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A PRELIMINARY EXAMINATION OF INTERIOR AIRCRAFT EMERGENCY LIGHTING UNDER SIMULATED POSTCRASH FIRE AND SMOKE CONDITIONS

by

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Approved by J. T. Woodall For

JOSEPH M. DEL BALZO
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INTRODUCTION

PURPOSE.

The purpose of this report is twofold: (1) examine typical and advanced wide-body aircraft emergency interior lighting systems and concepts under simulated postcrash fuel fire and smoke conditions, and (2) characterize cabin smoke levels under realistic external fuel fire conditions.

BACKGROUND.

The National Transportation Safety Board (NTSB) conducted a special study (reference 1) of several air carrier accidents that were survivable from an impact injury viewpoint. Postcrash evacuation was carried out at night or in the presence of fire and/or smoke. The NTSB concluded that the ability of the passengers to locate emergency exits and to move through the cabin was hindered by inadequate cabin illumination levels.

Tests conducted at the Civil Aeromedical Institute (CAMI) to determine the adequacy of emergency interior lighting were accomplished using a theatrical white smoke in a cabin mockup or a darker smoke generated in a test chamber from cotton waste, crankcase oil, and rubber tires. These tests have indicated a need to conduct realistic, full-scale tests under controlled conditions in which aviation jet fuel (JP-4) and cabin interior materials would be burned to provide more realistic crash/smoke conditions. These realistic test conditions could help determine criteria for governing the use of emergency interior lighting and guide the tests at CAMI using theatrical white smoke.

Flight Standard Service (FSS) issued a research and development (R&D) request (FAA-9550, AFS-100-76-151, June 25, 1976) to conduct evaluations of emergency lighting installations under realistic fire/smoke conditions. This report describes the examination of existing emergency interior lighting systems used in wide-body aircraft, as well as several advanced and improved lighting systems under fuel-fire smoke conditions. A later study will include the effect of smoke generated by cabin materials ignited by an external fuel fire.

EXPERIMENTAL OBJECTIVE.

The experimental objective of these tests was to examine the following emergency lighting systems or concepts under fuel-fire smoke conditions: (a) presently used passenger emergency awareness signs and cabin illumination lights; (b) lights lowered to different elevations; (c) lights with increased brightness and new lighting systems, including floor-mounted electro-luminescent and flashing light strips, and armrest lights. A secondary objective was to characterize the temporal distribution of smoke as a function of elevation for a range of typical smoke conditions.

DISCUSSION

DESCRIPTION OF THE TEST ARTICLE.

A surplus military C133 aircraft was modified to resemble a wide-body aircraft test article by the installation of a raised floor and drop ceiling. The test article layout is shown in figure 1. The cabin floored area (76 feet long, 15 feet wide, and 8 feet high) provides approximately 9,000 ft^3 of enclosure volume. The volume forward and aft of the installed floor provides a total cabin volume of 13,200 ft^3. The cabin area was lined with noncombustible materials and was without seats or hat racks; however, the next phase of testing will provide these components. The fuselage area around the fire entry door, sized to that of a standard wide-body entrance door, was fire hardened with stainless and mild steel. A carbon dioxide system was installed to protect the aircraft test article during fire tests. An external fuel-pan arrangement, adjacent to the fire entry door, provided a base fire size ranging from 4 by 4 feet to 8 by 10 feet, using 15 to 50 gallons of jet fuel, respectively, to provide a 4- to 5-minute fire duration.

TEST LIGHTING--LOCATION AND ARRANGEMENT.

A standard L1011 cabin lighting system (partial) was installed in the aft cabin area of the test article as shown in figure 1 and listed in table 1. The aft cabin portion of the test article was chosen because this area would present the least hostile environment and provide some protection to the instrumentation. This lighting system consisted of one exit locator, one cross-aisle light, two locator exit lights, four aisle lights, and was capable of providing the 0.05 foot-candle average illumination at the armrest height as required by Federal Aviation Regulations (FAR). These lights were all ceiling mounted except for the exit locator light, which was mounted on a bulkhead 78 inches above the floor level. An emergency exit signal/threshold light was also installed on a bulkhead, 78 inches above the floor. This installation simulated an over-the-door exit sign.

To study the effects of brightness and vertical location, five cargo compartment-type lights were used as source lights. Three lights in a horizontal plane, 61 1/2 inches above the floor, were compared at different brightness levels, and three lights of equal brightness in a vertical plane, 78, 61 1/2, and 38 inches above the cabin floor, were compared to examine the importance of location (figure 1). The voltage to these lights was adjustable from 0 to greater than 1,250 foot-lamberts from the forward observation booth.

A prototype armrest light was installed in the cabin test area (figure 1) for visual observation during the test program. This light was designed and manufactured by the Plumly Corporation for installation in the aisle-side armrest of aisle seats and provided exit direction information and illumination to the aisle floor area.

TABLE 1. LIGHTING EQUIPMENT INSTALLED IN CABIN TEST AREA

	LIGHT	MFG/MODEL NO.	CABIN USAGE
1.	Illuminated Locator Exit (Exit locator)	GRIMES/10-0481	Rear aisle to exit
2.	Light, Emergency Exit and Cross-Aisle (used to illuminate aisle intersections)	GRIMES/10-0544	Rear cross-aisle
3.	Light, Assembly Aisle and Emergency (general aisle and cabin illumination)	GRIMES/10-0452	Over cabin aisles
4.	Sign, Interior Illuminated-Exit Locator (used for exit direction)	GRIMES/10-0535	Cabin side wall (to simulate a bulkhead mounting)
5.	Sign, Emergency Exit Overdoor/Threshold Light (identify exit/illuminate threshold)	GRIMES/10-1705-1	Bulkhead over door position
6.	Light, Cargo Floor (used in the horizontal and vertical placement arrays)	GRIMES/B-5820A	Horizontal and vertical location arrangement
7.	Capsul Light Electroluminescent	Atkins & Merrill	Rear cabin floor aisle and cross-aisle to the door
8.	Sequential Flashing Light System	DME Corporation	Rear cabin floor cross aisle to door
9.	Armrest Light	Plumly Indus.	Rear cabin area armrest location

The above lights are shown on figure 1 and identified by corresponding number.

A sequence flashing light system was installed on the rear cabin floor (figure 1) and consisted of a 16-foot-long multiconductor bus strip with 14 lights attached approximately 1 foot apart. These lights were wired in seven groups of two each and flashed in pairs (1 & 8, 2 & 9, 3 & 10 etc.), each over a duration of 250 milliseconds. This light system was installed across the cabin floor starting at the aft observation window and terminating near the aft cabin exit door (smoke exhaust door) on the right side of the aircraft. This system was designed and manufactured by the DME corporation, and the sequence of flashing lights was intended to provide direction-of-travel information to passengers.

Atkins and Merrill's electroluminescent light (EL) system (Capsul® light) was attached to the rear cabin floor and formed an aisle/cross-aisle configuration (figure 1). These lights were 1 inch wide and consisted of butted random lengths totaling 40 feet. The Capsul light system was powered by 115-volt, 400-hertz (Hz) current. The brightness of this lighting system is a function of the frequency over a range of 60 to 400 Hz. During these tests, the EL lights were always operated at the 400-Hz level.

INSTRUMENTATION AND TEST EQUIPMENT.

Ten smokemeters, manufactured by the National Bureau of Standards (NBS), were installed in the rear cabin as shown in figure 2. These meters incorporated a collimated light source projected over a 1-meter distance that is received on a 1P39 phototube. The electronic circuitry was contained in a control console located in the aft observation room. A complete description of these meters is contained in an instruction manual "National Bureau of Standards Photometeric Smoke Measurement System" (reference 2).

Two "stacks," of five smokemeters each were located in the rear cabin: one "stack" was on the left side (test station 621), and the other was on the right side (test station 780) of the cabin. Thus, the "stacks" were 13 feet apart. The light path of the meters was perpendicular to the fuselage centerline, and each stack had a smokemeter at 2, 4, 5, 6, and 7 1/2 feet above the floor. The output of these meters was recorded on a Data General Nova 3 computer system and is presented as percent of light transmission or optical density.

Three Spectra® spotmeters, model UBD 1/2°, were used to measure the luminance of the cargo lights used in the vertical location and the brightness evaluation. These spotmeters are capable of measuring luminance at any distance from 2 1/2 inches to infinity, with a 1/2° viewing angle.

Two Spectra photometers, model FC-200, with remote photocell probes were used to measure cabin luminance provided by the emergency interior cabin lighting system.

A Spectra BSR-100 brightness source was used to periodically calibrate the light-measuring equipment.

Closed-circuit television, movie, and still photography were used during this evaluation. A miniature tape recorder and a LED stopwatch were used to record observer comments and visual data during the conduct of the tests.

TEST RESULTS

SMOKE DISTRIBUTION PATTERN AND CHARACTERISTICS.

Tests were conducted during the early morning hours when wind conditions were most predictable and uniform. Wind velocities through the test program ranged from 0 to 22 miles per hour. A more detailed description of the test article and data obtained under simulated postcrash fuel-fire conditions is contained in a National Aviation Facilities Experimental Center (NAFEC) Technical Letter Report, NA-78-28-LR, "Preliminary Wide-Body (C133) Hazard Measurements During a Post-Crash Fuel Fire" by Constantine P. Sarkos and Richard Hill (reference 3), and a final report on the same subject by Hill soon to be published.

During the C133 fuel-fire test series, the most important variables affecting the cabin smoke conditions for a given fire size were ambient windspeed and direction (reference 3). At zero wind or when ambient wind pushed the flames away from the fuselage, there were insignificant levels of smoke within the cabin. When there was some component of the wind velocity vector which pushed the flames into the cabin, an accumulation of smoke would result. For a given "uniform" windspeed, the greatest smoke accumulation occurred when the wind direction was perpendicular to the fuselage, although wind fluctuations also had an influence on the cabin smoke level (reference 3). Thus, tests were conducted over a range of wind conditions in order to study a wide range of smoke conditions (table 2). As the smoke density within the cabin increased, there was a corresponding, nonlinear increase in temperature. During or over a period of some tests, the temperatures were high enough as to be considered not survivable. The following paragraphs are a description of a selected number of tests producing light, medium, or heavy cabin smoke conditions.

The light transmission data obtained from the top smoke meter, located approximately 6 inches below the ceiling, gave the best indication of the smoke density near the ceiling. In some tests or test intervals, a "thin" layer of smoke near the ceiling obscured the ceiling-mounted interior emergency aisle lights. The light smoke conditions existing in test 30, shown plotted in figures 3 and 4, were a good example of a "thin" smoke layer. The light obscuration at 7 1/2 feet was significantly greater than at the remaining smokemeter locations (6 feet and below). Below the top smokemeter, visibility was hardly impaired, and the temperature increase was insignificant (figure 5). Yet, although visibility was good and the conditions were survivable from a thermal viewpoint, cabin illumination provided by the ceiling-mounted lights would have been significantly reduced by the "thin" ceiling smoke layer.

Test 31, plotted in figures 6 and 7, is an example of a more dense cabin smoke condition. Again, a very pronounced smoke layer is evident from the data, exhibiting a thickness of approximately 2 to 3 feet over the duration

TABLE 2. FULL-SCALE TEST SUMMARY (C133)

Test No.	Fuel Pan Size (ft)	Fuel Quantity (gal)	Windspeed (mph)	Wind Direction*	Aux. Fan (mph)**	Results
24	6 x 4	15	3-14	N		Medium to heavy smoke down to 24" level
28	6 x 8	30	2-4	NE		0.05 foot-candle general cabin lighting evaluation
30	6 x 8	30	2-13	South Variable		Light smoke accumulation down to 90" level
31	6 x 8	30	3-7	WSW		Medium smoke accumulation to 72" level
32	6 x 8	30	4-12	WNW		Heavy smoke accumulation below 24" level
46	6 x 8	30	3-12	NW		Horizontal/brightness evaluation
66	8 x 10	50	1	---	3.57	Vertical/location evaluation
72	8 x 10	50	0	---	3.57	0.05 foot-candle general cabin lighting evaluation

* Test aircraft oriented nose-south, tail-north, fire entry door-west

**Auxiliary fan used to provide air-flow directed through the fire entry door. Airspeed calibrated at this constant velocity.

plotted. Thus, total light obscuration can occur within the smoke layer without subjecting a standing individual (66 inches) to a significant amount of heat stress (figure 8).

Cabin thermal conditions which were approaching (if not exceeding) human survivable levels were produced in test 24. By 2 minutes, the temperature at the head of a standing individual was approximately 200° Fahrenheit (F), (figure 9). Smoke accumulation is plotted in figures 10 and 11. Although smoke stratification was still significant, it was not as pronounced as in tests 30 and 31.

Test 32 was one of the most severe tests and was an example of a non-survivable cabin thermal environment. At 2 minutes, the temperature at the head of a standing individual exceeded 300° F and was increasing (figure 12). A very pronounced smoke stratification was again evident. For example, at 60 seconds, total light obscuration was measured at 3 feet below the ceiling, but the amount of obscuration was relatively small a foot lower in the cabin. The smoke conditions measured during test 32 are probably in excess of the maximum smoke density that should be simulated in planned CAMI studies of the effect of smoke and cabin lighting on passenger visibility and emergency evacuation. Figures 13 and 14 exhibit a "crossover" in smoke density at the 2- and 4-foot elevations. This "crossover" or inversion was observed in some tests and is believed to be a result of the entrainment of air at the exhaust door and recirculation of smoke near the floor.

CABIN EMERGENCY ILLUMINATION.

Two photometers with remote photocell probes equipped with cosine receptors were used to determine the decay of illumination in the cabin area at the armrest height (FAR 25.812 (c)). The emergency interior cabin illumination was adjusted to provide 0.07 foot-candle of illumination at the armrest height (the minimum value of 0.05 foot-candle was not attainable). Under the light smoke conditions produced in test 28 (figure 15), this value of 0.07 foot-candle was increased to greater than 1.2 foot-candles approximately 30 seconds after the external fire was ignited. The increase in illumination is a result of light emitted by the fuel-fire flames penetrating the cabin environment. Although light transmission near the ceiling was eventually reduced to less than 40 percent, the fire provided illumination greater than the required 0.05 foot-candle. Apparently, the smoke layer was not thick enough to obscure the flames from the fuel fire.

Figure 16 represents data recorded during a much smokier test (test 72) where visual observations indicated "a very black smoke condition" at 52 seconds and zero visibility at the 60-inch level at 2 minutes. Because it was closer to the fire, the forward photometer measured higher cabin illumination than the aft photometer. During this test the smoke became dense enough to obscure the fuel-fire flames, and the photometer readings dropped to zero. Thus, during a postcrash cabin fire, emergency illumination lighting may be initially overpowered by light emitted by the fire but eventually blocked out by smoke accumulation.

EFFECT OF VERTICAL LOCATION.

The three vertical lights were adjusted as closely as possible to the same foot-lambert value. The three spotmeters were focused on the three lights, with the spotmeter viewing height fixed at 61 1/2 inches, as in the horizontal tests. Figure 19 contains data from test 66 which produced heavy cabin smoke conditions, and indicate that lowering the height of the lights will extend its time of providing passenger awareness information. Light transmission data for this test were obtained from NAFEC smokemeters. These meters incorporated the use of light beams over a 1-foot distance and a photosensitive device to measure light transmission. The data were converted to optical density per meter to keep values consistent in this report. Lowering the light from 78 inches to 61 1/2 inches only extends the time to the attainment of total obscuration by 15 seconds, but lowering the light to the 38-inch level extends this time approximately 45 seconds. The smoke optical density data in figure 20 indicate that the 78-inch and possibly the 61 1/2-inch lights become covered by the layer of smoke near the ceiling; however, the lower light would have remained visible if viewed from a height closer to its elevation. Thus, lights located closer to the floor would be highly beneficial to individuals crawling to get out of the smoke. Figure 20 pictorially shows the value of locating lights below the 61 1/2-inch level used extensively for measurements in this study. Under smoke conditions studied in the C133, it is very difficult for the eye to receive any information from a sign or light located in the ceiling or above the door at the 78-inch level. A horizontal path of vision at the 61 1/2-inch level is relatively better, but the lower levels present the best location, since now the "eye" is only looking through the "corners" of the more dense smoke levels.

NEW LIGHTING SYSTEMS.

Three new or prototype systems were evaluated during this phase of the test program: the Plumly armrest light, the sequence flashing light system, and the electroluminescent or Capsul light system.

The armrest light was designed to be installed in the aisle-side armrest of the aisle passenger seat. The light tested provided exit direction information as well as some illumination of the floor directly below it (the aisle area). There was no attempt to measure the luminance of the light during a test, and the evaluation consisted of observer comments during the test. Since the height of the light was 2 feet above the cabin floor, the smoke light transmission data at the 2-foot level gave an indication of the extended use of this light to provide passenger exit information as well as some additional illumination to the floor level.

Based on recorded visual observations and/or recorded light transmission data from 45 tests during the inital 2-minute period, the following information pertaining to smoke accumulation at the 2-foot level is presented. There was very little or no smoke accumulation during 35 tests. Light obscuration of

50 percent or less occurred during five tests, and total light obscuration occurred during five tests.

The sequence flashing light system was designed to orient a passenger to a specified direction and was installed on the floor of the aft cabin, extending from the aft observation booth window to the right-rear exit door. Unfortunately, the short flash duration prevented the measurement of the illumination output of the lights during the test. On the basis of video and motion picture coverage and recorded data by observers in the booth, this lighting system provided passenger awareness throughout the most severe tests. Only when the visibility in the cabin reached zero near the floor was this awareness lost, and then, by stooping, the time for usefulness was extended, making it apparent that a passenger would still be oriented to a direction of escape.

The Capsul light system was designed to be secured to the cabin floor, outlining the aisle and the cross-aisles leading to an exit. This system provided passenger awareness of the aisle configuration. This floor-mounted system continues to provide information throughout the duration of most tests when set at a constant illumination level. As with the sequence flashing light system, it was only at the point of almost total obscuration near the floor that the Capsul light system ceased to provide escape information. Again, this time would be extended when an individual stooped over or dropped to a crawling position.

MALFUNCTION OR FAILURE OF LIGHTING SYSTEMS.

Only one failure due to heat, of a major exit awareness sign was experienced during the test program. A modest in-house study was initiated as a result of this experience, and other wide-body signs were evaluated under controlled heating conditions. These signs, as well as the original sign modified by the manufacturer, successfully withstood temperatures up to 350° F (reference 4).

All of the plastic covers on the ceiling-mounted lights described in table 1, experienced various types of failures (melting, distortion, or collapse). This failure occurred when the temperature near the ceiling reached approximately 300° F. Although the plastic covers failed and/or distorted, the ability of the light or sign to provide illumination was not affected.

CONCLUSIONS

1. Smoke entering the cabin from an external fuel-fire will rapidly obscure ceiling-mounted lights/signs and cause significantly decreased values of cabin illumination even though temperatures are still at a survivable level.

2. Lowering the exit/cabin lighting fixtures below the 61 1/2-inch level will significantly increase their effectiveness.

3. Under most smoke conditions studied, increasing the illumination of lights located 61 1/2 inches above the floor does not substantially increase the time they remain visible.

4. Armrest lights provide both passenger awareness, exit information, and cabin illumination for a period of time longer than any of the ceiling-mounted or bulkhead lights.

5. Floor-mounted lights provide the maximum amount of time for passenger awareness information.

RECOMMENDATION

Emergency lighting and exit signs located near the cabin ceiling should be relocated or supplemented by lighting and signs located as close to the floor as is practical and useful in order to function effectively in a smoke-filled aircraft passenger environment.

REFERENCES

1. NTSB's Special Study, Safety Aspects of Emergency Evacuation from Air Carrier Aircraft, (No. AAS-74-3) adopted 11/13/74.

2. Bukowski, Richard W., Instruction Manual for National Bureau of Standards Photometric Smoke Measurement System, February 1977.

3. Sarkos, Constantine P. and Hill, Richard, Preliminary Wide-Body (C-133) Hazard Measurements During a Post-Crash Fuel Fire, NAFEC Technical Letter Report No. NA-78-28-LR, April 1978.

4. Demaree, James E., The Behavior of Wide-Body Aircraft Emergency Exit Signs at Elevated Air Temperatures, NAFEC Technical Letter Report No. NA-78-69-LR, December 1978.

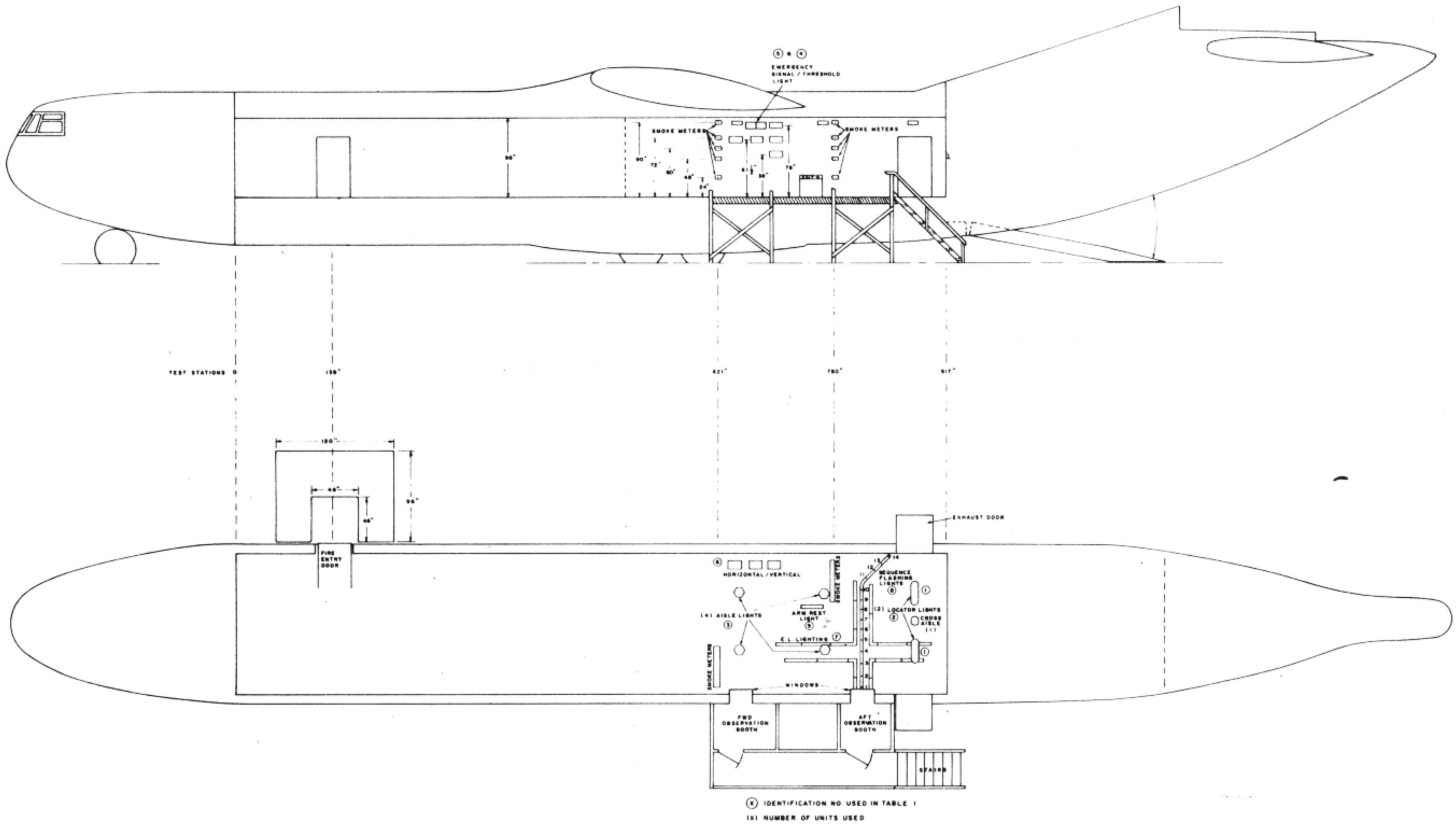

FIGURE 1. C-133 CABIN AND EMERGENCY LIGHTING LAYOUT

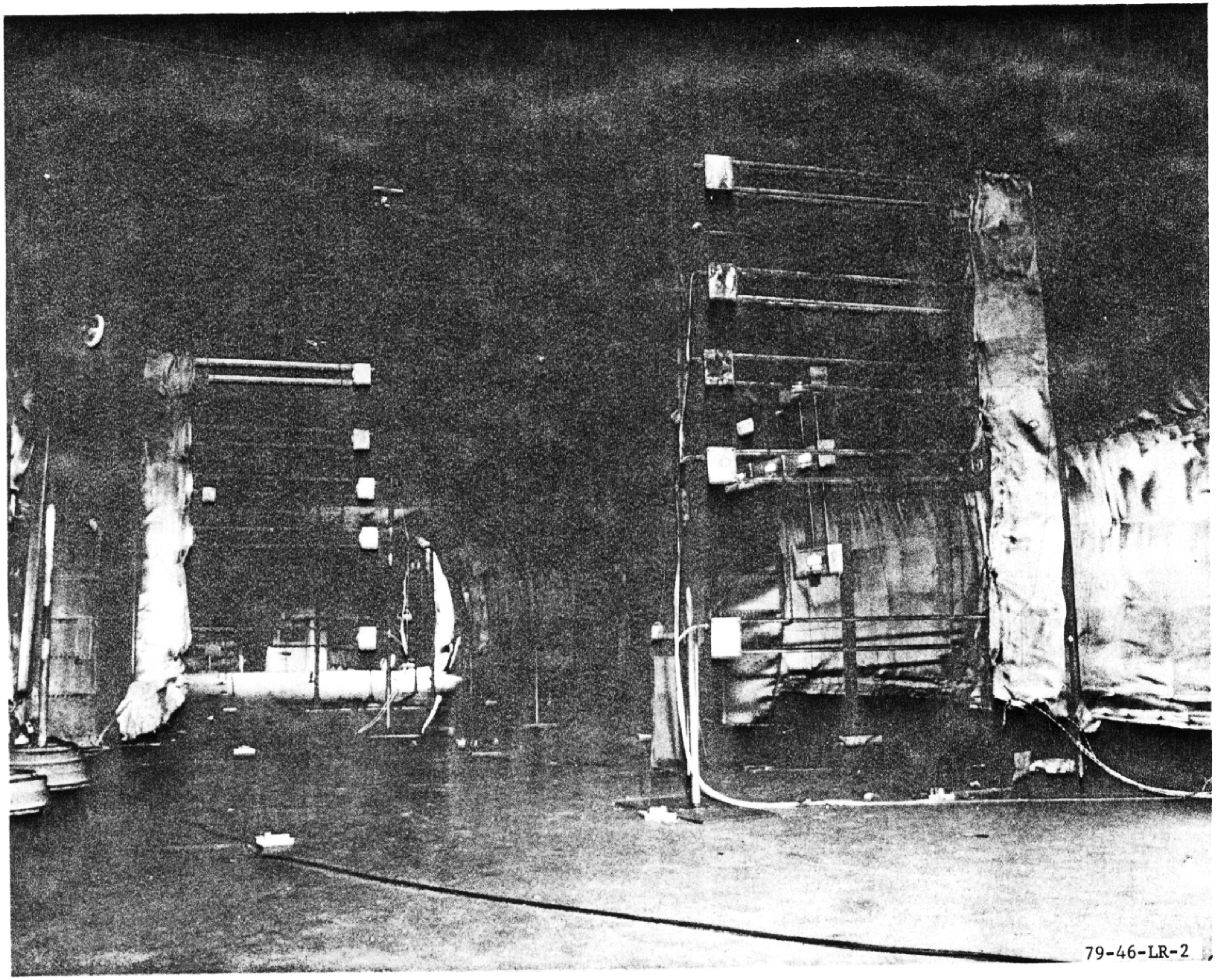

FIGURE 2. NATIONAL BUREAU OF STANDARDS SMOKEMETERS

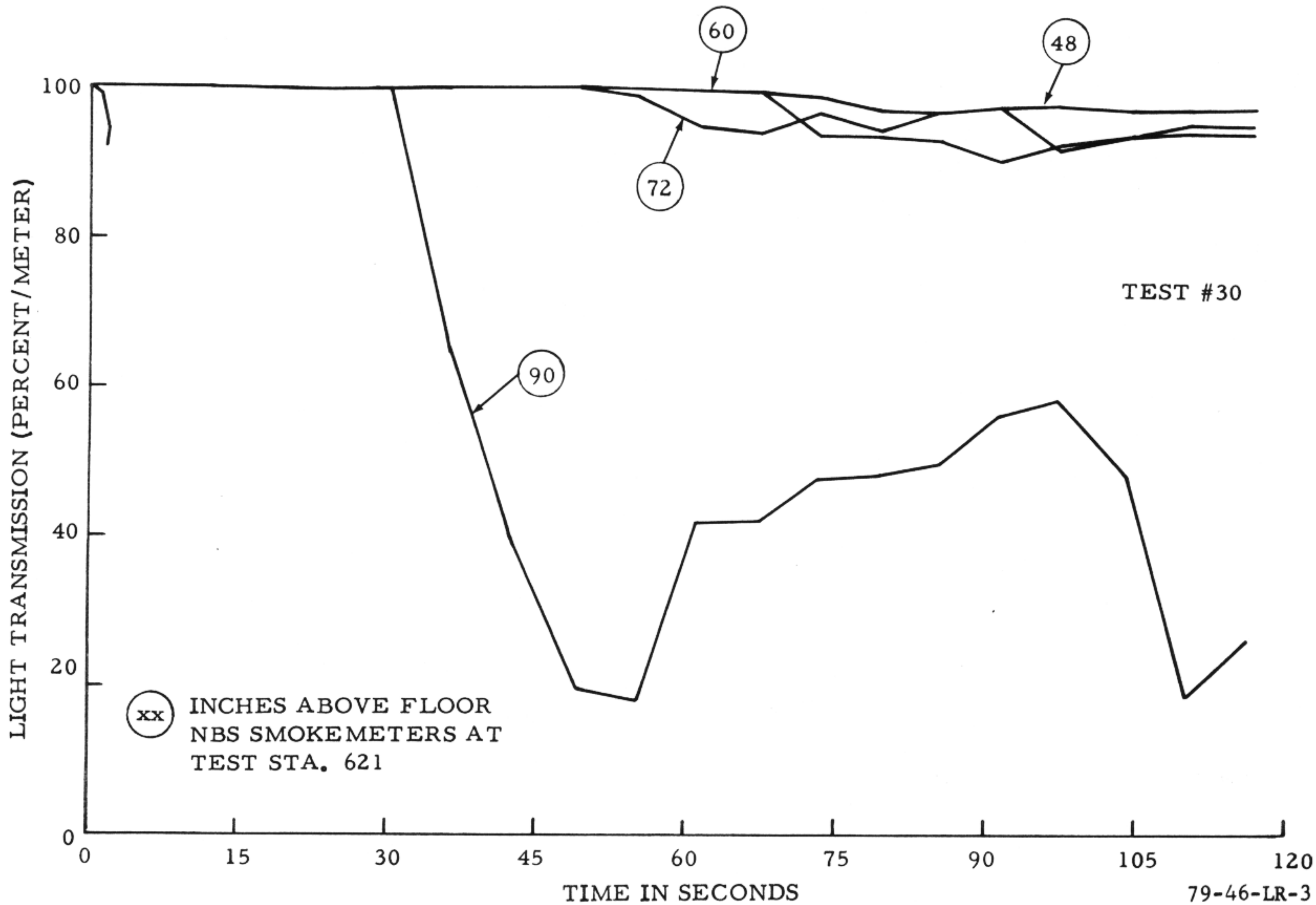

FIGURE 3. LIGHT TRANSMISSION (SMOKEMETER) PROFILE FOR "LIGHT SMOKE" AT STATION 621

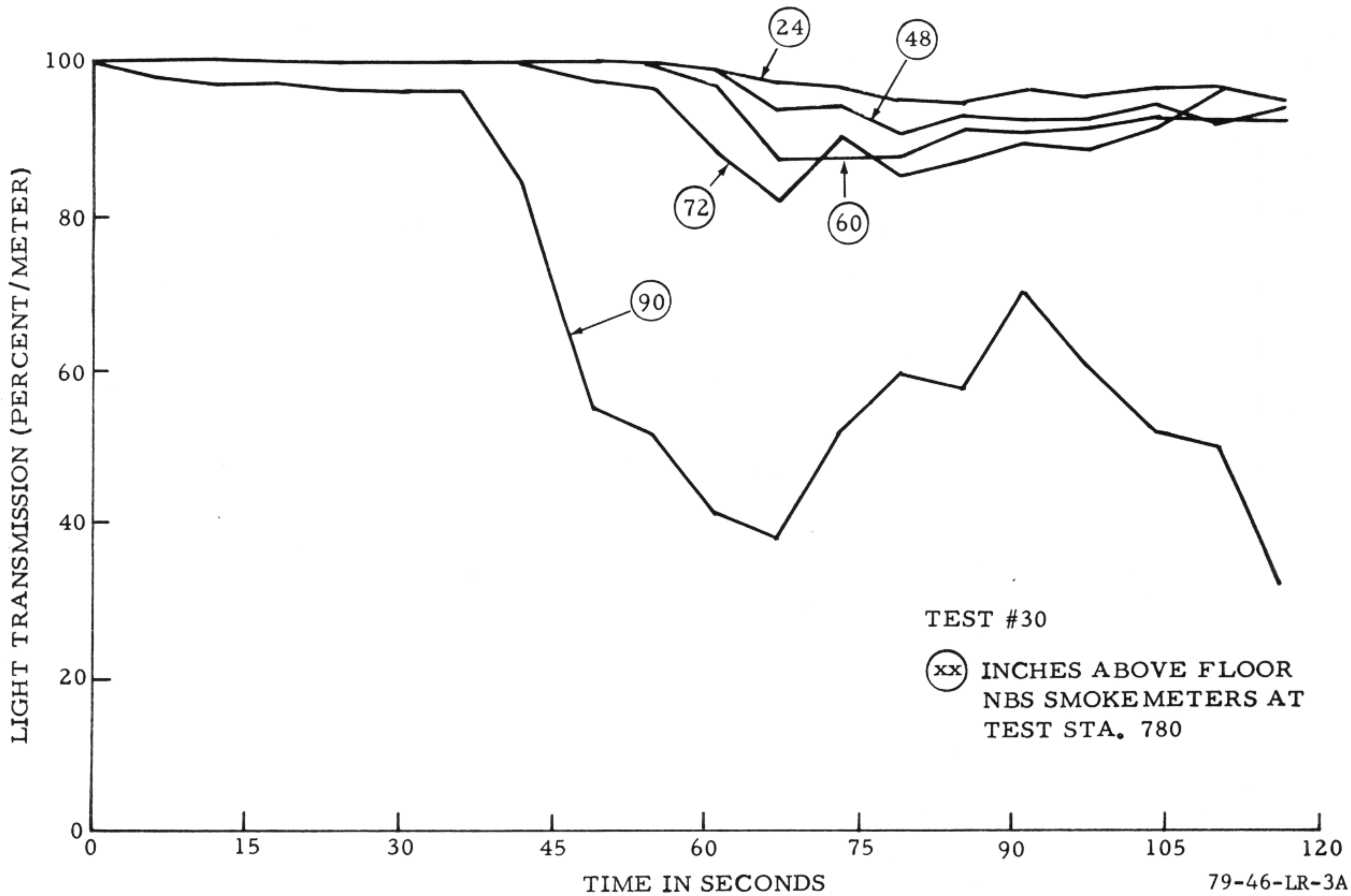

FIGURE 4. LIGHT TRANSMISSION (SMOKEMETER) PROFILE FOR "LIGHT SMOKE" AT STATION 780

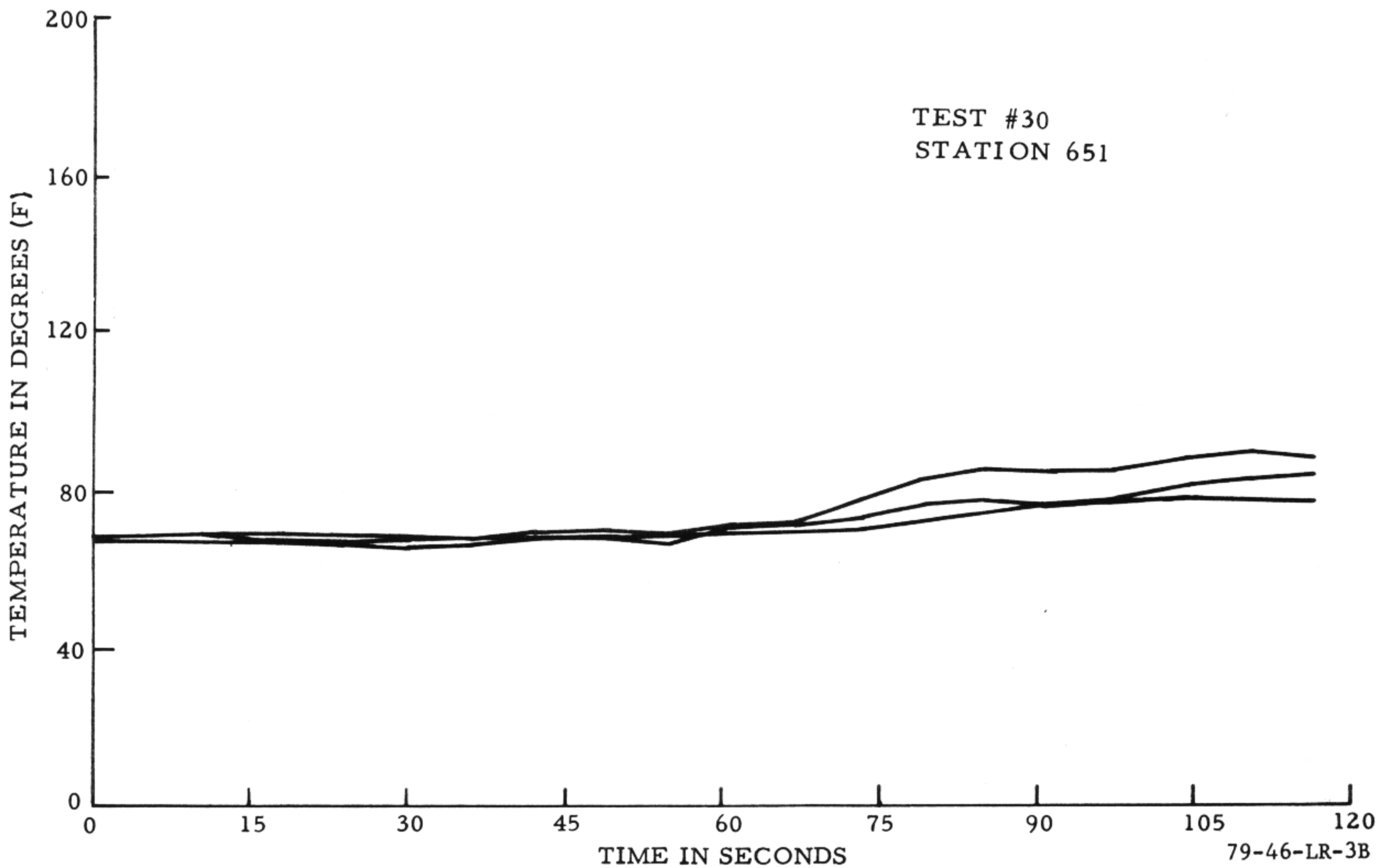

FIGURE 5. TEMPERATURE PROFILE AT THE 78-INCH LEVEL (EXIT SIGN LOCATION) DURING "LIGHT SMOKE" ACCUMULATION

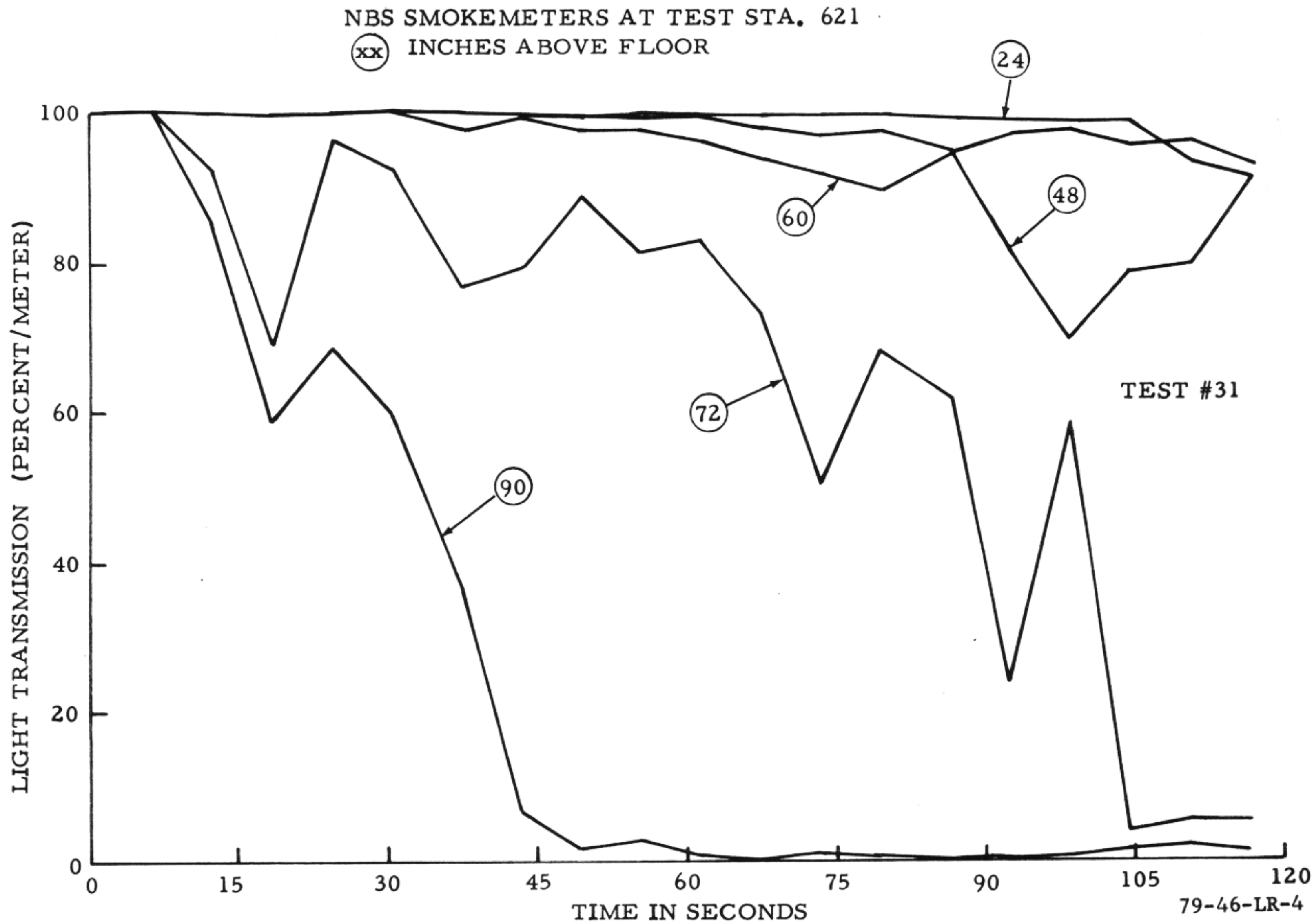

FIGURE 6. LIGHT TRANSMISSION (SMOKEMETER) PROFILE FOR "MEDIUM SMOKE" ACCUMULATION AT STATION 621

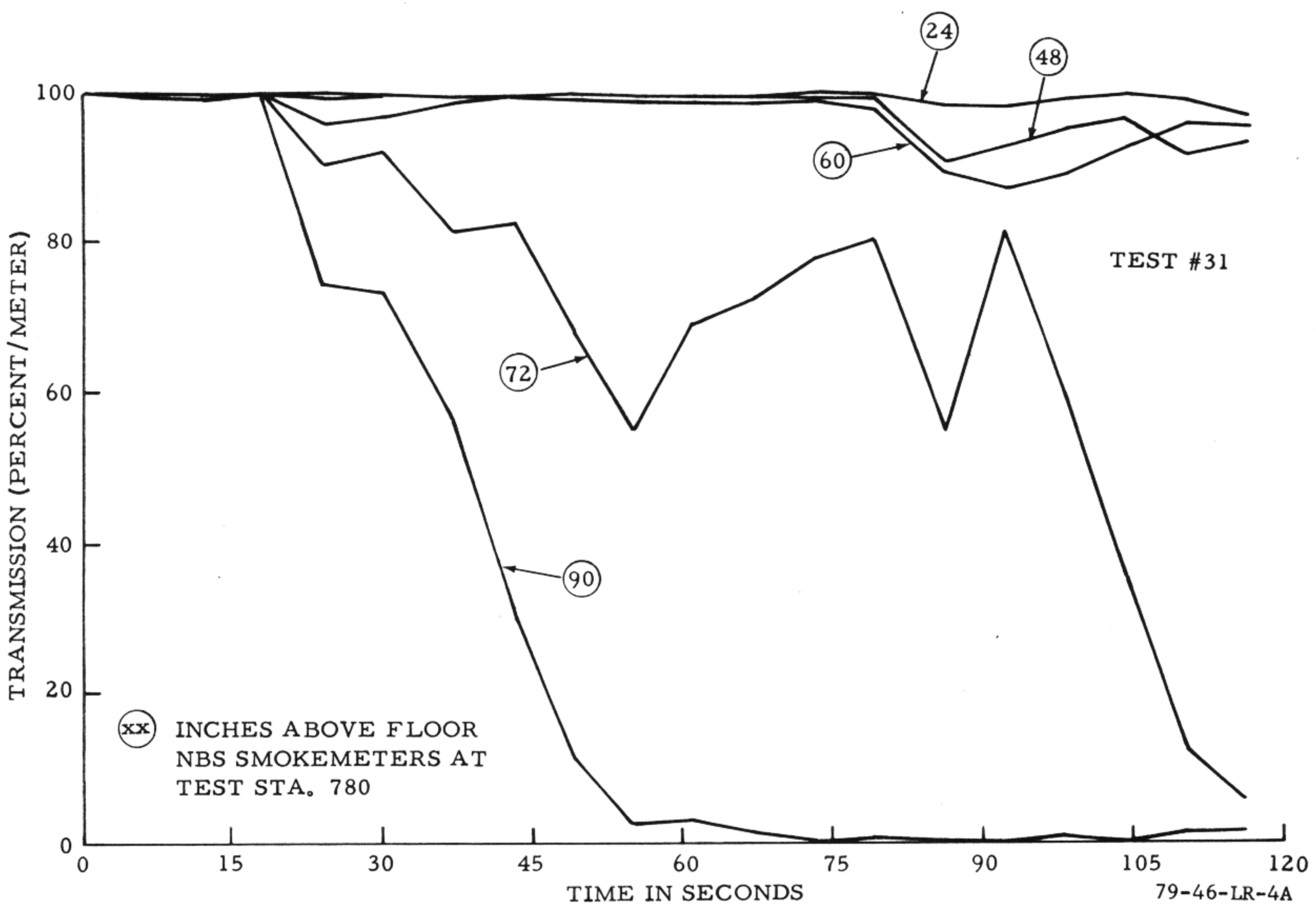

FIGURE 7. LIGHT TRANSMISSION (SMOKEMETER) PROFILE FOR "MEDIUM SMOKE" ACCUMULATION AT STATION 780

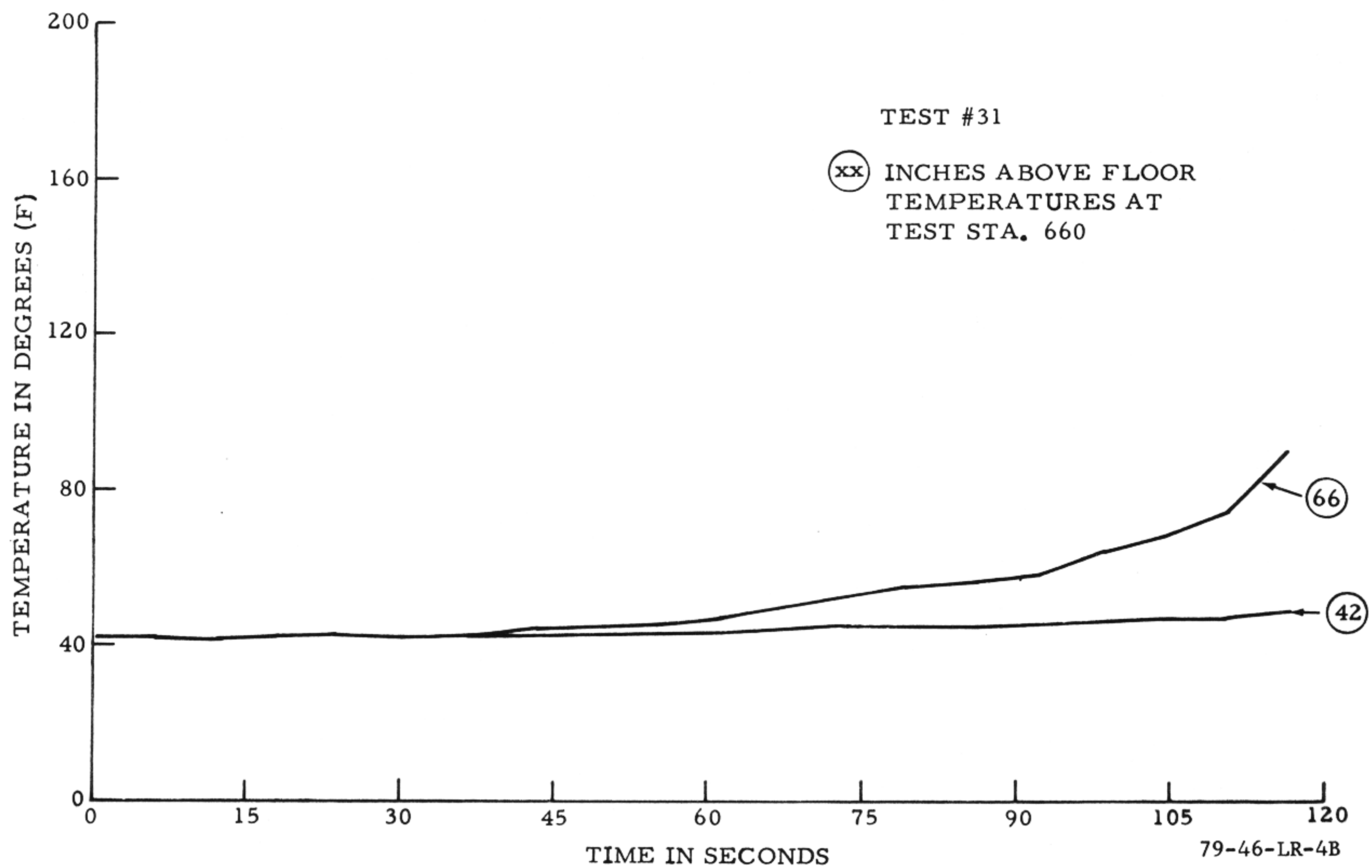

FIGURE 8. TEMPERATURE PROFILE DURING "MEDIUM SMOKE" ACCUMULATION

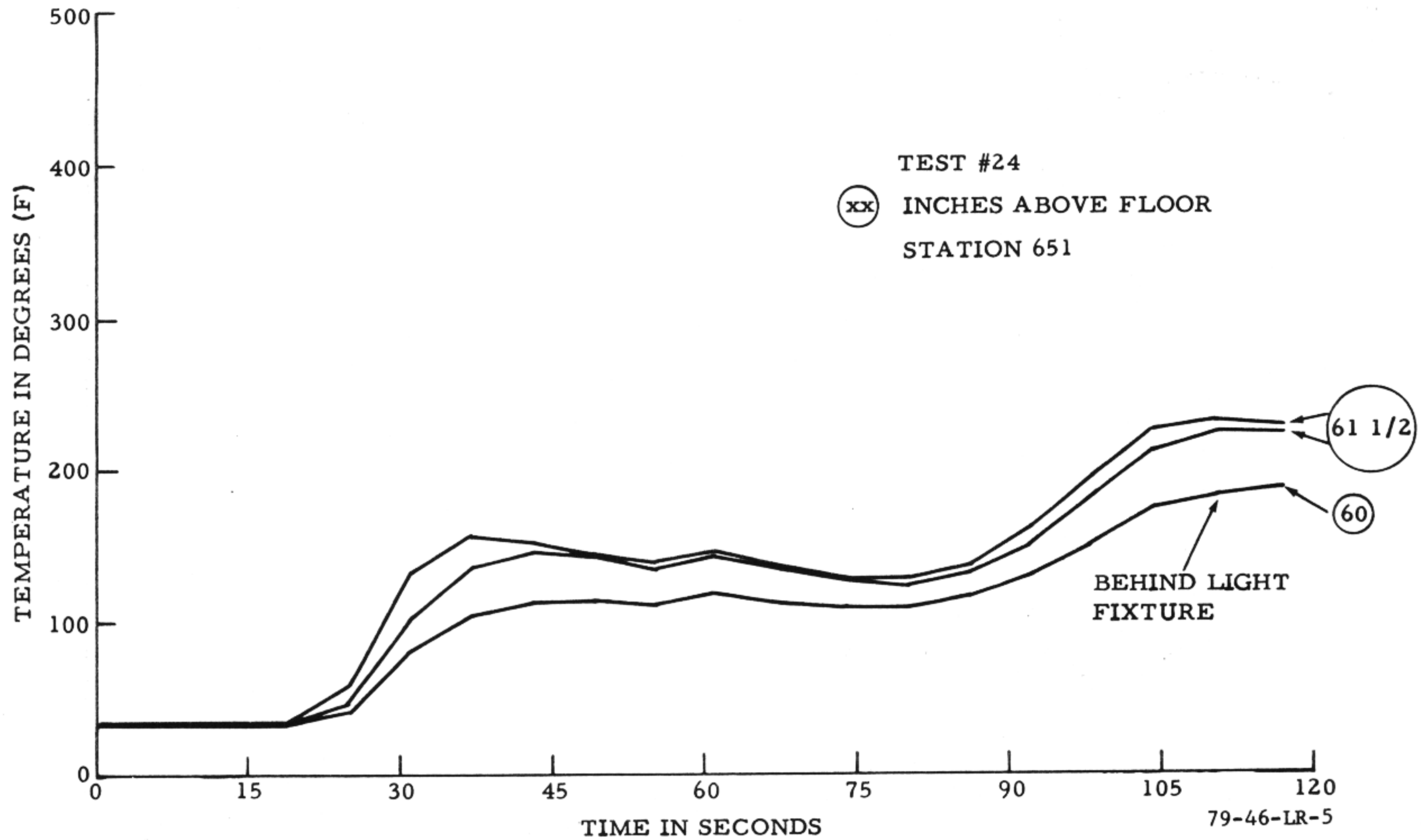

FIGURE 9. TEMPERATURE DURING "MEDIUM HEAVY" SMOKE ACCUMULATION

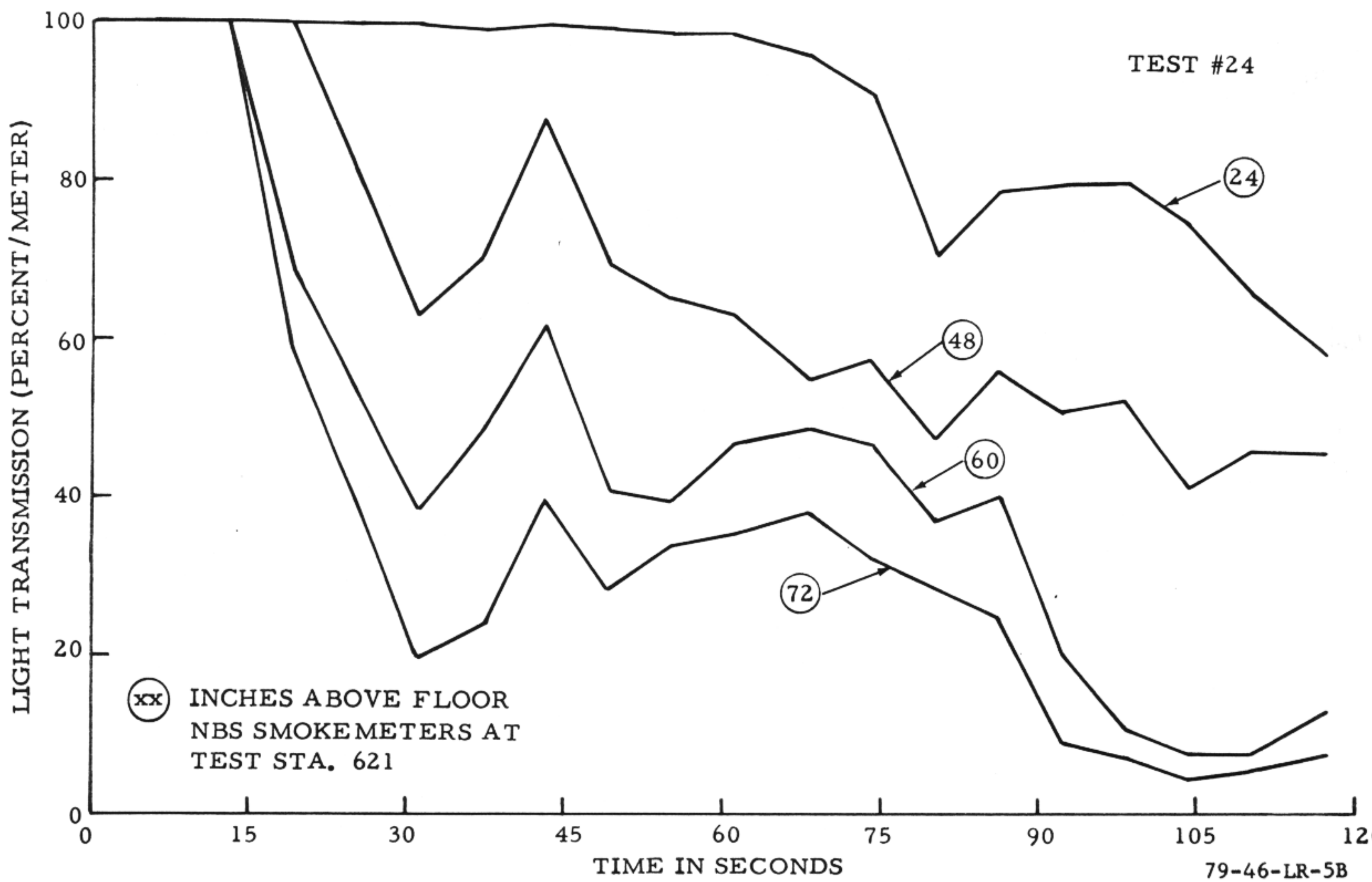

FIGURE 10. LIGHT TRANSMISSION (SMOKEMETER) PROFILE FOR "MEDIUM HEAVY" SMOKE ACCUMULATION AT STATION 621

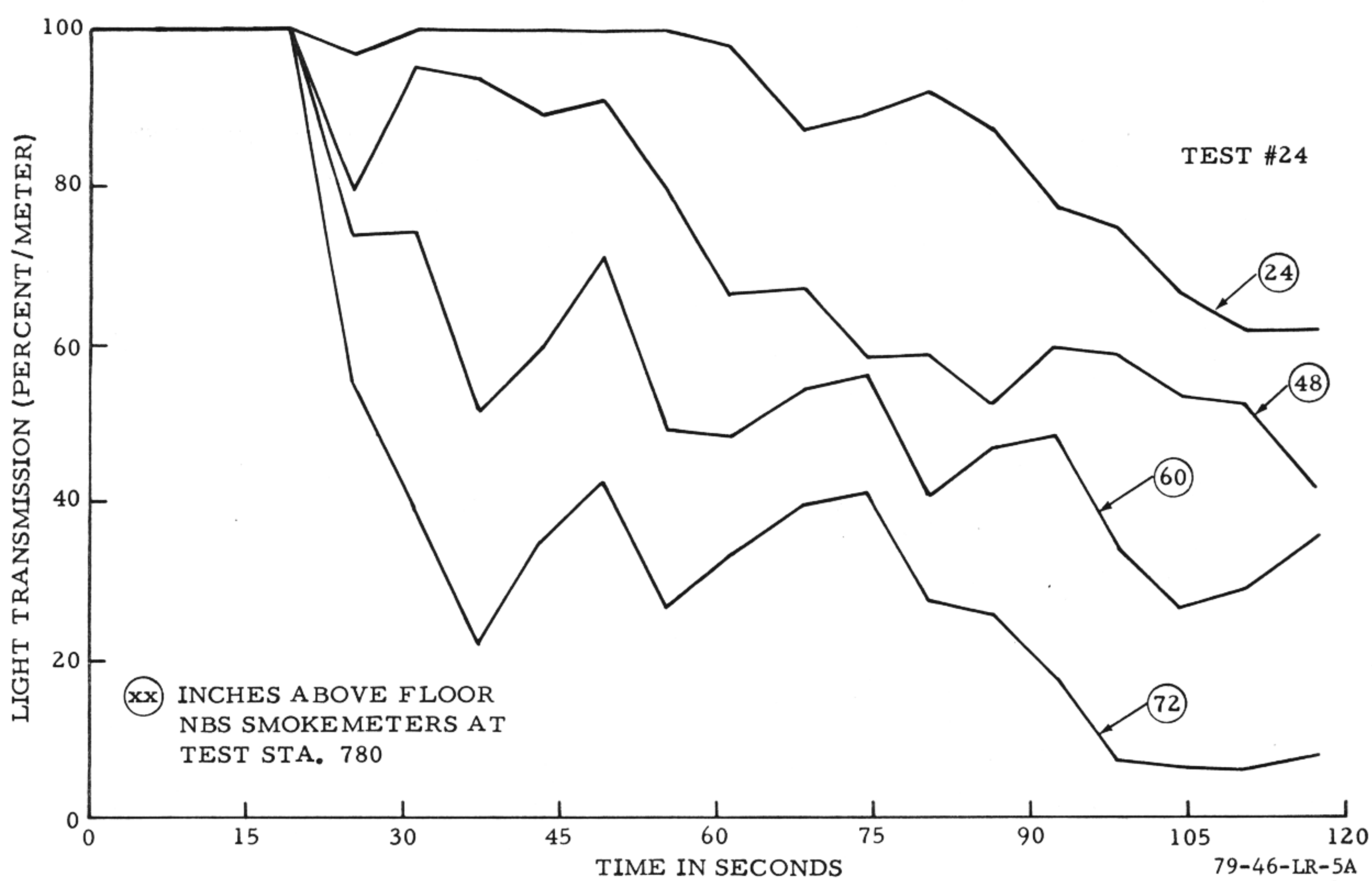

FIGURE 11. LIGHT TRANSMISSION (SMOKEMETER) PROFILE FOR "MEDIUM HEAVY" SMOKE ACCUMULATION AT STATION 780

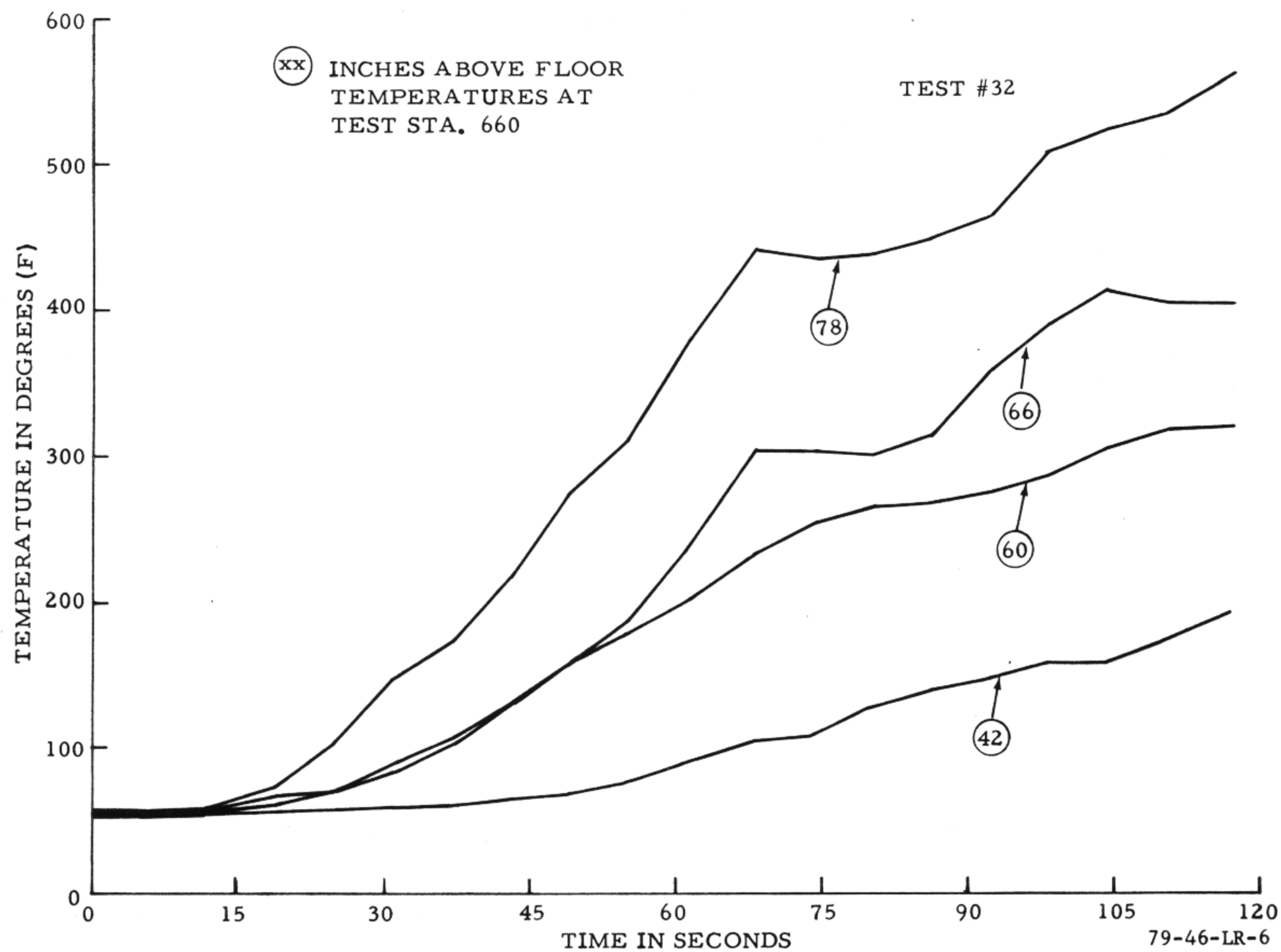

FIGURE 12. TEMPERATURE PROFILE DURING "HEAVY SMOKE" ACCUMULATION

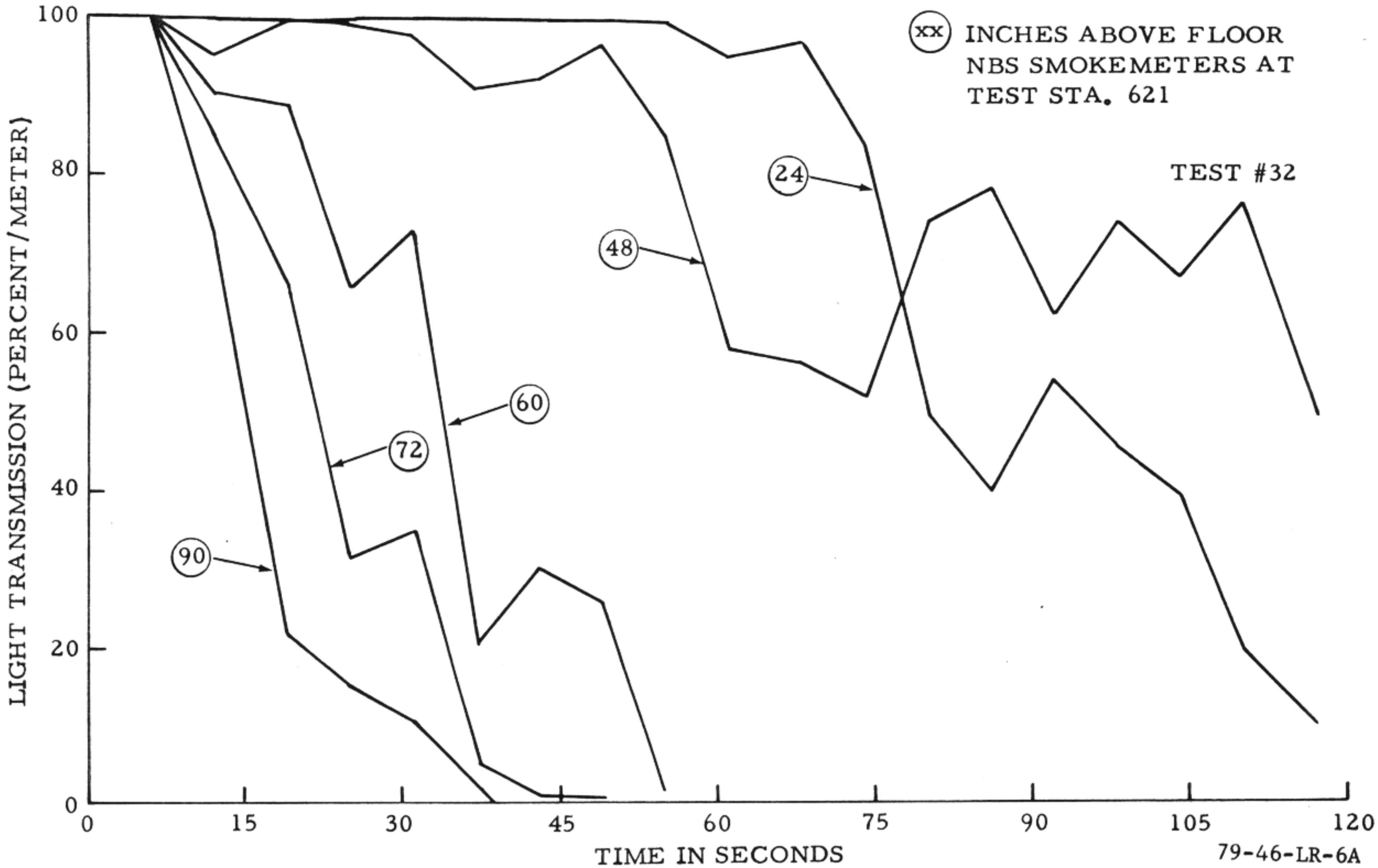

FIGURE 13. LIGHT TRANSMISSION (SMOKEMETER) PROFILE FOR "HEAVY SMOKE" ACCUMULATION AT STATION 621

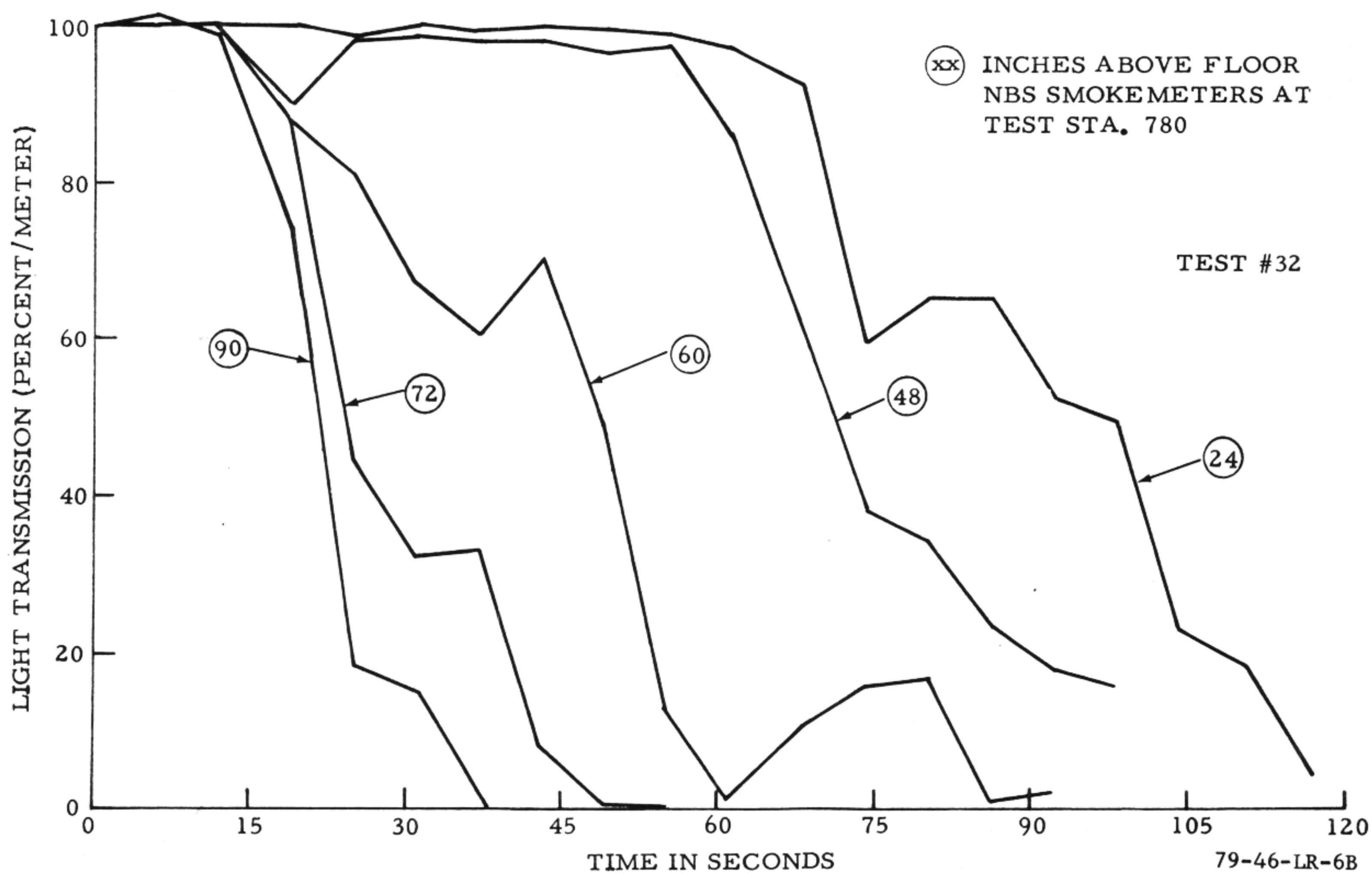

FIGURE 14. LIGHT TRANSMISSION (SMOKEMETER) PROFILE FOR "HEAVY SMOKE" ACCUMULATION AT STATION 780

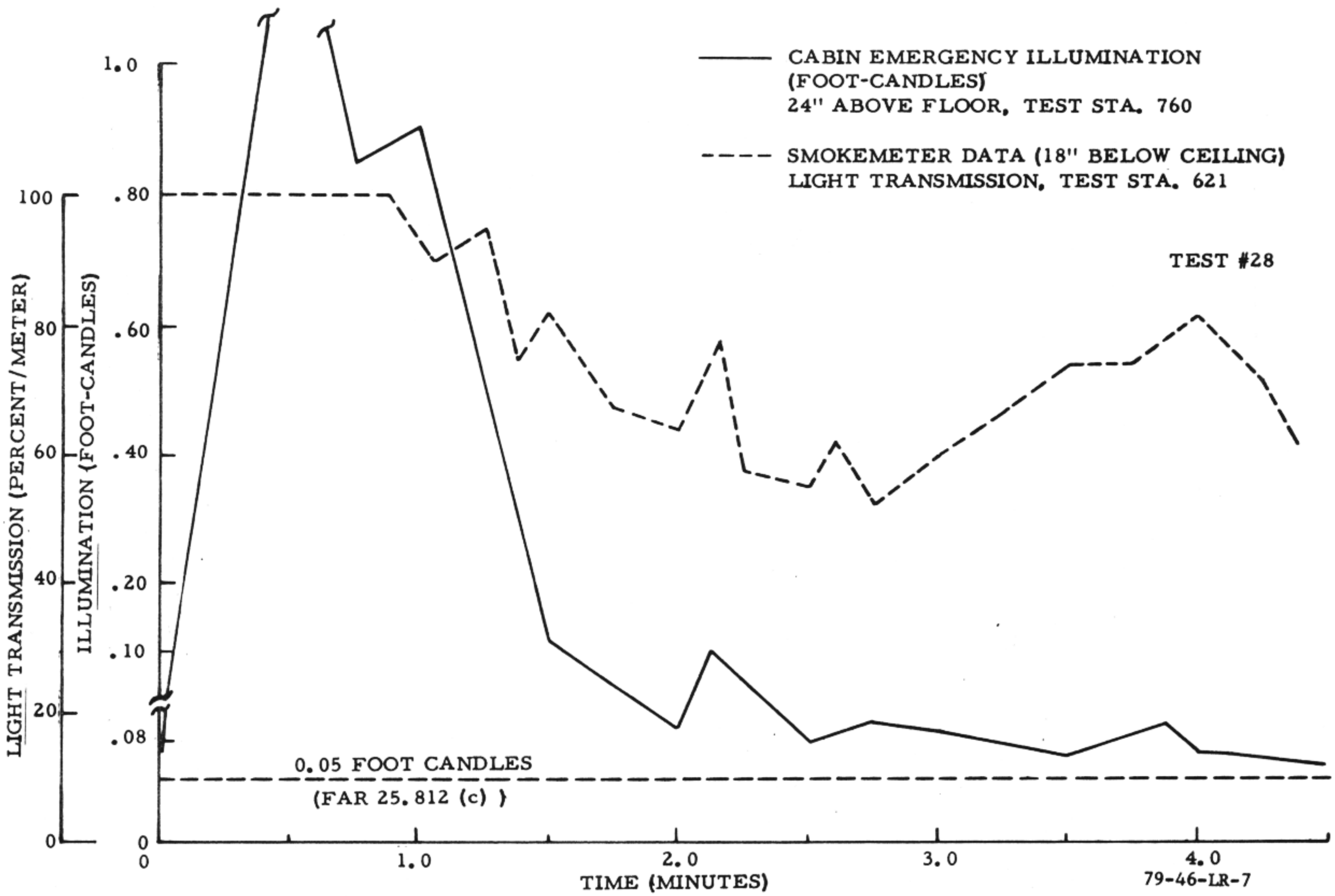

FIGURE 15. EFFECTS OF FIRE/SMOKE ON CABIN EMERGENCY ILLUMINATION, TEST 28

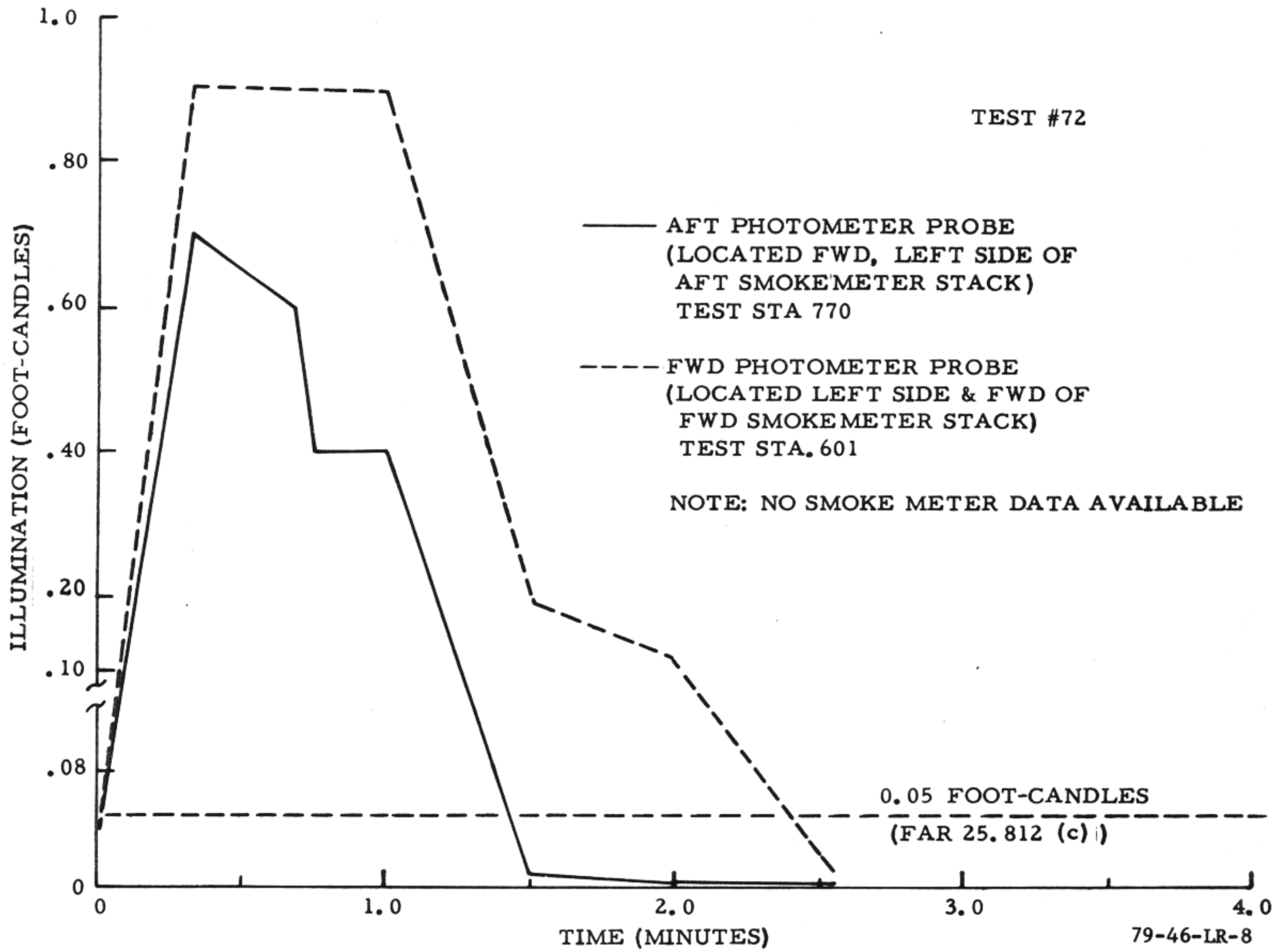

FIGURE 16. EFFECTS OF FIRE/SMOKE ON CABIN EMERGENCY ILLUMINATION, TEST 72

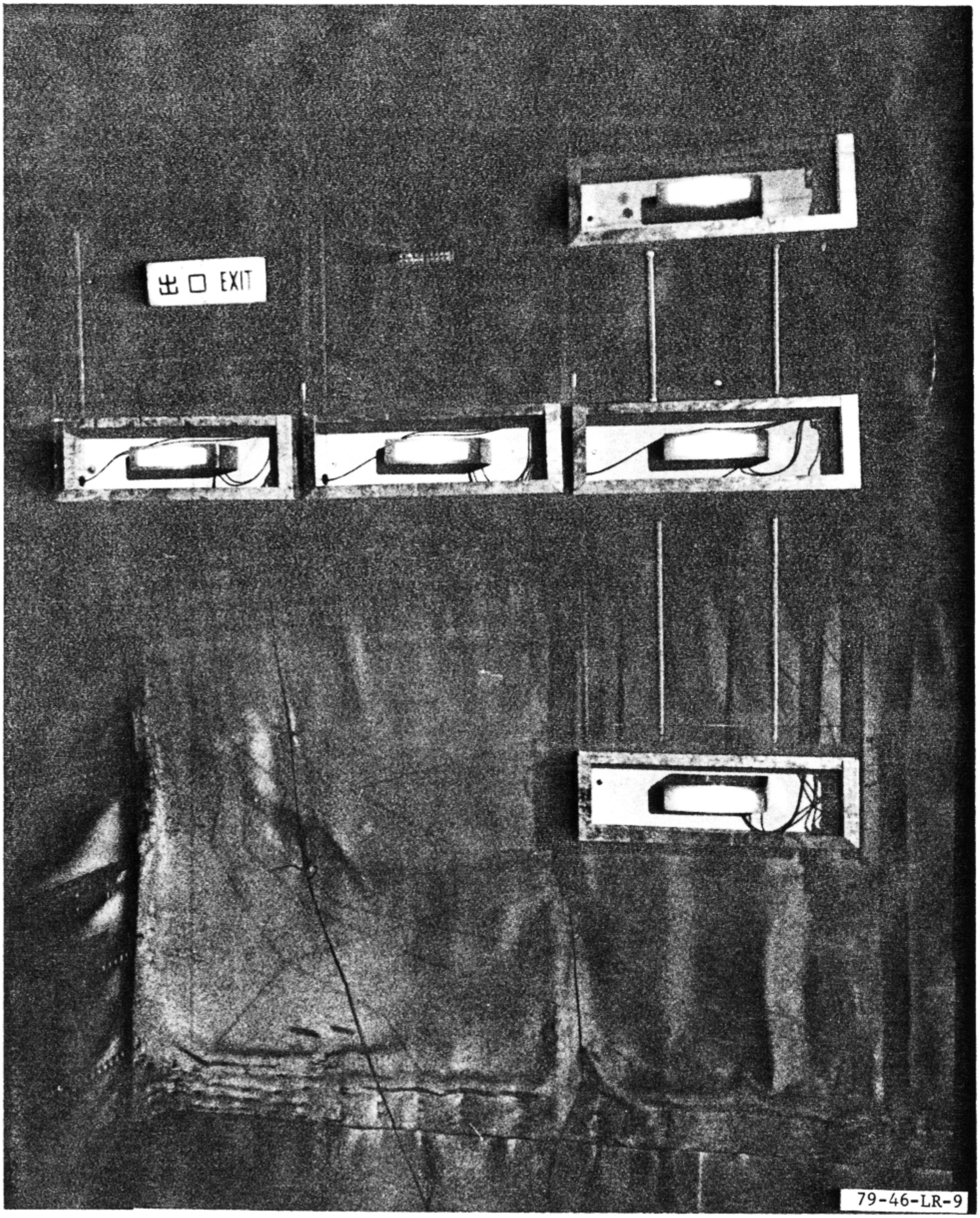

FIGURE 9. HORIZONTAL AND VERTICAL LIGHT CONFIGURATION

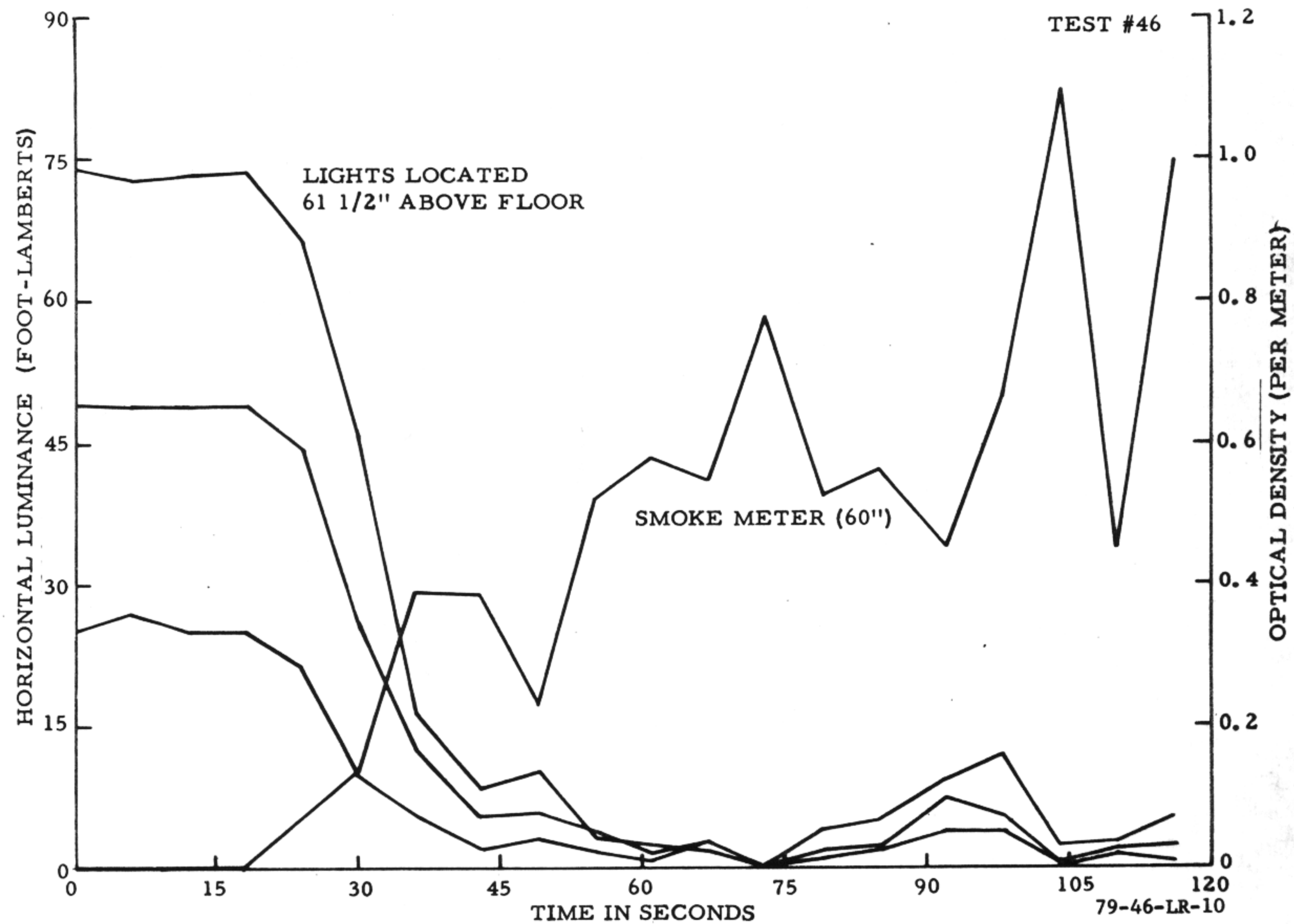

FIGURE 18. HORIZONTAL ILLUMINATION VERSUS OPTICAL DENSITY

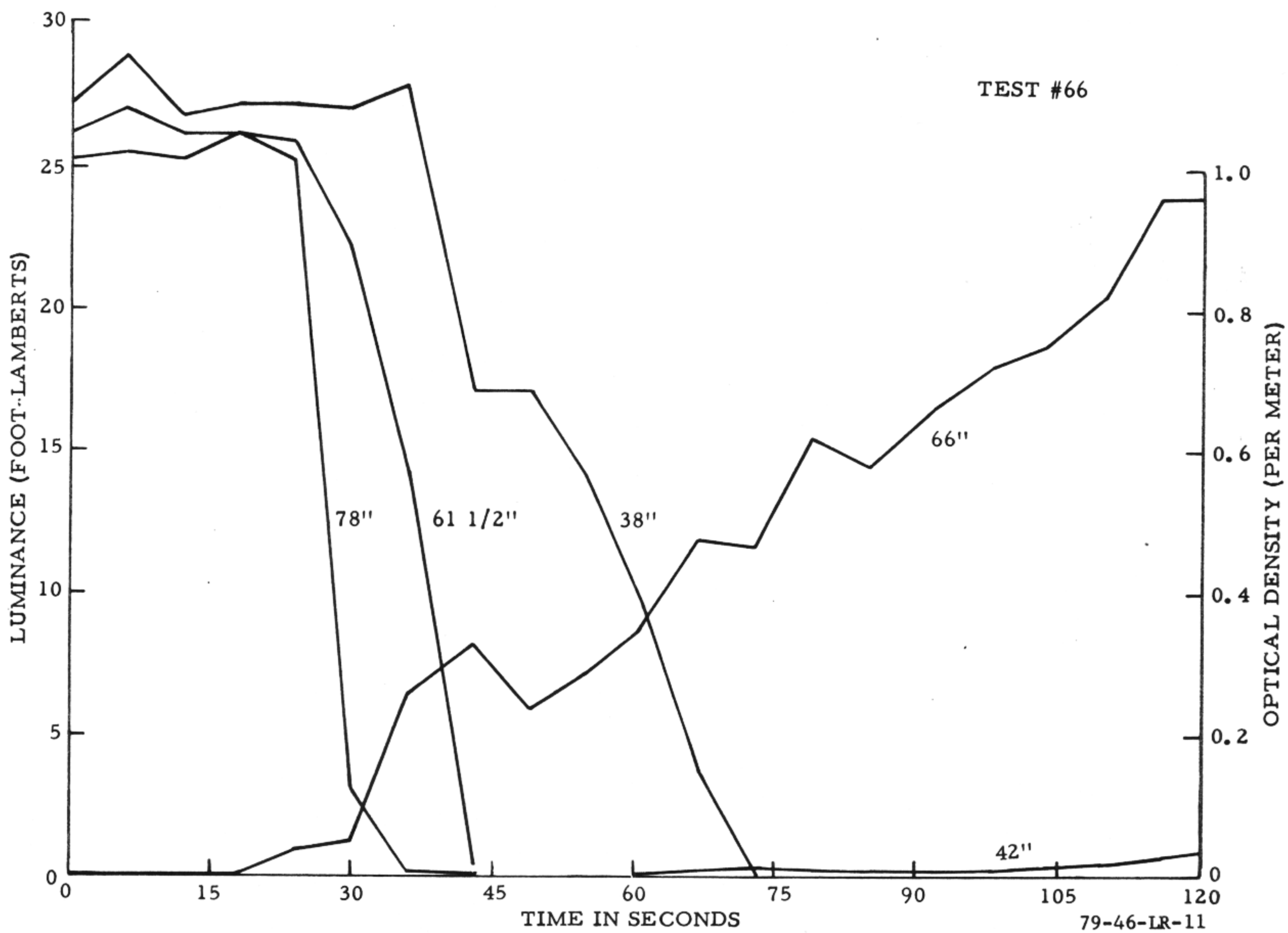

FIGURE 19. VERTICAL LIGHT ILLUMINATION PROFILE VERSUS OPTICAL DENSITY

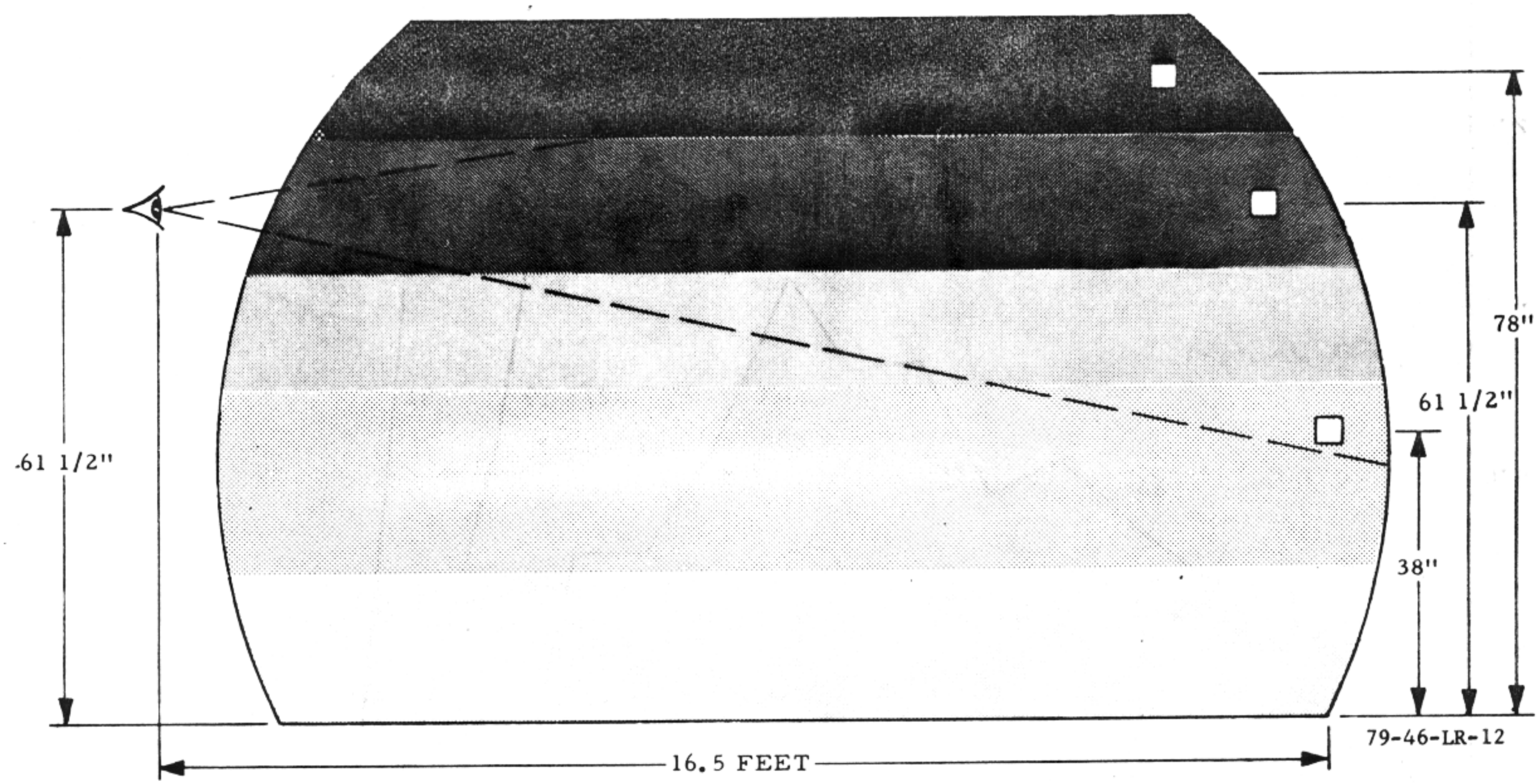

FIGURE 20. SMOKE LAYERING VERSUS "EYE LEVEL" OBSERVATION