technical note

Onboard Cabin Water Spray System Under Various Discharge Configurations

Timothy Marker

October 1991

DOT/FAA/CT-TN91/42

Document is on file at the Technical Center
Library, Atlantic City International Airport, N.J. 08405

U.S. Department of Transportation
Federal Aviation Administration

Technical Center
Atlantic City International Airport, N.J. 08405

FSS 000022 R

NOTICE

Technical Report Documentation Page

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
DOT/FAA/CT-TN91/42		

4. Title and Subtitle	
ONBOARD CABIN WATER SPRAY SYSTEM UNDER VARIOUS DISCHARGE CONFIGURATIONS	5. Report Date: October 1991
	6. Performing Organization Code
7. Author(s): Timothy Marker	8. Performing Organization Report No.: DOT/FAA/CT-TN91/42
9. Performing Organization Name and Address: Federal Aviation Administration Technical Center, Atlantic City International Airport, NJ 08405	10. Work Unit No. (TRAIS)
	11. Contract or Grant No.
12. Sponsoring Agency Name and Address: U.S. Dpartment of Transportation, Federal Aviation Administration Technical Center, Atlantic City International Airport, NJ 08405	13. Type of Report and Period Covered: Technical Note
	14. Sponsoring Agency Code: ACD-240

15. Supplementary Notes

16. Abstract

Six full-scale fire tests were conducted in a modified DC-10 fuselage to investigate the effects of spraying water at different cabin locations or "pre-wetting" the cabin, while keeping the fire conditions constant. The tests were part of a 28 test series using a wide body fuselage to study the performance of an onboard cabin water spray system. The spray system utilizes low flow rate nozzles which produce a fine mist consisting of a range of water droplet diameters. The system being tested was a "breadboard" design for the purpose of demonstrating concept feasibility only. Two tests involved spraying water in different sections of the cabin and overhead. Two other tests investigated the effects of spraying varying quantities of water before the fire was ignited to pre-wet the interior. For comparison, one test used spray throughout the cabin, while the last test performed was without water in order to establish a "baseline." Temperature, smoke, heat flux, and gas concentrations were monitored at various locations throughout the fuselage.

17. Key Words	18. Distribution Statement
Fire Safety Aiecraft Safety Water Spray System	Document is on file at the Technical Center Library, Atlantic City International Airport, New Jersey 08405

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	25	

Form DOT F 1700.7 (8-72)

TABLE OF CONTENTS

	Page
EXECUTIVE SUMMARY	v
INTRODUCTION	1
Purpose	1
Background	1
DISCUSSION	1
Test Description	1
Test Results	3
SUMMARY	6
CONCLUSIONS	6
REFERENCE	6

LIST OF ILLUSTRATIONS

Figure		Page
1	TC-10 Test Configuration	7
2	Water Spray Discharge Configurations	8
3	TC-10 Nozzle Configuration	9
4	Five-Foot Temperatures at 180 Seconds	10
5	Temperature Station 400 -- 5 Feet	11
6	Temperature Comparisons -- Stations 220 and 590 -- 5 Feet	12
7	Temperature Station 220 -- 7 Feet	13
8	Temperature Comparisons -- Station 940 -- 1 to 4 Feet	14
9	Temperature Comparisons -- Station 940 -- 5 to 8 Feet	15
10	Smoke Comparison Station 570 -- 1 Foot 6 Inches, 3 Feet 5 Inches, and 5 Feet 6 Inches	16
11	Smoke Comparison Station 1320 -- 1 Foot 6 Inches, 3 Feet 6 Inches, and 5 Feet 6 Inches	17
12	Light Transmission at 3 Feet 6 Inches	18
13	Carbon Monoxide Station 60 -- 5 Feet 6 Inches	19
14	Carbon Dioxide Station 60 -- 5 Feet 6 Inches	20
15	Oxygen Comparison Station 530 -- 3 Feet 6 Inches and 5 Feet 6 Inches	21
16	HCI Station 40 -- 5 Feet 6 Inches	22

EXECUTIVE SUMMARY

Several important regulatory changes have been implemented in the last 5 years aimed at controlling the spread of a cabin fire. From a materials standpoint, fire blocked seats and low heat release interior panels will significantly impede the progress of a cabin fire. A safety improvement beyond the fire hardening of cabin interior materials is a low flow rate cabin water spray system. Developed by Safety in Aircraft and Vehicles Equipment (SAVE) Limited, the system consists of an array of nozzles installed in the cabin and overhead, filling these areas with a water mist. Twenty-eight full-scale tests have been conducted in a modified DC-10 fuselage to study the performance of such a system. Six of these tests investigated the effects of spraying water in various locations throughout the fuselage or "pre-wetting" the cabin, while keeping the fire conditions constant. It was determined that the water spray has its greatest impact on prolonging survivability within the cabin when sprayed in the immediate area of the fire.

INTRODUCTION

PURPOSE.

The purpose of this report is to present the results of six cabin fire suppression water spray tests, identified as test numbers 23,24,25,26,27, and 28, conducted in a modified DC-10 (TC-10) fuselage to study the effects of spraying water in various sections of the cabin.

BACKGROUND.

The onboard cabin water spray program is composed of several phases aimed at developing a safe and effective system for installation in a commercial transport aircraft. To evaluate the ability of the Safety in Aircraft and Vehicles Equipment (SAVE), Limited, System in providing additional escape time during a postcrash fire scenario, full-scale tests were conducted in both narrow body and wide body fuselage configurations. Concurrently, a study was undertaken to address the various service considerations associated with an inadvertent discharge of water spray while the aircraft is in flight or on the ground. The results of these initial studies will be factored into a benefit analysis to determine the potential for lives saved. If the benefits of such a system outweigh the disbenefits, the next phase will be to optimize the system and, later, to develop design requirements and specifications. The initial full-scale tests, in both the narrow body and wide body configurations, have been completed with favorable results. Although the service considerations and benefit analysis studies were not complete at the time this report was written, preliminary indications are positive. In anticipation of this, a series of tests was run in the wide body fuselage to determine the ability of the water spray system to provide escape times comparable to those previously achieved, with less water and/or less nozzles (i.e., less weight). One of the simplest ways of reducing the amount of water required is to spray a fraction of the total area of the fuselage. During the initial wide body tests there were 296 nozzles in the cabin and 28 nozzles in the overhead. Because of concern over the total weight of the system, several tests were conducted to determine the reduction, if any, in performance of the system when spraying water in only certain areas of the fuselage. This was accomplished by using 252 of the 324 total nozzles (78 percent) for one test and only 72 (22 percent) for another, thereby reducing the amount of water required and ultimately the weight of the system. A separate study examined the impact of removing the overhead nozzles (reference 1).

DISCUSSION

TEST DESCRIPTION.

As shown in figure 1, the interior fire load consisted of four nonfire blocked seats positioned near the fire door. No other combustible interior materials were included in the tests. The six tests utilized a standard 8- by 10-foot pan fire adjacent to a type A door opening, with 55 gallons of JP-4 fuel used to create the pan fire. The fire was drawn into the fuselage with the aid of a fan mounted at the forward bulkhead (nose). The fan exhausted at a rate no greater than 5800 cubic feet per minute (CFM). The test article was fully fire hardened and instrumented with thermocouple trees, smoke meters, gas sampling stations, calorimeters, and photographic and video equipment.

Figure 2 details the water spray discharge configurations. Water was sprayed forward and aft of the fire section during test 23, in both the cabin and overhead. Conversely, in test 24, water was sprayed in the cabin and overhead in the immediate fire area only. For comparative purpose, water was sprayed throughout the entire cabin during test 25. In test 26 the water was sprayed throughout the entire cabin before the fire was ignited to "pre-wet" the seats. Due to a malfunctioning solenoid valve only two-thirds of the 195 gallons of water were discharged, so the test was repeated with full water discharge (test 27). In order to establish baseline data, test 28 was performed without water spray. A schematic of the nozzle configuration is shown in figure 3. The water spray in all tests lasted approximately 3 minutes, with a mixture of fine droplets and air for an additional 30 seconds. All tests were 5 minutes duration, with water spray activation simultaneous to fire ignition during tests 23, 24, and 25. A discription of the instrumentation follows:

THERMOCOUPLE TREES. Seven thermocouple trees continuously measured the temperature throughout the cabin. The trees were located at 40, 220, 400, 590, 750, 948, and 1180 inches from the front of the test article, or nose. Each tree consisted of eight thermocouple probes positioned at 1-foot intervals from 1 foot above the floor to 8 feet above the floor. The 8-foot location was just under the ceiling level. In addition to the seven trees, eight individual thermocouples were positioned in the overhead area, 16 inches above the ceiling level on the fuselage centerline. These were located at 72, 168, 264, 384, 480, 576, 672, and 768 inches from the nose of the fuselage.

SMOKE METERS. Smoke meter stations were located at 80, 340, 570, and 1320 inches from the nose. Each station contained three smoke meters consisting of a columnated light source and photocell separated by 1 foot. The smoke meters were positioned at 18, 42, and 66 inches from the floor level.

GAS ANALYSIS. Continuous gas sampling stations used to measure carbon monoxide (CO), carbon dioxide (CO_2), and oxygen (O_2) were located at 60 and 530 inches from the nose. Each station had two intakes at heights of 42 and 66 inches from the floor. In addition to the continuous gas sampling, "grab" sampling stations were located at 60 and 530 inches from the nose, at heights of 66 and 42 inches respectively. These stations measured the acid gas production of hydrogen bromide (HBr), hydrogen chloride (HCl), and hydrogen flouride (HF) for 38-second intervals from 90 to 120, 150 to 188, 210 to 240, and 270 to 300 seconds from the test start.

Hydrogen cyanide (HCN) was measured by two methods, amperometric analysis and gas chromatography (GC). The amperometric analysis was performed by a Kin-tech™ analyzer which sampled at 60 and 530 inches from the nose, both locations at a height of 66 inches. In addition, HCN concentration was determined by the GC method at station 60, 66 inches from floor level.

CALORIMETERS. Calorimeters were used to measure the heat flux at four locations: 80, 590, 940, and 1320 inches. The transducers were all mounted at a height of 42 inches. At stations 80 and 590, the transducers faced aft; at station 1320, the transducer faced forward. The transducer located at station 940 faced the fire door.

TEST RESULTS.

A simplified analysis follows, comparing the results of the six tests based on three parameters: temperature profiles, smoke levels, and gas concentrations at various locations throughout the cabin. A final analysis links these three parameters together and determines the mechanisms that are occurring during each test.

TEMPERATURE PROFILES. As shown in figure 4, the temperature at a height of 5 feet throughout the cabin was consistently lower when spraying water throughout the entire cabin and higher when there was no water sprayed in the cabin. Spraying water in the area of the seats which were adjacent to the fire (test 24) had nearly the same effect as spraying water throughout the entire cabin (test 25). This is demonstrated by observing the cabin temperatures in the areas forward and aft of the water spray in test 24. Even though water was not discharged in these areas, the temperatures were lower than in test 23 in which water was sprayed here but not in the area of the seats. This showed that by spraying directly on the seat area the fire could be controlled, drastically reducing the amount of heat produced in the cabin. Conversely, spraying water forward and aft, but not directly in the seat area, had a smaller impact on reducing cabin temperatures since the fire was able to develop and thereby overcome some of the cooling effects of the water spray.

By pre-wetting the seats (tests 26 and 27) the burning process was slowed somewhat, but not as much as when the water was sprayed on the seats during the fire (figure 5). This also illustrated the greater effectiveness of water spray in cooling the cabin environment when spraying during fire than by pre-wetting.

Figure 6 shows the temperature profiles at two stations forward of the seat area (220 and 590). Both diagrams show the reduction of temperatures, due to the water spray, by two distinct mechanisms. When spraying on the seats, although both stations 220 and 590 were out of the spraying area, the water spray suppressed the fire and reduced the temperatures by over 100 °F. In contrast, test 23 allowed the fire to progress since there was no water spray in the seat area, but the cooling affect of the spray had also reduced the temperatures by over 100 °F.

Figure 7 displays the temperature profiles of the six tests at a location closer to the ceiling (7 feet at station 220). As expected, the highest temperature existed with no spray; the lowest with full spray. Pre-wetting the seats lowered the cabin temperatures slightly. Although both tests 23 and 24 exhibited significantly lower temperature profiles than either of the pre-wet tests or nonspray tests, there exists a significant difference between the two. When spraying in the area of the seats, there was a gradual increase in temperature after the time the water spray was fully depleted (210 seconds). However, when spraying water forward and aft of the seat area, there was a rapid increase in temperature shortly after the water was fully depleted.

This further solidifies the theory that the water spray was not only reducing the cabin temperatures but controlling the burning rate of the seats. Figures 8 and 9 further support the trends discussed thus far. At station 940, which was centered at the fire door and seat area, the temperatures from the floor to ceiling were highest with no water and lowest with total water. Naturally, both of the pre-wet tests controlled the temperatures better at this location than when spraying forward and aft of the seat area (test 23).

This occurred since there was no water being sprayed in the seat area during test 23; the temperature profiles were therefore nearly identical to the non-spray test. Spraying water on the seats only yielded temperatures nearly as favorable as the total spray test.

<u>SMOKE LEVELS</u>. Figures 10 and 11 show the smoke levels within the cabin at stations 570 and 1320 for each of the six tests. It must first be noted that the light transmission at station 570 during tests 23 and 25 exceeded 100 percent for about 1 minute. Although it is not possible for the light transmission to exceed 100 percent, the data acquisition system reads the light transmission level immediately before the test is initiated and sets this as 100 percent. The reason the light transmission exceeded this level is most likely a result of the water droplets that had formed on the surface of the smoke meter lens. By doing so, the water acted as a medium which refracted the light within the cabin into the photocell, thereby increasing the indicated value. This phenomena existed at other locations but was most pronounced at station 570.

Several trends existed at the three heights of the two stations. Spraying on the seats only (test 24) tended to yield the highest visibility. The reasoning behind this is twofold. As discussed earlier, spraying water in the area of the seats controlled the burning rate, thereby lowering the amount of smoke produced. In addition, because stations 570 and 1320 were both located out of the spray area, the smoke produced by the burning seats restratified into the upper portion of the cabin. When the smoke stratified, it collected near the ceiling and slowly descended during the test until it reached the smoke meters.

Figures 10 and 11 also show that the visibility reached the lowest level during the nonspray tests. However, due to the stratification effect of smoke during the nonspray tests, this did not occur until at least several minutes into the test. In fact, the visibility during the initial minutes of the nonspray test was actually better when compared to the full spray test (test 25) and the test in which water was sprayed forward and aft of the seats (test 23). Conversely, the low visibility that occurred early on during test 23 (in which water was sprayed forward and aft of the seat area) can be attributed to the otherwise uninhibited burning of the seats, combined with the fact that the smoke was "pulled" down by the water being sprayed from the ceiling nozzles. The only difference in smoke levels between test 23 and test 25 (full spray) was that the full spray test controlled the fire propagation better, yielding slightly lower smoke levels. The smoke levels during the pre-wet tests were initially very favorable. The water content in the seats inhibited the burning process (i.e., less smoke production), and the lack of water sprayed during the test allowed the smoke to stratify towards the ceiling. The stratification effect can be fully realized by viewing the smoke levels at the three heights (figure 10). At 5 feet 6 inches, the visibility dropped off at around 2 minutes; at 3 feet 6 inches, the visibility diminished at around 3 minutes; and, finally, at a height of 1 foot 6 inches, the visibility did not decrease until over 4 minutes from the pan fire ignition.

It is interesting to note that when the test was terminated (5 minutes) and difference in stratification was no longer an effect, the smoke levels were directly proportional to the burning rate (figure 12). The full-spray test yielded the best visibility and no spray yielded the worst visibility. Spraying on the seats only was nearly as effective as the full spray, followed by the pre-wet tests. Spraying forward and aft of the seats was better than no spray at all.

GAS CONCENTRATIONS. The two nonsoluble "fire gases," CO and CO_2 were not directly washed out of the cabin atmosphere by the water spray. Figure 13 shows the CO profiles at station 60, 5 feet 6 inches from the floor. The fully sprayed test produced the lowest CO level, and the nonspray test the highest. In general, the level of fire gas concentration is indicative of the burning rate of materials.

If we compare the full-spray test (test 25) to the test in which water was sprayed on the seats only (test 24), we can see that there was a slight reduction in CO over the length of the cabin. The pre-wet tests inhibited the CO production slightly (the greater the amount of water, the lower the CO level). However, when spraying water forward and aft of the fire area (test 23), the CO profile indicates that there was very little or no reduction of the gas since this profile is nearly identical to that of the nonspray test. The CO_2 profiles (figure 14) also followed this trend. Similarly, there was very little oxygen reduction during the full spray test and seat only spray test (figure 15). The greatest oxygen depletion occurred during the nonspray test, followed closely by spraying forward and aft of the seats. The pre-wet tests yielded oxygen concentration profiles between these two extremes.

The acid gas profiles of HCl generally followed the results obtained with the fire gases CO, CO_2, and O_2 (figure 16). The primary difference existed during test 23 in which water was sprayed forward and aft of the seats. The fire gases, which are fairly insoluble, were washed out very little and as a result reached levels nearly equal to those obtained during the nonspray test. The acid gases HCl, HF, and HBr are soluble, however, and as a result were lower during test 23 than either of the pre-wet tests (26 and 27) or the nonspray test (28). Although HCN was measured continuously during the tests, it was not included in the analysis since the purpose of the six tests was to determine the different mechanisms that the water spray uses to control fire spread and not a detailed survivability model.

SUMMARY

In general, the test using the water spray throughout the entire cabin controlled the temperature and gas concentration levels better than any of the other tests. Spraying water in the area of the seats only was nearly as effective as the total spray test in terms of heat and gas reduction, with the added benefit of increased visibility during a majority of the test.

Pre-wetting the cabin interior and seats by spraying prior to pan fire ignition aided in reducing temperatures and allowed for smoke stratification. By allowing the smoke to stratify, the visibility was better early in the test; but once it descended to the smoke instrumentation level, the measured visibility declined and became less desirable than either the full spray or sectionally sprayed tests (23, 24, and 25). Spraying forward and aft of the seat area was much less effective in reducing the CO and CO_2 than spraying in the area of the seats, due to the insolubility of these fire gases. It was, however, quite effective in reducing the acid gases since they are more readily soluble in water.

CONCLUSIONS

Spraying water throughout the entire cabin using a low flow rate (3 minutes) is the most effective approach for curbing heat and toxic gas hazards due to the effects of a fuel-fed cabin fire.

However, it is possible that in actual service conditions, a quantity of water much less than that required for a 3-minute spray of the entire fuselage (195 gallons) would be available (in an effort to keep the overall weight of the system at a minimum). With this constraint, the most effective means of maximizing the usefullness of the limited water quantity is to spray only in the immediate fire area.

Spraying water only in the immediate area of the fire yields temperature and gas concentration levels at or near those obtained in a fully sprayed cabin. In addition, the visibility in the other sections of the cabin is better than in the fully sprayed cabin since the hot smoke layer tends to stratify and remain in the upper portion of the cabin. Thus, the benefits are not only in reduced temperatures and toxicity levels, but in the ability of passengers to escape the aircraft quicker due to increased visibility throughout the cabin.

REFERENCE

1. Marker, T., Effectiveness of Water Spray Within the Cabin Overhead Area, DOT/FAA/CT-TN91/29, August 1991.

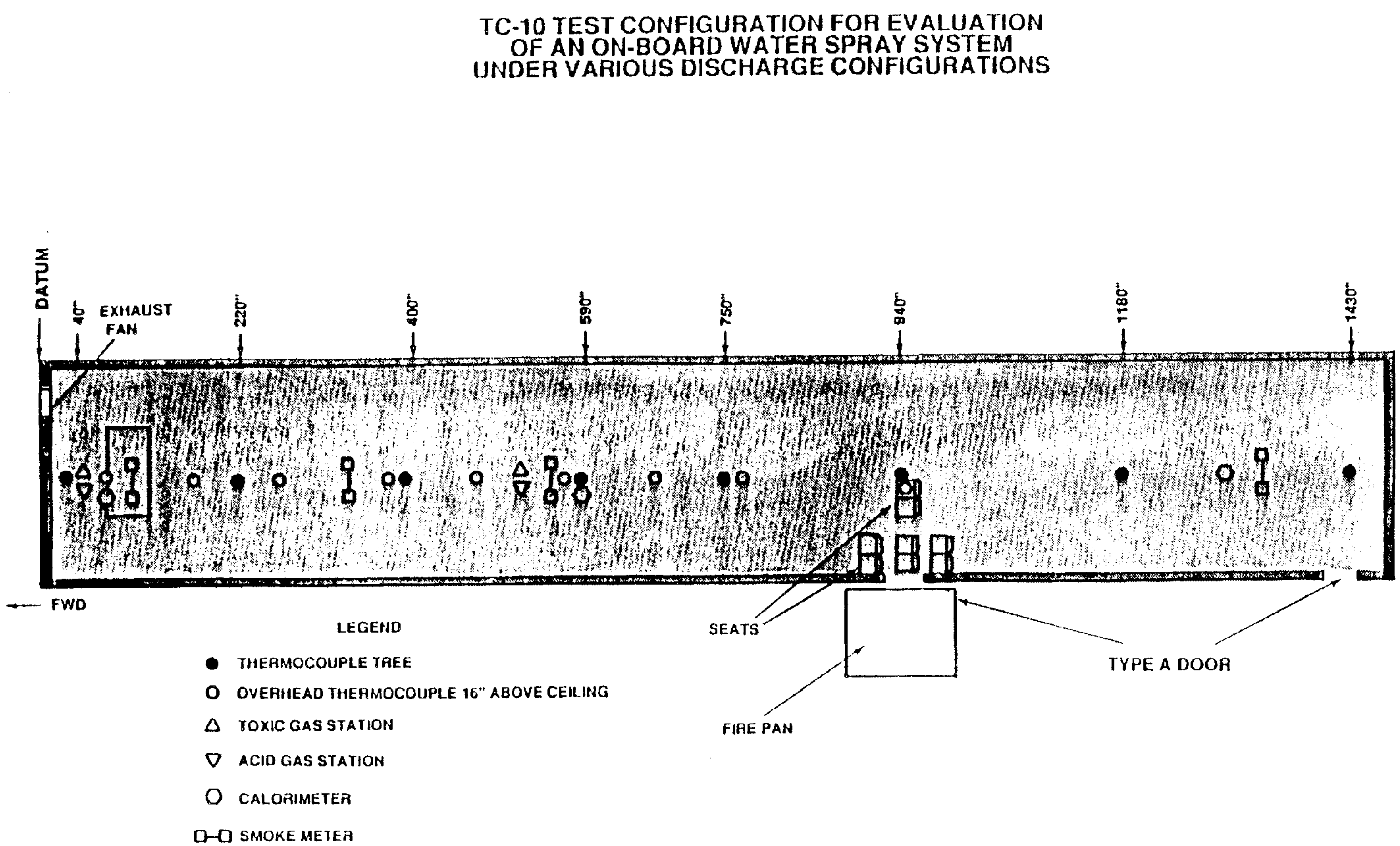

FIGURE 1. TC-10 TEST CONFIGURATION

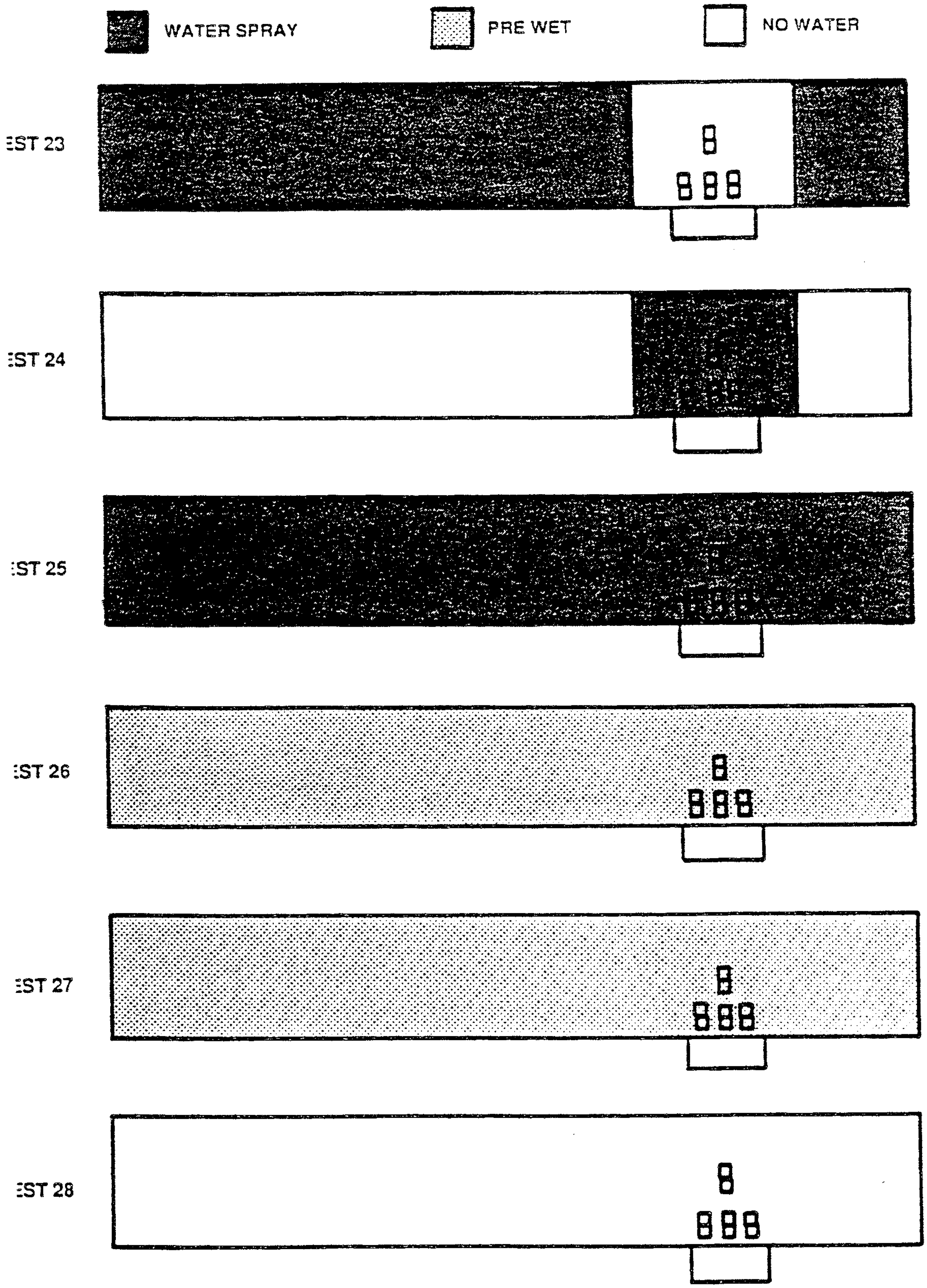

FIGURE 2. WATER SPRAY DISCHARGE CONFIGURATIONS

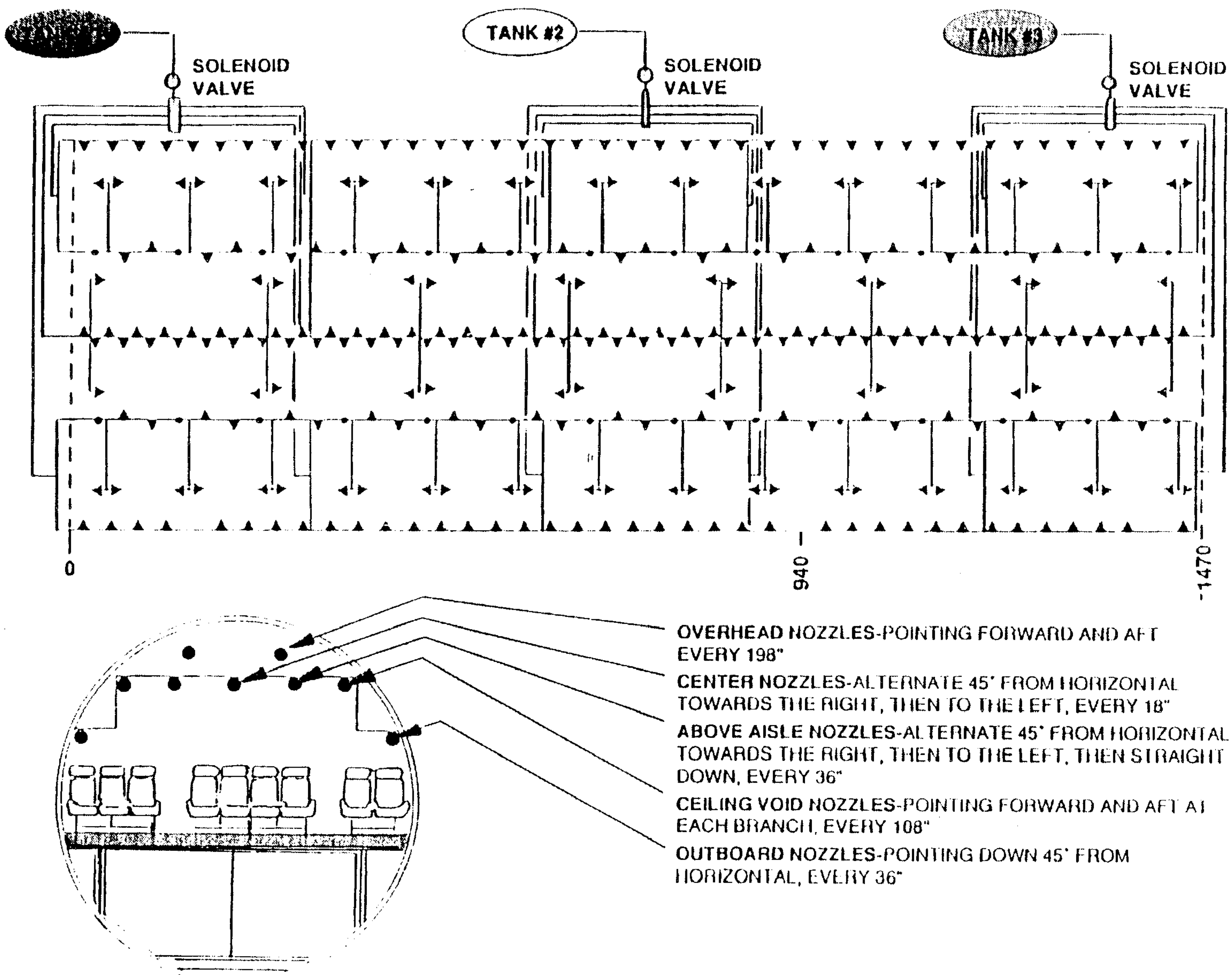

FIGURE 3. TC-10 NOZZLE CONFIGURATION

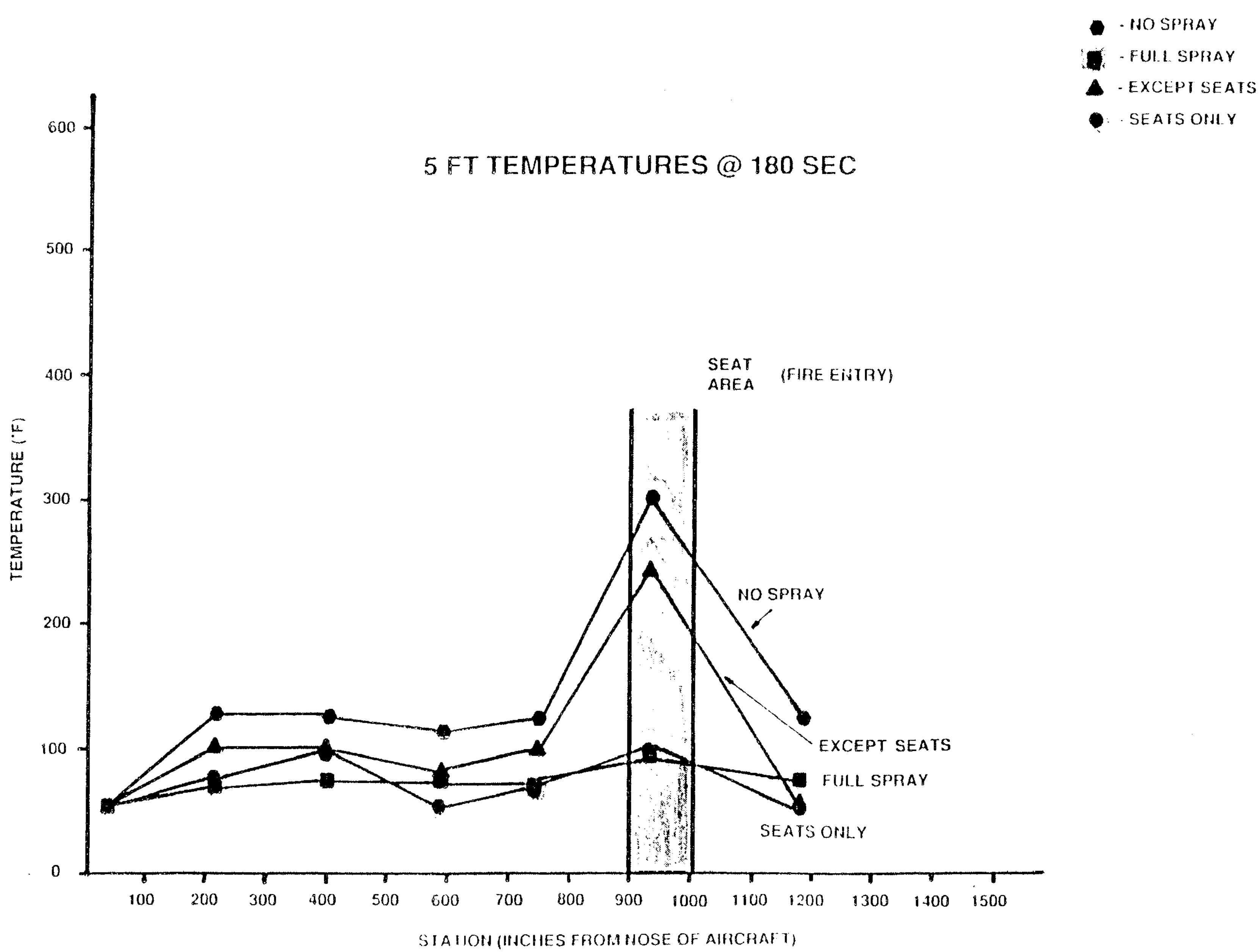

FIGURE 4. FIVE-FOOT TEMPERATURES AT 180 SECONDS

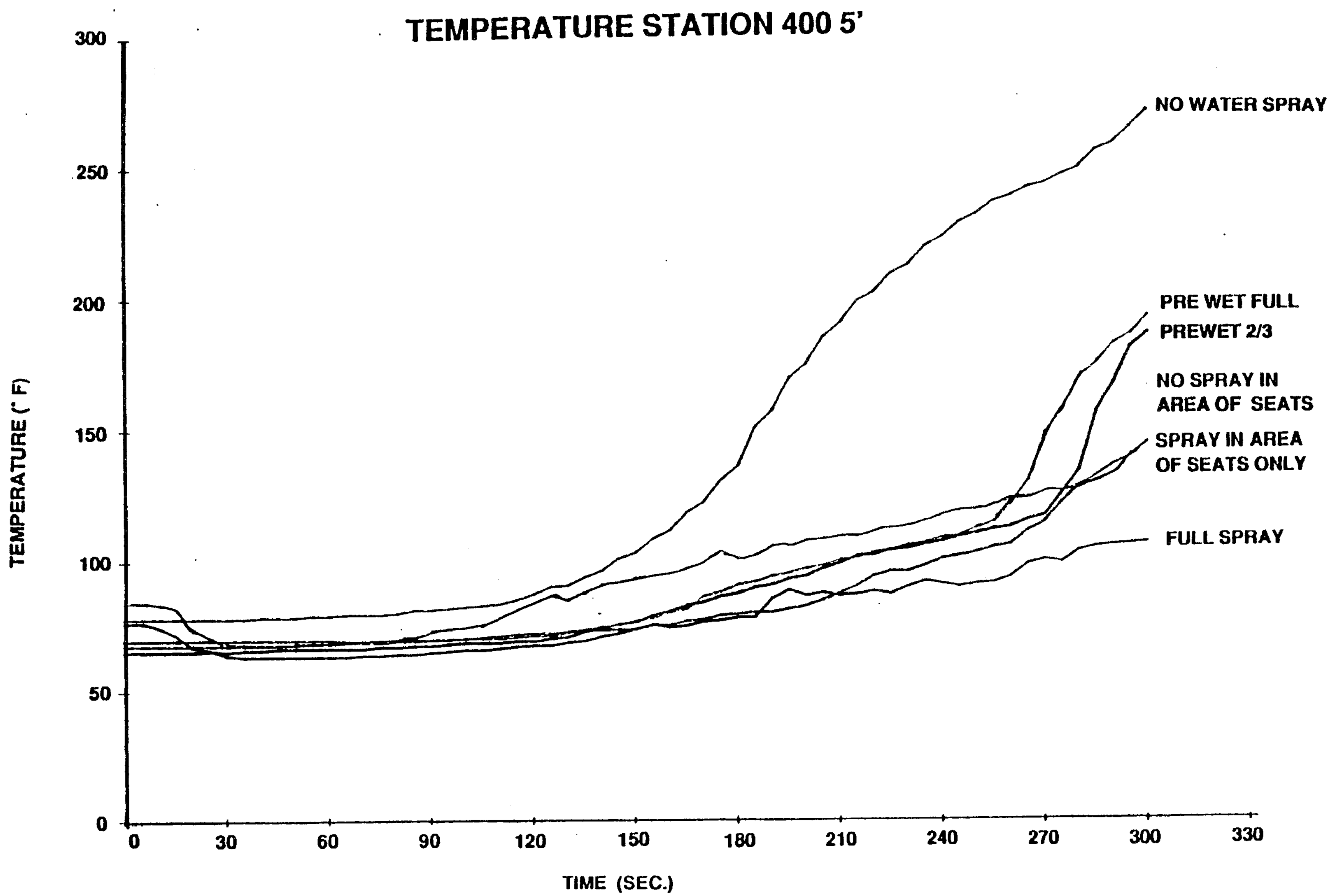

FIGURE 5. TEMPERATURE STATION 400 -- 5 FEET

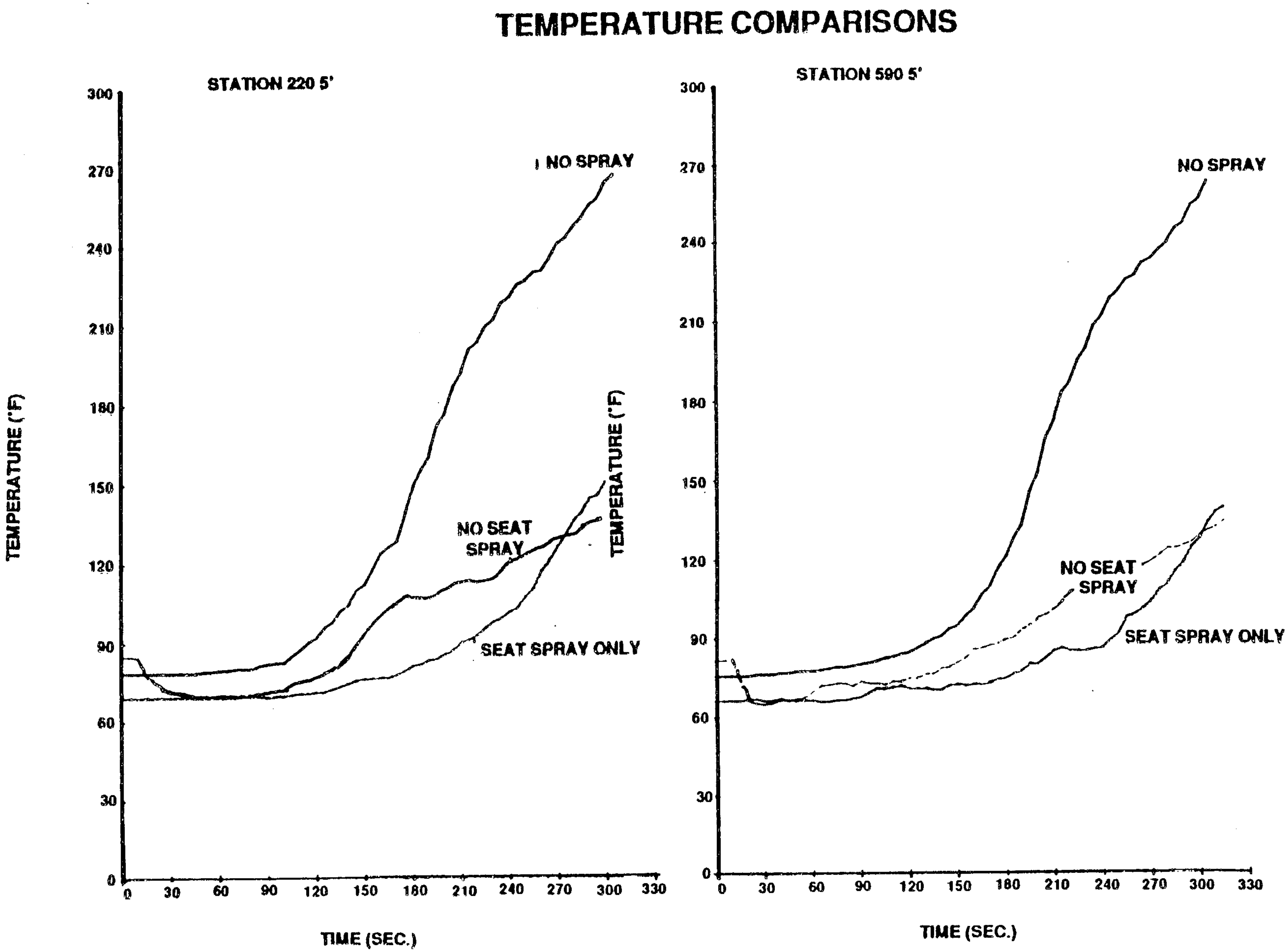

FIGURE 6. TEMPERATURE COMPARISONS -- STATIONS 220 AND 590 -- 5 FEET

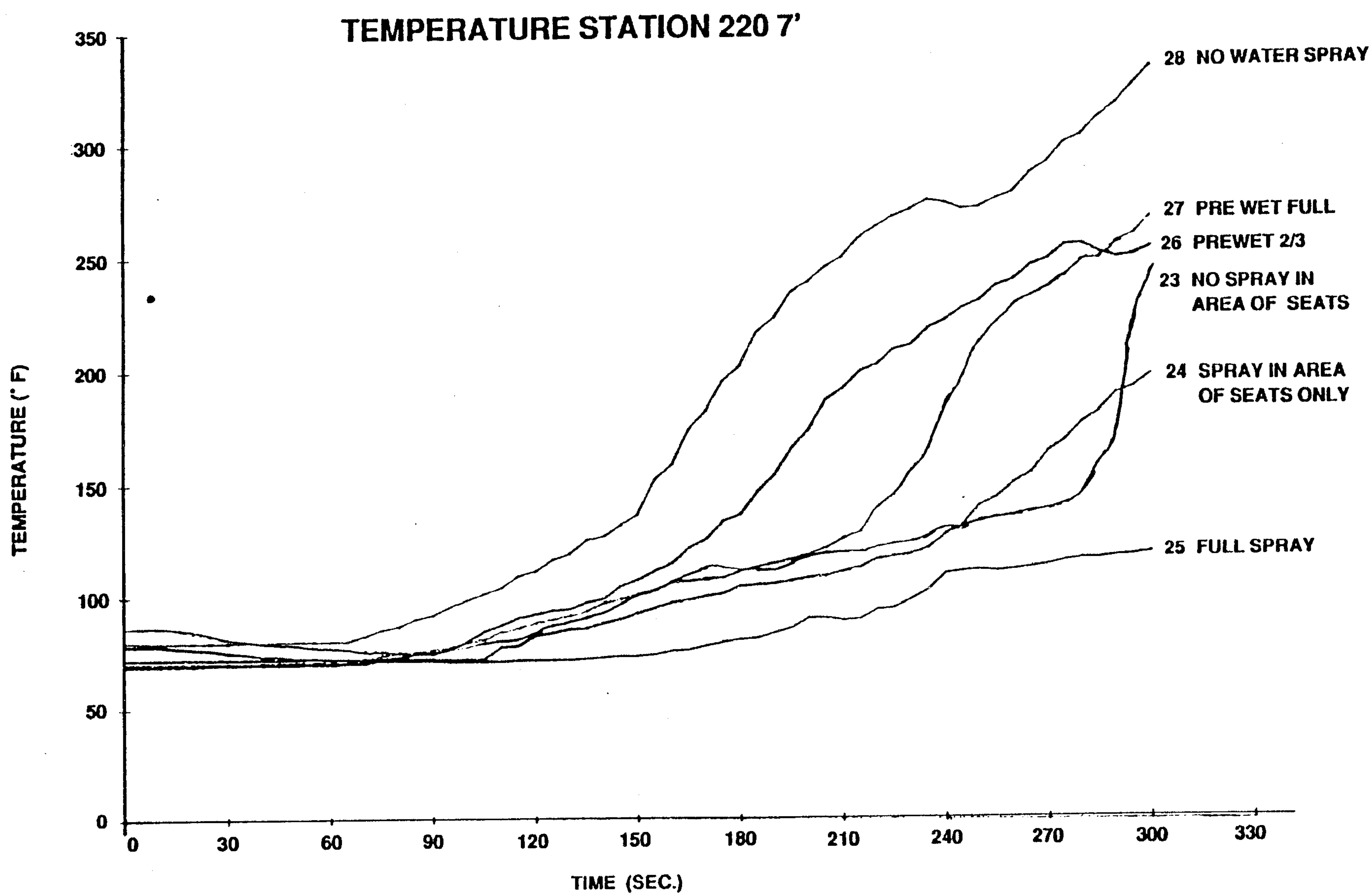

FIGURE 7. TEMPERATURE STATION 220 -- 7 FEET

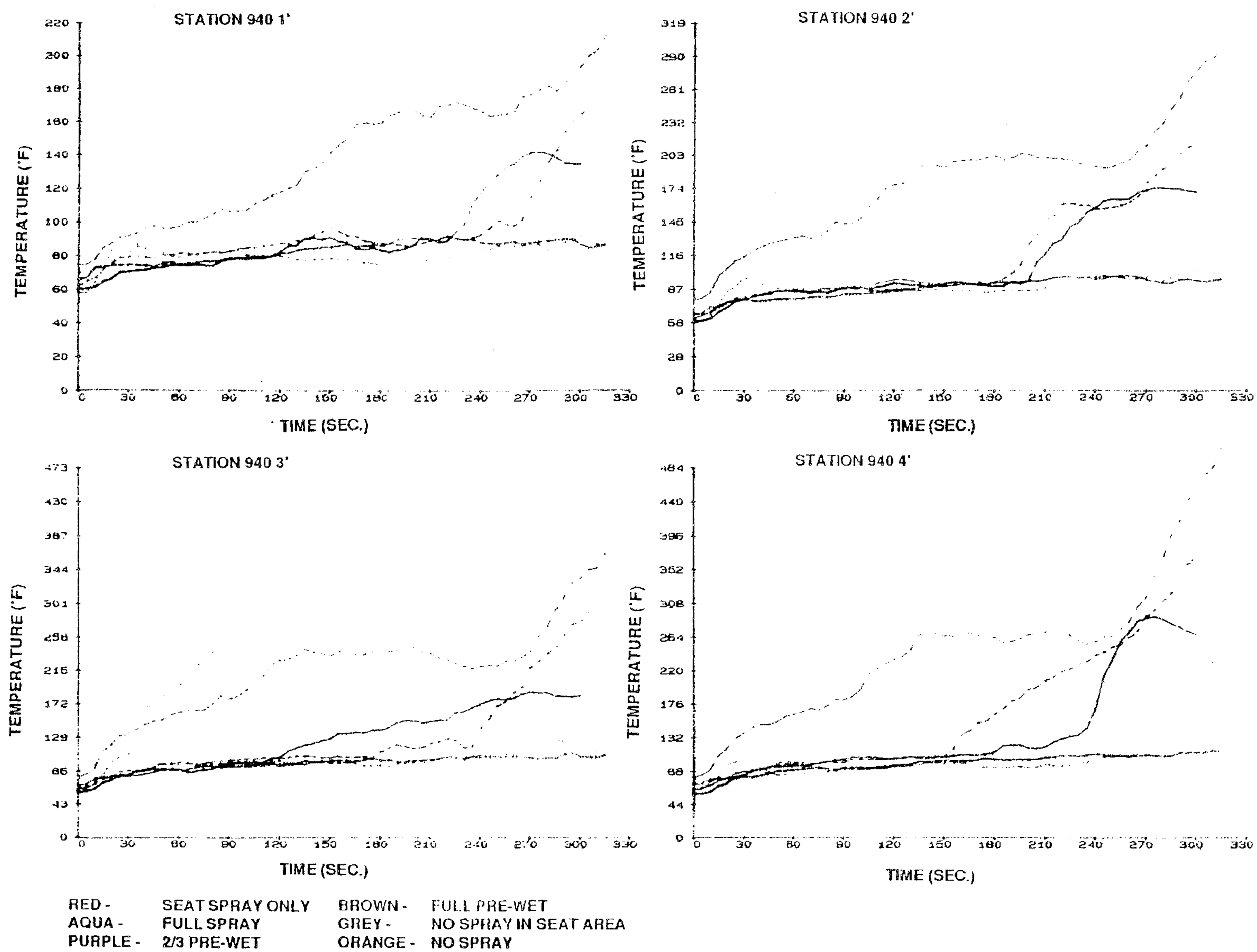

FIGURE 8. TEMPERATURE COMPARISONS -- STATION 940 -- 1 TO 4 FEET

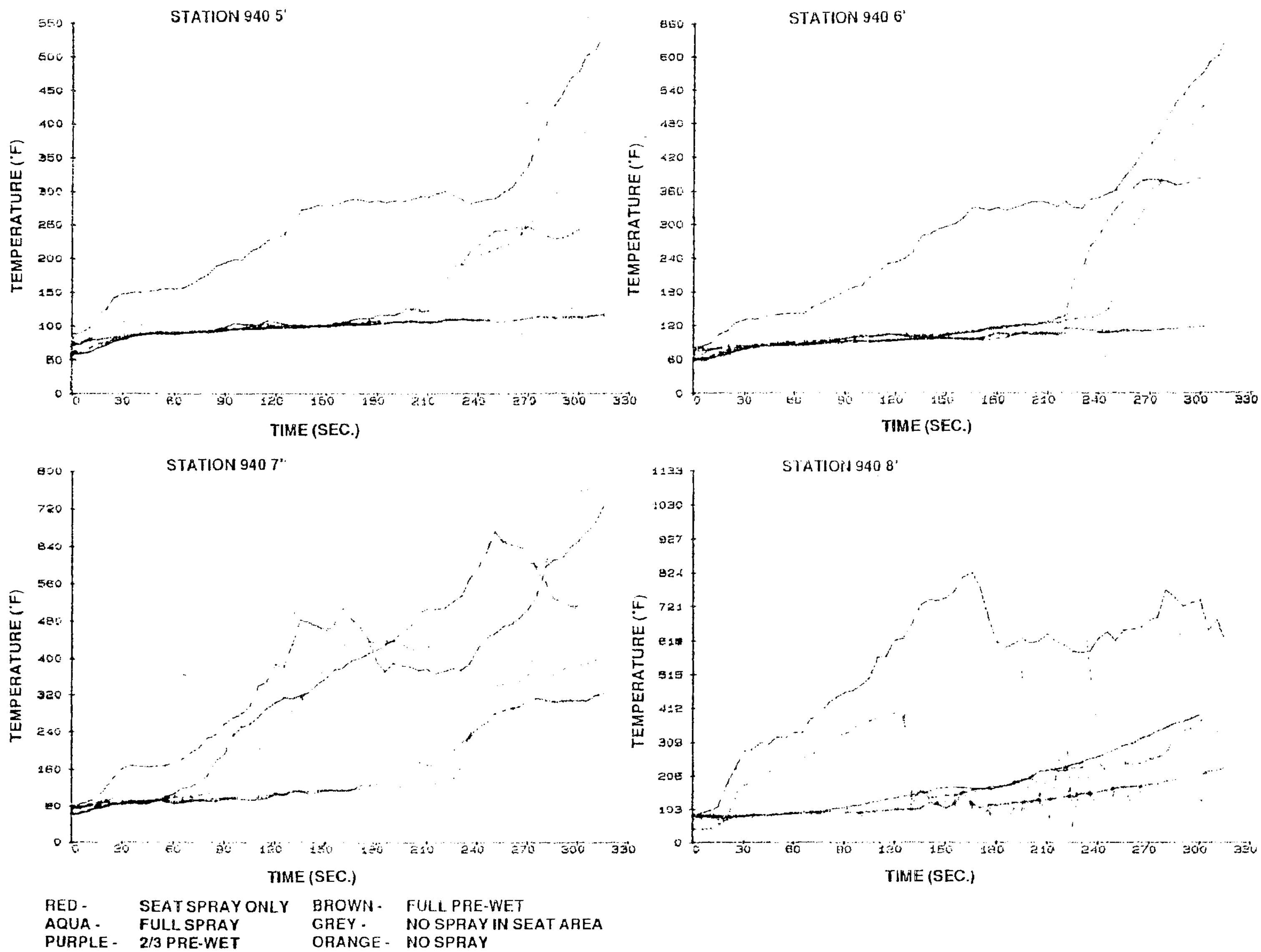

FIGURE 9. TEMPERATURE COMPARISONS -- STATION 940 -- 5 TO 8 FEET

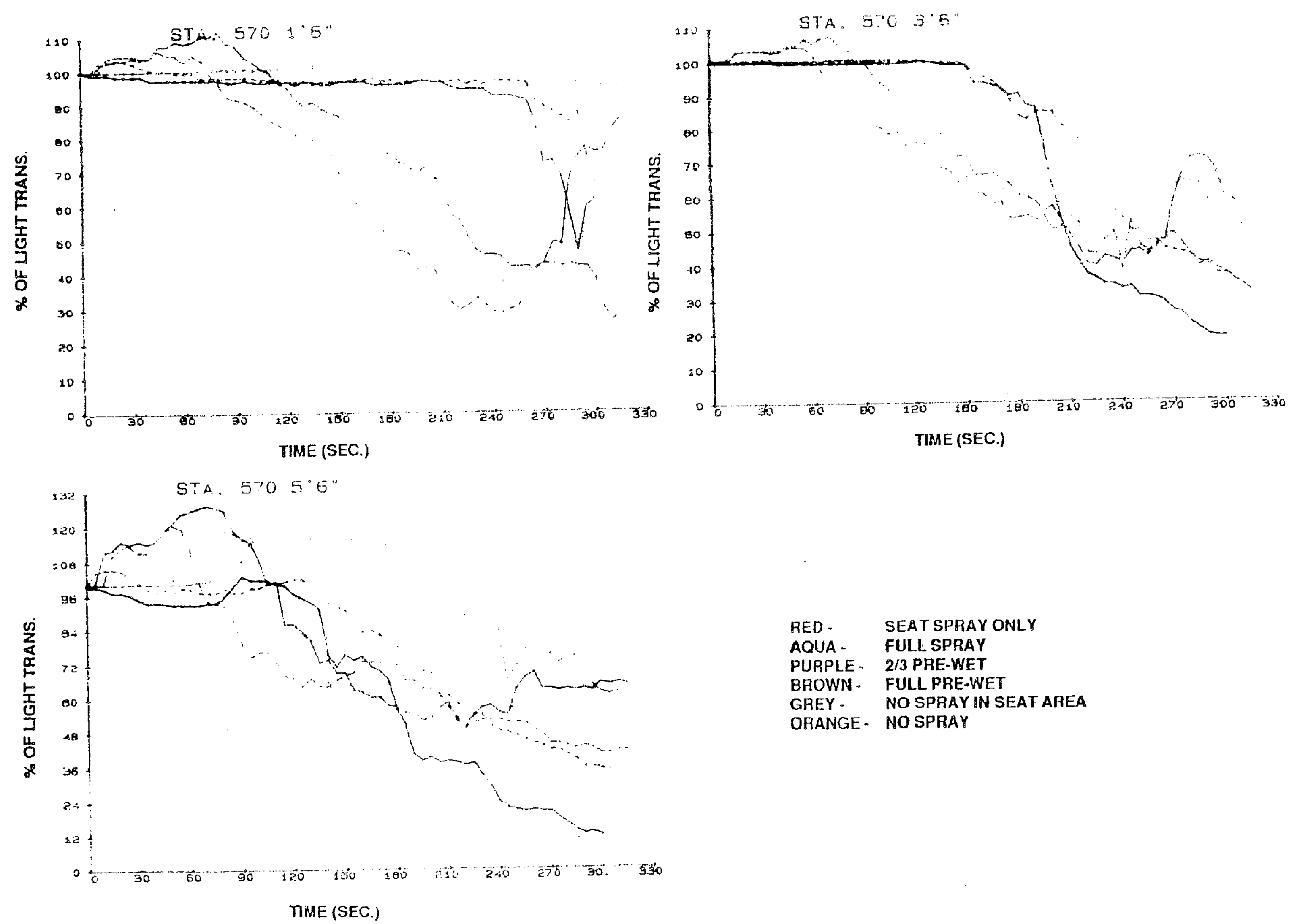

FIGURE 10. SMOKE COMPARISON STATION 570 -- 1 FOOT 6 INCHES, 3 FEET 5 INCHES, AND 5 FEET 6 INCHES

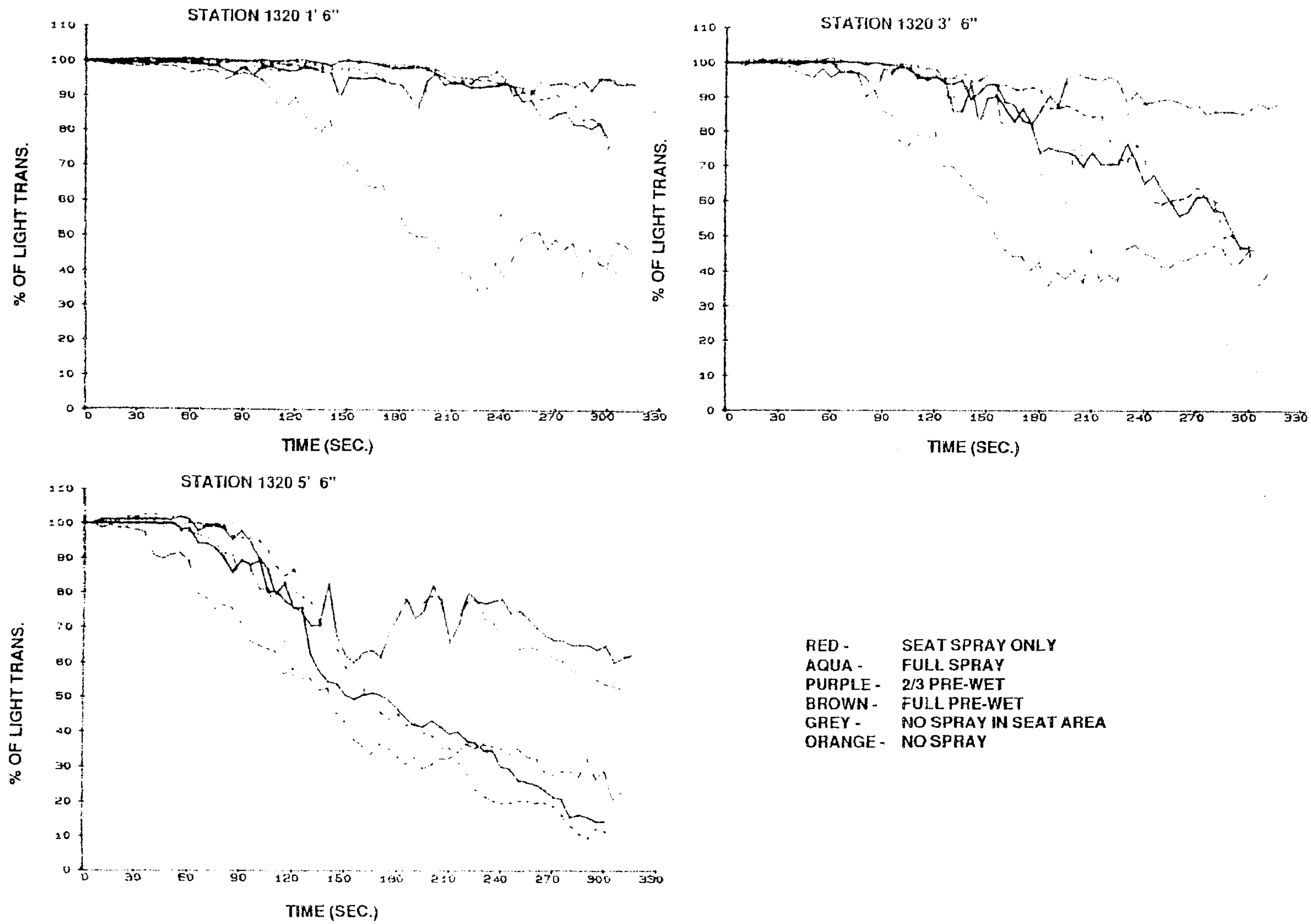

FIGURE 11. SMOKE COMPARISON STATION 1320 -- 1 FOOT 6 INCHES, 3 FEET 6 INCHES, AND 5 FEET 6 INCHES

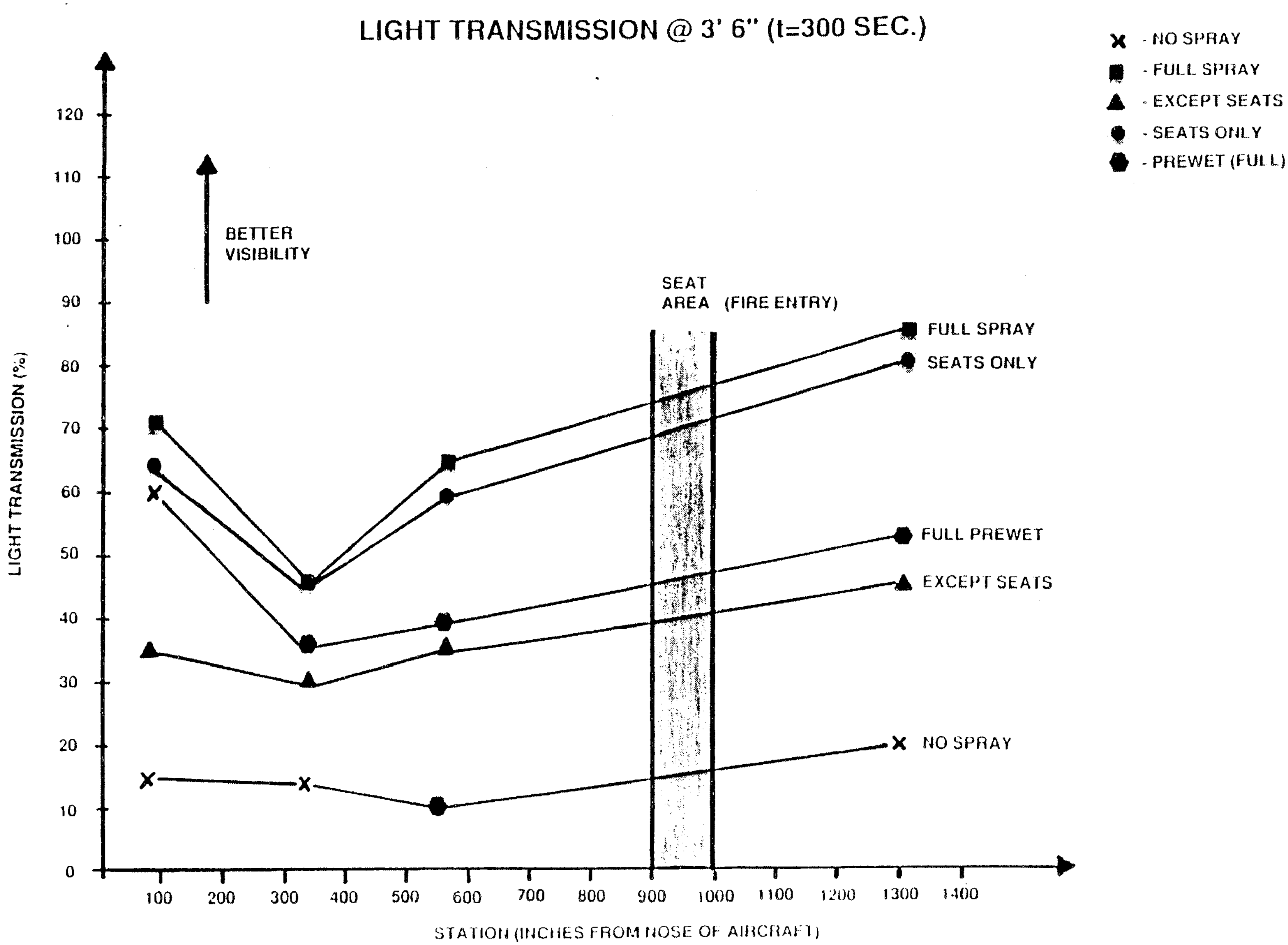

FIGURE 12. LIGHT TRANSMISSION AT 3 FEET 6 INCHES

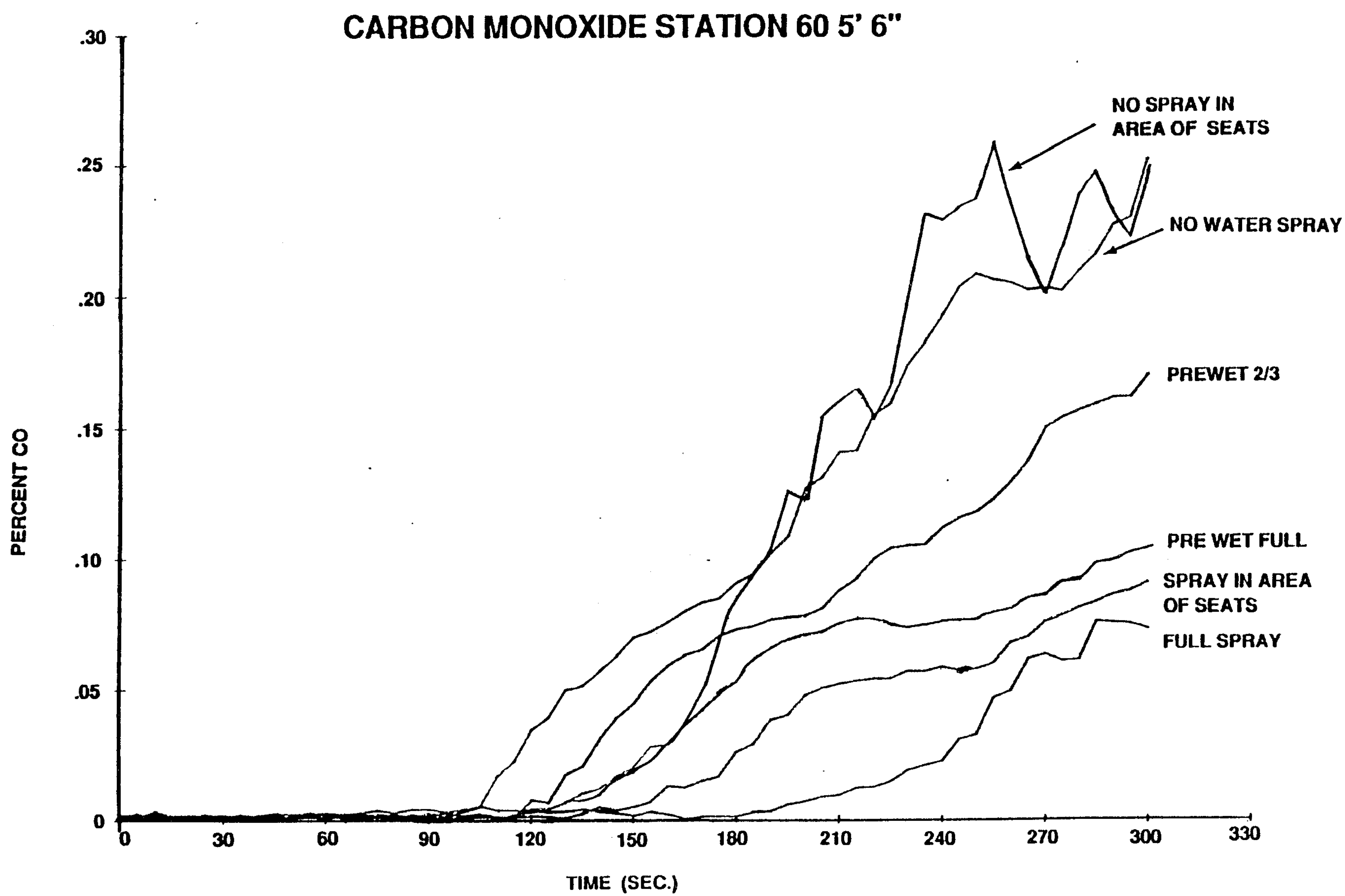

FIGURE 13. CARBON MONOXIDE STATION 60 -- 5 FEET 6 INCHES

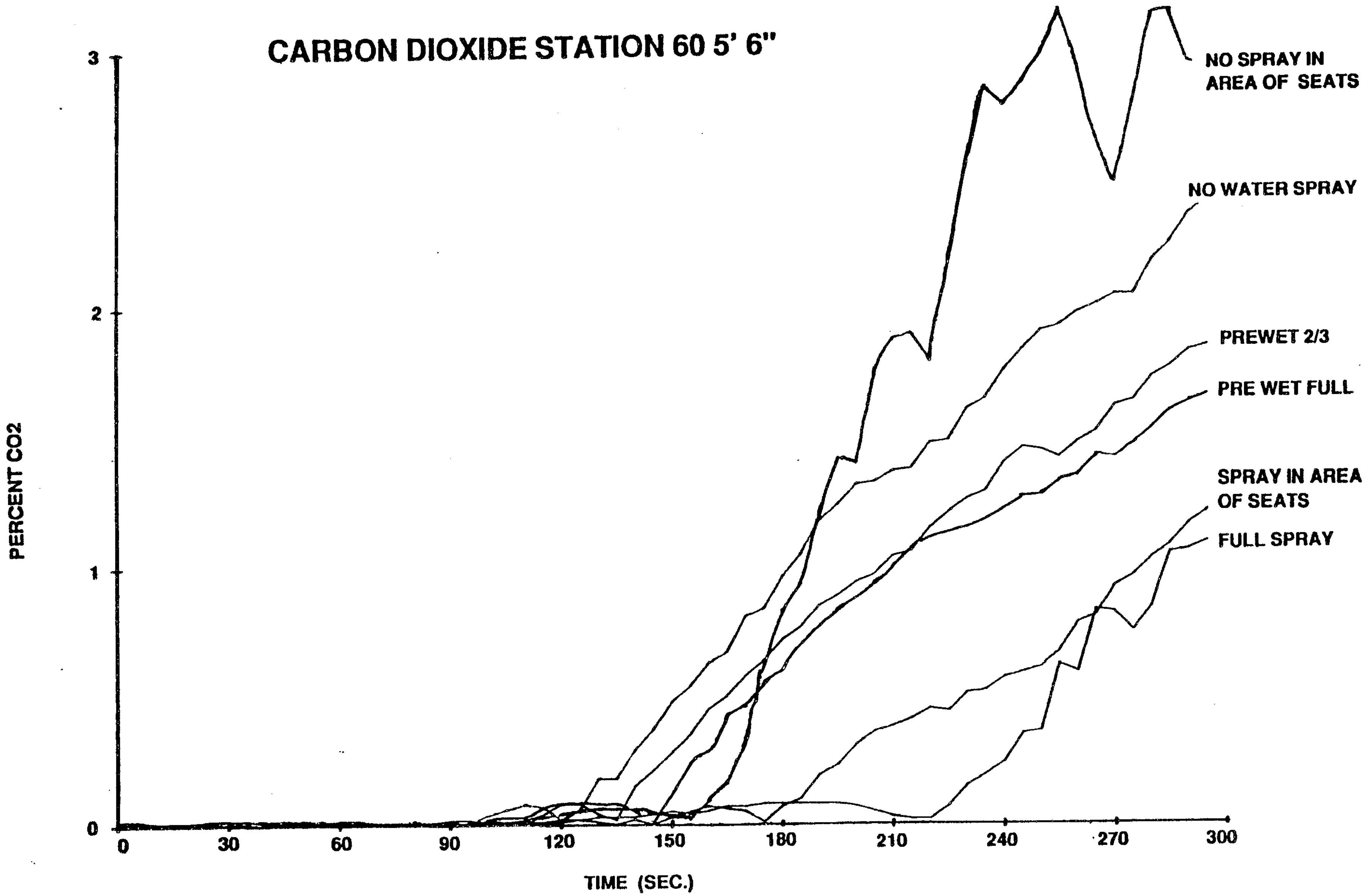

FIGURE 14. CARBON DIOXIDE STATION 60 -- 5 FEET 6 INCHES

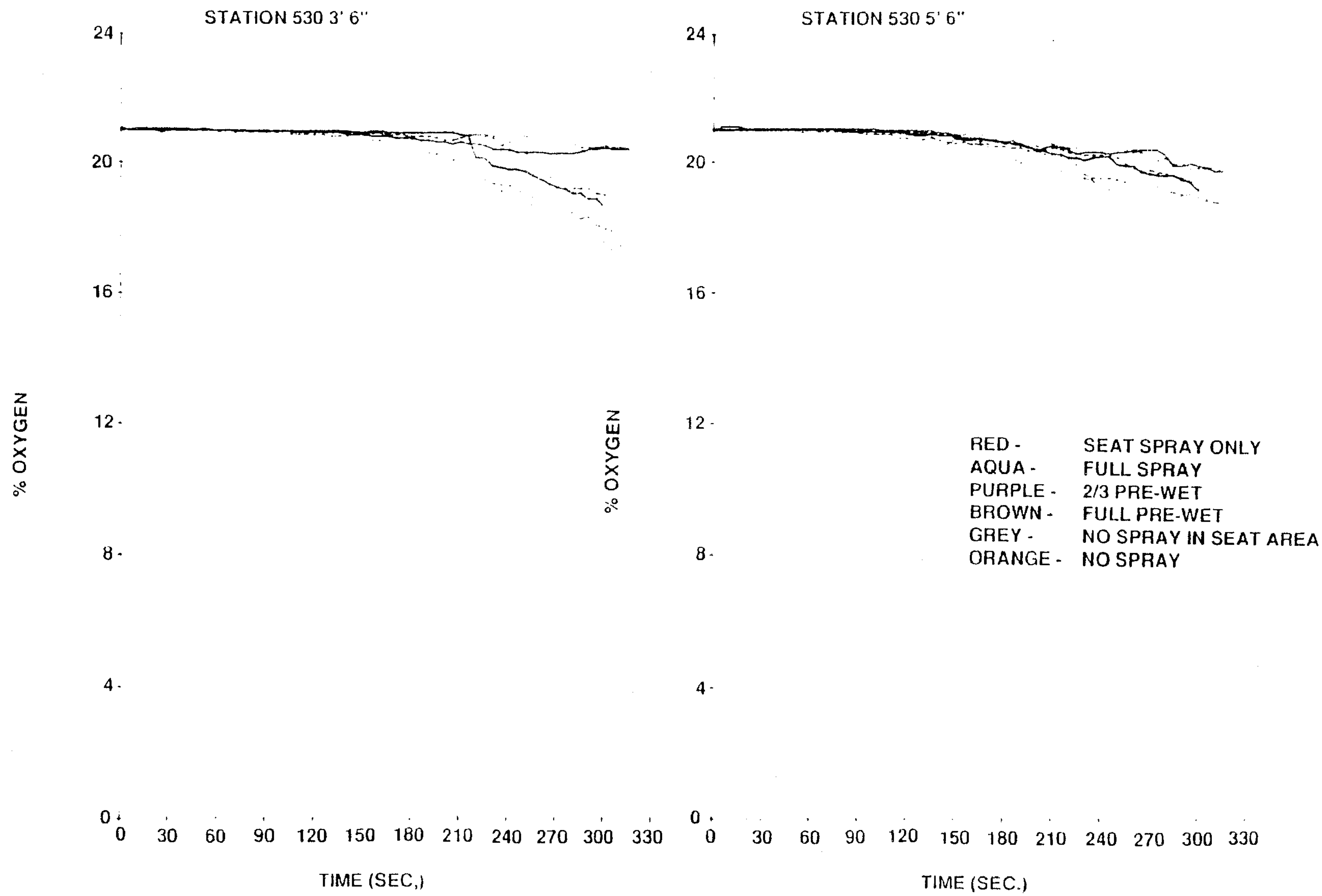

FIGURE 15. OXYGEN COMPARISON STATION 530 -- 3 FEET 6 INCHES AND 5 FEET 6 INCHES

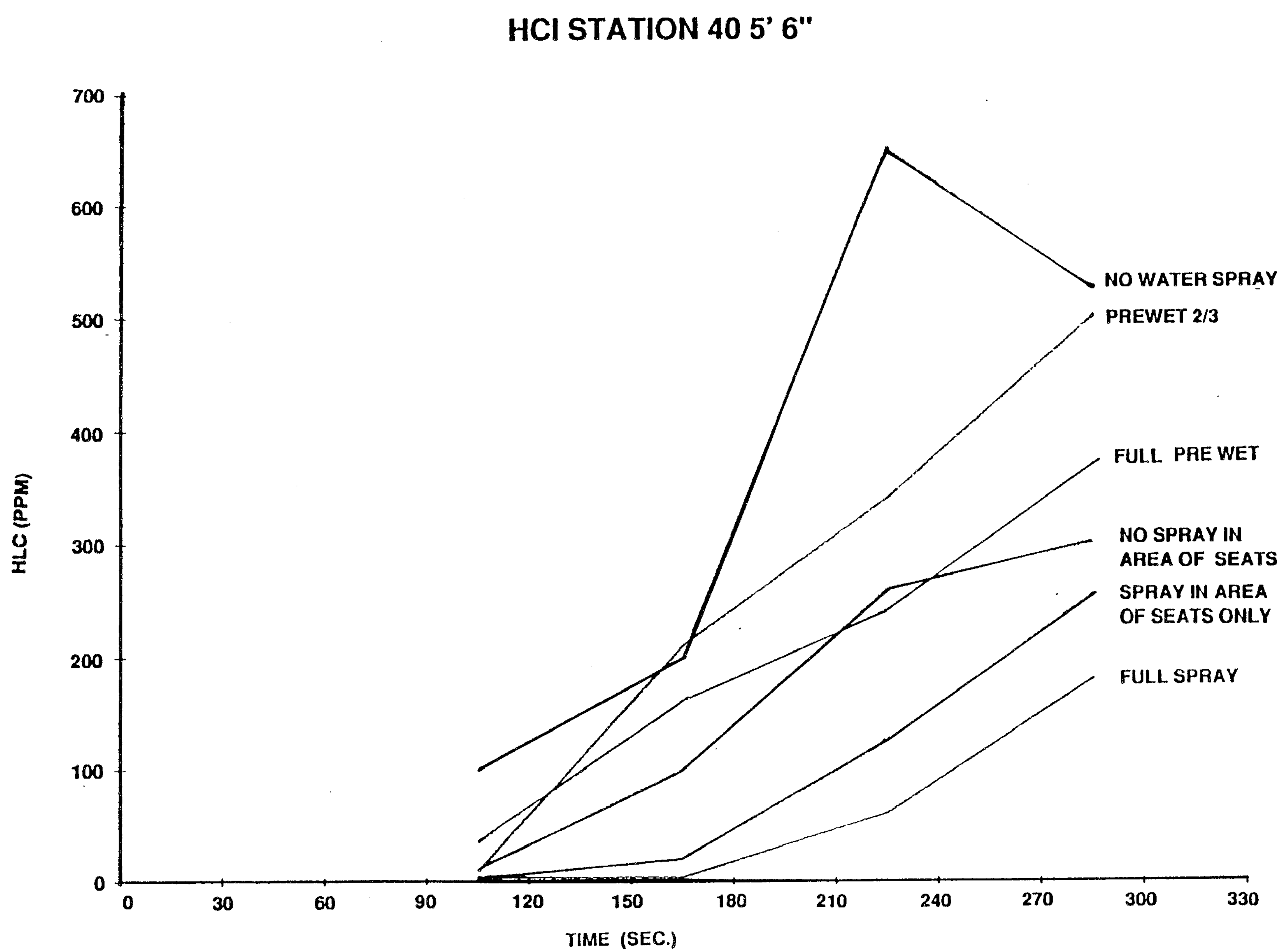

FIGURE 16. HCI STATION 40 -- 5 FEET 6 INCHES