VOLUMETRIC LEAK DETECTION IN LARGE UNDERGROUND STORAGE TANKS

VOLUME I

by

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Contract No. 68-03-3409

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CINCINNATI, OHIO 45268

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FOREWORD

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The Risk Reduction Engineering Laboratory is responsible for planning, implementing, and managing research, development, and demonstration programs to provide an authoritative, defensible engineering basis in support of the policies, programs, and regulations of the EPA with respect to drinking water, wastewater, pesticides, toxic substances, solid and hazardous wastes, and Superfund-related activities. This publication is one of the products of that research and provides a vital communication link between the researcher and the user community.

This document presents the results of experiments conducted on 190,000-L (50,000-gal) underground storage tanks (USTs) to determine how to test large tanks for leaks with volumetric leak detection systems. The work reported in this document has applications to the UST release detection technical standards in CFR 280 Subpart D.

E. Timothy Oppelt, Director
Risk Reduction Engineering Laboratory

ABSTRACT

The performance standards established by the EPA underground storage tank (UST) regulation (40 CFR Parts 280 and 281) for volumetric leak detection systems, which include tank tightness testing systems and automatic tank gauging systems (ATGS), were based upon experimental research in tanks having capacities of 30,000 L (8,000 gal) and 38,000 L (10,000 gal). However, the regulation requires the testing of tanks as large as 190,000 L (50,000 gal). The performance of volumetric systems in detecting leaks from large tanks is not well known, and there exist very little data from which an assessment can be made. As a consequence, there is not enough information to help owners and operators select systems that will be in compliance with the regulations when it comes to testing large tanks, i.e., those between 57,000 and 190,000 L (15,000 and 50,000 gal).

This report addresses three important questions about testing the larger underground storage tanks for leaks. First, can the EPA regulatory standards be met when volumetric methods are used to test tanks up to 190,000 L (50,000 gal) in capacity? Second, what is the precision required of the temperature and level sensors and what is the minimum duration of the data collection period in order for a volumetric system to accurately test larger tanks, particularly those that are partially filled? Third, what are the important features of a volumetric system that meets or exceeds the regulatory performance standards?

These questions were addressed in a set of experiments conducted on two partially filled 190,000-L (50,000-gal) underground storage tanks at Griffiss Air Force Base in upstate New York during late August 1990. The experiments suggested that the time required for the temperature inhomogeneities within the product and for the structural deformation of the tank system to become negligible after any large addition or removal of product and after topping is approximately the same as observed in 30,000-L (8,000-gal tanks); in tests on the 190,000-L (50,000-gal) tanks, however, the temperature inhomogeneities were greater than in tests on 30,000-L (8,000-gal) tanks. Thus, a system's performance in large tanks depends primarily on the accuracy of the temperature compensation, which is inversely proportional to the volume of the product in the tank. Volumetric tank tightness tests use a preset threshold value that, if exceeded, is the basis for declaring a leak; they employ a waiting period after any addition or removal of product so that both temperature inhomogeneities and structural deformation will have a chance to subside. The thermistors used in the Griffiss experiments were calibrated to

better than 0.001°C and spaced at 30-cm (12-in.) intervals. The data from these experiments suggest that, at the thresholds typical of those used in volumetric tank tightness tests, small leaks (up to 0.38 L/h (0.1 gal/h)) would be difficult to detect even if the waiting period were sufficient for temperature inhomogeneities and structural deformation to subside. Vertical gradients in the rate of change of temperature near the bottom and top of the tank and horizontal gradients between the centerline of the tank and the wall of the tank were still so large after the waiting period that the thermistor array used in the Griffiss experiments did not provide sufficient thermal compensation. The data also suggest, however, that if thresholds typical of monthly ATGS tests were used, reliable detection of leaks as small as 0.76 L/h (0.2 gal/h) would be possible.

As a result of the experiments on 190,000-L (50,000-gal) tanks, the important features of a volumetric leak detection system that would have the performance necessary to meet EPA's regulatory standards for volumetric tank tightness tests have been identified. These features include the instrumentation, test protocol, and analysis. The experiments suggest that volumetric systems now capable of testing 30,000- to 38,000-L (8,000- to 10,000-gal) tanks can be used to meet the regulatory standard for testing 190,000-L (50,000-gal) tanks if (1) the duration of the test is increased from 1 or 2 h to 4 h or more to ensure that the vertical gradients are accurately measured and to reduce the ambient and instrumentation noise, (2) the number of temperature sensors is increased from 5 to 10 or more so that the accuracy of estimating the average thermally induced volume change in the layer of product surrounding each sensor increases, (3) the waiting period after any addition or removal of product is increased from 6 h to 24 h or longer so that the horizontal and vertical temperature gradients dissipate, (4) the average rate of change of temperature in any one layer or in the tank as a whole is small enough to allow accurate temperature compensation, and (5) an accurate experimental estimate of the constants necessary for converting level and temperature changes to volume is made. The experiments further suggest that a multiple-test strategy is required to meet the tank tightness regulatory standard.

The duration of a test depends on the precision of the instrumentation and the amount of ambient noise present in the measured volume changes. The magnitude and frequency of the ambient noise observed in the Griffiss experiments suggest that a test should be at least 4 h long. Given a certain precision of the level and temperature instrumentation, the minimum duration can be calculated. Calculations based on the Griffiss experiments suggest that, when the level

sensors have a precision of 0.0005 cm (0.00025 in.) And the temperature sensors have a precision of 0.001°C (0.002°F), the test must be at least 2 h long. When the instrumentation is less precise, the test must be commensurately longer.

The number of temperature sensors should be sufficient to cover the vertical extent of the tank, with denser coverage near the bottom and top of the product, where the rate of change of temperature and the gradients in the rate of change of temperature are greatest. In the Griffiss experiments it was observed that, during the first 9 h after product addition or removal, the 10 thermistors equally spaced at 30-cm (12-in.) intervals did not provide a sufficiently accurate estimate of the rate of change of temperature near the bottom of the tank, where the largest changes in temperature occurred, or near the surface of the product. (Even in the mid-region of the tank, 30-cm (12-in.) spacing was not sufficient in cases when temperature reversals occurred; this, however, can be monitored). Thus, it is recommended that the thermistors at the top and bottom of the tank be spaced at intervals of 15 cm (6 in.) or less. Reducing the space between sensors reduces the volume of product in the "layer" around each sensor, thus minimizing any potential measurement errors.

In the Griffiss experiments, a waiting period of 4 to 6 h after the addition or removal of product was deemed sufficient for the dissipation of horizontal gradients in the rate of change of temperature that were observed along the long axis of the tank. Those observed between the centerline of the tank and the wall, however, were large enough during the first 18 h to prevent the reliable detection of leaks up to 0.38 L/h (0.1 gal/h). It is therefore recommended that, with large tanks, a waiting period of 24 h be used. A longer waiting period may be required if the rate of change of temperature is very great. To determine whether the waiting period is sufficient, it is recommended that a measurement of the temperature changes in the area between the centerline and the wall be made; if this is not possible, repeated tests should be made until there is no observable change over time in the measured compensated volume.

Ten potential sources of error in temperature compensation are discussed, any one of which may be large enough to produce a testing mistake. Since all errors in temperature compensation are proportional to the average rate of change of temperature during a test, the most direct approach for improving the accuracy of temperature compensation is to wait until this rate has decreased substantially before beginning a test. This requires real-time measurements of temperature.

This report was submitted in fulfillment of Contract No. 68-03-3409 by Vista Research, Inc., under the sponsorship of the U.S. Environmental Protection Agency. This report covers a period from 30 November 1989 to 14 September 1990, and work was completed as of 30 September 1990.

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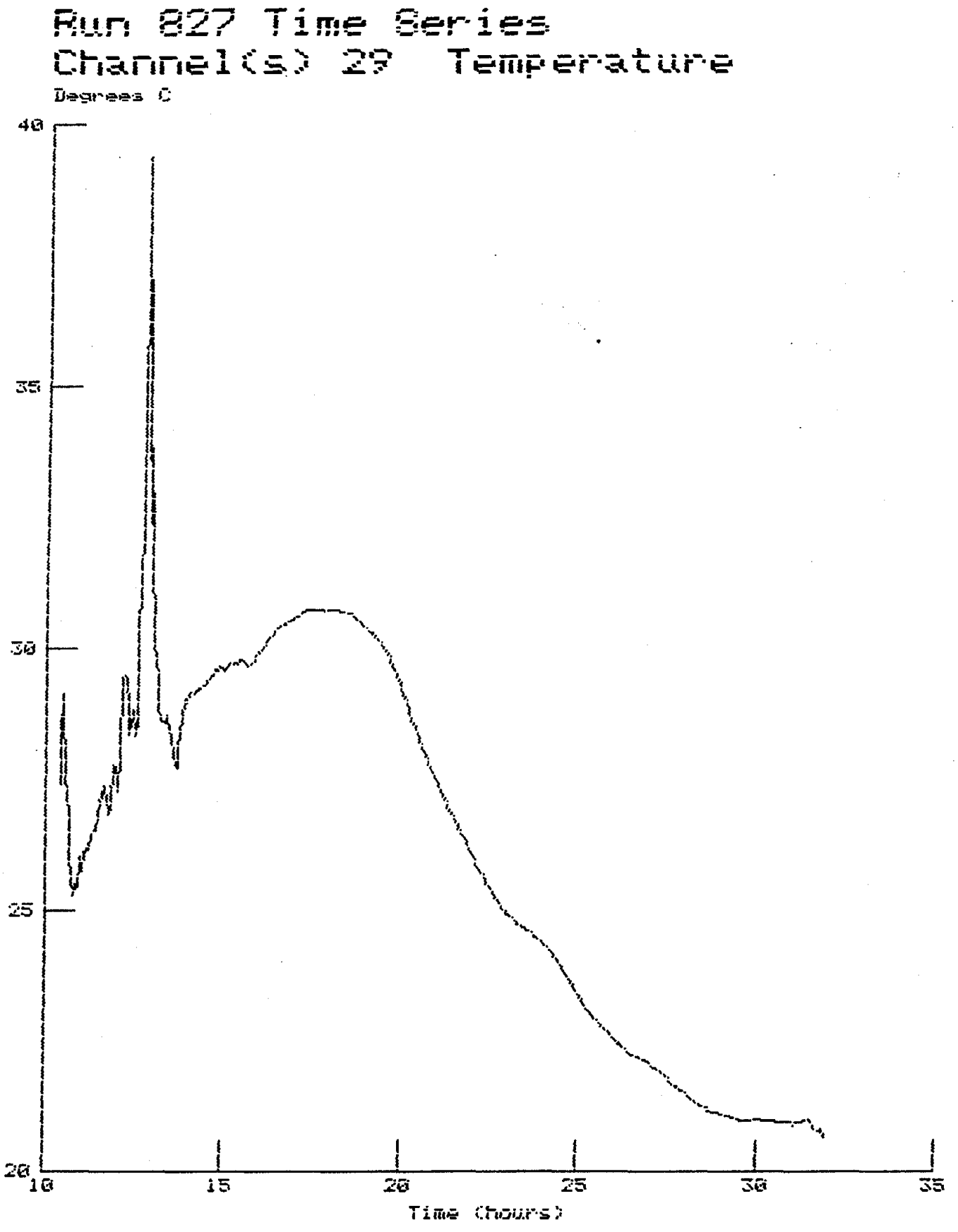
Appendix A

Overnight Test Begun at 1510 on 27 August 1990

The time series of temperature measured during the overnight test started on 27 August 1990 are presented in Appendix A. The raw data for Arrays A and B located in the 76-cm (30-in.) -diameter manway at B and the 10-cm (4-in.) -diameter fill hole at C, respectively, are shown. The time series for Array A are presented first. The times series are presented according to their location within the tank and on the array. All of the product thermistors located on the vertical portion of the array and in the product are displayed as a group; because the display software only allowed three time series on a display, several graphs are used to present the product time series. The thermistors on the horizontal are grouped together in one display and the thermistors in the vapor space and the air are also displayed together. Appendix A also includes the time series showing the difference in temperature between thermistors located on Arrays A and B. (Refer to Figure 3.)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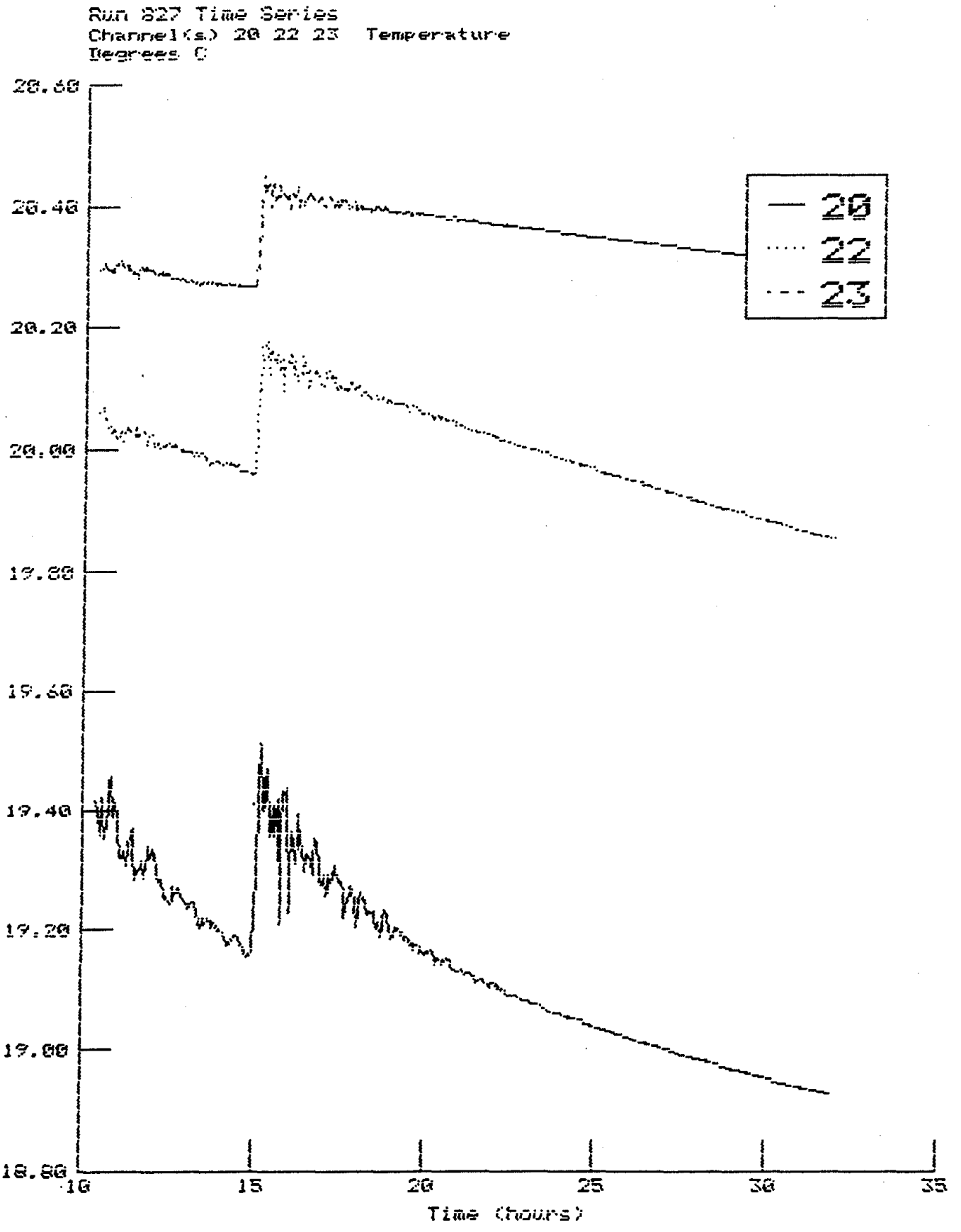
Degrees C
40
35
30
25
20
10
15
20
25
30
35
Time (hours)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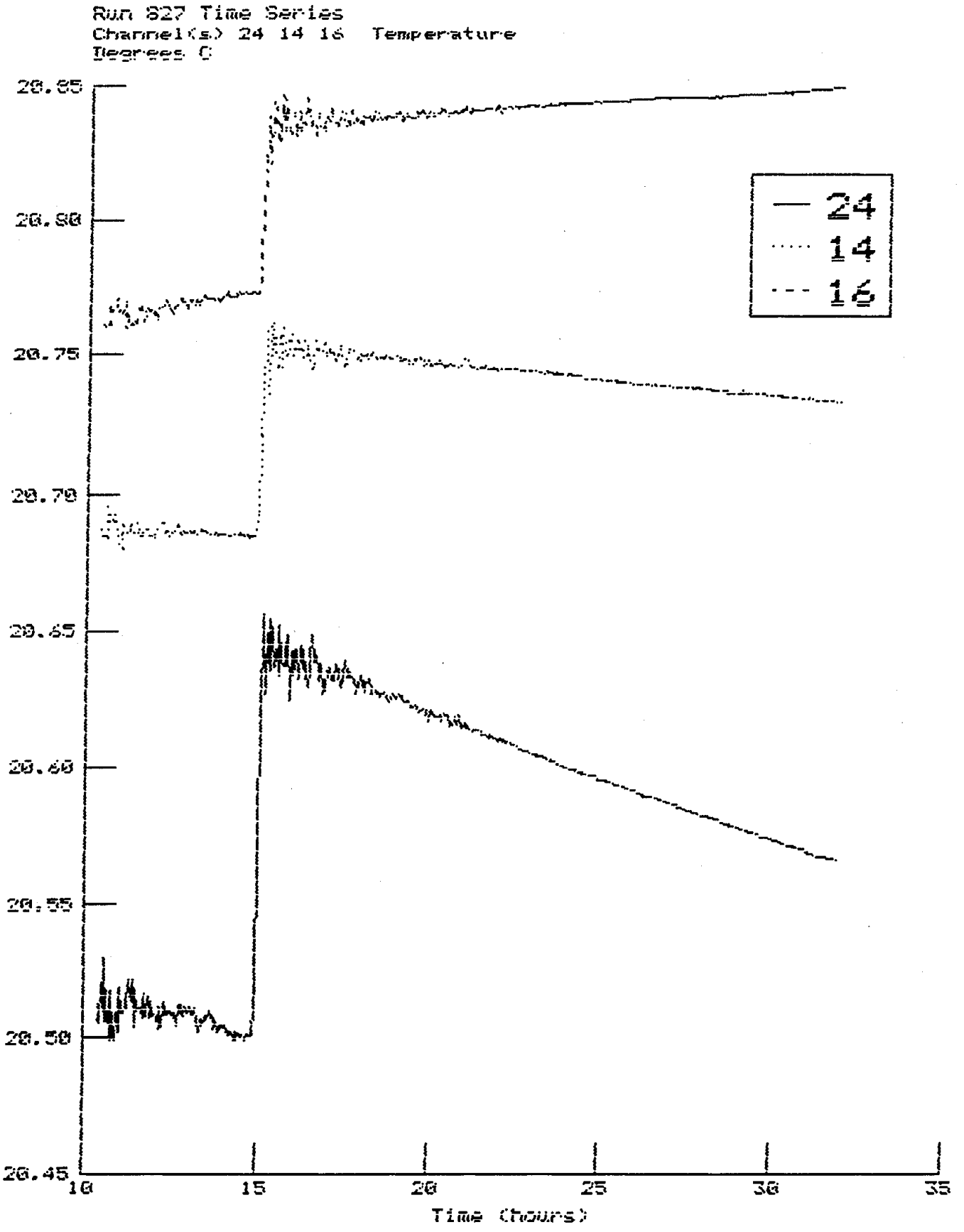
Channel(s) 20 22 23 Temperature
Degrees C
20.60
20.40
20.20
20.00
19.80
19.60
19.40
19.20
19.00
18.80
10
15
20
25
30
35
Time (hours)
20
22
23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Channel(s) 24 14 16 Temperature
Degrees C
20.85
20.80
20.75
20.70
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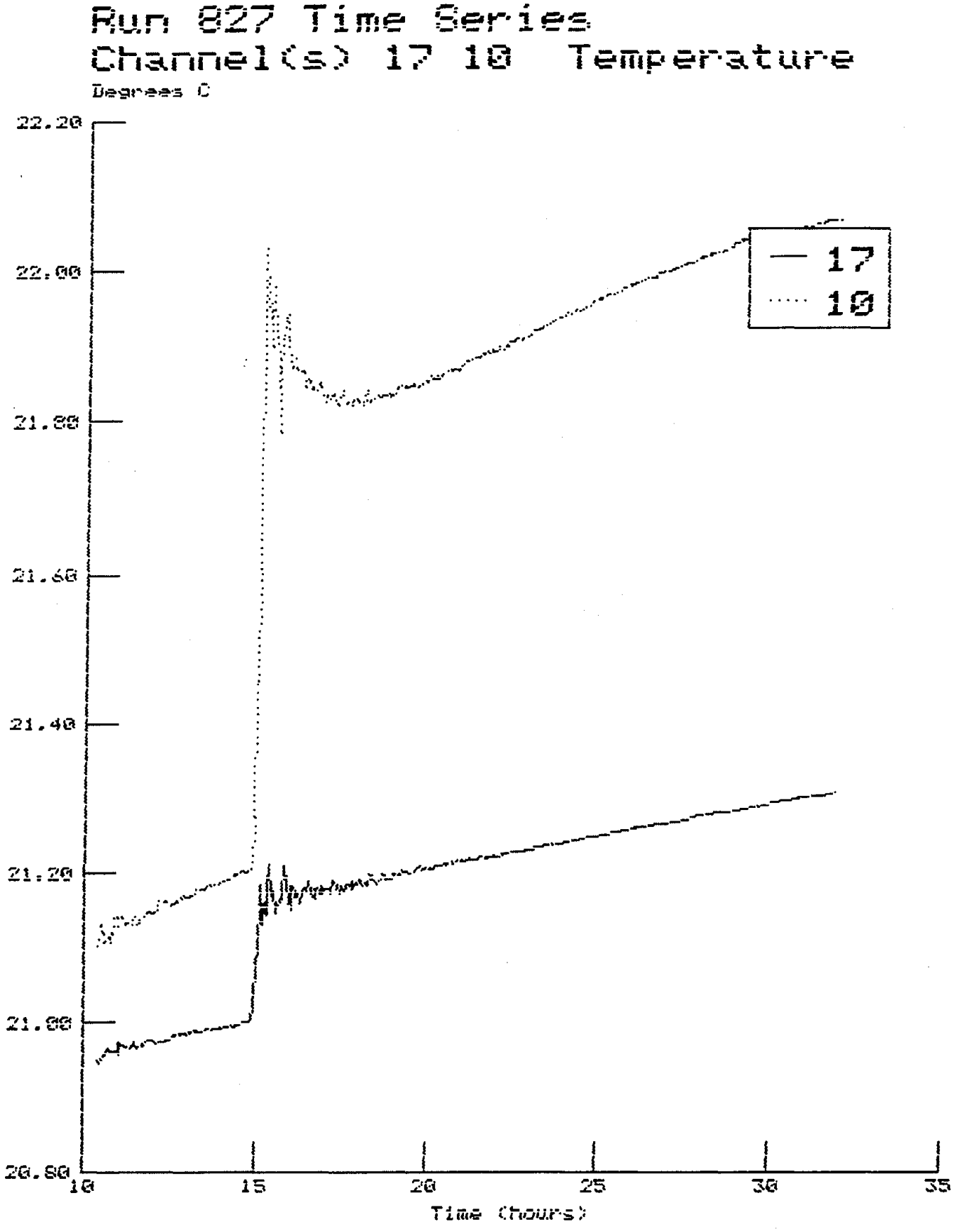
20.55
20.50
20.45
10
15
20
25
30
35
Time (hours)
24
14
16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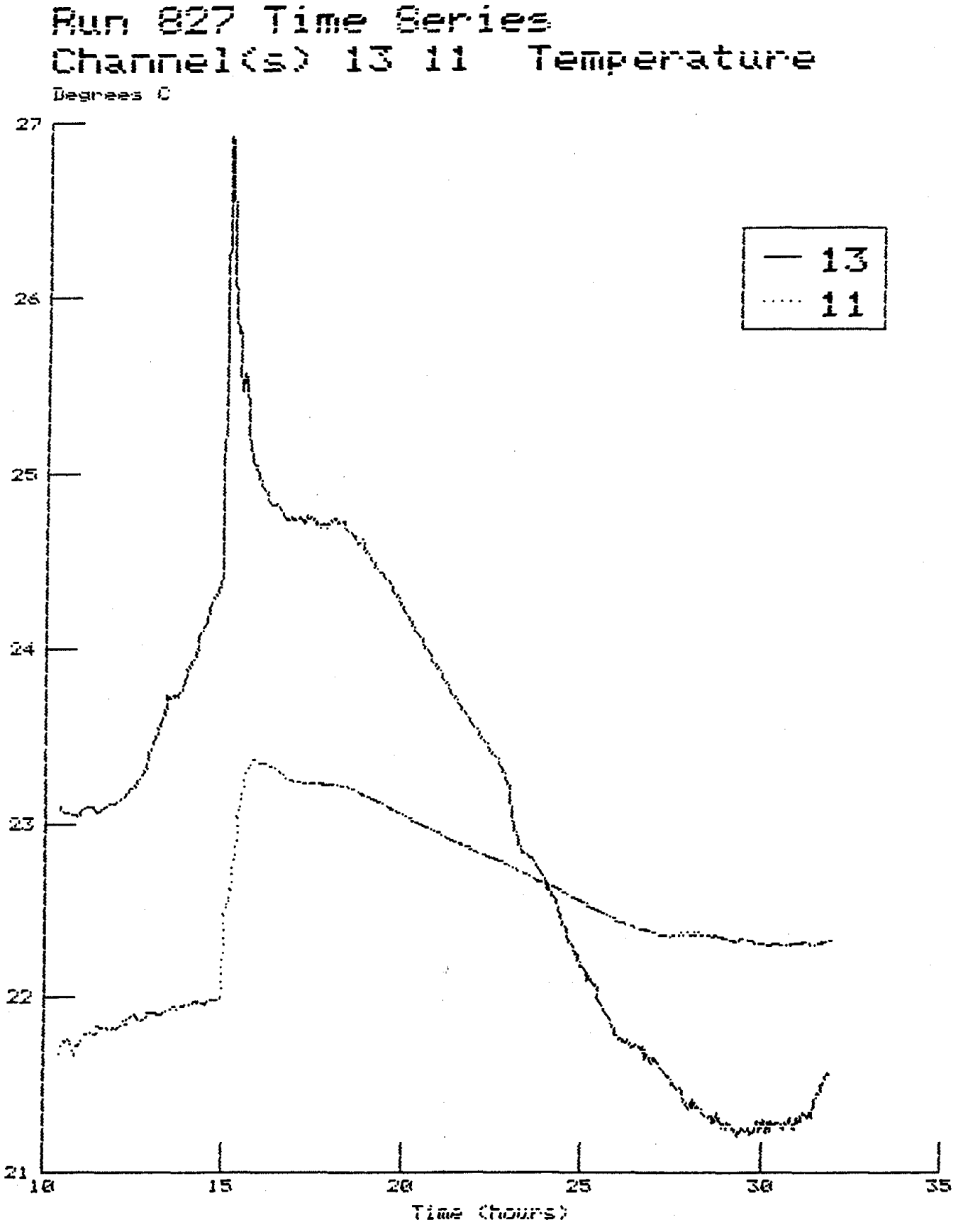
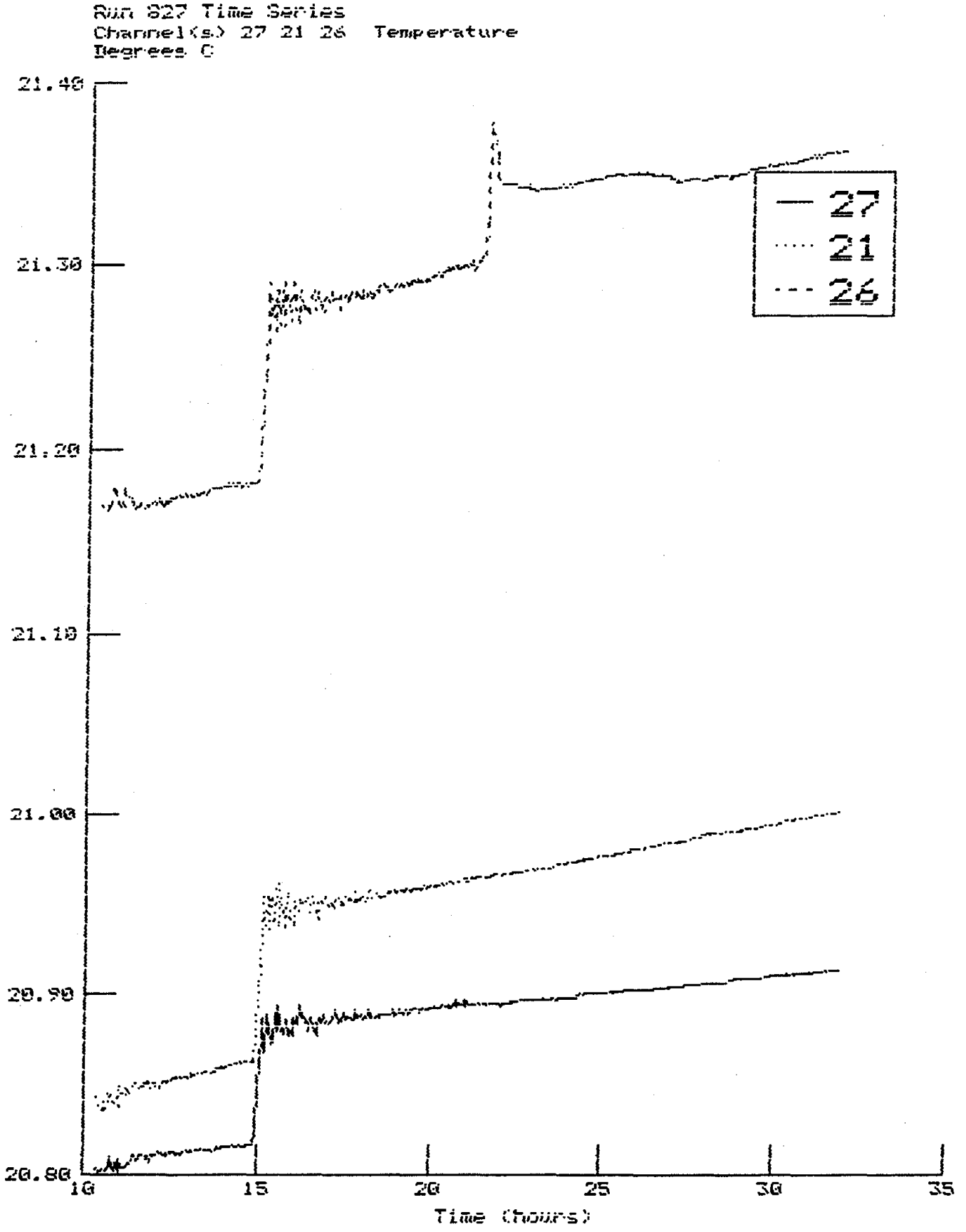
Channel(s) 17 10 Temperature
Degrees C
22.20
22.00
21.80
21.60
21.40
21.20
21.00
20.80
10
15
20
25
30
35
Time (hours)
17
10


Run 827 Time Series
Channel(s) 13 11 Temperature
Degrees C
27
26
25
24
23
22
21
10
15
20
25
30
35
Time (hours)
13
11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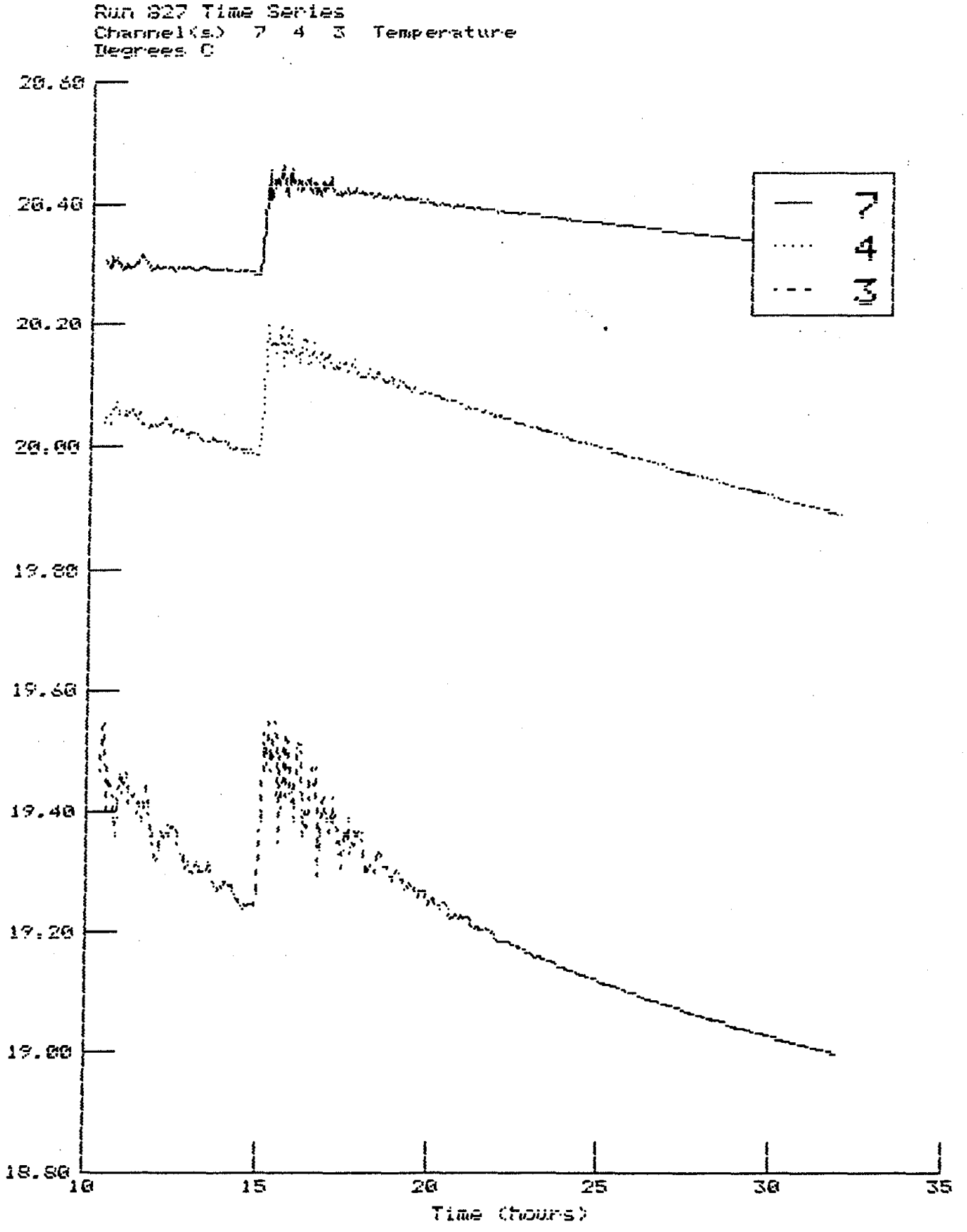
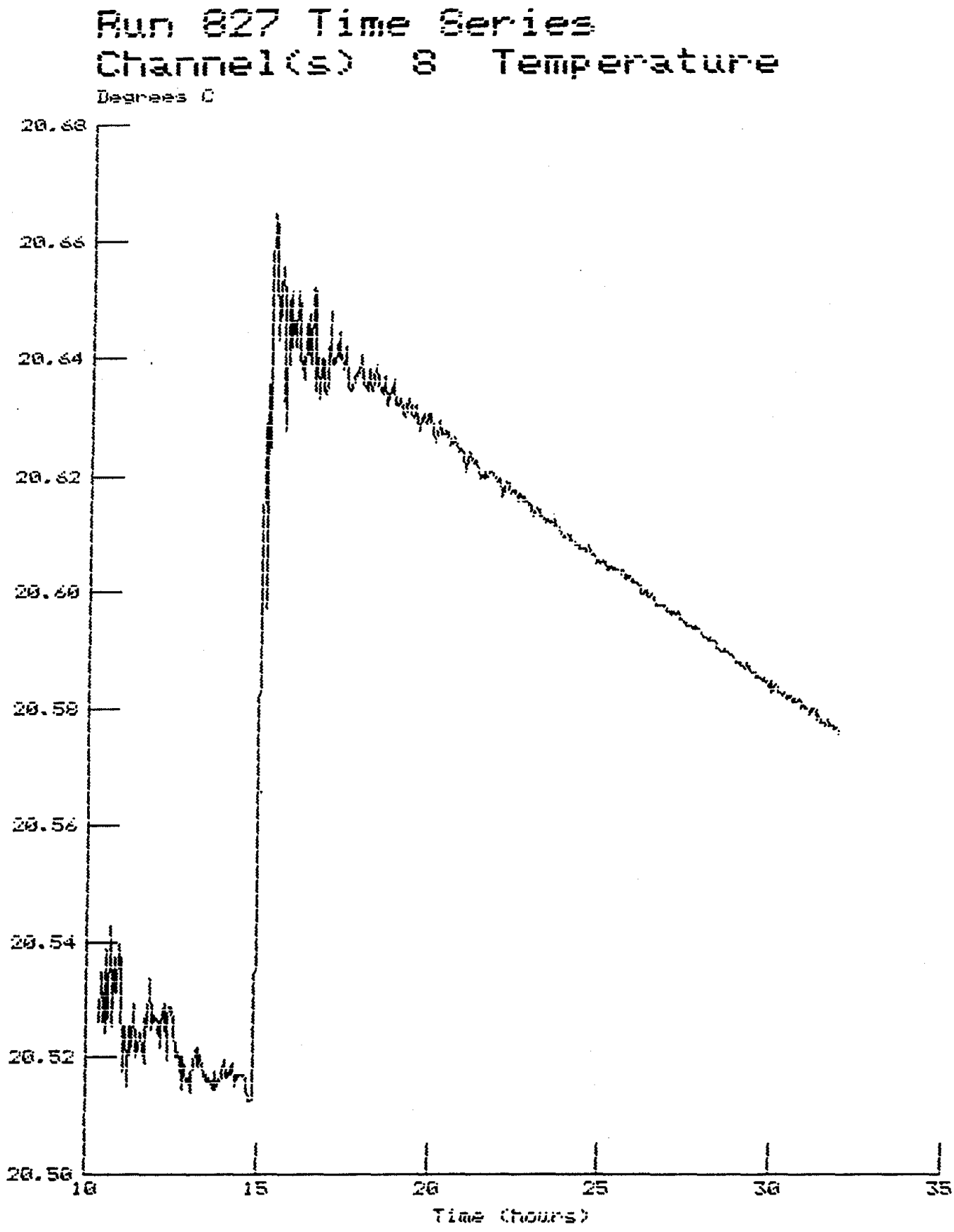
Channel(s) 27 21 26 Temperature
Degrees C
21.40
21.30
21.20
21.10
21.00
20.90
20.80
10
15
20
25
30
35
Time (hours)
27
21
26


Run 827 Time Series
Channel(s) 7 4 3 Temperature
Degrees C
20.60
20.40
20.20
20.00
19.80
19.60
19.40
19.20
19.00
18.80
10
15
20
25
30
35
Time (hours)
7
4
3

95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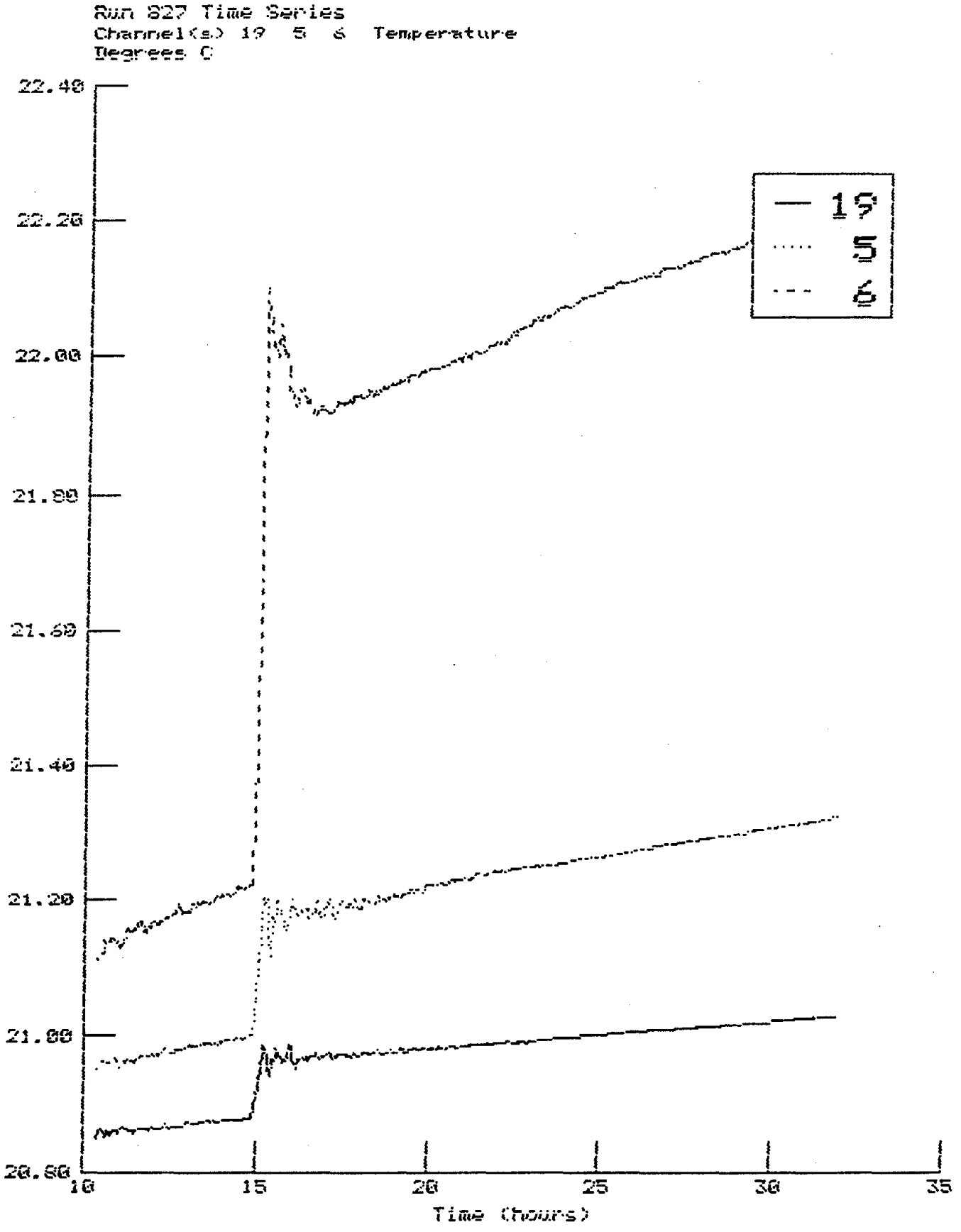
Channel(s) 8 Temperature
Degrees C
20.68
20.66
20.64
20.62
20.60
20.58
20.56
20.54
20.52
20.50
10
15
20
25
30
35
Time (hours)


Run 827 Time Series
Channel(s) 19 5 6 Temperature
Degrees C
22.40
22.20
22.00
21.80
21.60
21.40
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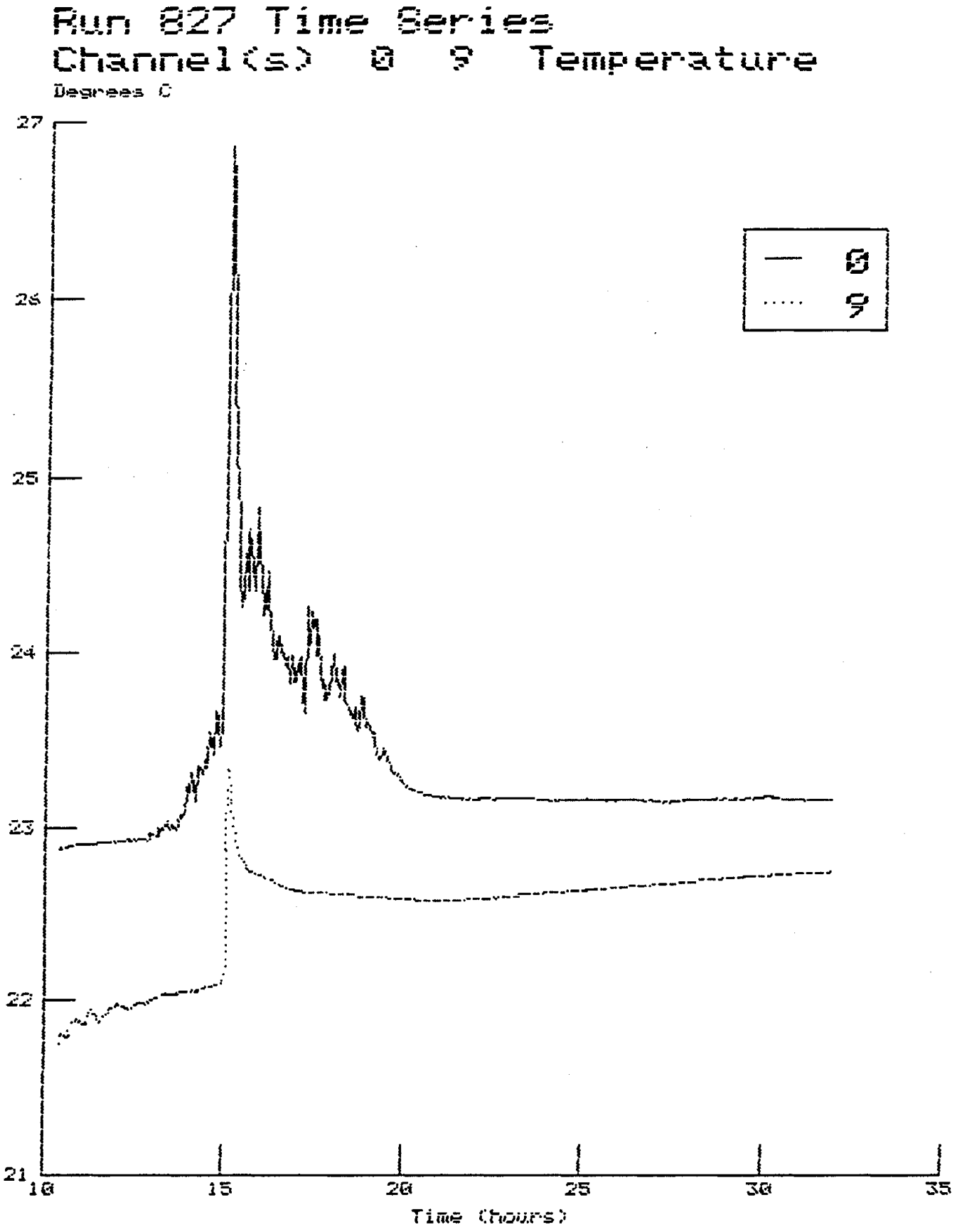
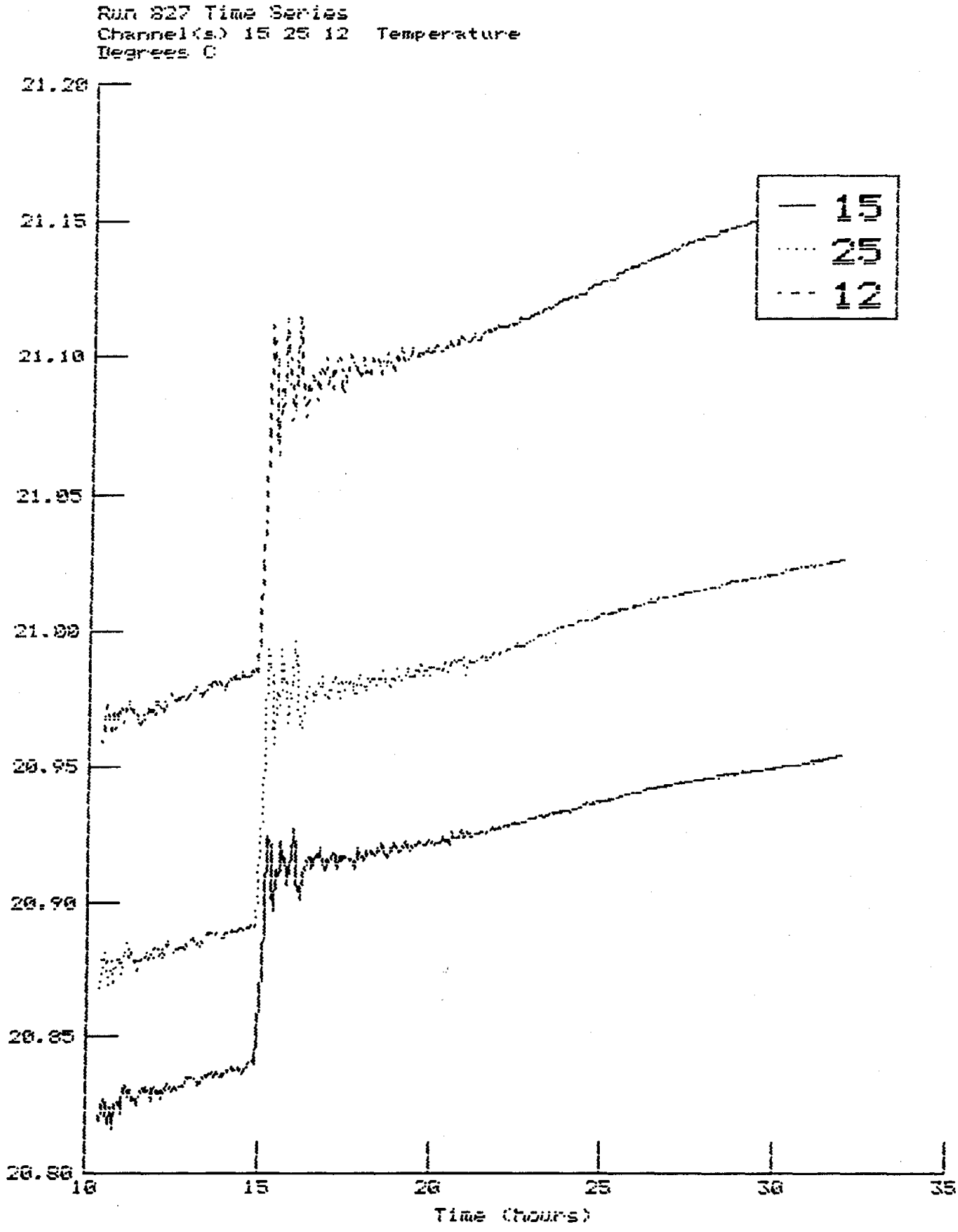
21.00
20.80
10
15
20
25
30
35
Time (hours)
19
5
6

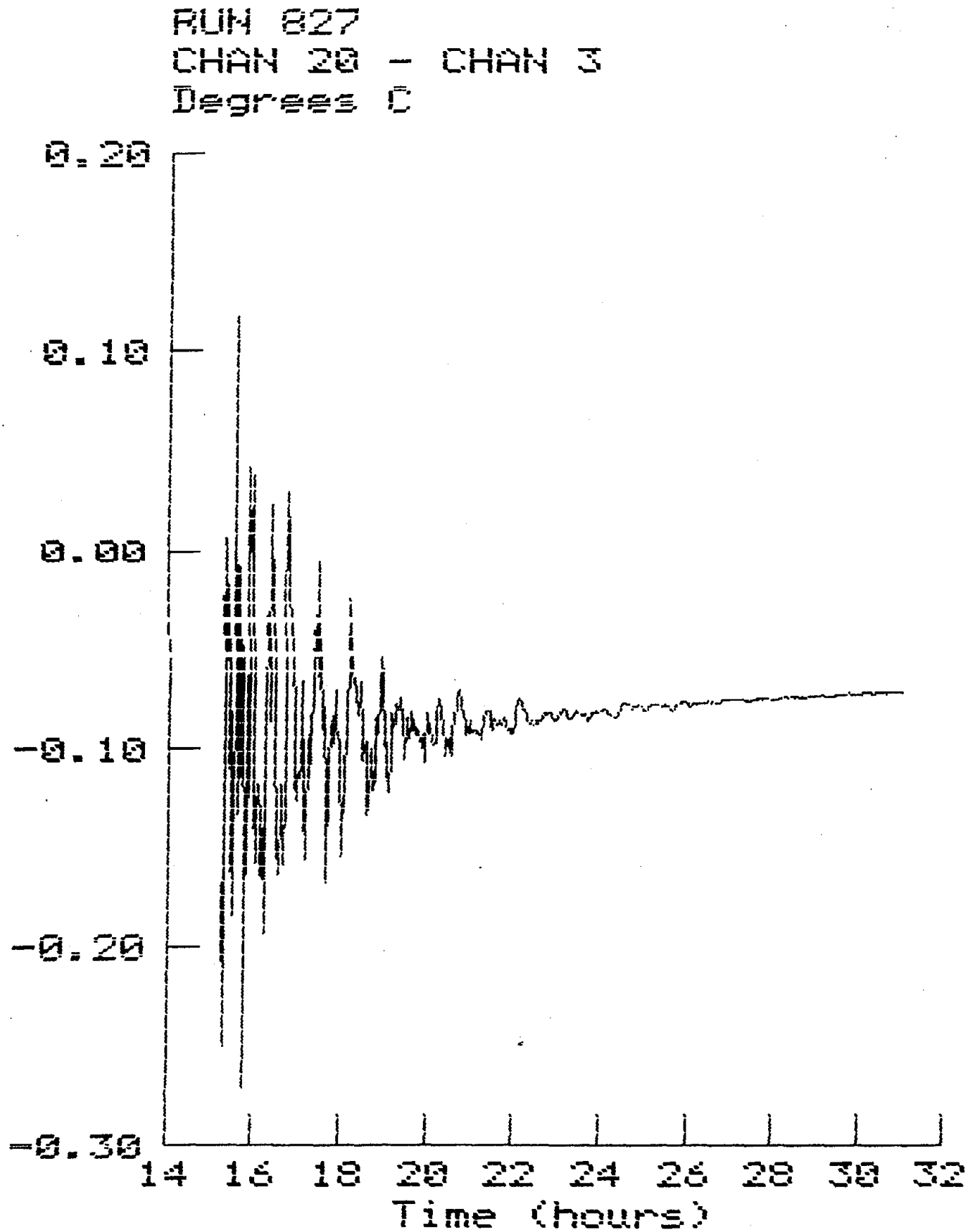
97

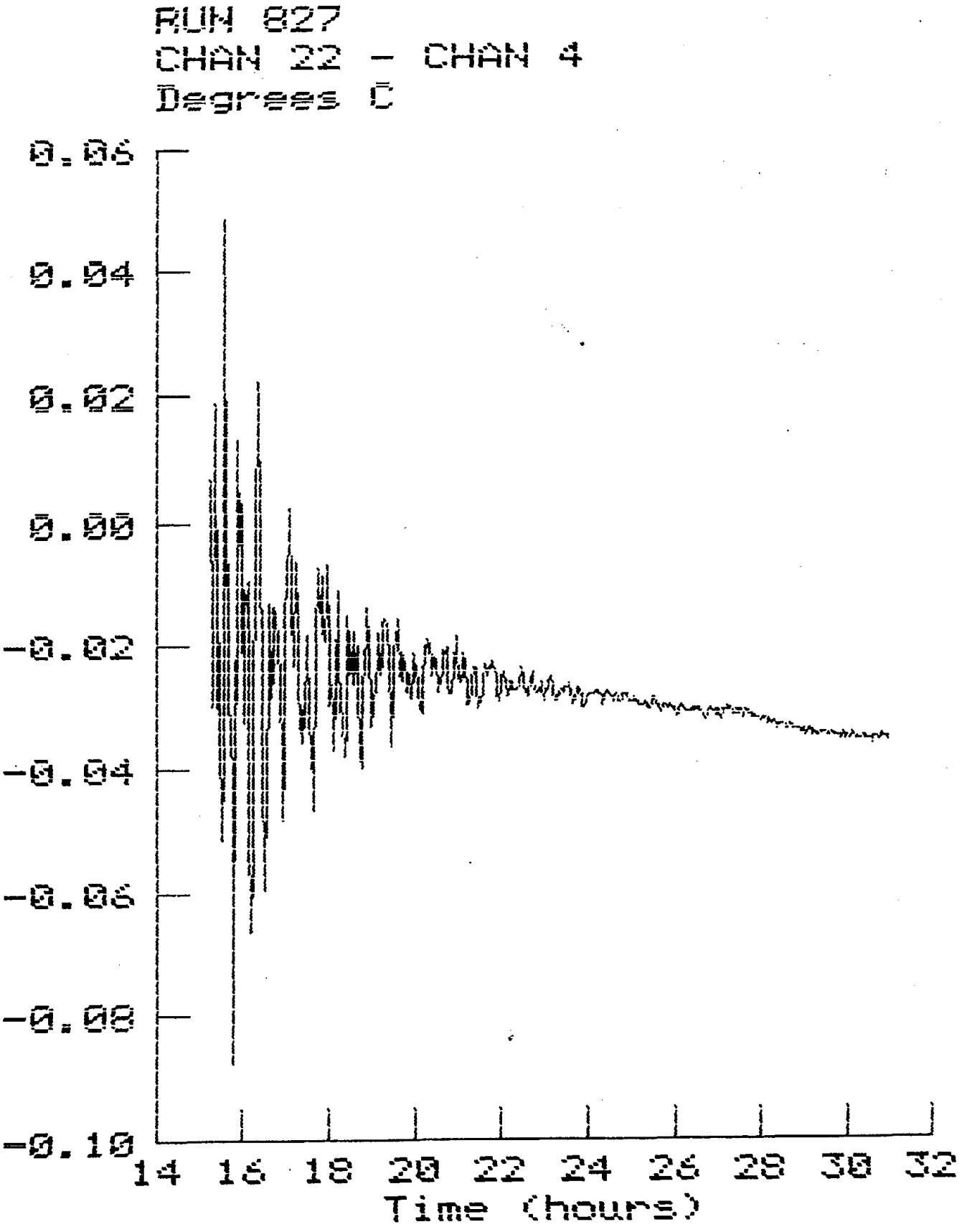

Run 827 Time Series
Channel(s) 0 9 Temperature
Degrees C
27
26
25
24
23
22
21
10
15
20
25
30
35
Time (hours)
0
9

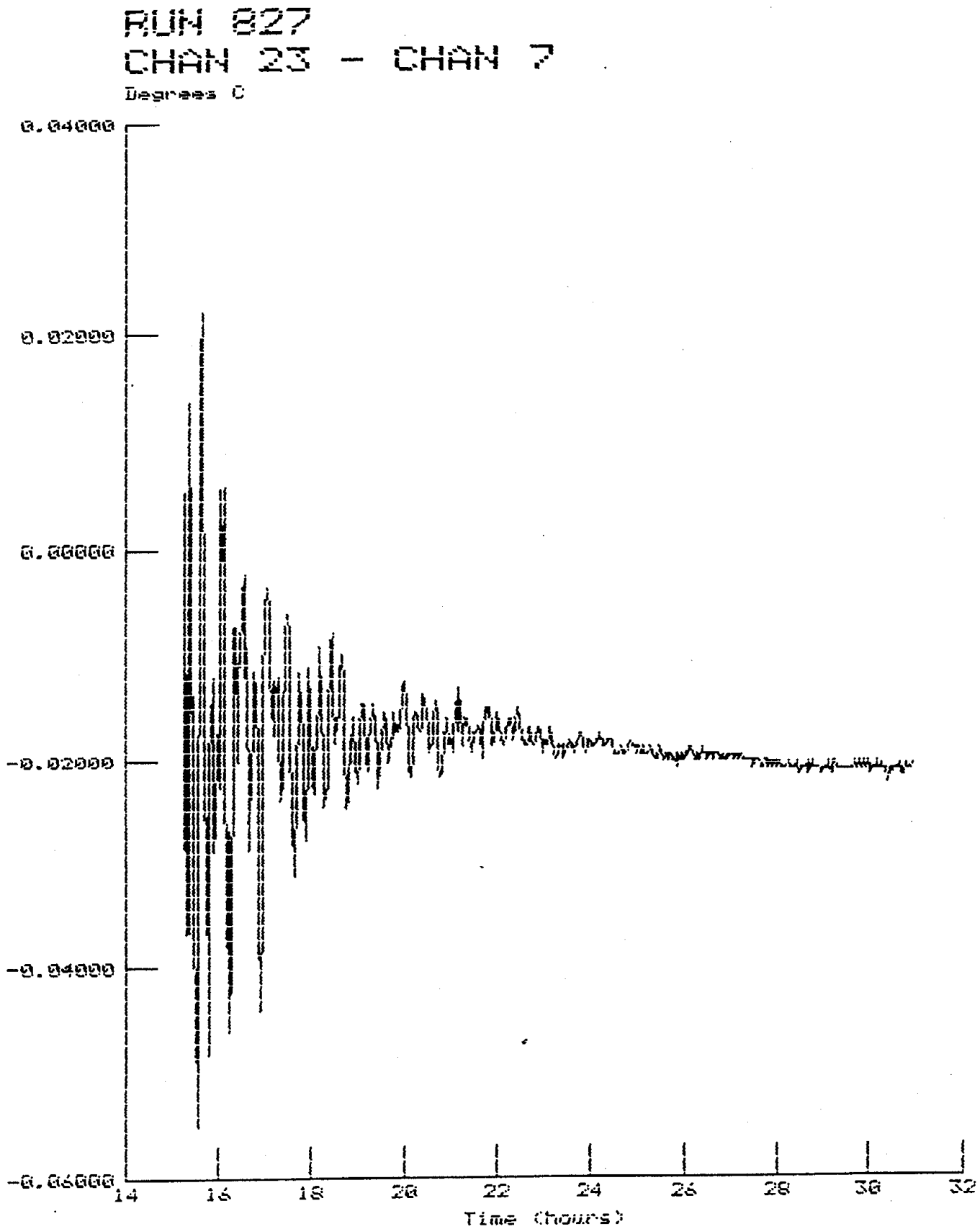
98


Run 827 Time Series
Channel(s) 15 25 12 Temperature
Degrees C
21.20
21.15
21.10
21.05
21.00
20.95
20.90
20.85
20.80
10
15
20
25
30
35
Time (hours)
15
25
12

99


RUN 827
CHAN 20 - CHAN 3
Degrees C
0.20
0.10
0.00
-0.10
-0.20
-0.30
14
16
18
20
22
24
26
28
30
32
Time (hours)


RUN 827
CHAN 22 - CHAN 4
Degrees C
0.06
0.04
0.02
0.00
-0.02
-0.04
-0.06
-0.08
-0.10
14
16
18
20
22
24
26
28
30
32
Time (hours)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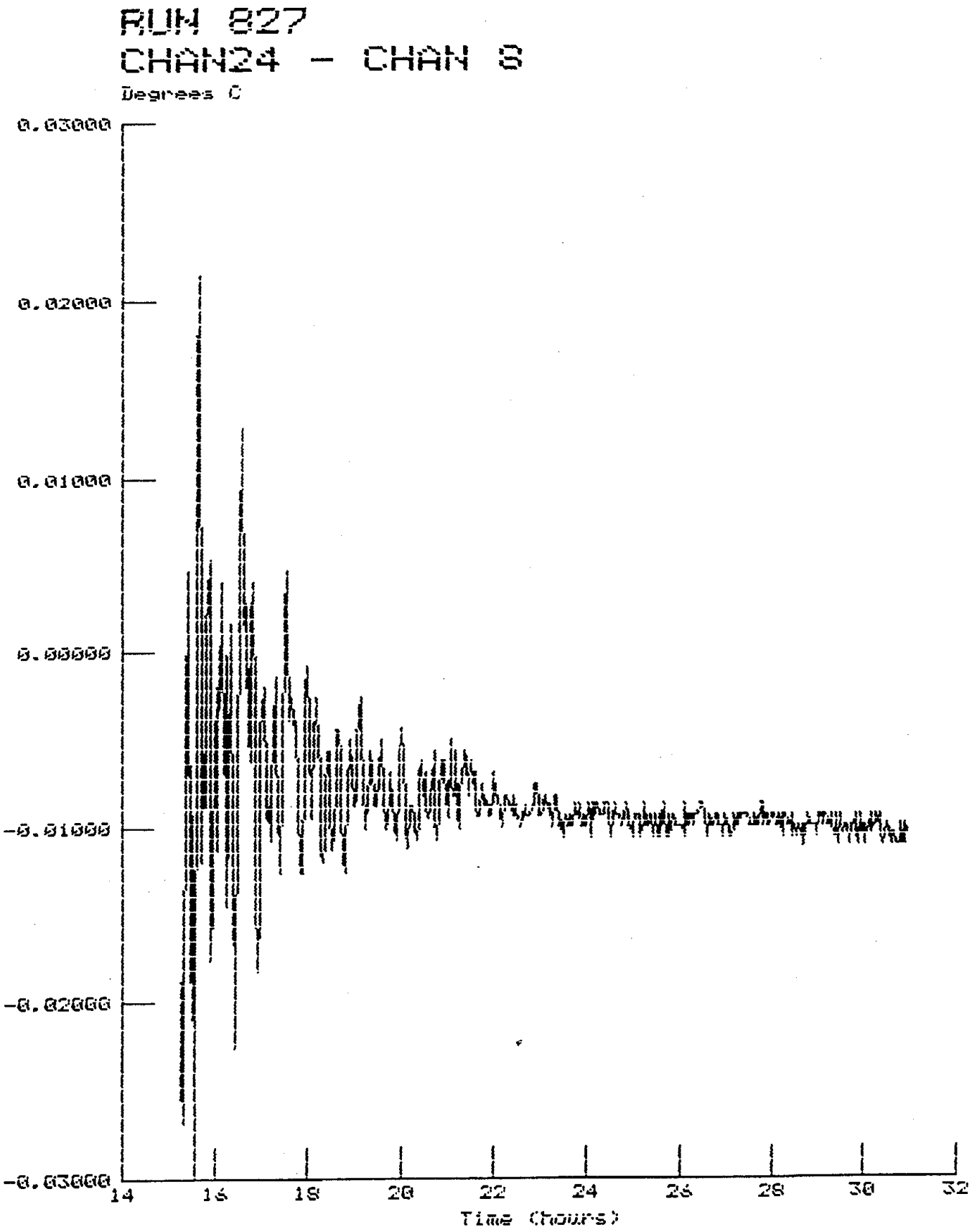
CHAN 23 - CHAN 7
Degrees C
0.04000
0.02000
0.00000
-0.02000
-0.04000
-0.06000
14
16
18
20
22
24
26
28
30
32
Time (hours)

102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CHAN24 - CHAN 8
Degrees C
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0.02000
0.01000
0.00000
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-0.02000
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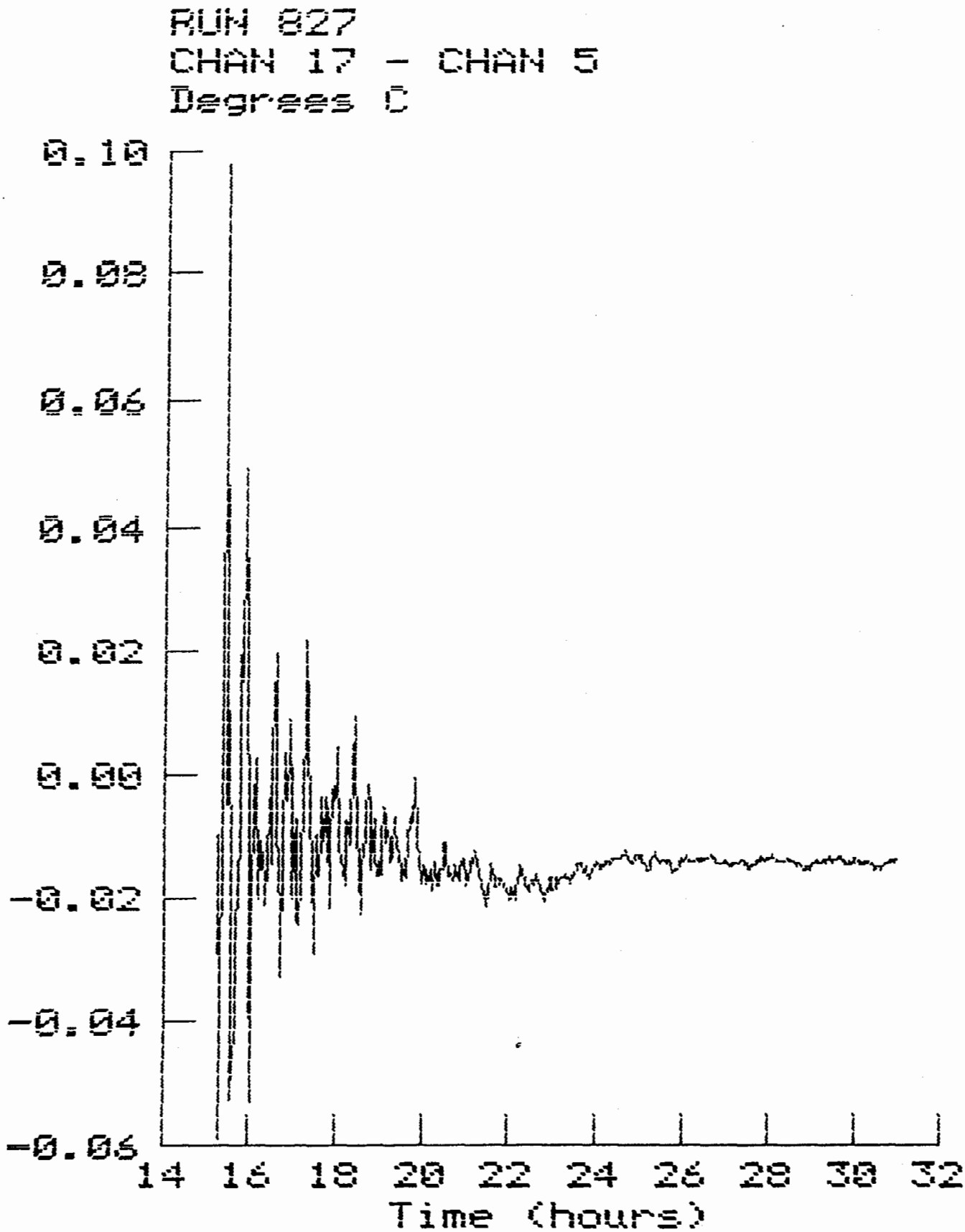
14
16
18
20
22
24
26
28
30
32
Time (hours)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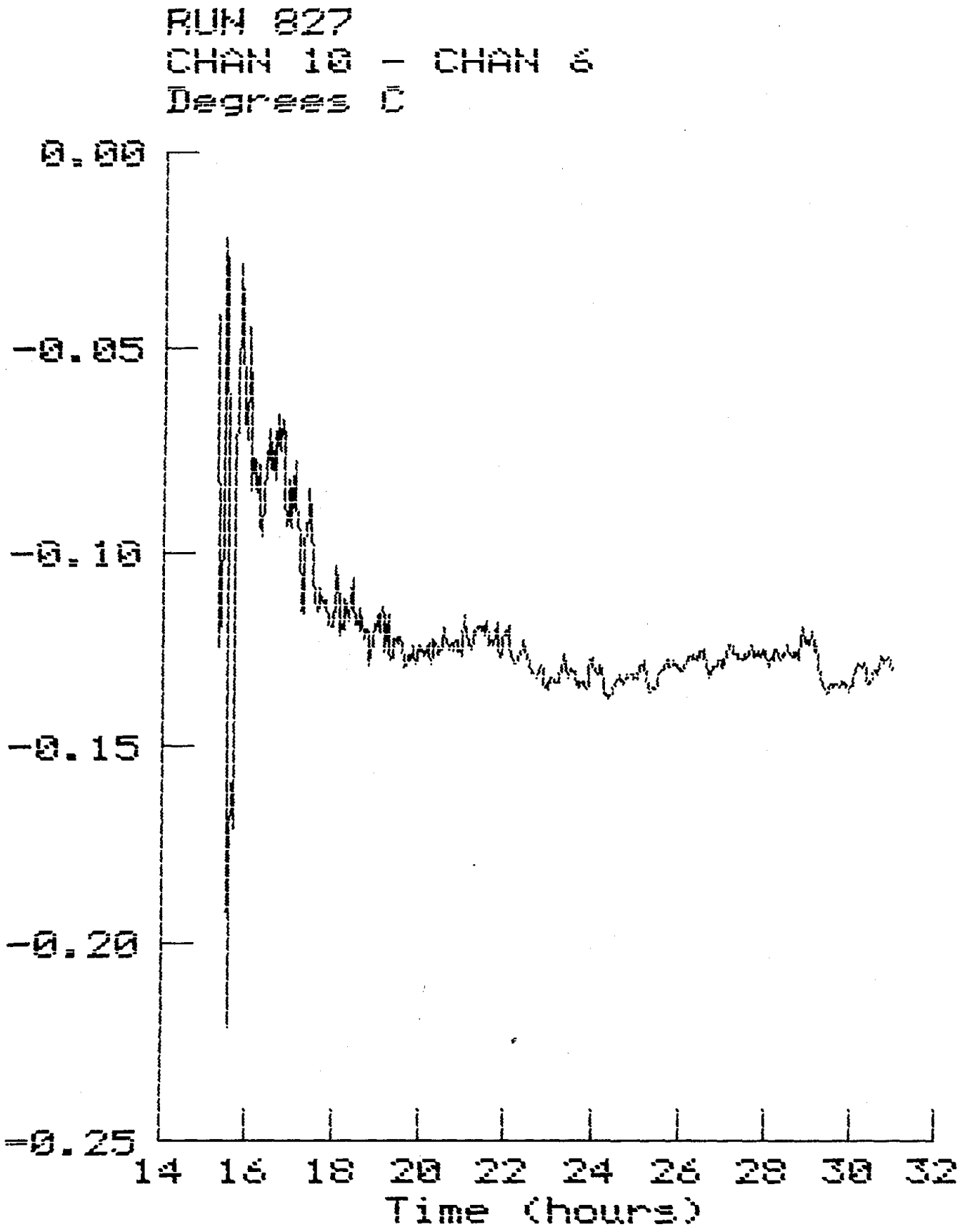
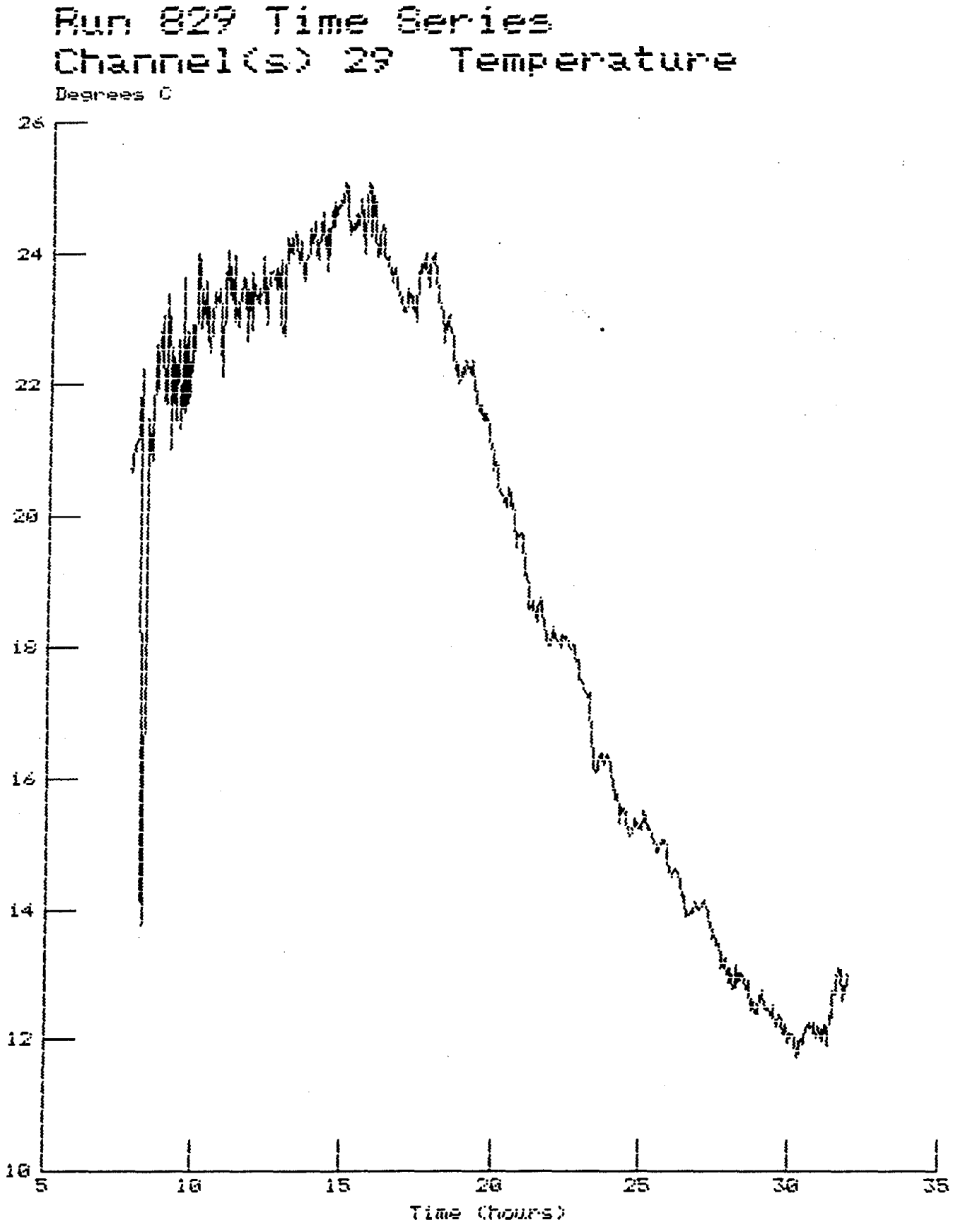
CHAN 17 - CHAN 5
Degrees C
0.10
0.08
0.06
0.04
0.02
0.00
-0.02
-0.04
-0.06
14
16
18
20
22
24
26
28
30
32
Time (hours)

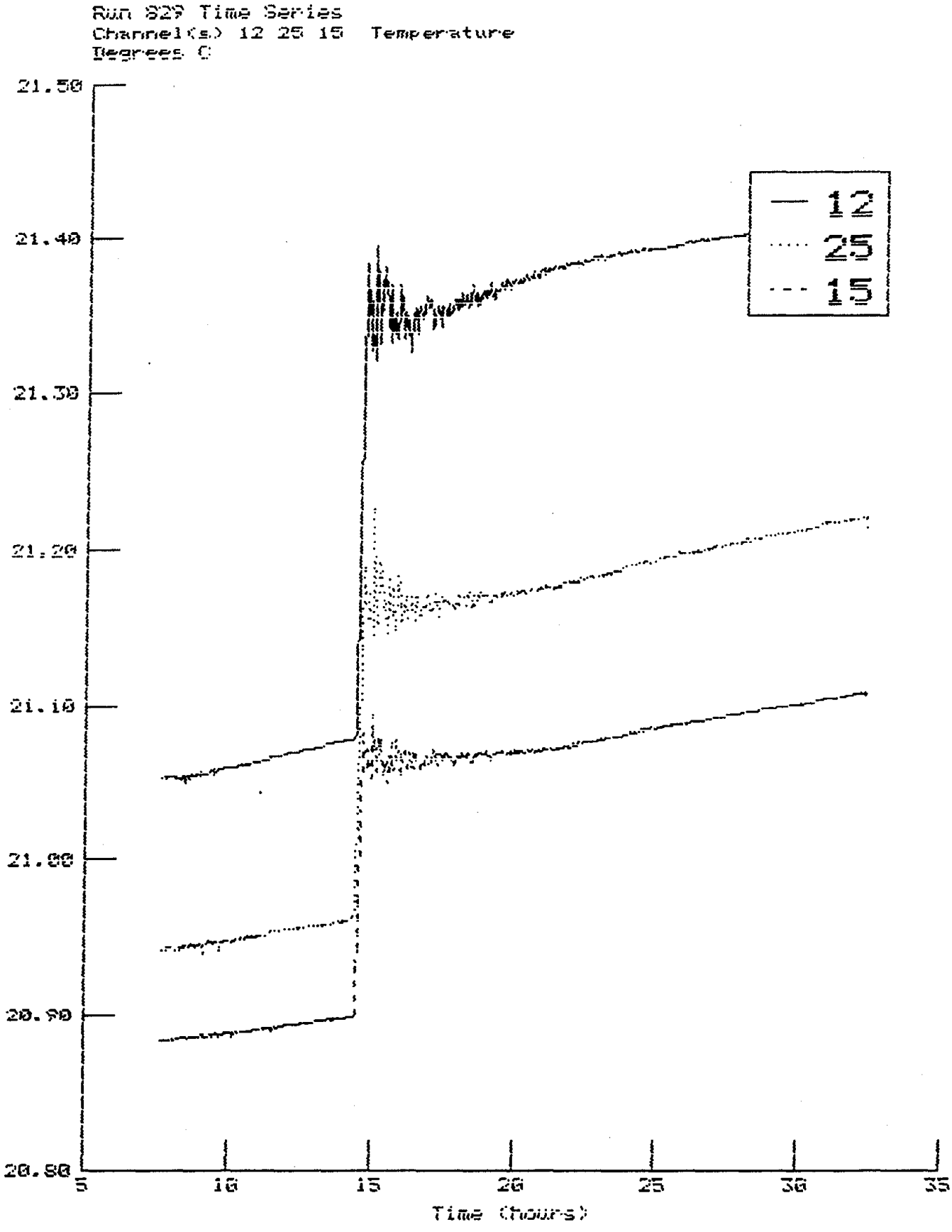

RUN 827
CHAN 10 - CHAN 6
Degrees C
0.00
-0.05
-0.10
-0.15
-0.20
-0.25
14
16
18
20
22
24
26
28
30
32
Time (hours)

Appendix B

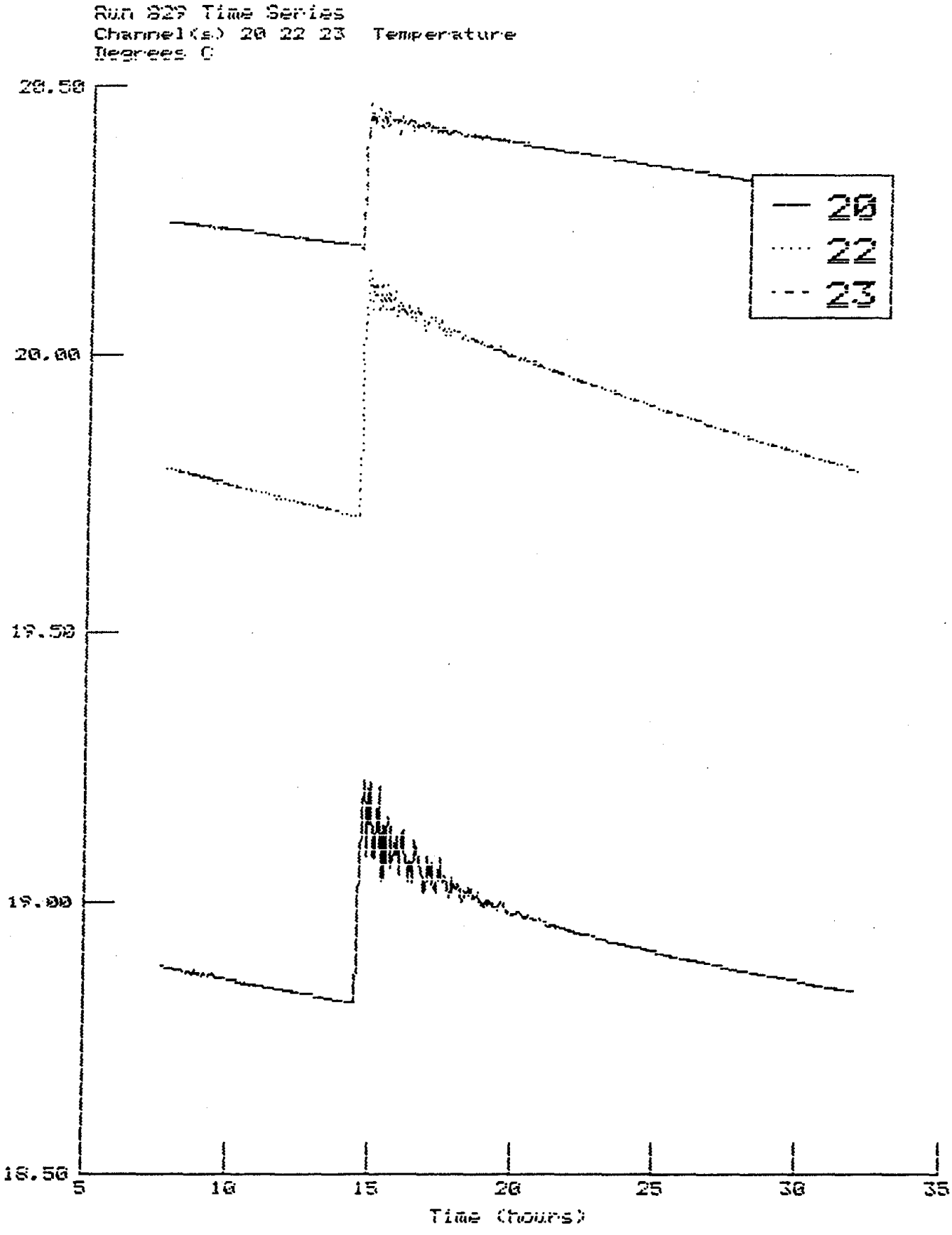
Overnight Test Begun at 1441 on 29 August 1990

The time series of temperature measured during the overnight test started on 29 August 1990 are presented in Appendix B. The raw data for Arrays A and B, located in the 76-cm (30-in.) -diameter manway at B and the 10-cm (4 in.) -diameter fill hole at C, respectively, are shown. The time series for Array A are presented first. The times series are presented according to their location within the tank and on the array. All of the product thermistors located on the vertical portion of the array and in the product are displayed as a group; because the display software only allowed three time series on a display, several graphs are used to present the product time series. The thermistors on the horizontal are grouped together in one display and the thermistors in the vapor space and the air are also displayed together. Appendix B also includes the time series showing the difference in temperature between thermistors located on Arrays A and B. (Refer to Figure 3.)


Run 829 Time Series
Channel(s) 29 Temperature
Degrees C
26
24
22
20
18
16
14
12
10
5
10
15
20
25
30
35
Time (hours)


Run 829 Time Series
Channel(s) 12 25 15 Temperature
Degrees C
21.50
21.40
21.30
21.20
21.10
21.00
20.90
20.80
5
10
15
20
25
30
35
Time (hours)
12
25
15

108


Run 829 Time Series
Channel(s) 20 22 23 Temperature
Degrees C
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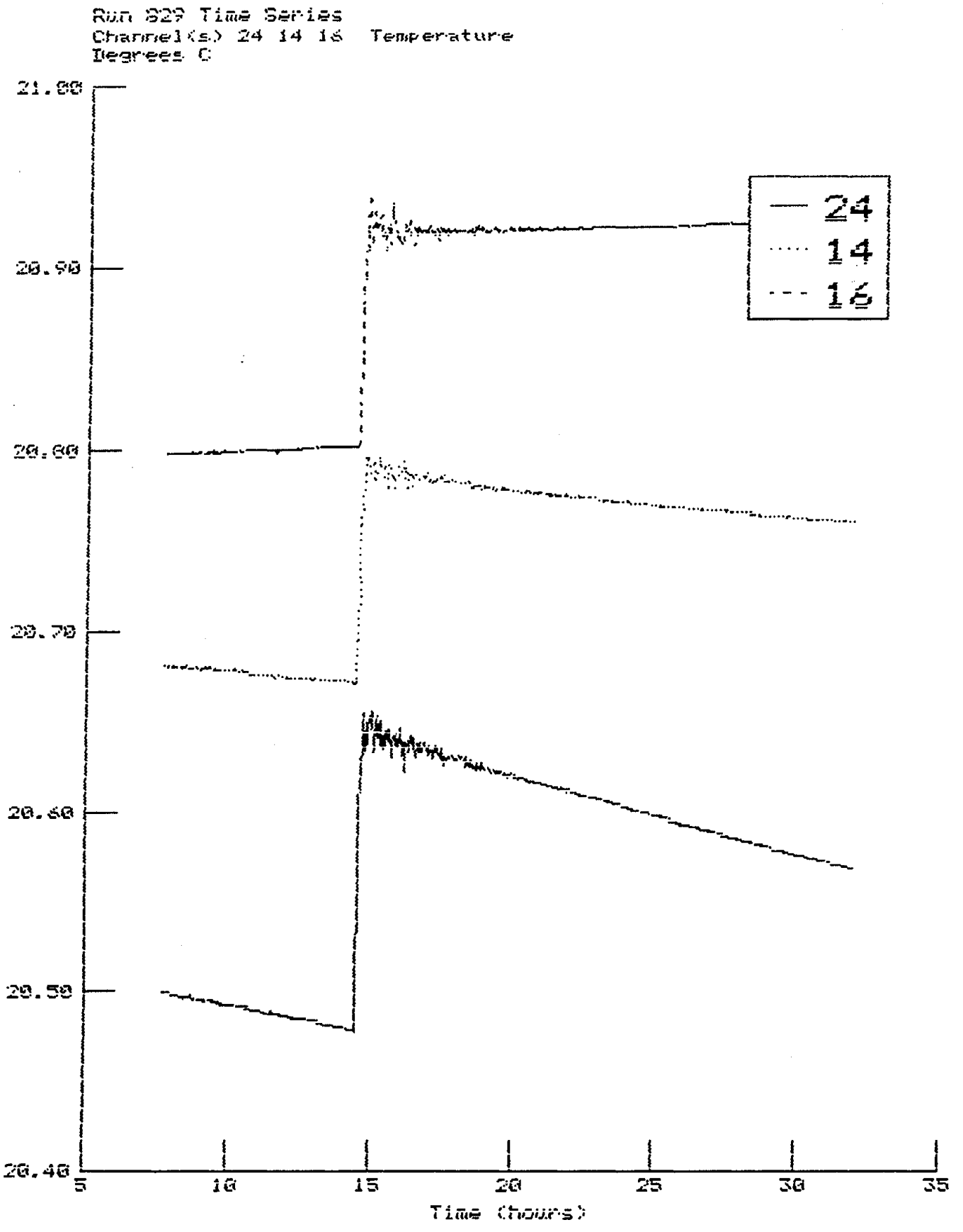
20.00
19.50
19.00
18.50
5
10
15
20
25
30
35
Time (hours)
20
22
23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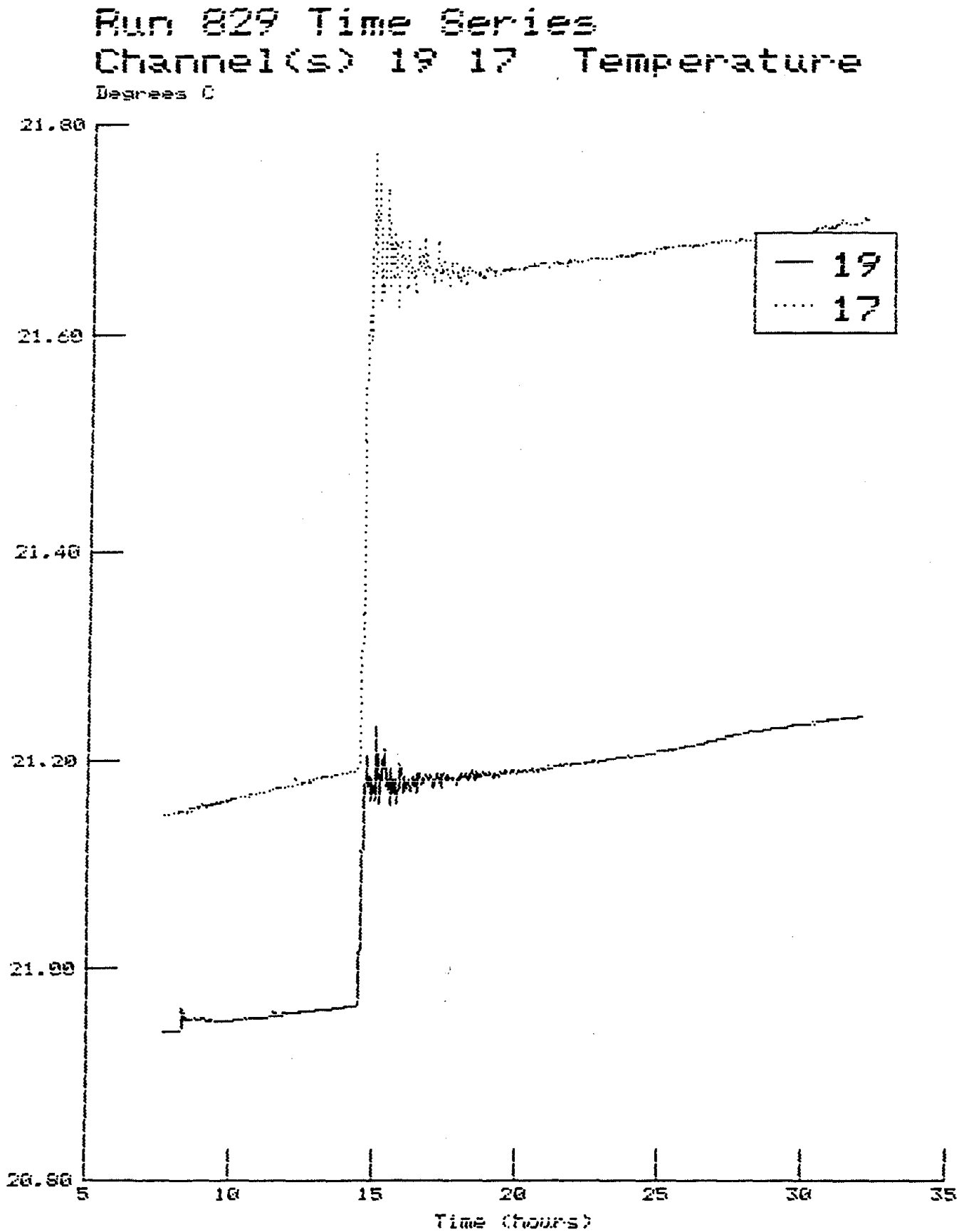
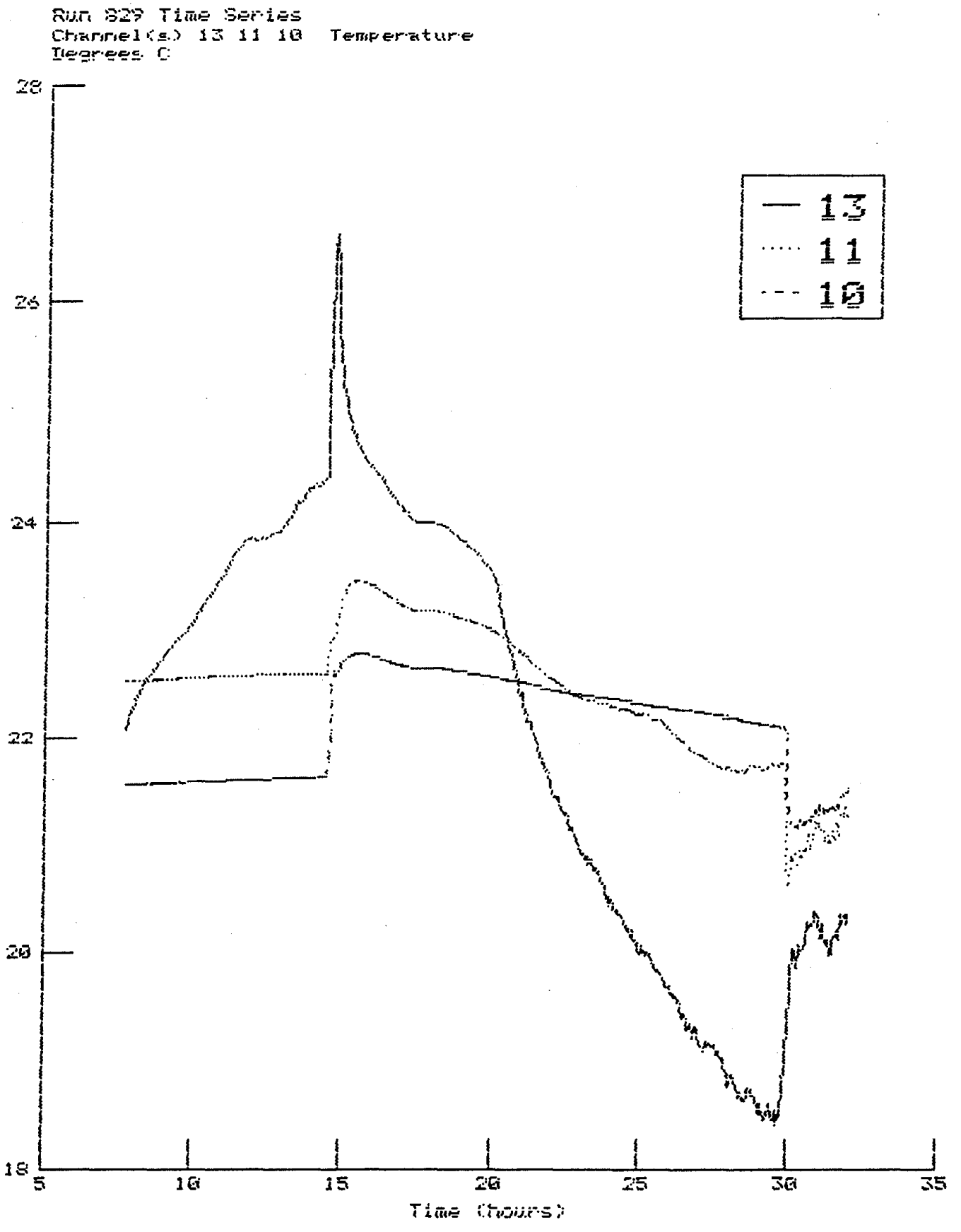
Channel(s) 24 14 16 Temperature
Degrees C
21.00
20.90
20.80
20.70
20.60
20.50
20.40
5
10
15
20
25
30
35
Time (hours)
24
14
16

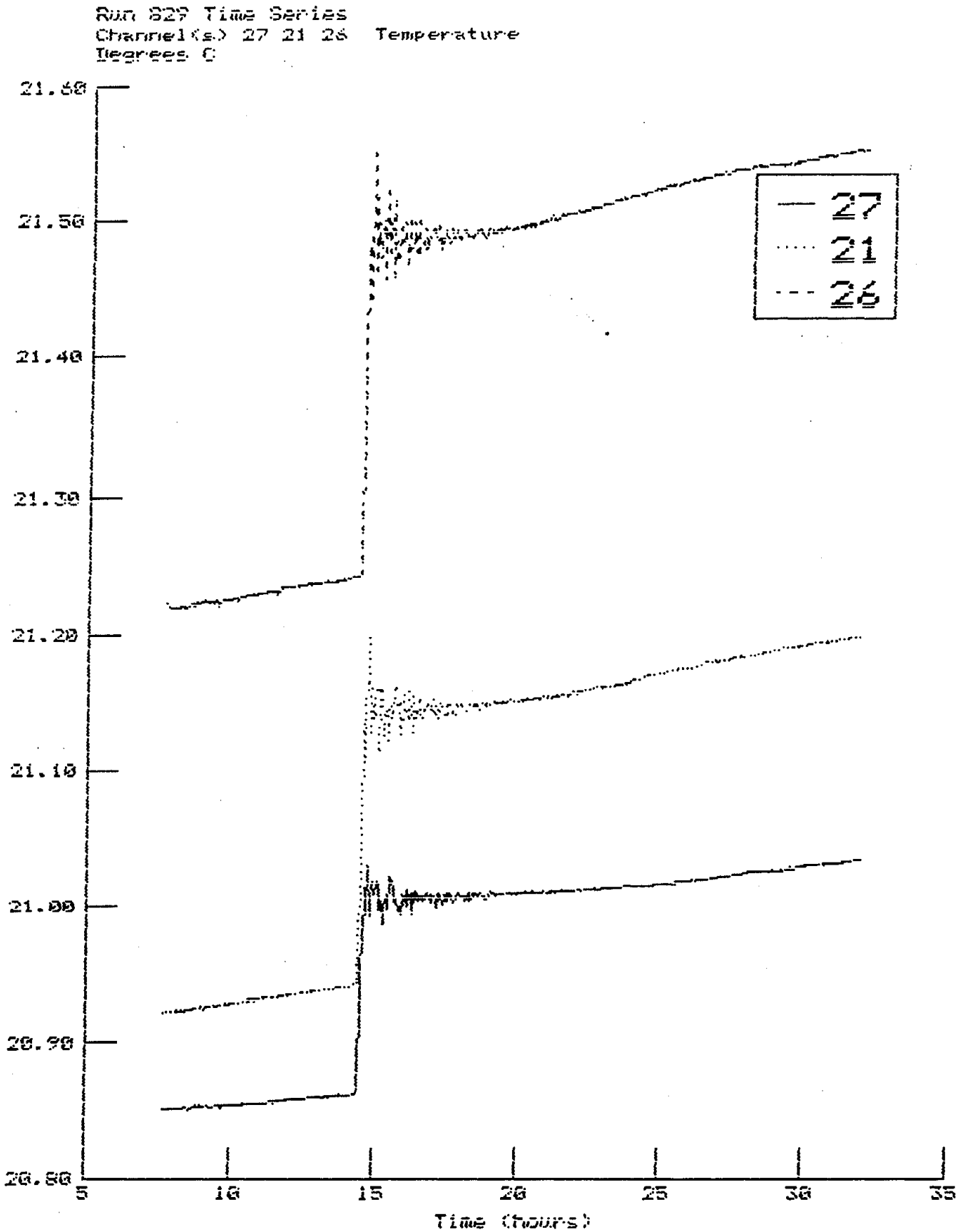
110

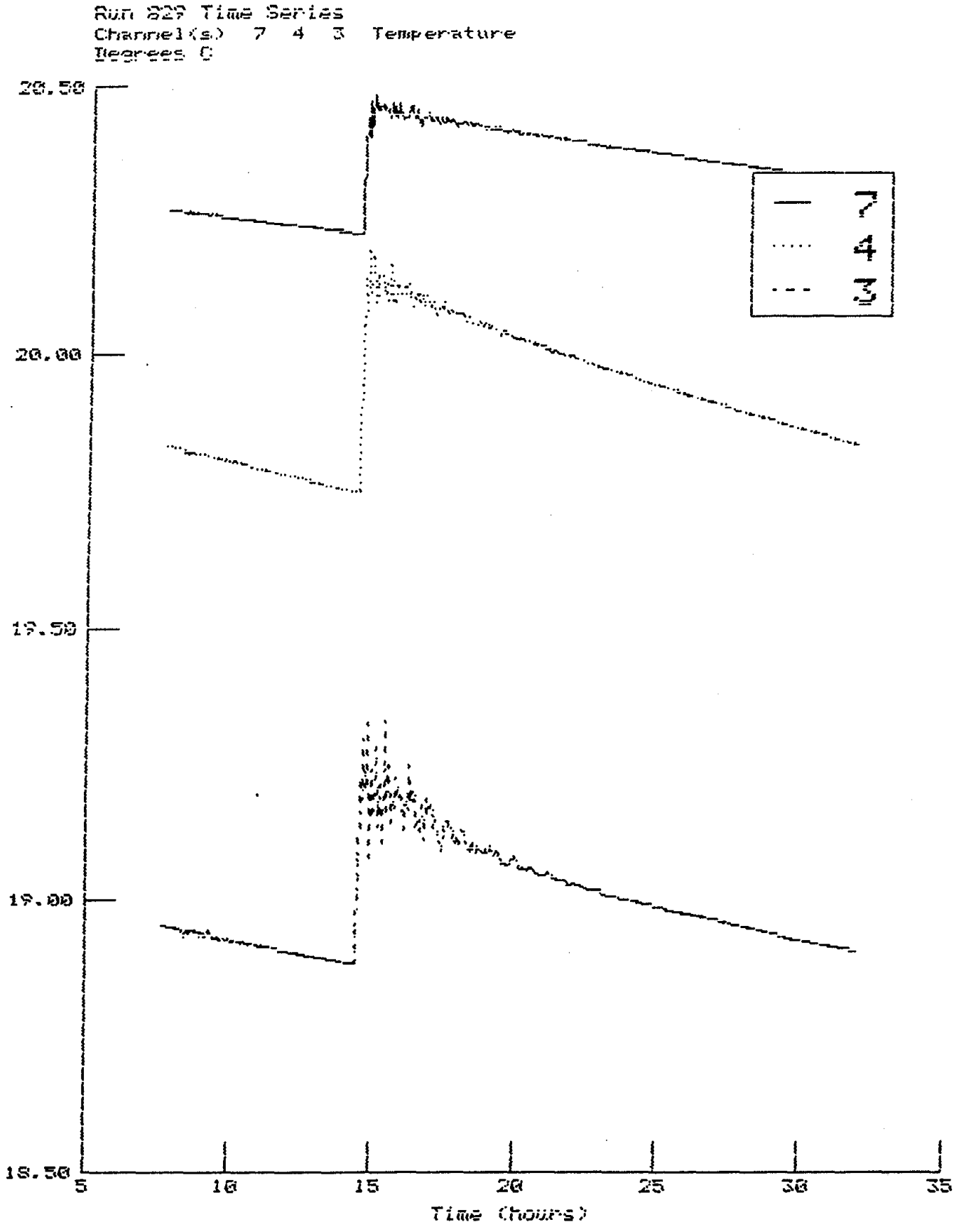

Run 829 Time Series
Channel(s) 19 17 Temperature
Degrees C
21.80
21.60
21.40
21.20
21.00
20.80
5
10
15
20
25
30
35
Time (hours)
19
17

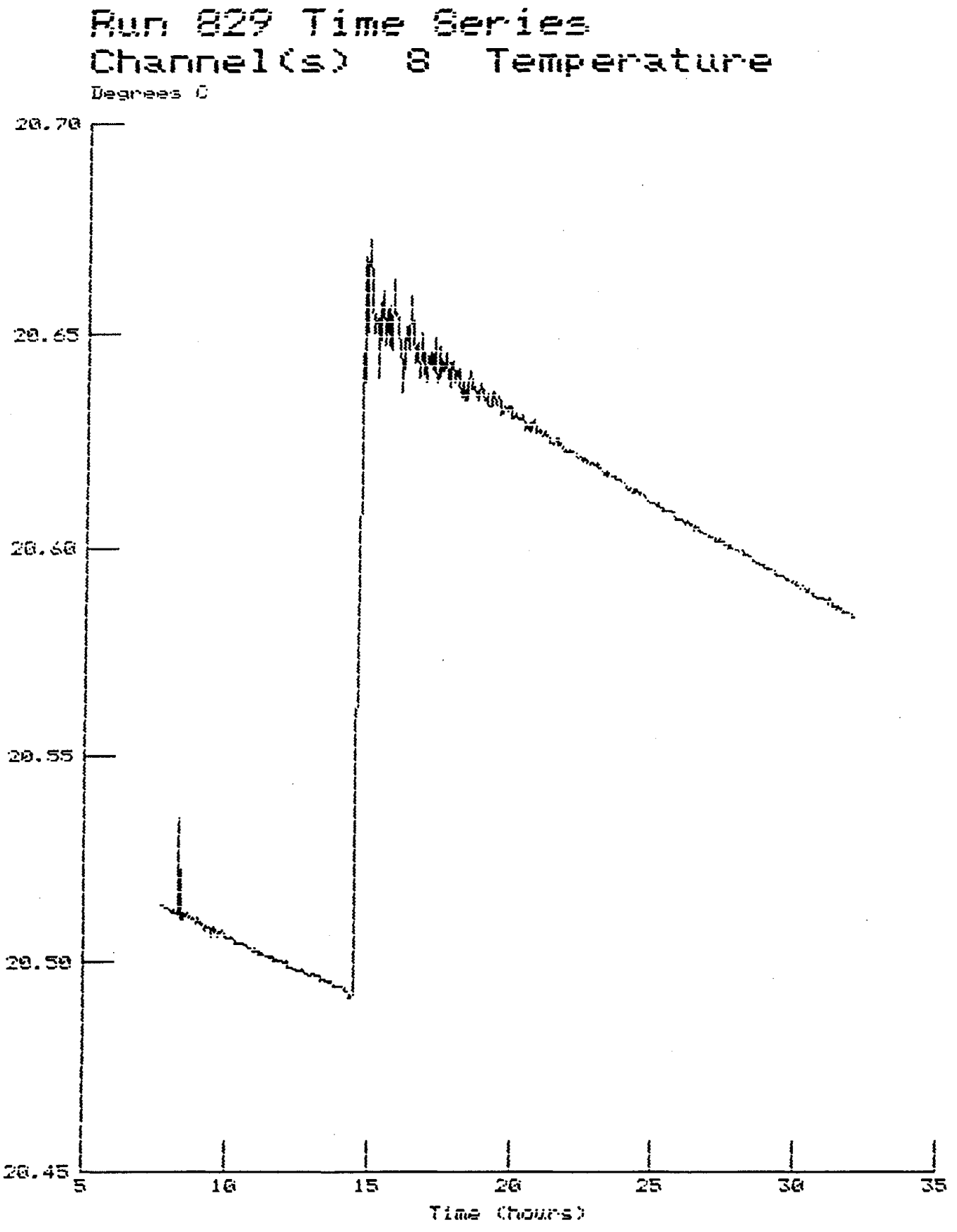
111

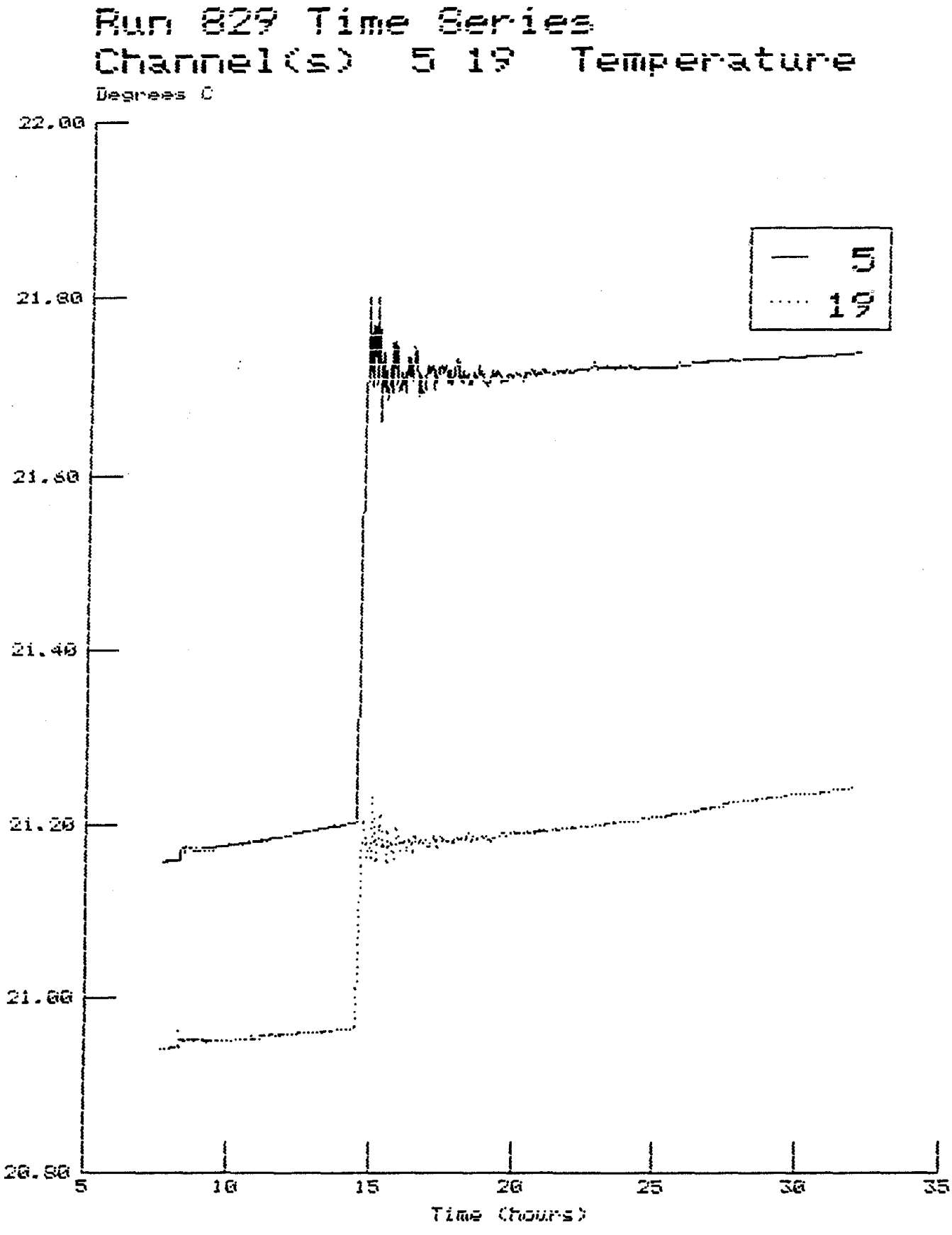

Run 829 Time Series
Channel(s) 13 11 10 Temperature
Degrees C
28
26
24
22
20
18
5
10
15
20
25
30
35
Time (hours)
13
11
10

112

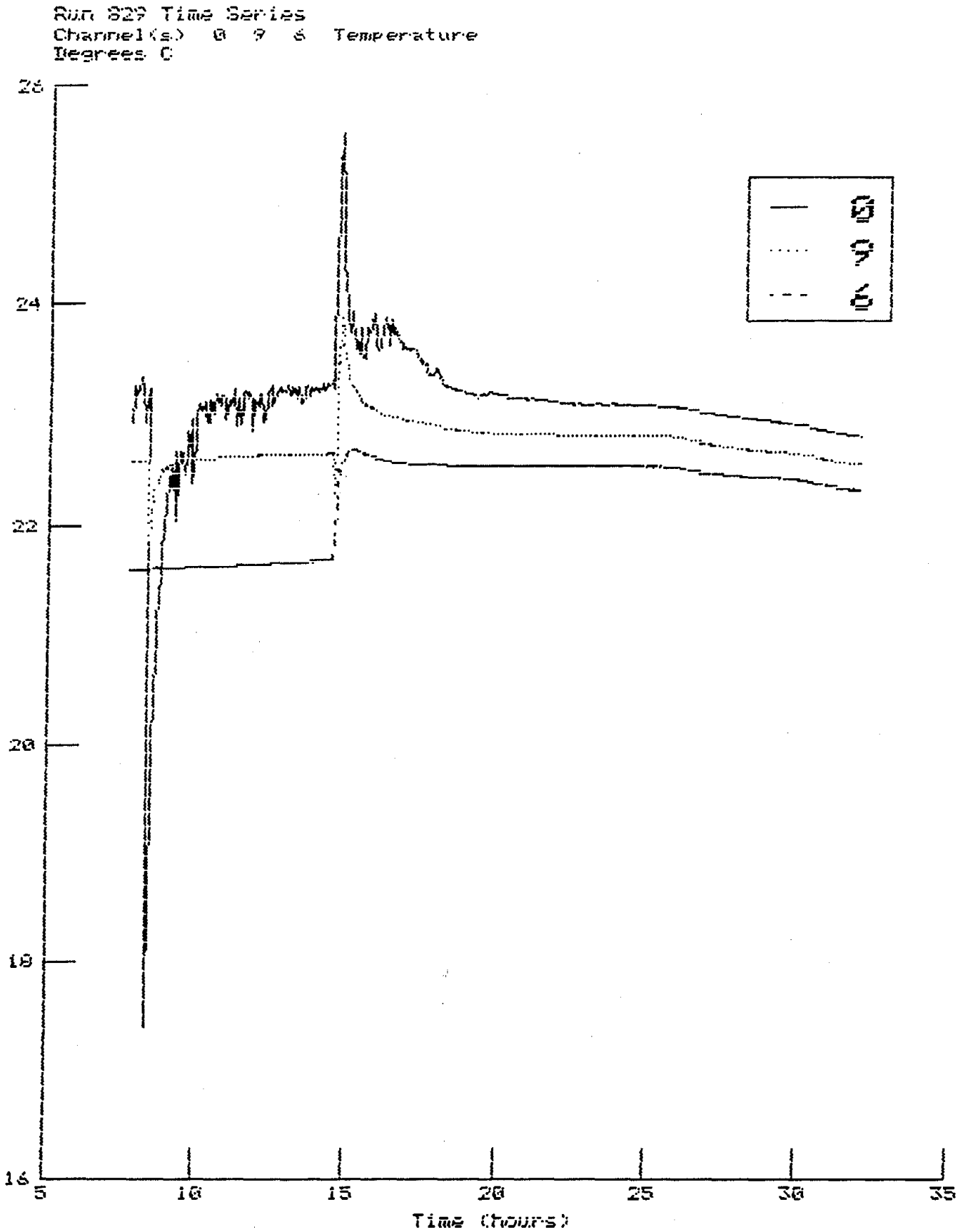

Run 829 Time Series
Channel(s) 27 21 26 Temperature
Degrees C
21.60
21.50
21.40
21.30
21.20
21.10
21.00
20.90
20.80
5
10
15
20
25
30
35
Time (hours)
27
21
26


Run 827 Time Series
Channel(s) 7 4 3 Temperature
Degrees C
20.50
20.00
19.50
19.00
18.50
5
10
15
20
25
30
35
Time (hours)
7
4
3

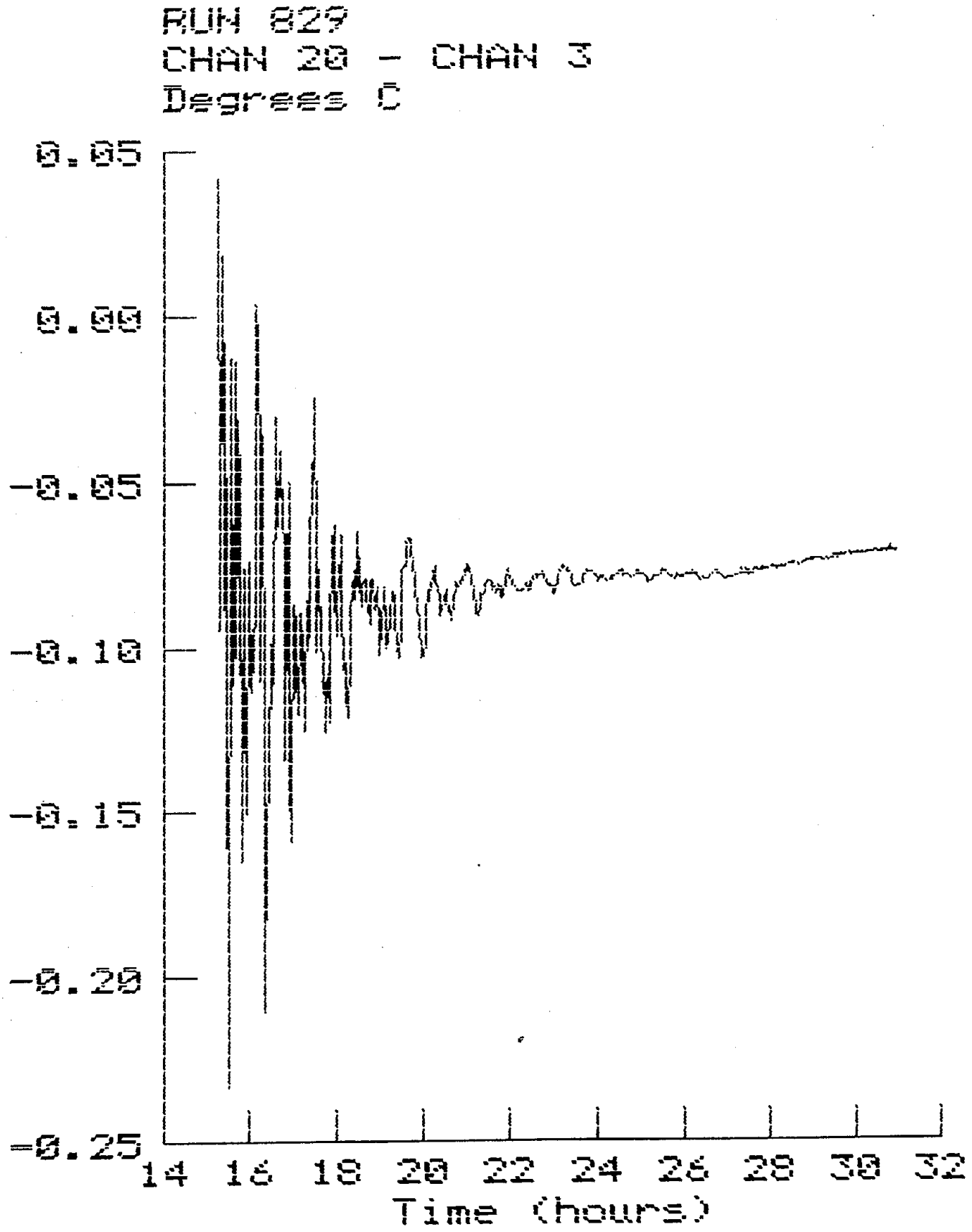

Run 829 Time Series
Channel(s) 8 Temperature
Degrees C
20.70
20.65
20.60
20.55
20.50
20.45
5
10
15
20
25
30
35
Time (hours)

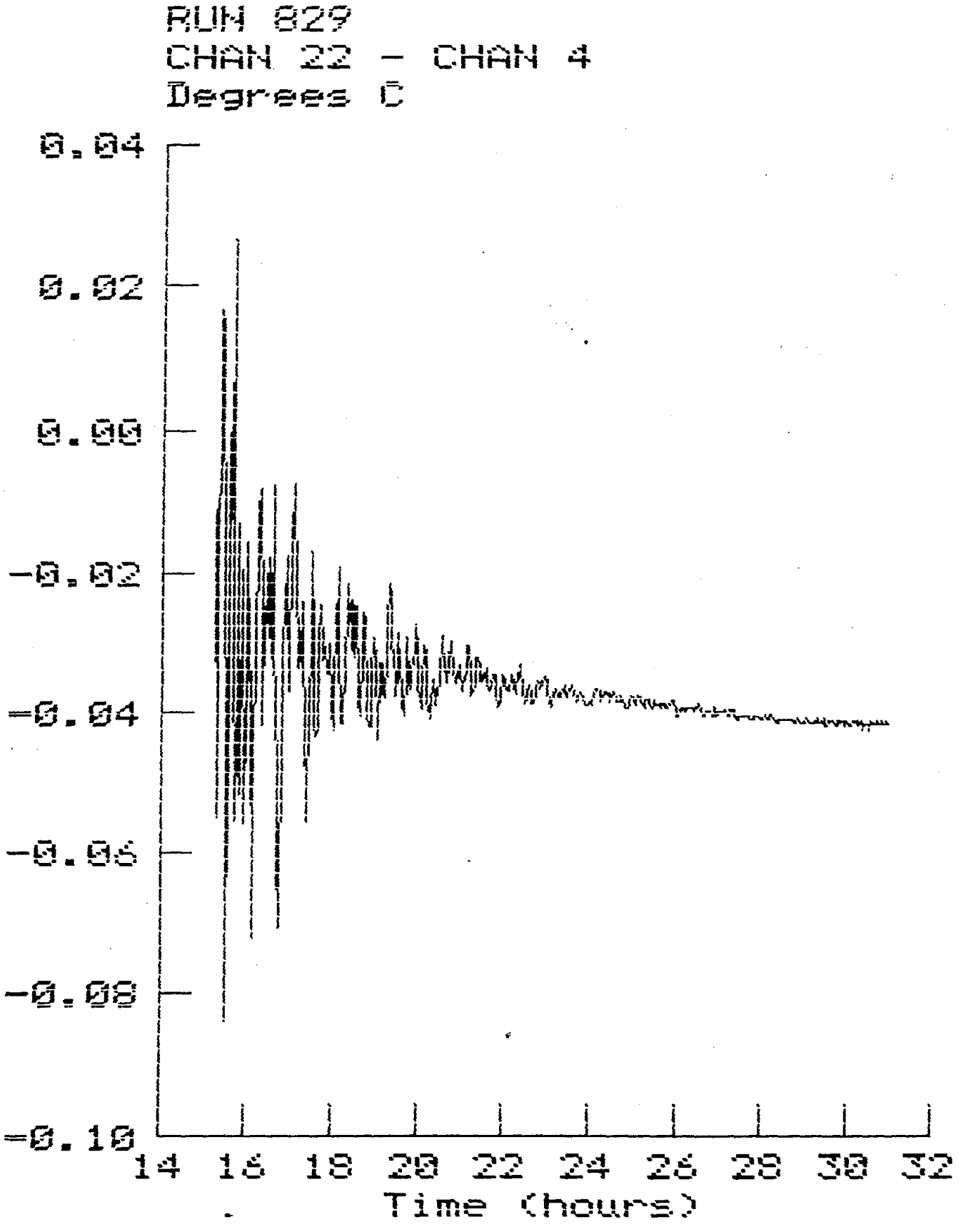

Run 829 Time Series
Channel(s) 5 19 Temperature
Degrees C
22.00
21.80
21.60
21.40
21.20
21.00
20.80
5
10
15
20
25
30
35
Time (hours)
5
19

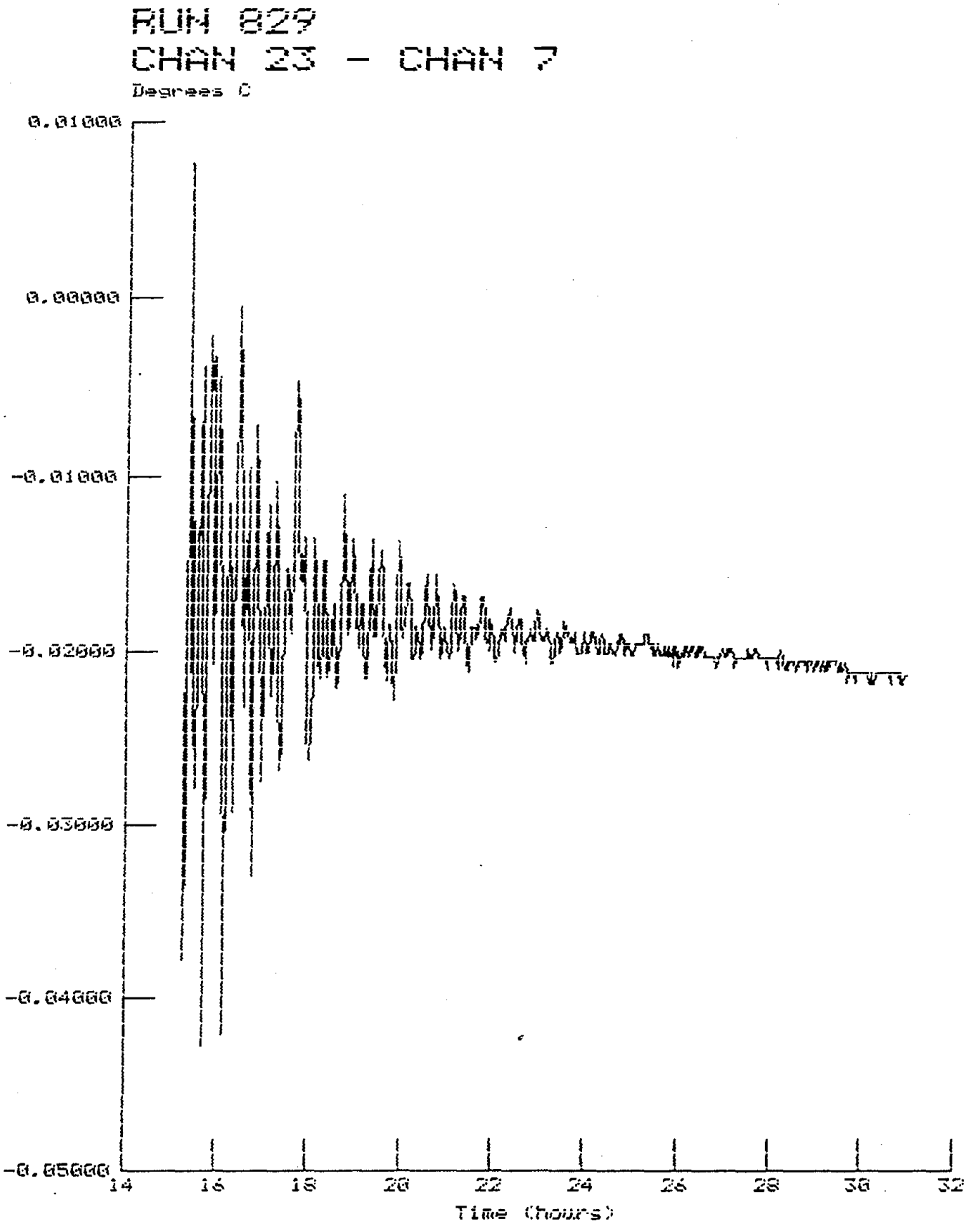
116


Run 829 Time Series
Channel(s) 0 9 6 Temperature
Degrees C
26
24
22
20
18
16
5
10
15
20
25
30
35
Time (hours)
0
9
6

117


RUN 829
CHAN 20 - CHAN 3
Degrees C
0.05
0.00
-0.05
-0.10
-0.15
-0.20
-0.25
14
16
18
20
22
24
26
28
30
32
Time (hours)


RUN 829
CHAN 22 - CHAN 4
Degrees C
0.04
0.02
0.00
-0.02
-0.04
-0.06
-0.08
-0.10
14
16
18
20
22
24
26
28
30
32
Time (hours)



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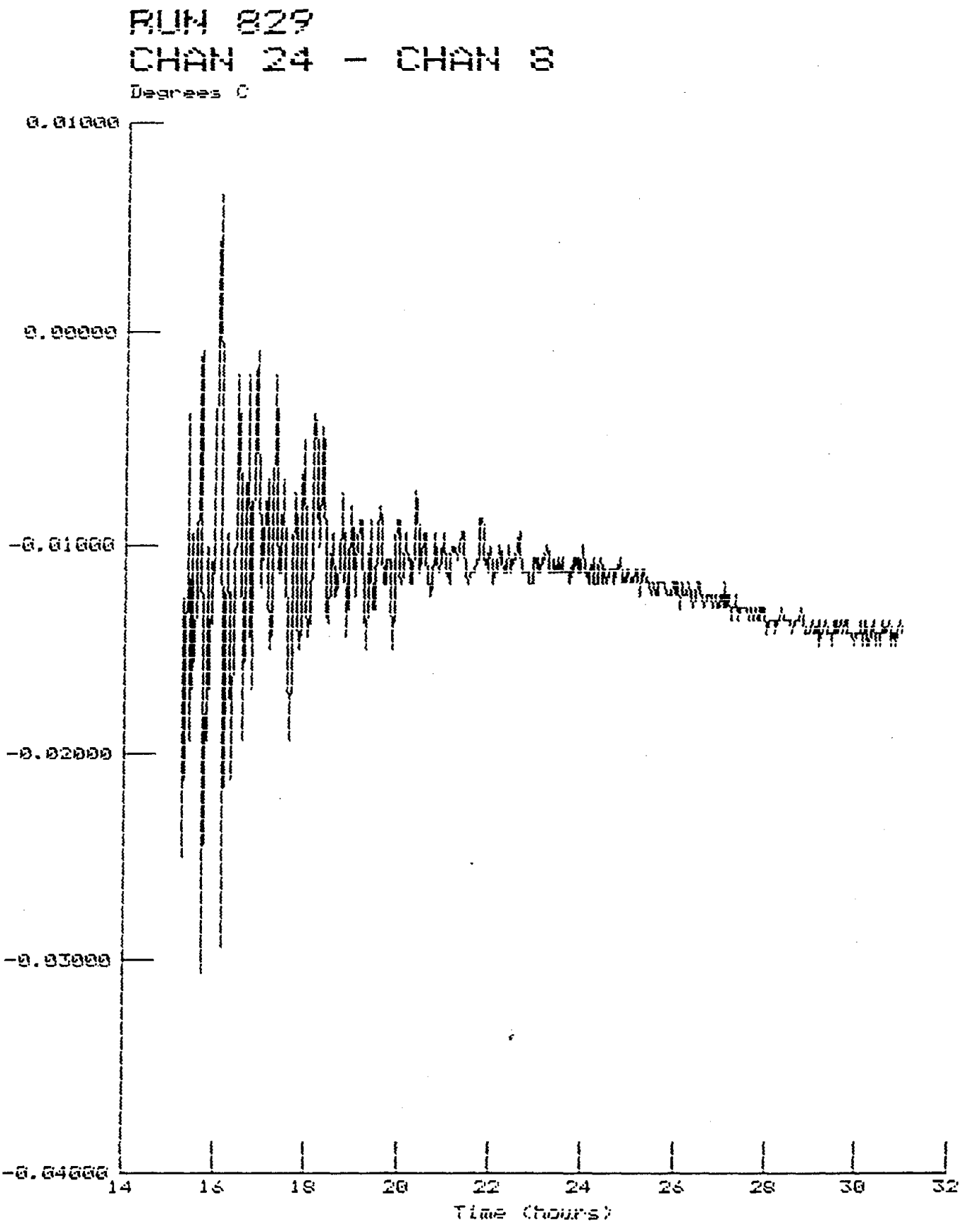
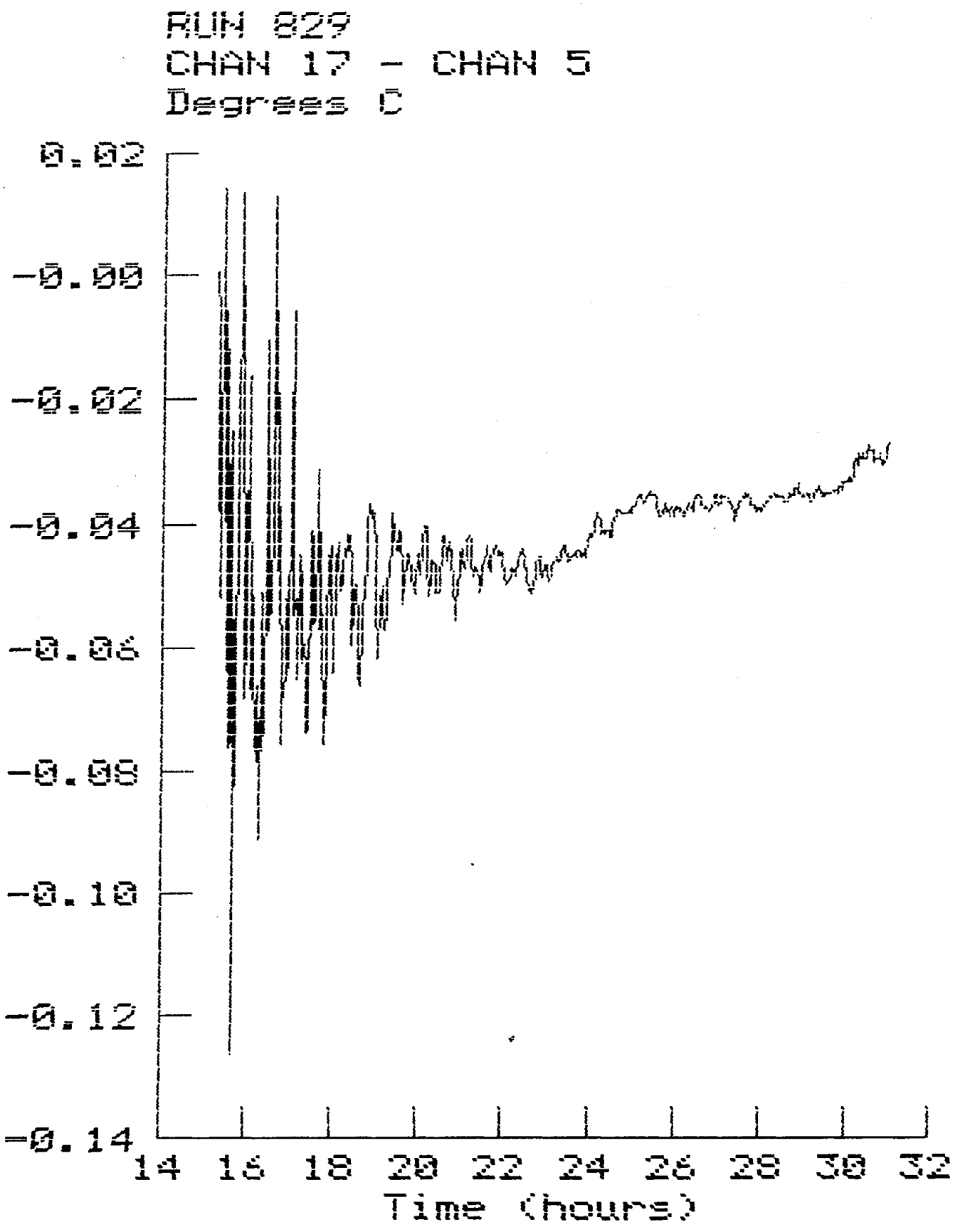
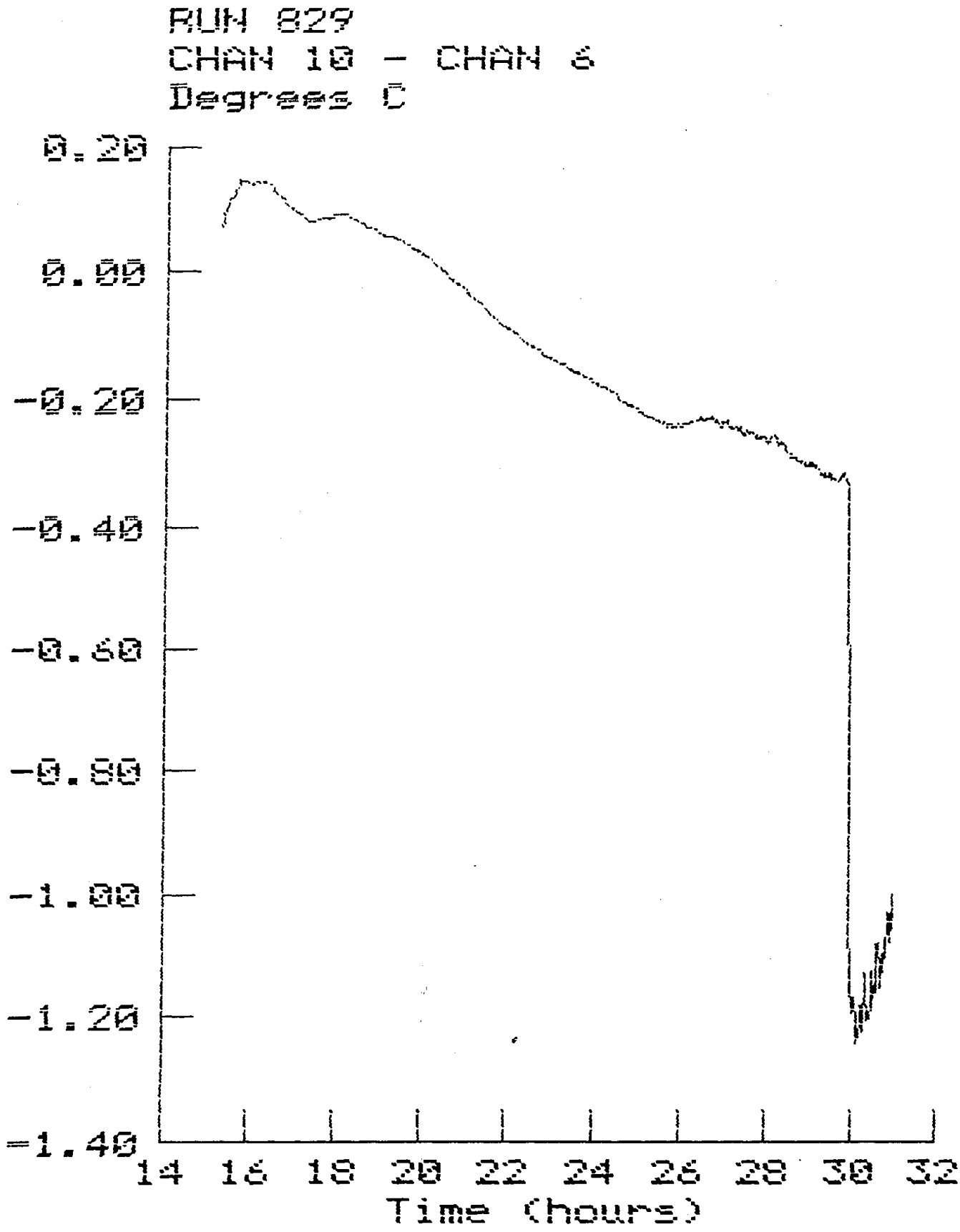

RUN 829
CHAN 24 - CHAN 8
Degrees C
0.01000
0.00000
-0.01000
-0.02000
-0.03000
-0.04000
14
16
18
20
22
24
26
28
30
32
Time (hours)

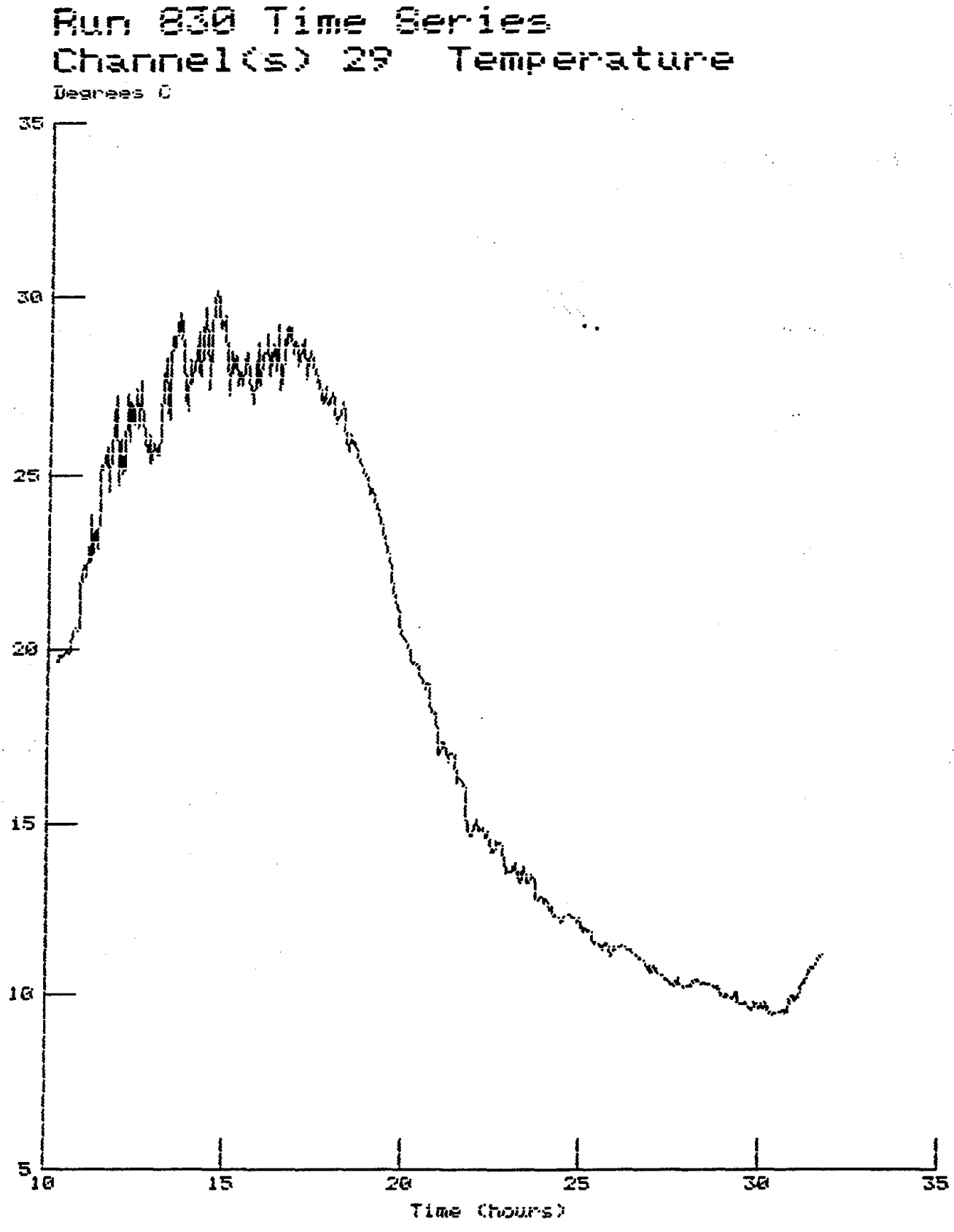

RUN 829
CHAN 17 - CHAN 5
Degrees C
0.02
-0.00
-0.02
-0.04
-0.06
-0.08
-0.10
-0.12
-0.14
14
16
18
20
22
24
26
28
30
32
Time (hours)


RUN 829
CHAN 10 - CHAN 6
Degrees C
0.20
0.00
-0.20
-0.40
-0.60
-0.80
-1.00
-1.20
-1.40
14
16
18
20
22
24
26
28
30
32
Time (hours)

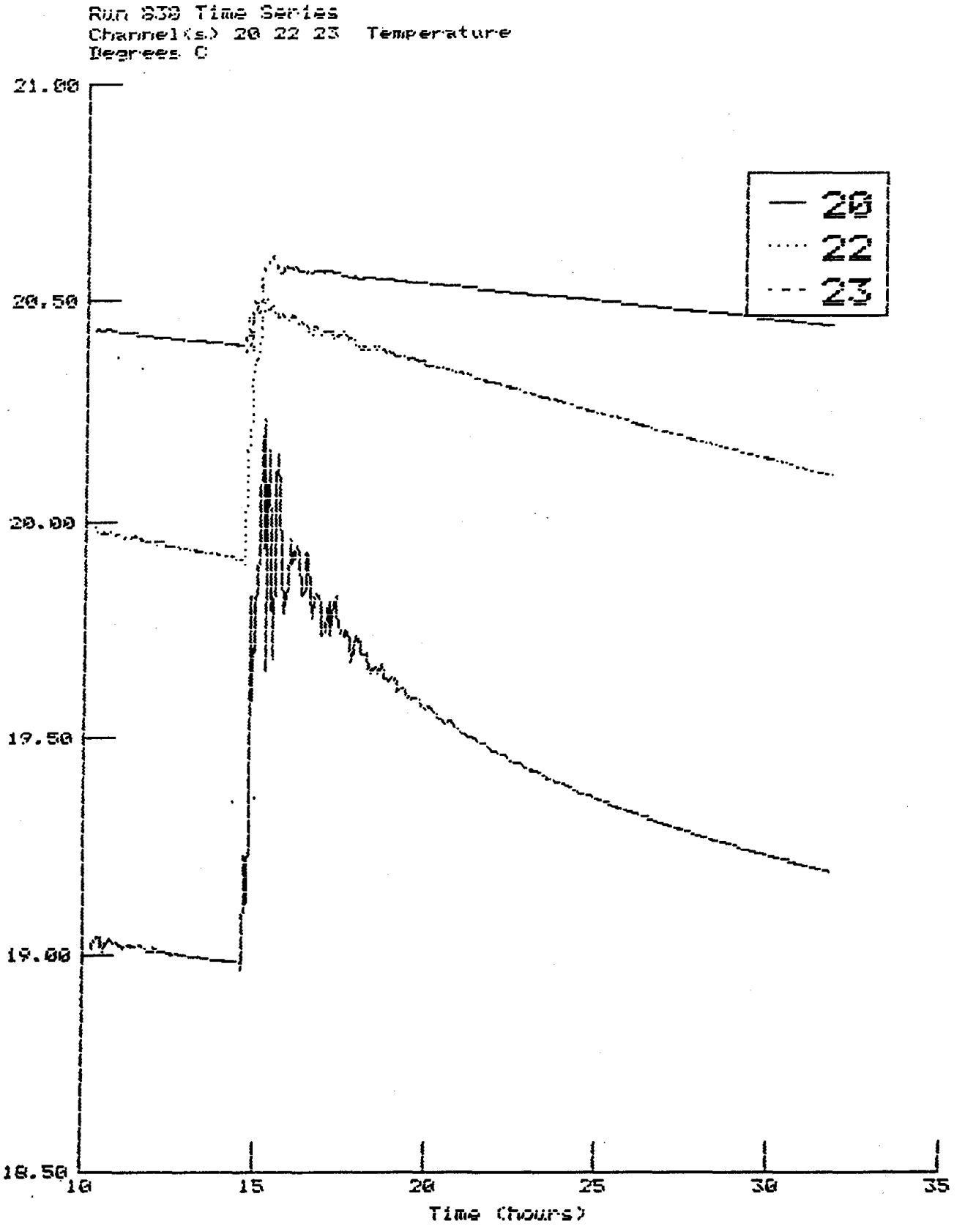
Appendix C

Overnight Test Begun at 1505 on 30 August 1990

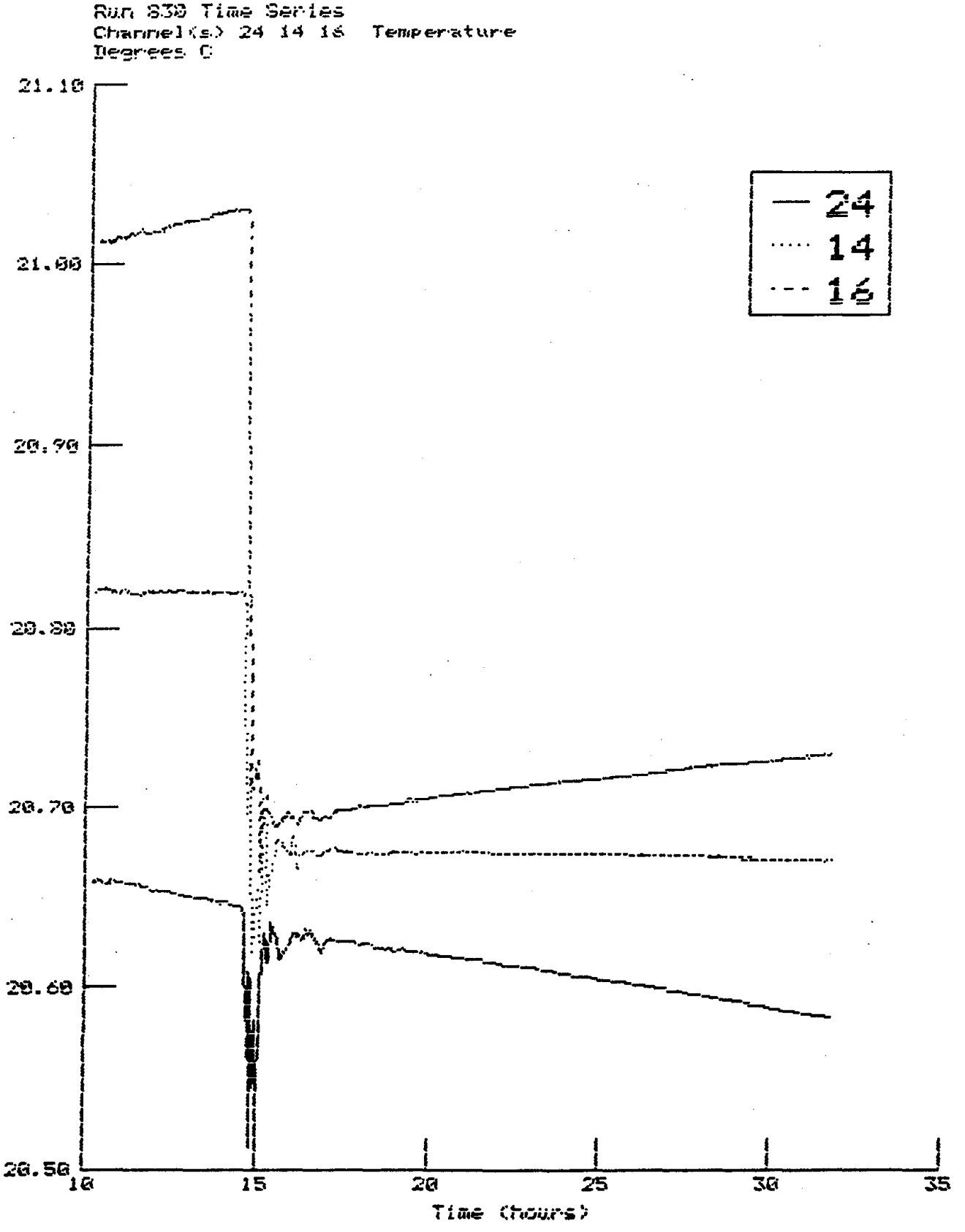
The time series of temperature measured during the overnight test started on 30 August 1990 are presented in Appendix C. The raw data for Arrays A and B, located in the 76-cm (30-in.) -diameter manways at B and A, respectively, are shown. The time series for Array A are presented first. The times series are presented according to their location within the tank and on the array. All of the product thermistors located on the vertical portion of the array and in the product are displayed as a group; because the display software only allowed three time series on a display, several graphs are used to present the product time series. The thermistors on the horizontal are grouped together in one display and the thermistors in the vapor space and the air are also displayed together. Appendix C also includes the time series showing the difference in temperature between thermistors located on Arrays A and B. (Refer to Figure 3.)

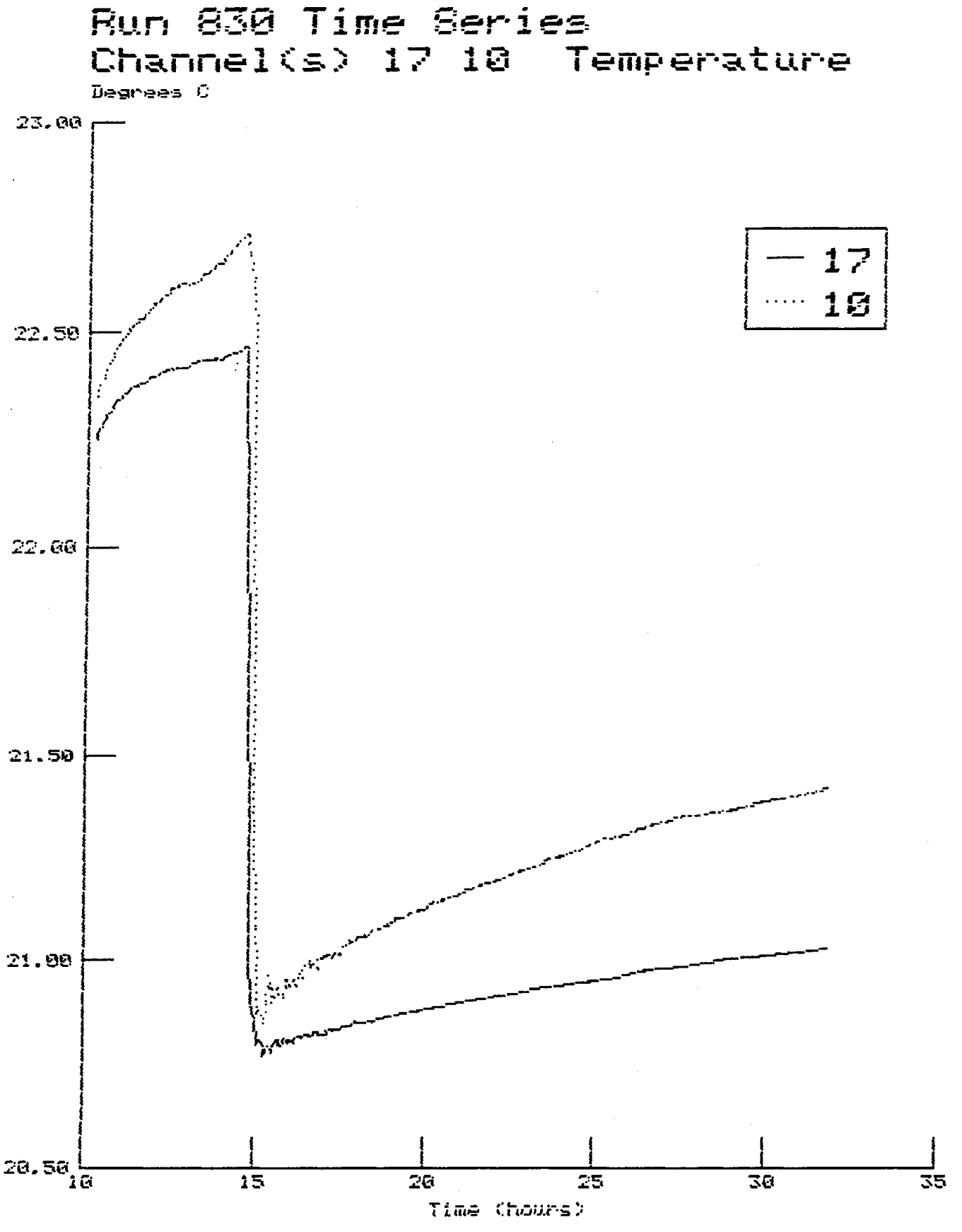

Run 830 Time Series
Channel(s) 29 Temperature
Degrees C
35
30
25
20
15
10
5
10
15
20
25
30
35
Time (hours)

125

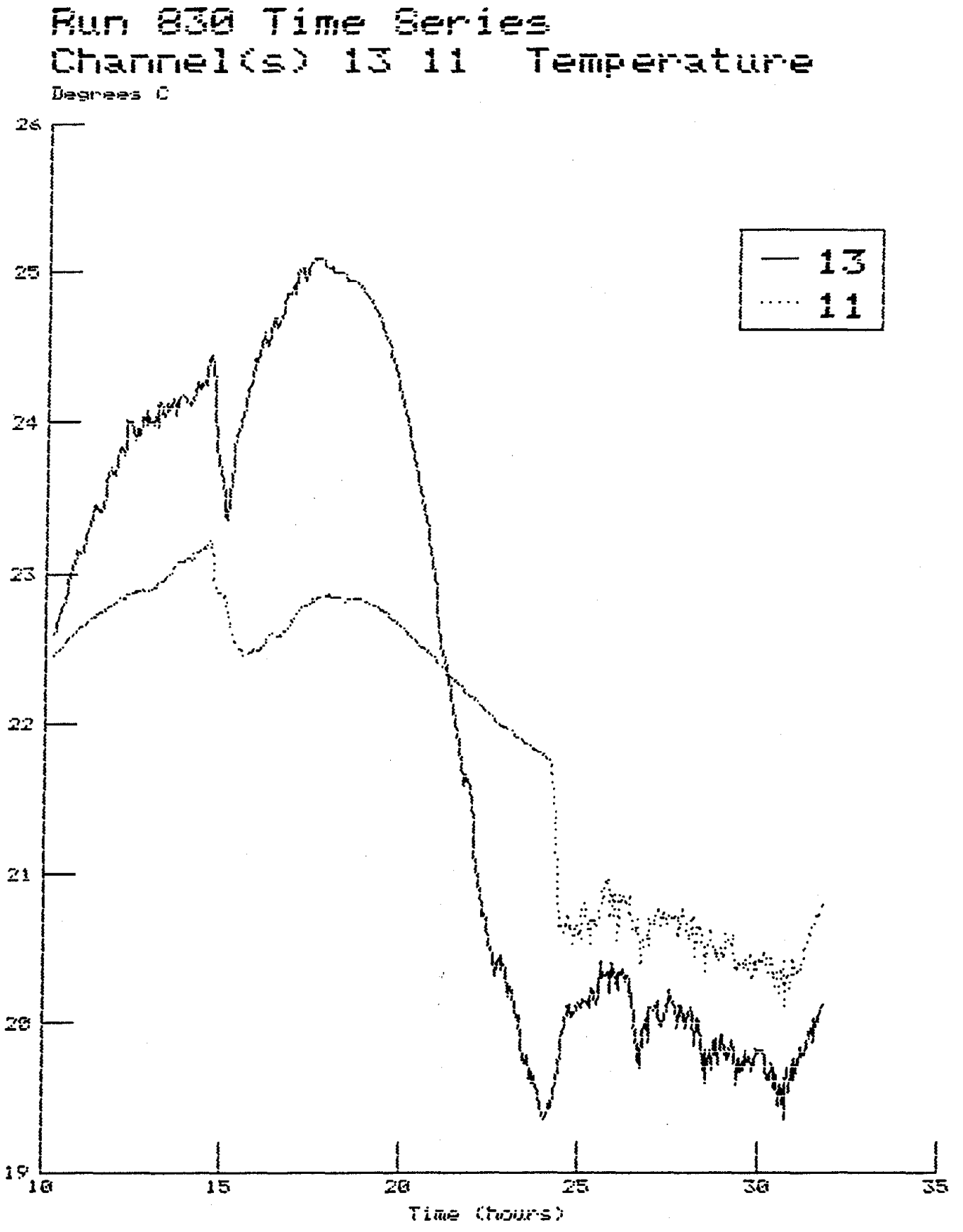

Run 838 Time Series
Channel(s) 20 22 23 Temperature
Degrees C
21.00
20.50
20.00
19.50
19.00
18.50
10
15
20
25
30
35
Time (hours)
20
22
23

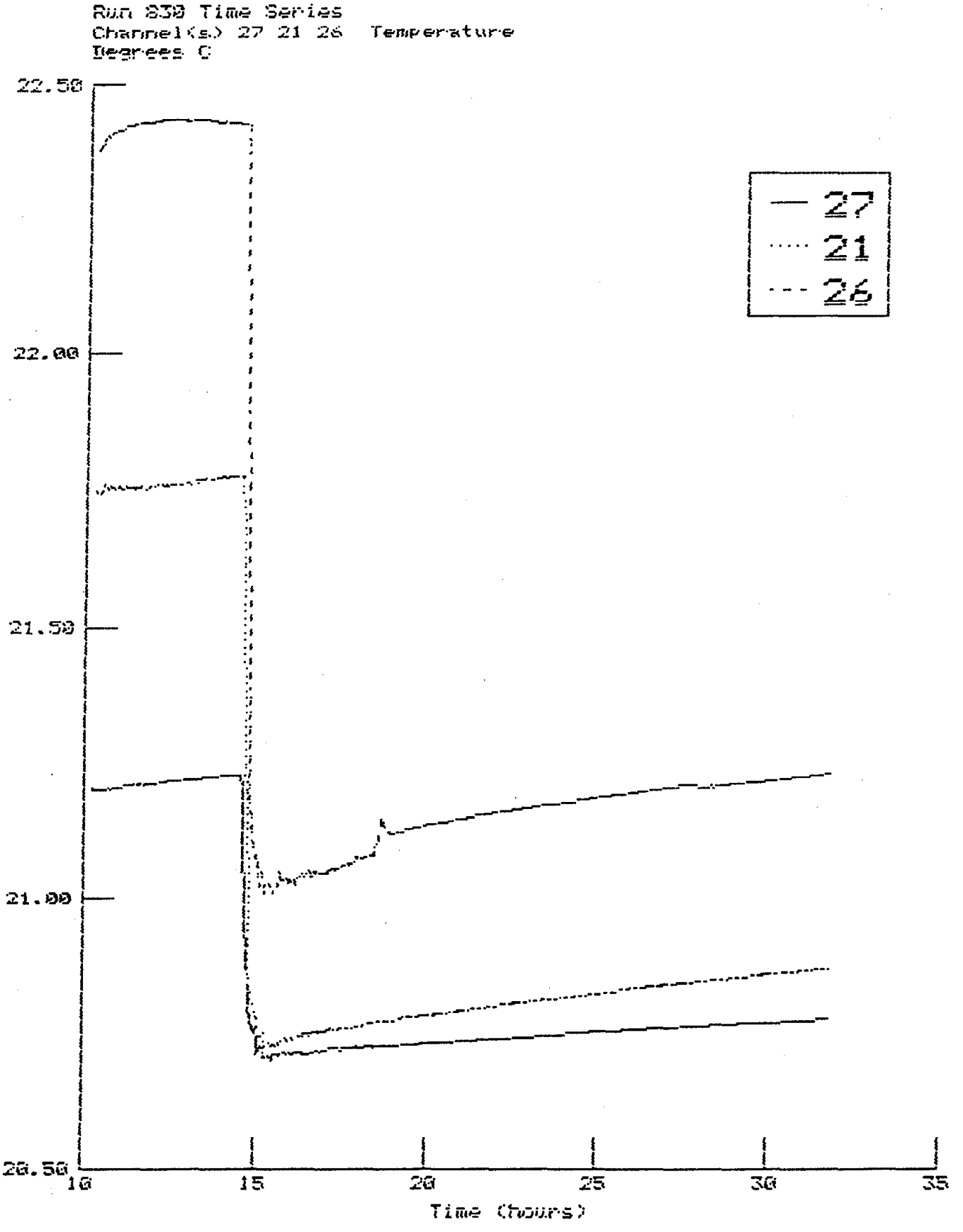
126


Run 830 Time Series
Channel(s) 24 14 16 Temperature
Degrees C
21.10
21.00
20.90
20.80
20.70
20.60
20.50
10
15
20
25
30
35
Time (hours)
24
14
16

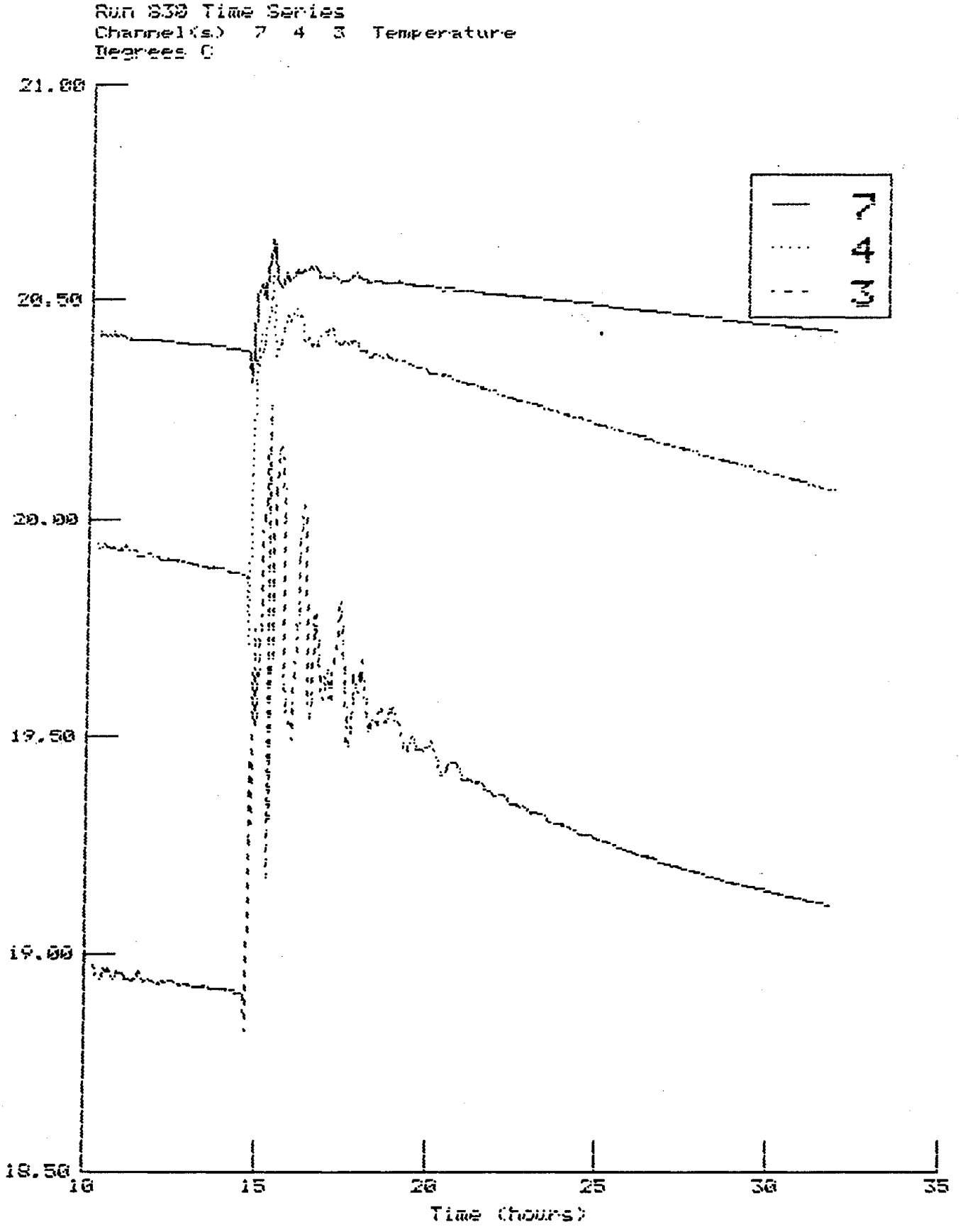

Run 830 Time Series
Channel(s) 17 10 Temperature
Degrees C
23.00
22.50
22.00
21.50
21.00
20.50
10
15
20
25
30
35
Time (hours)
17
10

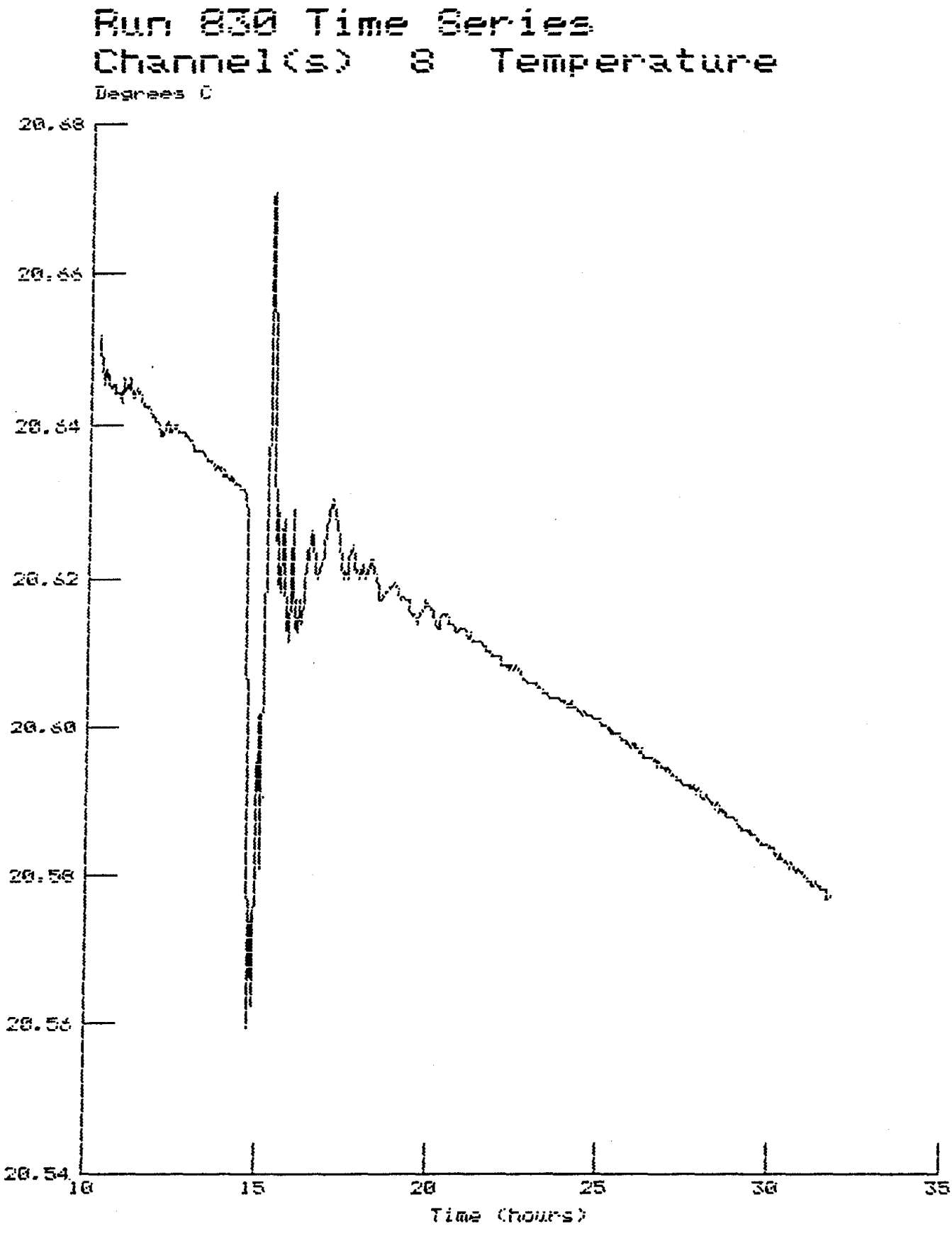
128

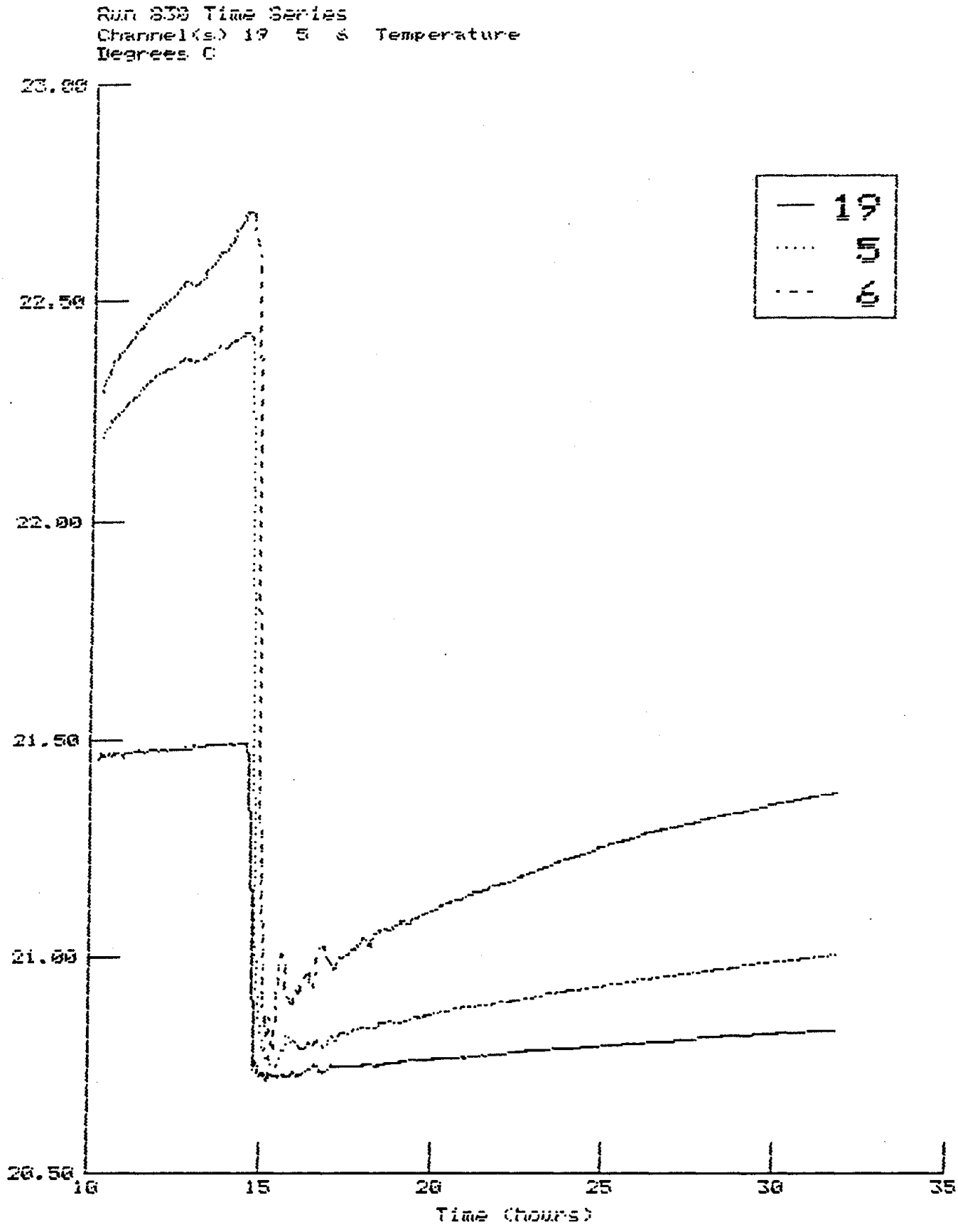

Run 830 Time Series
Channel(s) 13 11 Temperature
Degrees C
26
25
24
23
22
21
20
19
10
15
20
25
30
35
Time (hours)
13
11

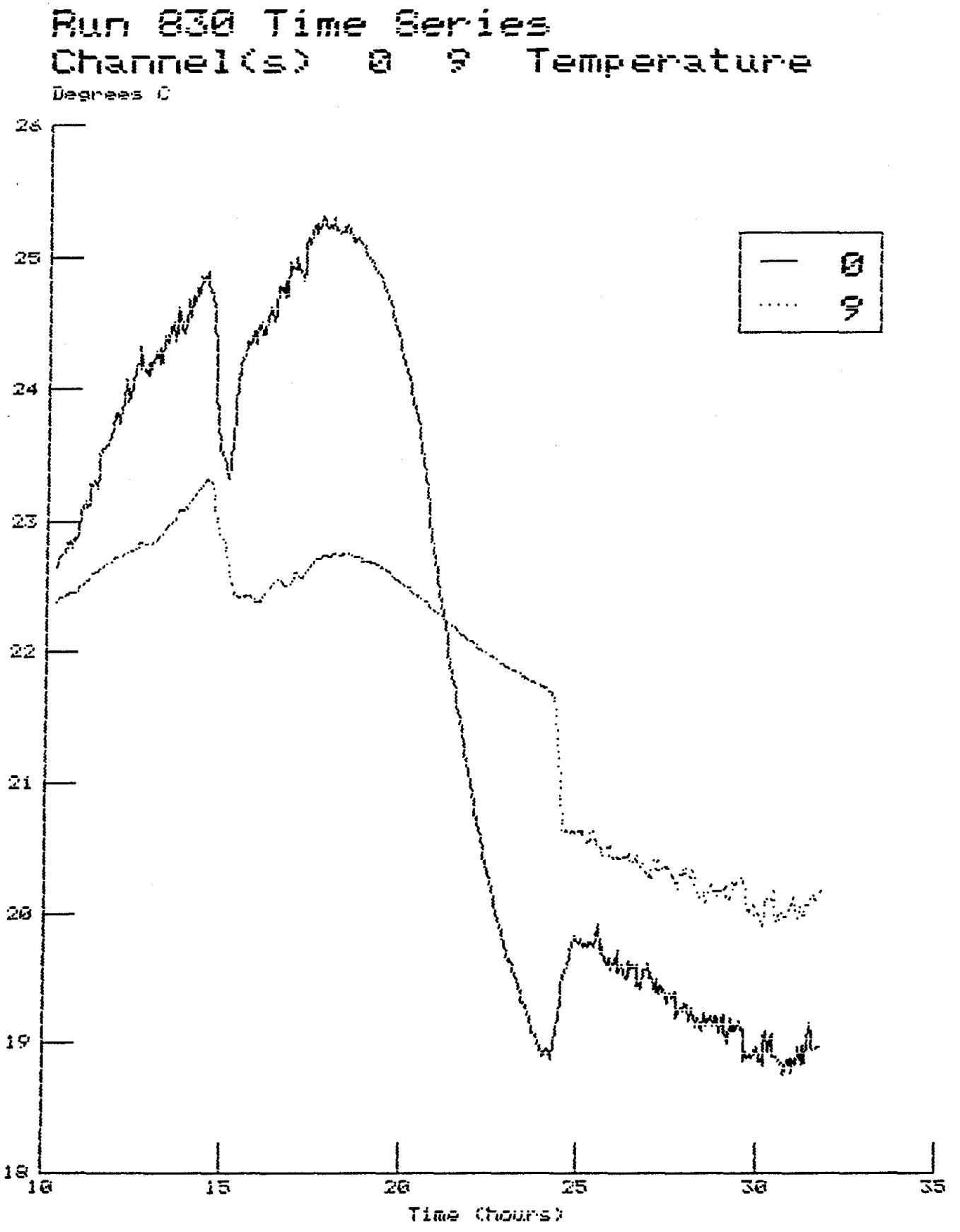

Run 830 Time Series
Channel(s) 27 21 26 Temperature
Degrees C
22.50
22.00
21.50
21.00
20.50
10
15
20
25
30
35
Time (hours)
27
21
26

130

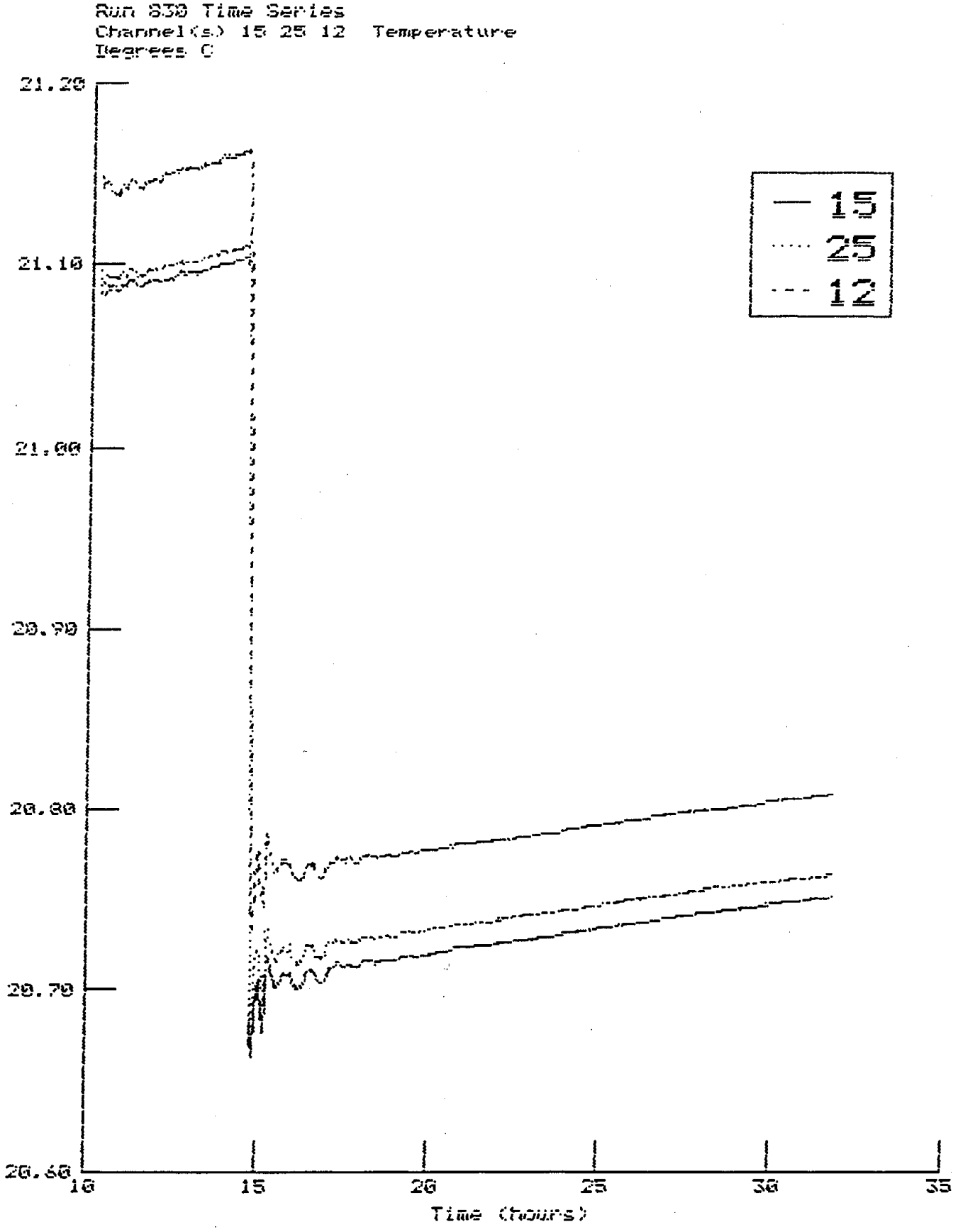

Run 830 Time Series
Channel(s) 7 4 3 Temperature
Degrees C
21.00
20.50
20.00
19.50
19.00
18.50
10
15
20
25
30
35
Time (hours)
7
4
3

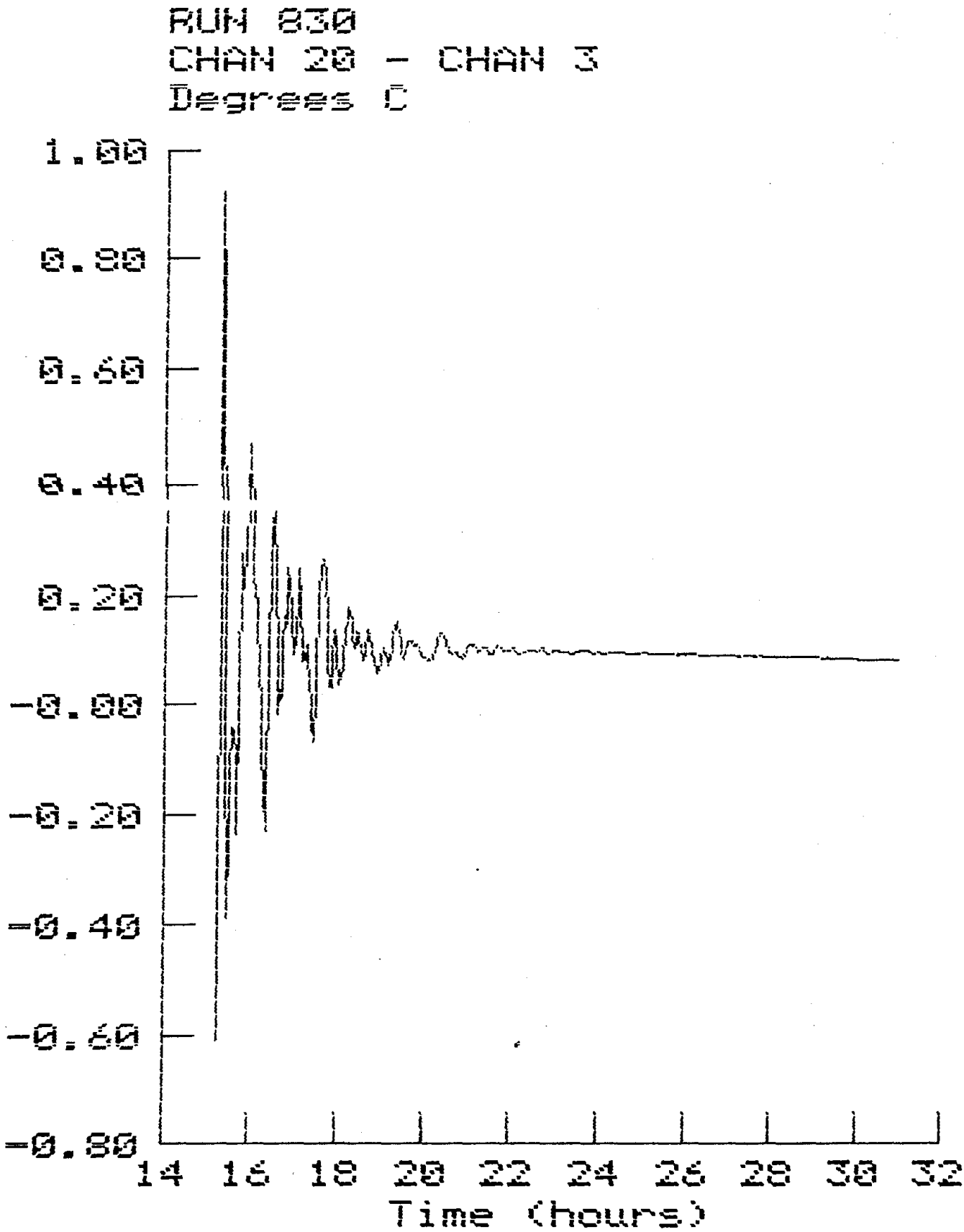

Run 830 Time Series
Channel(s) 8 Temperature
Degrees C
20.68
20.66
20.64
20.62
20.60
20.58
20.56
20.54
10
15
20
25
30
35
Time (hours)

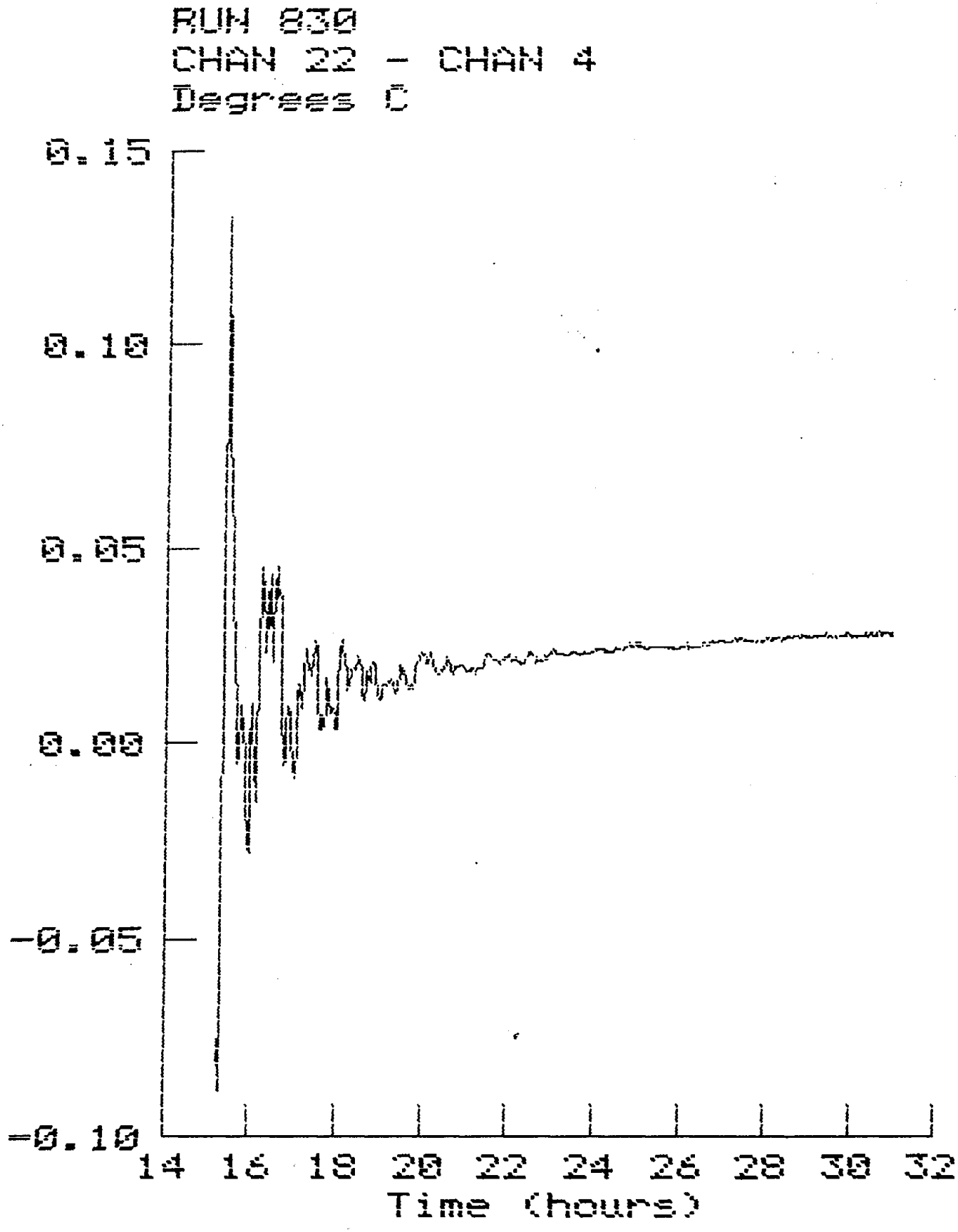

Run 838 Time Series
Channel(s) 19 5 6 Temperature
Degrees C
23.00
22.50
22.00
21.50
21.00
20.50
10
15
20
25
30
35
Time (hours)
19
5
6

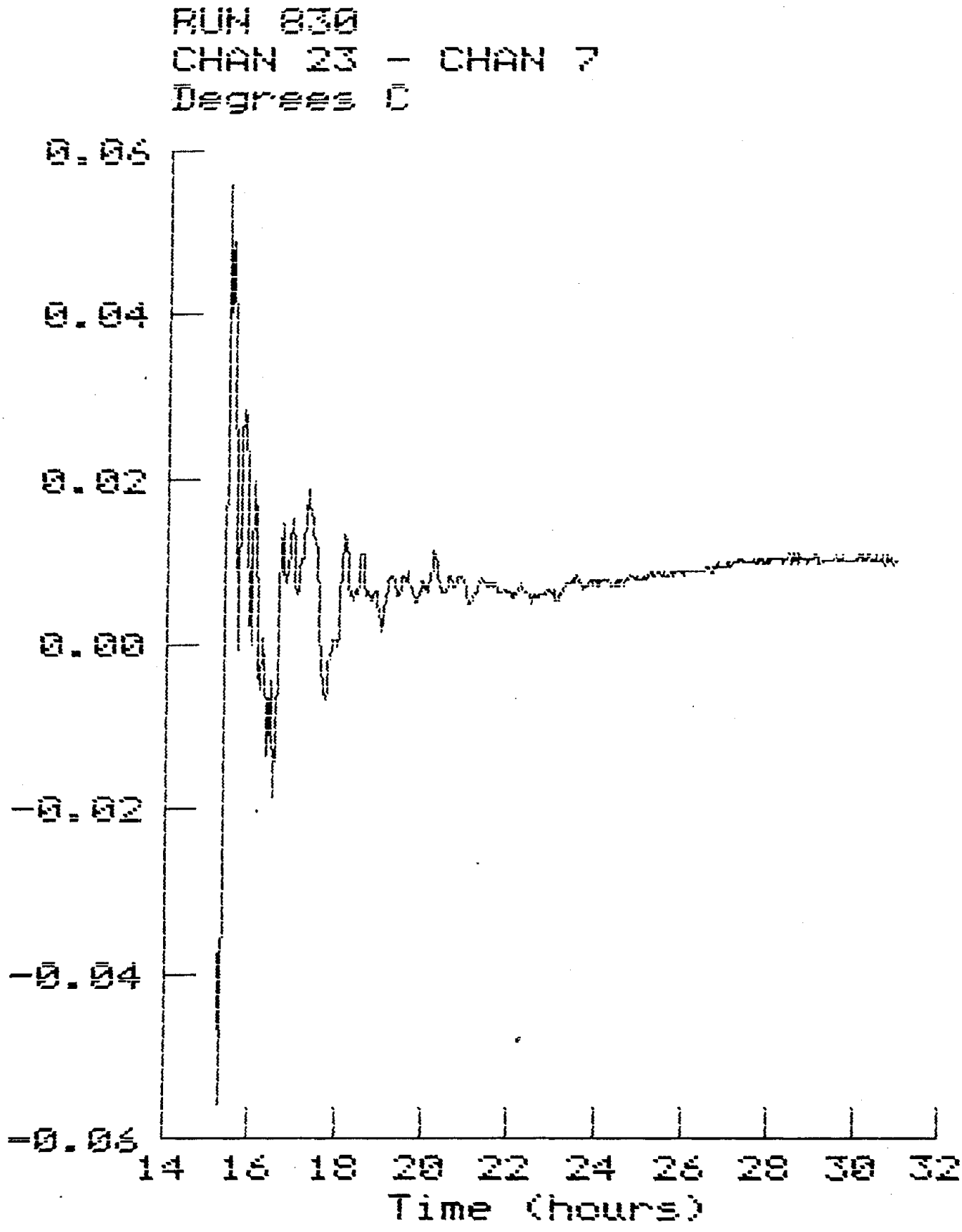

Run 830 Time Series
Channel(s) 0 9 Temperature
Degrees C
26
25
24
23
22
21
20
19
18
10
15
20
25
30
35
Time (hours)
0
9

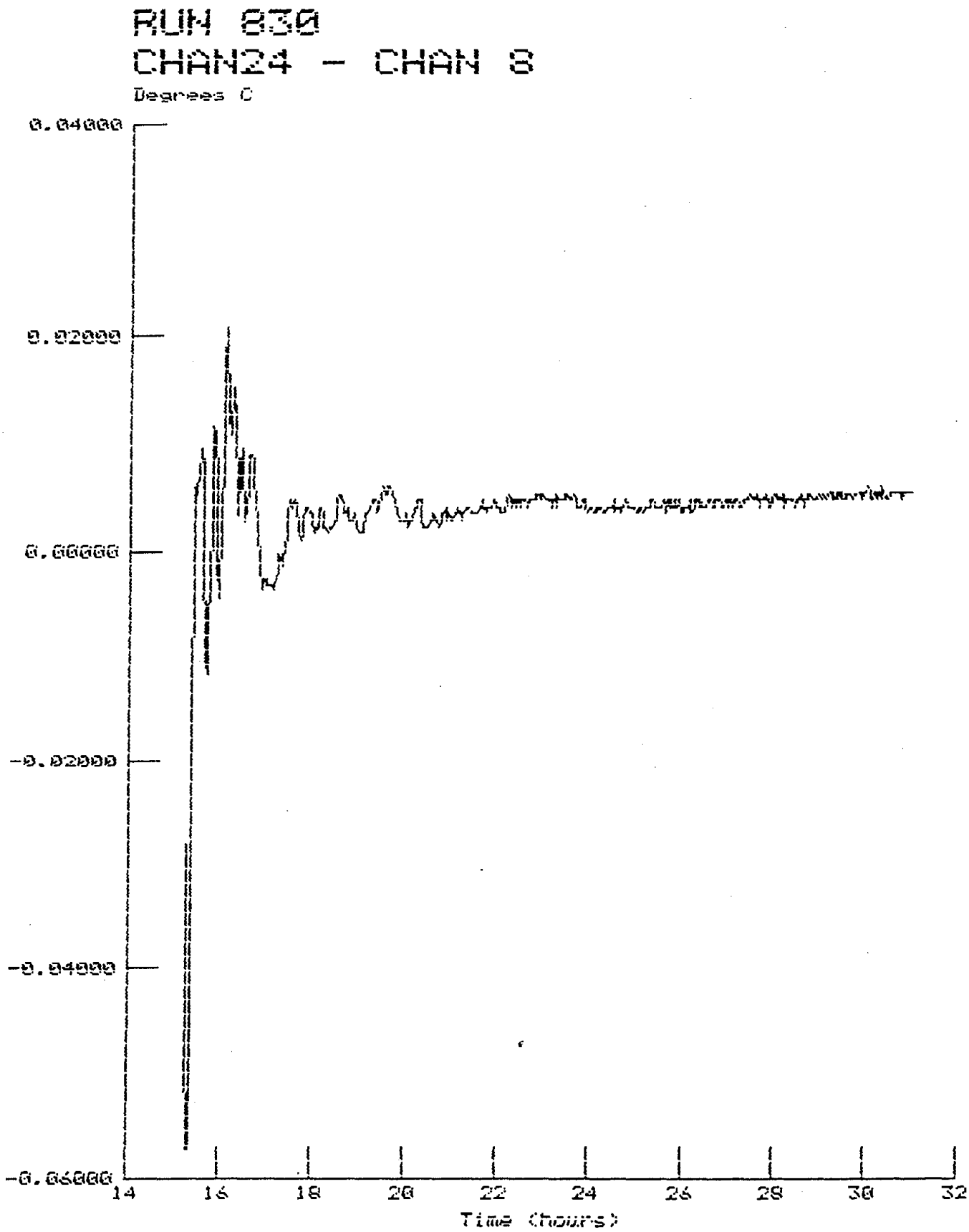
134


Run 830 Time Series
Channel(s) 15 25 12 Temperature
Degrees C
21.20
21.10
21.00
20.90
20.80
20.70
20.60
10
15
20
25
30
35
Time (hours)
15
25
12


RUN 830
CHAN 20 - CHAN 3
Degrees C
1.00
0.80
0.60
0.40
0.20
-0.00
-0.20
-0.40
-0.60
-0.80
14
16
18
20
22
24
26
28
30
32
Time (hours)


RUN 830
CHAN 22 - CHAN 4
Degrees C
0.15
0.10
0.05
0.00
-0.05
-0.10
14
16
18
20
22
24
26
28
30
32
Time (hours)


RUN 830
CHAN 23 - CHAN 7
Degrees C
0.06
0.04
0.02
0.00
-0.02
-0.04
-0.06
14
16
18
20
22
24
26
28
30
32
Time (hours)



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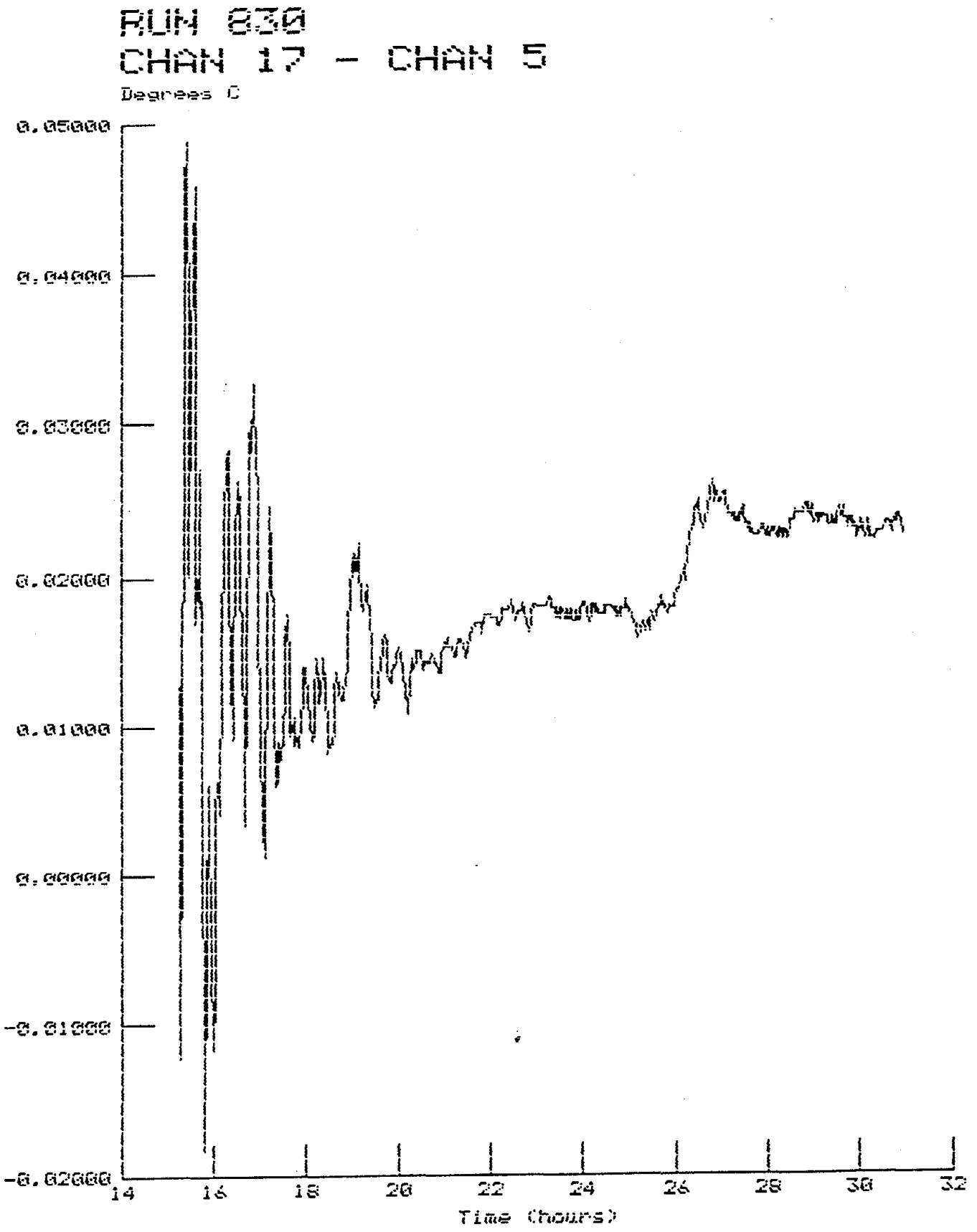
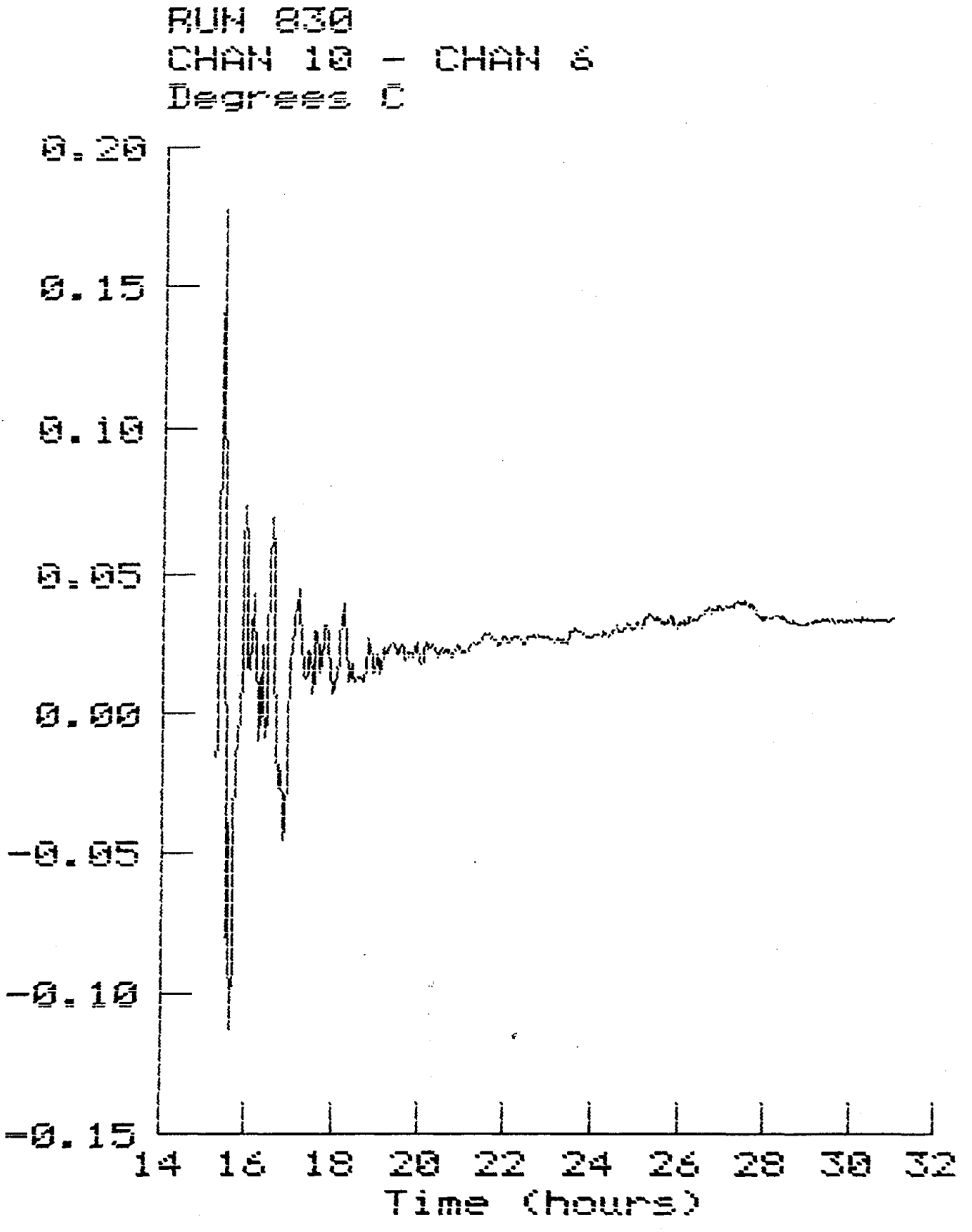
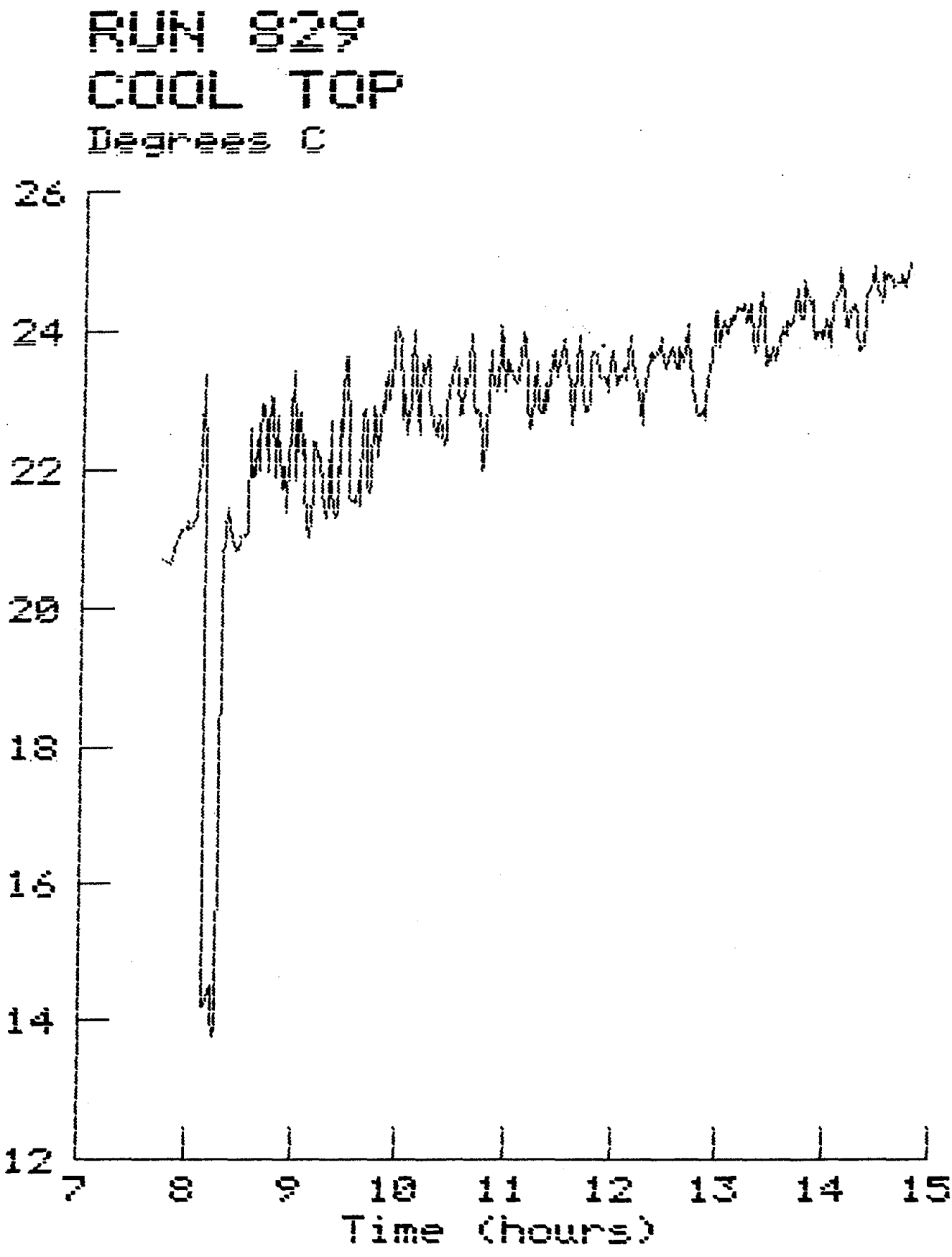

RUN 830
CHAN 17 - CHAN 5
Degrees C
0.05000
0.04000
0.03000
0.02000
0.01000
0.00000
-0.01000
-0.02000
14
16
18
20
22
24
26
28
30
32
Time (hours)

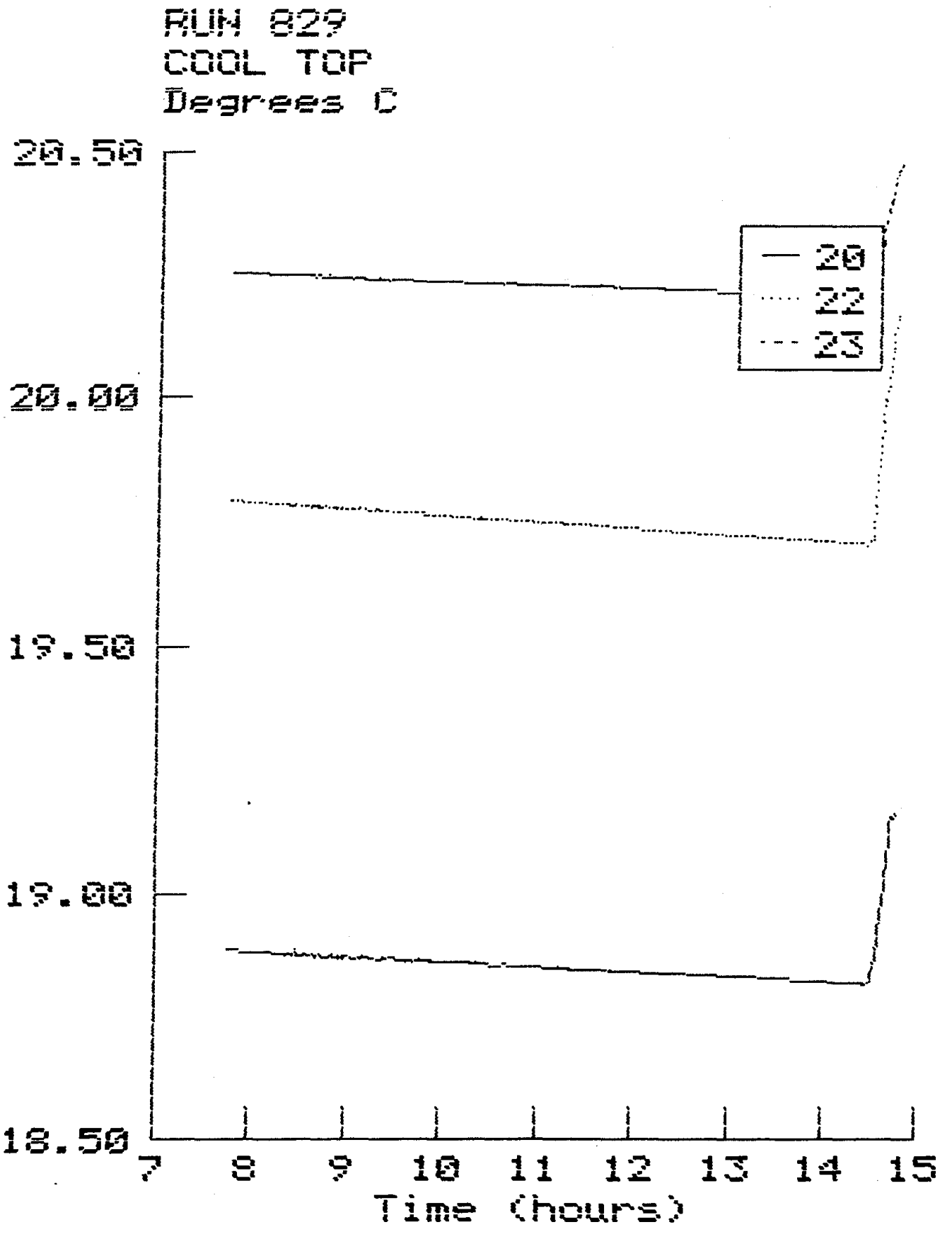

RUN 830
CHAN 10 - CHAN 6
Degrees C
0.20
0.15
0.10
0.05
0.00
-0.05
-0.10
-0.15
14
16
18
20
22
24
26
28
30
32
Time (hours)

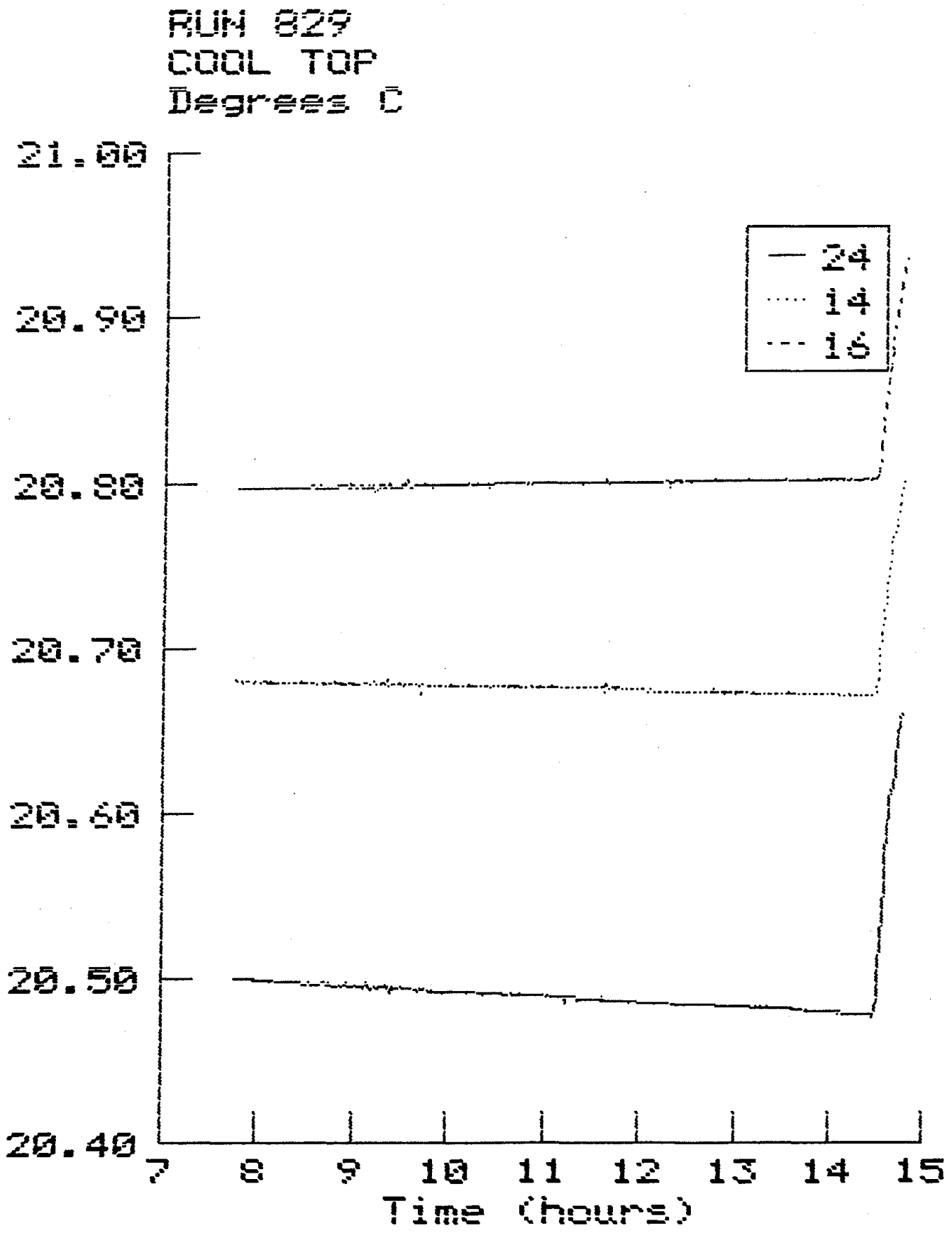
Appendix D

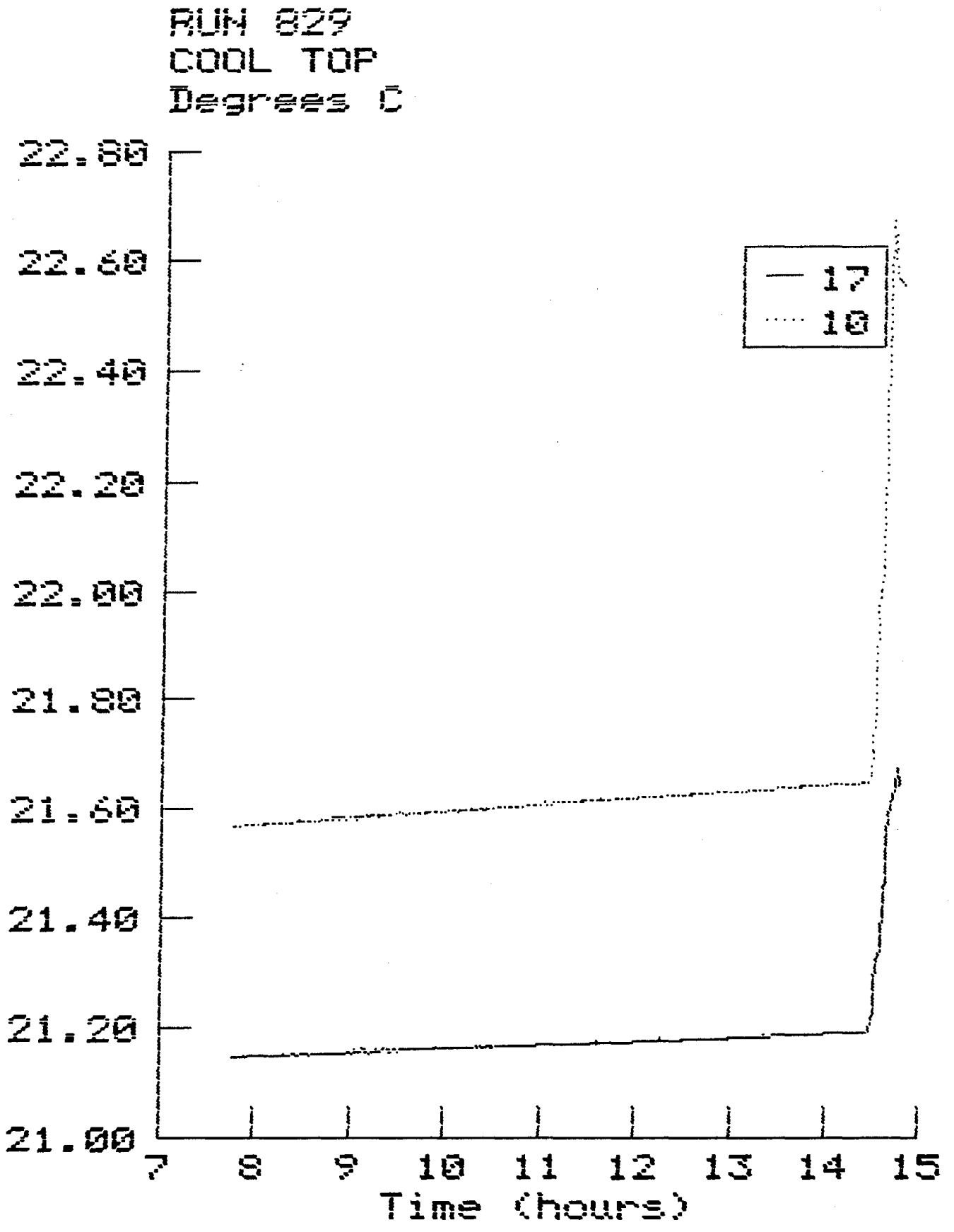
Cold Topping Test Begun at 0819 on 29 August 1990

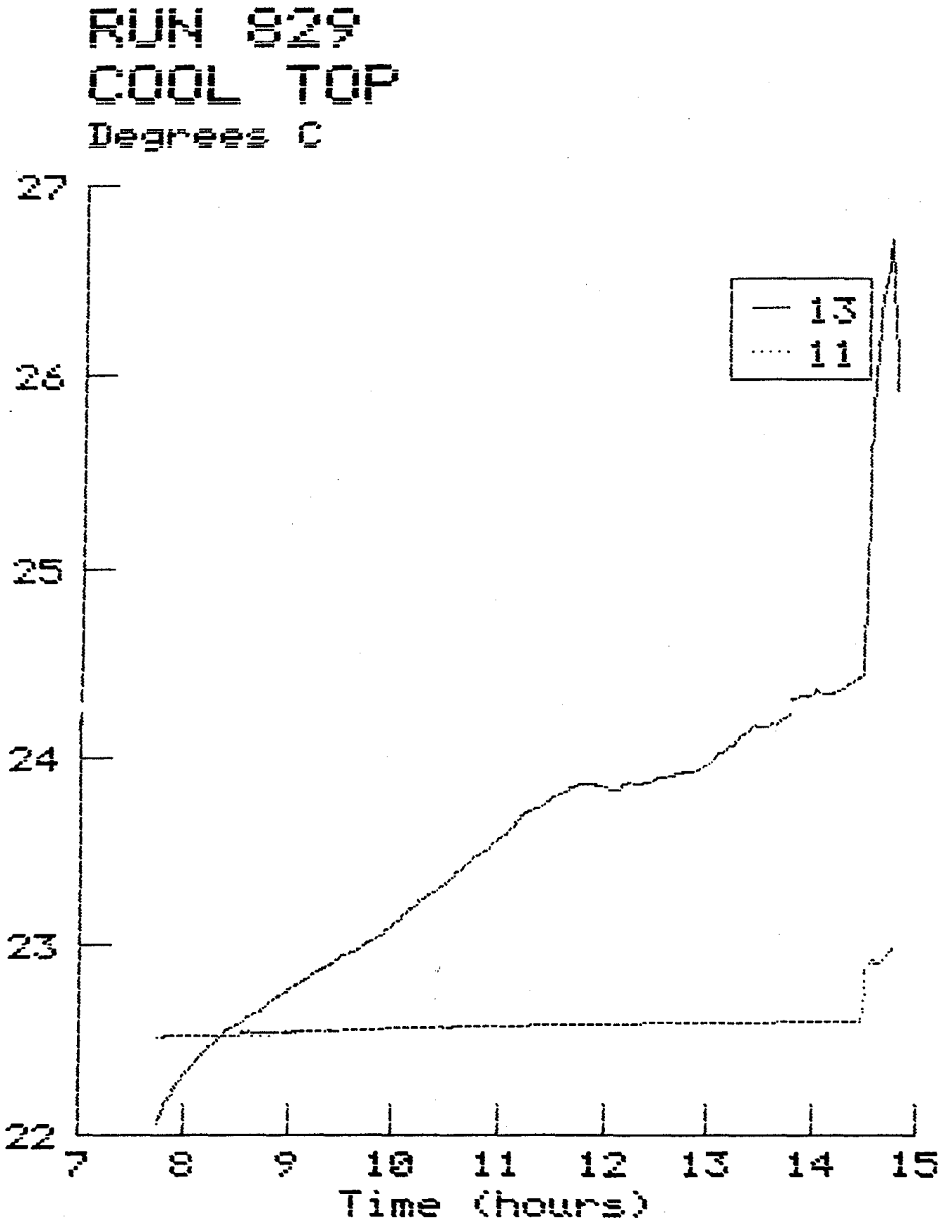
The time series of temperature measured during the overnight test started on 29 August 1990 are presented in Appendix D. The raw data for Arrays A and B located in the 76-cm (30-in.) -diameter manway at B and the 10-cm (4-in.) -diameter fill hole at C, respectively, are shown. The time series for Array A are presented first. The times series are presented by their location within the tank and on the array. All of the product thermistors located on the vertical portion of the array and in the product are displayed as a group; because the display software only allowed three time series on a display, several graphs are used to present the product time series. The thermistors on the horizontal are grouped together in one display and the thermistors in the vapor space and the air are also displayed together. Appendix D also includes the time series showing the difference in temperature between thermistors located on Arrays A and B. (Refer to Figure 3.)

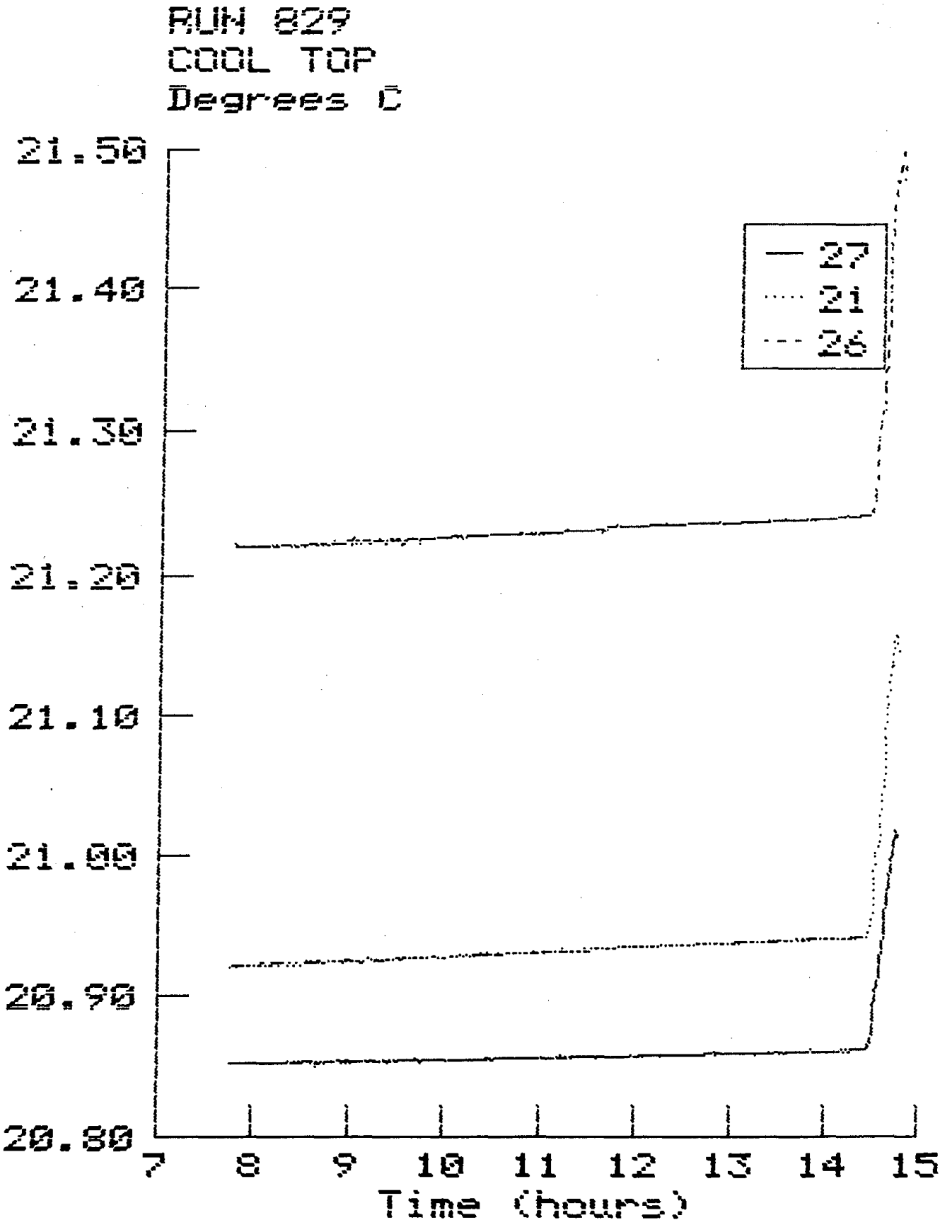

RUN 829
COOL TOP
Degrees C
26
24
22
20
18
16
14
12
7
8
9
10
11
12
13
14
15
Time (hours)

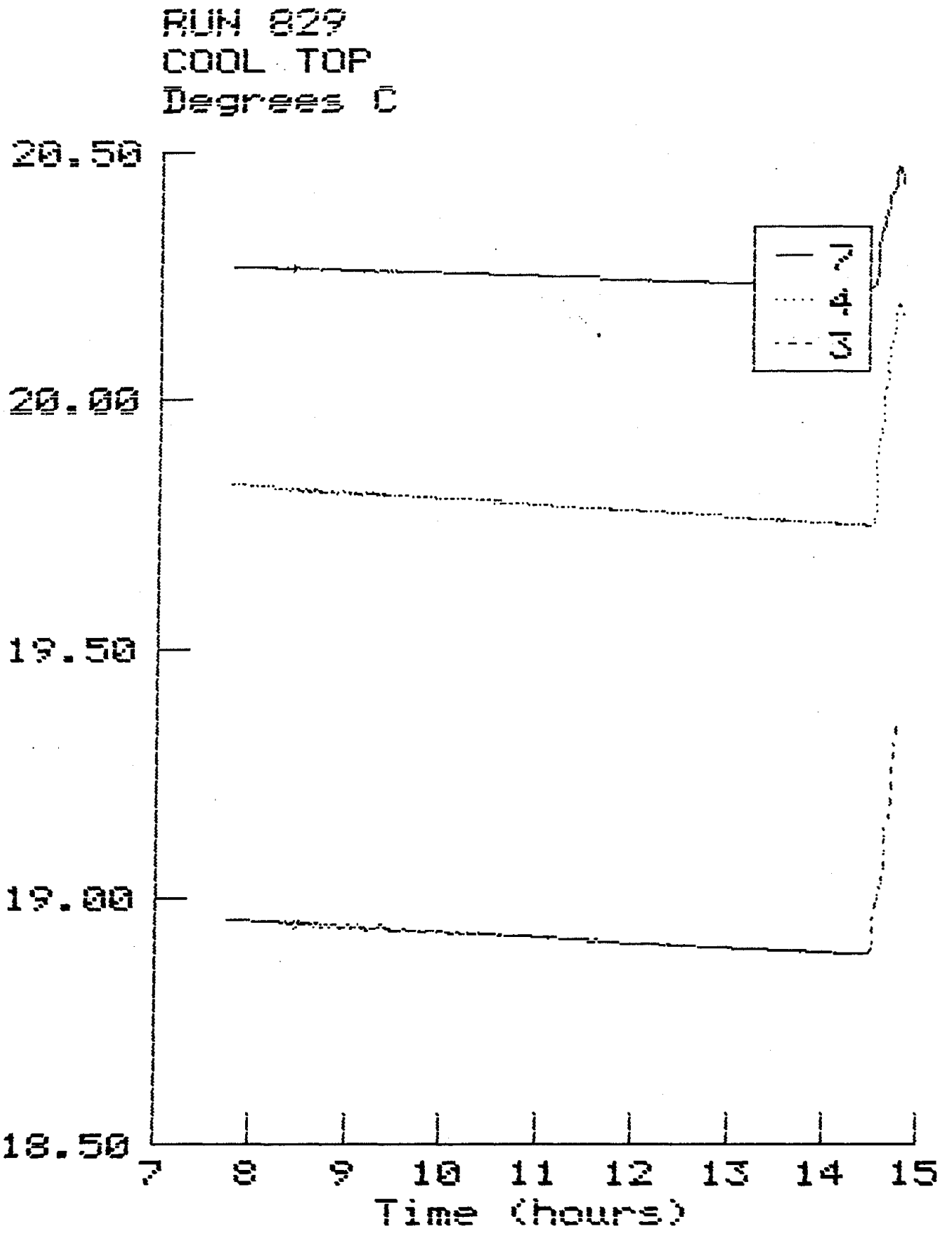

RUN 829
COOL TOP
Degrees C
20.50
20.00
19.50
19.00
18.50
20
22
23
7
8
9
10
11
12
13
14
15
Time (hours)

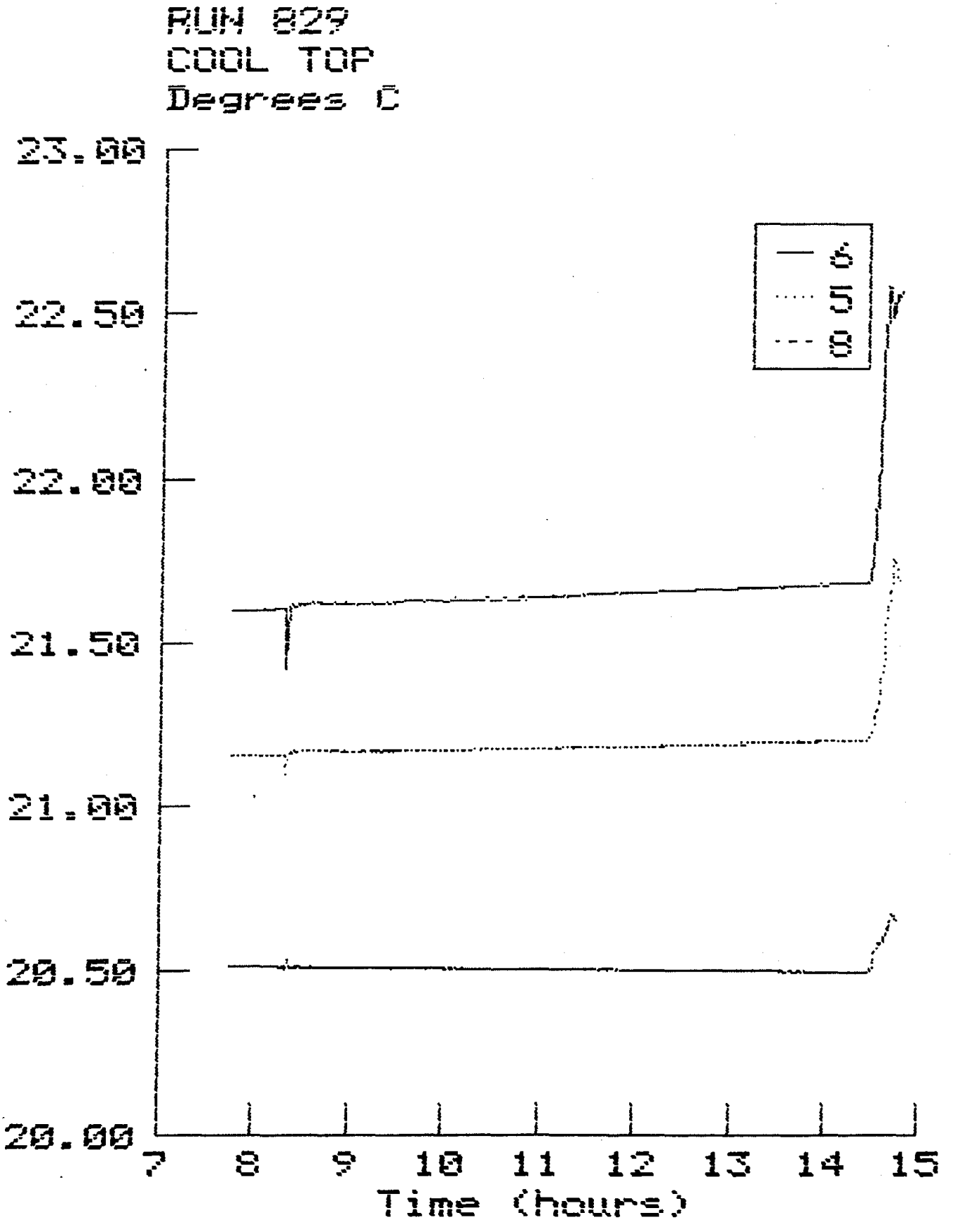

RUN 829
COOL TOP
Degrees C
21.00
20.90
20.80
20.70
20.60
20.50
20.40
24
14
16
7
8
9
10
11
12
13
14
15
Time (hours)


RUN 829
COOL TOP
Degrees C
22.80
22.60
22.40
22.20
22.00
21.80
21.60
21.40
21.20
21.00
17
10
7
8
9
10
11
12
13
14
15
Time (hours)


RUN 929
COOL TOP
Degrees C
27
26
25
24
23
22
13
11
7
8
9
10
11
12
13
14
15
Time (hours)


RUN 829
COOL TOP
Degrees C
21.50
21.40
21.30
21.20
21.10
21.00
20.90
20.80
27
21
26
7
8
9
10
11
12
13
14
15
Time (hours)


RUN 829
COOL TOP
Degrees C
20.50
20.00
19.50
19.00
18.50
7
8
9
10
11
12
13
14
15
Time (hours)


RUN 829
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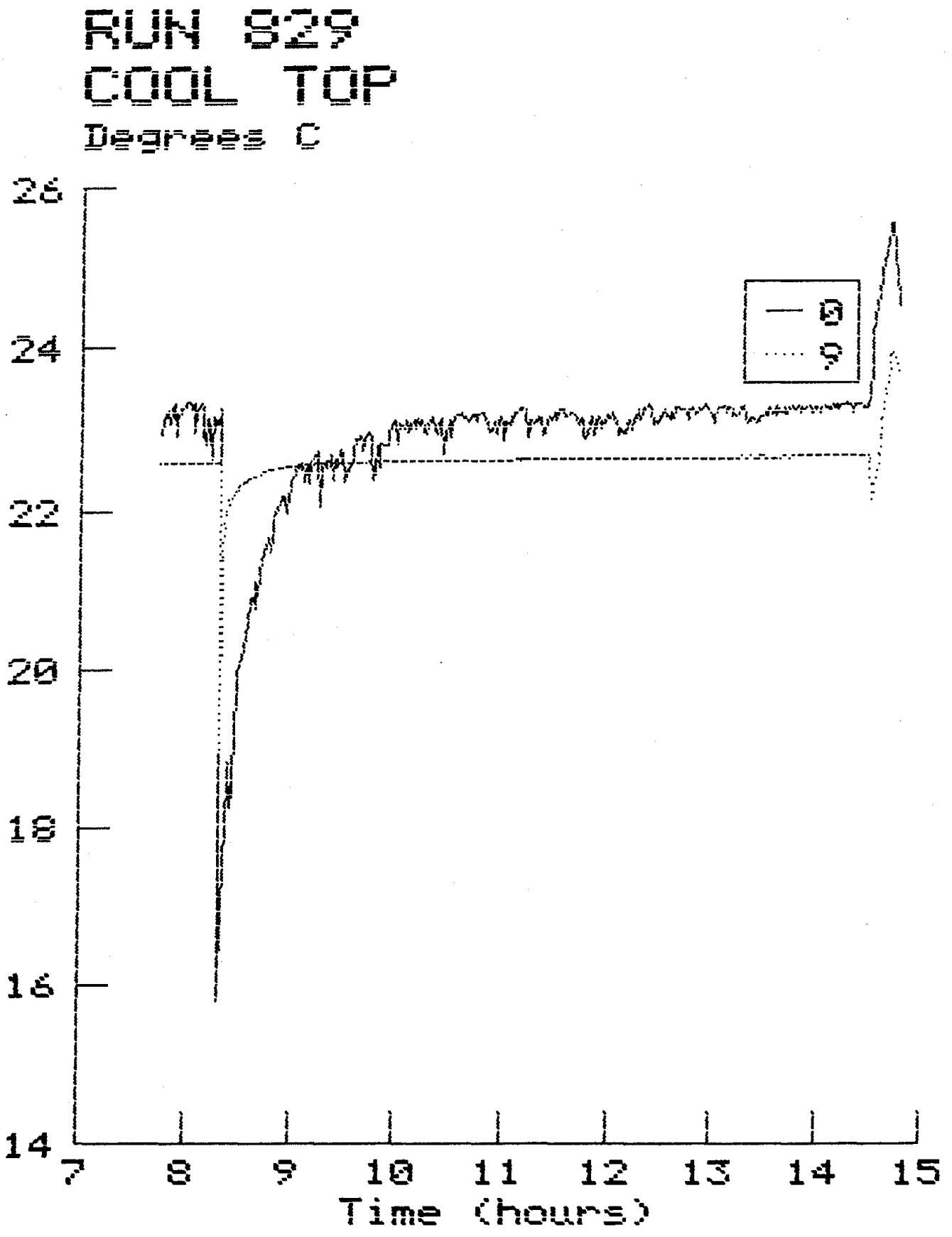
Degrees C
23.00
22.50
22.00
21.50
21.00
20.50
20.00
6
5
8
7
8
9
10
11
12
13
14
15
Time (hours)


RUN 929
COOL TOP
Degrees C
26
24
22
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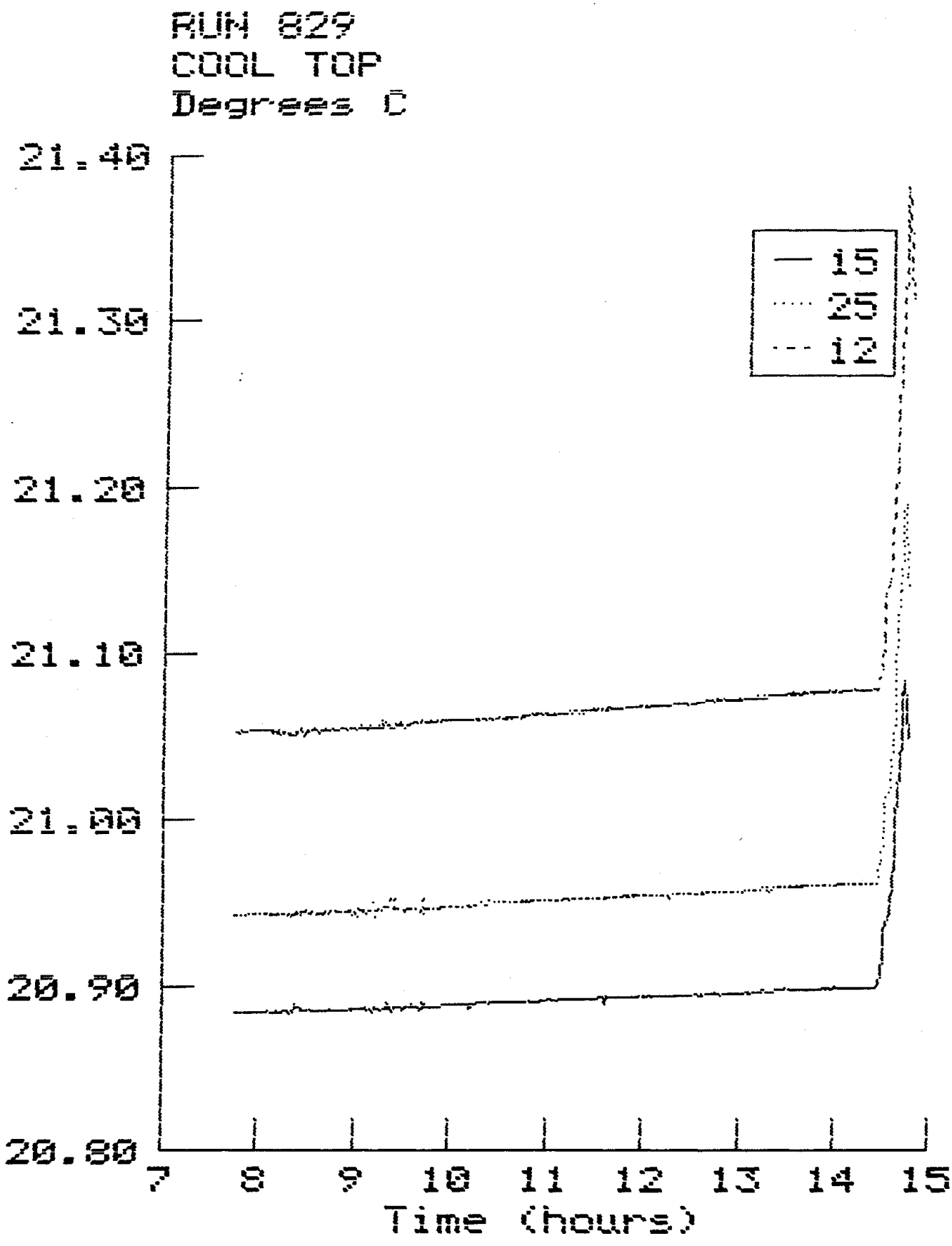
18
16
14
7
8
9
10
11
12
13
14
15
Time (hours)
0
9

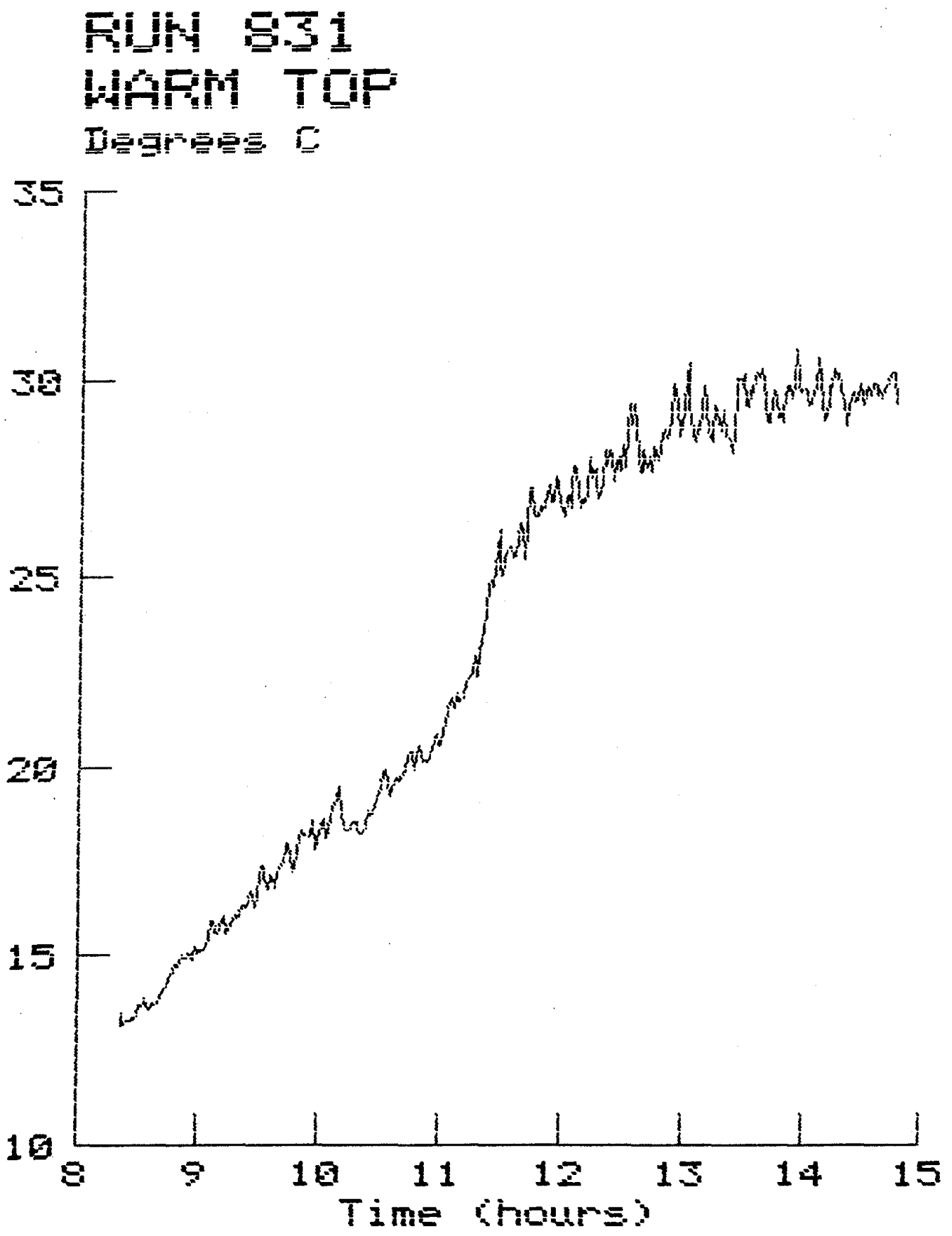
151


RUN 829
COOL TOP
Degrees C
21.40
21.30
21.20
21.10
21.00
20.90
20.80
15
25
12
7
8
9
10
11
12
13
14
15
Time (hours)

Appendix E

Warm Topping Test Begun at 0820 on 31 August 1990

The time series of temperature measured during the overnight test started on 31 August 1990 are presented in Appendix E. The raw data for Arrays A and B, located in the 76-cm (30-in.) -diameter manways at B and A, respectively, are shown. The time series for Array A are presented first. The times series are presented by their location within the tank and on the array. All of the product thermistors located on the vertical portion of the array and in the product are displayed as a group; because the display software only allowed three time series on a display, several graphs are used to present the product time series. The thermistors on the horizontal are grouped together in one display and the thermistors in the vapor space and the air are also displayed together. Appendix E also includes the time series showing the difference in temperature between thermistors located on Arrays A and B. (Refer to Figure 3.)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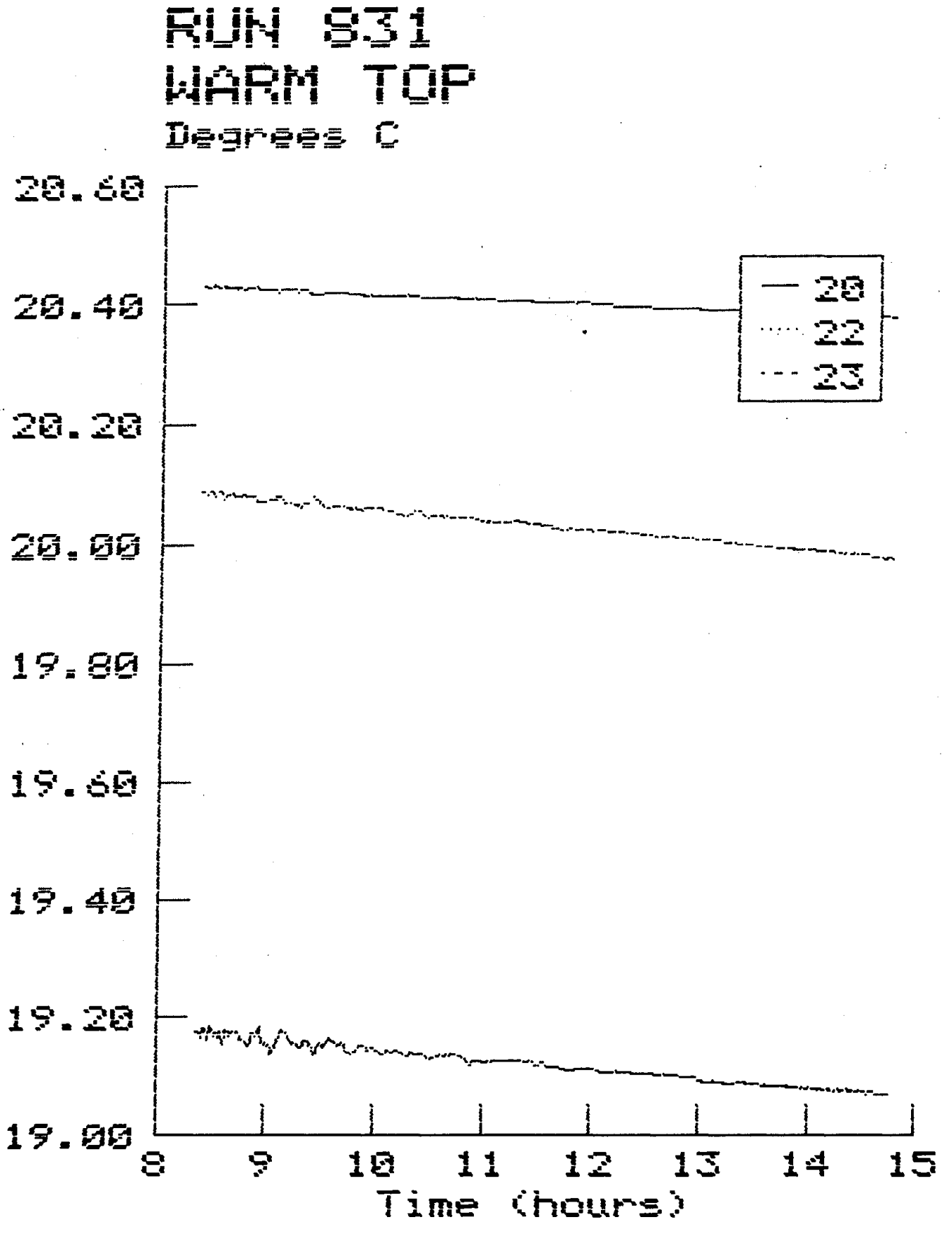
WARM TOP
Degrees C
35
30
25
20
15
10
8
9
10
11
12
13
14
15
Time (hours)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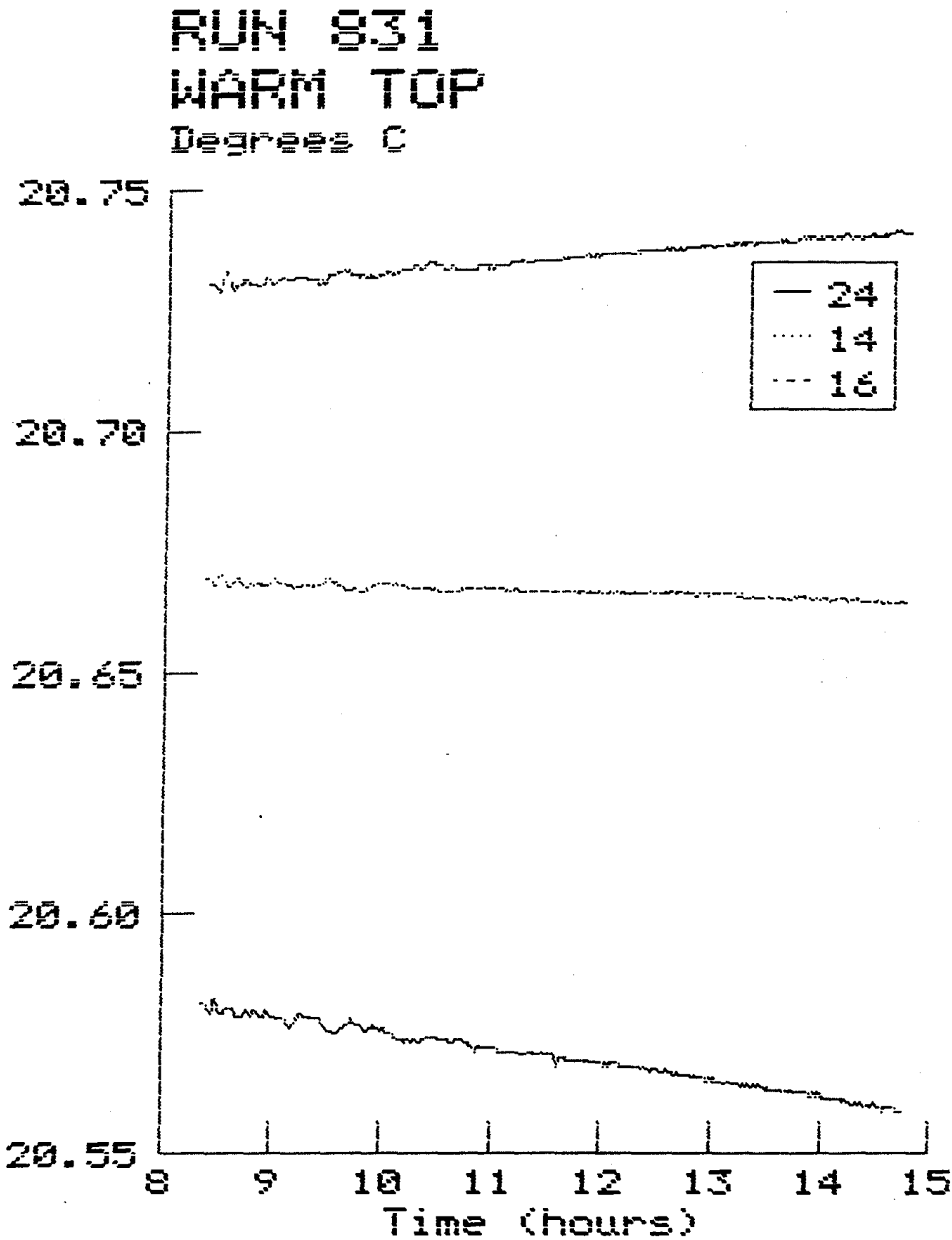
WARM TOP
Degrees C
20.60
20.40
20.20
20.00
19.80
19.60
19.40
19.20
19.00
20
22
23
8
9
10
11
12
13
14
15
Time (hours)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Degrees C
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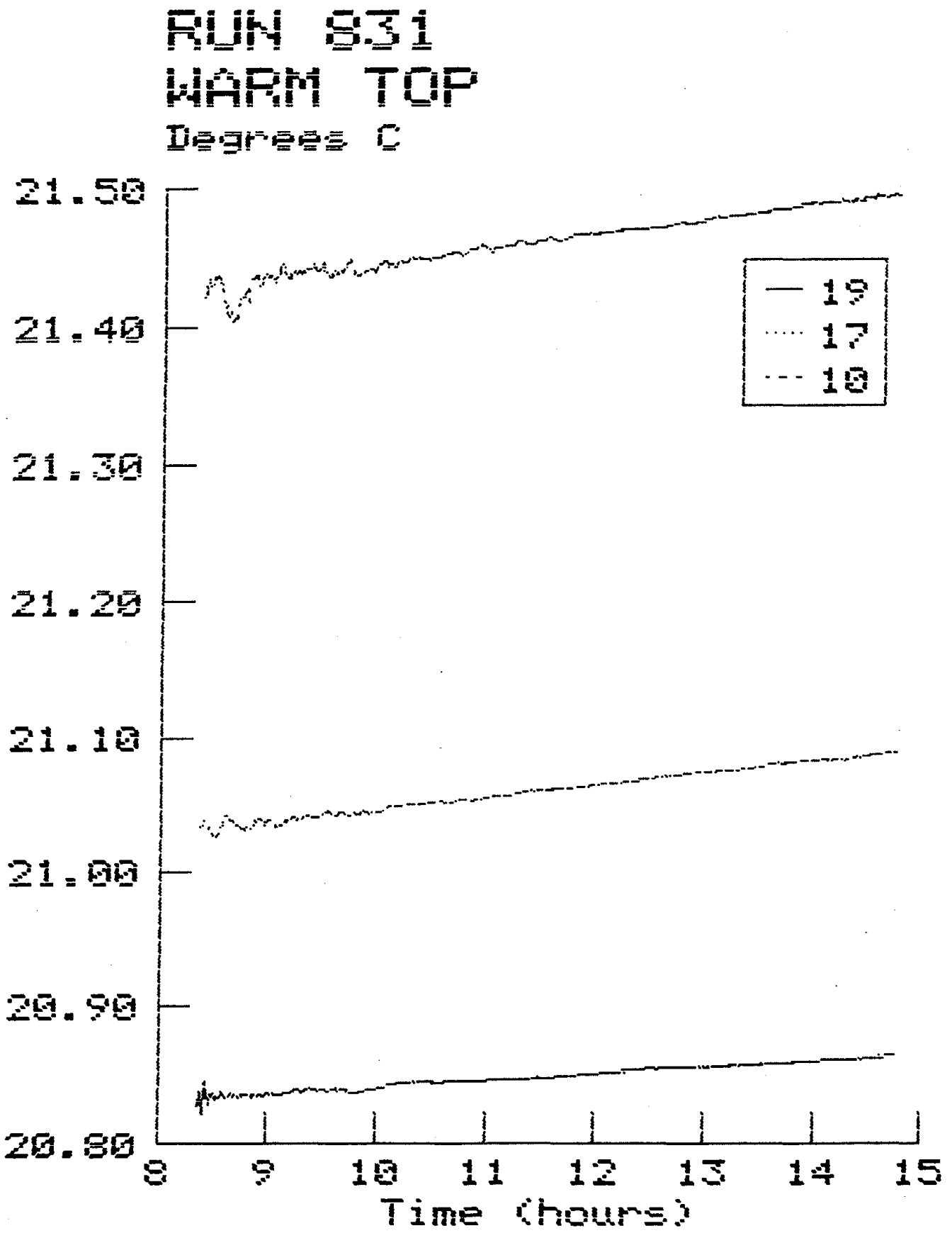
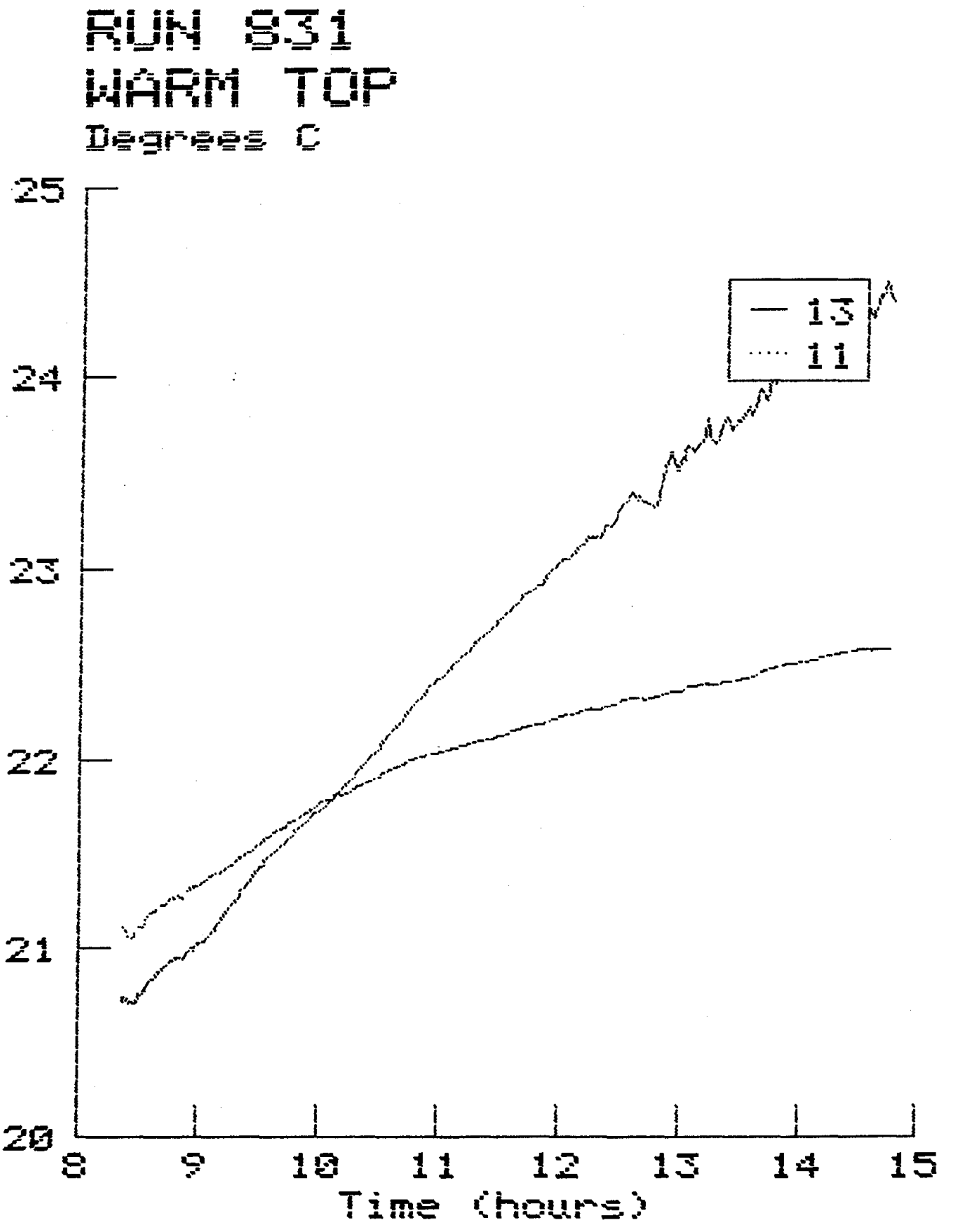
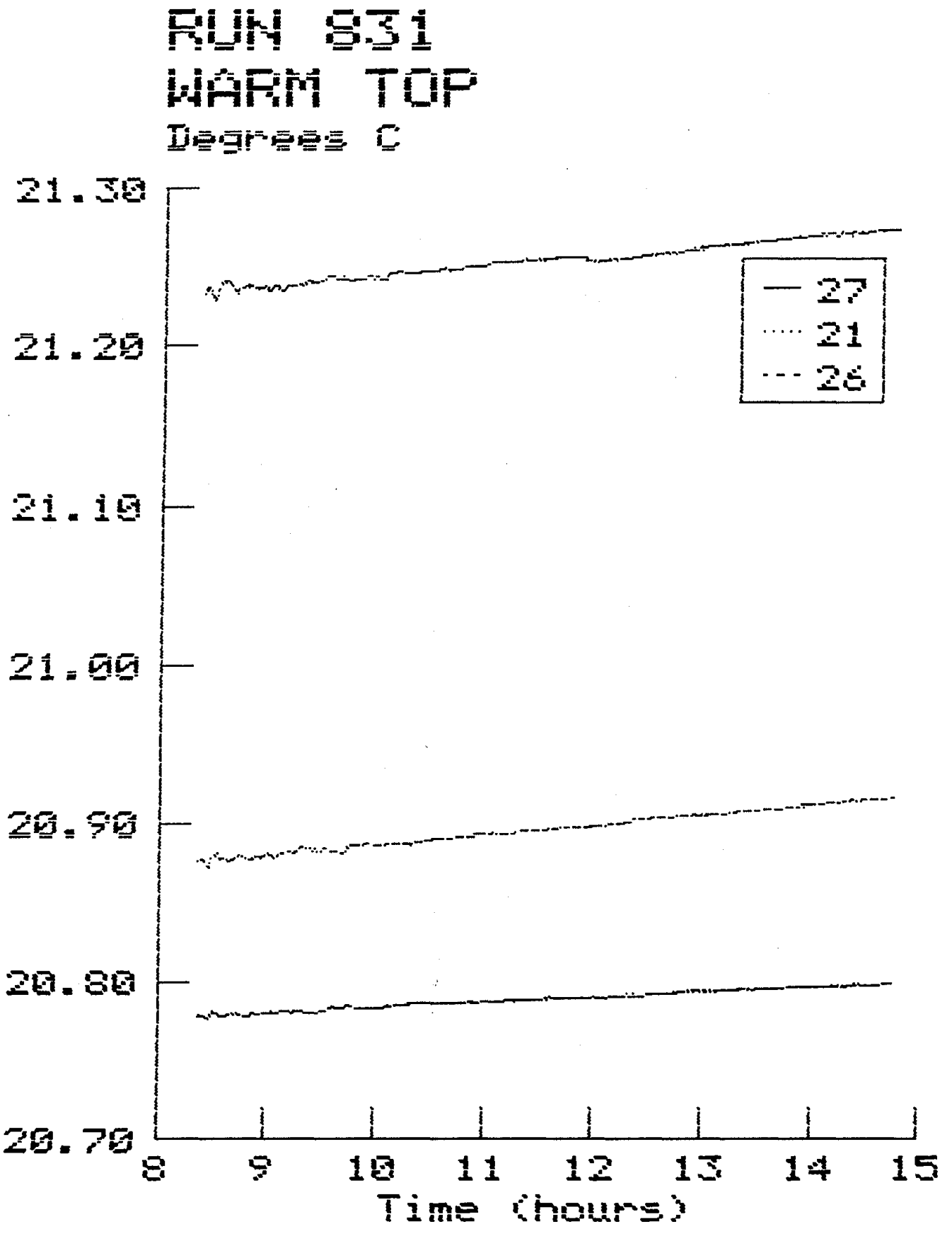
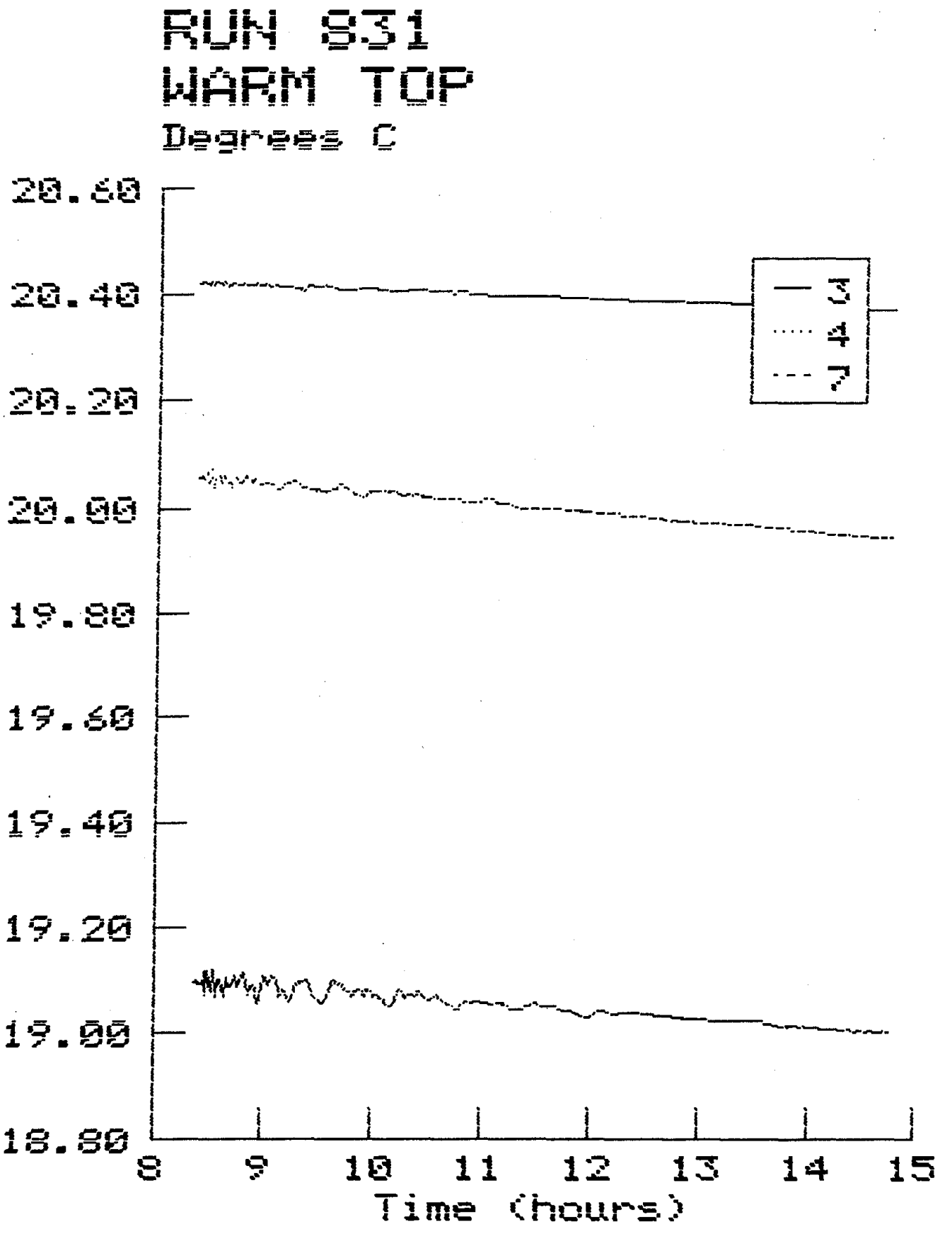
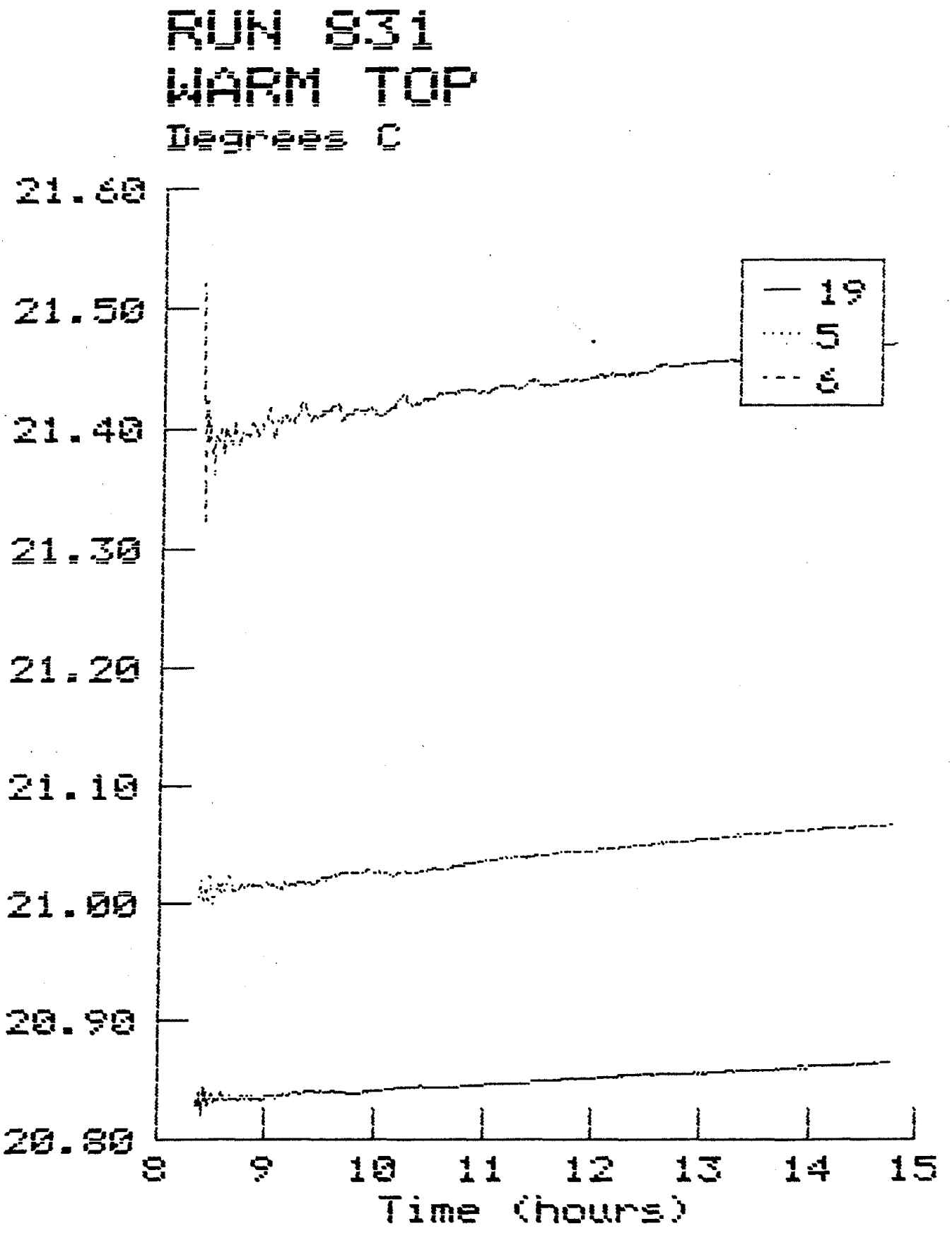
20.70
20.65
20.60
20.55
24
14
16
8
9
10
11
12
13
14
15
Time (hours)

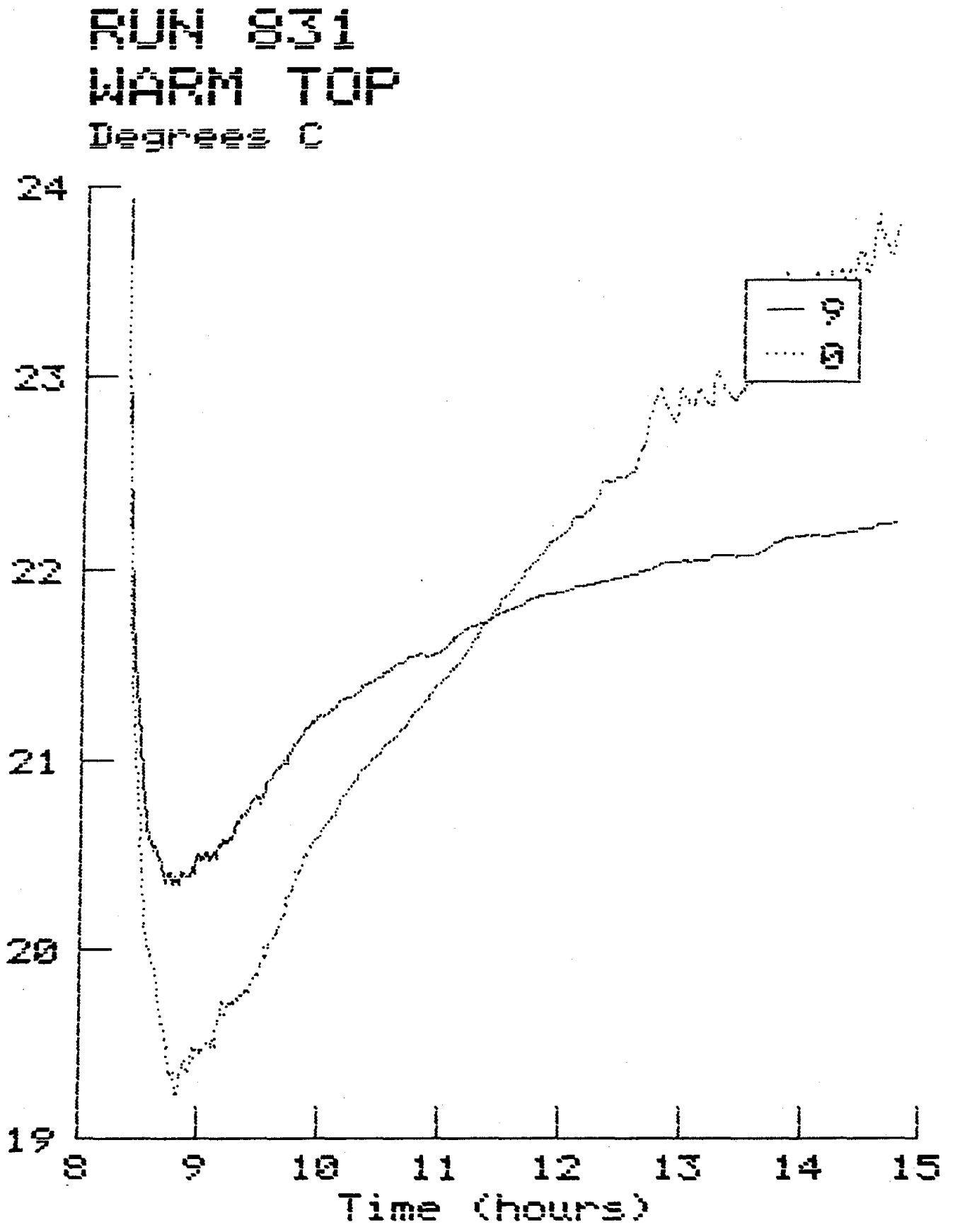

RUN 831
WARM TOP
Degrees C
21.50
21.40
21.30
21.20
21.10
21.00
20.90
20.80
19
17
10
8
9
10
11
12
13
14
15
Time (hours)


RUN 931
WARM TOP
Degrees C
25
24
23
22
21
20
13
11
8
9
10
11
12
13
14
15
Time (hours)

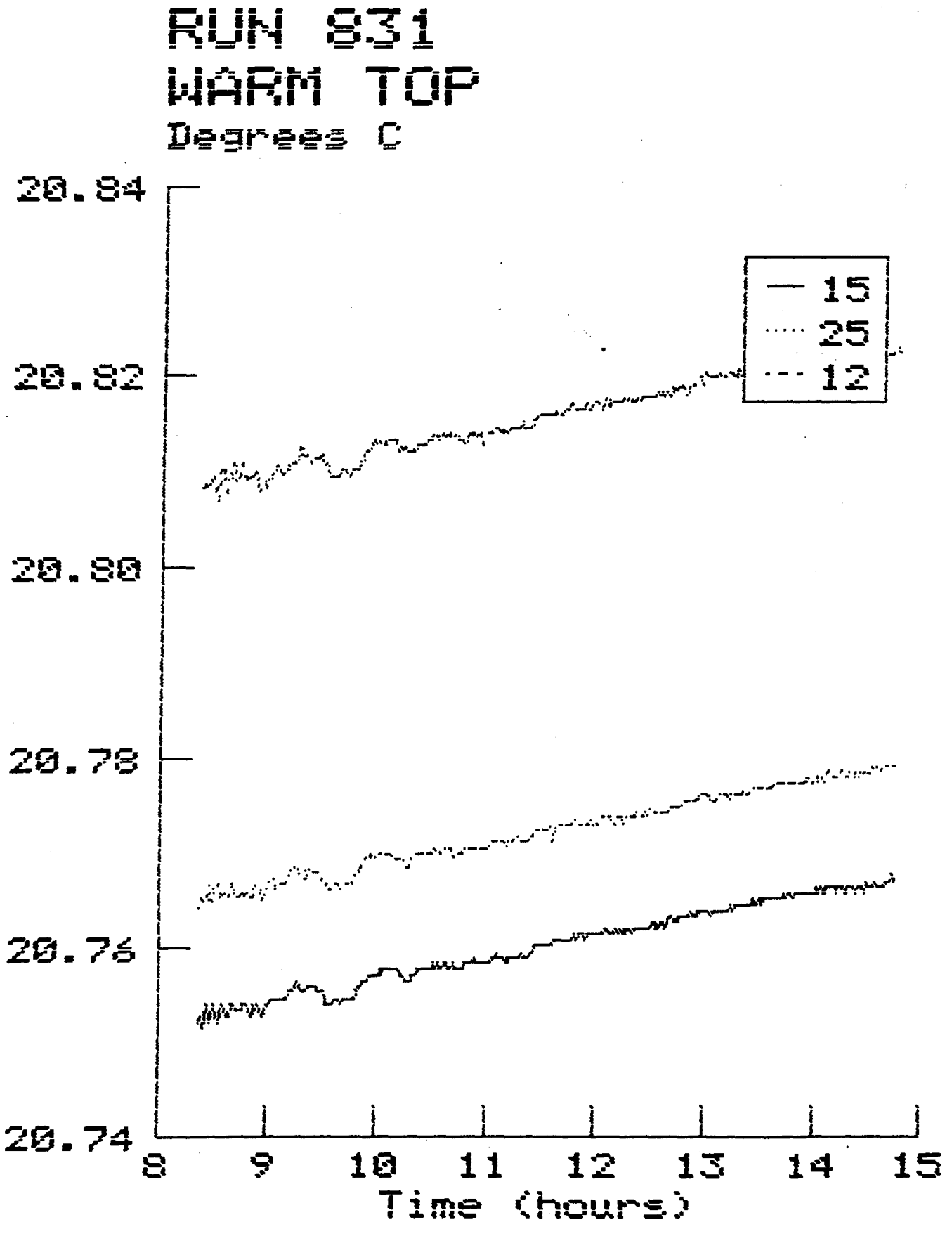

RUN 831
WARM TOP
Degrees C
21.30
21.20
21.10
21.00
20.90
20.80
20.70
27
21
26
8
9
10
11
12
13
14
15
Time (hours)


RUN 931
WARM TOP
Degrees C
20.60
20.40
20.20
20.00
19.80
19.60
19.40
19.20
19.00
18.80
8
9
10
11
12
13
14
15
Time (hours)
3
4
7


RUN 831
WARM TOP
Degrees C
21.60
21.50
21.40
21.30
21.20
21.10
21.00
20.90
20.80
8
9
10
11
12
13
14
15
Time (hours)
19
5
6


RUN 831
WARM TOP
Degrees C
24
23
22
21
20
19
8
9
10
11
12
13
14
15
Time (hours)
9
0

162


RUN 931
WARM TOP
Degrees C
20.84
20.82
20.80
20.78
20.76
20.74
15
25
12
8
9
10
11
12
13
14
15
Time (hours)

TECHNICAL REPORT DATA
(Please read Instructions on the reverse before complet

1. REPORT NO. EPA/600/2-91/044a	2.	3. PB92-114966
4. TITLE AND SUBTITLE Volumetric Leak Detection in Large Underground Storage Tanks Volume I		5. REPORT DATE August 1991
		6. PERFORMING ORGANIZATION CODE
7. AUTHOR(S) James W. Starr, Richard F. Wise, Joseph W. Maresca, Jr. Vista Research, Mountain View, CA 94042		8. PERFORMING ORGANIZATION REPORT N
9. PERFORMING ORGANIZATION NAME AND ADDRESS CDM Federal Programs Corporation 13135 Lee Jackson Memorial Highway - Suite 200 Fairfax, Virginia 22033		10. PROGRAM ELEMENT NO. CBRD1A
		11. CONTRACT/GRANT NO. 68-03-3409
12. SPONSORING AGENCY NAME AND ADDRESS Risk Reduction Engineering Laboratory--Cin., OH Office of Research and Development US Environmental Protection Agency Cincinnati, Ohio 45268		13. TYPE OF REPORT AND PERIOD COVERE Project Report
		14. SPONSORING AGENCY CODE EPA 600/14

15. SUPPLEMENTARY NOTES

Project Officer: Robert W. Hillger (FTS) 340-6639 Comm: (908) 321-6603

16. ABSTRACT

A set of experiments was conducted to determine whether volumetric leak detection system presently used to test underground storage tanks (USTs) up to 38,000 L (10,000 gal) in capacity could meet EPA's regulatory standards for tank tightness and automatic tank gauging systems when used to test tanks up to 190,000 L (50,000 gal) in capacity. The experiments, conducted on two partially filled 190,000-L (50,000-gal) USTs at Griffiss Air Force Base in upstate New York during late August 1990, showed that a system's performance in large tanks depends primarily on the accuracy of the temperature compensation, which is inversely proportional to the volume of product in the tank. Errors in temperature compensation that were negligible in tests in small tanks were important in large tanks. The experiments suggest that volumetric systems now capable of meeting regulatory standards when used to test 30,000- to 38,000-L (8,000- to 10,000-gal) tanks will also meet these standards when used to test 190,000-L (50,000-gal) tanks if (1) the duration of the test is increased from 1 or 2 to 4 h or more to ensure that the vertical gradients are accurately measured and to reduce the ambient and instrumentation noise, (2) the number of temperature sensors is increased from 5 to 10 or more so that the accuracy of estimating the average thermally induced volume change in the layer of product surrounding each sensor increases, (3) the waiting period after any addition or removal of product is increased from 6 h to 24 h or longer so that the horizontal and vertical temperature gradients dissipate, (4) the average rate of change of temperature in any one layer or in the tank as a whole is small enough to allow accurate temperature compensation, and (5) an accurate experimental estimate of the constants necessary for converting level and temperature changes to volume is made. The experiments further suggest that a multiple-test strategy is also required.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
	Underground storage tanks, Large USTs, Leak detection, Petroleum, Volumetric Precision testing, Internal tank tests	

18. DISTRIBUTION STATEMENT Release to Public	19. SECURITY CLASS (This Report) Unclassified	21. NO. OF PAGES 86
	20. SECURITY CLASS (This page) Unclassified	22. PRICE

EPA Form 2220-1 (9-73)