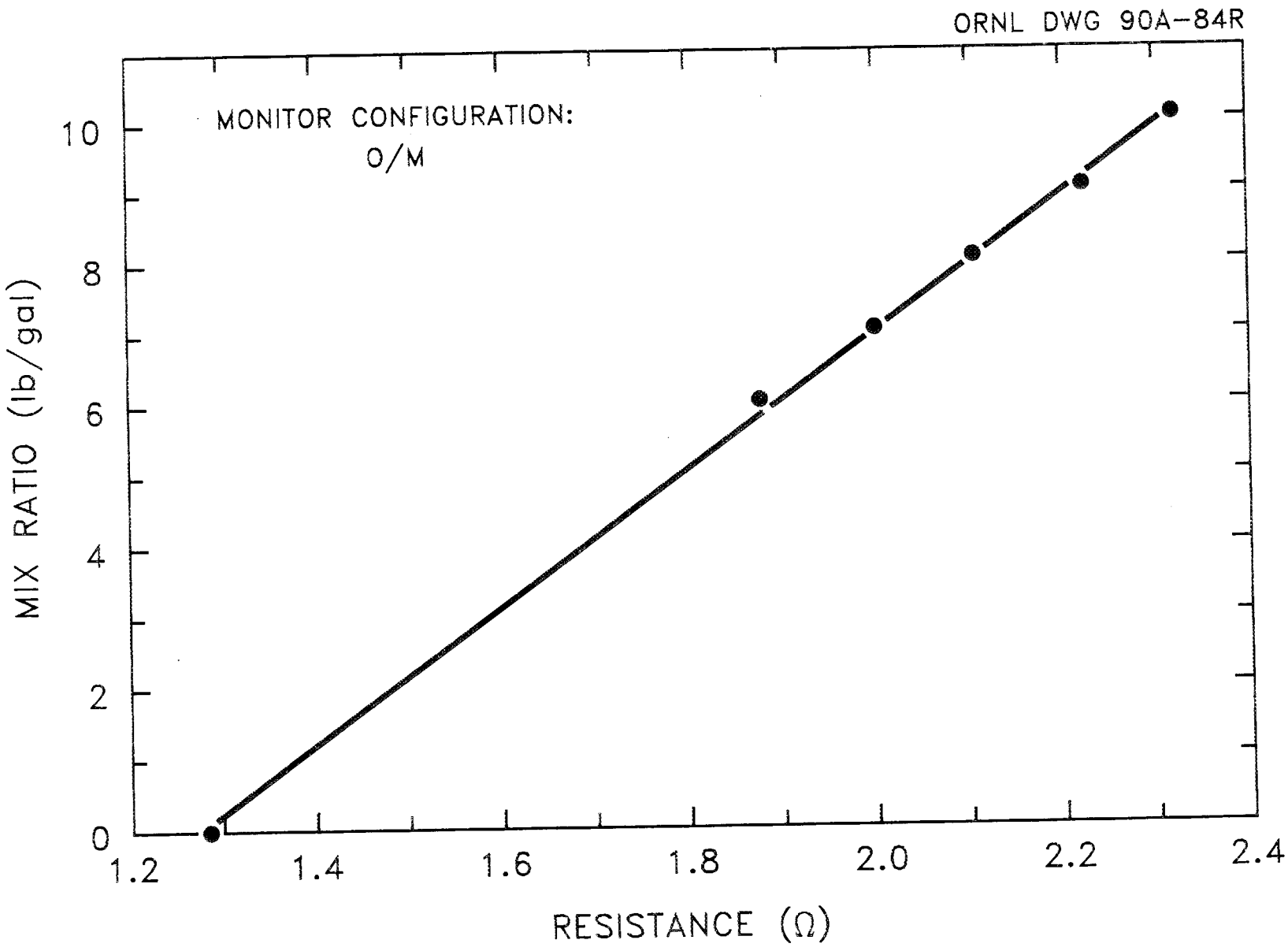

Fig. 10. Grout mix ratio as a function of resistance normalized to 20°C for Run 2.

in steps of 0.5 lb/gal and is designated Run 4. Linear regression on the resulting data, shown in Fig. 11, resulted in the following equation:

$$M = 9.65 \cdot R - 11.5. \tag{6}$$

The reduction in the spacing between the electrodes is thought to account for the differences in slope of this equation in comparison to Eqs. 4 and 5. A comparison between actual and calculated mix ratios using Eq. 6 is shown in Table 4. Calculated and actual values are in agreement to with ± 0.1 lb/gal. Additional data are shown in Figs. A.6 through A.8.

Table 4. Comparison of calculated and actual mix ratios for Run 4

Resistance[a] (Ω)	Mix ratio (lb/gal)	
	Actual	Calculated
1.216	0.0	0.1
1.810	6.0	5.9
1.862	6.5	6.4
1.913	7.0	6.9
1.972	7.5	7.4
2.027	8.0	8.0
2.096	8.5	8.6
2.142	9.0	9.1
2.196	9.5	9.6
2.243	10.0	10.1

[a]Normalized to 20° C.

3.8 EFFECT OF EXTENDED RUN TIME

In order to assess the behavior of the grout meter during an extended time period, a 24-h experiment designated Run 5 was conducted. In this experiment, dry-solids-blend material was

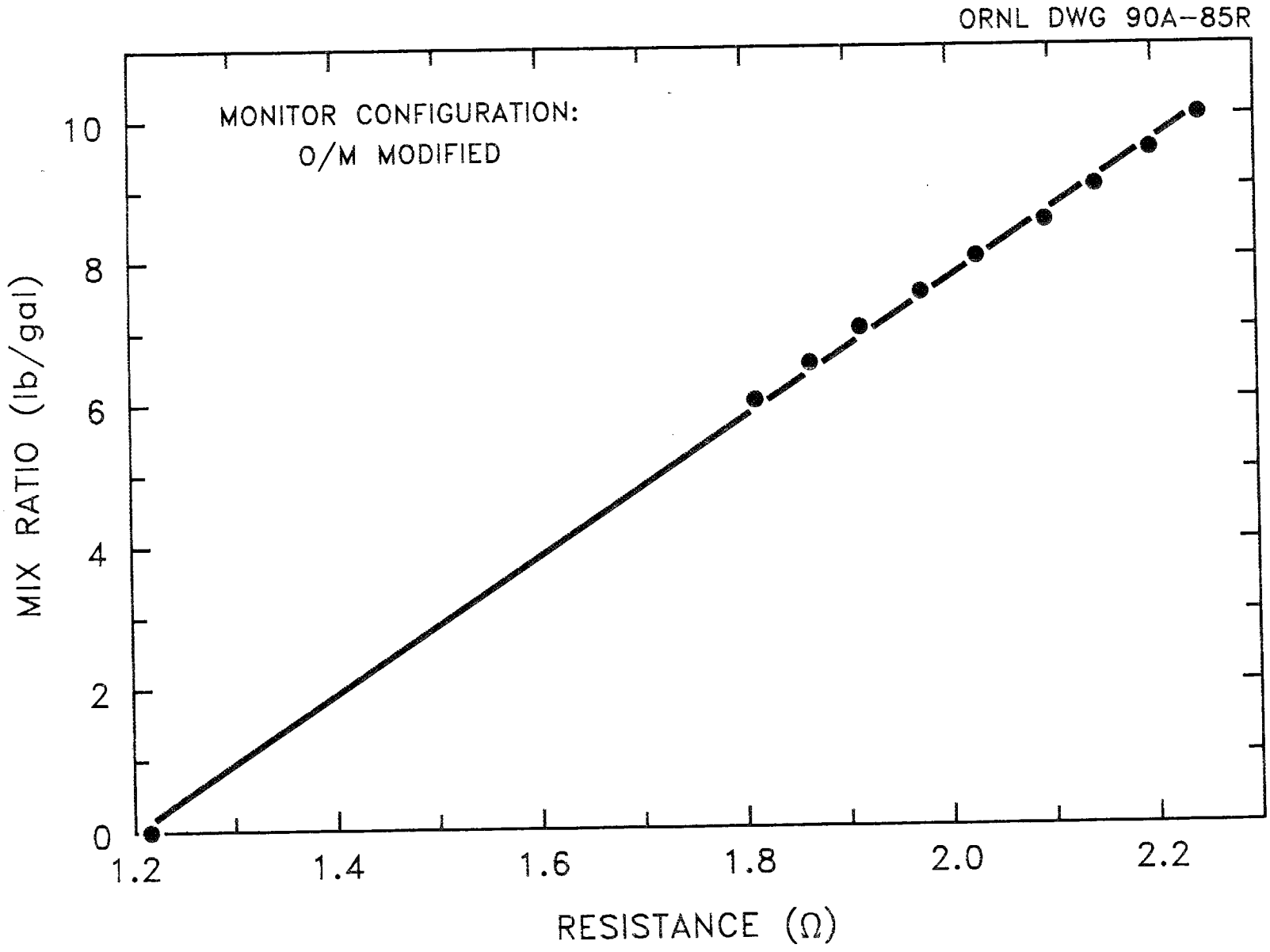

Fig. 11. Grout mix ratio as a function of resistance normalized to 20°C for Run 4.

added sequentially to a maximum mix ratio of 6 lb/gal in steps of 2 lb/gal. The maximum mix ratio of 6-lb/gal was chosen in order to avoid solidification of the grout during the test. The resistance as a function of time is shown in Fig. 12. Additional data are shown in Figs. A.9 through A.12. As shown in Fig. 12, the resistance gradually increased with time due to the onset of the hydration process. As far as the grout meter is concerned, the onset of hydration corresponded to an increase in mix ratio. In this context, the onset of hydration serves to define the limits of the monitoring time; however, it also tends to confirm the belief that, with additional development, the electrical response could be used to monitor progress of the hydration process. It should be noted that the sharp increase in resistance at the end of the run corresponds to increasing the mix ratio to 12 lb/gal. This was done in order to meet internal waste disposal requirements.

Significantly, the monitor was inspected at the end of the run, and no caking was observed. This indicated that the electrodes are truly unobtrusive and will promote caking no more than the pipe walls.

Linear regression on the data pairs (Figs. A.11 and A.12) resulted in the following equation:

$$M = 10.25 \cdot R - 12.1. \tag{7}$$

A comparison between actual and calculated mix ratios is shown in Table 5. As with previous runs, the values agree to within ± 0.1 lb/gal. However, Eq. 7 is significantly different from previous runs. Again, this is thought to be due to variations in the suspended solids content of the waste.

Table 5. Comparison of calculated and actual mix ratios for Run 5

Resistance[a] (Ω)	Mix ratio (lb/gal)	
	Actual	Calculated
1.180	0.0	0.0
1.376	2.0	2.0
1.567	4.0	4.0
1.767	6.0	6.0

[a]Normalized to 20°C.

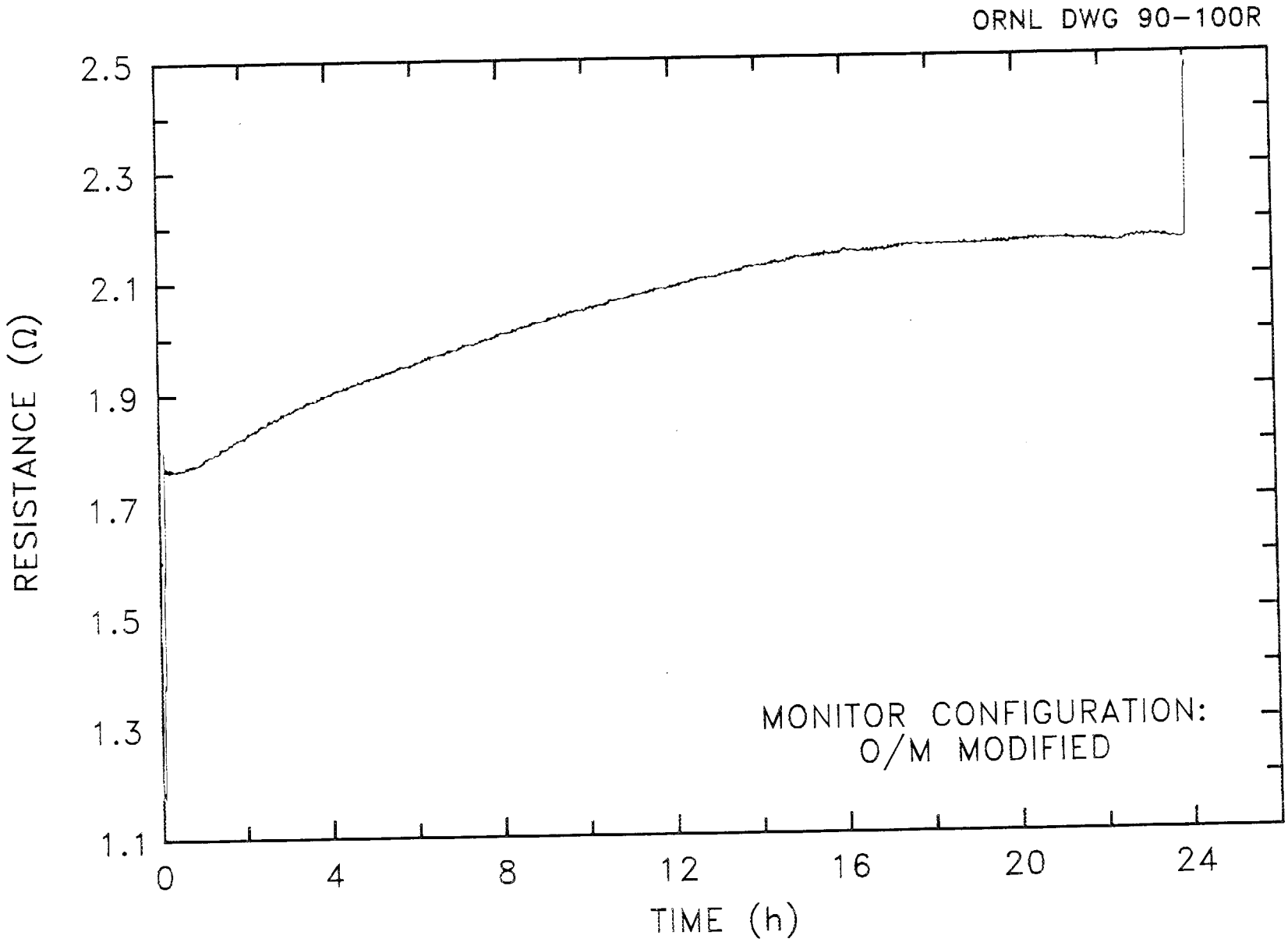

Fig. 12. Electrical response (resistance) normalized to 20°C as a function of time for Run 5.

3.9 EFFECT OF WASTE CONCENTRATION

As discussed in previous sections, the potential variable suspended solids content of the simulated 101-AW waste was thought to induce differences in the linear relationship between mix ratio and resistance. In order to qualitatively assess the impact of waste concentration on the resulting correlation of interest, an experiment was performed using a waste with no suspended solids. As noted in Sect. 3.3, suspended solids were present in water/simulated-waste mixtures at simulated waste content of 70 vol % or greater. Consequently, a waste was prepared with 60 vol % distilled water and 40 vol % reference 101-AW. Grouts were then prepared by the sequential addition of dry-solids-blend material to vary the mix ratio from 6 to 12 lb/gal in steps of 0.5 lb/gal. Data obtained from this run (designated as Run 6) as well as the resulting linear regression are shown in Fig. 13. Additional data are shown in Figs. A.13 through A.15.

Fig. 13 showed an excellent linearity between resistance and mix ratio as did the previous runs. The equation for the linear regression was:

$$M = 7.49 \cdot R - 9.2. \tag{8}$$

Clearly, this equation appears to be inconsistent from equations resulting from previous runs that used reference 101-AW. Table 6 compares the actual mix ratio with those calculated from Eq. 8. The calculated values are within 0.1 lbs/gal of the actual values with the exception of the lower mix ratio of zero.

The inconsistency at a mix ratio of zero is probably due to the soluble species present in the dry-solids blend. In the case of the saturated or reference waste, the contribution of soluble species from the dry-solids blend is negligible. For the diluted waste, the dry-solids blend will add to the ionic species in a way proportional to the amount of solids (mix ratio) until saturation is reached. Because of the linearity of this effect, the total behavior will be linear but with a diminished slope due to the lower than "expected" resistance consequence of the "extra" ions.

Collectively, the data from this and previous sections clearly indicate that the grout meter must account for variations in the waste concentration. It is envisioned that the final meter configuration will require a meter on the waste-feed line to provide a means to determine waste-feed concentration variations and their effect on the electrical response of the resulting grout.

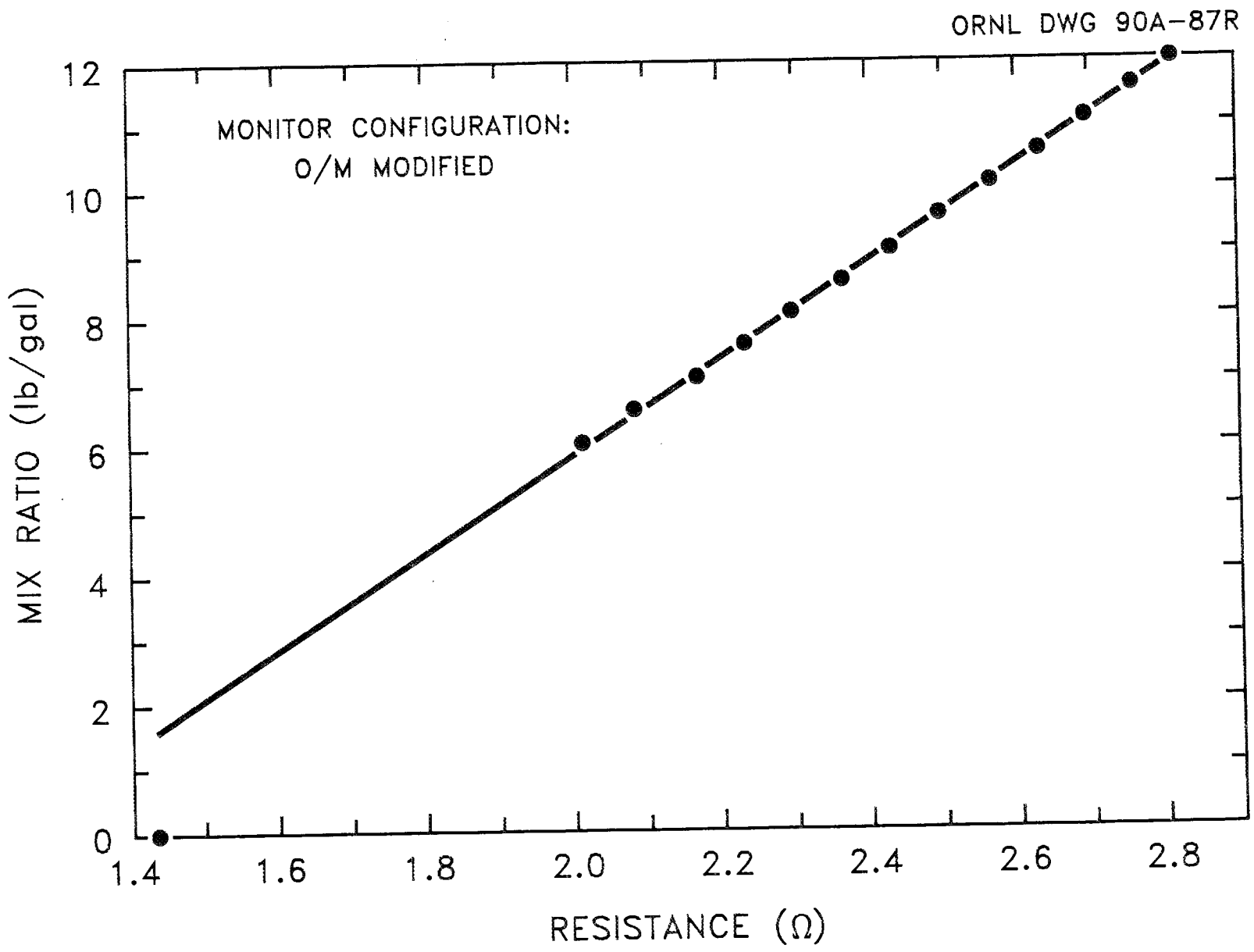

Fig. 13. Grout mix ratio as a function of resistance normalized to 20°C for Run 6.

Table 6. Comparison of calculated and actual mix ratios for Run 6

Resistance[a] (Ω)	Mix ratio (lb/gal)	
	Actual	Calculated
1.434	0.0	1.6
2.014	6.0	5.9
2.085	6.5	6.4
2.170	7.0	7.1
2.234	7.5	7.6
2.296	8.0	8.0
2.364	8.5	8.5
2.431	9.0	9.0
2.495	9.5	9.5
2.564	10.0	10.0
2.632	10.5	10.5
2.696	11.0	11.0
2.759	11.5	11.5
2.812	12.0	11.9

[a]Normalized to 20° C.

4. SUMMARY AND CONCLUSIONS

Data have been presented which show that electrical resistance of freshly prepared grouts containing simulated 101-AW waste is linear with respect to grout mix ratio over a wide range of values. The data serve to establish the meter's potential for application to the Westinghouse Hanford TGF. The data establish that special care must be maintained during design and installation to ensure that the electrodes are properly sealed. The data also indicate that a separate meter will be required in order to assess waste-feed variations.

In addition, the data provide guidance on future efforts to be addressed in subsequent progress reports. In particular, the data suggest that waste feed variability may be the most important future task. Future efforts will be directed towards assessing the effects of (1) variation in waste solids content and (2) variations in waste dilution.

Data presented in the text indicate that, under controlled laboratory conditions, the monitor can predict mix ratios to within ± 0.1 lb/gal. Minor differences in replicate runs were attributed to waste composition variations. Runs 1, 2, 4, and 5 were identical except for these suspected waste variations, assuming the effect of the equipment modification on Runs 4 and 5 was negligible as discussed in Sect. 3.7. Linear regression of all data from these runs (shown in Fig. 14) resulted in the following empirical equation:

$$M = 9.33 \cdot R - 11.09. \tag{9}$$

As shown in Fig. 14, the collective data are linear. However, using Eq. 9 to calculate mix ratios as shown in Table 7 indicates that the meter accuracy is on the order of ± 0.9 lb/gal rather than ± 0.1. Clearly, future development efforts will need to better quantify the effects of waste composition variations in order to consistently achieve an accuracy within the GTF operating limits (i.e. ± 0.5 lb/gal).

5. ACKNOWLEDGEMENTS

The authors gratefully acknowledge the technical review comments provided by J. A. Voogd, Westinghouse Hanford Company, and the following Martin Marietta Energy Systems, Inc., personnel: T. A. Bowers, E. S. Harrington, W. F. Johnson, and J. L. Shoemaker.

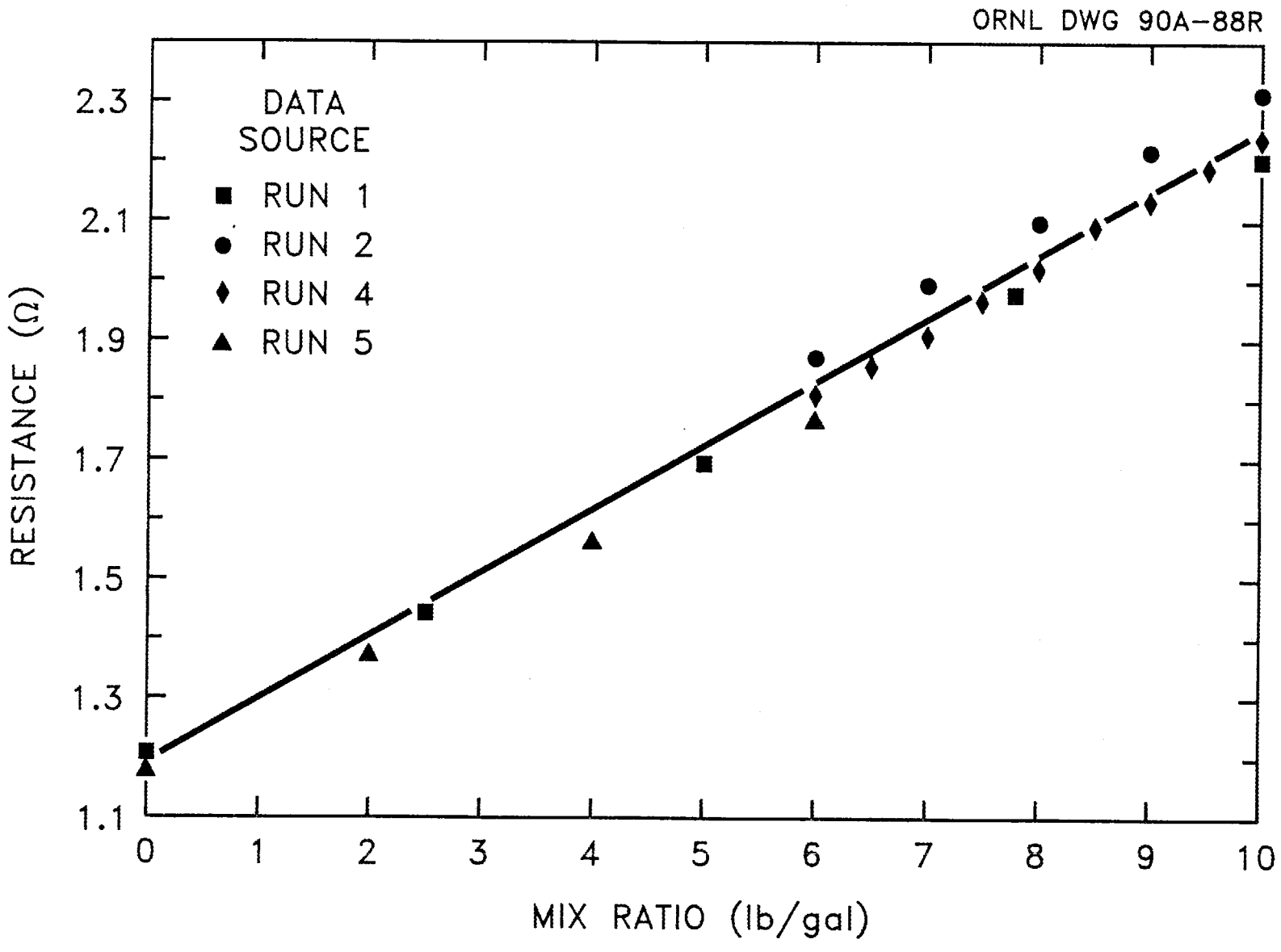

Fig. 14. Electrical response (resistance) normalized to 20°C a function of grout mix ratio for collective data from Runs 1, 2, 4, and 5.

Table 7. Comparison of calculated and actual mix ratio and resistance based on collective data from Runs 1, 2, 4, and 5

Source	Resistance[a] (Ω)	Mix ratio (lb/gal) Actual	Calculated
Run 1	1.206	0.0	0.2
	1.445	2.5	2.4
	1.695	5.1	4.7
	1.982	7.8	7.4
	2.207	10.0	9.5
Run 2	1.285	0.0	0.9
	1.877	6.0	6.4
	2.000	7.0	7.6
	2.106	8.0	8.6
	2.223	9.0	9.7
	2.319	10.0	10.6
Run 4	1.216	0.0	0.3
	1.810	6.0	5.8
	1.862	6.5	6.3
	1.913	7.0	6.8
	1.972	7.5	7.3
	2.027	8.0	7.8
	2.096	8.5	8.5
	2.142	9.0	8.9
	2.196	9.5	9.4
	2.243	10.0	9.8
Run 5	1.180	0.0	-0.1
	1.376	2.0	1.8
	1.567	4.0	3.5
	1.767	6.0	5.4

[a]Normalized to 20° C.

Appendix A: ADDITIONAL DATA FROM EXPERIMENTS DESCRIBED IN THE TEXT

Table A.1 Electrical response as a function of waste concentration for monitor configuration M/M

Waste concentration (vol %)	Temperature (°C)	Electrical response	
		Resistance (Ω)	Capacitance (μF)
10.0	20.0	2.940	22.0
20.0	20.0	1.715	46.7
30.0	21.3	1.325	62.7
33.3	21.9	1.222	68.2
40.0	21.8	1.151	72.1
50.0	21.8	1.054	78.0
50.0	22.0	1.051	77.9
60.0	22.0	0.974	83.2
66.6	22.0	0.952	84.8
70.0	22.0	0.956	85.2
80.0	22.4	0.962	84.2
90.0	22.8	0.977	83.3
100.0	23.0	0.991	81.9

Table A.2. Electrical response as a function of waste concentration for monitor configuration O/O

Waste concentration (vol %)	Temperature (°C)	Electrical response	
		Resistance (Ω)	Capacitance (μF)
10.0	22.0	3.610	13.2
20.0	22.9	2.170	31.4
30.0	22.8	1.703	44.9
40.0	22.8	1.483	54.4
50.0	22.8	1.363	60.0
50.0	22.8	1.361	60.4
60.0	22.8	1.281	64.6
66.6	23.0	1.247	66.7
70.0	23.0	1.260	66.1
80.0	22.8	1.259	66.2
90.0	22.8	1.261	65.5
100.0	22.5	1.356	60.9

Table A.3. Electrical response as a function of waste concentration for monitor configuration O/M

Waste concentration (vol %)	Temperature (°C)	Electrical response	
		Resistance (Ω)	Capacitance (μF)
10.0	22.0	3.220	19.1
20.0	22.3	1.904	41.4
30.0	22.5	1.488	55.3
33.3	23.1	1.377	60.2
40.0	22.8	1.293	64.3
50.0	23.3	1.180	70.4
50.0	23.0	1.174	69.8
60.0	23.1	1.110	74.2
66.6	23.2	1.086	75.3
70.0	23.0	1.098	74.5
80.0	23.2	1.096	74.7
90.0	23.1	1.125	73.1
100.0	23.0	1.135	72.6

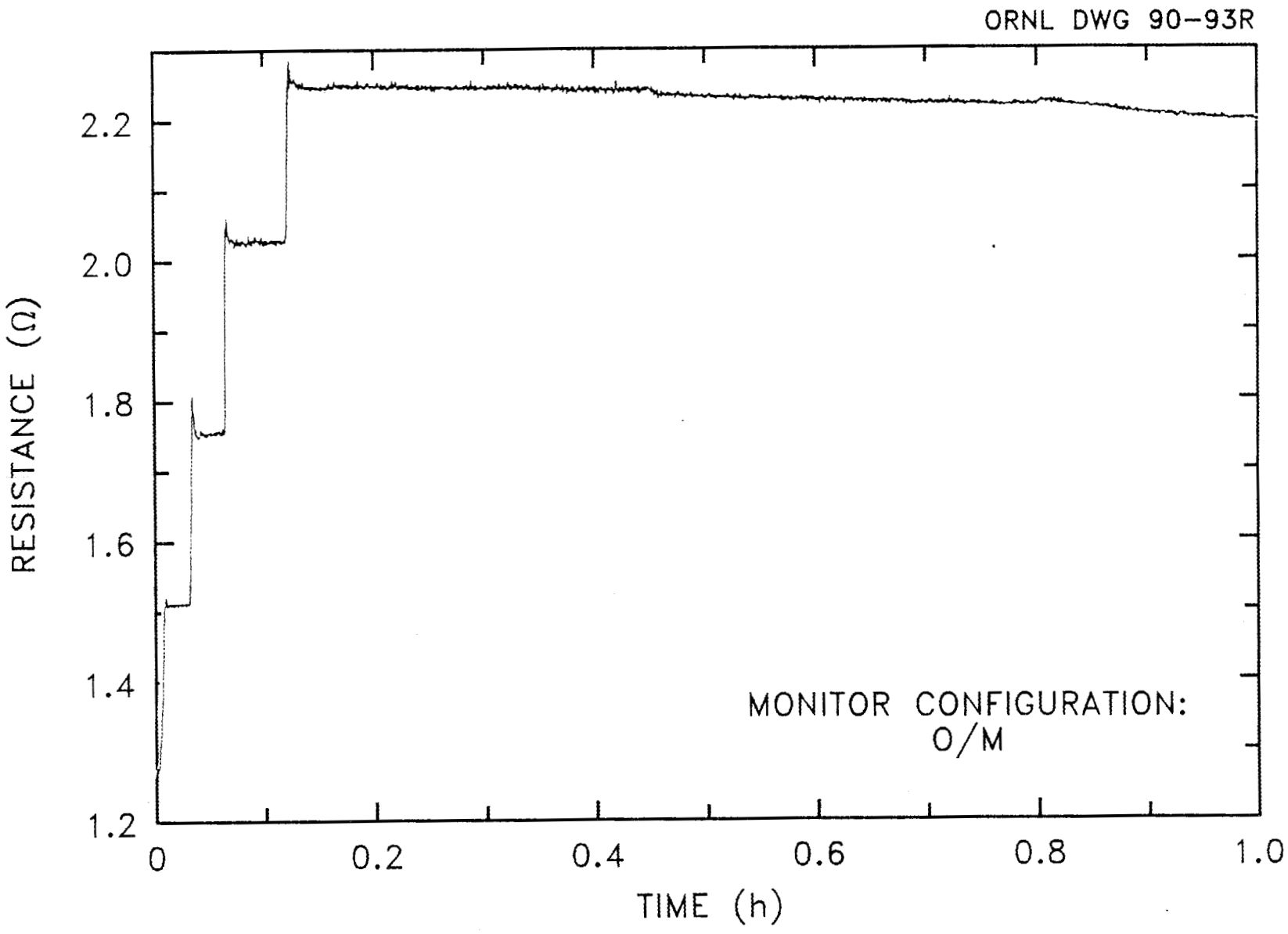

Fig. A-1. Electrical response (resistance) as a function of time for Run 1.

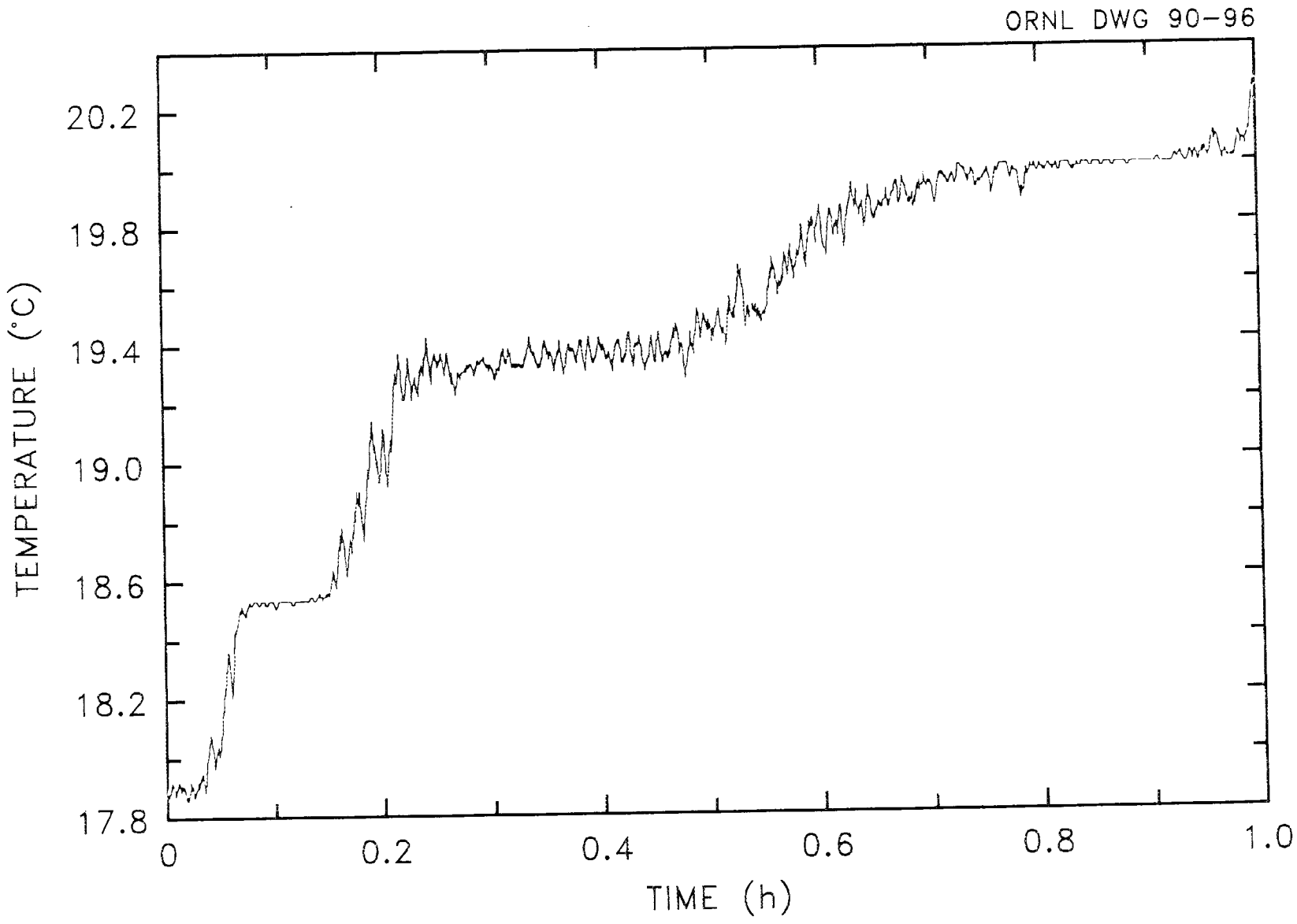

Fig. A.2. Grout temperature as a function of time for Run 1.

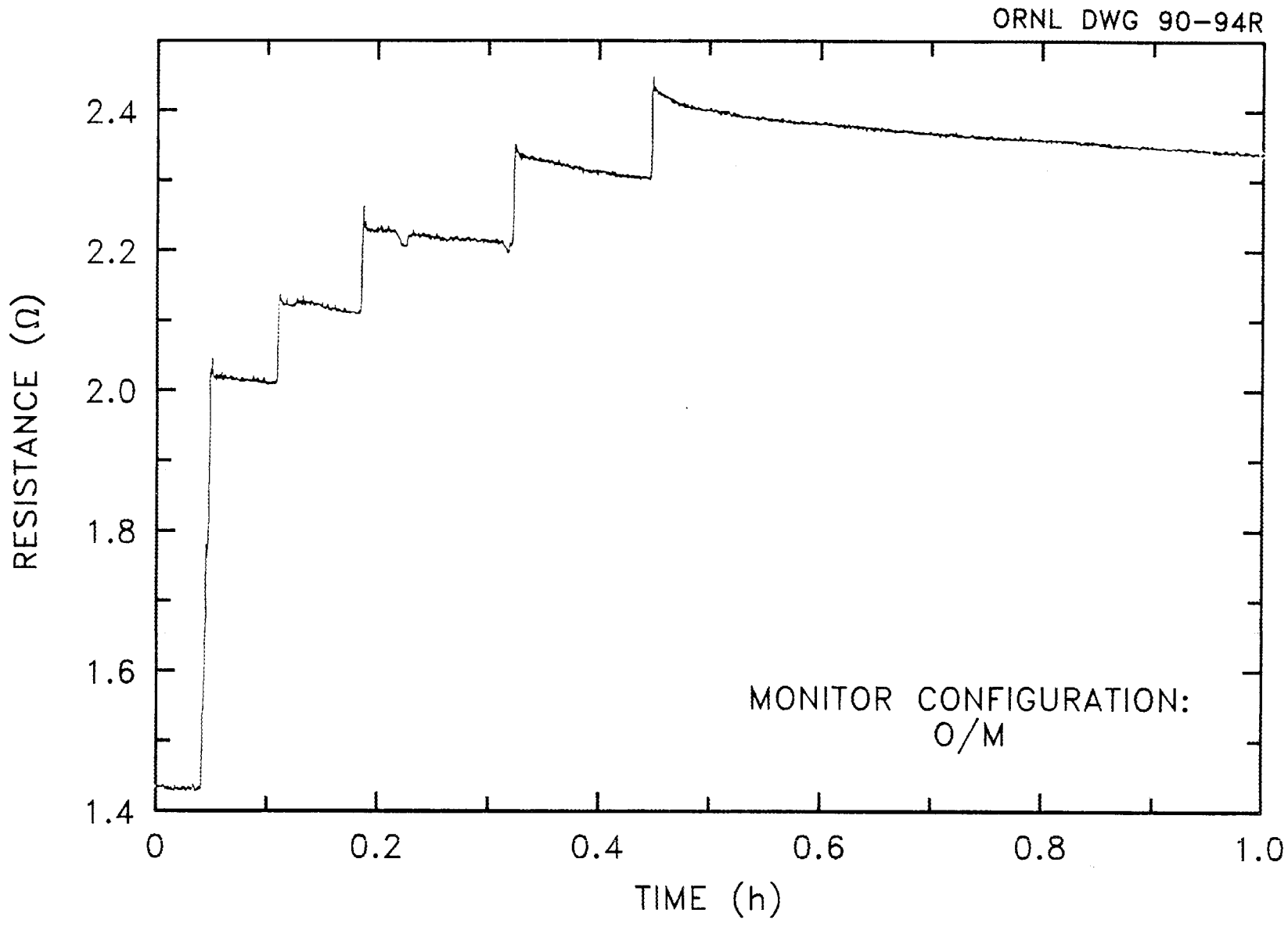

Fig. A.3. Electrical response (resistance) as a function of time for Run 2.

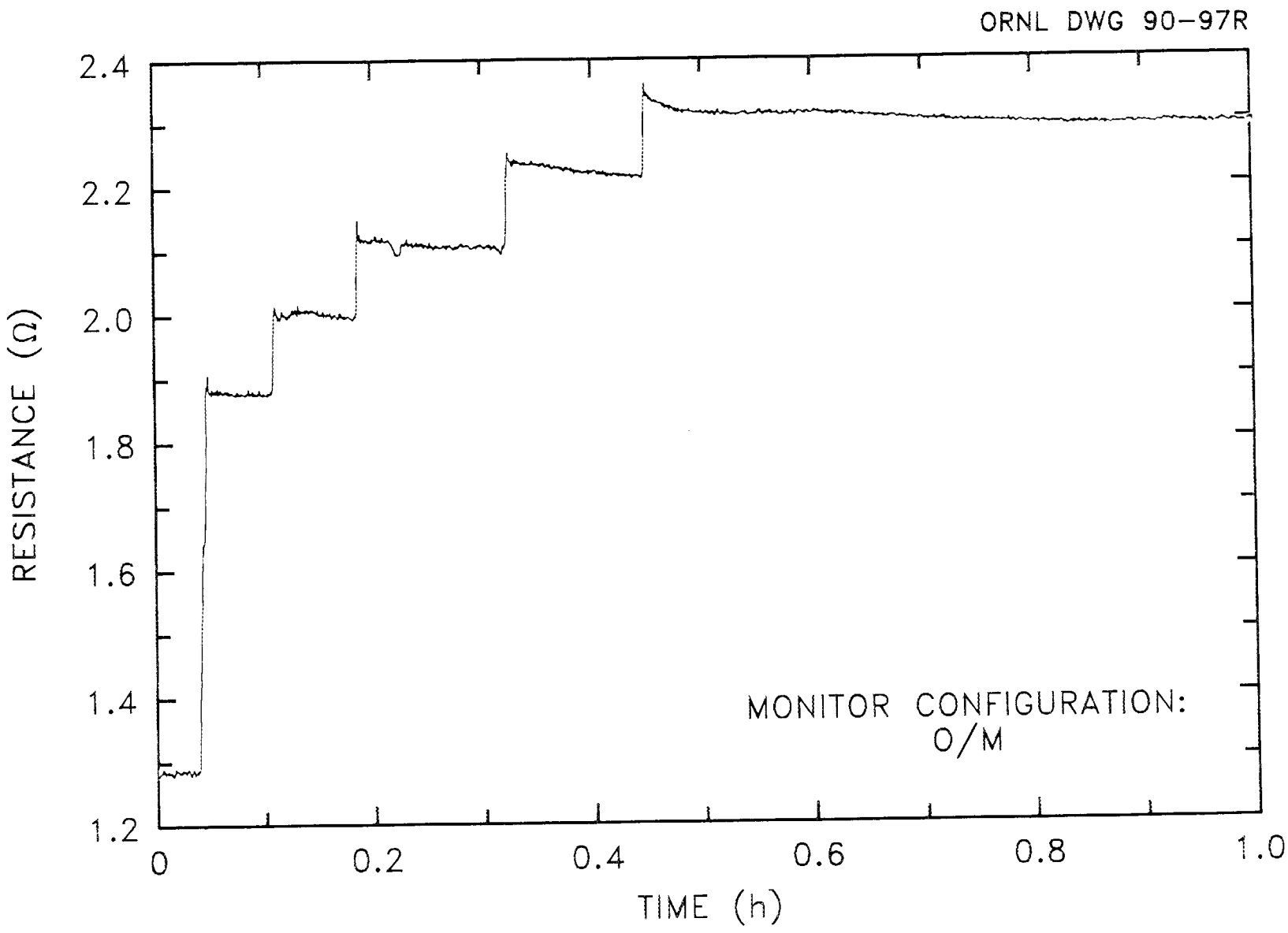

Fig. A.4. Electrical response (resistance) normalized to 20°C as a function of time for Run 2.

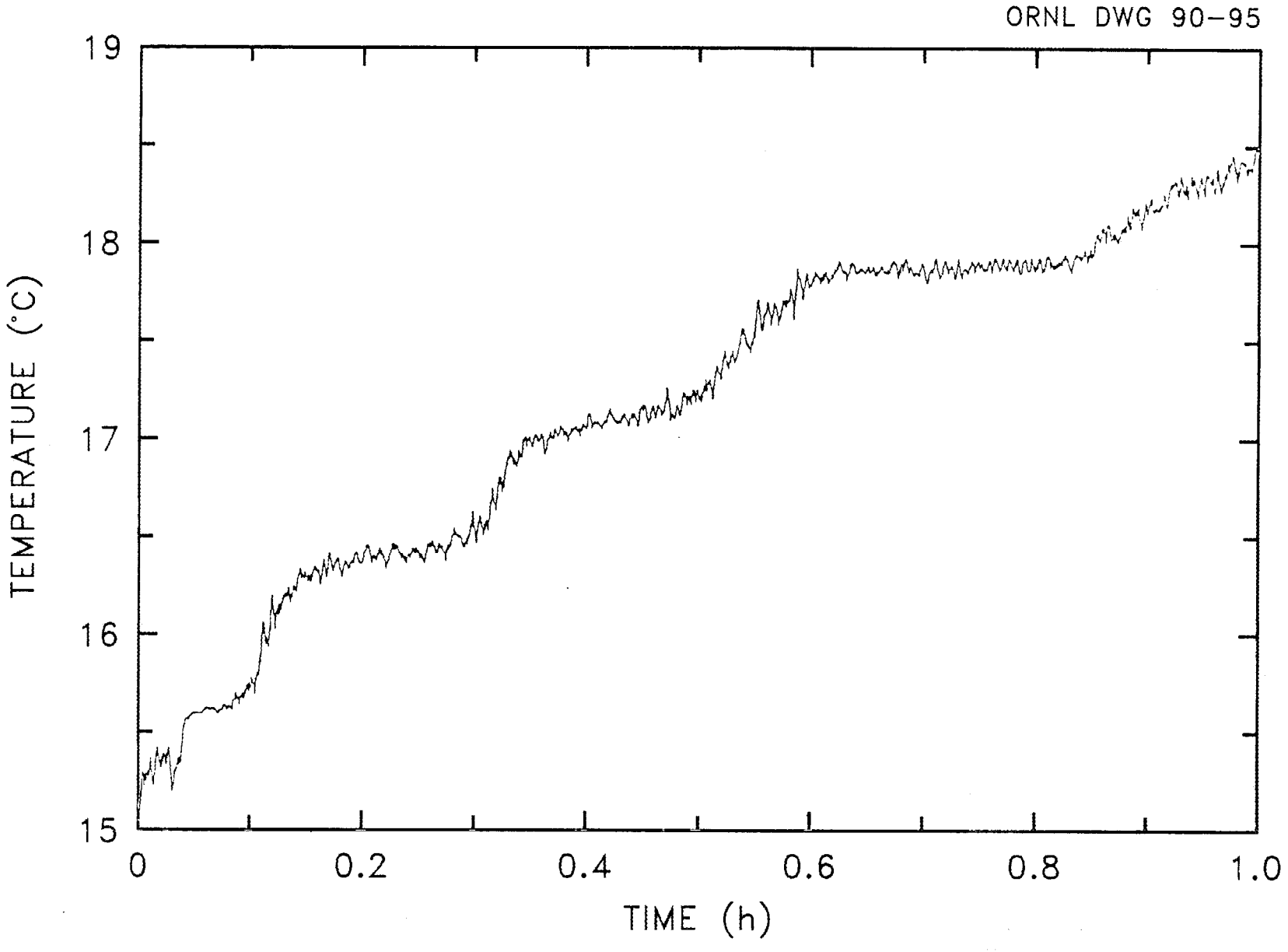

Fig. A.5. Grout temperature as a function of time for Run 2.

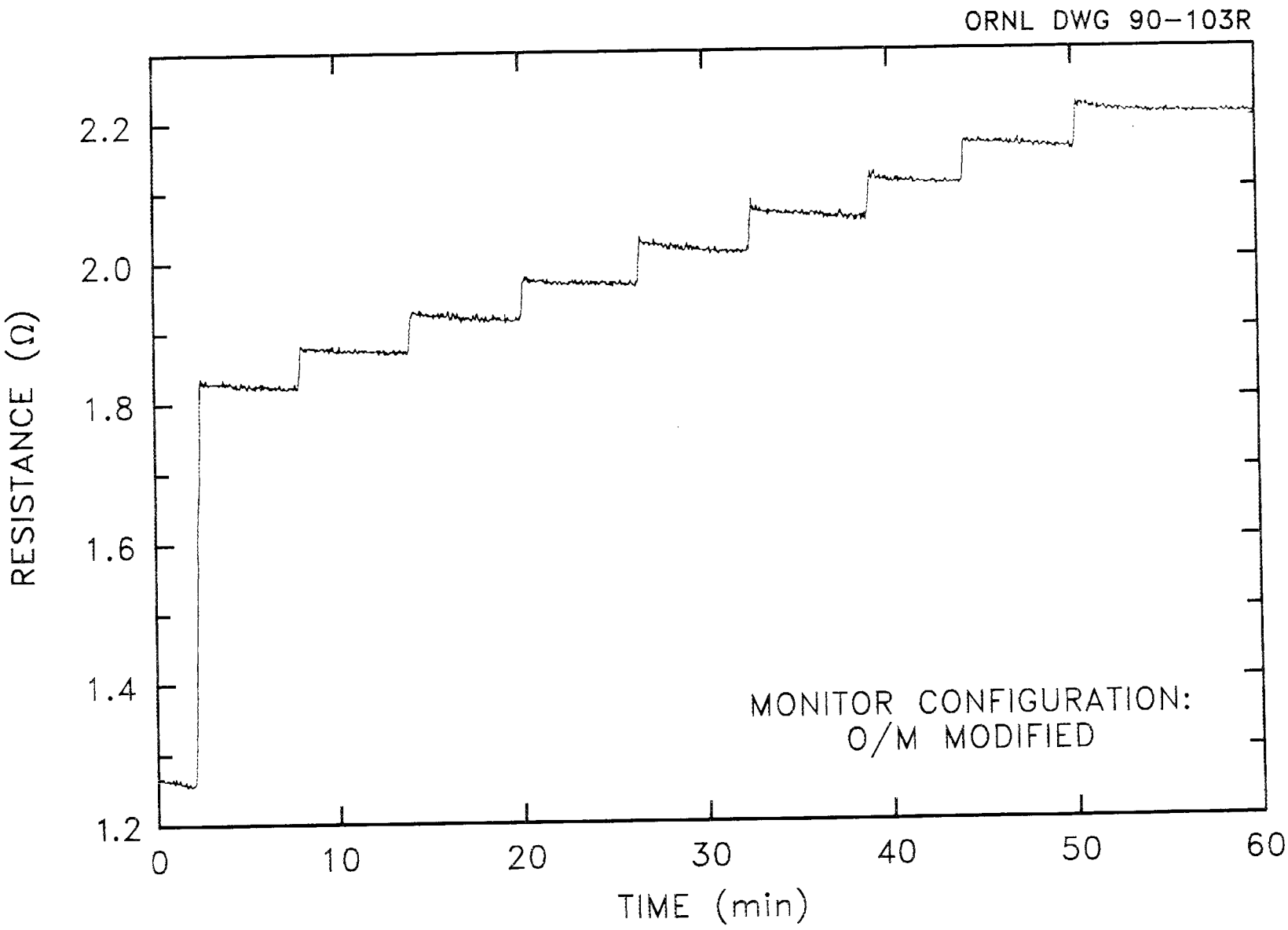

Fig. A.6. Electrical response (resistance) as a function of time for Run 4.

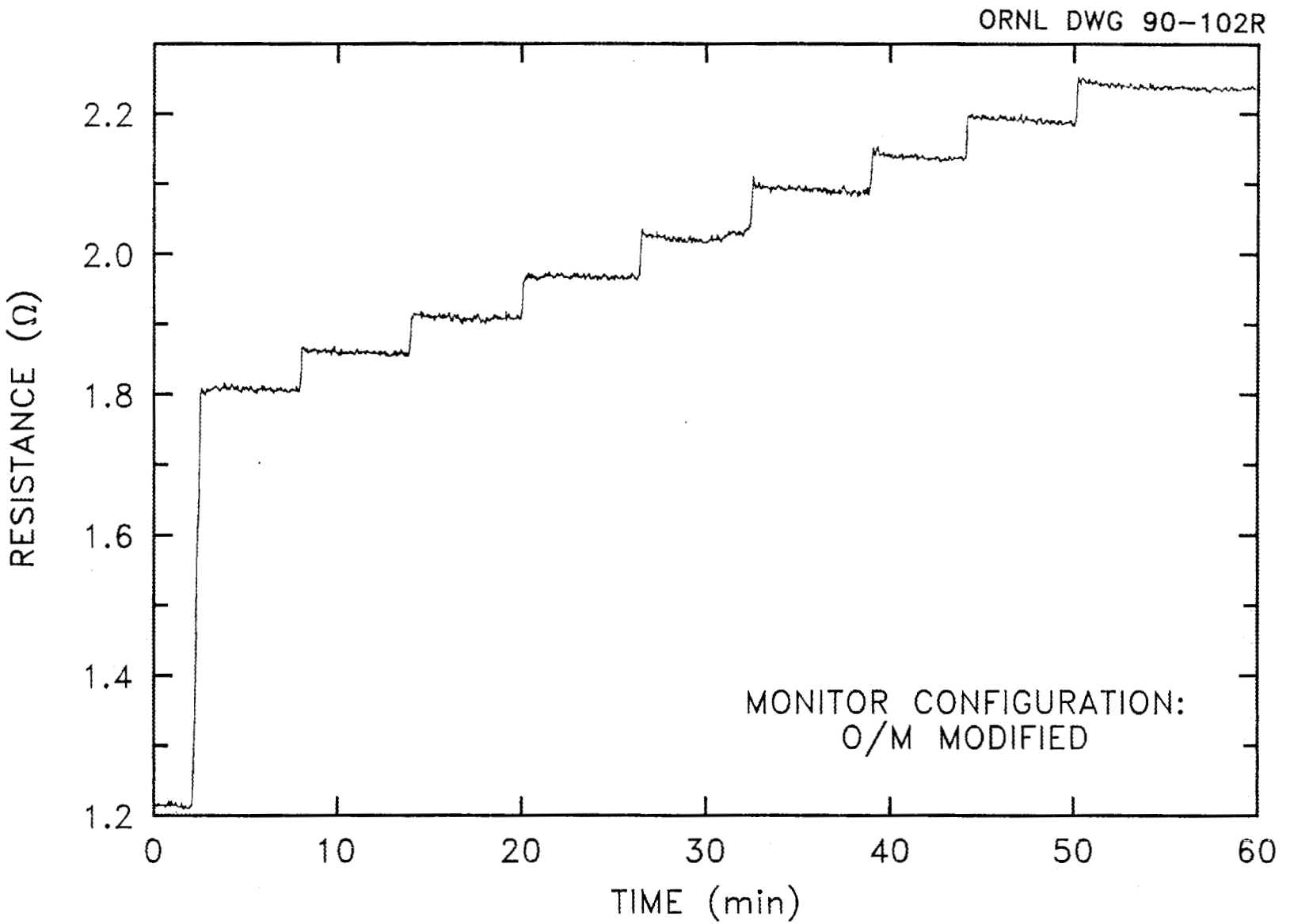

Fig. A.7. Electrical response (resistance) normalized to 20°C as a function of time for Run 4.

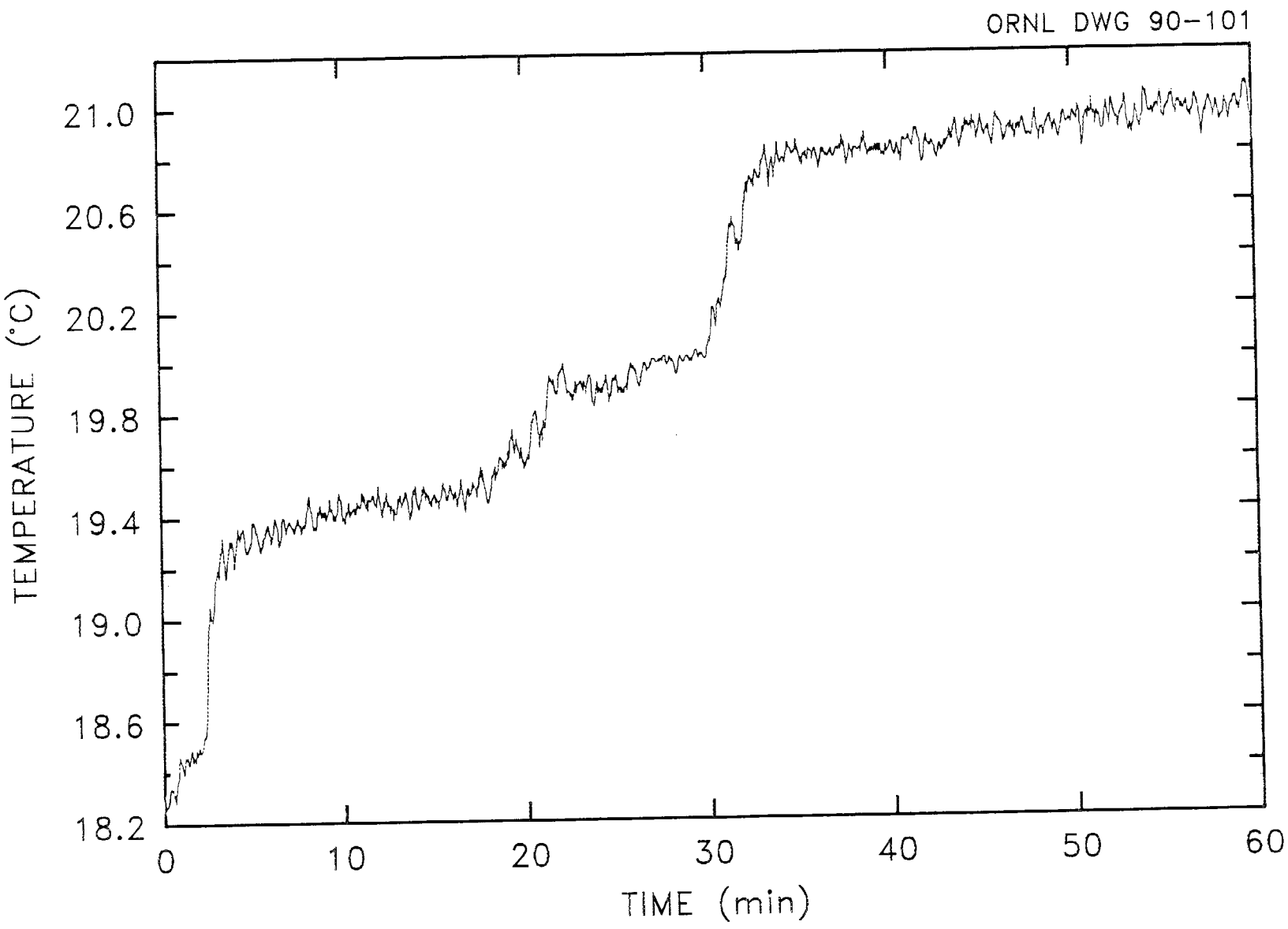

Fig. A.8. Grout temperature as a function of time for Run 4.

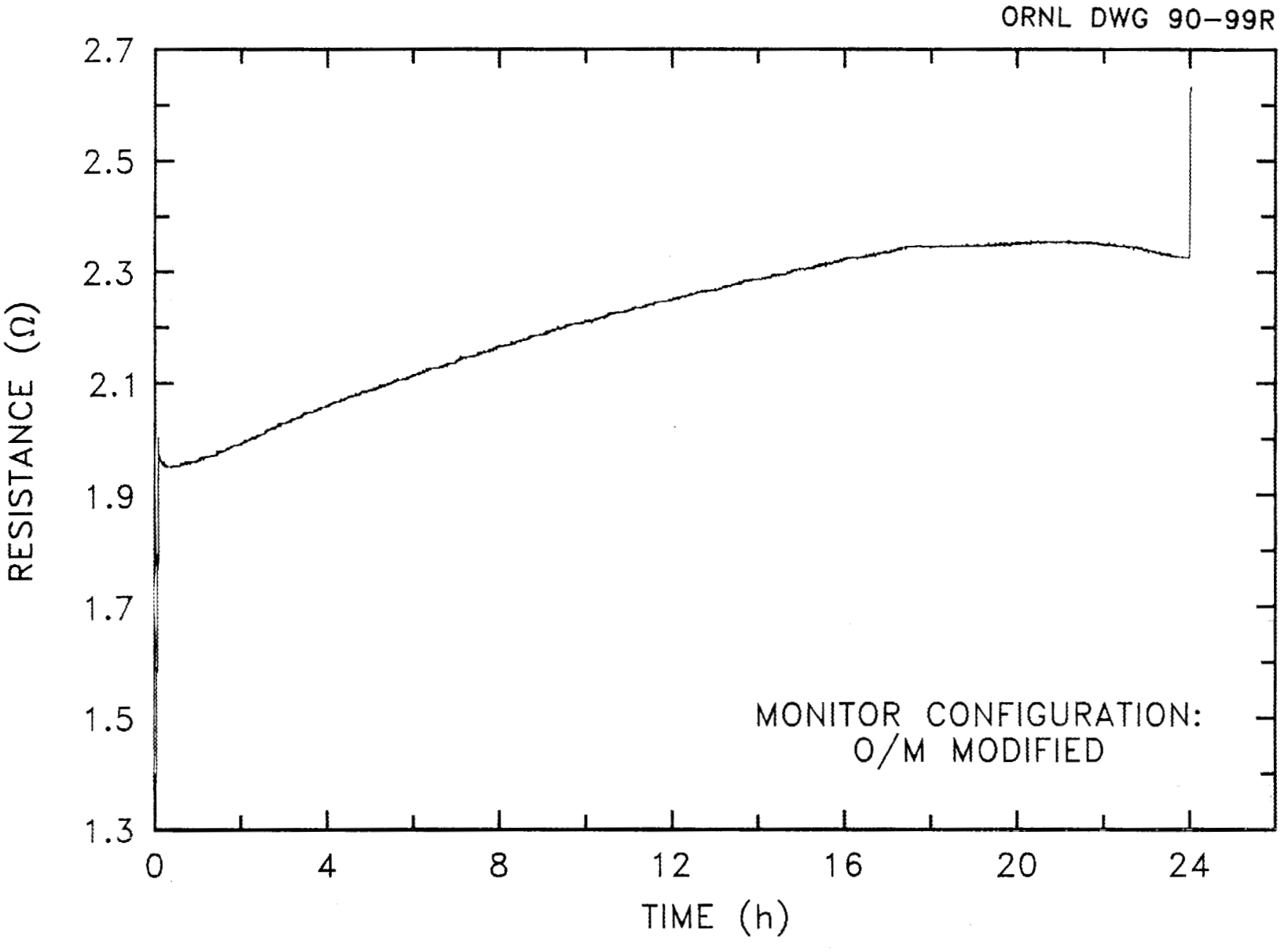

Fig. A.9. Electrical response (resistance) as a function of time for Run 5.

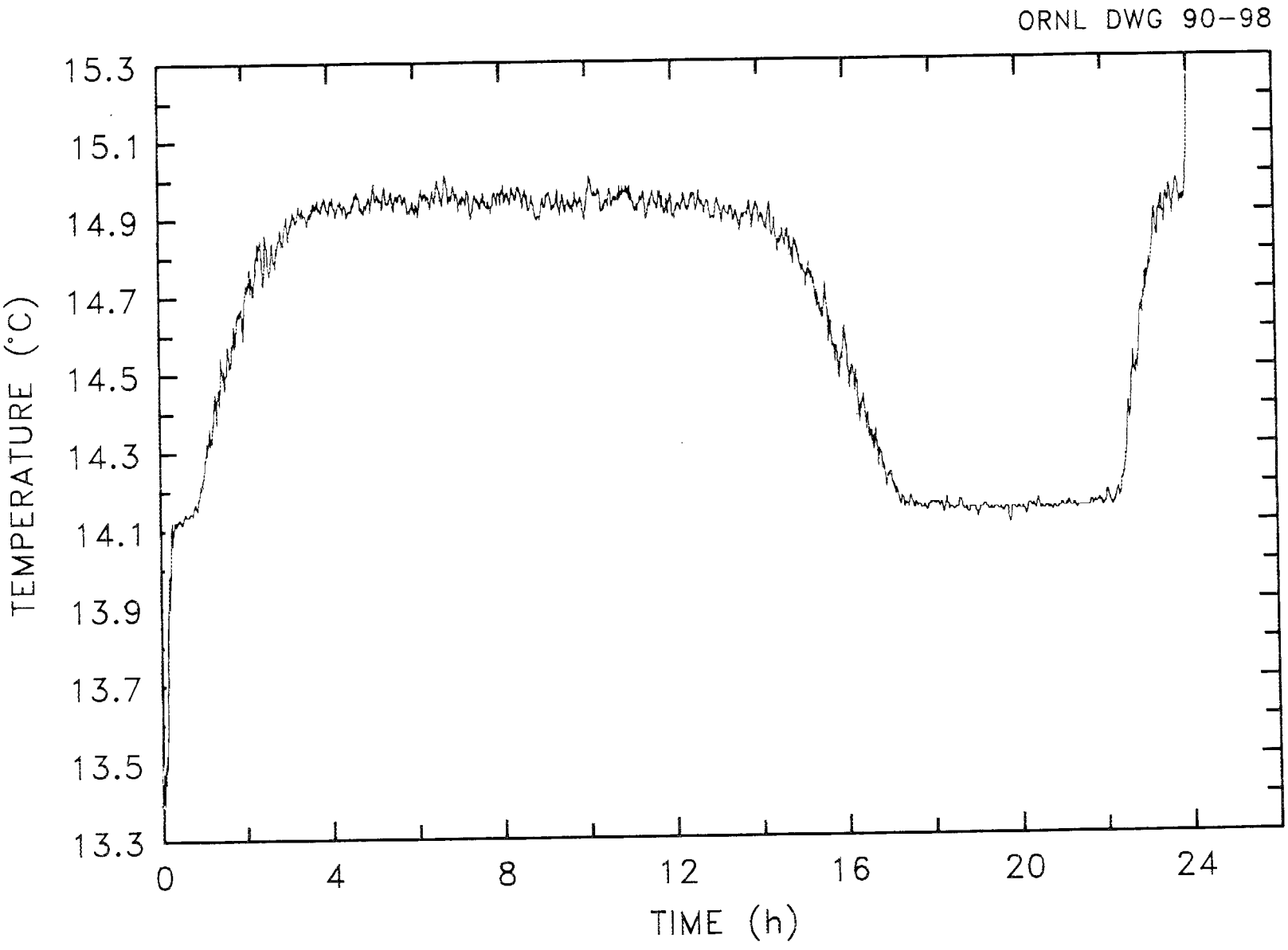

Fig. A.10. Grout temperature as a function of time for Run 5.

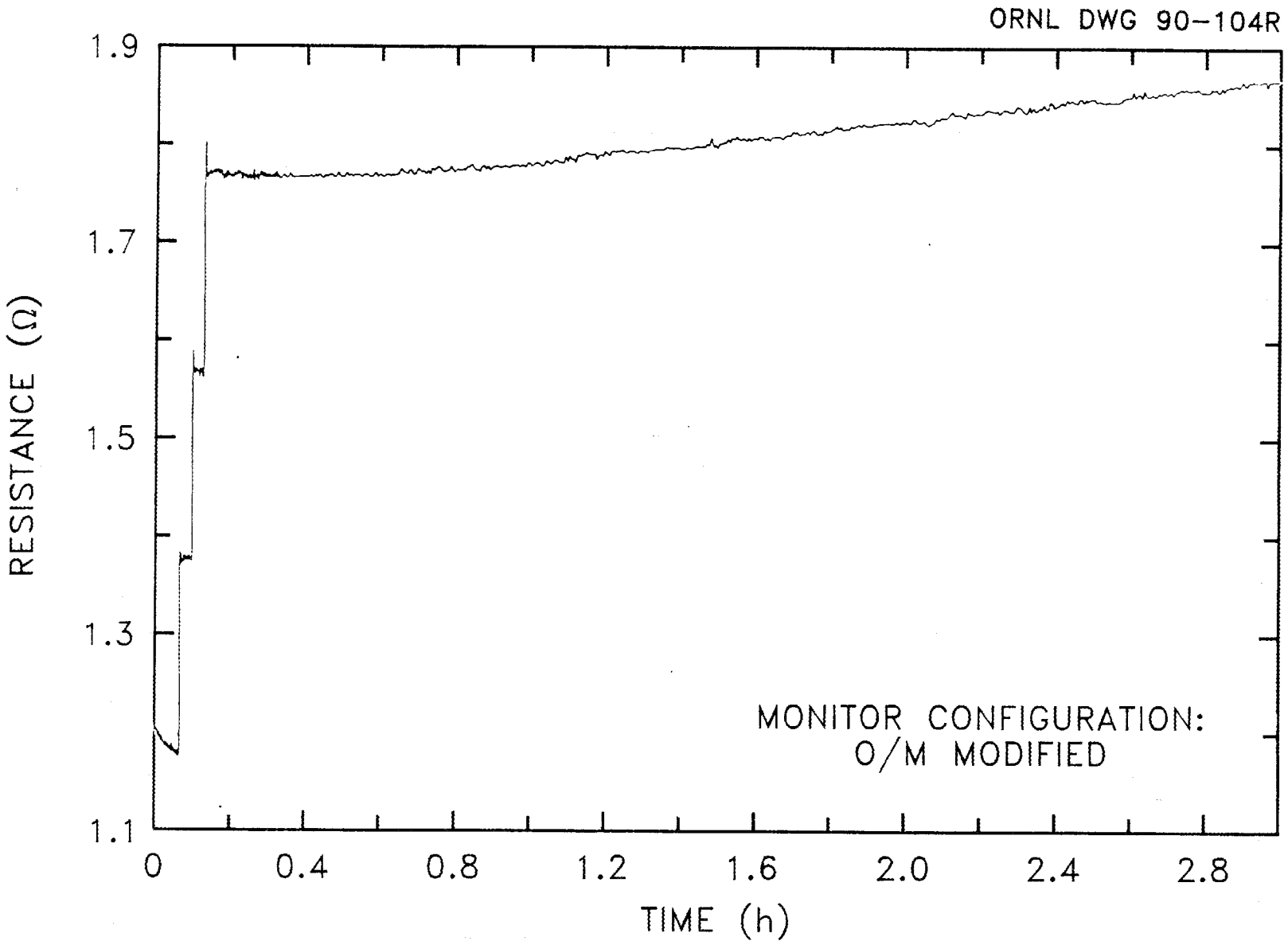

Fig. A.11. Electrical response (resistance) normalized to 20°C as a function of time for Run 5.

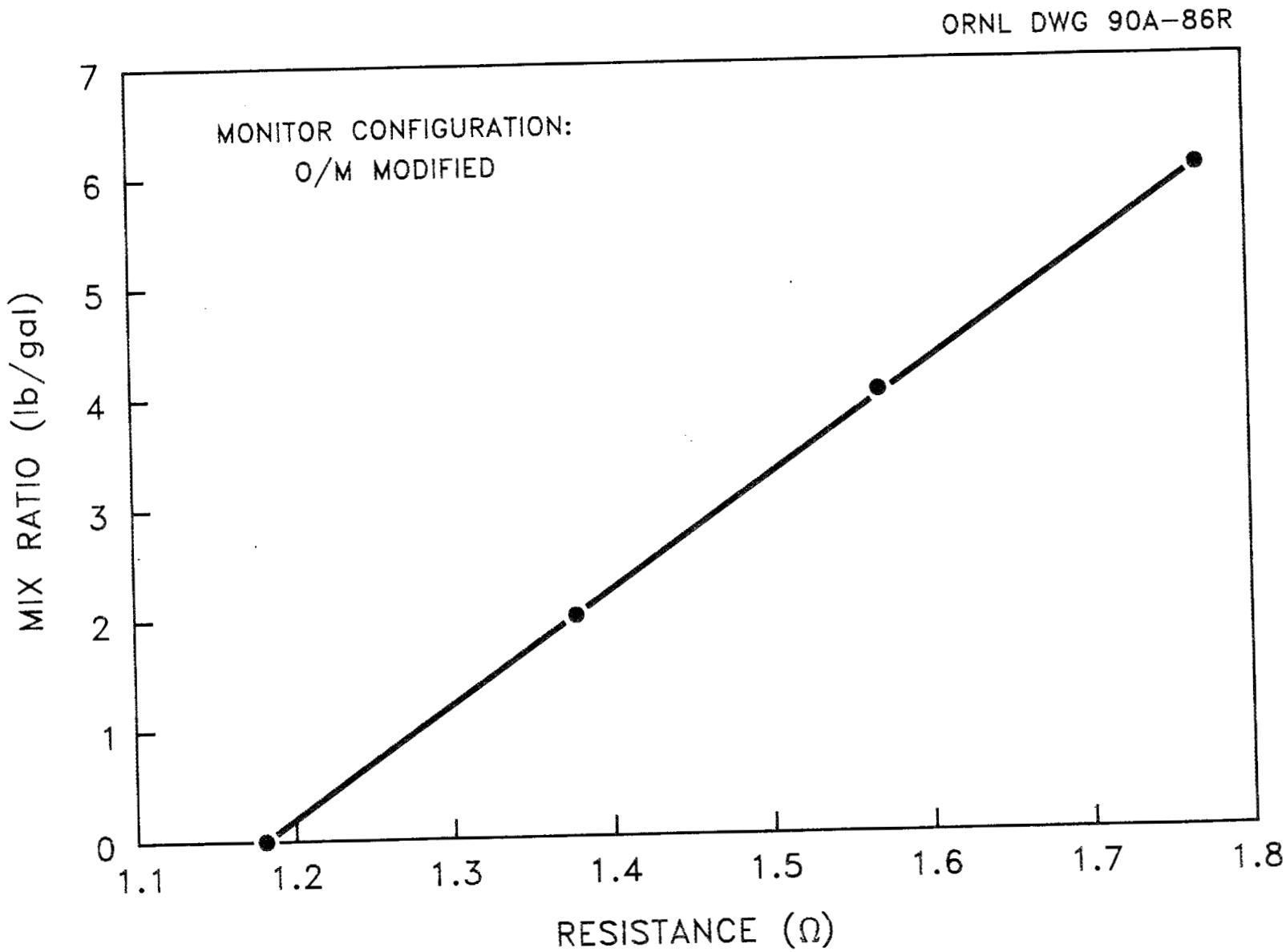

Fig. A.12. Grout mix ratio as a function of electrical response (resistance) normalized to 20°C for Run 5.

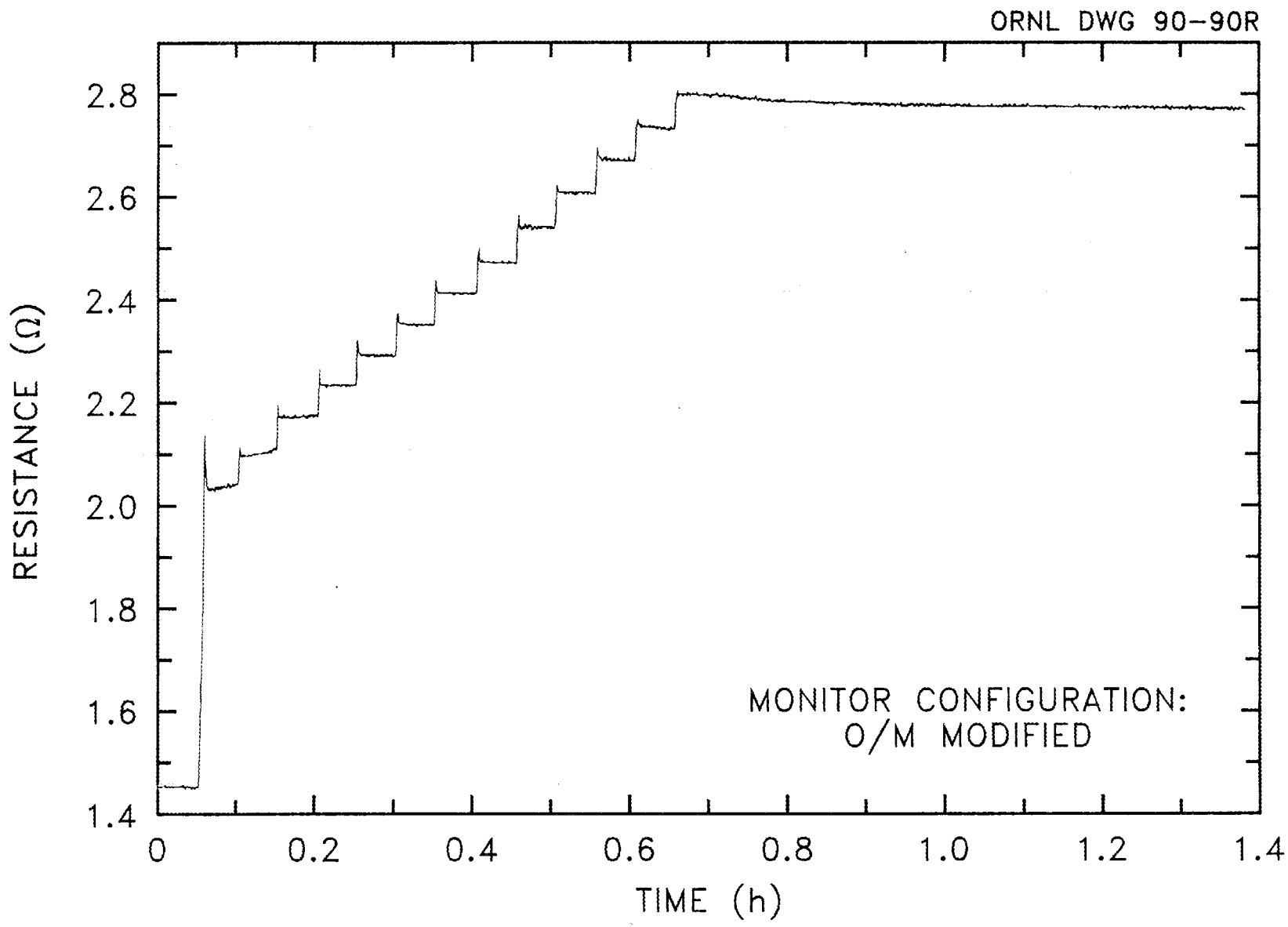

Fig. A.13. Electrical response (resistance) as a function of time for Run 6.

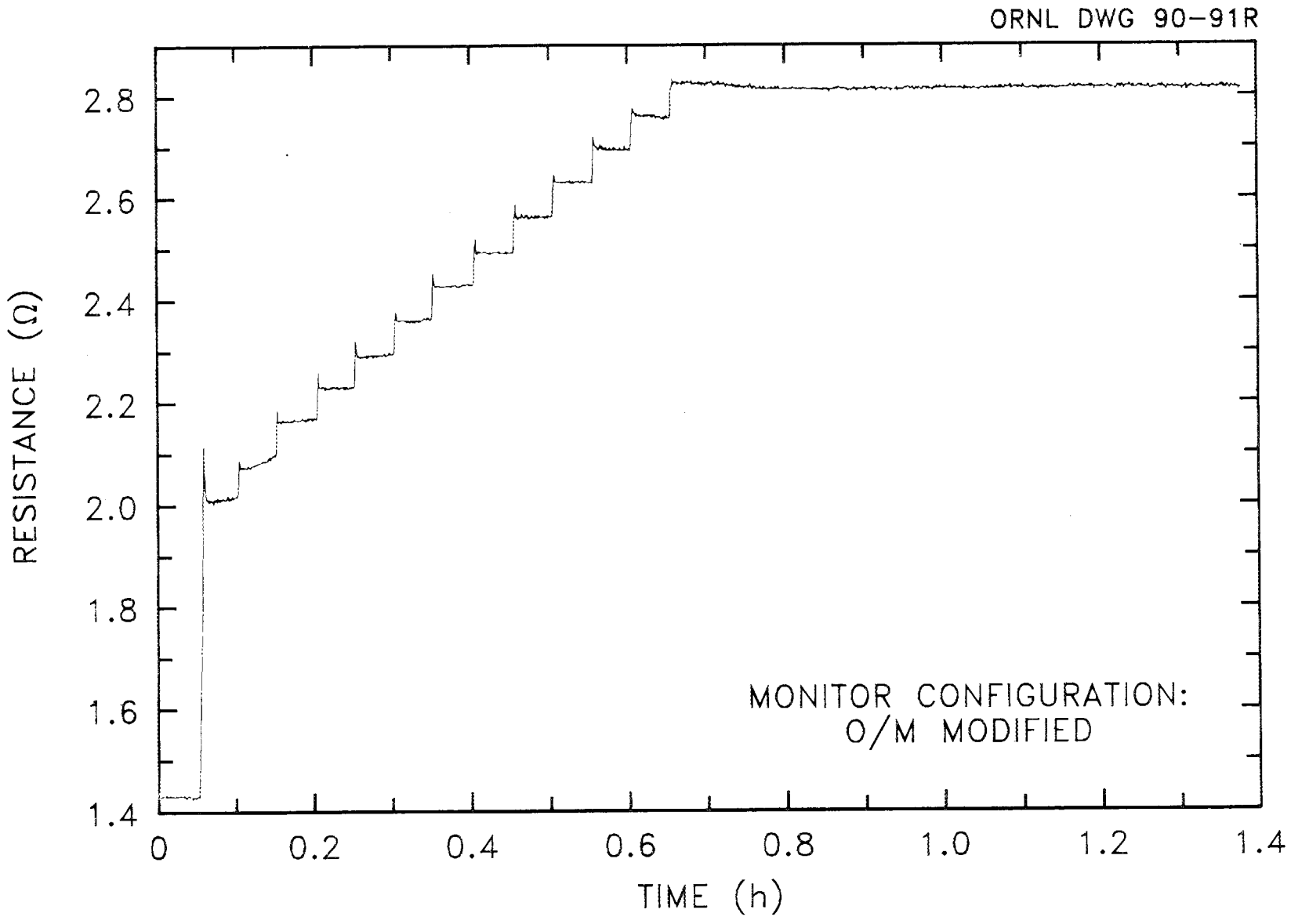

Fig. A.14. Electrical response (resistance) normalized to 20°C as a function of time for Run 6.

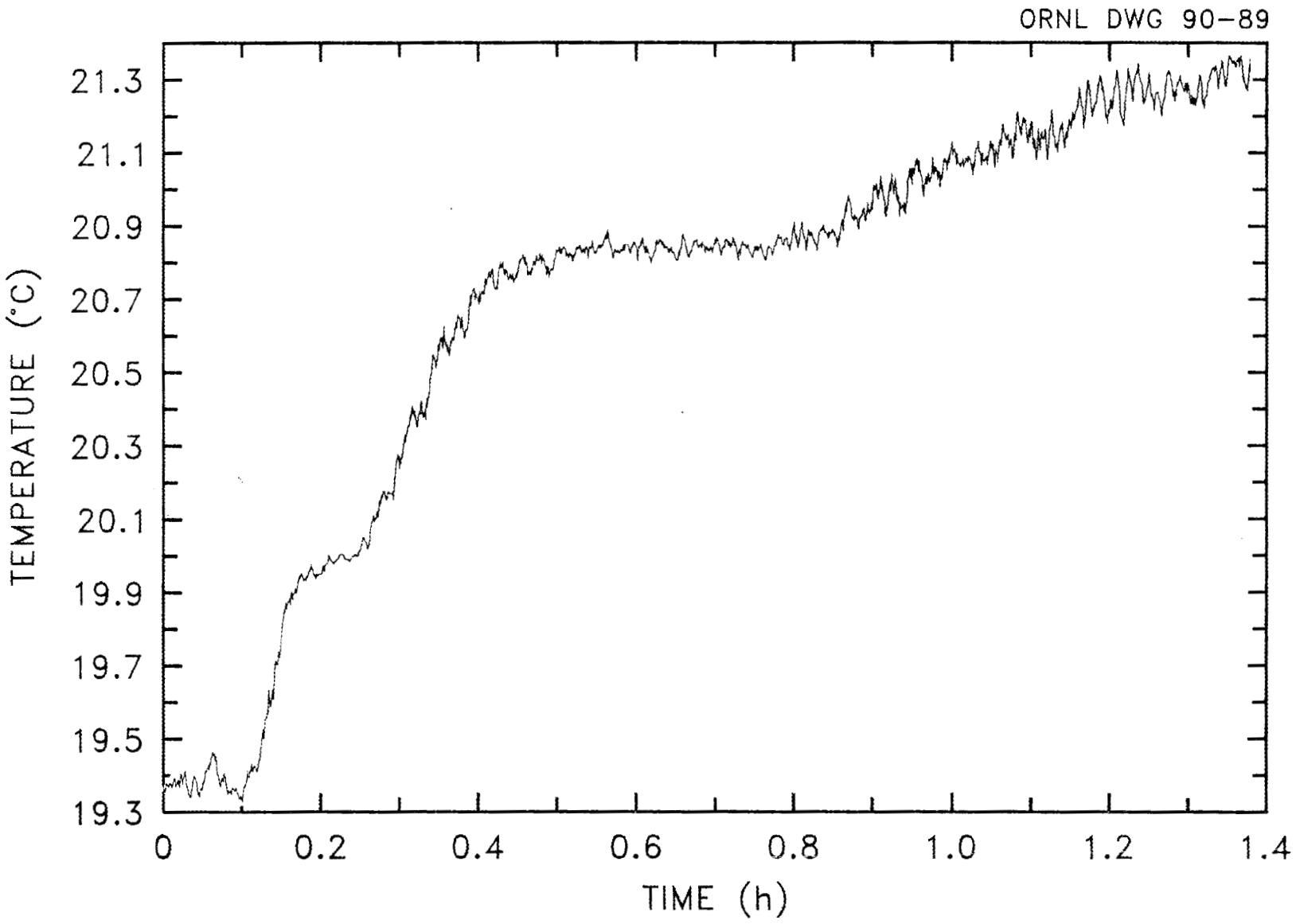

Fig. A.15. Grout temperature as a function of time for Run 6.

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