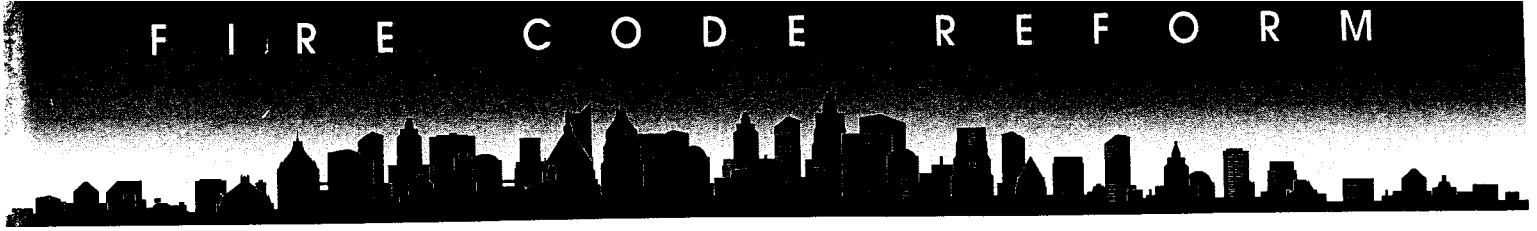

Technical Report
FCRC-TR 97-06

Simulated Shopping Centre Fire Tests

FCRC Project 6
Fire Safety Systems fur
Low-Rise, Sprinklered Shopping Centres

Fire Code Reform Research Program
March 1997

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Background

The Fire Code Reform Research Program is funded by voluntary contributions from regulatory authorities, research organisations and industry participants.

Project 6 of the Program involved investigation into factors affecting fire-safety in low-rise, sprinklered shopping centres. As part of this work a series of eleven experimental tests were undertaken to investigate the effects of fire in different areas and shops within of a centre.

This Report, which presents results of the tests was assembled by Dr Ian Bennetts of BHP Research, Melbourne Laboratories whilst located at 245 Wellington Road, Mulgrave, Victoria 3170. In particular the investigation examined the rate at which smoke developed in the different fire scenarios and measured the values and durations of the maximum air temperature attained.

Acknowledgements

Mr Max Croxford, Commissioner of the Building Control Commission (BCC), Victoria was primarily responsible for the initiation of FCRC's Project 6 relating to "Fire Safety Systems in Low-Rise, Sprinklered Shopping Centres". BCC, Victoria was additionally a significant financial contributor to the execution of this work. BHP Steel Division and BHP Research were additional contributors of substantial funding to Project 6. Generous contributions were also received from other donors.

The Board and management of Fire Code Reform Centre Limited acknowledge with sincere thanks receipt of all these financial contributions. The company also acknowledges the kind permission of BHP Research to the re-production and publishing of this document.

Comments

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FIRE CODE REFORM CENTRE
PROJECT 6

BHPR/SM/R/G/062

SIMULATED SHOPPING CENTRE FIRE TESTS

by
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Refereed by: K Watson

March 1997

Circulation: Unrestricted

The Broken Hill Proprietary Company Limited
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The work described in this report was undertaken as part of Project 6 “Fire Safety Systems for Sprinklered Low-Rise Shopping Centres” and as part of Australia’s Fire Code Reform Research Program. This project was aimed at studying the factors affecting fire safety in shopping centres with the purpose of developing cost-effective regulations and designs. As part of this project, eleven full-scale fire tests were conducted to investigate the effects of fires in various shops within a shopping centre especially the rate at which smoke is produced and the value and duration of maximum air temperatures.

Measurements taken in the tests included temperatures, radiation and the transmission of light at various positions. The time of sprinkler activation was also recorded. Although the tests were conducted in a large burn-hall the data can be used to determine the impact of these fires in a shopping mall or store.

Two tests were recorded to simulate a fire in a toy-shop and two to simulate a fire in a storage area of a specialty shoe shop. Both sprinklered and unsprinklered situations were considered. The non-sprinklered tests resulted in very intense fires that produced large quantities of dense black smoke, especially following full involvement of the combustibles. A series of five sprinklered fire tests were then conducted to look at smoke generated during sprinklered fires in clothing stores. Finally, two sprinklered tests were conducted to investigate the smoke generated in sprinklered book-shop/newsagent fires.

It was found that, up to the point of sprinkler activation, the clothing store fires grew much more rapidly than in the case of the book-shop fires. The smoke generated in both these situations was very much less than for the toys and shoe storage sprinklered tests, where the combustibles were stored in shelves and the water from the sprinklres was not able to be directed to the seat of the tires.

CONTENTS

1 INTRODUCTION

The construction of large shopping centres is an area of commercial development which is being pursued very actively in Australia at present. There is a belief that the current regulatory requirements for fire protection of these buildings may be unnecessarily onerous, imposing financial burdens on developers and owners which may not relate to the risk to life from fire in these buildings. The remit of Fire Code Reform Centre Project 6 is to review the requirements in the Building Code of Australia (BCA) which apply to low-rise sprinklered shopping centres, and to propose a more rationally based set of requirements which will improve the cost effectiveness of these buildings both in terms of construction costs and maintenance in operation without decreasing their fire safety.

In the design of shopping centres for fire safety, it is inevitable that questions will be raised, such as: what design fires are likely or appropriate and what are the characteristics of these fires? These questions are of fundamental importance. In order to answer these and other questions, and because of the paucity of relevant test data, it was considered essential to conduct a series of fire tests which would provide data to enable a more realistic assessment of the effects of various fires in shopping centre buildings.

This report presents the results of the eleven fire tests conducted as part of this project. The test program was cooperative effort between BHP Research, Building Control Commission of Victoria, Scientific Services Laboratory and Victoria University of Technology.

In addition to this report, a video film entitled “Retail Fire Tests” is available and gives a complete description of each of the tests.

Eleven full-scaled fire tests were conducted to investigate the effects of fires in specialty and major shops in a shopping centre. Two tests were conducted to simulate a fire in a toy shop and two to simulate fire in the storage area of a specialty shoe shop. These situations were chosen because they were considered to be representative of worst case scenarios as they involved substantially non-cellulosic material stored in a shelved arrangement. The presence of shelving means that the fire is likely to grow more rapidly and that it may interfere with the application of water to the seat of the fire, in the case of the sprinklered situations. Both sprinklered and non-sprinklered situations were considered. Again the non-sprinklered tests were considered to be representative of the fastest growing fires due to the type and arrangement of combustibles.

A series of five sprinklered fire tests was also conducted to investigate the smoke generated during sprinklered fires in clothing stores. This was considered important as clothing and the like constitute a high proportion of the floor area of a modem shopping centre [1]. Finally, two sprinklered tests were conducted to investigate the smoke generated in a sprinklered book shop fire. These tests were conducted to study the amount of smoke developed in situations with predominantly cellulosic combustibles.

The test program is summarised in Table 1 below.

TABLE 1 SUMMARY OF TEST PROGRAM

Test	*Test Number*	*Fire load*	*Sprinklered*	*Date*	*Time Start* *
1	BFT723	toys	yes	6 / 11 / 96	6:52:22 pm
2	BFT724	toys	no	19 / 11 / 96	6:37:50 pm
3	BFT725	shoes	yes	12 / 12 /96	7:28:35 pm
4	BFT726	shoes	no	22 I 1 /97	7:11:35 pm
5	BFT727	clothing	yes	24 /2 /97	1:58:25 pm
6	BFT728	clothing	yes	25 /2 /97	2:21:22 pm
7	BFT729	clothing	yes	26 / 2 / 97	2:26:20 pm
8	BF1730	clothing	yes	27 / 2 97	2:41:44 pm
9	BFT731	clothing	yes	28 / 2 / 97	2:47:22 pm
10	BFT732	books	yes	6 / 3 / 97	2:24:58 pm
11	BFT733	books	yes	7 / 3 97	2:19:50 pm

* Time at fire ignition obtained from video records

In all sprinklered tests, the spacing of sprinkler heads satisfied the spacing and area requirements for Ordinary Hazard sprinklers.

3

3.1 TEST STRUCTURE

The tests were conducted in the "Burn Hall" at the Scientific Services Laboratories, Port Melbourne (Figure 1). This building was chosen for its size with the main part of the building, in which the test structure was housed, having a volume of 12,500 m^3. There is no designed venting in the building except for small gaps at roof junctions and around roller doors at either end. These gaps were estimated to be equivalent to a 250 mm wide opening along the full length of the building (55.2 m). For the purpose of these tests, a steel test structure was constructed in the centre of the building. Figure 2 shows the general layout of the building and the test structure.

The test structure consisted of two large universal primary beams supported on four columns, with four secondary beams spanning between the primary members. Lightweight rectangular hollow section battens spanned between the secondary beams. A steel mesh was placed on top of the battens, and in turn, these supported 12 mm cement sheeting which was laid directly over the steel mesh. After each test, depending on the extent of damage, additional layers of cement sheeting, mesh, plasterboard, and steel sheet were added as required to ensure integrity of the floor. At the time at which Test 4 was conducted, the weight of test floor was considerable being approximately 6 tonne.

The set up of the test structure for each test was as follows:

- *Tests 1 and 2 ("toy tests")*

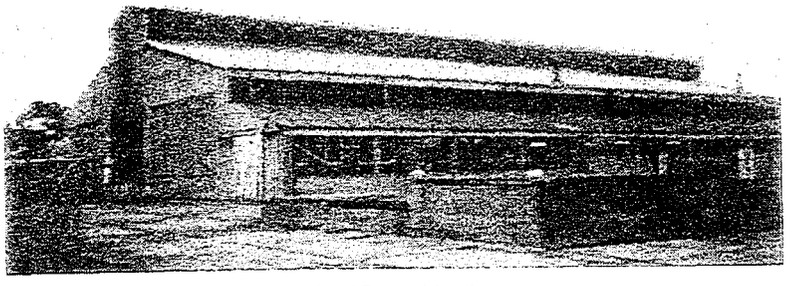
  The test set up area was positioned centrally in the test structure as shown in Figure 3. This was done to simulate a part of toy display area within a large store. No walls or ceiling were erected around the test area.

- *Tests 3 and 4 ("shoe tests")*

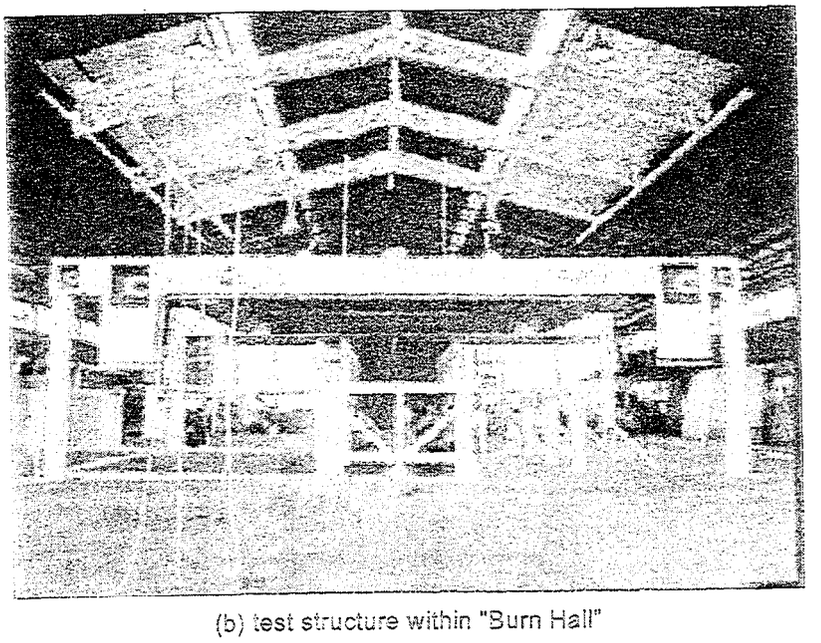
  Steel walls were placed around the test set up to simulate a typical shoe storage area, such at that which may be located at the back of a specialty or a major store. The walls were 3 m high on three sides and full height on the south side to represent an external wall (Figure 4). A 2 m ⊠ 2 m opening was positioned on the north wall to represent a doorway leading into the storage area.

- *Tests 5 to 11 ("clothing" and "book tests")*

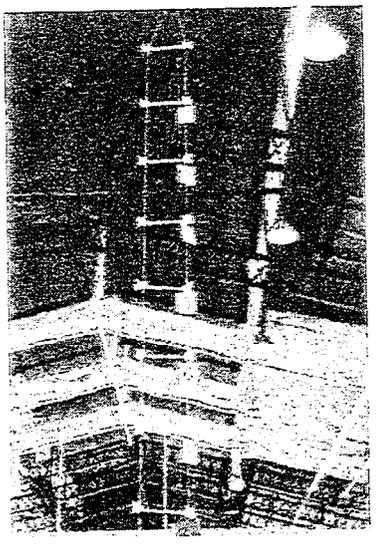
  3 m high steel stud walls were placed around the test set up area and a suspended plasterboard ceiling was erected over the area to simulate a small specialty shop (Figure 5). A 2 m wide x 2.4 m high opening was positioned on the north wall to represent a doorway.

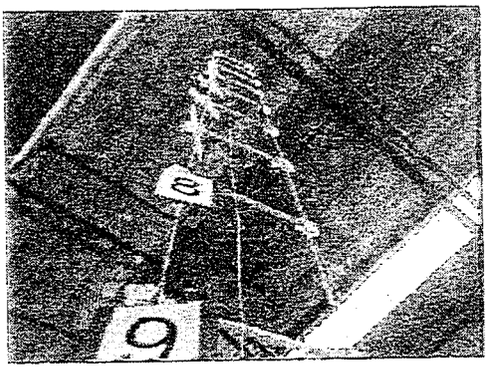


(a) "Burn Hall"



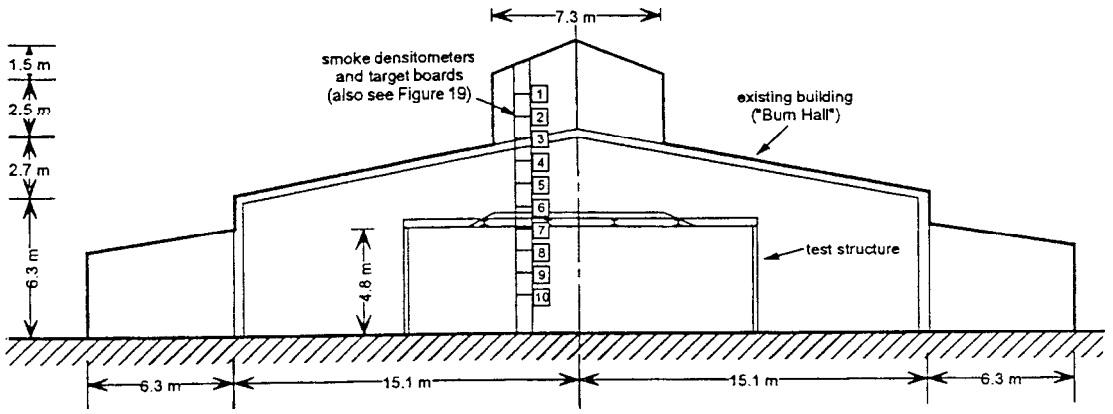
(b) test structure within "Burn Hall"





(c) string of smoke densitometers and target boards

FIGURE 1 TEST SET-UP



ELEVATION

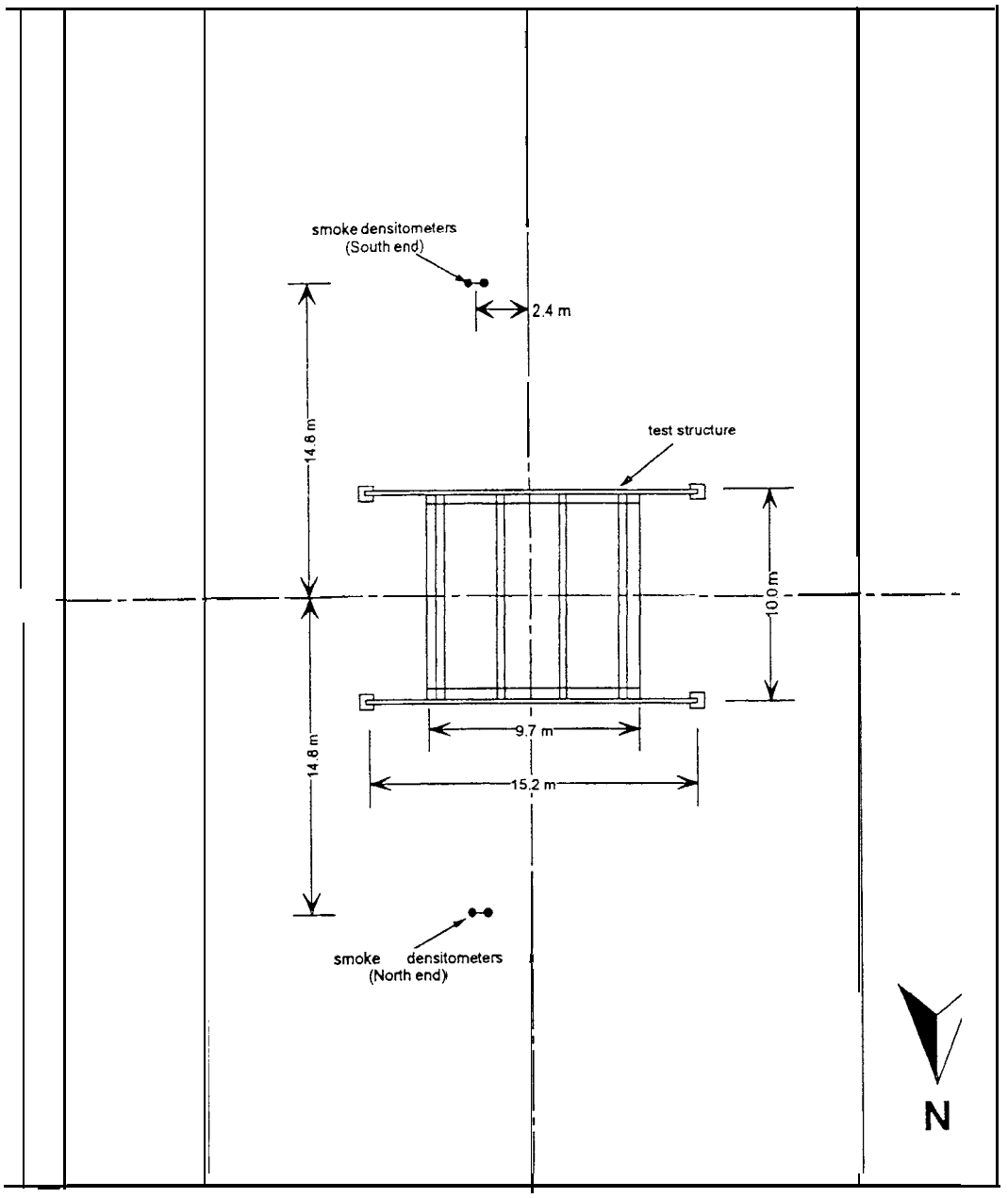


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FIGURE 2 "BURN HALL" AND TEST STUCTURE

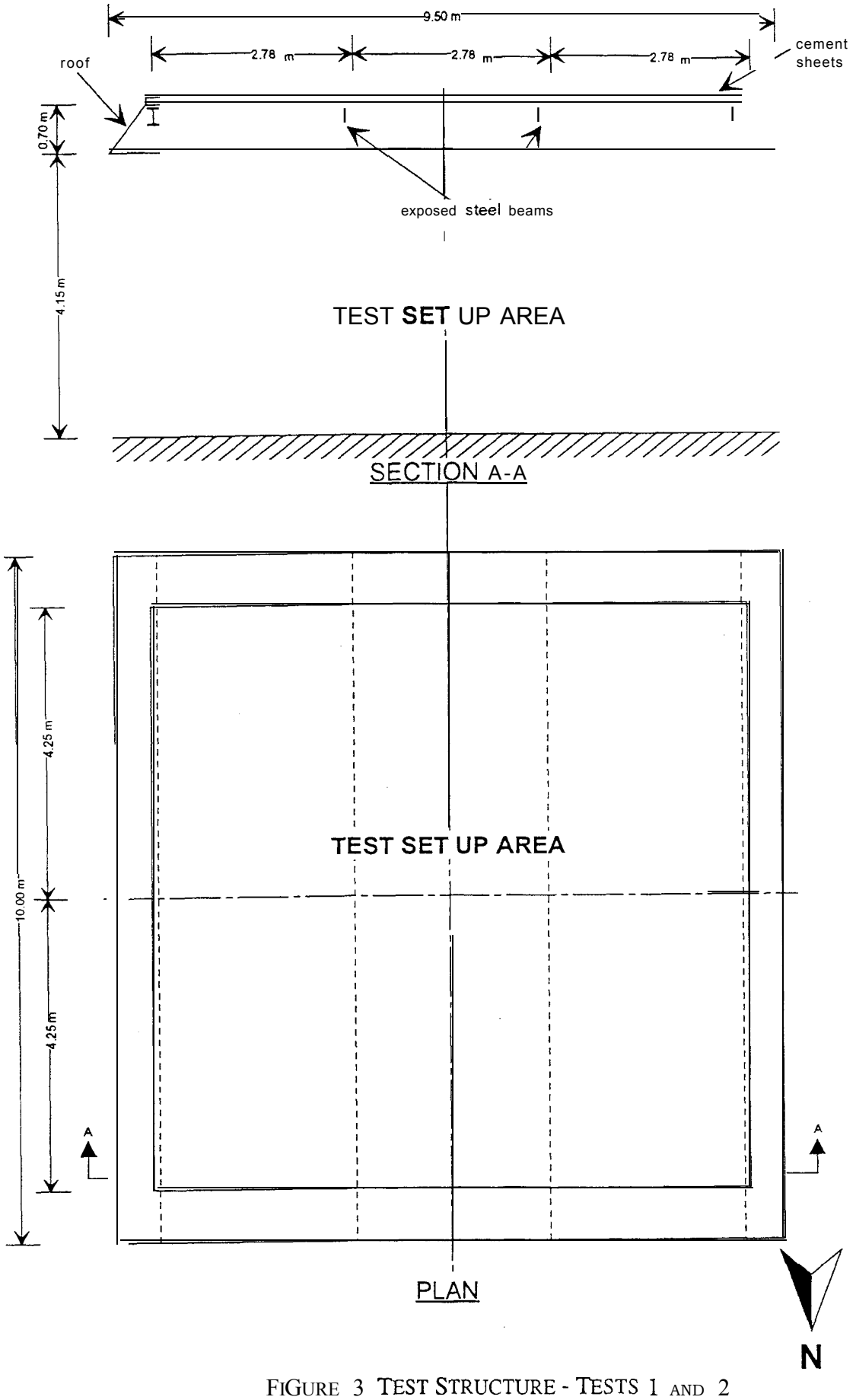


FIGURE 3 TEST STRUCTURE - TESTS 1 AND 2

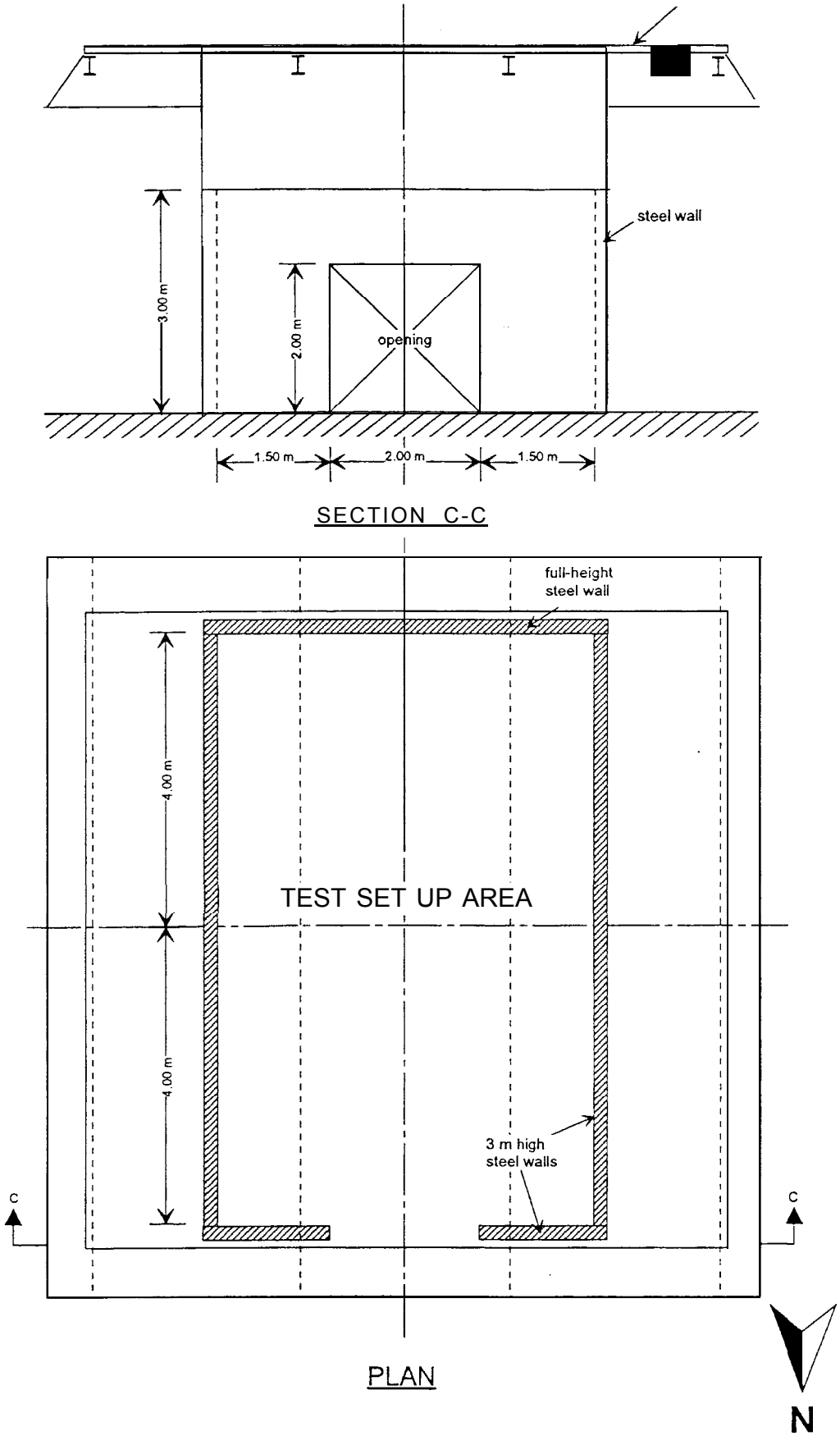
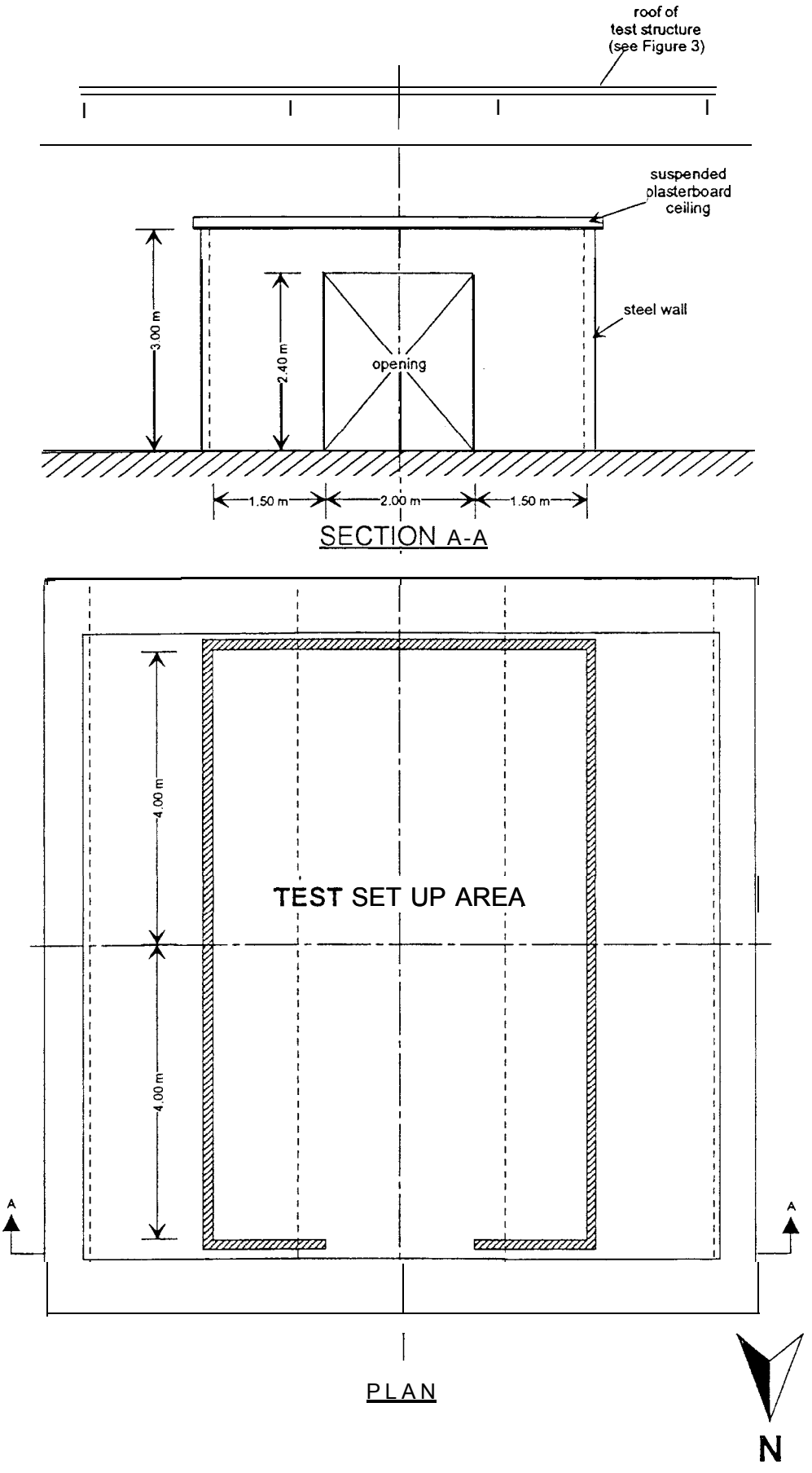


FIGURE 4 TEST STRUCTURE- TESTS 3 AND 4



F IGURE 5 TEST STRUCTURE - TESTS 5 TO 11

3.2 SPRINKLERS

In Tests 1 and 3, four active sprinkler heads were installed under the roof of the test structure. The heads were of the normal response type and arranged so that they were placed in the most disadvantageous position with respect to the shelving so that the water spray would not directly impinge on the area of ignition and extinguish the fire at an early stage. This was done because such situations occur in shopping centre buildings and it was considered important to understand this "worst-case" scenario. Non-active (or "dummy") normal and fast response heads were also positioned within the test structure (Figure 6)—dummy head numbers D1, D4, D5 and D8 were normal response type, while the rest were fast response. These dummy heads were charged with compressed air and no water was supplied to the heads. A pressure switch was connected to each of the dummy heads to monitor their activation times during the tests. The use of "dummy heads" was considered to give valuable additional data on activation times.

In Tests 2 and 4, the sprinklers heads were similarly set up except that no water was supplied to the sprinkler heads-ie. the heads acted as dummy heads.

In Tests 5 to 11, a different sprinkler layout was used (Figure 7). Two active sprinkler heads and 28 dummy sprinkler heads were installed at the ceiling level in each test. The type of sprinkler heads used are summarised in Table 2 and included normal response heads (Tests 5 and 10), fast response (Test 6), painted normal response (Test 7), flush mounted normal response (Tests S), and painted flush plates (Tests 9 and 11). These various heads were chosen because they represent situations which occur commonly in buildings.

TABLE 2. TYPE OF SPRINKLER HEADS USED—TESTS 5 TO 11

sprinkler head no.	*Test 5*	*Test 6*	*Test 7*	*Test 8*	*Test 9*	*Test 10*	*Test 11*
A1,2	NR	FR	NRP	FM	FMP	NR	FMP
D1,8,9,18,19,28	FR	*N-R*	FR	FR	FR	FR	FR
D2,7	NRP	NRP	NR	NRP	NRP	NRP	NRP
D3,6	FM	*FM*	*FM*	*NR*	*NR*	FM	FM
D4,5	FMP	FMP	FMP	FMP	FM	FMP	NR
D10,17,20,27	*N R P N R P N R N R N R N R P N R P*						
D11,16,21,26	*NR*	*F R N R P N R P N R P N R*					*NR*
D12,15,22,25	*FM*	*FM*	*FM*	FM	*FM*	FM	FM
D13,14,23,24	FMP	FMP	FMP	FMP	FMP	FMP	FMP

FM = FMP =
NR = NRP =
FR

Water to the sprinkler system was supplied by the mains water supply to the building and was considered to be representative of a minimum Ordinary Hazard III delivery system. The supply had a static pressure of around 1150 kPa and an operating pressure near the sprinkler valve of about 650 kPa with 1 head operating. The water flow rate at each head with 1, 2, 3 and 4 sprinkler heads open was measured and is summarised in the table below.

number of heads open	*1*	2	3	4
waterflow rate (L/min)	187.5	133.3	104.1	90.9

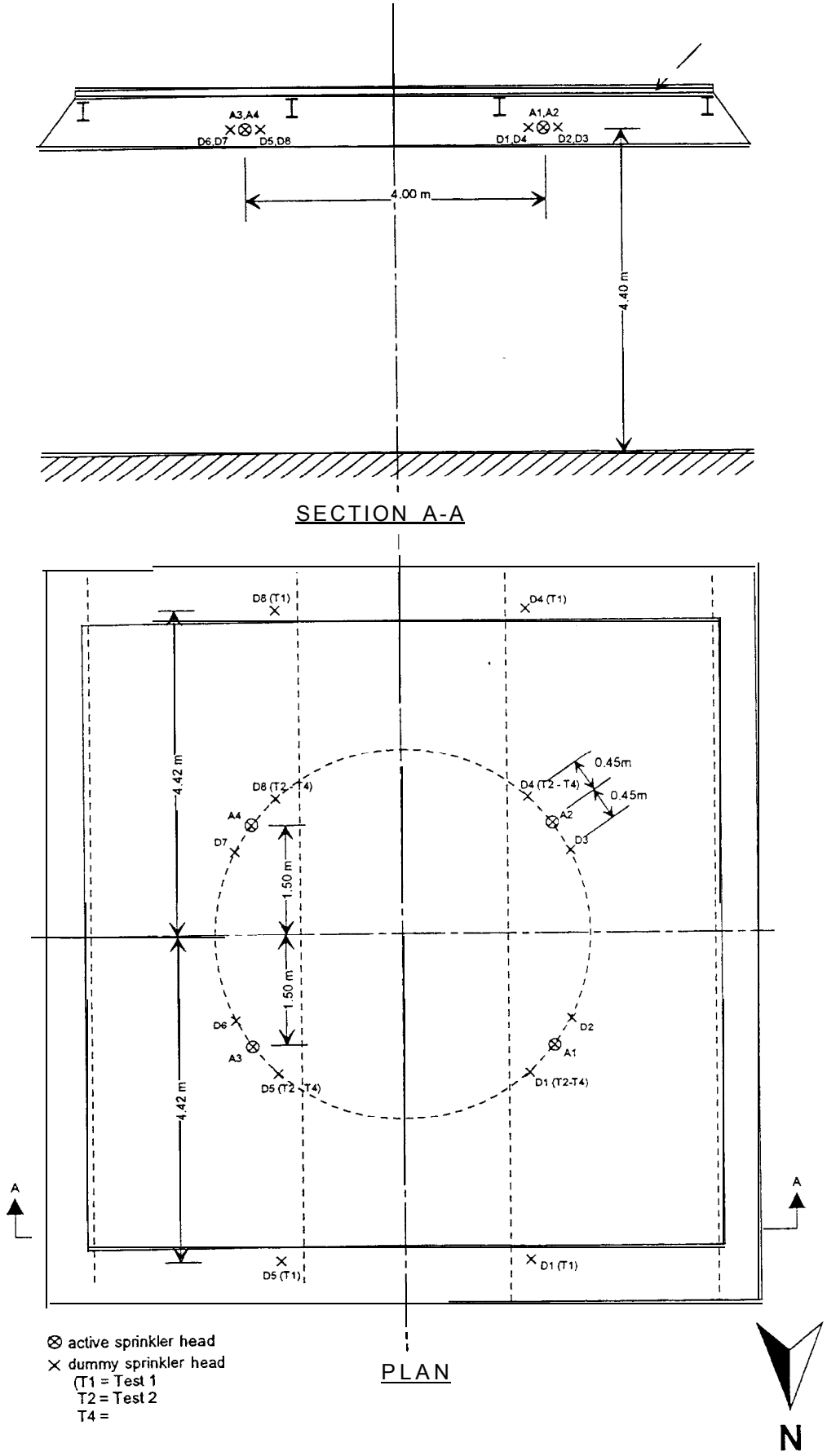
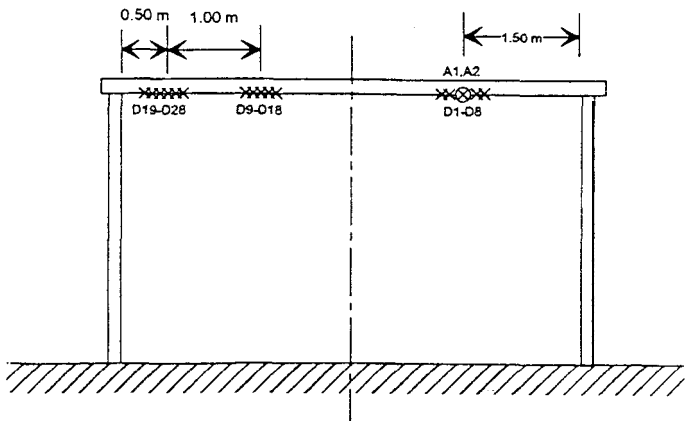


FIGURE 6 SPRINKLER LAYOUT - TESTS 1 TO 4



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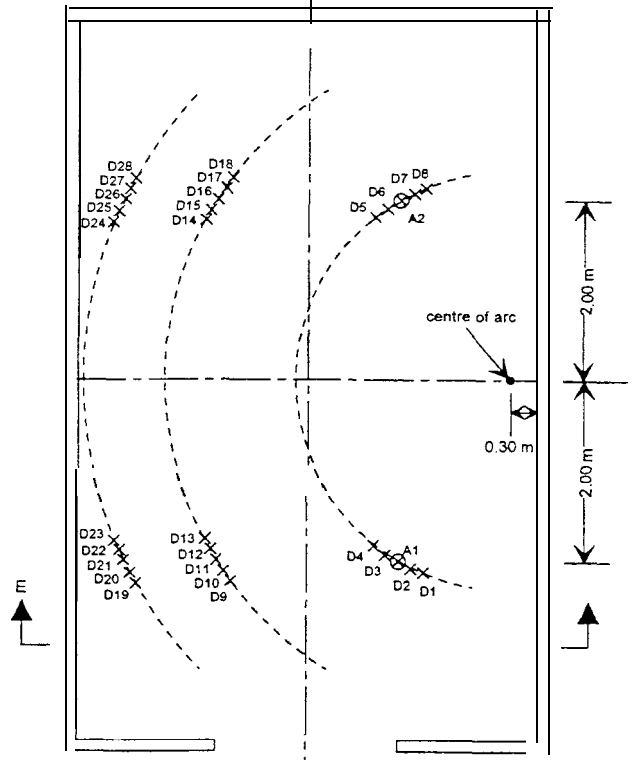

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⊗ active sprinkler head
× dummy sprinkler head

N

FIGURE 7 SPRINKLER LAYOUT - TESTS 5 TO 11

3.3 FIRE LOAD

In Tests 1 and 2, a mixture of hard and soft toys were displayed on a double-sided steel shelf and on a single-sided shelf positioned to give an aisle of 2.5 m wide (Figure 8). On the top of the shelves, boxes of toys were stacked in the fashion often seen in such shops. The toys and the packaging were weighed before setting up and the masses of combustibles are summarised in Table 3.

TABLE 3: MASS OF COMBUSTIBLES IN TESTS 1 AND 2—TOY TESTS

shelf	mass of combustibles (kg)					
	Test 1			Test 2		
	plastics	paper	subtotal	plastics	paper	subtotal
single unit	237.10	84.16	321.26	237.10	84.16	321.26
double unit (east)	240.31	106.51	346.82	237.59	122.11	349.70
double unit (west)	248.77	104.48	353.25	265.45	122.08	387.53
subtotal	726.18	295.15	1021.33	740.14	318.35	1058.49
timber pegboard			208.07			208.07
total combustibles			1229.40			1266.56

In Tests 3 and 4, shoes were packed in cardboard boxes and stacked on two double-sided steel shelves positioned to give an aisle of 1 m wide (Figure 9). On the top of the shelves, boxes of shoes were stacked in the fashion often seen in shoe storage areas. Empty shoe boxes were also stacked against the two walls parallel with the longer side of the shelves. These boxes were added to investigate fire spread to adjacent combustibles. The shoes and the boxes were weighed before setting up and the masses are summarised in Table 4.

TABLE 4 MASS OF COMBUSTIBLES 3 AND 4—SHOE TESTS

location	shoe type	mass of combustibles (kg)					
		Test 3			Test 4		
		paper	shoe	subtotal	paper	shoe	subtotal
East shelves	male	153.65	653.53	807.18	154.88	691.07	845.95
	female	153.65	363.82	517.47	154.88	337.28	492.16
West shelves	male	153.65	613.53	767.18	154.88	691.07	845.95
	female	153.65	352.81	506.46	154.88	337.28	492.16
empty boxes	—	27.98	—	27.98	27.98	—	27.98
total	—	642.58	1983.69	2626.27	647.50	2056.70	2704.20

In Tests 5 to 9, various types of clothing was hung on steel racks placed against the west wall and near the centre of the enclosure (Figure 10). The clothing was sorted into various types as shown in Table 5. Each type of clothing was weighed to estimate the unit mass. For each test, the clothing were not separately weighed but equal numbers of each type of clothing was used for all tests. The number and the estimated mass of clothing used are summarised in Table 5.

In Tests 10 and 11, books, magazines and newspapers were placed on the floor, on timber shelves placed against the west wall, and on a timber table and a steel magazine rack near the centre of the enclosure (Figure 11). The masses of paper and timber were weighed before setting up and are summarised in Table 6.

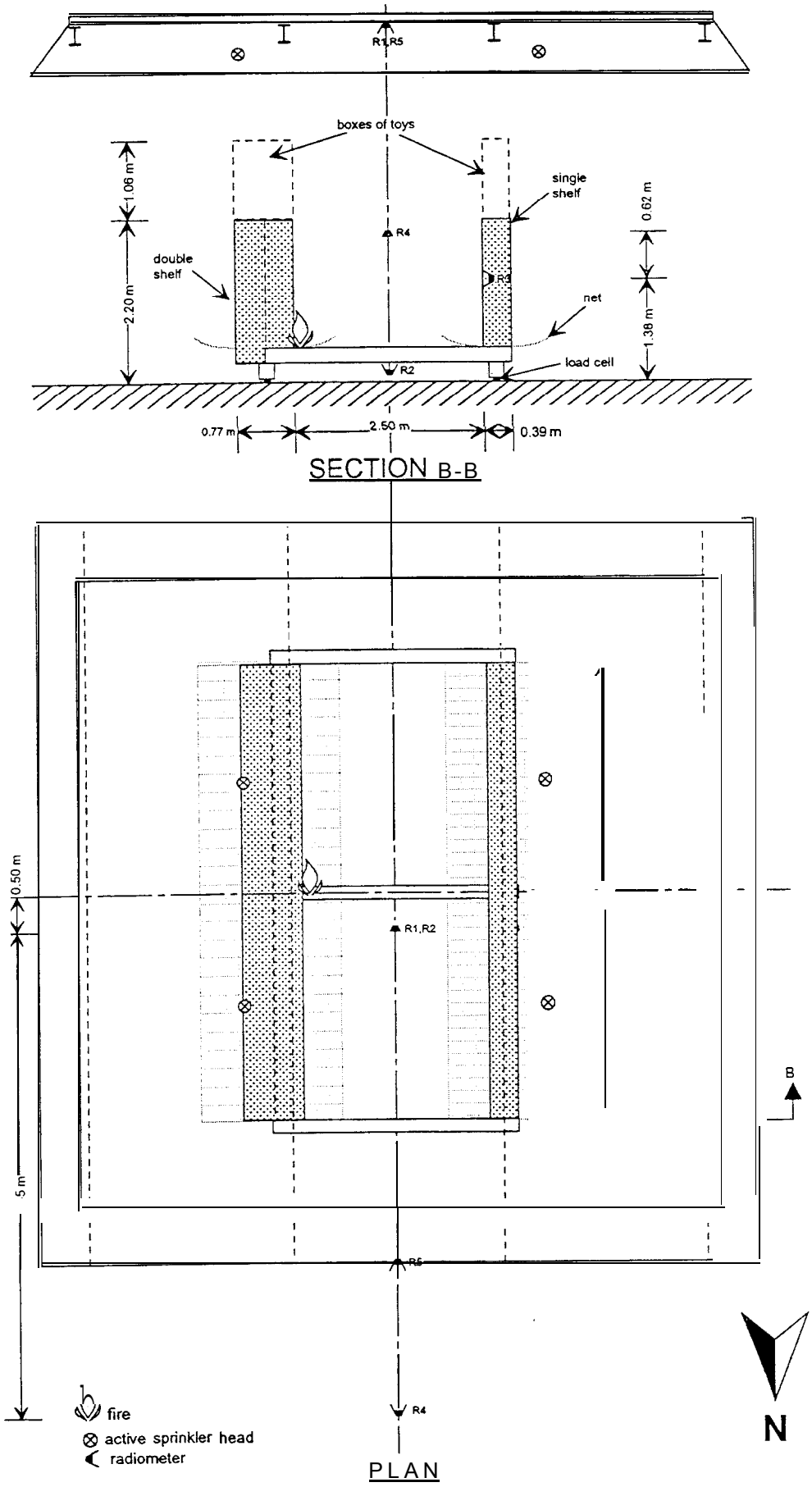


FIGURE 8 TEST SET UP (TOY STORE) - TESTS 1 AND 2

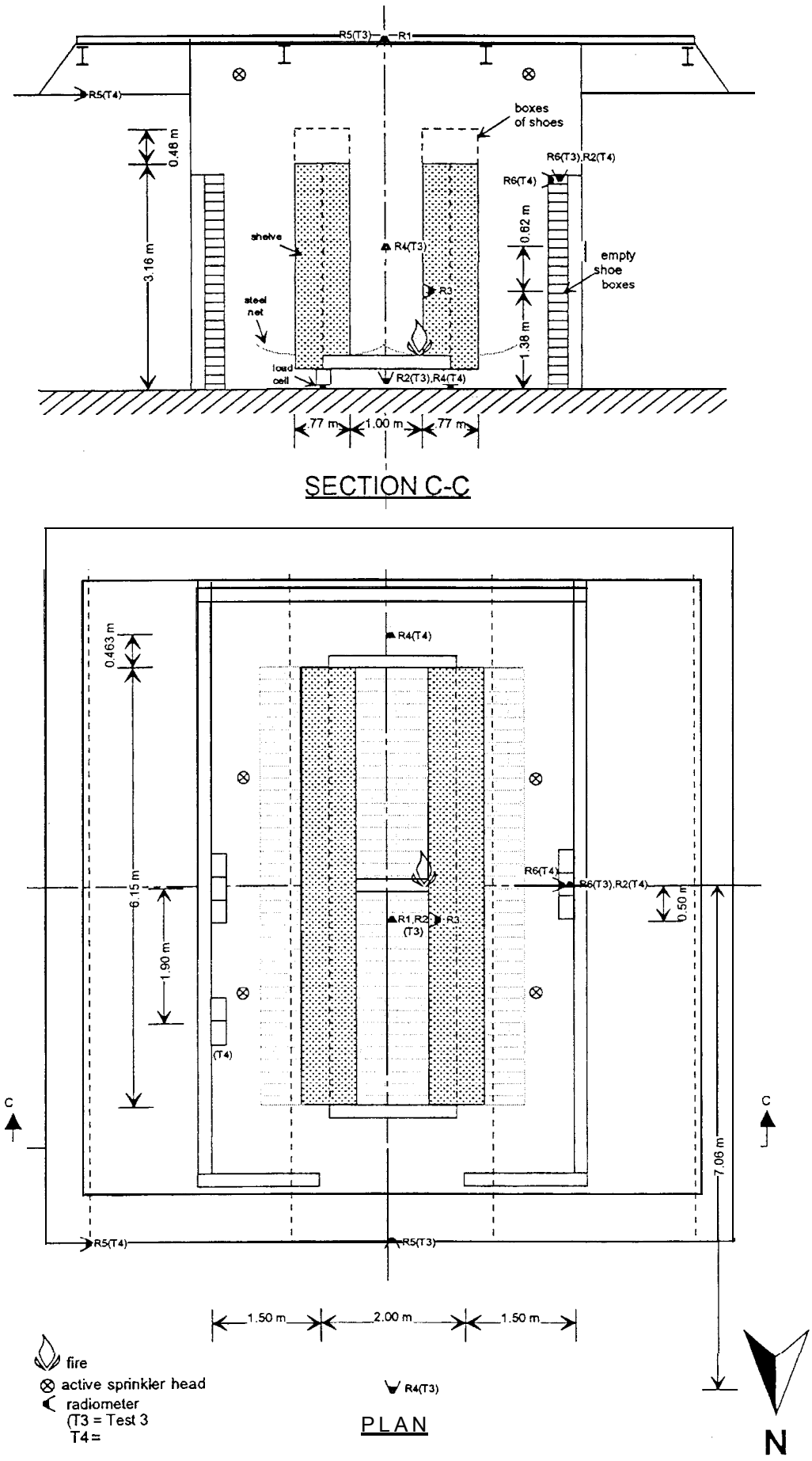


FIGURE 9 TEST SET UP (SHOE STORE) - TESTS 3 AND 4

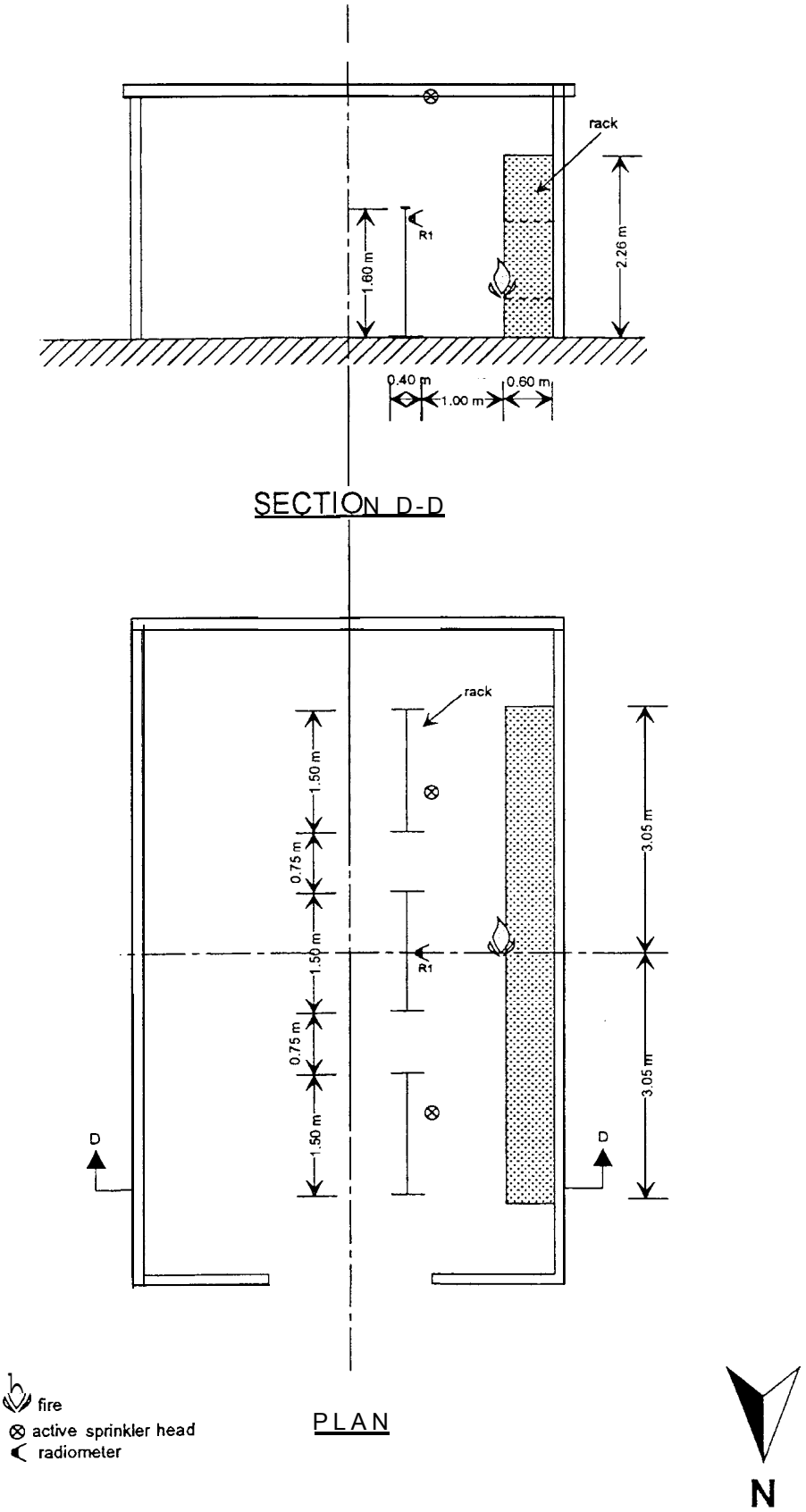


FIGURE 10 TEST SET UP (CLOTHING STORE) - TESTS 5 TO 9

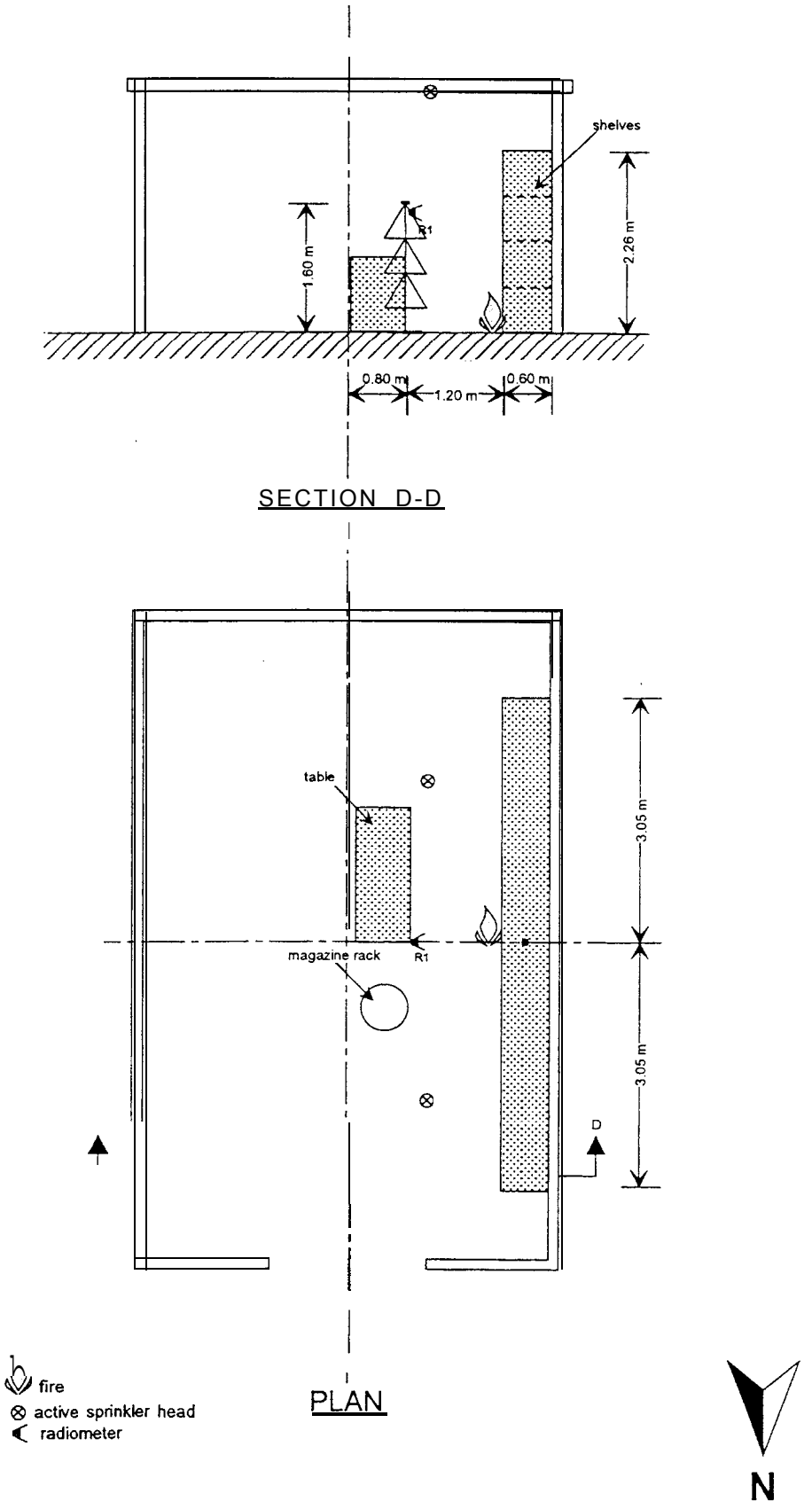


FIGURE 11 TEST SET UP (BOOK STORE) - TESTS 10 AND 11

TABLE 5 MASS OF COMBUSTIBLES IN TESTS 5 TO 9—CLOTHING TESTS

clothing type	quantity	average unit mass (kg)	total mass (kg)
slack	190	0.360	68.40
blouse	140	0.175	24.50
shirt	130	0.205	26.65
dress	127	0.356	45.21
skirt	90	0.302	27.18
jacket	64	0.494	31.60
suit	64	1.166	74.62
jumper	22	0.464	10.21
total	827	—	308.37

TABLE 6 MASS OF COMBUSTIBLES IN TESTS 10 AND 11—BOOK TESTS

mass of combustibles (kg)					
Test 10			Test 11		
paper	timber	total	paper	timber	total
755.22	209.91	965.13	947.32	139.16	1086.48

3.4 TEMPERATURE MEASUREMENT

In Tests 1 to 4, over one hundred thermocouples were used in measuring air and steel temperatures at various positions. Within the test structure, the air temperatures were measured primarily using three thermocouple trees positioned within the structure (Figures 12 and 13). The three thermocouple trees measuring air temperature were labelled AA, AB and AC. Trees AA and AB contained twelve thermocouples spaced 0.4 m apart; tree AC had six thermocouples that were spaced 0.8 m apart. Tree AA was placed at the centre of the structure, tree AB east of the centre and tree AC south of the centre. Other thermocouples measuring air temperatures were positioned at sprinkler, radiometer (Figures 14 and 15) and smoke densimeter locations (Figure 19).

The temperature of the secondary steel beams was measured with thermocouples located at ¼ positions as shown in Figure 16.

For Tests 5 to 11, air temperatures was measured at various heights close to the position of ignition, at radiometer locations, and sprinkler head positions (Figures 17 and 18), and at the smoke densimeter locations (Figure 19). For these tests the temperature of the steel beams was not measured.

All thermocouples used were type K.

3.5 RADIATION MEASUREMENT

Radiation measurements were taken in all of the tests. In Tests 1 and 2, five radiometers were positioned in various locations around the test structure. For Test 3, *seven* radiometers were used but one was found to be non-functional. In Test 4 only six radiometers were used. In Tests 5 to 11, only one radiometer was used and this was located directly adjacent to the position at which the fire was started. The positions of radiometers are given in Figures 14, 15, 17 and 18.

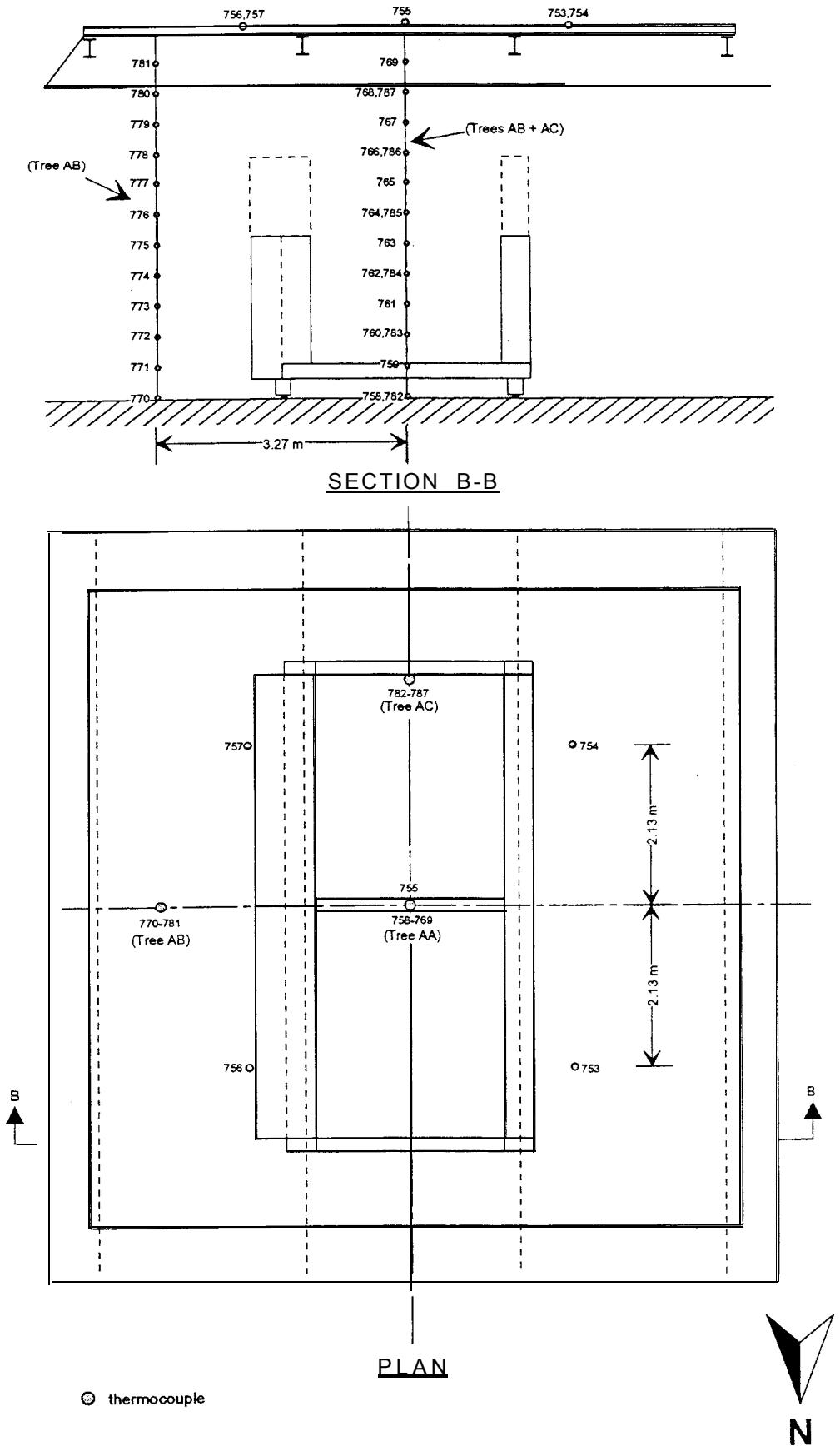


FIGURE 12 AIR TEMPERATURE THERMOCOUPLE POSITIONS - TESTS 1 AND 2

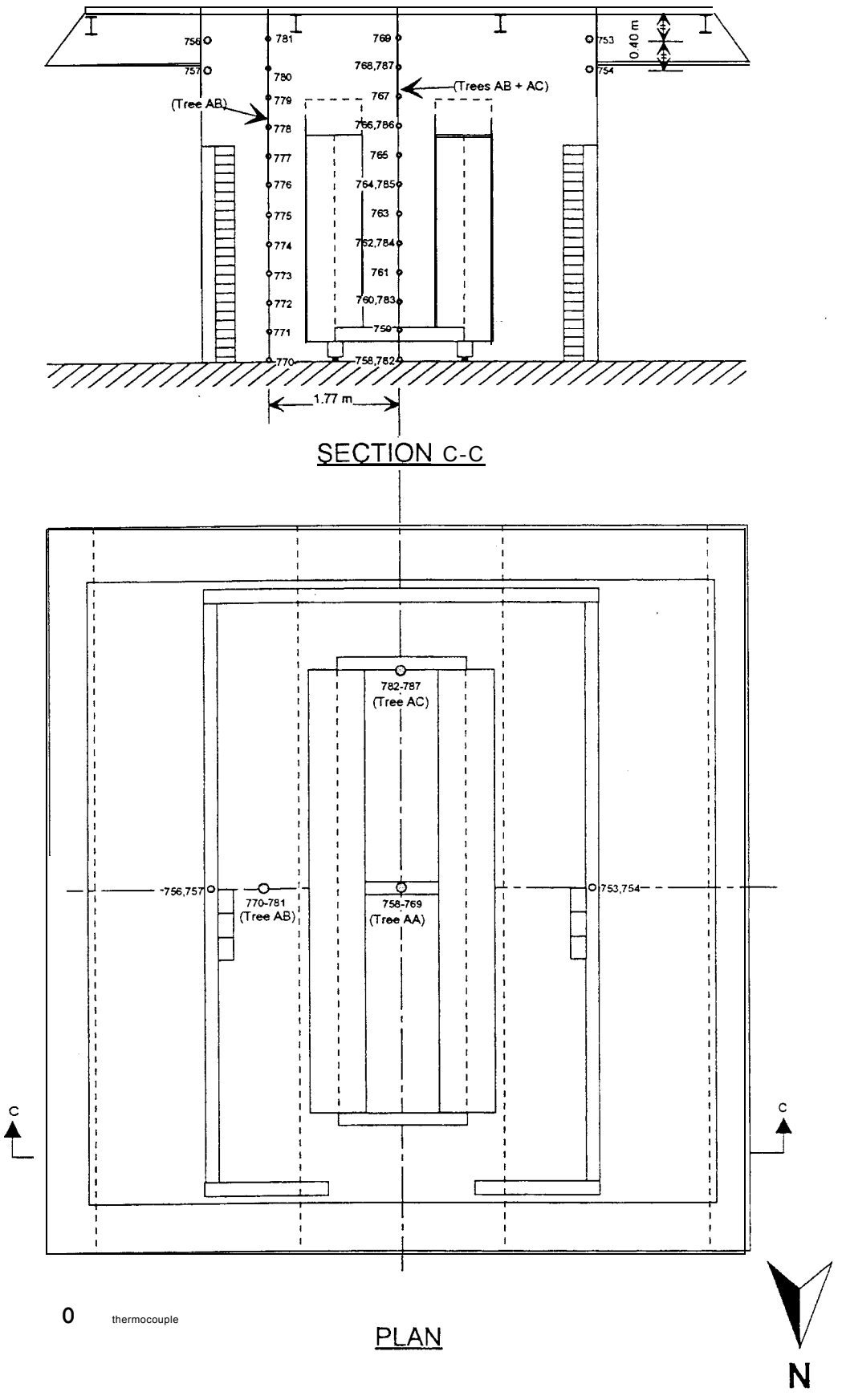
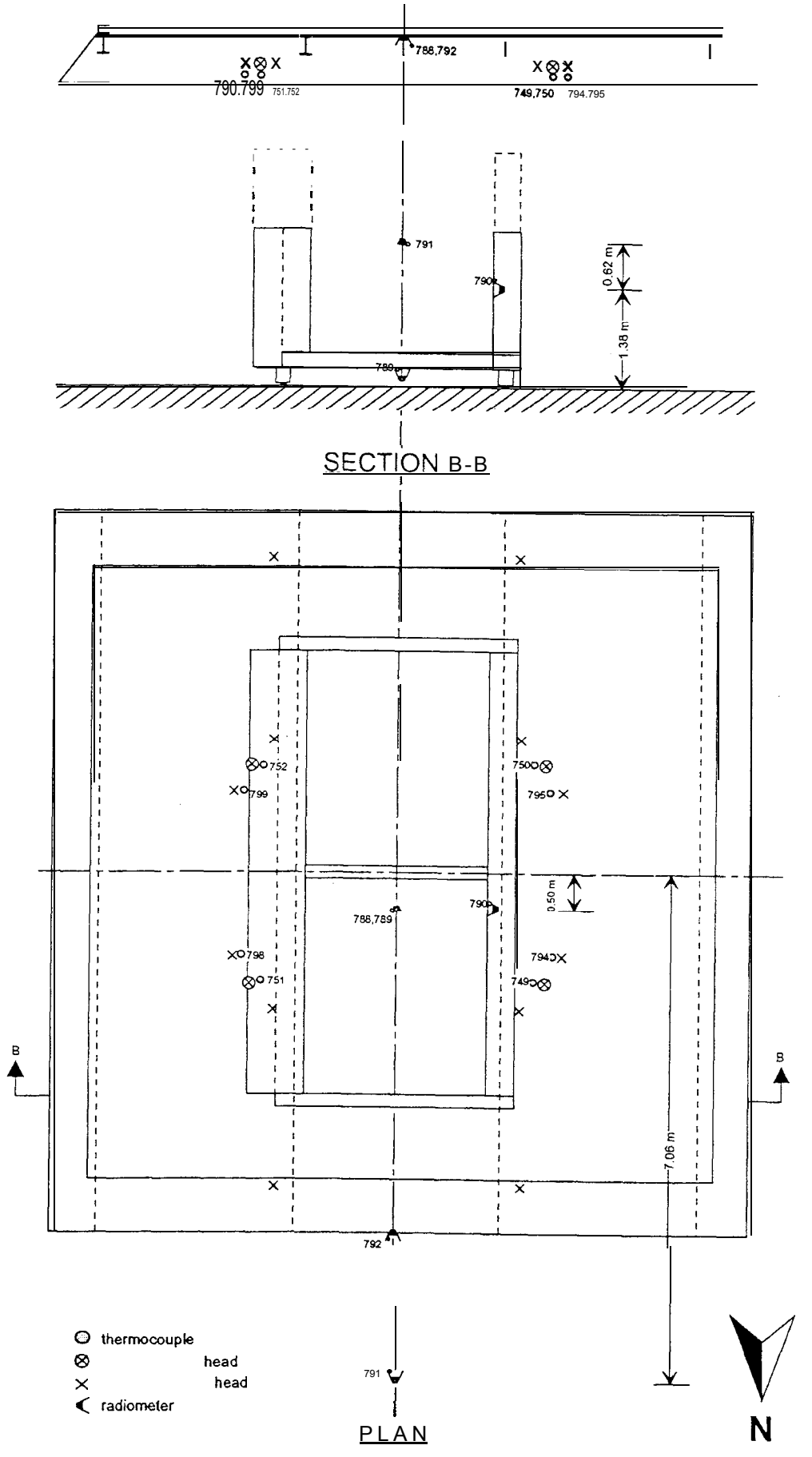
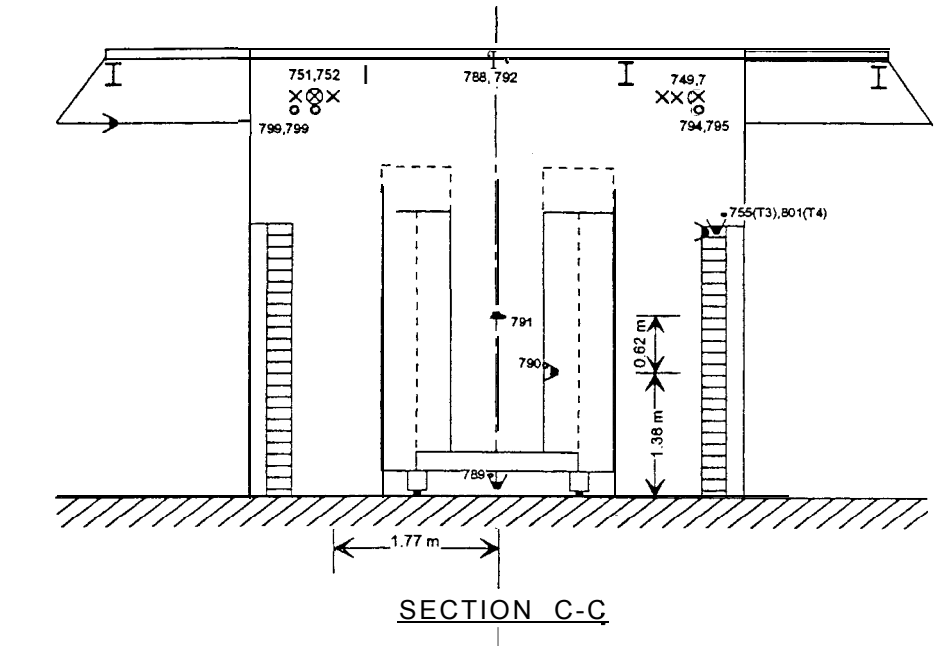


FIGURE 13 AIR POSITIONS - TESTS 3AND 4



F IGURE 14 AIR TEMPERATURE THERMOCOUPLES AT RADIOMETERS AND SPRINKLERS POSITIONS - TESTS 1 AND 2



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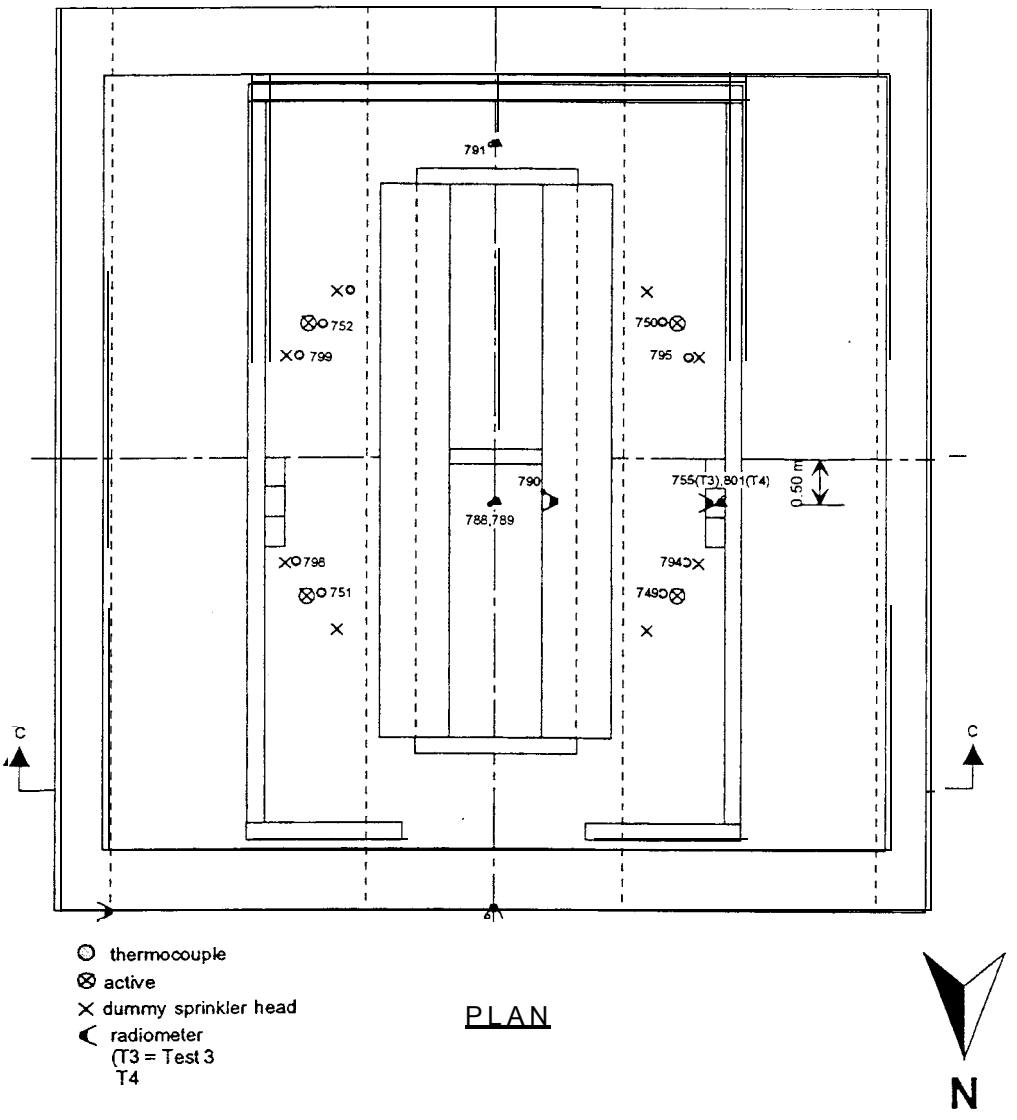
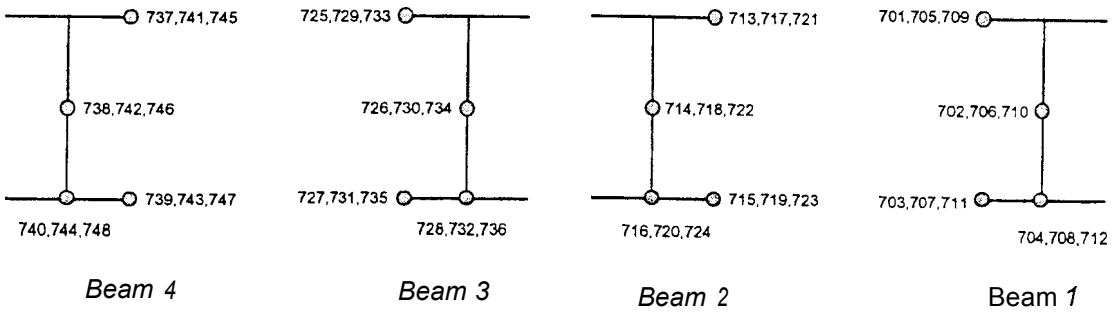
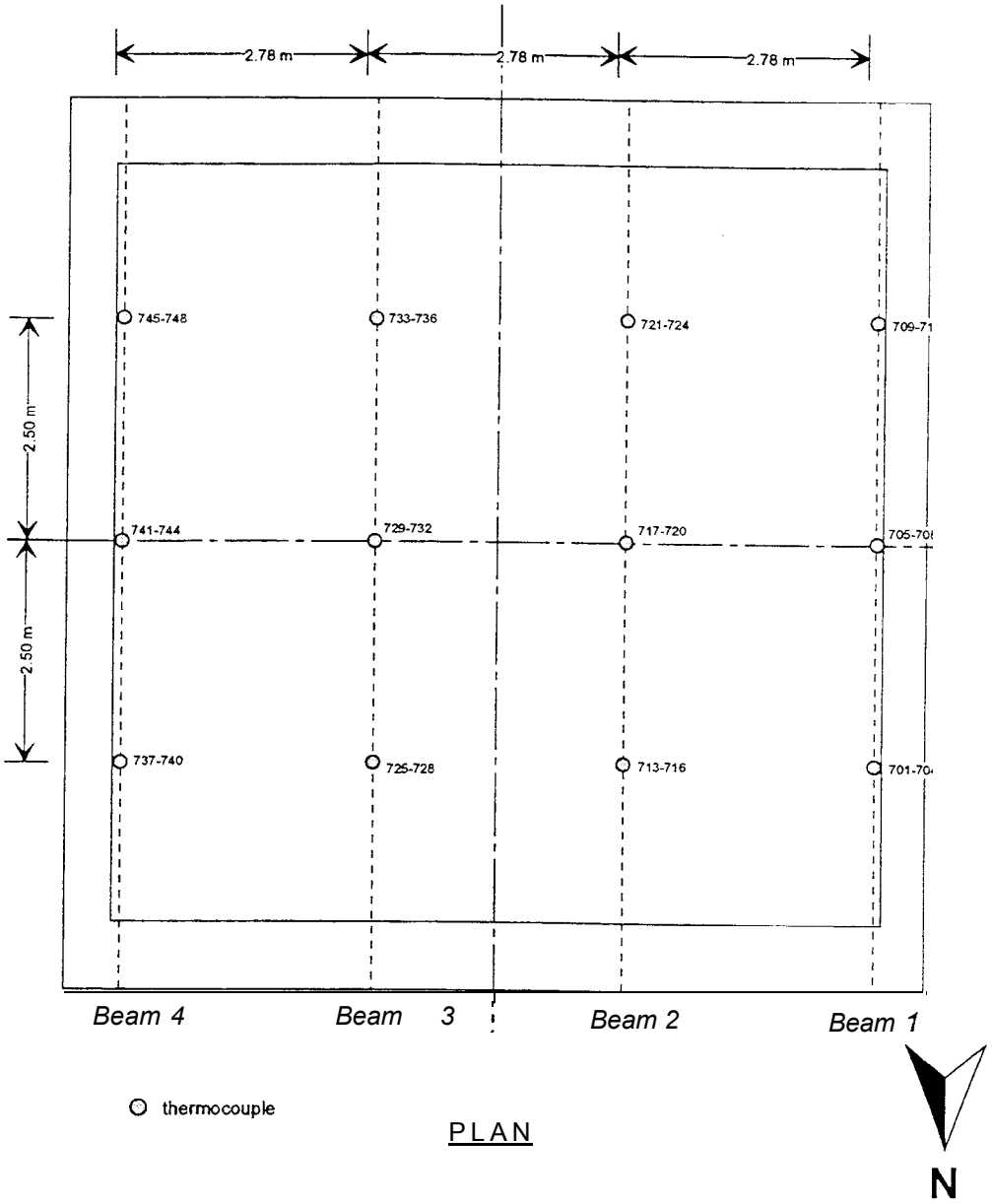


PLAN

FIGURE 15 AIR TEMPERATURE THERMOCOUPLES AT RADIOMETERS AND SPRINKLERS POSITIONS - TESTS 3 AND 4



CROSS SECTIONS



PLAN

F IGURE 16 STEEL POSITIONS - TESTS 1 TO 4

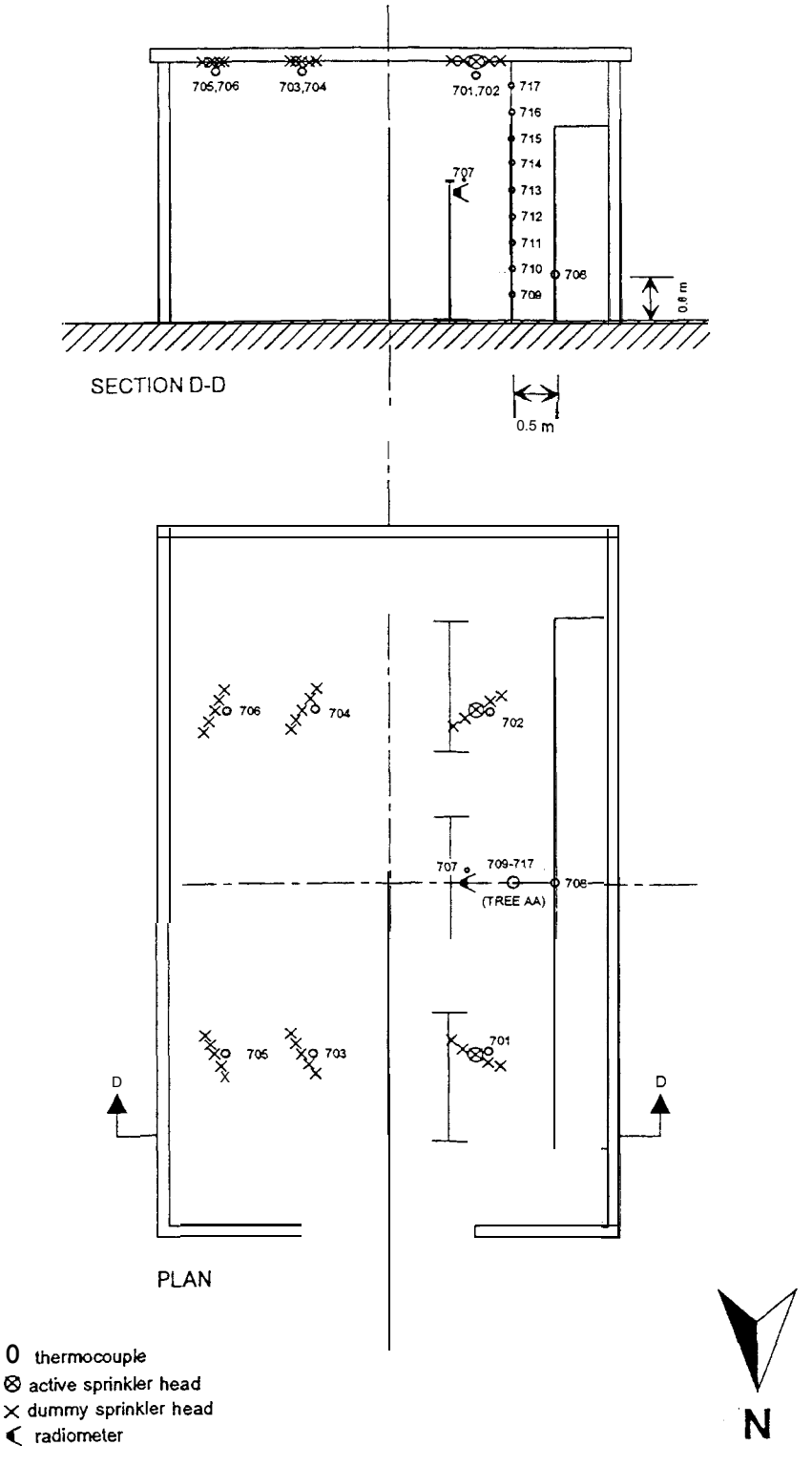


FIGURE 17 AIR TEMPERATURE THERMOCOUPLE POSITIONS - TESTS 5 TO 9

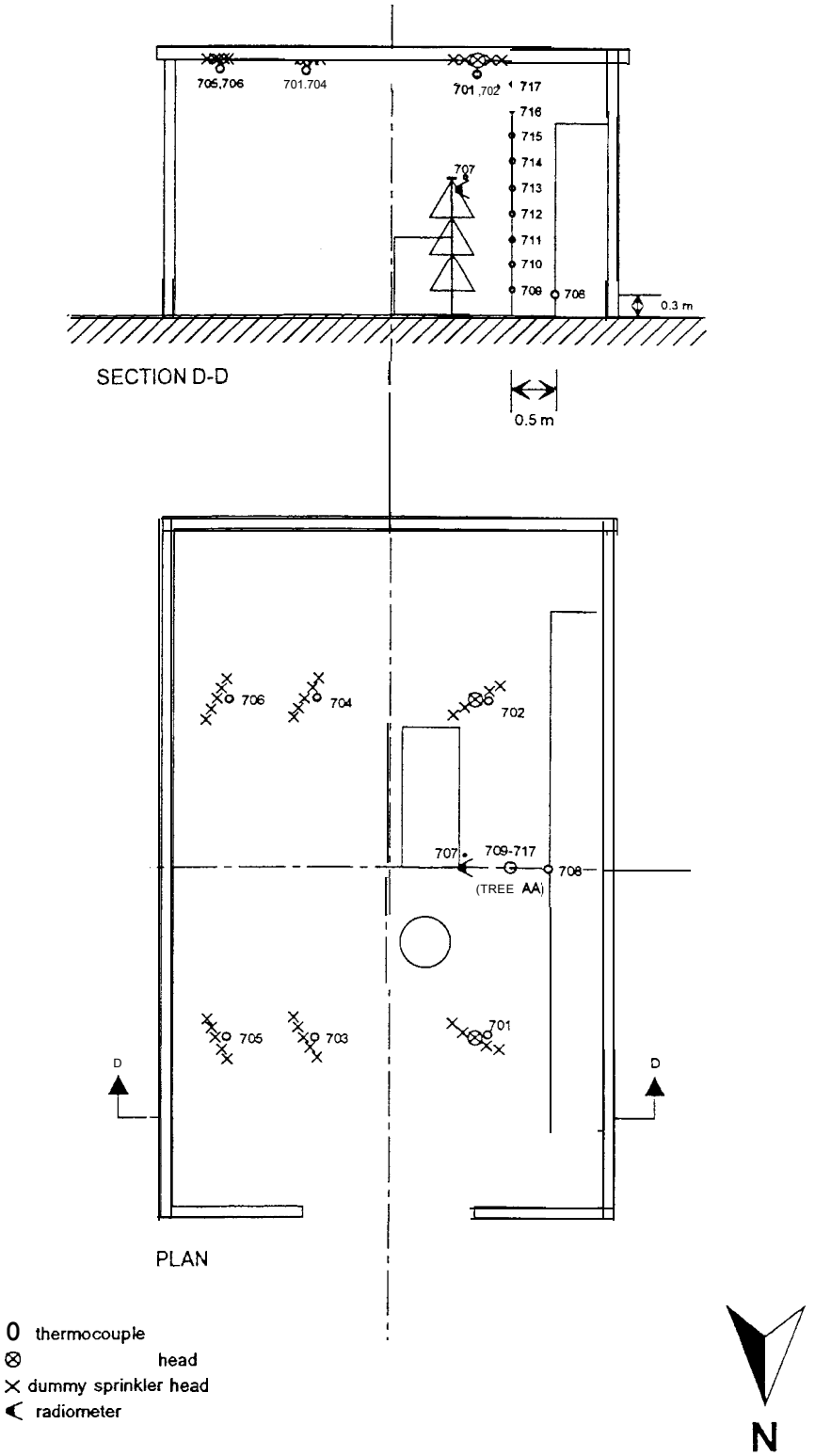


FIGURE 18 AIR POSITIONS - TESTS 10 AND 11

3.6 MASS LOSS MEASUREMENT

For Tests 1 to 4 the shelving was placed on load cells which measured the mass as the fire progressed. Steel nets were placed at the bottom of the shelves to catch any combustibles that fell from the shelves during the tests-so that the mass of any fallen combustibles was measured by the load cells. The measurement of mass loss combined with knowledge of the combustibles facilitates numerical analyses of the fires.

For Tests 5 to 11, mass loss was not measured.

3.7 SMOKE MEASUREMENT

Smoke densitometers were used to measure light transmission during the tests. Two strings of ten densitometers, 1 m apart, were hung from the roof of the building, one at the north and the other at the south side of the test structure (Figure 2). These strings also supported target boards with numbers which were observed during the tests to provide an alternative measurement of visibility (Figure 19). These latter readings consisted of an observer recording when the smoke first reached the various targets, and then, the time at which the target was not visible to an observer located about 10 m horizontally from the targets. In this report the signal from the densitometers has been converted into a transmission reading. Thus a value of 1.0 represents perfect transmission of light whereas a value of 0.0 represents zero transmission. Transmission values can be converted to obscuration by understanding that:

$$\text{Obscuration} = (1.0 - \text{Transmission}).$$

Drysdale [2] gives relationships between obscuration and optical density and between optical density and visibility as measured in metres.

3.8 VISUAL RECORDS

Visual observations were made and notes taken during each test. Records were kept of the times that smoke first reached the various targets (see Figure 19) and at which it was no longer possible to see the targets. These records were taken by persons positioned approximately 10 m (in a horizontal direction) from the strings of targets.

Still photographs and video recording of the tests were also taken from various vantage points.

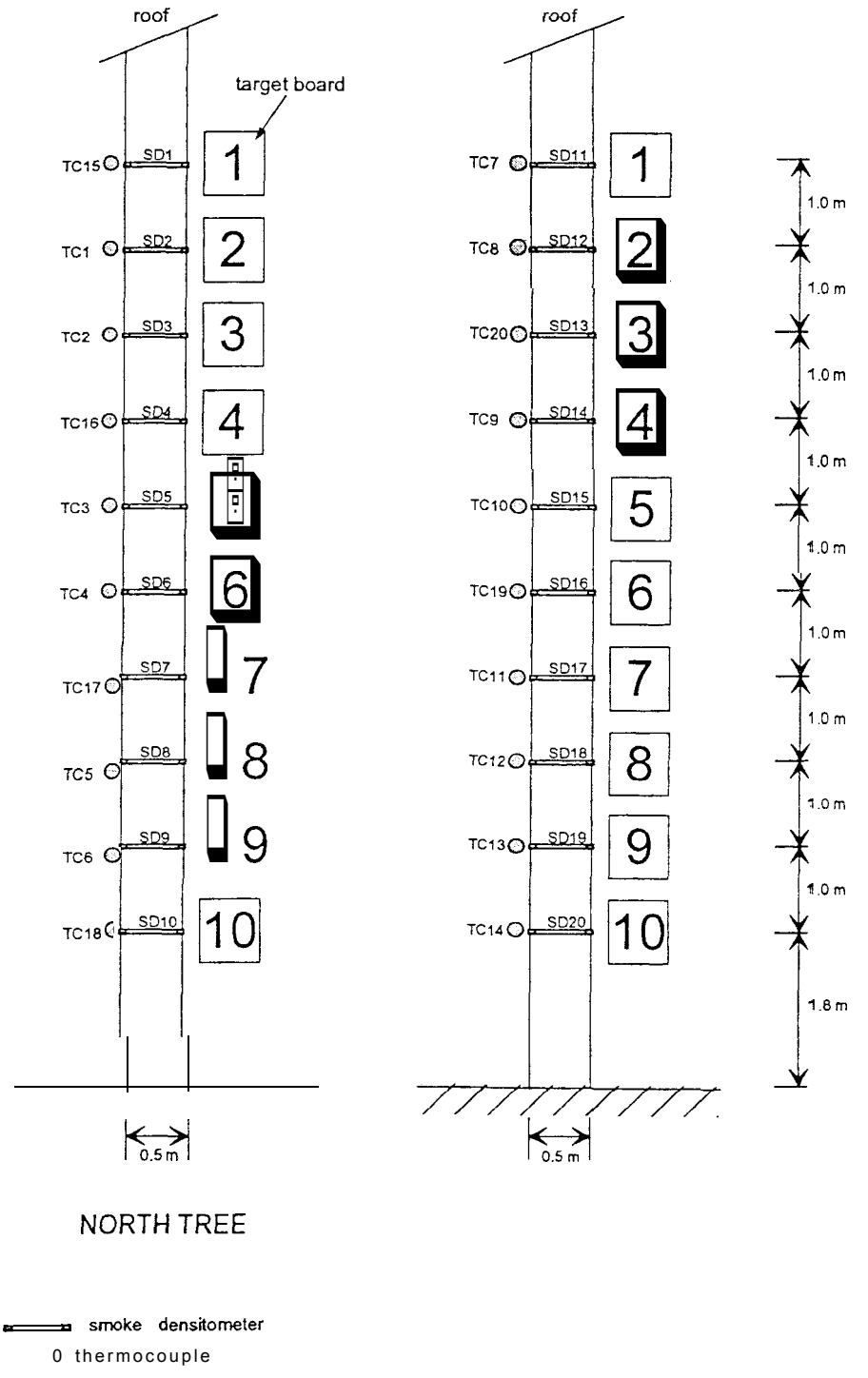


FIGURE 19 SMOKE DENSITOMETER POSITIONS

4 TEST RESULTS

4.1 MEASUREMENTS

Measurements taken during the tests are presented graphically in the Appendices as follow:

Appendix A: Air temperatures

Appendix B: Steel temperatures

Appendix C: Radiation

Appendix D: Mass loss

Appendix E: Transmission

All results are presented in terms of elapsed time from the start of fire ignition (ie. time zero is taken as the time of fire ignition-see Table 1 for the actual fire ignition time). Unfortunately, in the case of Test 2, some of the data logging equipment was exposed to smoke from the fire due to its location within the bum hall and substantial data was unable to be recorded because of equipment failure.

The activation time of active sprinklers were determined from video records and are summarised in Table 7.

TABLE 7: ACTIVATION ACTIVE SPRINKLER HEADS

sprkl.	*sprinkler head activation time (min:sec)*								
head	*Test 1*	*Test 3*	*Test 5*	*Test 6*	*Test 7*	*Test 8*	*Test 9*	*Test 10*	*Test 11*
A1	∞	42:42	1:51	1:03*	3:28	3:03	2:25	14:13	17:32
A2	∞	†	1:49	1:03*	3:34	3:03	2:18	14:07	∞
A3	12:30	42:42	—	—	—	—	—	—	—
A4	3:38	†	—	—	—	—	—	—	—

∞ = sprinkler not activated

† = unable to determine time of activation

* = no water supplied to sprinklers (water turned on at elapse time 1:27)

The activation time of the dummy sprinklers heads for Tests 1 to 4 and Tests 5 to 11 are summarised in Tables 8 and 9, respectively. It was not able to record the time of sprinkler activation in some of the tests due to equipment failure.

TIMES OF DUMMY SPRINKLER HEADS — TESTS 1 TO 4

sprinkler	*sprinkler head activation time (min:sec)*			
head	*Test 1*	*Test 2*	*Test 3*	*Test 4*
D1	7:11	2:33	42:13	25:27
D2	†	2:25	42:07	24:03
D3	†	2:12	42:15	25:22
D4	17:09	2:30	35:50	25:34
D5	12†11	2:57	42:15	25:25
D6	†	2:31	42: 14	25:28
D7		2:17	34:12	25:33
D8	16:03	2:49	42:18	25:40

† = unable to determine time of activation

TABLE 9: ACTIVATION TIMES OF DUMMY SPRINKLER HEADS TESTS 5 TO 11

sprinkler	*sprinkler head activation time (min:sec)**						
head	*Test 5*	*Test 6*	*Test 7*	*Test 8*	*Test 9*	*Test 10*	*Test 11*
D1	1:43	1:08	3:16	2:22	1:36	13:38	9:19
D2	1:49	1:08	3:22	2:41	1:50	∞	16:56
D3	9:39	1:14	∞	2:41	1:50	∞	16:49
D4	∞	1:21	∞	14:08	1:57	∞	16:14
D5	10:03	1:21	∞	∞	1:57	∞	17:03
D6	9:02	1:14	∞	2:41	1:43	∞	17:03
D7	2:08	1:01	3:35	2:35	1:43	∞	17:03
D8	1:43	1:01	3:22	2:22	1:36	13:44	6:41
D9	1:55	1:21	3:28	2:41	1:43	14: 14	17:03
DIO	9:45	1:14	∞	2:47	1:57	∞	17:16
D11	10:03	1:08	∞	3:06	2:04	14:08	16:56
D12	9:02	1:21	∞	3:06	2:04	∞	17:03
D13	12:16	1:21	∞	∞	∞	∞	∞
D14	10:15	1:39	∞	∞	∞	∞	∞
D15	3:13	1:21	∞	3:06	2:04	∞	17:03
D16	2:34	1:08	∞	5:00	1:57	∞	17:41
D17	2:53	1:14	∞	2:47	1:57	∞	17:28
D18	1:55	1:14	3:35	2:35	1:50	14:08	16:56
D19	1:55	1:21	3:28	2:47	1:43	∞	17:03
D20	∞	1:14	∞	2:53	1:57	∞	17:35
D21	9:57	1:08	∞	15.11	2:04	∞	17:16
D22	9:33	1:27	∞	∞	2:10	∞	17:22
D23	∞	∞	∞	∞	∞	∞	∞
D24	9:02	∞	∞	∞	2:23	∞	∞
D25	8:56	1:27	∞	15:42			17:22
D26	2:34	1:01	∞	∞	1:57	∞	∞
D27	3:13	1:14	∞	2:53	1:57	∞	17:47
D28	1:55	1:14	3:35	2:35	1:50	14:02	16:49

* accuracy = ± 6 sec

∞ = sprinkler not activated

4.2 OBSERVATIONS

Visual observations made of the tests are summarised in Figures 20 to 23. Records of the visibility of targets for Tests 1 to 4 (see Section 3.8) are given in Appendix F. Figures 24 to 34 show photographs which were taken at stages before, during, and after each test. As noted in the introduction, a video record of all fire tests has been prepared and is available on request.

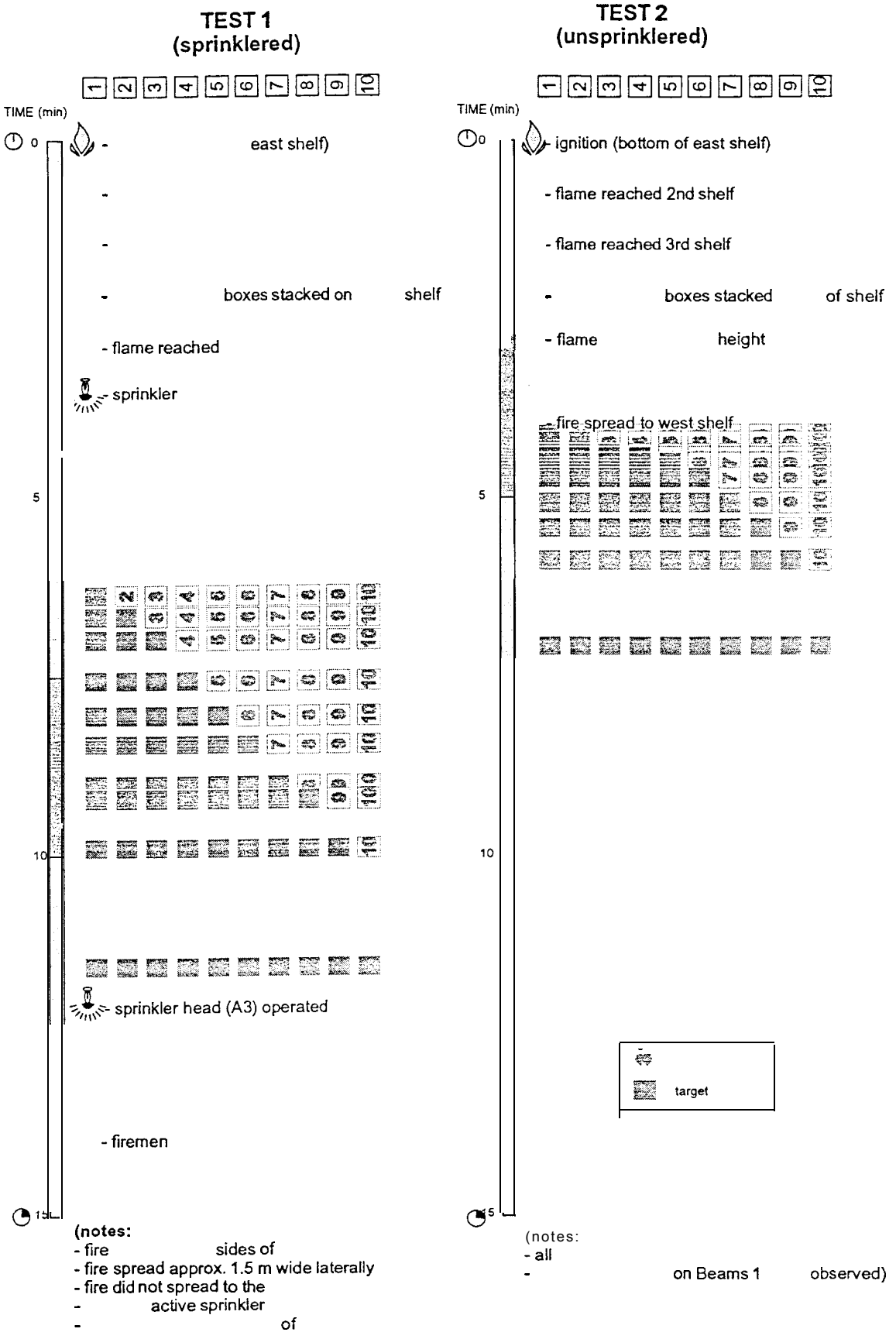


FIGURE 20TEST OBSERVATIONS - TESTS 1 AND 2

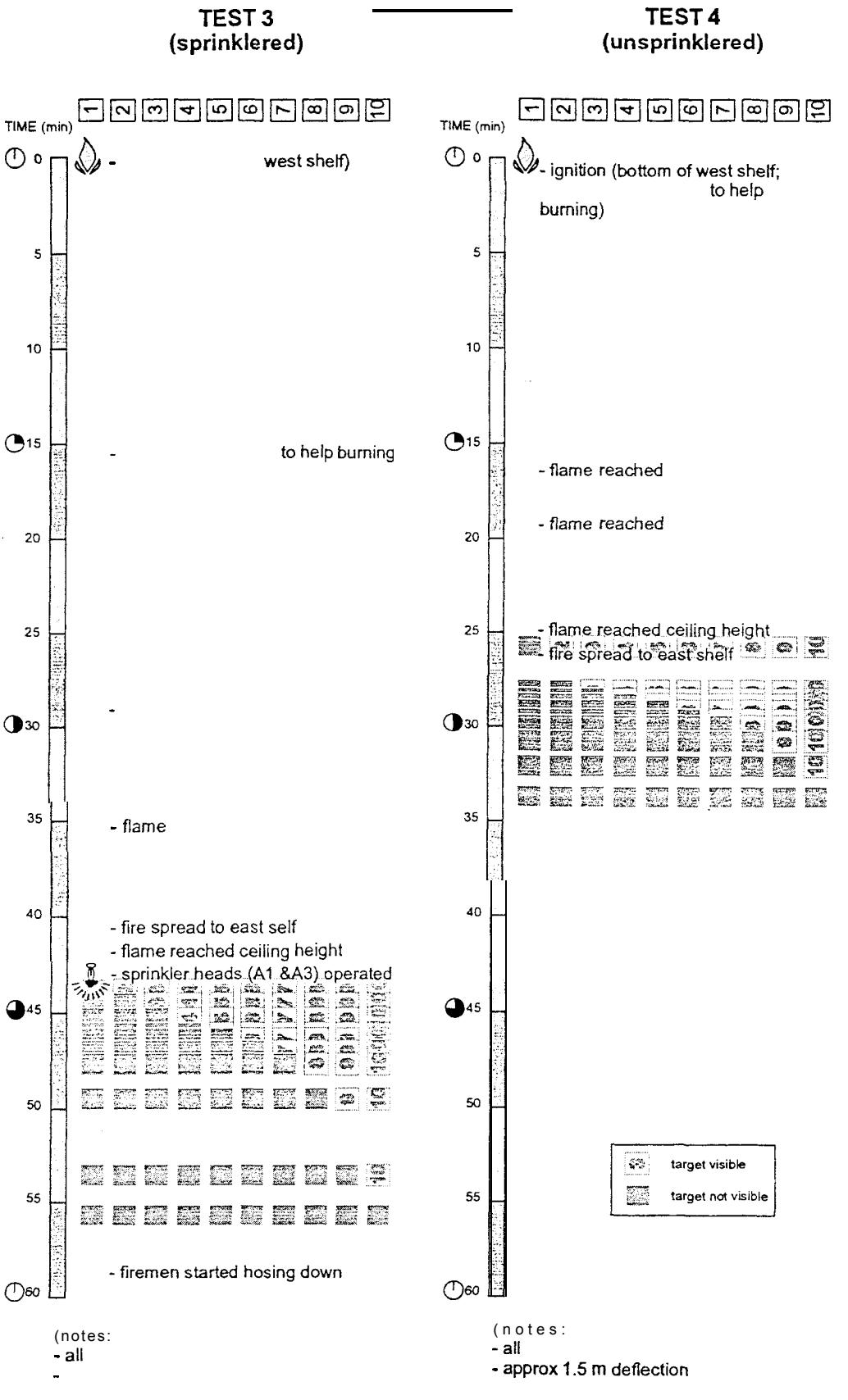


FIGURE 21 - TESTS 3 AND4

TESTS 5 TO 9

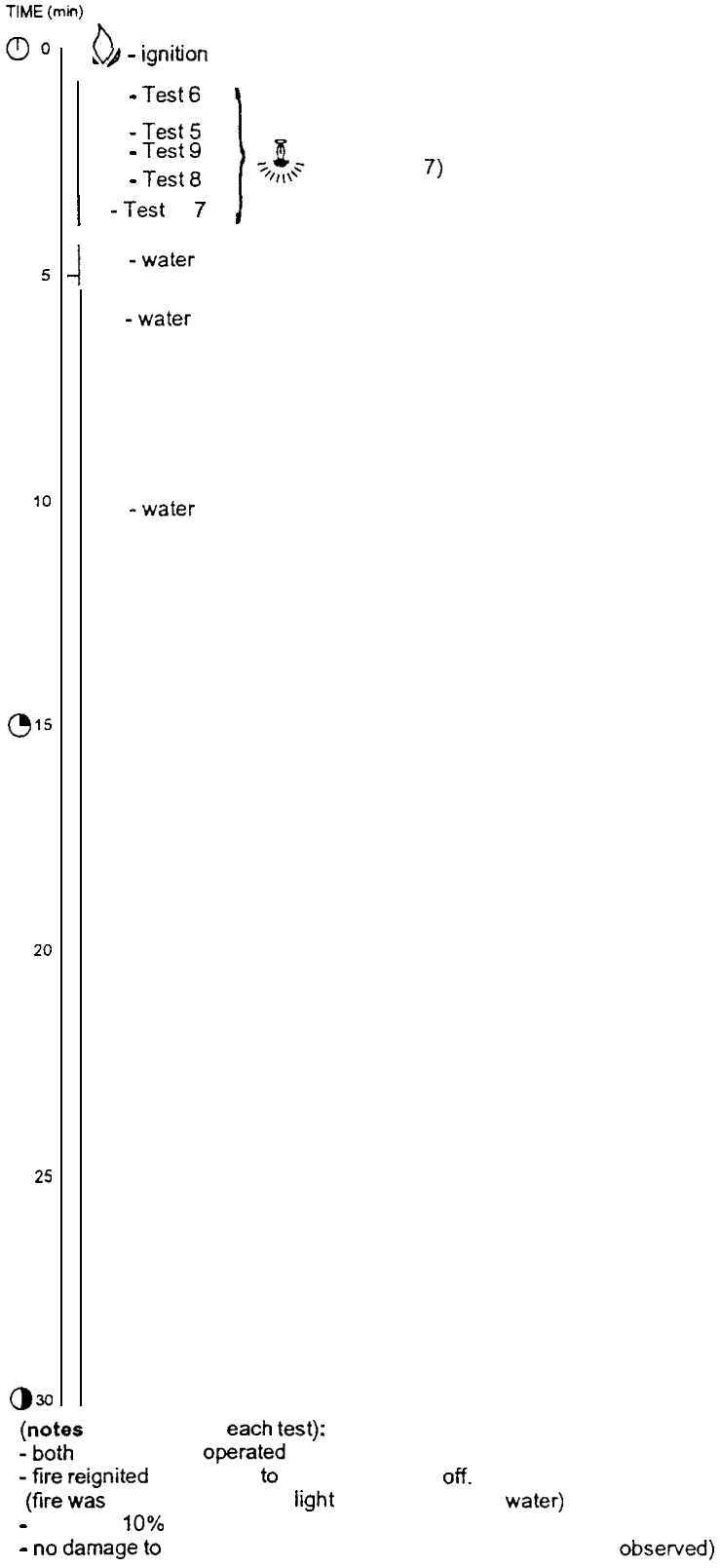


FIGURE 22 - TESTS 5 TO 9

SPRINKLERED BOOK TESTS

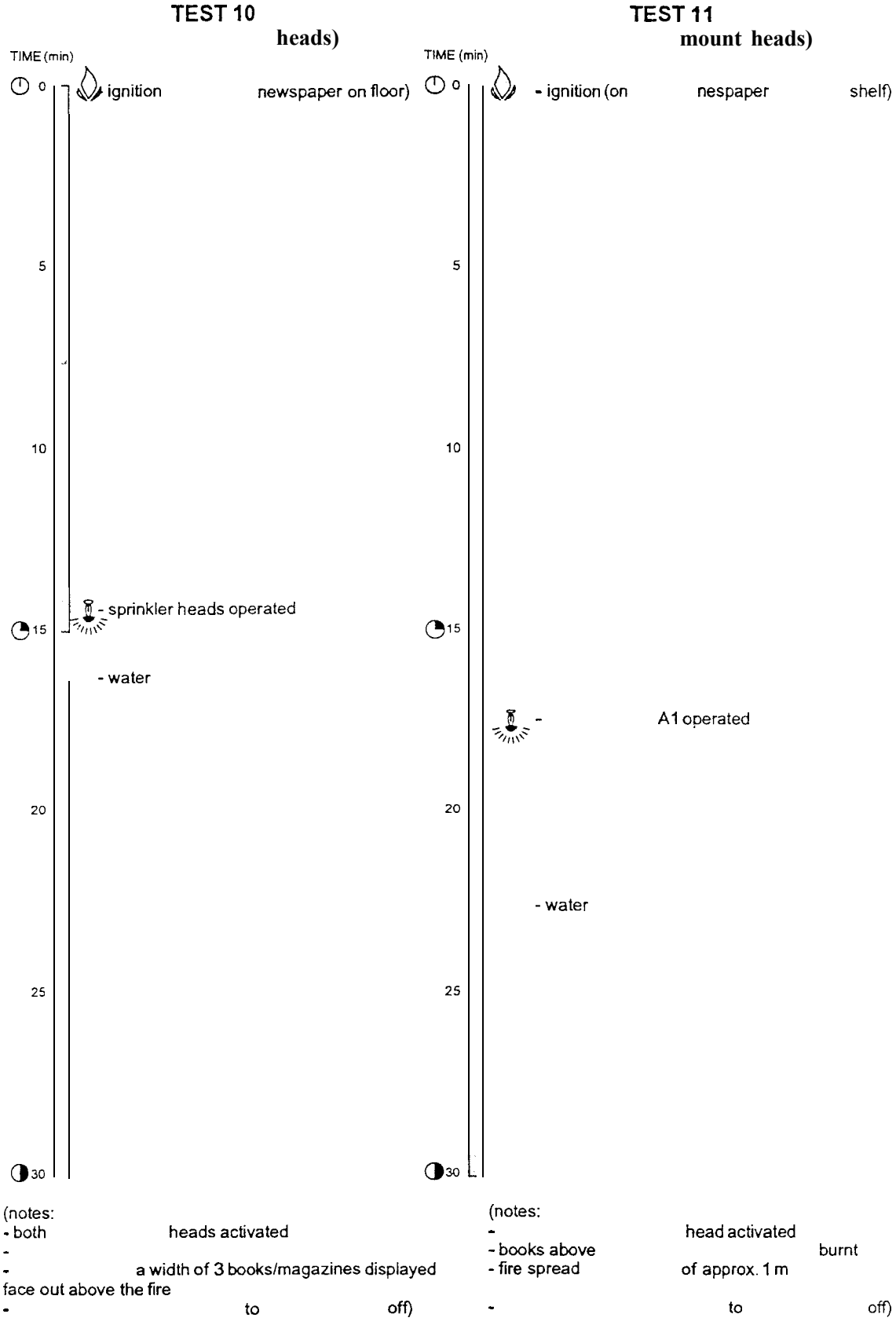
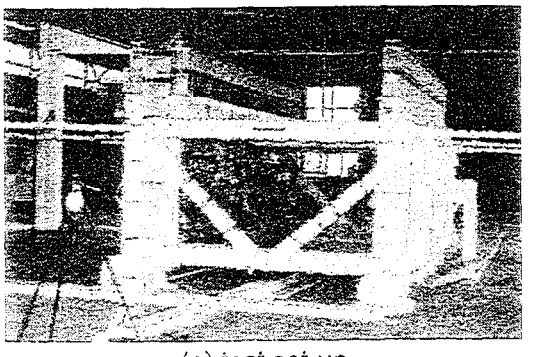
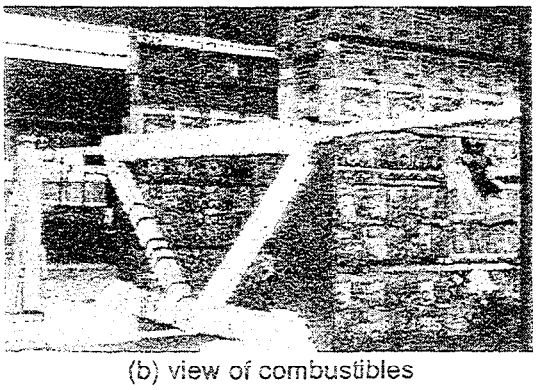


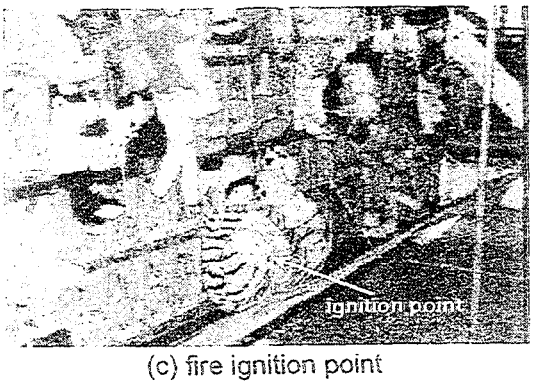
FIGURE 23 - TESTS 10 AND 11



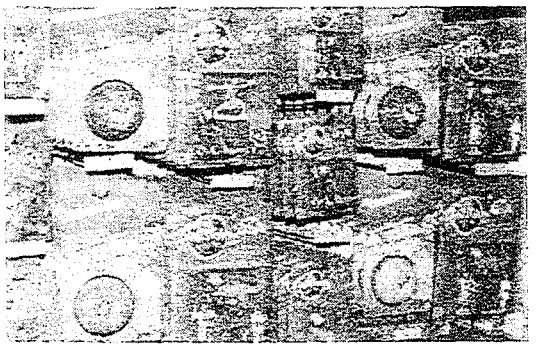
(a) test set-up



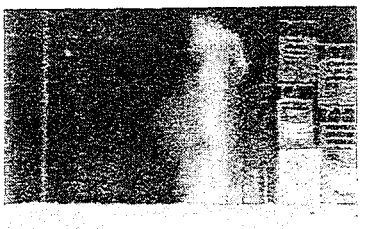
(b) view of combustibles

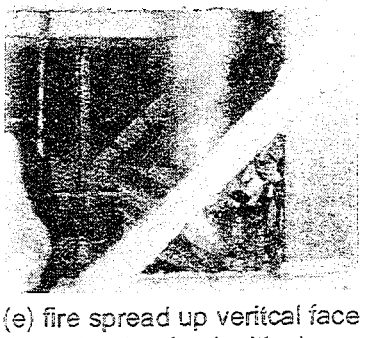


(c) fire ignition point

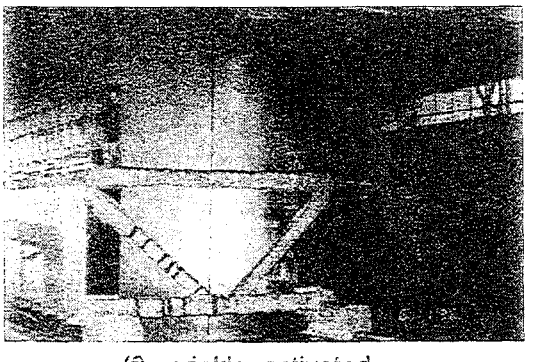


(d) close-up of combustibles



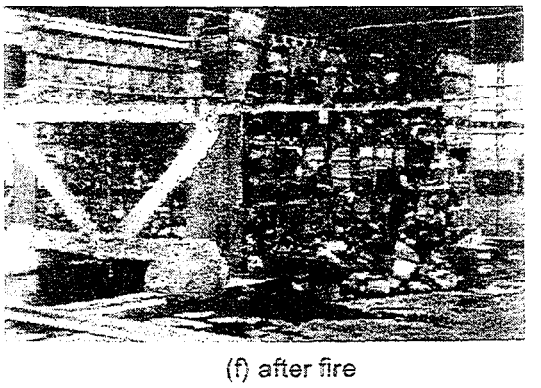


(e) fire spread up vertical face (shortly after ignition)



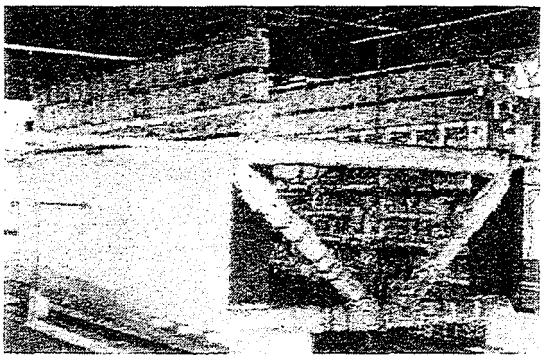
(f) sprinkler activated

(g) fire burning along shelving

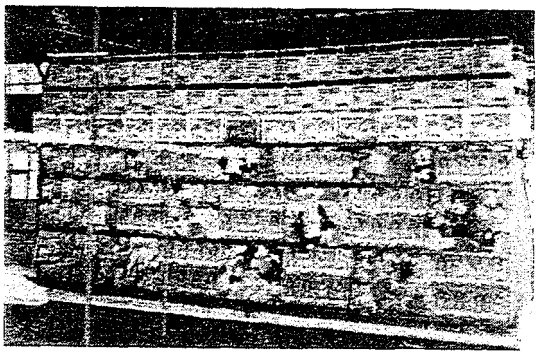


(f) after fire

FIGURE 24 TEST 1

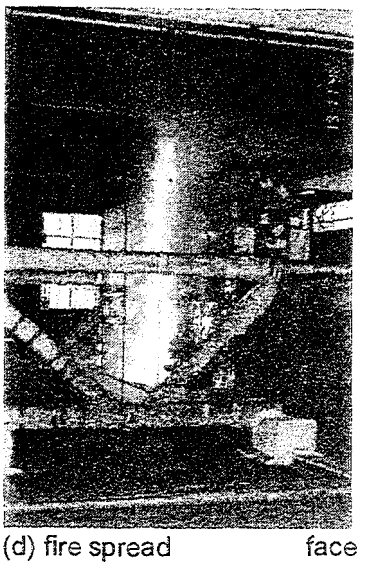


(a) test set-up

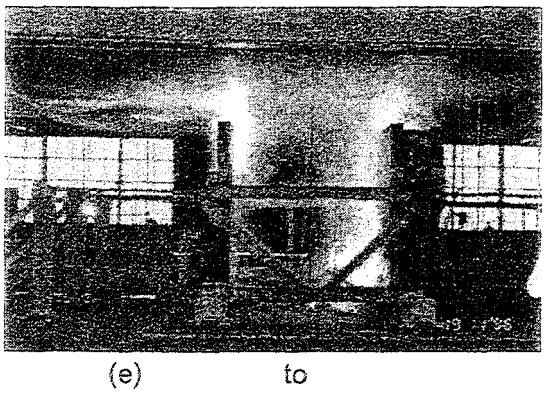


of combustibles

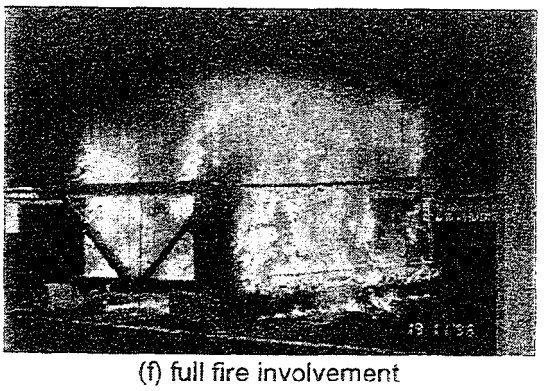
(c) fire ignition point



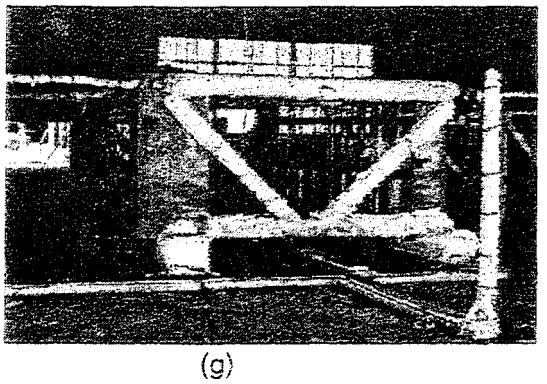
(d) fire spread face



(e) to



(f) full fire involvement



(g)

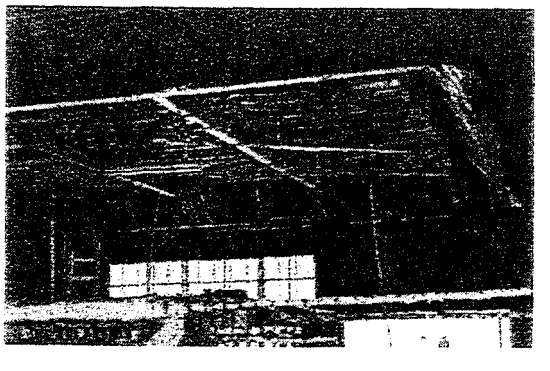
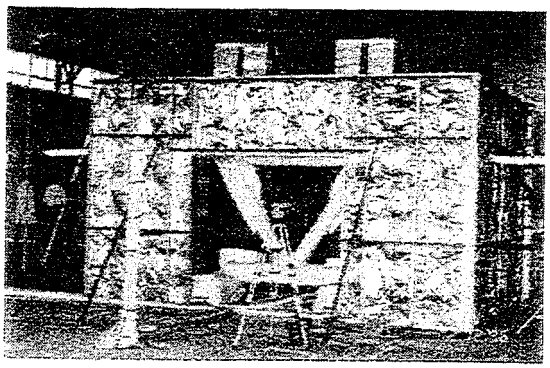
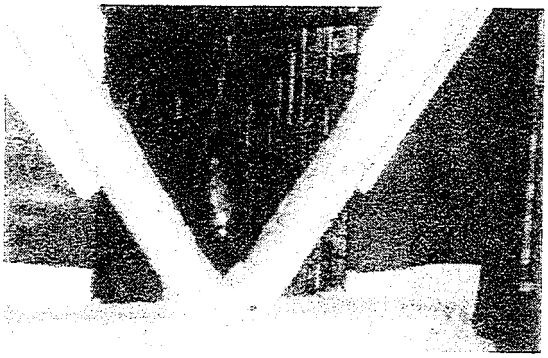


FIGURE 25 TEST 2



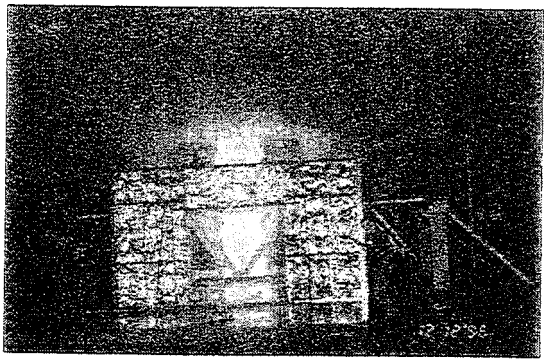
(a) enclosure around shelves

(b) close-up of combustibles



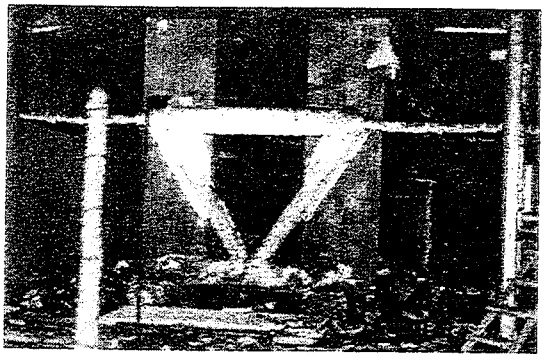
(c) fire ignition

(d) fire spread up vertical face



(e) full development with sprinklers operating

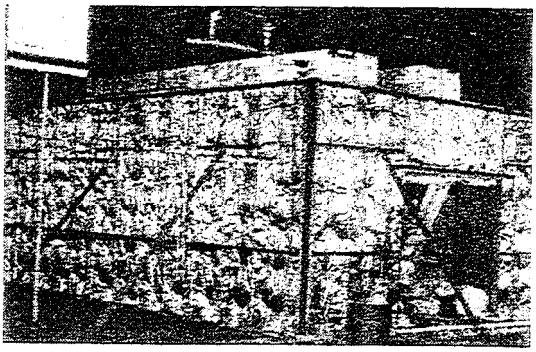
(f) full development with sprinklers operating



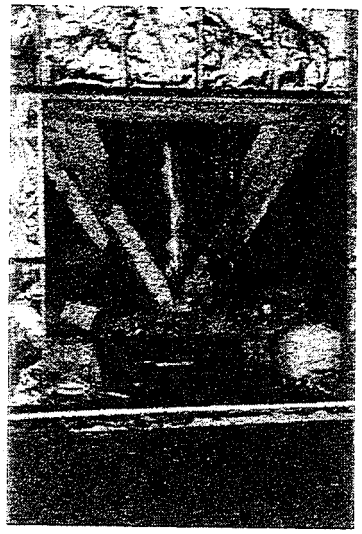
(g) after fire

(h) test structure after fire

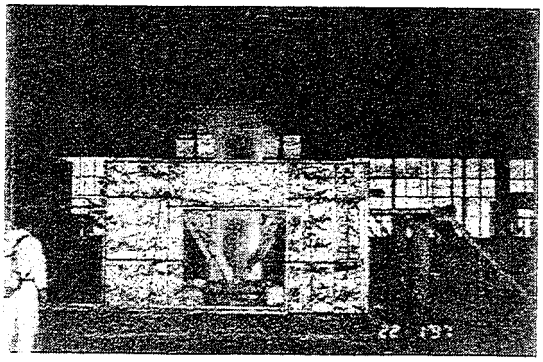
FIGURE 26 TEST 3



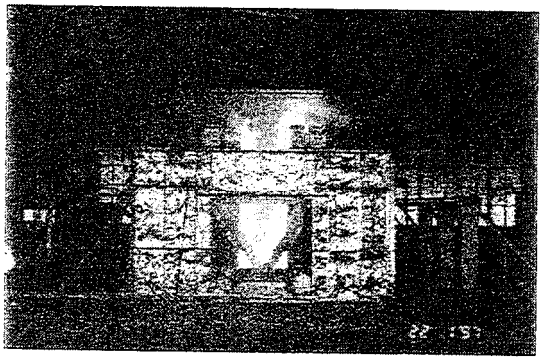
(a) enclosure around shelves



(b) fire ignition



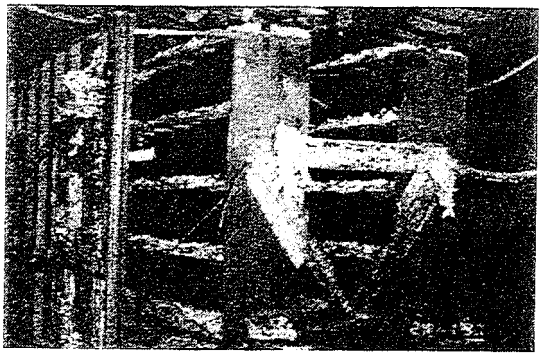
(c) fire spread to other shelf



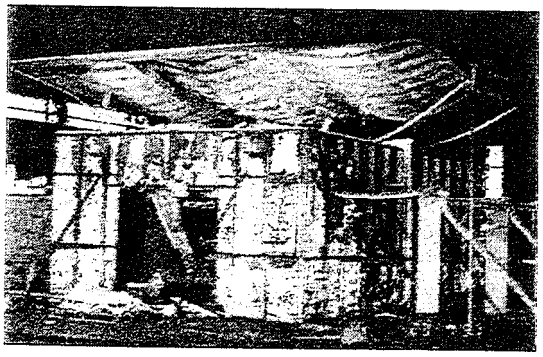
(d) both shelves burning

(e) full fire involvement

(f) full fire involvement



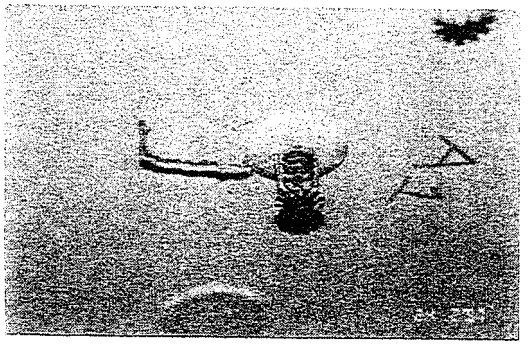
(g) after fire



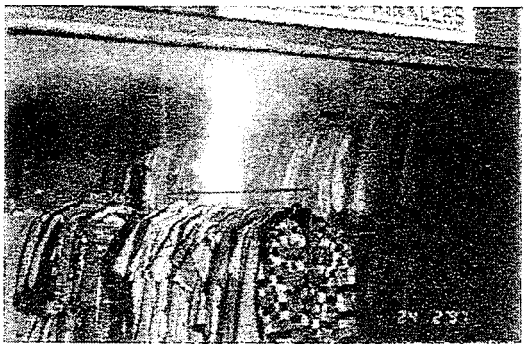
fire showing catenary action

FIGURE 27 TEST 4

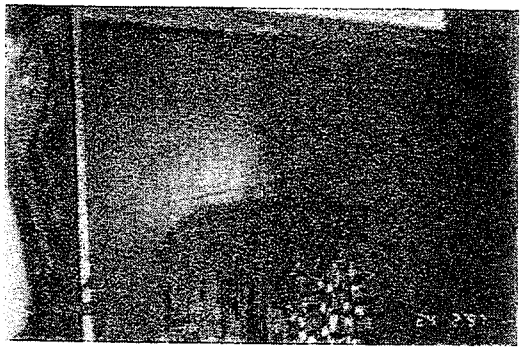
(a) test set-up showing clothing within enclosure



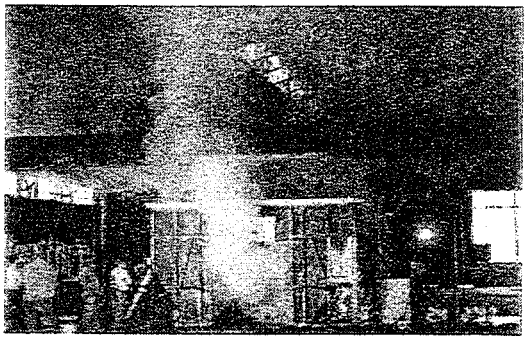
(b) active normal response sprinkler head - AI



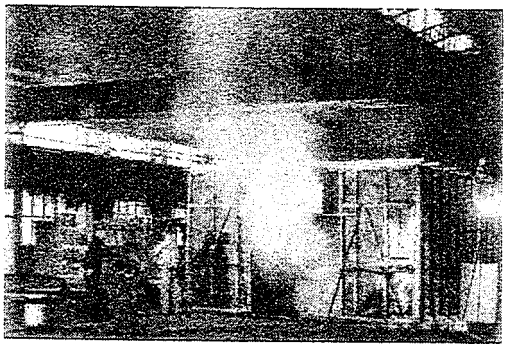
(c) fire before



(d) just after sprinkler activation



(e) steam and smoke from sprinklered fire

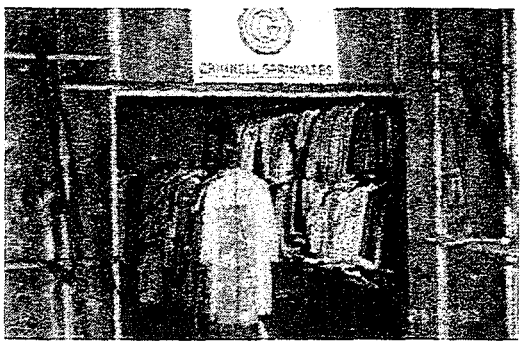


(f) as for (e) but later

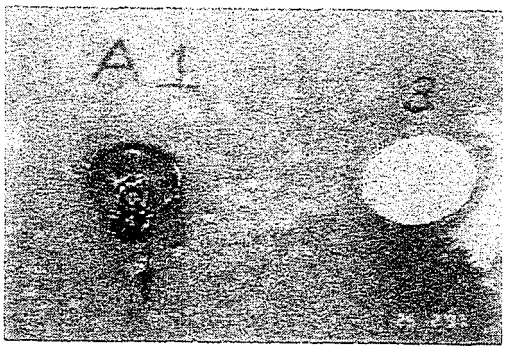
(g) after fire

(h) after fire

FIGURE 28 TEST 5



(a) test set-up showing clothing within enclosure



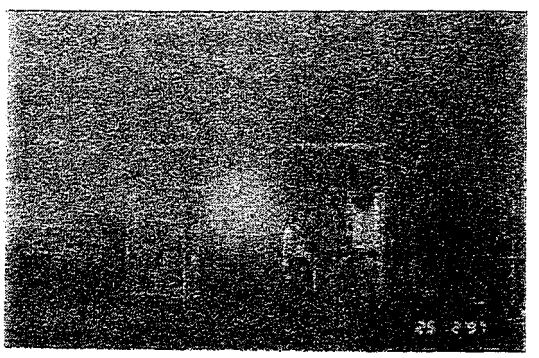
(b) active fast response sprinkler head - A1

(c) fire spread up vertically after ignition

(d) fire just before sprinkler activation

(e) steam and smoke from sprinklered fire

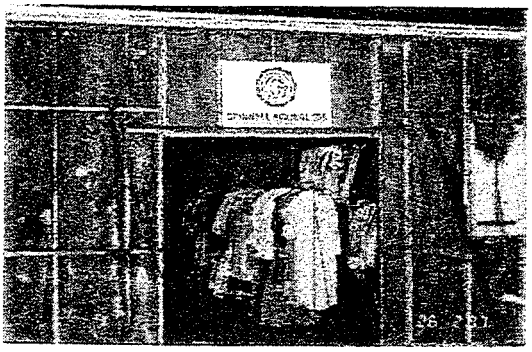
(f) as for (e) but later



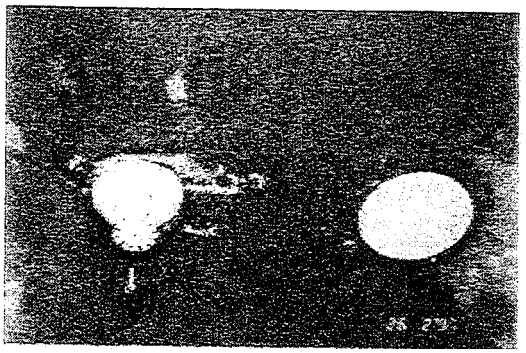
(gf person walking through “smoke”

(h) after fire

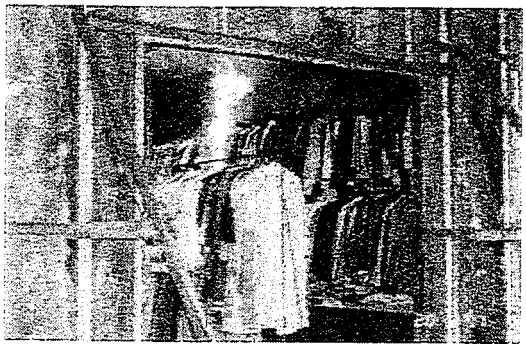
FIGURE 29 TEST 6



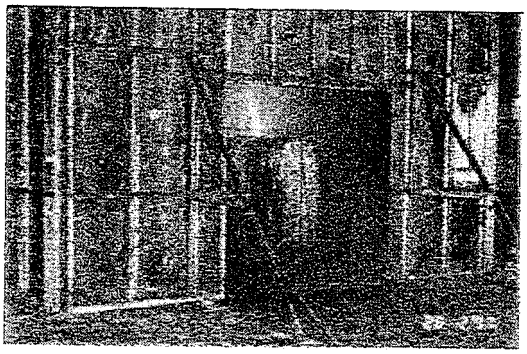
(a) test set-up showing clothing within enclosure



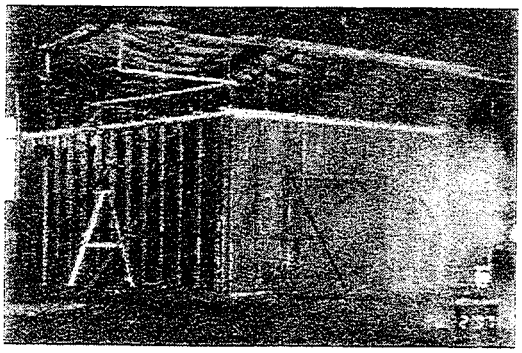
(b) active normal response painted sprinkler head - A1



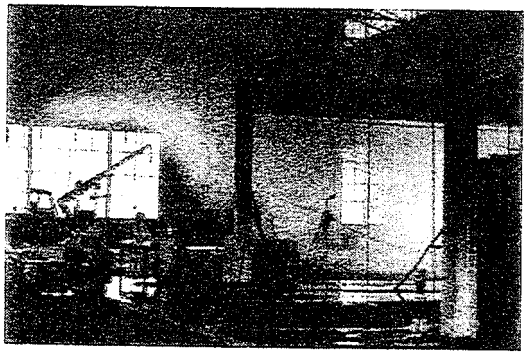
(c) fire before sprinkler activation



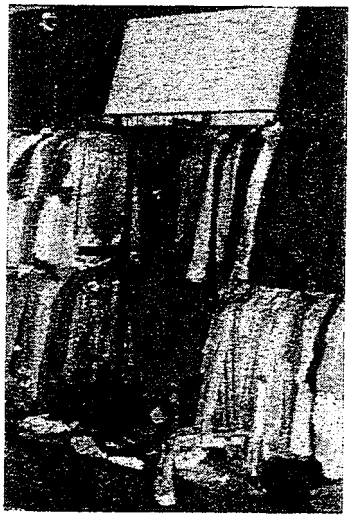
(d) just after sprinkler activation



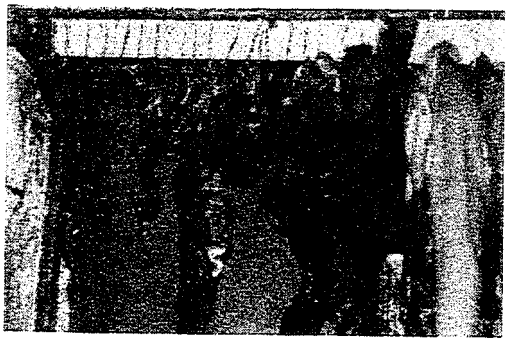
(e) steam and smoker from sprinklered fire



(f) view showing smoke within building

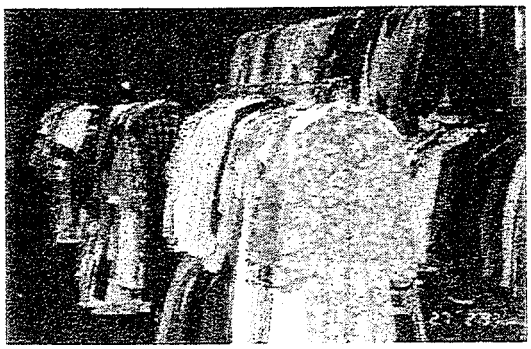


(g) after fire



(h) after fire

FIGURE 30 TEST 7



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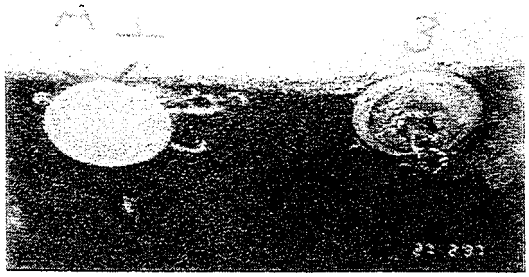
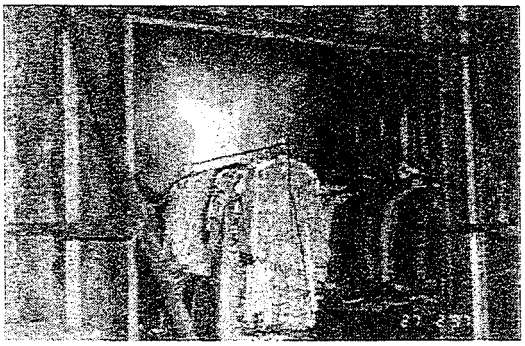
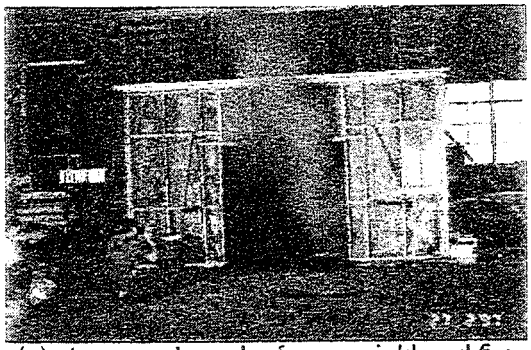


(b) active normal response flush plate sprinkler head - A1

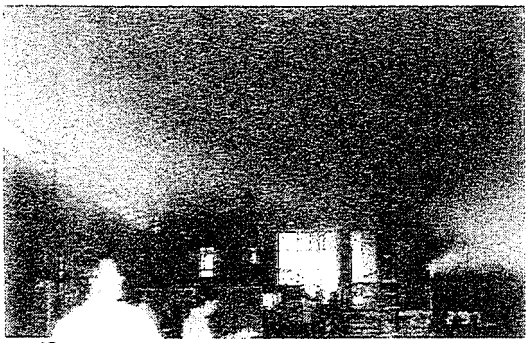
(c) fire before sprinkler activation



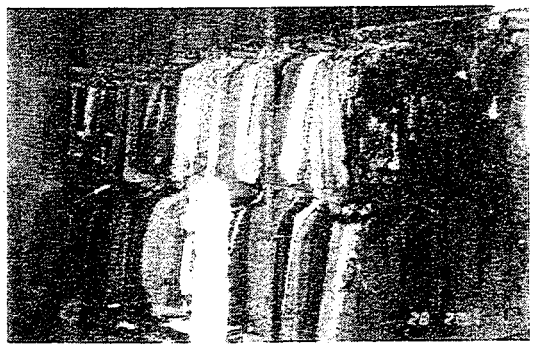
(d) just before sprinkler activation



(e) steam and smoke from sprinklered fire



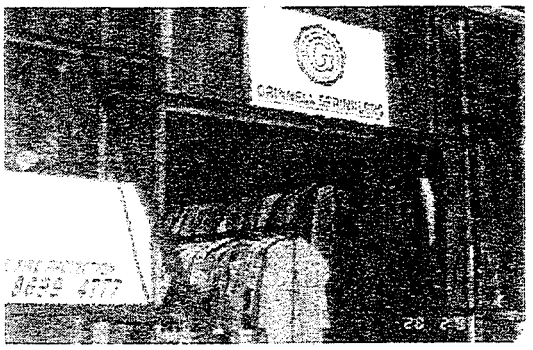
(f) view showing smoke within building



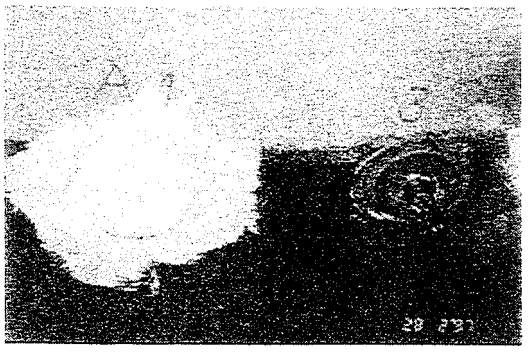
(g) after fire

(h) after fire

FIGURE 31 TEST 8

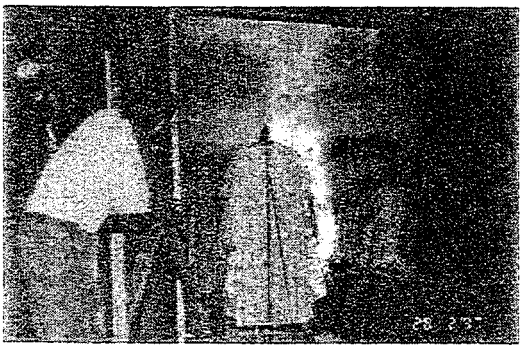


(a) test set-up showing clothing within enclosure

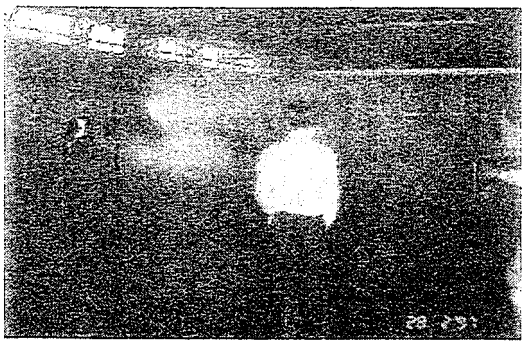


(b) active normal response painted flush plate sprinkler head -A?

fc) fire before sprinkler activation



(d) just before sprinkler activation



(f) smoke within building

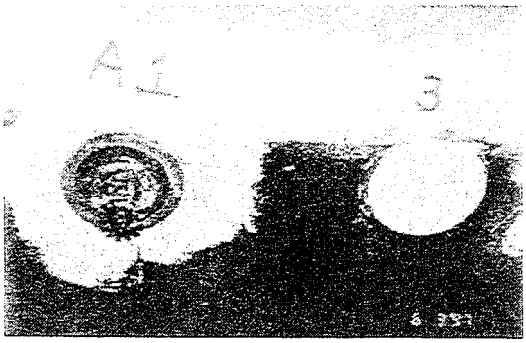
fe) smoke within building

(g) after fire

(h) after fire

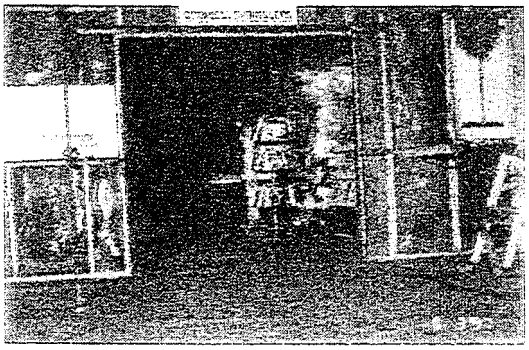
FIGURE 32 TEST 9

(a) test magazines and books

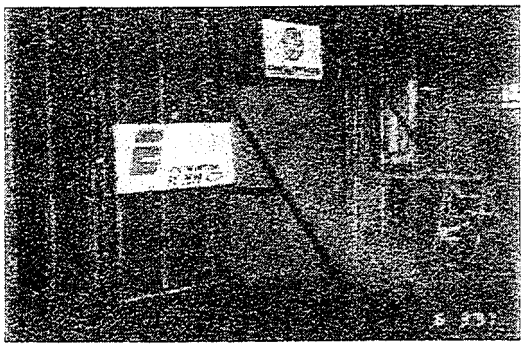


(b) active normal response sprinkler head - A1

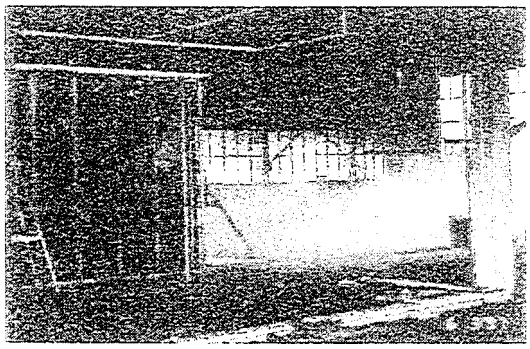
(c) fire ignition



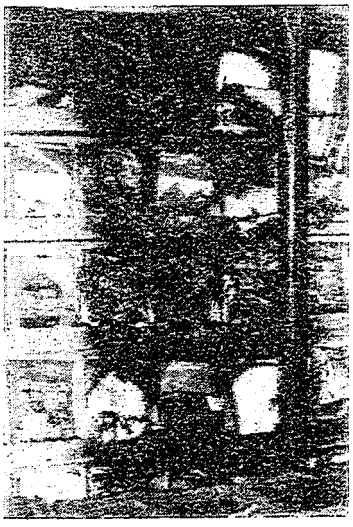
(d) fire before sprinkler activation



(e) steam and smoke from sprinklered fire



(f) smoke from



(g) after fire

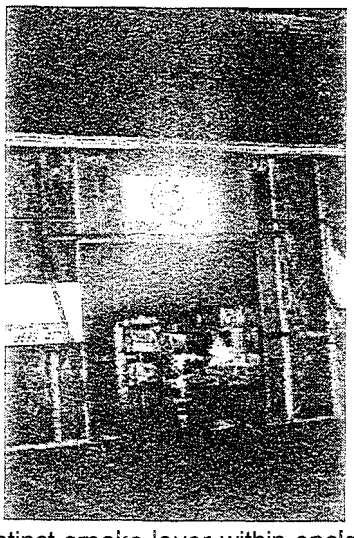
(h) after fire

FIGURE 33 TEST 10

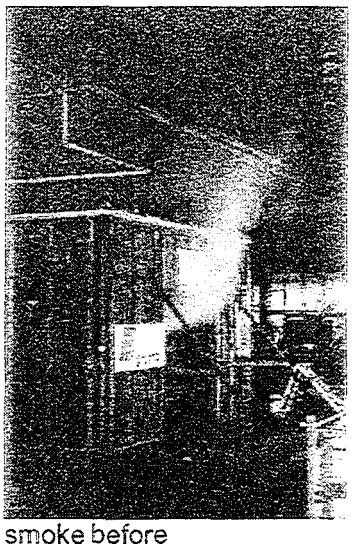
(a) test books

(b) active normal response plate sprinkler head - A1

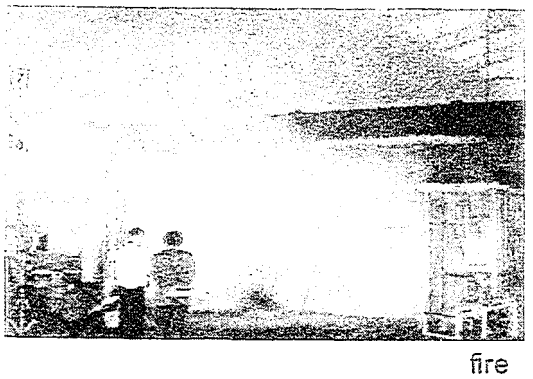
(c) fire ignition



(d) distinct smoke layer within enclosure

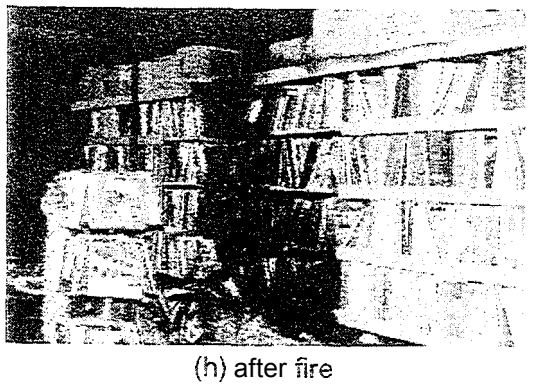


(e) smoke before



fire

(g) after fire



(h) after fire

FIGURE 34 TEST 11

4.3 COMMENTS

The following comments are made in relation to each test:

Tests I — This fire is probably representative of one of the most severe sprinklered fires in terms of the quantity of smoke produced. This was due to the combination of predominantly plastic combustibles arranged in high shelving, the absence of a ceiling, and the location of sprinkler heads away from the seat of the fire. Sufficient water was not able to get to the seat of the fire and the fire continued to burn along the shelving. Air entrainment into the hot smoke was primarily from the action of the sprinklers and this resulted in a substantial increase in the volume of smoke, although at a lower concentration. The effect of the edges of the test structure on air entrainment was considered to be small. The heat generated from the fire ensured that the smoke was sufficiently buoyant away from the test structure. Thus it was possible to stand in the burn hall for the majority of the test. The building was evacuated when smoke descended to about 1.5 m from the floor after 12 minutes.

Immediately *after* activation of the first sprinkler head, the temperature of the air close to the soffit dropped to less than 100°C. At the highest part of the burn hall (representative of the "hot layer" away from the immediate fire location) the air temperatures were less than 40°C.

The temperatures of the light steel members located directly above the fire were less

Fire spread to the other rack did not occur and the measured radiation at this shelf reached a maximum of 6.6 kW/m^2.

Test 2 — This fire is representative of one of the most severe non-sprinklered fires, in terms of the quantity and rate of smoke production, and in terms of the air temperatures associated with the fire. As with the previous test, this was due to the combination of predominantly plastic combustibles arranged in shelving such that "vertical" surfaces were created which greatly increased the rate of fire growth.

in the vicinity of the test structure, the air temperatures at the soffit reached a maximum of 1200°C and the steel temperatures reached a maximum of about 950°C. Unfortunately data associated with this test was lost and it would appear, at least as far as the steel temperatures are concerned, that higher temperatures would have achieved later in the test. Extensive spalling of the ground floor slab on which the test structure was supported occurred.

The temperature of the air at the highest level within the burn hall reached a maximum of 320 °C.

It was possible to remain within the burn hall during the test until approximately 7 minutes at which point the smoke layer began to descend rapidly to the floor.

Test 3 — In this test the shelves were higher and closer spaced than for Test 1, and although the arrangement was acceptable under AS21 18 [3], it was clear from the spray patterns that little water would be expected to reach the seat of the fire.

Interestingly, in both this test and Test 4, it took a very considerable time for the fire to develop due to the relatively compact nature of the combustibles. In the case of such a fire starting in a shopping centre, it is most likely that the fire would be noticed by an occupant or detected by a smoke detector, before it built to the size required to activate the sprinklers. Four sprinkler heads activated and the temperature of the air in the vicinity of the sprinklers reached around 200-250°C while the temperature of the steel members was between 85-240°C. At the highest part of the burn hall the air temperatures reached a maximum of 145°C.

It appears from these test results, that in a real sprinklered situation, many more than the four sprinkler heads would have been activated and this may have resulted in the sprinkler system being "overwhelmed". However, sprinkler heads had been positioned between the racks, the fire would have been rapidly suppressed. It would therefore appear, from a property protection viewpoint, that location of the sprinkler heads between or over the storage racks is desirable for this arrangement of combustibles.

It was possible to remain within the burn hall during the test until approximately 55 minutes at which point the smoke layer began to descend rapidly to the floor.

Test 4 — As noted for Test 3, this fire took a considerable time to develop and its presence would almost certainly have been noticed if the building was occupied. Once again, because of the significant quantity of non-cellulosic combustibles involved, this fire-became one of the most severe non-sprinklered fires likely to be encountered in a retail situation.

In the vicinity of the test structure, the air temperatures at the soffit reach a maximum of 1320°C and the steel temperatures reached a maximum of 4250°C which resulted in substantial deformation of the floor system as it resisted its self weight through catenary action which was enabled by the presence of larger cooler beams at the exterior of the test structure. The floor slab on which the test structure was supported suffered heavy spalling with pitting close to 50 mm deep.

The air temperature at the highest level within the burn hall reached a maximum of 360°C.

It was possible to remain within the burn hall during the test until approximately 34 minutes at which point the smoke layer began to descend rapidly to the floor.

Tests 5 -9 — A ceiling was present for all of these tests and this generally resulted in faster activation of the sprinklers due to the sprinklers being closer to the fire and the fact that the hot gases were directed onto the heads. The clothing burned vigorously, but once the sprinklers activated, the fires were rapidly controlled and reduced in intensity. Nevertheless, the clothing tended to shield the fire from the sprinklers so that the fire was not totally extinguished. The reality of this point was demonstrated by the fact that once the sprinklers were turned off, the fire redeveloped, and had to be put out manually or by turning the sprinklers on once again. Care should therefore be exercised in isolating sprinklers before the fire has been extinguished.

Shortly *after* activation of the sprinkler heads, the temperature of the air at the ceiling sprinkler heads dropped to generally less than 50°C. At the highest part of the burn hall the air temperatures were equal. to the ambient temperature.

As noted earlier, different forms of sprinklers were made the active heads in each of the tests in order to determine whether this had a significant impact on the level of smoke. It is difficult to see any significant difference in the level of smoke associated with each test. This is primarily due to the fact that the most important factor affecting the quantity of smoke produced is the amount of shielding offered to or by the combustibles. The painted flush plates were the slowest to activate and there did not appear to be any difference in response lime between the non-painted and painted normal response heads.

The smoke developed in these tests was sometimes buoyant. At other times during the test it formed cloud at ground level. This smoke was not life threatening and contained a high proportion of steam.

Tests 10-11— In both of these tests it took considerable time for the fire to build to a sufficient intensity for the sprinklers to be activated. It is believed that such fires in a shopping centre would most likely be detected by the occupants and extinguished before the sprinkler activated. A ceiling was also present for these tests. Once the sprinklers activated, the fires were rapidly controlled and reduced in intensity being extinguished by the sprinklers.

These tests (especially Test 11) allowed the development of a distinct hot smoke layer within the test enclosure due to the lengthy period before activation of the heads.

Shortly *after* activation of the sprinkler heads, the temperature of the air at ceiling level dropped to less than 50 °C. At the highest part of the burn hall. the air temperatures were equal to the ambient temperature.

The smoke developed in these tests was whiter than in Tests 5 to 9 and also contained substantial steam. The smoke outside the test enclosure was transparent and did not prevent a threat to the occupants within the test building. The painted flush plate sprinkler (Test 11) took longer to activate than the normal sprinkler head but this did not appear to have a significant impact on the amount of smoke generated.

5 CONCLUSIONS

The results of eieven full-scale fire tests, simulating fires in shopping centres under sprinklered and non-sprinklered conditions, are presented. These tests provide valuable data on the quantity and rate of smoke production, and on the impact of sprinklers on the air temperatures close to the fire and associated with the "hot smoke" layer.

The combination of non-cellulosic combustibles in rack storage with the active sprinkler heads remote from the location of fire ignition was found to give rise to substantial volumes of black smoke-but the rate of smoke production was significantly less than that associated with the corresponding non-sprinklered fires.

It was also found that the combination of high shelving at close spacing may lead to situations where the sprinkler system is overwhelmed, and in these cases, the sprinkler heads should be located between the racks of shelving.

The volume and severity of smoke resulting from sprinklered fires associated with shelving rack situations are likely to be much greater than in other situations-especially if sprinklers are not located between the racks.

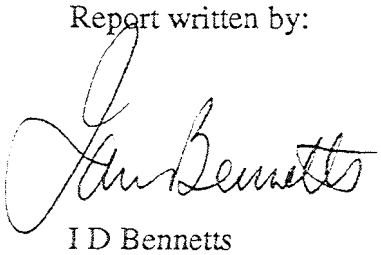
The volume of smoke generated by a sprinklered fire is more a consequence of the level of shielding against the sprinkler spray pattern, than the type of sprinkler head.

6 ACKNOWLEDGMENTS

The authors would like to acknowledge the substantial contribution of Entire Fire Protection who designed and supplied the sprinkler system used for the tests. The assistance of the Metropolitan Fire Brigade (particularly Station Officer P Wright, Inspector J Clampett (now with ABCB) and Acting Inspector M Coombes) in giving advice and providing fire-fighting appliances is also acknowledged. are recognised for their provision of sprinkler heads for Tests 5 to 11.

7 SIGNATURE PAGE

Report written by:



I D Bennetts
(representing
M Culton, M L Dickerson,
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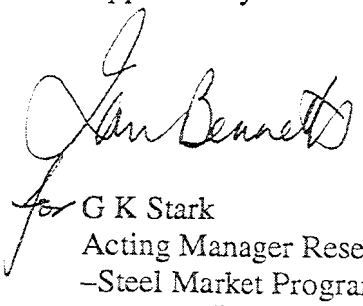
S L Poon, R Ralph)
BHP Research

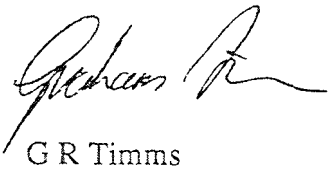
Approved by:



for G K Stark
Acting Manager Research
–Steel Market Programs

A C Lee
Building Control Commission

P F Beever
Victoria University of Technology



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(representing R J Cooper, P I Haggar,
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Scientific Services Laboratory

8 REFERENCES

1. Bennetts, I. M., Dickerson, M., Lewins, R. R., Poh, K. S. L., Ralph, R., Lee, A. C., and Beever, P. F., "Shopping Centre Review", (Fire Code Reform Centre Project 6), BHP Research Report No. BHPR/SM/R//G/058, January 1997.
2. Drysdale, D, "An Introduction to Fire Dynamics", Chichester, Wiley - Interscience, 1986.
3. *Fire Sprinkler Systems (SAA Code for* ***Automatic Fire Sprinkler Systems),*** 1982.

APPENDIX A: AIR TEMPERATURES

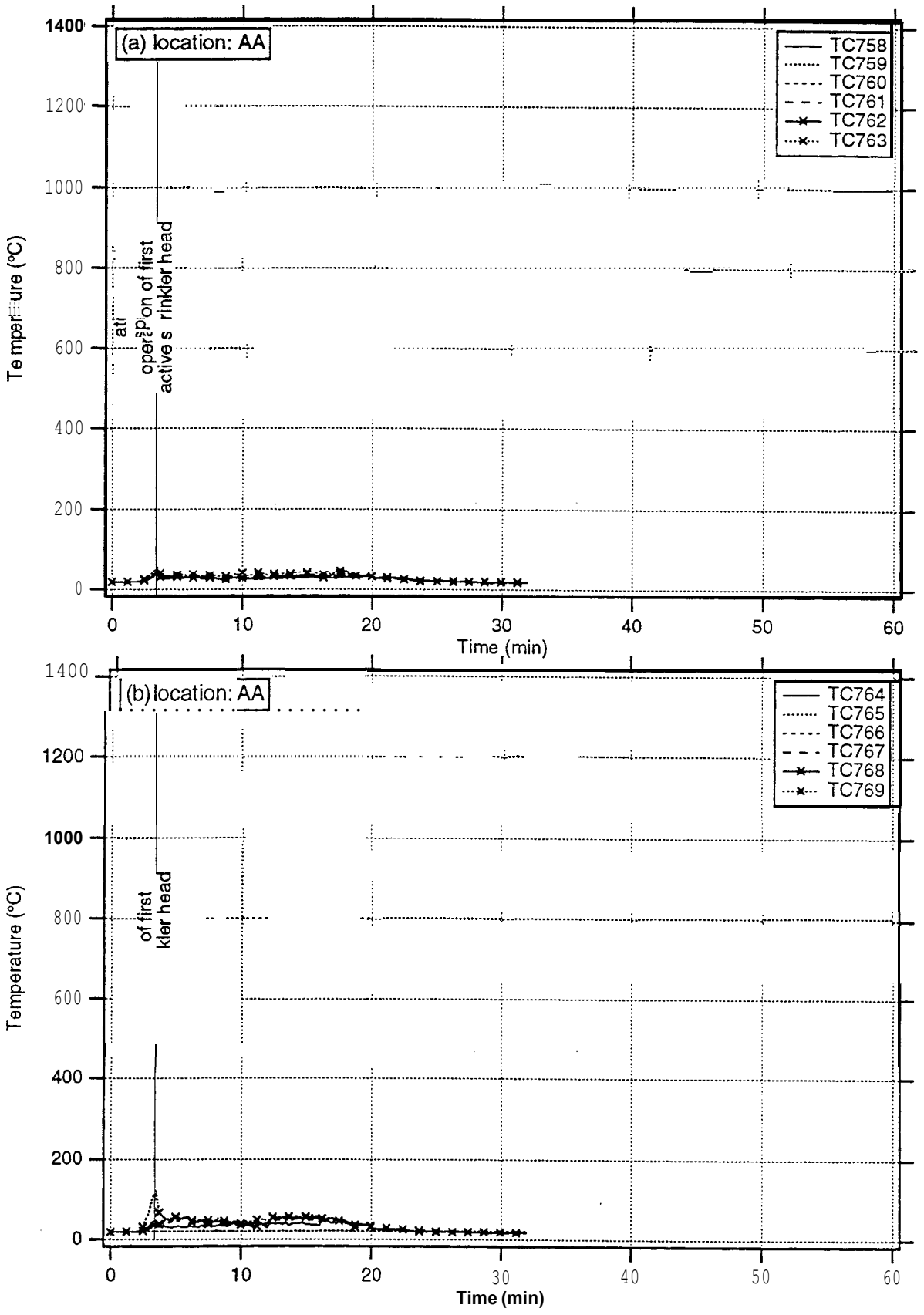


FIGURE A1(A)AND (B) AIR TEMPERATURES - TEST 1

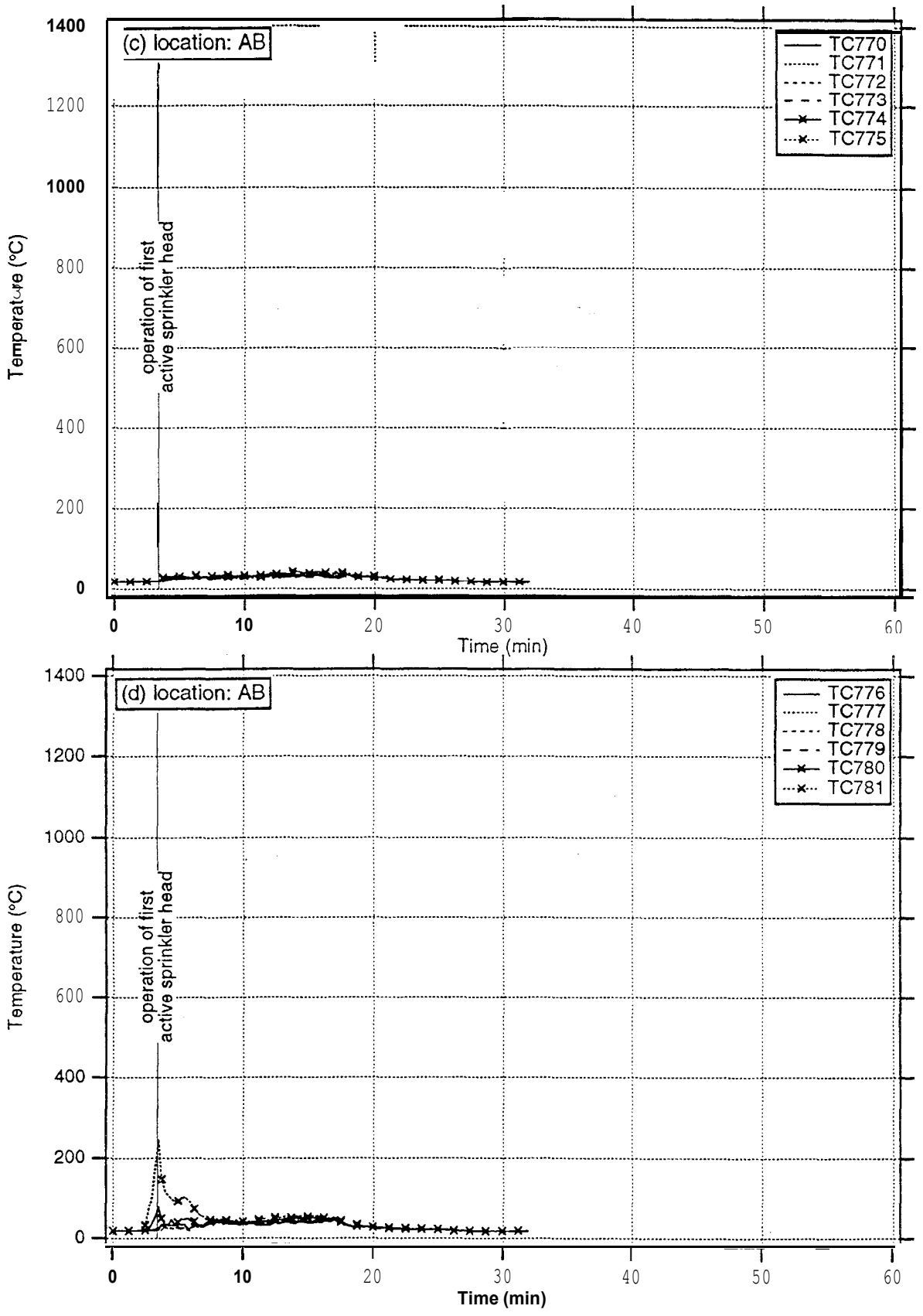


FIGURE A1(C)AND (D) AIR TEMPERATURES - TEST 1

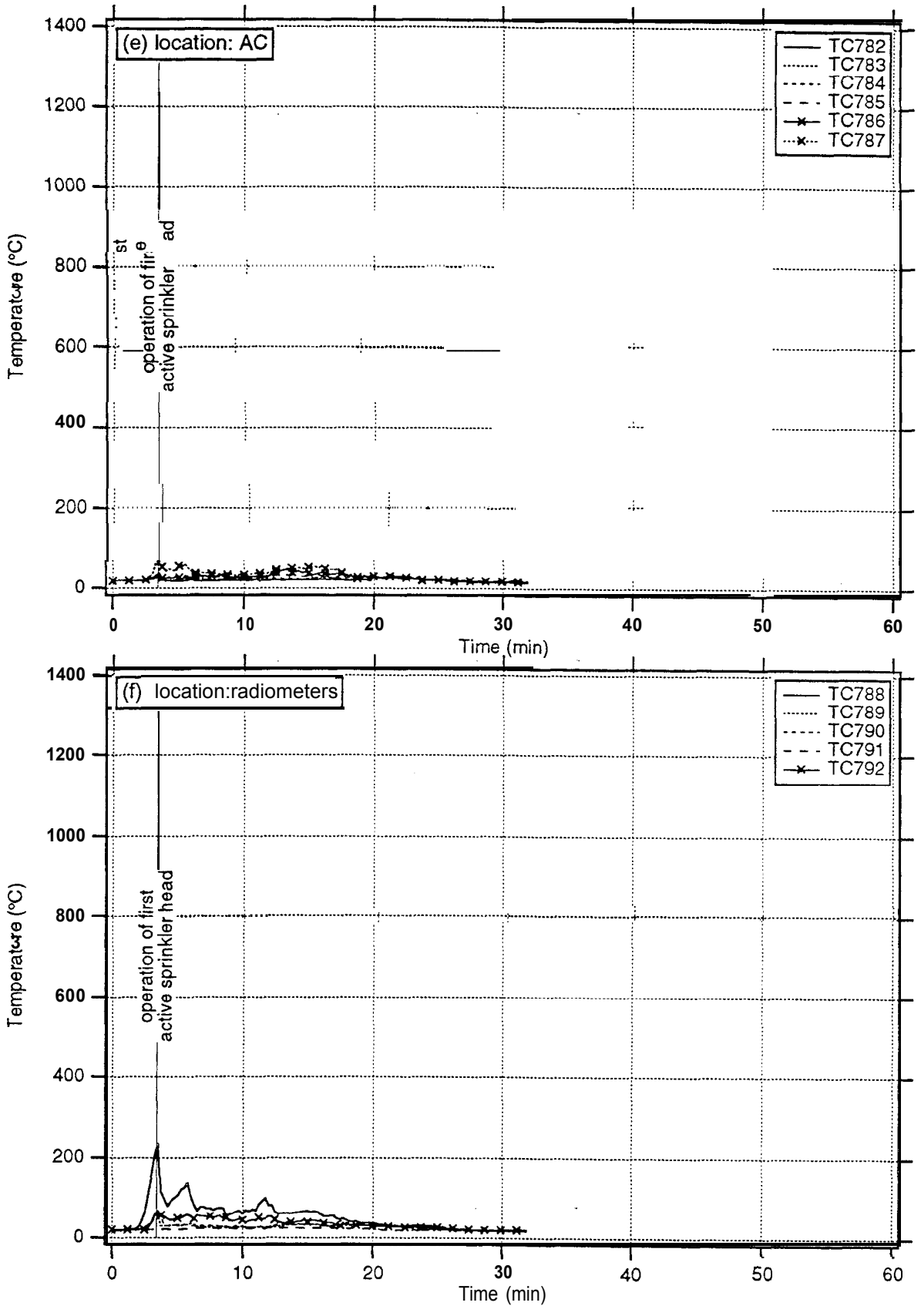


FIGURE A1 (E) AND (F) AIR TEMPERATURES - TEST 1

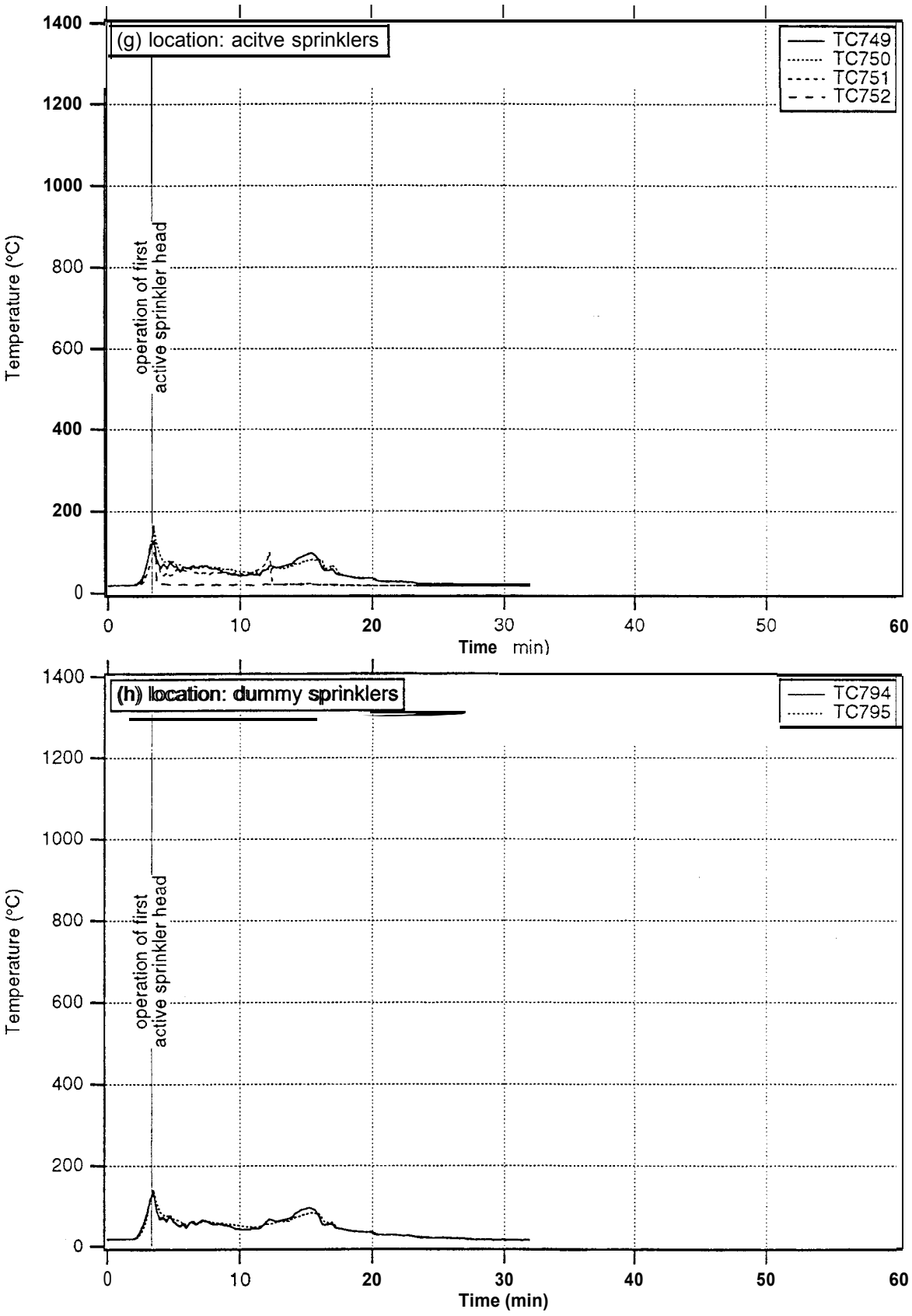


FIGURE A1 (G) AND (H) AIR TEMPERATURES-TEST 1

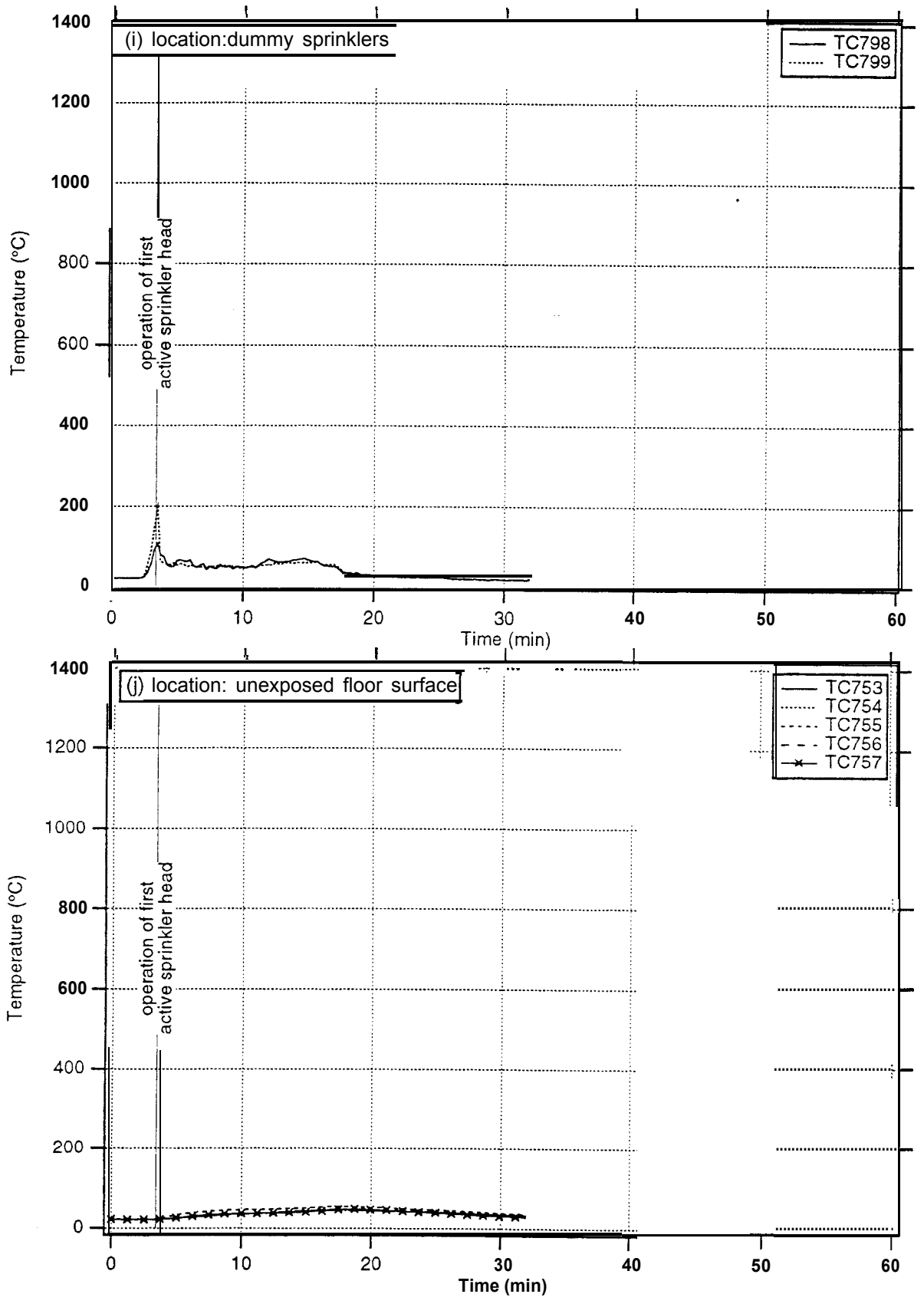


FIGURE A 1 (I) AND (J) AIR TEMPERATURES - TEST 1

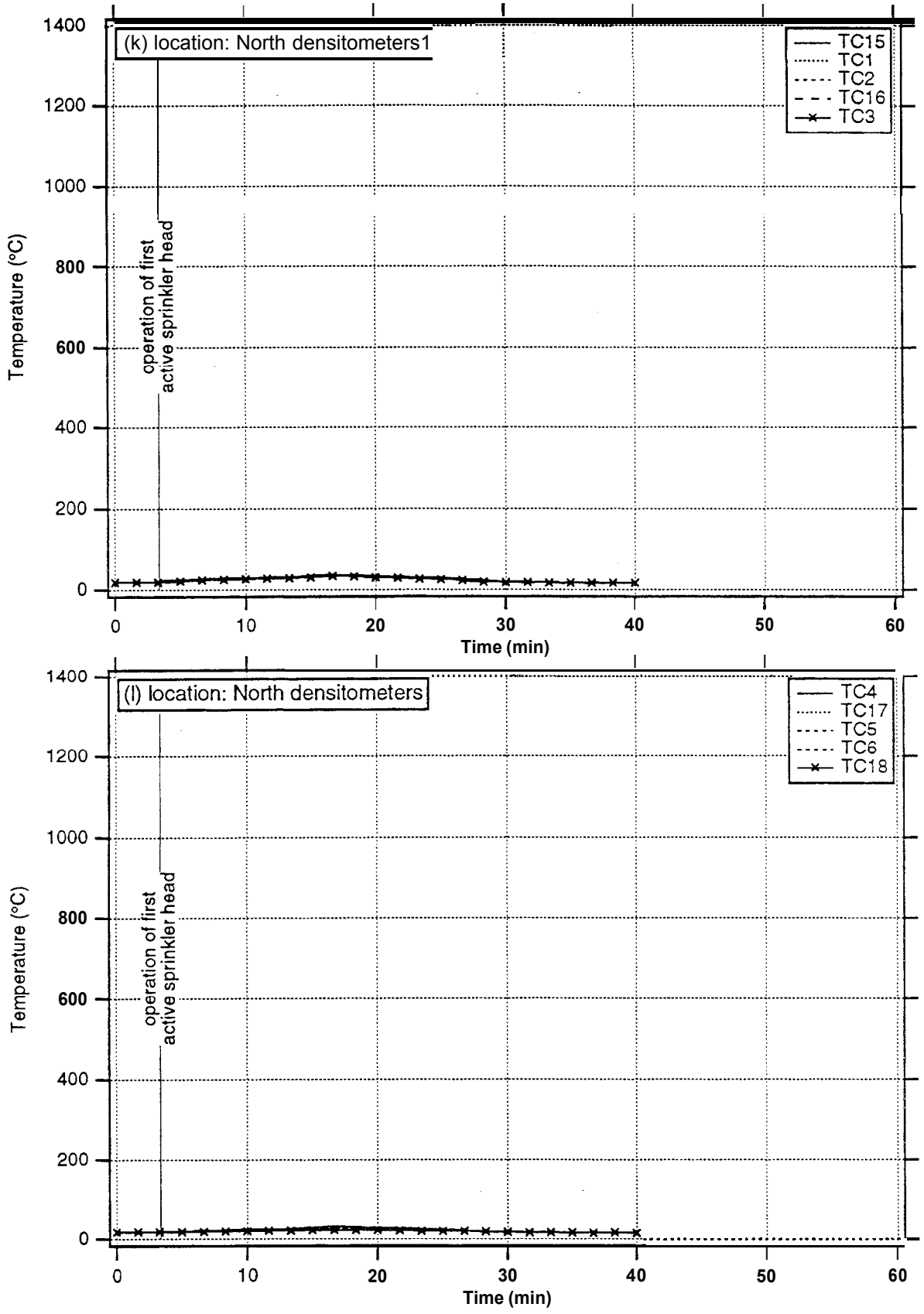


FIGURE A1(K) AND (L) AIR TEMPERATURES - TEST 1

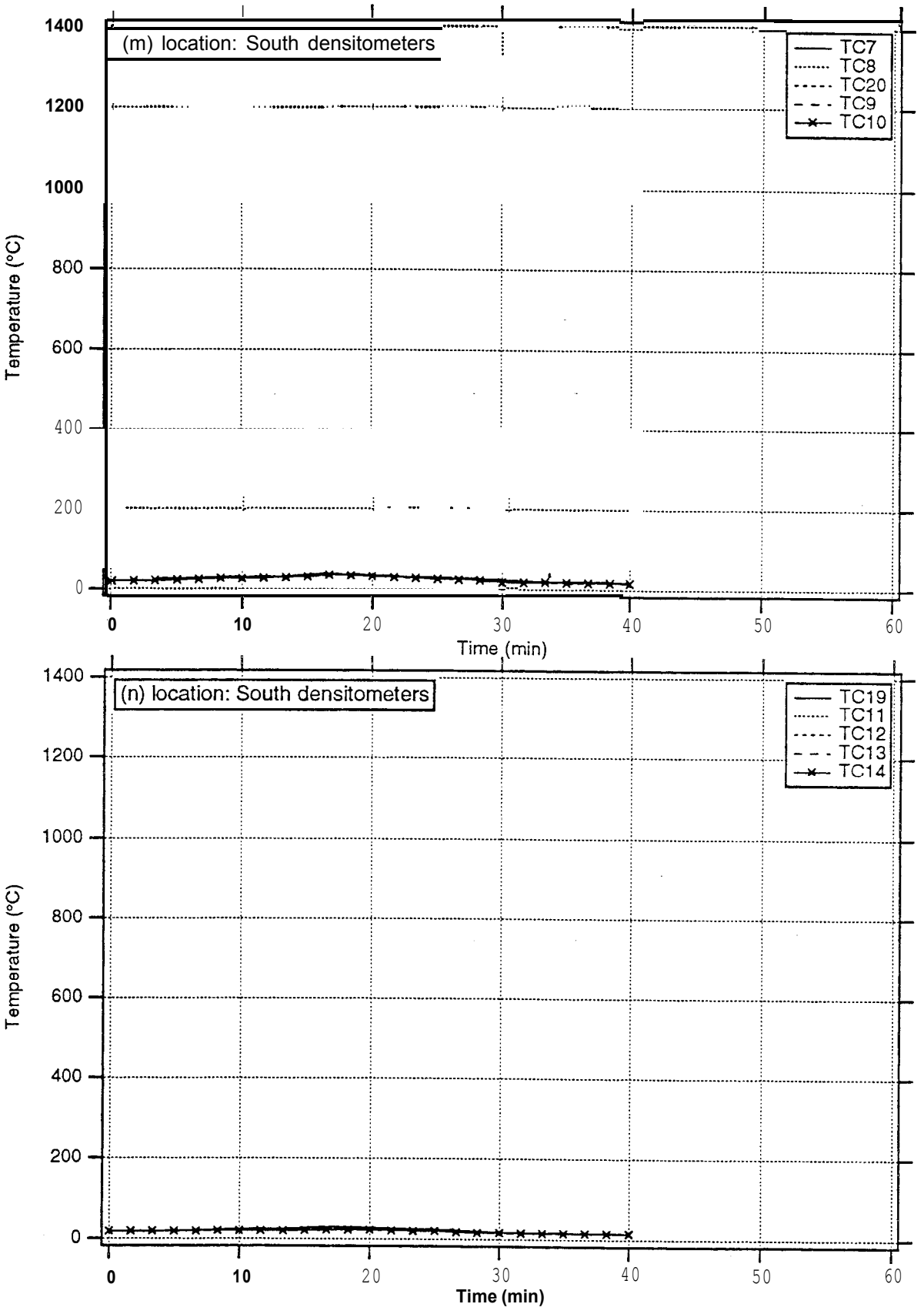


FIGURE AI (M) AND (N) AIR TEMPERATURES - TEST 1

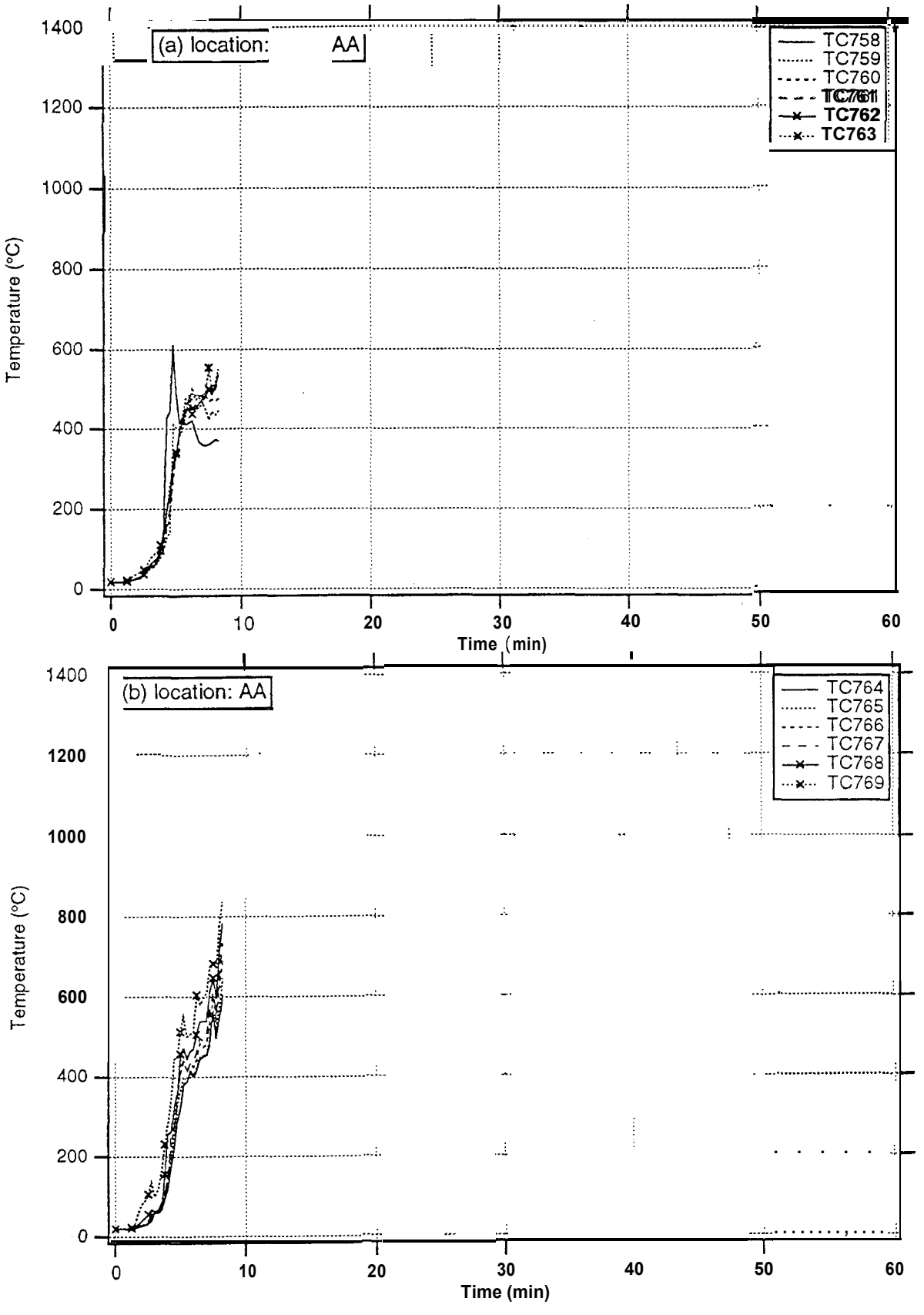


FIGURE A2(A) AND (B) AIR TEMPERATURES-TEST 2

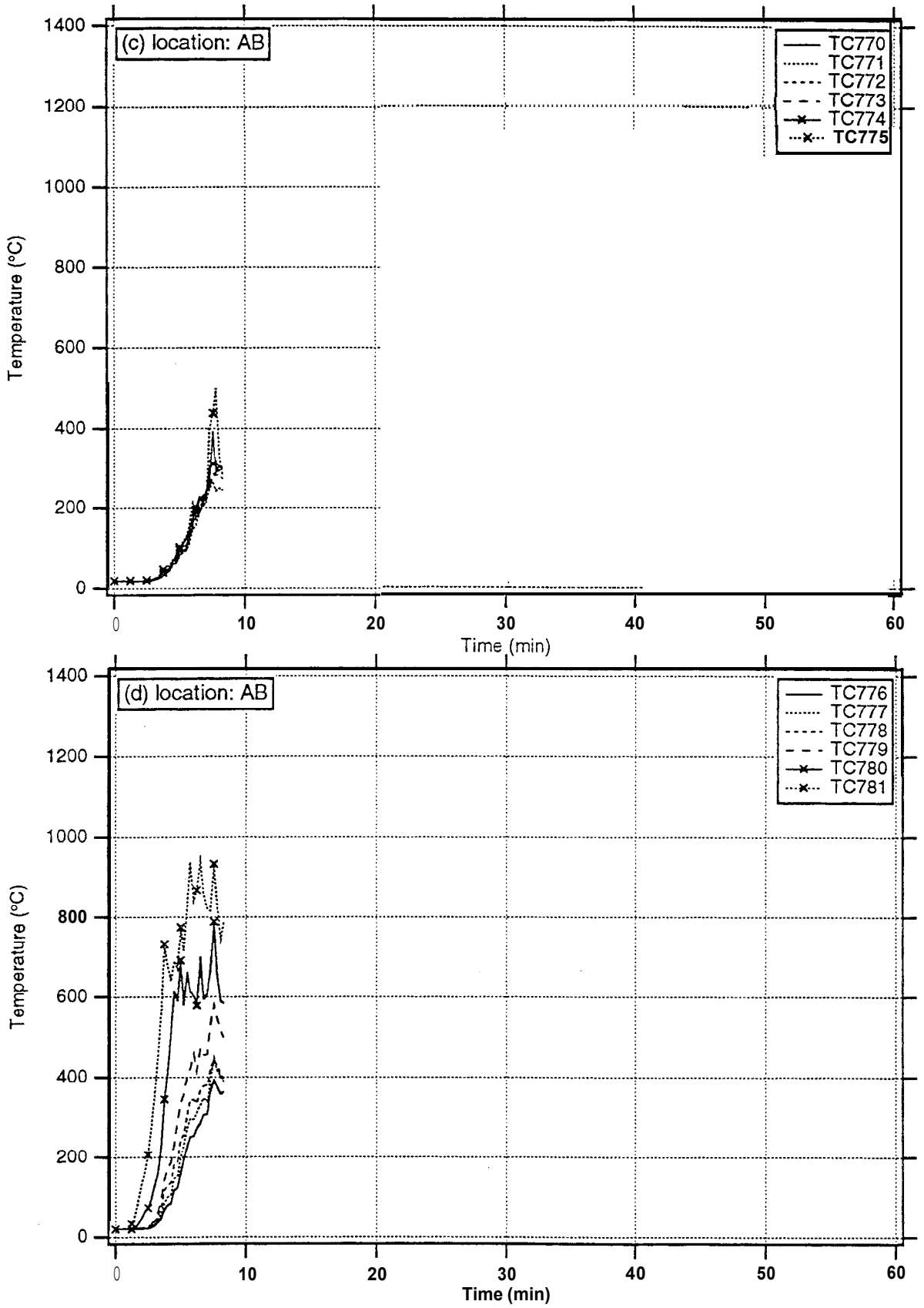


FIGURE A2(C) AND (D) AIR TEMPERATURES -TEST 2

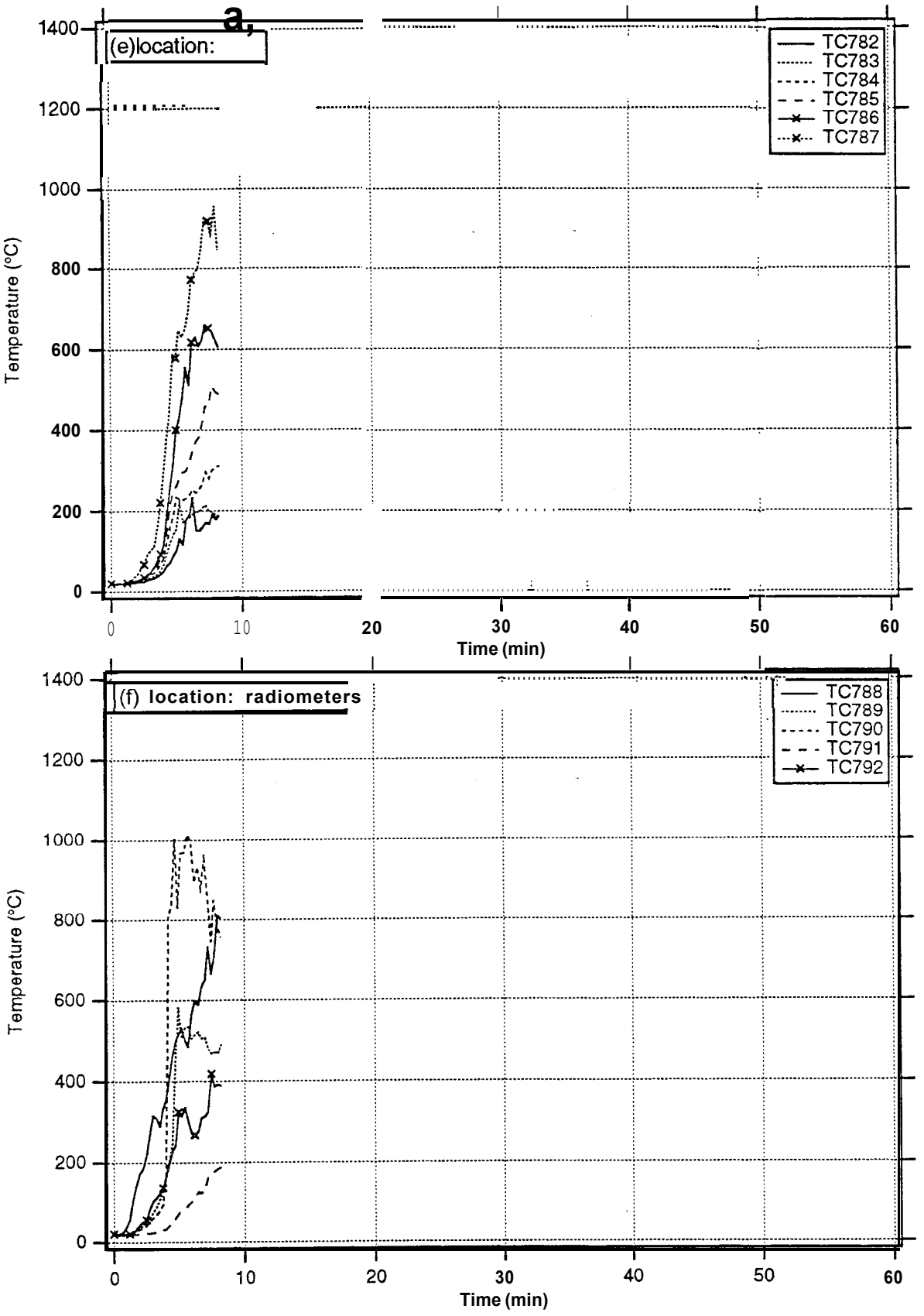


FIGURE A2(E) AND (F) AIR TEMPERATURES - TEST 2

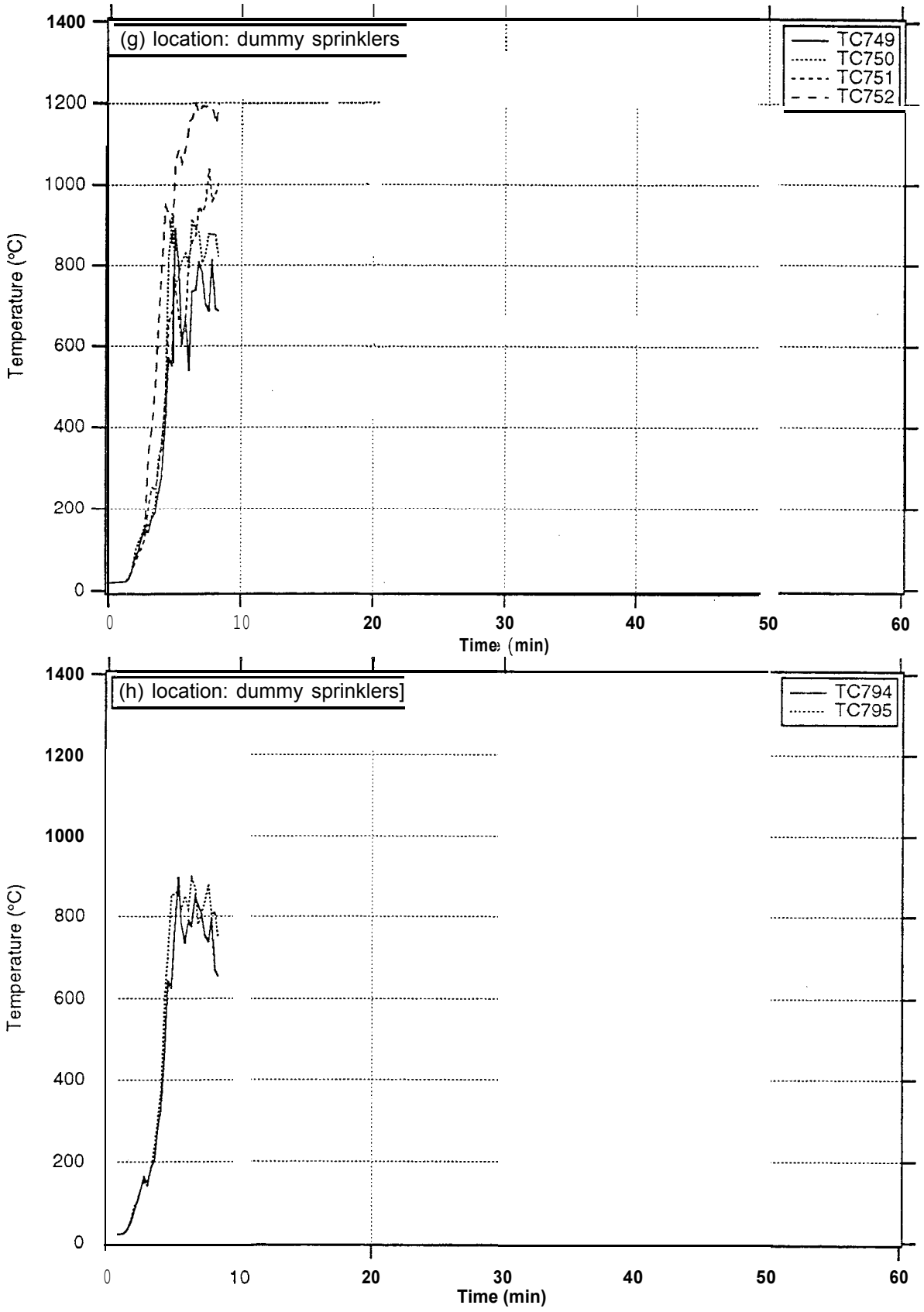


FIGURE A2(G) AND (H) AIR TEMPERATURES - TEST 2

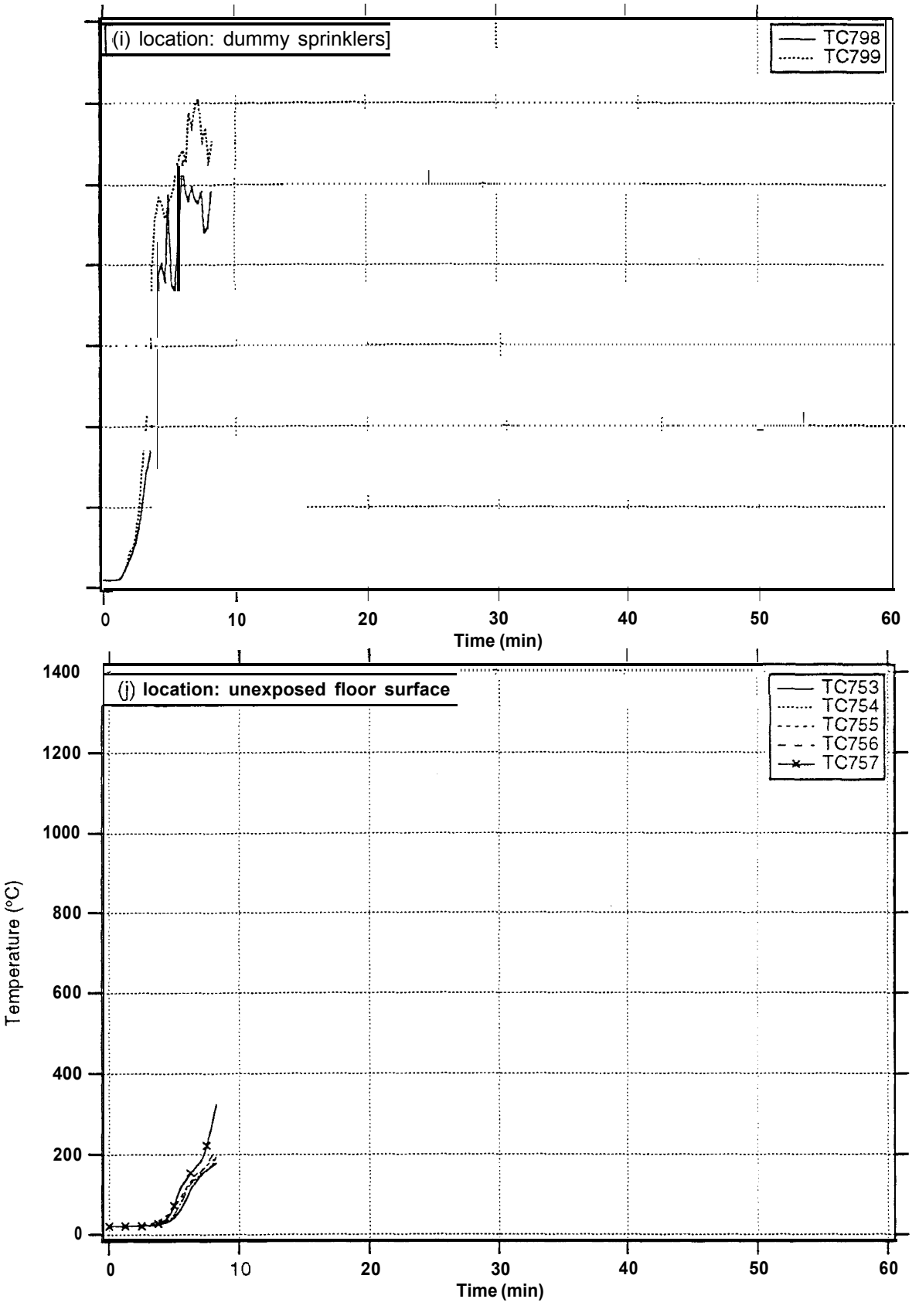


FIGURE A2(I) AND (J) AIR TEMPEFUTURES-TEST 2

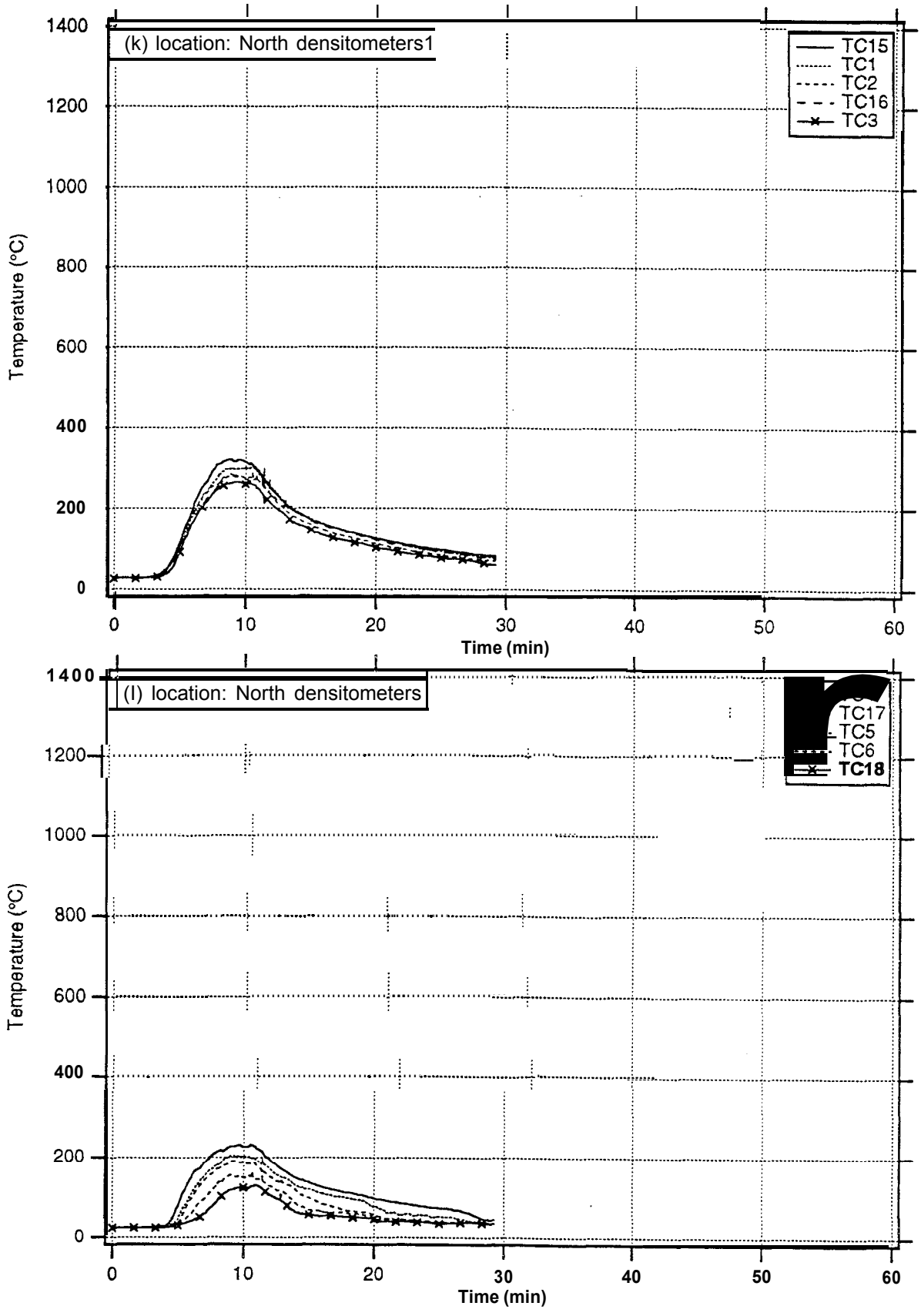


FIGURE A2(K) AND (L) AIR TEMPERATURES - TEST 2

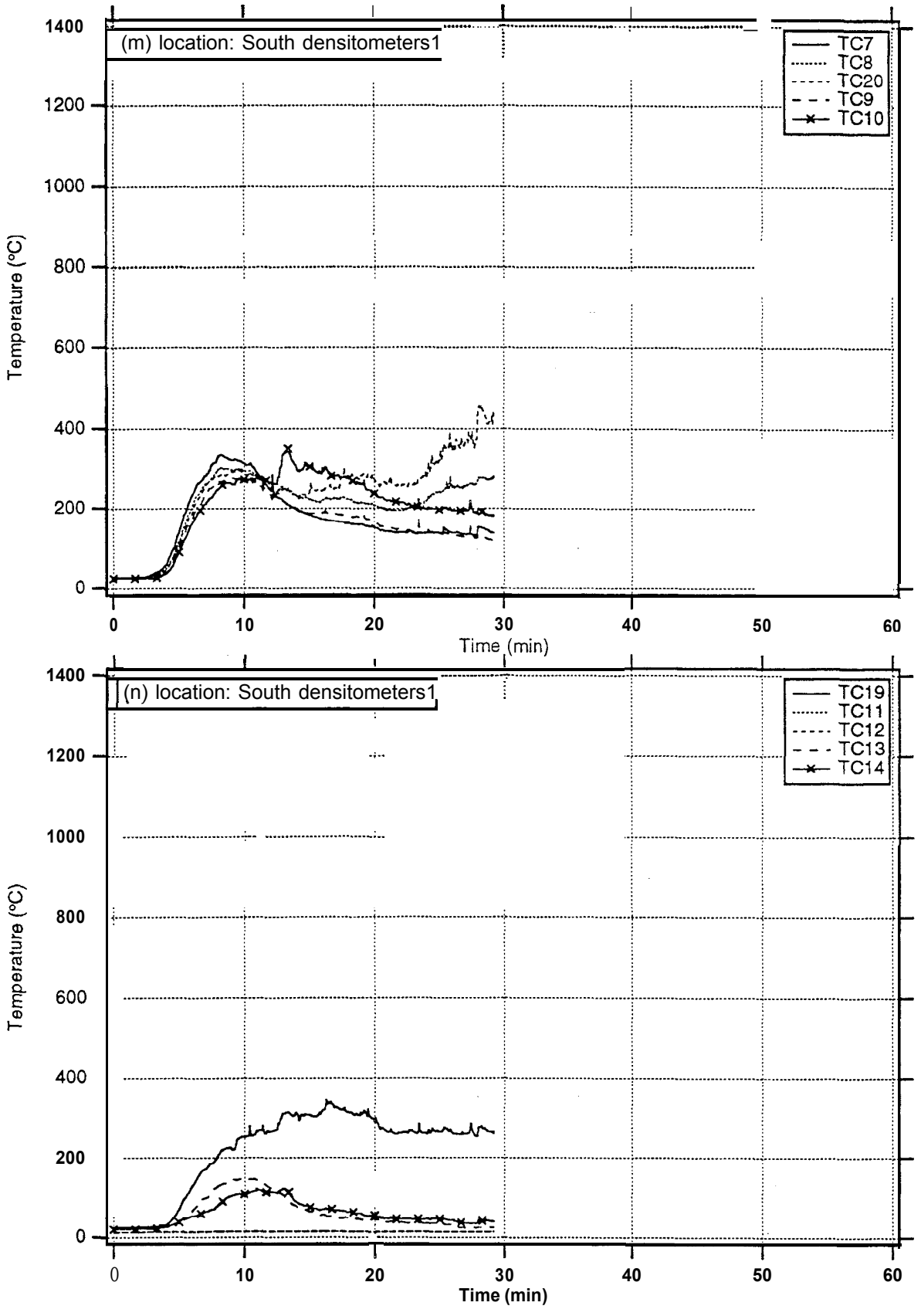


FIGURE A2(M) AND (N) AIR TEMPERATURES - TEST 2

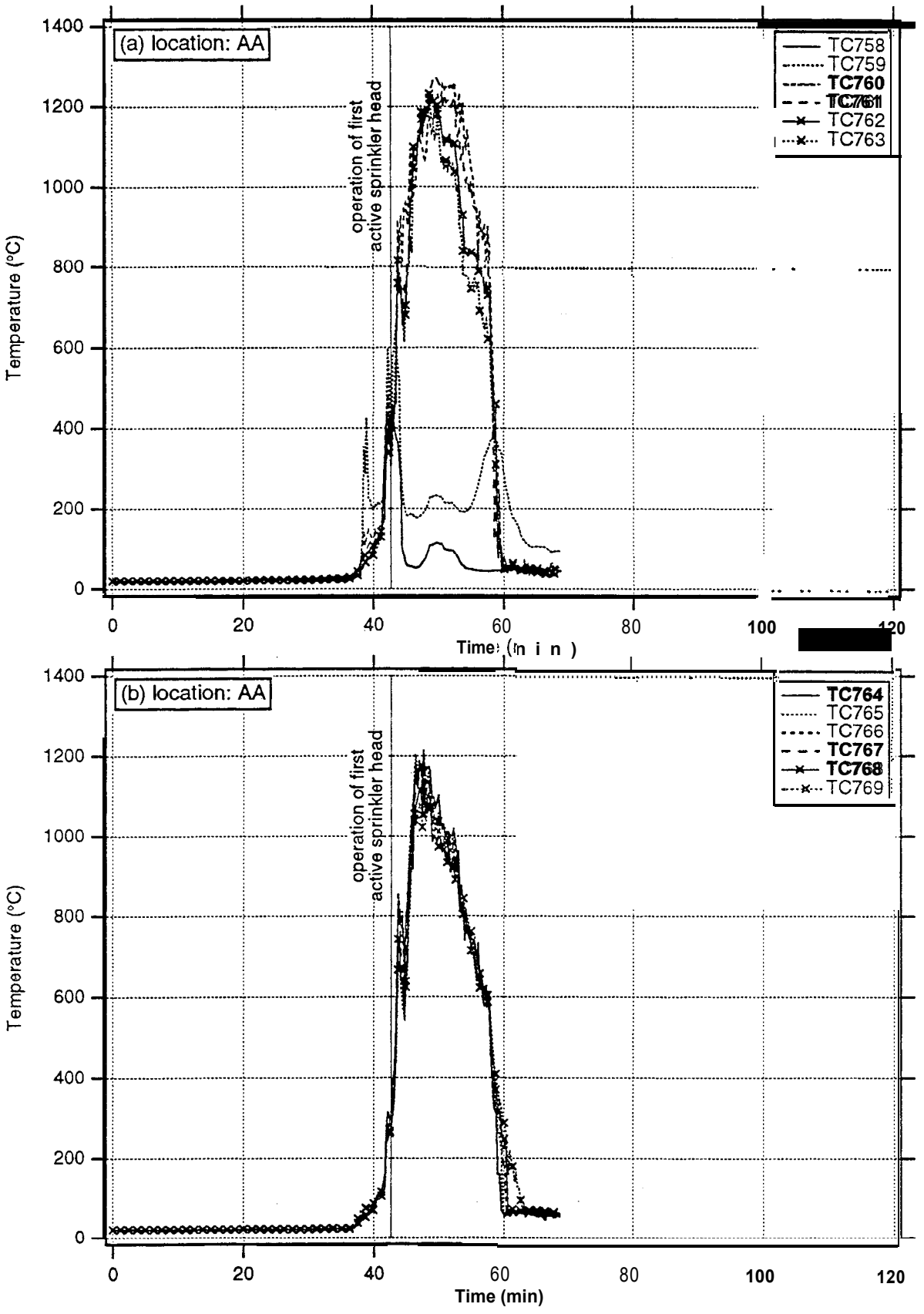


FIGURE A3(A) AND (B) AIR TEMPERATURES - TEST 3

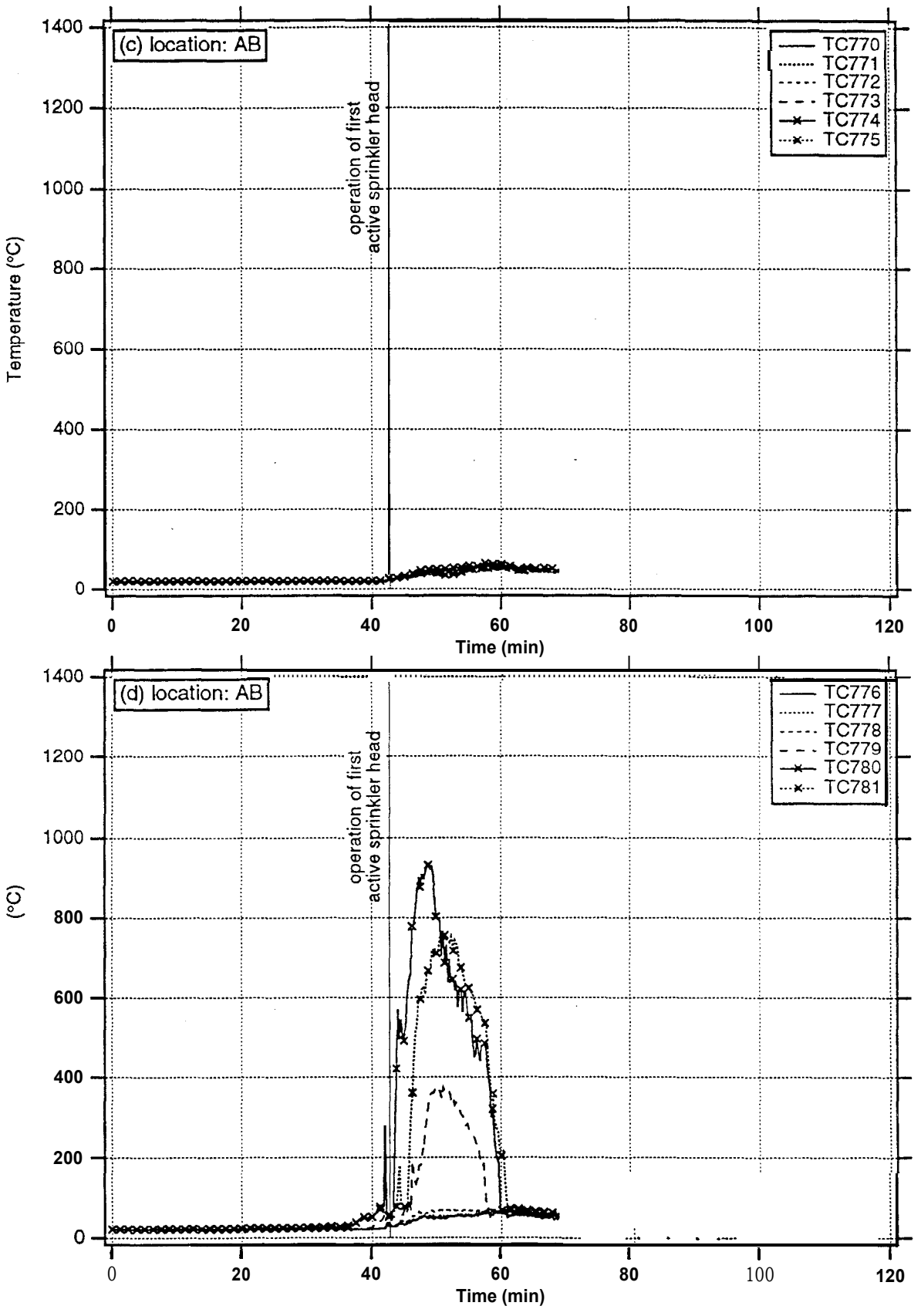
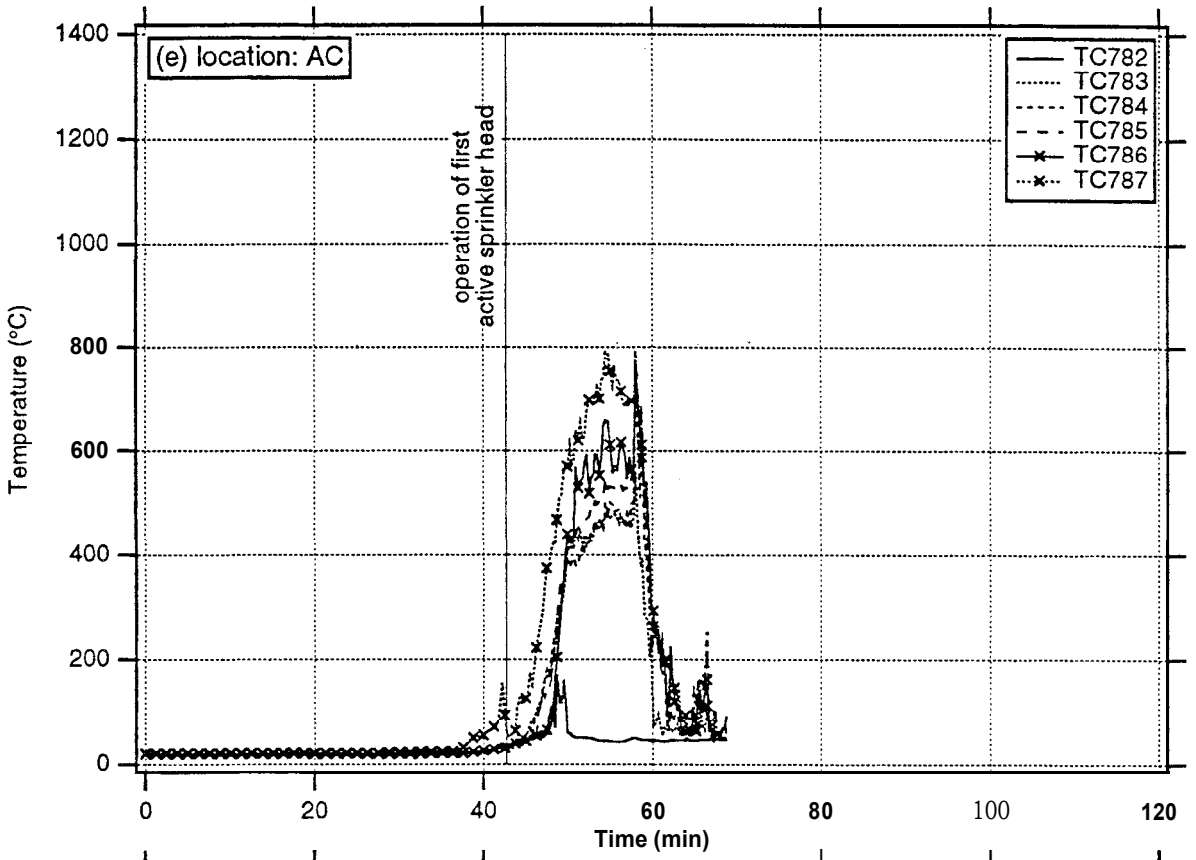


FIGURE A3(C) AND (D) AIR TEMPERATURES - TEST 3



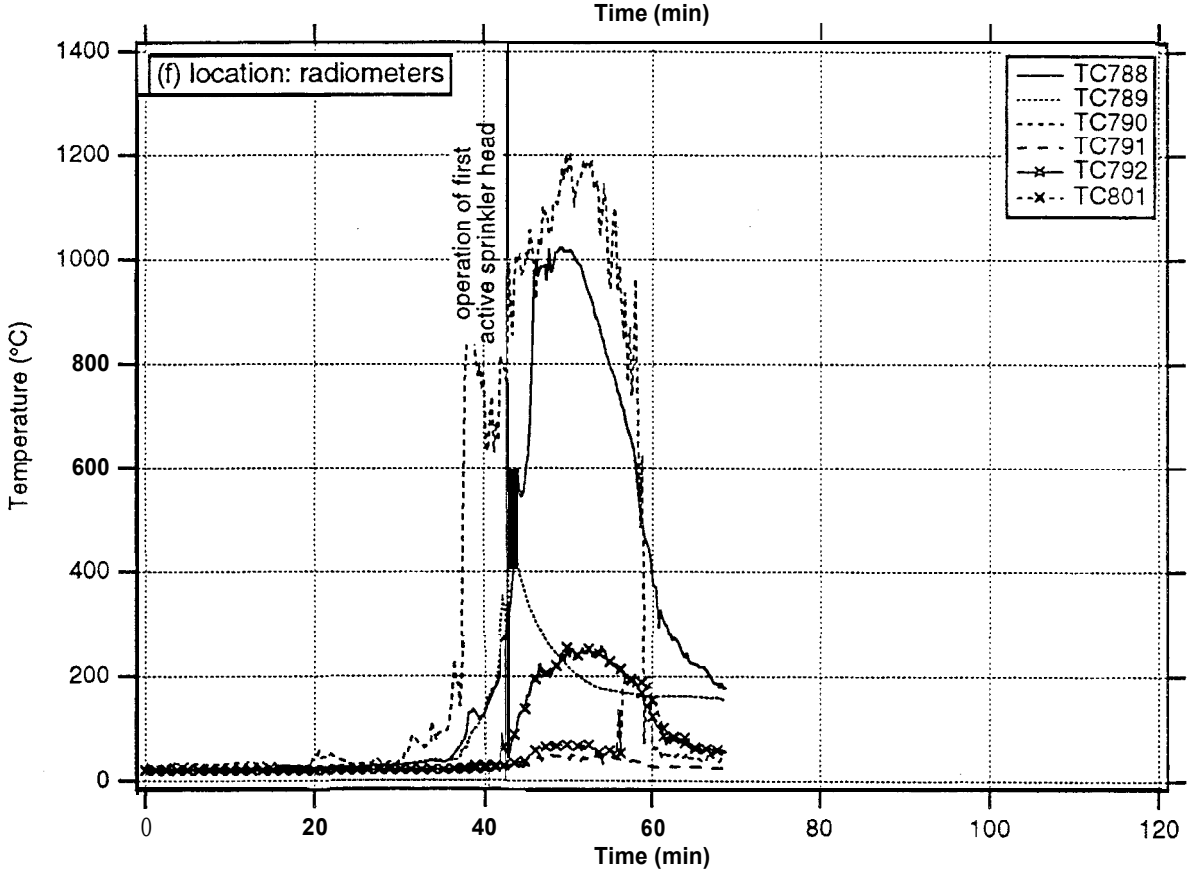
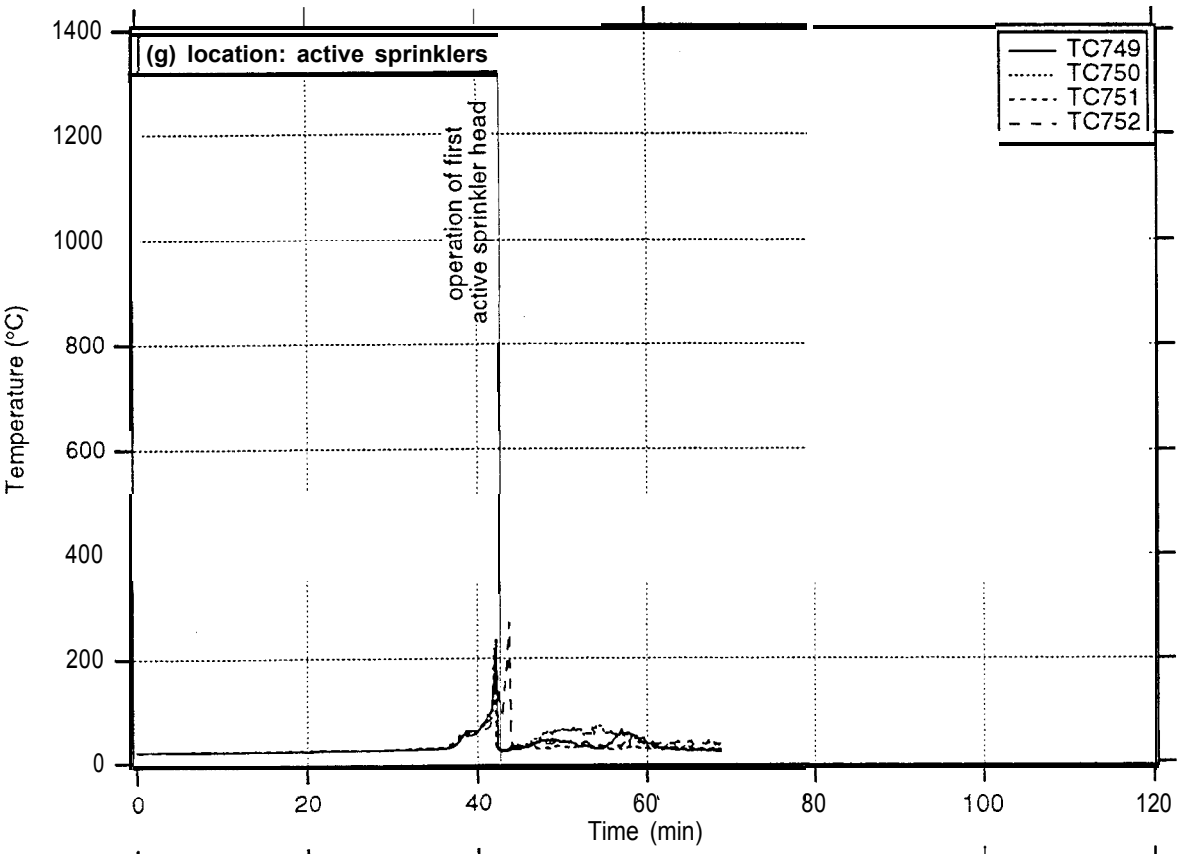


FIGURE A3(E) AND (F) AIR TEMPERATURES - TEST 3



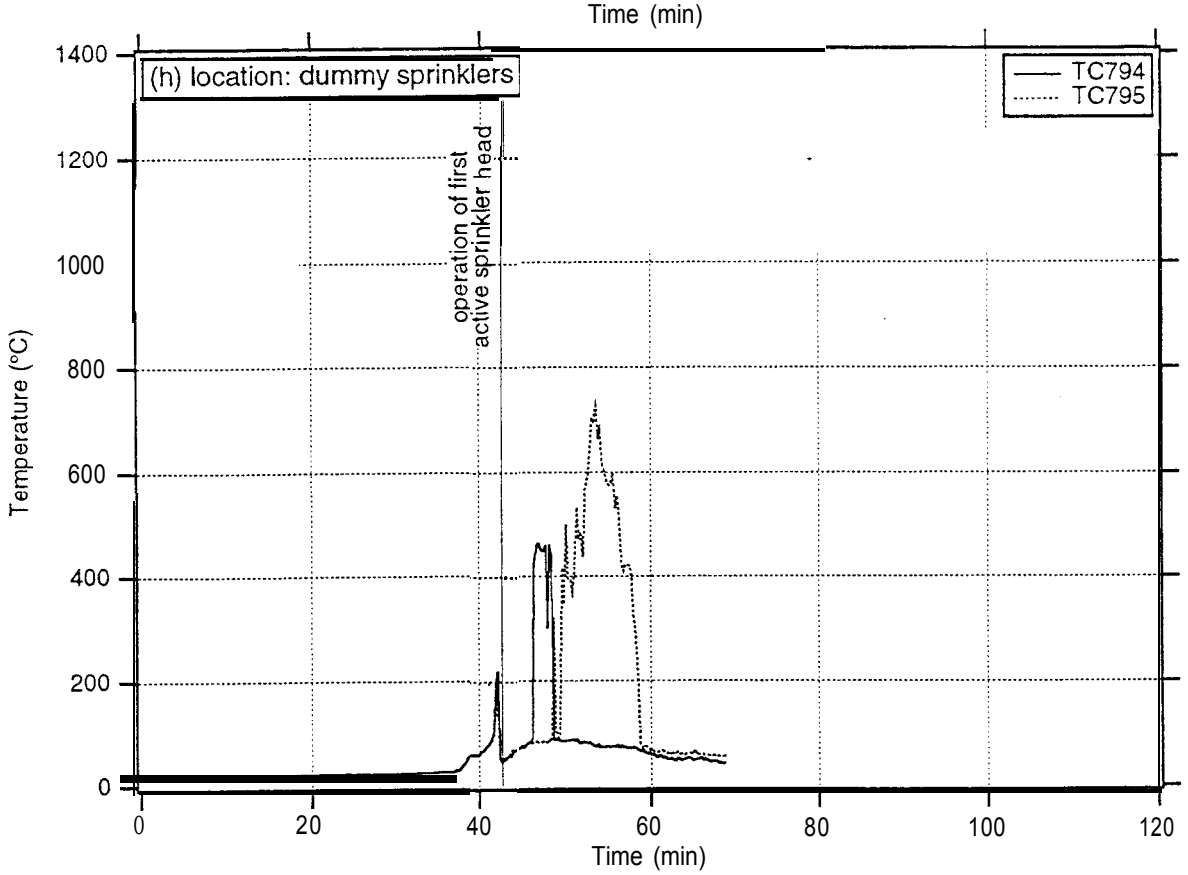


FIGURE A3(G) AIR TEMPERATURES - TEST 3

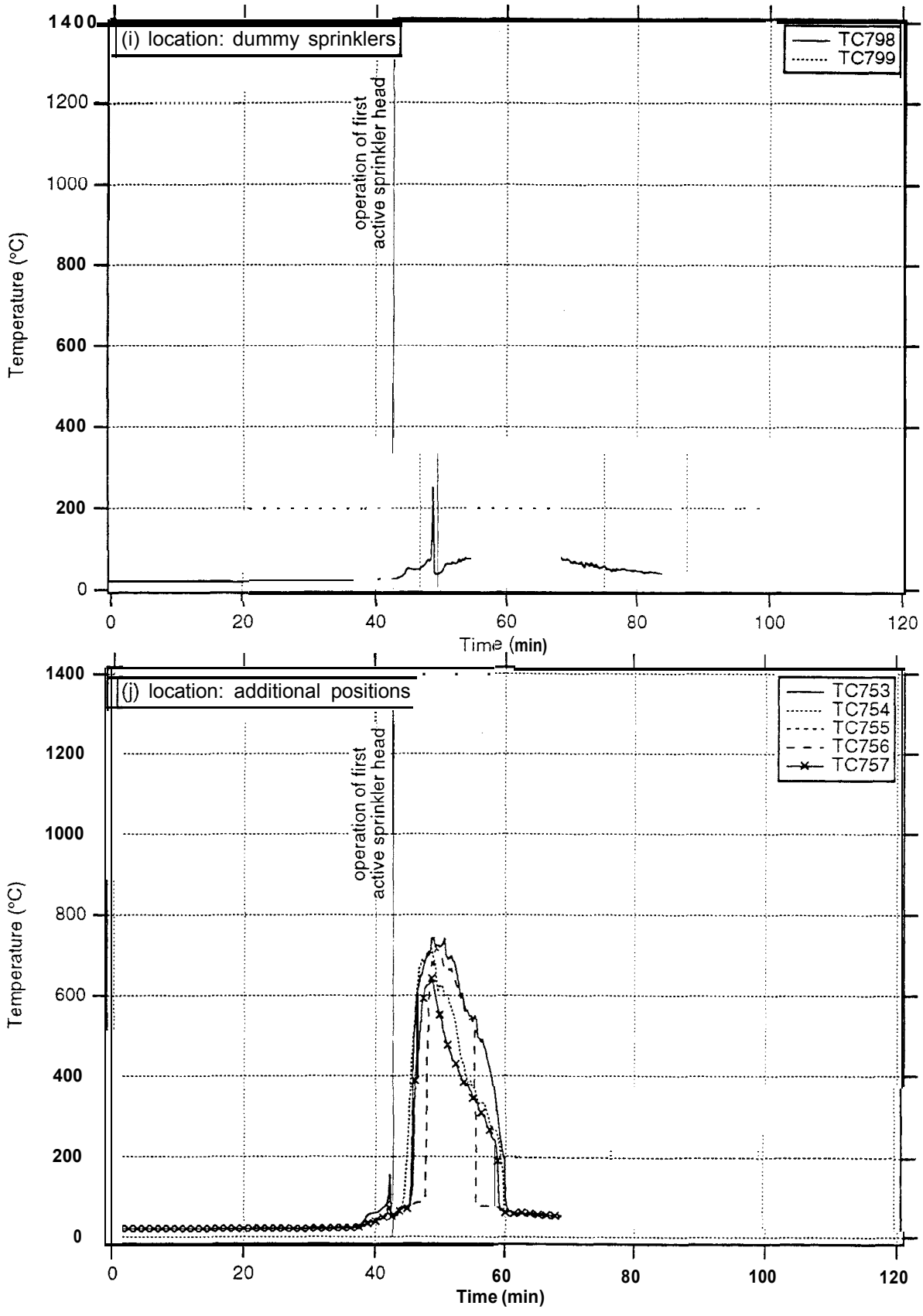


FIGURE A3(I) AND (J) AIR TEMPERATURES - TEST 3

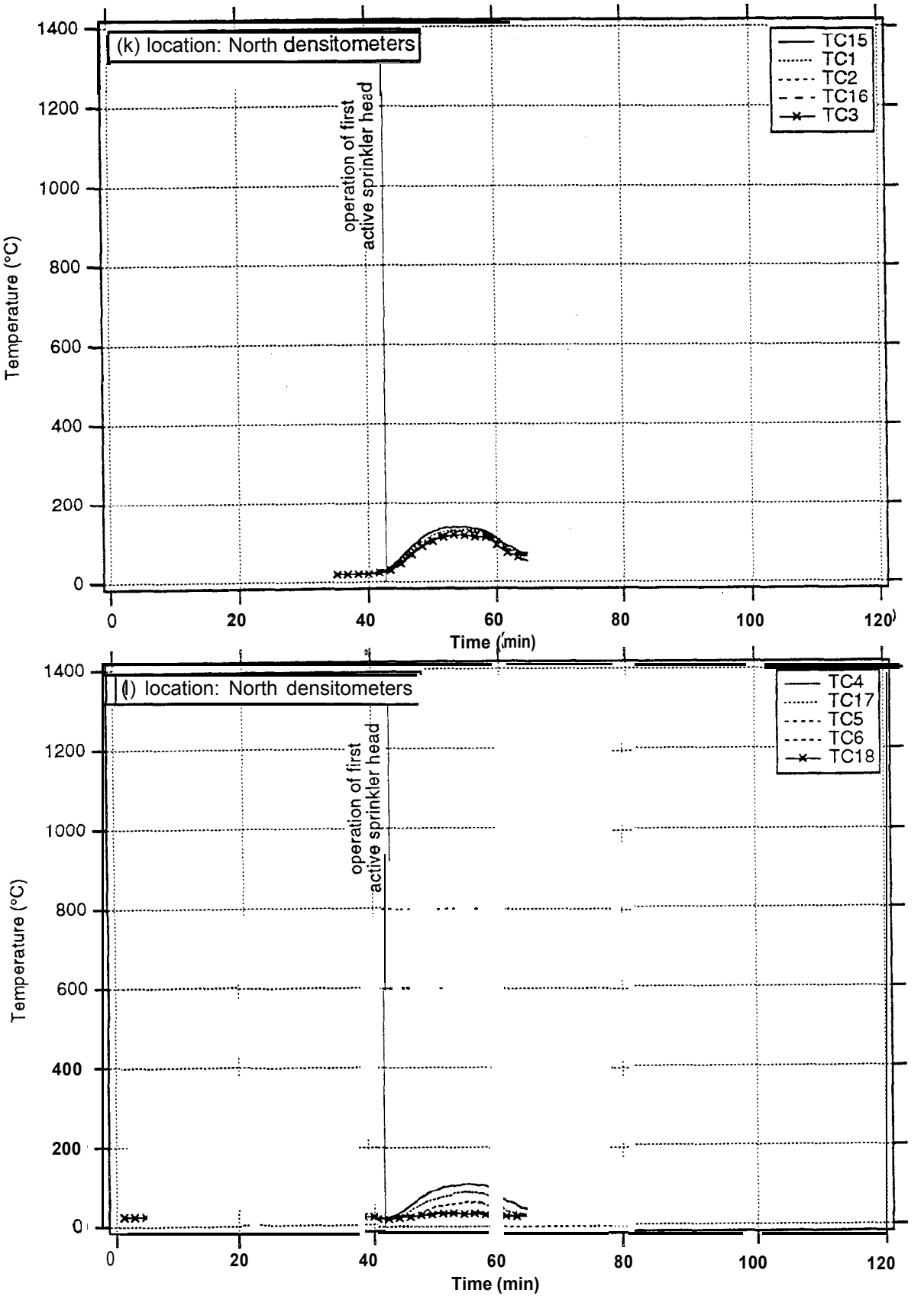


FIGURE A3(K) AND (L) AIR TEMPERATURES - TEST 3

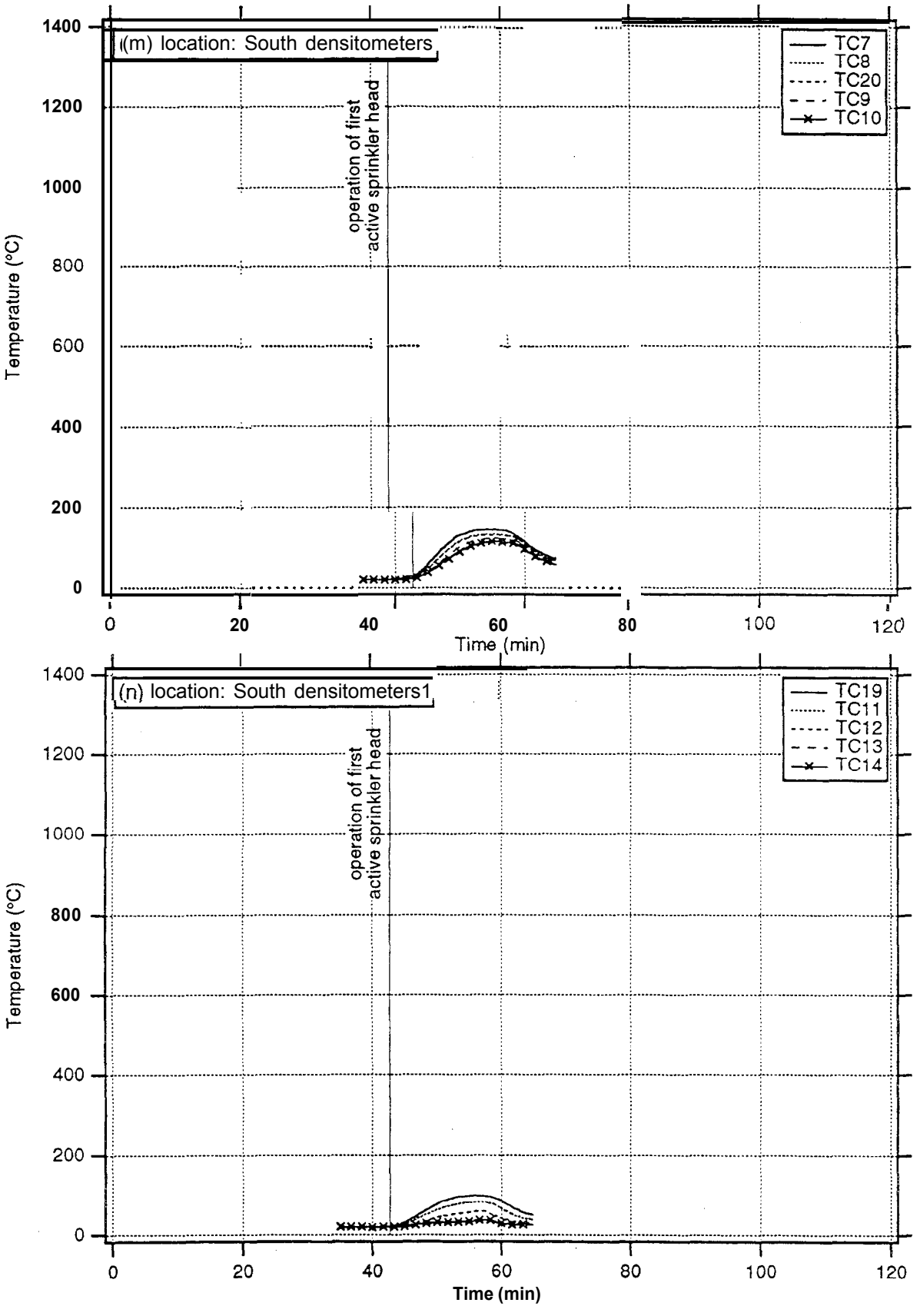


FIGURE A3(M) AND (N) AIR TEMPERATURES - TEST 3

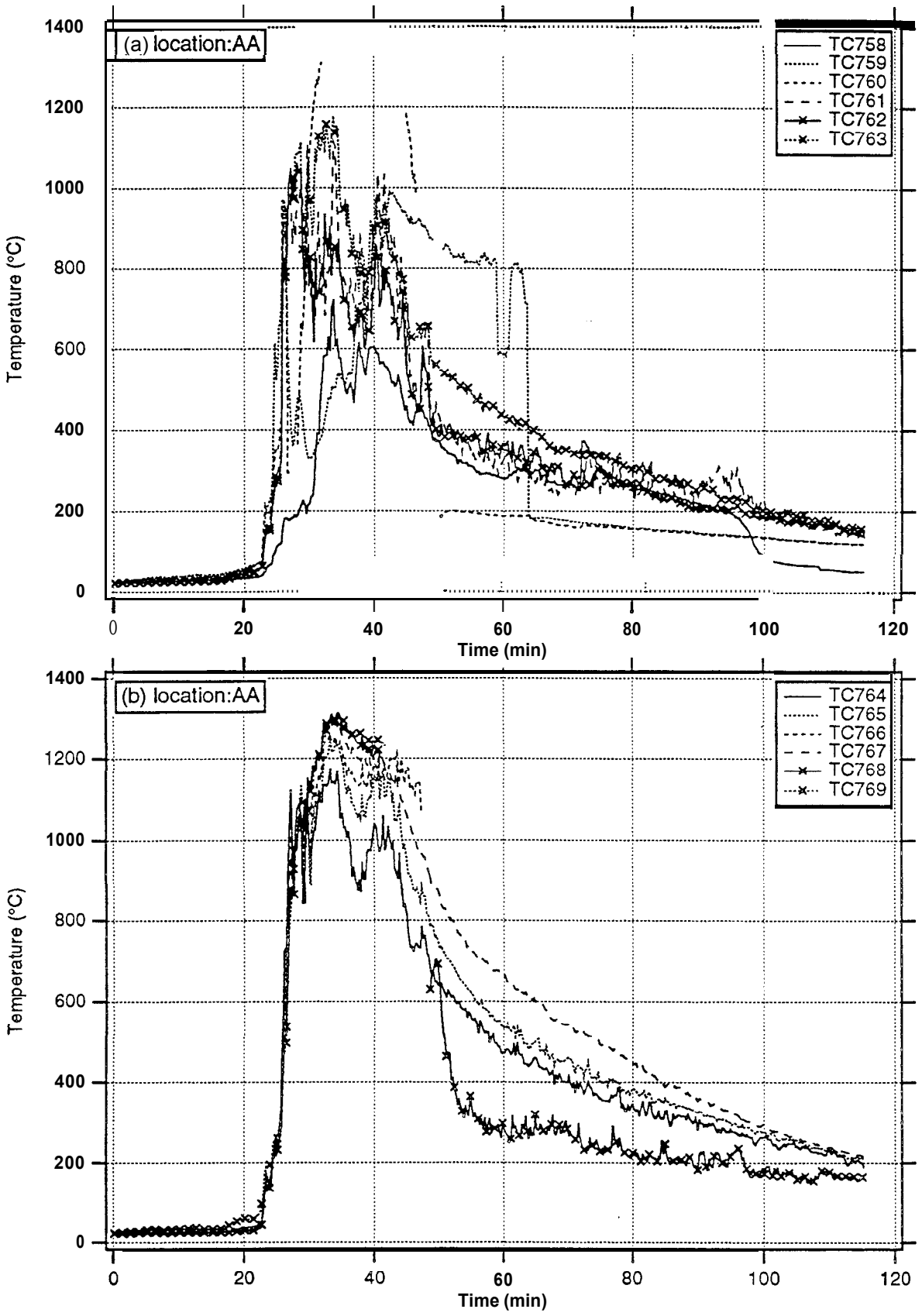
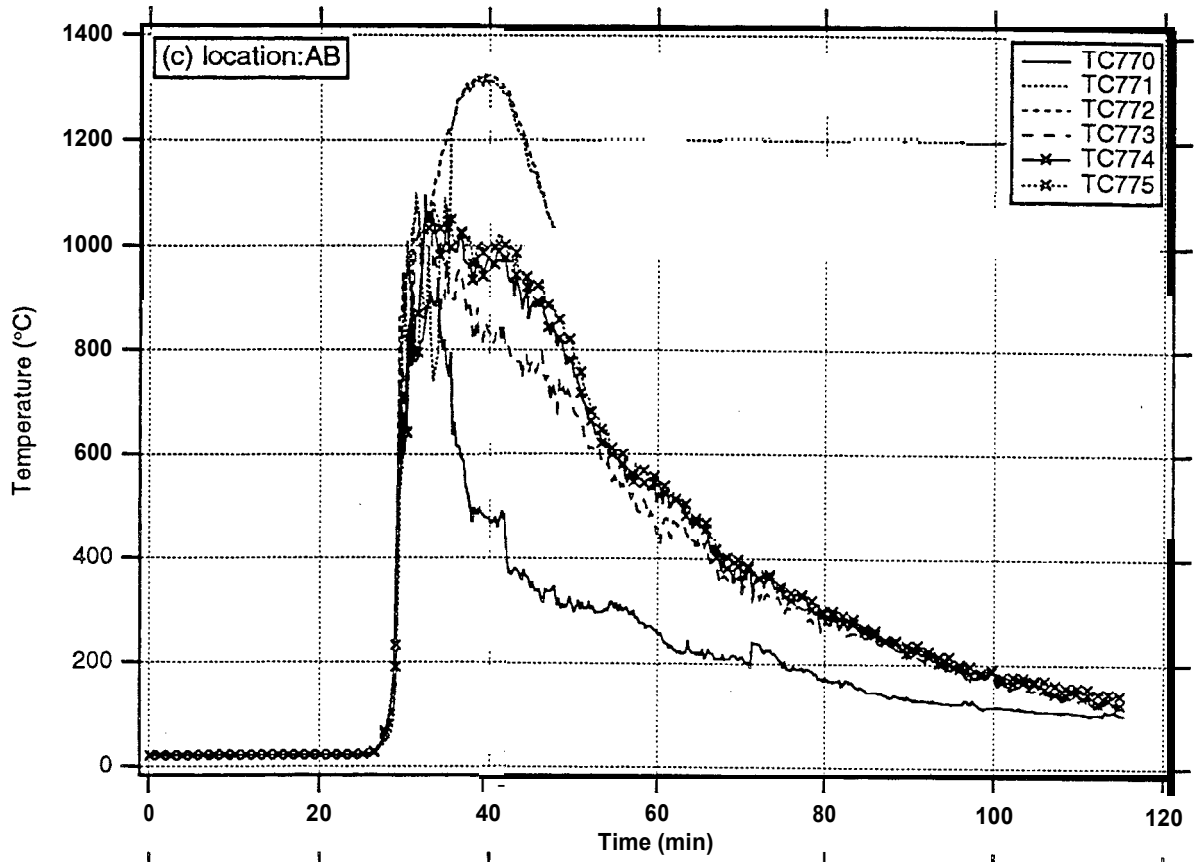


FIGURE A4(A) AND (B) AIR TEMPERATURES - TEST 4



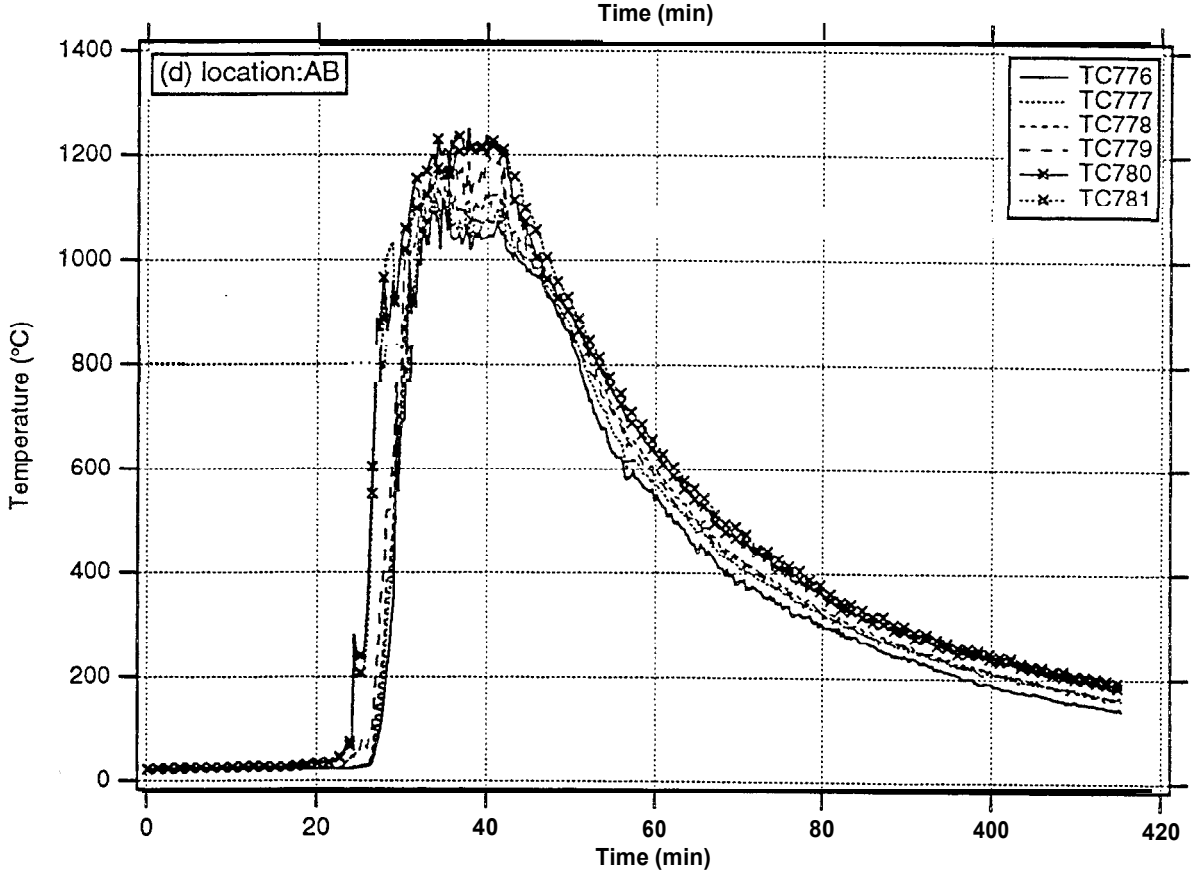


FIGURE A4(C) AND (D) AIR TEMPERATURES - TEST 4

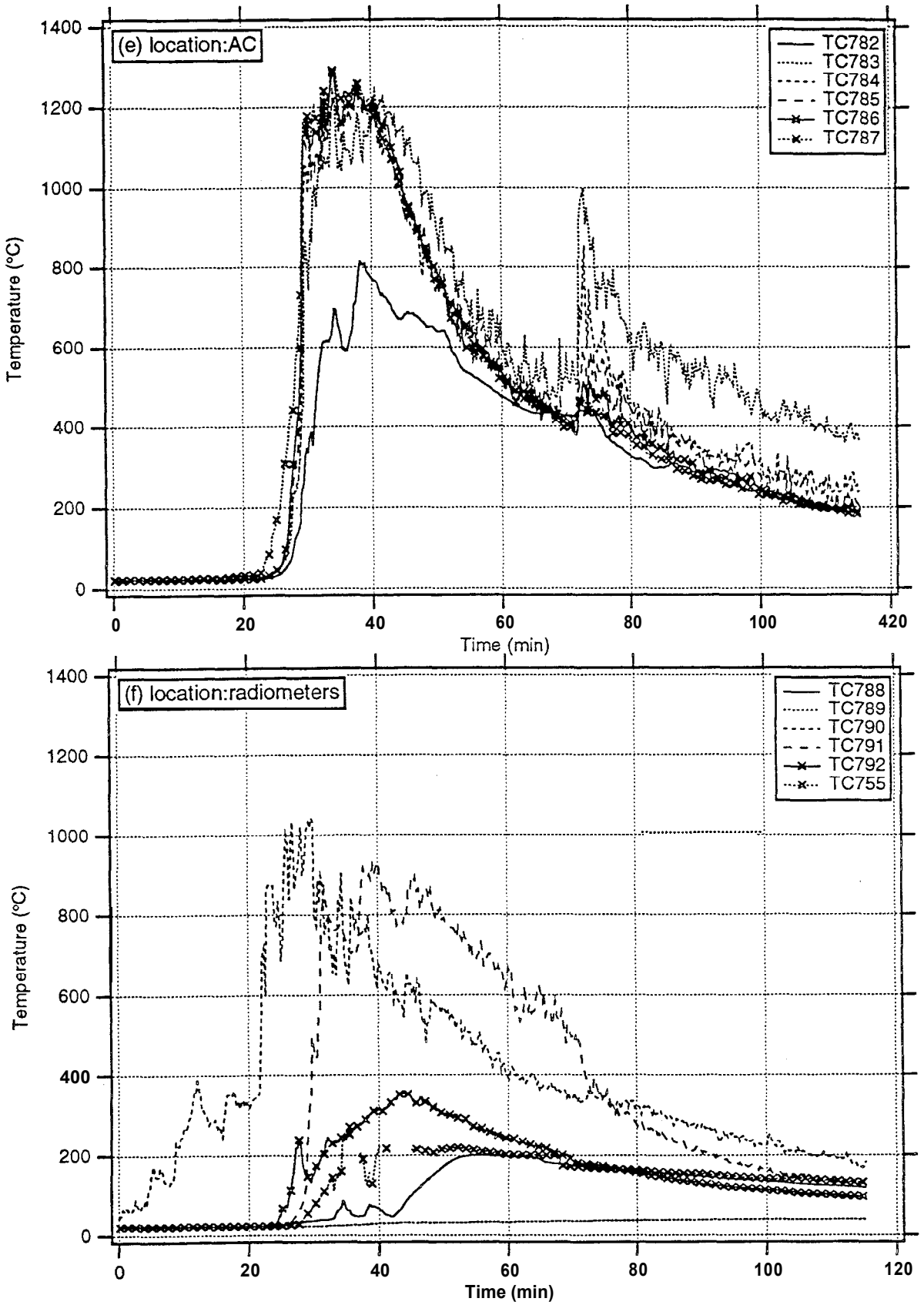
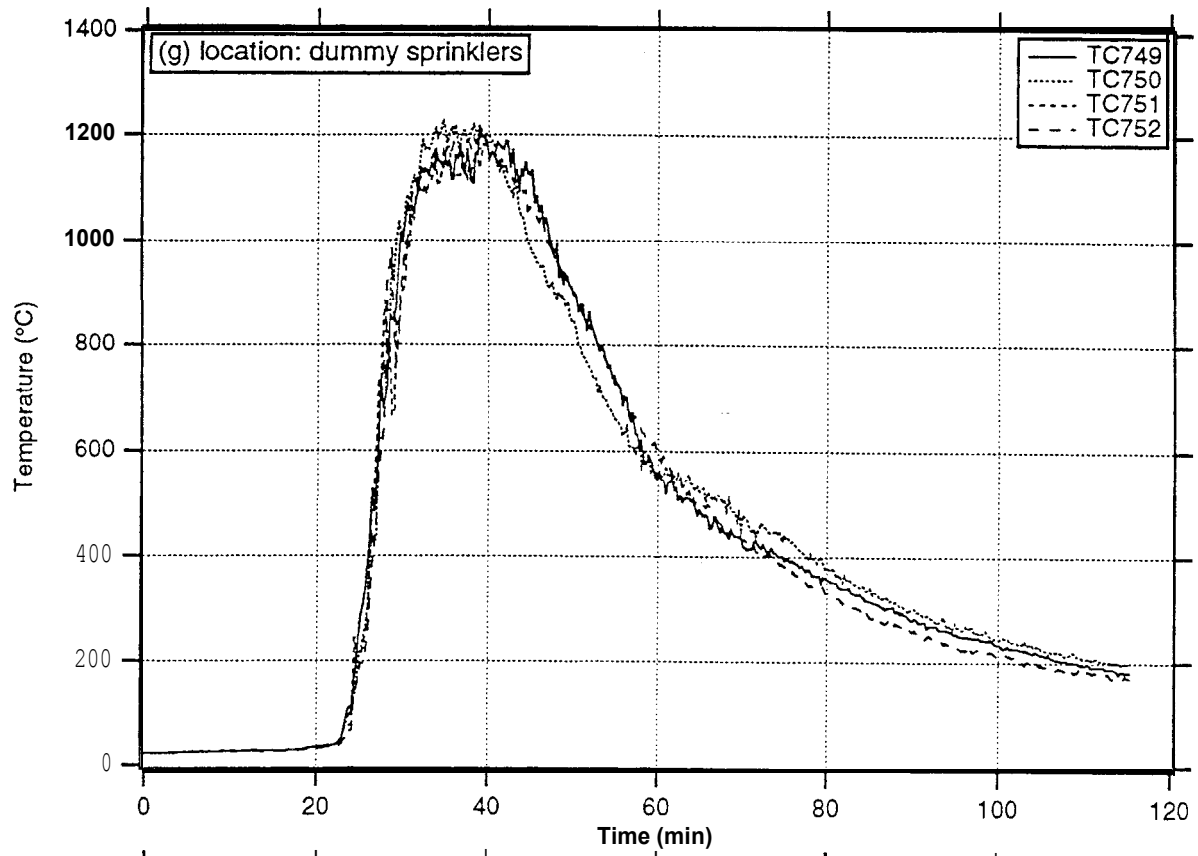


FIGURE A14(E) AND (F) AIR TEMPERATURES - TEST 4



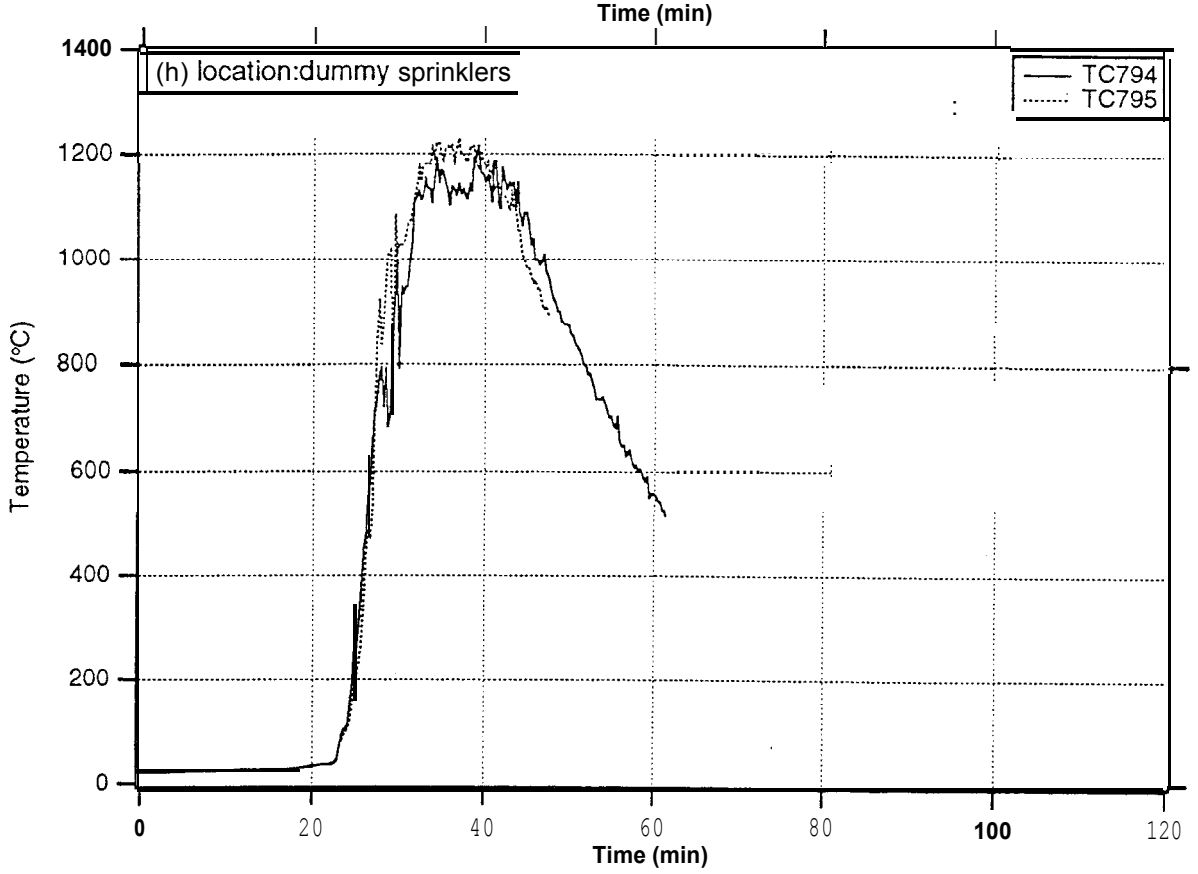


FIGURE A4(G) AND (H) AIR TEMPERATURES - TEST 4

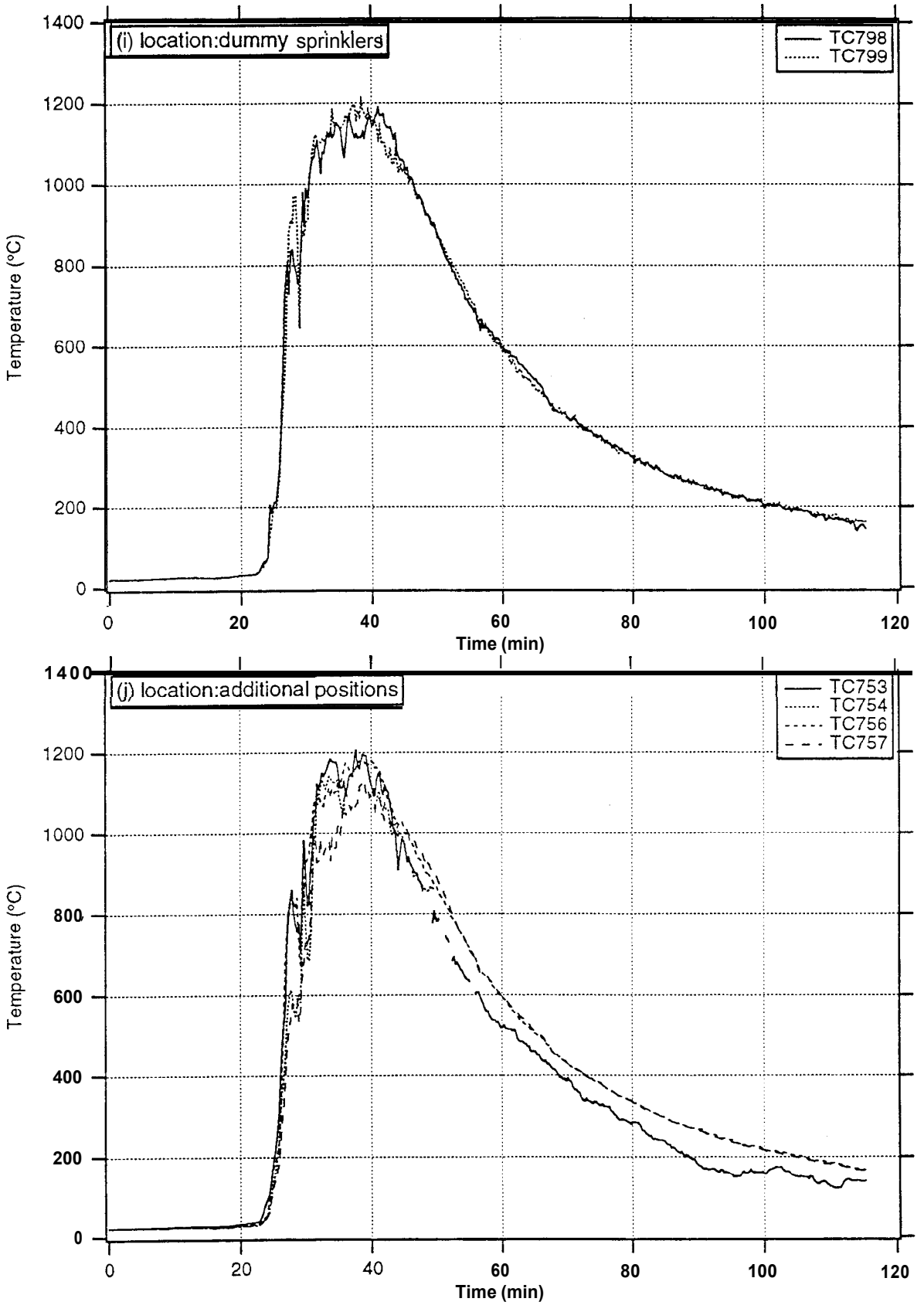


FIGURE A4(I) AND (J) AIR TEMPERATURES - TEST 4

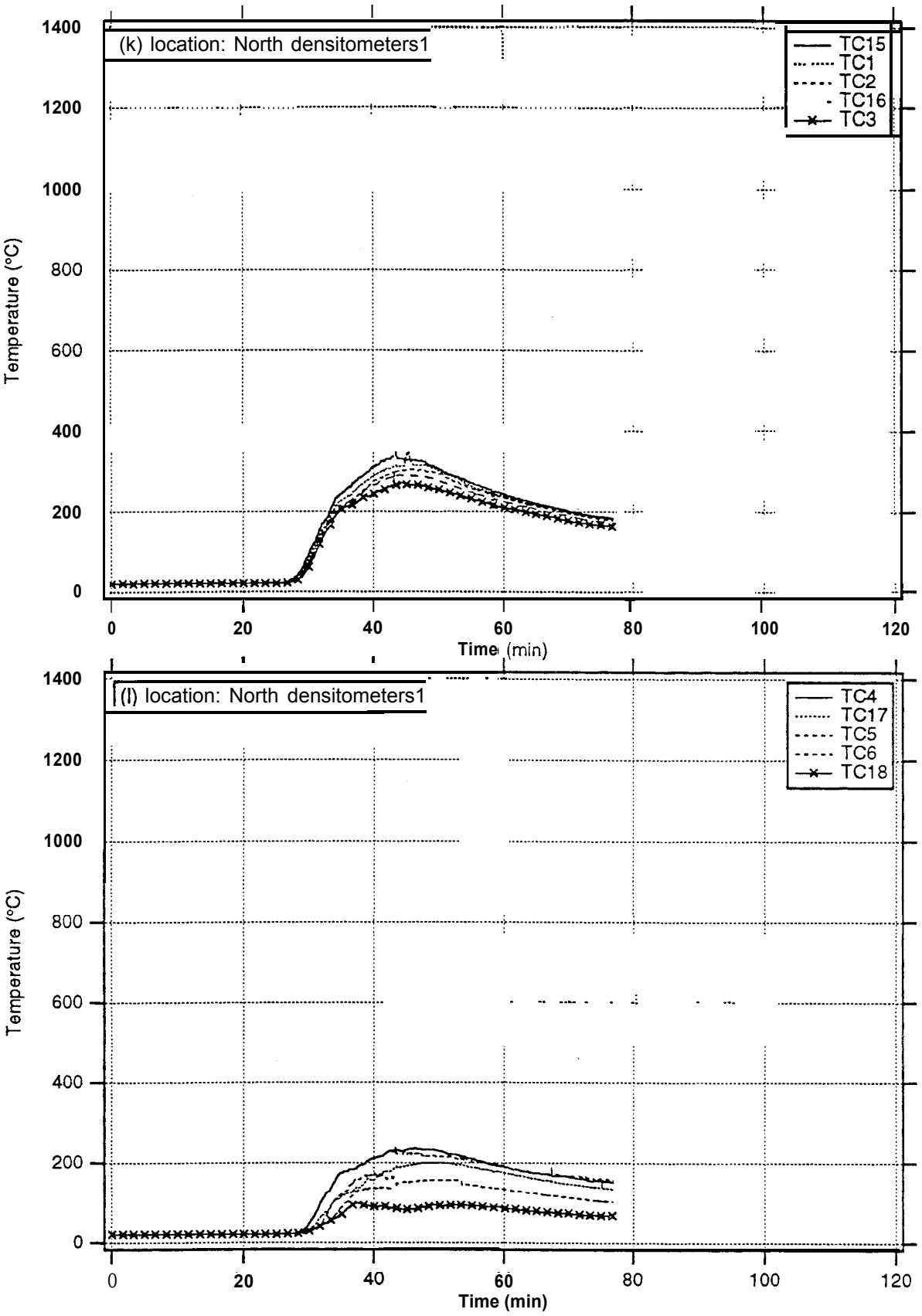


FIGURE A4(K) AND (L) AIR TEMPERATURES - TEST 4

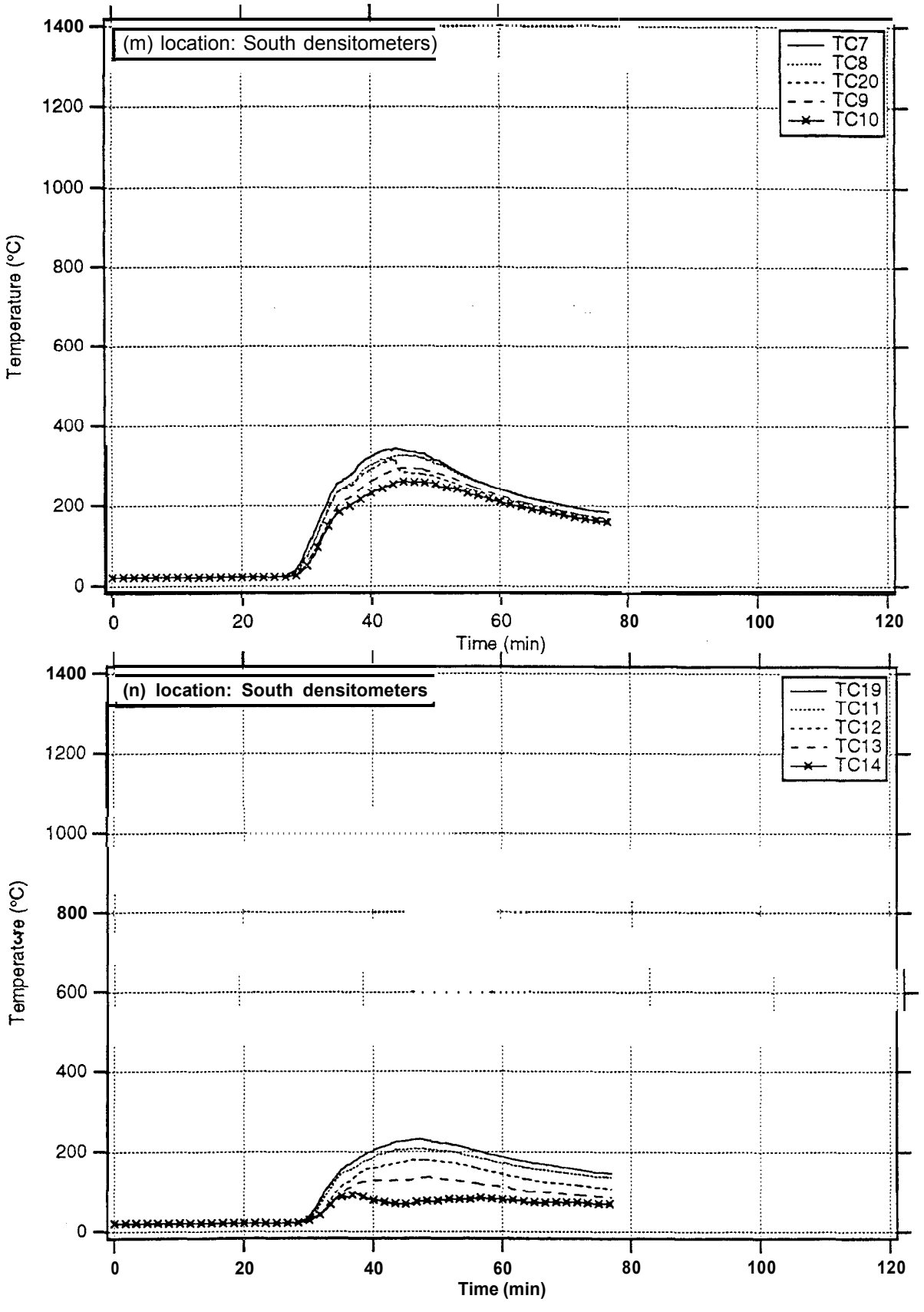


FIGURE A4(M) AND (N) AIR TEMPERATURES - TEST 4

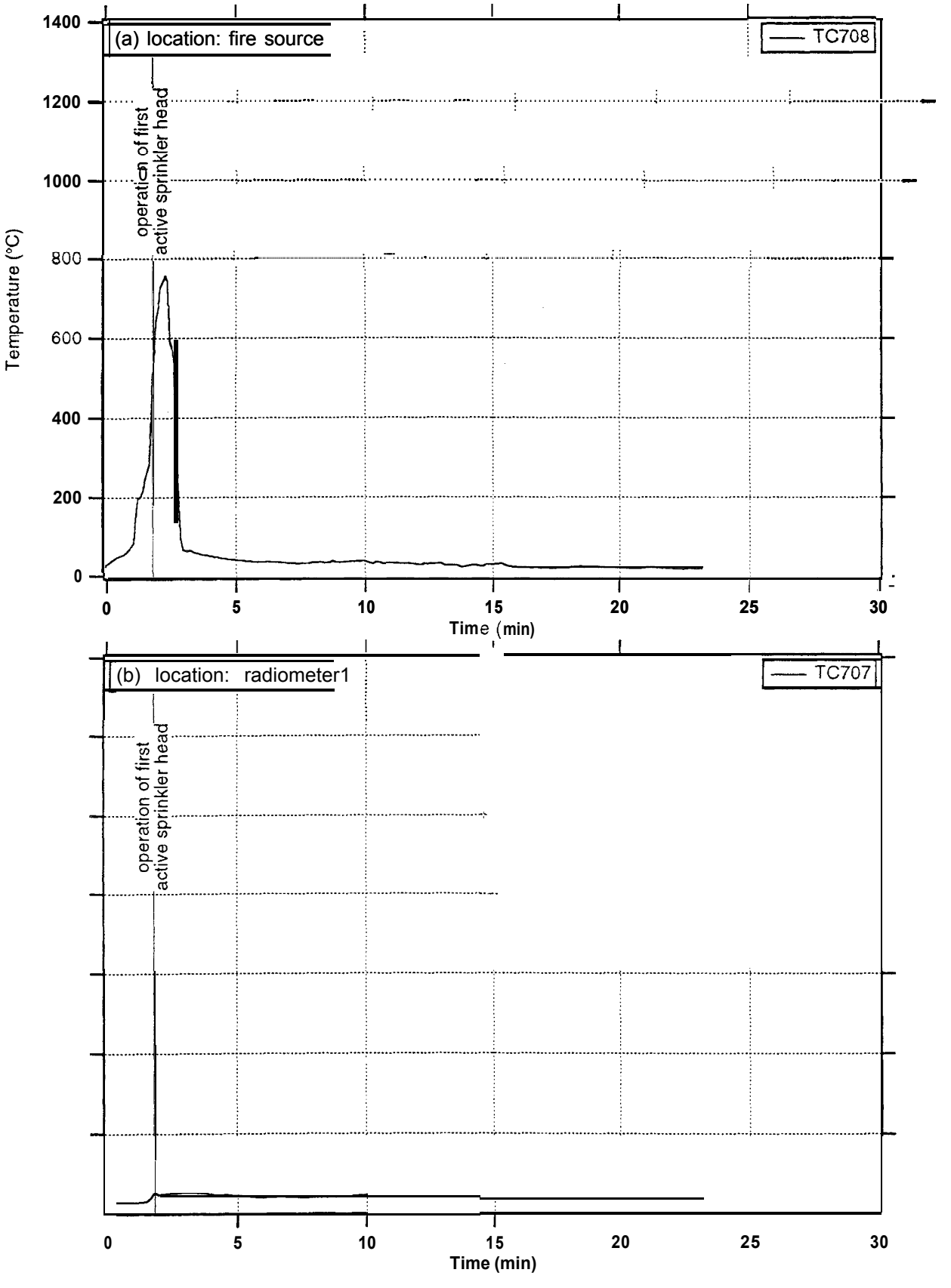


FIGURE A5(A) AND (B) AIR TEMPERATURES - TEST 5

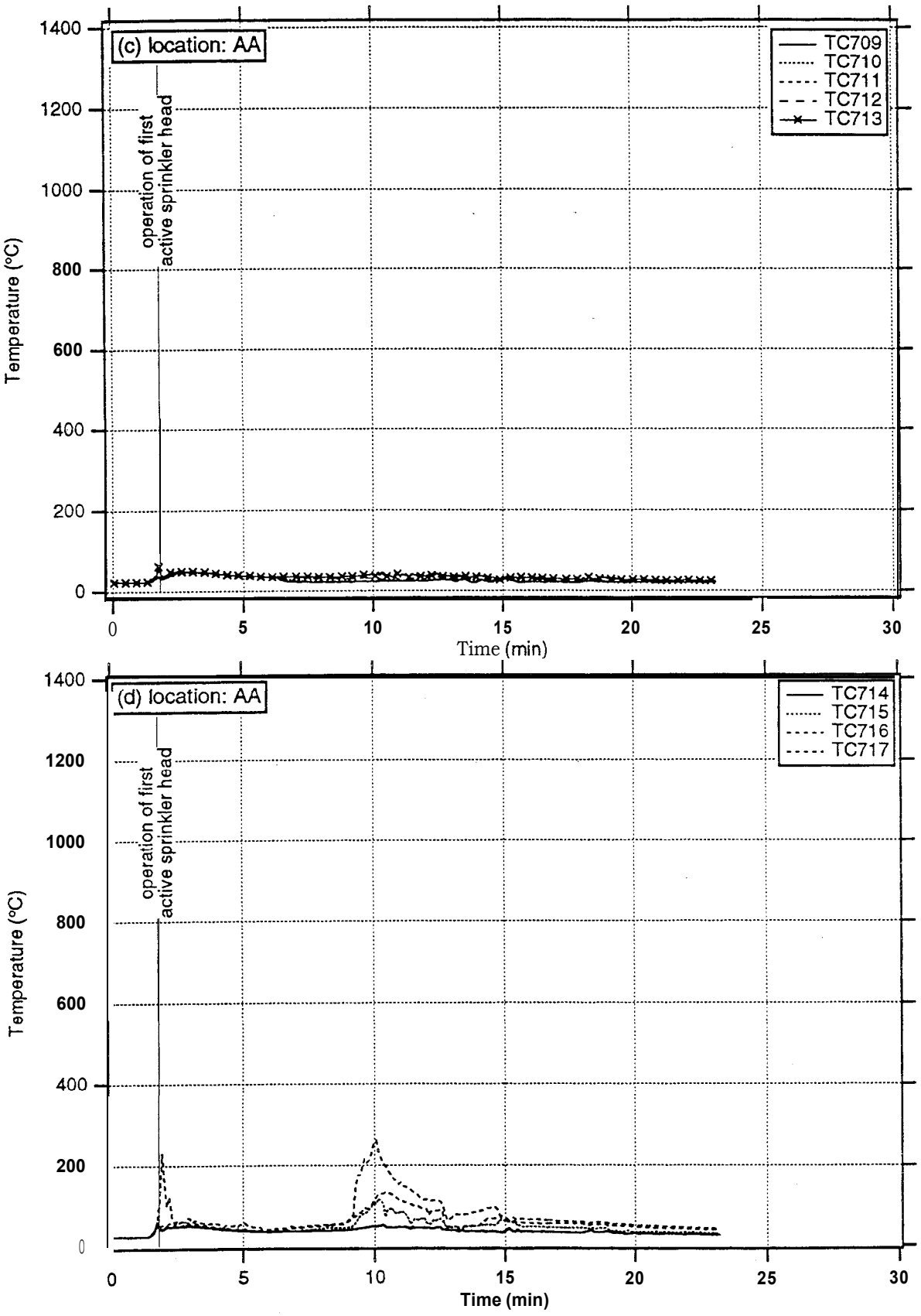


FIGURE A5(C) AND (D) AIR TEMPERATURES - TEST 5

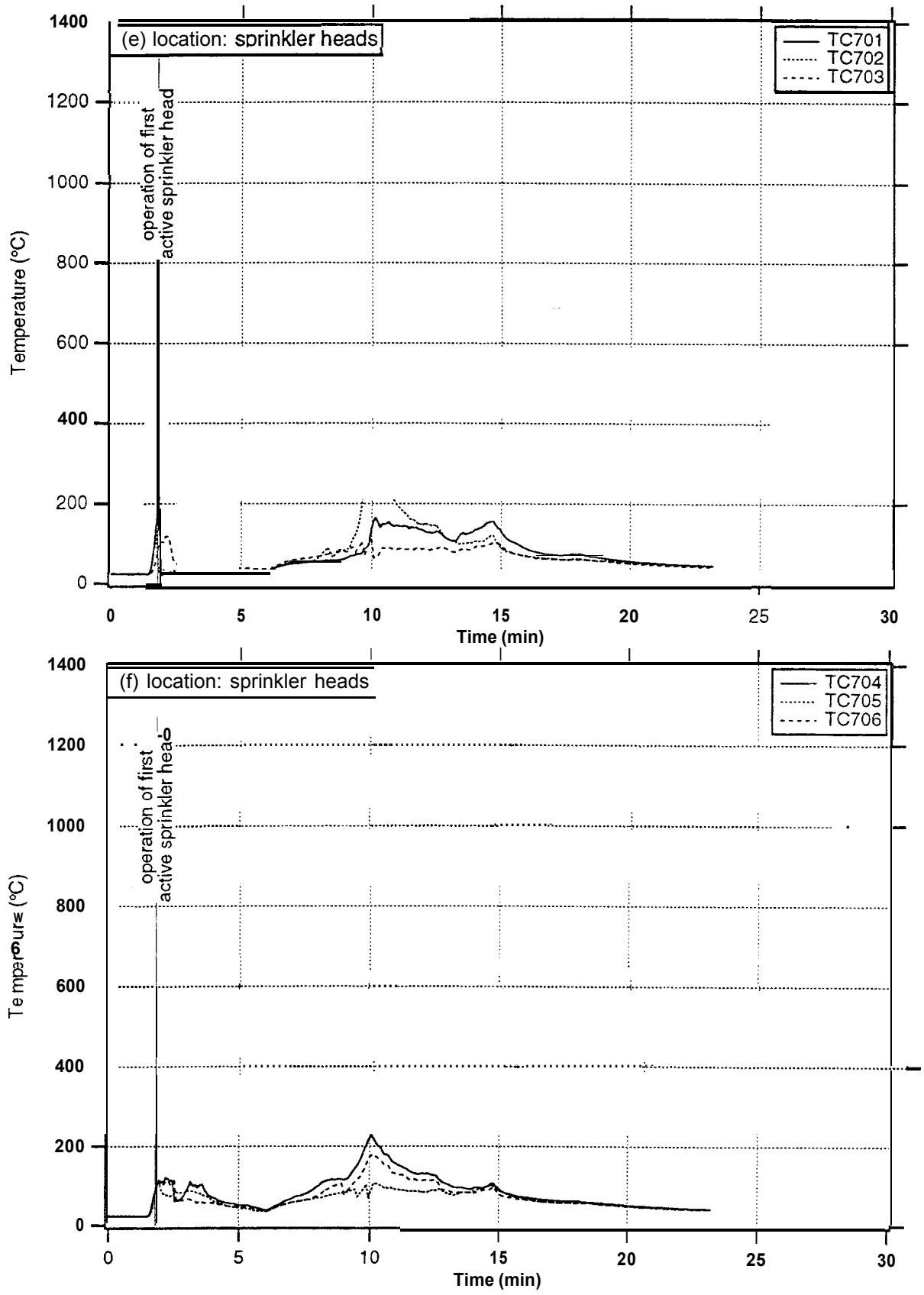


FIGURE A5(E) AND (F) AIR TEMPERATURES - TEST 5

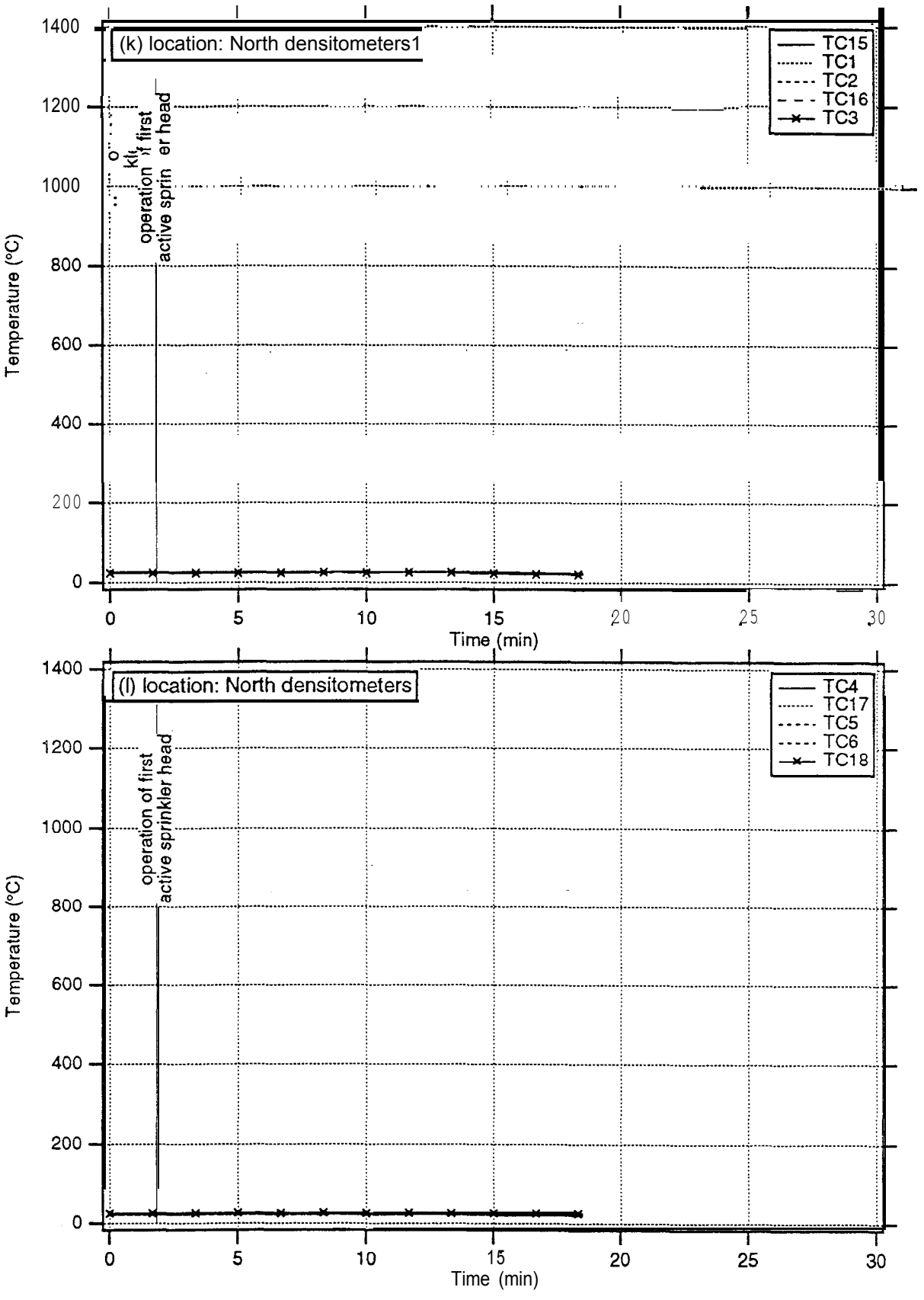


FIGURE A5(G) AND (H) AIR TEMPERATURES - TEST 5

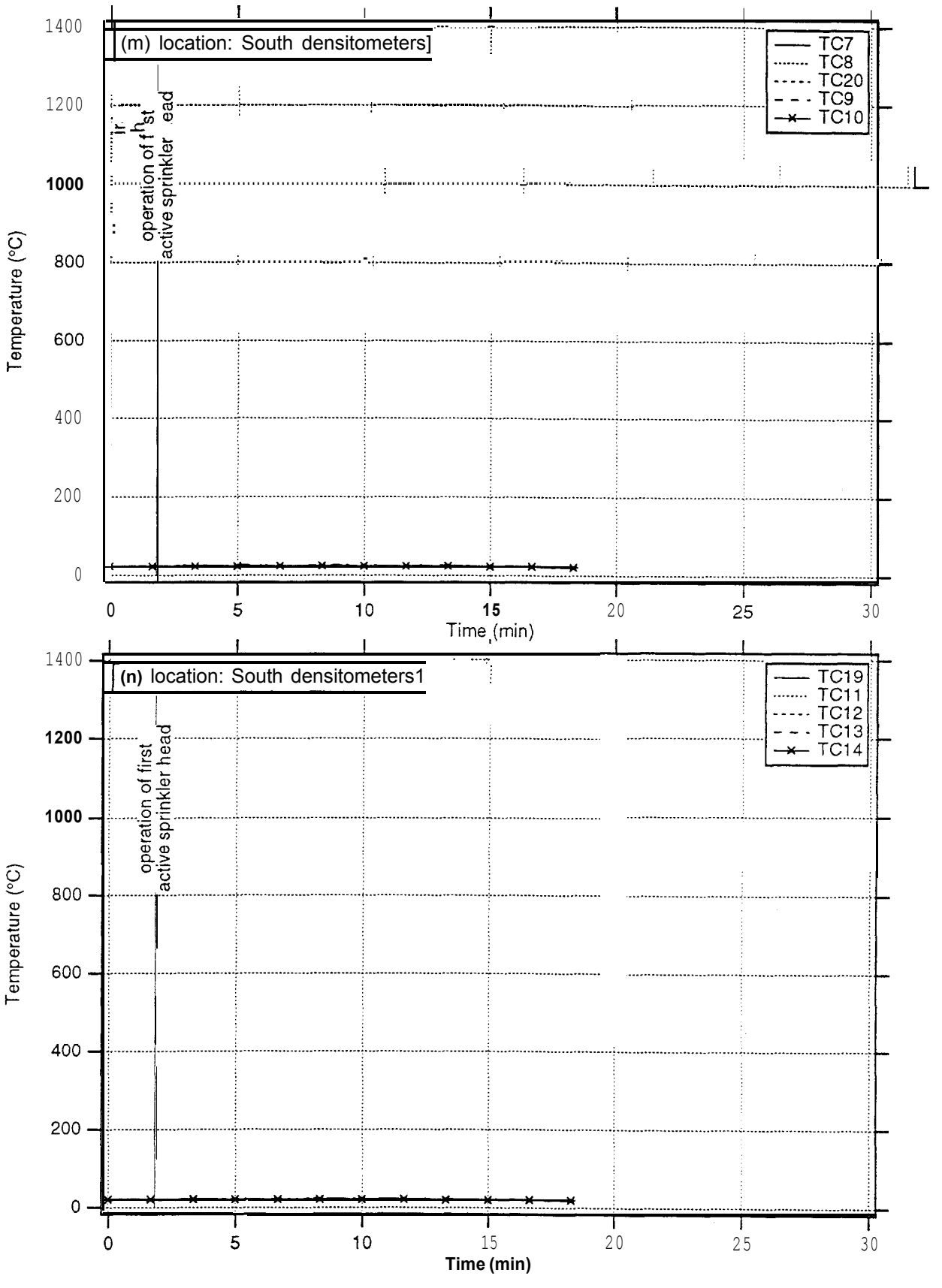


FIGURE A5(I) AND (J) AIR TEMPERATURES - TEST 5

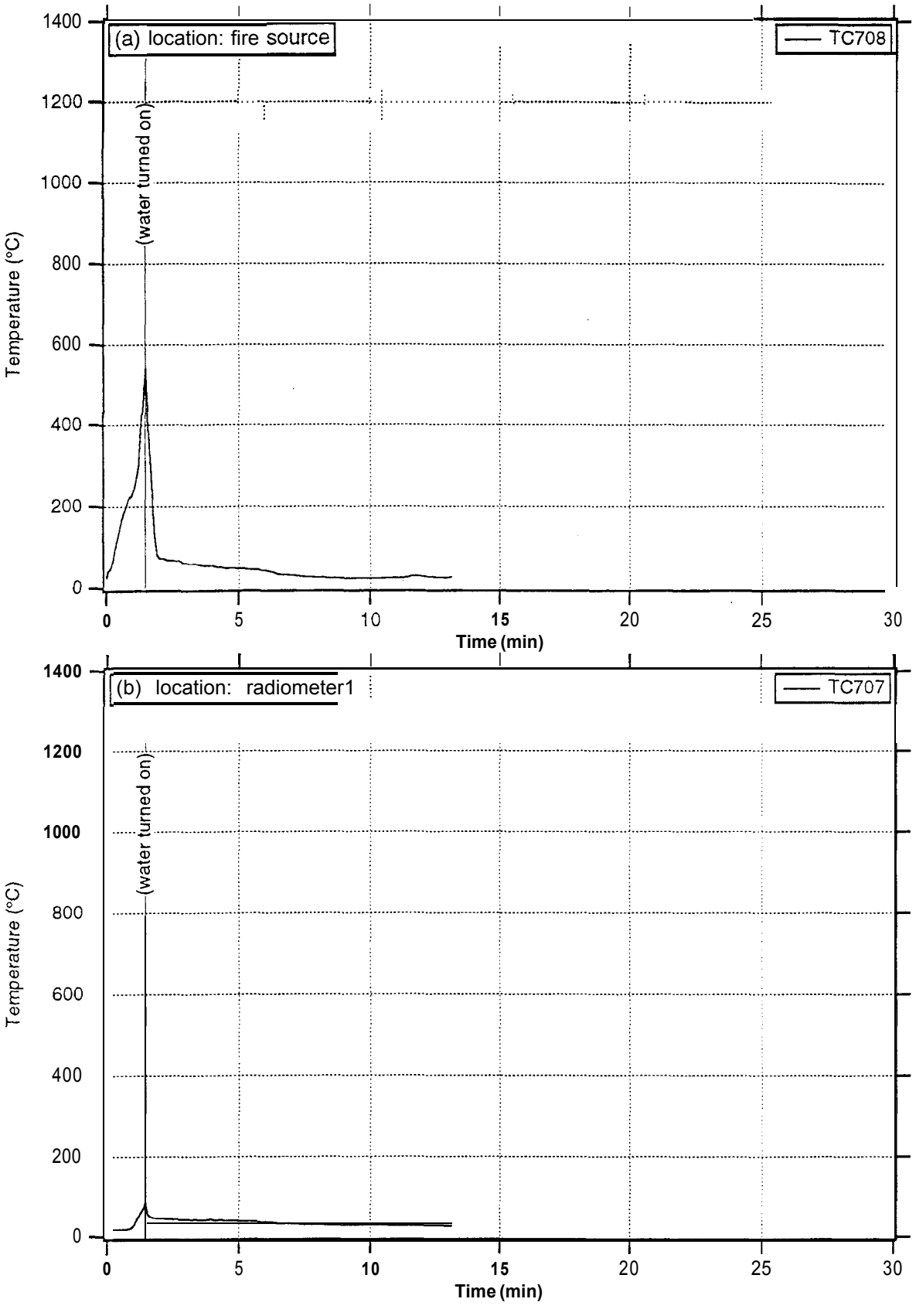


FIGURE A6(A) AND (B) AIR TEMPERATURES - TEST 6

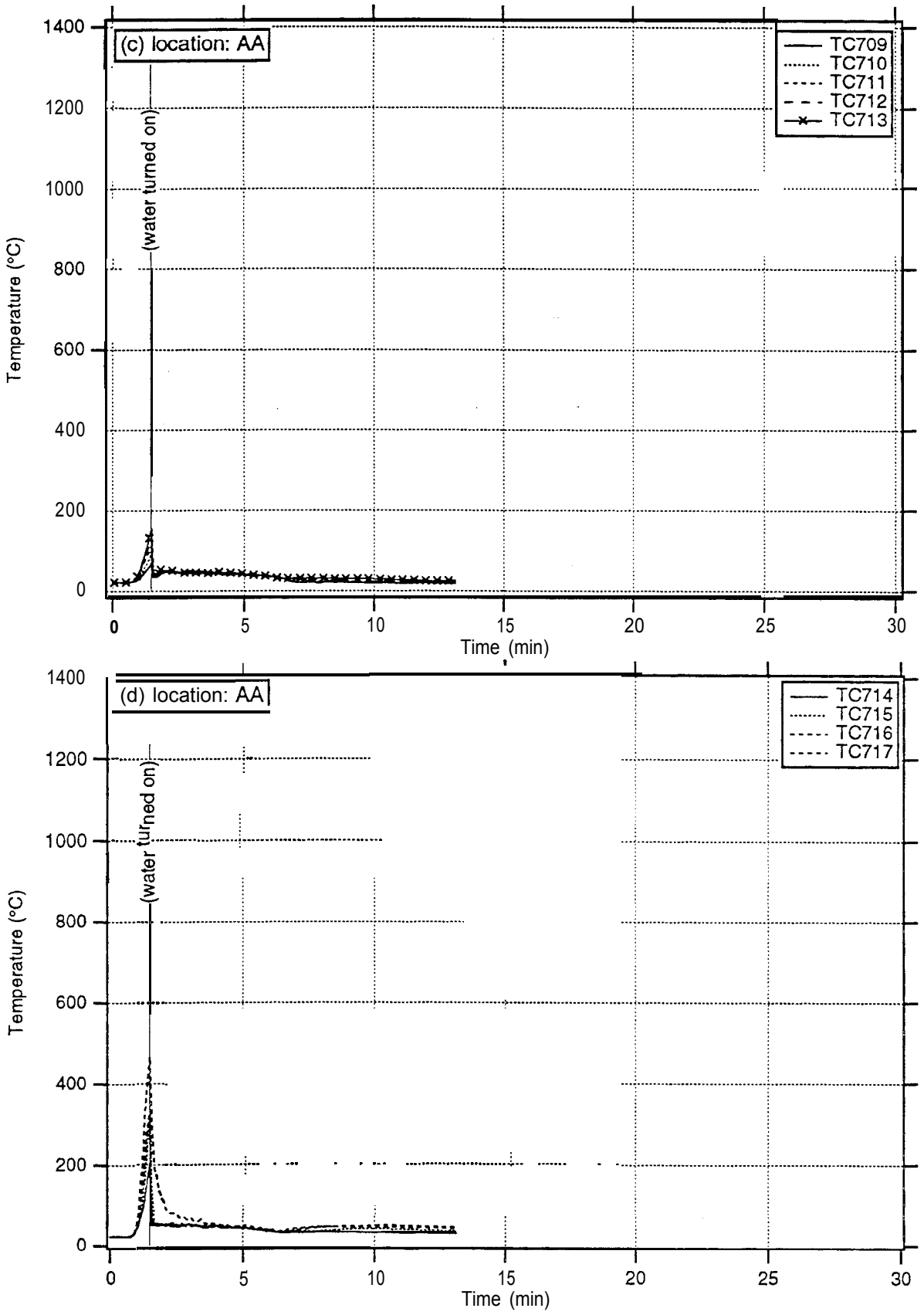


FIGURE A6(C) AND (D) AIR TEMPERATURES - TEST 6

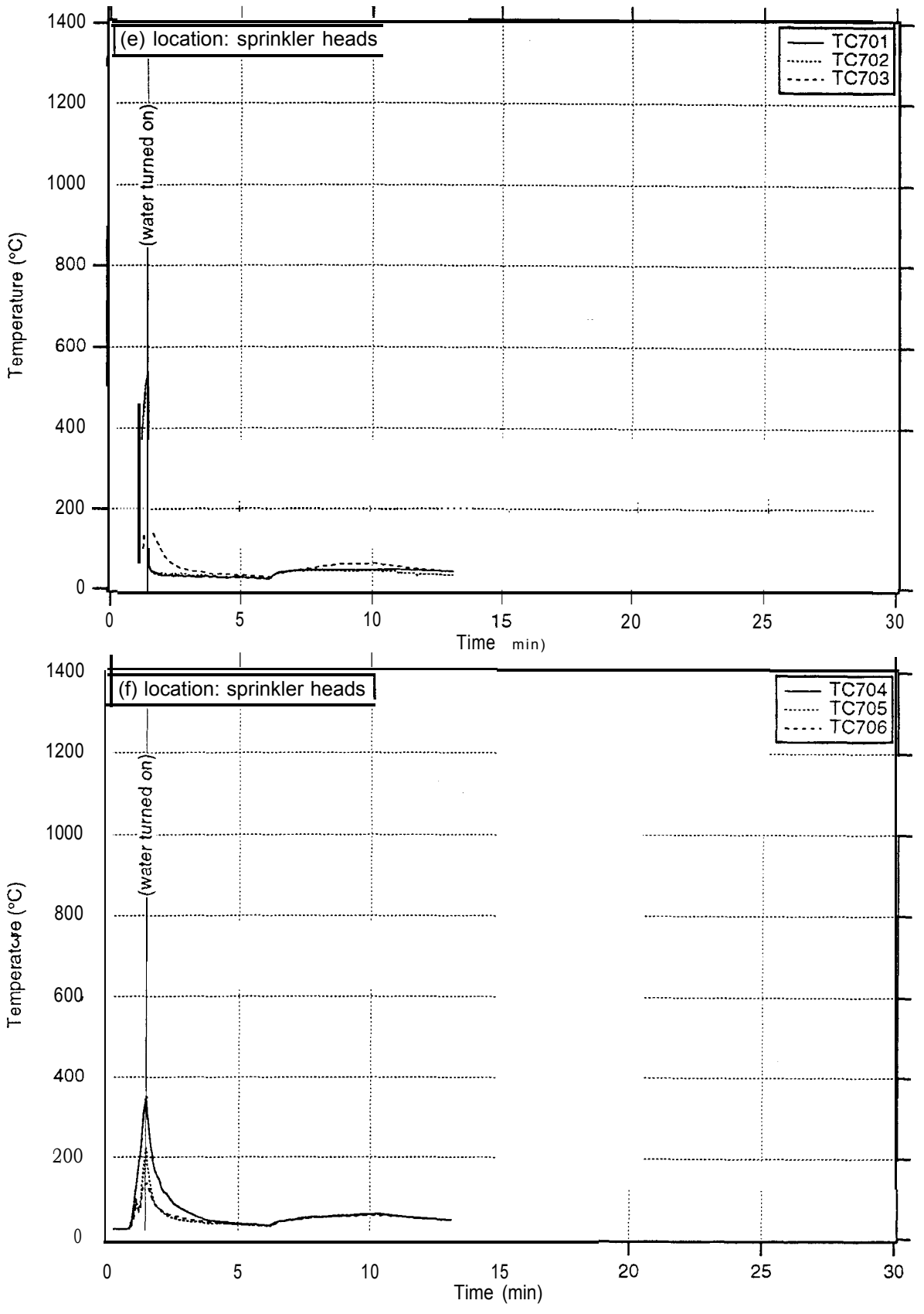


FIGURE A6(E) AND (F) AIR TEMPERATURES - TEST 6

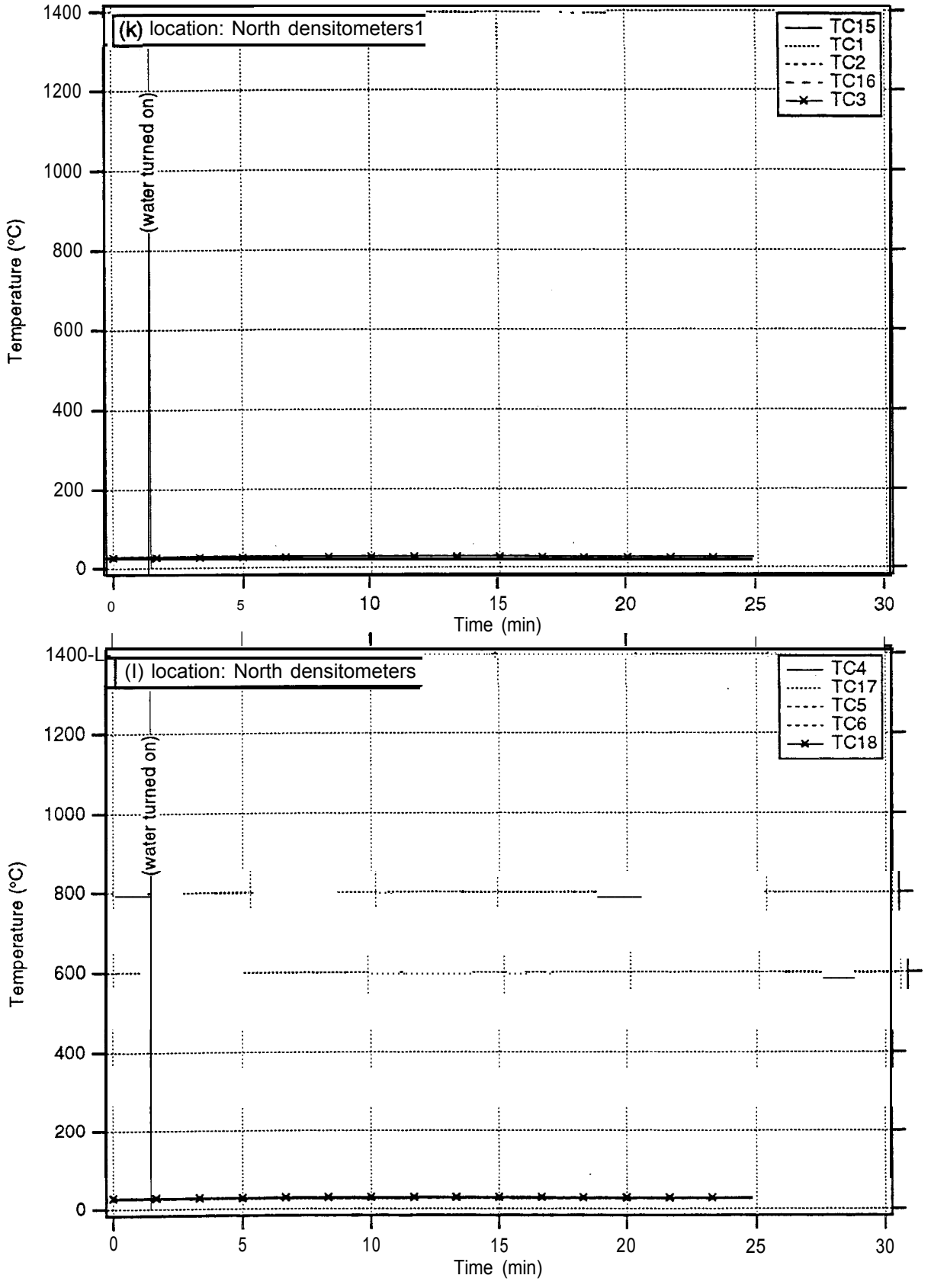


FIGURE A6(G) AND (H) AIR TEMPERATURES - TEST 6

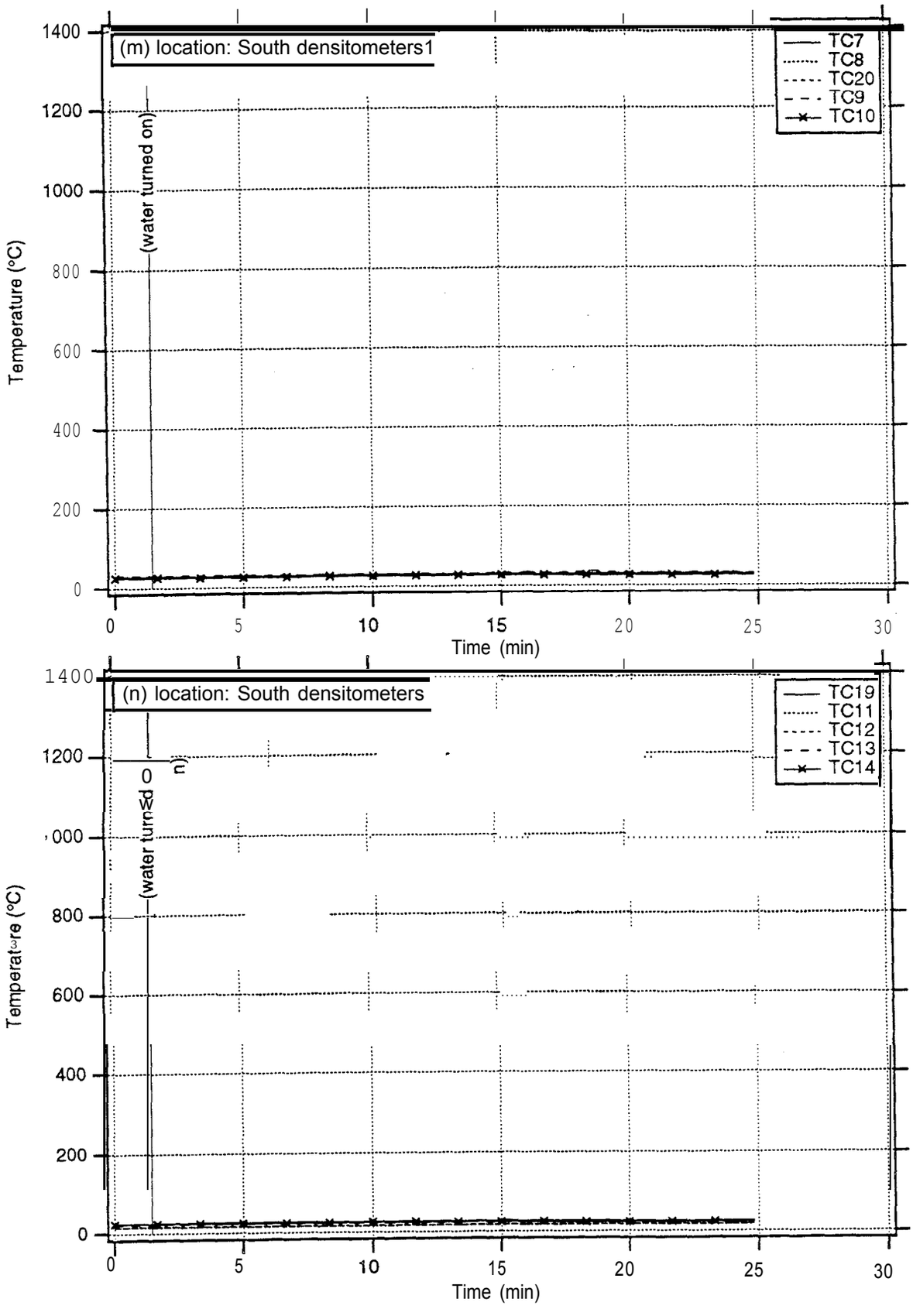


FIGURE A6(I) AND (J) AIR TEMPERATURES - TEST 6

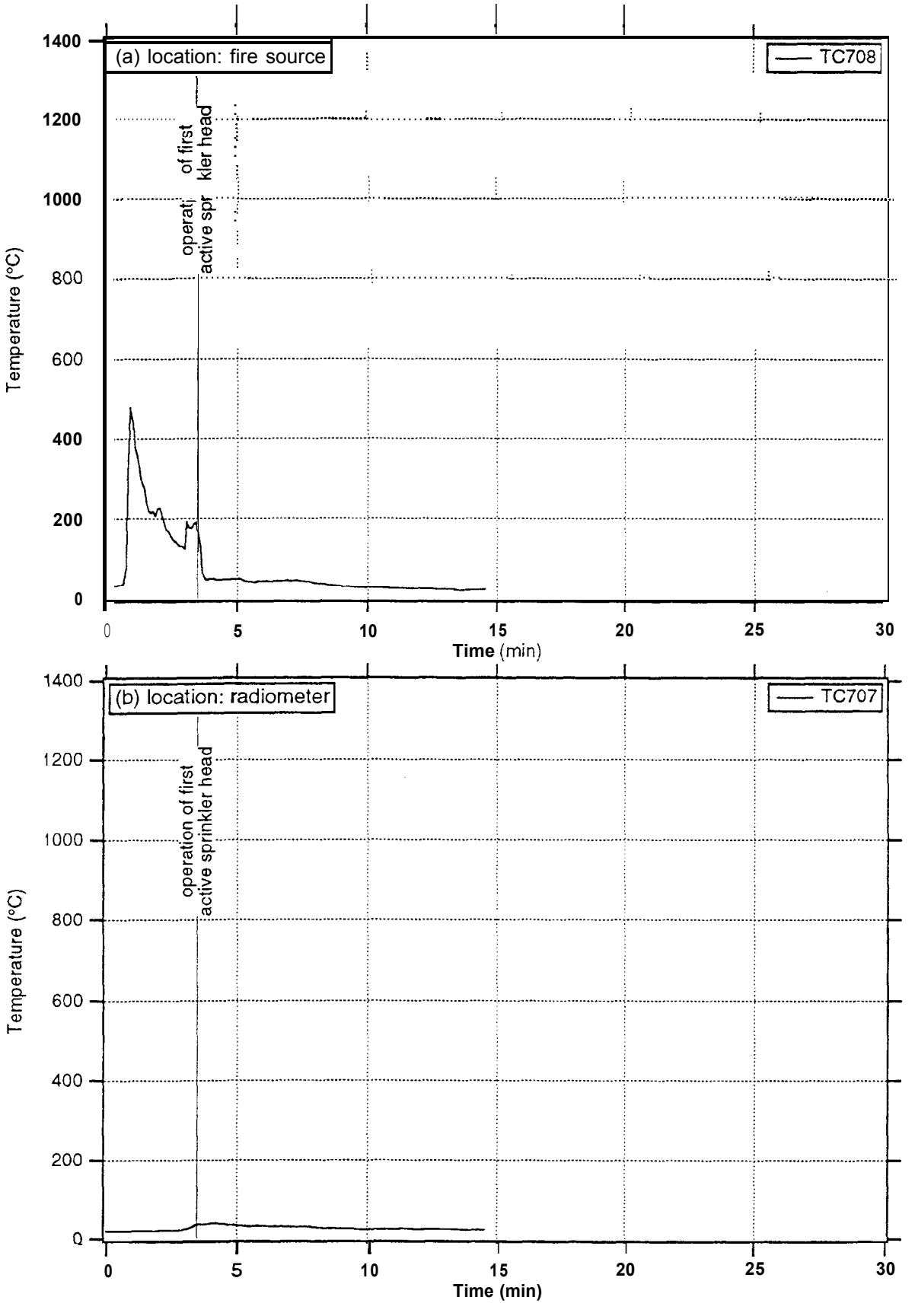
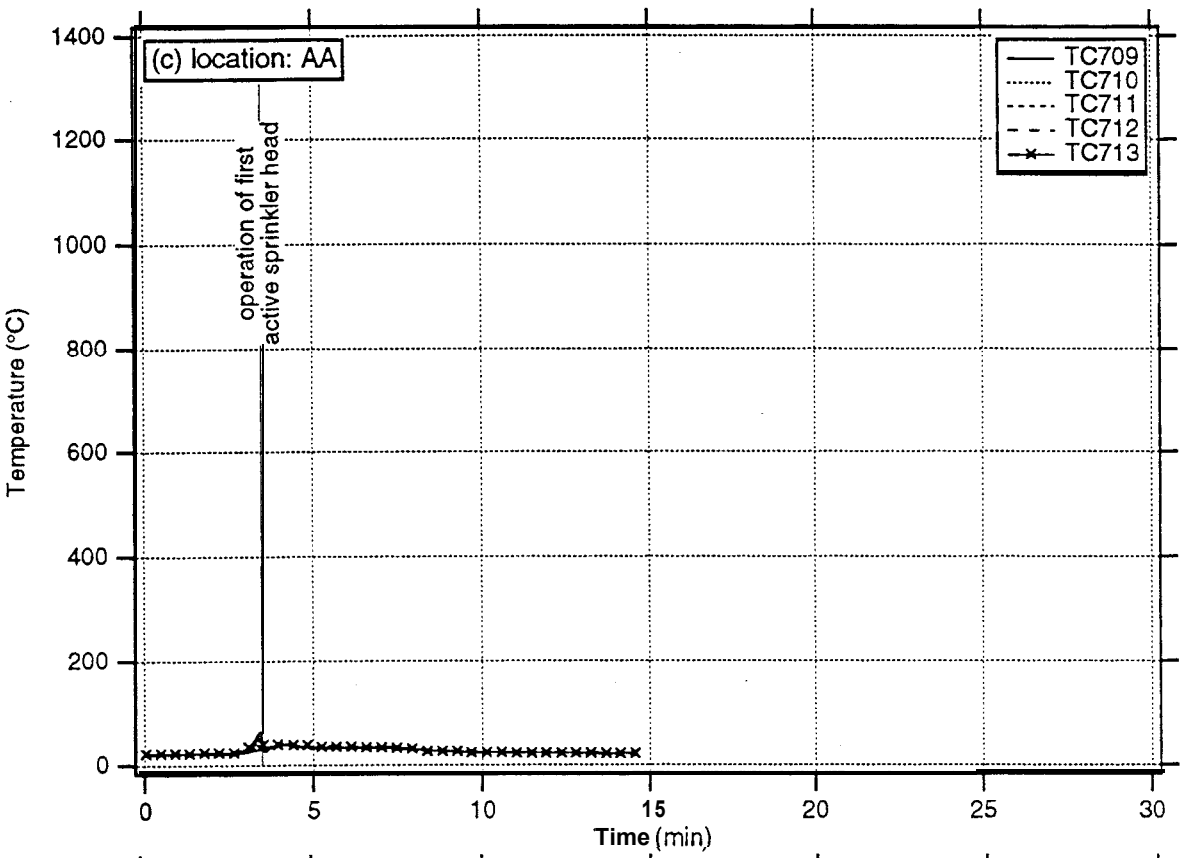


FIGURE A7(A) AND (B) AIR TEMPERATURES - TEST 7



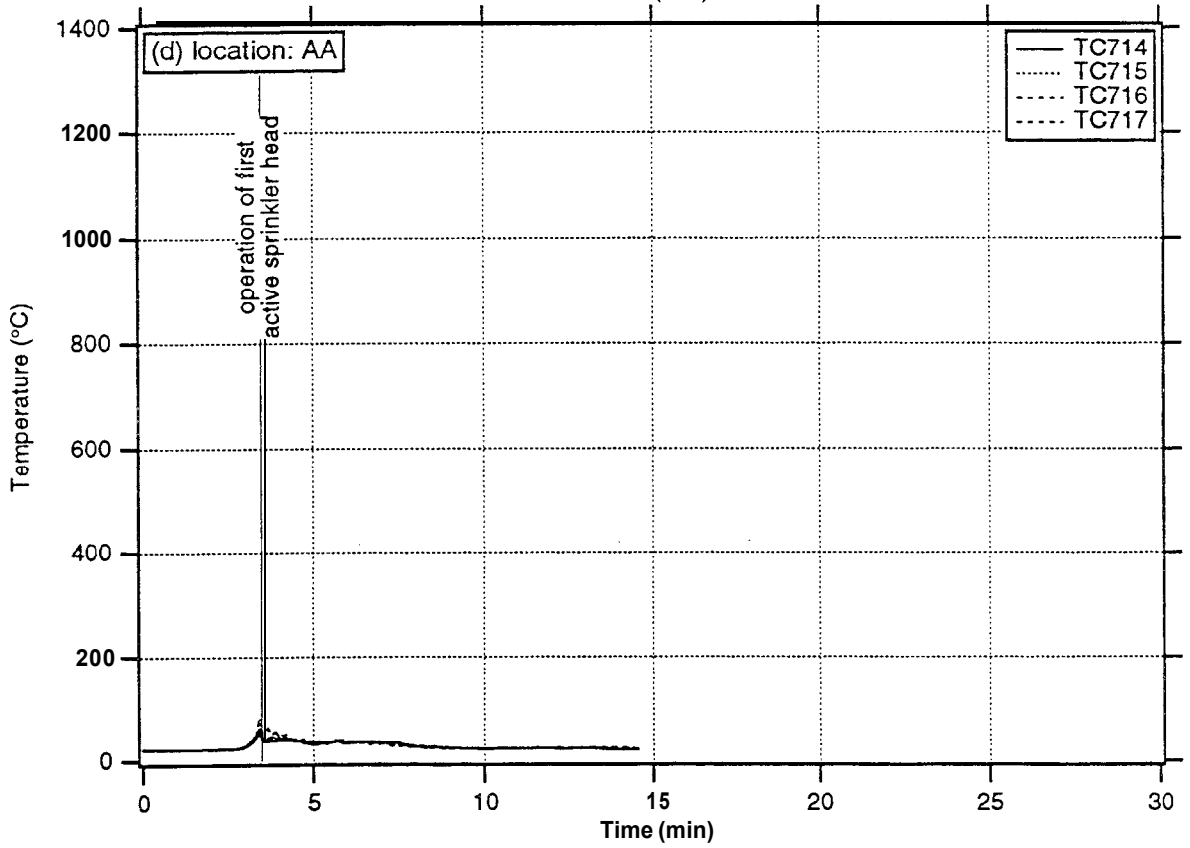


FIGURE A7(C) AND (D) AIR TEMPERATURES - TEST 7

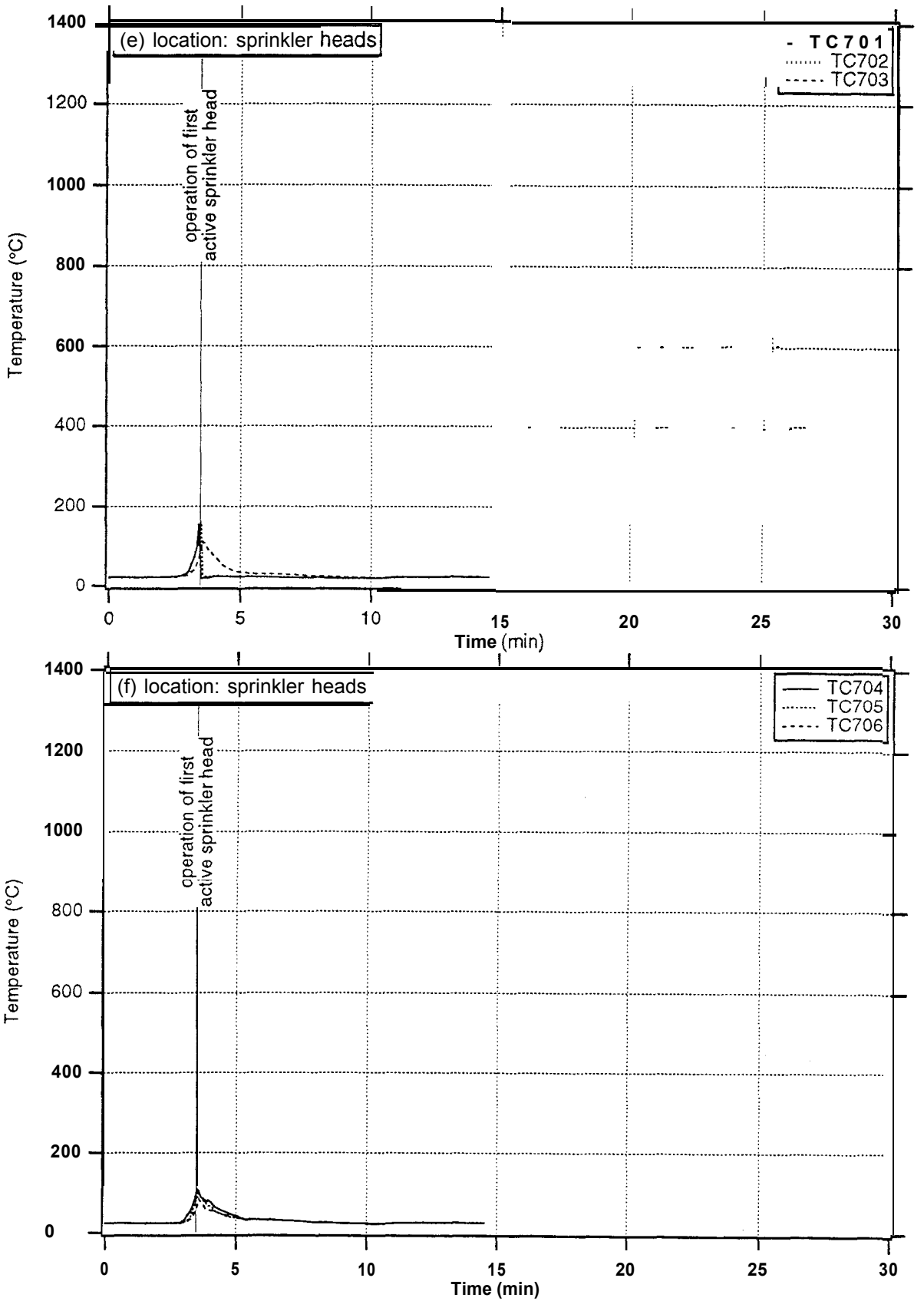


FIGURE A7(E) AND (F) AIR TEMPERATURES - TEST 7

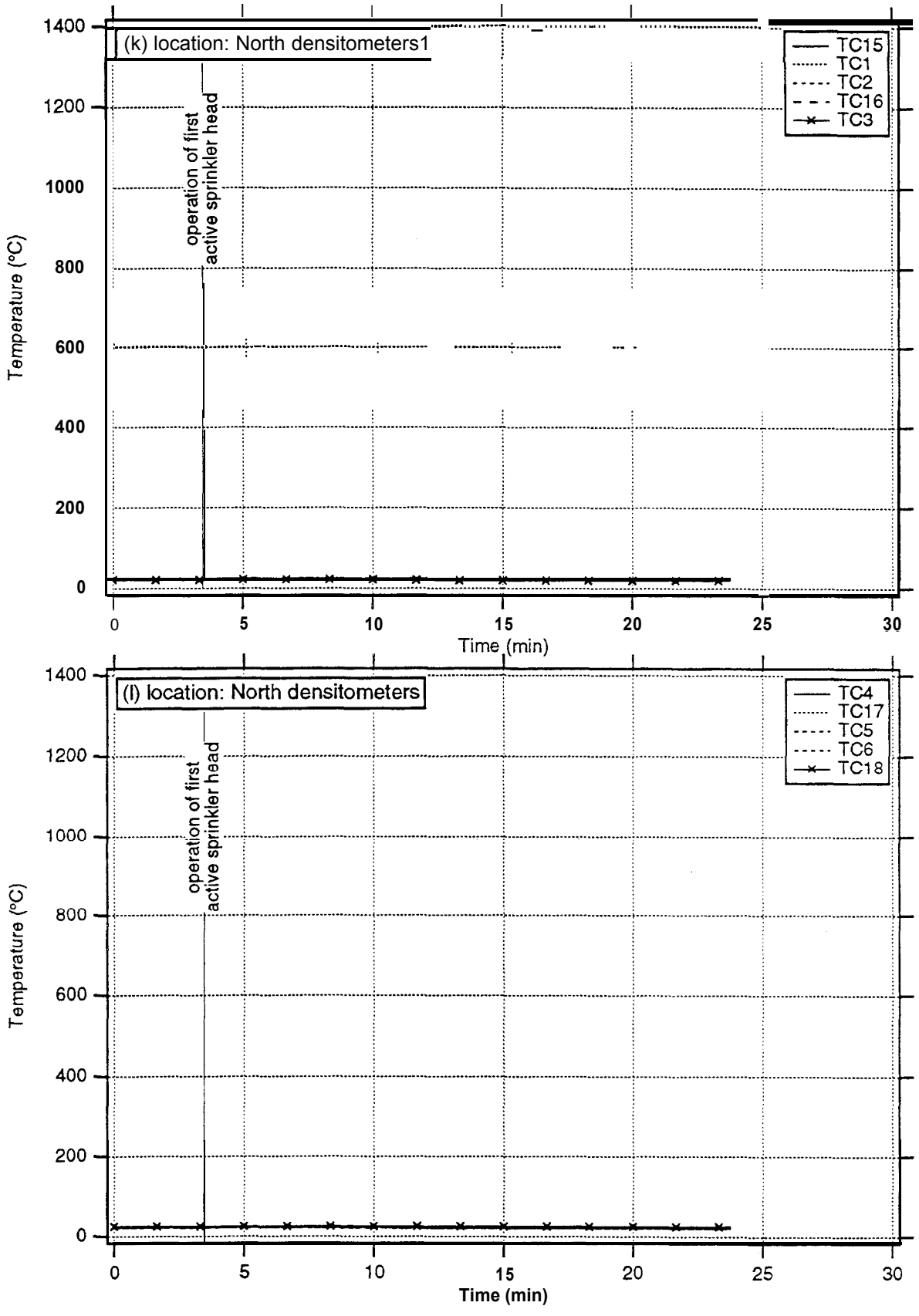


FIGURE A7(G) AND (H) - TEST 7

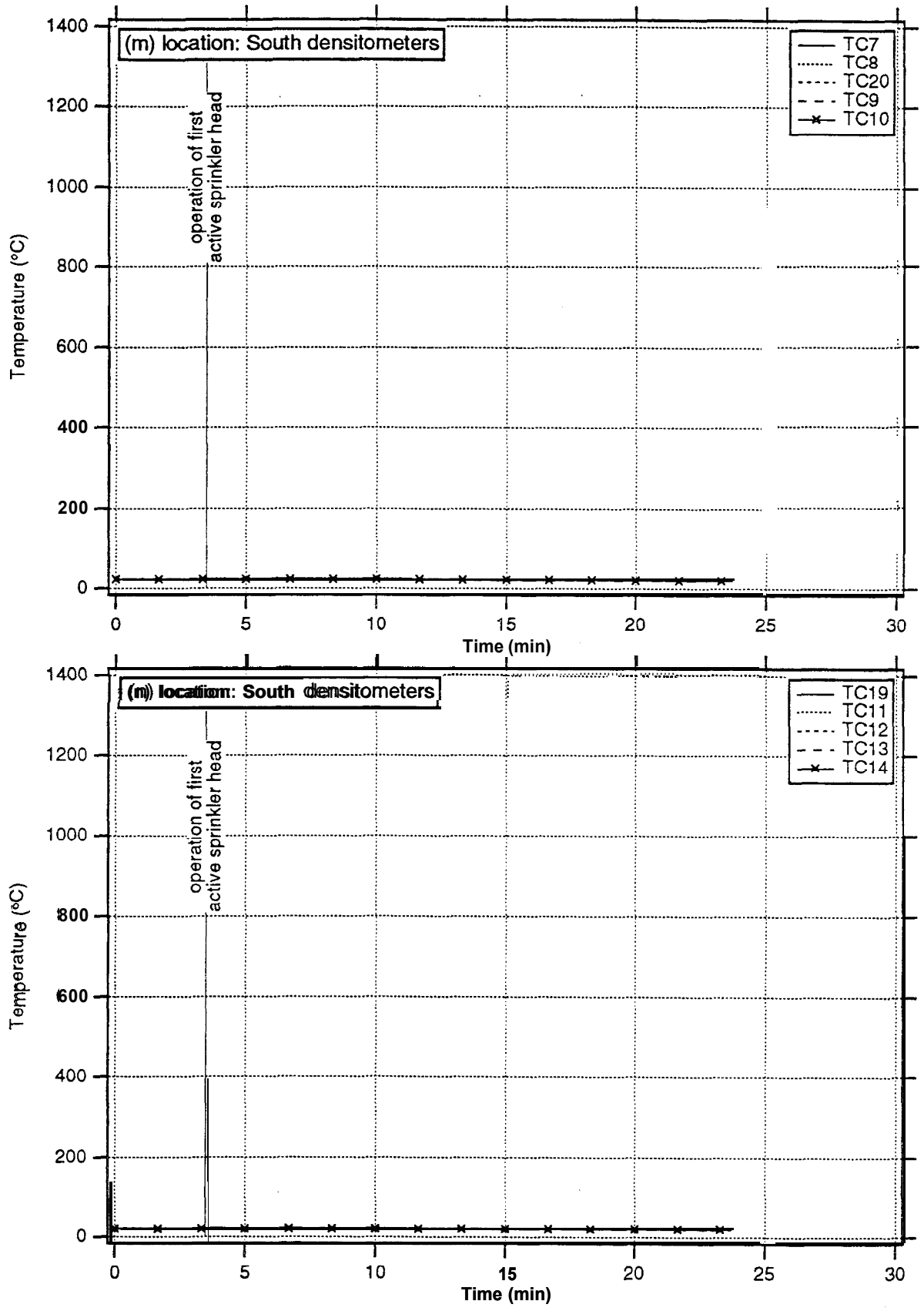


FIGURE A7(I) AND (J) AIR TEMPERATURES -TEST 7

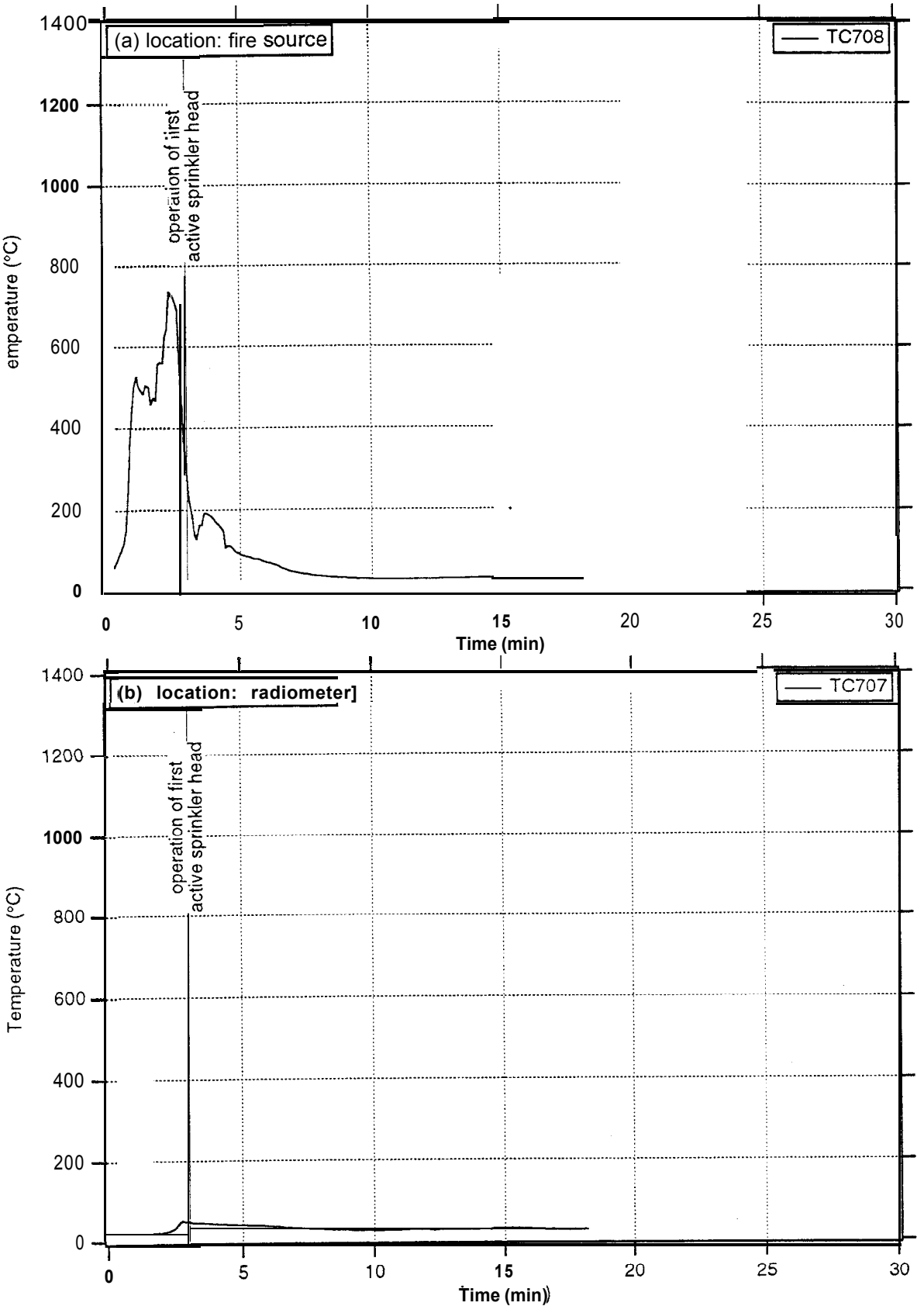

(a) location: fire source
TC708
operation of first active sprinkler head
emperature (°C)
1400
1200
1000
800
600
400
200
0
0
5
10
15
20
25
30
Time (min)
(b) location: radiometer]
TC707
operation of first active sprinkler head
Temperature (°C)
1400
1200
1000
800
600
400
200
0
0
5
10
15
20
25
30
Time (min)

FIGURE A8(A)

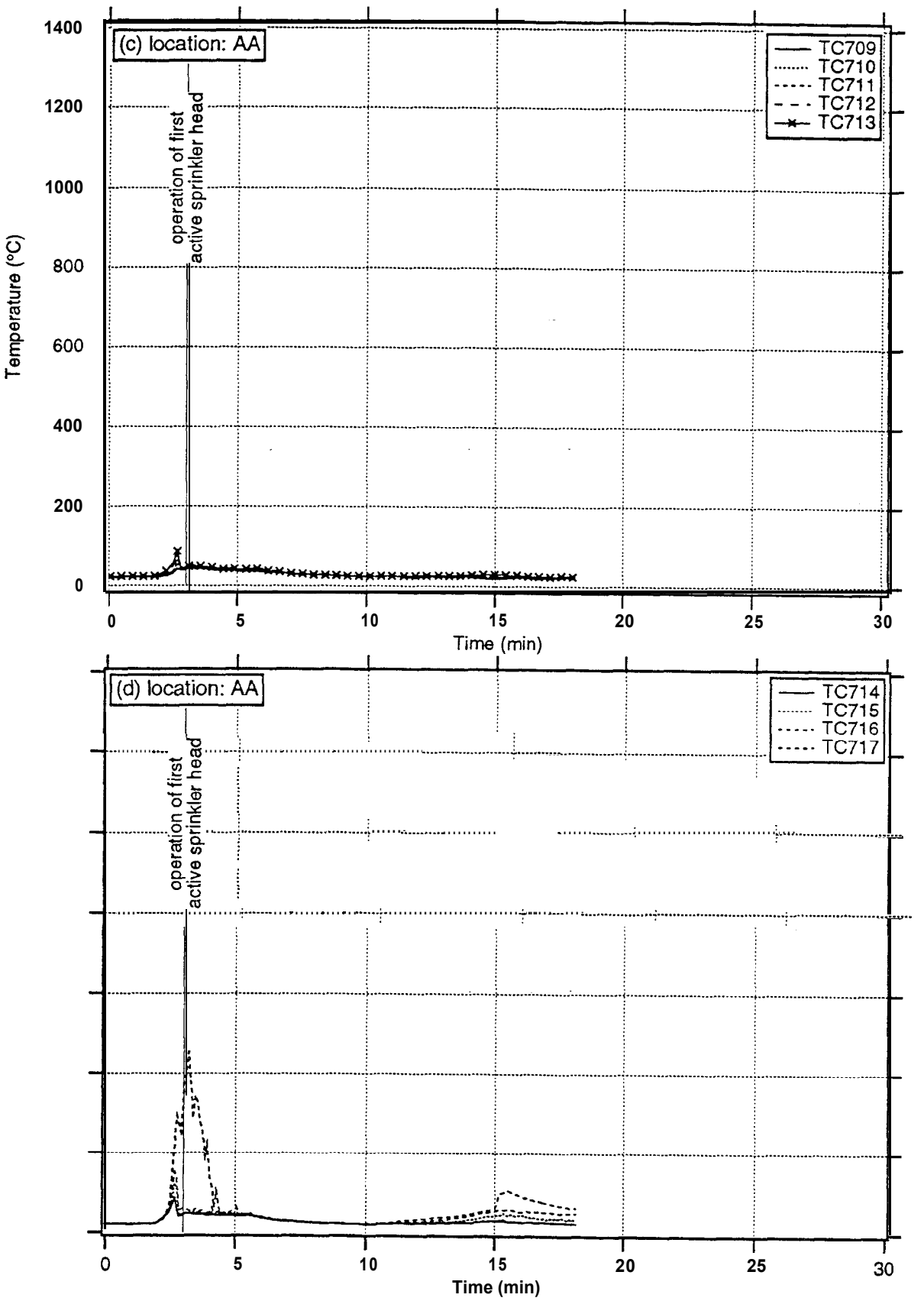
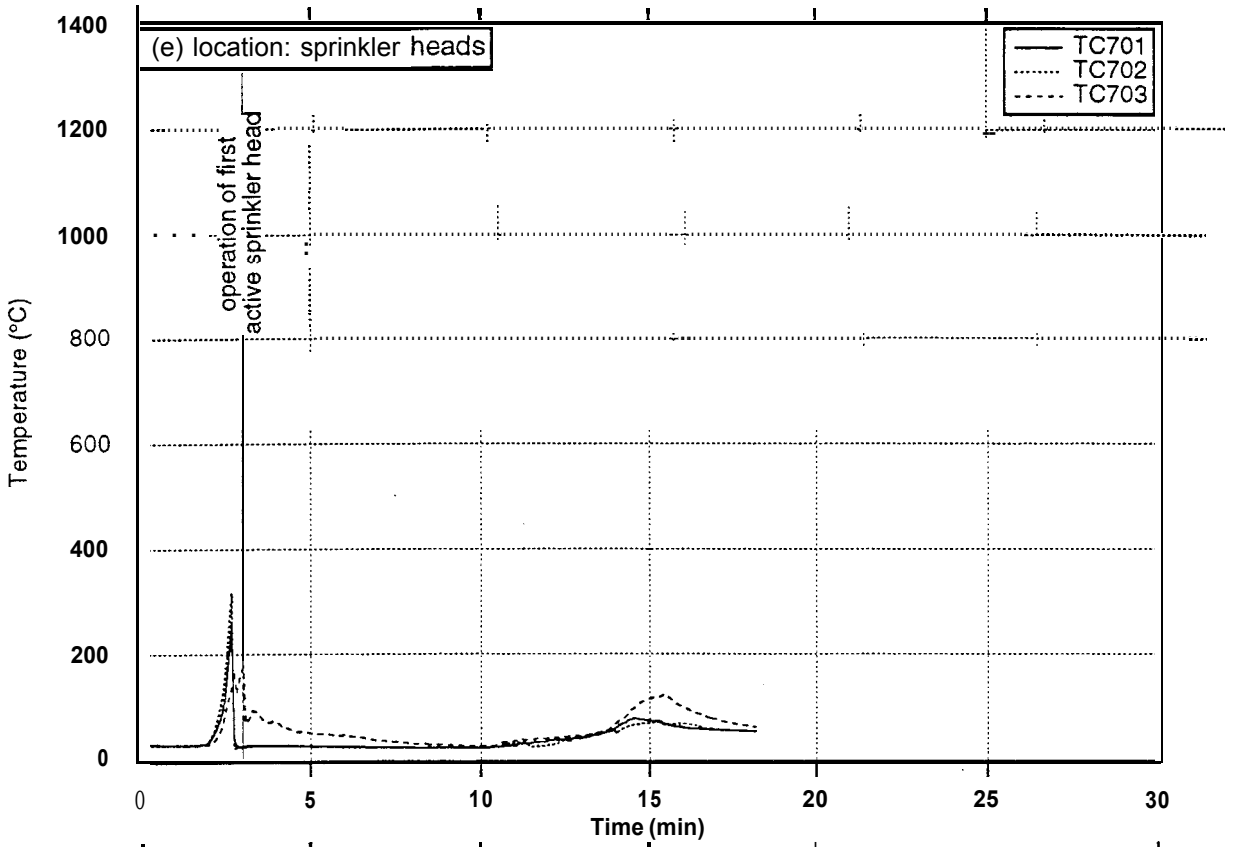


FIGURE A8(C) AND (D) AIR TEMPERATURES - TEST 8



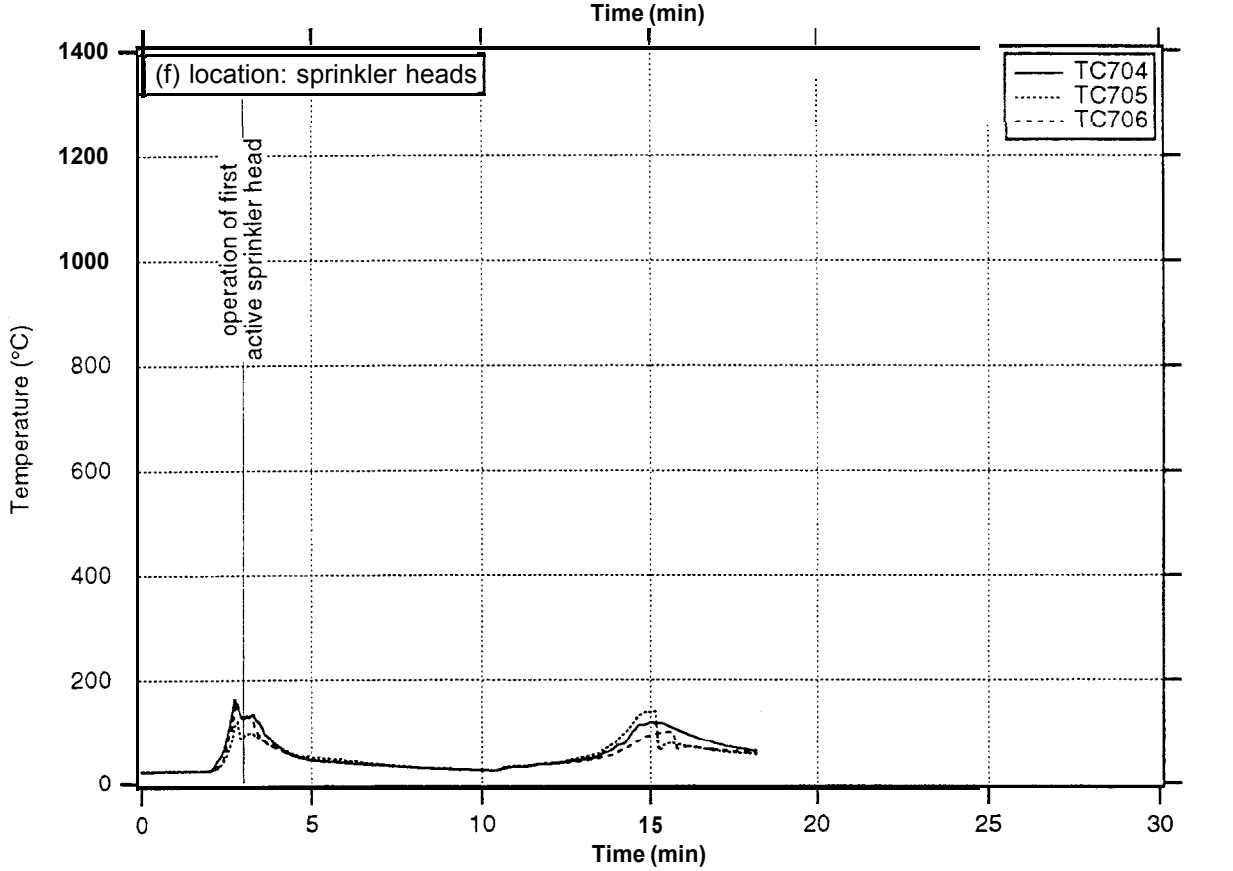


FIGURE A8(E) AND(F) AIR TEMPERATURES-TEST 8

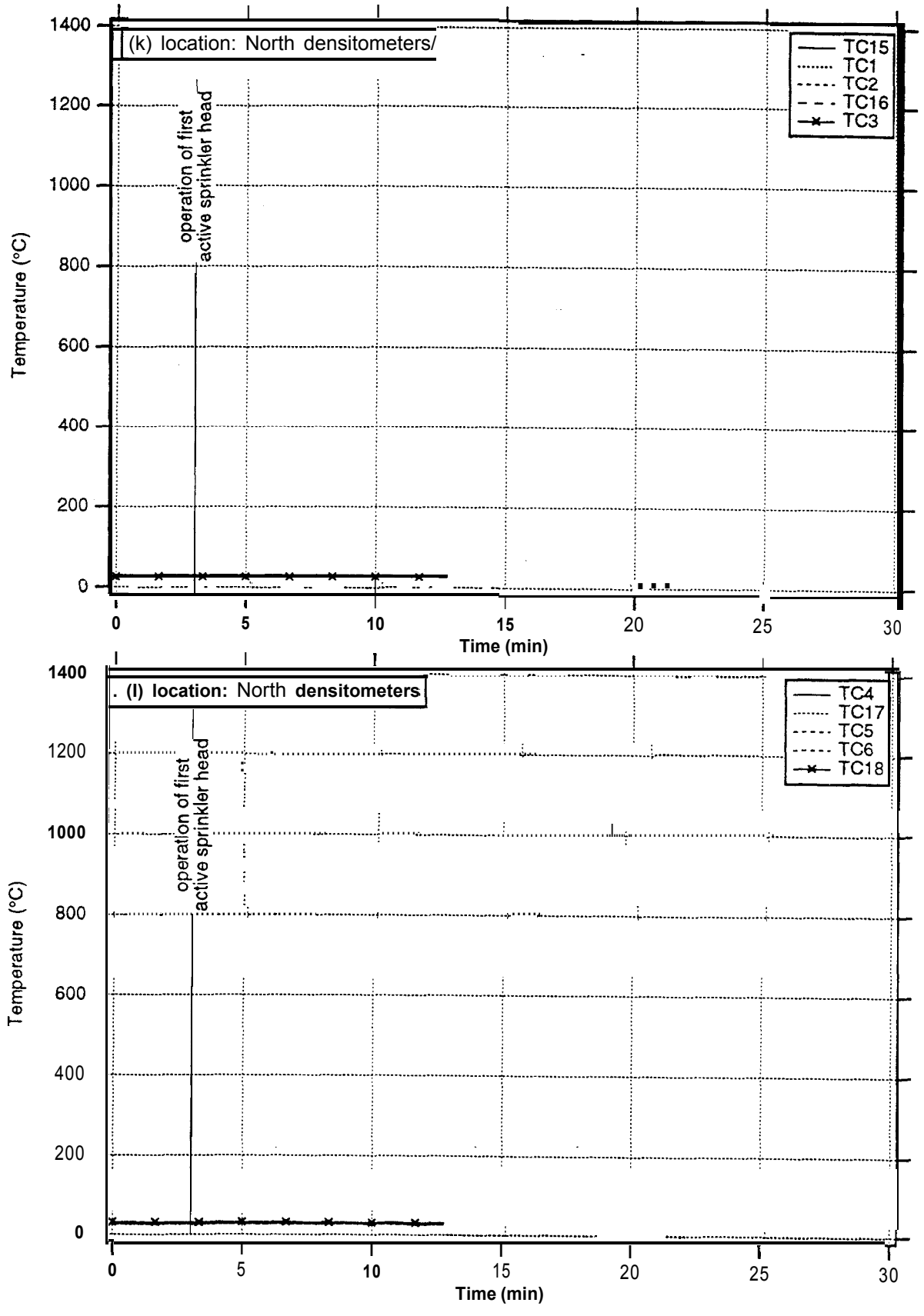


FIGURE A8(G) AND (H) AIR TEMPERATURES - TEST 8

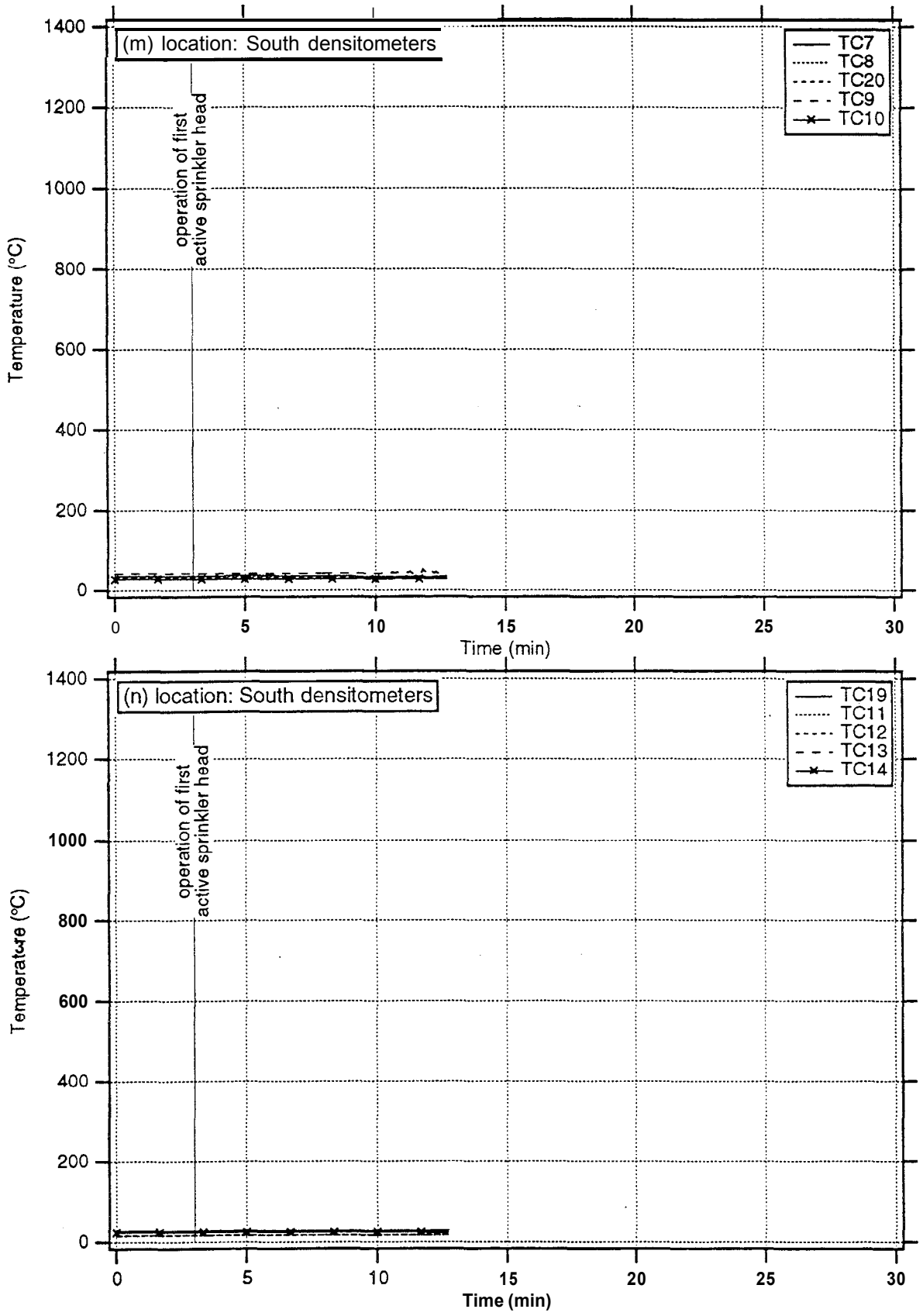


FIGURE A8(I) AND (J) AIR TEMPERATURES - TEST 8

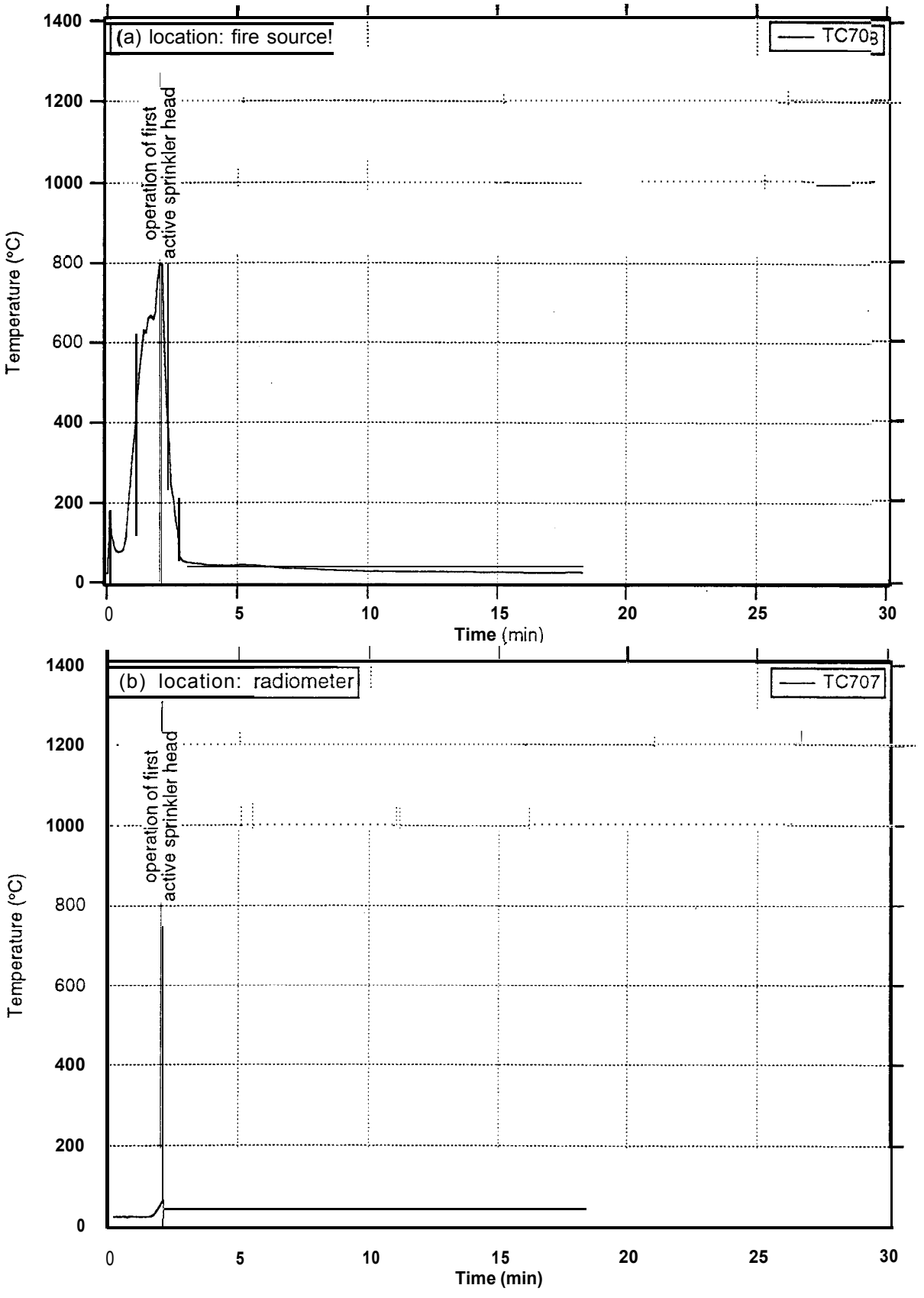


FIGURE A9(A) AND (B) AIR TEMPERATURES - TEST 9

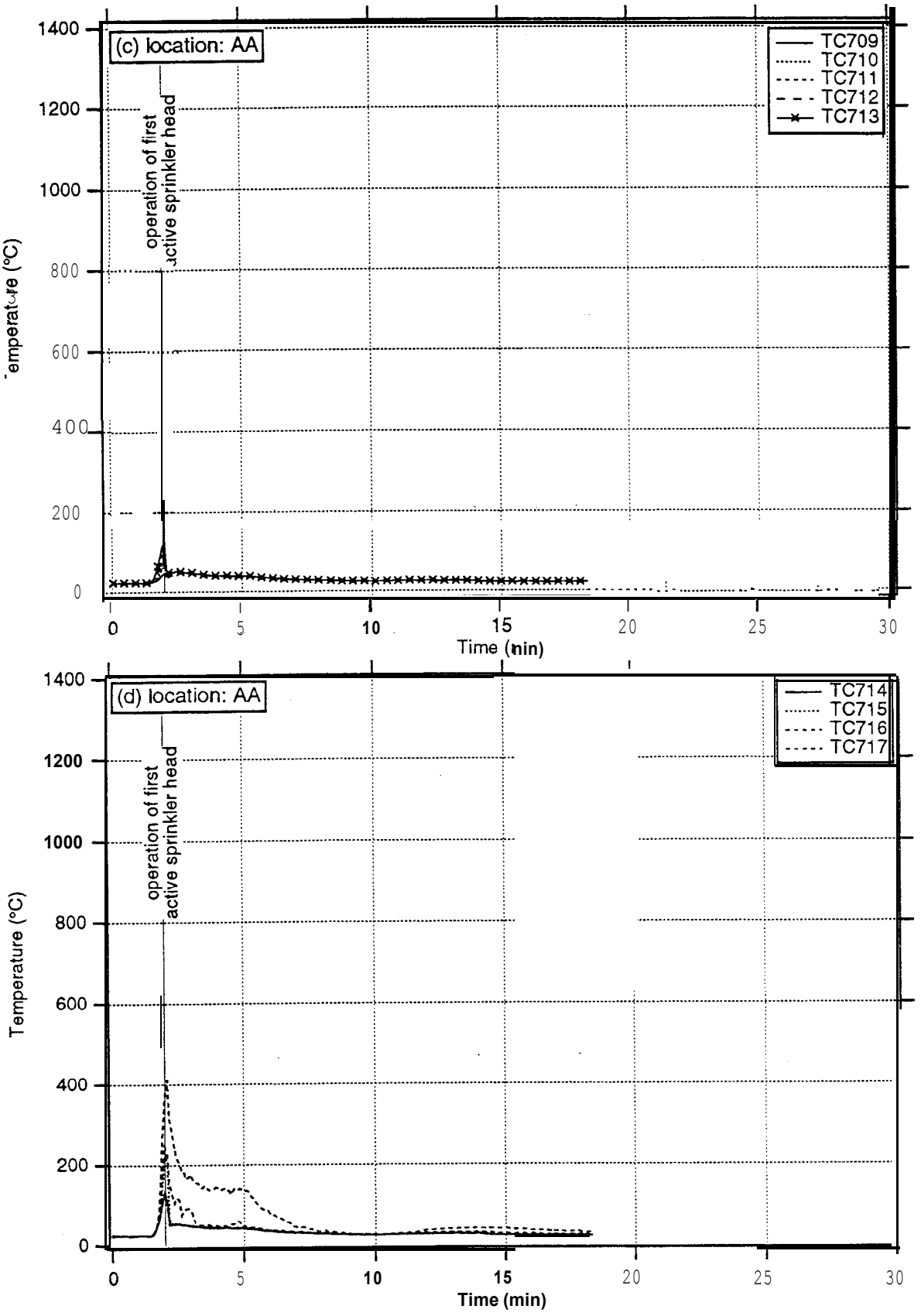


FIGURE A9(C)AND (D) AIR TEMPERATURES - TEST 9

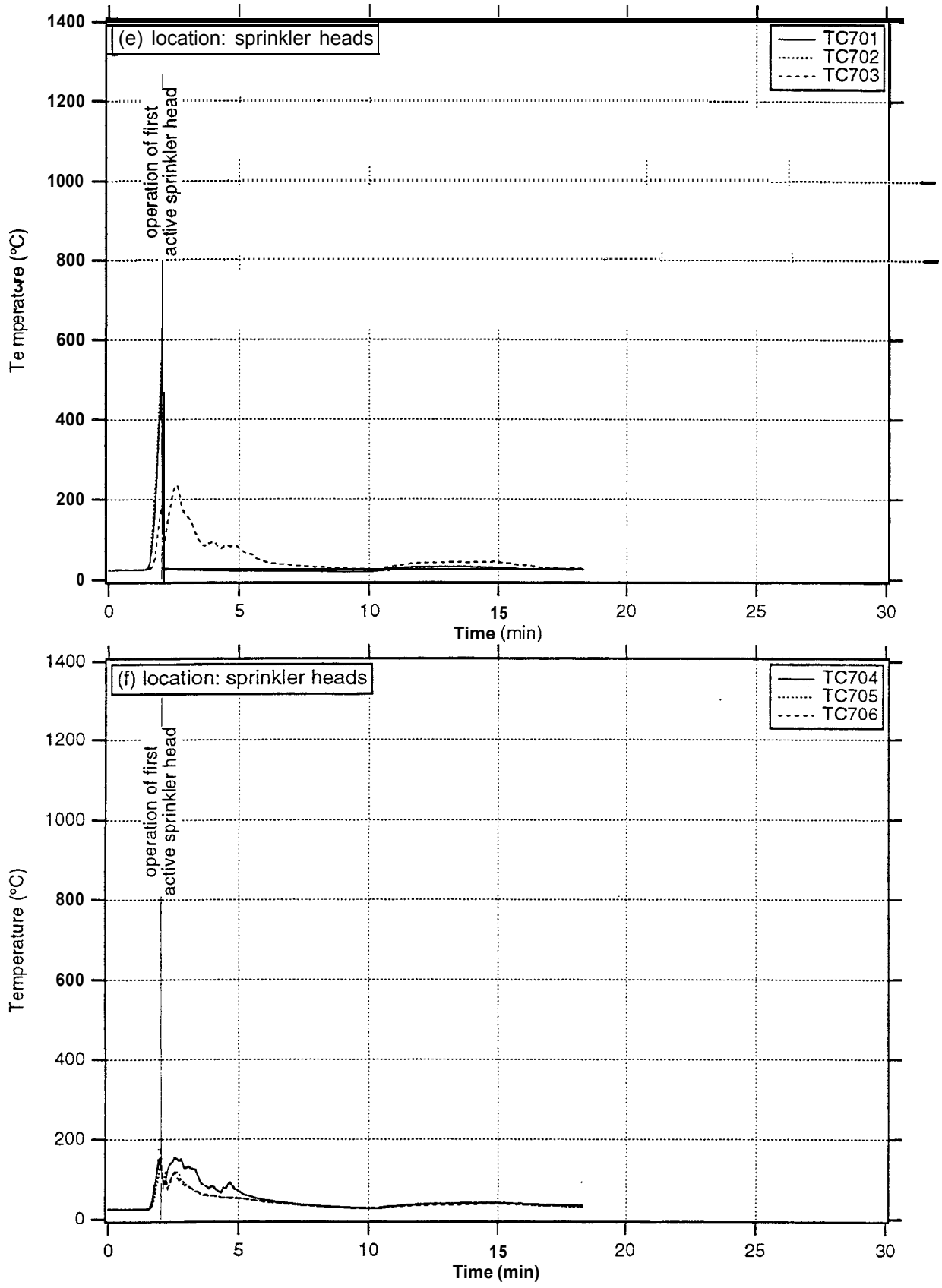


FIGURE A9(E) AND (F) AR TEMPERATURES - TEST 9

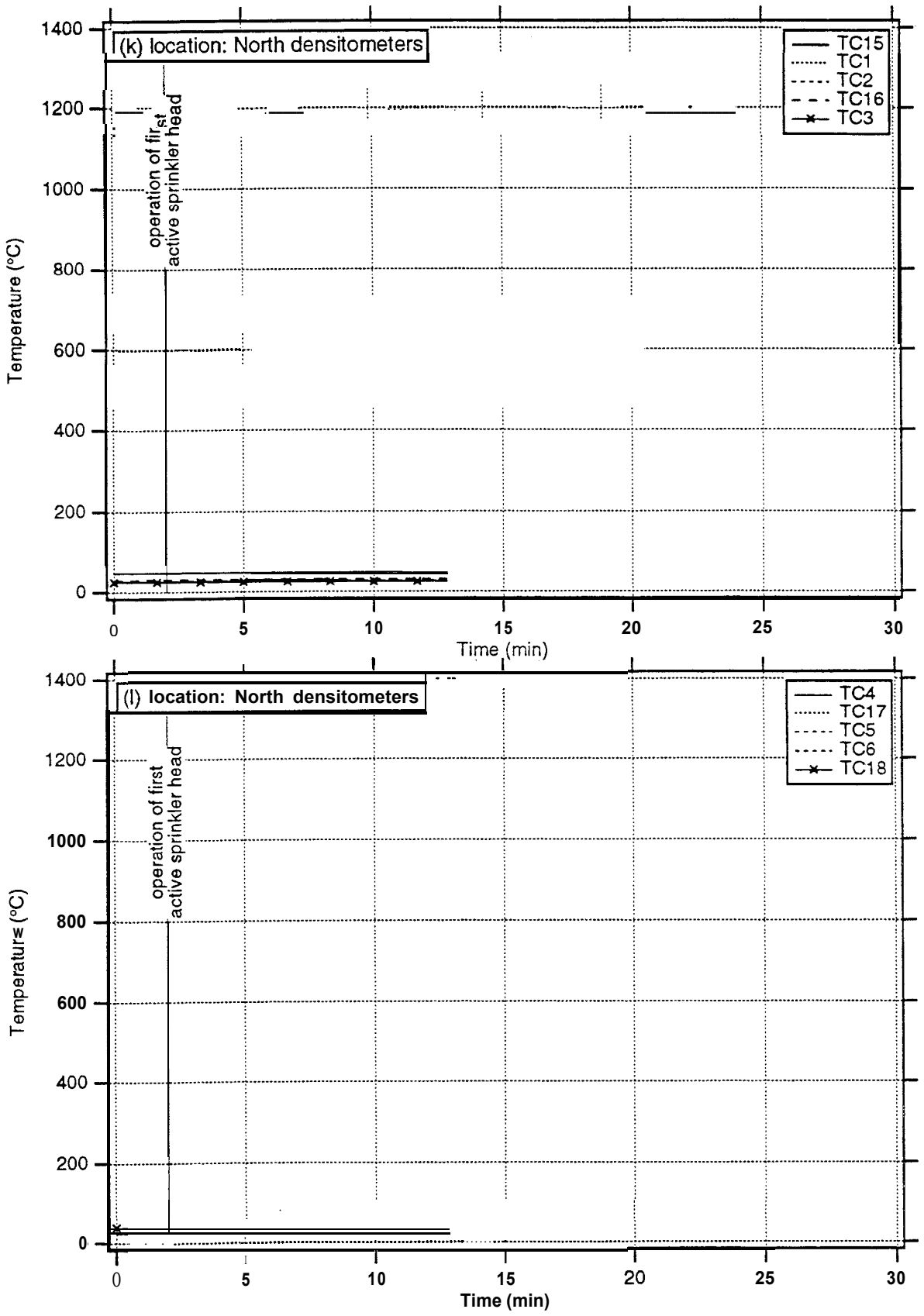


FIGURE A9(G) AND (H) AIR TEMPERATURES - TEST 9

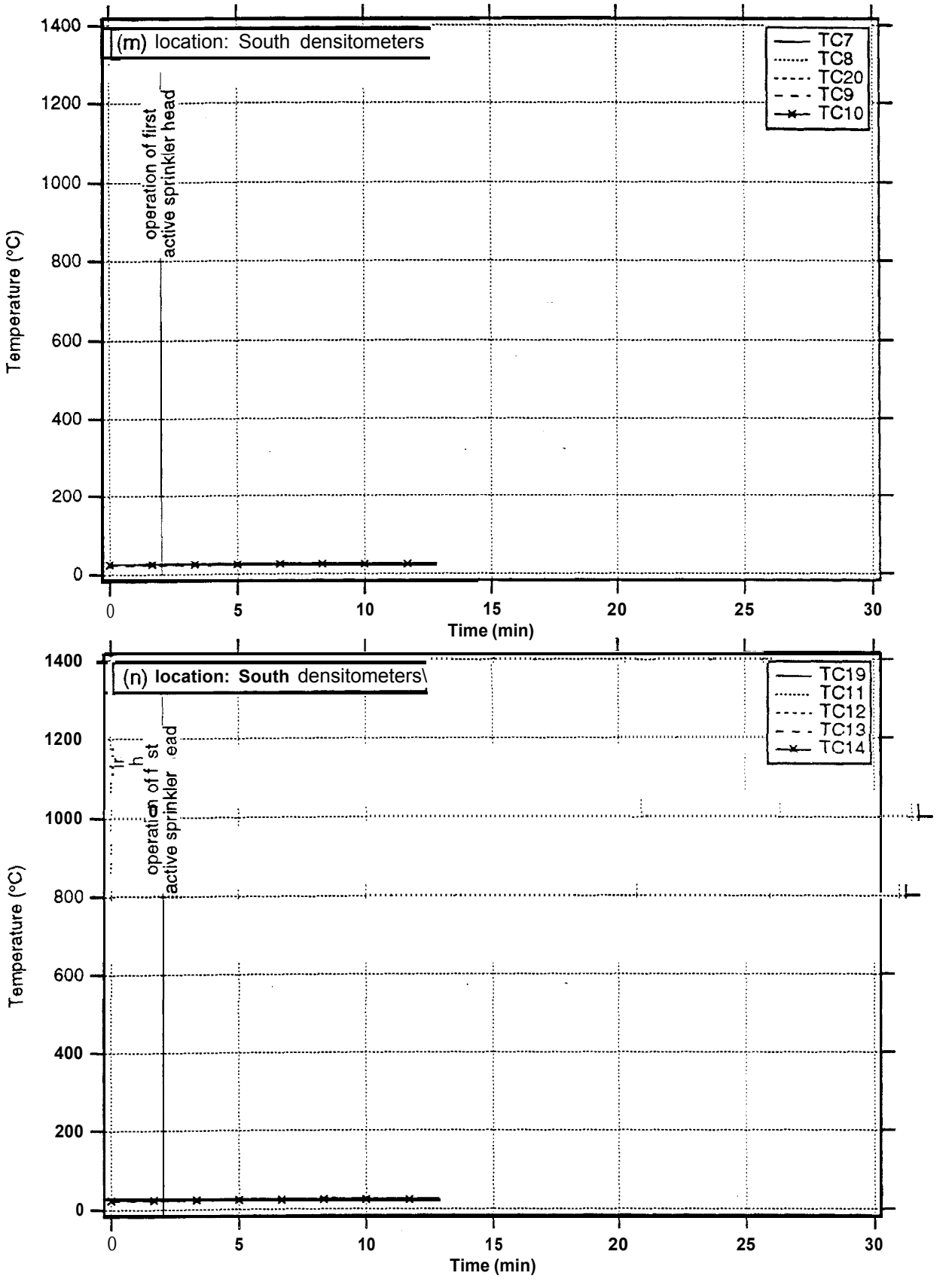


FIGURE A9(I) AND (J) AIR TEMPERATURES - TEST 9

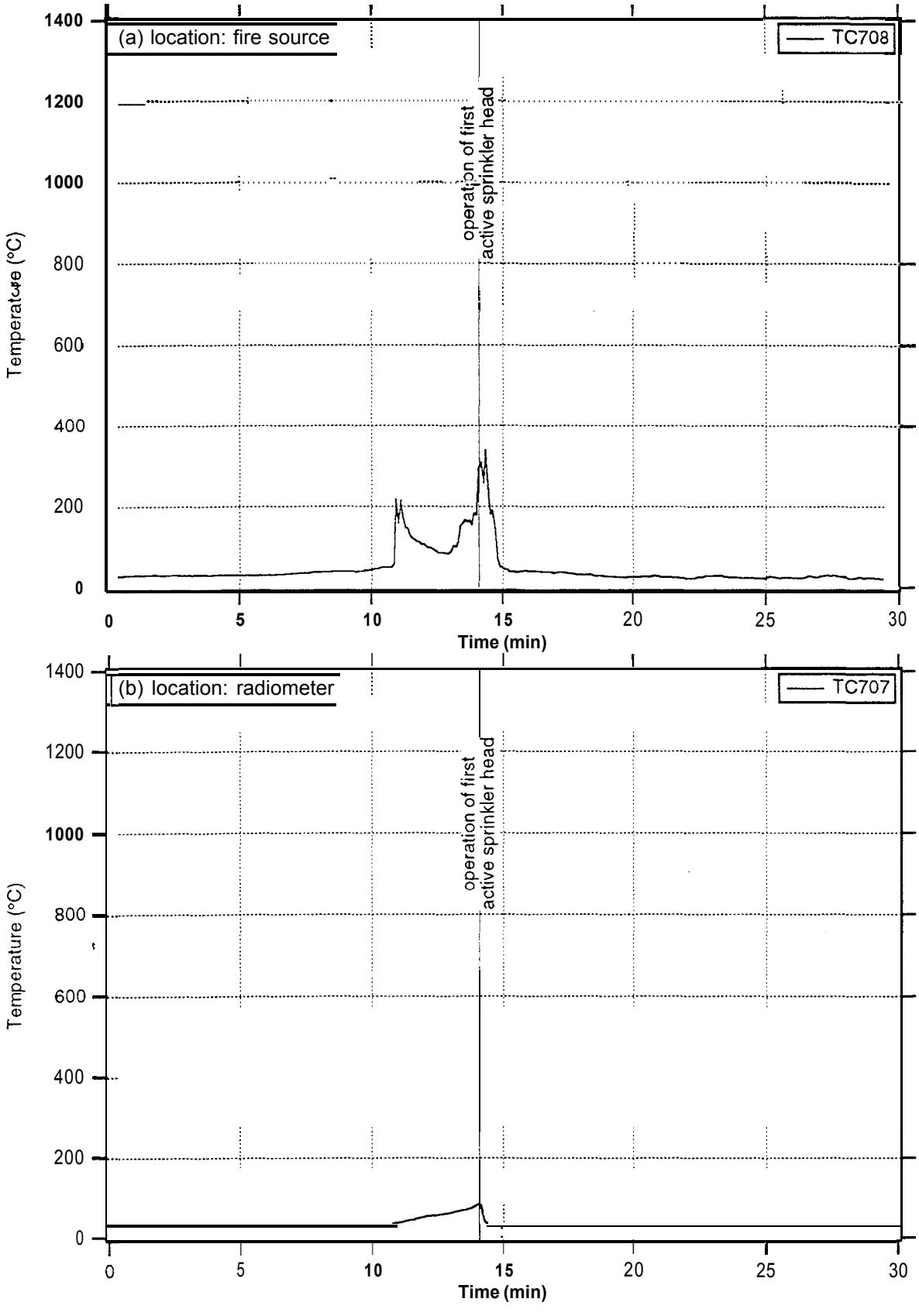


FIGURE A10(A) AND (B) AIR TEMPERATURES - TEST 10

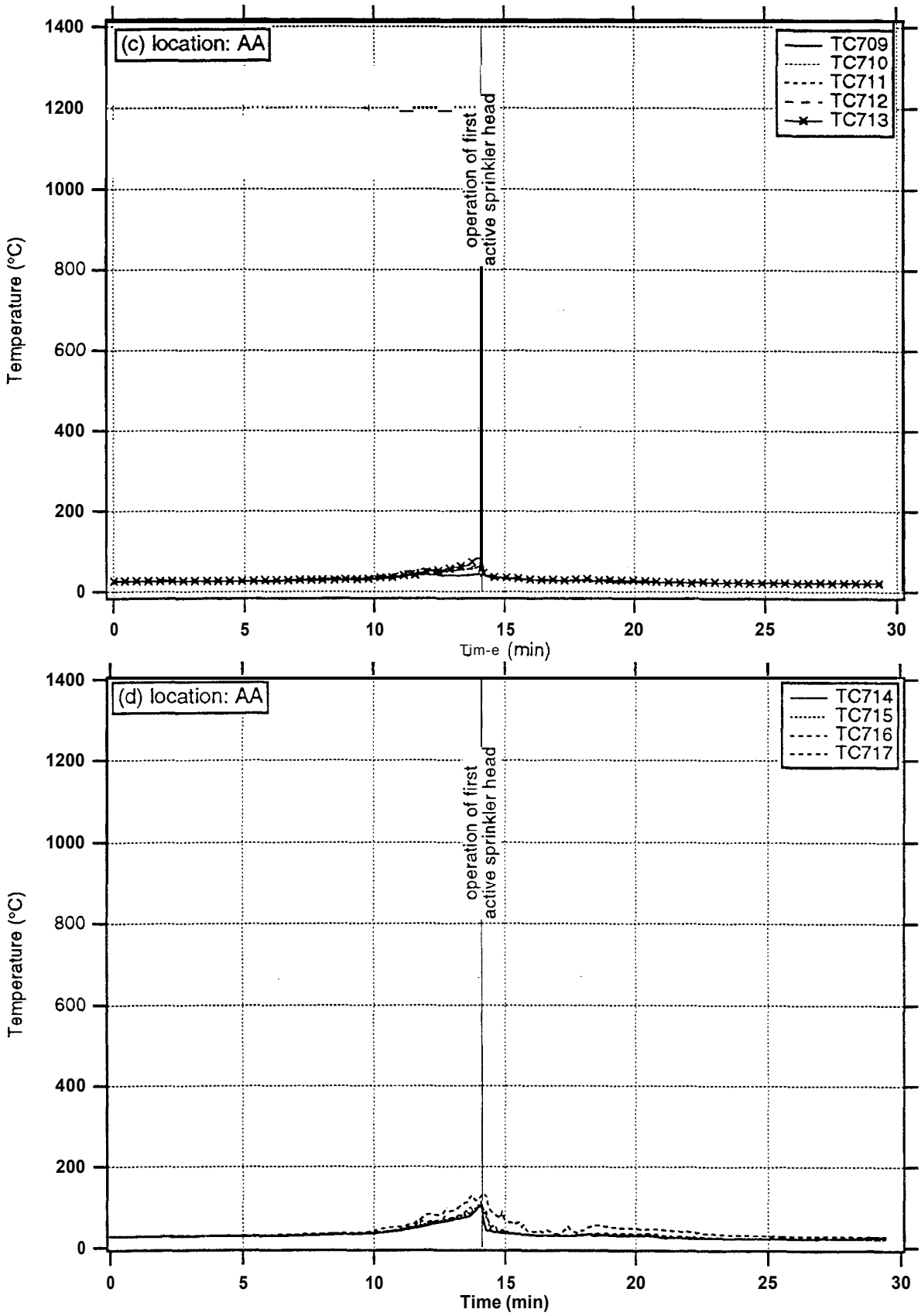


FIGURE A10(C) AND (D) AIR TEMPERATURES - TEST 10

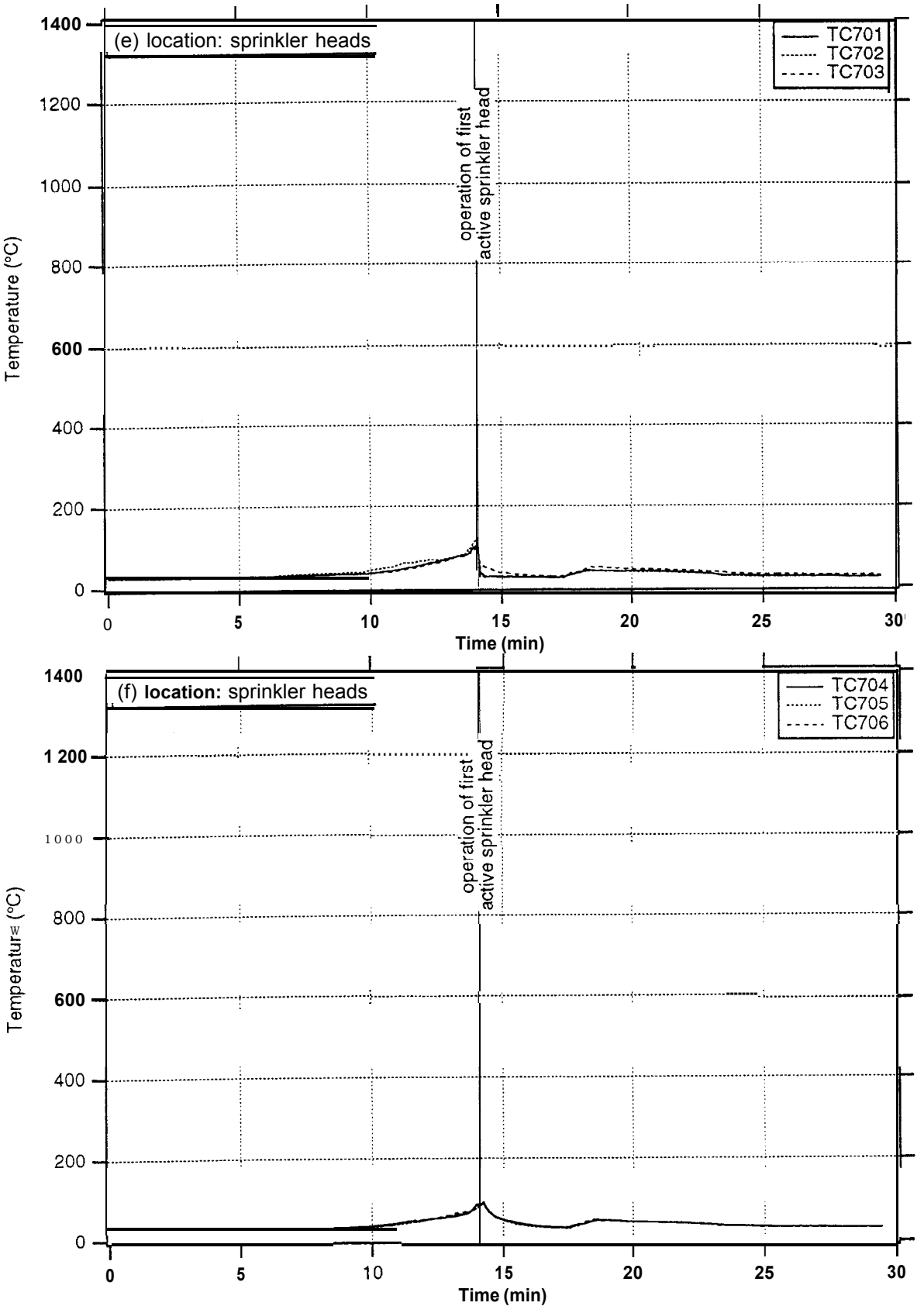


FIGURE A10(E) AND (F) AIR TEMPERATURES-TEST 10

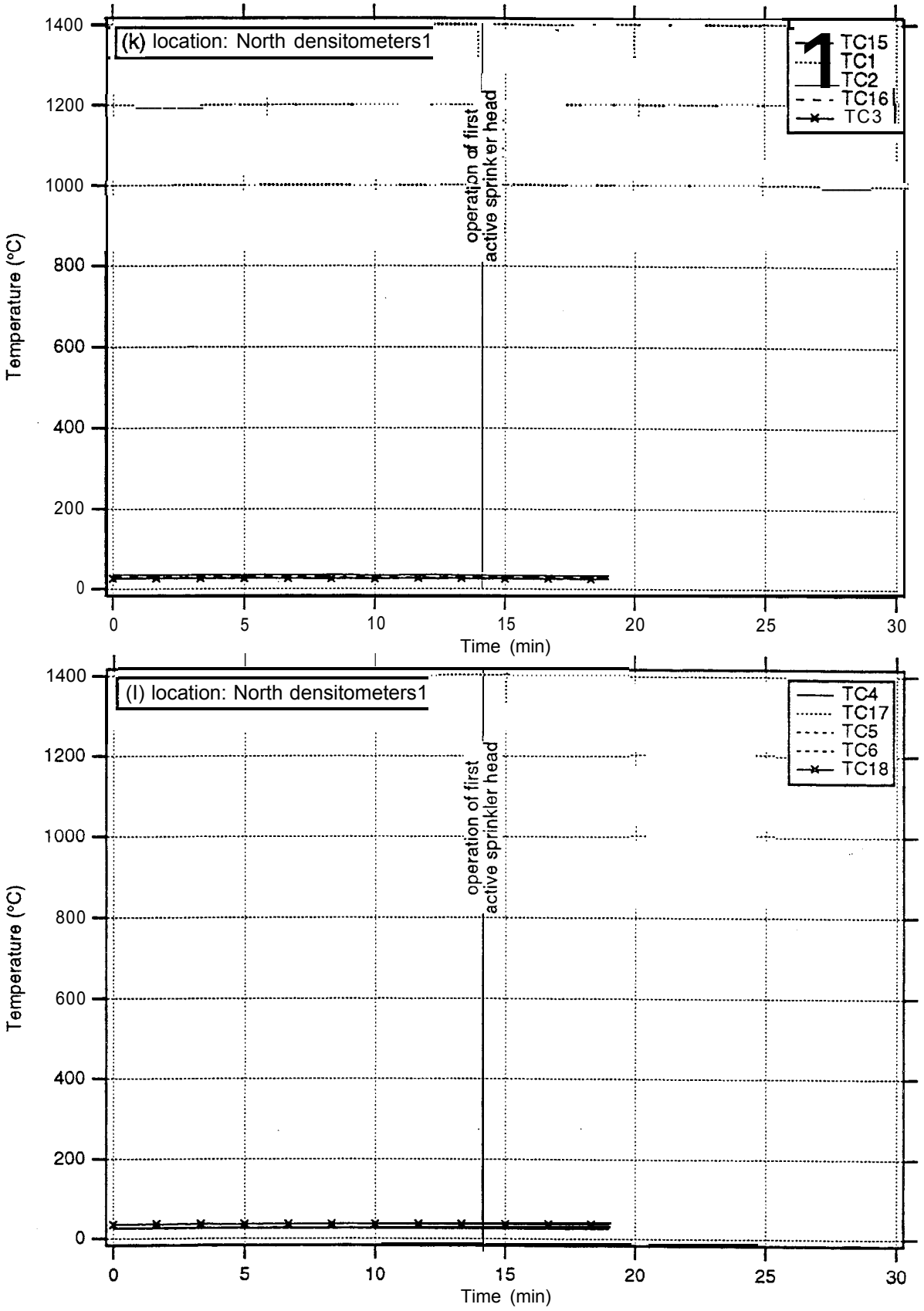


FIGURE A10(G) AND (H) AIR TEMPERATURES - TEST 10

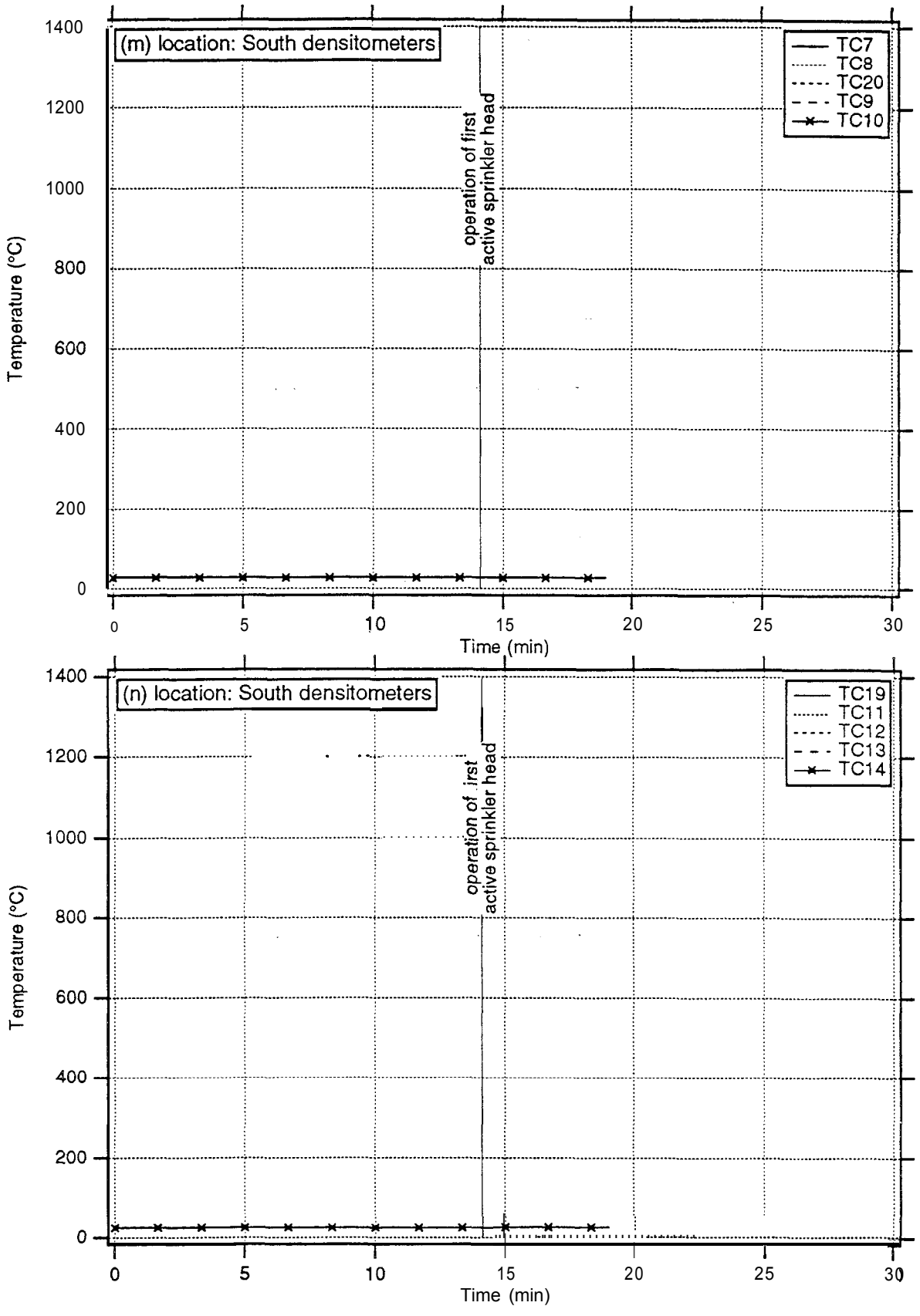


FIGURE A10(I) AND (J) AIR TEMPERATURES - TEST 10

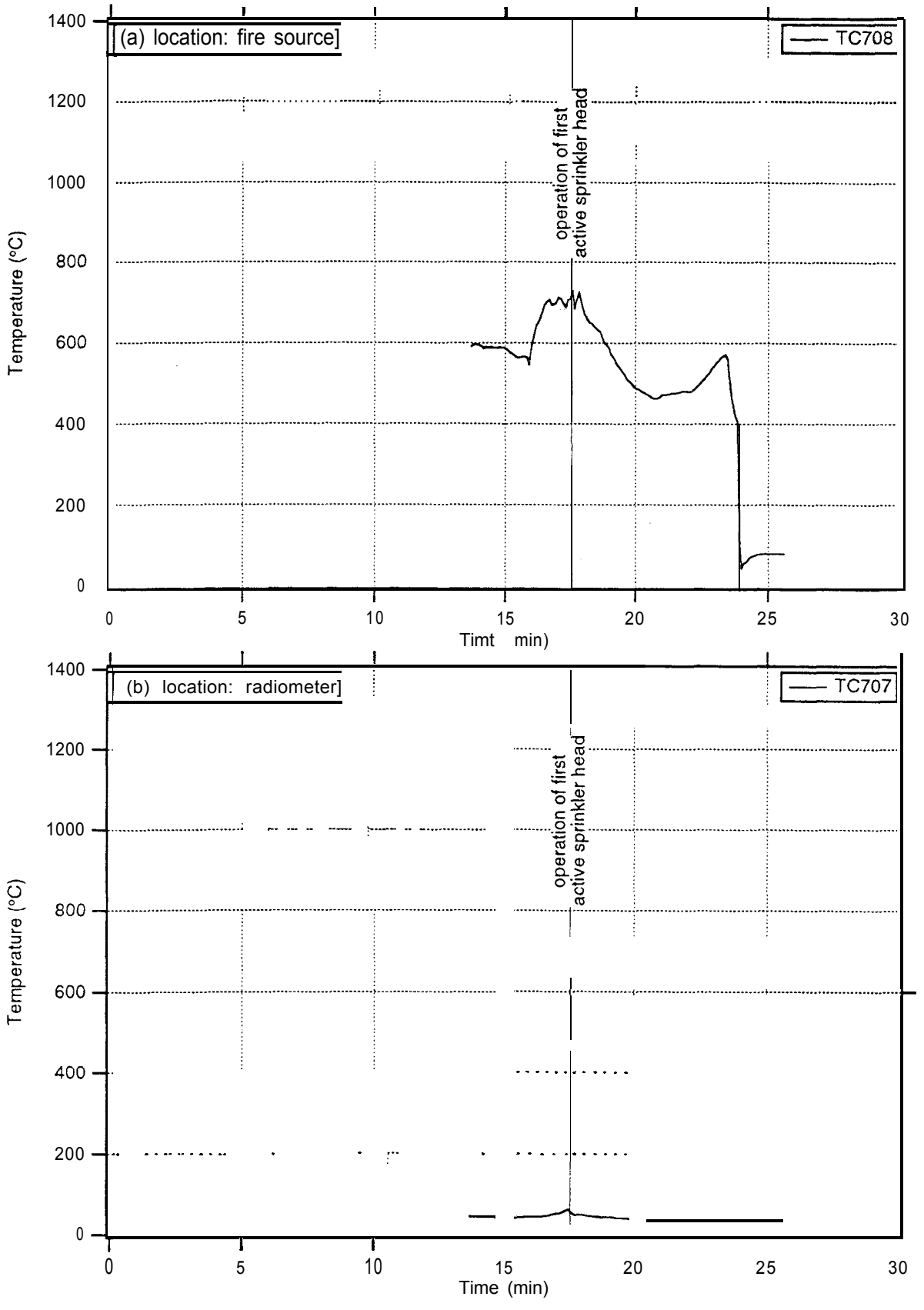


FIGURE A1 1(A) AND (B) AIR TEMPERATURES - TEST 11

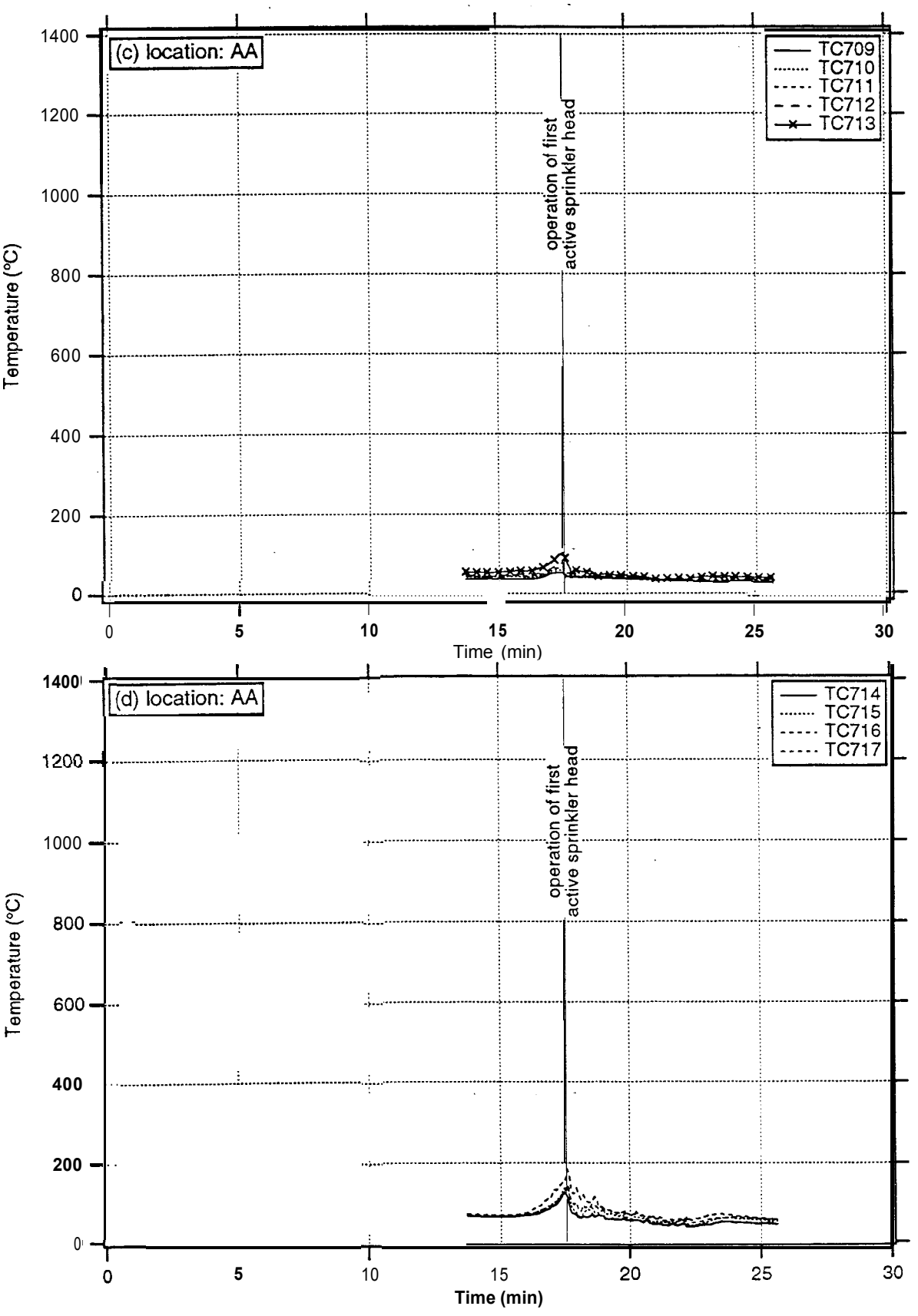


FIGURE A1 1 (C) AND (D) AIR TEMPERATURES - TEST 11

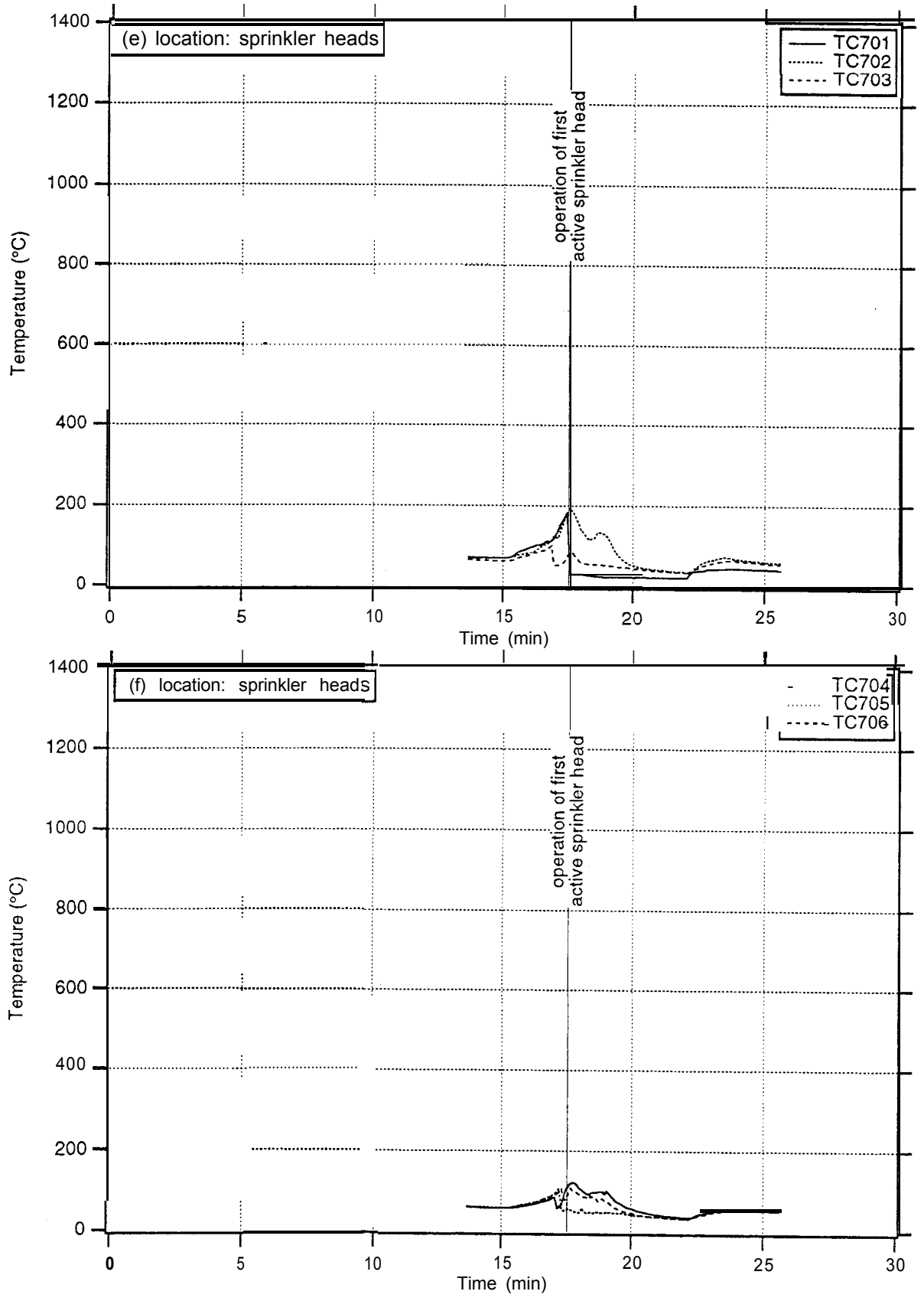


FIGURE A11 (E) AND (F) AIR TEMPERATURES - TEST 11

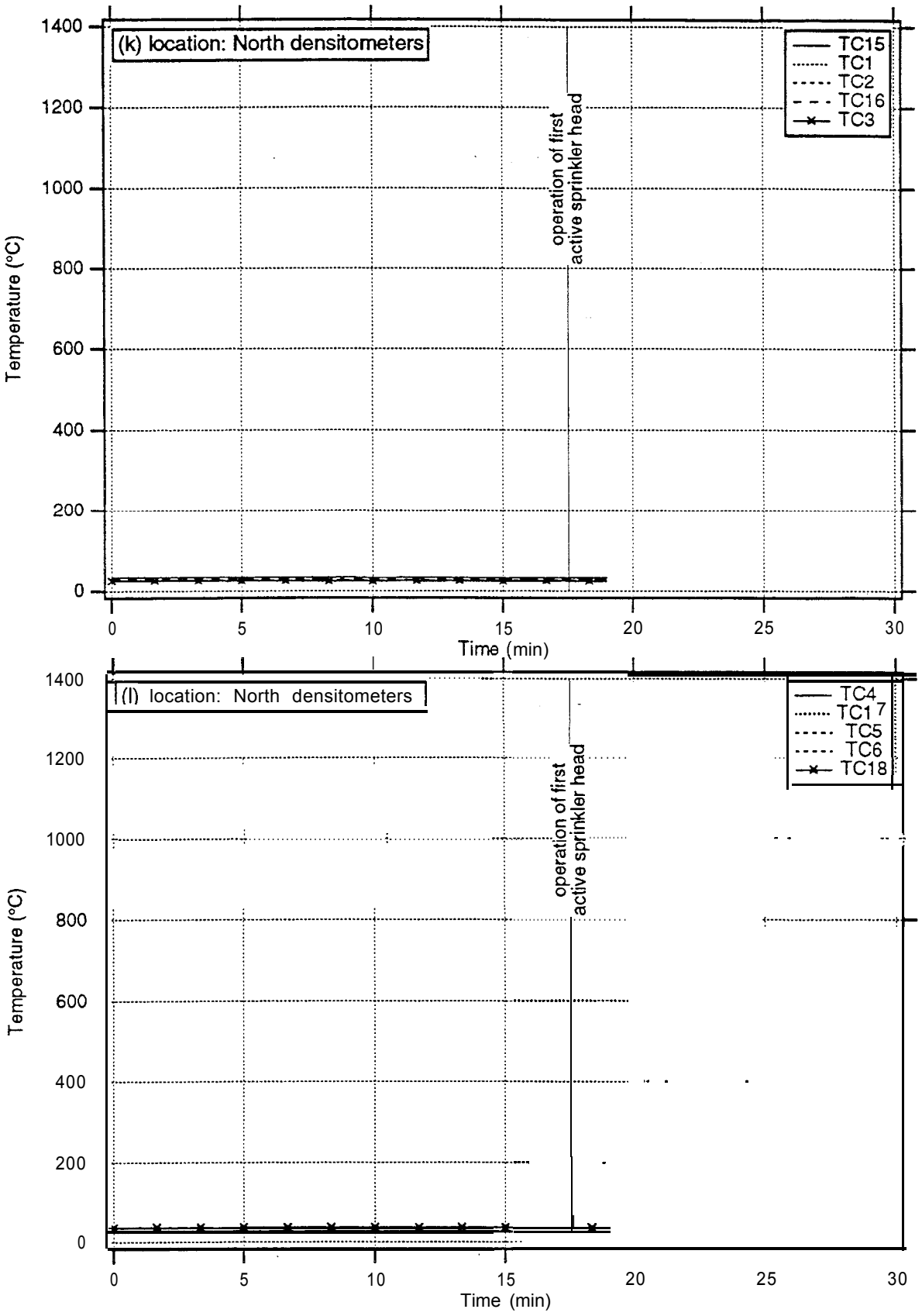


FIGURE A11 (G) AND (H) AIR TEMPERATURES - TEST 1

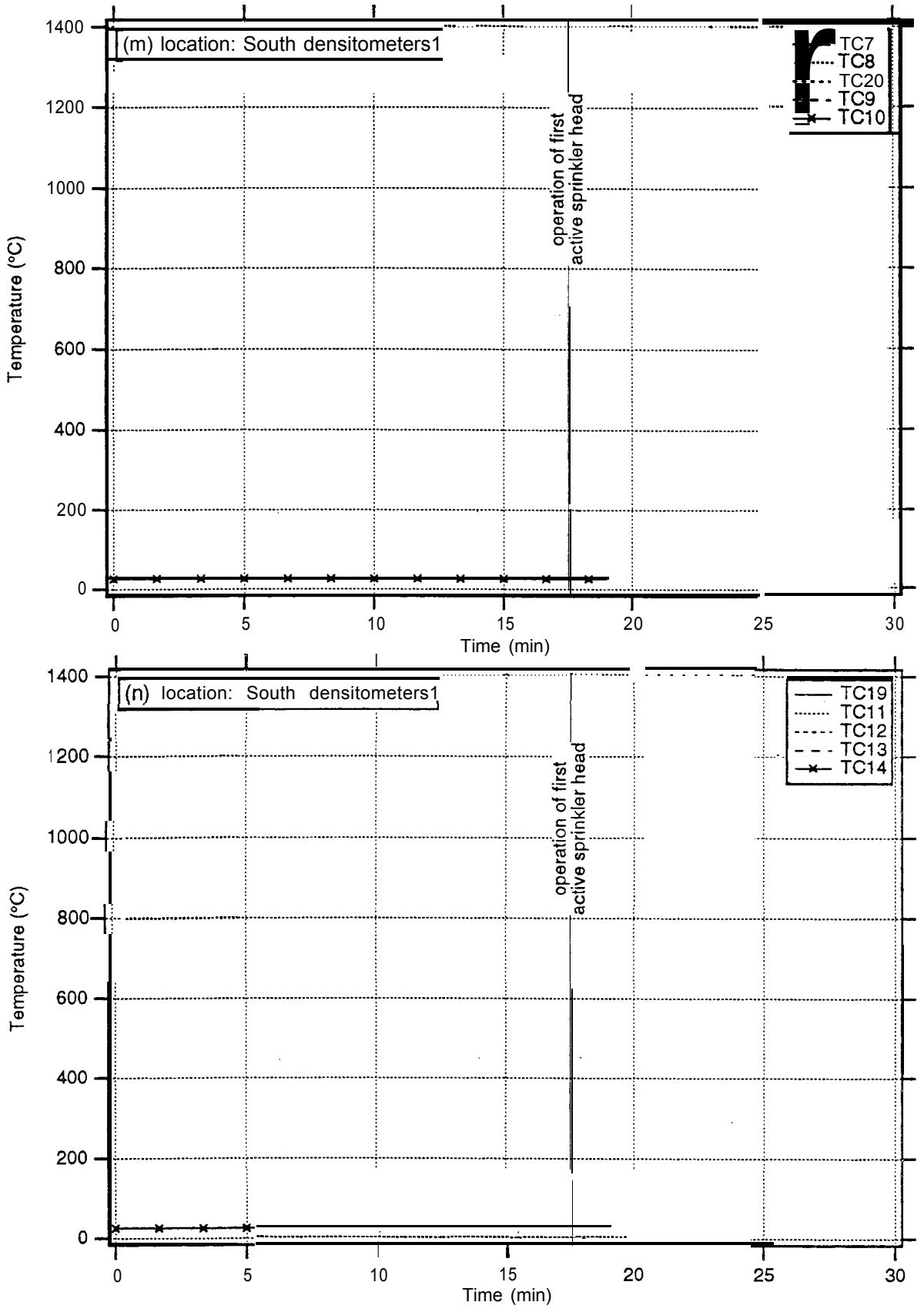


FIGURE A1 I(1) AND (J) AIR TEMPERATURES - TEST 1 I

APPENDIX B: STEEL TEMPERATURES

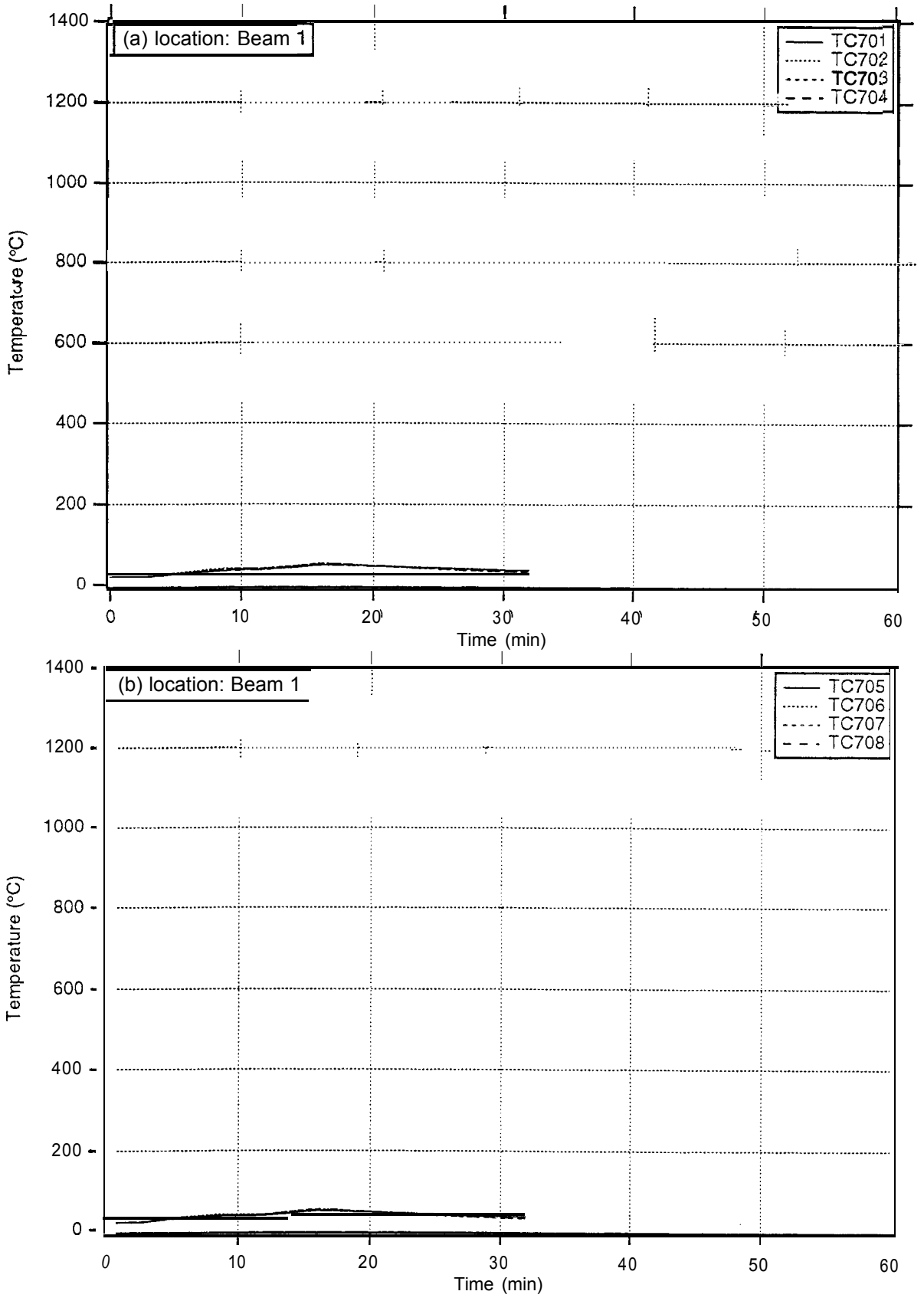


FIGURE B1(A) AND (B) STEEL TEMPERATURES - TEST 1

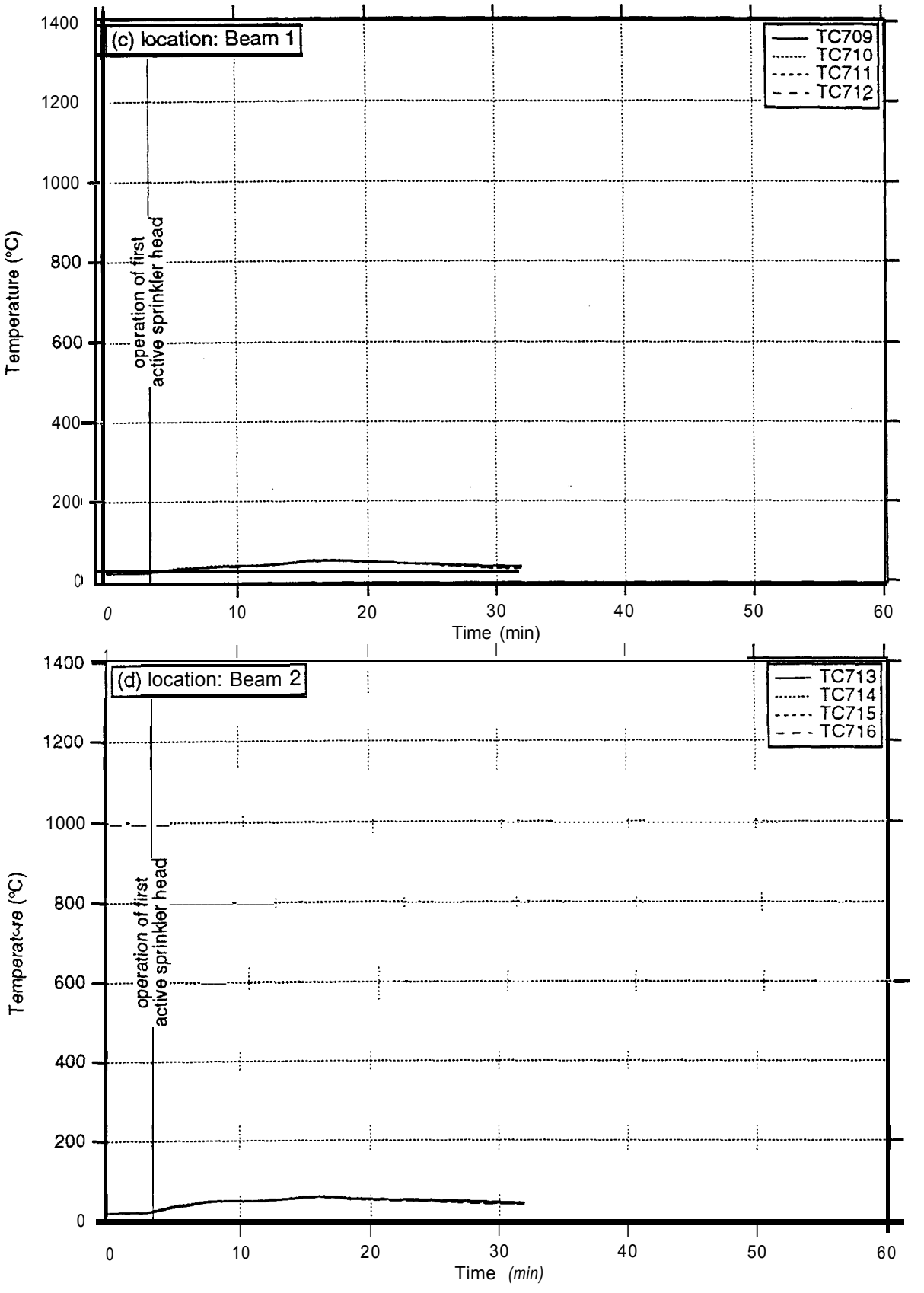


FIGURE B1 (C) AND (D) STEEL TEMPERATURES - TEST 1

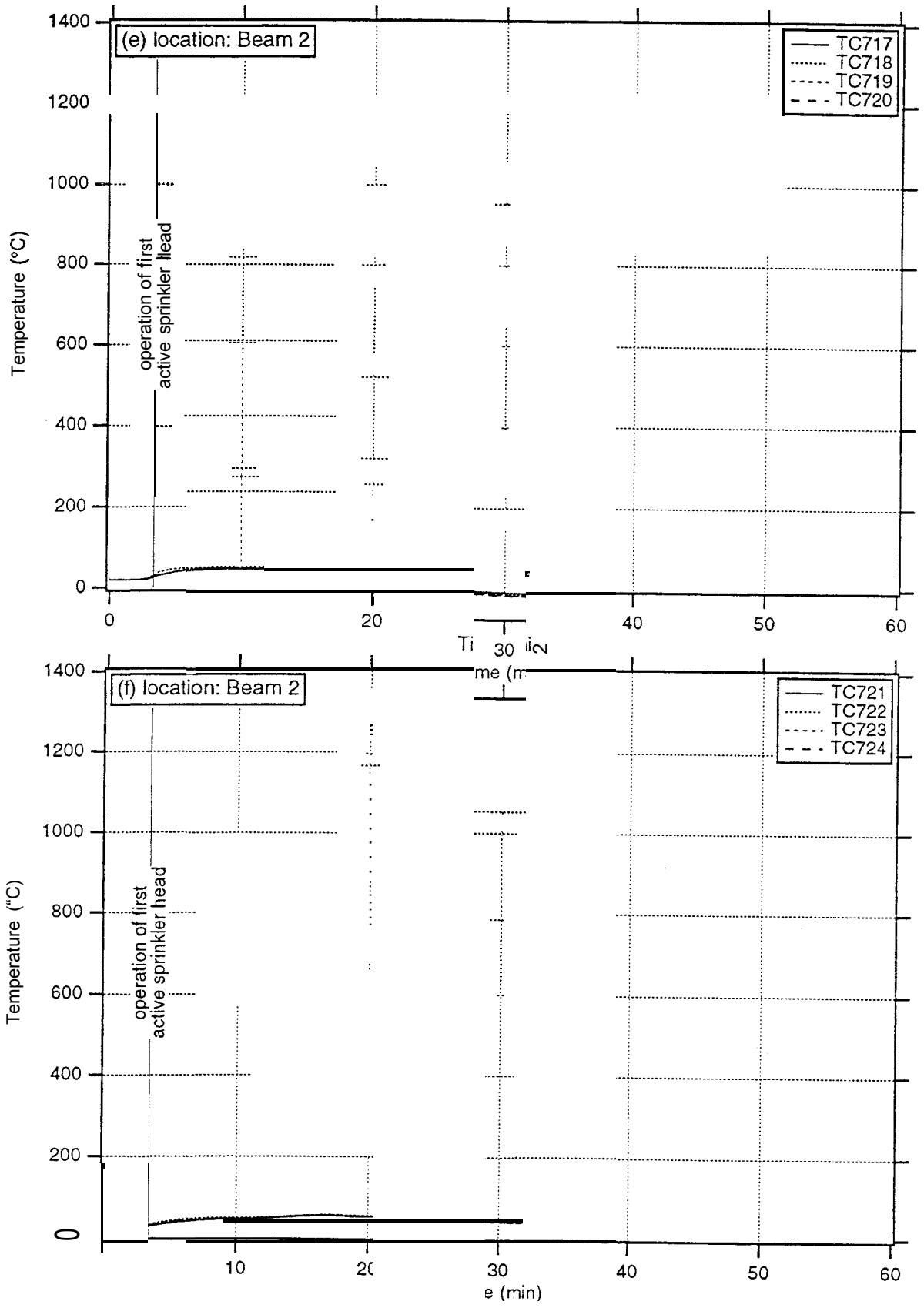


FIGURE B1(E) AND (F) STEEL TEMPERATURES - TEST 1

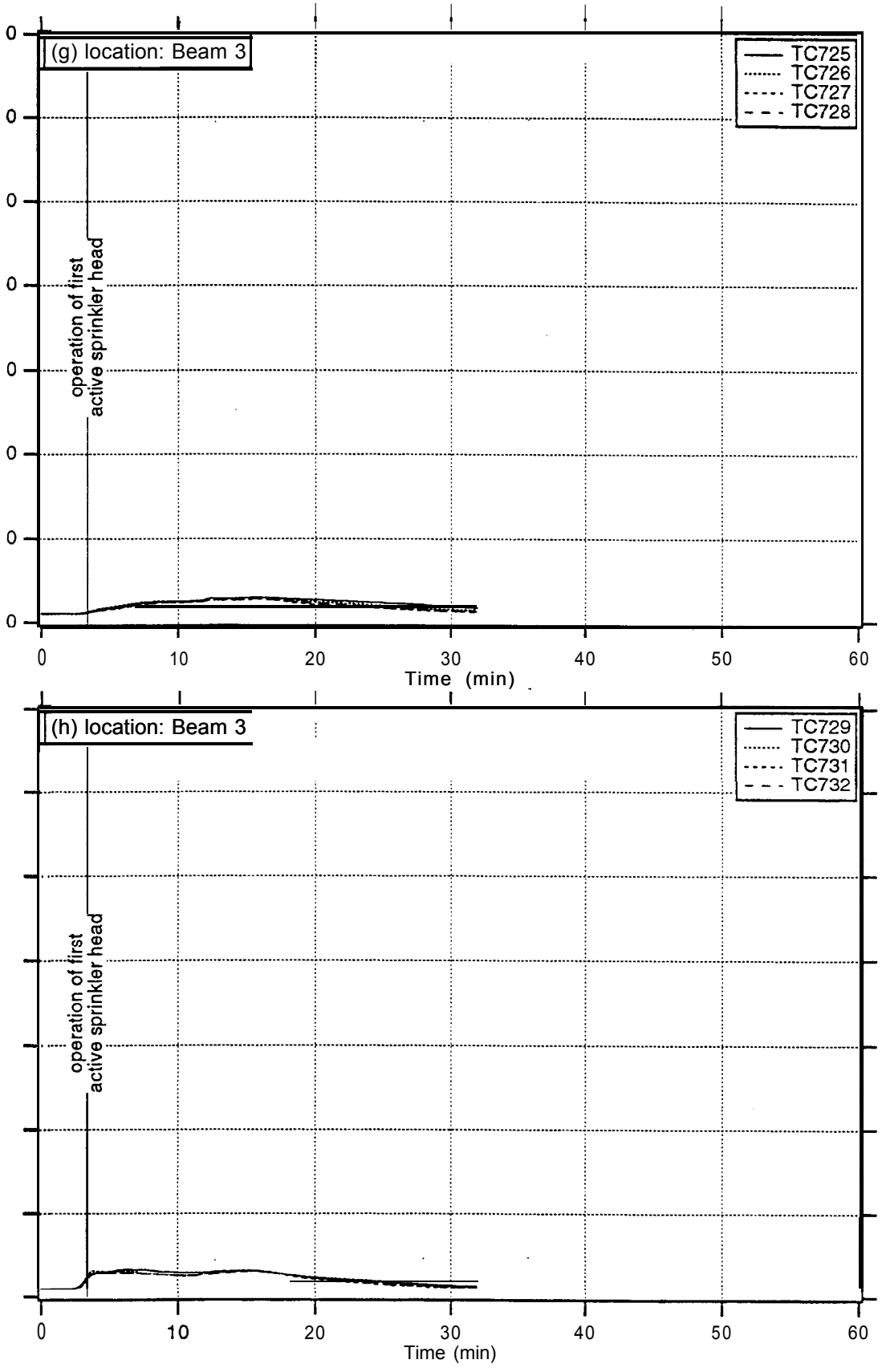


FIGURE B 1(G) AND (H) STEEL TEMPERATURES - TEST 1

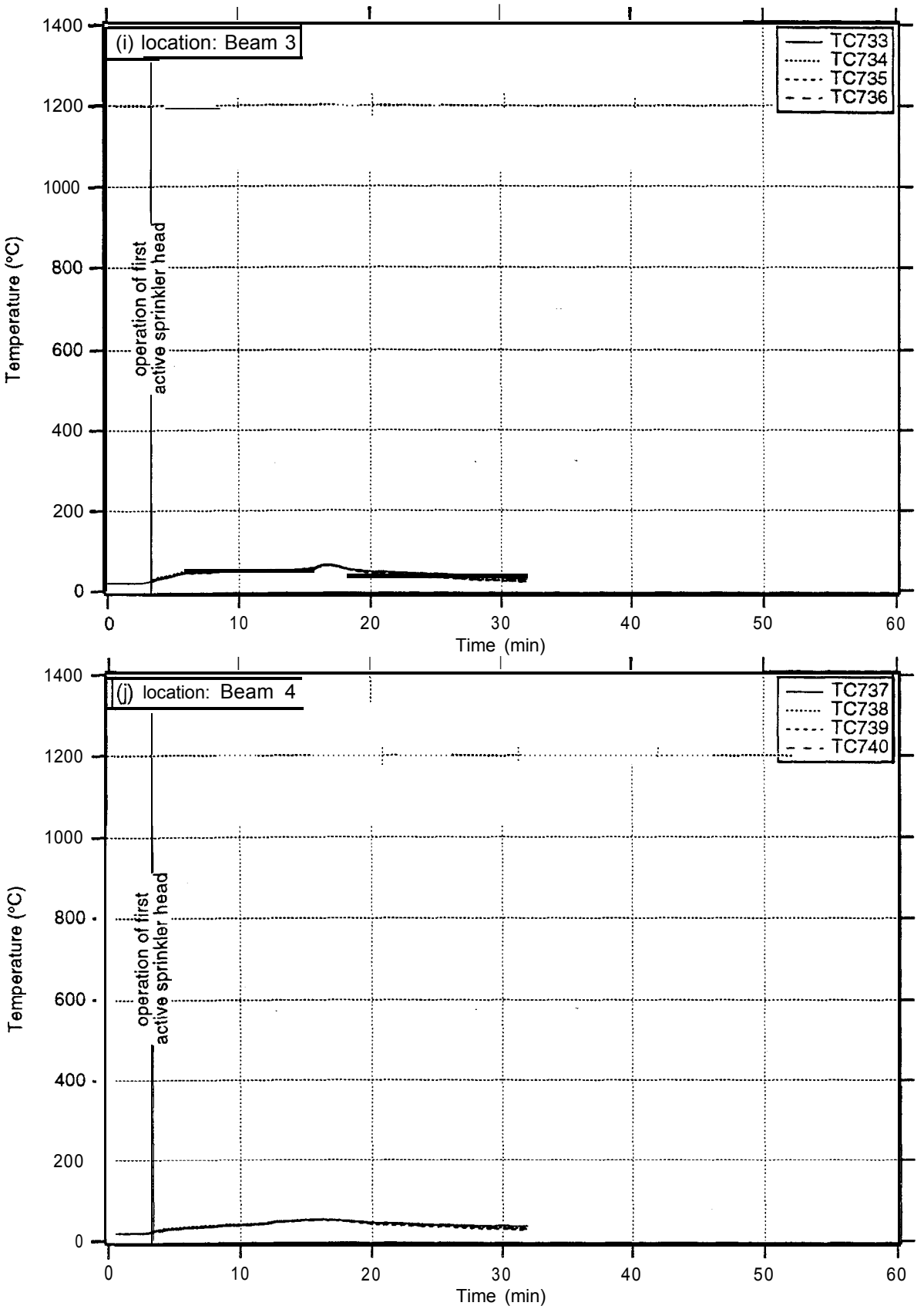


FIGURE B1(I) AND (J) STEEL TEMPERATURES - TEST 1

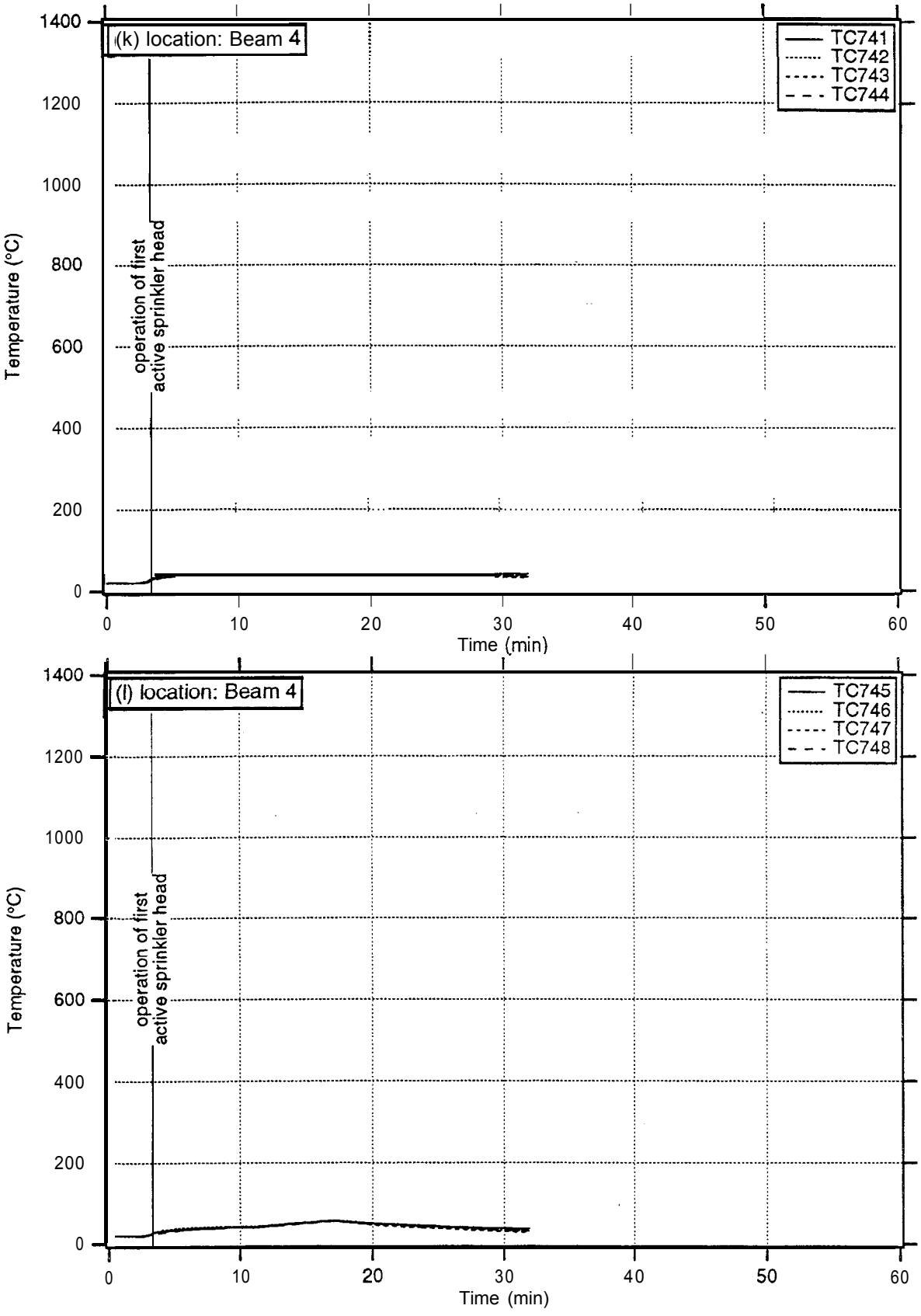


FIGURE B 1(K) AND (L) STEEL TEMPERATURES - TEST 1

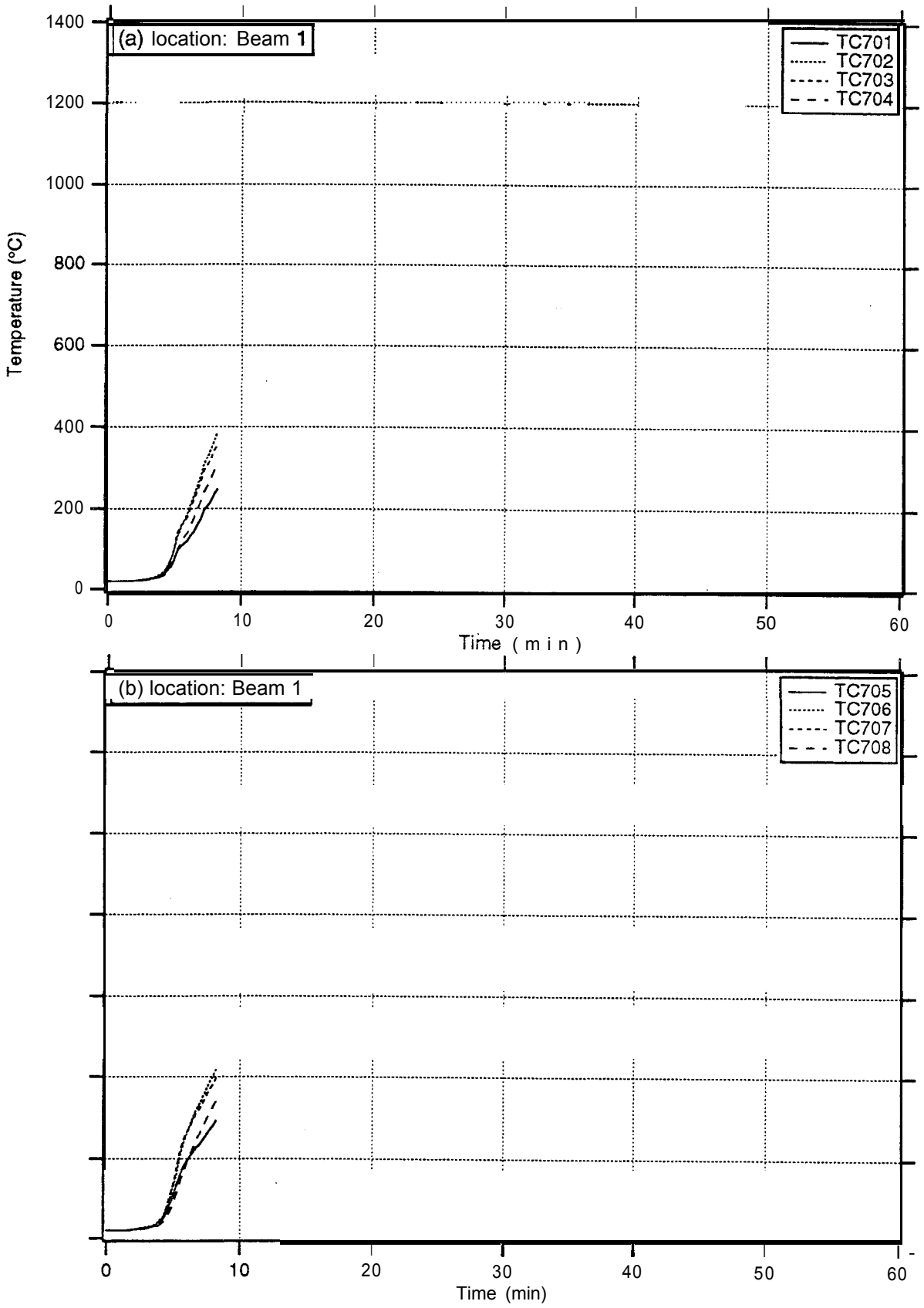


FIGURE B2(A) AND (B) STEEL TEMPERATURES - TEST 2

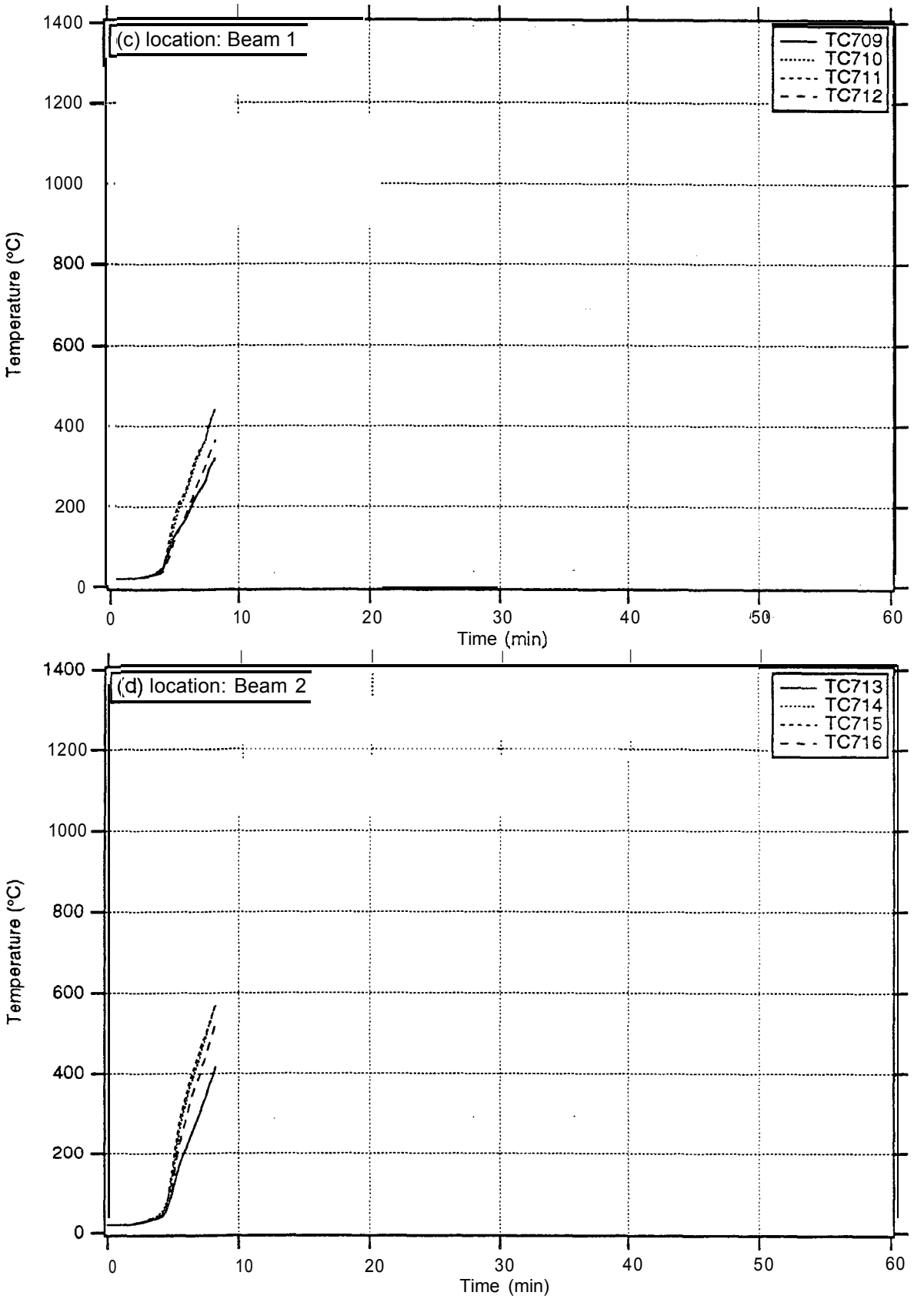


FIGURE B2(C) AND (D) STEEL TEMPERATURES - TEST 2

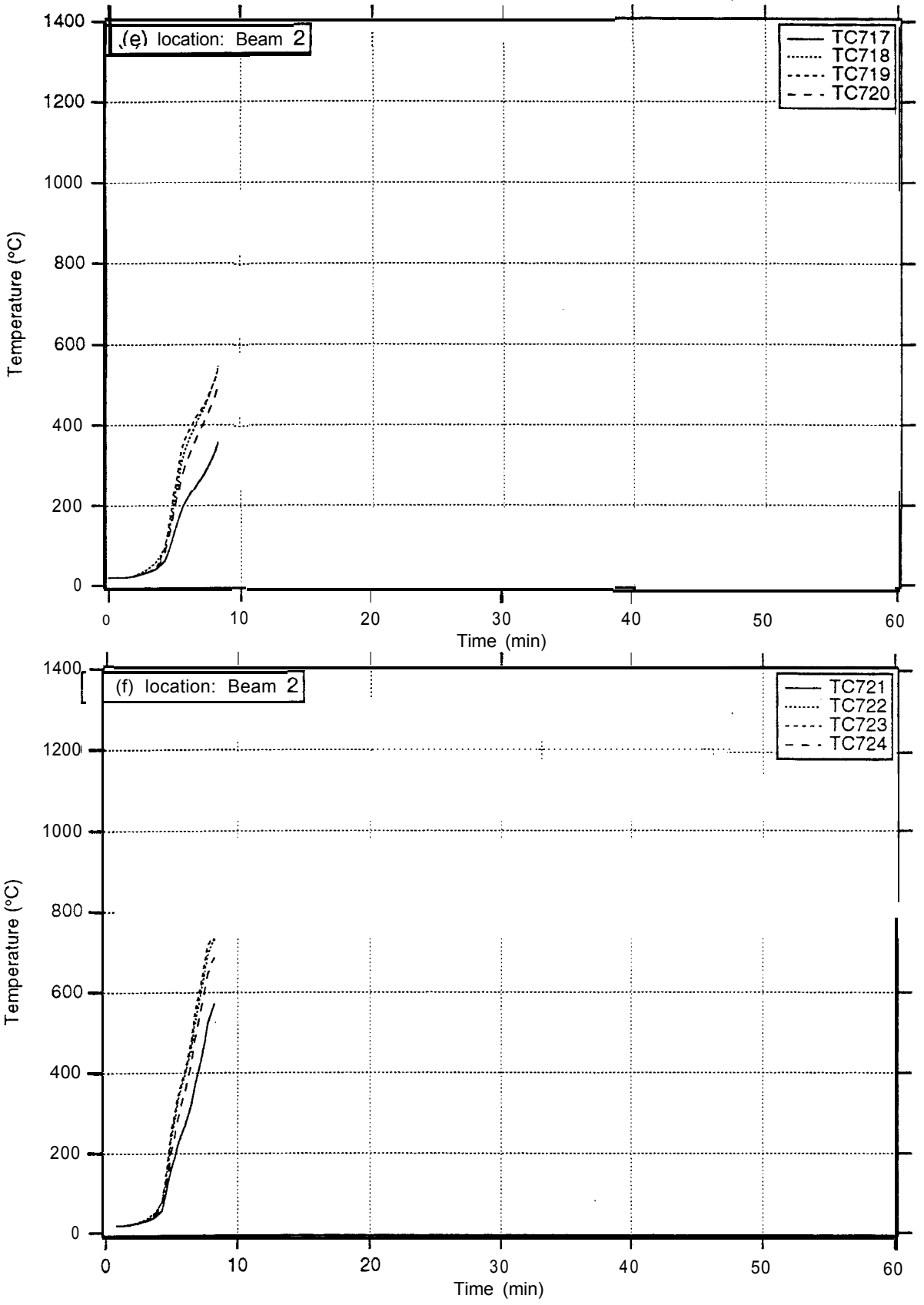


FIGURE B2(E) AND(F) STEEL TEMPERATURES - TEST 2

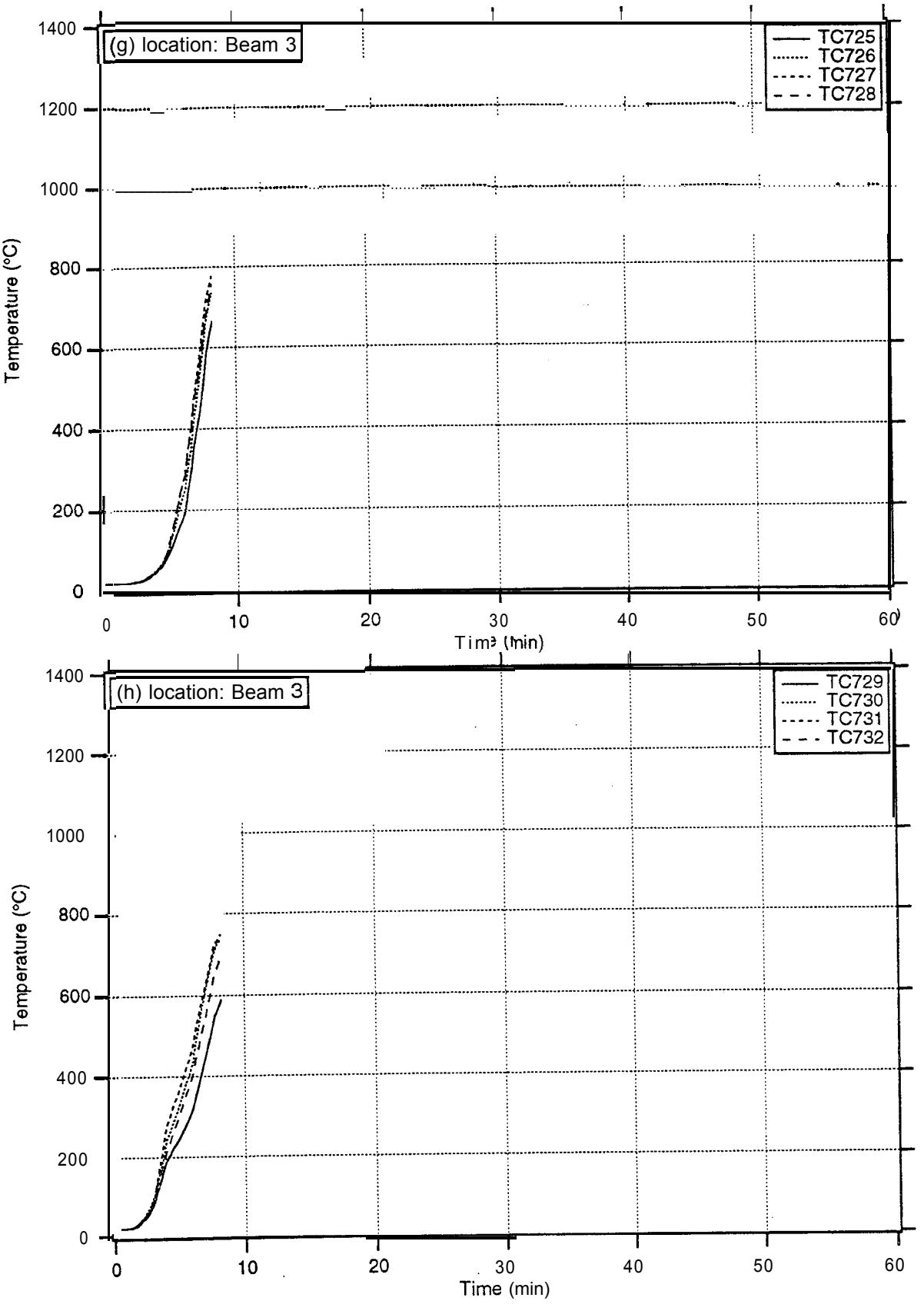


FIGURE B2(G) AND (H) STEEL TEMPERATURES - TEST 2

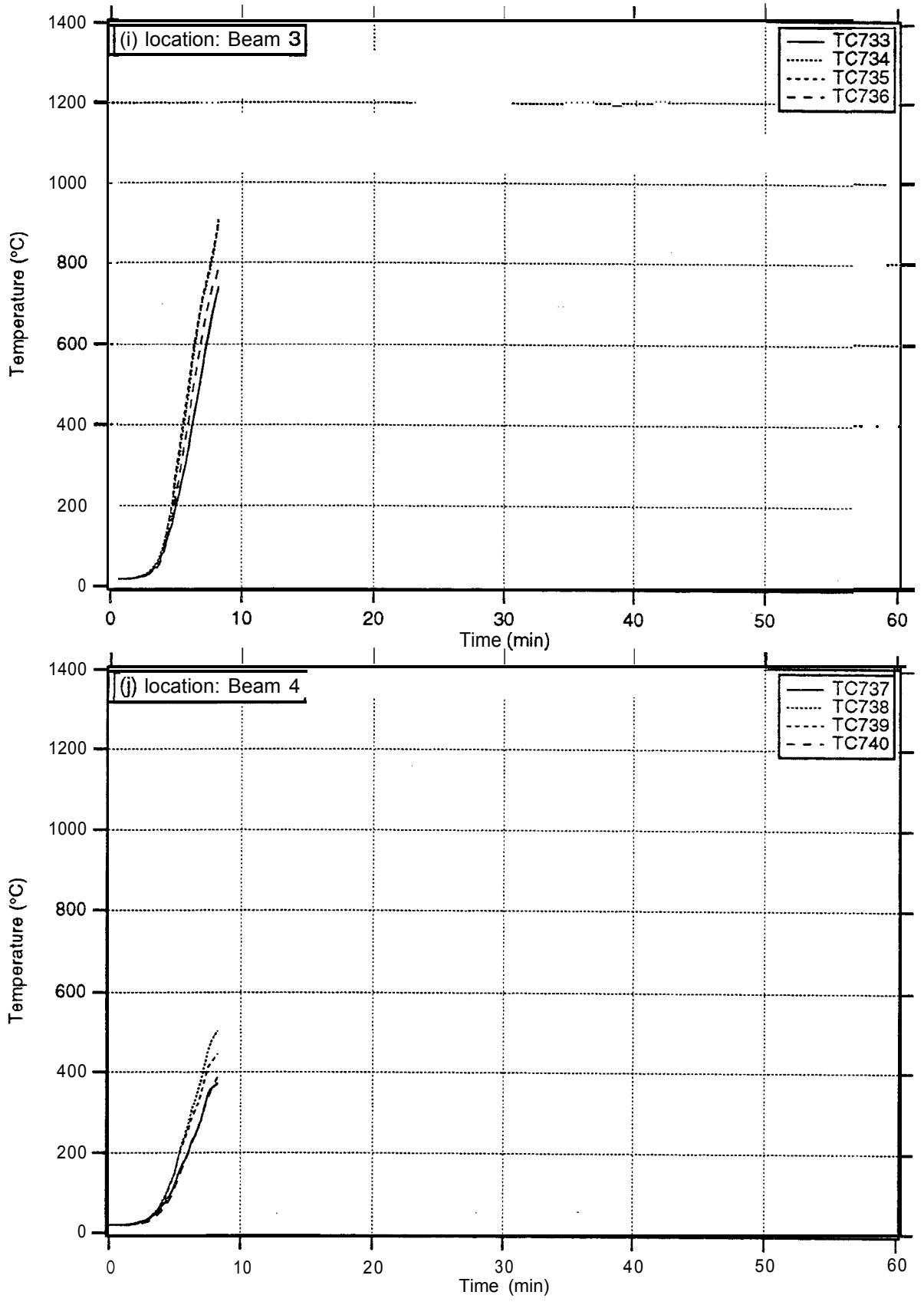


FIGURE B2(I) AND (J) STEEL TEMPERATURES - TEST 2

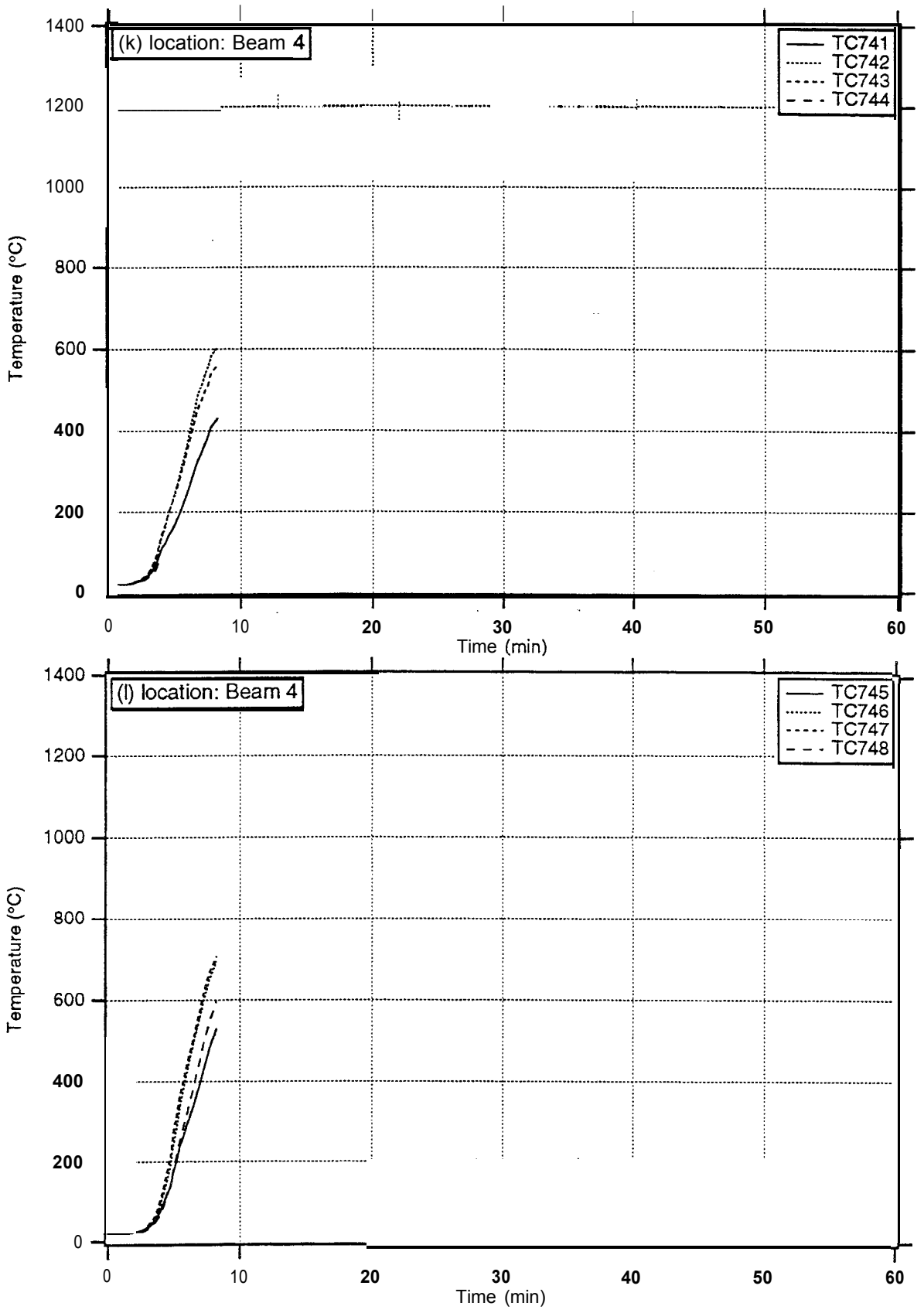


FIGURE B2(K) AND (L) STEEL TEMPERATURES - TEST 2

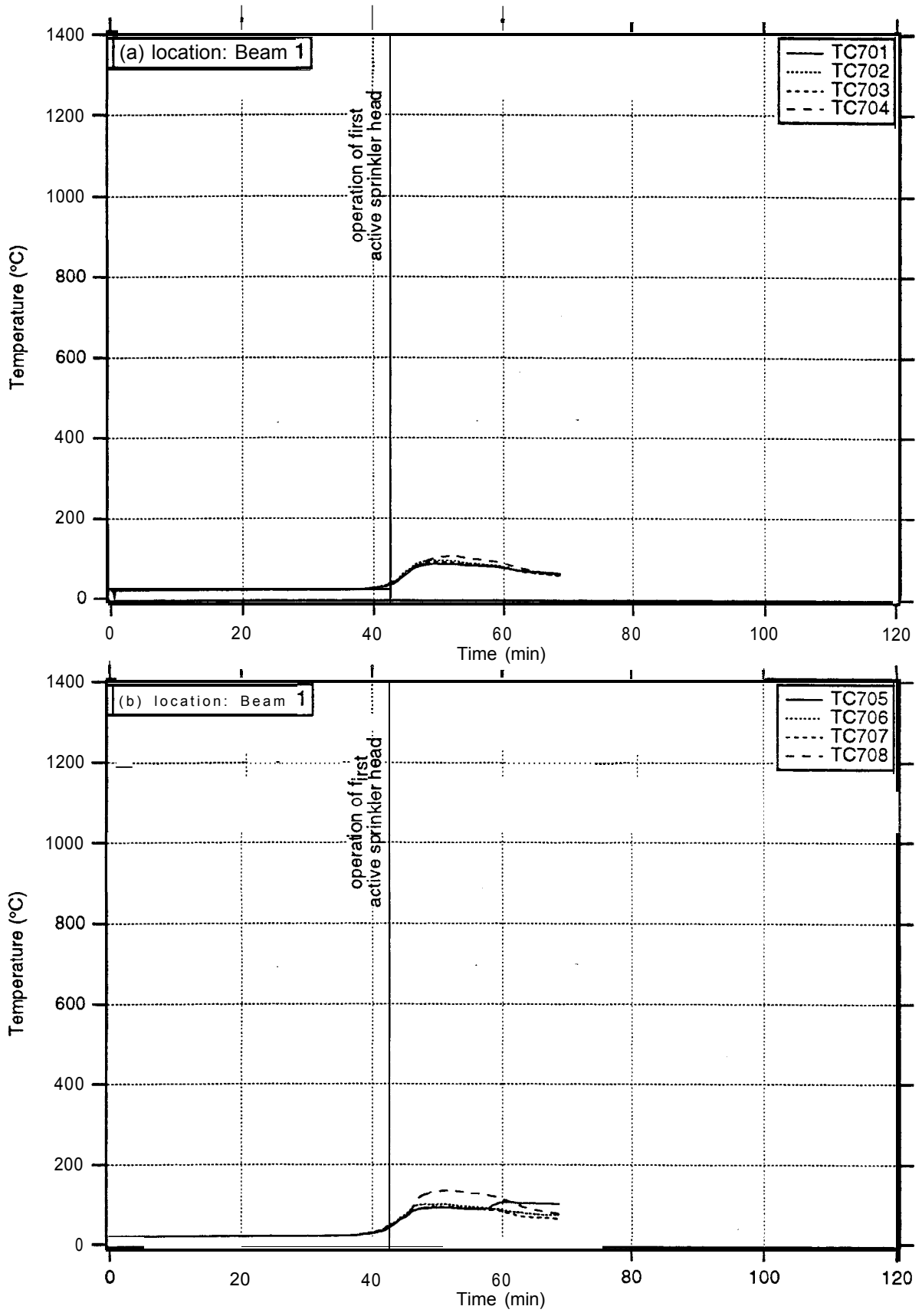


FIGURE B3(A) AND (B) STEEL TEMPERATURES - TEST 3

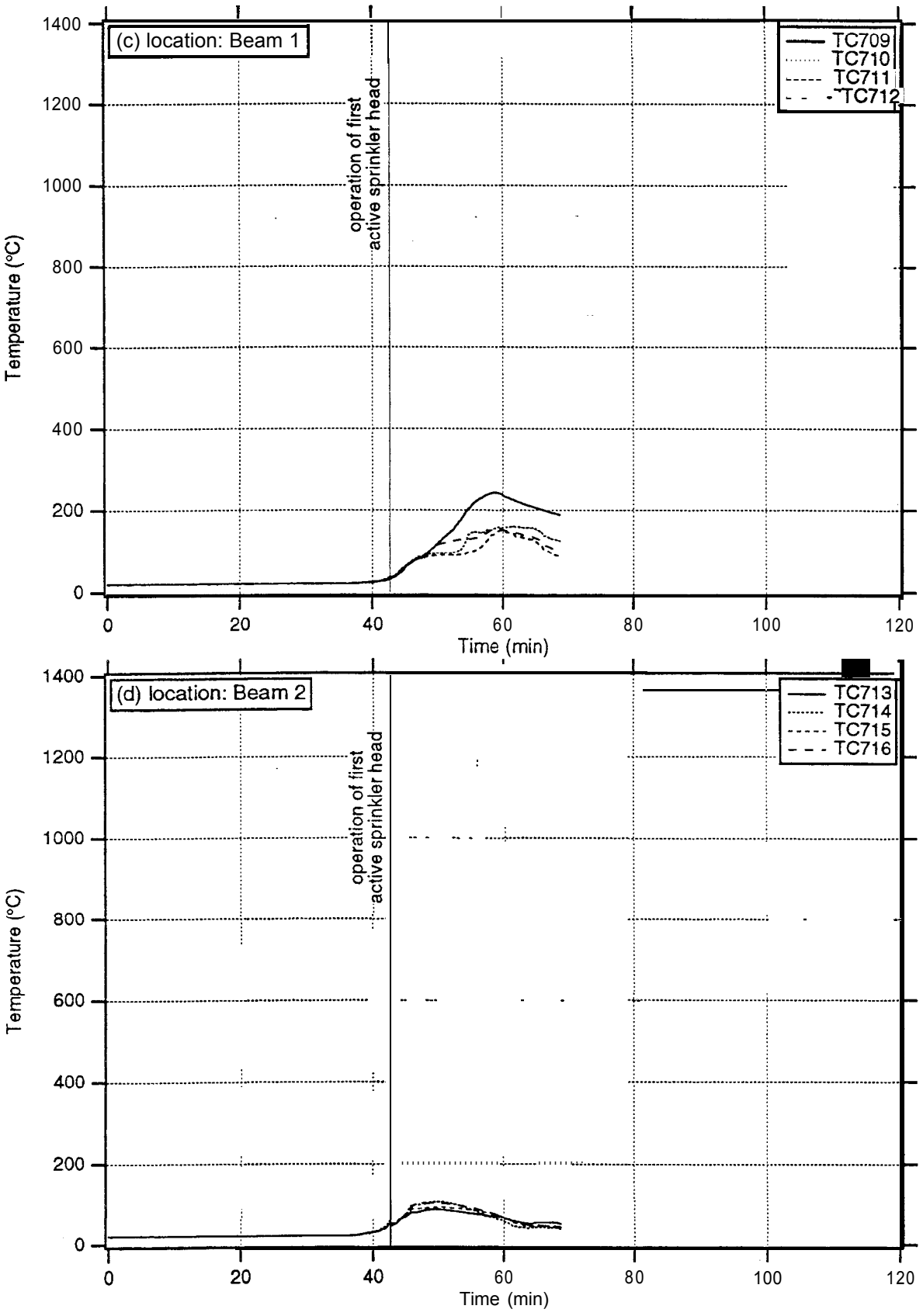


FIGURE B3(C) AND (D) STEEL TEMPERATURES - TEST 3

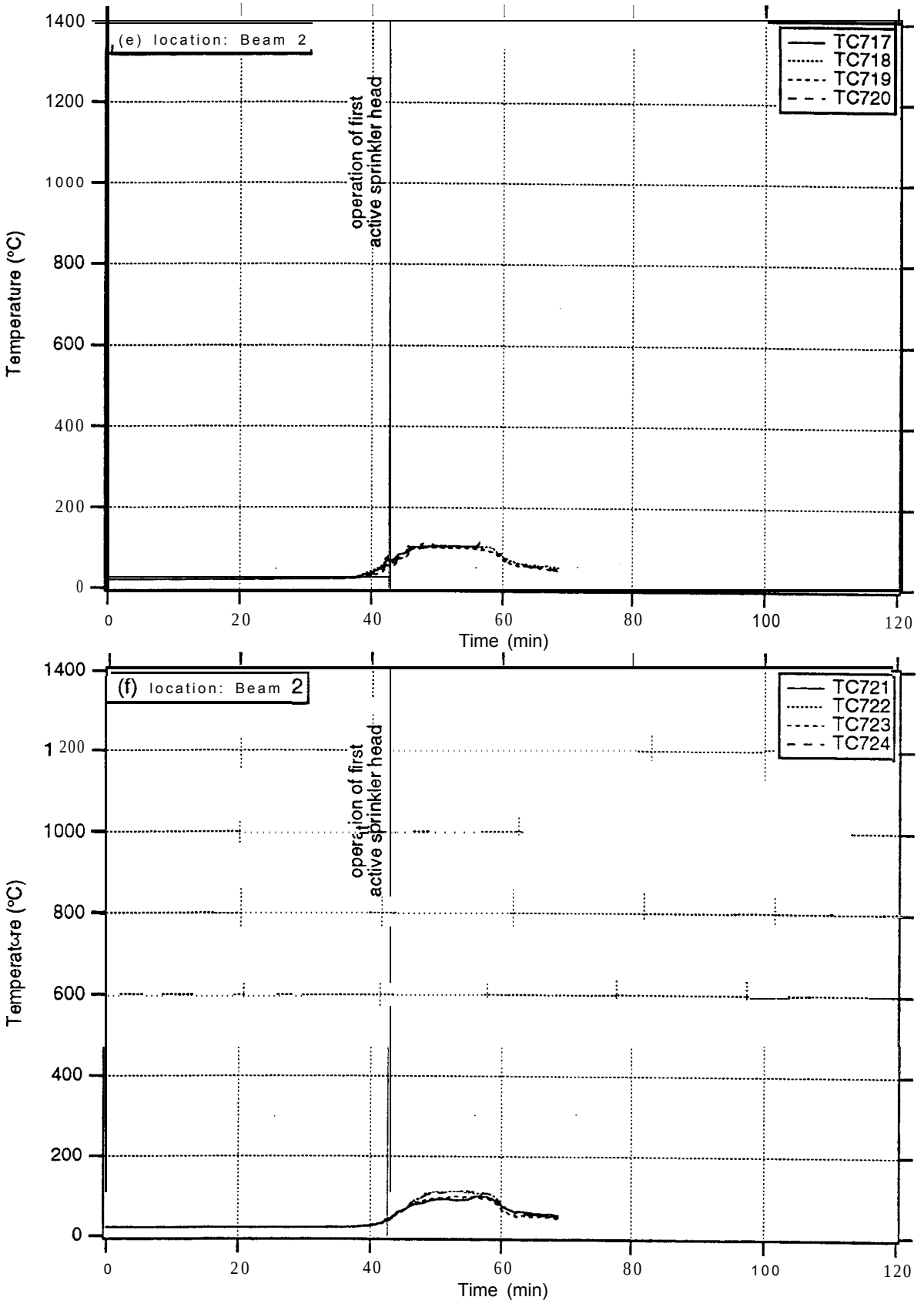


FIGURE B3(E) AND (F) STEEL TEMPERATURES - TEST 3

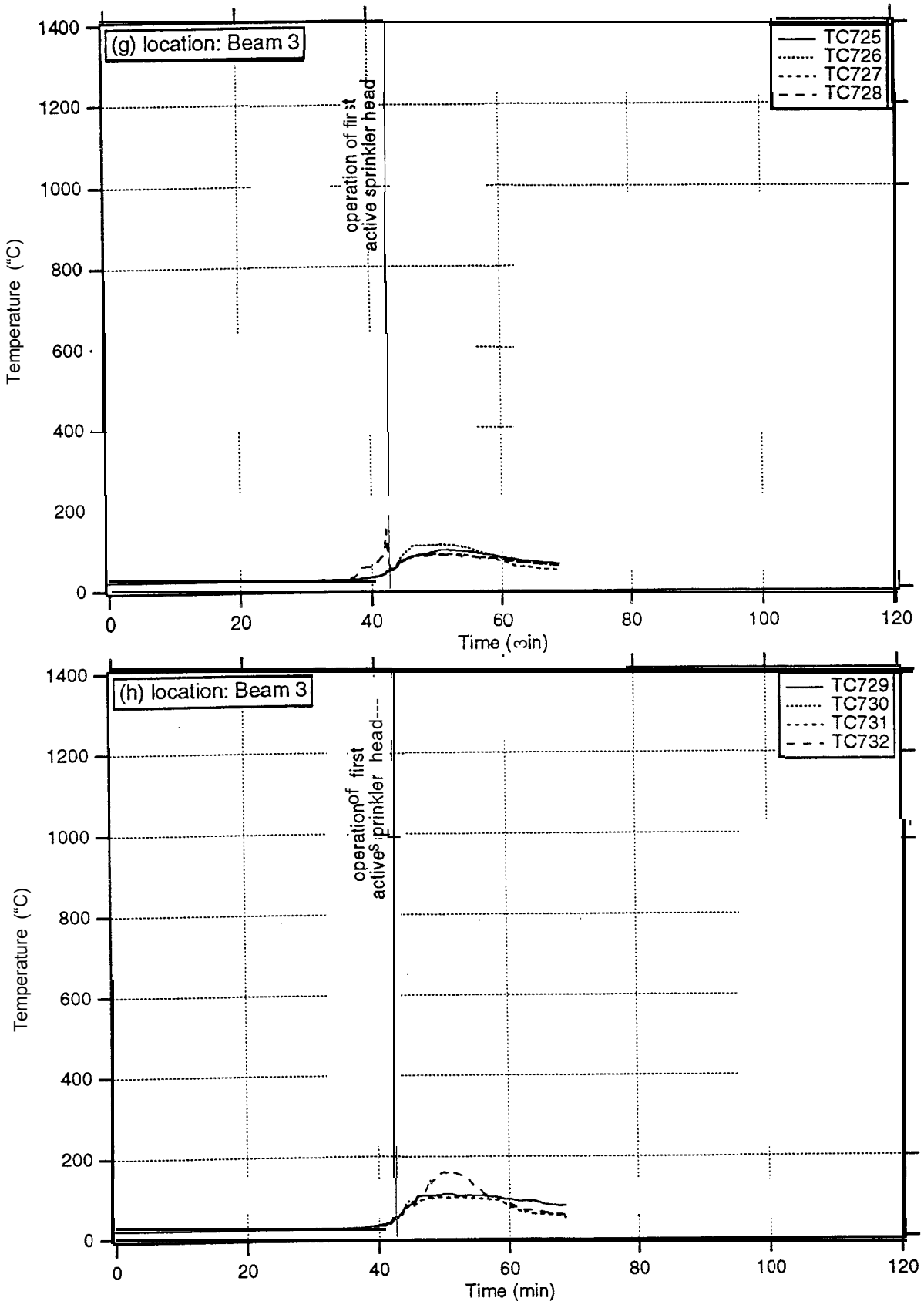


FIGURE B3(G) AND (H) STEEL TEMPERATURES - TEST 3

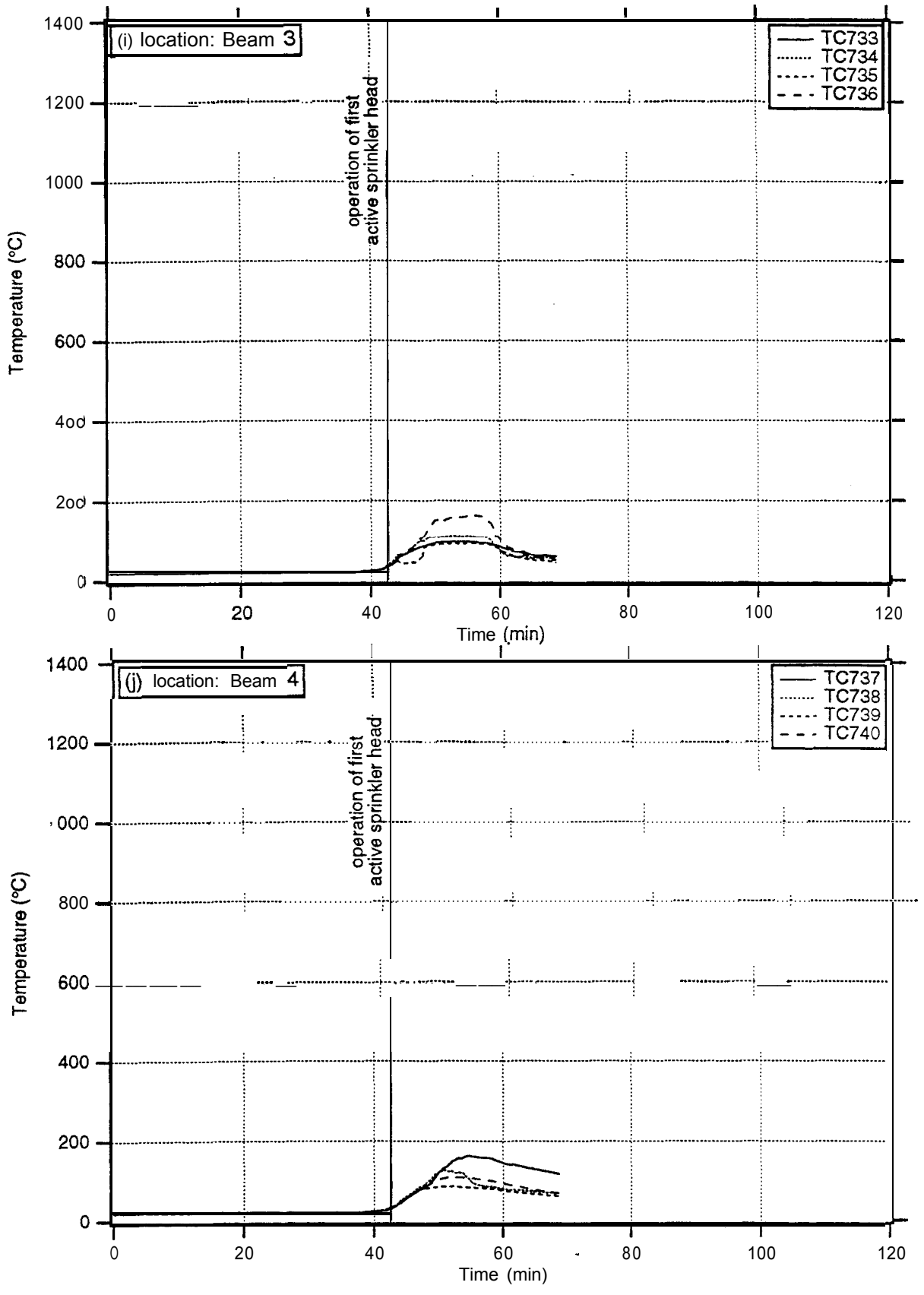
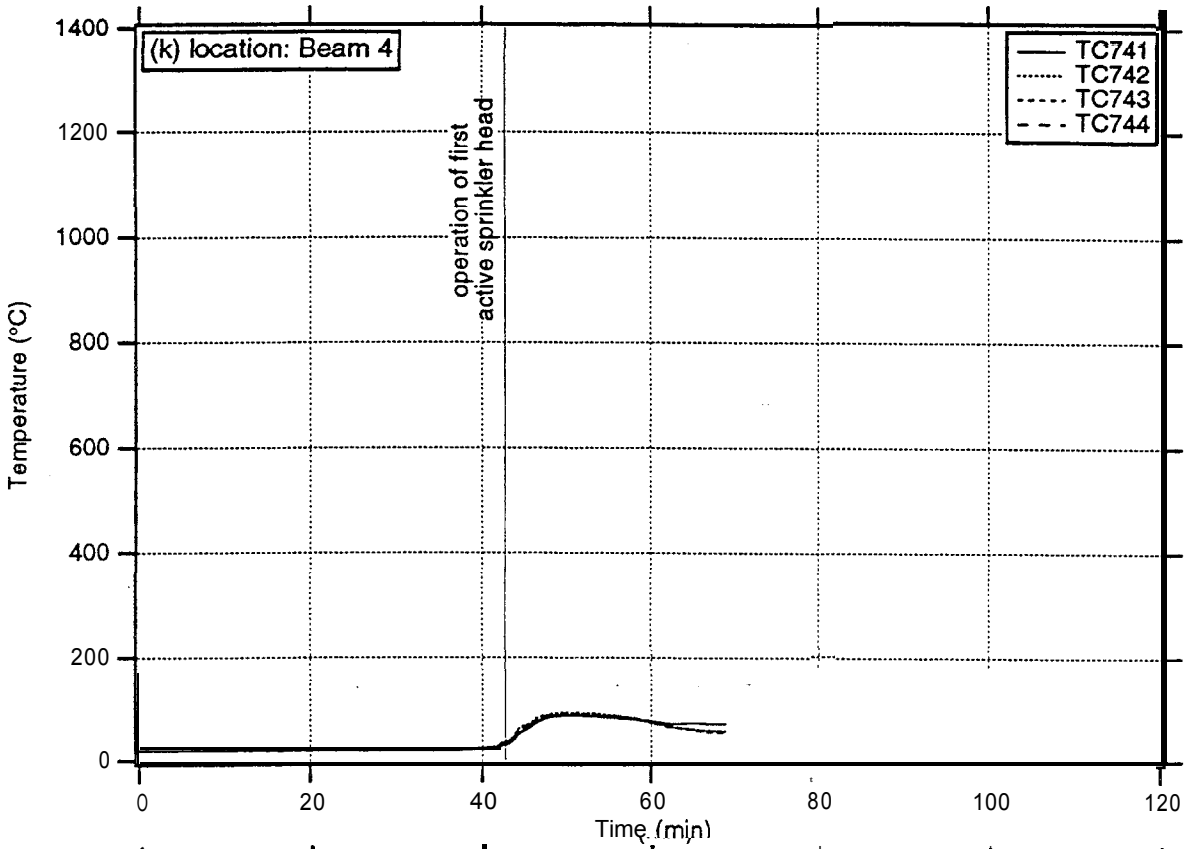


FIGURE B3(I) AND (J) STEEL TEMPERATURES - TEST 3



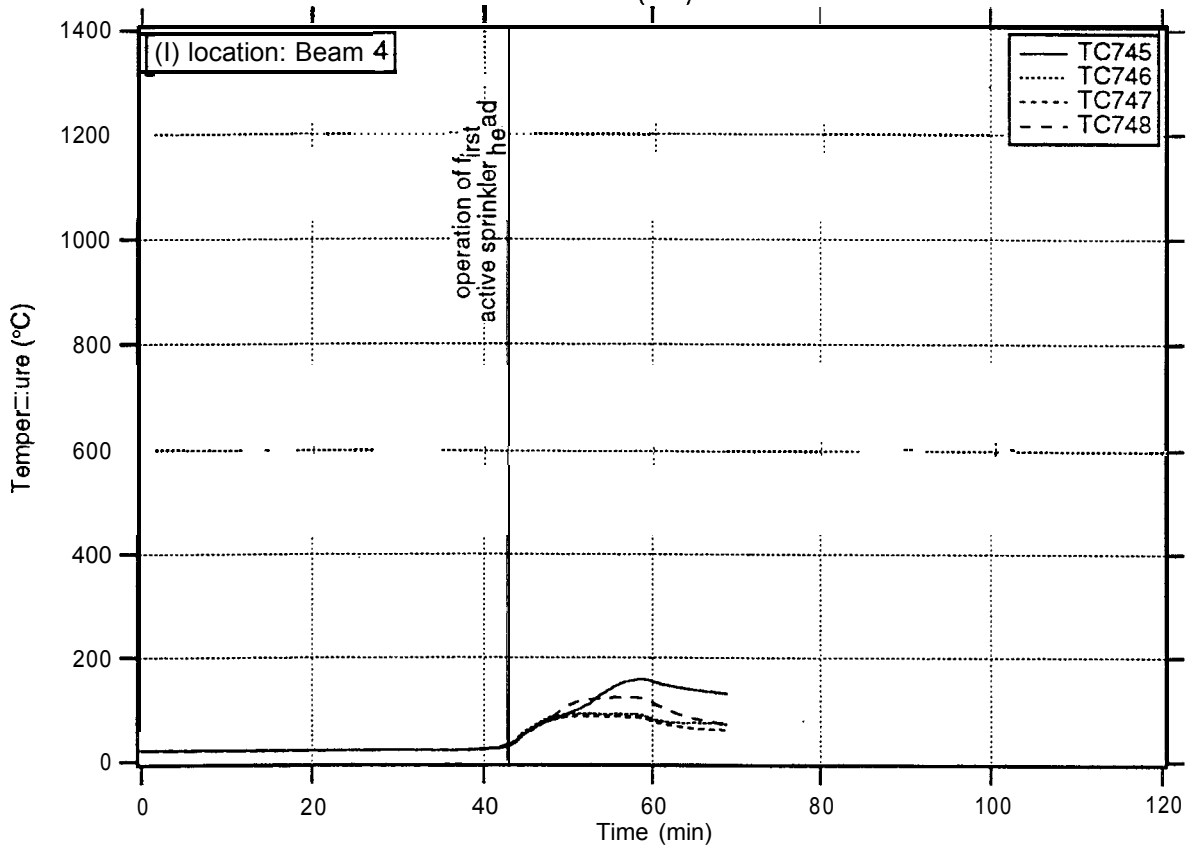


FIGURE B3(K) AND (L) STEEL TEMPERATURES - TEST 3

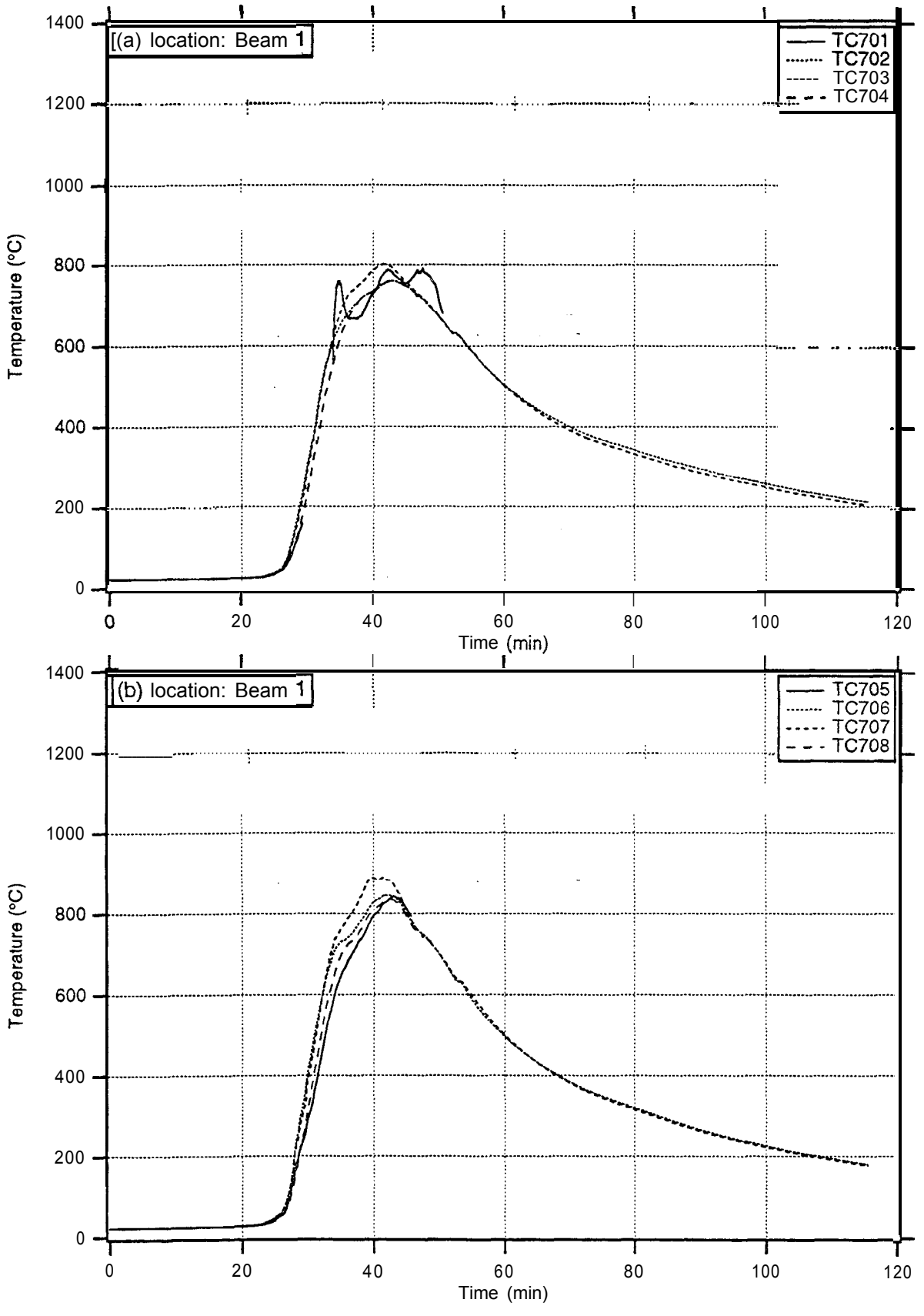


FIGURE B4(A) AND (B) STEEL TEMPERATURES - TEST 4

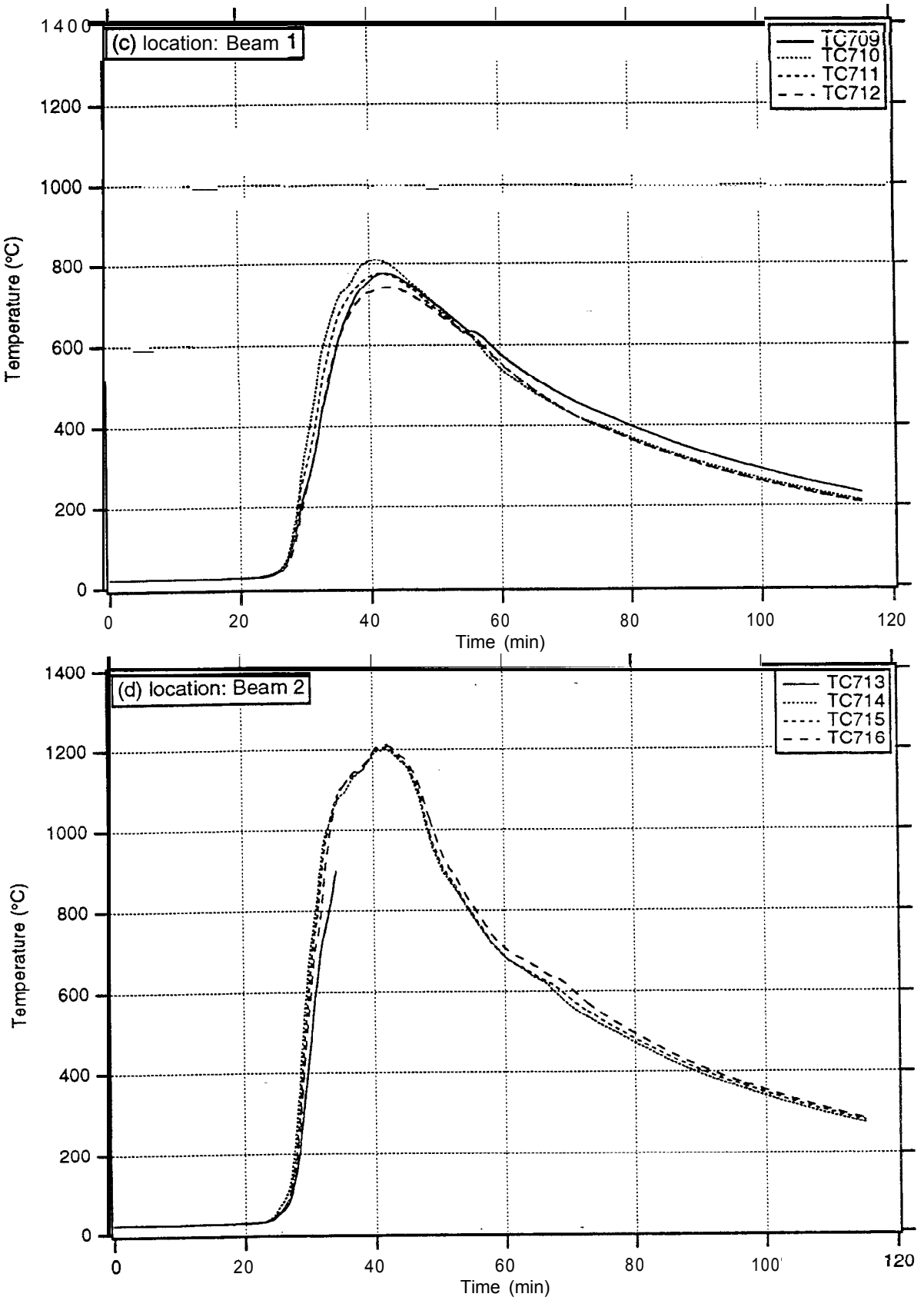


FIGURE B4(C) AND (D) STEEL TEMPERATURES - TEST 4

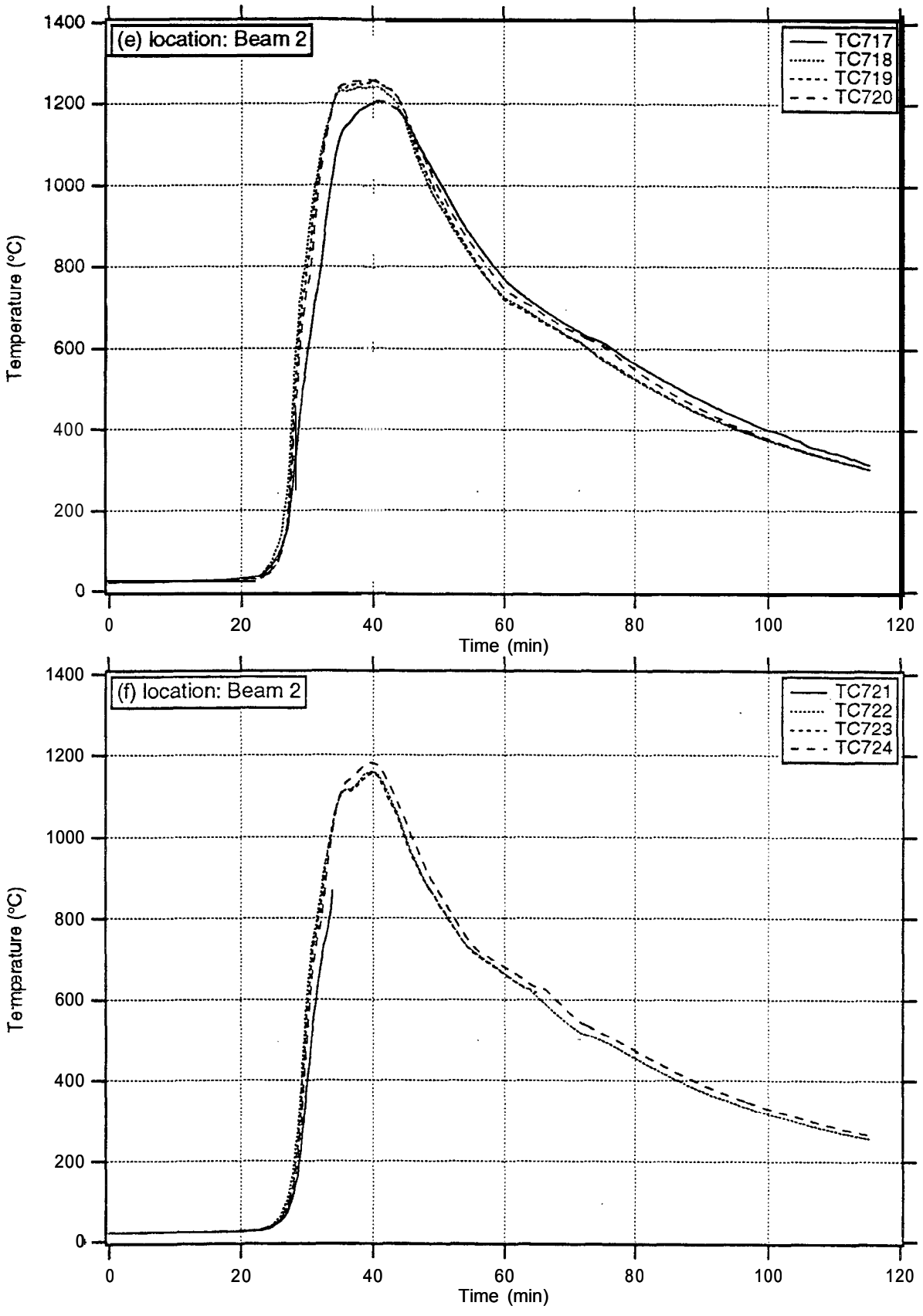


FIGURE B4(E) AND (F) STEEL TEMPERATURES - TEST 4

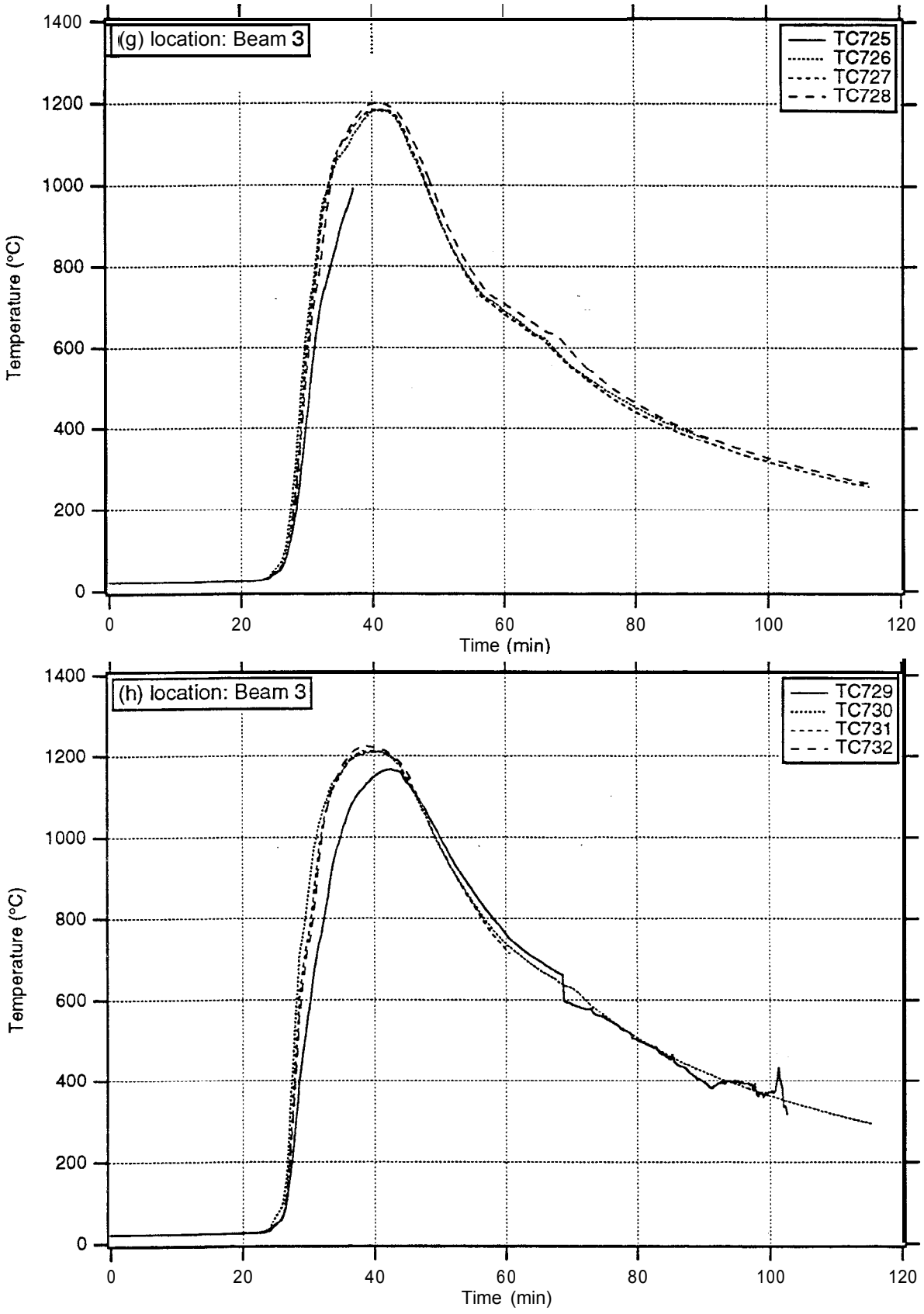


FIGURE B4(G) AND (H) STEEL TEMPERATURES - TEST 4

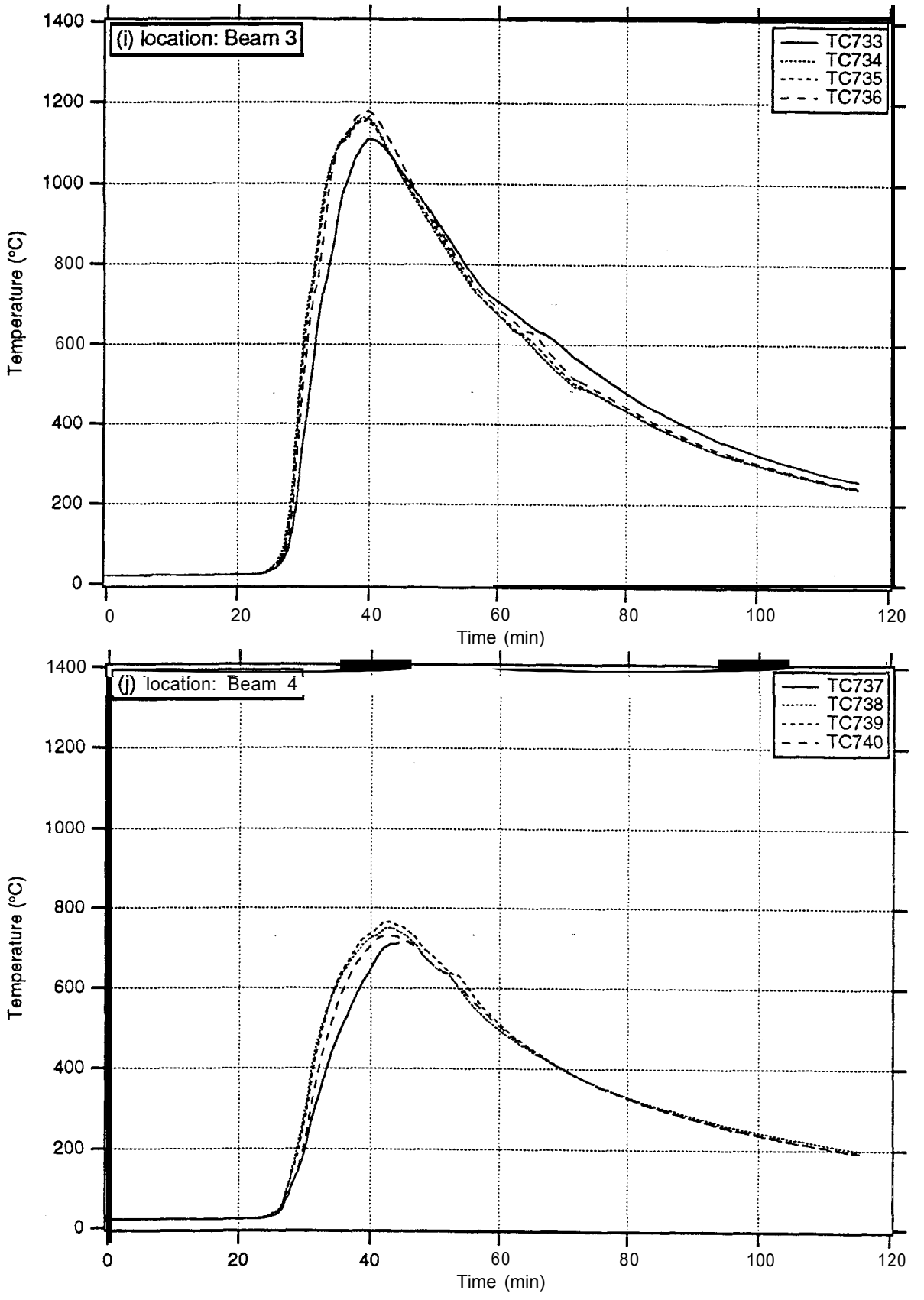


FIGURE B4(I) AND (J) STEEL TEMPERATURES - TEST 4

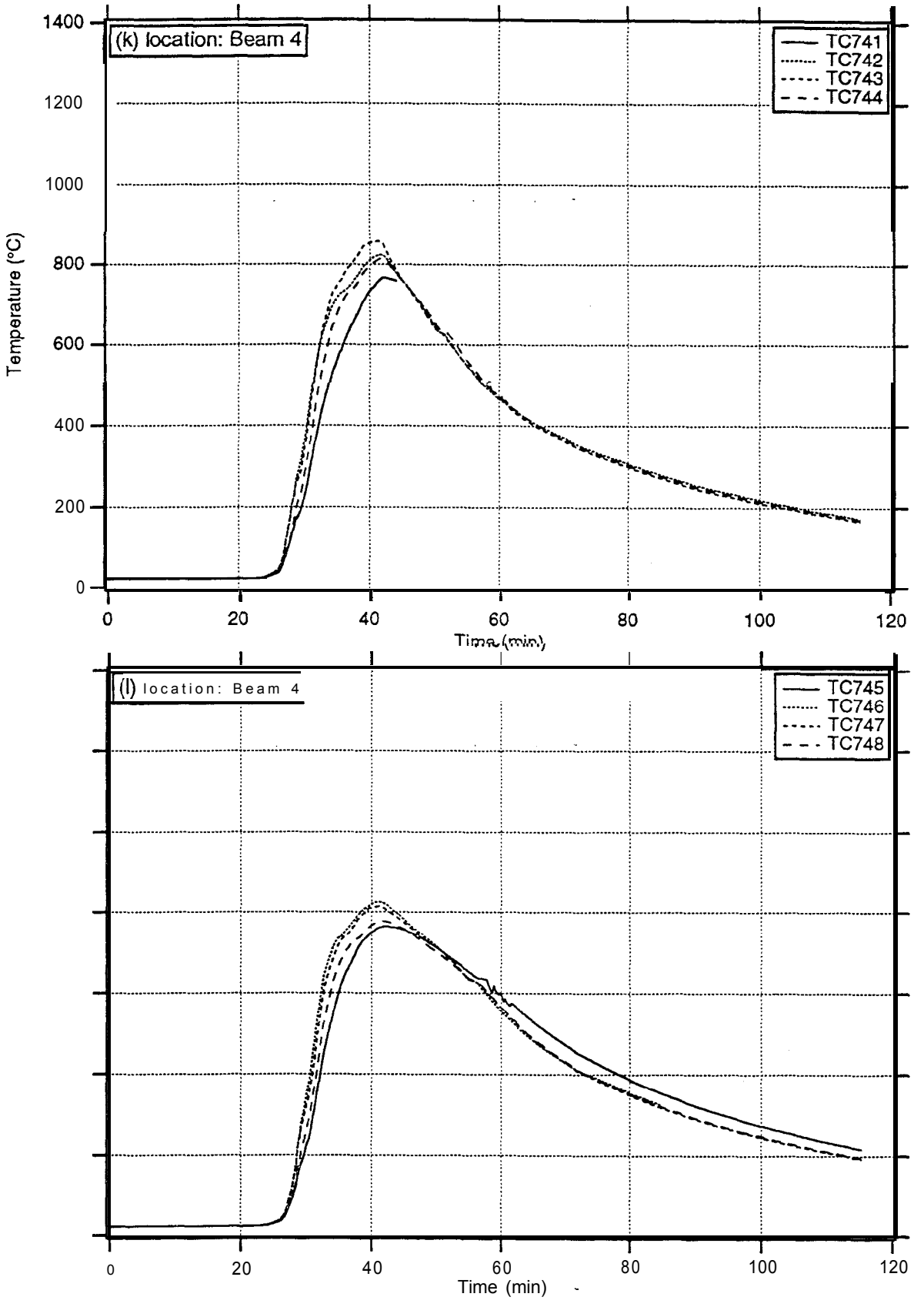


FIGURE B4(K) AND (L) STEEL TEMPERATURES - TEST 4

APPENDIX C: RADIATION

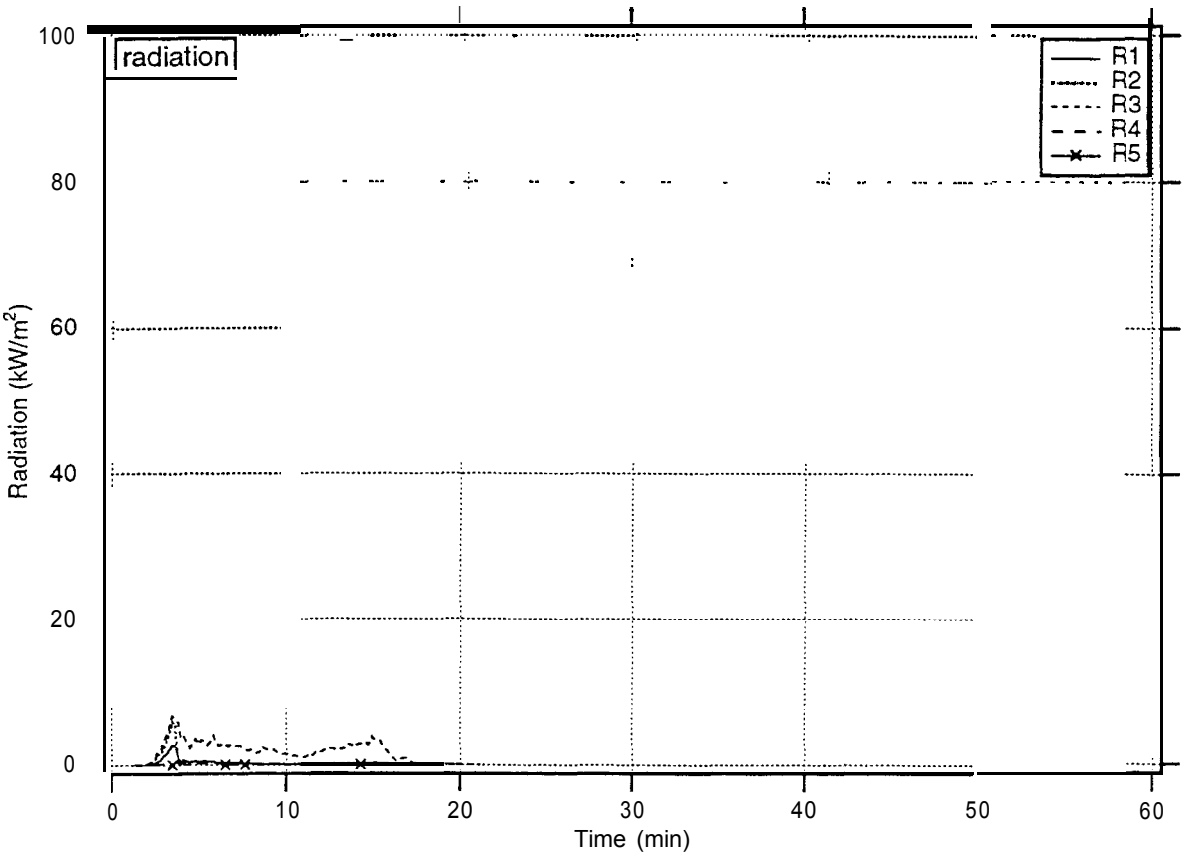


FIGURE C1 RADIATION - TEST 1

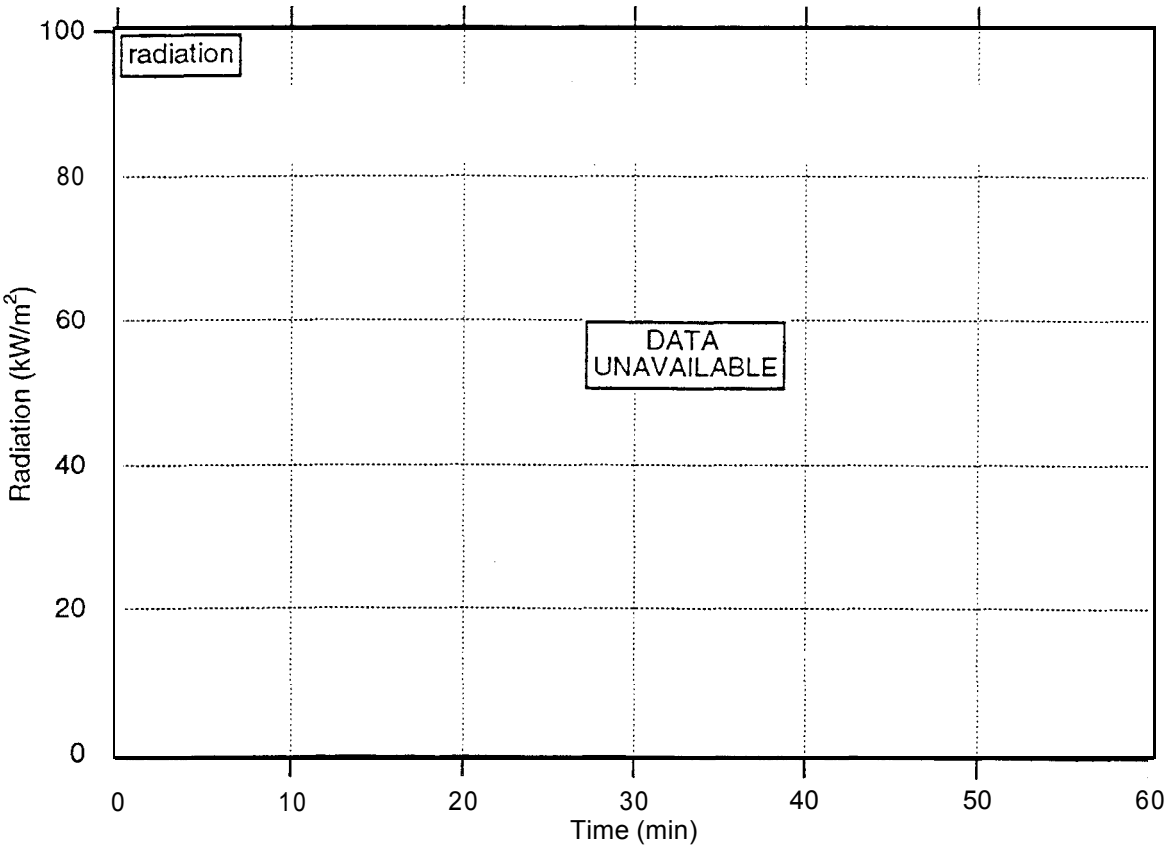


FIGURE C2 RADIATION - TEST 2

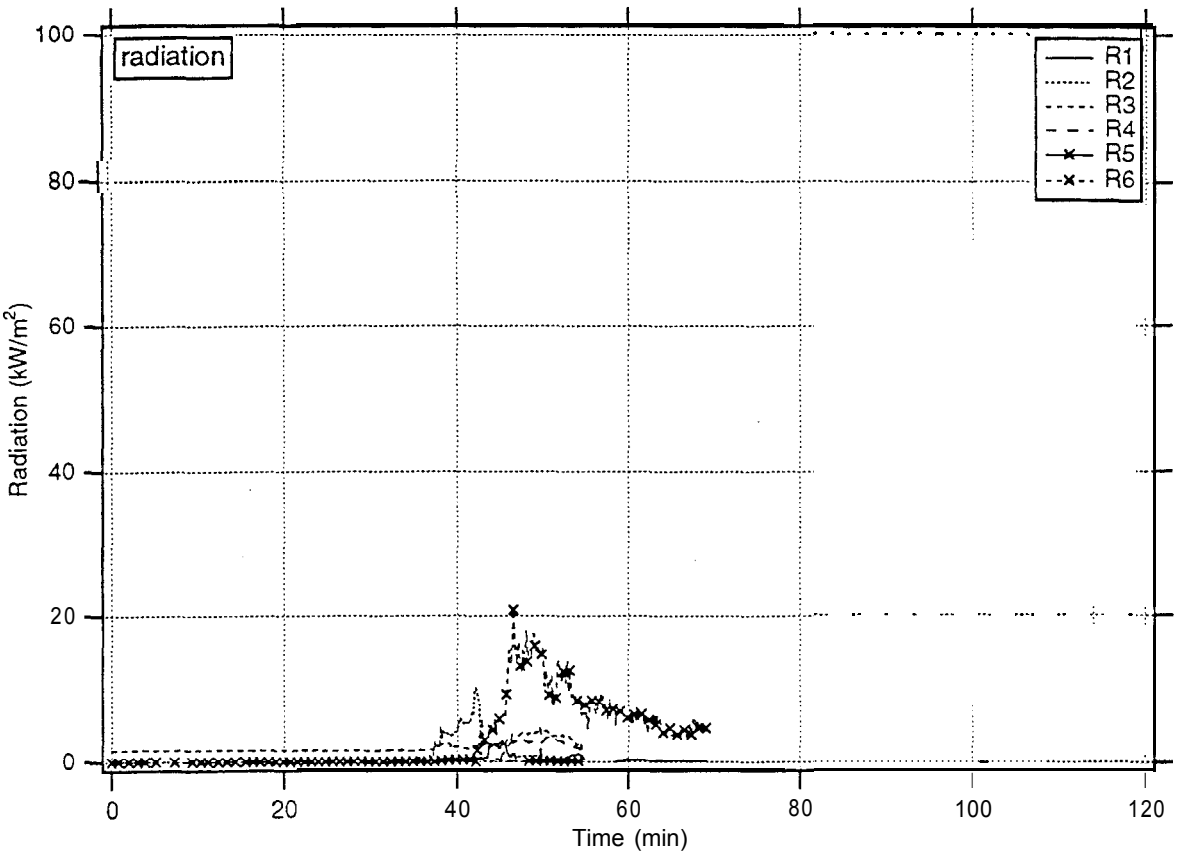


FIGURE C3 RADIATION - TEST 3

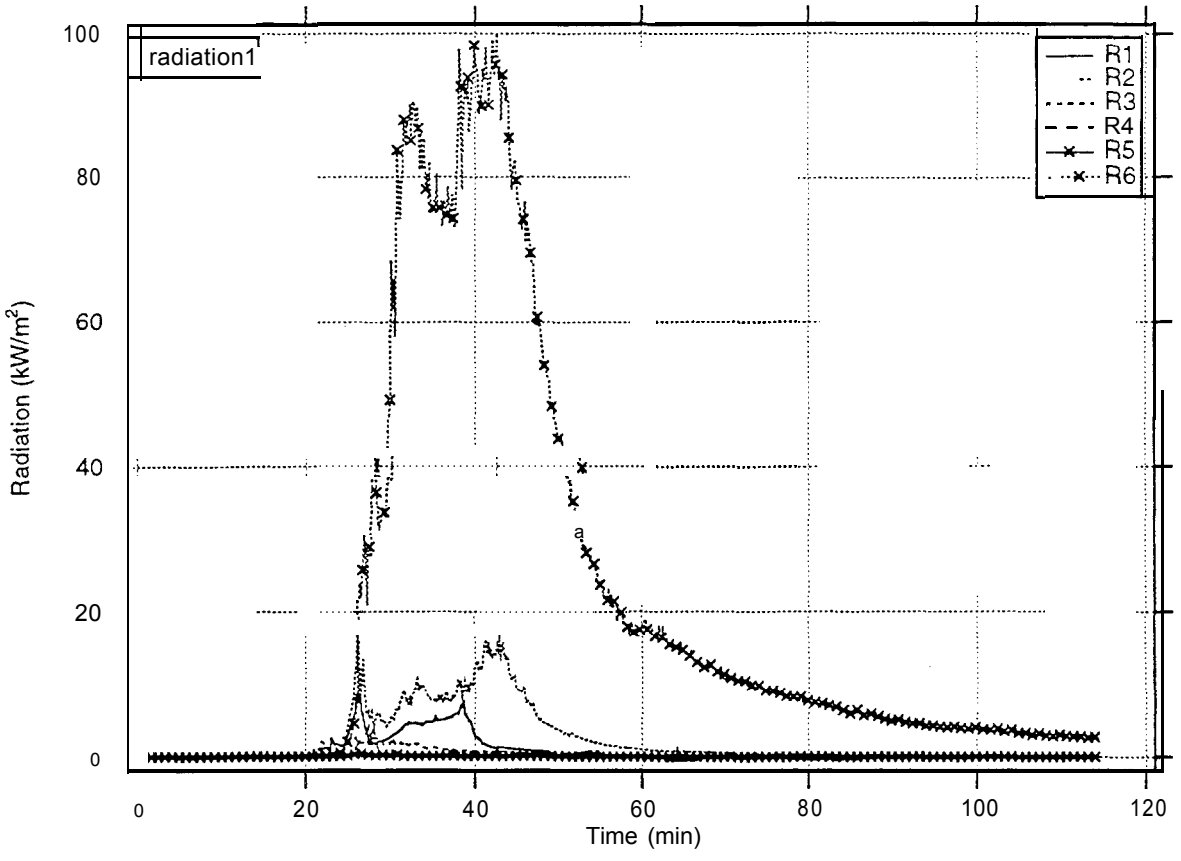


FIGURE C4 RADIATION - TEST 4

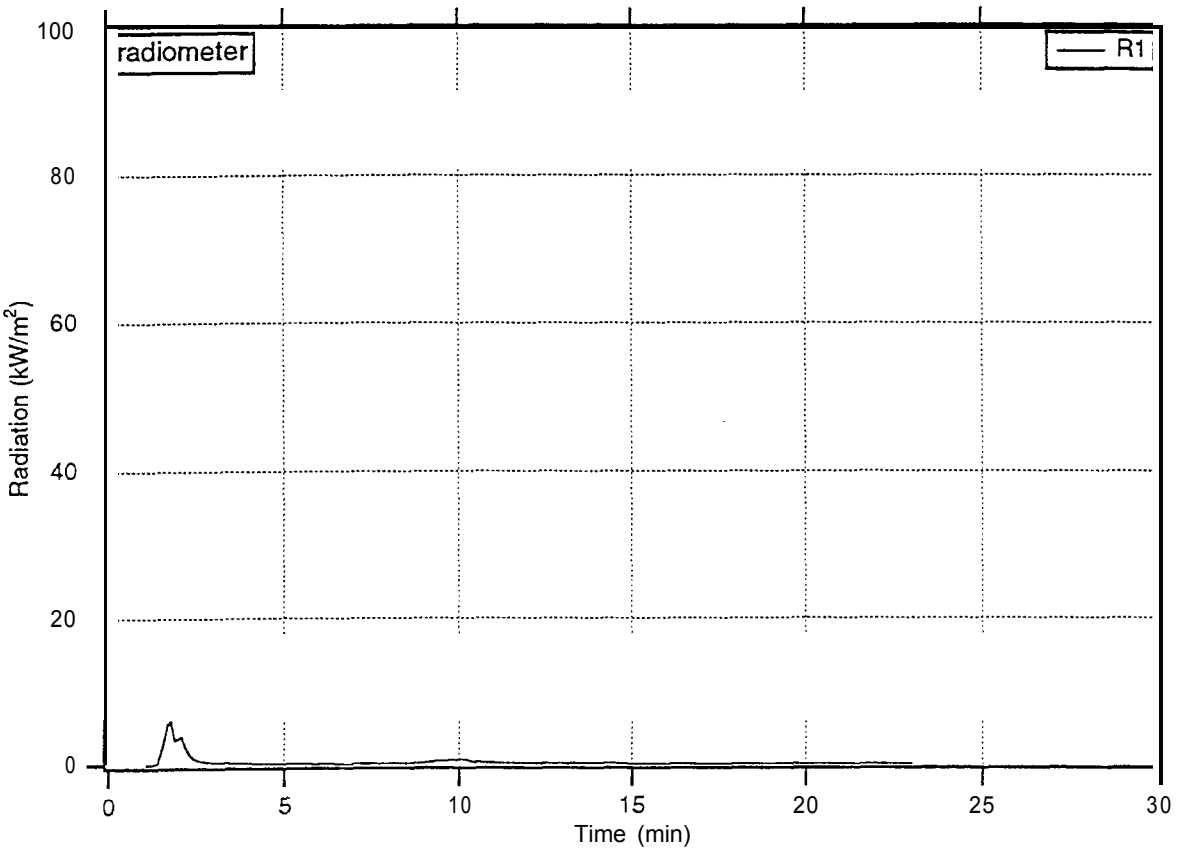


FIGURE C5 RADIATION - TEST 5

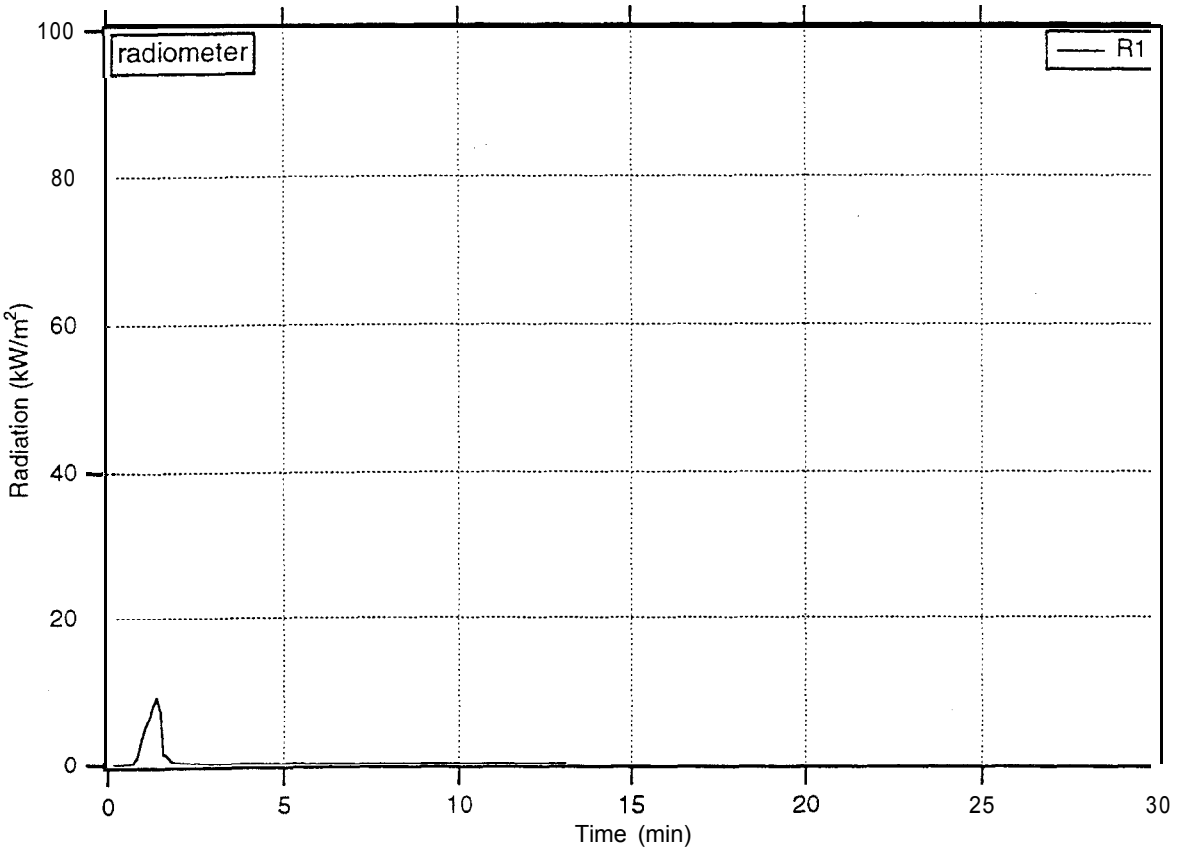


FIGURE C6 RADIATION - TEST 6

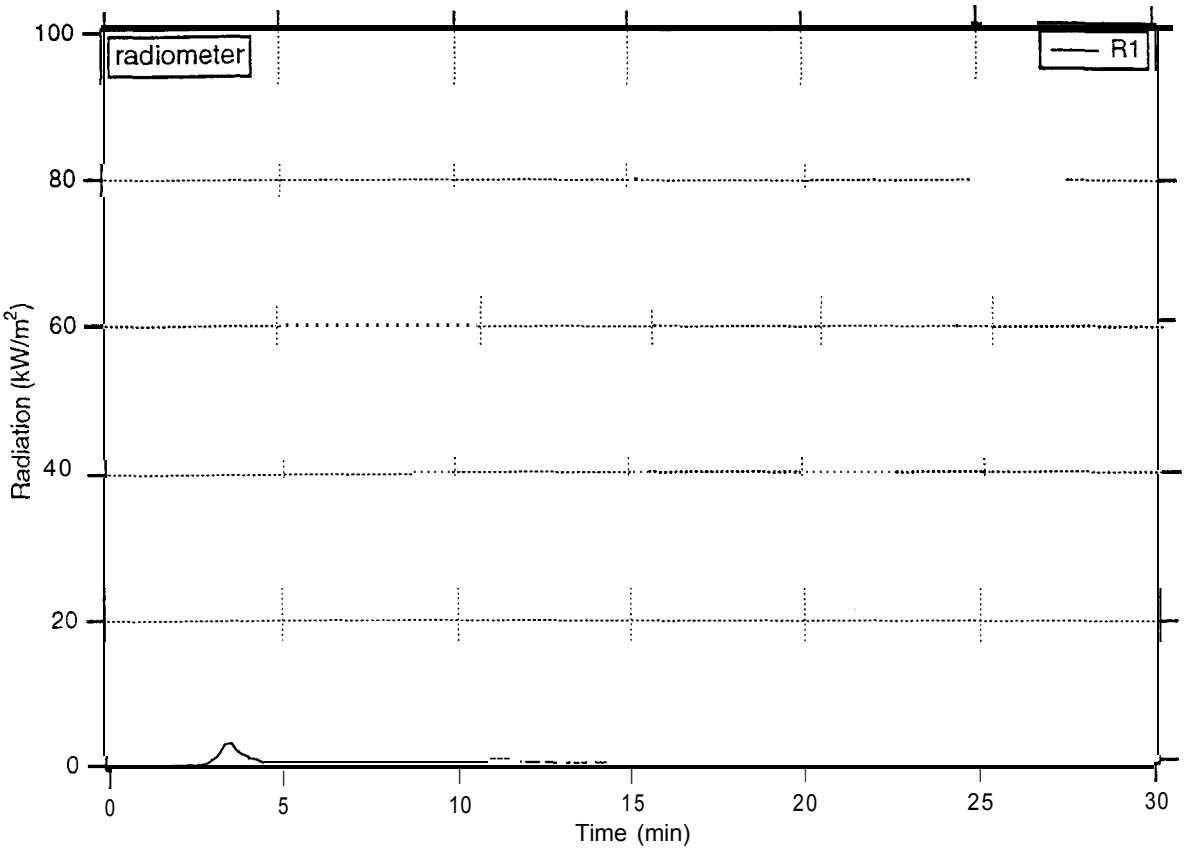


FIGURE C7 RADIATION - TEST 7

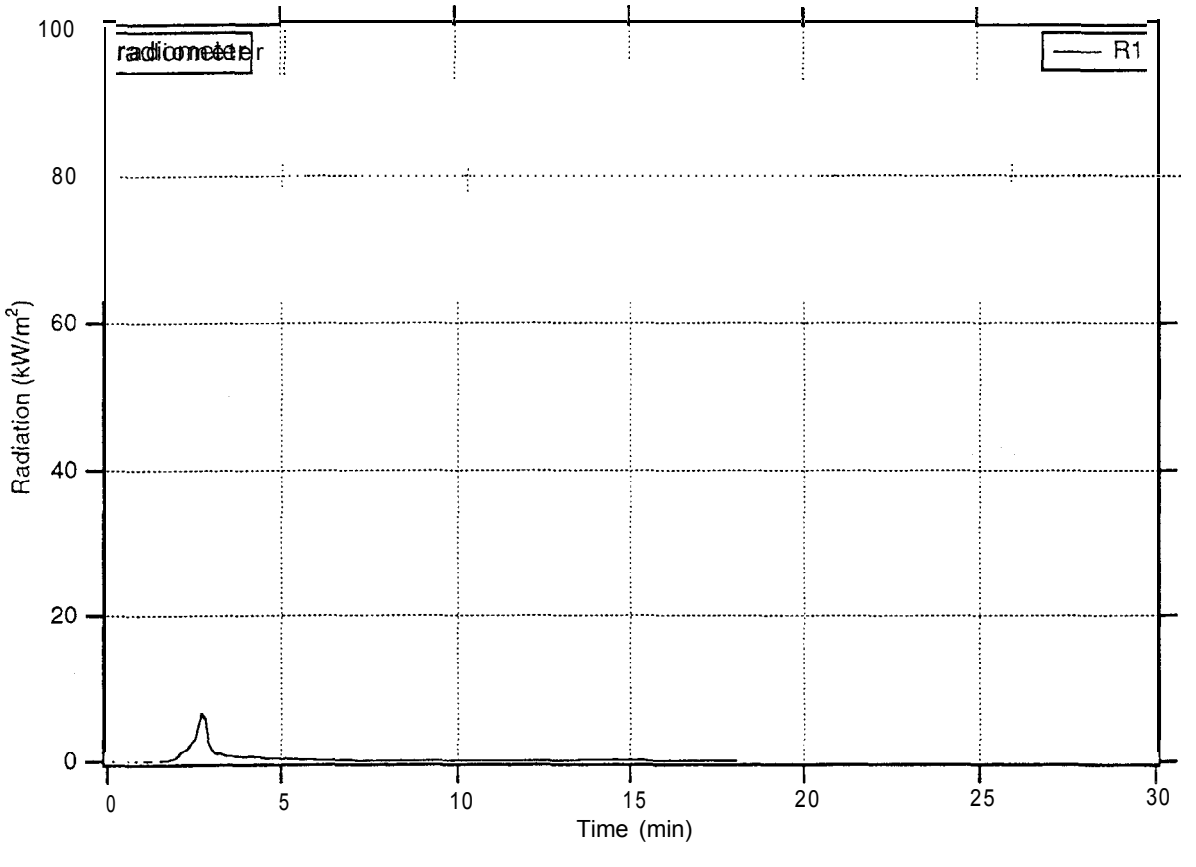


FIGURE C 8 RADIATION-TEST 8

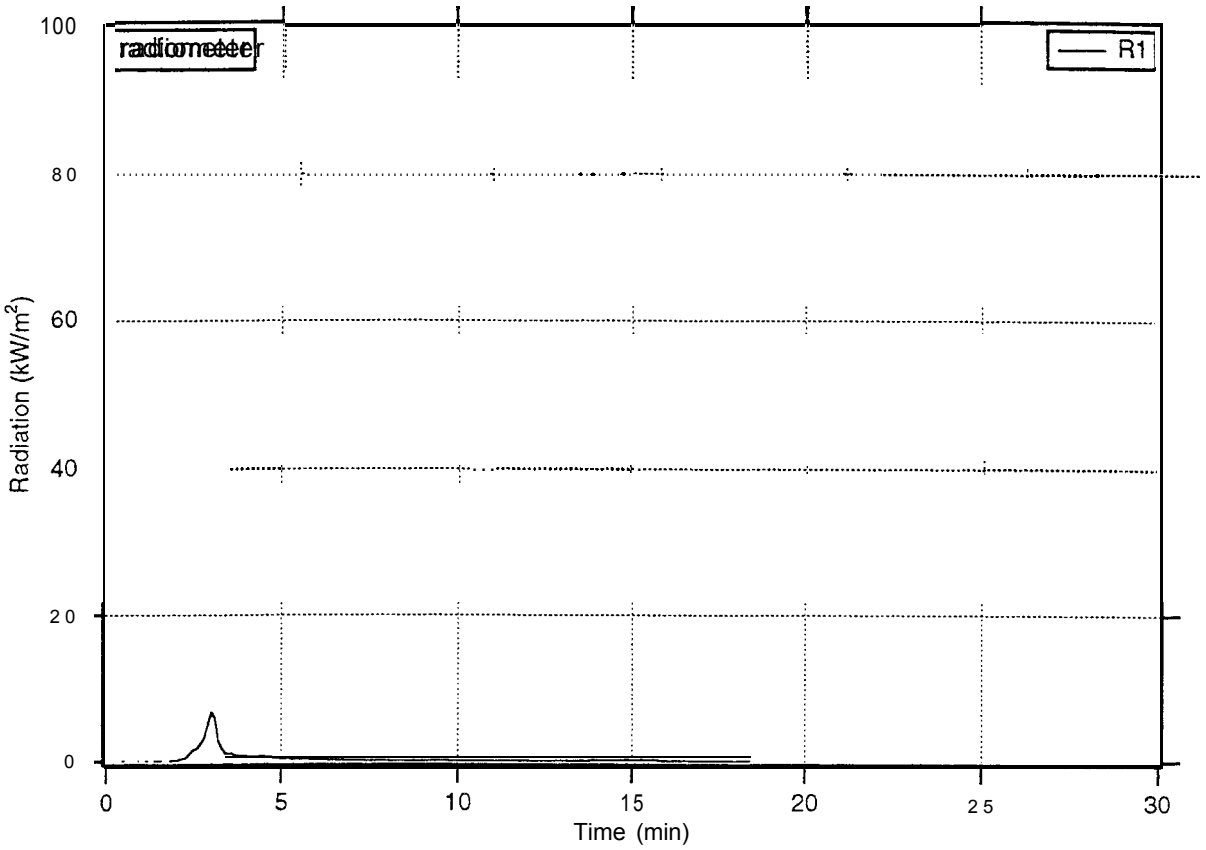


FIGURE C9 RADIATION - TEST 9

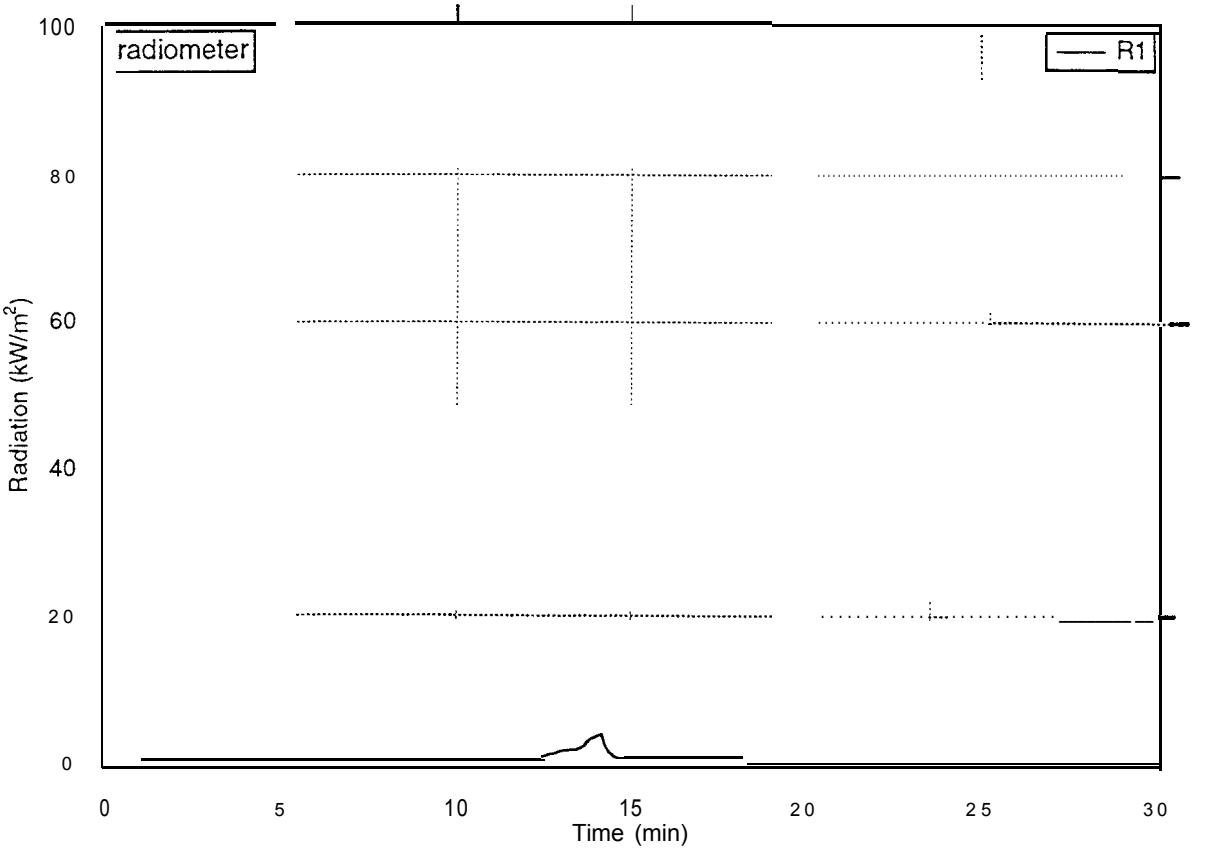


FIGURE C10 RADIATION-TEST 10

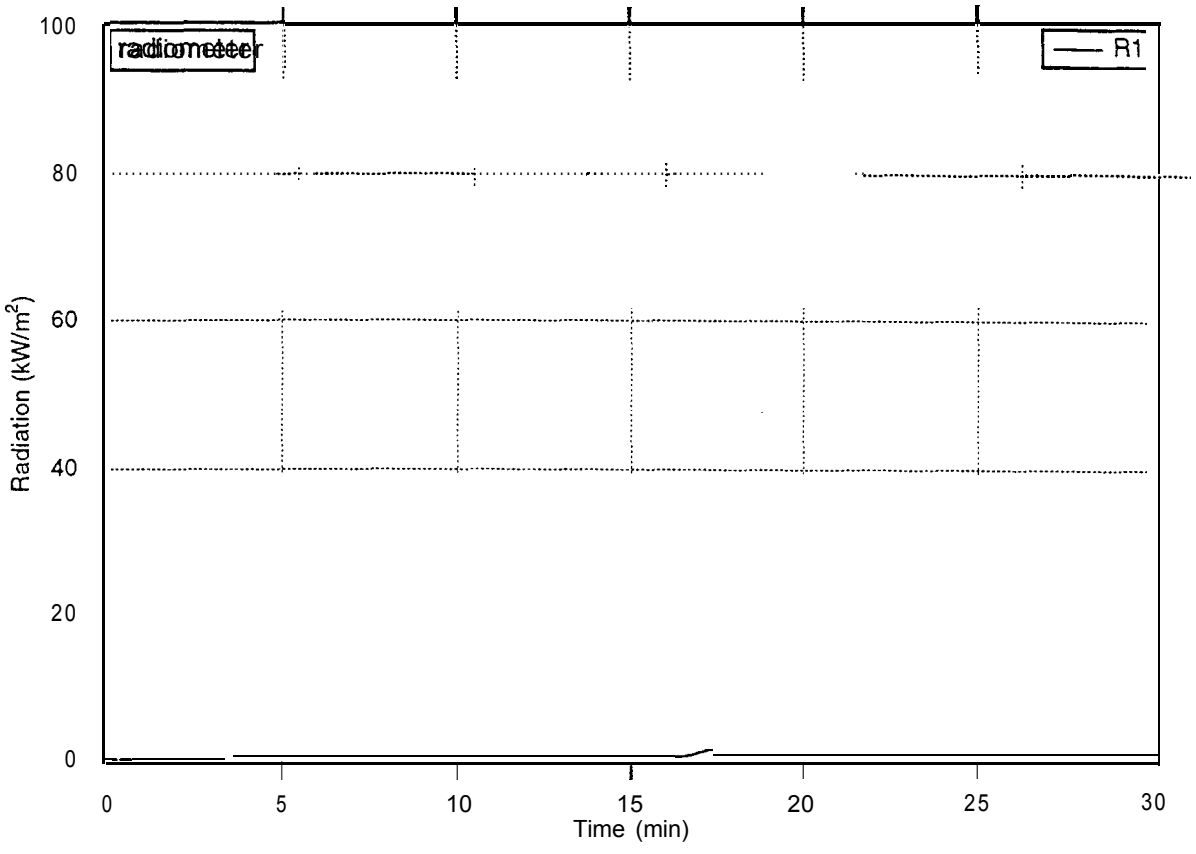


FIGURE C11 RADIATION - TEST 11

APPENDIX D: MASS LOSS

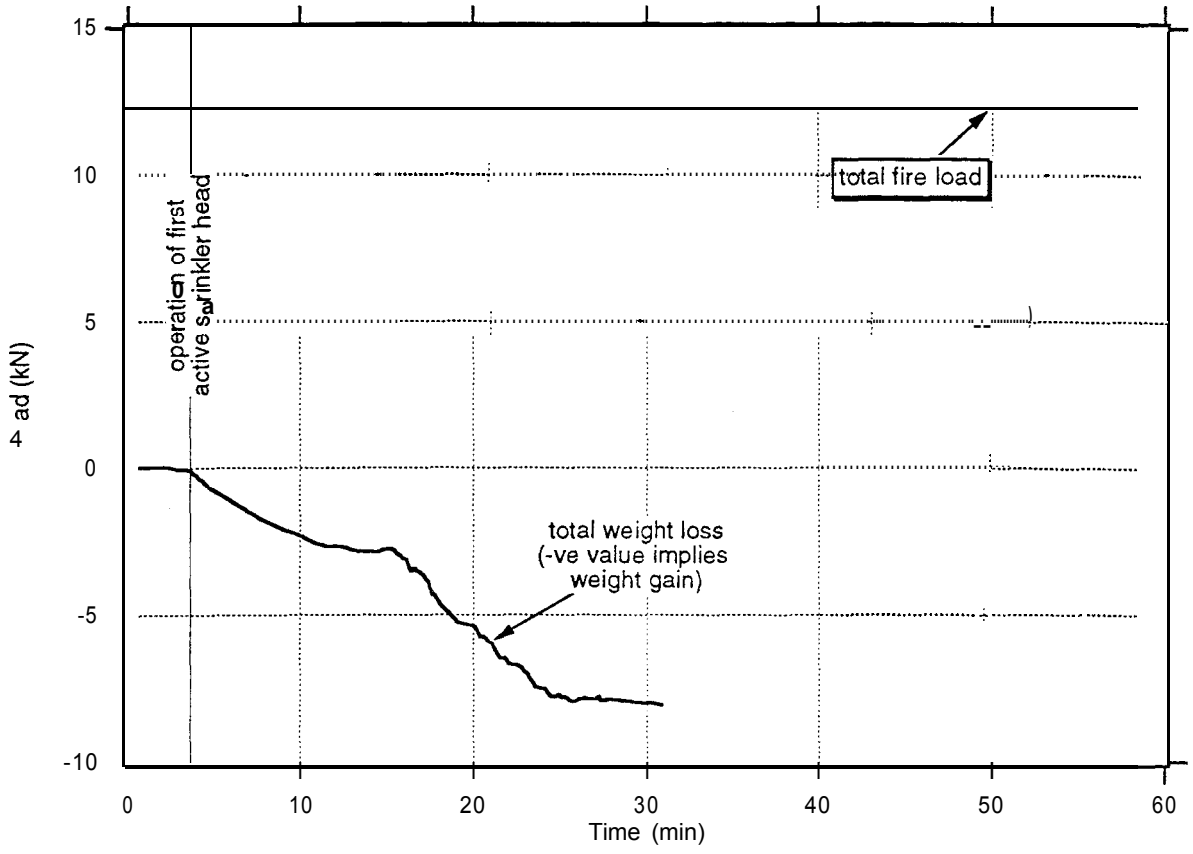


FIGURE D1 MASS LOSS - TEST 1

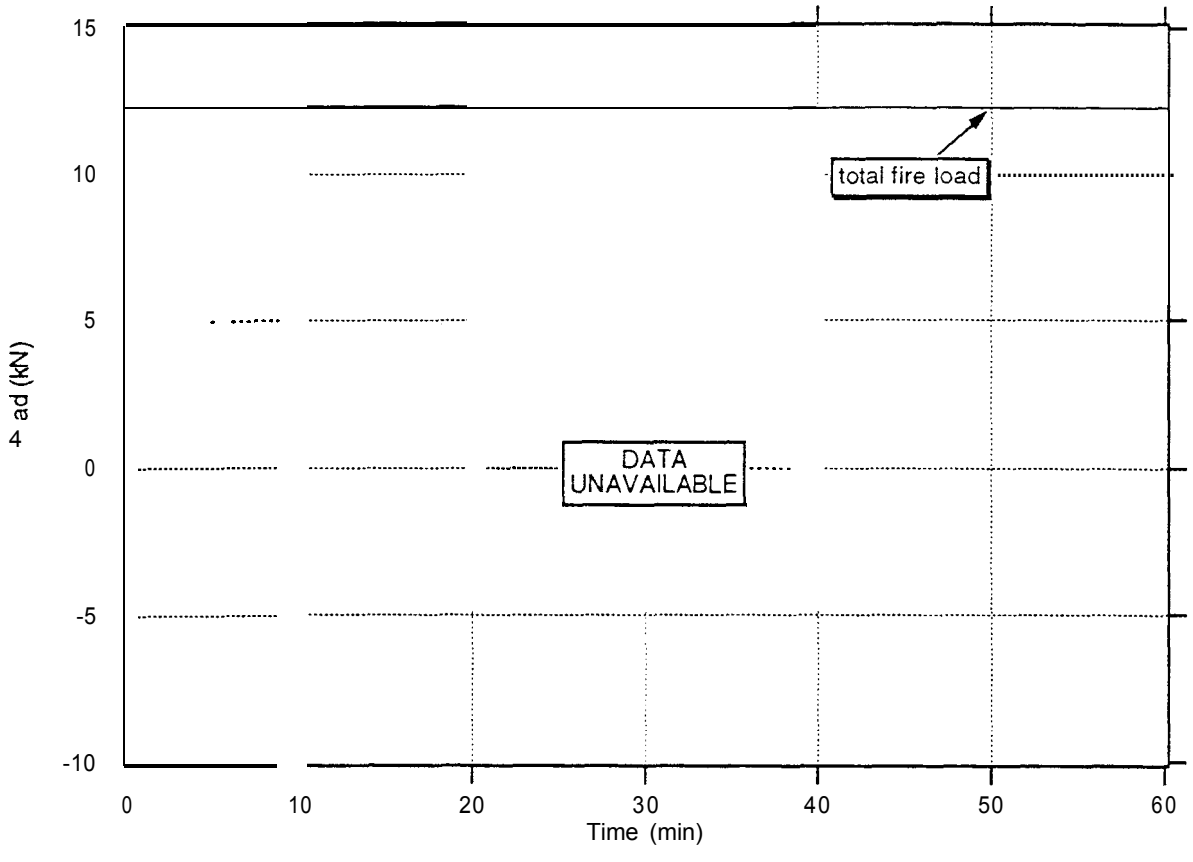


FIGURE D2 MASS LOSS - TEST 2

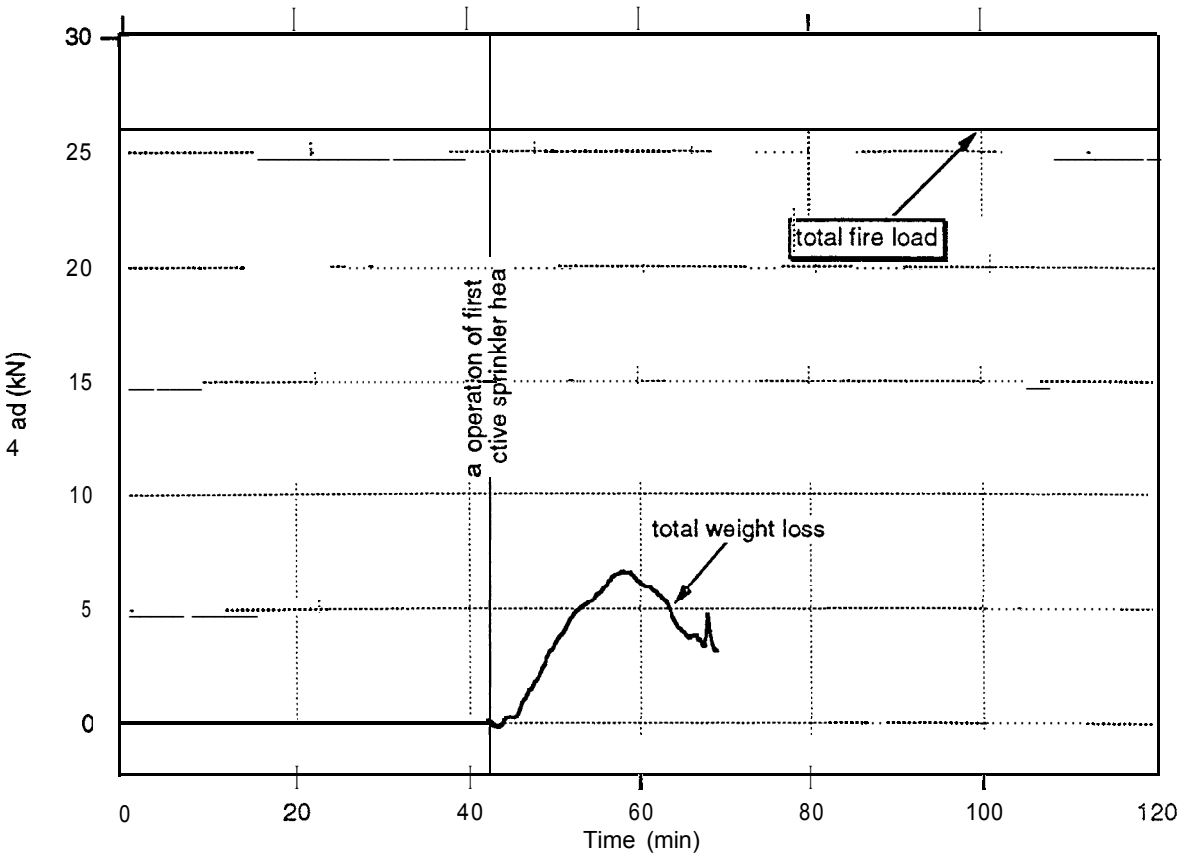


FIGURE D3 MASS LOSS - TEST 3

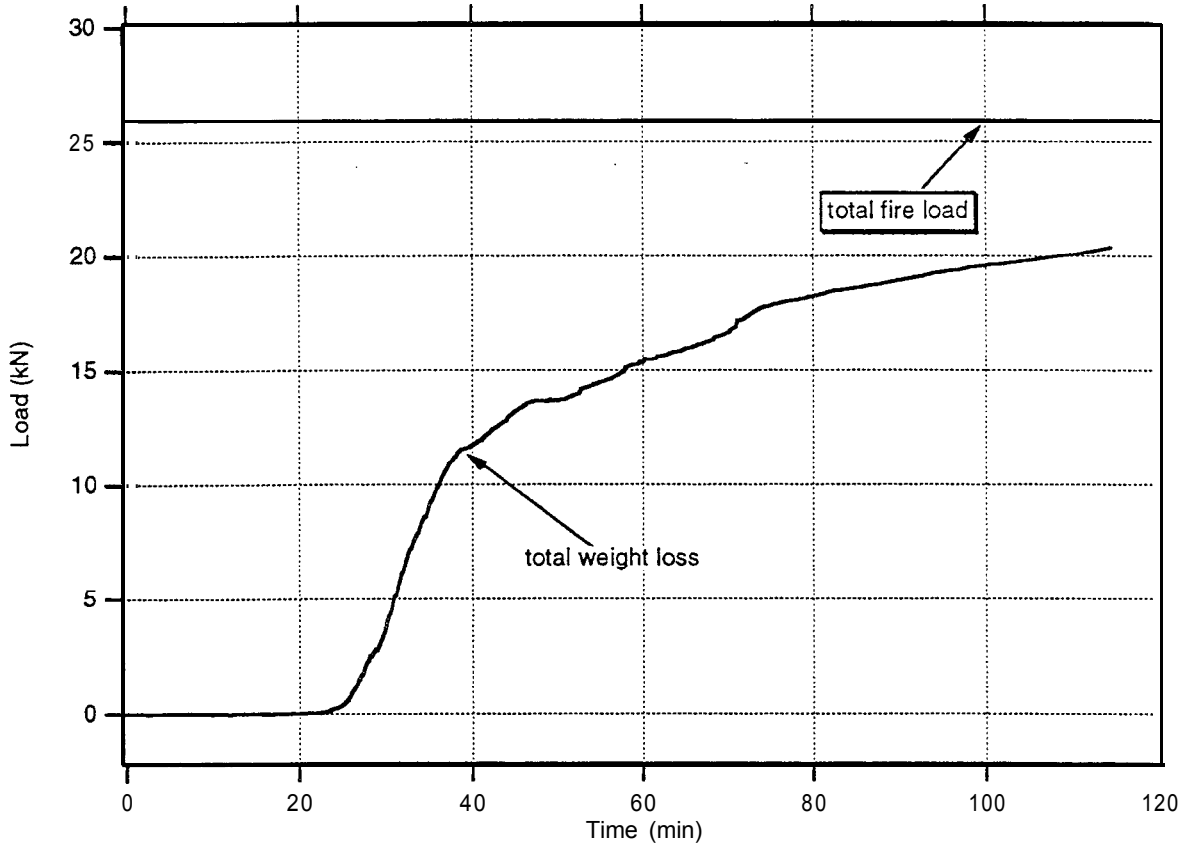
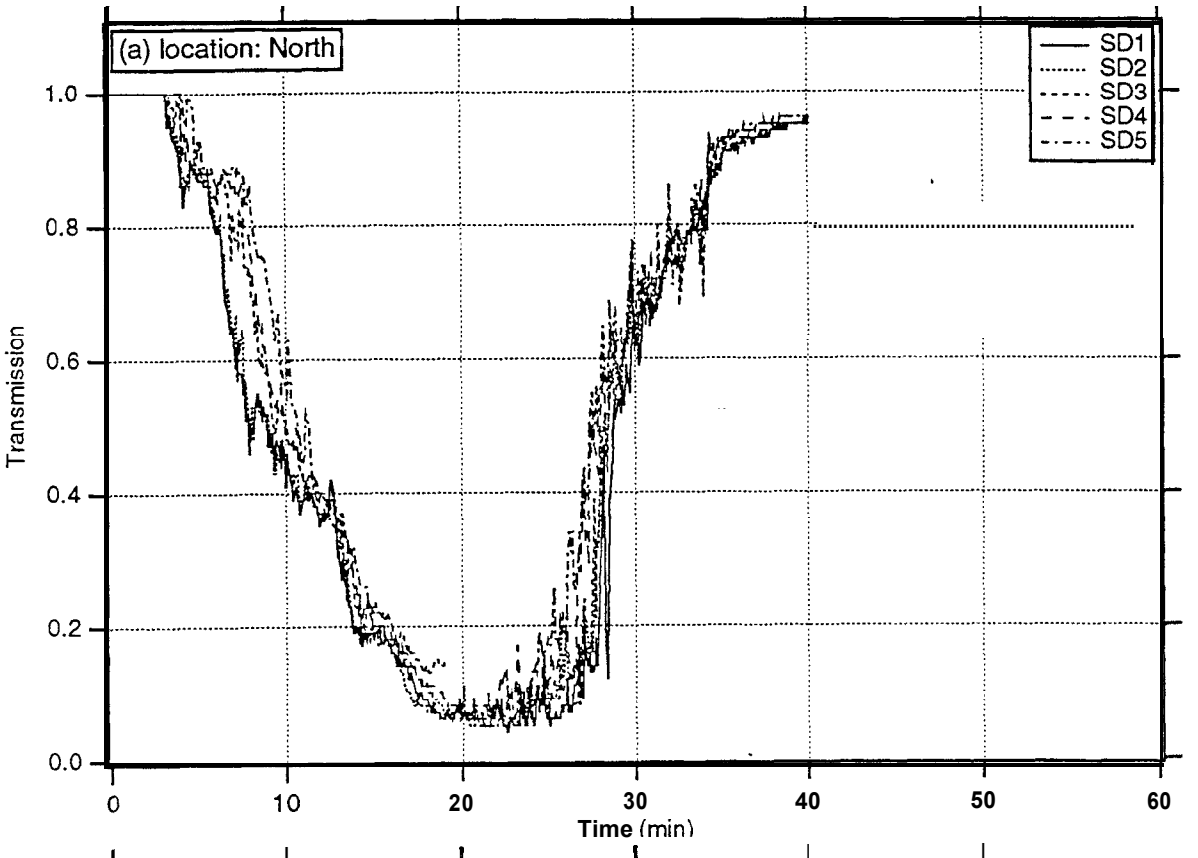


FIGURE D4 MASS LOSS - TEST 4

APPENDIX E: TRANSMISSION



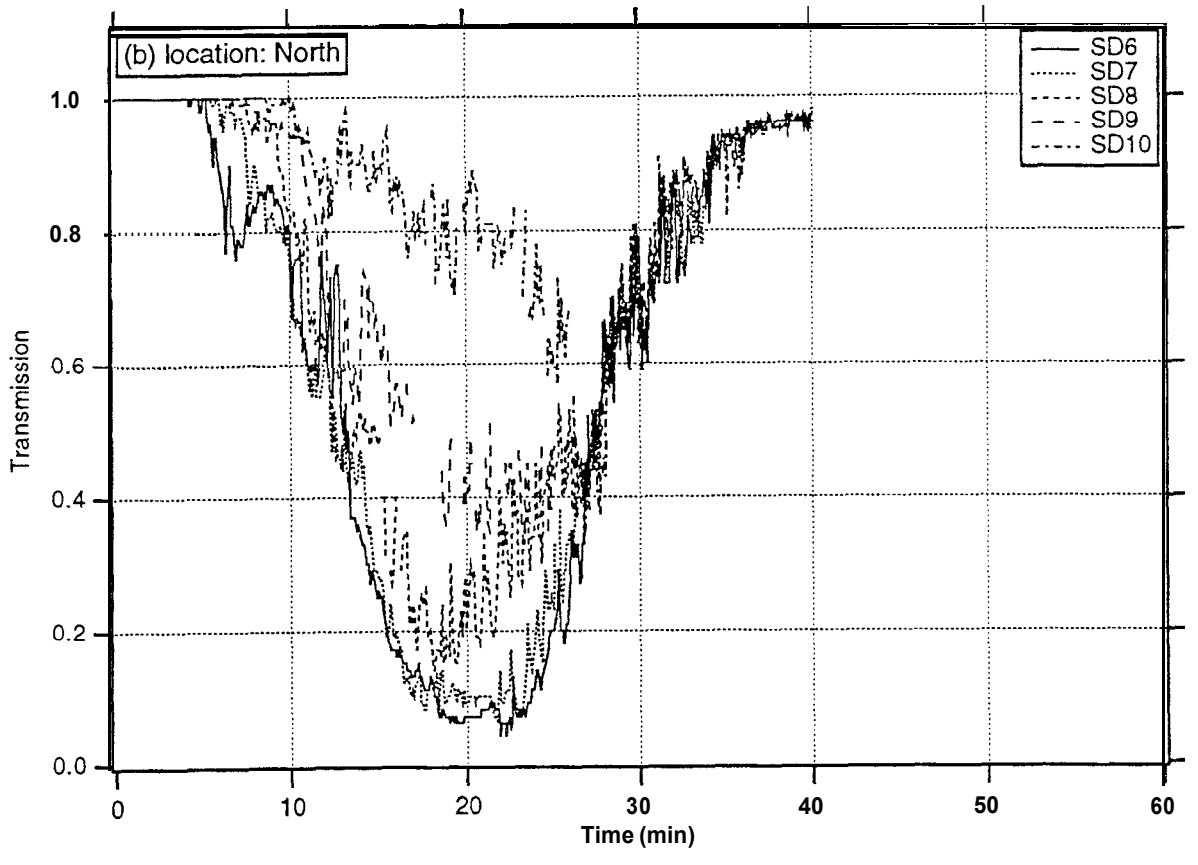


FIGURE E1(A) AND (B) TRANSMISSION - TEST 1

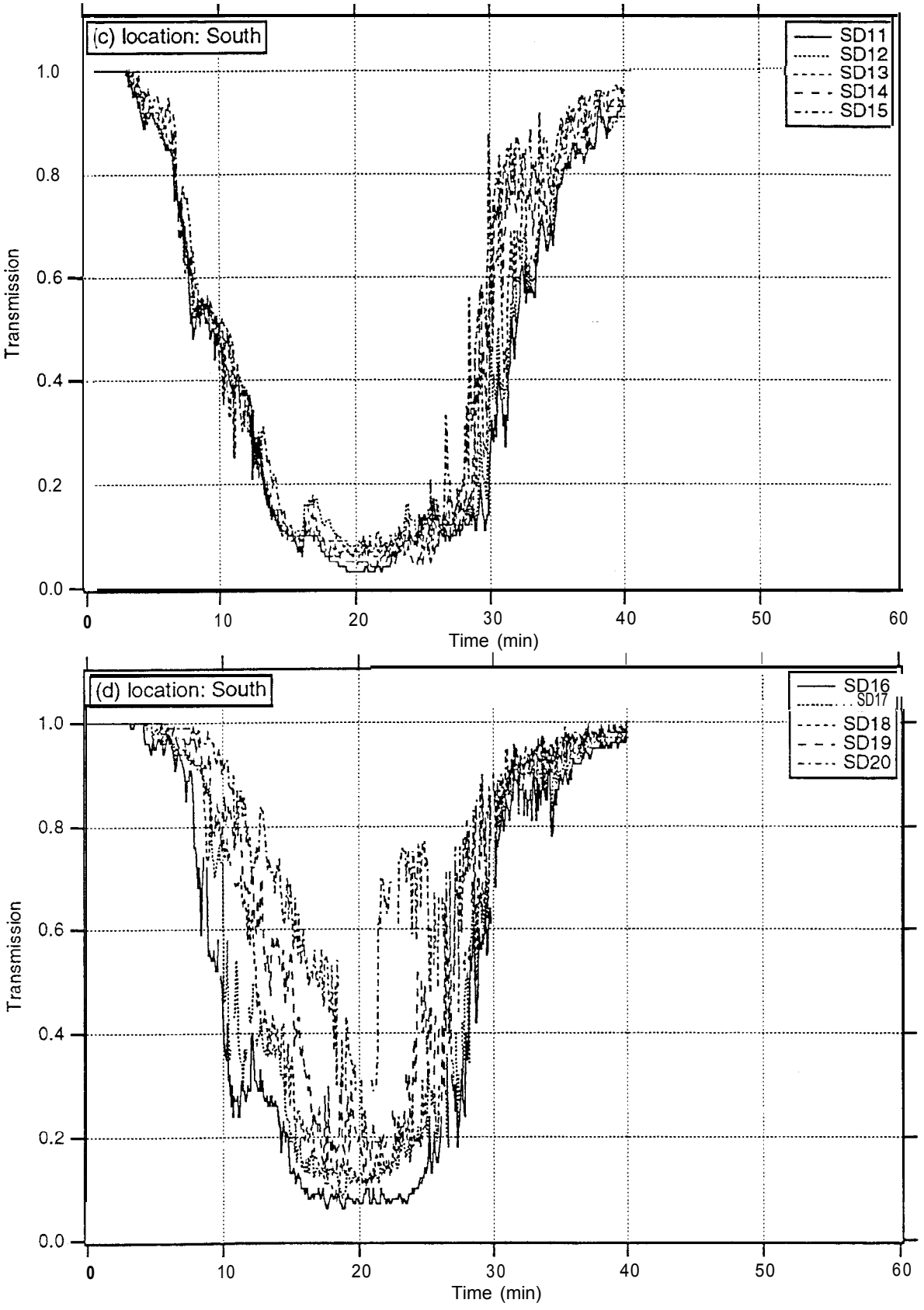


FIGURE E1(C) AND (D) TRANSMISSION - TEST 1

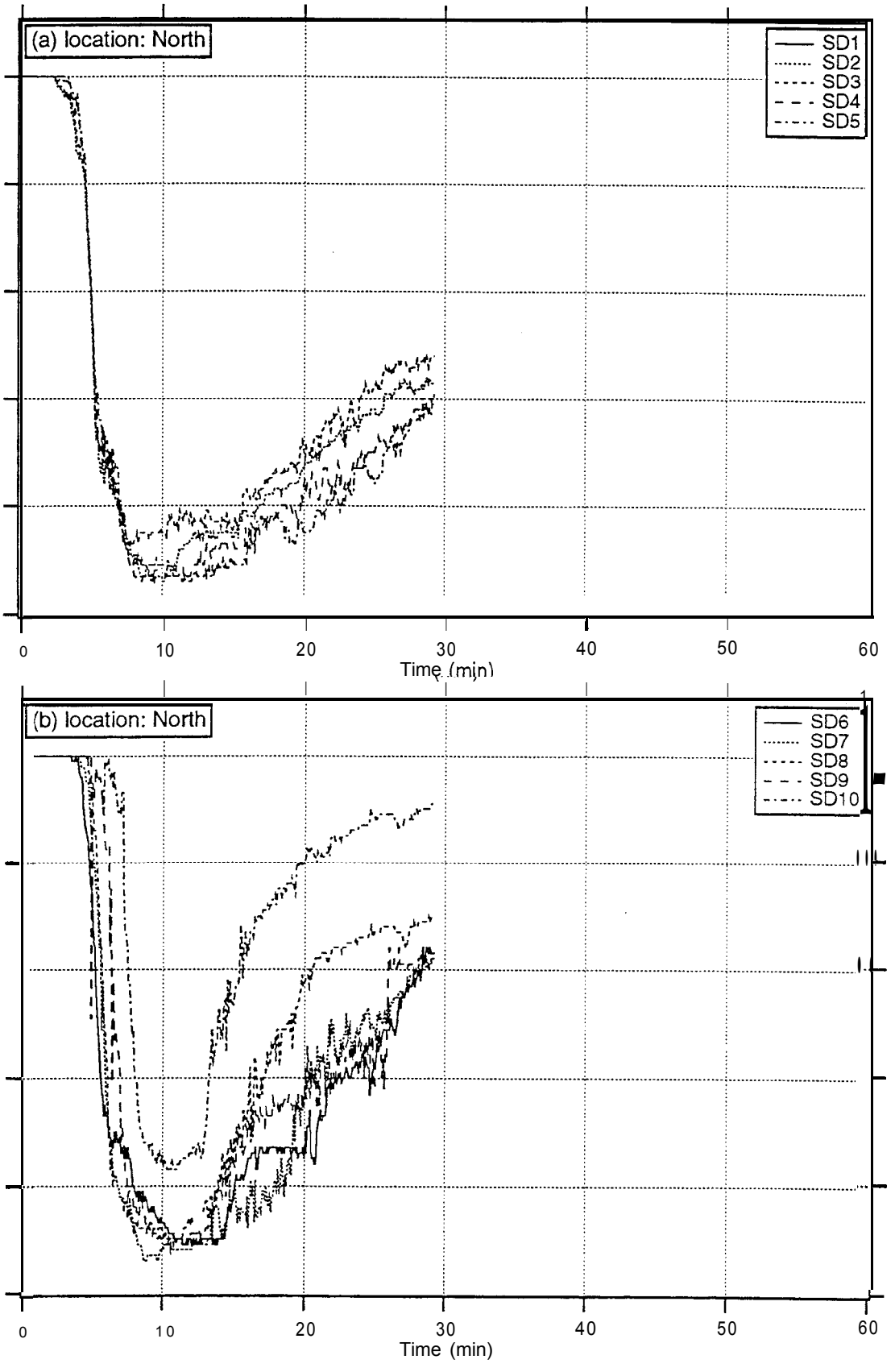
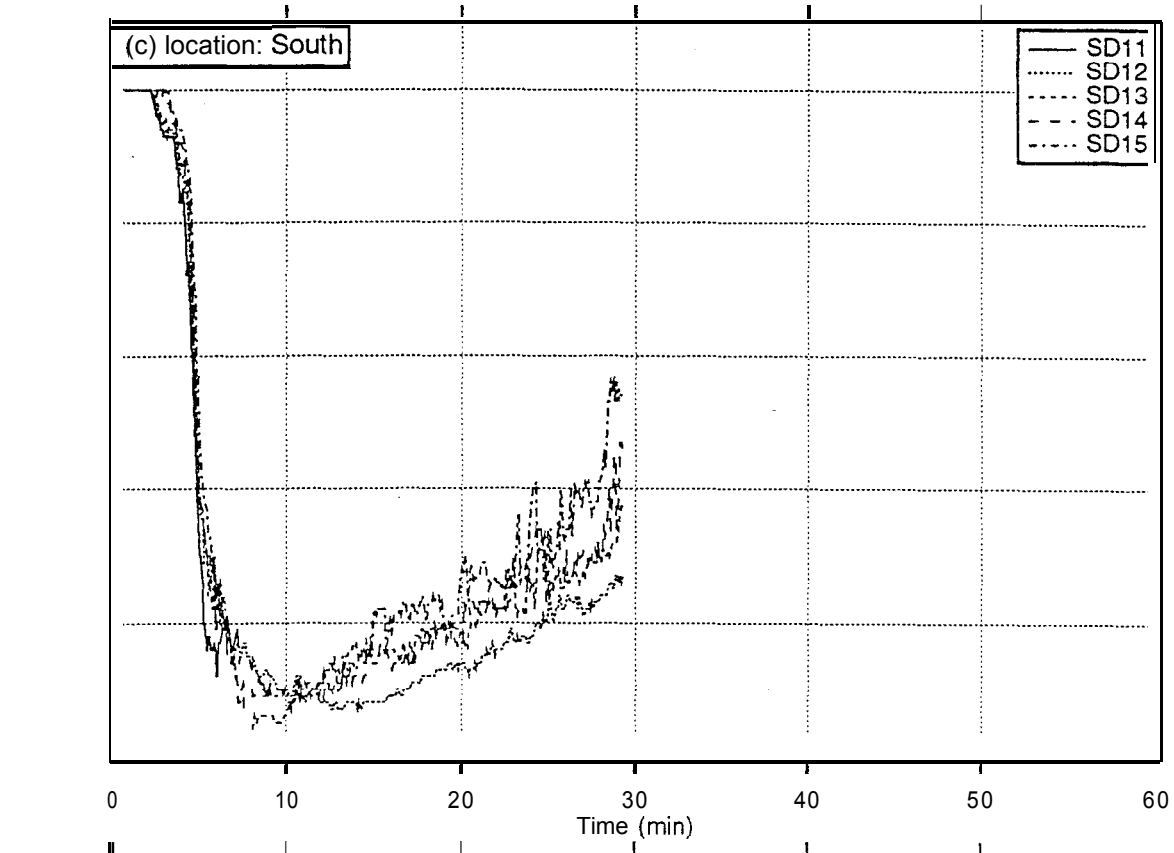


FIGURE E2(A) AND(B) TRANSMISSION - TEST 2



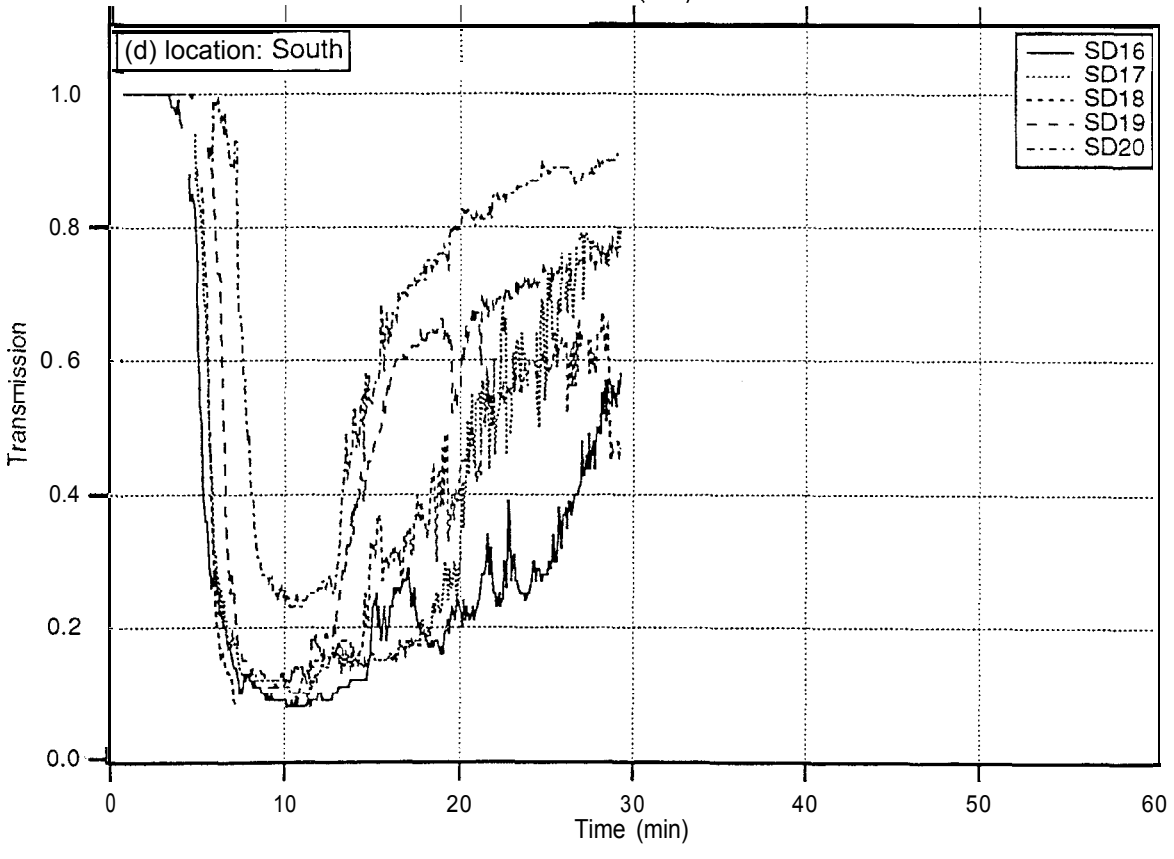


FIGURE E2(C) AND (D) TRANSMISSION - TEST 2

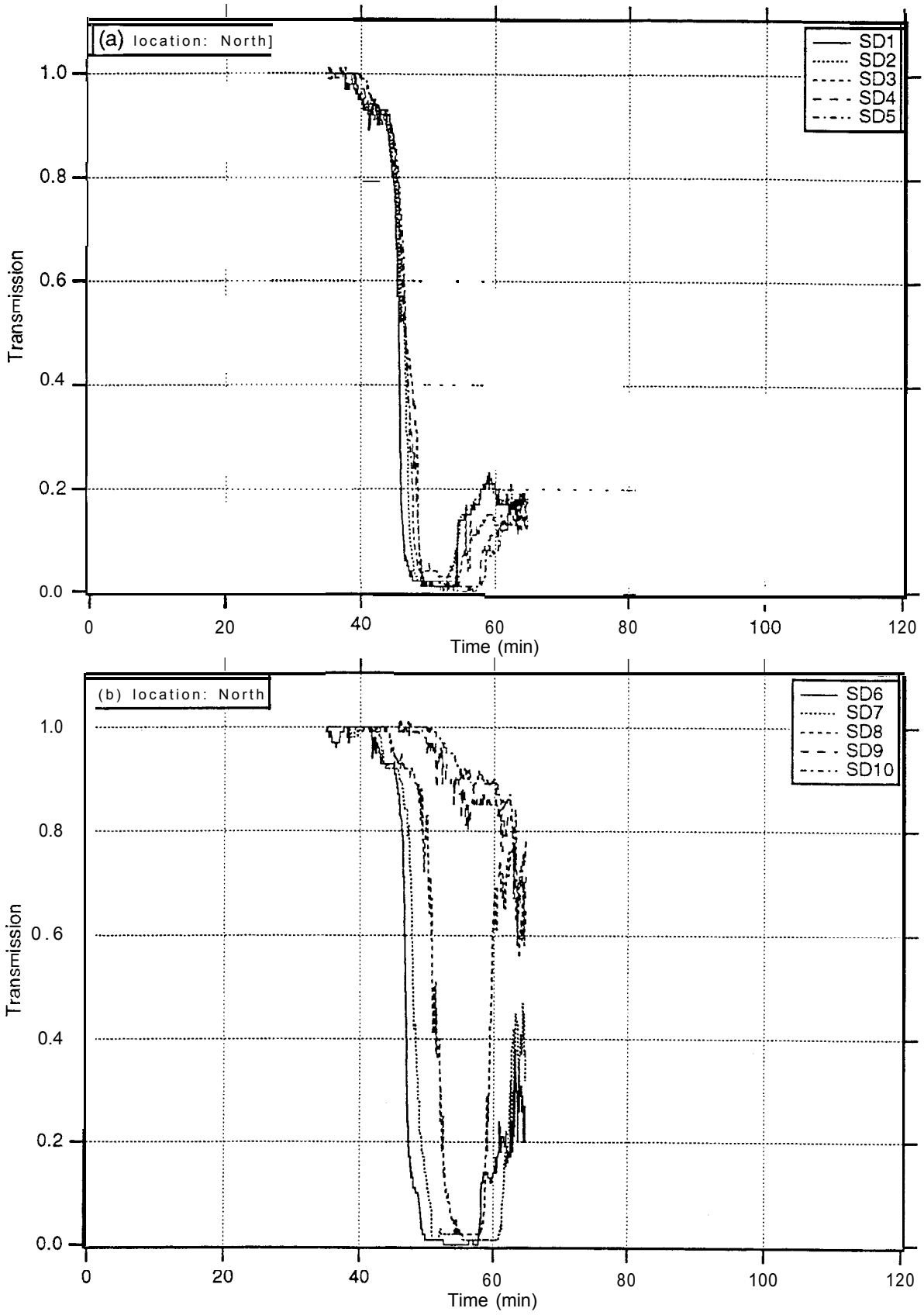
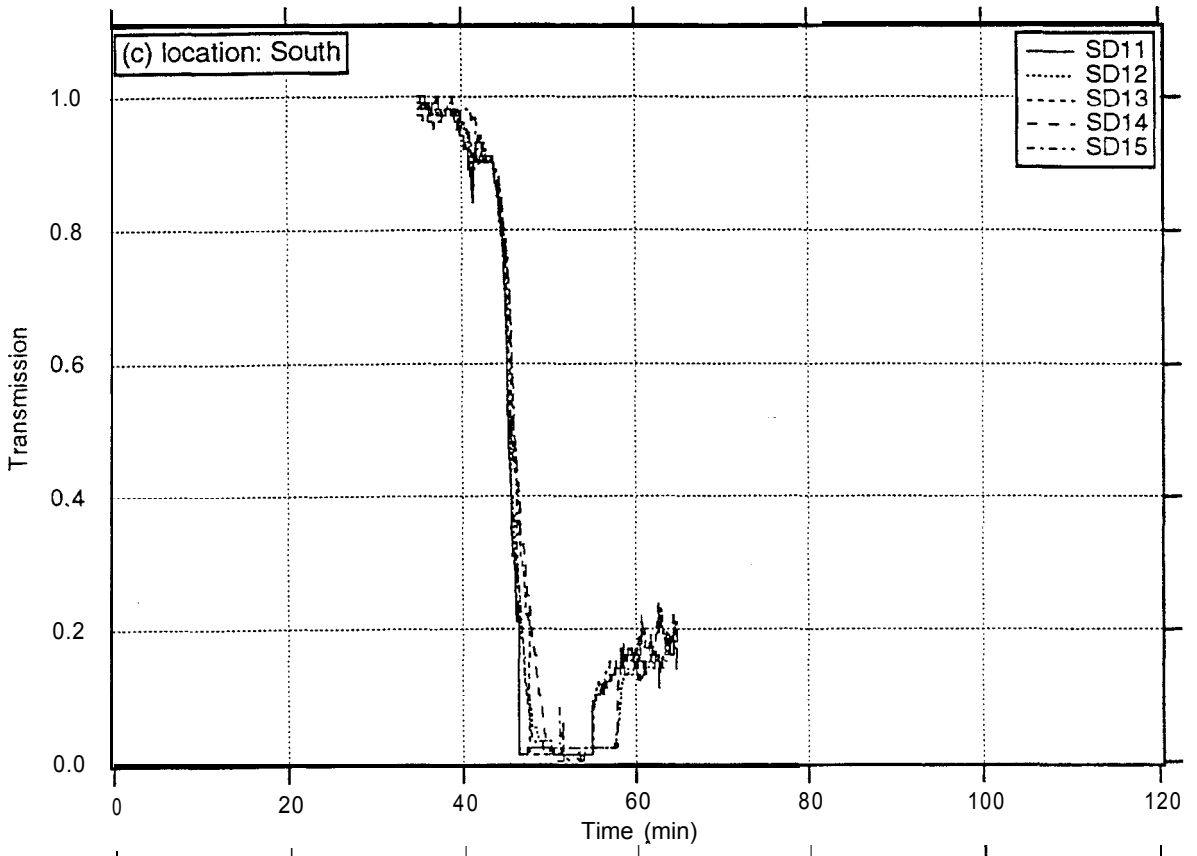


FIGURE E3(A) AND - TEST 3



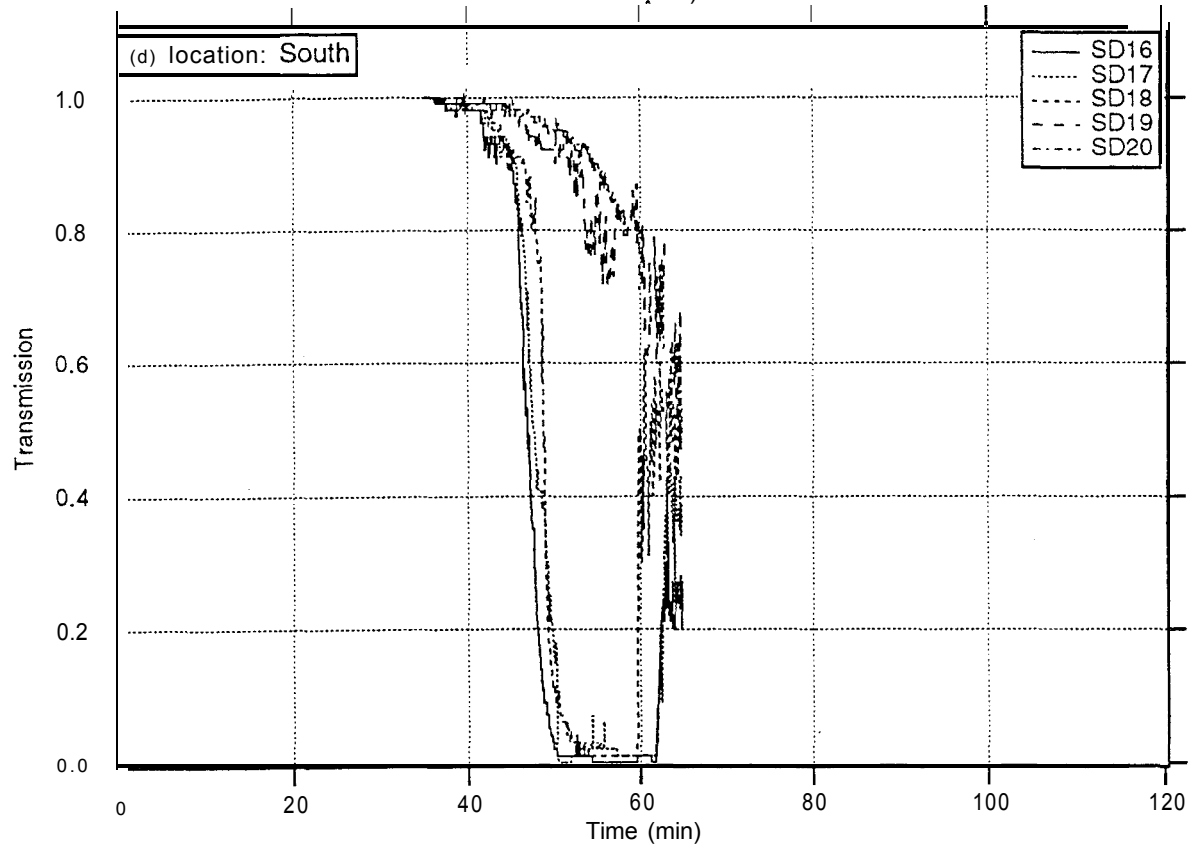


FIGURE E3(C) AND (D) TRANSMISSION - TEST 3

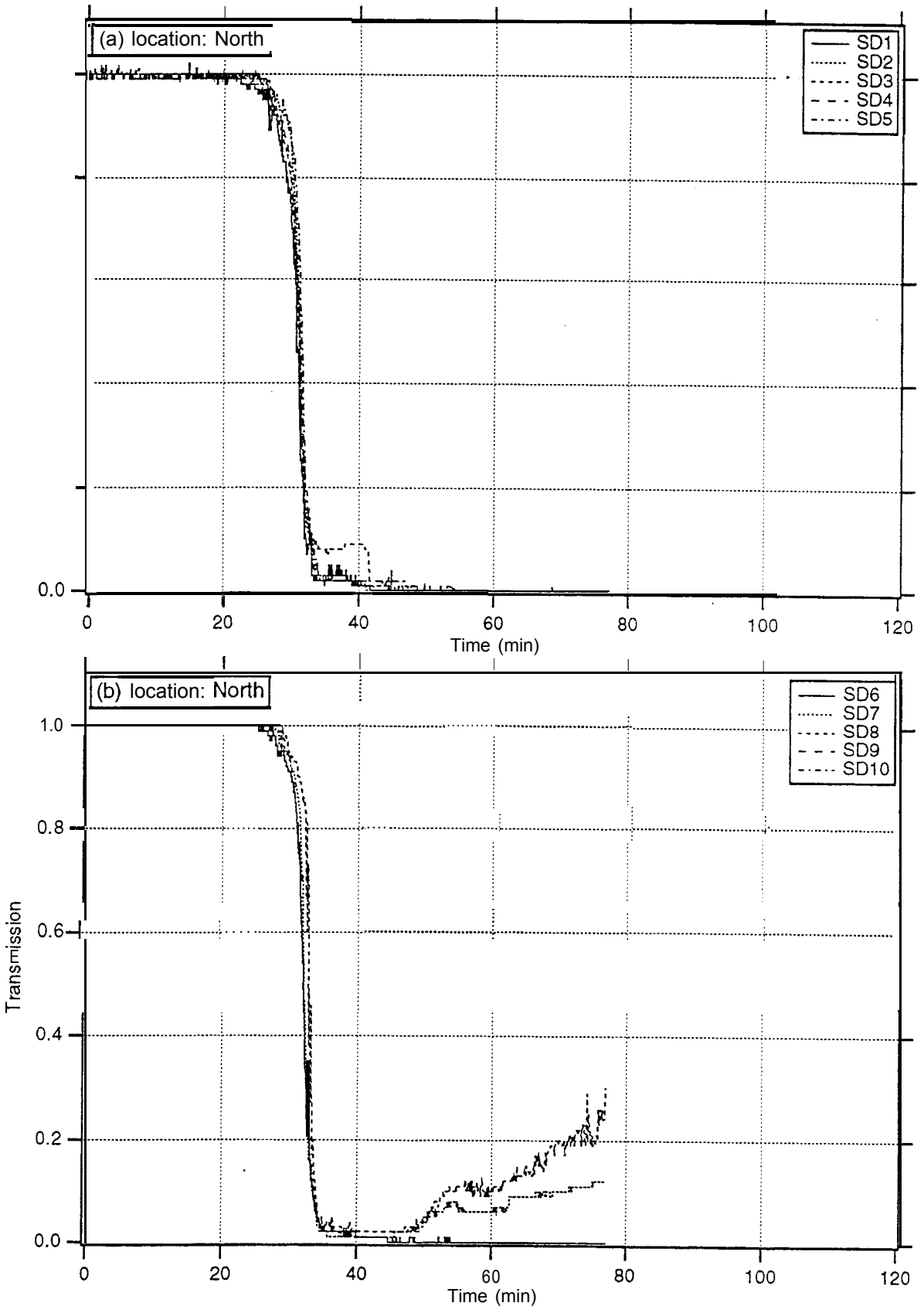


FIGURE E4(A) AND (B) TRANSMISSION - TEST 4

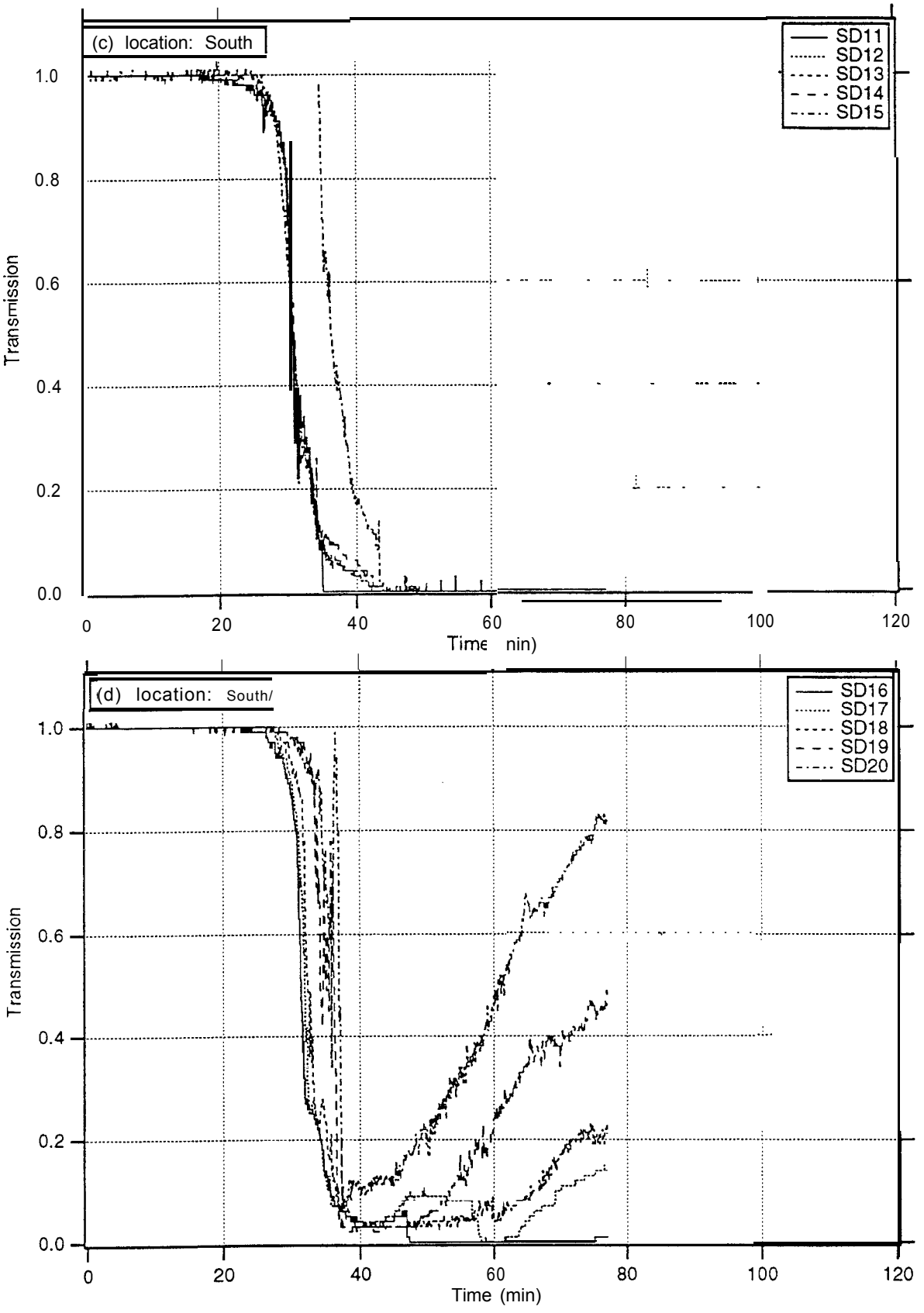


FIGURE E4(C) AND (D) TRANSMISSION - TEST 4

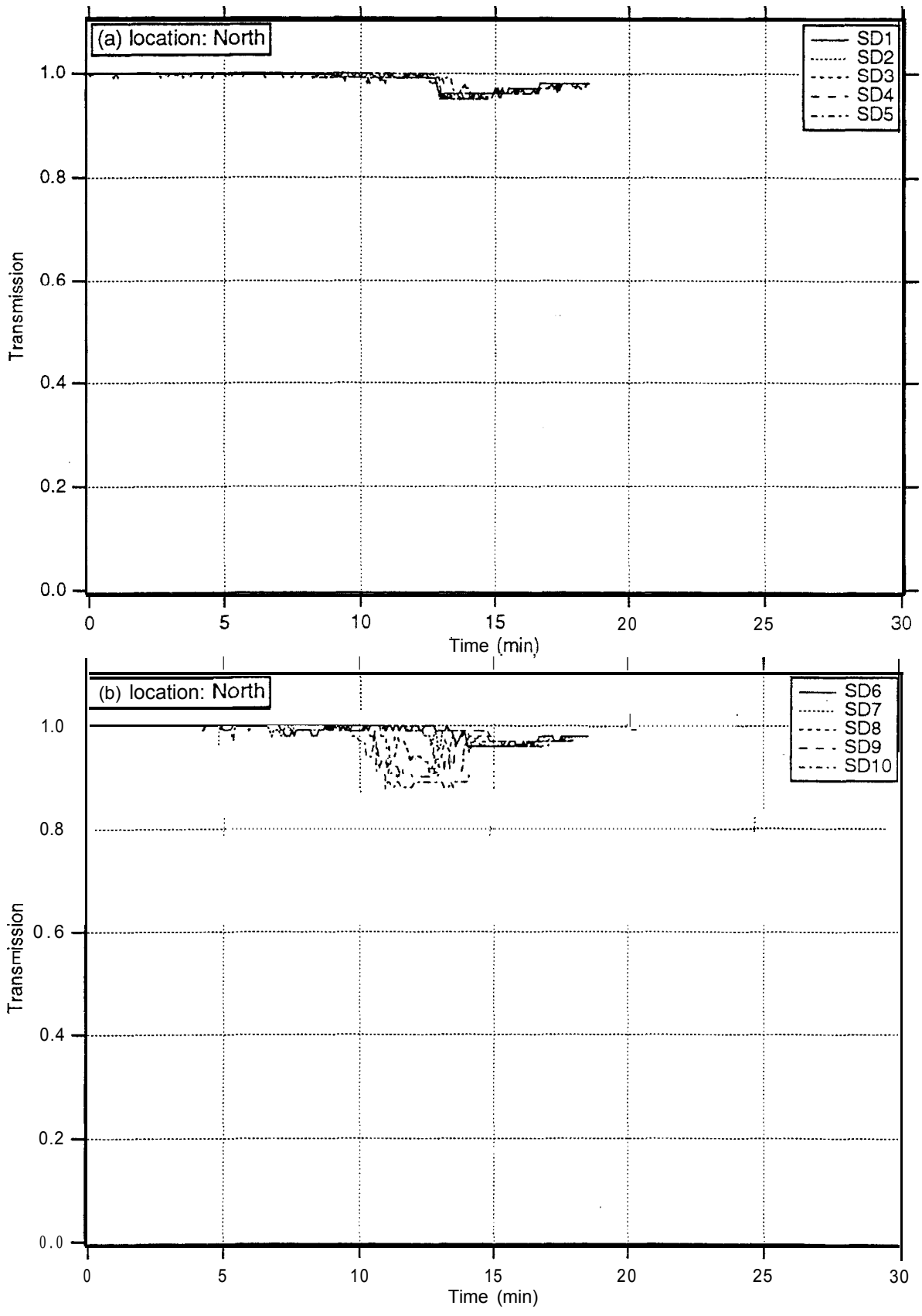


FIGURE E5(A) AND (B) TRANSMISSION - TEST 5

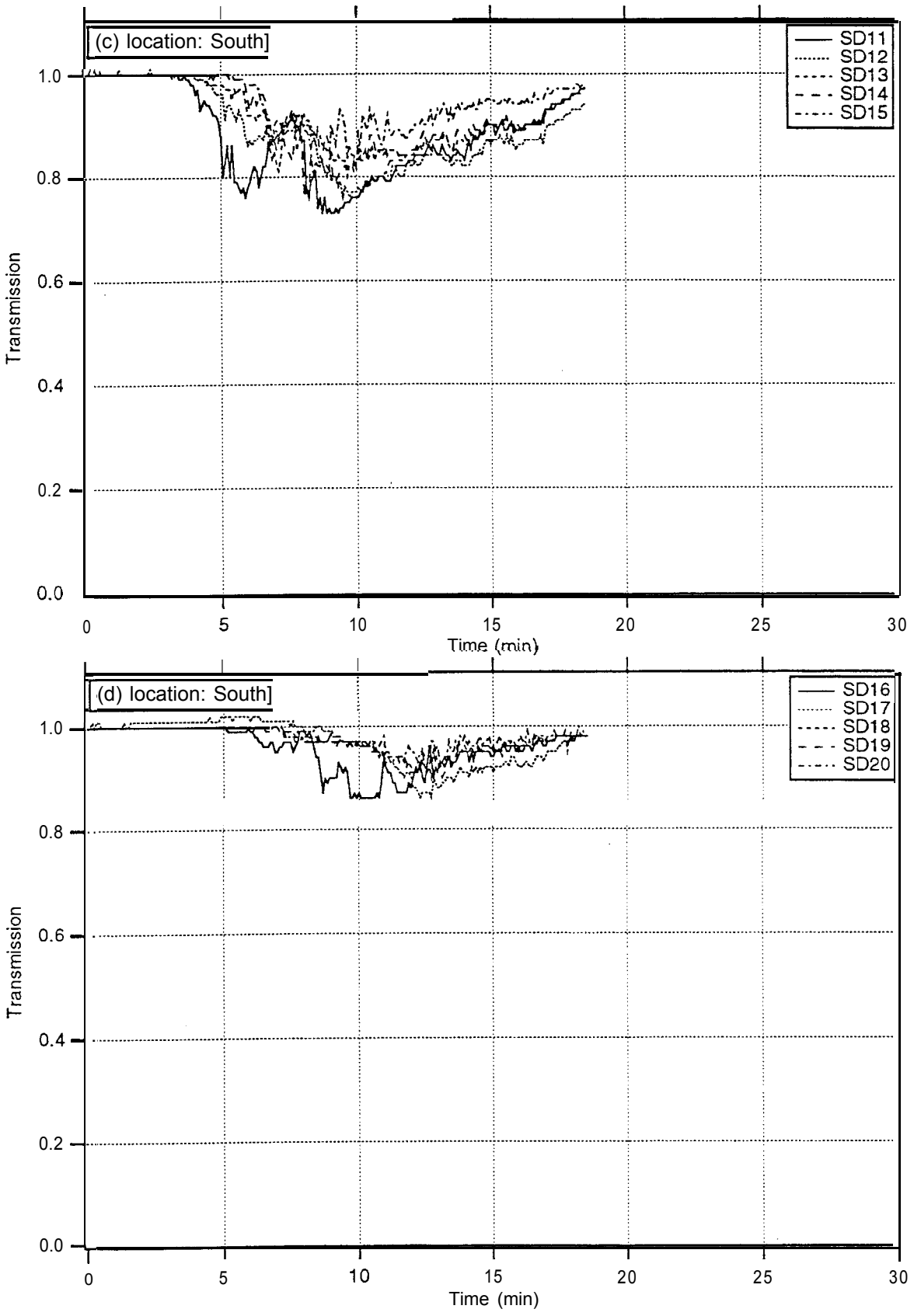


FIGURE E5(C) AND (D) TRANSMISSION - TEST 5

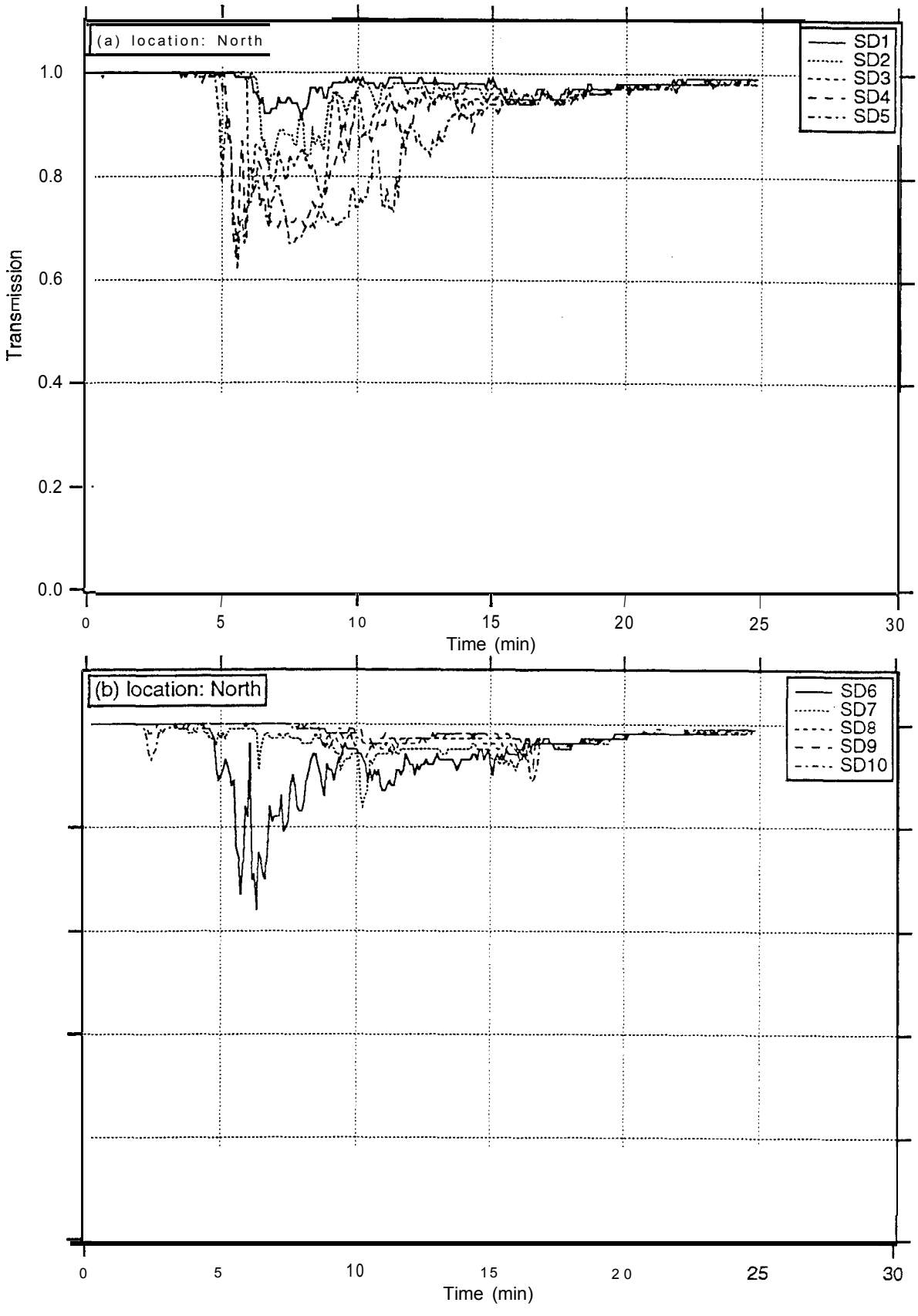


FIGURE E6(A) AND (B) TRANSMISSION - TEST 6

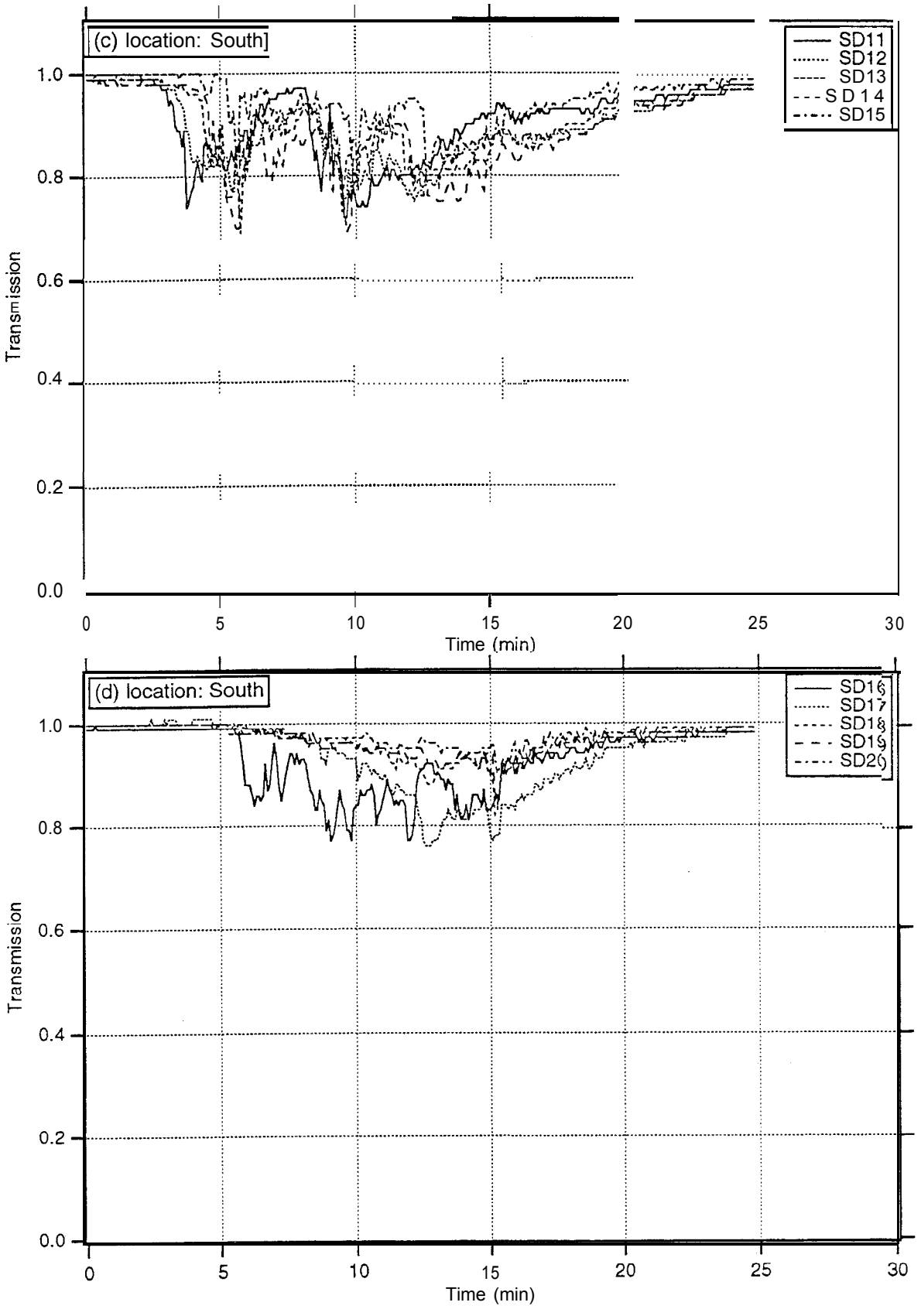


FIGURE E6(C) AND (D) TRANSMISSION - TEST 6

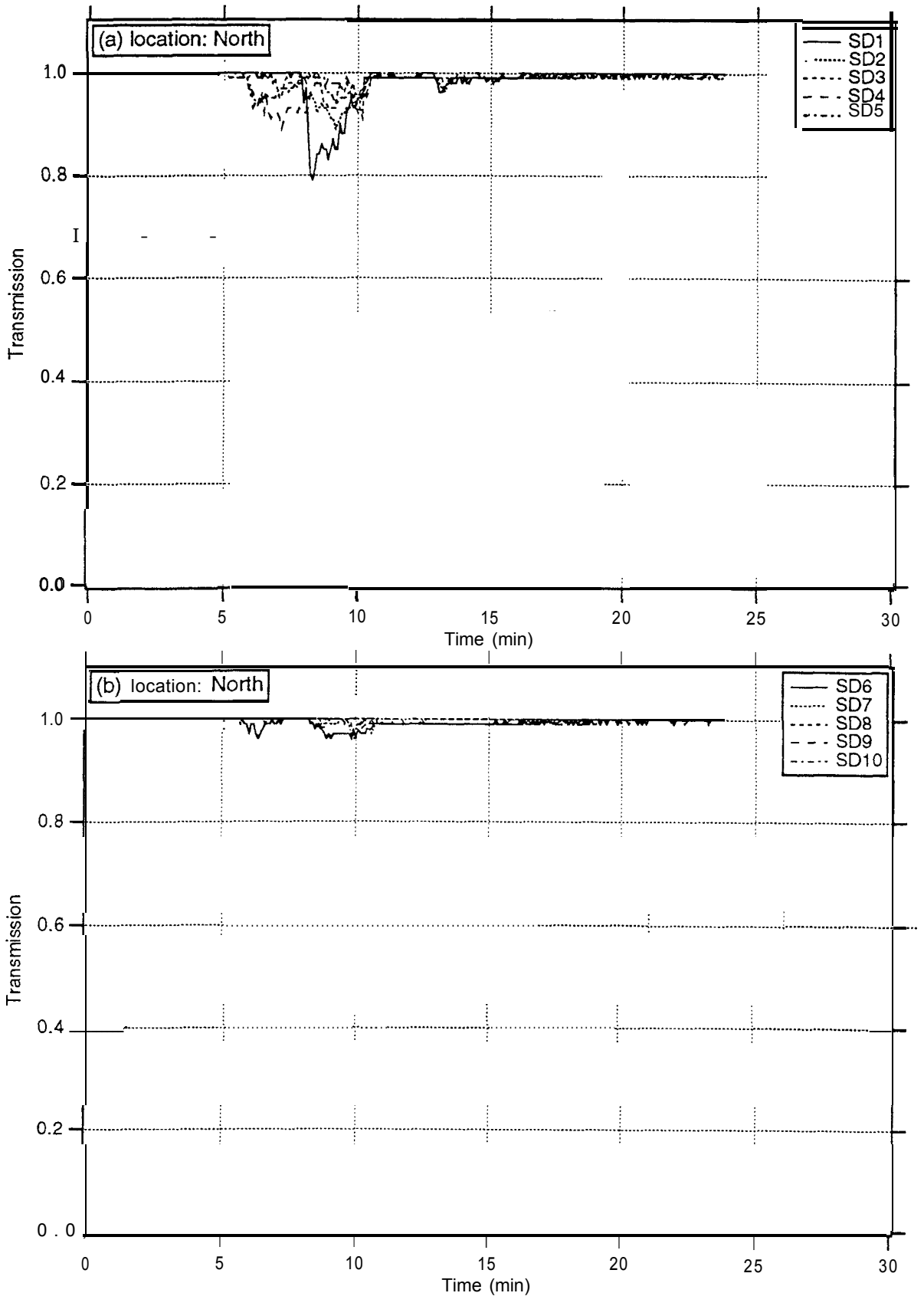


FIGURE E7(A) AND (B) TRANSMISSION - TEST 7

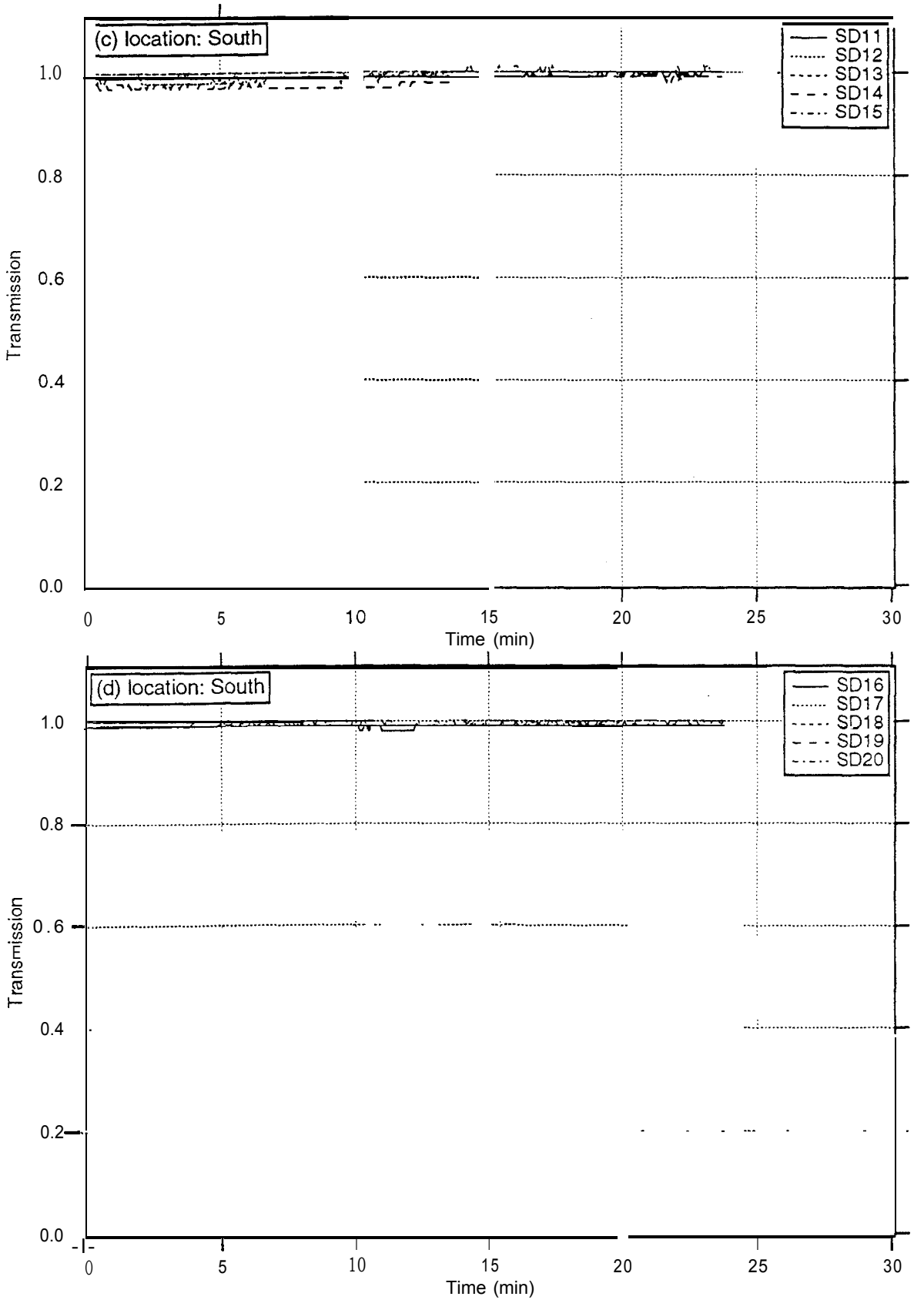
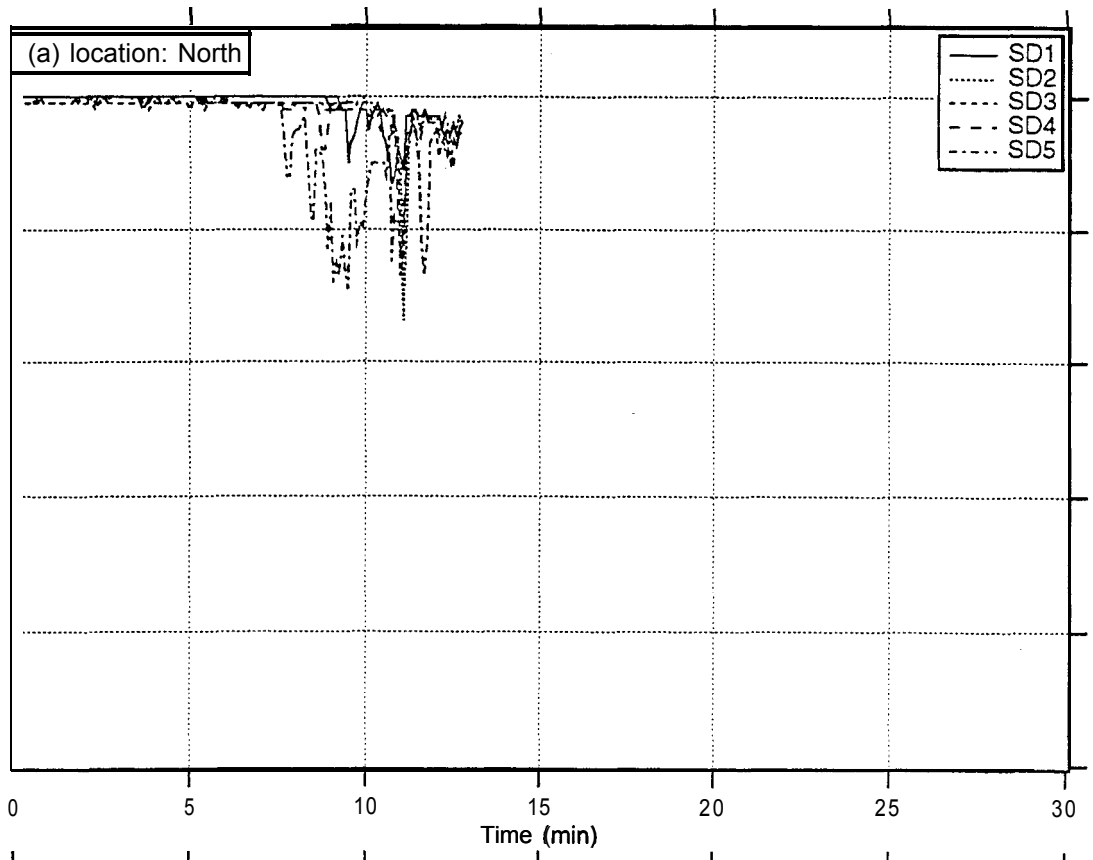


FIGURE E7(C) AND(D) TRANSMISSION-TEST 7



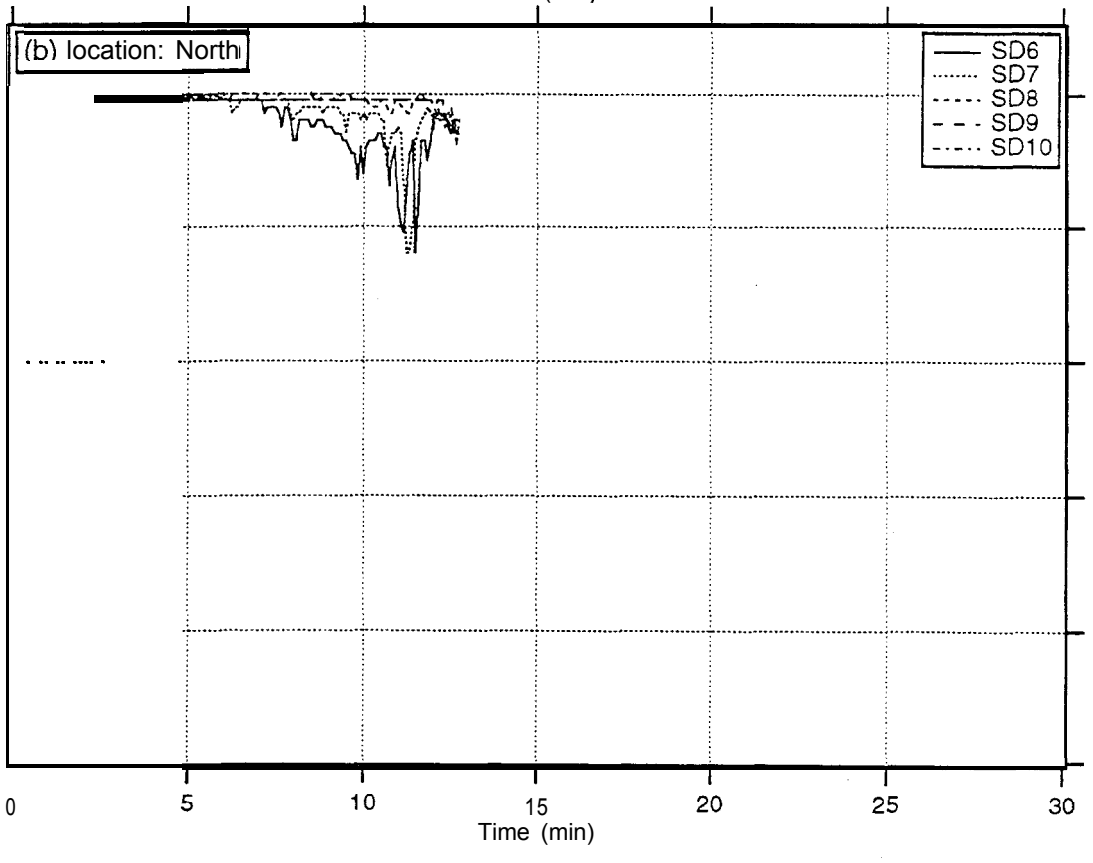


FIGURE E8(A) AND (B) TRANSMISSION - TEST 8

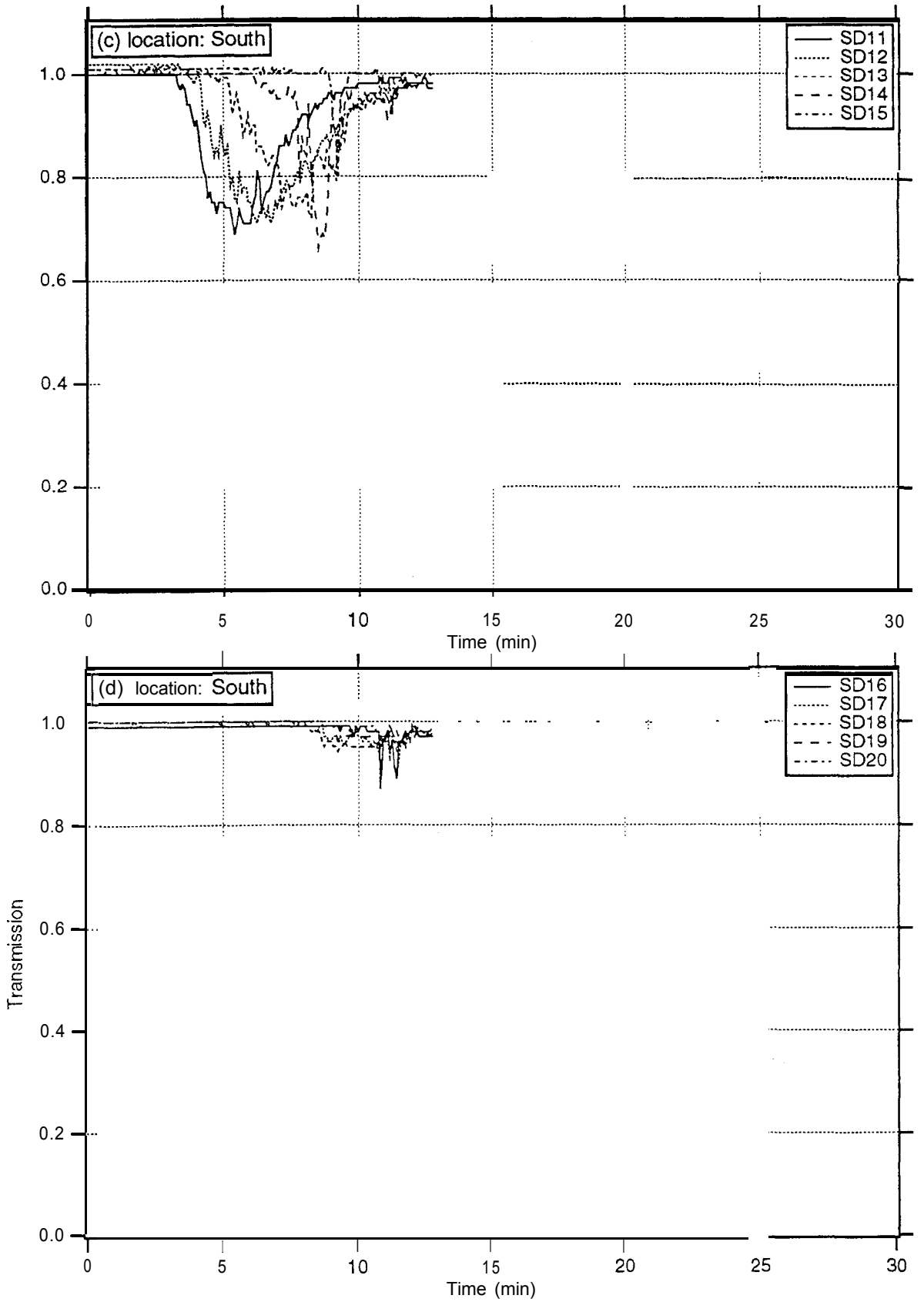


FIGURE E8(C) AND (D) TRANSMISSION - TEST 8

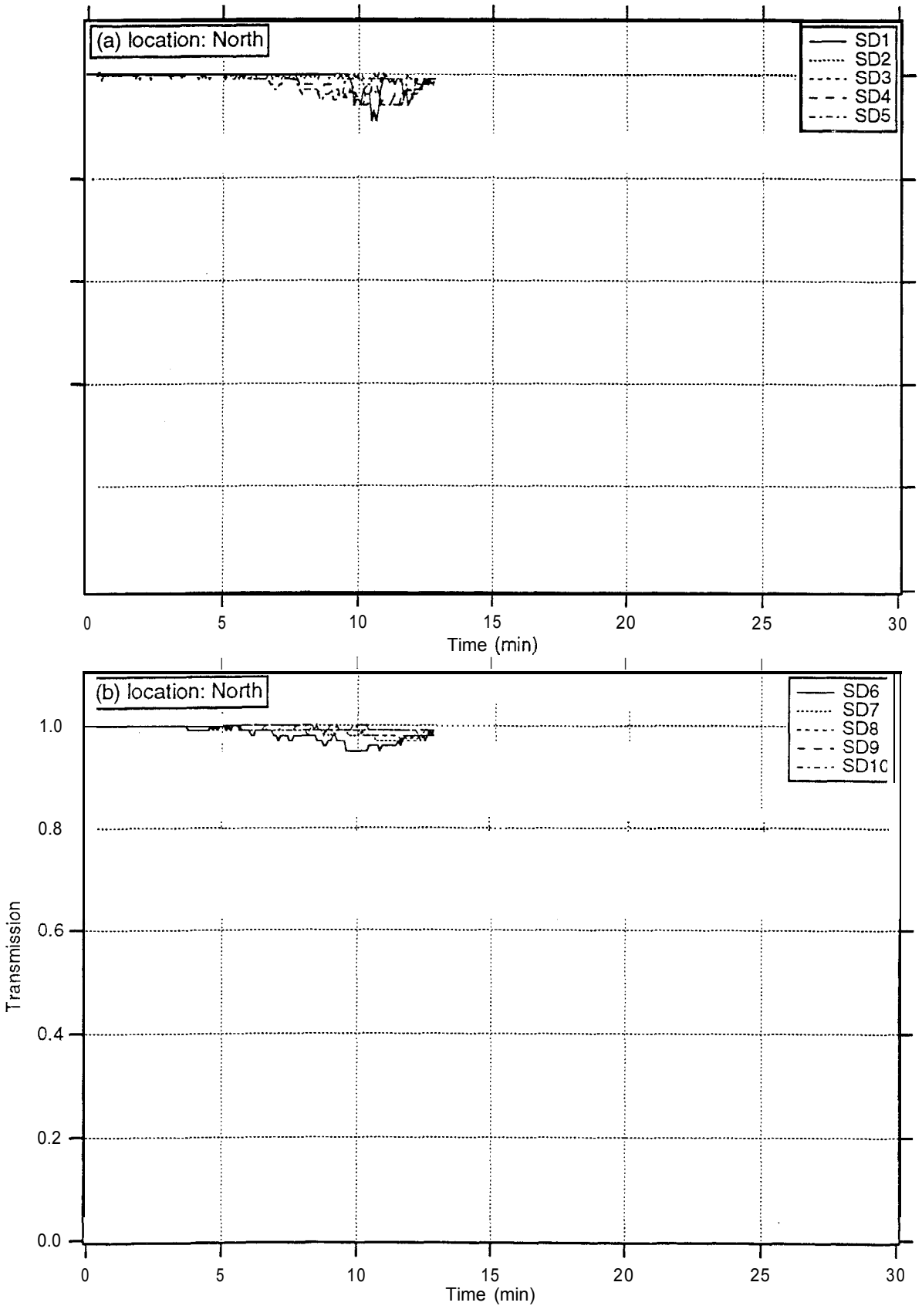


FIGURE E9(A) AND(B) TRANSMISSION - TEST 9

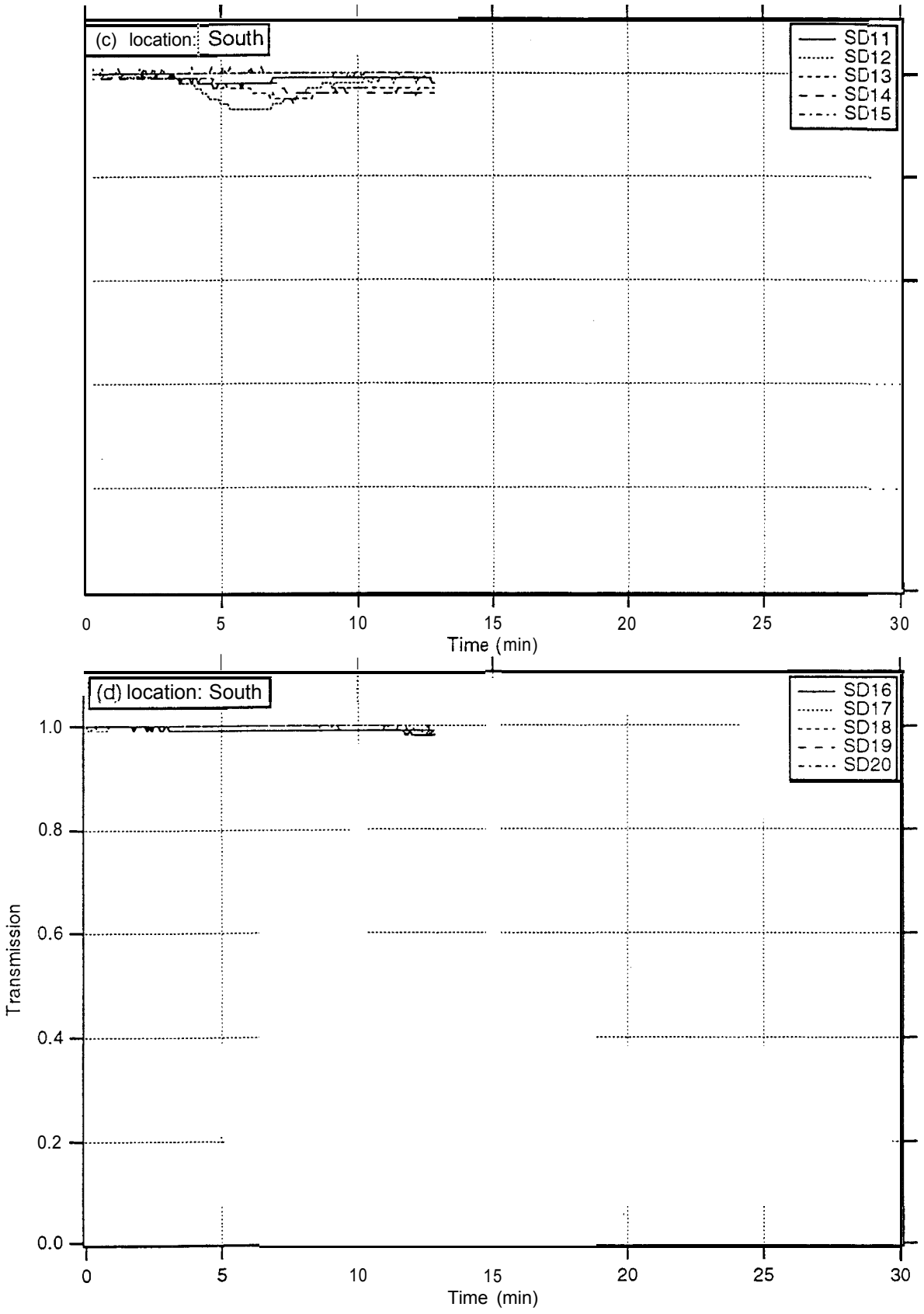


FIGURE E9(C) AND (D) TRANSMISSION - TEST 9

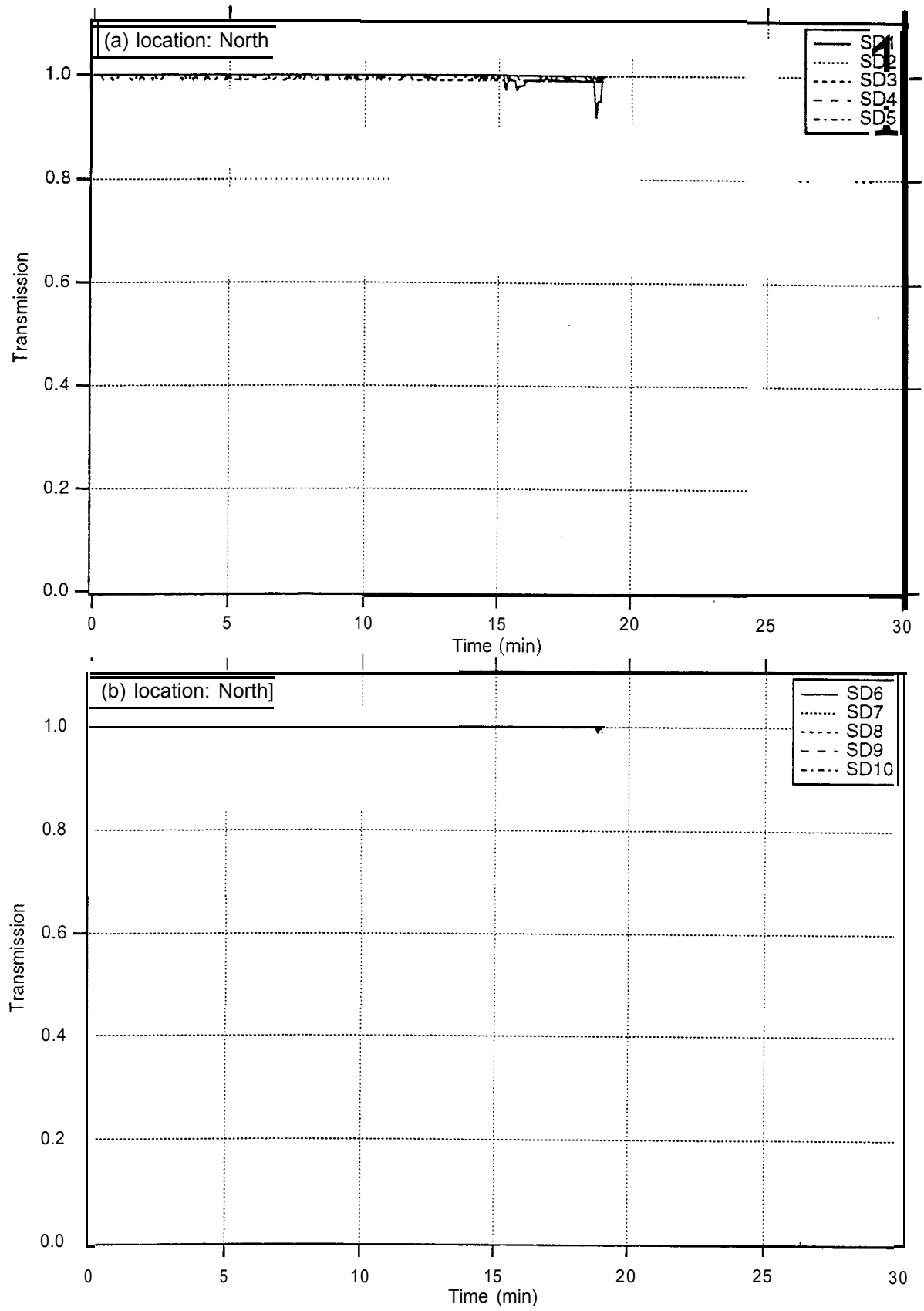
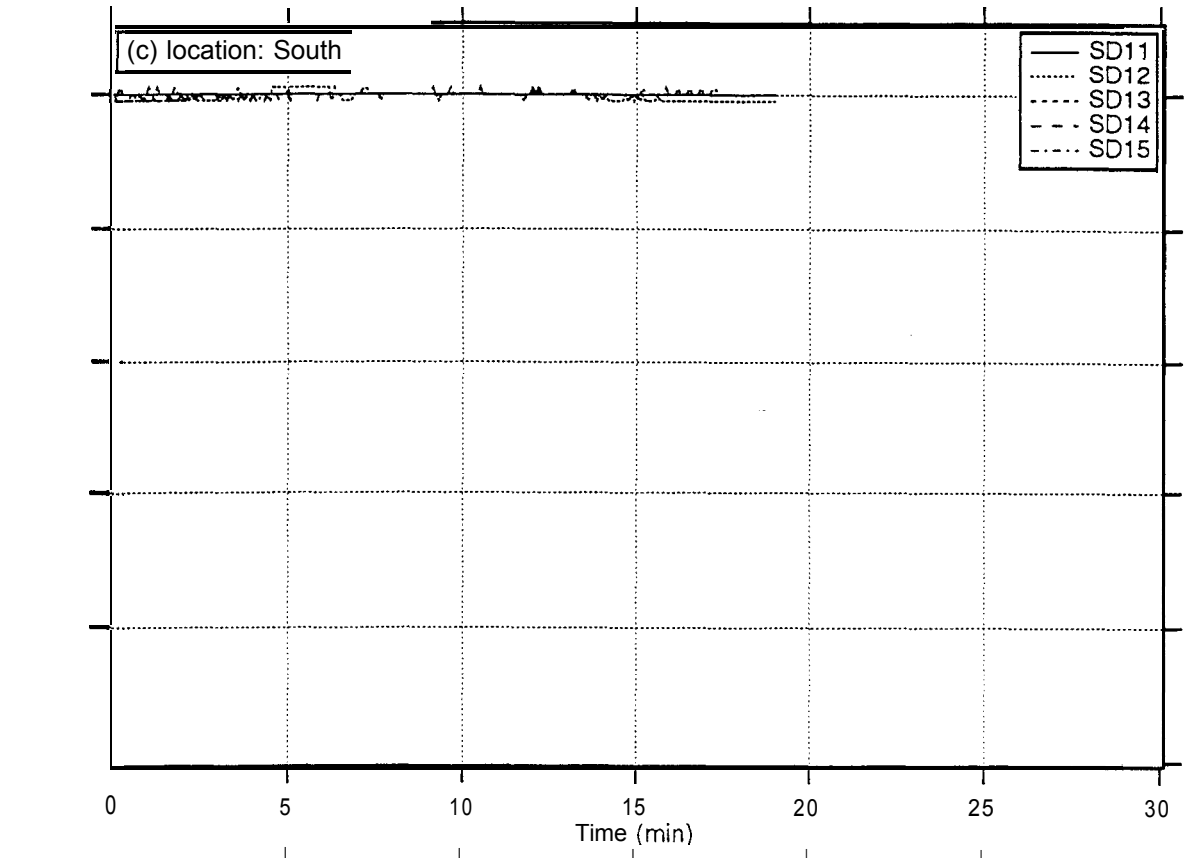


FIGURE E10(A) AND (B) TRANSMISSION-TEST 10



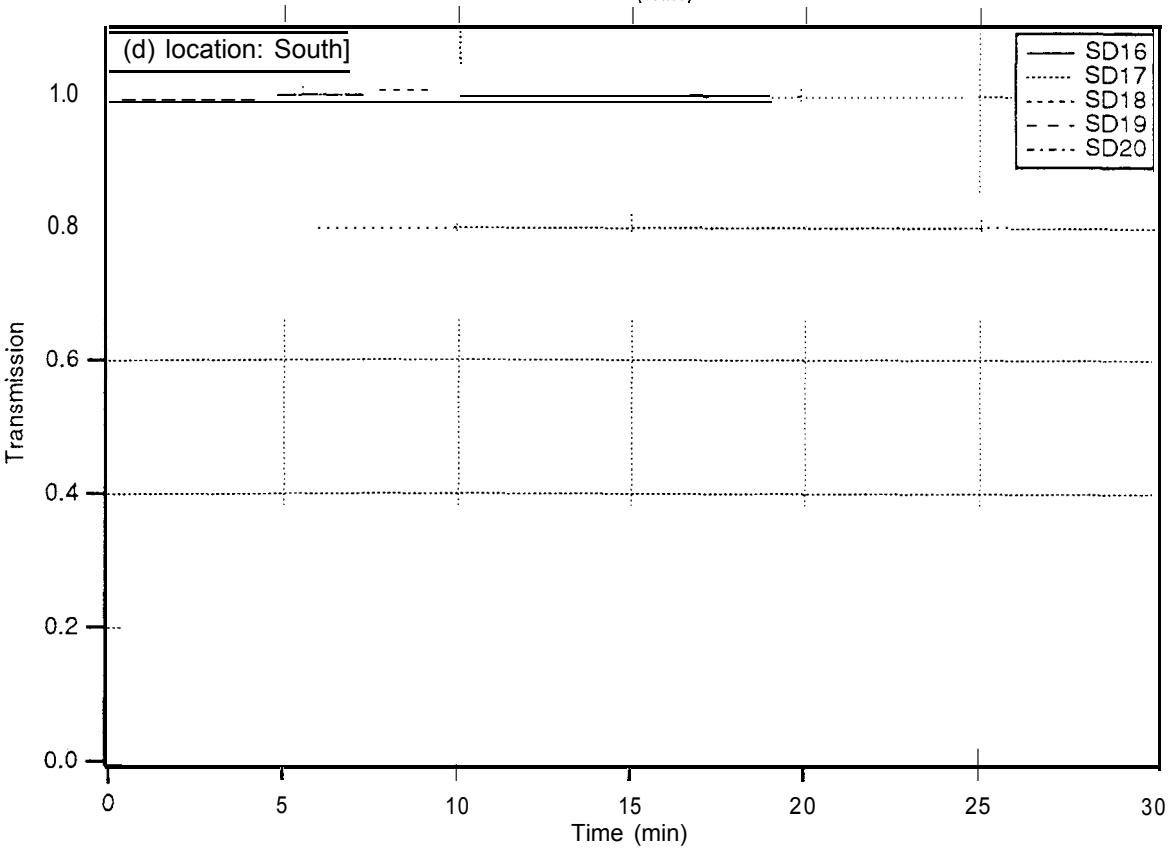


FIGURE E10(C) AND (D) TRANSMISSION - TEST 10

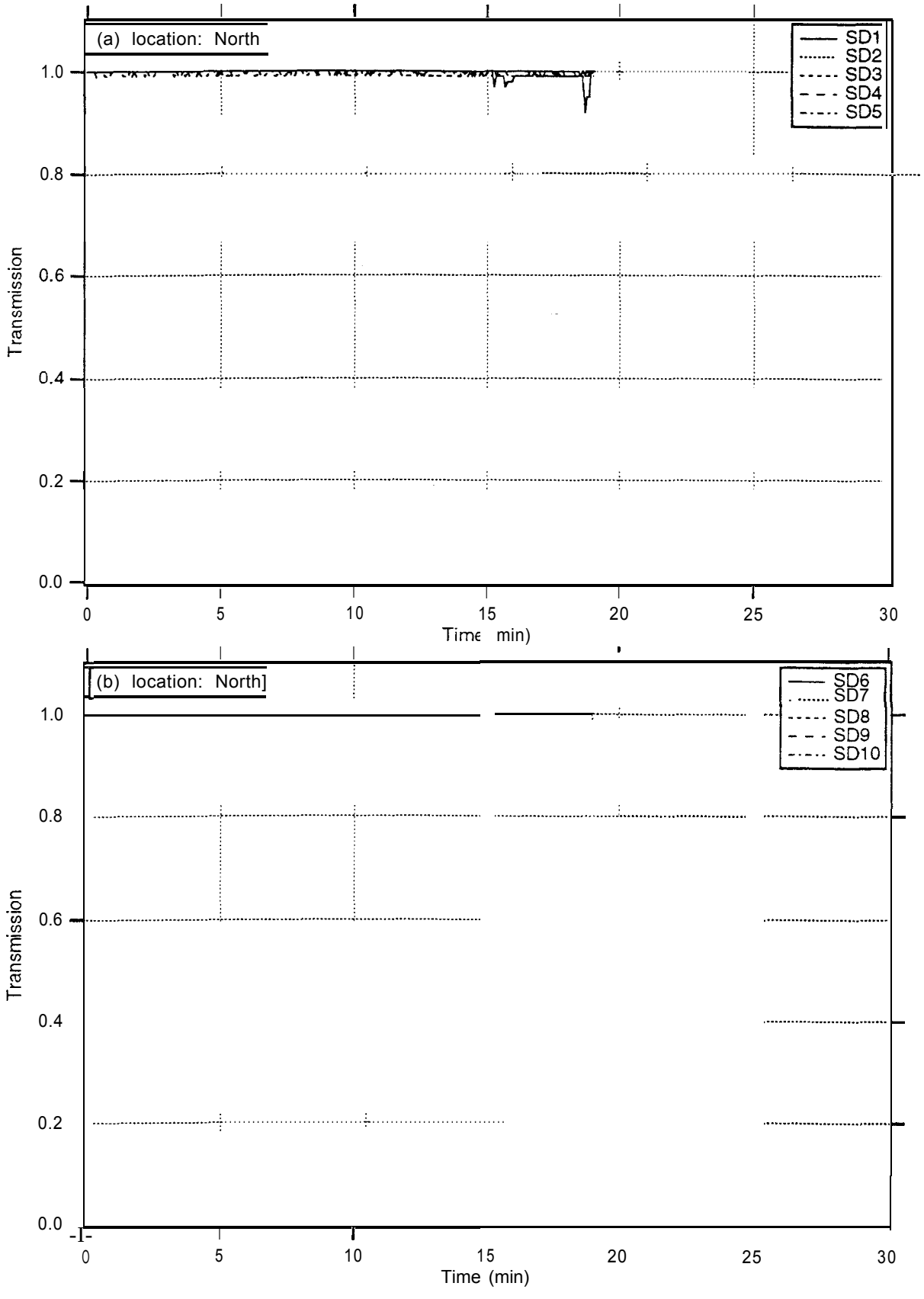


FIGURE E1 1(A) AND (B) TRANSMISSION-TEST 11

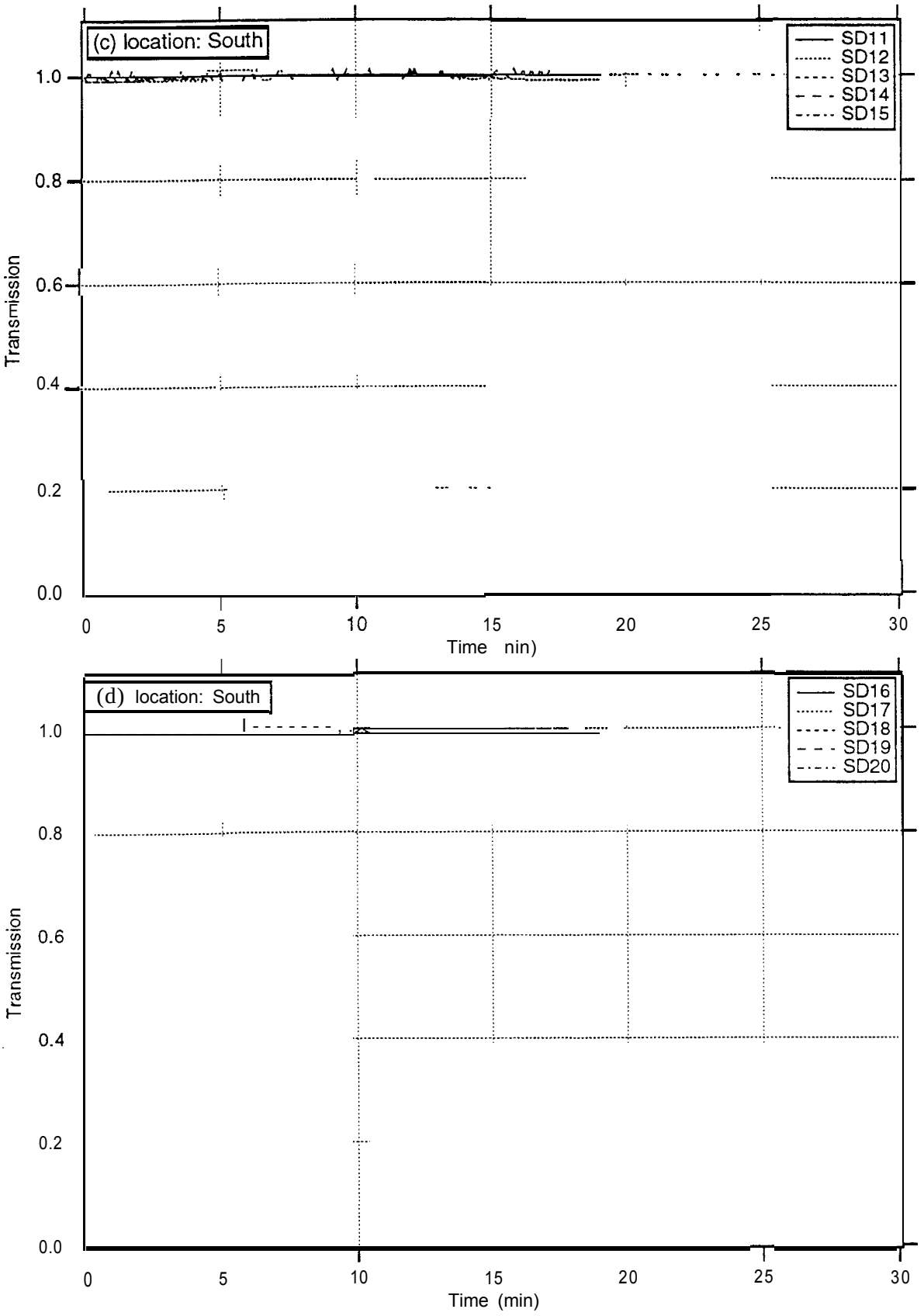


FIGURE E1 1(C) AND (D) TRANSMISSION - TEST 11

APPENDIX F: SMOKE LAYER AND TARGET VISIBILITY

TABLE F1 - TEST 1

	Observed time *(min.sec)*							
	South End Targets				North End Targets			
	Observer 1		Observer 2		Observer 3		Observer 4	
Target Number	*smoke layer*	*not visible*	*smoke layer*	*not visible*	*smoke layer*	*not visible*	*smoke layer*	*not visible*
1	3.40	6.56	3.40	6.30	3.20	5.50	3.30	5.45
2	3.59	7.26	3.56	6.40	3.40	6.00	3.45	6.00
3	4.25	7.27	4.30	6.50	4.17	6.14	4.15	7.00
4	4.37	7.42	4.50	7.00	4.40	7.10	4.30	7.50
5	4.46	8.10	5.00	7.25	5.20	7.40	5.30	8.25
6	4.56	8.29	5.20	7.40	6.00	8.10	6.15	9.00
7	4.57	9.07	5.30	8.10	6.20	8.30	7.30	9.50
8	5.23	9.16	6.05	8.15	7.50	9.00	8.00	10.00
9	7.14	9.25	7.00	9.20	9.10	9.40	9.00	10.45
10	8.11	10.26	8.00	10.26	9.30	11.30	10.30	13.30

TABLE F2 - TEST 2

	Observed time *(min.sec)*							
	South End Targets				North End Targets			
	Observer 1		Observer 2		Observer 3		Observer 4	
Target Number	*smoke layer*	*not visible*	*smoke layer*	*not visible*	*smoke layer*	*not visible*	*smoke layer*	*not visible*
1	2.35	4.00	2.42	4.00	–	4.15	3.04	4.16
2	3.05	4.10	3.00	4.15	2.40	4.15	3.20	4.20
3	3.19	–	3.24	4.20	3.30	4.15	3.30	4.30
4	3.30	–	3.35	4.29	4.00	4.15	4.00	4.35
5	3.40	4.30	3.47	4.35	–	4.20	–	4.40
6	3.55	4.40	4.09	4.40	–	–	4.45	4.50
7	4.30	5.25	4.29	5.00	–	4.45	5.15	5.05
8	5.00	5.40	4.38	5.15	5.00	5.30	5.20	5.25
9	5.28	5.55	4.50	5.37	5.30	6.00	5.40	6.10
10	–	–	–	–	6.00	–	6.50	7.04

TABLE F3 - TEST 3

	Observed time *(min.sec)*							
	South End Targets				North End Targets			
	Observer 1		Observer 2		Observer 3		Observer 4	
Target Number	*smoke layer*	*not visible*	*smoke layer*	*not visible*	*smoke layer*	*not visible*	*smoke layer*	*not visible*
1	39.00	42.00	30.00	–	30.00	41.00	–	–
2	40.00	42.20	33.00	–	31.00	42.00	–	–
3	40.30	43.30	35.00	–	33.00	42.30	–	–
4	41.30	44.00	36.00	–	35.00	44.00	–	–
5	42.15	44.30	37.00	44.30	36.00	44.18	–	–
6	42.50	45.30	38.00	45.00	37.00	44.50	–	–
7	43.50	46.30	–	45.20	40.00	45.30	–	–
8	44.30	47.00	44.30	46.50	44.00	49.30	–	–
9	47.00	–	45.40	48.00	46.30	53.00	–	–
10	–	–	–	55.00	50.00	55.00	–	–

TABLE F4 - TEST 4

	Observed time *(min.sec)*							
	South End Targets				North End Targets			
	Observer 1		Observer 2		Observer 3		Observer 4	
Target Number	*smoke layer*	*not visible*	*smoke layer*	*not visible*	*smoke layer*	*not visible*	*smoke layer*	*not visible*
1	–	–	–	–	15.40	23.40	–	–
2	21.00	–	–	–	19.30	25.40	–	–
3	23 .OO	28.00	–	–	21.10	27.55	–	–
4	24.00	28.10	–	–	23.00	28.25	–	–
5	24.40	28.20	–	–	23.30	29.00	–	–
6	25 .25	28.35	–	–	24.00	29.10	–	–
7	26.35	29.10	–	–	25.08	30.10	–	–
8	27.50	29.40	–	–	26.15	31.30	–	–
9	29.00	30.43	–	–	28.37	33.00	–	–
10	30.40	–	–	–	30.40	33.50	–	–