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PRELIMINARY EVALUATION OF THE EFFECTS OF WIND AND DOOR OPENINGS ON HAZARD DEVELOPMENT WITHIN A MODEL FUSELAGE FROM AN EXTERNAL POOL FIRE

by

Thor I. Eklund

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FEDERAL AVIATION ADMINISTRATION

NATIONAL AVIATION FACILITIES EXPERIMENTAL CENTER

Atlantic City, New Jersey 08405

PREFACE

This evaluation was conducted as part of the Aircraft Systems Fire Safety Program, NPD No. 18-471, sponsored by ARD-520, Mr. Robert C. McGuire. The project number is 181-521-190 and the NAFEC Program Manager is Mr. Constantine P. Sarkos.

Messrs. Louis J. Brown, William E. Neese, and Joseph A. Wright assisted in preparation of the test article and in testing the model. Miss Ramona Hill assisted in analysis of the data.

Further information can be obtained from Thor I. Eklund, ANA-420, (609) 641-8200, extension 2322.

ABSTRACT

A series of tests was conducted on the effects of wind and door openings on hazard development within a model fuselage from an external pool fire. A one-quarter-scale model fuselage was designed and fabricated. Data from thermocouples, calorimeters, and motion pictures was documented for tests with and without an external wind. The cabin temperature, smoke accumulation, and ceiling heat flux are shown to be related. Opening upwind fuselage doors is shown to abet hazard development within the fuselage.

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INTRODUCTION

PURPOSE.

The purpose of this program is to experimentally evaluate promising methods of conducting small-scale cabin fire tests. These evaluations are motivated by a need for more economical but suitably realistic methods of aircraft fire testing. This report describes the experimental results from a series of approximately 50 fire tests on a 26.5 foot (ft) long fuselage model. The model was placed adjacent to pool fires, and the interior hazards were documented as to their dependence on fire size and door openings in the presence of winds.

BACKGROUND.

Previous work resulted in documentation of radiative heat flux from external quiescent pool fires through the doorway of a simulated fuselage (reference 1). Because of the large quantities of aviation kerosene carried aboard commercial jets, there remains the potential for large pool fires during an impact-survivable crash. The work on radiative fluxes showed that cabin materials in the vicinity of doorways can be subjected to high heat fluxes even in the absence of wind and without any flame penetration through the door.

Ongoing full-scale tests at the National Aviation Facilities Experimental Center (NAFEC) have been evaluating the effects of wind and pan size on fire penetration into a door on the side of a C-133 test bed (reference 2). These tests have demonstrated that wind has a significant effect on the hazard development within a fuselage from an external pool fire. As a result of these full-scale tests, it became apparent that earlier small-scale radiation tests (reference 1) should be extended to include wind and door opening effects. To meet this requirement, a fuselage model with floors, ceilings, and six doorways was fabricated. The model was built to be one-quarter the width of the C-133 test bed (reference 2), and the finished model is shown in figure 1.

EXPERIMENTAL OBJECTIVE.

The experimental objective of these wind-blown pool fire tests was to quantify the heat flux through a fuselage door in the presence of wind and determine any effects due to opening or closing selected doors. The testing involved fires with 1- and 4-ft square pans with wind created by exhaust fans in the NAFEC Building 205 components laboratory.

DISCUSSION

FABRICATION.

The fuselage model was made from mild steel in three sections. The sections were hinged together at their flanged ends to allow easy access for instrumentation and maintenance. The ducts were made from shaped and welded 0.062 inch (in.) mild steel reinforced with 2 in. x 0.187 in. bands. The flanges were made from 0.187 in. mild steel sheets. Each of the three sections was mounted on legs of 2.5 in. x 2.5 in. x 0.25 in. angle iron fitted with wheels. The center and rear sections were 10 ft long each, and the forward section was 6.5 ft long. Six doors were cut into the model. Each door measured 10 in. by 20.6 in. and each had an individual aluminum cover plate fastened by sheet metal screws.

Figures 2 and 3 show the fabrication within the duct work. A floor frame was constructed of 1 in. x 1 in. x 0.125 in. angle iron. This floor was covered first by galvanized iron sheets of 0.040 in. thickness, and then transite sheets of 0.25 in. thickness were laid over the metal. A layer of Kaowool was then fitted across the upper circumference of the duct. The Kaowool was held in place by chicken wire and further covered by fiberglass cloth which was sewn to the chicken wire with steel wire. Metal tabs were welded to the duct to support a transite ceiling. The maximum distance from the floor to the duct bottom was 20 in. The maximum distance from the ceiling to the duct top was 4 in. This gave a 2-ft distance between floor and ceiling in the test article. The doors to be exposed to pool fires were reinforced with additional steel strips to minimize warping from the heat.

Figures 4 and 5 show the interior of the finished product. Note that windows were placed in each end of the fuselage for photographic purposes. In addition, galvanized strips were used to secure the insulation around the floor and the doorways. Figure 6 shows a view of the fuselage opened at one of the hinged joints. The dolls in the figure are 1 ft in height. (Actually the dolls would have to be 16 in. in height for true simulation.) In the background of figure 6 is a thermocouple tree and a prototype smoke meter used in some of the early tests.

Figure 7 shows an overall view of the test bed at the fire door. The fuel pan was set in a water pan which was placed on a wheeled dolly with four scissor jacks. These jacks allowed easy leveling and height adjustment of the fire pan. Also visible in figure 7 are the carbon dioxide (CO_2) horns used to extinguish the fire as well as the water supply line used to fill the water pan and cool the calorimeters and radiometers.

Although reference 1 indicated that a 4-ft fuselage model was too large for accurate radiation data for fire sizes attainable in Building 205, it was also known that the floor-to-ceiling height should be a minimum of 2 ft if any attempt at Froude modeling is to be made. Consequently, this series of tests should be considered tentative as to results until larger fire sizes are attained in outdoor tests.

INSTRUMENTATION.

The instrumentation for the test series included two cup anemometers, five calorimeters within the fuselage, an external radiometer, two thermocouple trees within the fuselage, and various smokemeters. The tests were further documented by a minimum of three movie cameras. One movie camera viewed the external fire along the side of the fuselage. The second viewed the interior of the fuselage from outside the fuselage end windows with the fire situated at the opposite end of the fuselage. The third camera was located roughly halfway down the length of the fuselage and was focused in the region of the door facing the fire. In the earlier tests, a fourth camera was located on the opposite side of the fuselage from the fire. This fourth camera essentially looked from inside the fuselage out through the fire. However, the information derived from this camera was inadequate to warrant continued use. The first camera was used to evaluate the behavior of the external pool fire as a function of time. The second camera provided a qualitative measure of obscuration by smoke across the length of the fuselage. The third camera was used to evaluate fire penetration through the fuselage doorway. All cameras were synchronized to allow film development for split screen viewing.

The wind cup anemometers were Taylor Windscope model number 3105, and the wind velocities were manually recorded from the meter. The anemometers are called out in figure 7.

Data from calorimeters, smokemeters, and thermocouples were recorded remotely in a van adjacent to the test building. A heat shielded umbilical cord connected the sensors to the recorders. The interior calorimeter placements are shown in figure 8. The calorimeters were Hy-cal model C1300-A, and factory calibrations were used in the data analysis. Previous work indicated the importance of radiation to the floor. Consequently, two calorimeters were placed on the floor for these tests. A calorimeter was also placed in the ceiling because of the expected convective heat transfer at that location. Although two calorimeters were mounted on stands, one was considered as a backup. The heat flux to stand number 1, as shown in figure 8, was needed for comparison with results from reference 1.

The smokemeters presented a problem in these tests. Initially, identical devices to those used in the C-133 tests were used. However, the movie camera lights provided a significant portion of the light reaching the photo-detector. Consequently, the data from the smokemeters had no quantitative significance. Later in the test program, a laser system was devised which overcame this problem and gave satisfactory data.

Figure 9 shows one of the two thermocouple trees used in the tests. Each tree contained four chromel-alumel thermocouples. In these tests, the thermo-couples trees were located in the two end sections of fuselage. The short section of fuselage, 6.5 ft long, is considered the front, and the doors are 1R, 2R, 3R, 1L, 2L, and 3L according to aircraft notation. The front thermocouple tree was located 12 in. from the flange, and the thermocouples were 3, 8, 13.8, and 21 in. from the ceiling. The rear thermocouple tree had the thermocouples located 3 in. from the flange and at distances 2, 7.3, 13, and 21 in. from the ceiling. The thermocouple channels were 1 through 8 and were assigned to the thermocouples in the order stated above. A ninth thermocouple was positioned over the fuel pan to record the start of the fire on the Esterline Angus model D2020 thermocouple recorder. The tem-peratures were monitored every 4 seconds during a test.

The smokemeters and calorimeters were recorded on a Honeywell oscillograph as described in reference 1. The data traces were damped to cause limited time averaging on the oscillograph chart.

Figure 10 shows a view of the instrumentation leads entering the fuselage from the rear. It should be noted that access to the ceiling calorimeter is through a small hatch on the top surface of the fuselage. At each door of the fuselage, there is a removable transite section of flooring to allow easy transferral of floor calorimeters to a different door.

TEST PROCEDURE.

The tests described in this report are numbered 1 through 47. Two prior tests were accomplished with black and white movie film to check out the photographic system. Tests 1 through 30 were conducted with wind created by the building fans. Tests 31 through 47 were conducted in a quiescent environment.

Prior to each test, the test configuation was established as to model door openings, fire pan size and location, and wind environment. The model was placed 35 ft from the building roll-up door and parallel thereto. In tests 1 through 8, the roll-up door was opened to a height of 3 ft 4 in. and an opening 8.5 ft wide was made by blocking the remainder of the door opening with sheet metal. This opening was located so that the building fans would draw air directly over the fuel fire. Figure 11 shows a plan view of the arrangement.

In test 9 through 30 the fire pan was moved to the other end of the fuselage and the roll-up door was opened to a height of 4.5 ft. No blockage was employed, and the entire model was subjected to any winds caused by the fans.

In tests 1 through 30, 4 gallons of fuel was placed in the 4 ft x 4 ft pan or 1 quart in the 1 ft x 1 ft pan. The recording equipment and the cameras were started. Then the fire was remotely ignited by electrical spark. In the wind tests the fans were not started until 10 seconds into the test. This prevented the JP-4 vapors from being blown away from the fuel surface with subsequent ignition difficulty. The fire generally began to bend over the fuselage at 20 to 25 seconds into the test. Figure 12 shows a 1-ft fire, while figures 13 and 14 show views of the 4-ft pan fire. At 60 seconds, the fire was extinguished by CO_2 from a Cardox® system as shown in figure 15.

With no winds as in tests 31 through 47, the roll-up door was kept closed and the building fans off. The model was rotated 90 degrees (°) so the fire could be placed under the building peak to prevent building-induced fire plume bending as mentioned in reference 1.

The fuselage model was given a minimum of 20 minutes to cool between tests, and enough fresh fuel was added to bring the fuel level at least equivalent to the amount in the previous test.

The test duration was usually limited to 60 seconds, while the fire pans were constrained to 4-ft square because of the limited fire resistance of the test building.

RESULTS

HEAT FLUX.

Table 1 presents a listing of all tests run along with the position of the fire, the fire size, the wind speed, the doors open, and any comments needed for a clearer description. The doors are numbered according to standard practice— for example, 1R refers to the front starboard door while 3L refers to the rear port door. All fires were placed at either 1R or 3R, and the door at the fire pan was always open in a test.

Table 2 shows heat fluxes at 10-second increments for two calorimeters. The midplane calorimeter (C-9) took data for comparison with earlier quiescent pool fire data with open-ended ducts. The ceiling calorimeter (C-13) took data which would be indicative of increased heat flux caused by convective heat transfer from flames blown in at the ceiling. The midplane calorimeter was centered with respect to the model door. It was 10 in. above the model floor and 24 in. back from the door edge. The ceiling calorimeter was also centered with respect to the door and was located 6 in. from the edge of the ceiling. The data shown in table 2 start at 30 seconds into the test. Because of the delay in establishing wind within the building, data taken through the first 20 or 25 seconds would be representative of a zero-wind condition.

Generally, the heat fluxes to the midplane calorimeters in the zero-wind tests are of the same magnitudes reported in reference 1. This is significant because the tests described in reference 1 were with open-ended ducts and without a floor or ceiling.

Table 3 shows representative data from one of the floor calorimeters (C-1) during the first 14 tests. This calorimeter was 2.5 in. from the door edge and the heat fluxes in this region near the door edge are significantly higher than those shown by the calorimeters in table 2.

TEMPERATURES.

Figures 16 through 23 show plots of temperature rises during the tests. Each figure shows the results of a different series of tests. The difference between the thermocouple reading before the test and the heated temperature during the test is designated by ΔT. Shaded regions at the bottom represent the tests where the temperature of the top thermocouple closest to the fire rose less than 50 degrees Fahrenheit (°F) in the course of the test. Most of these tests were of 60 seconds maximum duration, so it is possible that significant additional temperature increases would occur if the tests had been of longer duration.

Also, because of the short test duration, the rise of the lower thermocouples was small. Figure 24 shows the placement of the thermocouples, and figures 25 and 26 show two examples of the history of lower thermocouple height readouts.

Of particular interest are the results of tests 4, 5, and 6 on figure 16 and the results of tests 46 and 47 on figure 23. In all these tests, there was an interior fire. The interior fires of 4, 5, and 6 resulted from fuel vapors on the end wall of the model, while the interior fires of tests 46 and 47 resulted from placement of some typical interior materials near the model doorway. The debris from one of these material tests was recovered and photographed for figure 27.

Since these five tests were run under different door opening configurations and both with and without wind, they provide strong evidence that an interior fire will generate a heat and smoke hazard regardless of the particular wind conditions or specific door openings Two additional tests were conducted to determine whether the ventilation rates that prevented interior smoke development could also purge an existing heavy smoke concentration in the fuselage. Test 48 and 49 were run at the same conditions as tests 31, 32, and 33 on table 1 to assure a heavy smoke accumulation within the fuselage. At the start of the tests, only the door at the fire, 3R, was open. There was no wind, and the roll-up door of the facility was closed. In test 48, the 1R, 2R, 1L, and 2L doors were opened at 35 seconds into the test. In test 49, doors 1R, 2R, 1L, and 2L were opened at 40 seconds into the test. In neither test did opening the doors result in clearing of the smoke. Thus, when heavy smoke fills the fuselage from either an interior fire or an external fire, the smoke cannot be removed in a zero-wind situation simply by opening more doors.

A dashed line is drawn on the figures at the 50 °F mark, as this represents an empirical prediction of the smoke hazard developed. Generally, there is a significant smoke hazard only when the temperature rises more than 50 °F at the ceiling thermocouple closest to the fire.

MOTION PICTURES.

Table 4 shows the type smoke hazard evident during the test as documented by the movie camera viewing the entire length of the model. These movies showed, in cases of total obscuration, that a smoke layer moved down the fuselage at approximately 3 ft per second. Obscuration resulted when the smoke layer hit the end bulkhead and turned down over the view window. The smoke layer initially was stratified at the ceiling.

The external camera showed that the fire was not bent by the wind until approximately 25 seconds into a test. Apparently there was a 15-second delay between turning the building fans on and development of a wind through the test building.

The interior camera, halfway down the fuselage, provided significant information on both flame penetration and interior gas movements. Flame and smoke penetration generally proceed by pulsations at the cabin ceiling. In tests where the door opening configuration resulted in no smoke accumulation, a type of breathing of the fuselage was evident. A fire pulsation would result in some smoke at the ceiling in the vicinity of the doorway. This smoke would gradually flow back to the door along the ceiling and out in the fire. Additionally, any vapors that would come off the floor as it was radiatively heated could be observed flowing out the door and into the fire.

COMPARISONS.

Comparing the temperature, heat flux, and visibility data clearly show a strong relation between temperature, smoke obscuration, and ceiling heat flux. Table 4 summarizes this relationship by listing temperature and ceiling heat flux as a function of test number and door openings. Smoke obscuration is also included as total obscuration (TO), heavy smoke (HS), light smoke (LS), or no smoke (NS). From this data table, some tentative comments can be made about door openings and interior fire effects. When no wind is present the interior fire hazard is severe if the fuselage door at the fire is open while all others are closed. There is usually no heat or smoke at all when even one additional door is opened. When only the door at the fire is open and a wind is blowing the fire towards and over the fuselage, the interior heat and smoke hazards are again consistently severe. Opening additional doors upwind of the fuselage results in minimal hazards since air apparently flows through the fuselage and out into the fire. In this way, flame penetration is reduced. Opening downwind doors resulted in no hazard in test 16 and intermediate cabin hazard in test 24. Opening both upwind and downwind doors generally results in minimized interior hazards.

A ceiling heat flux of above 0.7 British thermal units per square foot second (Btu/ft^2 s) at 50 seconds generally corresponds to a smoke and temperature hazard. Below this value there will generally be no smoke. Flame penetration through the door is indicated by high ceiling heat fluxes. As the products of combustion flow down the model ceiling, the thermocouples sense higher temperatures and the smokemeters sense more smoke.

The trends relating cabin hazards to wind and door openings are developed from the results of tests 9 through 24. In tests 1 through 8, smoke occurred in all tests. This was caused by the partial blockage of the building roll-up door. In these eight tests, the wind was directed at the fire and the 1R door. The other doors consequently were not subjected to aerodynamic forces which would have caused a purging airflow through the model. The contrast in results between these eight tests and tests 9 to 24 demonstrate that the entire fuselage must be immersed in wind to avoid spurious test conditions.

Additional anomalies are apparent in tests 25 through 30 on table 4. In these tests, smoke always occurred in the cabin even though the entire fuselage was immersed in the wind. The cause is probably the small size of the fire. With a large fire covering the entire fuselage door, the products of combustion flow up over the fuselage. The fire is not affected by the presence of the door. However, when the fire is of the same size as the door or smaller, the wind can easily push the fire plume into the door. Hence, it is apparent that the fire pan width to door width ratio is an important experimental parameter. This is due to aerodynamic considerations as well as the radiative considerations discussed in reference 1.

CONCLUSIONS

Preliminary tests of the effects of an external pool fire on a quarter-scale model fuselage lead to five conclusions:

1. The number and location of door openings have a strong effect on the interior cabin hazard development.

2. The presence of end walls provides a turning point for smoke with consequent implications to location of emergency exit lights.

3. Interior cabin temperatures, smoke obscuration, and ceiling heat fluxes are all related.

4. The entire aircraft fuselage must be immersed in a wind to determine the effects of door openings on interior hazard development.

5. Fuel fire or material fire within the cabin will cause smoke buildup regardless of the door opening configuration.

RECOMMENDATIONS

The preliminary tests indicate that future testing should be directed at the following objectives:

1. Since temperatures within the model were generally survivable but rising, tests should be conducted for longer time periods and under wind conditions from the start.

2. Because of the significant difference in heat fluxes from the 1-ft fire and 4-ft fire, tests should be conducted with a larger pan fire.

3. Because of the observed fluid mechanics of the smoke movement, consideration should be given to the effect of seats and bulkheads on interior hazard development.

4. Full-scale cabin fire tests should include evaluation of the effects of door openings on test results.

REFERENCES

1. Eklund, T. I., Pool Fire Radiation through a Door in a Simulated Aircraft Fuselage, Federal Aviation Administration, National Aviation Facilities Experimental Center, Report No. FAA-RD-78-135, 1978.

2. Sarkos, C. P. and Hill, R. G., Preliminary Wide Body (C-133) Cabin Hazard Measurements During a Postcrash Fuel Fire, Federal Aviation Administration, National Aviation Facilities Experimental Center, Report No. NA-78-28-LR, 1978.

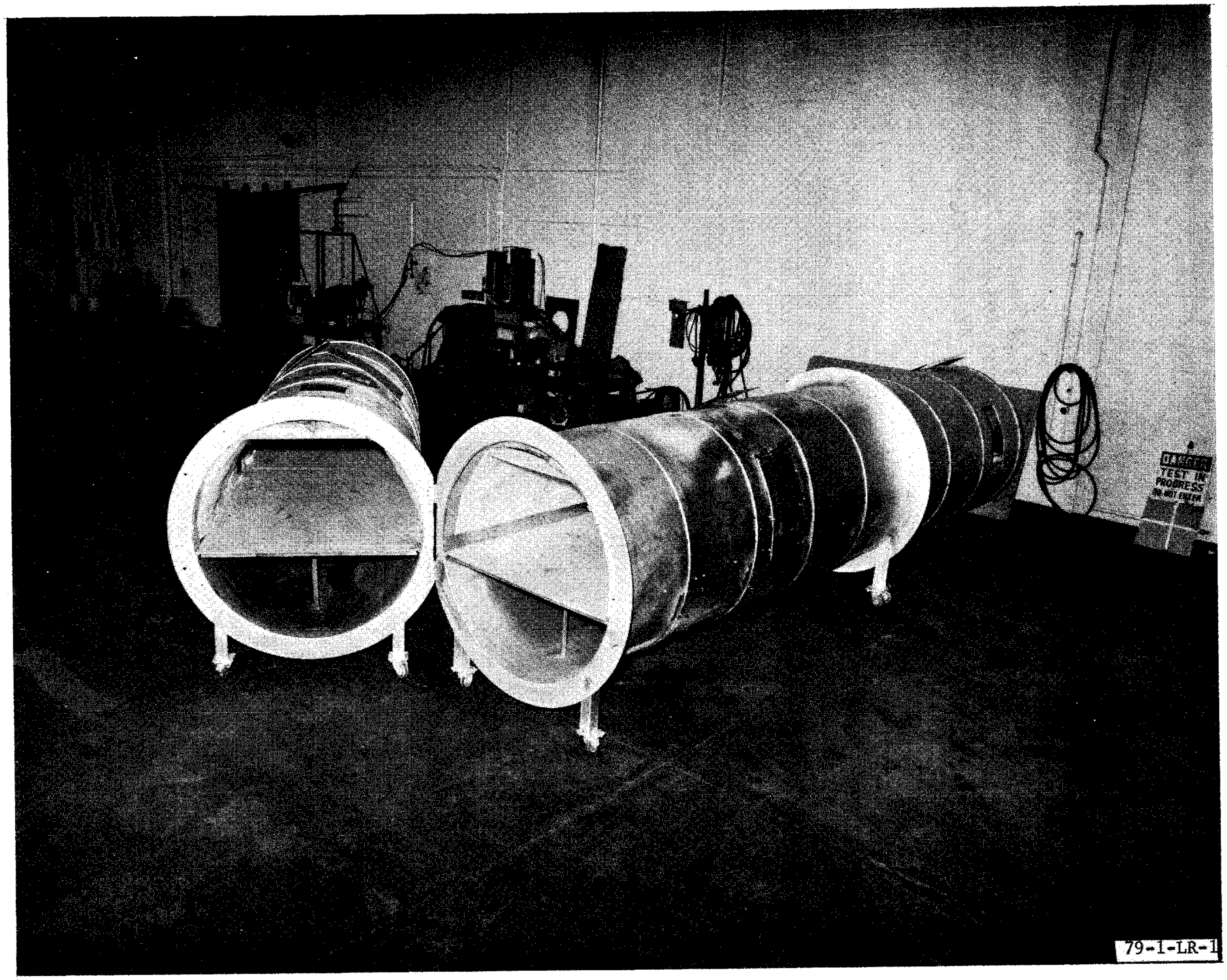

FIGURE 1. FUSELAGE MODEL

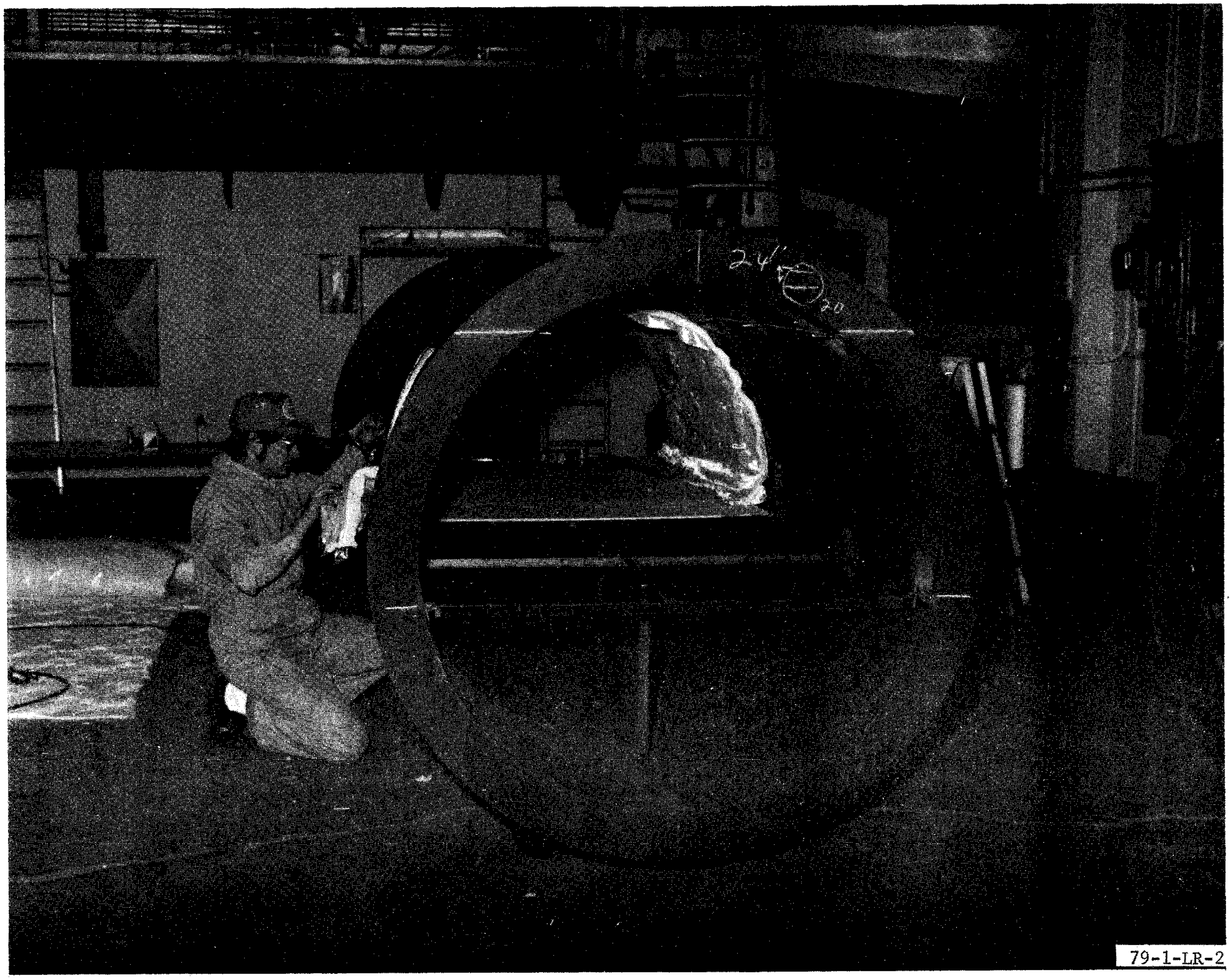

FIGURE 2. FLOOR CONSTRUCTION

FIGURE 3. MODEL INSULATION

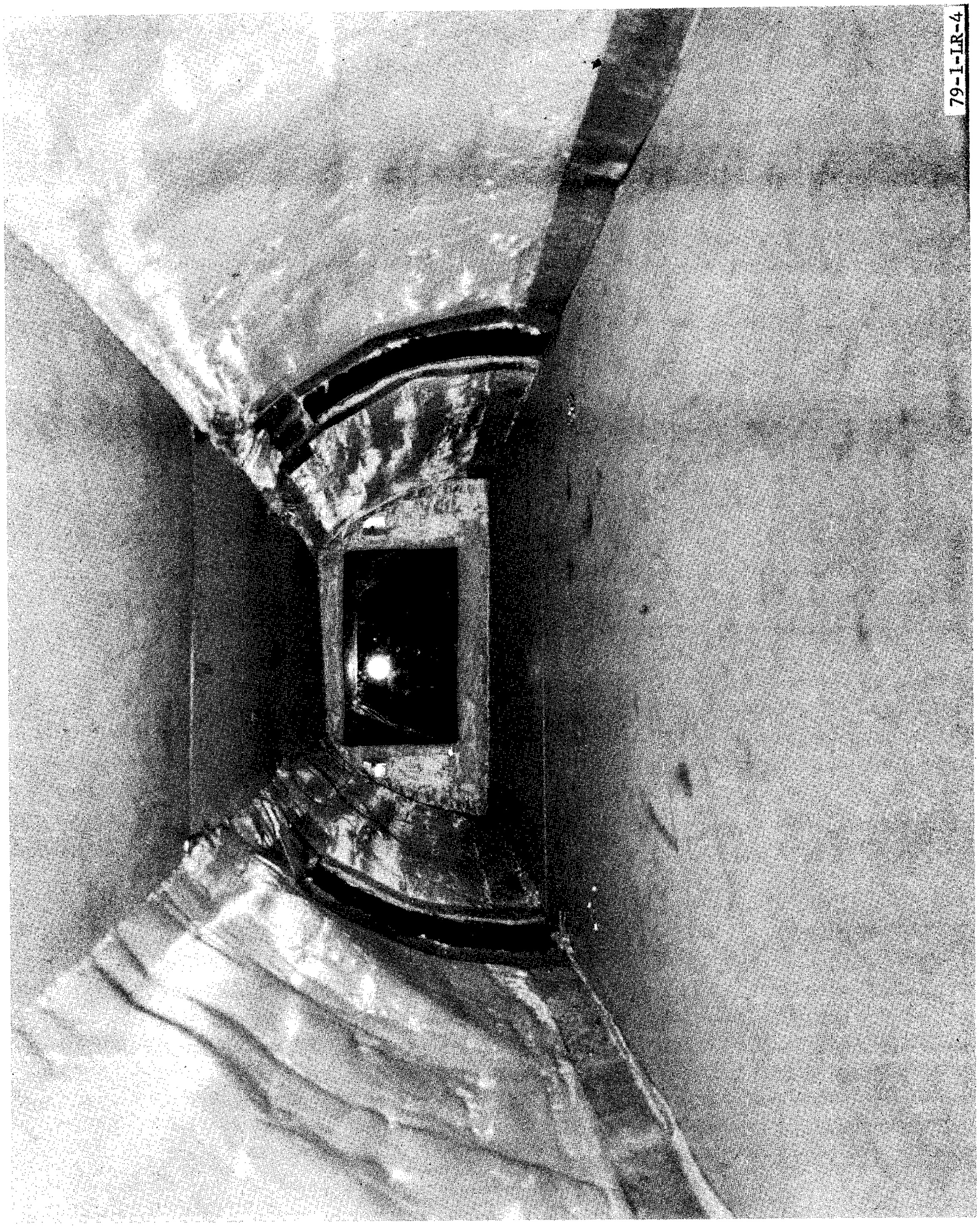

FIGURE 4. COMPLETED INTERIOR

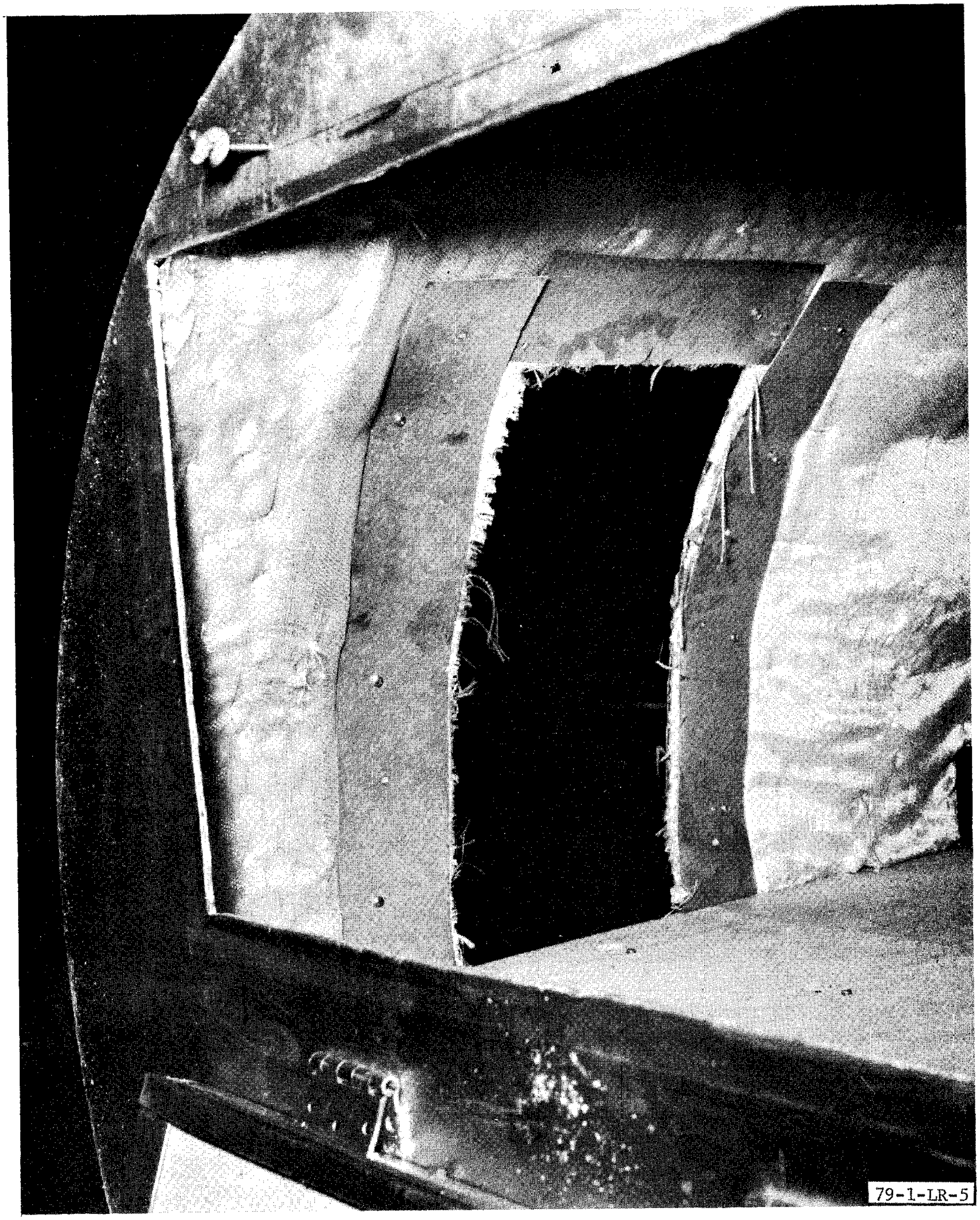

FIGURE 5. INTERIOR VIEW OF DOOR OPENING

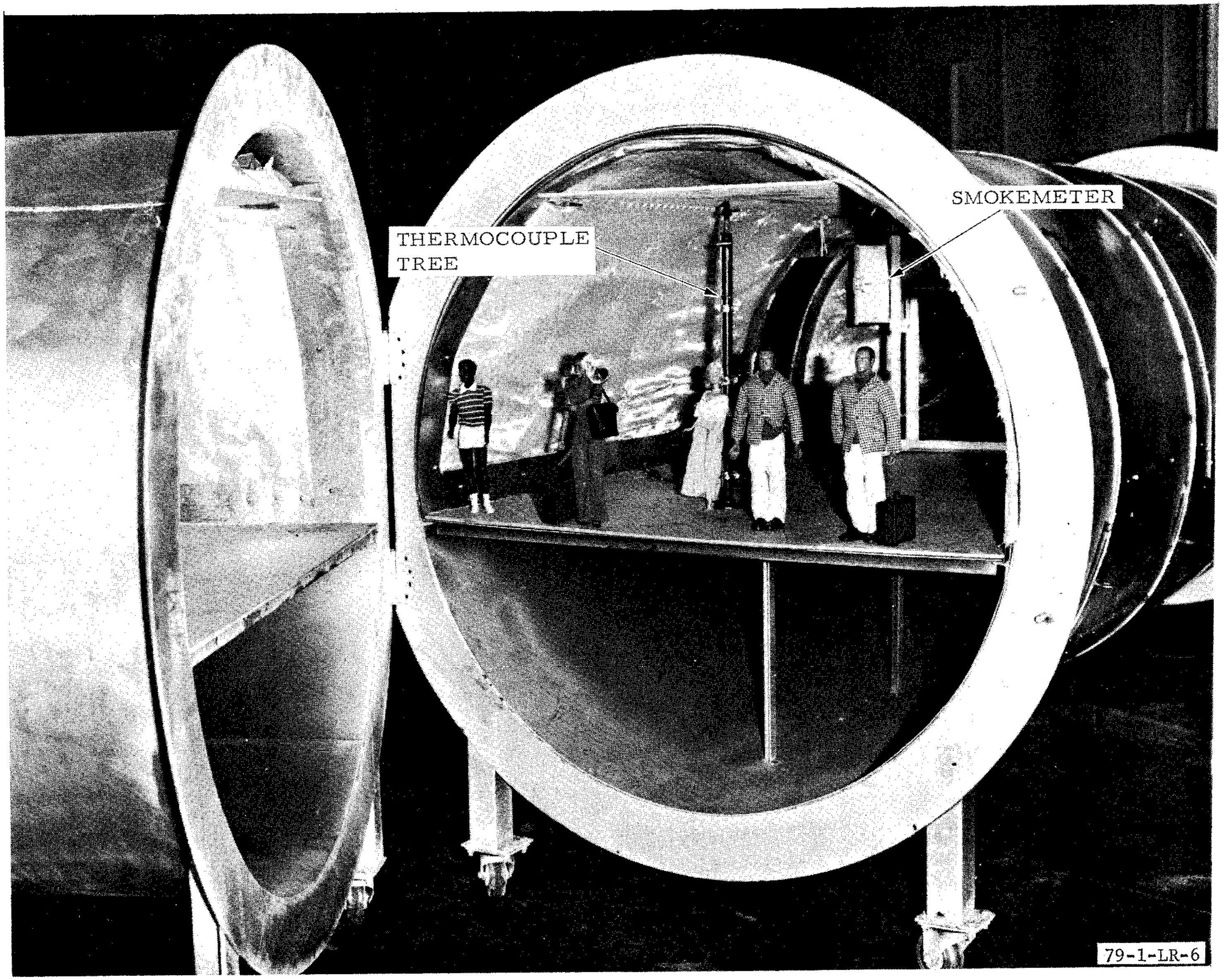

FIGURE 6. CUTAWAY WITH FIGURES

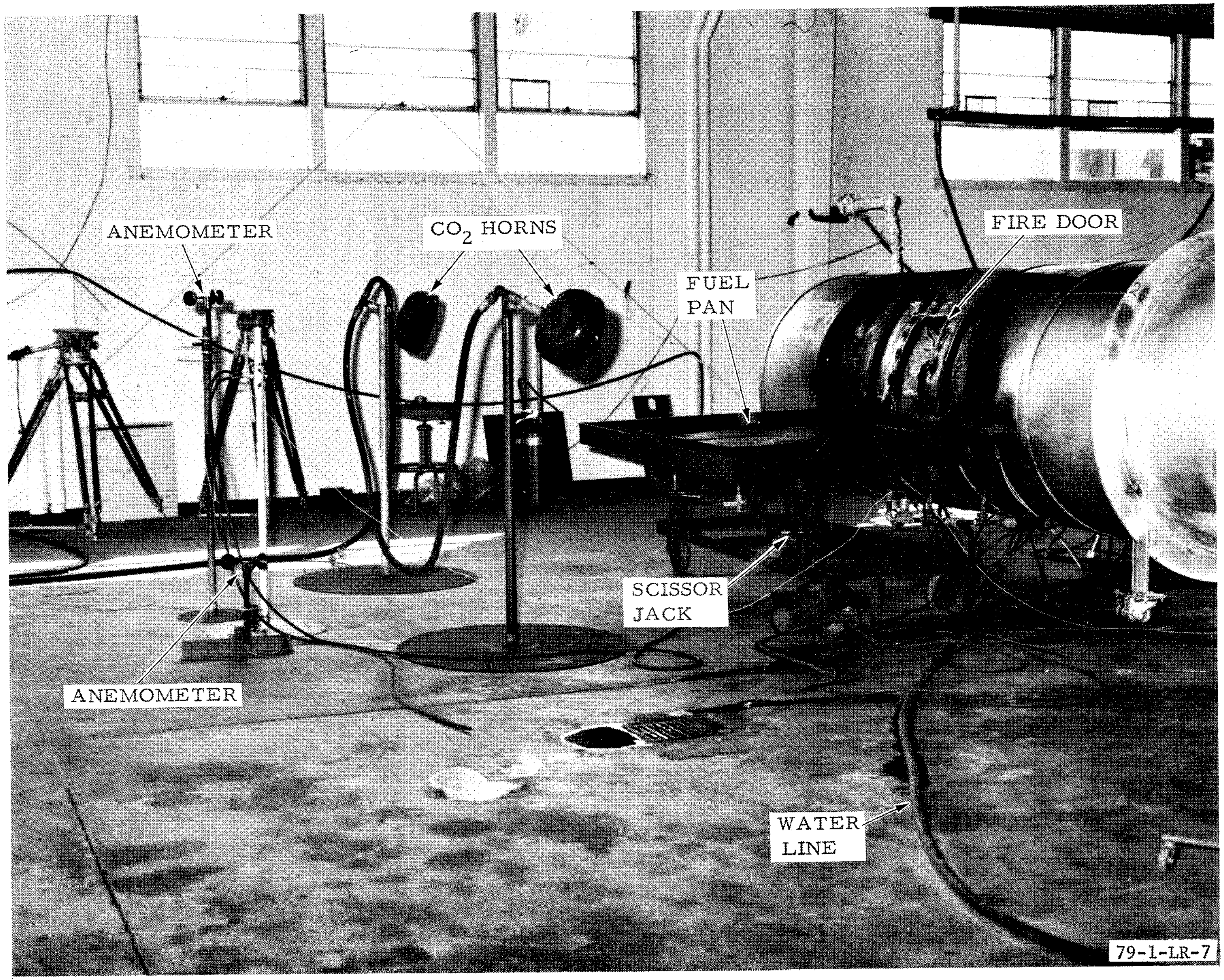

FIGURE 7. OVERALL TEST CONFIGURATION

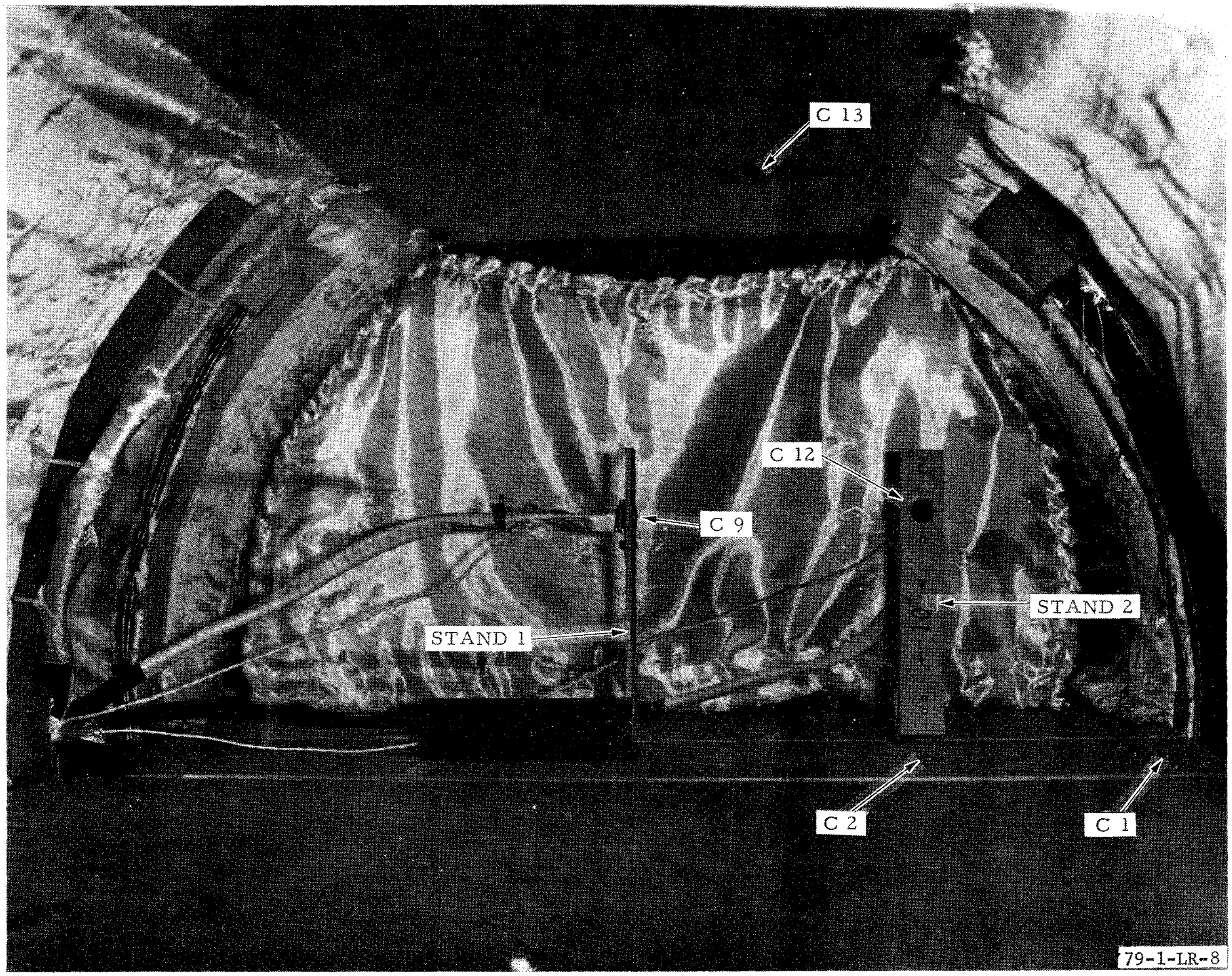

FIGURE 8. INTERIOR CALORIMETERS

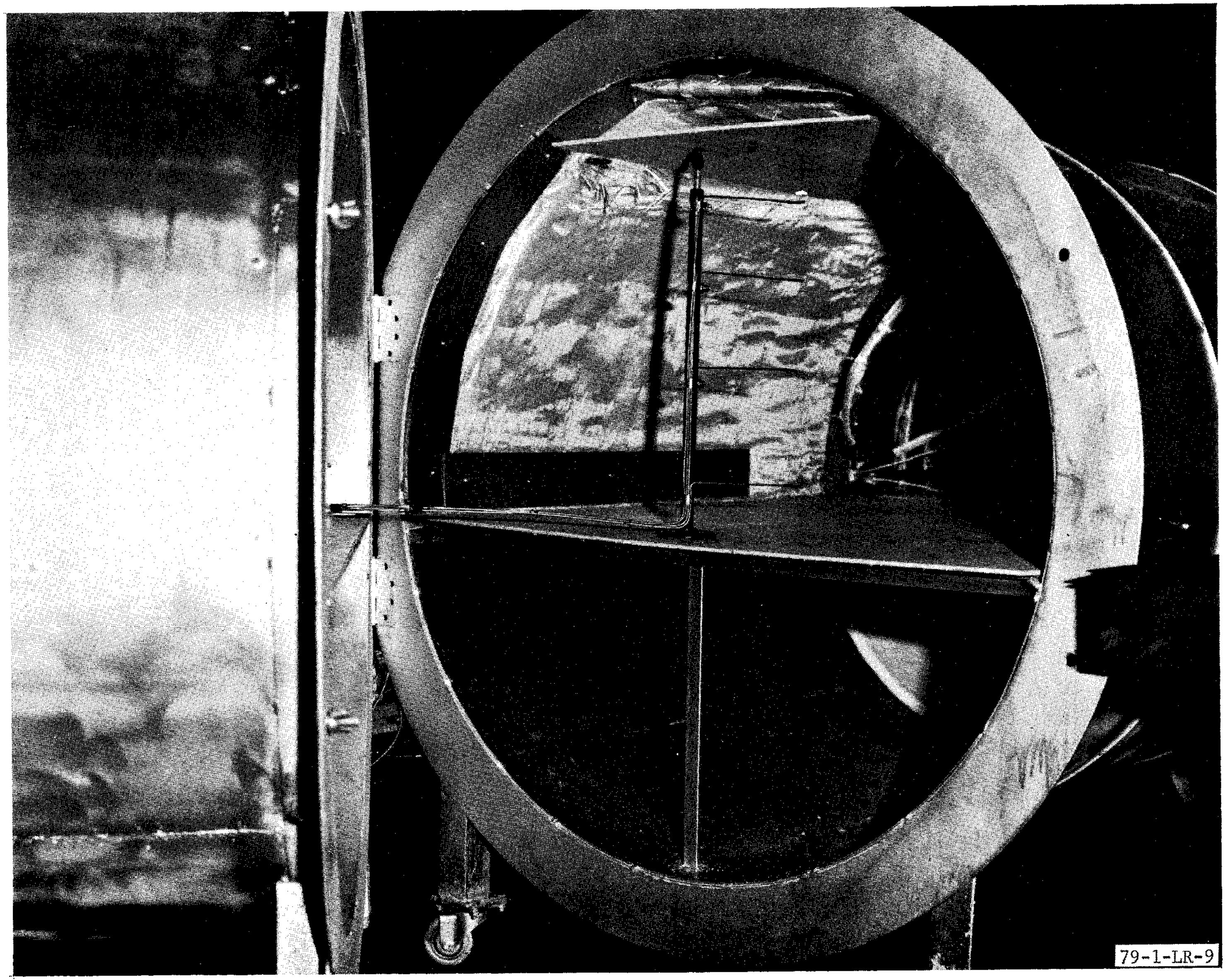

FIGURE 9. THERMOCOUPLE TREE

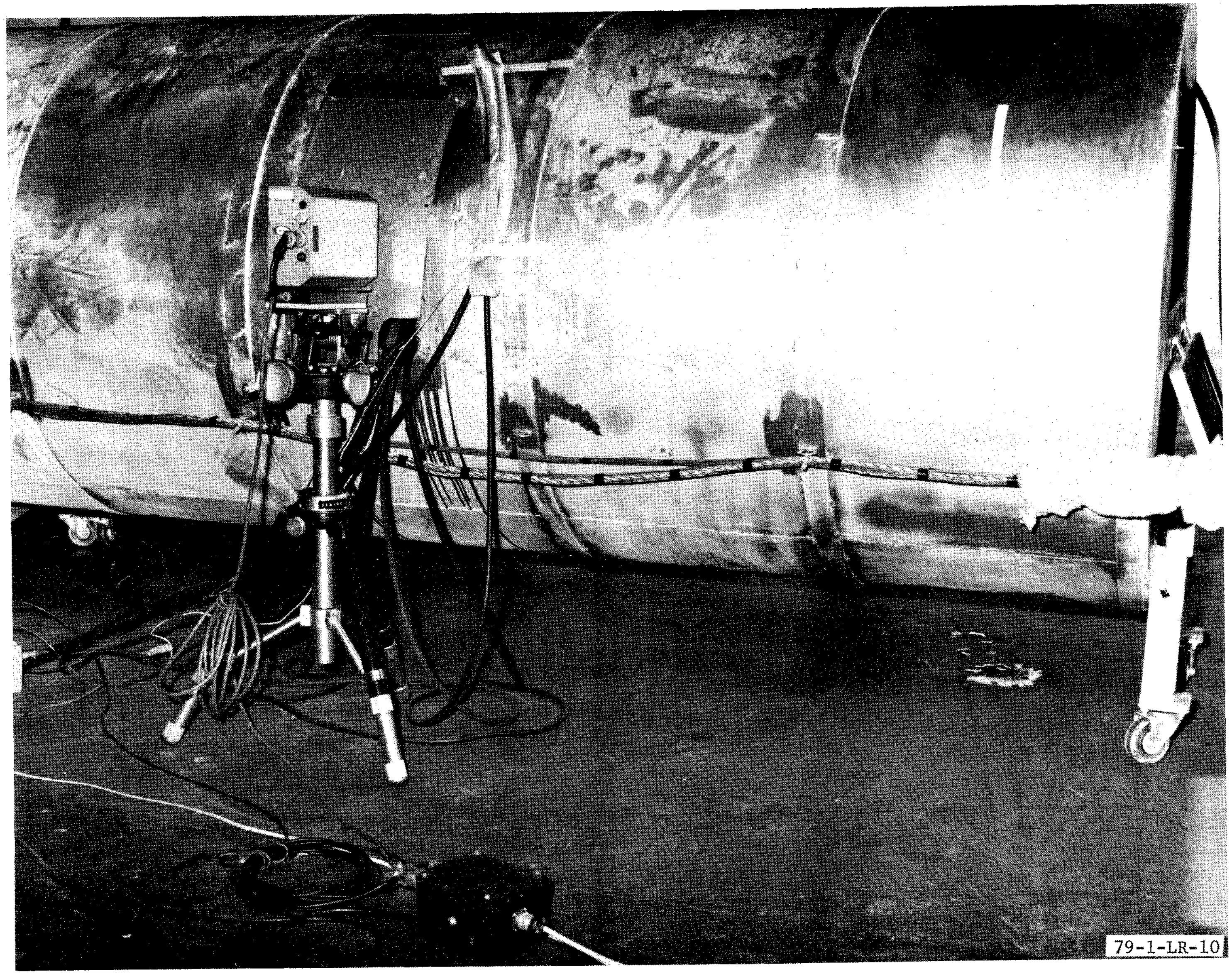

FIGURE 10. INSTRUMENTATION LEADS AND MOVIE CAMERA

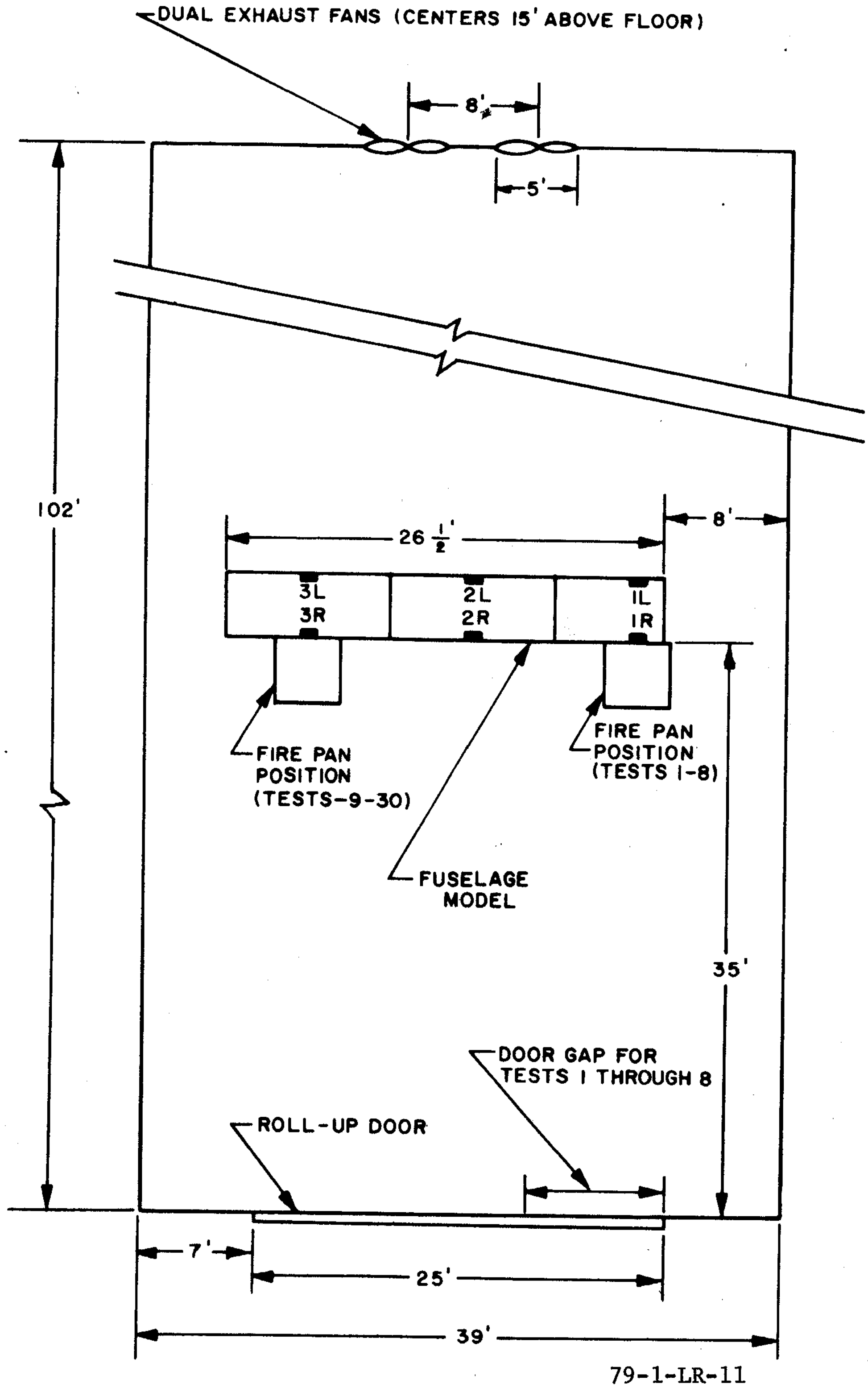

FIGURE 11. PLAN VIEW OF TEST BUILDING

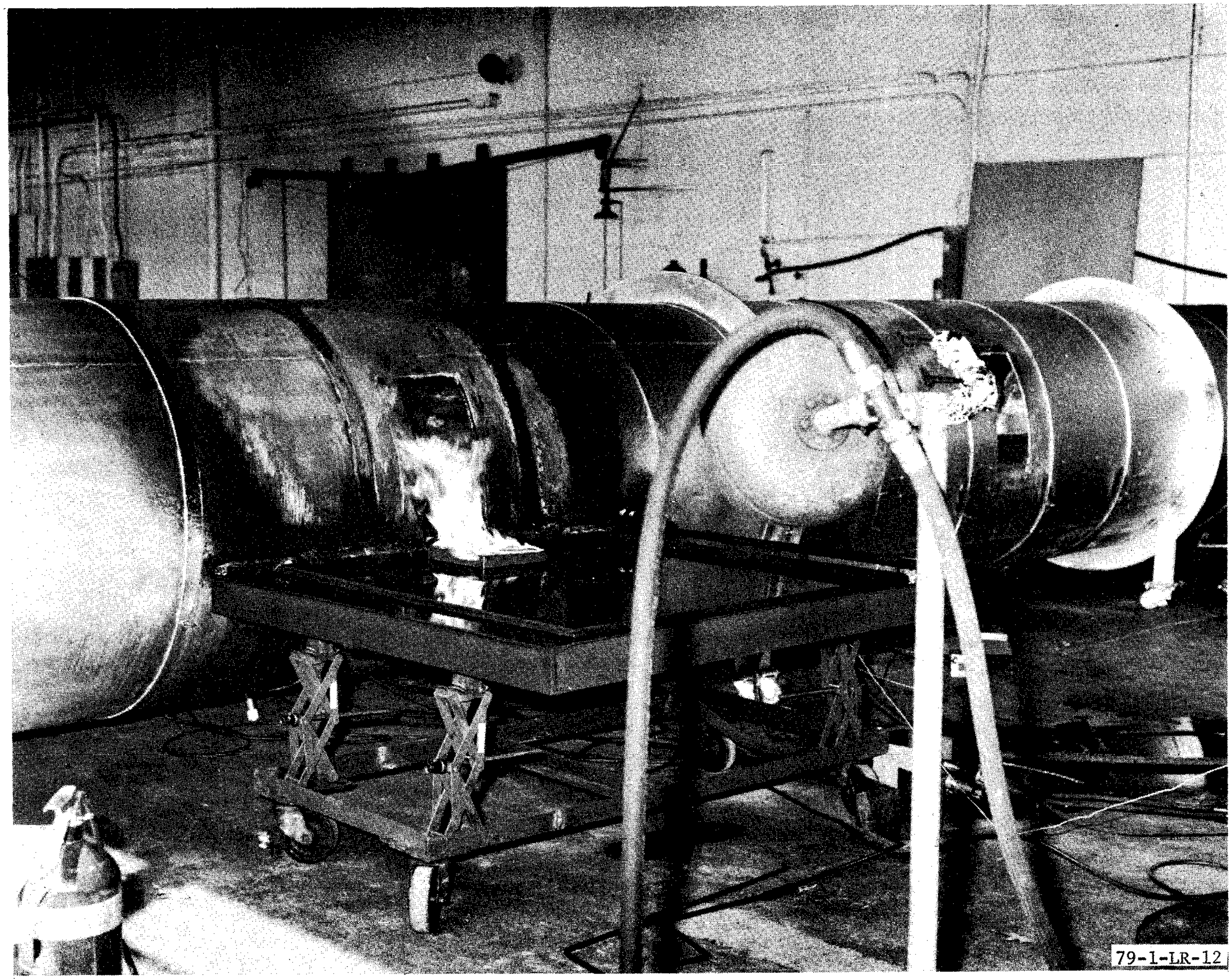

FIGURE 12. ONE-FOOT PAN FIRE

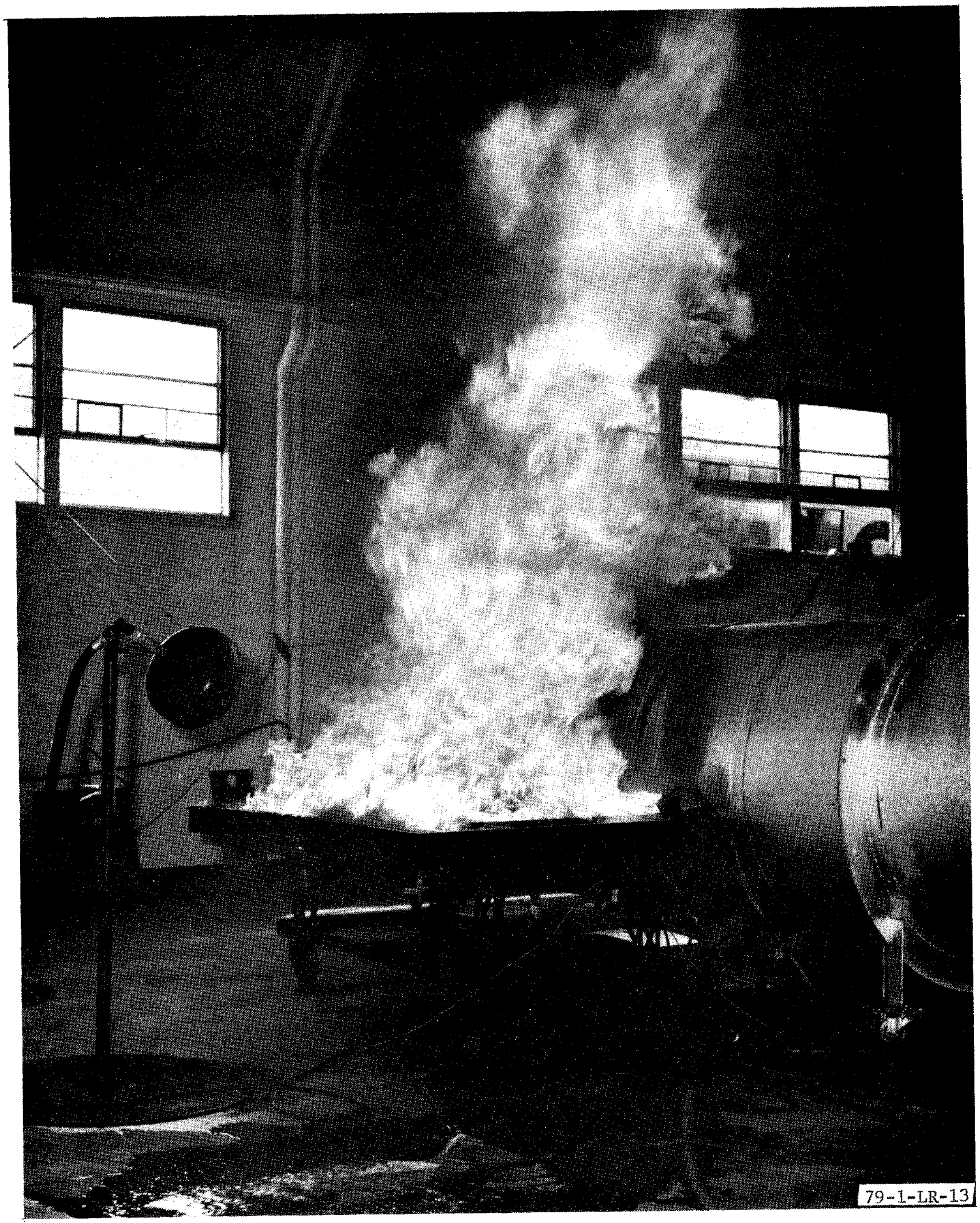

FIGURE13. FRONT VIEW OF 4-FOOT PAN FIRE

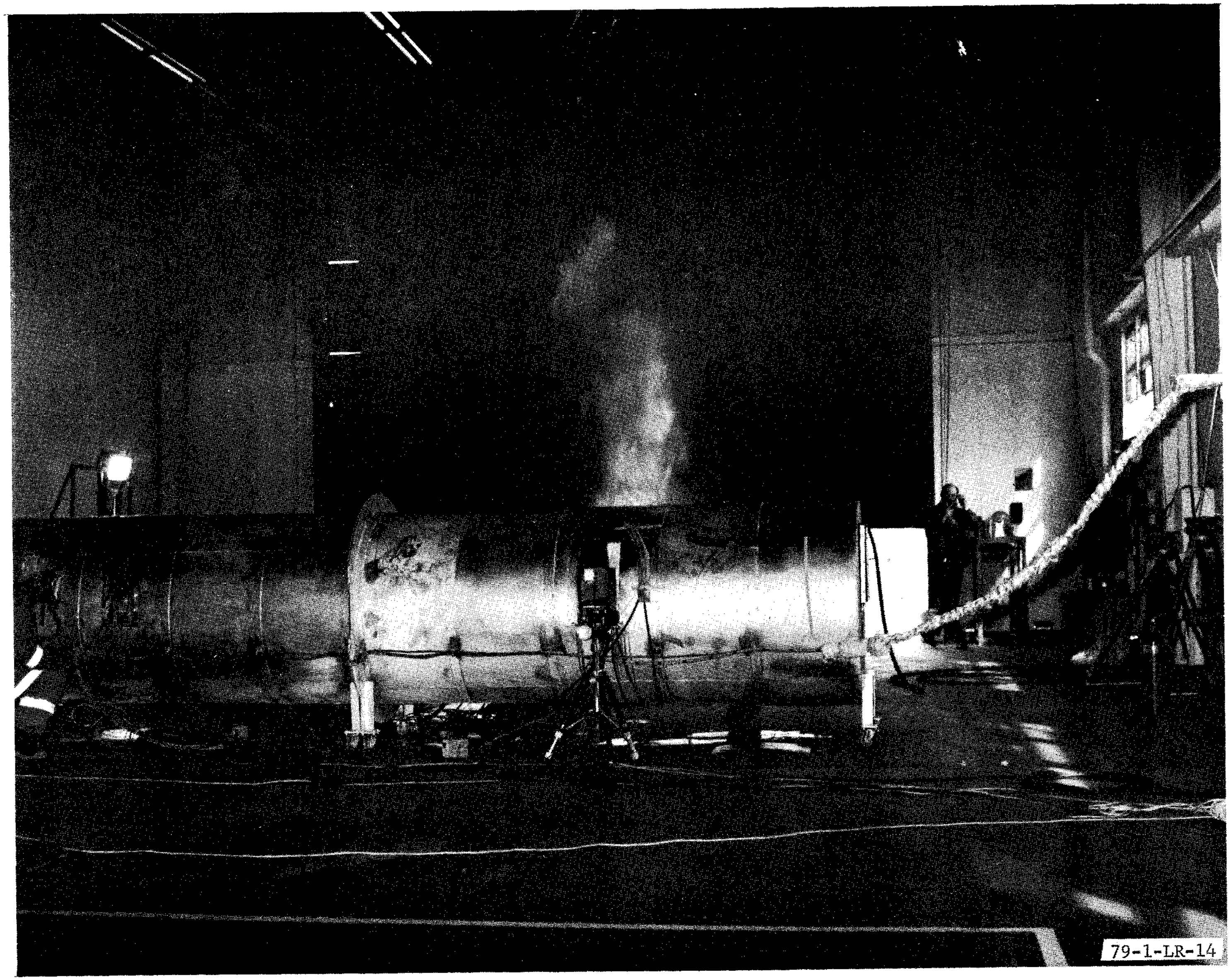

FIGURE 14. REAR VIEW OF 4-FOOT PAN FIRE

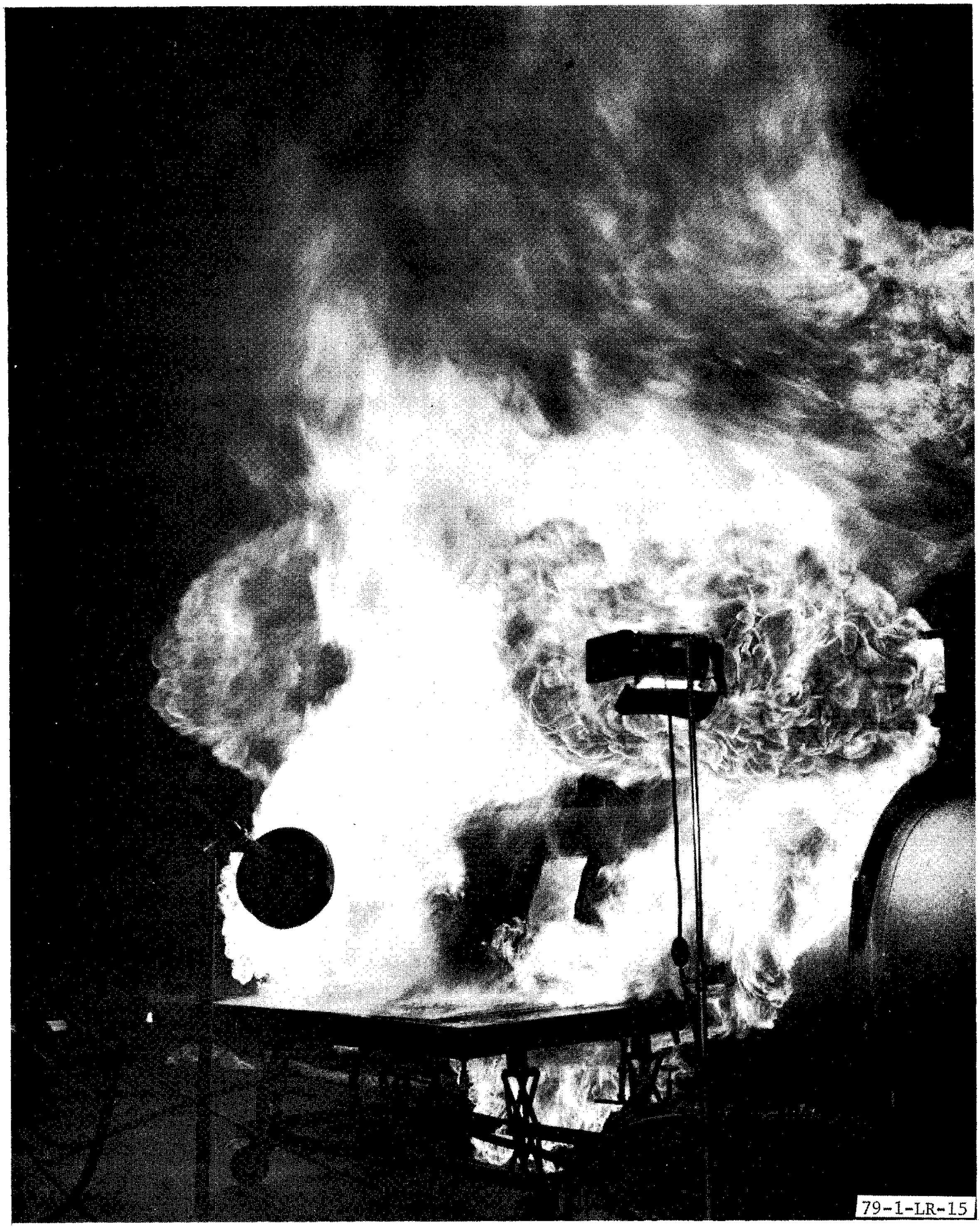

FIGURE 15. FIRE EXTINGUISHMENT

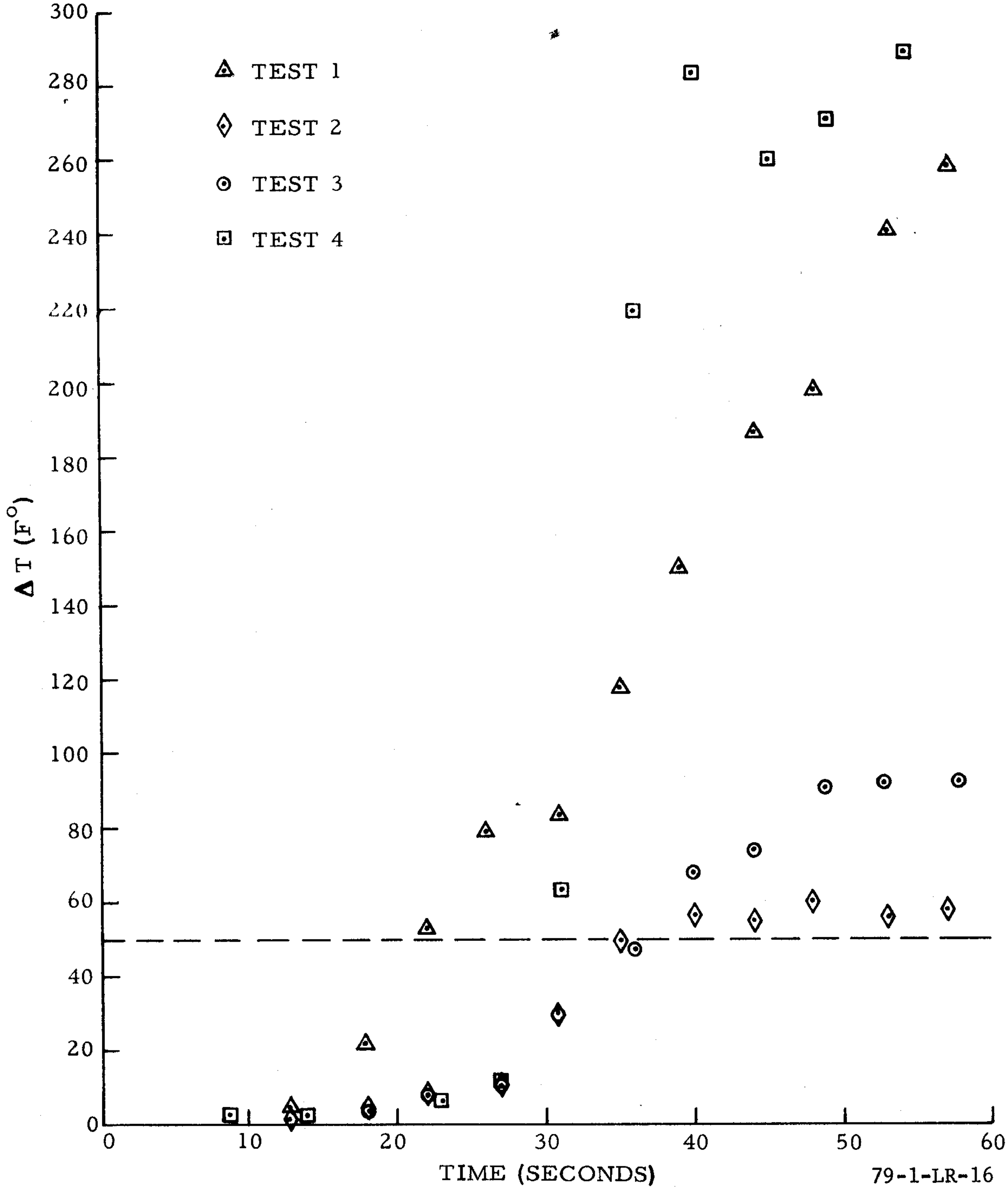

FIGURE 16. CEILING TEMPERATURES (TESTS 1-4, THERMOCOUPLE NO. 1)

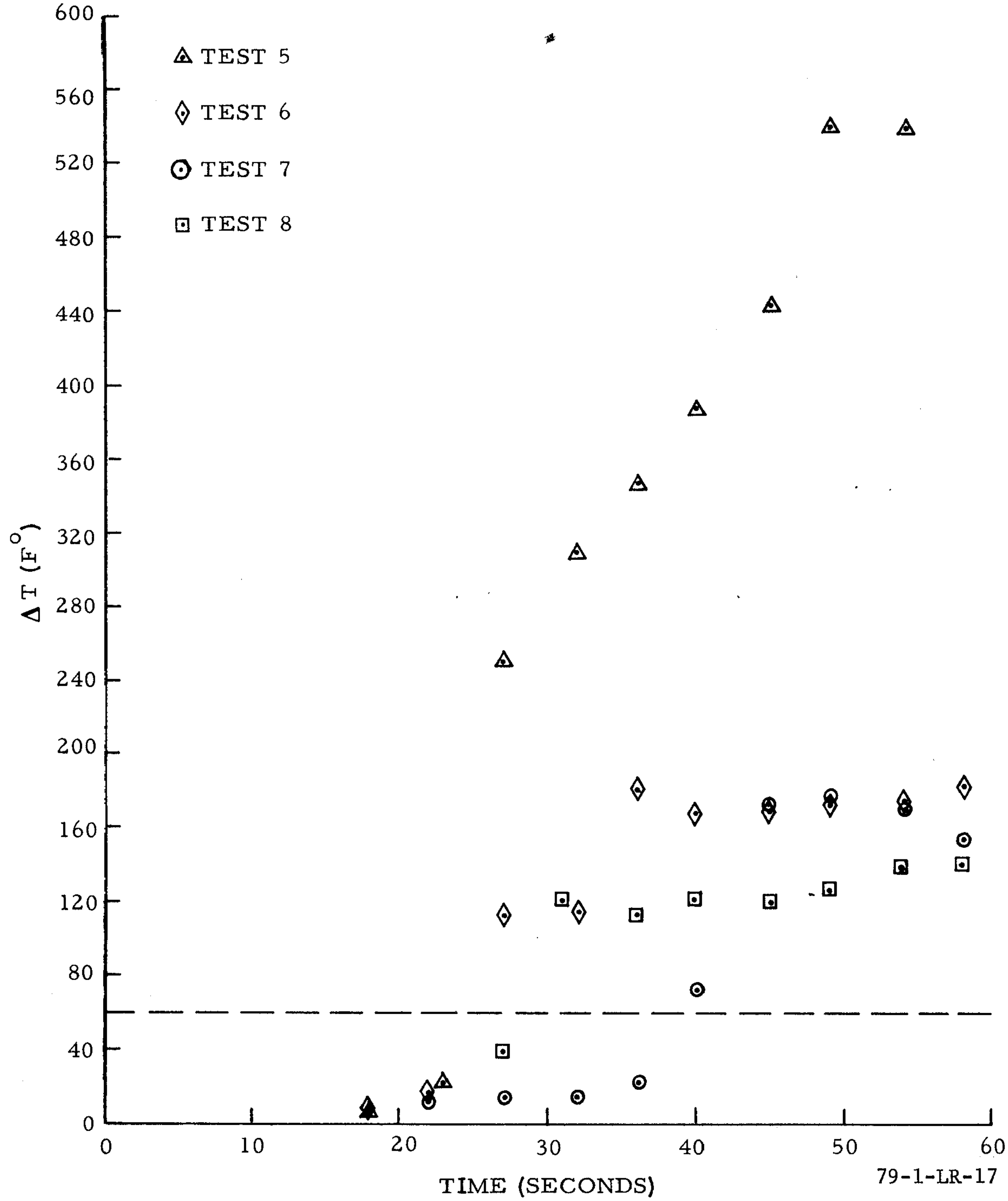

FIGURE 17. CEILING TEMPERATURES (TESTS 5-8, THERMOCOUPLE NO. 1)

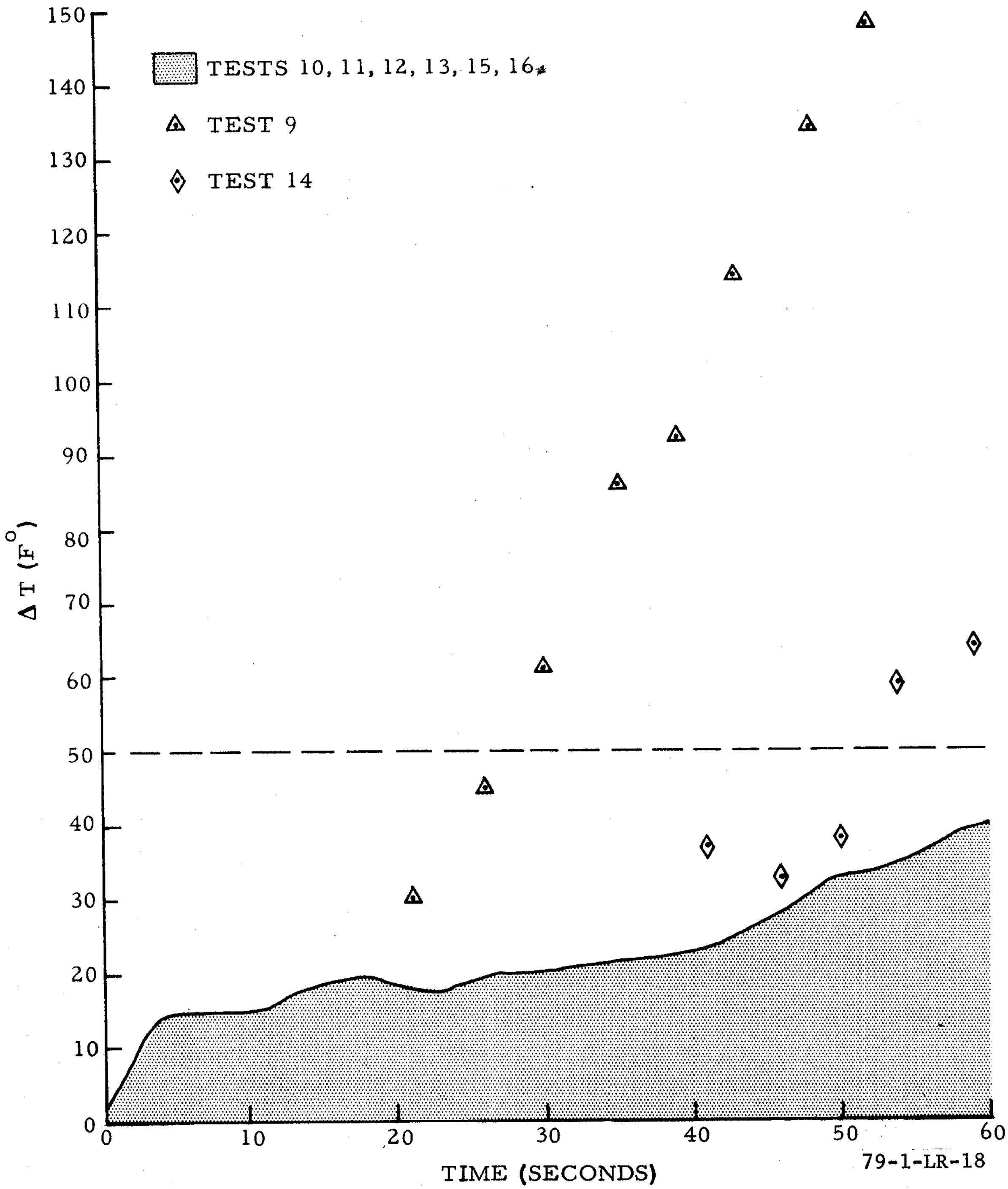

FIGURE 18. CEILING TEMPERATURES (TESTS 9-16, THERMOCOUPLE NO. 5)

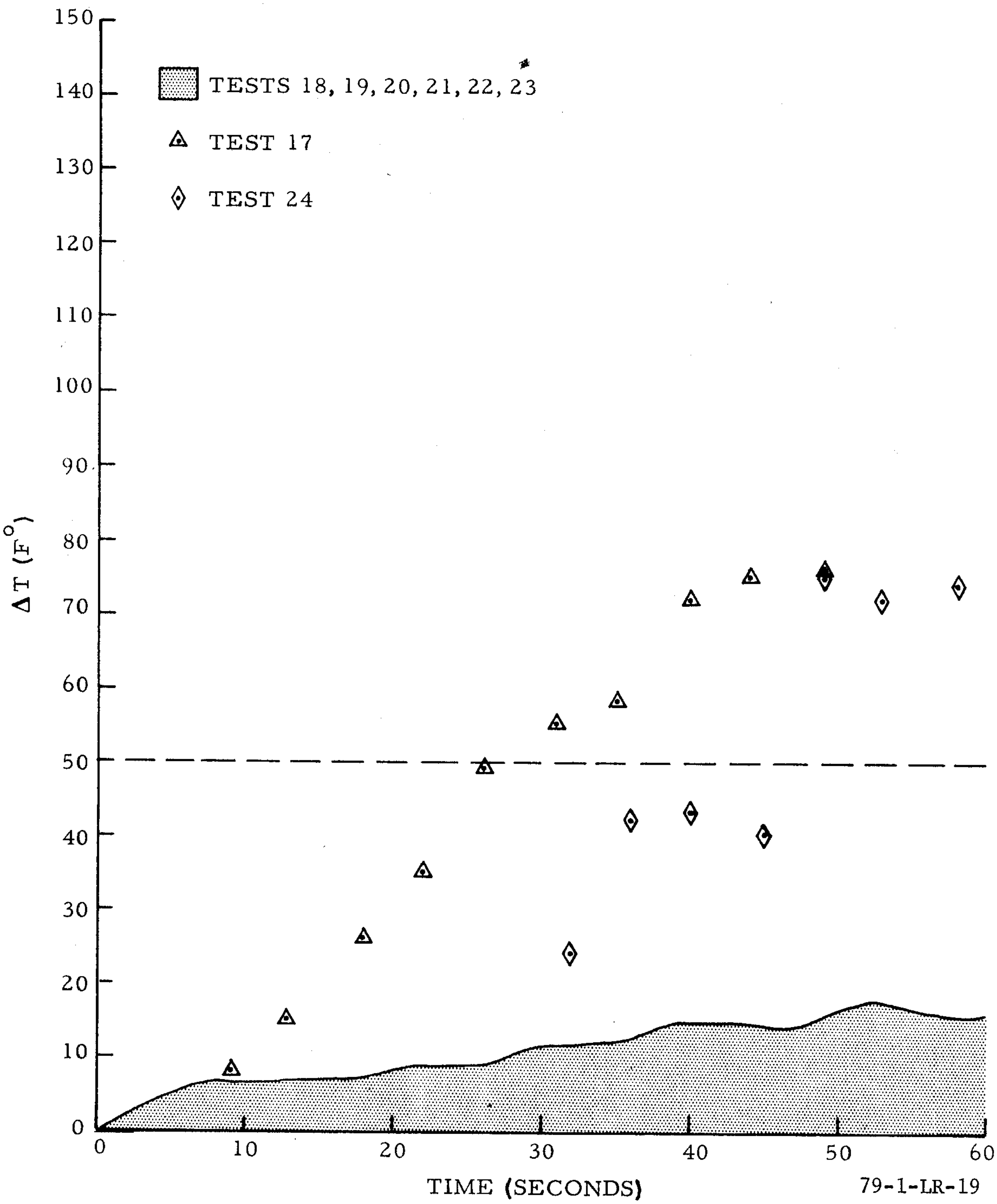

FIGURE 19. CEILING TEMPERATURES (TESTS 17-24, THERMOCOUPLE NO. 5)

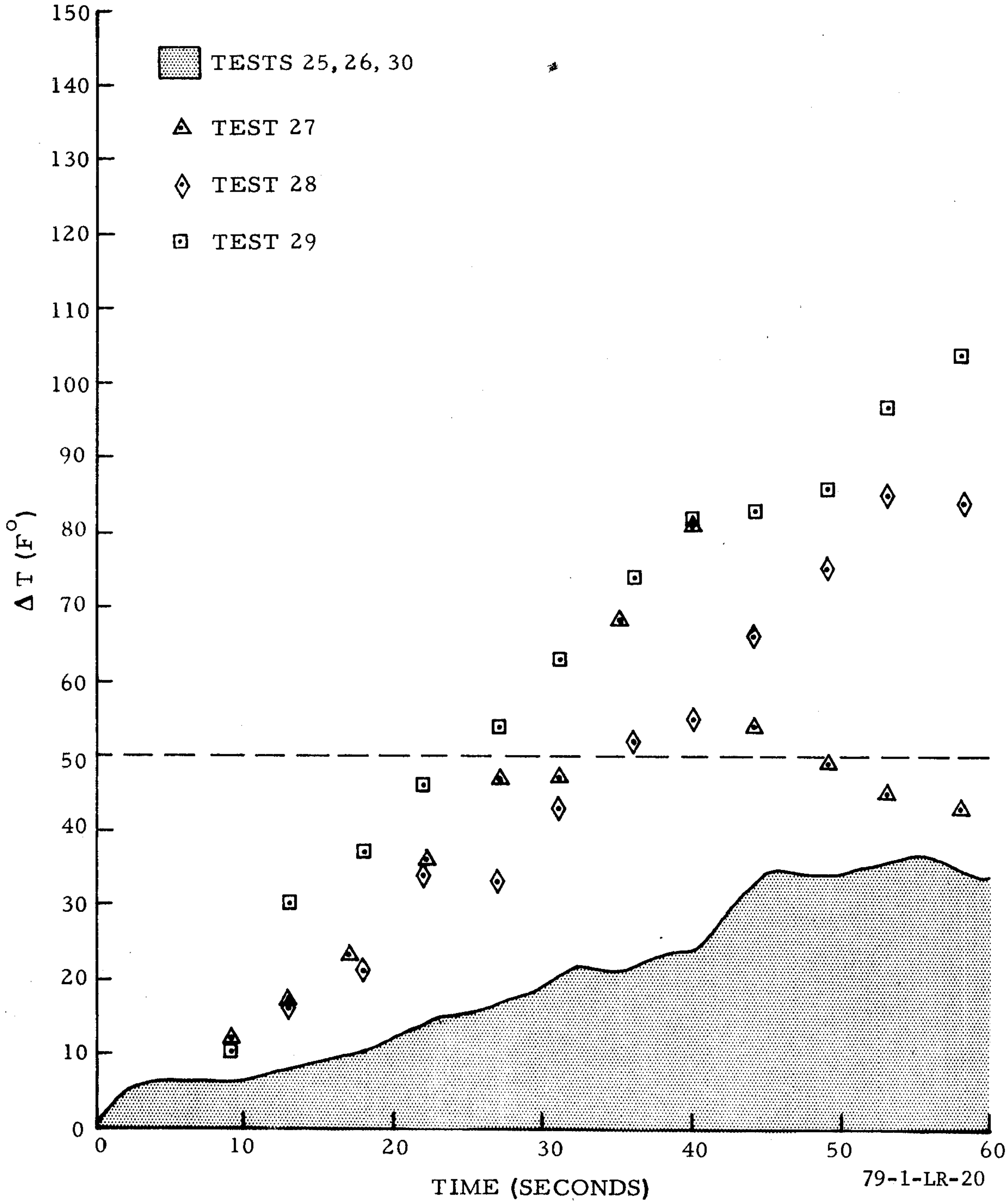

FIGURE 20. CEILING TEMPERATURES (TESTS 25-30, THERMOCOUPLE NO. 5)

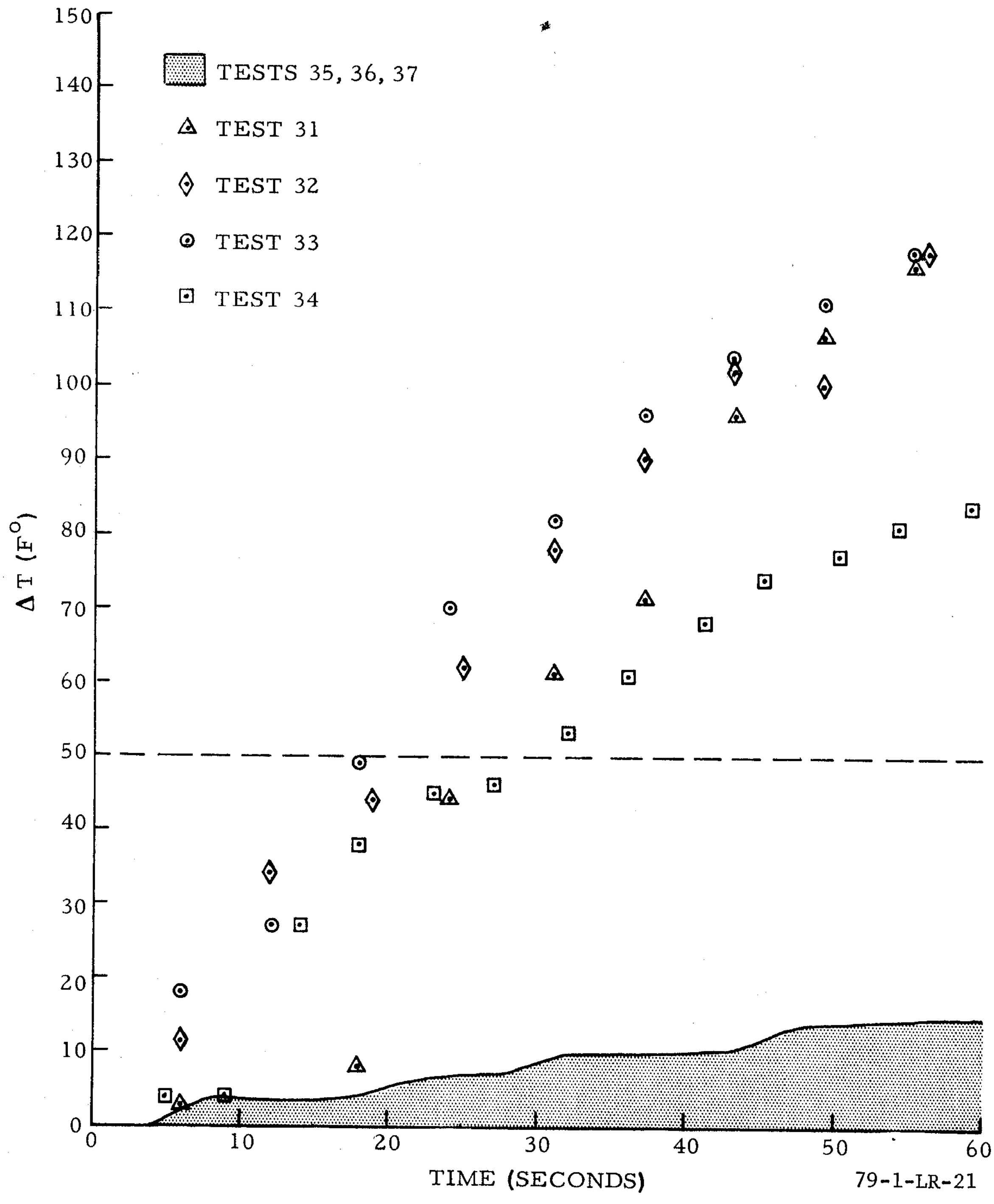

FIGURE 21. CEILING TEMPERATURES (TESTS 31-37, THERMOCOUPLE NO. 5)

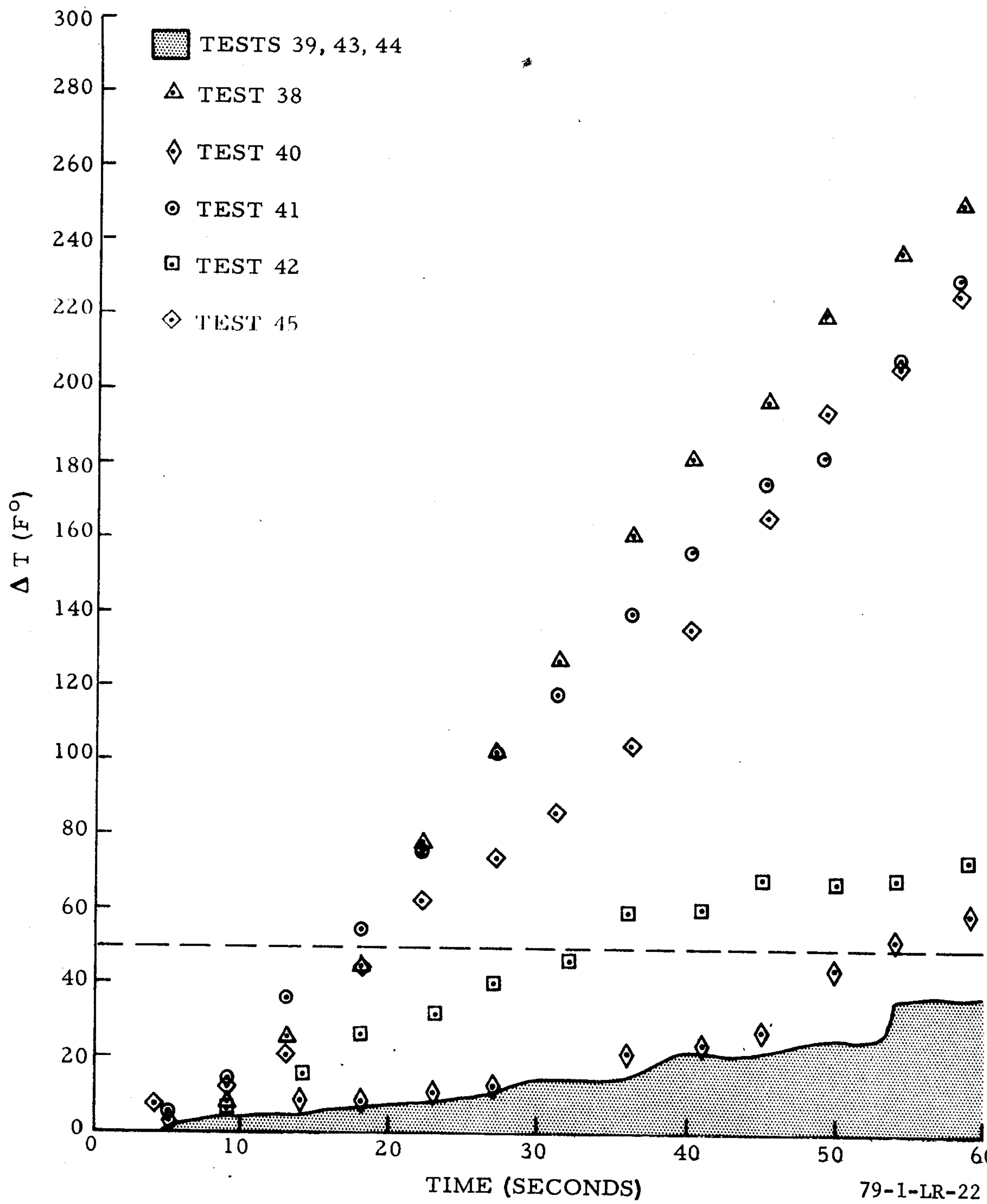

FIGURE 22. CEILING TEMPERATURES (TESTS 38-45, THERMOCOUPLE NO. 5)

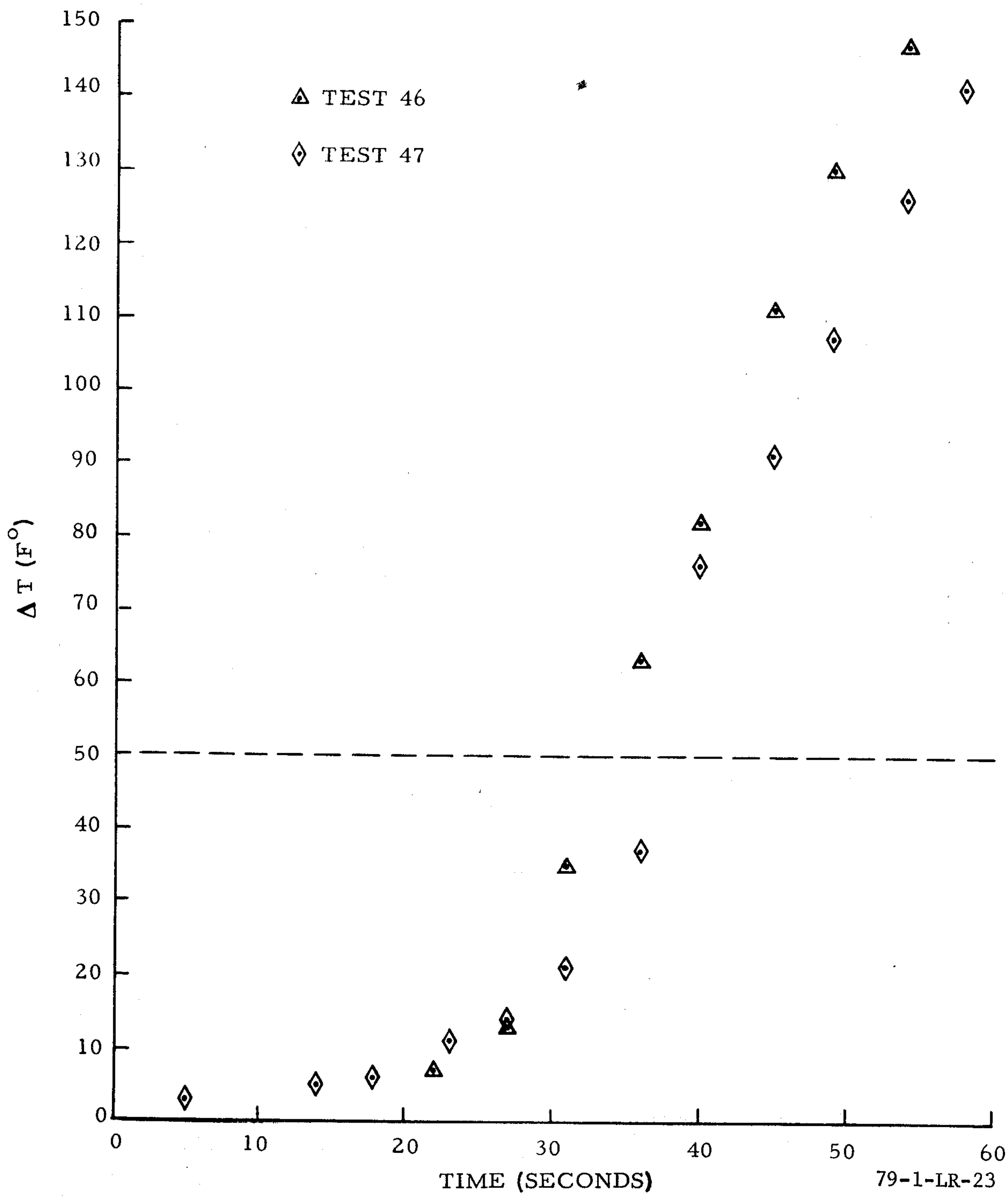

FIGURE 23. CEILING TEMPERATURES (TESTS 46-47, THERMOCOUPLE NO. 5)

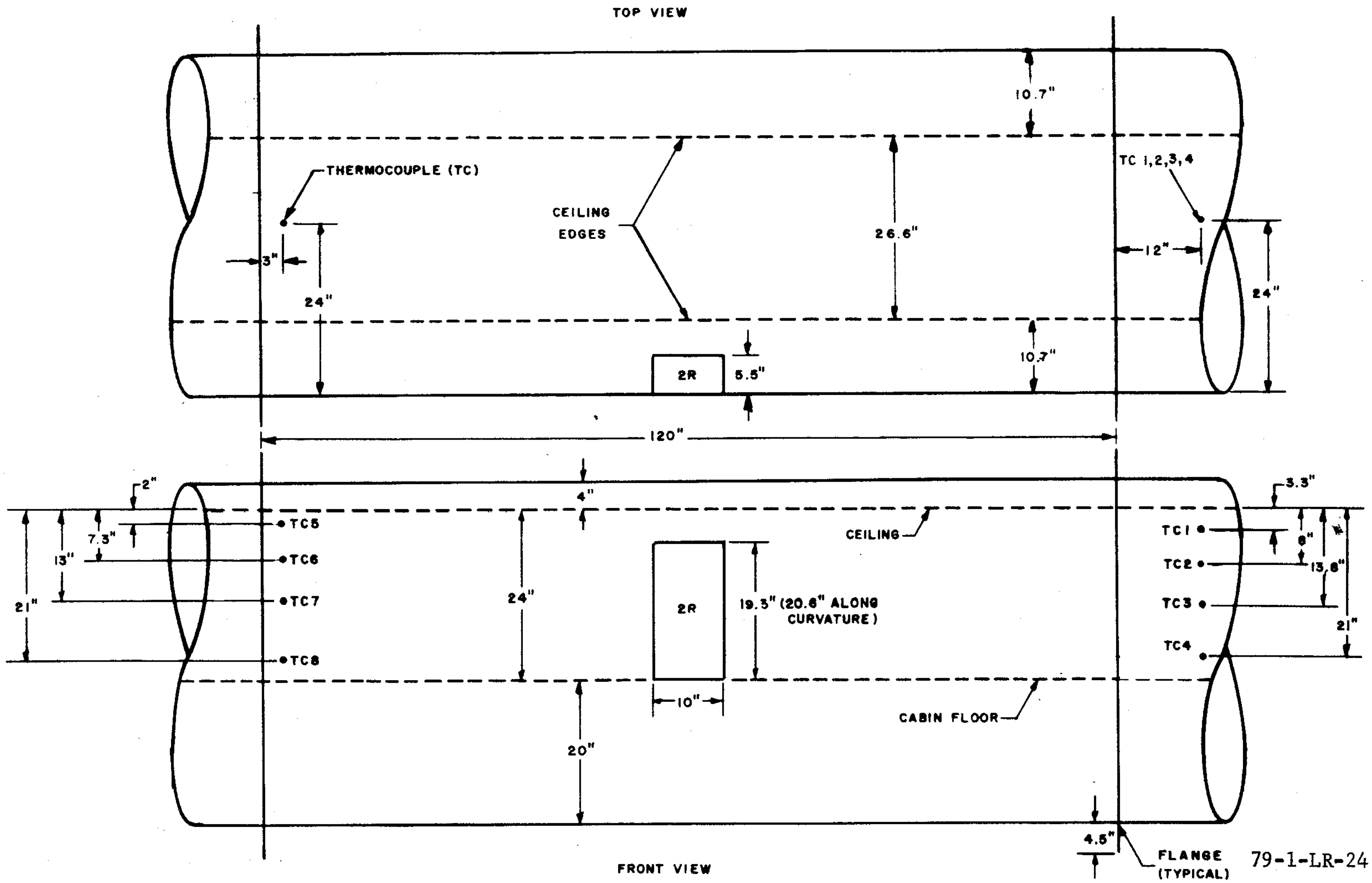

FIGURE 24. THERMOCOUPLE PLACEMENT

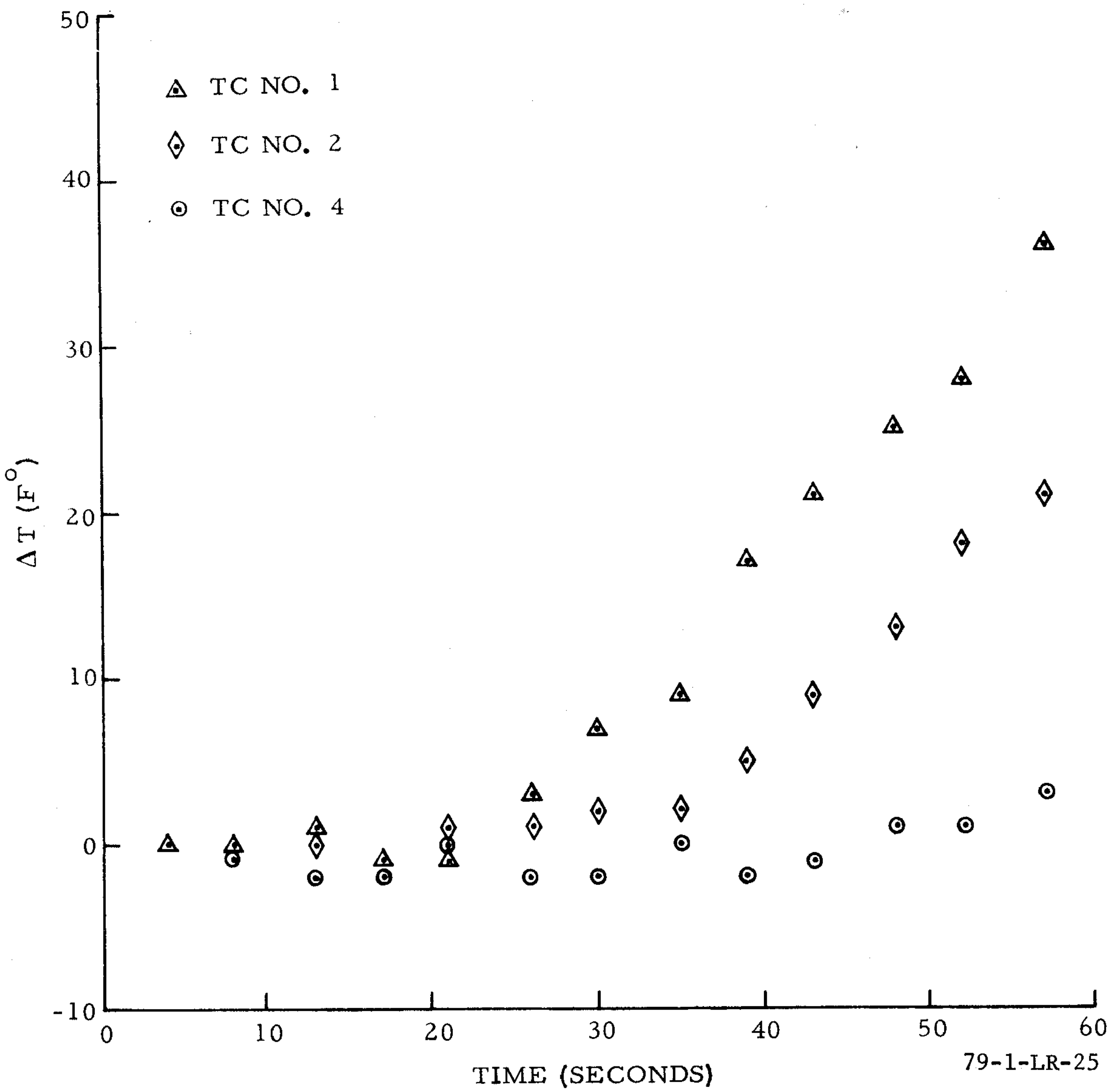

FIGURE 25. COMBINED THERMOCOUPLE READINGS (TEST 9)

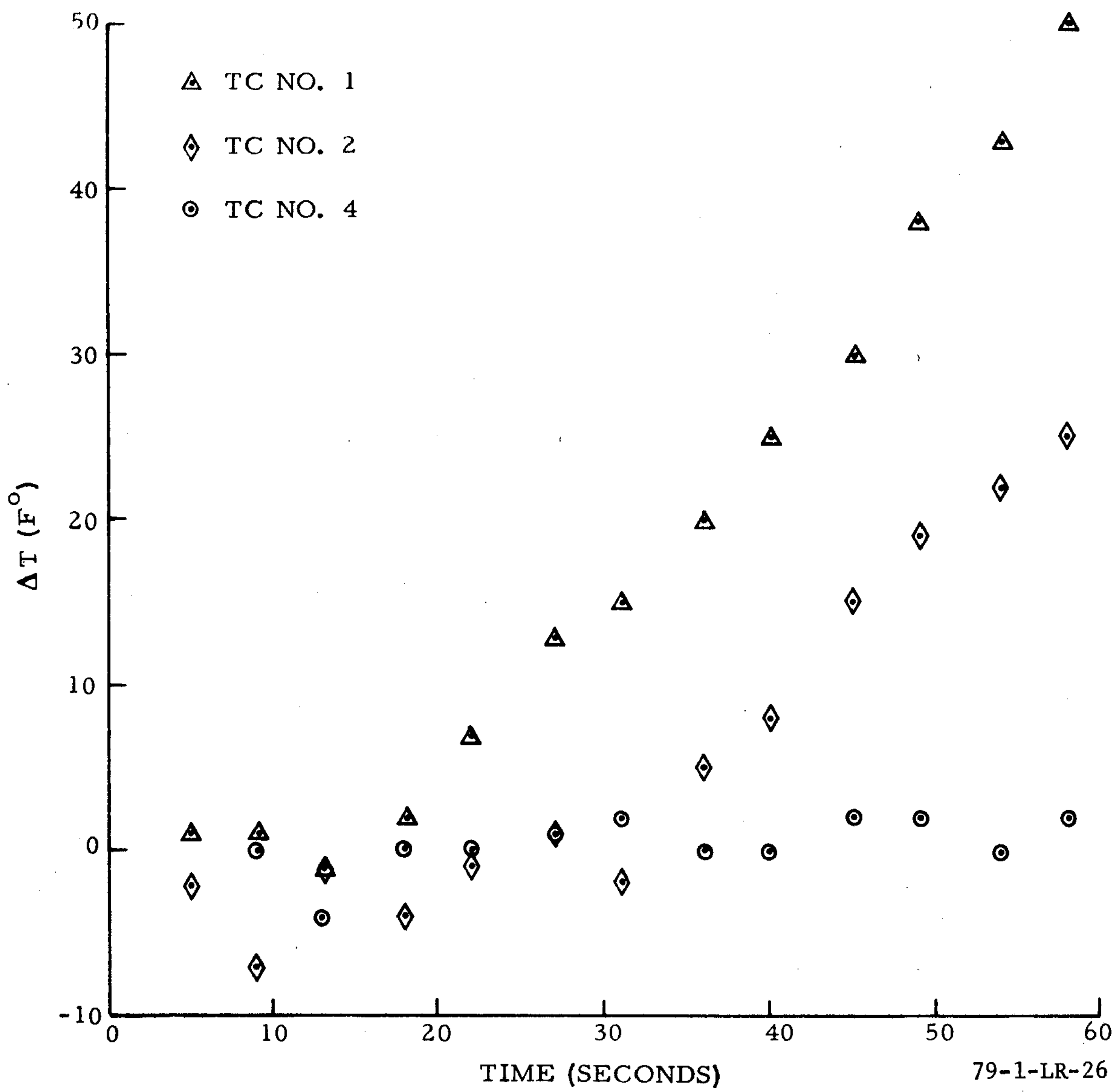

FIGURE 26. COMBINED THERMOCOUPLE READINGS (TEST 38)

FIGURE 27. RESIDUE FROM INTERIOR MATERIALS FIRE

TABLE 1. TEST VARIABLES

TEST RUN	DOOR SUBJECT TO FIRE	FIRE SIZE (ft)	WIND SPEED (mi/h)	DOORS OPEN DURING TEST	COMMENTS
1	1R	4 x 4	4-6	1R	Roll-up door opening 3.3 ft high and 8.5 ft wide. T = 14°C. Fuel pan 29 in. off floor. Model door bottom 30 in. off floor.
2	1R	4 x 4	5-7	1R, 3R	Roll-up door opening 3.3 ft high and 8.5 ft wide. T = 14°C. Fuel pan 29 in. off floor. Model door bottom 30 in. off floor.
3	1R	4 x 4	7-9	1R, 3R, 3L	Roll-up door opening 3.3 ft high and 8.5 ft wide. T = 14°C. Fuel pan 29 in. off floor. Model door bottom 30 in. off floor.
4	1R	4 x 4	8-11	1R, 2R, 3R, 3L	Roll-up door opening 3.3 ft high and 8.5 ft wide. T = 14°C. Fuel pan 29 in. off floor. Model door bottom 30 in. off floor.
5	1R	4 x 4	8-11	1R, 2R, 3R, 2L, 3L	Roll-up door opening 3.3 ft high and 8.5 ft wide. T = 14°C. Fuel pan 29 in. off floor. Model door bottom 30 in. off floor.
6	1R	4 x 4	9-12	1R, 2R, 3R, 1L, 2L, 3L	Roll-up door opening 3.3 ft high and 8.5 ft wide. T = 14°C. Fuel pan 29 in. off floor. Model door bottom 30 in. off floor.
7	1R	4 x 4	10-15	1R, 3R, 1L, 3L	Roll-up door opening 3.3 ft high and 8.5 ft wide. T = 14°C. Fuel pan 29 in. off floor. Model door bottom 30 in. off floor.
8	1R	4 x 4	9-11	1R, 1L, 2L, 3L	Roll-up door opening 3.3 ft high and 8.5 ft wide. T = 14°C. Fuel pan 29 in. off floor. Model door bottom 30 in. off floor.
9	3R	4 x 4	5-8	3R	Roll-up door opening 4.5 ft high and 25 ft wide. T = 18°C. Fuel pan 29 in. off floor. Model door bottom 30 in. off floor. Fans turned on at t = 10 s, off at t = 60 s.
10	3R	4 x 4	4-5	2R, 3R	Roll-up door opening 4.5 ft high and 25 ft wide. T = 18°C. Fuel pan 29 in. off floor. Model door bottom 30 in. off floor. Fans turned on at t = 10 s, off at t = 60 s.
11	3R	4 x 4	5-6	2R, 3R, 2L	Roll up door opening 4.5 ft high and 25 ft wide. T = 18°C. Fuel pan 29 in. off floor. Model door bottom 30 in. off floor. Fans turned on at t = 35 s, off at t = 75 s.

TABLE 1. TEST VARIABLES (Continued)

TEST RUN	DOOR SUBJECT TO FIRE	FIRE SIZE (ft)	WIND SPEED (mi/h)	DOORS OPEN DURING TEST	COMMENTS
12	3R	4 x 4	5-8	1R, 2R, 3R, 2L	Roll-up door opening 4.5 ft high and 25 ft wide. T = 18°C. Fuel pan 29 in. off floor. Model door bottom 30 in. off floor. Fans turned on at t = 10 s, off at t = 60 s.
13	3R	4 x 4	5-8	1R, 2R, 3R, 1L, 2L	Roll-up door opening 4.5 ft high and 25 ft wide. T = 18°C. Fuel pan 29 in. off floor. Model door bottom 30 in. off floor. Fans turned on at t = 10 s, off at t = 60 s.
14	3R	4 x 4	5-7	1R, 2R, 3R, 1L, 2L, 3L	Roll-up door opening 4.5 ft high and 25 ft wide. T = 18°C. Fuel pan 29 in. off floor. Model door bottom 30 in. off floor. Fans turned on at t = 10 s, off at t = 60 s.
15	3R	4 x 4	5-7	2R, 3R, 1L, 2L, 3L	Roll-up door opening 4.5 ft high and 25 ft wide. T = 18°C. Fuel pan 29 in. off floor. Model door bottom 30 in. off floor. Fans turned on at t = 10 s, off at t = 60 s.
16	3R	4 x 4	5-8	3R, 1L, 2L, 3L	Roll-up door opening 4.5 ft high and 25 ft wide. T = 18°C. Fuel pan 29 in. off floor. Model door bottom 30 in. off floor. Fans turned on at t = 10 s, off at t = 60 s.
17	3R	4 x 4	5	3R	Roll-up door opening 4.5 ft high and 25 ft wide. T = 11°C. Fuel pan 29 in. off floor. Model door bottom 30 in. off floor. Fans turned on at t = 10 s, off at t = 60 s.
18	3R	4 x 4	4-6	2R, 3R	Roll-up door opening 4.5 ft high and 25 ft wide. T = 11°C. Fuel pan 29 in. off floor. Model door bottom 30 in. off floor. Fans turned on at t = 10 s, off at t = 60 s.
19	3R	4 x 4	4-6	2R, 3R, 2L	Roll-up door opening 4.5 ft high and 25 ft wide. T = 11°C. Fuel pan 29 in. off floor. Model door bottom 30 in. off floor. Fans turned on at t - 10 s, off at t = 60 s.
20	3R	4 x 4	4-7	1R, 2R, 3R, 2L	Roll-up door opening 4.5 ft high and 25 ft wide. T = 11°C. Fuel pan 29 in. off floor. Model door bottom 30 in. off floor. Fans turned on at t = 10 s, off at t = 60 s.

TABLE 1. TEST VARIABLES (Continued)

TEST RUN	DOOR SUBJECT TO FIRE	FIRE SIZE (ft)	WIND SPEED (mi/h)	DOORS OPEN DURING TEST	COMMENTS
21	3R	4 x 4	6-10	1R, 2R, 3R, 1L, 2L	Roll-up door opening 4.5 ft high and 25 ft wide. T = 11°C. Fuel pan 29 in. off floor. Model door bottom 30 in. off floor. Fans turned on at t = 10 s, off at t = 60 s.
22	3R	4 x 4	4-7	1R, 2R, 3R, 1L, 2L, 3L	Roll-up door opening 4.5 ft high and 25 ft wide. T = 11°C. Fuel pan 29 in. off floor. Model door bottom 30 in. off floor. Fans turned on at t = 10 s, off at t = 60 s.
23	3R	4 x 4	4-6	2R, 3R, 1L, 2L, 3L	Roll-up door opening 4.5 ft high and 25 ft wide. T = 11°C. Fuel pan 29 in. off floor. Model door bottom 30 in. off floor. Fans turned on at t = 10 s, off at t = 60 s.
24	3R	4 x 4	4-8	3R, 1L, 2L, 3L	Roll-up door opening 4.5 ft high and 25 ft wide. T = 11°C. Fuel pan 29 in. off floor. Model door bottom 30 in. off floor. Fans turned on at t = 10 s, off at t = 60 s.
25	3R	1 x 1	4-7	3R	Roll-up door opening 4.5 ft high and 25 ft wide. Fuel pan 29 in. off floor. Model door bottom 30 in. off floor. Fans turned on at t = 10 s, off at t = 80 s.
26	3R	1 x 1	4-6	2R, 3R	Roll-up door opening 4.5 ft high and 25 ft wide. Fuel pan 29 in. off floor. Model door bottom 30 in. off floor. Fans turned on at t = 10 s, off at t = 80 s.
27	3R	1 x 1	4-6	2R, 3R, 2L	Roll-up door opening 7.5 ft high and 25 ft wide. Fuel pan 29 in. off floor. Model door bottom 30 in. off floor. Fans turned on at t = 10 s, off at t = 80 s.
28	3R	1 x 1	2-4	2R, 3R, 2L, 3L	Roll-up door opening 7.5 ft high and 25 ft wide. Fuel pan 29 in. off floor. Model door bottom 30 in. off floor. Fans turned on at t - 10 s, off at t = 80 s.
29	3R	1 x 1	0-4	3R, 2L, 3L	Roll-up door opening 7.5 ft high and 25 ft wide. Fuel pan 29 in. off floor. Model door bottom 30 in. off floor. Fans turned on at t = 10 s, off at t = 80 s.

TABLE 1. TEST VARIABLES (Continued)

TEST RUN	DOOR SUBJECT TO FIRE	FIRE SIZE (ft)	WIND SPEED (mi/h)	DOORS OPEN DURING TEST	COMMENTS
30	3R	1 x 1	0-4	3R	Roll-up door opening 7.5 ft high and 25 ft wide. Fuel pan 29 in. off floor. Model door bottom 30 in. off floor. Fans turned on at t = 10 s, off at t = 80 s.
31	3R	4 x 4	0	3R	Roll-up door closed. Fans off. Fuel pan 29 in. off floor. Model door bottom 30 in. off floor. Test duration 60 s. T = 22°C.
32	3R	4 x 4	0	3R	Roll-up door closed. Fans off. Fuel pan 29 in. off floor. Model door bottom 30 in. off floor. Test duration 60 s. T = 22°C.
33	3R	4 x 4	0	3R	Roll-up door closed. Fans off. Fuel pan 29 in. off floor. Model door bottom 30 in. off floor. Test duration 60 s. T = 22°C.
34	3R	4 x 4	0	3R	Roll-up door closed. Fans off. Fuel pan 29 in. off floor. Model door bottom 30 in. off floor. Test duration 60 s. T = 15°C.
35	3R	4 x 4	0	2R, 3R	Roll-up door closed. Fans off. Fuel pan 29 in. off floor. Model door bottom 30 in. off floor. Test duration 60 s. T = 15°C.
36	3R	4 x 4	0	1R, 2R, 3R	Roll-up door closed. Fans off. Fuel pan 29 in. off floor. Model door bottom 30 in. off floor. Test duration 60 s. T = 15°C.
37	3R	4 x 4	0	1R, 2R, 3R, 3L	Roll-up door closed. Fans off. Fuel pan 29 in. off floor. Model door bottom 30 in. off floor. Test duration 60 s. T = 15°C.
38	3R	4 x 4	0	3R	Roll-up door closed. Fans off. Fuel pan 19 in. off floor. Model door bottom 30 in. off floor. Test duration 60 s. T = 20°C.
39	3R	4 x 4	0	2R, 3R	Roll-up door closed. Fans off. Fuel pan 19 in. off floor. Model door bottom 30 in. off floor. Test duration 60 s. T = 20°C.
40	3R	4 x 4	0	1R, 2R, 3R	Roll-up door closed. Fans off. Fuel pan 19 in. off floor. Model door bottom 30 in. off floor. Test duration 60 s. T = 20°C.
41	3R	4 x 4	0	3R	Roll-up door closed. Fans off. Fuel pan 19 in. off floor. Model door bottom 30 in. off floor. Test duration 60 s. T = 16°C.

TABLE 1. TEST VARIABLES (Continued)

TEST RUN	DOOR SUBJECT TO FIRE	FIRE SIZE (ft)	WIND SPEED (mi/h)	DOORS OPEN DURING TEST	COMMENTS
42	3R	4 x 4	0	3R, 3L	Roll-up door closed. Fans off. Fuel pan 19 in. off floor. Model door bottom 30 in. off floor. Test duration 60 s. T = 16°C.
43	3R	4 x 4	0	1R, 3R, 3L	Roll-up door closed. Fans off. Fuel pan 19 in. off floor. Model door bottom 30 in. off floor. Test duration 60 s. T = 16°C.
44	3R	4 x 4	0	1R, 3R, 1L	Roll-up door closed. Fans off. Fuel pan 19 in. off floor. Model door bottom 30 in. off floor. Test duration 60 s. T = 16°C.
45	3R	4 x 4	0	3R	Roll-up door closed. Fans off. Fuel pan 19 in. off floor. Model door bottom 30 in. off floor. Test duration 60 s. T = 16°C.
46	3R	4 x 4	0	1R, 2R, 3R	Roll-up door closed. Fans off. Aircraft materials placed at doorway within model. Only interior temperatures recorded
47	3R	4 x 4	0	1R, 2R, 3R	Roll-up door closed. Fans off. Aircraft materials placed at doorway within model. Only interior temperatures recorded.

TABLE 2. HEAT FLUXES TO CABIN INTERIOR

TEST RUN	CALORIMETER IDENTITY	HEAT FLUX (Btu/ft^2 s) AT VARIOUS TIMES INTO TEST AFTER FUEL IGNITION (s)					
		30 s	40 s	50 s	60 s	70 s	80s
1	C-9 *	1.6	1.6	1.8	2.0	--	--
	C-13 **	2.1	2.1	2.4	3.2	--	--
2	C-9	1.1	1.2	1.3	--	--	--
	C-13	0.8	0.6	0.6	--	--	--
3	C-9	1.4	1.2	1.2	--	--	--
	C-13	1.0	0.9	0.8	--	--	--
4	C-9	1.2	1.4	1.4	--	--	--
	C-13	1.3	1.9	1.6	--	--	--
5	C-9	1.9	2.3	3.1	--	--	--
	C-13	3.3	3.6	--	--	--	--
6	C-9	1.5	1.5	1.2	1.4	--	--
	C-13	2.2	2.7	1.1	1.0	--	--

TABLE 2. HEAT FLUXES TO CABIN INTERIOR (continued)

TEST RUN	CALORIMETER IDENTITY	HEAT FLUX (Btu/ft^2 s) AT VARIOUS TIMES INTO TEST AFTER FUEL IGNITION (s)					
		30 s	40 s	50 s	60 s	70 s	80s
7	C-9	1.1	1.3	--	--	--	--
	C-13	0.4	5.6	--	--	--	--
8	C-9	--	--	--	--	--	--
	C-13	--	--	--	--	--	--
9	C-9	1.2	1.3	1.6	--	--	--
	C-13	1.0	1.1	2.5	--	--	--
10	C-9	1.2	1.1	1.2	--	--	--
	C-13	0.5	0.5	0.5	--	--	--
11	C-9	1.4	1.4	1.2	1.2	1.3	--
	C-13	0.4	0.5	0.5	0.6	0.6	--
12	C-9	1.1	1.1	1.2	--	--	--
	C-13	0.6	0.7	0.7	--	--	--

TABLE 2. HEAT FLUXES TO CABIN INTERIOR (continued)

TEST RUN	CALORIMETER IDENTITY	HEAT FLUX (Btu/ft^2 s) AT VARIOUS TIMES INTO TEST AFTER FUEL IGNITION (s)					
		30 s	40 s	50 s	60 s	70 s	80s
13	C-9	1.2	1.2	1.1	--	--	--
	C-13	0.5	0.6	0.5	--	--	--
14	C-9	1.1	1.1	1.3	1.2	--	--
	C-13	0.5	0.6	1.1	1.2	--	--
15	C-9	1.1	1.1	1.2	1.2	--	--
	C-13	0.5	0.4	0.7	0.5	--	--
16	C-9	1.2	1.1	1.3	1.3	--	--
	C-13	0.3	0.4	0.7	0.6	--	--
17	C-9	1.2	1.2	1.2	--	--	--
	C-13	1.3	1.2	1.2	--	--	--
18	C-9	1.2	1.0	1.1	--	--	--
	C-13	0.5	0.4	0.6	--	--	--

TABLE 2. HEAT FLUXES TO CABIN INTERIOR (continued)

TEST RUN	CALORIMETER IDENTITY	HEAT FLUX (Btu/ft^2 s) AT VARIOUS TIMES INTO TEST AFTER FUEL IGNITION (s)					
		30 s	40 s	50 s	60 s	70 s	80s
19	C-9	1.1	1.2	1.2	1.3	--	--
	C-13	0.5	0.6	0.6	0.6	--	--
20	C-9	1.1	1.0	1.0	1.2	--	--
	C-13	0.4	0.4	0.5	0.5	--	--
21	C-9	1.1	1.1	1.2	1.2	1.2	--
	C-13	0.4	0.5	0.6	0.6	0.5	--
22	C-9	1.0	1.2	1.2	1.1	1.1	--
	C-13	0.4	0.4	0.5	0.5	0.5	--
23	C-9	1.2	1.1	1.1	1.0	1.1	--
	C-13	0.7	0.5	0.5	0.4	0.5	--
24	C-9	1.5	1.4	1.5	1.3	1.3	--
	C-13	2.0	1.3	2.0	1.0	0.7	--

TABLE 2. HEAT FLUXES TO CABIN INTERIOR (continued)

TEST RUN	CALORIMETER IDENTITY	HEAT FLUX (Btu/ft^2 s) AT VARIOUS TIMES INTO TEST AFTER FUEL IGNITION (s)					
		30 s	40 s	50 s	60 s	70 s	80s
25	C-9	--	--	--	0.1	0.1	0.1
	C-13	--	--	--	--	--	--
26	C-9	0.1	0.1	0.1	0.1	0.1	0.2
	C-13	--	--	--	--	--	--
27	C-9	0.1	0.1	0.2	0.2	0.2	0.4
	C-13	--	--	--	--	--	--
28	C-9	0.2	0.2	0.2	0.2	0.2	0.3
	C-13	--	--	--	--	--	--
29	C-9	0.1	0.1	0.3	0.2	0.4	0.4
	C-13	--	--	--	--	--	--
30	C-9	0.1	0.1	0.1	0.2	0.2	0.1
	C-13	--	--	--	--	--	--

TABLE 2. HEAT FLUXES TO CABIN INTERIOR (continued)

TEST RUN	CALORIMETER IDENTITY	HEAT FLUX (Btu/ft^2 s) AT VARIOUS TIMES INTO TEST AFTER FUEL IGNITION (s)					
		30 s	40 s	50 s	60 s	70 s	80s
31	C-9	1.4	1.5	1.5	1.5	1.9	--
	C-13	0.9	1.7	1.3	1.2	1.8	--
32	C-9	1.6	1.5	1.4	1.4	--	--
	C-13	1.1	1.1	0.8	1.0	--	--
33	C-9	1.3	1.3	1.3	1.2	--	--
	C-13	0.8	0.9	1.3	0.9	--	--
34	C-9	1.4	1.4	1.4	1.4	--	--
	C-13	0.4	0.6	0.9	0.5	--	--
35	C-9	1.5	1.4	1.4	1.4	--	--
	C-13	0.3	0.3	0.3	0.3	--	--
36	C-9	1.2	1.2	1.2	1.2	--	--
	C-13	0.3	0.3	0.3	0.3	--	--

TABLE 2. HEAT FLUXES TO CABIN INTERIOR (continued)

TEST RUN	CALORIMETER IDENTITY	HEAT FLUX (Btu/ft^2 s) AT VARIOUS TIMES INTO TEST AFTER FUEL IGNITION (s)					
		30 s	40 s	50 s	60 s	70 s	80s
37	C-9	1.2	1.1	1.1	1.2	--	--
	C-13	0.2	0.2	0.2	0.3	--	--
38	C-9	1.8	2.0	2.1	2.2	--	--
	C-13	2.6	3.6	4.3	4.4	--	--
39	C-9	1.4	1.4	1.3	1.4	--	--
	C-13	0.5	0.5	0.5	0.7	--	--
40	C-9	1.3	1.3	1.5	1.5	--	--
	C-13	0.5	0.4	1.0	1.3	--	--
41	C-9	1.8	2.0	2.0	2.1	--	--
	C-13	2.5	3.3	2.8	4.1	--	--
42	C-9	1.6	1.6	1.6	1.5	--	--
	C-13	0.6	1.0	0.7	0.5	--	--

TABLE 2. HEAT FLUXES TO CABIN INTERIOR (continued)

TEST RUN	CALORIMETER IDENTITY	HEAT FLUX (Btu/ft^2 s) AT VARIOUS TIMES INTO TEST AFTER FUEL IGNITION (s)					
		30 s	40 s	50 s	60 s	70 s	80s
43	C-9	1.4	1.4	1.4	1.6	--	--
	C-13	0.4	0.5	0.4	1.4	--	--
44	C-9	1.2	1.3	1.3	1.3	--	--
	C-13	0.3	0.4	0.4	0.6	--	--
45	C-9	1.4	1.6	2.0	2.2	--	--
	C-13	0.9	2.1	4.1	4.5	--	--

* midplane calorimeter
** ceiling calorimeter

TABLE 3. HEAT FLUX TO FLOOR CALORIMETER (C-1)

TEST RUN	FLOOR HEAT FLUX (Btu/ft^2 s) AT VARIOUS TIMES INTO TEST AFTER FUEL IGNITION (S)				
	30 s	40 s	50 s	60 s	70 s
1	4.7	5.6	5.7	6.4	--
2	4.0	4.7	5.1	--	--
3	5.0	4.6	4.3	--	--
4	4.8	5.9	6.4	--	--
5	7.2	7.9	8.6	--	--
6	4.7	5.1	4.5	5.6	--
7	4.1	4.0	--	--	--
8	--	--	--	--	--
9	4.3	4.1	4.9	--	--
10	3.1	3.1	3.6	--	--
11	4.3	4.1	3.7	4.3	4.1
12	3.0	3.2	3.4	--	--
13	3.6	3.7	3.4	--	--
14	2.4	2.7	3.1	2.7	--

TABLE 4. COMPARISON FOR SMOKE, HEAT FLUX, AND TEMPERATURE

TEST RUN	DOOR OPENINGS	WIND SPEED (mi/h)	CEILING TEMPERATURES AT 50 ± 2 s ΔT*	CEILING HEAT FLUX AT 50 s (Btu/ft^2 s)	SMOKE
1	1R	4-6	198	2.4	TO
2	1R, 3R	5-7	60	0.6	LS
3	1R, 3R, 3L	7-9	90	0.8	HS
4	1R, 2R, 3R, 3L	8-11	270	1.6	TO
5	1R, 2R, 3R, 2L, 3L	8-11	539	--	TO
6	1R, 2R, 3R, 1L, 2L, 3L	9-12	171	1.1	TO
7	1R, 3R, 1L, 3L	10-15	174	--	TO
8	1R, 1L, 2L, 3L	9-11	125	--	TO
9	3R	5-8	134	2.5	TO
10	2R, 3R	4-5	11	.5	NS
11	2R, 3R, 2L	5-6	16	0.5	NS
12	1R, 2R, 3R, 2L	5-8	26	0.7	NS
13	1R, 2R, 3R, 1L, 2L	5-8	25	0.5	NS
14	1R, 2R, 3R, 1L, 2L, 3L	5-7	38	1.1	HS
15	2R, 3R, 1L, 2L, 3L	5-7	17	0.7	NS

TABLE 4. COMPARISON FOR SMOKE, HEAT FLUX, AND TEMPERATURE (Continued)

TEST RUN	DOOR OPENINGS	WIND SPEED (mi/h)	CEILING TEMPERATURES AT 50 +2 s ΔT*	CEILING HEAT FLUX AT 50 s (Btu/ft^2 s)	SMOKE
16	3R, 1L, 2L, 3L	5-8	33	0.7	NS
17	3R	5	76	1.2	TO
18	2R, 3R	4-6	9	0.6	NS
19	2R, 3R, 2L,	4-6	11	0.6	NS
20	1R, 2R, 3R, 2L	4-7	10	0.5	NS
21	1R, 2R, 3R, 1L, 2L	6-10	11	0.6	NS
22	1R, 2R, 3R, 1L, 2L, 3L	4-7	3	0.5	NS
23	2R, 3R, 1L, 2L, 3L	4-6	14	0.5	NS
24	3R, 1L, 2L, 3L	4-8	75	2.0	HS
25	3R	4-7	34	--	LS
26	2R, 3R	4-6	22	--	NS
27	2R, 3R, 2L,	4-6	49	--	HS
28	2R, 3R, 2L, 3L	2-4	75	--	HS
29	3R, 2L, 3L,	0-4	86	--	TO
30	3R	0-4	24	--	HS

TABLE 4. COMPARISON FOR SMOKE, HEAT FLUX, AND TEMPERATURE (Continued)

TEST RUN	DOOR OPENINGS	WIND SPEED (mi/h)	CEILING TEMPERATURES AT 50 $\pm$2 s ΔT*	CEILING HEAT FLUX AT 50 s (Btu/ft^2 s)	SMOKE
31	3R	0	107	1.3	TO
32	3R	0	100	0.8	TO
33	3R	0	111	1.3	TO
34	3R	0	77	0.9	TO
35	2R, 3R	0	10	0.3	NS
36	1R, 2R, 3R,	0	14	0.3	NS
37	1R, 2R, 3R, 3L	0	9	0.2	NS
38	3R	0	220	4.3	TO
39	2R, 3R	0	25	0.5	NS
40	1R, 2R, 3R	0	44	1.0	NS*
41	3R	0	182	2.8	TO
42	3R, 3L	0	67	0.7	LS
43	1R, 3R, 3L	0	21	0.4	NS
44	1R, 3R, 1L,	0	22	0.4	NS
45	3R	0	194	4.1	TO
46	1R, 2R, 3R	0	130	--	TO
47	1R, 2R, 3R	0	107	--	HS

-- not available
* temperature of the thermocouple minus temperature before test

Legend: TO - Total Obscuration
HS - Heavy Smoke
LS - Light Smoke
NS - No Smoke

APPENDIX
NA-79-1-LR

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