NATIONAL BUREAU OF STANDARDS REPORT

5310

A STUDY OF THE TEMPERATURE CHANGES IN A NIKE INSTALLATION DURING SIMULATED MISSILE-LAUNCHING OPERATIONS

by

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Report to
Office of Chief of Engineers
Missiles Branch, Engineering Division
Military Construction
Washington 25, D. C.

NBS

U. S. DEPARTMENT OF COMMERCE
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ABSTRACT

Field tests were conducted in a Nike installation near Paoli, Pennsylvania, at the request of the Office of the Chief of Engineers, to study the temperature changes in such an underground chamber during simulated missile launching operations with outdoor temperatures approximately 100 degrees below the chamber temperature. These studies were planned to reveal how cold it would get in such a chamber located in the Arctic when the outdoor temperature was -50°F and the chamber temperature was maintained at +50°F. Because these tests were made in November, outdoor temperatures in Pennsylvania were near 32°F, and the chamber was heated to about 140°F to provide the desired temperature difference. The chamber was heated for nine days prior to starting tests to produce a suitable temperature in the chamber and the surrounding concrete walls and earth. Several tests were made simulating the firing of a single missile using the time schedule proposed for actual use of the equipment, and two tests were made employing ten consecutive cycles to observe whether or not the temperatures in the chamber became significantly lower under these conditions.

The tests showed that the air temperature in the underground chamber decreased from 21 to 35 degrees during the 40 seconds required to open the hatch doors and raise the elevator. When the elevator was subsequently lowered after launching the missile, the temperature decreased during the 60 seconds required for this operation to a level from 47 to 56 degrees below the initial chamber temperature. The data show that 11,000 to 18,000 cu ft of outdoor air entered the chamber during the first opening, and up to 54,000 cu ft during the second opening and the two minutes immediately thereafter when the scavenging exhaust blower was used.

The results showed that the temperature drop experienced in the chamber during brief periods when the hatchway was opened was limited primarily by the heat capacity of the air in the chamber and was only affected to a small degree by heat transfer from the walls and by a steady heat input rate of 476,000 Btu/hr. However, the heat capacity of the walls assisted materially in rewarming the air after a launching operation. Means for increasing the rewarming rate and for reducing the air exchange between the chamber and the outdoors are suggested.

INTRODUCTION

In accordance with a request from the Office of the Chief of Engineers in a letter dated November 18, 1955, field tests were made on an underground Nike installation at Nike Launcher Site 82L near Paoli, Pennsylvania, during the period November 10, 1955 through November 21, 1955. The field tests were conducted to observe temperature changes in an underground Nike installation during simulated launching operations under special elevated temperatures. The tests were planned to indicate the magnitude of the temperature changes within the structure under arctic conditions and also for comparison with the performance of a model of the prototype chamber. Certain modifications of the prototype underground structure and its heating plant were recommended to representatives of the Office of the Chief of Engineers based upon the analysis of the field test results. The investigation was intended to provide design information that could be used to avoid possible damage to operating equipment and deleterious effects on personnel efficiency and to avoid condensation or ice accumulation on critical parts of the equipment in arctic installations.

DESCRIPTION OF INSTALLATION

The Nike underground installation used in the tests consisted of a steel-reinforced concrete chamber, approximately 62 1/2 feet long, 62 feet wide and 14 1/2 feet deep, under a three-foot earth cover. An elevator opening, 52' x 9', in the center top of the chamber extended to the ground level and was fitted with two hinged doors. Also, a stairway, two escape hatchways, and intake and exhaust vents were extended to the ground surface. An elevator platform underneath the opening was capable of moving its top surface from below the chamber floor to the ground surface level. The elevator pit was 6 1/2 feet below the floor level and was 13 feet wide and 60 feet long. The pit provided space for the elevator platform structure and part of the operating machinery. Fig. 1 and Fig. 2 are simplified drawings of the plan and elevation of the underground chamber. The control room is designated as A, the north part of the chamber as B, the south

part of the chamber as C and the elevator section as D. The underground chamber tested was constructed for single missile launching. Fig. 3 shows part of the doors, power mechanism and door gasket. Fig. 4 and Fig. 5 show the views of the structure from above ground and the propane tanks installed for heating the chamber during the test period.

During a typical firing operation, the hatch would be opened to allow the elevator platform, with a missile in position on the launcher, to rise to the ground surface. If required after firing, a blower (designated as J in Fig. 1.) with a capacity of 12,000 cfm would be turned on to exhaust contaminated air from the structure to the atmosphere. After the launching of the missile the elevator would be lowered and the hatch doors closed. Two fresh air intake vents are shown at E and G in Fig. 1.

TEST PROCEDURE

In addition to the two electric heaters already installed in the underground chamber, five portable propane-fired heaters were used to warm the air in the chamber. This was done to obtain a temperature difference between the chamber air and outdoor air approximating that likely to occur in the Arctic. The locations of the propane heaters at the beginning of the tests are shown in Fig. 1 and are designated as H 1, through H 5. Fig. 6 shows one of the heaters (H 1 in Fig. 1) in position. The propane heaters were located generally at the following positions:

H 1	North section (B)
H 2	Center of south section (C)
H 3	East end of pit (D)
H 4	West end of pit (D)
H 5	West half of south section (C)

Eight 16" electric fans were used to increase air movement and mixing of air in the chamber: (Fig. 1 shows the locations of the fans designated as F 1 through F 8.)

F 1	North wall 9 feet above floor (B)
F 2	North wall 9 feet above floor (B)
F 3	South wall 9 feet above floor (C)
F 4	South wall 9 feet above floor (C)
F 5	West end in pit (D)
F 6	East end in pit (D)
F 7	West end of north side of pit on floor (B)
F 8	East end of south side of pit on floor (C)

Locations of heaters and fans in the pit were changed during the course of tests as will be shown later in test schedules. Fig. 6 shows one of the fans (F 2) situated on the wall facing downward at an angle. All wall fans were installed in this manner.

The total capacity of the heating by lights, electric heaters, and fans was 12.8 k.w. (43,700 Btu/hr), and the gross heat input of the propane-fired heaters averaged 432,000 Btu/hr.

During tests when the 12,000 cfm exhaust blower (J in Fig. 1) was not operated, the exhaust vent above the ground surface was closed to prevent air flow by gravity. Fig. 7 shows the canvas enclosure over this exhaust vent. The 12,000 cfm exhaust blower was in operation during the tests only where it is indicated in the test schedule.

A ventilating blower with a capacity of approximately 650 cfm was installed above ground during operation of the unvented propane heaters to supply fresh air for combustion and ventilation continuously from outdoors. The duct for this air extended through the south air intake vent into the southwest corner of the chamber. Fig. 8 shows the installation of this blower. The other air intake vent located at northeast corner was closed except when the exhaust blower was in operation.

The doors in the elevator opening and elevator were operated on the established time schedule for the firing of single or consecutive missiles up to the full storage capacity of the battery. When the propane heaters and 16" electric fans were located in the pit, the elevator platform rested three feet above the floor level. Prior to the start of each test, the elevator was lowered to the floor level. Then the elevator was raised after opening the hatch. Test No. 0 in Table 1 shows the planned time schedule for all simulated missile firings.

Observations were made of changes in air temperatures during the tests at the one- five- and nine-foot levels from the floor, above the doors and at the southwest air discharge. Also observations were made of changes in surface temperatures of the simulated missiles and bottom of the first structural beam east of the chamber center. Prior to and after each test, additional surface temperature measurements were made of the walls, elevator opening edge gasket, and metallic objects such as hatch wall, hatch flange, elevator platform, control switches, and hydraulic door-cylinder. Temperatures at 48 locations were measured every hour by means of copper-constantan thermocouples using two electronic constant-balance type potentiometers. Air temperature changes were rapid when the hatch doors were open, so temperatures at 22 stations were measured continuously. During the temperature recovery period after the simulated firing of a missile and subsequent lowering of the elevator and closing of the doors, temperature measurements were made at 48 stations with increasing time intervals of 5, 10 and 20 minutes as the rate of temperature change decreased. Table 2 is a list of thermocouple locations. In Fig. 1, 2 and 3, the thermocouple positions are designated as TC 1 through TC 48. Fig. 9 shows one of the simulated guided missiles located on the rack.

TEST RESULTS

The underground chamber was heated for nine days before the average inside air temperature reached a steady level of 142°F. The outdoor air temperature measured five feet above the hatch ranged from 32°F to 79°F during the same period. The average rate of propane consumption at this temperature level for a period prior to and during the tests, was approximately 20 pounds per hour. At the end of this preliminary heating period, the average observed wall temperature and outside air temperature were 126.9°F and 40.4°F respectively. The heat input was approximately 12.8 kilowatts or 43,700 Btu/hr by electric heaters, lights and fans and 432,000 Btu/hr by the propane-fired heaters. The heat necessary to warm 650 cfm of outdoor air from 40°F to 142°F was 71,600 Btu/hr. Therefore, the effective heat input to the installation was 432,000 + 43,700 - 71,600 = 404,100 Btu/hr.

The heat transmission through the hatchway doors was computed to be 41,000 Btu/hr based on a temperature difference of 100 degrees and the resistance of two air films adjacent to the horizontal steel doors with heat flow upward.

The heat input to the concrete surfaces of the floor, walls, and ceiling would then be 34.5 Btu/hr $(ft)^2$ by difference; and the heat transmission coefficient for the air film would be approximately 2.29 Btu/hr $(ft)^2(°F)$.

Table 1 shows the planned time schedule and actual time schedules for each test. For Test No. I and Test No. II the controls for lowering the elevator and closing the hatch doors did not function properly and the controls had to be shunted to continue these tests. The controls were repaired and functioned properly for the remainder of the tests.

The test data are shown in graphic forms for each test as follows:

Test No. I. Single missile-firing cycle with all heaters operating and floor-mounted fans stopped. Graph No. 1 - 1 shows the average temperature differences between outside air and inside air at north pit edge and south pit edge plotted against time. The inside air temperatures plotted were the average of the temperatures at one-foot and five-foot levels from the floor for all seven tests.

Test No. II. Single missile-firing cycle with pit heaters and pit fans stopped. Graph 2 - 1 shows the changes with time in temperature differences between outside air and inside air at north and south pit edges.

Graph 2 - 2 shows the changes in temperature differences between outside air and simulated missiles located near south wall and south pit edge.

Test No. III. Single missile-firing cycle with all heaters operating and floor-mounted fans stopped. Fan (F6) and heater (H3) at east end of the pit were moved out of the pit to the south side edge of the pit on the floor at the east end. Fan (F5)

and heater (H4) at the west end of the pit were moved out of the pit to the north edge of the pit on the floor at the west end. These fans and heaters remained at the same positions for all of the following tests.

Graph 3 - 1 shows the changes in temperature differences between outside air and inside air at north and south pit edges.

Graph 3 - 2 shows the changes in temperature differences between outside air and simulated missiles located near south wall and south pit edge.

Test No. IV. Single missile-firing cycle with all heaters operating and floor-mounted fans stopped. The exhaust blower (J) was in operation for three minutes during the firing cycle.

Graph 4 - 1 shows the changes in temperature differences between outside air and inside air at north and south pit edges.

Graph 4 - 2 shows the changes in temperature differences between outside air and simulated missiles located near south wall and south pit edge.

Test No. V. Ten consecutive missile-firing cycles with all heaters and fans operating. The exhaust blower (J) was in operation three minutes for each cycle.

Graph 5 - 1 shows the changes in temperature differences between outside air and inside air at north and south pit edges.

Graph 5 - 2 shows the changes in temperature differences between outside air and simulated missiles near south wall and south pit edge.

Graph 5 - 3 shows the changes in temperature differences between outside air and inside air in north section (B) and south section (C). The air temperatures plotted were the averages of those observed one and five feet above the floor near the edge of the pit and near the far wall.

Test No. VI. The operating conditions were the same as Test No. V except sheets of canvas were installed around the elevator hatchway to limit the entry of cold air into the missile storage section of the structure. Fig. 10 shows part of one side of the canvas enclosure.

Graph 6 - 1 shows the changes in temperature differences between outside air and inside air at north and south pit edges.

Graph 6 - 2 shows the changes in temperature differences between outside air and simulated missiles located near south wall and south pit edge.

Graph 6 - 3 shows the change in temperature differences between outside air and structure wall; also between outside air and inside air.

Test No. VII. All floor fans and blowers turned off and all heaters operating. Elevator platform was lowered to the bottom. Elevator aperture was opened and left open for duration of test to simulate conditions that would develop if the hatch doors failed to close and the elevator platform could not be raised again. Observations of temperature changes were made upon opening of the hatch.

Graph 8 - 1 shows the changes in temperature differences between outside air and inside air near north and south pit edges.

Graph 8 - 2 shows the changes in temperature differences between outside air and simulated missiles located near south wall and south pit edge; also between outside air and interior structure wall.

The temperature at each of 22 thermocouple locations was observed approximately every 24 seconds during most of the tests. Because some of the time intervals in the sequence of operations of the simulated missile firing schedule were less than 24 seconds, the maximum and minimum temperatures were probably not always observed.

Tests I, II, and III each simulated the firing of a single missile and the recovery of temperature conditions in the underground chamber immediately thereafter. The temperature difference between outdoor air and the inside air varied during the three-minute firing cycle from an initial value of about 105°F to a minimum value of approximately 60°F. The only differences between the operating conditions for the three tests were the location of some of the circulating fans and propane heaters and the number of fans and heaters that were in operation during the firing cycle. The two propane heaters in the elevator pit, H3 and H4, were turned off during Test II, but no significant difference in results was noted. The air temperatures in the structure returned to their initial level about 15 minutes after the start of the firing cycle. There was a maximum of 30 seconds difference in the duration of the three firing cycles due to malfunctioning of some of the controls.

Lengths of corrugated iron drain pipe were used to simulate Nike missiles during the test because the heat capacity of such pipe was believed to be comparable to that of the Nike housing. Fig. 2 - 2 and 3 - 2 show that the surface temperature of the simulated missiles dropped from seven to eight degrees during the three-minute firing cycle. The simulated missile near the pit edge was about three degrees colder than that farthest from the elevator pit. More than 30 minutes were required for the simulated missiles to return to the initial temperature.

The results of Test IV were significantly different from those observed in Tests I, II, and III, probably because the exhaust blower (J) was operated for three minutes after the firing operation in Test IV to simulate the clearing of foul gas from the structure. Fig. 4 - 1 shows that the air temperature in the chamber decreased about nine degrees more, relative to the outdoor air in Test IV, than for the first three tests, and the air temperature near the pit edge was 9°F lower than that near the south wall at the lowest level of observation, one foot above the floor. As would be expected, the air temperature did not rise as rapidly after closing the hatch when the exhaust blower was in operation as for the first three tests without the exhaust blower. Recovery to the initial air temperature occurred in about the same length of time in all four tests, however. The surface temperatures of the simulated missiles near the south edge of the pit and near the south wall decreased 15 and 10 degrees, respectively, during Test IV.

The results plotted in Fig. 5 - 1 for the ten consecutive firing cycles performed in Test V show that the air temperature inside the structure near the south edge of the pit decreased 58 degrees during the tenth firing operation as compared to the initial temperature when the exhaust blower was operated for three minutes during each cycle. The lowest air temperature for the tenth cycle was only about 7°F below the minimum observed for the first cycle. The possible trend toward lower air temperatures inside the structure with repeated cycles may have been somewhat obscured by variations in the timing of the temperature observations with respect to the physical motions of the elevator and the hatch-doors. Both Fig. 5 - 1 and 5 - 3 show no major changes in the temperature of the air in the structure during repetitive firing cycles.

The surface temperatures of the simulated missiles near the south wall and the south edge of the elevator pit decreased 29 and 37 degrees respectively, during the first eight cycles and levelled off for the remaining two cycles.

The results of Test VI, plotted in Fig. 6 - 1, 6 - 2, and 6 - 3, show that the canvas curtain enclosing the elevator-way reduced the temperature changes of the air in the structure and the simulated missiles approximately 10°F during ten consecutive firing cycles as compared to Test V without the curtain. Presumably the curtain reduced the exchange of air between outdoors and the underground structure under the natural convection forces. The exhaust blower was operated on the same time schedule in both tests.

The average temperature of the concrete surface in the underground chamber decreased from 128 degrees to 123 degrees during the first six firing cycles in Test VI and then remained constant for the remaining four cycles. The average structure air temperature during the last four cycles was 104°F. Using the heat transfer coefficient developed earlier in this report for the heat exchange between the air and concrete surfaces of the chamber, the average rate of heat removal from the wall surfaces during the last four cycles of Test VI would be:

$$Q = A\,U\,\Delta\,T = 10{,}518 \times 2.29\ (123 - 104)$$

$$= 458{,}000 \text{ Btu/hr}$$

Since the average gross heat output of the propane heaters was 432,000 Btu/hr and of the electric heaters 43,700 Btu/hr, the total heat available for warming the outdoor air entering the underground chamber during the last four cycles of this test would be 933,700 Btu/hr. Assuming that all of the air leaving the chamber was at an average temperature of 104°F, these data indicate that 68,000 cu ft of outdoor air entered the chamber during the 1 minute 40 seconds that the hatchway was open or partially open, and the period of exhaust blower operation during each six minute interval, or an average of about 17,000 cfm.

For the corresponding period in Test V when there were no curtains around the elevator-way, the total heat available for warming the outdoor air entering the chamber was 1,126,700 Btu/hr, based on an observed average air temperature of 97°F in the chamber, and an average interior wall surface temperature of 124°F. Making the same assumptions as before regarding the temperature of the exhaust air, these data indicate that 85,400 cu ft of outdoor air entered the chamber during the time in each of the last four cycles of Test V when the hatchway was open or the exhaust blower running, at an average rate of about 21,350 cfm.

This comparison indicates that the canvas curtains around the elevator may have reduced the air exchange rate by about 4,400 cfm during repetitive firing cycle conditions.

A comparison of graphs 5 - 1 and 6 - 1 indicates a much smaller change of air temperature in the chamber in Test VI than in Test V during the second minute of each firing cycle, i.e., from 7 to 8 minutes of elapsed time, from 13 to 14 minutes of elapsed time, etc., in these two figures. This comparison indicates that the canvas curtain around the elevator-way significantly limited the entry of cold air into the main portion of the underground chamber during the time required for opening the doors and raising the elevator to ground level.

The results of Test VII, plotted in graphs 8 - 1 and 8 - 2, show that the major decrease in interior air temperature and simulated missile temperature occurred in the first 15 minutes after opening the hatchway doors under conditions that would prevail if the elevator could not be raised or the doors closed to prevent air exchange between indoors and outdoors. The initial decrease in air temperature during this 15-minute period was about 60 degrees, whereas the continued slow decrease during the succeeding four hours was only about 7.5 degrees, reflecting a gradual cooling of the interior wall surfaces.

The average interior surface temperature of the walls, floor and ceiling decreased about five degrees during the first 15 minutes and an additional 9.5 degrees during the succeeding four hours with the hatchway continuously open, as shown in graph 8 - 2. This test illustrates the large heat capacity of the concrete enclosure of the chamber and its ability to provide substantial amounts of heat to the chamber air during extended cooling periods.

The temperatures were observed periodically on a number of components of the operating equipment that might be affected by low temperatures in actual use. The differences, observed during Test V, between these component temperatures and outdoor air are plotted in graph 5 - 4 for two stations on the door gasket at ground level, one on the switch box mounted on the elevator platform, one on a hydraulic cylinder on the south door, and one on the limit switch of the north door.

Graph 5 - 4 shows that the top edge of the door gasket was initially about 30 degrees above outdoor temperature and decreased in temperature about ten degrees during the course of the ten firing cycles, whereas the bottom edge of the same gasket was initially about 70 degrees above outdoor temperature and cooled about 15 degrees during the ten firing cycles. There was very little wind outdoors when these temperatures were observed. The temperature of the top edge of the gasket would be nearer to outdoor temperature in windy weather. The stations of temperature measurement on the door gasket are identified in Fig. 3.

Graph 5 - 4 shows that the control switch mounted on a post on the elevator platform cooled about 50 degrees during the ten firing cycles. In its position on the elevator platform this switch would be exposed directly to outdoor conditions for about one minute out of every six minutes during repetitive firing cycles. The station of temperature observation on this component was on the switch box; the working parts on the inside probably experienced somewhat less change than the case.

Graph 5 - 4 shows that the hydraulic cylinder on the south door and the box of the limit switch on the north door were 100 degrees and 90 degrees above the outdoor temperature, respectively, at the beginning of the test and decreased 17 degrees and 22 degrees, respectively, during the ten firing cycles. The location of the thermocouple in the hydraulic cylinder is shown in Fig. 3.

ANALYSIS AND DISCUSSION

The temperatures observed in the underground chamber and in the air at ground level over the hatchway indicated that outdoor air moved downward into the chamber around the edges of the opening to replace warm air that was traveling upward through the central portion of the hatchway when the doors were open and natural convection forces were free to motivate the air. In actual practice, the swinging action of the doors when they were opened and the piston action of the elevator as it was raised or lowered controlled the air motion briefly during each firing cycle. The temperatures observed in the chamber when the doors were open also indicated rather good mixing of the chamber air and incoming cold air.

Analysis of the air exchange between the outdoors and the chamber is further complicated by use of the exhaust blower which was provided to scavenge combustion products of the missile from the chamber after firing. This blower was rated at 12,000 cfm and sucked air through grilles in the walls of the elevator pit and from the top of the elevator section, and exhausted the air above ground level. The operation of the blower would cause the inward flow of air through the hatchway to exceed the outward flow and would increase the total exchange of air in the chamber, but probably not by an amount equal to the capacity of the blower. The operation of the blower prolonged the cooling period of the chamber when the hatchway was opened the second time in a cycle by lowering the elevator. The computation earlier in this report of the air exchange rate required to cause the heat loss observed during the last few cycles of Tests V and VI indicates that the air delivery rate of the exhaust blower may have been 56 to 70 percent of the average air exchange rate during the period when the hatch was open or the exhaust blower was running.

Graphs 4 - 1 and 5 - 1 show that the temperature of the air in the chamber began to rise after the elevator was lowered and the doors were closed at the end of the firing period even while the exhaust blower was still running. Although operation of the exhaust blower produced a lower minimum temperature in the chamber during the time the hatch

was open and probably delayed full recovery of the chamber temperature a little, a rise in air temperature was noted before the exhaust blower was stopped in these two tests. This same rise in temperature before stopping the blower is not evident in Graph 6 - 1, when the hatchway was surrounded with canvas curtains, probably because the curtains provided a time lag in mixing the cold air in the hatchway and the chamber.

A computation can be made of the approximate amount of outdoor air entering the chamber during each of the two periods in each firing cycle when the hatch was open on the basis of the quantity of heat lost by the air and by the chamber walls, and the quantity of heat generated by the heaters during these intervals. These quantities can be expressed as follows:

Enthalpy change of chamber air, Btu:

$$E = Vc_pd_2T_2 - Vc_pd_3T_3 = Vc_p(d_2T_2 - d_3T_3) \tag{1}$$

Heat input by the propane heaters and electric heaters, Btu:

$$H_H = \frac{475,700}{60} \; \frac{(f+1)t}{2} \tag{2}$$

Heat given up by the concrete walls to the air, Btu:

$$H_W = \frac{Afi}{60} \; \frac{(T_W - T_3)ft}{2} \tag{3}$$

$$H_W' = \frac{Afi}{60} \left(T_W - \frac{T_2' + T_3'}{2}\right)t' \tag{4}$$

Volume of outside air required to remove heat, cu ft:

$$V_o = \frac{E + H_H + H_W}{\left(\frac{T_2 + T_3}{2} - T_1\right)c_pd_1} = \frac{H}{\left(\frac{T_2 + T_3}{2} - T_1\right)c_pd_1} \tag{5}$$

T_1 = outside air temperature, $^{\circ}F$.
T_2 = initial steady state air temperature in the chamber, $^{\circ}F$.
T_3 = air temperature inside the chamber after hatch has been open for time interval, t, to raise elevator, $^{\circ}F$.
T_2' = air temperature inside chamber just before doors are opened to lower elevator, $^{\circ}F$.
T_3' = air temperature inside chamber when hatch is closed after lowering elevator, $^{\circ}F$.
T_w = temperature of interior surface of chamber enclosure, $^{\circ}F$.
d, d_2, d_3, d_2', d_3' = density of air at temperatures, T_1, T_2, T_3, T_2', T_3', lb/ft^3.
c_p = specific heat of air = 0.24.
V = volume of Nike chamber, ft^3, = 55,700 ft^3.
t,t' = time intervals hatch doors are open during first and second periods, min.
A = interior surface area of Nike chamber, ft^2,=10,520 sq ft.
fi = surface conductance from interior walls of chamber to chamber air, computed from heat loss data to be 2.29 Btu/hr (ft)^2($^{\circ}$F).
f = fraction of time interval, t or t', during which chamber air temperature was below the wall temperature.
H = E + H_H + H_W, Btu.

Primed symbols refer to the second period when hatchway was open in each cycle.

The value of A, interior surface of the chamber, was computed without allowance for beams, projections, interior fixtures, etc.

From the time the hatchway doors began to open to permit raising the elevator until the elevator sealed the opening t minutes later, heat was lost from the air in the chamber and from the wall surfaces, while heat continued to be supplied by the propane and electric heaters. Air exchange between the chamber and outdoors was the only means by which this heat was dissipated during this period. Consequently, the amount of air required to carry away this heat can be computed on the assumption that the air was exhausted at the mean chamber temperature from moment to moment.

Table 3 shows the computed values of the air exchange in cubic feet, V_o, between the prototype Nike chamber and outdoors during the period when the doors were opened to raise the elevator in Tests I, III, IV, and V, and corresponding values V_o' during the period when the elevator was lowered and the doors were closed in Tests I and IV. These data show that the amount of air exchanged between the chamber and outdoors ranged from 11,000 cu ft to 18,000 cu ft during the time required to open the doors and raise the elevators, a period which averaged 43 seconds in length. No specific reason was found for the difference in magnitude between Tests I and III, and Tests IV and V, other than possible differences in the time of observing the minimum air temperature and possible differences in outdoor wind velocity and direction during the several tests. Complete records were not made of wind velocity during the tests. The exhaust fan was not in operation during this time, in any of the four tests.

Table 3 shows that the amount of air exchanged between the chamber and outdoors ranged from about 30,000 to 32,000 cu ft for Tests I and IV during the time required to lower the elevator and close the doors. Normally about 60 seconds would be required for these operations, but 84 seconds were required in Test I because of faulty control operation. This is the primary reason for the higher air exchange in Test I. The exhaust blower was in operation during the entire time the elevator was being lowered in Test IV, and for two minutes after the doors were closed. The operation of the blower while lowering the elevator undoubtedly explains why V_o' was so large in Test IV. However, the value of V_o' for Test IV in Table 3 only accounts for the air exchange during the time the hatchway was open.

If the reported rating of 12,000 cfm for the exhaust blower was accurate for the conditions existing after the hatch was closed, an additional 24,000 cu ft of outdoor air would have been drawn into the chamber in Test IV during a single firing cycle. If 24,000 cu ft are added to the sum of V_o and V_o' in Test IV, the total air exchange for the single cycle of this test would be computed to be 72,700 cu ft, as compared to an average of 68,000 cu ft computed earlier in this report for each of the last four cycles of Test V, based on substantially a repetitive air temperature pattern in each cycle. It is to be expected that the air exchanged during the first cycle would

exceed that in later cycles under a consecutive firing schedule because the average temperature difference between chamber air and outdoor air would decrease after the first firing cycle.

The data in Table 3 show that a large fraction of the heat lost during the periods when the hatch was open was heat stored in the air in the chamber. The chamber had a volume of about 55,700 cu ft or about 4000 lb, depending somewhat on its temperature. Under the conditions of the tests at Paoli, Pa., the heat capacity of the air in the chamber was about 100,000 Btu relative to the outdoor air temperature, whereas the propane heaters delivered from 4200 to 5400 Btu and the walls transferred from 900 to 2800 Btu to the air during the time required to open the doors and raise the elevator. Thus, the heat output of the heaters had a relatively small effect on the minimum air temperature resulting in the chamber during a single or multiple firing schedule. It can be shown from the data that the minimum air temperature would have been only about 5 degrees lower if the heaters had not been operating during the time the hatch was open, and that the heating capacity would have to be doubled approximately to raise the minimum temperature 5 degrees. Similar analysis shows that the heat output of the heaters during the period of lowering the elevator only raised the minimum air temperature in the chamber about 5 degrees.

The data in Table 3 can be used to compute the anticipated recovery of temperature in the chamber during the one minute period while the elevator is up and the missile is actually being fired. This recovery would depend on the rate of heat transfer from the walls to the chamber air and the rate of heat supply by the heaters. For Test I, approximately 4100 Btu were transferred from the walls to the air and about 8500 Btu were supplied by the heaters. The corresponding values in Test V were about 7200 Btu and 7700 Btu, respectively.

Comparison of the values of V_o and V_o' in Table 3 indicates that the door and elevator movements inhibited natural air exchange somewhat more when the elevator was being raised than when it was being lowered. It might be theorized that the elevator helped to establish a chimney action in the elevator opening when it was lowered and did not when it was being raised, but the data observed during the test are not adequate to explain the relative magnitudes of V_o and V_o'. The computed air exchange shown in Table 3 is less than would be determined

by the chimney equation, assuming that air enters through half of the door area and leaves through the remaining half with an effective chimney height of 6 feet corresponding to the height of the enclosed upper end of the elevator shaft.

CONCLUSIONS

Table 3 shows that the air temperature in the underground chamber decreased from 21 to 35 degrees during the time required to open the doors and raise the elevator for an indoor-outdoor temperature difference in the range from 100 to 110 degrees and a heat input rate of 476,000 Btu/hr. The total decrease in chamber temperature when the elevator was lowered, relative to the initial chamber temperature before starting the missile-launching operation, ranged from 47 to 55.5 degrees in Table 3, with the higher value occurring when the exhaust blower was used. The air temperature in the chamber recovered from 11 to 16 degrees during the one minute period after the elevator was raised to close the hatch and before it was subsequently lowered.

It is estimated from the analysis of these tests that an instantaneous heating rate in the range from 5 million to 10 million Btu/hr would be required to maintain a temperature of 50°F in a Nike underground structure of the type tested when the outdoor temperature was -50°F during a missile-launching operation. Since a heat input rate of this magnitude would be difficult to provide, it is considered more practical to limit the decrease in chamber air temperature by taking advantage of the stored heat in the surrounding concrete surfaces and in the fixtures, and by decreasing the air exchange with the outdoors when the hatchway is open.

Under Arctic conditions, thermal insulation between the chamber and the surrounding permafrost is necessary to prevent melting the permafrost over a period of time. The results of these tests indicate that the insulation should be placed between the permafrost and the concrete, thus permitting the concrete to attain a temperature nearer to the chamber air temperature than in the prototype tested. One foot thickness of concrete surrounding the chamber would constitute a reservoir of heat on the order of 30,000,000 Btu with respect to outdoor air 100 degrees cooler than the concrete. If the insulation were placed on the inside of the chamber, the concrete would be

near the temperature of the permafrost, and there would be much less stored heat available for rewarming the air.

The heat stored in the concrete would be available for warming the chamber air at the rate of about 20,000 Btu/hr per degree temperature difference between concrete surface and the air under normal air velocity conditions in the storage area. The rate of heat transfer could be increased a little by using fans to move the air over the walls more rapidly, or by providing more surface area for heat exchange. More area could be provided by roughening the surface, or by building passages or lattices into the walls and using fans to circulate air through them when the hatch was open and during recovery. However, the computations in Table 3 indicate that the heat transfer from the walls would have to be increased by at least tenfold to make an important change in the temperature drop experienced when the hatch was open. It appears, therefore, that the principal benefit of the heat storage in the walls is for rewarming the air in a relatively short time after the missile launching is completed, and for limiting the capacity of the heating units required for rewarming.

The amount of air exchange between the chamber and outdoors could be reduced by the use of curtains around the elevator pit. Such curtains were shown to reduce the air exchange in the missile storage area somewhat, but they would undoubtedly increase the difficulty of moving the missiles from the storage racks to the elevator platform.

The exhaust blower should be operated only when required to scavenge combustion products from the chamber since it increased the exchange of air between the chamber and outdoors. The use of an above-ground blower to drive the combustion gases laterally from the door area before lowering the elevator might reduce the need for using the exhaust blower in the chamber considerably.

There is a possibility that a horizontal air curtain, forced across the bottom of the elevator doorway, might materially reduce the air exchange caused by chimney action.

The results of the tests in the full scale chamber indicated that the temperature drop experienced in the chamber during brief periods when the hatchway was open was primarily

limited by the heat capacity of the approximately 4000 lb of air in the chamber and was only affected to a small degree by heat transfer from the walls and by a steady heat input rate or 476,000 Btu/hr from the electric and propane heaters. The minimum temperature attained in the chamber when the hatchway was open for 40 to 60 seconds at a time was closely related to the mixed air temperature resulting from combining 55,700 cu ft of chamber air and 11,000 to 32,000 cu ft of outdoor air approximately 100 degrees colder than the chamber air.

TABLE

TIME SCHEDULES FOR SIMU-

TEST NO.	0 c)		I		II
Item of Simulated Firing Schedule	Elapsed Time Min:Sec	Time Interval Sec	Elapsed Time Min:Sec	Time Interval Sec	Elapsed Time Min:Sec
Signal to Open Doors	0:00		0:00		0:00
				12	
Doors Start to Open			0:12		-
				8	
Doors Fully Open			0:20		0:14
		22		4	
Elevator Starts Up	0:22		0:24		0:17
		32		28	
Elevator on Locking Bars	0:54		0:52		0:45
				60	
Signal to Lower Elevator			1:52		1:45
		60		7	
Elevator Starts Down	1:54		1:59 b)		1:49 b)
				-	
Start Ventilating Blower			-		-
				35	
Elevator Down			2:34		2:30
				14	
Signal to Close Doors			2:48 b)		2:35
		45		26	
Doors Start to Close	2:39		3:14		2:46
		8		9	
Doors Fully Closed	2:47		3:23		2:52
		133		-	
North Vent Closed) Stop Ventilating Blower)	5:00		-		-

a) See Graphs 5 - 1 and 6 - 1 for each cycle.
b) Controls did not function; controls were shunted
c) Planned Schedule.

I

LATED MISSILE FIRING

II	III		IV		V Average of 10 cycles[a)]		VI	
Time Interval Sec	Elapsed Time Min:Sec	Time Interval Sec	Elapsed Time Min:Sec	Time Interval Sec	Elapsed Time Min:Sec	Time Interval Sec	Elapsed Time Min:Sec	Time Interval Sec
	0:00		0:00		0:00		0:00	
-		8		8		7.5		7
	0:08		0:08		0:07.5		0:07	
14		8		7		8		7
	0:16		0:15		0:15		0:14	
3		7		9		5		6
	0:23		0:24		0:20		0:20	
28		27		33		28		28
	0:50		0:57		0:48		0:48	
60		75				-		-
	2:05		-		-		-	
4		5		70		60		60
	2:10		2:07		1:48		1:48	
-		-		-		12		11
	-		1:57		2:00		1:59	
41		39		51		32		32.5
	2:49		2:48		2:32		2:31.5	
5		4		4		2		6
	2:53		2:52		2:34		2:37.5	
11		2		-		7		-
	2:55		-		2:41		-	
6		10		9		6		10
	3:05		3:01		2:47		2:47	
-		-		119		131		131
	-		5:00		4:57		4:58	

TABLE 2

SUMMARY OF STATIONS OF TEMPERATURE MEASUREMENT

Thermocouple Number	Thermocouple Location	Section of Underground Chamber	Material Whose Temperature Was Being Measured
1	Center of Ceiling	North	Concrete Ceiling
2	Center of East Wall	North	Concrete Wall
3	Center of North Wall	North	Concrete Wall
4	Center of West Wall	North	Concrete Wall
5	Center of Floor	North	Concrete Floor
6	Center of East Wall	Elevator	Concrete Wall
7	Center of West Wall	Elevator	Concrete Wall
8	Center of Floor	Elevator	Concrete Floor
9	Center of Ceiling	South	Concrete Ceiling
10	Center of East Wall	South	Concrete Wall
11	Center of South Wall	South	Concrete Wall
12	Center of West Wall	South	Concrete Wall
13	Center of Floor	South	Concrete Floor
14	Center of Pit Edge, 9' Above Floor	North	Air
15	Center of North Wall, 9' Above Floor	North	Air
16	Center of Pit Edge, 5' Above Floor	North	Air
17	Center of North Wall, 5' Above Floor	North	Air
18	Center of Pit Edge, 1' Above Floor	North	Air
19	Center of North Wall, 1' Above Floor	North	Air
20	Above Center of Doors, 6" from Edge Gasket	Door	Air
21	Above Center of Doors, 12" from Edge Gasket	Door	Air
22	Above Center of Doors, 24" from Edge Gasket	Door	Air
23	Above Center of Doors, Center of Opening	Door	Air
24	Above Center of Doors, 5 ft Above Ground Level	Door	Air
25	Top Surface of Door Edge Gasket	Door	Rubber Gasket
26	Top Surface of Door Edge Flange, 2" from Edge	Door	Steel Flange
27	Bottom Surface of Door Edge Flange	Door	Steel Flange
28	Bottom Surface, Center of East Half of North Door	Door	Steel Doors
29	Bottom Surface, Center of West Half of South Door	Door	Steel Doors
30	Bottom Surface, Door Edge Gasket	Door	Rubber Gasket

TABLE 2 (Cont'd)

Thermocouple Number	Thermocouple Location	Section of Underground Chamber	Material Whose Temperature Was Being Measured
31	Control Switch on Elevator	Elevator	Steel Box
32	Bottom Surface of Elevator Platform	Elevator	Steel
33	North Door Limit Switch	Elevator	Steel Box
34	Elevator Up-Position Override Limit Switch	Elevator	Steel Box
35	West Hydraulic Cylinder on South Door	Door	Steel Cylinder
36	Simulated Missile on Rack Nearest to Pit	South	Steel Pipe
37	Simulated Missile on Rack Farthest From Pit	South	Steel Pipe
38	Bottom of First Beam East of Center	North	Structural Steel Beam
39	Discharge of Southwest Ventilator	South	Air
40	Northwest Corner, 9' above Floor	North	Air
41	Southeast Corner, 9' above Floor	South	Air
42	Center of Pit Edge, 9' above Floor	South	Air
43	Center of South Wall, 9' above Floor	South	Air
44	Center of Pit Edge, 5' above Floor	South	Air
45	Center of South Wall, 5' above Floor	South	Air
46	Center of Pit Edge, 1' above Floor	South	Air
47	Center of South Wall, 1' above Floor	South	Air
48	Ice Bath Reference near Instruments	Control Room	Ice Water

TABLE 3

COMPUTED AIR EXCHANGE BETWEEN NIKE CHAMBER AND OUTDOORS DURING A SINGLE FIRING CYCLE

		Test No.			
		I	III	IV	V
T_1	^oF	32	35	29	29
T_2	^oF	139.5	138.3	141.5	140.3
T_3	^oF	115.8	117.8	106	105.3
T_w	^oF	131.0	129.5	130.7	130.9
d_1	lb/ft^3	.0810	.0802	.0812	.0812
d_2	"	.0662	.0664	.0660	.0662
d_3	"	.0689	.0687	.0701	.0703
t	sec	40	42	49	40.5
E	Btu	16700	14430	25510	25130
H_H	"	4340	4370	5490	4630
H_W	"	1360	940	2830	2550
H	"	22400	19740	33830	32310
V_o	ft^3	12000	11000	18300	17800
T_2'	^oF	126.8	133.5	121	118
T_3'	^oF	92.5		86	
d_2'	lb/ft^3	.0676		.0684	
d_3'	"	.0718		.0727	
t'	sec	84		54	
E'	Btu	25920		27130	
H_H'	"	11100		7140	
H_W'	"	12000		9810	
H'	"	49020		44080	
V_o'	ft^3	32460		30400	

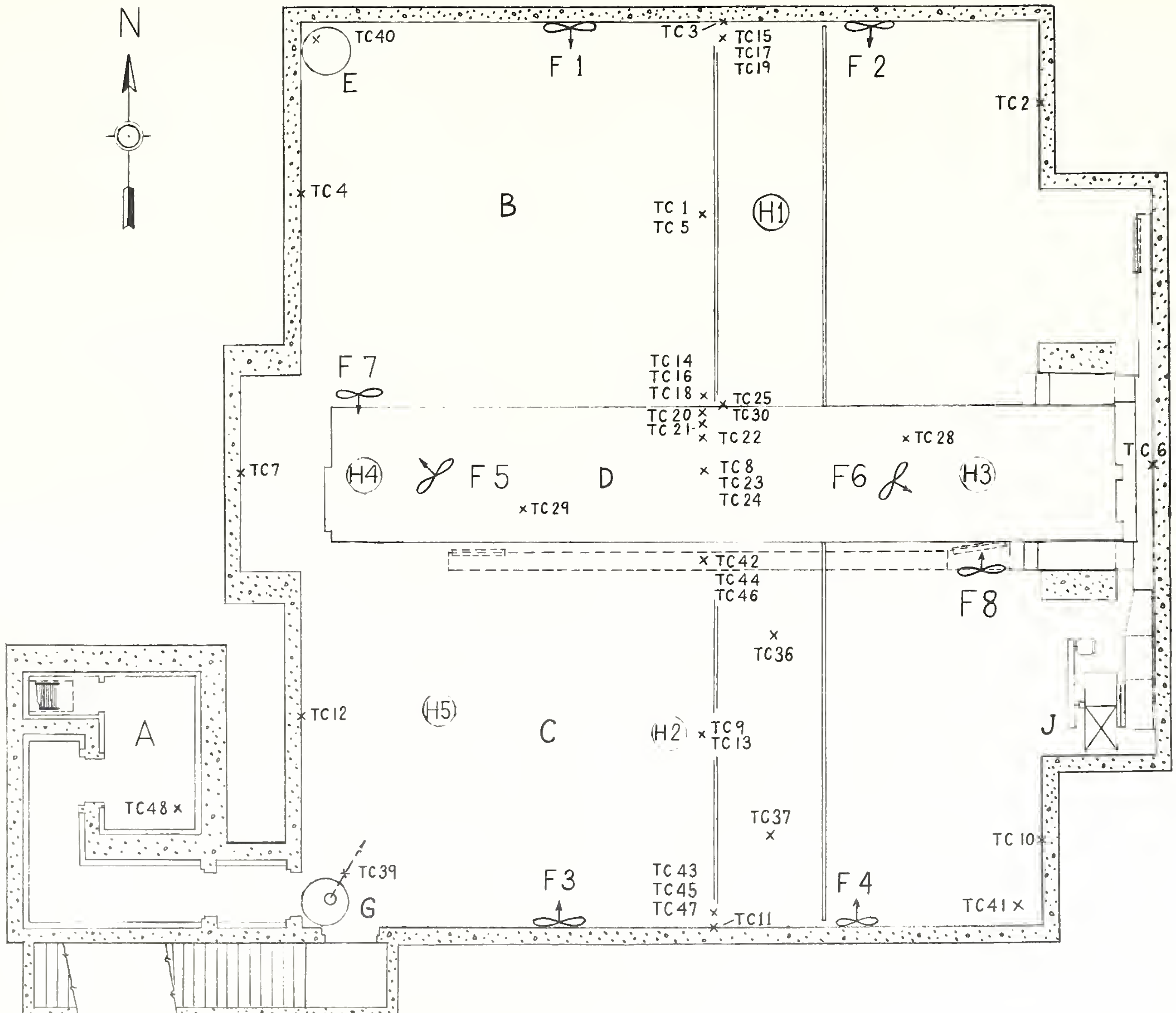
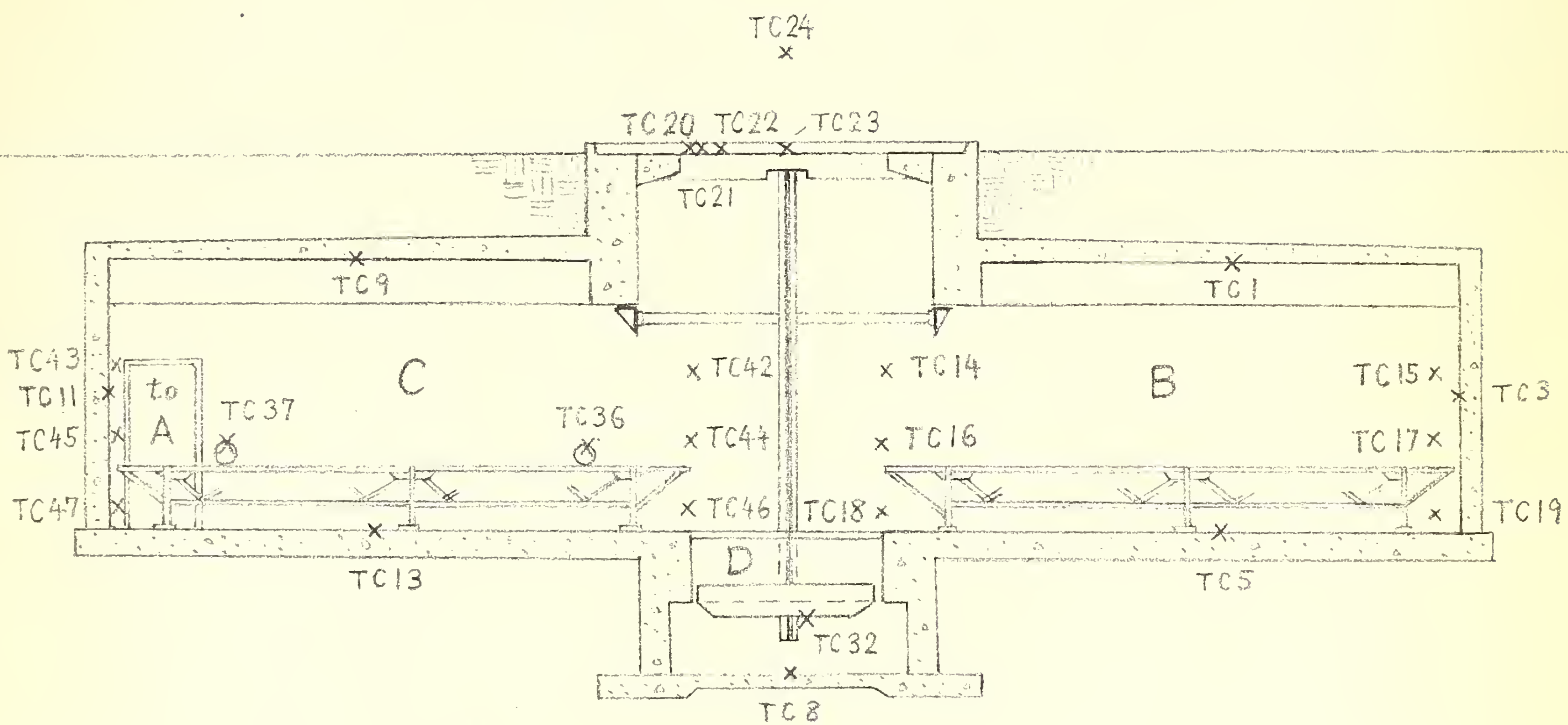

N
TC40
E
F 1
TC 3
TC15
TC17
TC19
F 2
TC2
TC 4
B
TC 1
TC 5
H1
F 7
TC 14
TC 16
TC 18
TC 20
TC 21
TC25
TC30
TC 22
TC 28
TC7
H4
F 5
TC 29
D
TC 8
TC 23
TC 24
F6
H3
TC 6
TC42
TC 44
TC 46
F8
TC36
A
TC12
H5
C
H2
TC9
TC13
J
TC48
TC37
TC 10
TC39
G
F 3
TC 43
TC 45
TC 47
TC11
F 4
TC41

FIG. 1



TC24
TC20 TC22 TC23
TC21
TC9
TC1
TC43
TC11
TC45
TC47
to
A
C
TC37
TC36
TC42
TC44
TC46
TC14
TC16
TC18
B
TC15
TC17
TC3
TC19
TC13
D
TC5
TC32
TC8

FIG. 2

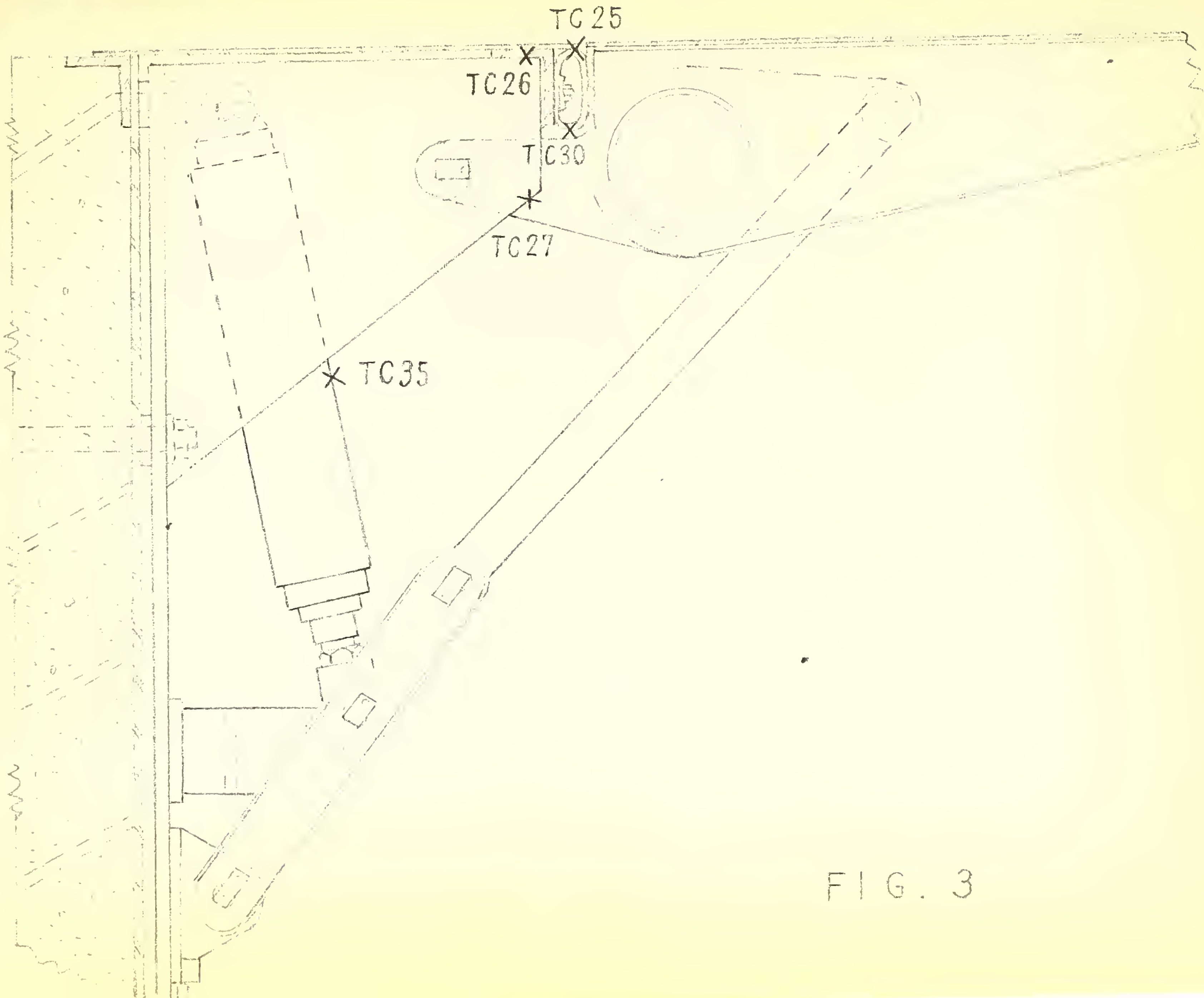


FIG. 3

Fig. 4

Fig. 5

Fig. 6

Fig. 7

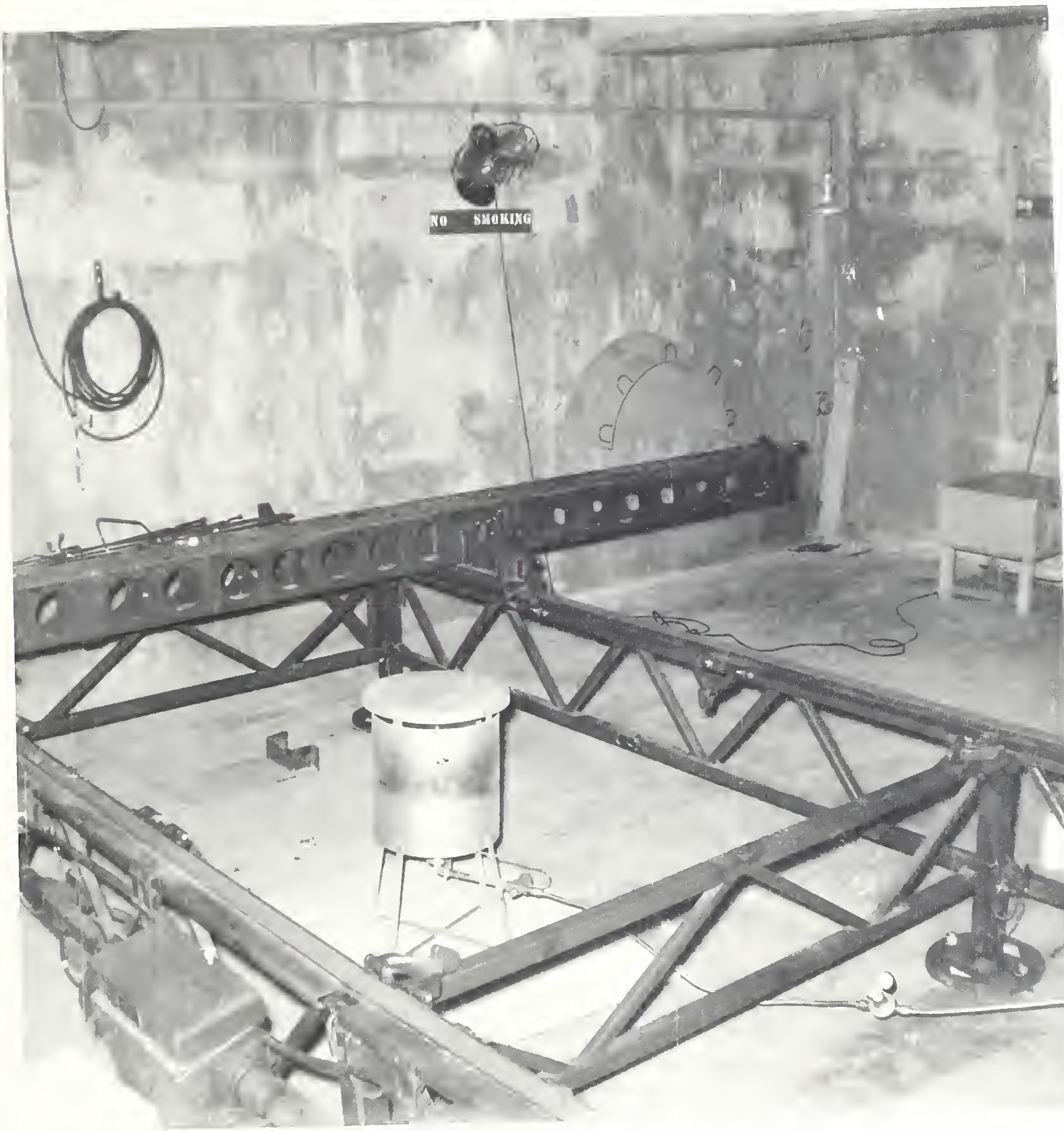


Fig. 8

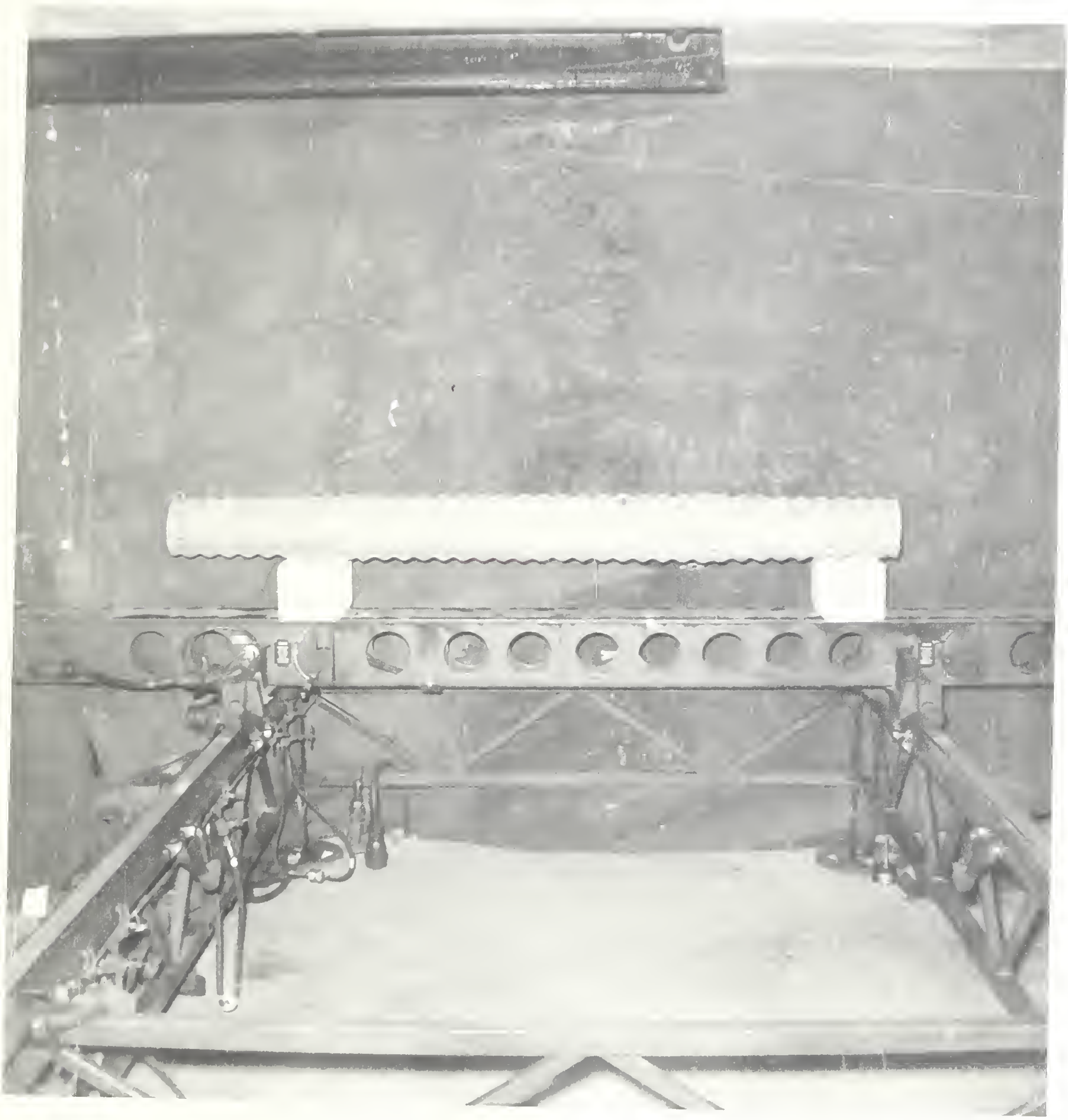
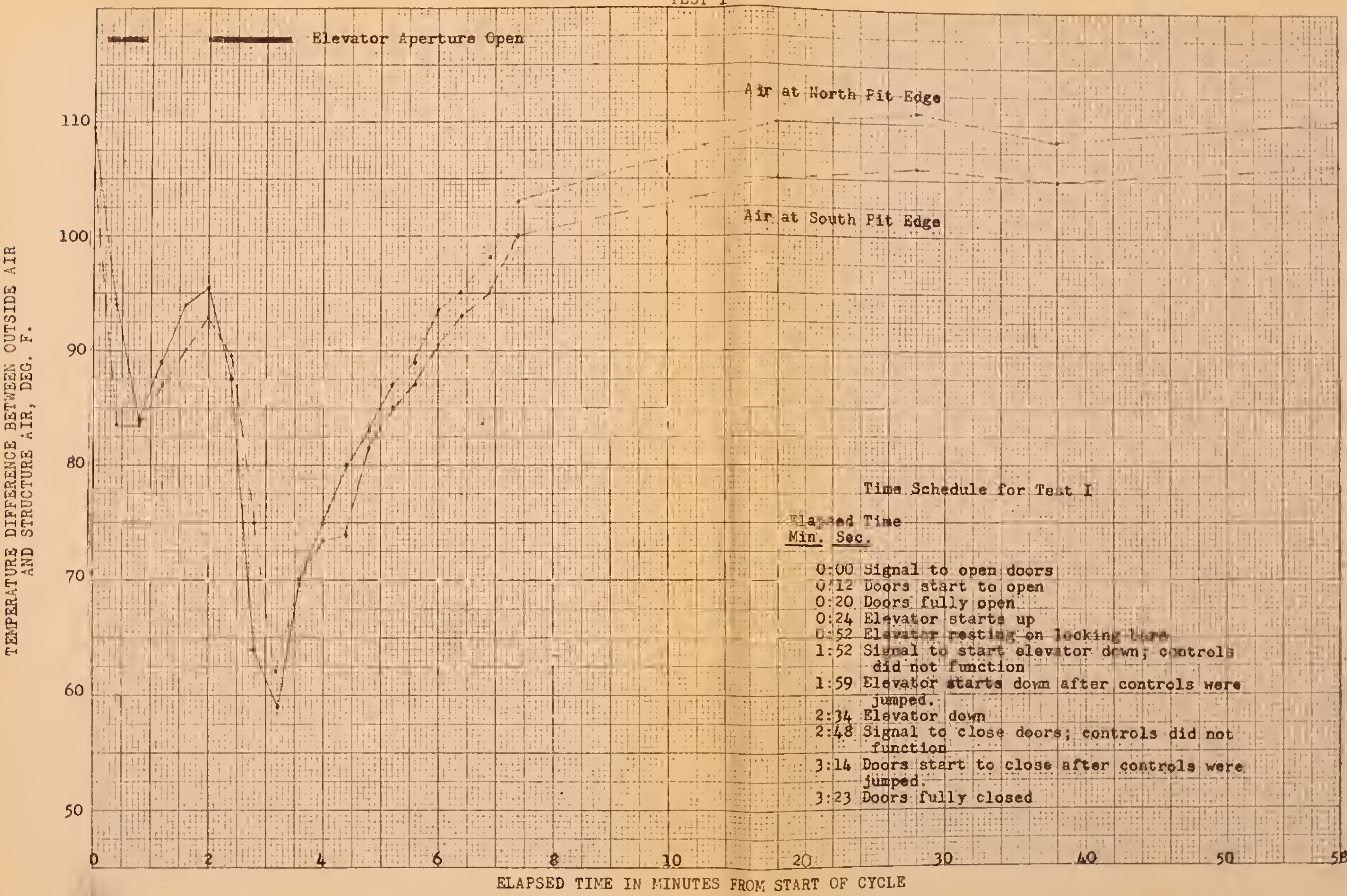


Fig. 9

Fig. 10

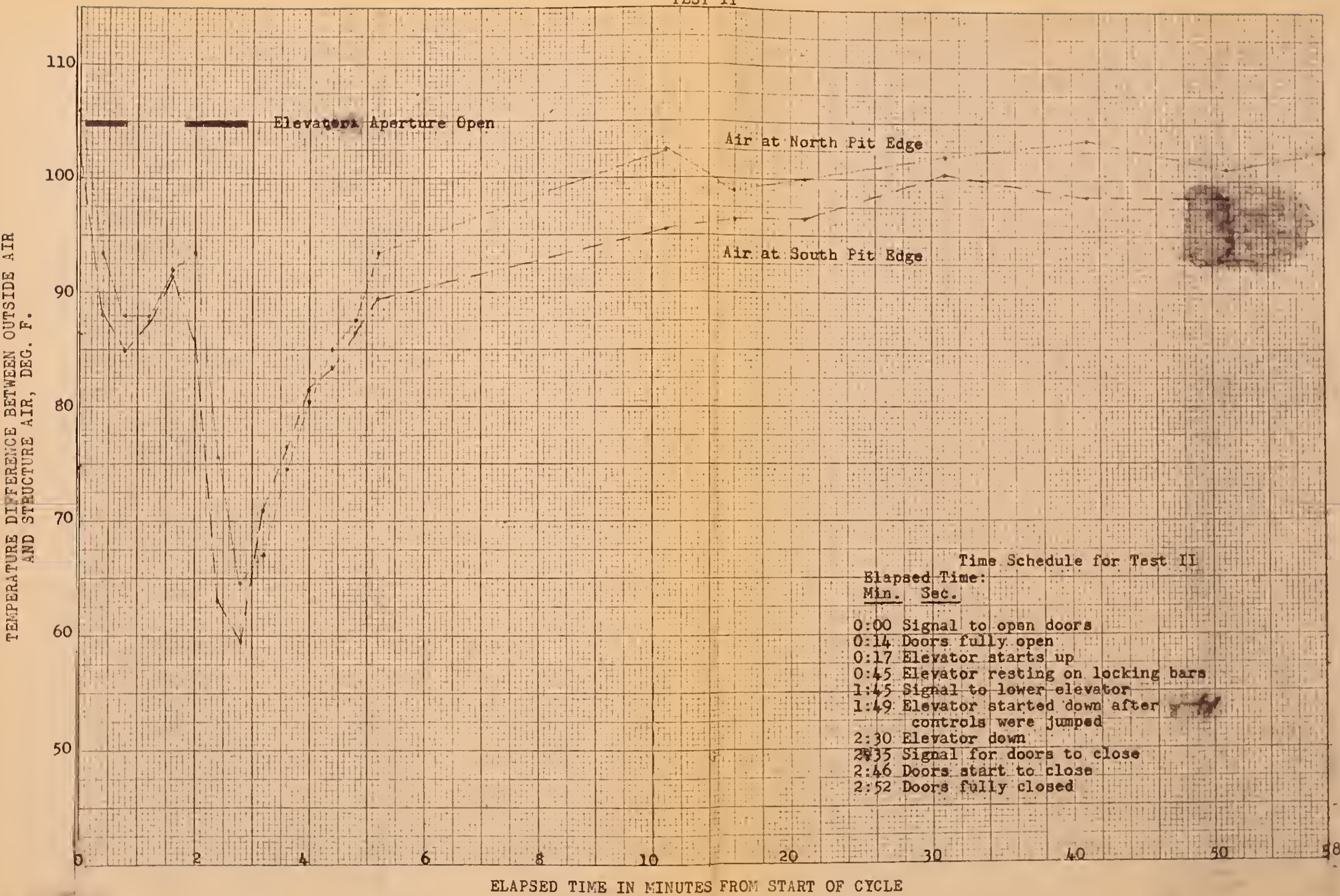
TEMPERATURE CHANGES IN NIKE UNDERGROUND STRUCTURE DURING ONE FIRING CYCLE

TEST I

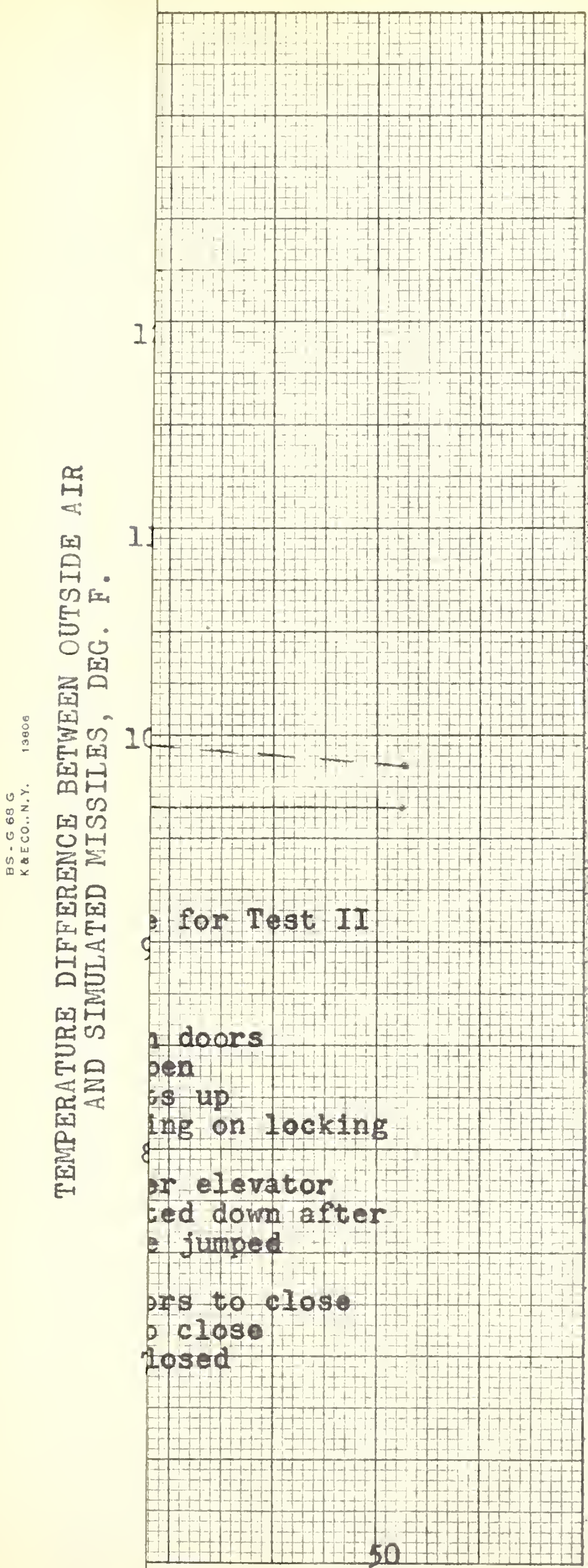


GRAPH NO. 1- 1

TEMPERATURE CHANGE IN NIKE UNDERGROUND
STRUCTURE DURING ONE FIRING CYCLE
TEST II

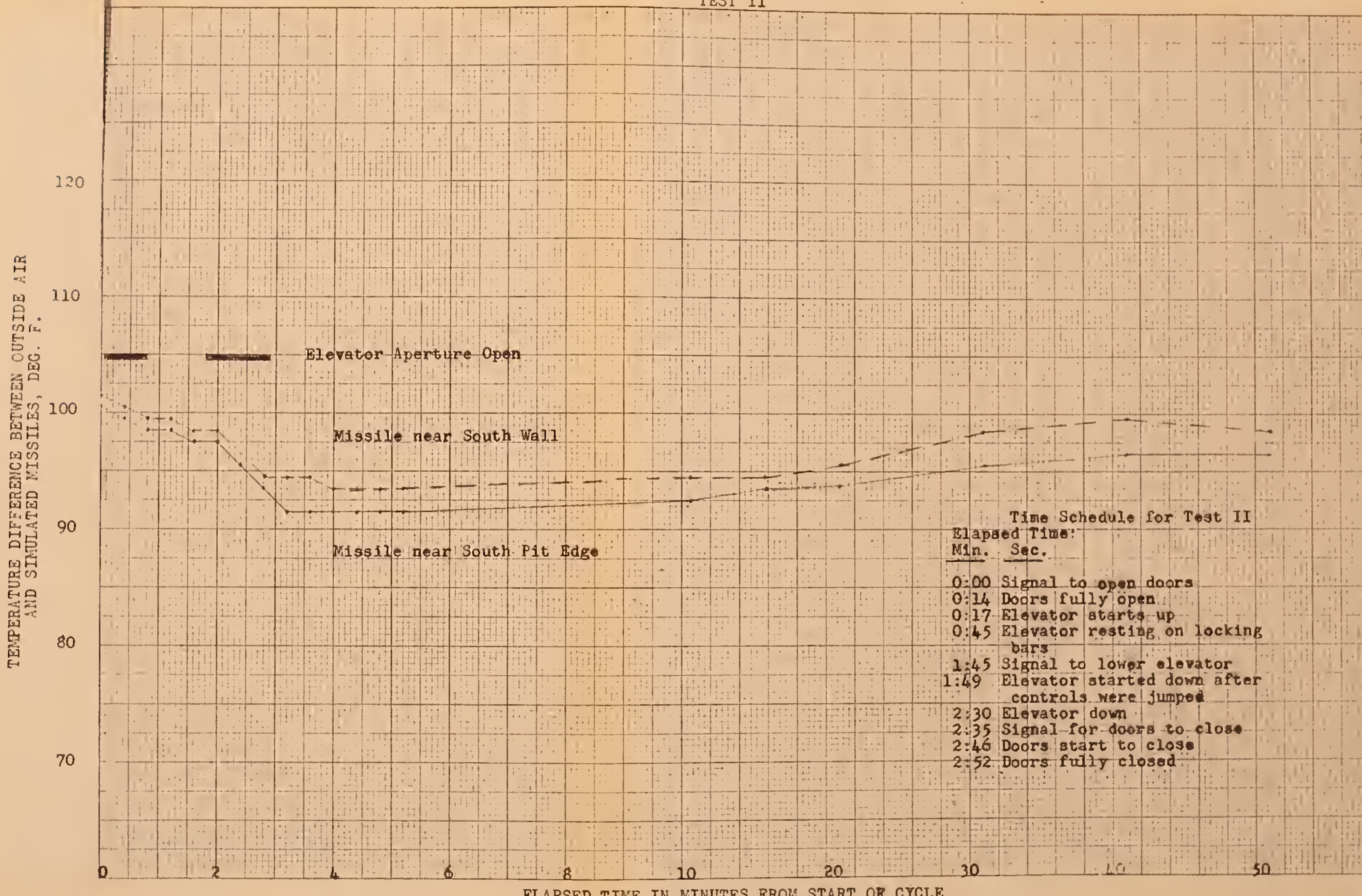


GRAPH 2-1

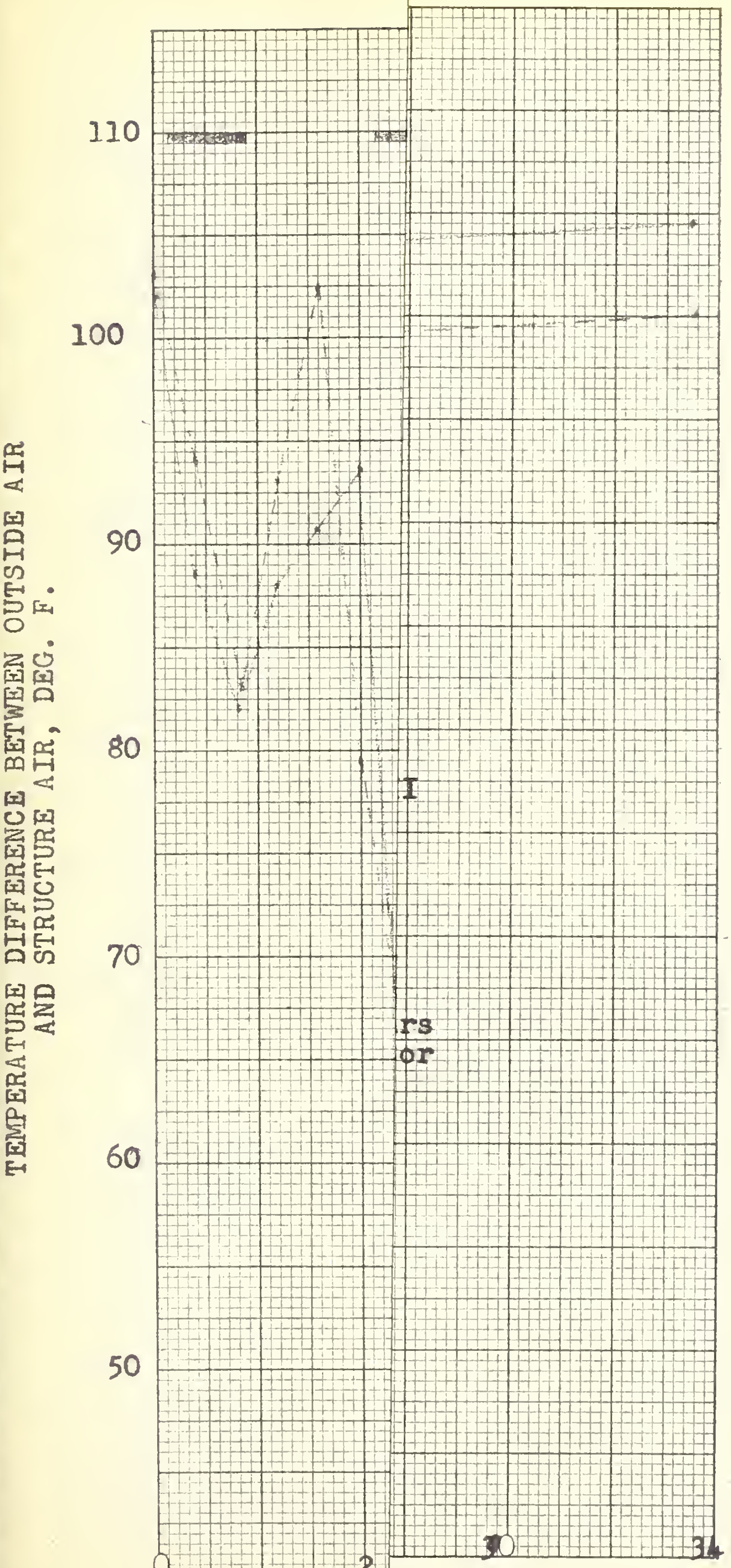

BS-G68G K&E CO., N.Y. 13806
TEMPERATURE DIFFERENCE BETWEEN OUTSIDE AIR
AND SIMULATED MISSILES, DEG. F.
1
1
10
9
8
50
e for Test II
n doors
pen
ts up
ing on locking
er elevator
ted down after
e jumped
ors to close
o close
losed

TEMPERATURE CHANGE IN NIKE UNDERGROUND STRUCTURE DURING ONE FIRING CYCLE

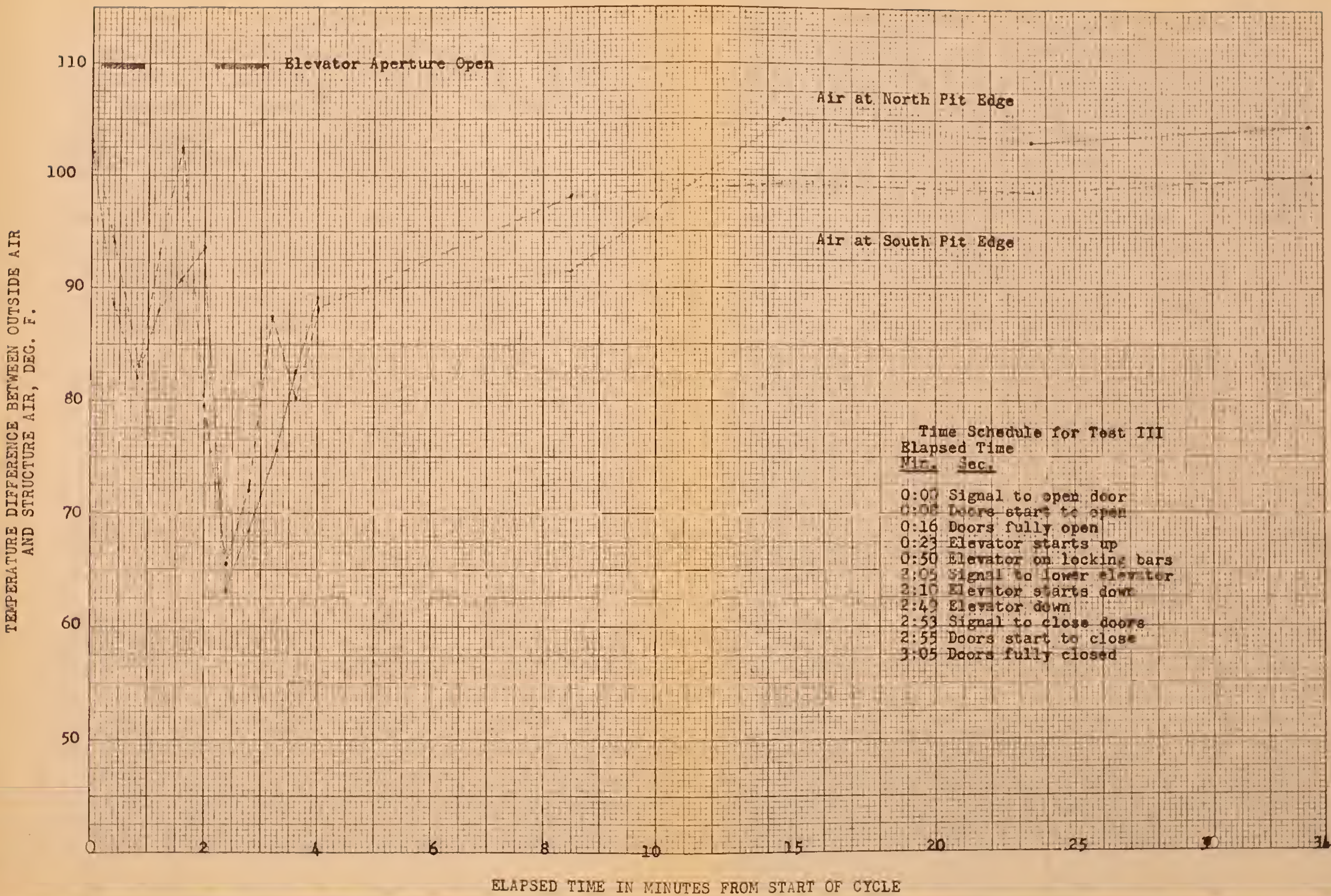
TEST II



GRAPH 2-2

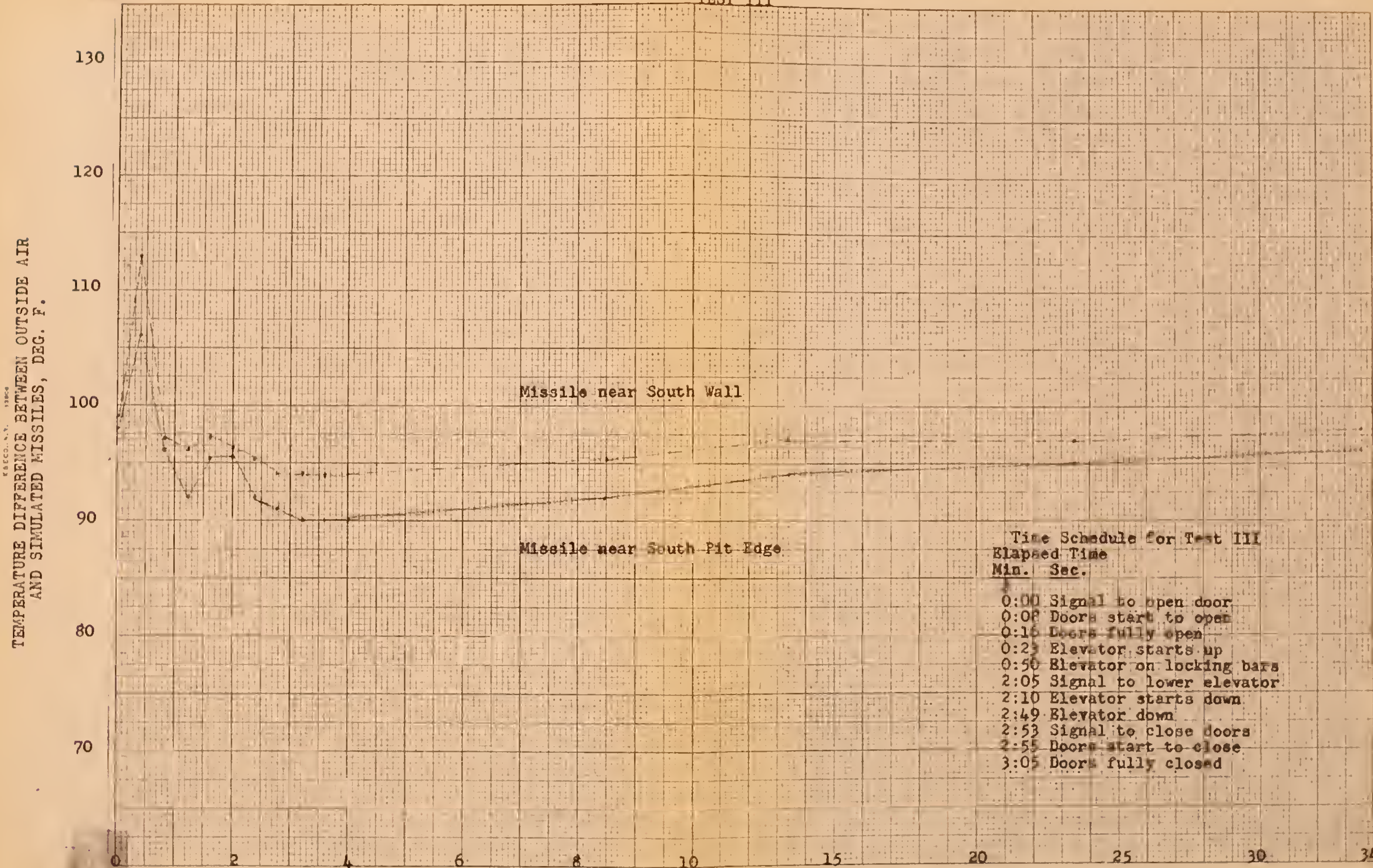

110
100
90
80
70
60
50
TEMPERATURE DIFFERENCE BETWEEN OUTSIDE AIR
AND STRUCTURE AIR, DEG. F.
0
2
I
rs
or

TEMPERATURE CHANGE IN NIKE UNDERGROUND
STRUCTURE DURING ONE FIRING CYCLE
TEST III



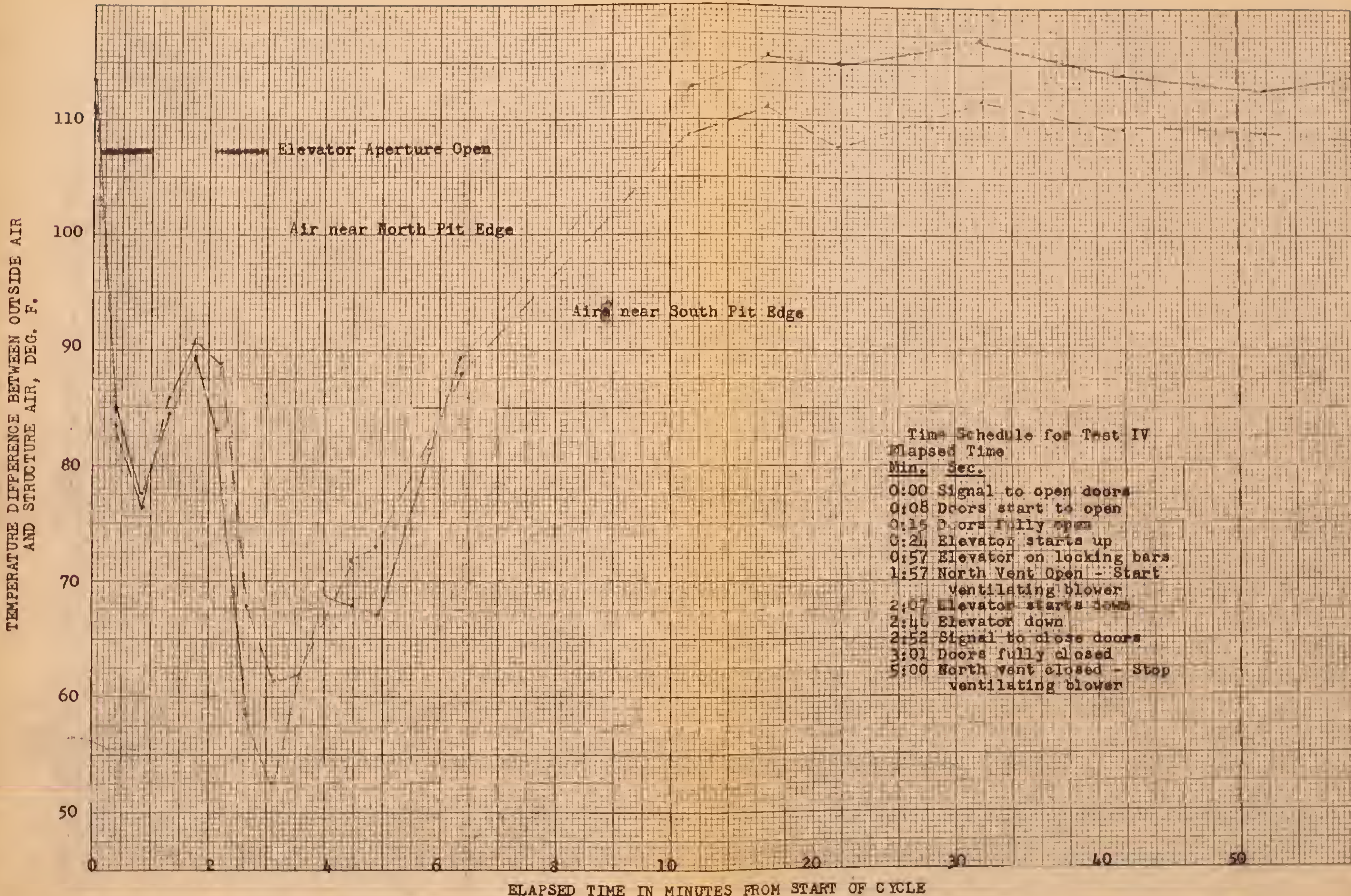
GRAPH 3-1

TEMPERATURE CHANGE IN NIKE UNDERGROUND
STRUCTURE DURING ONE FIRING CYCLE
TEST III

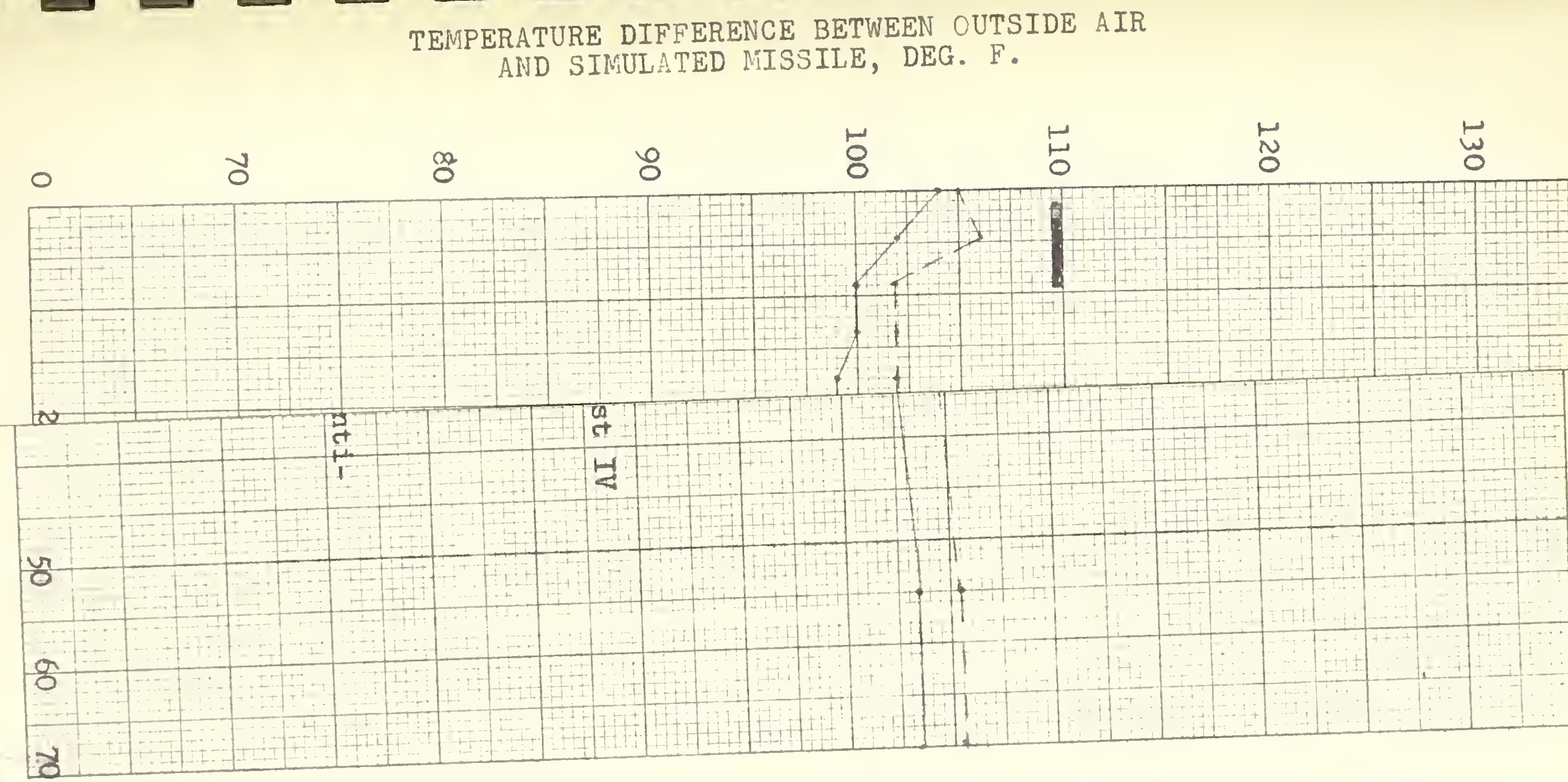


ELAPSED TIME IN MINUTES FROM START OF CYCLE
GRAPH 3-2

TEMPERATURE CHANGE IN NIKE UNDERGROUND
STRUCTURE DURING ONE FIRING CYCLE
TEST IV

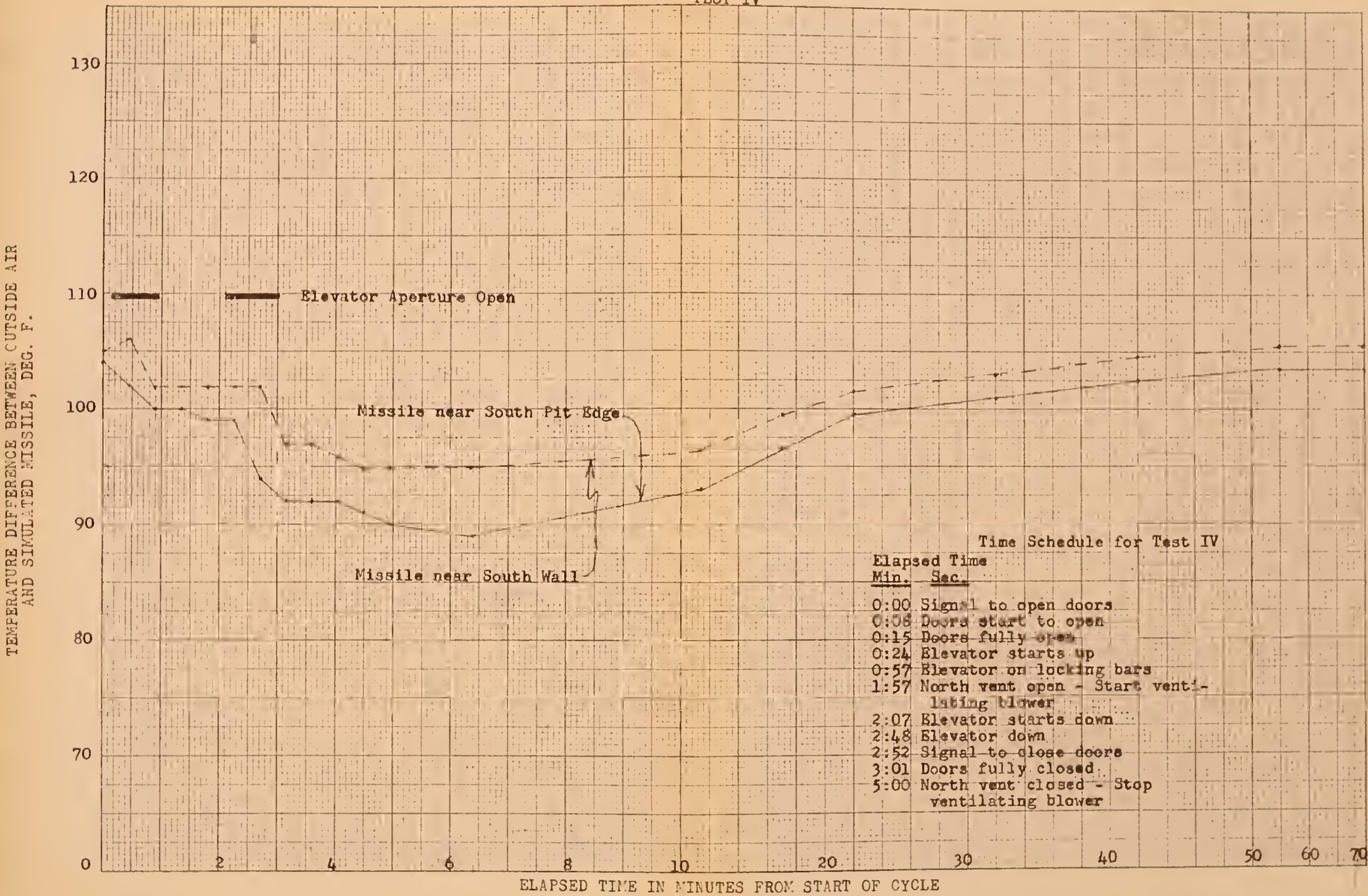


GRAPH 4-1



K&E CO., N.Y. 13806

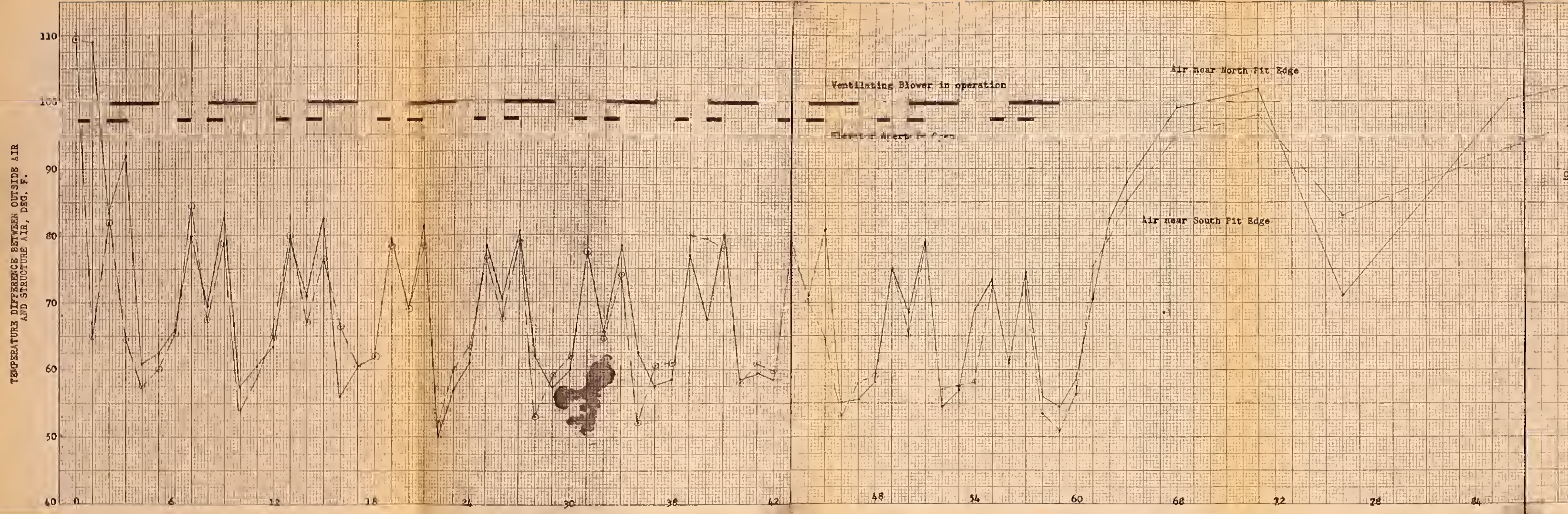
TEMPERATURE CHANGE IN NIKE UNDERGROUND
STRUCTURE DURING ONE FIRING CYCLE
TEST IV



GRAPH 4-2

Doors Begin to Open	
0:07	
6:08	
12:08	
18:07	
24:08	
30:07	1/2
36:07	1/2
42:07	
48:07	1/2
54:48	

TEMPERATURE CHANGE IN NIKE UNDERGROUND
STRUCTURE DURING TEN FIRING CYCLES
TEST V



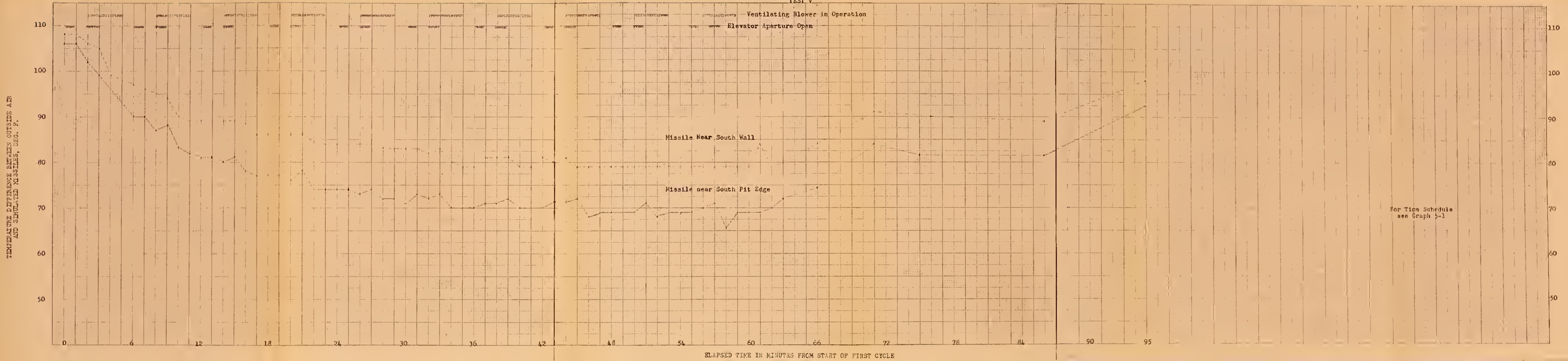
Time Schedule for Test 5
Elapsed Time in Minutes and Seconds
From Start of Cycle No. 1

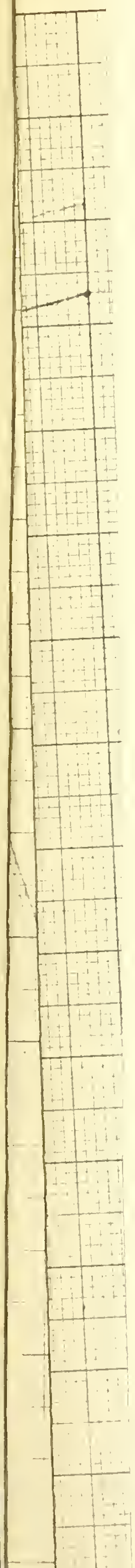
Cycle	Signal to Open Doors	Doors Begin to Open	Doors Fully Open	Elevator Starts Up	Elevator Up	Elevator Starts Down	Start Vent Blower	Elevator Down	Signal to Close Doors	Doors Start to Close	Doors Closed	Stop Vent Blower
1	0:00	0:07	0:15	0:20	0:48	1:48	2:00	2:31	2:33	2:57	3:03	5:00
2	6:00	6:08	6:16	6:20	6:48	7:48	8:00	8:30	8:33	8:42	8:43	11:00
3	12:00	12:08	12:15	12:21	12:48	13:48	14:00	14:30	14:33	14:35	14:43	17:00
4	18:00	18:07	18:15	18:20	18:48	19:48	20:00	20:30	20:33	20:35	20:42	23:00
5	24:0	24:08	24:15	24:20	24:49	25:49	26:00	26:31	26:33	26:35	26:42	29:00
6	30:00	30:07 1/2	30:16	30:20	30:49	31:49	32:00	32:31	32:33	32:34	32:41	35:00
7	36:00	36:07 1/2	36:15	36:20	36:48	37:48	38:00	38:31	38:32	38:33	38:39	41:00
8	42:00	42:07	42:15	42:19	42:48	43:48	44:00	44:30	44:32	44:45	44:52	47:00
9	48:00	48:07 1/2	48:16	48:20	48:49	49:58	50:00	50:40	50:42	50:48	50:55	53:00
10	54:00	54:48	54:56	55:00	55:27	56:27	56:00	57:08	57:09	57:17	57:23	59:00

ELAPSED TIME IN MINUTES FROM START OF FIRST CYCLE
GRAPH 5-1

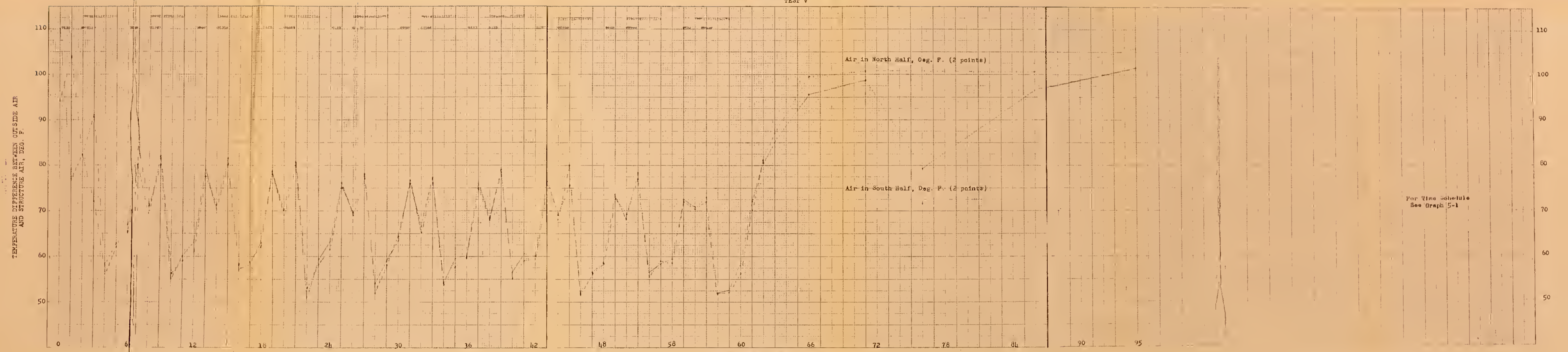
95

TEMPERATURE CHANGE IN NIKE UNDERGROUND
STRUCTURE DURING TEN FIRING CYCLES
TEST V





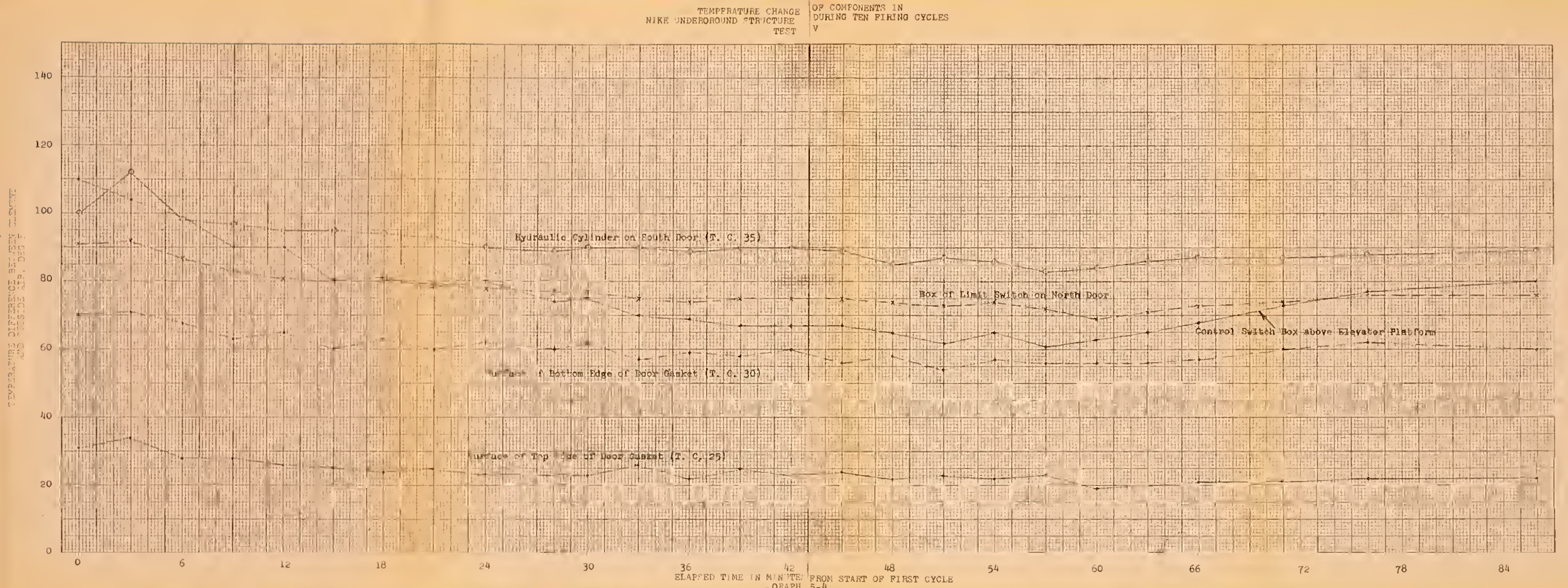
TEMPERATURE CHANGE IN NIKE UNDERGROUND
STRUCTURE DURING TEN FIRING CYCLES
TEST V



GRAPH 5-3

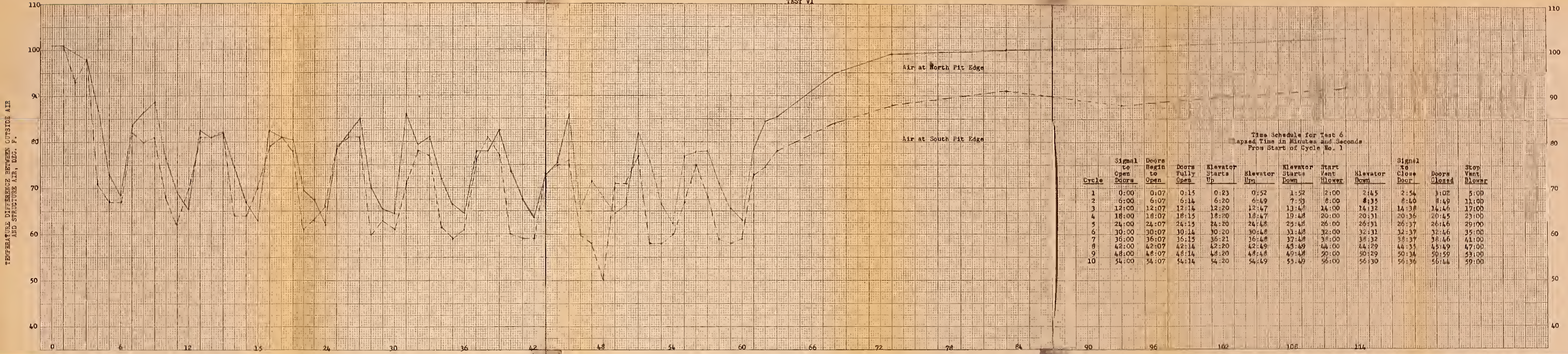
NEN
EN

O


TEMPERATURE CHANGE OF COMPONENTS IN
NIKE UNDERGROUND STRUCTURE DURING TEN FIRING CYCLES
TEST V
Hydraulic Cylinder on South Door (T. C. 35)
Box of Limit Switch on North Door
Control Switch Box above Elevator Platform
Surface of Bottom Edge of Door Gasket (T. C. 30)
Surface of Top Edge of Door Gasket (T. C. 25)
0
20
40
60
80
100
120
140
0
6
12
18
24
30
36
42
48
54
60
66
72
78
84
ELAPSED TIME IN MINUTES FROM START OF FIRST CYCLE
GRAPH 5-4

Doors Fully Open	Eleva Start Up
0:15	0:2
6:14	6:2
12:14	12:2
18:15	18:2
24:15	24:2
30:14	30:2
36:15	36:2
42:14	42:2
48:14	48:2
54:14	54:2

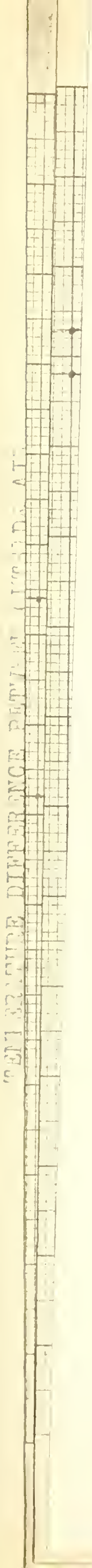
TEMPERATURE CHANGE IN NIKE UNDERGROUND
STRUCTURE DURING TEN FIRING CYCLES
TEST VI



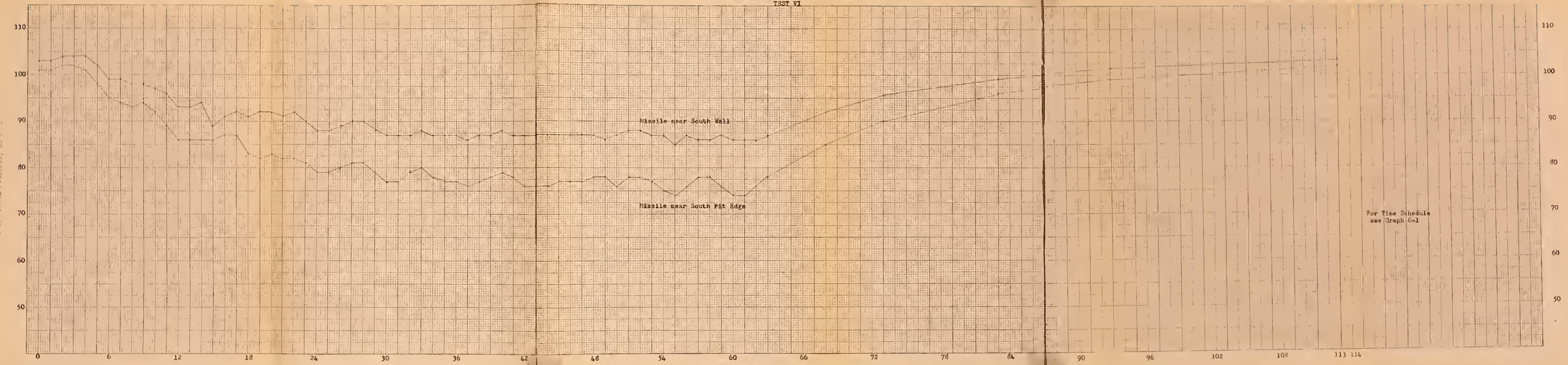
Time Schedule for Test 6
Elapsed Time in Minutes and Seconds
From Start of Cycle No. 1

Cycle	Signal to Open Doors	Doors Begin to Open	Doors Fully Open	Elevator Starts Up	Elevator Up	Elevator Starts Down	Start Vent Blower	Elevator Down	Signal to Close Door	Doors Closed	Stop Vent Blower
1	0:00	0:07	0:15	0:23	0:52	1:52	2:00	2:45	2:54	3:02	5:00
2	6:00	6:07	6:14	6:20	6:49	7:53	8:00	8:35	8:40	8:49	11:00
3	12:00	12:07	12:14	12:20	12:47	13:48	14:00	14:32	14:38	14:46	17:00
4	18:00	18:07	18:15	18:20	18:47	19:48	20:00	20:31	20:36	20:45	23:00
5	24:00	24:07	24:15	24:20	24:48	25:48	26:00	26:31	26:37	26:46	29:00
6	30:00	30:07	30:14	30:20	30:48	31:48	32:00	32:31	32:37	32:46	35:00
7	36:00	36:07	36:15	36:21	36:48	37:48	38:00	38:32	38:37	38:46	41:00
8	42:00	42:07	42:14	42:20	42:49	43:49	44:00	44:29	44:35	45:49	47:00
9	48:00	48:07	48:14	48:20	48:48	49:48	50:00	50:29	50:34	50:59	53:00
10	54:00	54:07	54:14	54:20	54:49	55:49	56:00	56:30	56:36	56:44	59:00

ELAPSED TIME IN MINUTES FROM START OF CYCLE
GRAPH 6-1

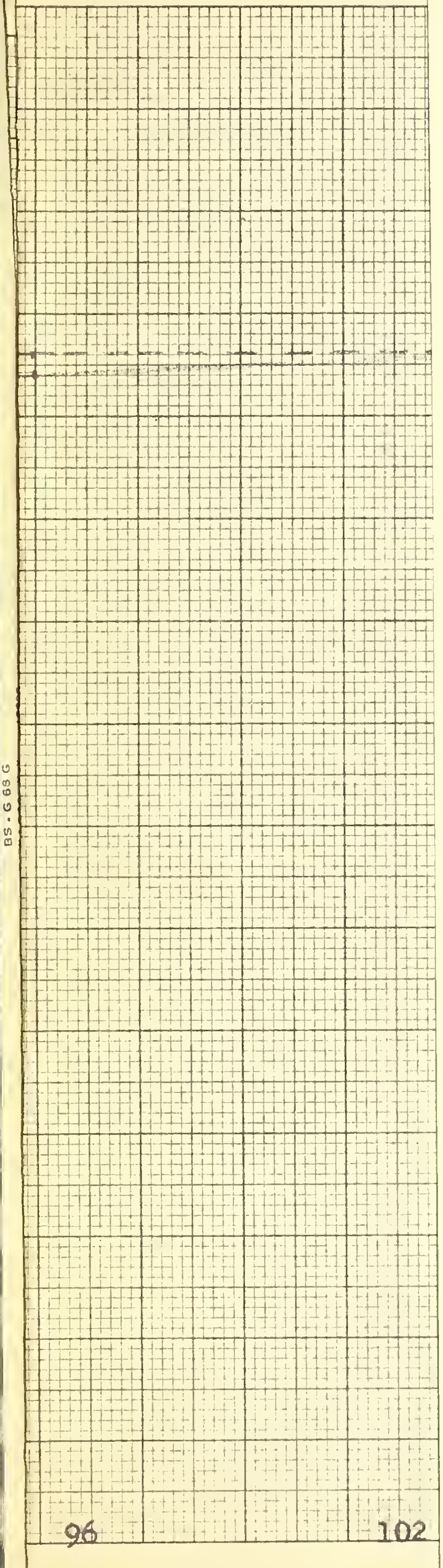


TEMPERATURE CHANGE IN NIKE UNDERGROUND
STRUCTURE DURING TEN FIRING CYCLE
TEST VI



ELAPSED TIME IN MINUTES FROM START OF CYCLE

GRAPH 6-2


BS.G 68 G
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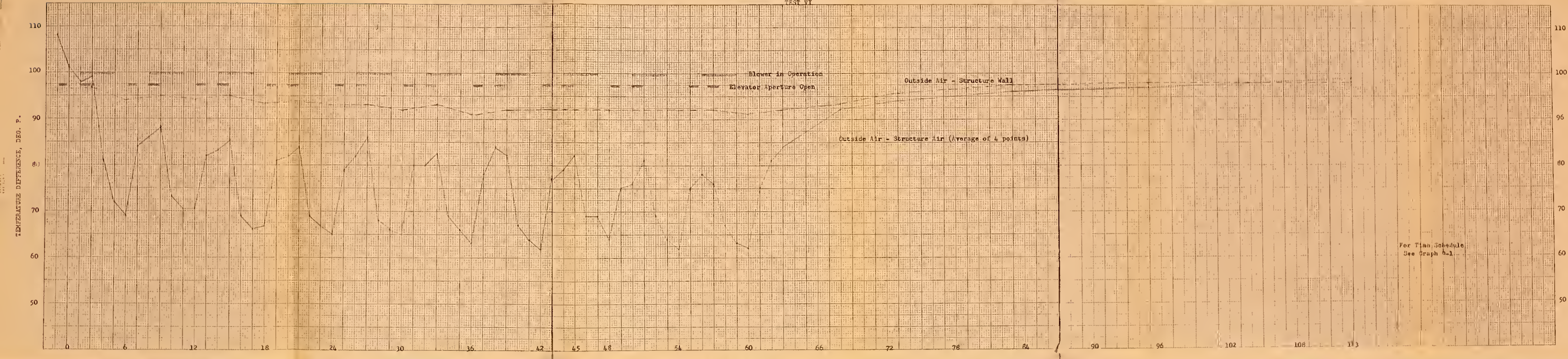
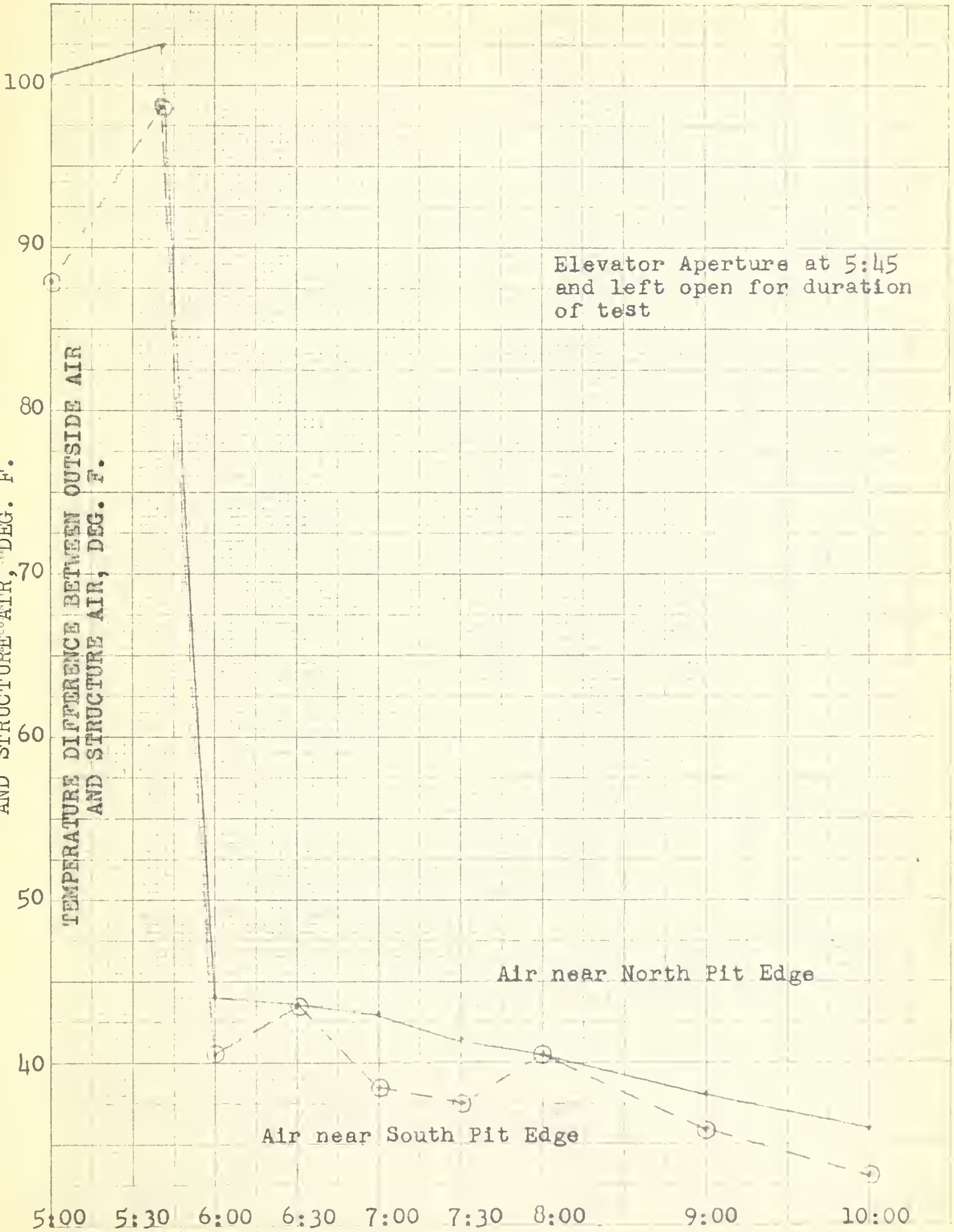
TEMPERATURE CHANGE IN NIKE UNDERGROUND
STRUCTURE DURING TEN FIRING CYCLES
TEST VI



ELAPSED TIME IN MINUTES FROM START OF FIRST CYCLE
GRAPH 6-3

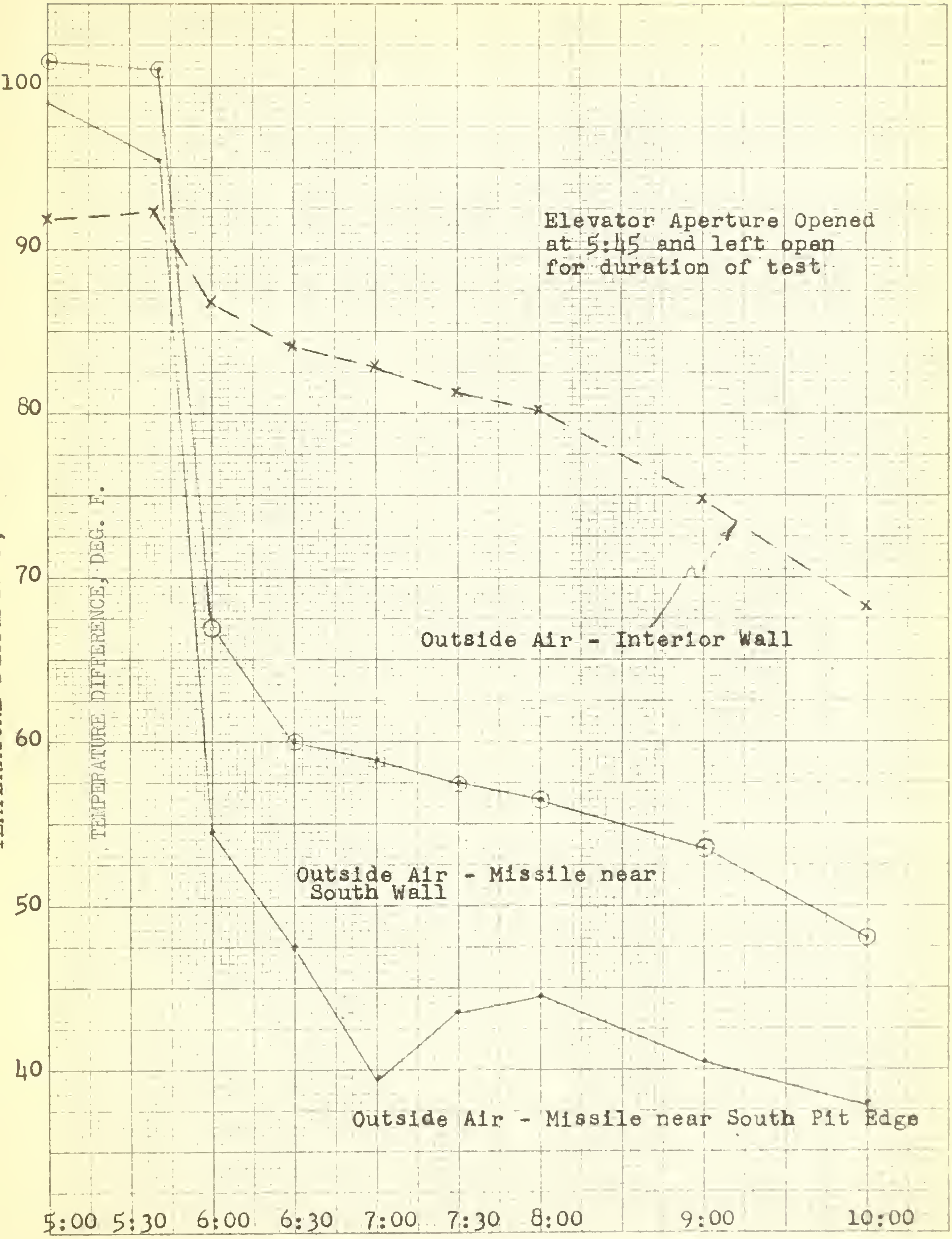
TEMPERATURE CHANGES IN NIKE UNDERGROUND STRUCTURE
TEST VII



CLOCK TIME
GRAPH 8-1

TEMPERATURE CHANGES IN NIKE UNDERGROUND STRUCTURE

TEST VII



GRAPH 8-2

U. S. DEPARTMENT OF COMMERCE
Sinclair Weeks, *Secretary*

NATIONAL BUREAU OF STANDARDS
A. V. Astin, *Director*

THE NATIONAL BUREAU OF STANDARDS

The scope of activities of the National Bureau of Standards at its headquarters in Washington, D. C., and its major field laboratories in Boulder, Colorado, is suggested in the following listing of the divisions and sections engaged in technical work. In general, each section carries out specialized research, development, and engineering in the field indicated by its title. A brief description of the activities, and of the resultant reports and publications, appears on the inside front cover of this report.

WASHINGTON, D. C.

Electricity and Electronics. Resistance and Reactance. Electron Tubes. Electrical Instruments. Magnetic Measurements. Dielectrics. Engineering Electronics. Electronic Instrumentation. Electrochemistry.

Optics and Metrology. Photometry and Colorimetry. Optical Instruments. Photographic Technology. Length. Engineering Metrology.

Heat and Power. Temperature Physics. Thermodynamics. Cryogenic Physics. Rheology and Lubrication. Engine Fuels.

Atomic and Radiation Physics. Spectroscopy. Radiometry. Mass Spectrometry. Solid State Physics. Electron Physics. Atomic Physics. Nuclear Physics. Radioactivity. X-rays. Betatron. Nucleonic Instrumentation. Radiological Equipment. AEC Radiation Instruments.

Chemistry. Organic Coatings. Surface Chemistry. Organic Chemistry. Analytical Chemistry. Inorganic Chemistry. Electrodeposition. Gas Chemistry. Physical Chemistry. Thermochemistry. Spectrochemistry. Pure Substances.

Mechanics. Sound. Mechanical Instruments. Fluid Mechanics. Engineering Mechanics. Mass and Scale. Capacity, Density, and Fluid Meters. Combustion Controls.

Organic and Fibrous Materials. Rubber. Textiles. Paper. Leather. Testing and Specifications. Polymer Structure. Organic Plastics. Dental Research.

Metallurgy. Thermal Metallurgy. Chemical Metallurgy. Mechanical Metallurgy. Corrosion. Metal Physics.

Mineral Products. Engineering Ceramics. Glass. Refractories. Enameled Metals. Concreting Materials. Constitution and Microstructure.

Building Technology. Structural Engineering. Fire Protection. Heating and Air Conditioning. Floor, Roof, and Wall Coverings. Codes and Specifications.

Applied Mathematics. Numerical Analysis. Computation. Statistical Engineering. Mathematical Physics.

Data Processing Systems. SEAC Engineering Group. Components and Techniques. Digital Circuitry. Digital Systems. Analogue Systems. Application Engineering.

- Office of Basic Instrumentation
- Office of Weights and Measures

BOULDER, COLORADO

Cryogenic Engineering. Cryogenic Equipment. Cryogenic Processes. Properties of Materials. Gas Liquefaction.

Radio Propagation Physics. Upper Atmosphere Research. Ionospheric Research. Regular Propagation Services. Sun-Earth Relationships.

Radio Propagation Engineering. Data Reduction Instrumentation. Modulation Systems. Navigation Systems. Radio Noise. Tropospheric Measurements. Tropospheric Analysis. Radio Systems Application Engineering.

Radio Standards. Radio Frequencies. Microwave Frequencies. High Frequency Electrical Standards. Radio Broadcast Service. High Frequency Impedance Standards. Calibration Center. Microwave Physics. Microwave Circuit Standards.

NBS