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QUICK RESPONSE SPRINKLERS IN CHEMICAL LABORATORIES: FIRE TEST RESULTS

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QUICK RESPONSE SPRINKLERS IN CHEMICAL LABORATORIES: FIRE TEST RESULTS

William D. Walton

ABSTRACT

A series of fire tests in typical chemical laboratories was conducted in order to address the use of quick response sprinkler technology. For each test, the performance of an automatic sprinkler system in extinguishing a fire originating in an acetone spill was evaluated. The test parameters included 1) standard sprinklers with exposed steel piping, 2) quick response sprinklers with exposed steel piping, 3) quick response sprinklers with exposed plastic piping, 4) quick response sidewall sprinklers and 5) no sprinklers. Measurements of air temperature and the concentration of oxygen, carbon monoxide and carbon dioxide were taken. A free burn test was conducted to characterize the heat release rate of the initial items ignited.

Key Words: automatic sprinklers; burning rate; compartment fires; fire growth; fire tests; heat release rate; laboratories; oxygen consumption calorimetry; quick response sprinklers; room fires; toxicity.

1. INTRODUCTION

The National Institutes of Health has expressed a need for developing sprinkler design criteria for use in chemical laboratories which ensure adequate, cost effective fire protection. The Center for Fire Research at the National Bureau of Standards under the sponsorship of the National Institutes of Health, has completed a series of demonstration tests addressing the use of quick response sprinkler technology in chemical laboratories. The major emphasis of this project was to 1) examine the potential applicability of quick response sprinkler technology to chemical laboratories, 2) characterize a laboratory fuel package and 3) examine the use of exposed plastic piping. The work to date has demonstrated some of the potential benefits of using quick response sprinkler technology and provided part of the basis for developing design criteria.

Automatic sprinkler technology has been used to protect commercial and industrial property for more than a century. The success of this technology in reducing property damage and life loss from fire is widely accepted. Advances in sprinkler technology have lead to the development of quick response sprinklers which actuate faster than conventional sprinklers. The use of quick response sprinklers offers the potential for improved life and property protection by actuating earlier in the fire growth than conventional sprinklers. Research into the use of quick response sprinklers has lead to the development of NFPA 13D, Standard for the Installation of Sprinkler Systems In One- and Two-Family Dwellings and Mobile Homes[1][1].

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[1] Number in brackets indicate literature references at the end of the paper.

In addition, the Early Suppression Fast Response (ESFR) Program coordinated by the National Fire Protection Research Foundation (NFPRF) focuses on the development of criteria and hardware to apply quick response sprinkler technology to warehouse and high challenge fires [2].

Currently there are no design criteria for the use of quick response sprinklers in chemical laboratories. The benefits of applying quick response sprinkler technology to chemical laboratories include the potential for:

1) Improved life safety. By suppressing fires in the early stages, fast responding sprinklers can reduce the quantity of smoke and toxic gases generated. Fires in chemical and biological laboratories may present special life safety hazards as a result of rapid fire growth in chemical fuels and the release of toxic chemical and biological products. In occupancies where total evacuation in the event of a fire is not desirable, fast responding sprinklers have the potential for maintaining survivable conditions.

2) Improved property protection. In occupancies where down time is critical or sensitive scientific experiments are underway, fast responding sprinklers can reduce property loss and thus down time.

3) Reduced system cost. The potential exists to reduce piping sizes and water supply requirements.

In order to address the use of existing quick response sprinkler technology in chemical laboratories, the Center for Fire Research conducted a series of feasibility tests for the National Institutes of

Health. These tests included: 1) a heat release rate test designed to characterize the burning rate of a typical chemical laboratory fuel package and 2) full scale fire tests designed to examine the effectiveness of quick response sprinklers in several typical chemical laboratory fires.

2. HEAT RELEASE RATE TEST

A release rate (free burn) test was conducted to characterize a typical chemical laboratory fuel package. The fuel package consisted of a laboratory bench with shelving above and an acetone spill fire as the first item ignited. The heat release rate was compared to the fire growth rates used in the 1984 edition of NFPA 72E Appendix C Guide for Automatic Fire Detector Spacing[3].

2.1 Heat Release Rate Test Configuration

The heat release rate test, using oxygen consumption calorimetry, was conducted under a large exhaust collection hood. A discussion of the principles of oxygen consumption calorimetry can be found in reference [4] and its use in determining the heat release rate of large furniture items in reference [5]. To summarize the method of oxygen consumption calorimetry, all of the gaseous combustion products from the burning item are designed to flow through a duct where the mass flow rate and oxygen concentration are measured as a function of time. From these measurements, the rate at which oxygen is consumed by the fire in the combustion process can be determined. For most common fuels, the rate of heat release is a nearly constant proportion of rate of oxygen consumption regardless of the fuel burned. In this test, the collection and processing has been computerized with measurements taken and reported every 10 seconds.

A laboratory fuel package was chosen in cooperation with the project sponsor to be representative of a typical fire in a chemical laboratory. The fuel package consisted of a 296 lb (134.3 kg) steel laboratory bench with closed drawers and a stone laboratory bench top. Above the bench was a 53 lb (24.0 kg) open wooden shelving unit with three shelves. A diagram of this unit is shown in Figure 1. The overall size of the bench was 48 in. wide by 37 in. high by 22 in. deep (1.23 by 0.94 by 0.56 m) and the shelving unit was 37 in. wide by 39 in. high by 12 in. deep (0.94 by 0.99 by 0.30 m). The shelves and bench top were loaded with a number of items which are listed in Table 1. The total weight of these loading items was 112 lb (50.8 kg).

Acetone was used as the initial fuel ignited in the test. Three liters of acetone was placed in a 30 by 48 in. (0.76 by 1.23 m) steel pan on the floor and one liter in a 18 by 24 in. (0.46 by 0.61 m) pan on the bench top. The acetone in the floor pan was ignited by a remote system to begin the test. A cardboard box of the type used for glass disposal was placed in the floor pan in front of the bench.

2.2 Heat Release Rate Test Results

The free burn heat release rate for the laboratory fuel package is shown in Figure 2. The integrated or total heat released is shown in Figure 3. The maximum rate of heat release was 2.0 MW. In addition to the heat release rate determined from the test, Figure 2 shows heat release rates for the fast, medium and slow fires specified in NFPA 72E Appendix C Guide for Automatic Fire Detector Spacing[3]. The fast, medium and slow fires are based on fires that grow with the square of time and are sometimes referred to as t-squared fires. These fires are often compared to the early stages of fire growth for the purposes of estimating activation time of thermal devices such as heat detectors or sprinklers. The comparison of t-squared fires to actual fires is sensitive to the location of time zero. In the tests analyzed here, no attempt has been made to adjust the starting times of the t-squared fires in order to provide an exact match. Instead, a general comparison is made with the slope of the growth rates. Figure 2 shows that the laboratory bench fire grew at a rate which was initially faster than the fast fire, although the fast fire reached the same growth rate after approximately 200 seconds.

Test observations show that at approximately 2 seconds after ignition of the acetone in the floor pan, flames from the floor pan ignited the acetone in the counter pan. At 30 seconds, the materials on the bench and all of the shelves were well involved and the cardboard glass disposal box was beginning to collapse. At 90 seconds, the size of the acetone fire in the floor pan was reduced and nearly out at 180 seconds. At 300 seconds the fire in the floor pan was completely out and the fire in the shelves began to subside. After 300 seconds the heat release rate leveled off at a nearly constant 0.2 MW until 1800 seconds when the test was terminated.

3. CHEMICAL LABORATORY TESTS

A series of 5 full scale tests were conducted in chemical laboratories. These consisted of a test with each of the following configurations: 1) no sprinkler, 2) standard response upright sprinklers with exposed steel piping, 3) quick response pendent sprinklers with exposed steel piping, 4) quick response pendent sprinklers with exposed plastic piping and 5) quick response sidewall sprinkler with concealed piping. A summary of the test conditions is given in Table 2.

The tests were conducted in a laboratory building prior to undergoing renovation. Each of the tests was conducted in a different laboratory and the configuration of each laboratory was slightly different. All laboratories were constructed with concrete floors and ceilings with tile block walls. A single 83 in. high by 36 in. wide (2.11 by 0.91 m) open doorway connected each laboratory to the building corridor and a closed wooden double hung window connected the laboratory to the outside. A plan view of each of the laboratories is shown in Figures 4 through 8. A photograph typical of these laboratories is shown in Figure 9.

The fuel for each of the laboratory tests was similar to that used in the heat release tests. The fuel, an assortment of laboratory materials supplied by the project sponsor, was placed on the laboratory bench and shelves in the area of fire initiation. The initial fuel ignited in the laboratory tests was the same as used in the heat release test, i.e. three liters of acetone was placed in a 30 by 48 in. (0.76 by 1.22 m) steel pan on the floor and one liter in a 18 by 24 in. (0.46 by 0.61 m) pan on the bench top. The acetone in the floor pan was ignited by a remote system to begin the test. A cardboard box of the type used for glass disposal was placed in the floor pan in front of the bench.

3.1 Chemical Laboratory Test Instrumentation

Instrumentation inside the laboratories consisted of 0.02 in. (0.05 mm) diameter chromel-alumel thermocouples located in the corner of the room near the door, 12 in. (0.30 m) from each wall and centered in the doorway. The location of these thermocouples is shown in the plan view for each laboratory and the elevation of the thermocouples is given in Table 3. Thermocouples were also located over the floor pan 1, 6 and 10 in. (0.03, 0.15 and 0.25 m) below the ceiling. Gas sampling probes for carbon dioxide, carbon monoxide and oxygen were centered in the doorway 60 in. (1.52 m) above the floor.

To simplify presentation of the data, only data from the corner thermocouples 107, 83, 59, 35 and 11 in. (2.72, 2.11, 1.50, 0.89 and 0.28 m) above the floor will be given. This represents heights of approximately 9, 7, 5, 3 and 1 ft above the floor. Likewise, only data from the doorway thermocouples 70, 61, 52, 42, and 31.5 in. (1.78, 1.55, 1.31, 1.07 and 0.80 m) above the floor are given. Thermocouples below this level remained at approximately ambient temperature throughout the tests. The thermocouples above the fire all indicated approximately the same temperature so only the data for the thermocouples 6 in. (0.15 m) below the ceiling will be given.

3.2 Laboratory Test With No Sprinkler

A test was conducted in a laboratory with no sprinklers. The floor plan for this laboratory is shown in Figure 4. Unlike the tests in laboratories with sprinklers, additional fuel in the form of paper was added to the shelves throughout the laboratory. Experience had shown that fuel beyond the area of fire origin would not become involved in the fire when sprinklers were used.

Figure 10 shows the temperatures measured by the corner thermocouples, Figure 11 the temperatures for the door thermocouples, and Figure 12 the gas concentrations. Table 4 shows the maximum gas concentrations of CO and CO_2 and minimum concentrations of O_2 for all of the tests. In order to facilitate comparisons between the tests, Figures 13 through 16 show combined data for all of the tests. Figure 13 shows the temperatures measured by the thermocouples over the fire and 6 in. (0.15 m) below the ceiling, Figure 14 the temperatures for the thermocouples in the corner 59 in.

(1.50 m) above the floor, Figure 15 the temperatures for the thermocouples in the door 61 in. (1.55 m) above the floor, and Figure 16 the carbon monoxide concentrations.

Test observations showed that within 10 seconds of ignition, the acetone on the bench pan had ignited, within 20 seconds flames reached the ceiling and within 30 seconds a visible smoke layer had formed. At 38 seconds, fire spread quickly to all of the combustible materials within the laboratory. Within 60 seconds the operating fluorescent lights within the laboratory failed and the flames in the floor pan began to recede. By 300 seconds the fire within the laboratory had receded from its peak to a relatively steady rate. The fire remained at that relatively steady rate until it was manually extinguished at approximately 900 seconds.

The observations and data indicated that the fire peaked at approximately 60 seconds with observed conditions normally associated with flashover. No flames were observed beyond the laboratory of origin, which may have been a result of the primarily cellulosic fuels within the laboratory. Damage in the hallway outside the laboratory was limited to the melting of light fixtures. Damage within the laboratory was extensive although the fire was contained by the noncombustible construction.

Although a complete analysis of the gas concentration data is beyond the scope of this report, a simple comparison to CO lethality data can be made. LC_{50} (Lethal Concentration 50%) is the concentration of gas which will cause the death of 50% of test animals exposed for a specified period of time. LC_{50} values for carbon monoxide as a function of exposure time for rats is provided in Table 5[6]. For example, from Table 5, the minimum concentration of CO required to cause the death of 50% of test animals over a continuous 300 second exposure is 1.4%. From Table 4 the maximum CO concentration measured at the 5 foot level was 1.21%. This corresponds to an LC_{50} value for an approximately 300 second exposure. While the CO concentration in the test with no sprinklers in itself would not be immediately lethal, when combined with a maximum CO_2 value of 15.6%, a minimum O_2 value of 3.9%, and a maximum temperature at the 5 foot level of 445°C, conditions within the laboratory would have certainly been lethal within a short period of time.

3.3 Laboratory Test With Standard Upright Sprinkler

A test was conducted in a laboratory with 165°F (74°C) standard response upright sprinklers and exposed steel sprinkler piping. The sprinkler deflectors were located 9.5 in. (0.24 m) below the ceiling. The layout of this laboratory is shown in Figure 5. Table 2 gives the activation times and the water flow rates for all of the tests. Water flow rates were in accordance with the manufacturer's recommendations. Figure 17 shows the temperatures measured by the corner thermocouples, Figure 18 the temperatures for the door thermocouples, and Figure 19 the gas concentrations.

Test observations showed that by 20 seconds after ignition, the counter pan and materials on the shelves were involved and flames had reached the ceiling. The cardboard box in the floor pan was beginning to collapse when the first sprinkler, nearest the ignition source, operated at 39 seconds. A second sprinkler operated at 47 seconds. After sprinkler operation, visibility in the room was reduced to near zero until approximately 65 seconds when it began to improve. At 100 seconds all fire in the room appeared to be out except the flames in the floor pan which reached approximately 2 ft (0.61 m) above the pan. By 200 seconds, the flames in the pan were almost extinguished.

Damage to the laboratory was limited to counter and shelf area immediately above the ignition source. It appeared that the first sprinkler almost immediately extinguished all of the fire except for the acetone. Acetone is soluble in water, and the application of water to acetone increases the flashpoint of the acetone water mixture. The sprinkler spray cooled the acetone fire until either all the acetone was consumed or the acetone water mixture was sufficiently dilute that it could no longer support burning.

The maximum temperature reached at the 5 ft level was 194°C. The maximum CO concentration was 0.12%, the maximum CO_2 concentration was 2.5%, and a minimum O_2 concentration of 17.9%. Although these levels may not be lethal, they may be considered hazardous.

3.4 Laboratory Test With Quick Response Pendent Sprinkler, Steel Piping

A test was conducted in a laboratory with 160°F (71°C) quick response pendent sprinklers and exposed steel sprinkler piping. The sprinkler deflectors were located 11 in. (0.28 m) below the ceiling. The layout of this laboratory is shown in Figure 6. Figure 20 shows the temperatures measured by the corner thermocouples, Figure 21 the temperatures for the door thermocouples, and Figure 22 the gas concentrations.

Test observations showed that within 18 seconds of ignition, flames had reached the ceiling when the first sprinkler, closest to the ignition source, operated. A second sprinkler operated at 22 seconds. At 50 seconds, the cardboard box in the floor pan collapsed and by 80 seconds the flames in the floor pan were reduced to the counter level. At 180 seconds, the flames in the floor pan were almost out.

Like the test with the standard response sprinklers, fire damage was limited to the counter and shelf area immediately above the ignition source. Unlike the test with the standard response sprinklers, visibility within the laboratory remained good throughout the test.

The maximum temperature reached at the 5 ft level was 85°C. The maximum CO concentration was 0.05%, the maximum CO_2 concentration was 4.1%, and a minimum O_2 concentration of 16.2%. Although these levels may not be lethal, they may be considered hazardous.

3.5 Laboratory Test With Quick Response Pendent Sprinkler, Plastic Piping

A test was conducted in a laboratory with 160°F (71°C) quick response pendent sprinklers and exposed CPVC plastic sprinkler piping. The sprinkler deflectors were located 13 in. (0.33 m) below the ceiling. The layout of this laboratory is shown in Figure 7. Figure 23 shows the temperatures measured by the corner thermocouples, Figure 24 the temperatures for the door thermocouples, and Figure 25 the gas concentrations.

Test observations showed that within 14 seconds of ignition, flames reached the ceiling and the first sprinkler, closest to the ignition source, operated at 16 seconds. The fire in the floor pan was substantially reduced after sprinkler operation, but resumed at 35 seconds with flames approximately 3 ft (0.91 m) above the counter level. At 83 seconds, the second sprinkler operated and by 120 seconds the flames in the floor pan were to the counter level and almost out at 180 seconds.

Like the test with the standard response sprinklers and quick response sprinklers on steel pipe, fire damage was limited to the counter and shelf area immediately above the ignition source. Like the test with quick response sprinklers on steel pipe, visibility with the laboratory remained good throughout the test. No damage to the plastic pipe was evident.

The maximum temperature reached at the 5 ft level was 71°C. The maximum CO concentration was 0.06%, the maximum CO_2 concentration was 3.4%, and a minimum O_2 concentration of 17.2%. Although these levels may not be lethal, they may be considered hazardous.

3.6 Laboratory Test With Quick Response Sidewall Sprinkler

A test was conducted in a laboratory with 160°F (71°C) quick response sidewall sprinkler with concealed steel sprinkler piping. The sprinkler deflector was located 8 in. (0.20 m) below the ceiling. The layout of this laboratory is shown in Figure 8. Figure 26 shows the temperatures measured by the corner thermocouples, Figure 27 the temperatures for the door thermocouples, and Figure 28 the gas concentrations.

Test observations showed that within 15 seconds of ignition, flames reached the ceiling and the sidewall sprinkler operated at 26 seconds. Within 40 seconds the fire in the shelving above the ignition source was extinguished and flames from the floor pan extended 3 ft (0.91 m) above the counter level. At 80 seconds the visible smoke in the room was increasing, but was decreasing at 180 seconds when the fire in the floor pan was nearly out.

Like the other tests, damage was limited to the counter and shelf area immediately above the ignition source. The visibility was reduced within the laboratory to a greater extent than the tests with quick response pendent sprinklers, but the reduction was not as great as it was for the test with standard response sprinklers.

The maximum temperature reached at the 5 ft level was 71°C. The maximum CO concentration was 0.11%, the maximum CO_2 concentration was 5.0%, and a minimum O_2 concentration of 15.7%. Although these levels may not be lethal, they may be considered hazardous.

4. SUMMARY AND CONCLUSIONS

The heat release rate of a chemical laboratory fuel package has been characterized. The initial growth rate of this fire was faster than the fast fire used in NFPA 72E. This suggests that the selection of one of these commonly used fire growth rates to represent chemical laboratory fire scenarios involving flammable liquids is inappropriate.

Both standard and quick response sprinklers were effective in controlling the fires, reducing temperatures and reducing carbon monoxide and carbon dioxide levels. The conditions in the laboratory without sprinklers would be considered lethal, while the conditions away from the immediate fire area, in laboratories with sprinklers would generally be considered nonlethal. This does not suggest that occupants should remain in the fire area, but rather the spread of hazardous conditions throughout the building would be substantially reduced with the operation of sprinklers.

The laboratories with quick response sprinklers showed lower maximum temperatures at the 5 foot level than the laboratory with standard sprinklers. The maximum temperature at the 5 foot level was 445°C with no sprinklers, 194°C with standard sprinklers and 85, 71 and 175°C with quick response sprinklers. The laboratories with pendent quick response sprinklers showed lower maximum temperatures at the 5 foot level than the laboratory with a quick response sidewall sprinkler. The maximum temperatures at the 5 foot level with pendent quick response sprinklers were 71 and 85°C and was 175°C with the sidewall sprinkler. This temperature difference was most likely due to the distance between the sprinkler and the ignition source. The pendent sprinklers were within 2 ft

(0.61 m) of the ignition source and the sidewall sprinkler was approximately 12 ft (3.66 m) from the ignition source.

In the test with exposed plastic pipe and quick response pendent sprinklers, no damage to the plastic pipe was evident. The ignition source, however, was not located directly under the pipe so as to provide the most severe exposure to the pipe.

In conclusion, these tests have provided some limited evidence that sprinklers can substantially improve life safety and property protection in chemical laboratories as compared to laboratories without sprinklers. Quick response sprinklers operated earlier in the fire than standard response sprinklers resulting in somewhat lower temperatures.

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Table 1. Laboratory Bench Loading

Notebooks with paper	16 lb	(7.3 kg)
Computer Paper	43 lb	(19.5 kg)
Laboratory bench Covers	13 lb	(5.9 kg)
Folders with paper	29 lb	(13.2 kg)
Boxes	3 lb	(1.4 kg)
Miscellaneous supplies	8 lb	(3.6 kg)
Total	112 lb	(50.8 kg)

Table 2. Laboratory Tests Summary

Sprinkler	Piping	Sprinkler Actuation		Total Water Flow	
		1st	2nd	1 Sprinkler	2 Sprinklers
None					
SSU	Steel	39 s	47 s	18 gpm	37 gpm
QR	Steel	18 s	22 s	25 gpm	36 gpm
QR	CPVC	16 s	83 s	25 gpm	36 gpm
QR/SW	NA	26 s		25 gpm	

Table 3. Thermocouple Locations

Corner Thermocouples		Doorway Thermocouples	
Height Above Floor			
inches	meters	inches	meters
On Ceiling			
119	3.02		
113	2.87		
107	2.72*		
101	2.57		
95	2.41		
89	2.26		
83	2.11*		
77	1.96		
71	1.80	70	1.78*
65	1.65	61	1.55*
59	1.50*		
53	1.35	51.5	1.31*
47	1.20		
41	1.04	42	1.07*
35	0.89*		
29	0.74	31.5	0.80*
23	0.58	22	0.56
17	0.43	14	0.36
11	0.28*		
5	0.13	7	0.18

* indicates thermocouples for which data is shown in report

Table 4. Gas Concentrations

Sprinkler	Piping	CO (%) (maximum)	CO_2 (%) (maximum)	0_2 (%) (minimum)
None		1.21	15.6	3.9
SSU	Steel	0.12	2.5	17.9
QR	Steel	0.05	4.1	16.2
QR	CPVC	0.06	3.4	17.2
QR/SW	NA	0.11	5.0	15.7

Table 5. LC_{50} Values for Carbon Monoxide [6]

Exposure Time (s)	CO Concentration (%)	CO Concentration (ppm)
60	10.7	107000
120	4.25	42500
300	1.4	14000
600	0.98	9800
1200	0.74	7400
1800	0.66	6600
3600	0.49	4900

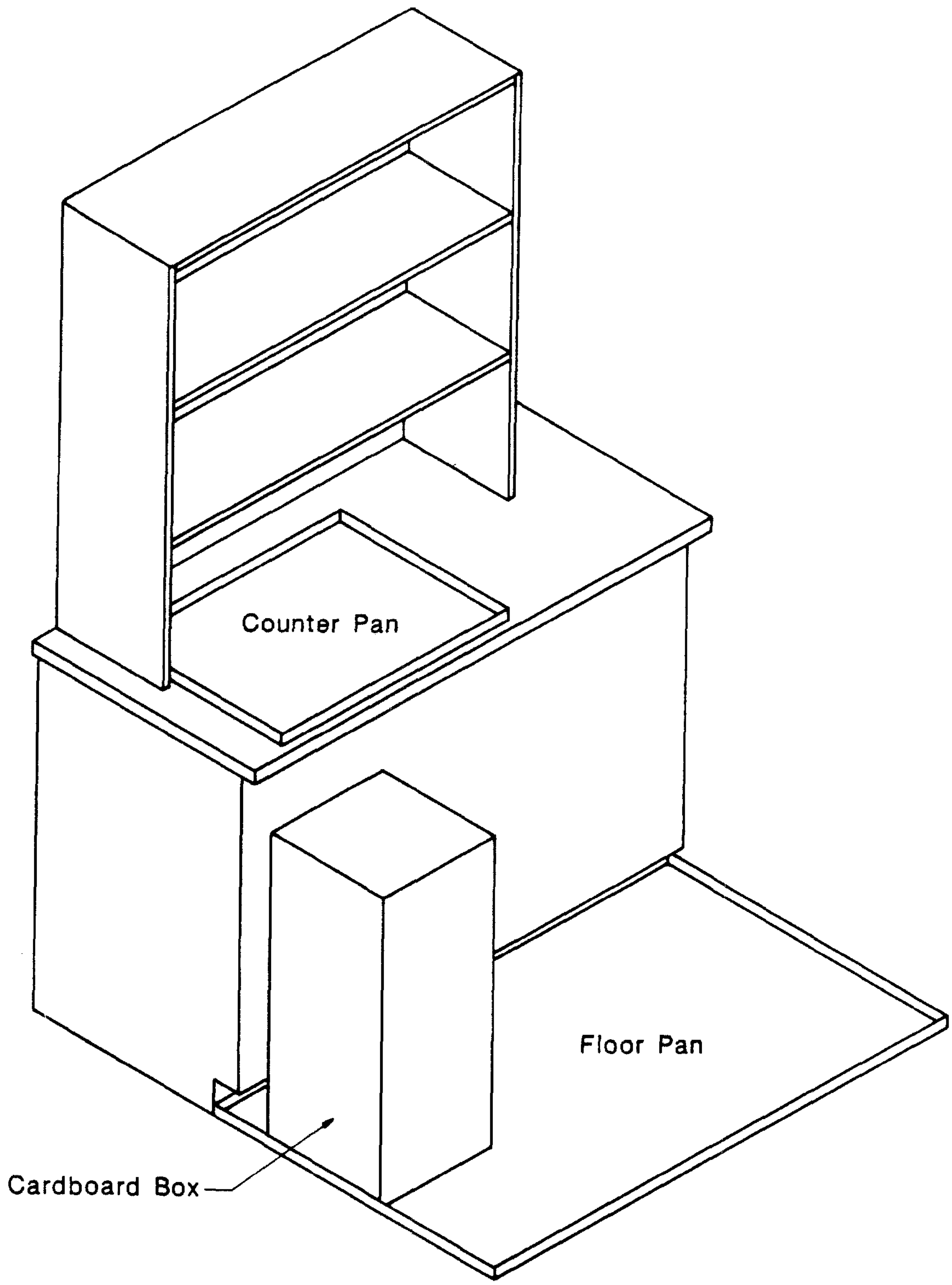

Figure 1. Laboratory bench

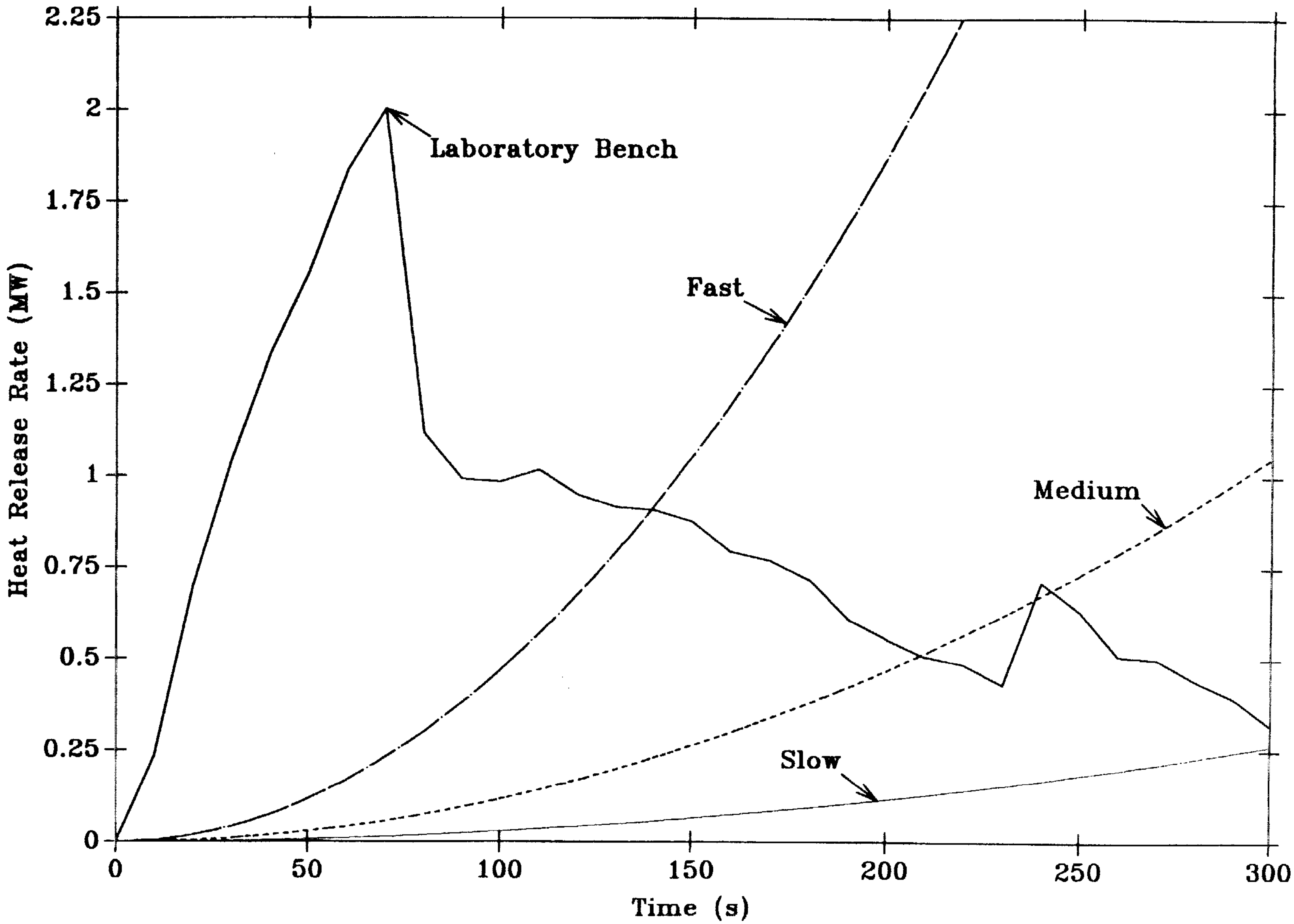

Figure 2. Laboratory bench heat release rate (free burn)

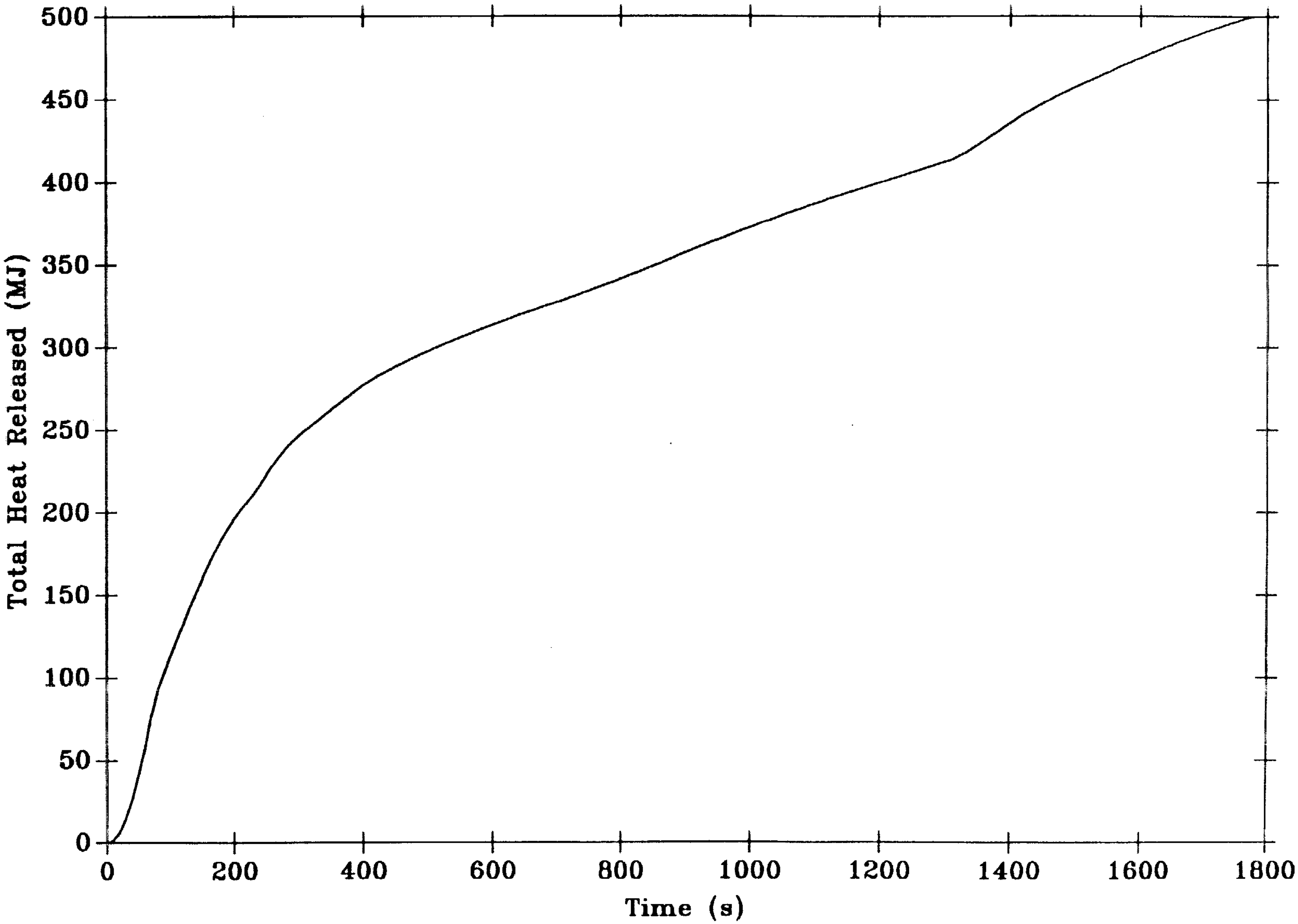

Figure 3. Laboratory bench total heat released (free burn)

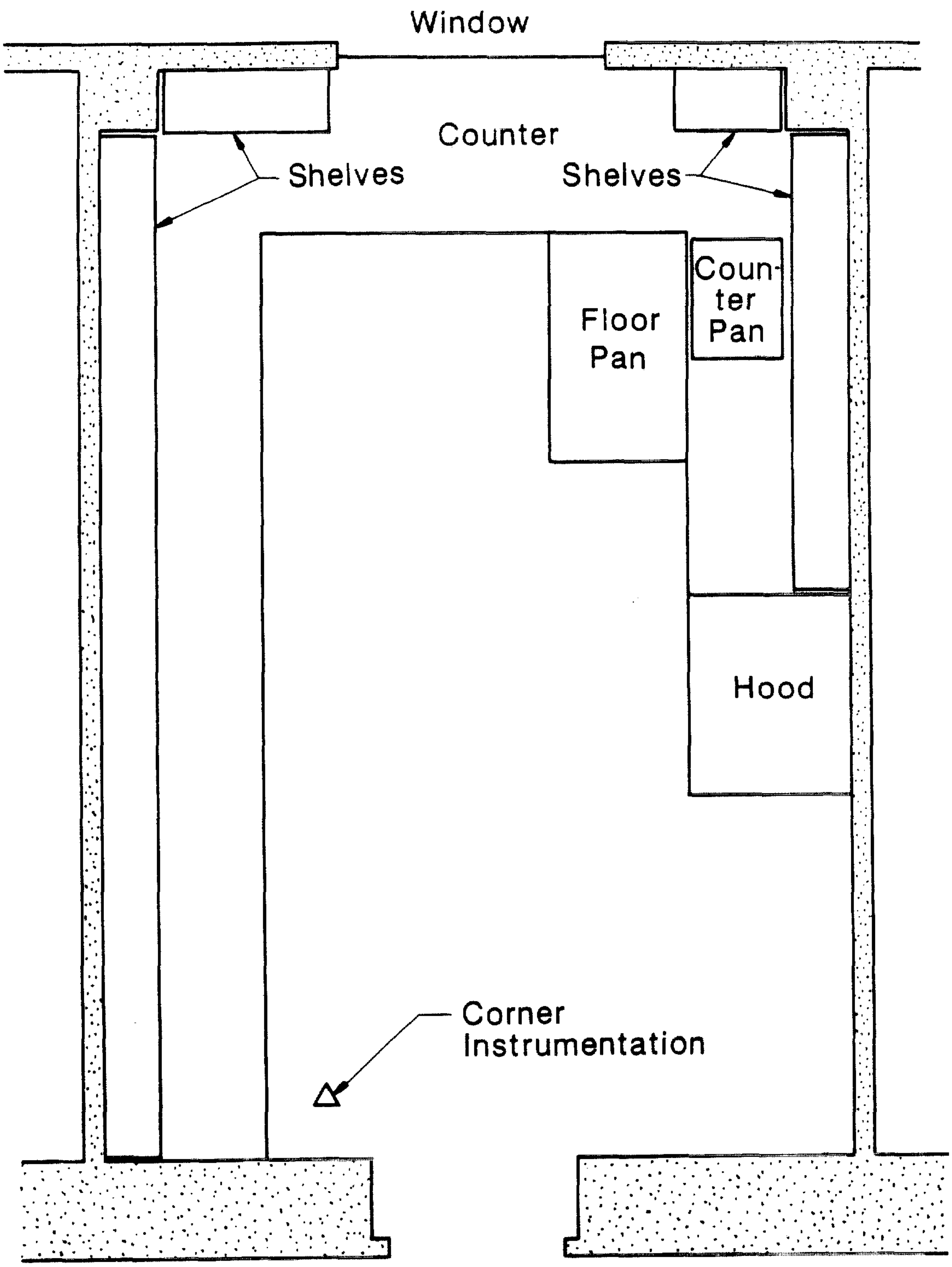

Figure 4. Laboratory plan for test with no sprinkler
(Note: Room 12' wide by 18' deep)

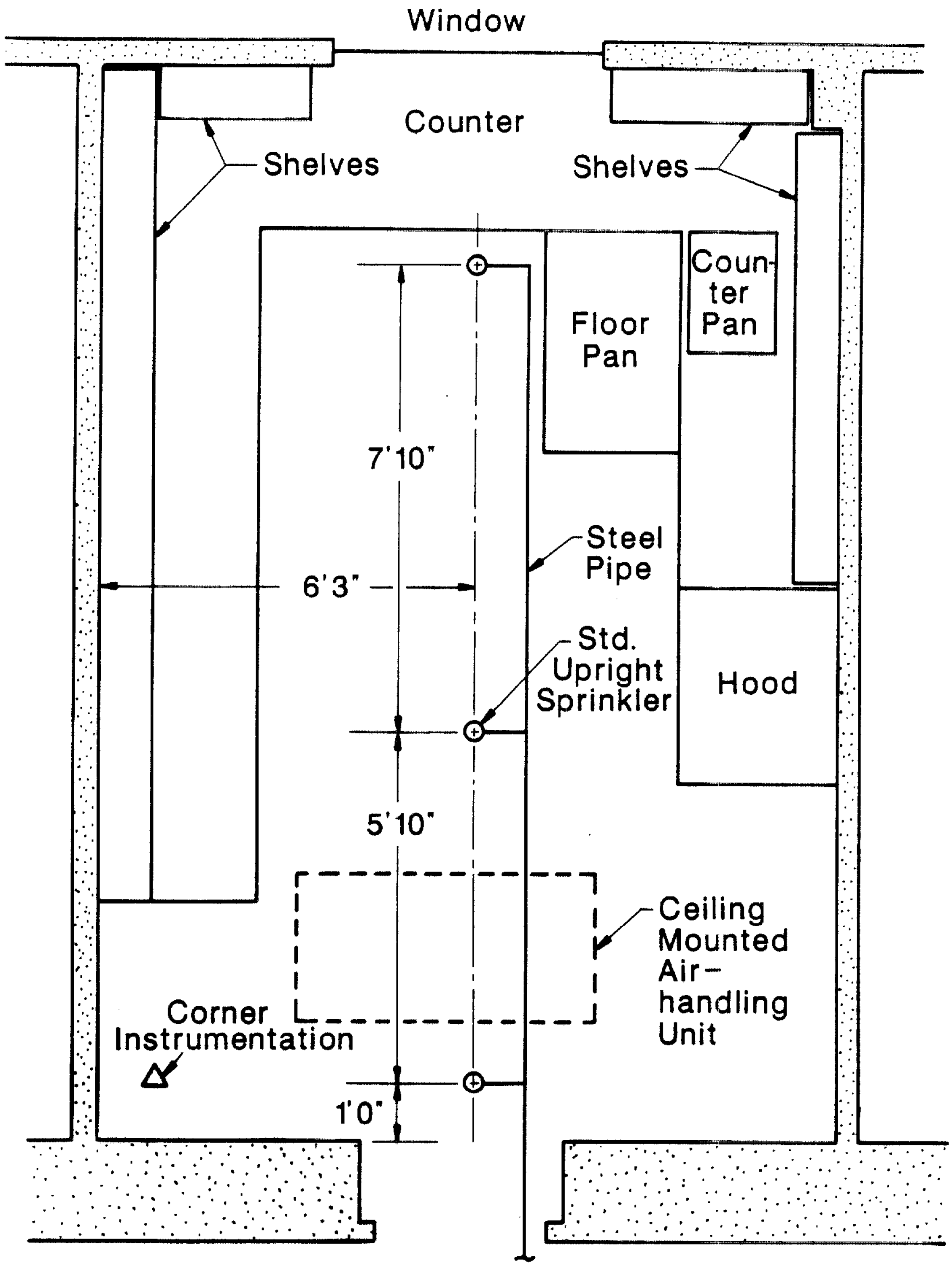

Figure 5. Laboratory plan for test with standard upright sprinkler
(Note: Room 12' wide by 18' deep)

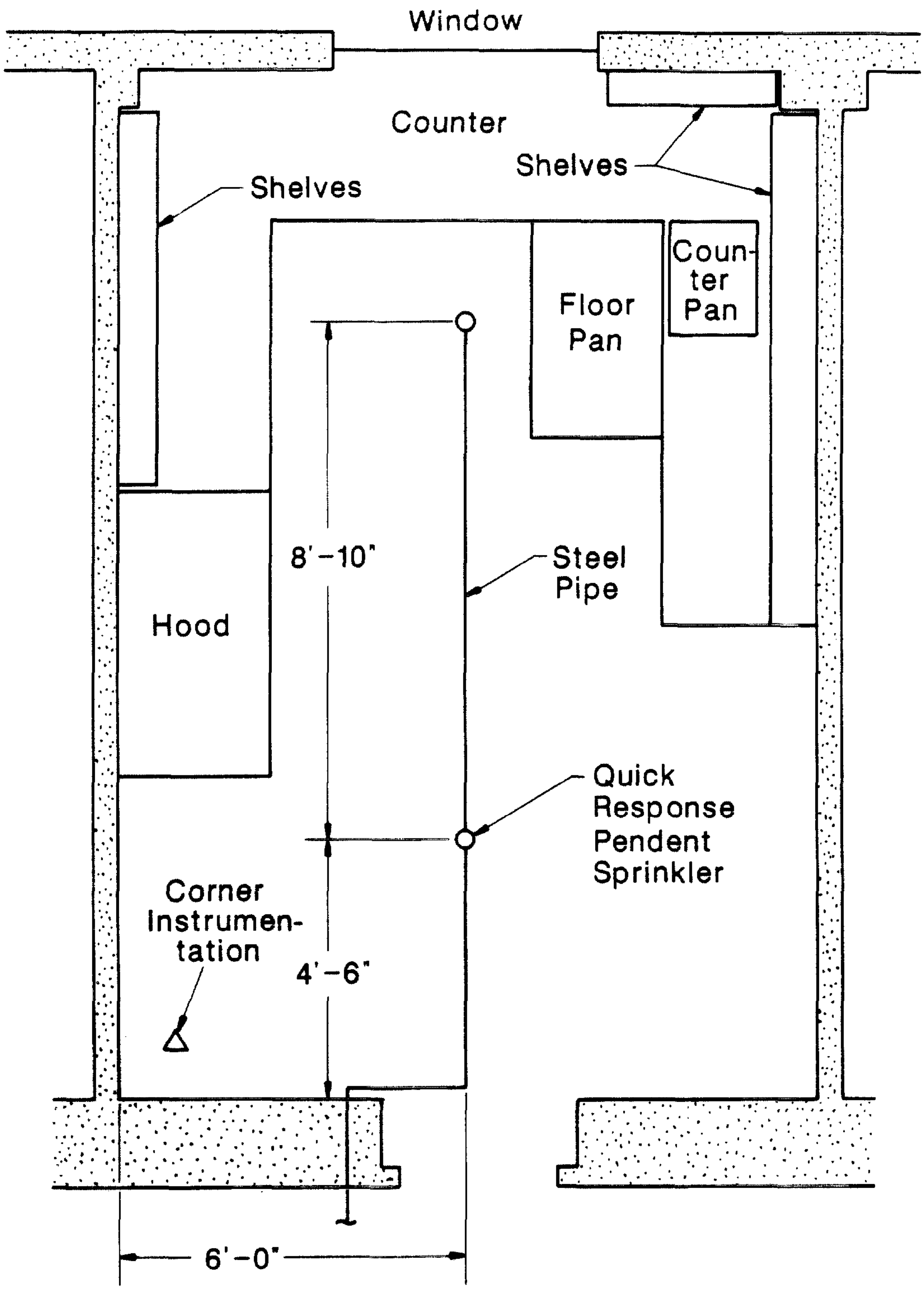

Figure 6. Laboratory plan for test with quick response pendent sprinkler, steel piping (Note: Room 12' wide by 18' deep)

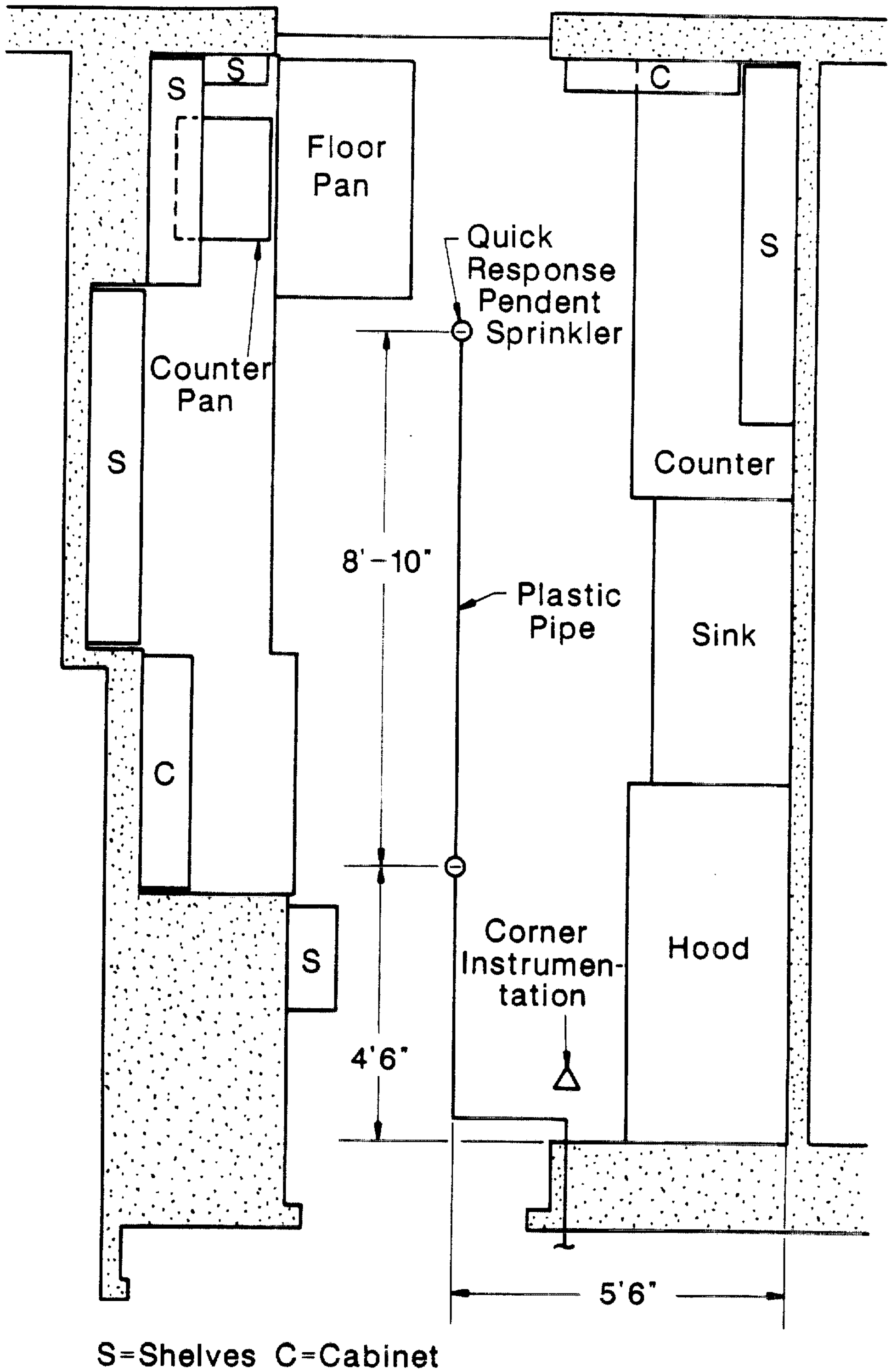

Figure 7. Laboratory plan for test with quick response pendent sprinkler, plastic piping (Note: Room 10.75' wide by 18' deep)

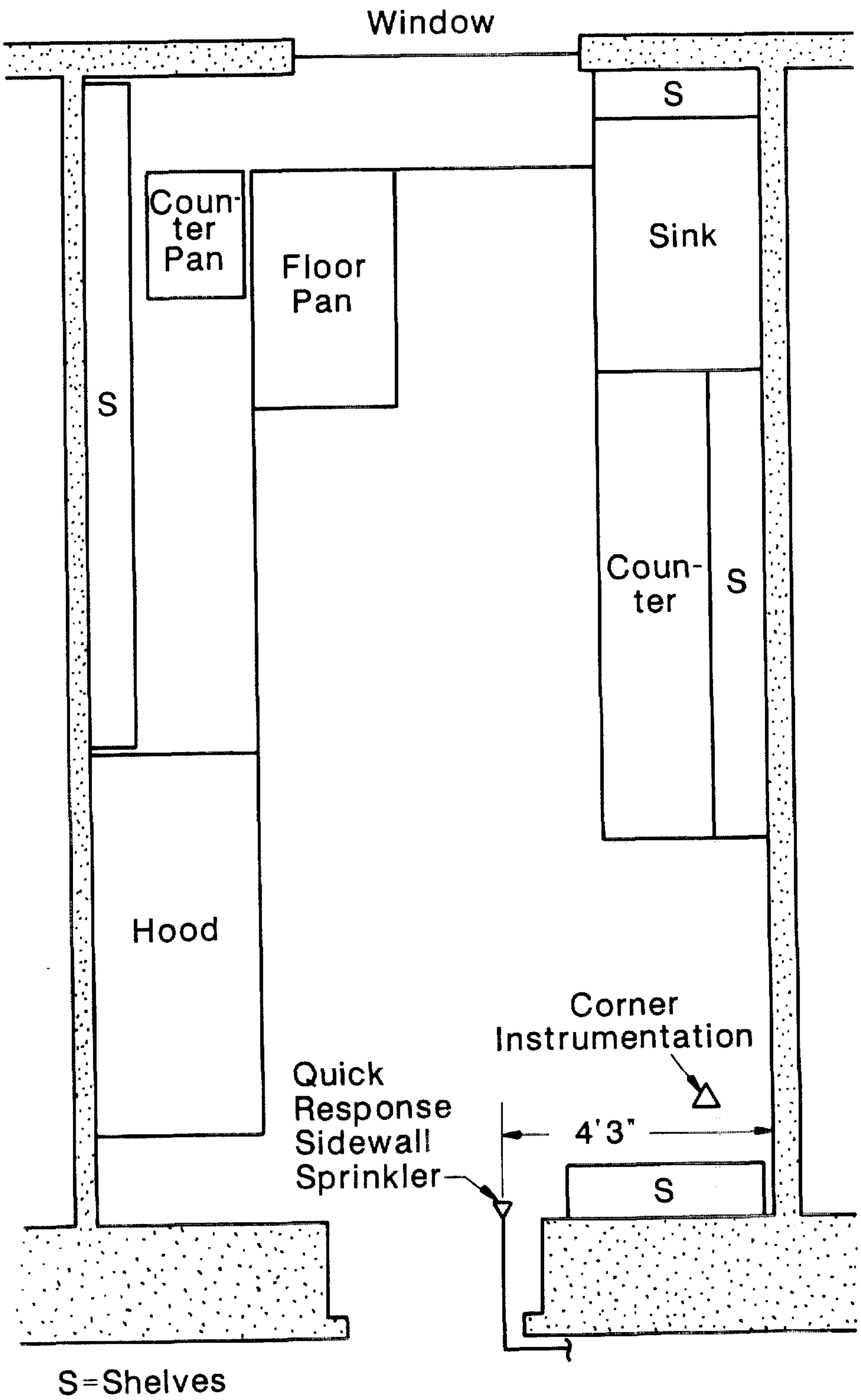

Figure 8. Laboratory plan for test with quick response sidewall sprinkler (Note: Room 10.5' wide by 18' deep)

Figure 9. Photograph of typical laboratory

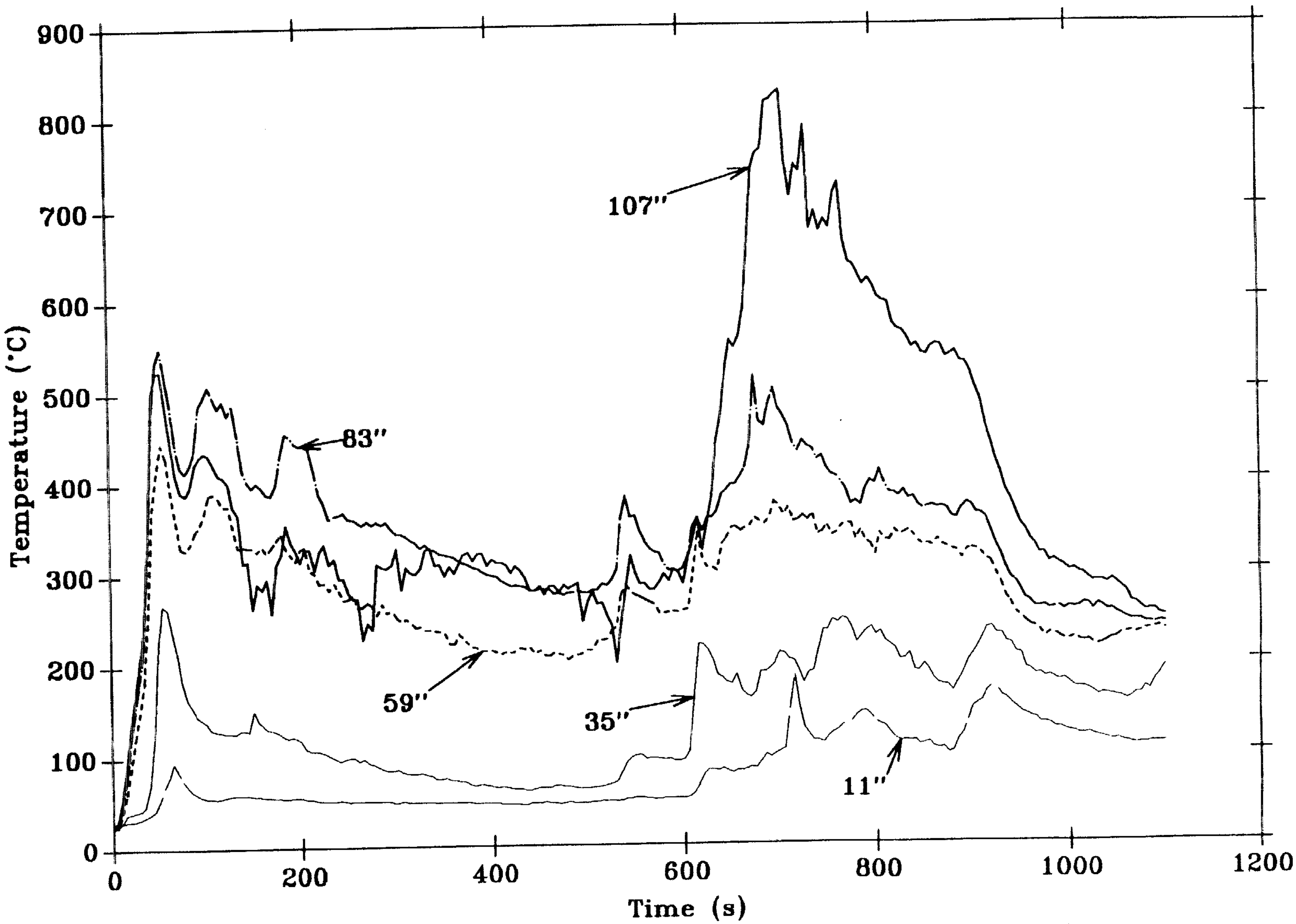

Figure 10. Corner thermocouples, no sprinkler (distances above the floor)

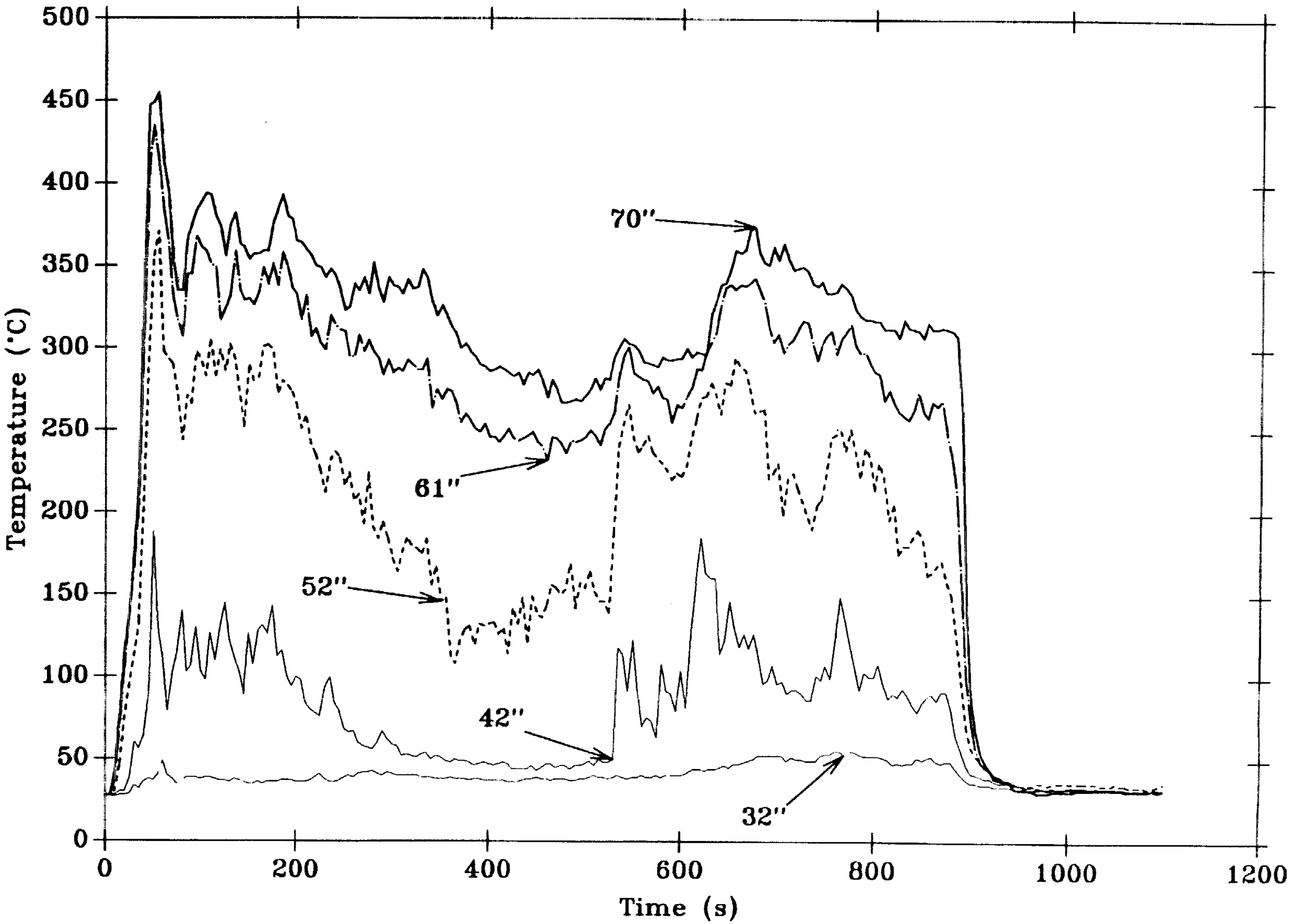

Figure 11. Door thermocouples, no sprinkler (distances above the floor)

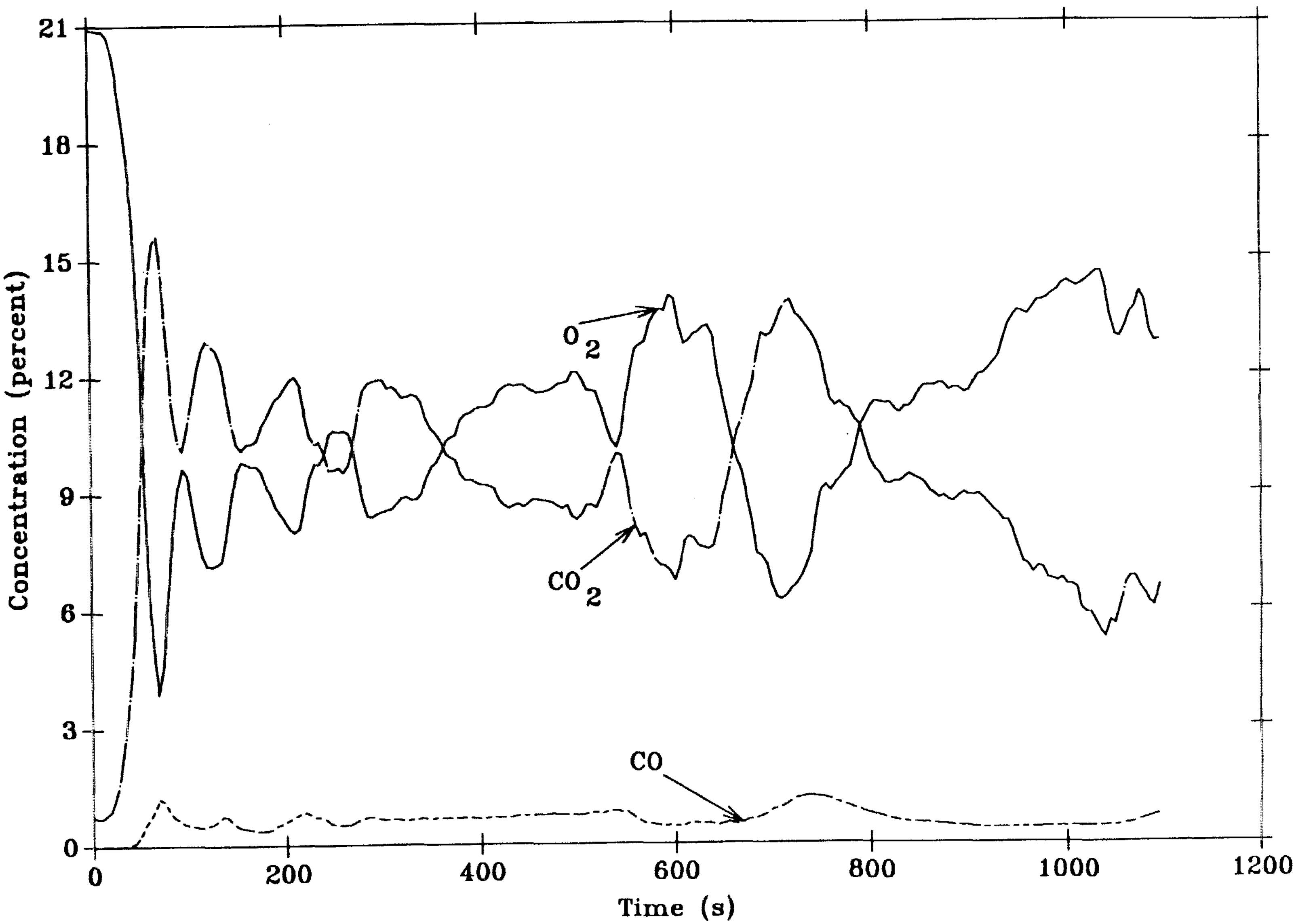

Figure 12. Gas concentrations, no sprinkler

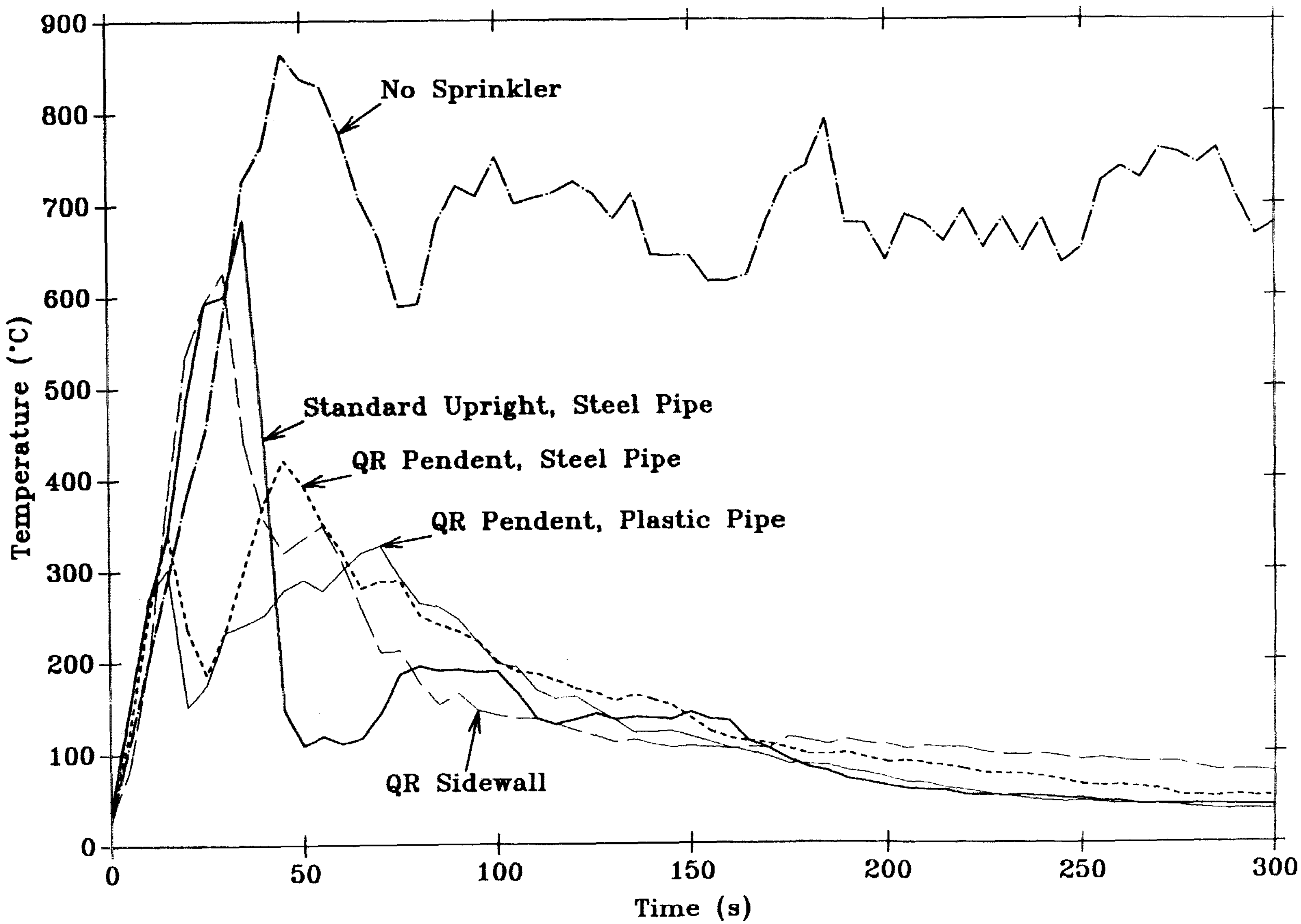

Figure 13. Thermocouples over fire 6 in. below ceiling, all tests

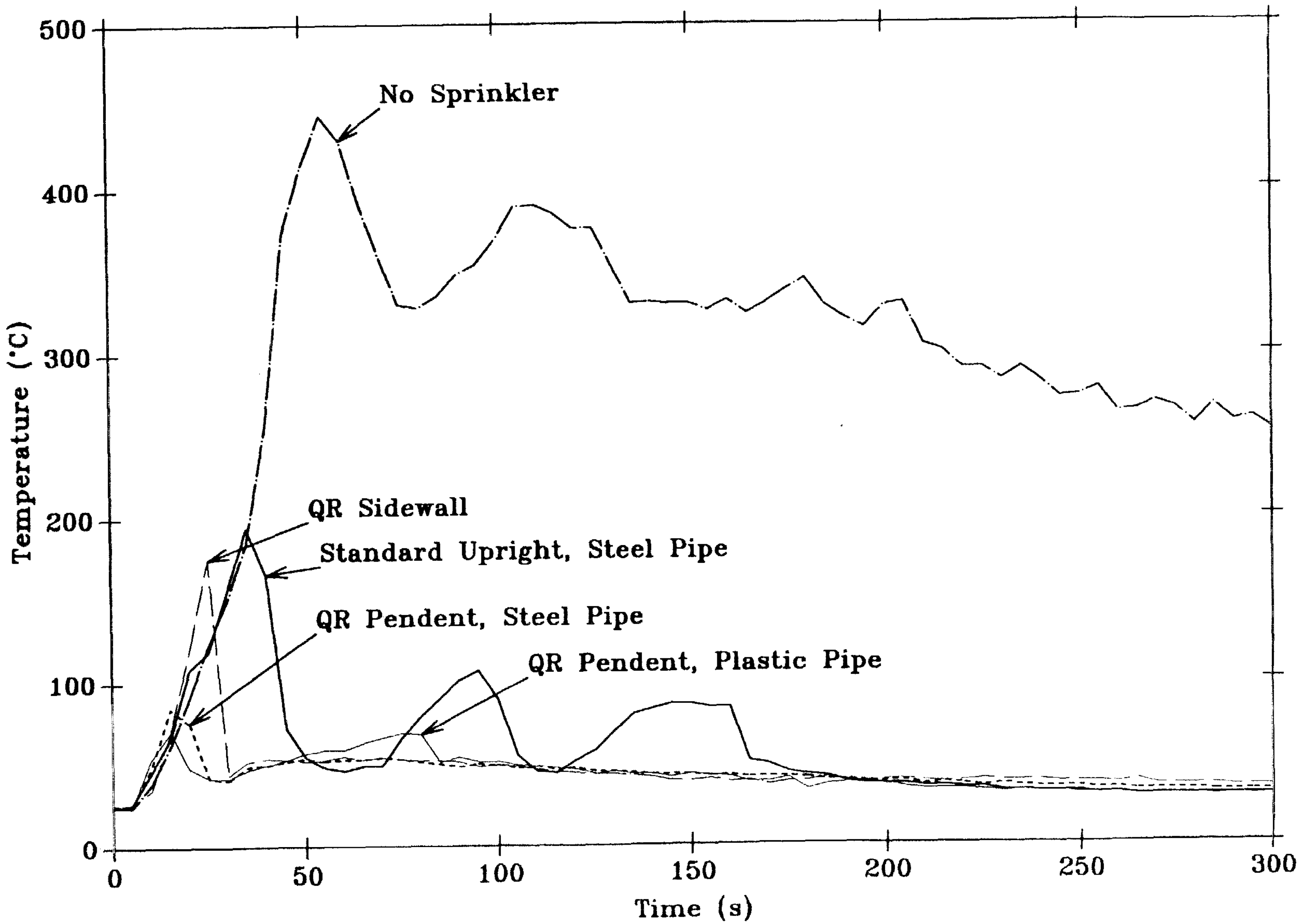

Figure 14. Corner thermocouples 59 in. above floor, all tests

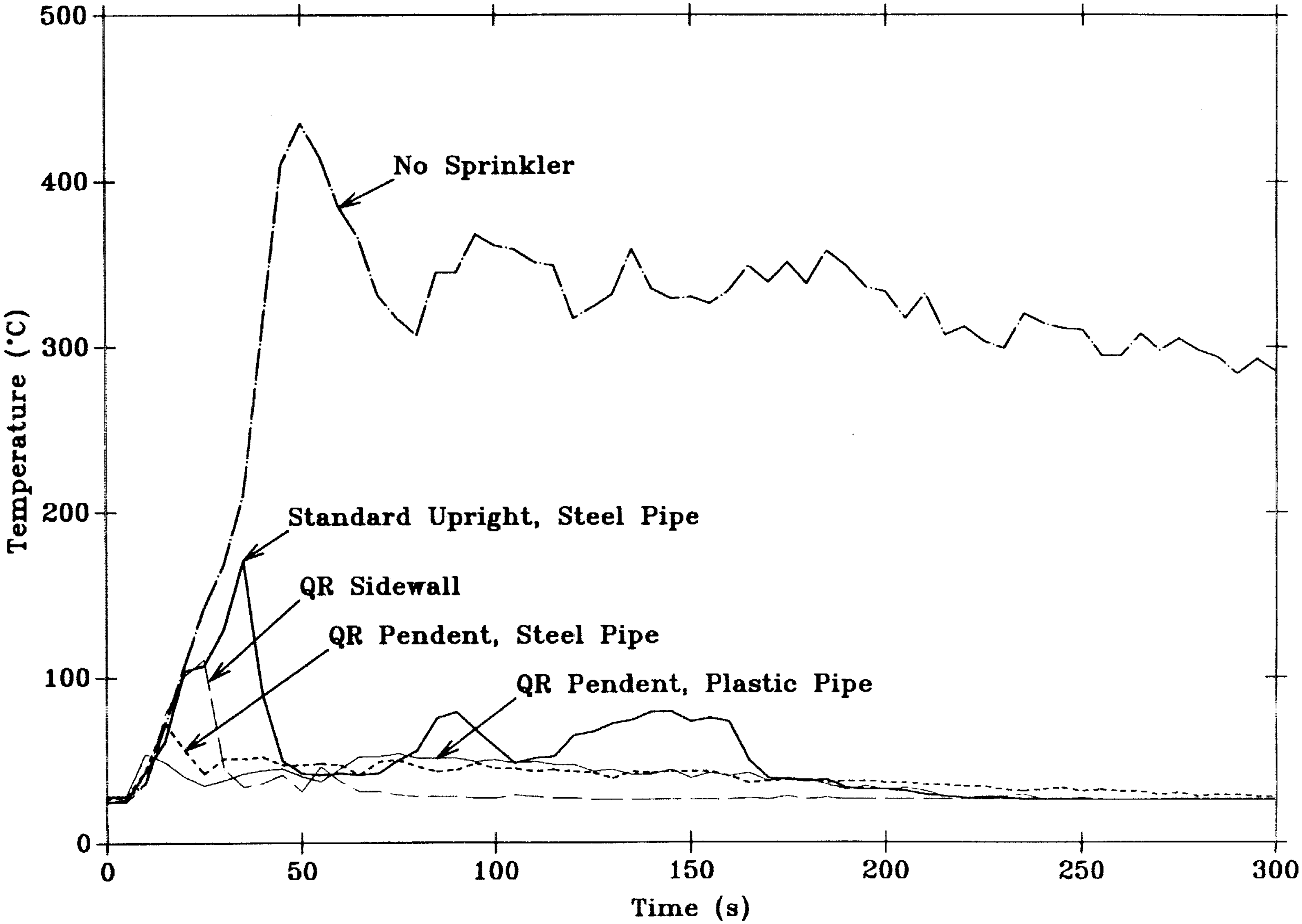

Figure 15. Door thermocouples 61 in. above floor, all tests

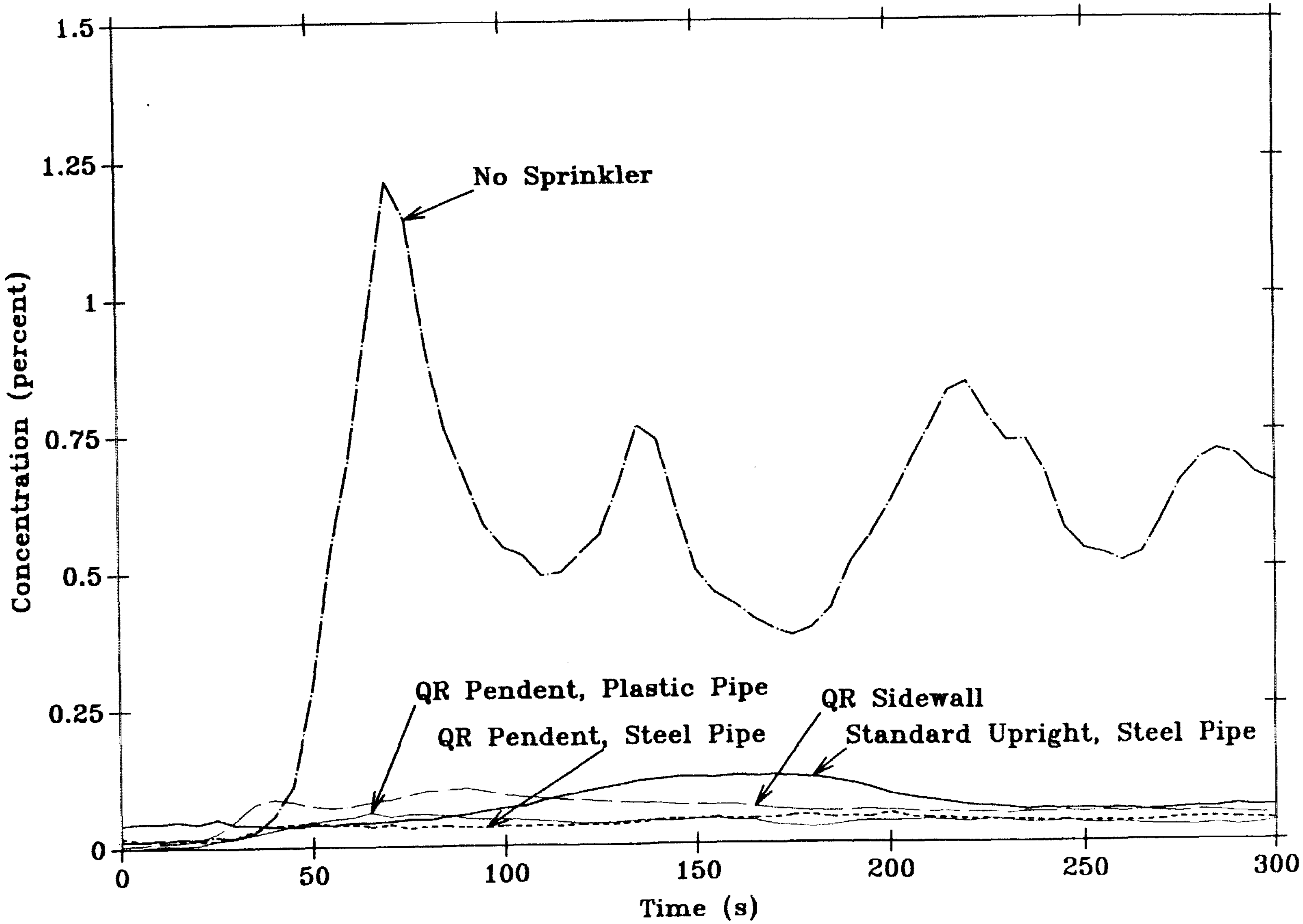

Figure 16. Carbon monoxide concentrations, all tests

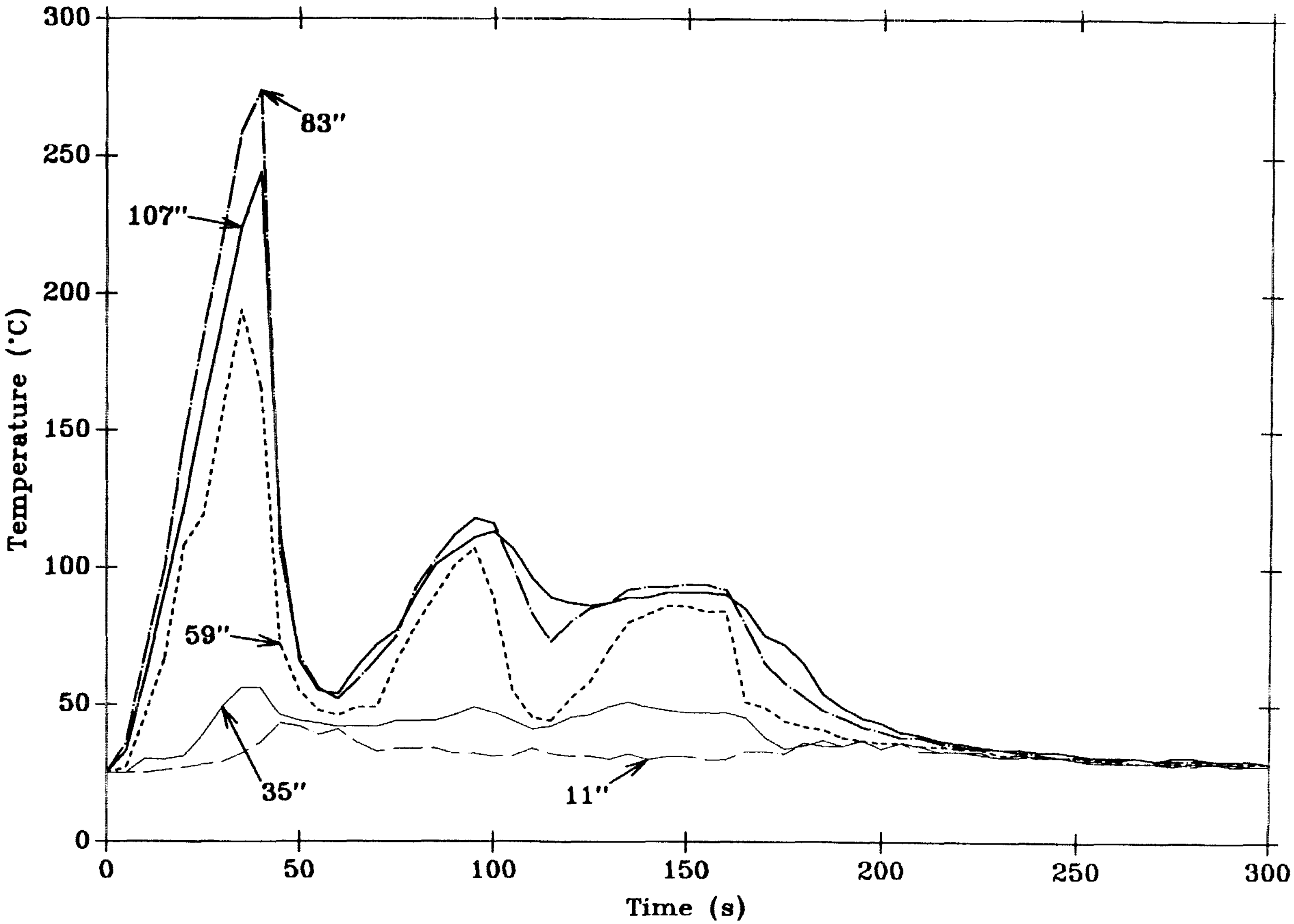

Figure 17. Corner thermocouples, standard upright sprinkler (distances above the floor)

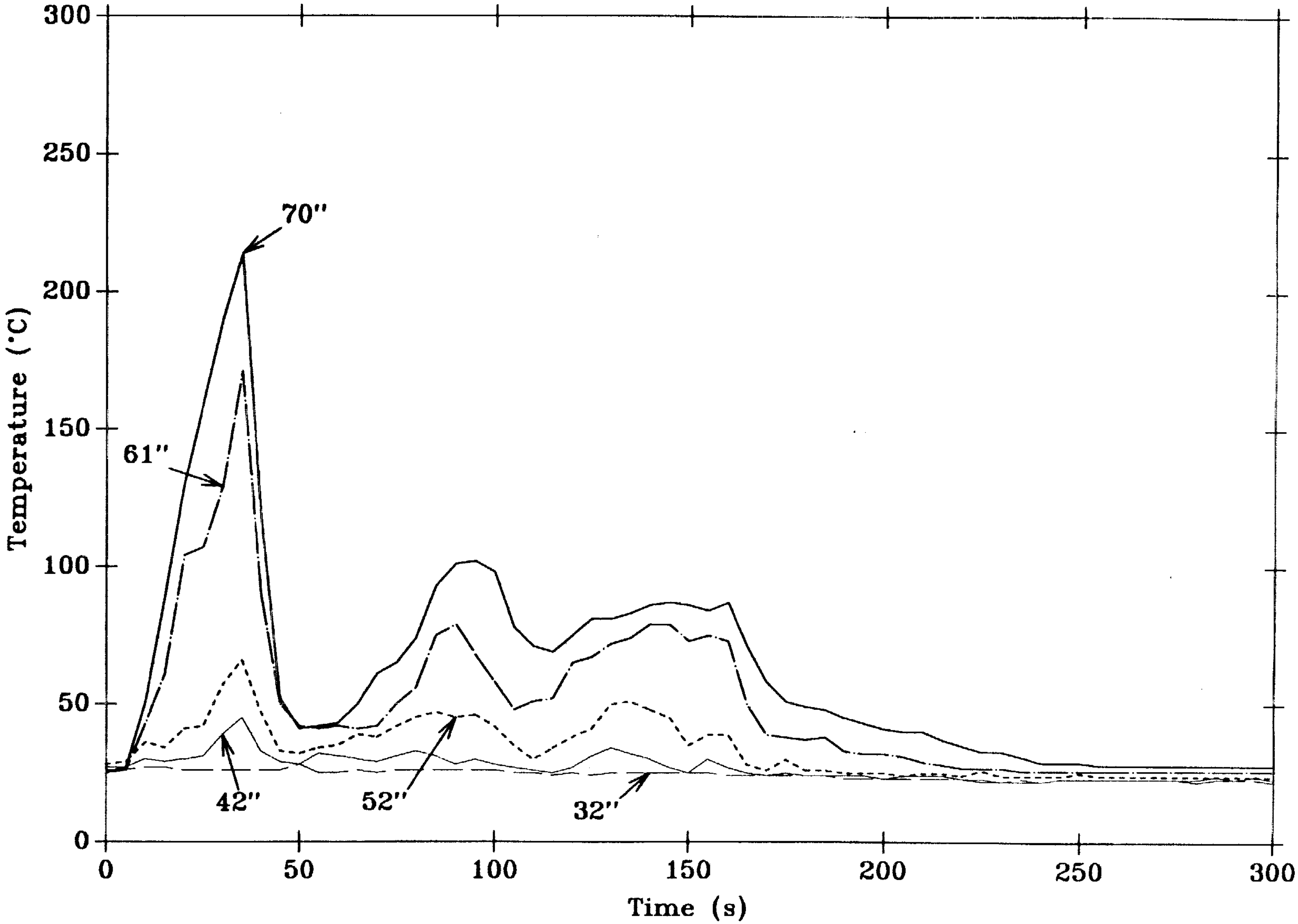

Figure 18. Door thermocouples, standard upright sprinkler (distances above the floor)

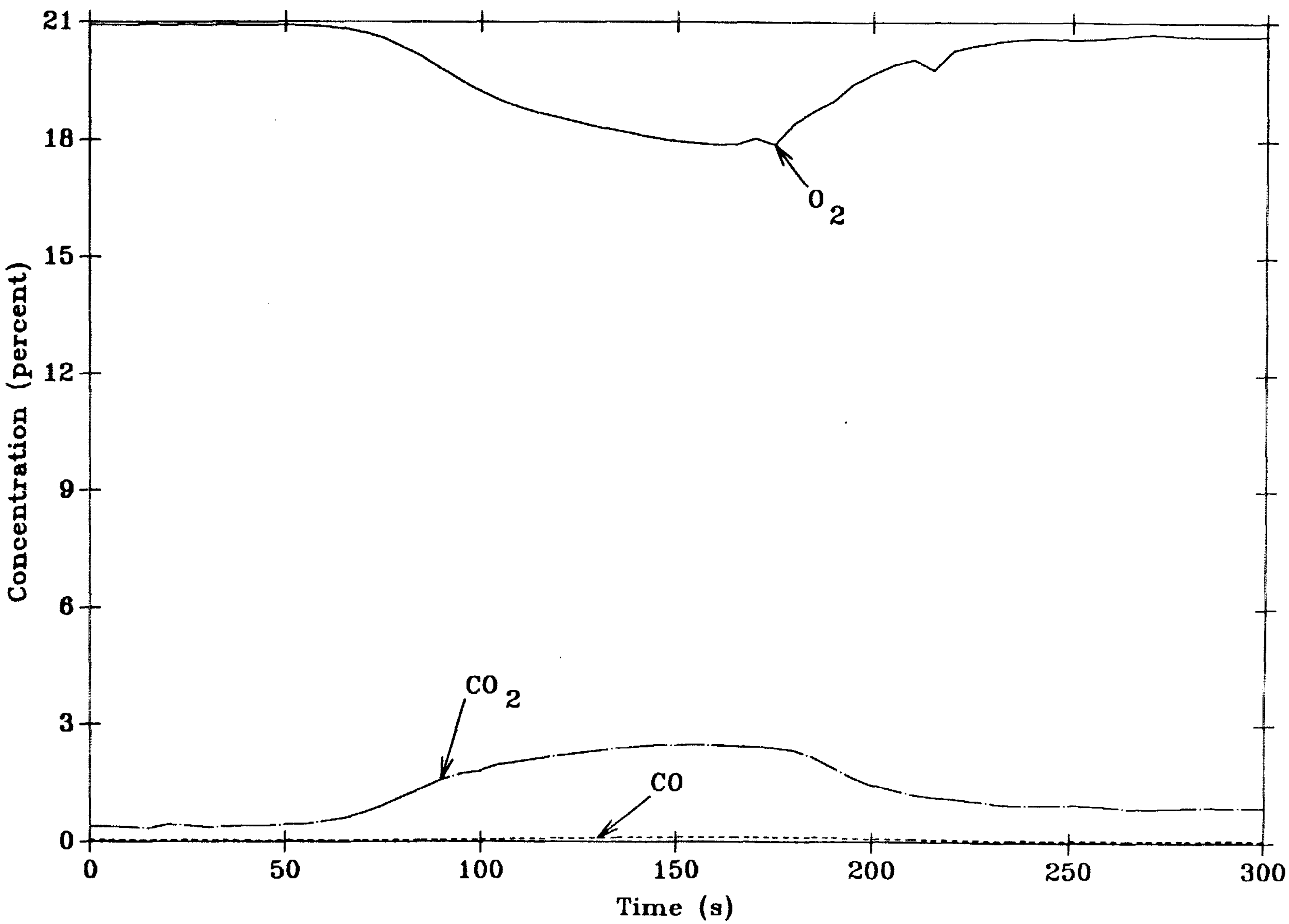

Figure 19. Gas concentrations, standard upright sprinkler

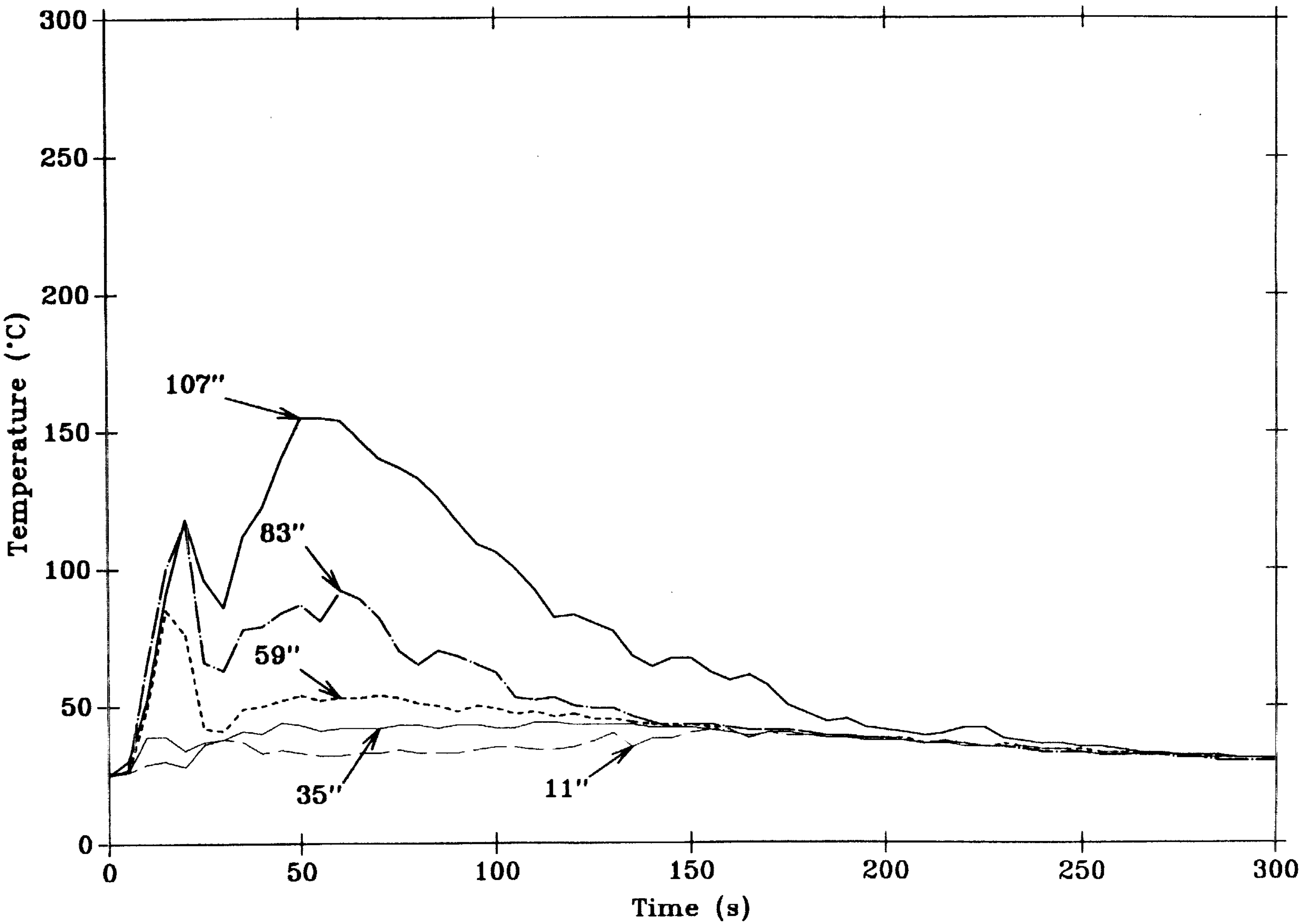

Figure 20. Corner thermocouples, quick response pendent sprinkler, steel piping (distances above the floor)

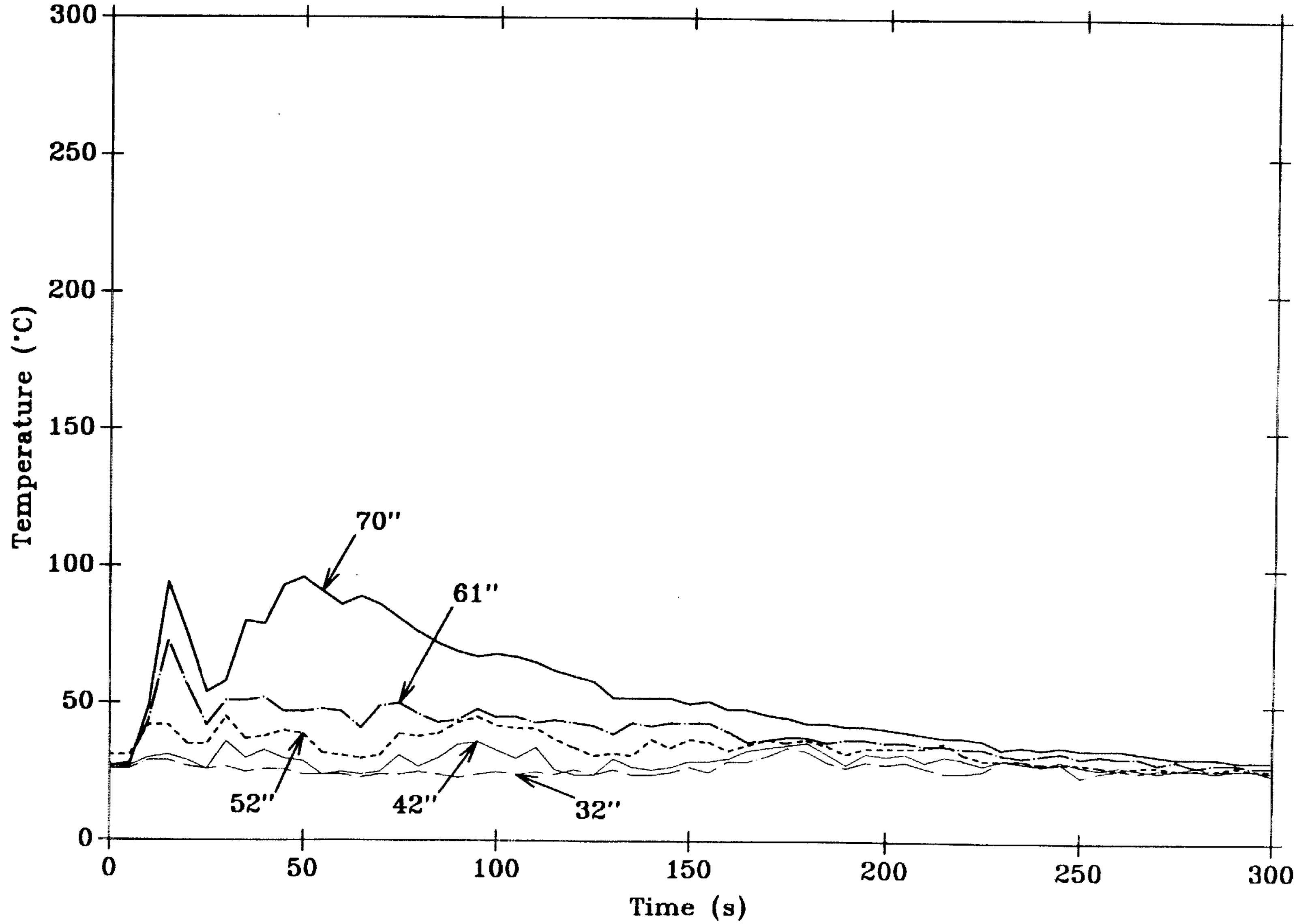

Figure 21. Door thermocouples, quick response pendent sprinkler, steel piping (distances above the floor)

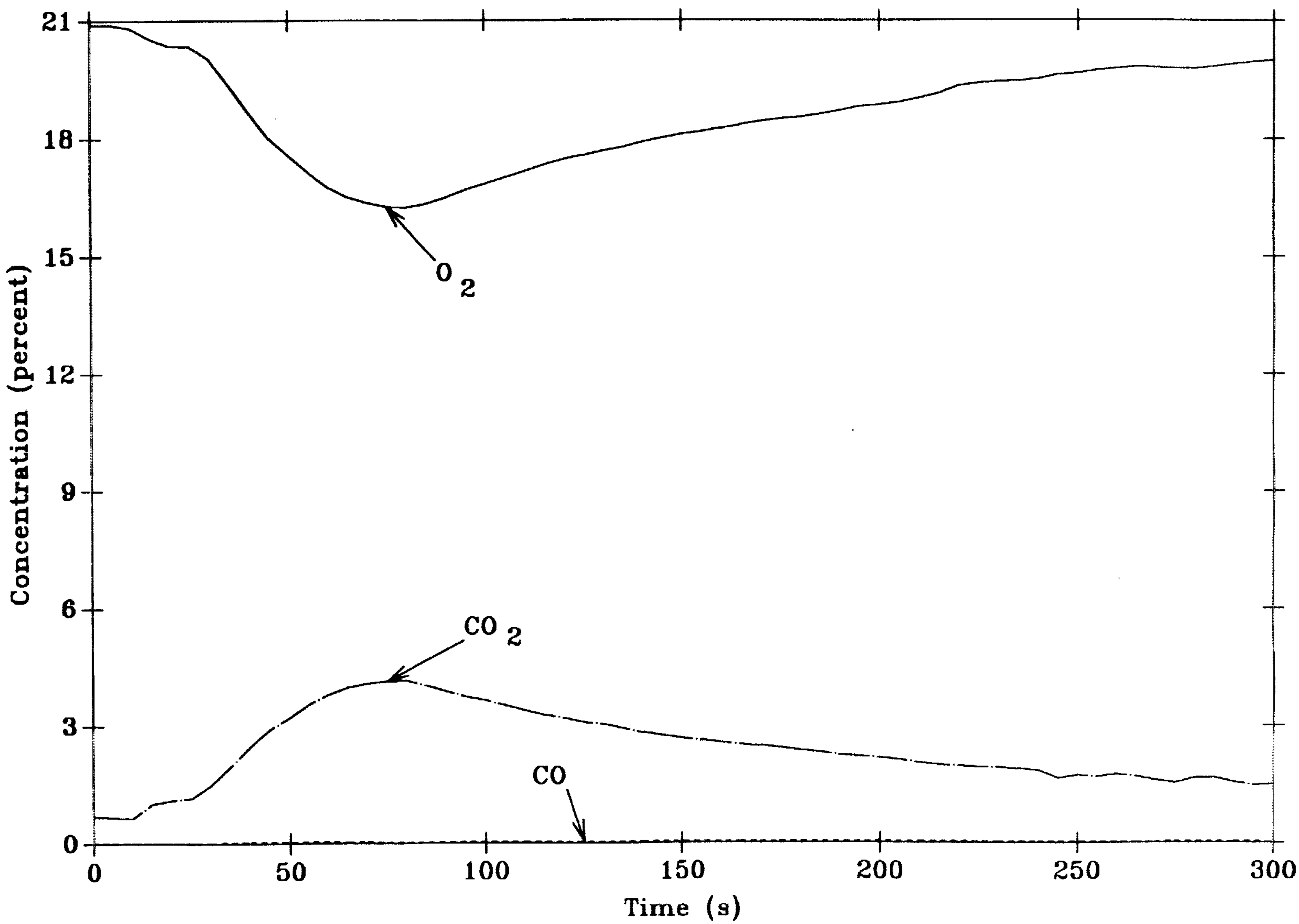

Figure 22. Gas concentrations, quick response pendent sprinkler, steel piping

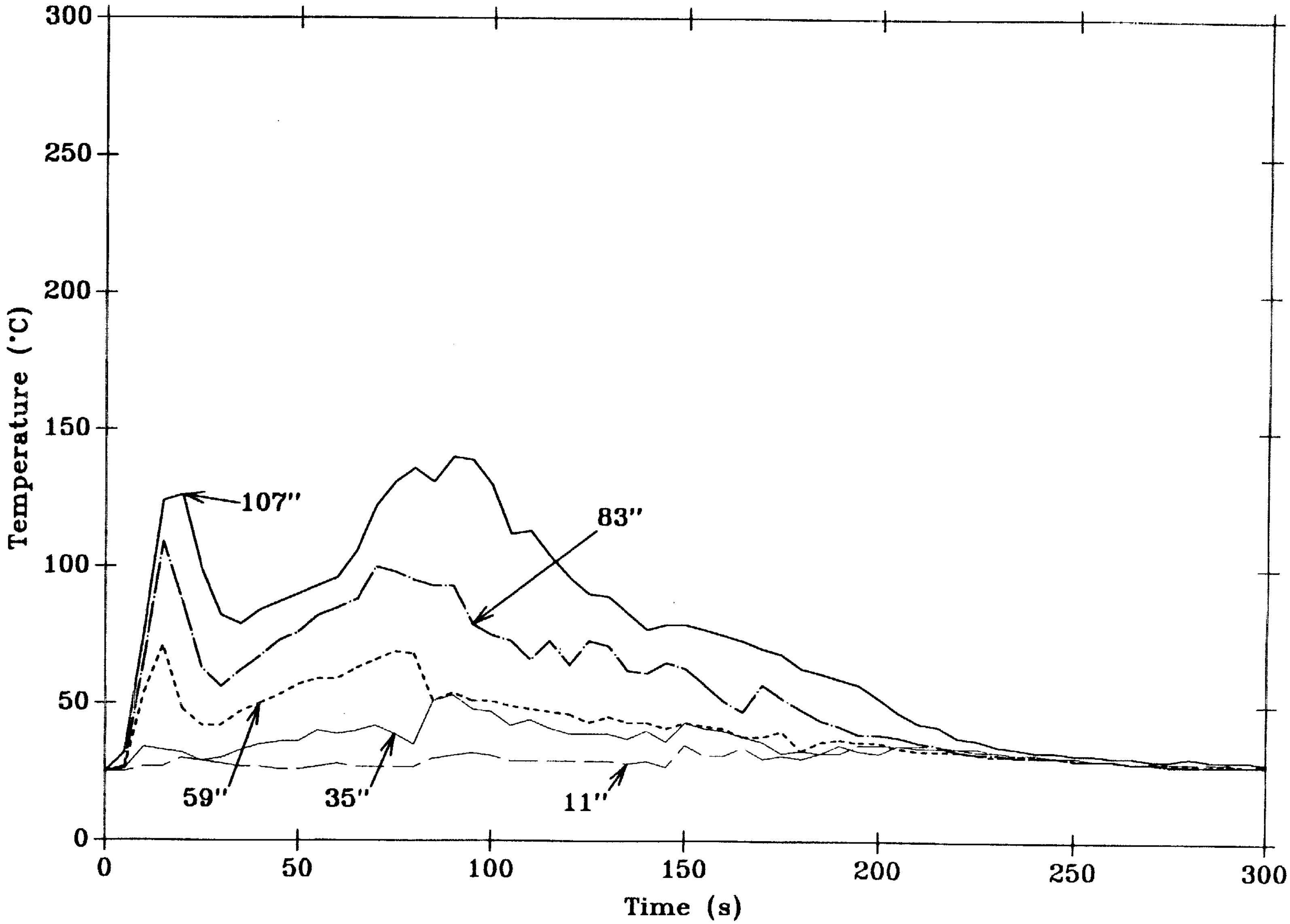

Figure 23. Corner thermocouples, quick response pendent sprinkler, plastic piping (distances above the floor)

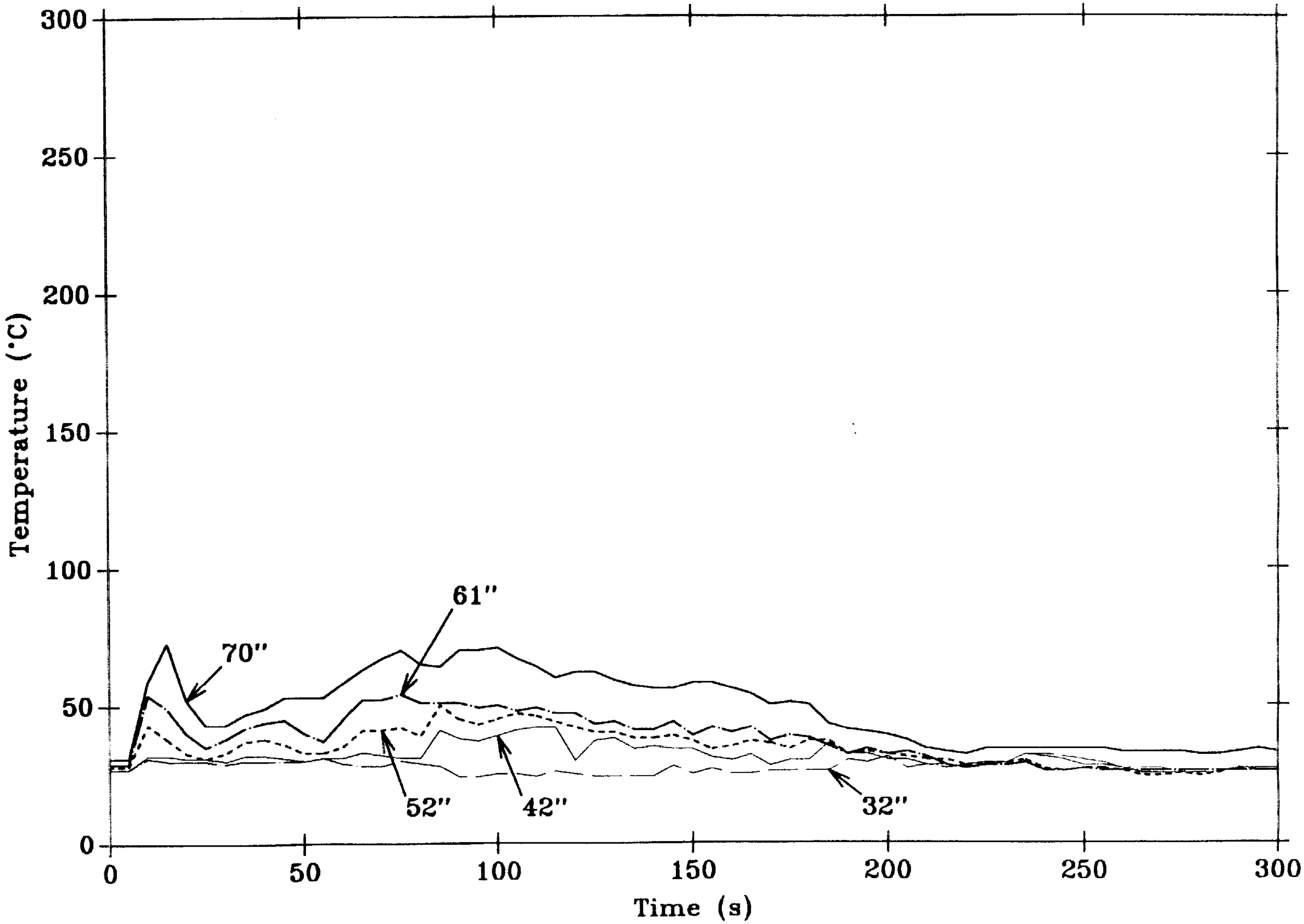

Figure 24. Door thermocouples, quick response pendent sprinkler, plastic piping (distances above the floor)

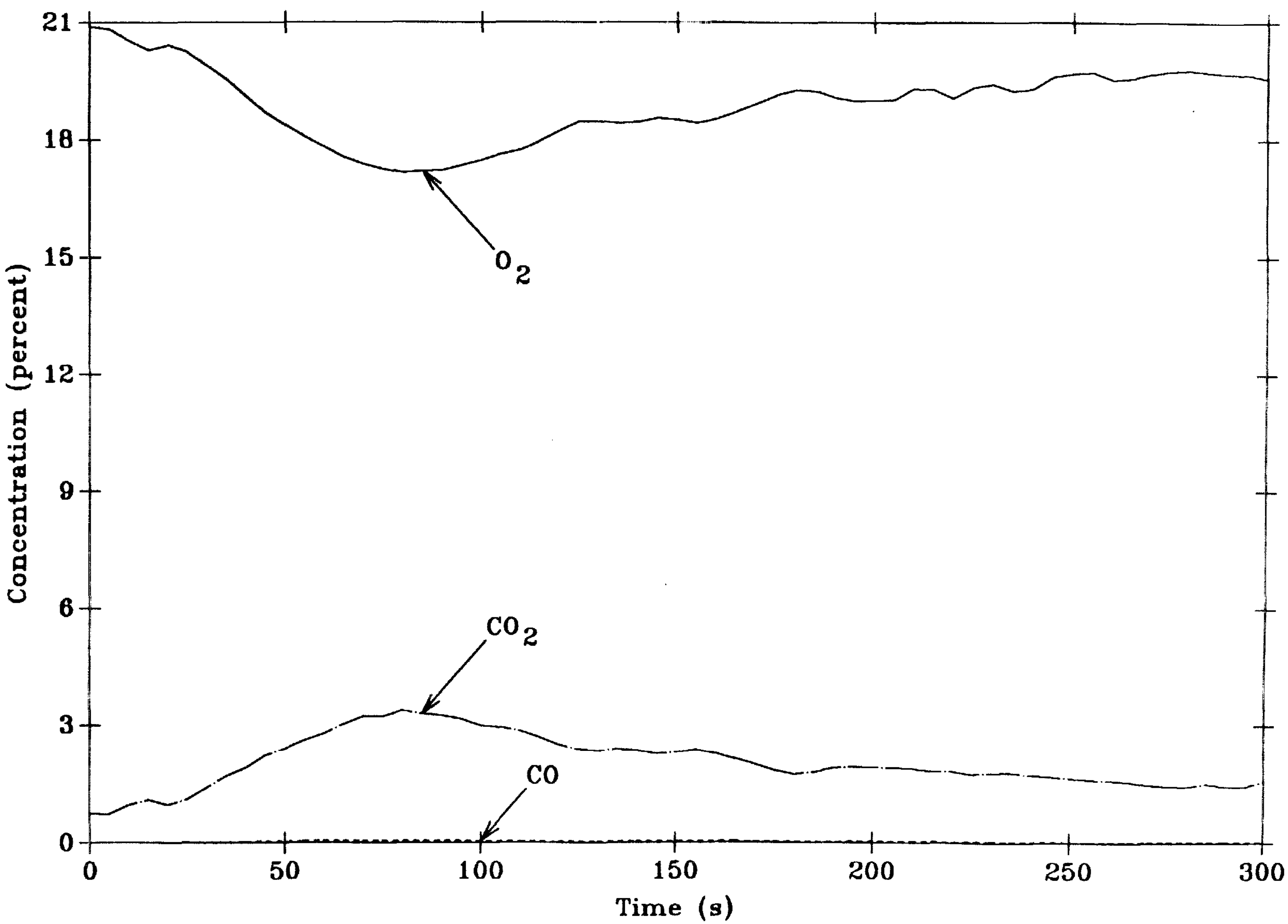

Figure 25. Gas concentrations, quick response pendent sprinkler, plastic piping

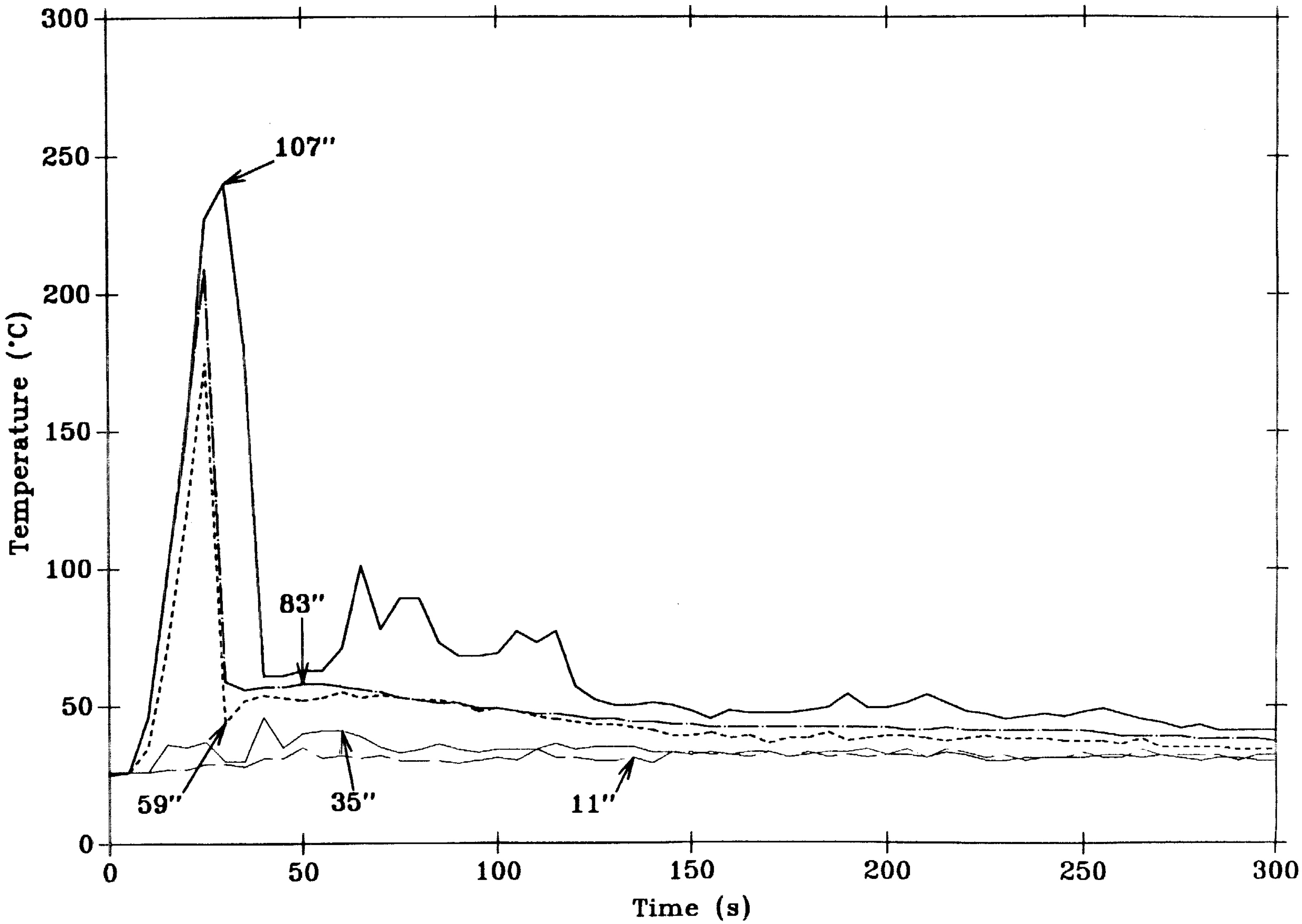

Figure 26. Corner thermocouples, quick response sidewall sprinkler (distances above the floor)

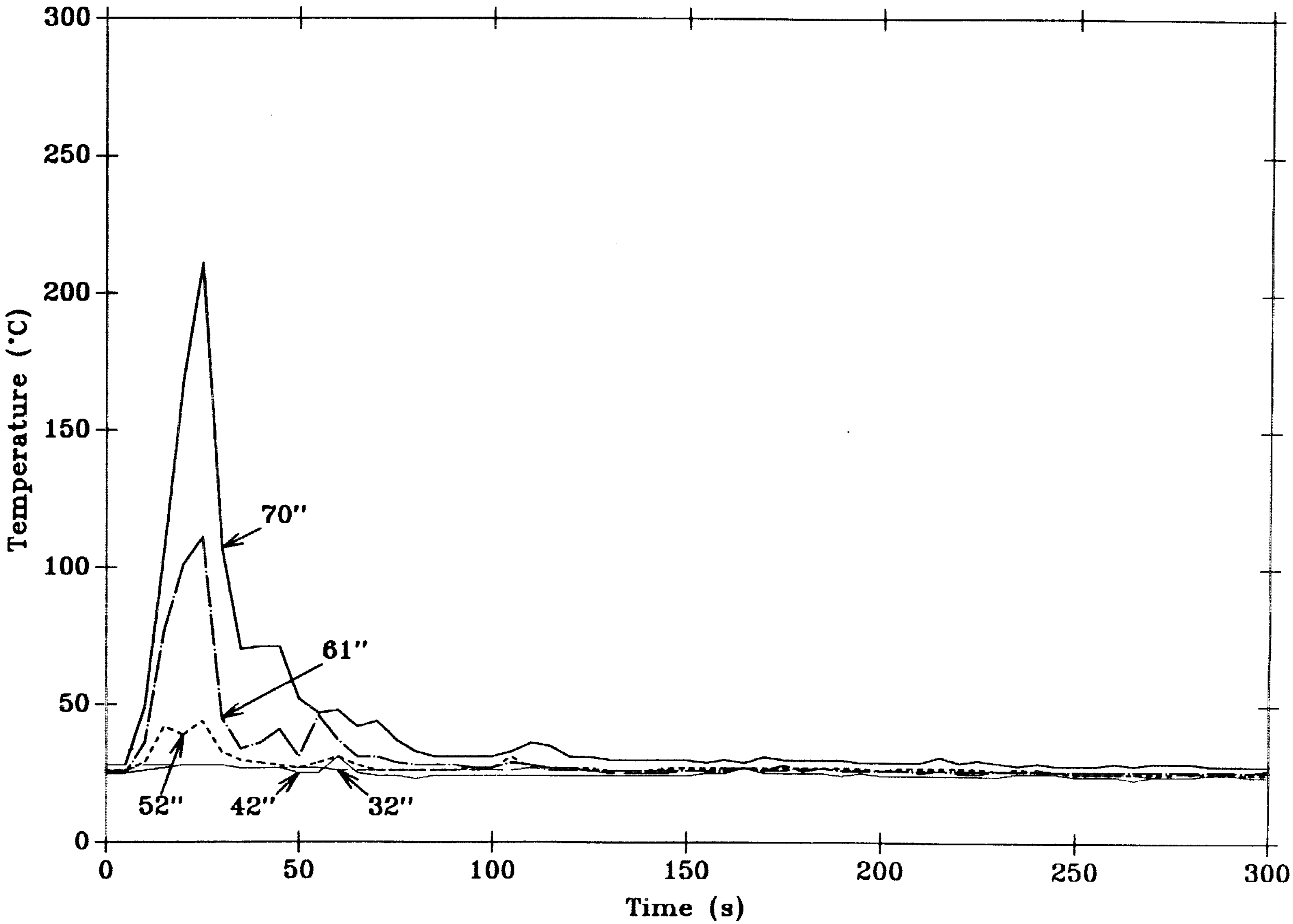

Figure 27. Door thermocouples, quick response sidewall sprinkler (distances above the floor)

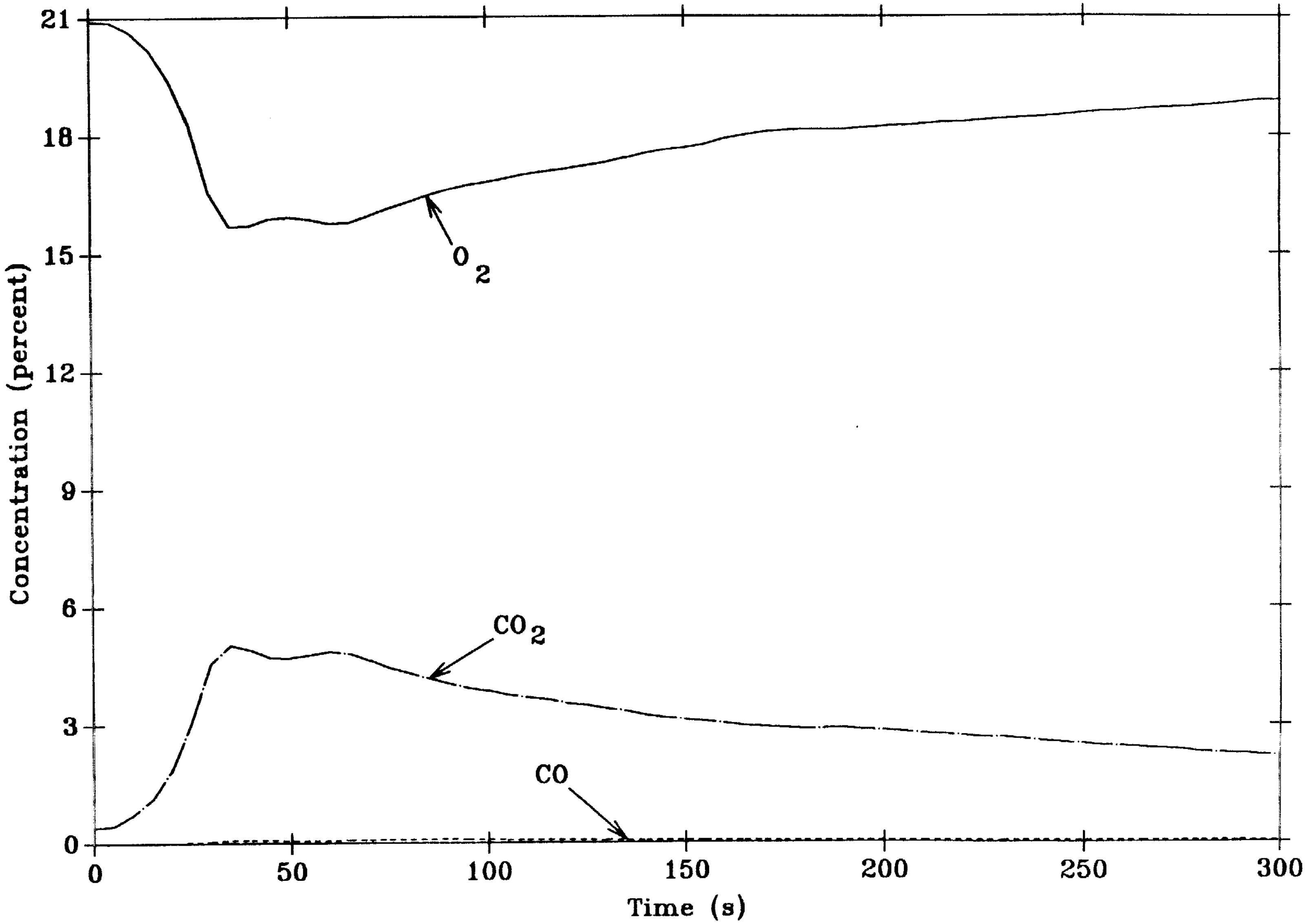

Figure 28. Gas concentrations, quick response sidewall sprinkler

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10. SUPPLEMENTARY NOTES

☐ Document describes a computer program; SF-185, FIPS Software Summary, is attached.

11. ABSTRACT (A 200-word or less factual summary of most significant information. If document includes a significant bibliography or literature survey, mention it here)

A series of fire tests in typical chemical laboratories was conducted in order to address the use of quick response sprinkler technology. For each test, the performance of an automatic sprinkler system in extinguishing a fire originating in an acetone spill was evaluated. The test parameters included 1) standard sprinklers with exposed steel piping, 2) quick response sprinklers with exposed steel piping, 3) quick response sprinklers with exposed plastic piping, 4) quick response sidewall sprinklers and 5) no sprinklers. Measurements of air temperature and the concentration of oxygen, carbon monoxide and carbon dioxide were taken. A free burn test was conducted to characterize the heat release rate of the initial items ignited.

12. KEY WORDS (Six to twelve entries; alphabetical order; capitalize only proper names; and separate key words by semicolons)

automatic sprinklers; burning rate; compartment fires; fire growth; fire tests; heat release rate; laboratories; oxygen consumption calorimetry; quick response sprinklers; room fires; toxicity

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