May 31, 2000

MEMORANDUM TO: Mark A. Cunningham, Chief
Probabilistic Risk Analysis Branch
Division of Risk Analysis and Applications

THRU: Nathan O. Siu, Senior Technical Advisor
Probabilistic Risk Analysis Branch
Division of Risk Analysis and Applications

FROM: Hugh W. Woods
Probabilistic Risk Analysis Branch
Division of Risk Analysis and Applications

SUBJECT: PLACEMENT OF THE ATTACHED DOCUMENT "FLAME PROPAGATION TESTS OF POWER AND CONTROL CABLES," IN THE PUBLIC DOCUMENT ROOM (PDR)

By copy of this memorandum, the subject document will be placed in the PDR. This will allow us to distribute SNL's final letter report, "Circuit Failure Mode and Likelihood Analysis," which references the subject document.

Written permission to release this copyrighted document to the public domain (attached) was granted by Mr. Mike Cass of the American Nuclear Insurance Co. (ANI), which succeeded Nuclear Energy Liability - Property Insurance Association, which sponsored the work through Underwriters' Laboratories, Inc. (UL).

Attachments:
UL report
Message from Mr. Mike Cass, ANI

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UNITED STATES
NUCLEAR REGULATORY COMMISSION
WASHINGTON, D.C. 20555-0001

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Attachments:
UL report
Message from Mr. Mike Cass, ANI

From: Mike Cass <MCass@AmNucIns.com>
To: "'NOS@nrc.gov'" <NOS@nrc.gov>
Date: Fri, May 19, 2000 2:02 PM
Subject: flame propagation test report

ANI has considered your request to place in the public domain a flame propagation test report which we sponsored through UL. while we are generally reluctant to approve making our reports public due to the risk of third party reliance that accompanies such action, we do grant you permission to make the UL test report referenced in Sandia Report USNRC JCN Y6037 available to the public. any reproductions of the report must be complete.

Michael Cass

CC: Ron Sanacore <RSanacore@AmNucIns.com>

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an independent, not-for-profit organization testing for public safety

File NC555
Project 74NK8900

August 23, 1976

REPORT

on

FLAME PROPAGATION TESTS OF POWER AND CONTROL CABLES

Sponsored by:

Nuclear Energy Liability - Property Insurance Association
Hartford, Connecticut

INTRODUCTION

Recently, some authorities of jurisdiction have used the fire test method included in IEEE 383-1974, "Guide for Type Test of Class IE Electric Cables, Field Splices and Connections for Nuclear Power Generating Stations," as a basis for evaluating the flammability characteristics of insulated power control cables. The method utilizes a 10 in. wide ribbon burner with a propane gas supply regulated to provide a theoretical heat input of 70,000 BTU/hr. The resultant flame exposes the lower end of six 8 ft lengths of cable strapped in a vertical open ladder-type tray. Favorable cable performance is indicated when a char height of less than 8 ft is incurred during a 20 min exposure period.

In response to interest expressed by authorities of jurisdiction and others, the investigation Reported here was undertaken to explore two general considerations of the test method: exposure source energy input and flame size, and specimen orientation. Further interest was expressed in developing data on maintenance of circuit integrity under the exposure conditions of the fire test. For purposes of this investigation, the conditions of the IEEE 383-1974 test method were modified by placing a 16 ft high vertical tray adjacent to the two wall surfaces of an open corner. Placement of the tray adjacent to the wall surfaces was designed to increase the severity of the exposure by providing for a conservation of exposure fire energy and reradiation of energy from adjacent surfaces as they were heated through the fire exposure. In a second general specimen mounting condition, samples were placed in each of four levels of 10 ft long horizontal trays, placed within a simulated corridor. In both the vertical and horizontal geometries, three different exposure intensities were used: 70,000 BTU/hr, 210,000 BTU/hr and 400,000 BTU/hr. A variety of cable constructions were used in the investigation.

Accordingly, the objectives of the investigation were to:

1. Determine the influence of ignition source energy input and flame size on the fire performance of various cables using the apparatus described by the fire test method of IEEE 383-1974 (with a modified geometry) and to determine whether the rank order of performance of cables insulated with various materials is changed by variation of ignition source energy input and flame size.

2. Determine the relationship between the fire performance of cable placed in a vertical orientation versus a horizontal orientation intended to reproduce the manner in which cable might typically be installed.

3. Subject a variety of cable insulation types to the general fire exposure conditions of the vertical test geometry to determine whether the response of the materials to the flame exposure influences the propagation of flame and damage or the general progress of the test.

4. Develop data on duration for which circuit integrity is maintained for various cable constructions under the various fire exposures.

As a supplement to cable fire test data developed using the apparatus of IEEE 383-1974, data was also developed on the flame size, temperature, and theoretical heating output produced by the burning of typical transformer oil. This data is reported in the Appendix of this Report.

PLAN:

The plan of the investigation was to subject cable samples to a series of vertical and horizontal fire tests. In each series were further divided by the use of three different ignition source flame intensities. Eight different cable constructions were tested.

The burner apparatus described by IEEE 383-1974 including burners, venturi air-gas mixer, controls, and propane fuel type was used as the ignition source in all tests.

VERTICAL SERIES

In the vertical series, the cable tray was placed in an open corner configuration, as shown by ILL. 1, to provide for conservation of energy and reradiation of energy as the wall surfaces were heated through each test. It was anticipated that the addition of the 16 ft high corner geometry would increase the severity of the exposure and amplify fire performance differences among various cable constructions. The height of the cable tray was increased to 16 ft to permit extended observations of cable fire performance. The positioning of the burner face with respect to the cable tray interface was adjusted as necessary, depending on flame intensity, to center the flame intensity at the cable.

HORIZONTAL SERIES

The horizontal series consisted of the placement of four horizontal 10 ft long trays, vertically spaced 1 ft apart, parallel to one another, adjacent to one wall of a 16 ft long corridor configuration as shown in ILL. 2. The burner was positioned between the bottom and next-to-bottom tray at one end of the configuration. The flame impinged longitudinally along the trays such that it would tend to propagate along the trays.

The horizontal series was designed to allow for both vertical propagation (tray-to-tray) and horizontal propagation (along trays). The burner location was adjusted for the various flame intensities to maintain a constant flame impingement point. The proximity of the trays to the walls, ceiling, and to one another, was designed to reinforce flame involvement through conservation of energy and reradiation from wall and ceiling surfaces as they were heated through the fire exposure.

THE INVESTIGATION

TEST FACILITY:

The vertical corner tests were conducted inside a brick building, 40 by 40 ft in floor area, with a ceiling height of 50 ft. The horizontal corner tests were conducted in an adjoining building, 37 by 67 ft in floor area, with a ceiling height of 21 ft in one area and 24 ft in the remaining area.

Test building views and placement of the cable test structures within the test buildings is indicated in ILL. 3. A 10 ft high, 12 ft wide door connecting the two building areas was left open during the testing. All exterior doors were closed during the vertical test series. However, the 10 ft high by 12 ft wide exterior door in the 37 by 67 ft room was left partially open for drafting purposes during the horizontal series. The roof vents in the 40 by 40 ft room were left open during all test work.

The roof vents were ducted to an exhaust and smoke incineration system for removal of the products of combustion. The volume flow rate through the afterburner system totalled approximately 16,000 cfm, providing the equivalent of one air change in approximately 9 min. The test building had sufficient air leakage through perimeter floor-level shuttered vents that atmospheric pressure was maintained while the incinerators were in operation.

BURNER:

The burner apparatus consisted of the burner and mixer as described by IEEE 383-1974. Controls were provided to meter the air and gas flows as required to maintain the 70,000, 210,000 and 400,000 BTU/hr flame intensities. The indicated flame intensities are predicated on the theoretical heating value of the propane gas consumed during the 20 minute test duration. The actual heat output of the burner may have been less than the theoretical input as a result of incomplete combustion.

The burner supply and control system was provided with supplementary components to provide for measurement of gas and air pressures as supplied to the mixer. The gas consumption rate was established through trial operating periods of the burner with the air and gas controls fixed. Actual gas consumption during each test was recorded as the weight difference of the propane cylinders used to provide the gas to the burner.

Flame sizes and temperatures were determined as a characterization of the exposure fires. The burner flame profiles and temperatures for the three test flame intensities are shown by ILL. 4.

TEST CONFIGURATIONS:

VERTICAL SERIES

The vertical cable tests were conducted with a 16 ft high tray placed adjacent to one of the interior walls of a 16 ft high corner configuration. The corner was constructed using two 4 ft wide by 16 ft high steel framed modules, each faced with 1/2 in. thick asbestos millboard. The two modules were placed to form a 90 degree intersection and secured at their common edge. The corner configuration was open at its top. The tray and corner configuration is shown by ILL. 1.

The vertical tray was of an "open ladder" construction, fabricated of No. 16 gauge cold-rolled steel, 3 in. deep, 12 in. wide, and 16 ft high with ladder-rung spacing of 9 in. on center. The tray was secured in a vertical position, parallel to the axis of the corner intersection. The tray was spaced 12 in. from each of the two surfaces of the corner configuration, with the plane of the tray rungs parallel to one of the walls.

HORIZONTAL SERIES

In the horizontal geometry, the cable trays were placed within a corridor. The corridor configuration was provided by an enclosure of two 16 ft long by 8 ft high walls, with a roof. Each wall consisted of four 4 ft wide by 8 ft high steel framed modules, each faced with 1/2 in. thick asbestos millboard. The roof consisted of 1-1/2 in. deep cellular steel decking sections, supported along the tops of the respective wall modules. One end of the corridor, opposite the end at which the ignition flame was applied to the cables, was enclosed at its upper 1 ft, across the width of the corridor. The lower portion of that end of the corridor was opened over its entire width into a height of 7 ft. The opposite end of the corridor was opened over its entire 8 ft wide by 8 ft high area. The overall corridor dimensions were 16 ft in length, 8 ft in width and 8 ft in height.

A support system was installed against one wall to provide for positioning of four 10 ft long by 12 in. wide cable trays at distances below the ceiling of 1 ft, 2 ft, 3 ft, and 4 ft. The trays were also positioned 1 ft from the adjacent wall surface.

The trays were of an "open ladder" construction, identical to those used in the vertical tests, except for length, and were fabricated of No. 16 gauge cold-rolled steel, 3 in. deep, 12 in. wide by 10 ft long, with a rung spacing of 9 in. on center. The corridor configuration and tray positioning are shown by ILL. 2.

TEST PROCEDURE:

VERTICAL SERIES

For each test, six 16 ft lengths of cable were arranged in a single layer centered in the tray, with a separation of one-half cable diameter between each cable. The cables were secured to every other rung on the tray using nylon cable ties, with a steel wire tie used at the uppermost rung.

The burner was ignited and then placed in its test position as shown by ILL. 1, perpendicular to the cable tray at test time zero. The burner was mounted horizontally behind the tray, centered on the tray, at a height of approximately 18 in. above the base, and 3 in., 5 in., or 11 in. from the tray for the 70,000, 210,000, or 400,000 BTU/hr flame exposure, respectively.

The test flame was applied to the specimen for 20 min.

For purposes of this Report, vertical tests are referenced as Procedure A, for the 70,000 BTU/hr exposure, Procedure B for the 210,000 BTU/hr exposure, and Procedure C for the 400,000 BTU/hr exposure.

HORIZONTAL SERIES

Six 10 ft lengths of the cable specimen were arranged in a single layer in each of the four horizontal trays, centered in the tray, with a separation of one-half cable diameter between adjacent cables.

To initiate a test, the burner flame was ignited and the burner placed in its test position, as shown by ILL. 2, at test time zero. The burner was placed in a horizontal orientation, positioned between the bottom and next-to-bottom tray in such a manner that the flame impinged upon the cable in the next bottom tray at a distance of approximately 2 ft from the end of the tray. The burner was accordingly situated 3 in. below the tray and 1 ft 7 in. from the end of the tray for the 70,000 BTU/hr exposure. For the 210,000 BTU/hr exposure, the burner was situated 5 in. below the tray and 1 ft 5 in. from the end of the tray. For the 400,000 BTU/hr exposure, the burner was positioned 5 in. below the tray and 1 ft 1 in. from the end of the tray.

For purposes of this Report, the horizontal tests are referenced as Procedure D, Procedure E, and Procedure F for the 70,000 BTU/hr, 210,000 BTU/hr, and 400,000 BTU/hr exposure, respectively.

INSTRUMENTATION:

TEMPERATURE MEASUREMENT

Vertical Series

Thermocouples were used to record temperatures at eight locations in the vertical test. The thermocouples were No. 16 gauge chromel-alumel with thermocouple junctions spaced approximately 1/2 in. from the face of the cable specimen at the center of the tray width. The thermocouples were placed opposite the fire exposed side of the tray. Locations of thermocouples are shown by ILL. 5.

Horizontal Series

Thermocouples were used to record temperatures at 24 locations in the horizontal test. The thermocouples were No. 16 gauge chromel-alumel with thermocouple junctions spaced approximately 1/2 in. from the face of the cable specimen at the center of the tray width. The thermocouples were placed opposite the fire exposed side of the tray. Locations of the thermocouples are shown by ILL. 6.

CIRCUIT INTEGRITY

In each test, the individual conductors were wired to a direct-current power supply through circuit continuity instrumentation. The circuit failure detection circuit is shown by ILL. 7. All six cables in each individual tray in the horizontal series were wired in parallel, such that the cable in which failure first occurred could not be specifically identified. The nature of the circuit failure detection system was such that a phase-to-ground failure would not be detected, unless it occurred prior to a phase-to-phase failure.

MEASUREMENTS AND OBSERVATIONS:

Various measurements and data were compiled as indicated in the following.

1. Visual observations.
    a. Time ignition of the cable jacket. (Vertical series)
    b. The flame propagation distance at periodic intervals.
    c. Over-all response of the cable to fire exposure.
    d. Post-test char distance in jacket material.
    e. Post-test char distance in conductor insulation material. (Vertical series)
2. Circuit failure time.
3. Temperature record.
4. Burner operating parameters.
    a. Air pressure supply to mixer.
    b. Gas pressure supplied to mixer.
    c. Indicated gas flow rate.
    d. Total weight of propane consumed.
    e. Calculated flame intensity (theoretical heat input).
5. Photographic documentation.

SAMPLES:

The cable specimens used in this investigation consisted of seven (copper) conductor, No. 12 Awg, construction, with eight different conductor and jacket insulation systems. The specimens were provided by the sponsor of the investigation, with generic composition identifications as indicated in the following table.

Designation	Conductor Insulation	Jacket Material
XLPE-PVC/PVC	Crosslinked polyethylene-polyvinyl chloride	Polyvinyl chloride
EPR/Neoprene	Ethylene propylene rubber	Neoprene
XLPE/XLPE (two constructions)	Crosslinked polyethylene	Crosslinked polyethylene
Silicone-glass asbestos	Silicone with glass overbraid	Impregnated asbestos braid
TE-PVC/PVC	Polyethylene-polyvinyl chloride	Polyvinyl chloride
XLPE/Neoprene	Crosslinked polyethylene	Neoprene
EPR-Hypalon/ Hypalon	Ethylene propylene rubber-Hypalon	Hypalon

Because the objective of the investigation was not to evaluate the relative performance of various cable constructions, the cable designations do not appear in connection with the test data and results reported in following sections. Rather, a random letter identification is provided as a means of common reference through the data. Please note that there is no relationship between the letters designations or sequence and the cable types as indicated above. Instead, for reference purposes, each cable type was assigned a three letter designation, selected by picking random groups of three letters. These random designations are: CSA, EMD, FVT, KPB, LUH, OWR, XGY, and ZQJ.

RESULTS:

A tabulated summary of test data is provided in ILLS. 8 through 23. The tabulated data for vertical and horizontal tests of respective cable constructions appears as follows:

Cable Code	Vertical Tests	Horizontal Tests
CSA	ILL. 8	ILL. 16
EMD	ILL. 9	ILL. 17
FVT	ILL. 10	ILL. 18
KPB	ILL. 11	ILL. 19
LUH	ILL. 12	ILL. 20
OWR	ILL. 13	ILL. 21
XGY	ILL. 14	ILL. 22
ZQJ	ILL. 15	ILL. 23

OBSERVATIONS DURING TEST

The visual test observations of each cable construction, for the entire range of flame intensities, for both vertical and horizontal test geometries are encapsulated below:

Construction CSA

Ignition of the cable occurred 4 to 9 sec after application of the burner flame for all intensities. Upon ignition, a "sparkler" effect developed as small char particulate from the jacket "popped" away from the test sample and leaving smoke trails in the path of their fall. There was some continued smoking from the accumulation of particles on the floor. The accumulated fallen char did not ignite. The production of heavy black smoke was noted, in the region of exposure flame impingement, which increased as flames propagated beyond the ignition flame region and the area of involvement expanded. The cables appeared to swell slightly, but not to the extent that char from adjacent cables closed the space between cables. The ignition flame continued to penetrate through the cables. In the vertical series, three tests were conducted at the 70,000 BTU/hr flame level because of the varying flame travel distances which were observed (approximately 4-1/2 ft to 10-1/2 ft). As the flame intensity was increased to 210,000 and 400,000 BTU/hr, the flame travel distances remained within the range observed for the 70,000 BTU/hr flame (approximately 8 to 10 ft), and the average jacket damage distance did increase over that observed for the 70,000 BTU/hr flame. However, the average jacket damage distance as well as the average flame distance travel actually decreased when the ignition flame was increased from 210,000 to 400,000 BTU/hr. In the horizontal series, the degree of involvement and damage was relatively proportional to ignition flame intensity. Fire growth did not result in ignition of the upper tray for the 70,000 BTU/hr exposures. At the 210,000 and 400,000 BTU/hr flame exposures, the uppermost tray burst into flames between 5 and 7 min into the test. At the 400,000 BTU/hr exposure, the tray beneath the burner ignited at 3 min and 4 min, in respective tests, although there was no direct flame contact, either from the ignition burner or from falling flaming particles. Virtually no afterburn was observed in the vertical series. All tests in the horizontal series exhibited afterburn which ranged in duration from 1 min to 10-1/2 min.

Construction EMD

Ignition of the cables ranged from 11 to 17 seconds after application of the ignition flame for all intensities. Relatively light to heavy smoke development was observed, depending upon intensity of ignition flame. Within a minute of the application of the burner flame, the cable jacket swelled, causing the space between adjacent cables to decrease, thereby blocking the flame and impairing its penetration of the test sample. Some loss of char was noted, and in the case of the 210,000 and 400,000 BTU/hr flame intensities, some bare conductors were visible. The flame travel distances increased as the intensity of the ignition flame, ranging from approximately 4 ft to 13 ft. After approximately 7 to 10 min in the vertical series, at flame exposure levels of 210,000 and 400,000 BTU/hr, the flame front separated from the ignition source and continued to burn as long as the ignition flame was applied. Afterburn in all tests ranged from approximately 2 to 15-1/2 minutes. During the last half of the horizontal test series at the 400,000 BTU/hr exposure level, the lower tray (identified as tray No. 1) ignited. This occurred even though there was no direct flame contact, either from the ignition burner or from falling flaming particles. In the horizontal series, at the 210,000 and 400,000 BTU/hr flame levels, it was observed that the flame front became separated from the ignition flame approximately at the 15 minute mark of the test.

Construction FVT

Ignition of the cable occurred 5 to 18 seconds after application of the burner flame for all intensities. Light to medium-heavy smoke was observed after ignition. Some minor jacket swelling was observed, however, the swelling was not to the extent that the flame source was impaired from penetrating the space between cables. In the vertical series, after the heat from the ignition flame at the 210,000 and 400,000 BTU/hr levels melted the lower cable ties holding the cable to the tray, all of the cables twisted as a group approximately 30 to 45 degrees, reducing the effective sample surface exposed to the flame. This did not appear to have any significant effect on the flame propagation or charring of the jacket since the cable spacing remained fairly constant and the sample did not twist out of the ignition flame area. No loss of char was noted. The flame travel distances ranged from 4 ft to 10 ft in the vertical series, depending upon the intensity of the ignition source. The jacket char distances were approximately 3-1/2 ft, 6 ft and 8 ft for the 70,000, 210,000, and 400,000 BTU/hr flame intensities, respectively. For the vertical tests conducted at the 210,000 and 400,000 BTU/hr flame levels, the flame front separated from the ignition flame about the 10 minute point of the tests, and by the 15 minute mark of the tests, the separated front had extinguished. No afterburn was observed for any vertical tests.

In the horizontal series at the 70,000 BTU/hr level, the area of involvement was confined to the two trays immediately above the burner, and total damage per test was approximately 2 ft. In the 210,000 and 400,000 BTU/hr horizontal tests, the total damage was increased to approximately 9-1/2 and 13-1/2 ft respectively. Separation of the flame front occurred approximately at the 10 minute mark. As was the case in the vertical series, no afterburn was observed except in the upper tray of one of the 400,000 BTU/hr tests, which burned for approximately 5 minutes after the removal of the ignition source. After all tests, it was noted that the jacket and/or insulation material had a long afterglow which produced an extensive amount of gray-white smoke. Afterglow times were not recorded. The char remaining was basically gray and black with a whitish crystalline ash.

Construction KPB

Ignition of the cable occurred in 4 to 9 seconds after the application of the burner flame. Upon ignition, and for the entire duration of the flaming, heavy black smoke was generated. As the jacket and insulation material became involved, it melted, and flaming droppings of molten plastic were observed. In the vertical series, separation occurred and the flame continued to propagate until the entire jacket and conductor insulating materials were consumed to ash. When the ignition flame was increased to 210,000 BTU/hr, the same burning pattern was evidenced, the only significant difference being that the time which was required for the flame to reach the top of the tray was reduced to between 7 and 9 minutes, and the afterburn time was reduced to less than 5 minutes. Increasing the flame to 400,000 BTU/hr served to further reduce the time required for the flame to reach the top of the tray to between 5 and 6 minutes. Between the 14 and 16 minute marks, the flaming of the separated flame front terminated as a result of all of the insulation material being consumed. In one test at 400,000 BTU/hr, reverse propagation was noted, and at the test termination, the area below the burner was the sole contributor to the afterburning. In the horizontal series, in all cases, cable was damaged in all three trays located above the burner, and the extent of damage was relative to the intensity of the ignition source. At the 210,000 and 400,000 BTU/hr flame levels, the cable in the lower tray (the tray located under the burner) ignited within 10 minutes as a result of the dripping, flaming plastic from the trays above. Flame separation occurred within approximately 10 minutes, and at the 400,000 BTU/hr source level the flame propagated to within 1 ft of the far end of the upper tray prior to extinguishing. Afterburn periods of up to 17-1/2 minutes were observed. Where burning had been present, there remained a brittle black char in some areas, or in most areas just the bare conductors remained.

Construction LUH

Ignition of the cable occurred 6 to 8 seconds after the application of the burner flame, at which time very heavy black smoke was given off. The heavy smoke then continued until the burning cable went out. Upon ignition and involvement, the jacket and insulation materials melted in the form of flaming drops and blobs which, in the case of the horizontal series, caused the lower tray to become involved at the 10 minute mark of the 400,000 BTU/hr test. The vertical series at 70,000 BTU/hr was not reproducable in the two tests conducted. In the first test, the flame continued to propagate until it reached the top of the ladder, requiring 19 minutes. In the second test the flame reached approximately 8-1/2 ft at the 20 minute mark, and did not propagate beyond that point after the ignition flame was removed. Afterburns of 11 and 14-1/2 minutes respectively were recorded. When the flame intensity was increased to 210,000 and 400,000 BTU/hr, the flame propagated to the top of the ladder. Only the times required for the flame to reach the top was different, 14 to 15 minutes at 210,000, and approximately 16 minutes at 400,000 BTU/hr. A combination of brittle, black char and bare conductors were all that remained in the involved areas.

Construction OWR

Upon application of the burner flame, ignition occurred in 11 to 17 seconds in all cases. At the time of ignition, the jacket material exhibited a "sparkler" effect developed as small particles of the jacket material broke away from the sample leaving smoke trails in their paths. The accumulated fallen char particles only smoked and did not ignite after having fallen away from the test sample. A moderate amount of grayish smoke was produced and subsided to a very light density after propagation subsided. No jacket or insulation swelling was observed. No significant loss of char was observed in any of the tests, and only small areas of bare conductors were observed in the immediate ignition source areas. Flame travel distances in the vertical series increased with ignition flame intensity. Flame heights of 4 ft, 7 ft, and 9 ft were observed for the 70,000, 210,000, and 400,000 BTU/hr flame levels, respectively, and no afterburn was observed in any of the tests conducted on this construction. By approximately the 12 minute mark of all of the tests, all of the burning of the insulating materials in the area of involvement appeared to cease, and no further propagation of the flame was in evidence. The char which was developed was of a gray/black color, and very brittle.

Construction XGY

Very slow ignition of the cable sample was observed, ranging from 3-1/2 minutes at the 70,000 BTU/hr flame intensity to approximately 45 seconds at the 400,000 BTU/hr flame intensity. Once ignition occurred, moderate to heavy grayish smoke was generated and prevailed until the flame went out. In the vertical series flame distances of 5-1/2 ft, 7 ft and 8 ft were recorded for the 70,000, 210,000, and 400,000 BTU/hr flame intensities, respectively. When flame separation did occur, at the higher flame intensities, it took place at approximately the 10 minute point of the test, and continued to burn as long as the ignition flame was being applied. Afterburn in the vertical series ranged from 1-1/2 to 5-1/2 minutes. In the horizontal series, at the 70,000 BTU/hr level, the flame did not propagate beyond the two trays immediately above the burner. At the 210,000 and 400,000 BTU/hr flame level, the flame separation occurred at between 6 and 8 minutes, and the cable in the upper tray burned itself out before propagating beyond 4 ft from the burner-end of the tray, and before the 20 minute test duration. In all cases in the horizontal series, there was no afterburn, dripping, or flaming particles. The only "char" observed was a white chalky crustation on the outer jacket of the cable, which only slightly increased the cable diameter but did not impair the penetration of the flame through and between cables.

Construction ZQJ

Ignition of the cable occurred 7 to 12 seconds after application of the burner flame for all intensities. Upon ignition, the production of heavy gray-black smoke was observed. With continued application of the flame, the cable jacket swelled partially blocking the flame from the ignition source, but not to the extent that flame penetration was totally impaired. No loss of char was observed in any of the tests. Flame travel distances in the vertical series were 4 ft at 70,000 BTU/hr, 6-1/2 ft at 210,000 BTU/hr, and 7-3/4 ft at 400,000 BTU/hr. Except at the 70,000 BTU/hr flame level, where the maximum flame distance occurred at approximately 15 minutes, the maximum flame height observed occurred within the first 10 minutes and then receded to the height of the ignition flame. A maximum of 1 minute of afterburn was observed during the vertical series above the ignition flame, and that occurred during the 70,000 BTU/hr flame exposure tests. The only afterburn noted in the increased flame intensity tests was a 3 minute afterburn after one of the 400,000 BTU/hr tests which was due to reverse propagation of the flame to the sample located below the burner. In the horizontal series, the area of involvement in the 70,000 BTU/hr exposure was limited only to the two trays immediately above the ignition flame, with no separation of flame front, and only 2-1/2 to 3 min of afterburn was observed. At the 210,000 BTU/hr flame level, the area of involvement extended to the uppermost tray with a flame separation observed at the 10 to 14 min point of the tests. No afterburn was observed. When the ignition source was further increased to 400,000 BTU/hr, the damage area increased slightly, with flame separation occurring at the 12 min mark of the test. Approximately 3-1/2 min of afterburn was observed in the uppermost tray.

OBSERVATIONS AFTER TEST

Damage to the jacket material was recorded after each test and is shown for each cable construction in ILLS. 8 through 23.

The average cable char distances are tabulated in ILL. 24 for the vertical tests and ILL. 25 for the horizontal tests. The char distance data is further summarized with respect to rank order of char distances for the respective exposure intensities, and is shown in ILL. 26.

CIRCUIT INTEGRITY

Specific circuit failure information for each test is included in the data summary of ILLS. 8 through 23.

The earliest time of occurance of circuit failure is reported, whether the failure was phase-to-ground or phase-to-phase. In the tests utilizing the horizontal configuration, the earliest failure is reported regardless of the tray in which it occurred. The earliest failure ordinarily occurred in the second from the bottom tray, directly above the ignition fire. Graphs of circuit failure times versus ignition flame intensities are shown by ILLS. 27 through 30. The circuit integrity is further summarized with respect to rank order under the respective ignition source sizes in ILL. 31.

The nature of the circuit integrity circuitry permitted record of phase-to-ground failure time only if it occurred prior to the occurance of phase-to-phase failure.

TEMPERATURES

Temperature records were provided separately to the test sponsor, and are not included in this Report.

PHOTOGRAPHIC RECORD

All tests were recorded with Super-8 motion picture time-lapse photography. The rate of film exposure was approximately one frame per second. The motion pictures have been provided to the sponsor.

SUPPLEMENTARY HORIZONTAL TEST

After completion of the planned tests, a supplementary test was conducted in accordance with Procedure F, with the test configuration modified with the intention of increasing the heat reradiation inside the corridor and retaining heat energy within the corridor enclosure.

Three modifications were made to the established corridor configuration: The first change was to decrease the width of the corridor from 8 to 5 ft. Further, the draft curtain at the end of the corridor was extended from 12 in. to 18 in., and a second 18 in. draft curtain was installed at the opposite end of the corridor. Application of the ignition source was continued for a 25 min duration.

Total cable jacket damage sustained increased by approximately 20 percent from the damage sustained in Procedure F, although the rate of flame growth was less during the early part of the test. The jacket damage incurred in the upper two trays increased by over 30 percent.

During the test, the circuit failure times remained consistent with those observed for the standard tests utilizing Procedures E and F.

S U M M A R Y

1. In both the vertical and horizontal tests, it was observed that:

    a) Discrimination of cable performance occurred under all ignition energy and test configuration conditions, i.e., under any given ignition source or configuration some cables performed better than others.

    b) An increase in the ignition source intensity resulted in an increase in the extent of cable damage in both the vertical and horizontal configurations.

    c) The difference in performance between various cable constructions tended to increase as the ignition source size was increased.

    d) The rank order of cable performance (extent of damage) was not specifically maintained as ignition source size was increased, although better performing cables generally performed better regardless of exposure intensity, and more poorly performing cables performed more poorly regardless of exposure intensity.

    e) Repeatability (similarity of the repeat of a test to the first test) tended to be better at greater ignition source intensities.

2. Comparison of the performance of cable in the horizontal tests to performance in the vertical tests leads to the observations that:

    a) The rank order of cable performance (extent of damage) was not specifically maintained when tests were conducted with cable tested in the horizontal configuration as compared to the vertical configuration, although in general cables which performed better in the vertical tests also performed better in the horizontal tests, and cables which performed more poorly in the vertical tests also performed more poorly in the horizontal tests.

    b) Two cable constructions sustained char damage to the full height of the tray in the vertical tests under 210,000 and 400,000 BTU/hr exposures. No cables burned the full specimen length in any of the horizontal tests at any ignition intensity.

3. Characteristic responses of some cable constructions influenced propagation of flame and extent of damage or otherwise influenced the progress of the test, including:

   a) Swelling of insulation and/or jacket material upon application of the ignition source resulting in inhibition of the ignition flames ability to penetrate through the spaces between adjacent cables. The effect was more significant at a flame exposure of 70,000 BTU/hr than at 210,000 or 400,000 BTU/hr. At greater flame intensities, the larger size of the flame provided a more fully encompassing flame such that there was a greater tendency to expose all surfaces of the cable to the igniting flames, regardless of the swelling of the cable insulation or jacket materials.

   b) Development of a separate flame front occurred for some cable constructions. The propensity for a separated flame front to develop, increased with an increase in the ignition source size. The propensity for the flame front to continue to propagate increased with increased ignition intensity. The separated flame front tended to reduce in intensity or discontinue upon removal of the ignition flame source.

   c) There is no single characteristic response of various materials to fire exposure. While some materials tend to puff and swell under fire exposure, others melt and drip, others exhibit a tendency for insulation and jacket material to produce small flying pieces of charred material and sparks, and others simply char without any other apparent change in condition. Some materials tend to respond to fire exposure in a highly repeative fashion, while others perform differently under various exposure levels or in repeat tests at a single exposure intensity.

4. In measurements of circuit integrity, it was observed that:

   a) There is no particular relationship between circuit integrity and extent of char damage.

   b) Rank order of cable performance with respect to circuit integrity, is generally consistent regardless of ignition source, energy size, or test configuration.

Report by:

J. W. SKJORDAHL
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Reviewed by:

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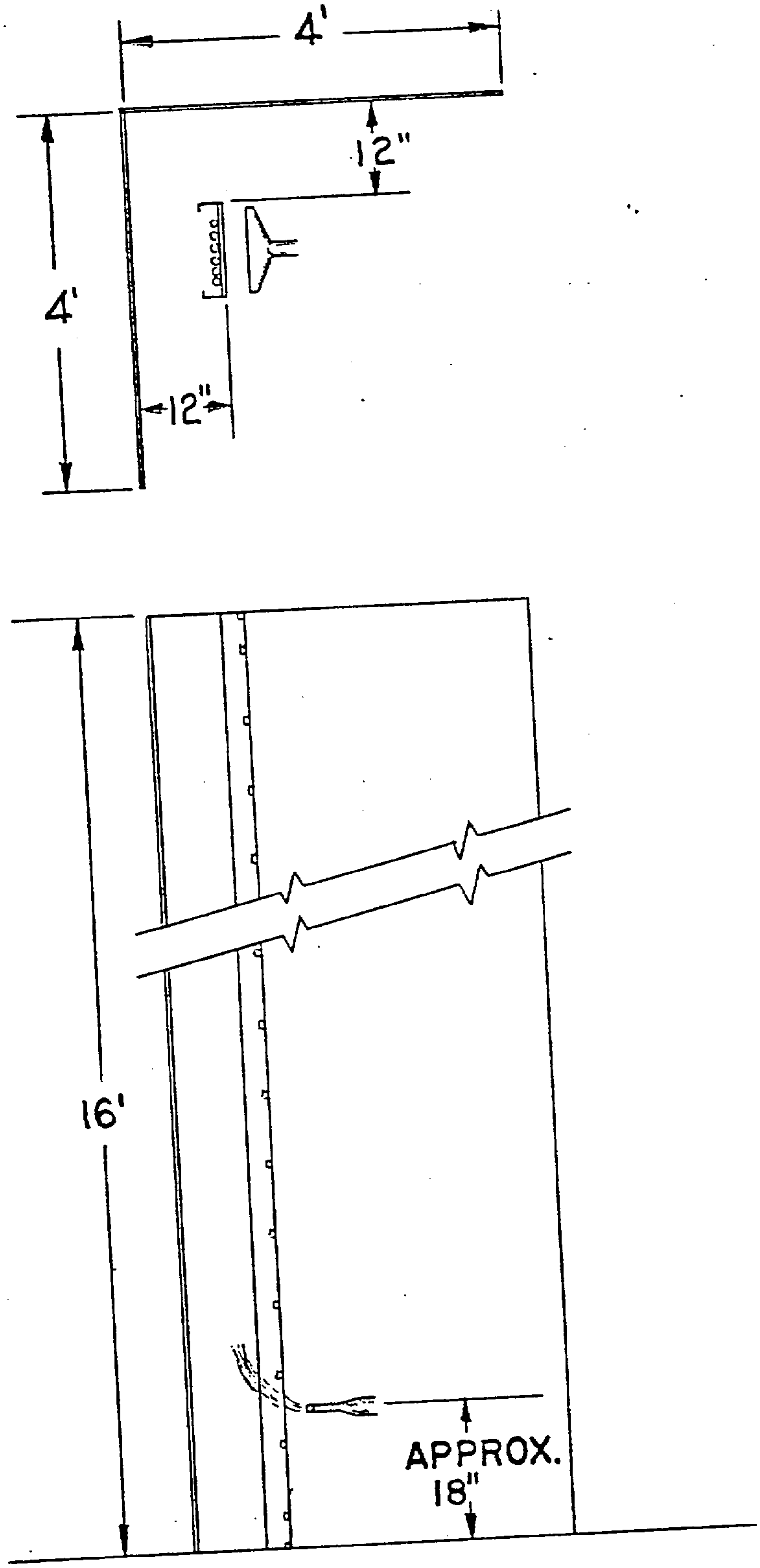
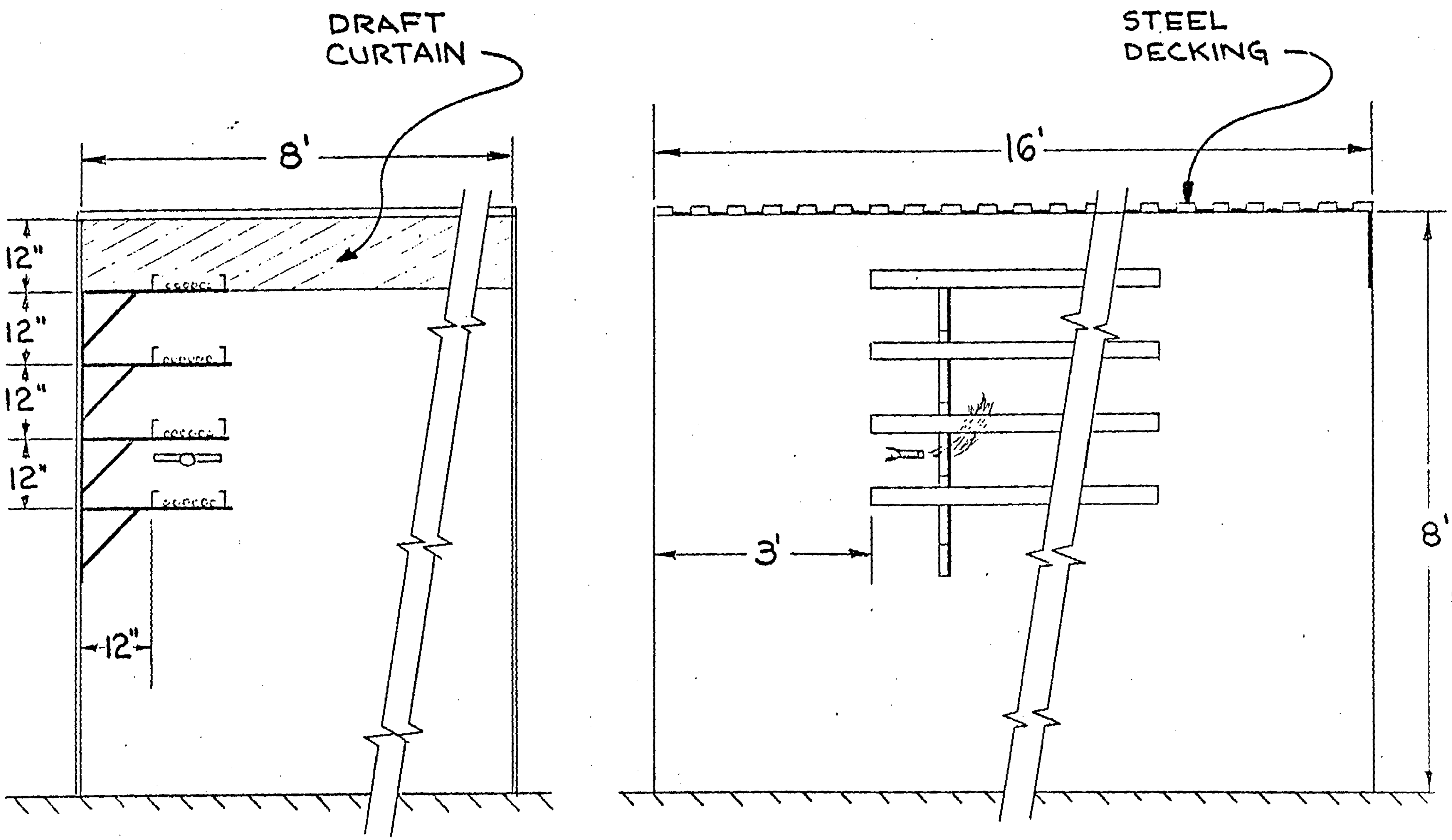


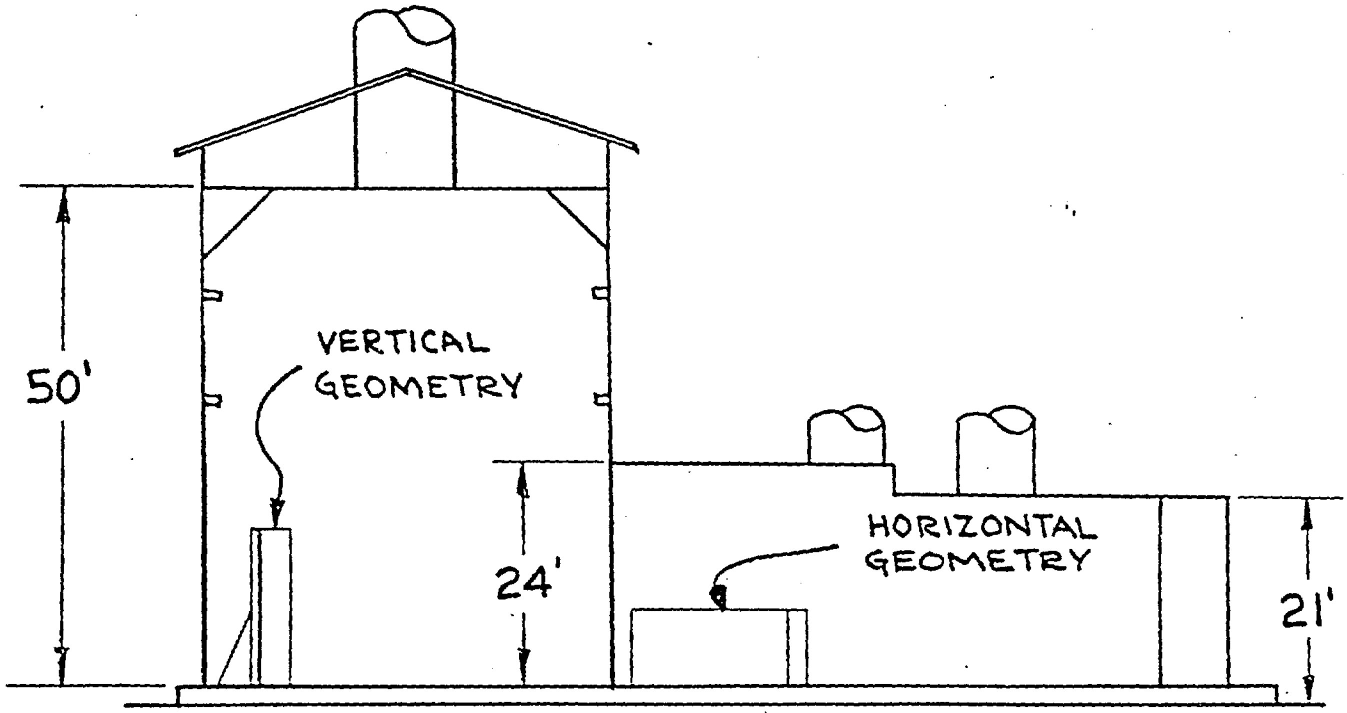
VERTICAL TEST GEOMETRY

NC555
ILL. 1

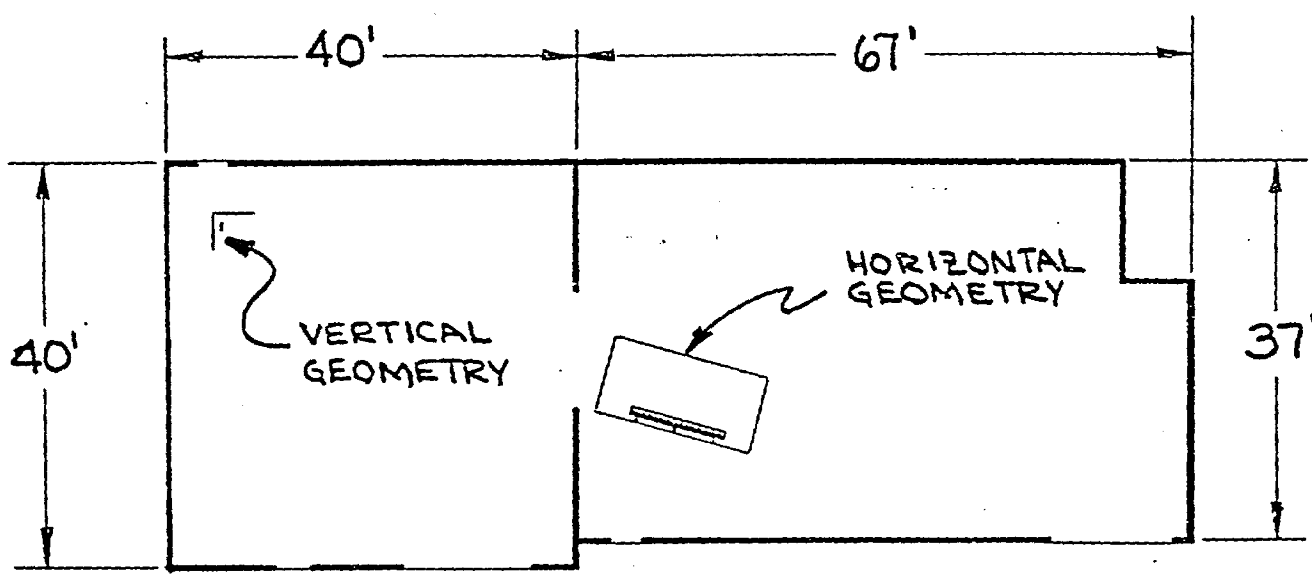


HORIZONTAL TEST GEOMETRY

NC 555
ILL. 2



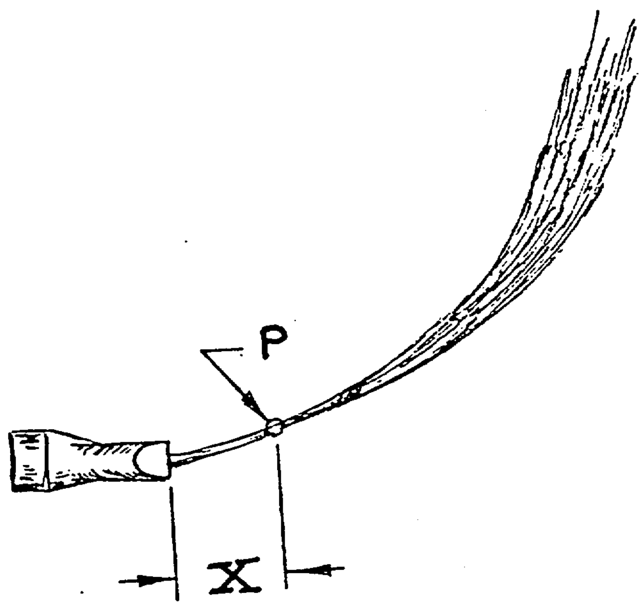
ELEVATION VIEW



PLAN VIEW

TEST BUILDING

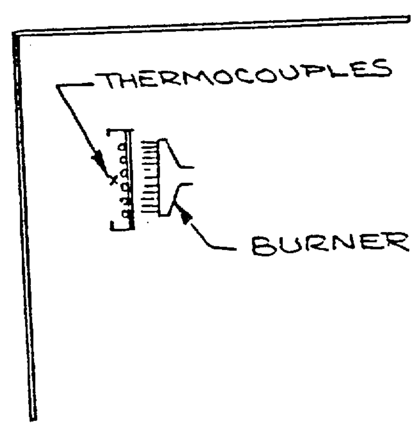
NC 55
ILL. 3



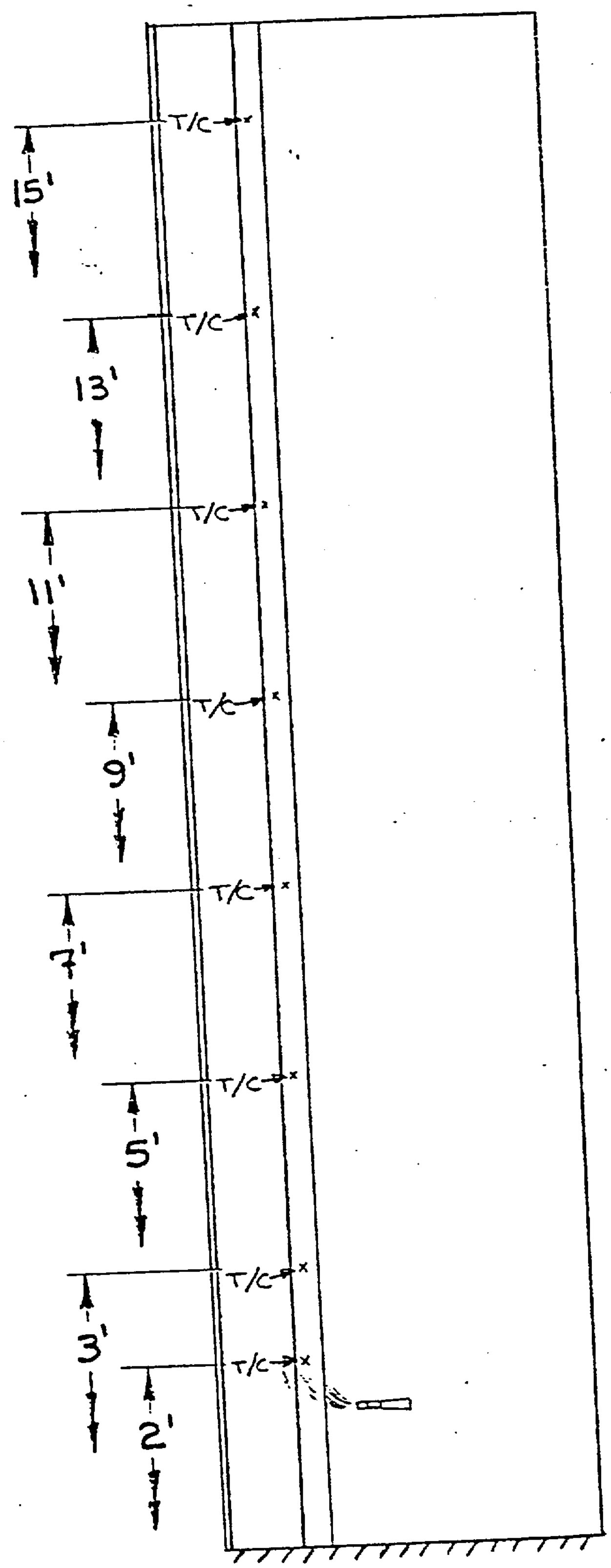
IGNITION FLAME INTENSITY	DISTANCE 'X' (IN.)	TEMPERATURE AT 'P' (°F)
70,000 BTU/hr.	3	1640
210,000 BTU/hr.	5	1610
400,000 BTU/hr.	11	1690

FLAME PROFILE
AND TEMPERATURES

NC555
ILL. 4



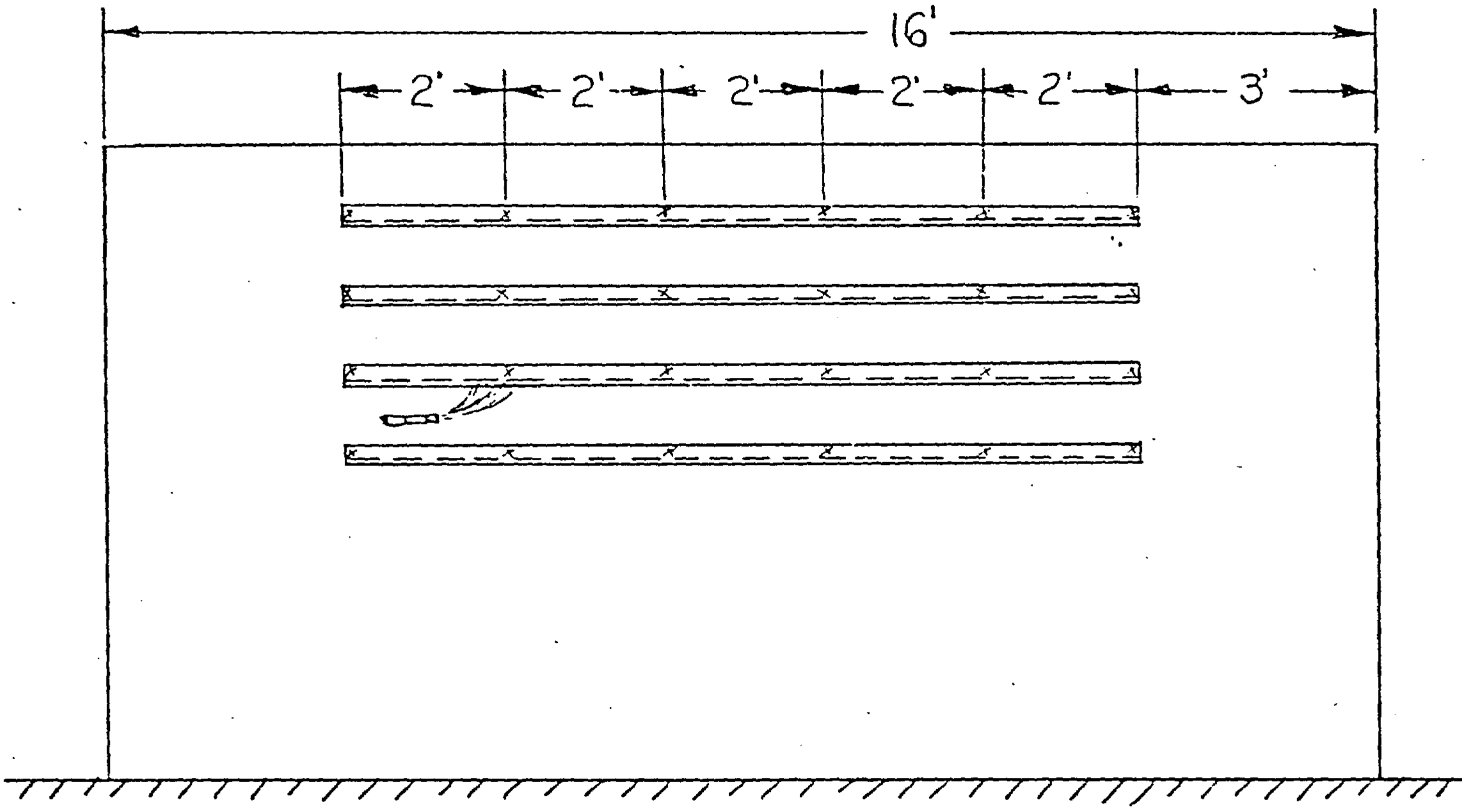
TOP VIEW



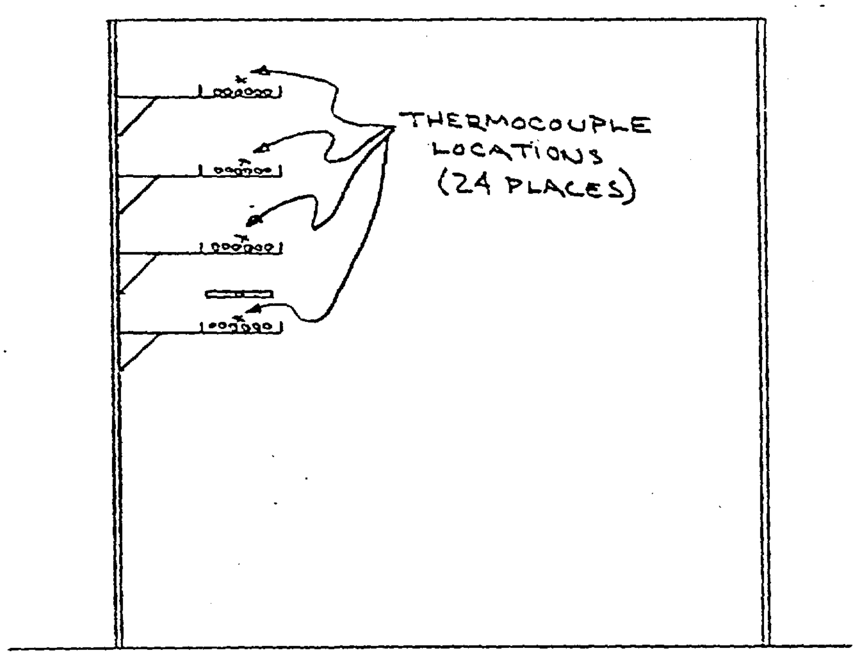
SIDE VIEW

THERMOCOUPLE LOCATIONS
VERTICAL GEOMETRY

NC 5:
ILL. 5

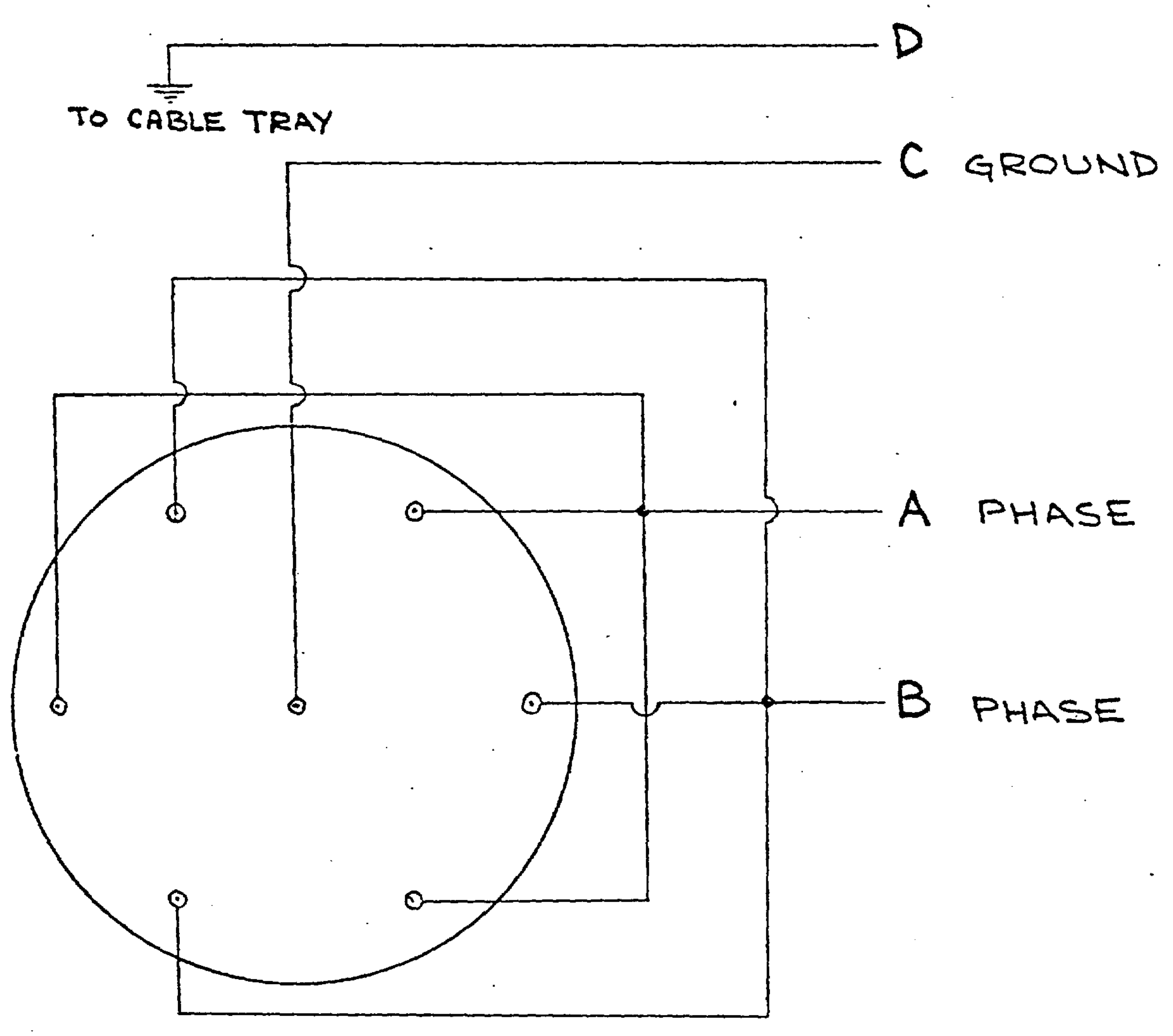


SIDE VIEW



END VIEW

NC 555
ILL. 6



TYPICAL 7 CONDUCTOR CABLE

CIRCUIT FAILURE WIRING

NC 555
ILL. 7

VERTICAL SERIES
CONSTRUCTION - CSA

Test No.	1	2	3	4	5	6	7
Calculated Heat Value (BTU's/Hr)	69,951	71,900	68,632	209,164	209,164	392,184	408,525
Circuit Failure (Time)							
Phase-To-Ground	-	-	-	-	-	-	-
Phase-To-Phase	7:25	8:31	8:23	5:20	5:17	4:01	4:17
Damage Height (Distance)							
Jacket	4'-2"	6'-8"	8'-3"	8'-0"	8'-9"	7'-6"	7'-7"
Conductor	3'-2"	5'-6"	7'-10"	7'-2"	7'-10"	6'-8"	7'-1"
Ignition Time	:09	:08	:08	:08	:07	:04	:06
Flame Height At Time (Minutes)							
0:30	-	-	3'-0"	4'-9"	4'-9"	5'-0"	5'-6"
1:00	3'-6"	3'-6"	3'-4"	4'-6"	5'-0"	5'-9"	6'-2"
2:00	4'-0"	3'-10"	3'-9"	5'-6"	6'-0"	6'-6"	6'-9"
3:00	3'-9"	3'-6"	-	-	-	7'-0"	-
4:00	3'-6"	3'-6"	3'-6"	5'-3"	6'-0"	8'-0"	7'-0"
5:00	-	-	-	6'-9"	-	-	-
6:00	3'-0"	4'-0"	3'-8"	7'-6"	7'-0"	8'-0"	8'-0"
8:00	3'-9"	5'-3"	5'-4"	7'-0"	7'-4"	7'-0"	7'-6"
10:00	4'-3"	5'-4"	6'-6"	7'-0"	7'-9"	6'-10"	7'-8"
12:00	4'-4"	6'-0"	8'-0"	7'-9"	10'-0"	6'-10"	7'-0"
13:00	-	6'-9"	10'-4"	-	-	Out	7'-0"
14:00	4'-0"	7'-0"	9'-0"	9'-0"	8'-6"	-	6'-8"
16:00	3'-10"	7'-0"	7'-4"	8'-0"	Out	-	5'-3"
18:00	3'-9"	7'-3"	Out	8'-0"	-	-	Out
Flame Out	19:00	20:00	20:00	21:19	20:00	20:00	20:00

File NC555

ILL. 8

Issued: 8-23-76

VERTICAL SERIES
CONSTRUCTION - EMD

Test No.	1	2	3	4	5	6
Calculated Heat Value (BTU's/Hr)	71,900	71,900	209,164	205,891	408,525	398,720
Circuit Failure (Time)						
Phase-To-Ground	13:28	-	-	-	-	-
Phase-To-Phase	13:53	13:55	8:45	8:54	8:07	7:43
Damage Height (Distance)						
Jacket	3'-6"	3'-4"	7'-9"	7'-1"	10'-4"	11'-6"
Conductor	3'-2"	3'-0"	6'-10"	6'-3"	8'-2"	9'-8"
Ignition Time	:13	:11	:16	:17	:12	:14
Flame Height At Time (Minutes)						
0:30	-	-	-	-	-	-
1:00	3'-0"	3'-0"	4'-6"	5'-0"	6'-6"	6'-0"
2:00	-	3'-3"	5'-6"	5'-6"	8'-3"	7'-6"
3:00	3'-6"	-	5'-9"	-	8'-0"	6'-9"
4:00	-	3'-6"	5'-9"	5'-0"	6'-9"	-
5:00	-	-	-	-	-	6'-6"
6:00	3'-6"	3'-6"	5'-9"	5'-3"	7'-0"	6'-6"
8:00	3'-6"	3'-6"	6'-0"	7'-0"	12'-0"	10'-0"
10:00	3'-6"	3'-3"	9'-6"	8'-3"	11'-6"	10'-6"
12:00	3'-6"	3'-3"	8'-4"	8'-6"	11'-0"	10'-6"
13:00	-	-	8'-6"	-	-	-
14:00	4'-0"	3'-6"	8'-9"	8'-3"	10'-9"	10'-6"
16:00	3'-9"	3'-9"	8'-10"	7'-9"	10'-6"	10'-9"
18:00	3'-6"	3'-6"	8'-4"	7'-6"	10'-6"	13'-0"
20:00	3'-8"	3'-9"		7'-6"	10'-0"	11'-6"
Flame Out	23:16	22:12	23:35	23:50	23:30	26:48

File NC555

ILL. 9

Issued: 8-23-76

VERTICAL SERIES
CONSTRUCTION - FVT

Test No.	1	2	3	4	5	6
Calculated Heat Value (BTU's/Hr)	70,593	68,632	210,472	202,628	395,452	401,989
Circuit Failure (Time)						
Phase-To-Ground	11:40	-	-	3:46	-	-
Phase-To-Phase	13:10	10:20	6:23	7:51	4:21	4:57
Damage Height (Distance)						
Jacket	3'-4"	3'-6"	6'-2"	6'-0"	8'-4"	7'-3"
Conductor	3'-0"	2'-11"	5'-0"	5'-2"	7'-6"	6'-7"
Ignition Time	:12	:13	:05	:06	:18	:17
Flame Height At Time (Minutes)						
0:30	-	-	5'-0"	-	6'-2"	7'-0"
1:00	3'-0"	3'-0"	5'-0"	5'-0"	6'-3"	7'-0"
2:00	3'-4"	3'-4"	5'-0"	5'-8"	6'-4"	6'-9"
3:00	-	-	-	5'-3"	5'-9"	7'-0"
4:00	3'-0"	3'-0"	5'-4"	4'-6"	6'-0"	6'-4"
5:00	-	3'-3"	-	-	-	6'-6"
6:00	3'-0"	3'-3"	5'-6"	5'-0"	6'-0"	7'-4"
8:00	3'-4"	3'-4"	6'-3"	6'-0"	7'-0"	8'-3"
10:00	3'-10"	3'-6"	8'-0"	7'-0"	8'-0"	9'-0"
12:00	4'-0"	3'-9"	6'-4"	7'-0"	10'-0"	9'-4"
13:00	-	3'-9"	Out	Out	-	-
14:00	4'-0"	4'-0"			9'-0"	Out
16:00	4'-0"	4'-0"			Out	
18:00	4'-3"	3'-6"				
Flame Out	20:02	20:00	20:00	20:00	20:00	20:00

File NC555

ILL. 10

Issued: 8-23-76

VERTICAL SERIES
CONSTRUCTION - KPB

Test No.	1	2	3	4	5	6
Calculated Heat Value (BTU's/Hr)	68,632	71,900	205,897	209,165	399,447	392,184
Circuit Failure (Time)						
Phase-To-Ground	3:58	-	-	-	-	-
Phase-To-Phase	4:21	4:53	2:53	3:38	2:08	2:15
Damage Height (Distance)						
Jacket	15'-0"	16'-0"	16'-0"	16'-0"	16'-0"	16'-0"
Conductor	13'-10"	16'-0"	16'-0"	16'-0"	16'-0"	16'-0"
Ignition Time	:04	:09	:07	:08	:04	:04
Flame Height At Time (Minutes)						
0:30	-	-	5'-9"	5'-8"	8'-0"	7'-6"
1:00	4'-0"	4'-0"	7'-0"	-	9'-0"	8'-6"
2:00	4'-3"	4'-6"	7'-6"	-	7'-6"	7'-9"
3:00	4'-6"	-	-	8'-0"	9'-0"	10'-6"
4:00	-	5'-0"	9'-0"	11'-0"	13'-6"	13'-6"
5:00	5'-6"	6'-6"	11'-6"	12'-6"	14'-6"	15'-6"
6:00	7'-0"	7'-6"	13'-9"	14'-0"	16'-0"	16'-0"
8:00	7'-6"	9'-6"	13'-6"	14'-0"	-	-
10:00	7'-6"	11'-0"	16'-0"	-	-	-
12:00	11'-3"	12'-0"	16'-0"	-	-	-
14:00	13'-0"	11'-9"	-	-	-	-
15:00	10'-0"	-	-	-	-	-
16:00	11'-0"	12'-6"	-	-	-	-
18:00	14'-6"	16'-0"	-	-	-	-
Flame Out	49:10	-	22:10	24:50	20:00	20:24

File NC555

ILL. 11

Issued: 8-23-76

File NC555

ILL. 12

Issued: 8-23-76

VERTICAL SERIES
CONSTRUCTION - LUH

Test No.	1	2	3	4	5	6
Calculated Heat Value (BTU's/Hr)	68,632	71,900	202,628	209,165	395,452	398,720
Circuit Failure (Time)						
Phase-To-Ground	3:20	-	-	-	-	1:10
Phase-To-Phase	3:30	3:15	2:50	2:43	2:05	1:35
Damage Height (Distance)						
Jacket	16'-0"	8'-10"	16'-0"	16'-0"	16'-0"	16'-0"
Conductor	16'-0"	7'-9"	16'-0"	16'-0"	16'-0"	16'-0"
Ignition Time	:08	:07	:07	:06	:06	-
Flame Height At Time (Minutes)						
0:30	-	-	-	5'-6"	-	7'-0"
1:00	3'-3"	3'-3"	5'-6"	6'-0"	5'-9"	7'-6"
2:00	4'-0"	3'-9"	6'-4"	7'-4"	8'-0"	8'-9"
3:00	4'-3"	4'-0"	6'-9"	7'-10"	8'-9"	9'-6"
4:00	4'-9"	4'-6"	8'-9"	9'-3"	10'-0"	10'-4"
5:00	5'-6"	5'-0"	9'-2"	10'-0"	11'-6"	11'-3"
6:00	6'-10"	5'-4"	11'-4"	10'-10"	13'-3"	12'-4"
8:00	8'-3"	5'-0"	13'-0"	11'-9"	15'-3"	14'-3"
10:00	-	-	13'-6"	12'-3"	16'-0"	-
11:00	9'-6"	5'-9"	15'-0"	14'-0"	-	16'-0"
12:00	12'-0"	7'-0"	16'-0"	15'-4"	-	-
14:00	13'-4"	7'-3"	-	16'-0"	-	-
16:00	15'-6"	7'-9"	-	-	-	-
18:00	16'-0"	8'-4"	-	-	-	-
Flame Out	30:52	34:21	21:40	31:10	20:10	34:60

VERTICAL SERIES
CONSTRUCTION - OWR

Test No.	1	2	3	4	5	6
Calculated Heat Value (BTU's/Hr)	65,364	71,900	209,165	212,433	392,184	395,452
Circuit Failure (Time)						
Phase-To-Ground	-	-	-	-	1:50	3:30
Phase-To-Phase	7:22	7:14	6:12	5:01	3:20	3:36
Damage Height (Distance)						
Jacket	2'-11"	3'-3"	5'-4"	5'-11"	7'-0"	7'-1"
Conductor	2'-5"	2'-7"	4'-2"	5'-0"	6'-1"	6'-0"
Ignition Time	:13	:12	:12	:14	:17	:11
Flame Height At Time (Minutes)						
0:30	-	-	-	-	7'-0"	7'-0"
1:00	3'-3"	3'-6"	5'-9"	6'-0"	8'-0"	7'-6"
2:00	3'-4"	3'-6"	6'-0"	6'-0"	6'-4"	6'-3"
3:00	3'-1"	3'-6"	5'-6"	5'-9"	6'-6"	6'-0"
4:00	3'-2"	3'-4"	5'-6"	5'-10"	7'-6"	7'-0"
5:00	-	3'-3"	5'-4"	5'-10"	8'-4"	8'-0"
6:00	3'-0"	3'-3"	6'-0"	6'-6"	8'-0"	9'-0"
8:00	3'-3"	3'-9"	6'-6"	7'-0"	7'-6"	7'-3"
10:00	3'-3"	4'-0"	5'-0"	6'-6"	7'-4"	6'-3"
11:00	-	-	Out	5'-3"	6'-6"	6'-2"
12:00	-	3'-9"	-	Out	Out	6'-2"
14:00	3'-0"	3'-6"	-	-	-	Out
16:00	3'-0"	3'-3"	-	-	-	-
18:00	3'-0"	3'-0"	-	-	-	-
Flame Out	20:00	20:00	20:00	20:00	20:00	20:00

File NC555

ILL. 13

Issued: 8-23-76

VERTICAL SERIES
CONSTRUCTION - XGY

Test No.	1	2	3	4	5	6
Calculated Heat Value (BTU's/Hr)	67,325	68,632	202,628	205,897	424,866	385,648
Circuit Failure (Time)						
Phase-To-Ground	-	-	-	-	-	-
Phase-To-Phase	-	-	-	-	-	-
Damage Height (Distance)						
Jacket	4'-3"	4'-6"	6'-11"	5'-11"	7'-1"	7'-10"
Conductor	4'-3"	4'-6"	6'-11"	5'-11"	7'-1"	7'-10"
Ignition Time	3:55	3:38	3:35	2:57	:50	:45
Flame Height At Time (Minutes)						
0:30	3'-1"	-	-	-	-	-
1:00	3'-0"	3'-2"	5'-0"	5'-0"	6'-3"	6'-0"
2:00	3'-0"	3'-3"	5'-0"	5'-0"	6'-6"	6'-4"
3:00	-	-	5'-0"	-	7'-4"	7'-0"
4:00	3'-6"	3'-6"	-	5'-0"	7'-0"	7'-6"
5:00	-	3'-9"	5'-6"	5'-3"	7'-6"	7'-9"
6:00	3'-6"	4'-0"	6'-0"	5'-6"	7'-4"	7'-4"
8:00	4'-3"	5'-0"	7'-0"	6'-0"	7'-0"	7'-9"
10:00	4'-6"	5'-0"	7'-0"	6'-3"	7'-0"	8'-0"
12:00	5'-0"	-	7'-0"	6'-4"	-	7'-9"
14:00	5'-3"	5'-0"	7'-0"	6'-3"	7'-4"	8'-0"
16:00	5'-3"	4'-9"	7'-0"	6'-3"	7'-4"	8'-0"
18:00	5'-0"	4'-9"	7'-0"	6'-3"	7'-3"	8'-0"
Flame Out	26:33	24:42	24:00	24:30	21:38	25:30

VERTICAL SERIES
CONSTRUCTION - ZQJ

Test No.	1	2	3	4	5	6
Calculated Heat Value (BTU's/Hr)	70,593	71,900	211,126	209,818	408,525	392,184
Circuit Failure (Time)						
Phase-To-Ground	-	7:12	-	-	2:43	3:35
Phase-To-Phase	8:23	7:25	5:41	5:37	3:00	3:41
Damage Height (Distance)						
Jacket	3'-1"	3'-6"	5'-4"	5'-3"	6'-3"	5'-11"
Conductor	3'-0"	3'-8"	5'-2"	5'-1"	5'-11"	5'-6"
Ignition Time	:09	:07	:11	:09	:07	:12
Flame Height At Time (Minutes)						
0:30	-	-	-	5'-0"	6'-0"	5'-9"
1:00	-	3'-3"	5'-0"	5'-4"	6'-6"	6'-0"
2:00	3'-0"	3'-0"	4'-6"	4'-0"	5'-6"	5'-2"
3:00	-	-	4'-4"	-	5'-6"	5'-9"
4:00	3'-0"	3'-0"	4'-0"	4'-0"	-	6'-4"
5:00	-	-	-	-	6'-3"	6'-6"
6:00	3'-0"	3'-0"	4'-0"	4'-6"	7'-6"	7'-0"
8:00	3'-0"	3'-2"	6'-3"	6'-9"	7'-3"	6'-10"
10:00	3'-1"	3'-9"	5'-9"	6'-0"	7'-9"	7'-0"
12:00	3'-4"	4'-0"	5'-0"	5'-9"	7'-0"	6'-6"
14:00	3'-6"	4'-2"	Out	Out	6'-0"	5'-6"
16:00	3'-9"	4'-0"	-	-	Out	Out
18:00	4'-0"	3'-10"	-	-	-	-
Flame Out	20:57	20:08	20:00	20:00	20:00	22:47

HORIZONTAL SERIES
CONSTRUCTION - CSA

Test No.	1	2	3	4	5	6
Calculated Heat Value Btu's/Hr	67,325	66,671	205,897	209,165	392,184	392,184
Circuit Failure (Time)						
Phase-To-Ground (Upper)	-	-	10:05	-	-	7:30
Phase-To-Phase (Upper)	-	-	10:45	11:50	8:55	8:30
Phase-To-Ground (Upper Center)	-	-	-	-	-	-
Phase-To-Phase (Upper Center)	15:30	15:10	7:20	7:45	5:35	5:20
Phase-To-Ground (Lower Center)	-	-	-	-	-	-
Phase-To Phase (Lower Center)	15:15	12:00	7:15	7:30	4:55	4:20
Phase-To-Ground (Lower)	-	-	-	-	-	-
Phase-To-Ground (Lower)	-	-	-	-	-	-
Jacket Damage Length						
Upper	11"	1'-3"	3'-11"	4'-0"	5'-9"	5'-7"
Upper Center	1'-2"	1'-3"	2'-6"	2'-4"	3'-4"	3'-11"
Lower Center	1'-1"	1'-1"	2'-3"	2'-4"	3'-0"	2'-11"
Lower	-	-	1'-5"	2'-4"	2'-3"	2'-0"
Total Damage	3'-2"	3'-7"	10'-1"	11'-0"	14'-4"	14'-5"
Flame Out						
Upper	20:00	20:00	27:52	27:25	20:00	22:55
Upper Center	20:54	24:50	20:00	20:00	27:47	23:30
Lower Center	24:50	23:45	20:00	24:10	30:38	23:20
Lower	20:00	20:00	20:00	20:00	26:25	23:25

File NC555 ILL. 16 Issued: 8-23-76

HORIZONTAL SERIES
CONSTRUCTION - EMD

Test No.	1	2	3	4	5	6	Special (25 Min)
Calculated Heat Value Btu's/Hr	69,939	73,861	207,204	212,433	395,452	398,720	402,642
Circuit Failure (Time)							
Phase-To-Ground (Upper)	-	-	-	16:05	9:30	-	-
Phase-To-Phase (Upper)	-	-	15:05	17:55	10:40	10:00	10:45
Phase-To-Ground (Upper Center)	-	-	-	-	-	-	-
Phase-To-Phase (Upper Center)	-	-	9:50	9:15	7:20	7:05	7:20
Phase-To-Ground (Lower Center)	-	-	-	-	-	-	-
Phase-To-Phase (Lower Center)	13:25	16:35	7:00	6:50	7:05	5:50	7:15
Phase-To-Ground (Lower)	-	-	-	-	19:55	-	20:20
Phase-To-Phase (Lower)	-	-	-	-	-	-	20:55
Jacket Damage Length							
Upper	-	-	4'-1"	3'-10"	5'-0"	5'-11"	8'-7"
Upper Center	7"	11"	3'-2"	3'-0"	4'-7"	4'-7"	5'-3"
Lower Center	10"	1'-5"	3'-1"	2'-11"	4'-0"	4'-0"	4'-4"
Lower	-	-	2'-9"	2'-5"	3'-2"	3'-6"	3'-6"
Total Damage	1'-5"	2'-4"	13'-1"	12'-2"	16'-9"	18'-0"	21'-8"
Flame Out							
Upper	20:00	20:00	30:40	34:00	33:05	30:50	25:15
Upper Center	20:00	20:00	29:45	35:35	25:10	28:35	32:15
Lower Center	25:10	27:25	26:50	26:25	24:45	25:45	30:20
Lower	20:00	20:00	20:00	20:00	24:55	26:20	32:45

File NC555

ILL. 17

Issued: 8-23-76

HORIZONTAL SERIES
CONSTRUCTION - FVT

Test No.	1	2	3	4	5	6
Calculated Heat Value Btu's/Hr	68,632	68,632	209,165	212,433	401,989	405,257
Circuit Failure (Time)						
Phase-To-Ground (Upper)	-	-	10:50	-	8:50	6:30
Phase-To-Phase (Upper)	-	-	-	9:35	8:55	6:30
Phase-To-Ground (Upper Center)	-	-	-	-	-	-
Phase-To-Phase (Upper Center)	-	16:40	8:35	6:45	6:40	5:55
Phase-To-Ground (Lower Center)	-	-	-	-	-	-
Phase-To-Phase (Lower Center)	9:15	12:17	8:10	7:30	5:05	5:00
Phase-To-Ground (Lower)	-	-	-	-	-	-
Phase-To-Phase (Lower)	-	-	-	-	6:35	-
Jacket Damage Length						
Upper	-	-	3'-6"	3'-8"	5'-4"	5'-10"
Upper Center	8"	11"	2'-5"	2'-0"	3'-7"	3'-4"
Lower Center	8"	10"	2'-3"	1'-9"	2'-7"	3'-1"
Lower	-	-	1'-4"	1'-4"	2'-1"	2'-5"
Total Damage	1'-4"	1'-9"	9'-6"	8'-9"	13'-7"	14'-8"
Flame Out						
Upper	20:00	20:00	20:00	20:00	20:00	25:15
Upper Center	20:00	20:00	20:00	20:00	20:00	20:00
Lower Center	20:00	20:00	20:00	20:00	20:00	20:00
Lower	20:00	20:00	20:00	20:00	20:00	20:00

File NC555

Ill. 19

Issued: 8-23-76

HORIZONTAL SERIES
CONSTRUCTION -- KPB

Type No.	1	2	3	4	5	6
Calculated Heat Value Btu's/Hr	68,632	73,208	212,433	209,165	396,759	398,720
Circuit Failure (Time)						
Phase-To-Ground (Upper)	-	-	-	-	-	-
Phase-To-Phase (Upper)	-	-	4:15	3:25	3:05	2:55
Phase-To-Ground (Upper Center)	-	-	2:25	1:55	-	-
Phase-To-Phase (Upper Center)	13:41	14:20	2:50	2:10	2:45	2:25
Phase-To-Ground (Lower Center)	-	-	-	-	-	-
Phase-To-Phase (Lower Center)	9:07	5:17	2:20	1:48	1:45	1:40
Phase-To-Ground (Lower)	-	-	-	-	-	-
Phase-To-Phase (Lower	-	-	-	-	6:12	3:40
Jacket Damage Length						
Upper	1'-7"	1'-2"	5'-9"	6'-2"	8'-11"	7'-8"
Upper Center	1'-9"	1'-4"	5'-6"	5'-0"	8'-0"	6'-9"
Lower Center	1'-8"	1'-6"	4'-0"	4'-1"	4'-10"	4'-10"
Lower	-	-	2'-3"	2'-5"	3'-8"	3'-6"
Total Damage	5'-0"	4'-0"	17'-6"	17'-8"	25'-5"	22'-9"
Flame Out						
Upper	20:00	20:00	-	27:45	37:40	31:00
Upper Center	27:40	26:15	-	27:25	31:00	30:20
Lower Center	25:45	27:20	-	27:00	32:10	27:16
Lower	20:00	20:00	-	20:00	25:20	24:30

HORIZONTAL SERIES
CONSTRUCTION - LUH

Test No.	1	2	3	4	5	6
Calculated Heat Value Btu's/Hr	71,900	65,364	207,204	205,897	392,184	398,724
Circuit Failure (Time)						
Phase-To-Ground (Upper)	10:05	9:40	-	-	2:40	2:45
Phase-To-Phase (Upper)	11:10	9:45	3:20	4:30	2:50	3:00
Phase-To-Ground (Upper Center)	-	5:40	-	-	-	-
Phase-To-Phase (Upper Center)	6:30	5:55	2:45	2:40	2:05	2:15
Phase-To-Ground (Lower Center)	-	3:15	1:45	2:35	-	-
Phase-To-Phase (Lower Center)	3:05	4:20	1:50	2:55	2:00	2:05
Phase-To-Ground (Lower)	-	-	-	-	-	8:20
Phase-To-Phase (Lower	-	-	-	-	10:05	9:30
Jacket Damage Length						
Upper	1'-1"	1'-6"	3'-11"	4'-5"	5'-11"	6'-1"
Upper Center	1'-6"	1'-6"	3'-3"	3'-10"	4'-4"	4'-6"
Lower Center	1'-4"	1'-9"	2'-11"	2'-11"	3'-1"	4'-0"
Lower	-	-	1'-4"	1'-9"	2'-7"	2'-10"
Total Damage	3'-11"	4'-9"	11'-5"	12'-11"	15'-11"	17'-5"
Flame Out						
Upper	20:00	20:00	20:00	23:35	25:15	23:40
Upper Center	20:00	20:00	21:40	25:35	20:00	21:25
Lower Center	20:00	20:00	23:05	25:30	20:00	24:55
Lower	20:00	20:00	20:00	24:15	25:05	24:00

File NC555

Ill. 20

Issued: 8-23-76

HORIZONTAL SERIES
CONSTRUCTION - OWR

Test No.	1	2	3	4	5	6
Calculated Heat Value Btu's/Hr	65,364	68,632	218,969	215,701	408,525	405,257
Circuit Failure (Time)						
Phase-To-Ground (Upper)	-	-	-	-	3:55	-
Phase-To-Phase (Upper)	-	-	6:35	7:10	4:35	5:05
Phase-To-Ground (Upper Center)	-	-	-	-	-	-
Phase-To-Phase (Upper Center)	-	-	4:15	5:20	3:20	3:25
Phase-To-Ground (Lower Center)	-	-	4:20	-	-	3:20
Phase-To-Phase (Lower Center)	7:15	9:45	4:35	4:45	3:10	3:30
Phase-To-Ground (Lower)	-	-	-	-	-	-
Phase-To-Phase (Lower)	-	-	-	-	-	-
Jacket Damage Length						
Upper	-	-	2'-0"	2'-4"	3'-11"	3'-10"
Upper Center	11"	10"	1'-10"	2'-0"	2'-10"	2'-11"
Lower Center	10"	11"	1'-8"	1'-8"	2'-10"	2'-4"
Lower	-	-	-	-	1'-11"	1'-9"
Total Damage	1'-9"	1'-9"	5'-6"	6'-0"	11'-6"	10'-10"
Flame Out						
Upper	20:00	20:00	20:00	20:00	20:00	20:00
Upper Center	20:00	20:00	20:00	20:00	20:00	20:00
Lower Center	20:00	20:00	20:00	20:00	20:00	20:00
Lower	20:00	20:00	20:00	20:00	20:00	20:00

File NC555

ILL. 21

Issued: 8-23-76

HORIZONTAL SERIES
CONSTRUCTION - XGY

Test No.	1	2	3	4	5	6
Calculated Heat Value Btu's/Hr	69,939	70,593	205,897	209,165	402,240	401,989
Circuit Failure (Time)						
Phase-To-Ground (Upper)	-	-	-	-	-	-
Phase-To-Phase (Upper)	-	-	-	-	-	-
Phase-To-Ground (Upper Center)	-	-	-	-	-	-
Phase-To-Phase (Upper Center)	-	-	-	-	-	-
Phase-To-Ground (Lower Center)	-	-	-	-	-	-
Phase-To-Phase (Lower Center)	-	-	-	-	-	-
Phase-To-Ground (Lower)	-	-	-	-	-	-
Phase-To-Phase (Lower)	-	-	-	-	-	-
Jacket Damage Length						
Upper	-	1"	2'-3"	1'-6"	3'-11"	4'-8"
Upper Center	11"	10"	1'-8"	1'-4"	2'-5"	2'-10"
Lower Center	11"	11"	1'-8"	1'-5"	2'-6"	2'-7"
Lower	-	-	-	-	-	-
Total Damage	1'-10"	1'-10"	5'-7"	4'-3"	8'-10"	10'-1"
Flame Out						
Upper	20:00	20:00	20:00	20:00	13:00	20:00
Upper Center	20:00	20:00	20:00	20:00	13:00	20:00
Lower Center	20:00	20:00	20:00	20:00	13:00	20:00
Lower	20:00	20:00	20:00	20:00	13:00	20:00

File NC555

ILL. 22

Issued: 8-23-76

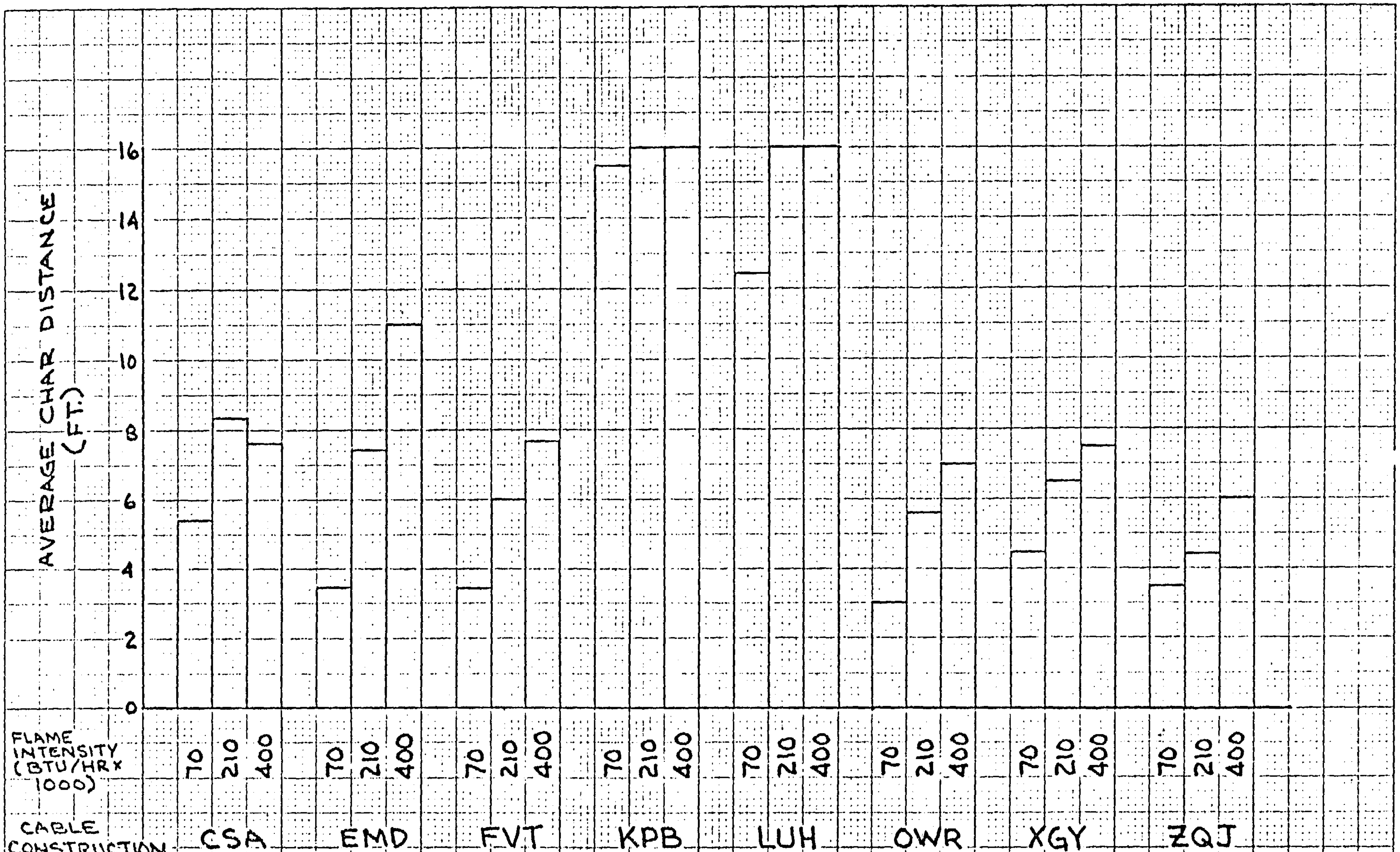
HORIZONTAL SERIES
CONSTRUCTION - ZQJ

Test No.	1	2	3	4	5	6
Calculated Heat Value Btu's/Hr	68,632	71,900	212,433	215,701	401,989	400,028
Circuit Failure (Time)						
Phase-To-Ground (Upper)	-	-	-	-	-	-
Phase-To-Phase (Upper)	-	-	9:10	8:05	8:05	7:55
Phase-To-Ground (Upper Center)	-	-	-	-	-	-
Phase-To-Phase (Upper Center)	-	-	4:55	6:25	4:20	5:17
Phase-To-Ground (Lower Center)	-	15:23	-	-	-	-
Phase-To-Phase (Lower Center)	10:40	16:15	5:50	6:10	4:25	4:50
Phase-To-Ground (Lower)	-	-	-	-	-	-
Phase-To-Phase (Lower)	-	-	-	-	17:50	-
Jacket Damage Length						
Upper	-	-	2'-10"	3'-4"	4'-10"	4'-2"
Upper Center	1'-0"	11"	2'-9"	3'-3"	4'-1"	3'-7"
Lower Center	1'-3"	1'-5"	2'-5"	2'-7"	3'-6"	3'-6"
Lower	-	-	2'-10"	1'-7"	2'-8"	2'-8"
Total Damage	2'-3"	2'-4"	10-10"	10'-9"	15'-1"	13'-11"
Flame Out						
Upper	20:00	20:00	20:00	20:00	23:20	-
Upper Center	20:00	20:00	20:00	20:00	21:30	-
Lower Center	22:30	22:50	20:00	20:00	20:30	-
Lower	20:00	20:00	20:00	20:00	20:00	-

File NC555

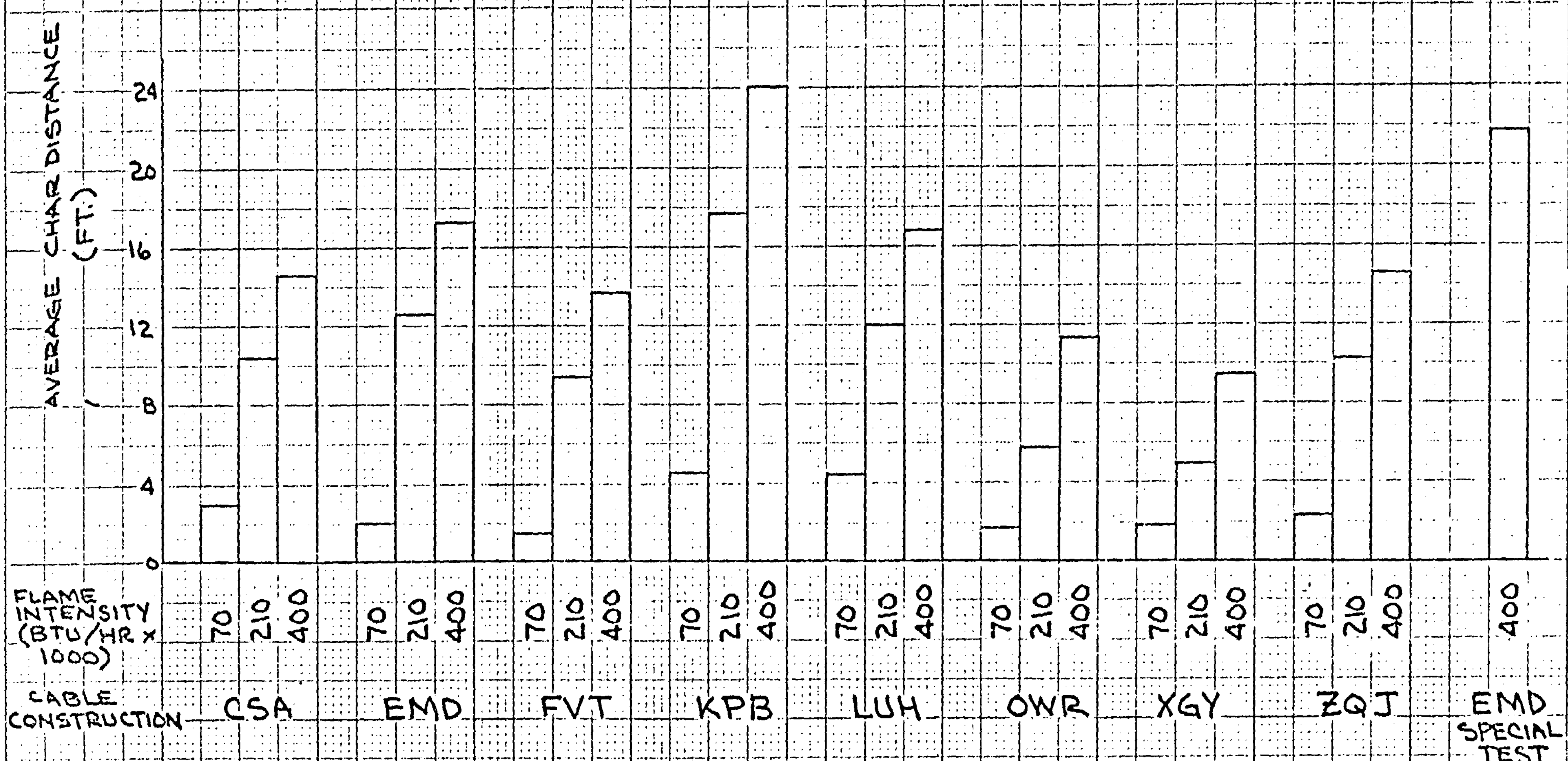
ILL. 23

Issued: 8-23-76



VERTICAL SERIES - AVERAGE CHAR DISTANCE

NC555 ILL. 24



HORIZONTAL SERIES - AVERAGE CHAR DISTANCE

NC 555 ILL. 25

File NC555

RANK ORDER - JACKET DAMAGE
(BEST TO WORST)

Vertical Series

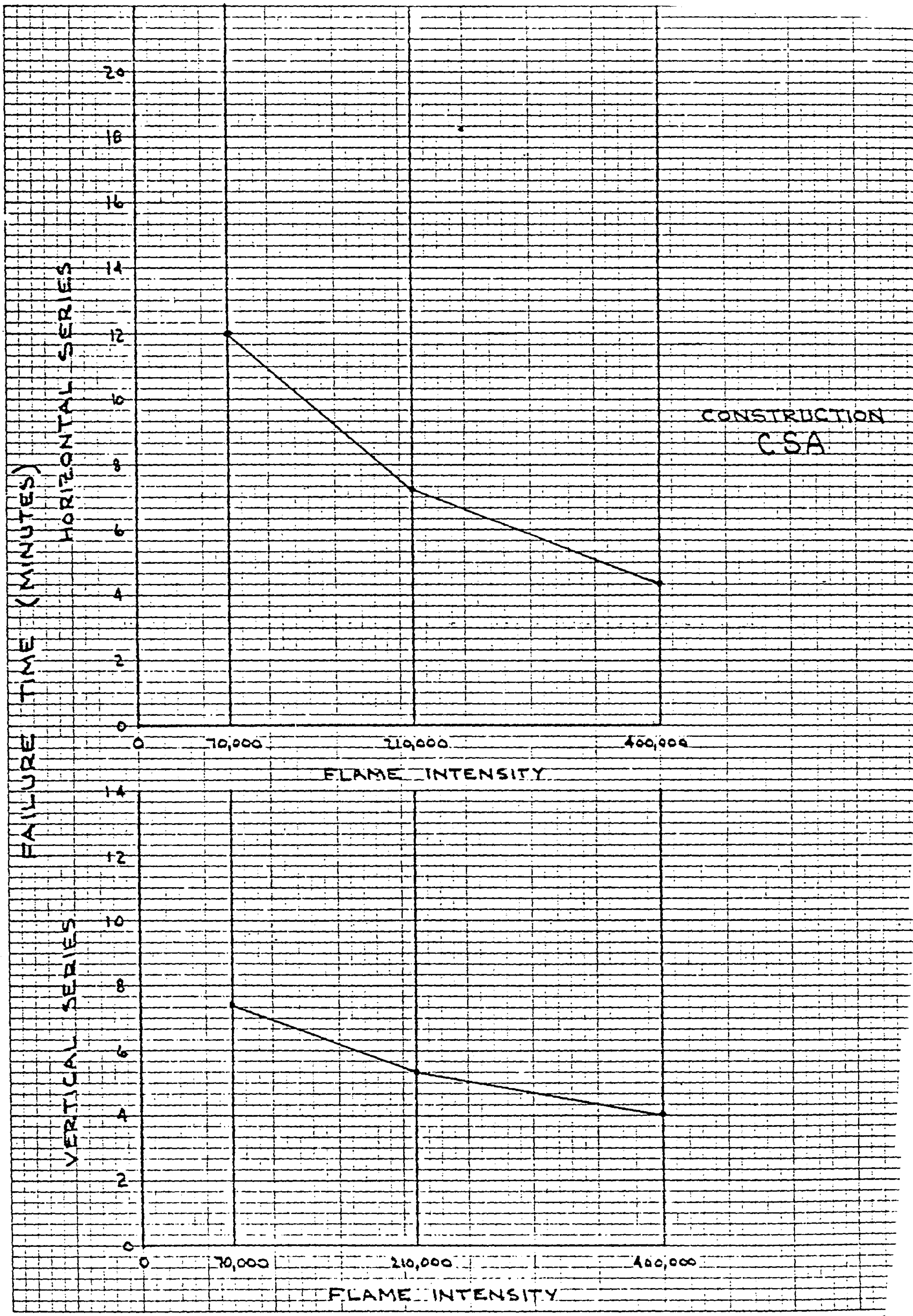
70,000 BTU/hr	210,000 BTU/hr	400,000 BTU/hr
OWR	ZQJ	ZQJ
ZQJ	OWR	OWR
FVT	FVT	XGY
EMD	XGY	CSA
XGY	EMD	FVT
CSA	CSA	EMD
LUH	LUH	LUH
KPB	KPB	KPB

Horizontal Series

70,000 BTU/hr	210,000 BTU/hr	400,000 BTU/hr
FVT	XGY	XGY
OWR	OWR	OWR
XGY	FVT	CSA
EMD	CSA	FVT
ZQJ	ZQJ	ZQJ
CSA	LUH	LUH
LUH	EMD	EMD
KPB	KPB	KPB

ILL. 26

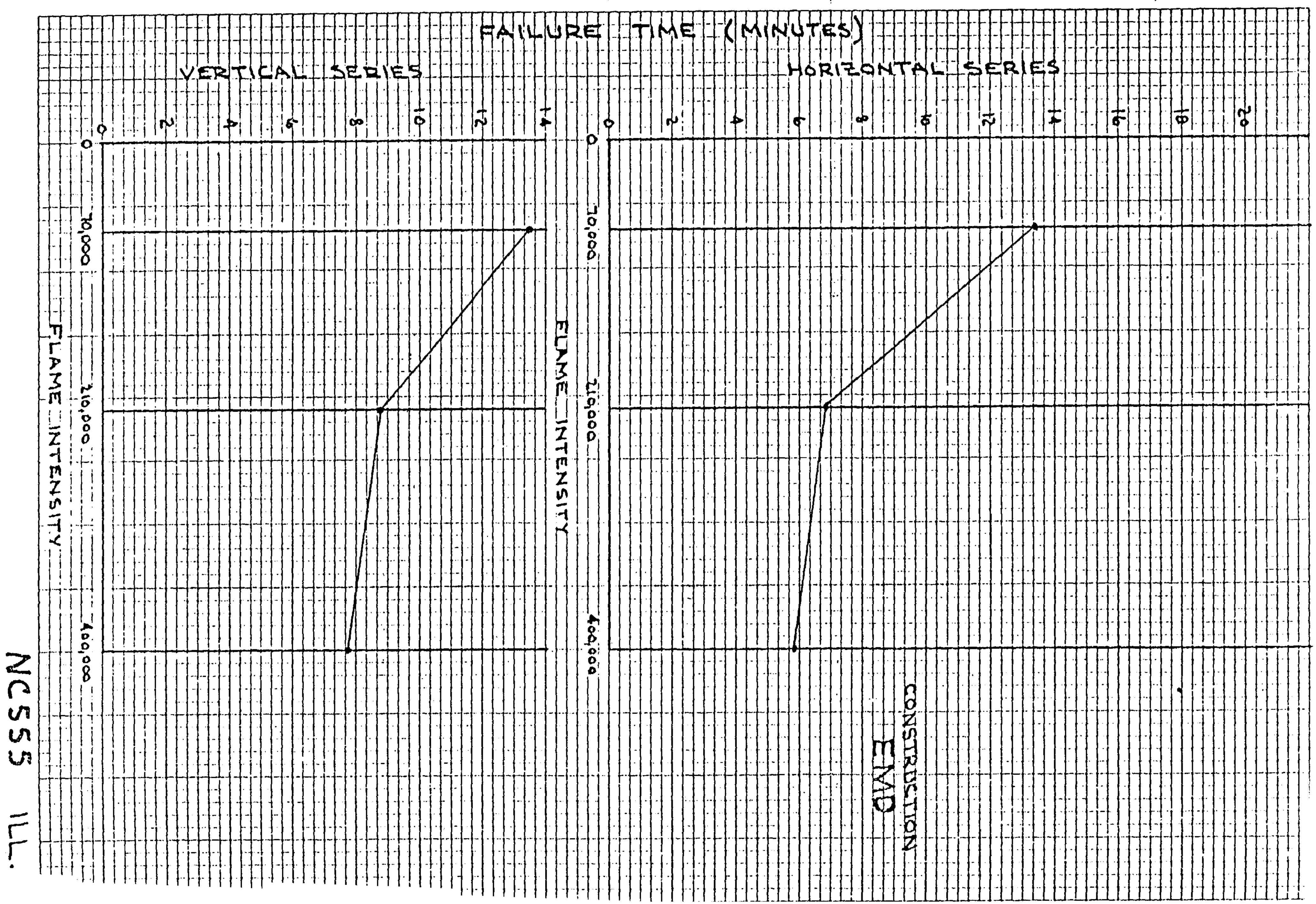
Issued: 8-23-76

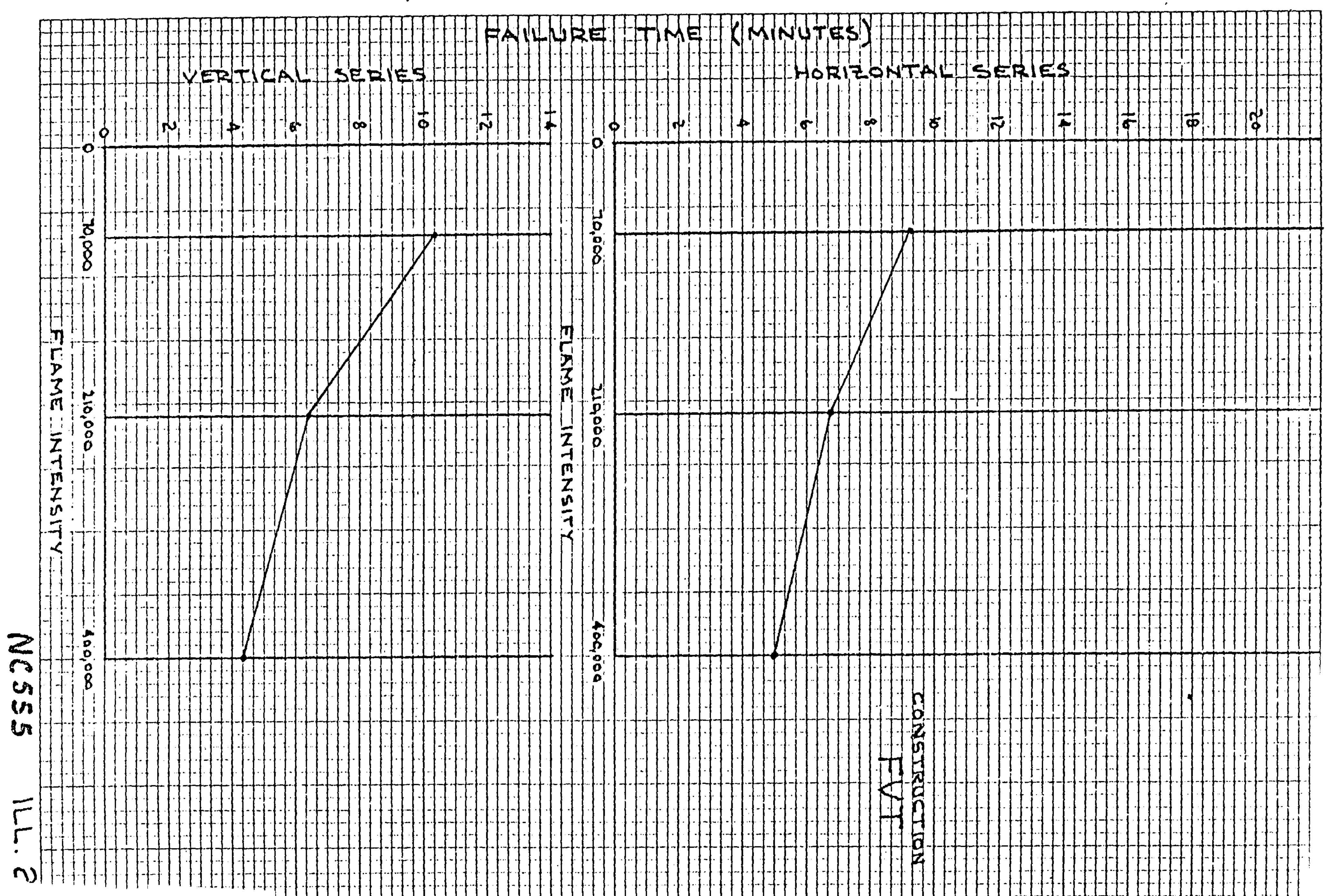


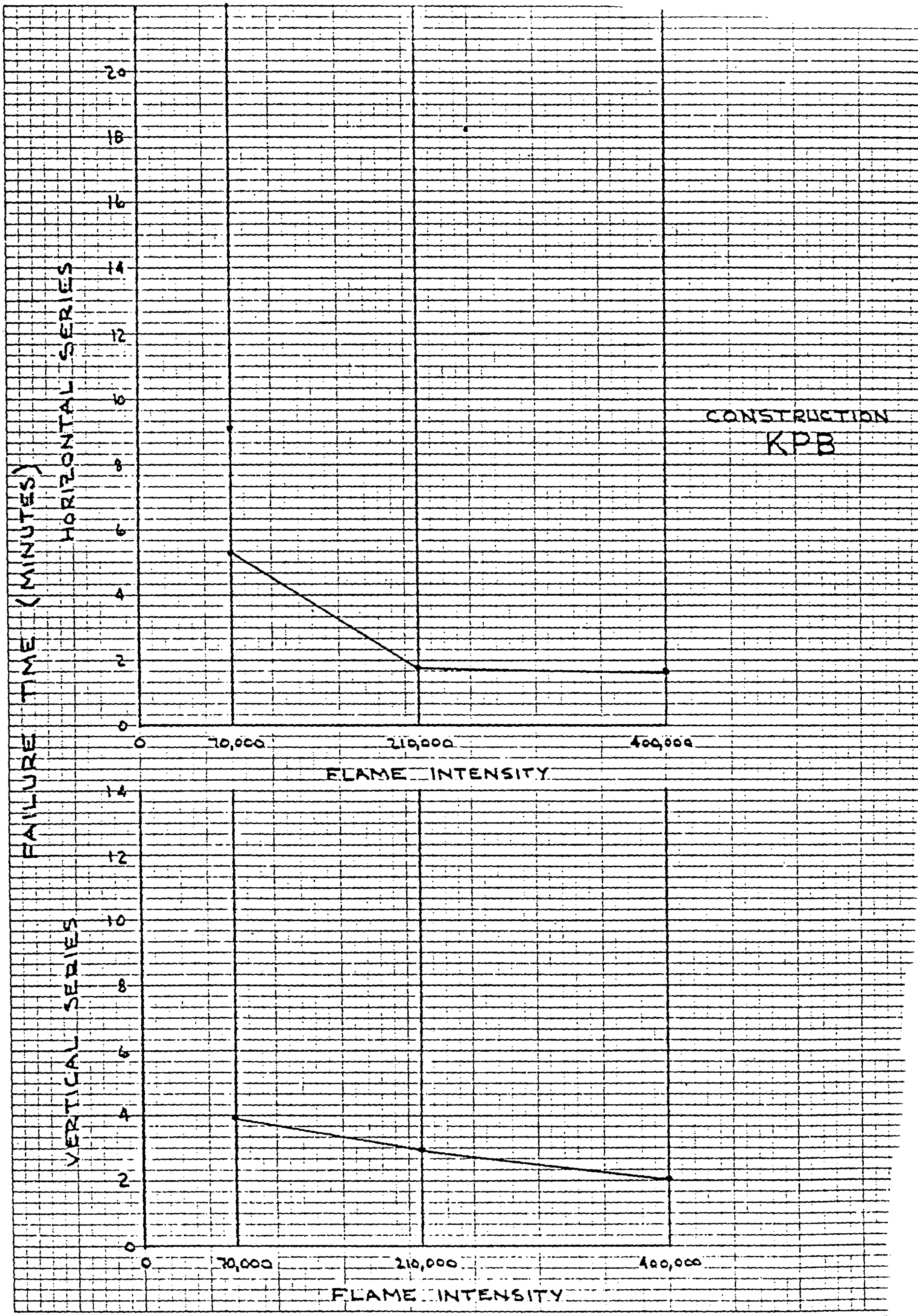
NC555 ILL.

46 1930

K·E 10 TO THE INCH · 7 X 10 INCHES
KE & ESSER CO. MADE IN U.S.A.

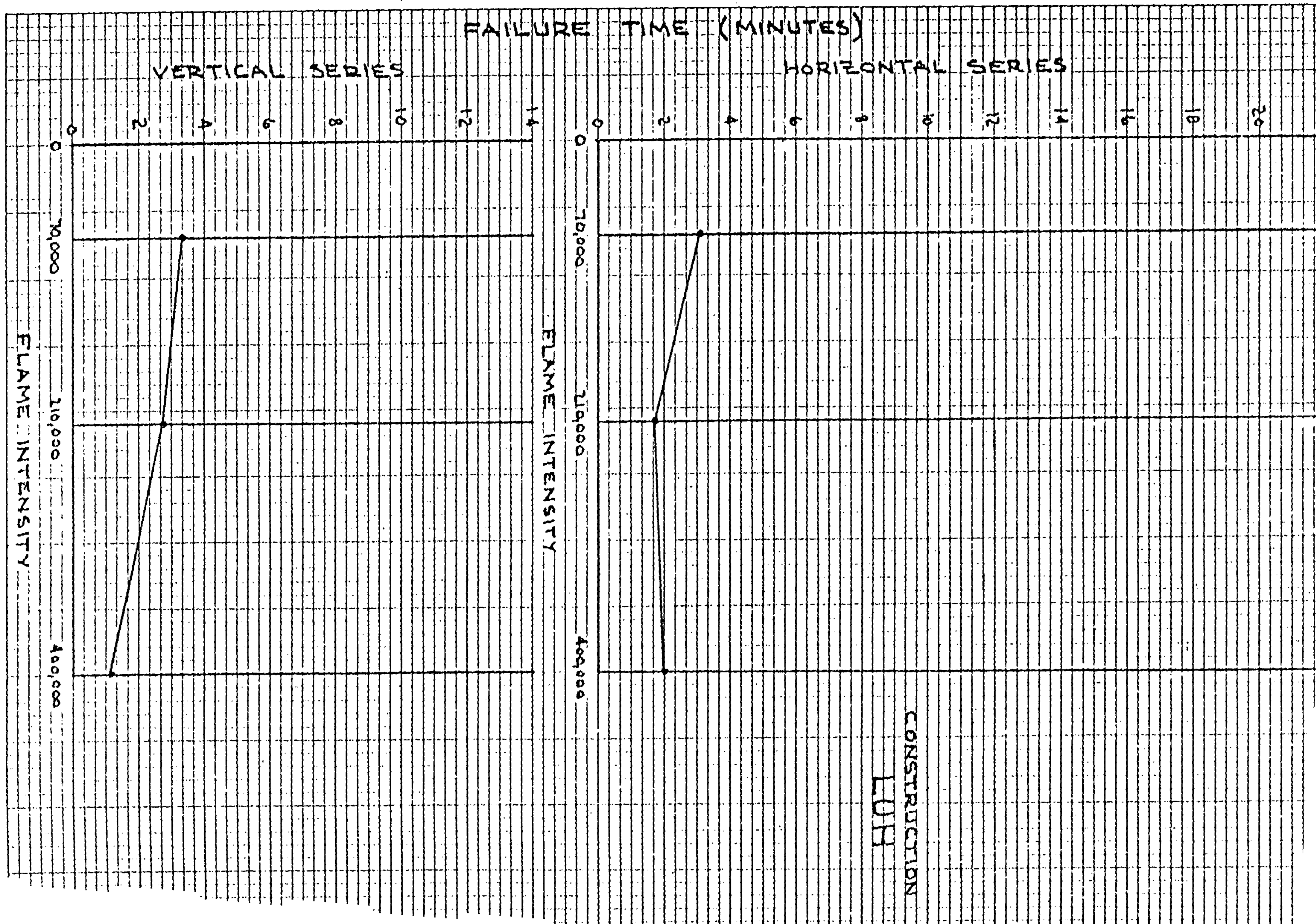

FAILURE TIME (MINUTES)
VERTICAL SERIES
HORIZONTAL SERIES
0
2
4
6
8
10
12
14
16
18
20
0
70,000
210,000
400,000
FLAME INTENSITY
CONSTRUCTION
EMD
NC555 ILL.


FAILURE TIME (MINUTES)
VERTICAL SERIES
HORIZONTAL SERIES
0
2
4
6
8
10
12
14
16
18
20
FLAME INTENSITY
0
70,000
210,000
400,000
CONSTRUCTION
FVT
NC555 ILL. 2

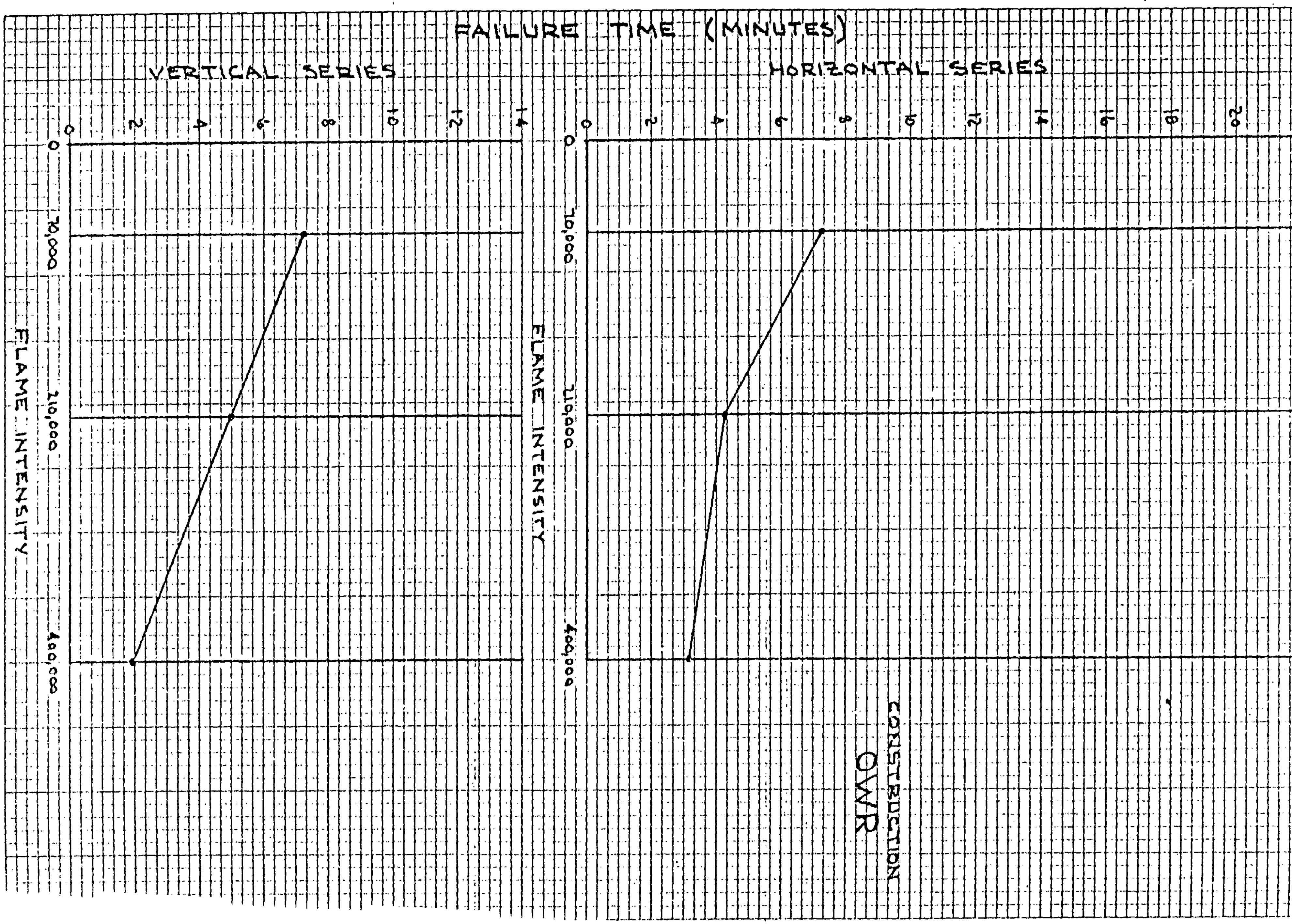


NC555 ILL. 2

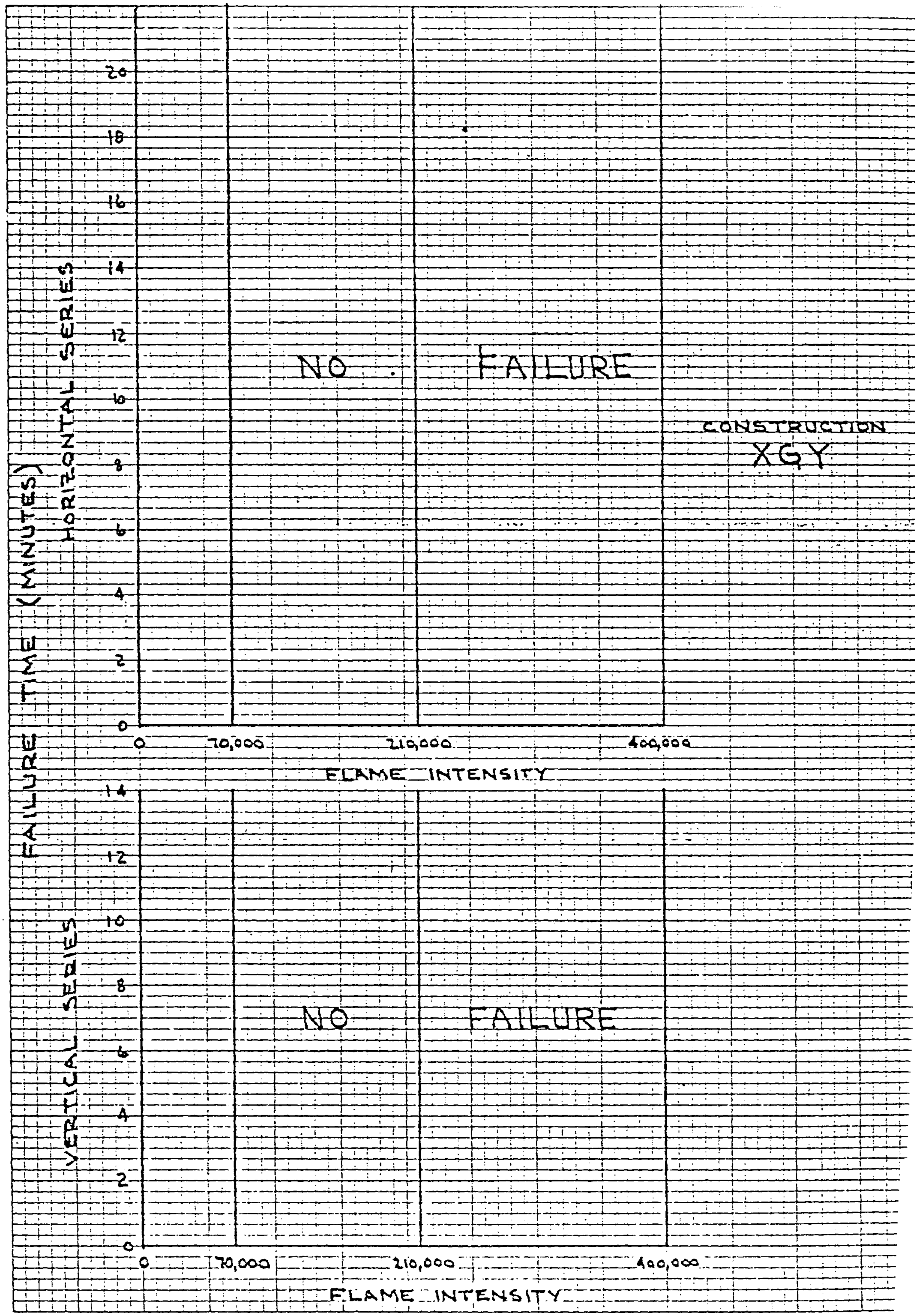
K•E 10 X 10 TO THE INCH • 7 X 10 INCHES
KEUFFEL & ESSER CO. MADE IN U.S.A.
46 1930


FAILURE TIME (MINUTES)
VERTICAL SERIES
HORIZONTAL SERIES
0 2 4 6 8 10 12 14
0 2 4 6 8 10 12 14 16 18 20
FLAME INTENSITY
0
70,000
210,000
400,000
CONSTRUCTION
LOH

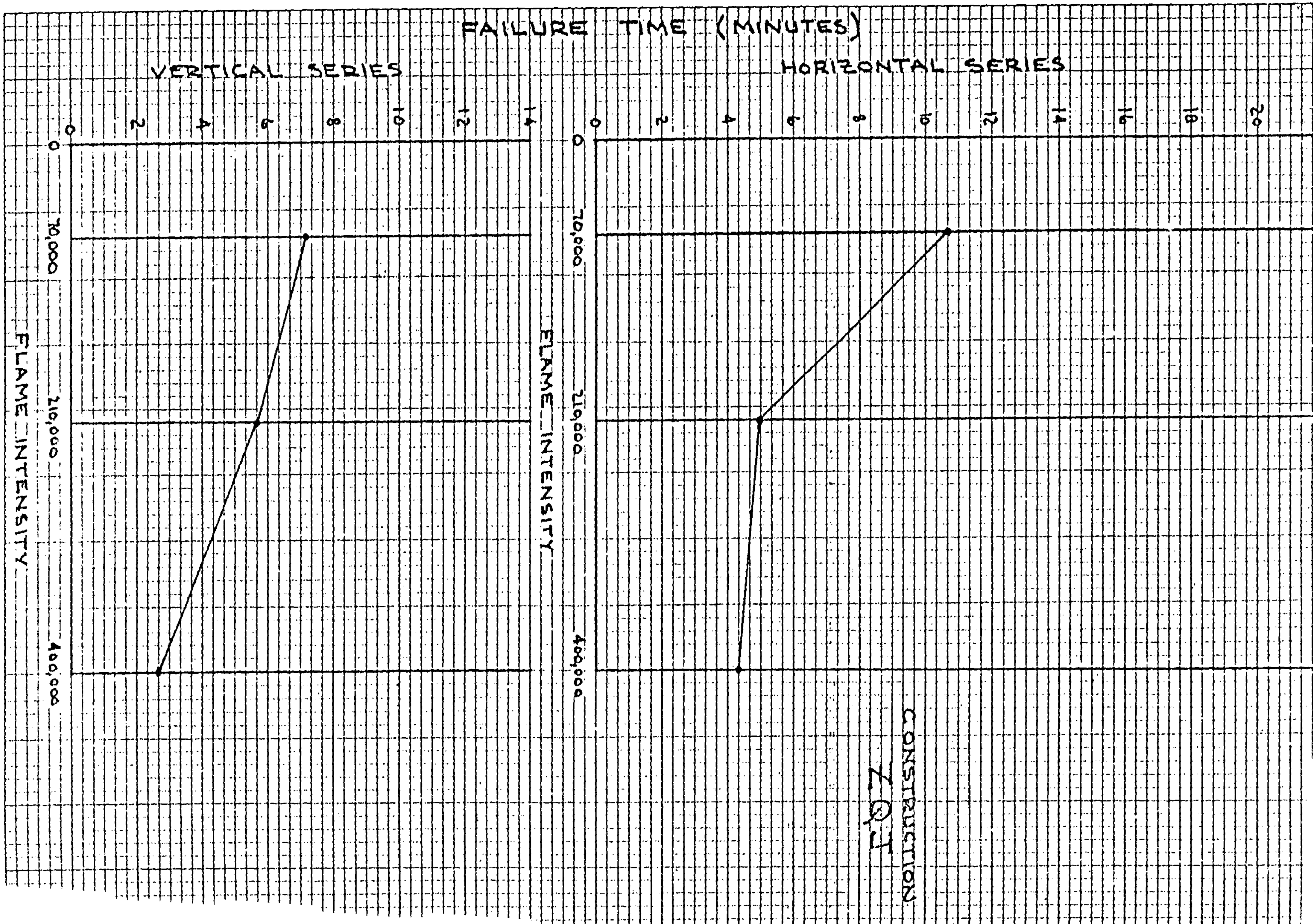
NC555 ILL.


FAILURE TIME (MINUTES)
VERTICAL SERIES
HORIZONTAL SERIES
0
2
4
6
8
10
12
14
16
18
20
FLAME INTENSITY
70,000
210,000
400,000
CONSTRUCTION
OWR

NC555 ILL. 2


FAILURE TIME (MINUTES)
HORIZONTAL SERIES
20
18
16
14
12
10
8
6
4
2
0
NO FAILURE
CONSTRUCTION
XGY
0
70,000
210,000
400,000
FLAME INTENSITY
VERTICAL SERIES
14
12
10
8
6
4
2
0
NO FAILURE
0
70,000
210,000
400,000
FLAME INTENSITY

NC555 ILL. 3


FAILURE TIME (MINUTES)
VERTICAL SERIES
HORIZONTAL SERIES
0
2
4
6
8
10
12
14
16
18
20
70,000
210,000
400,000
FLAME INTENSITY
CONSTRUCTION

NC555

ILL.

RANK ORDER - CIRCUIT INTEGRITY
(BEST TO WORST)

Vertical Series

70,000 BTU/hr	210,000 BTU/hr	400,000 BTU/hr
XGY	XGY	XGY
EMD	EMD	EMD
FVT	ZQJ	FVT
CSA	OWR	CSA
ZQJ	CSA	ZQJ
OWR	FVT	OWR
KPB	KPB	KPB
LUH	LUH	LUH

Horizontal Series

70,000 BTU/hr	210,000 BTU/hr	400,000 BTU/hr
XGY	XGY	XGY
CSA	CSA	EMD
EMD	FVT	FVT
ZQJ	EMD	CSA
FVT	ZQJ	ZQJ
OWR	OWR	OWR
KPB	KPB	KPB
LUH	LUH	LUH

APPENDIX A

TRANSFORMER OIL BURNING TEST

Sample

The transformer oil was provided by the sponsor, and identified as a typically used transformer oil.

Transformer Oil Heat Of Combustion

The total heat of combustion value of the transformer oil was determined using a Parr Oxygen Bomb calorimeter, as approximately 19,400 BTU/lb.

Test Procedure

A nominal 5 gal pail, containing the transformer oil, was placed on a platen supported between two platform scales, as shown by ILL. A1.

The pail was of steel construction, 14-1/2 in. high and 12 in. in diameter. The surface of the transformer oil was 1/8 in. below the top edge of the open pail.

The oil was ignited by applying a propane torch to the surface. The oil resisted ignition until after approximately 12 min of exposure to the propane flame.

Measurements

Weight - The weight loss of the transformer oil was determined as the oil burned, by periodically recording the weight of the oil, pail and support assembly, and calculating the incremental weight losses.

Temperature - Five, 28 ga., Type K (chromel-alumel), grounded junction thermocouples were used to record flame temperatures. The thermocouples were of twist and weld construction, and the bare bead of the thermocouple was exposed to provide the temperature measurement.

RANK ORDER - CIRCUIT INTEGRITY
(BEST TO WORST)

Vertical Series			Horizontal Series		
70,000 BTU/hr	210,000 BTU/hr	400,000 BTU/hr	70,000 BTU/hr	210,000 BTU/hr	400,000 BTU/hr
XGY	XGY	XGY	XGY	XGY	XGY
EMD	EMD	EMD	CSA	CSA	EMD
FVT	ZQJ	FVT	EMD	FVT	FVT
CSA	OWR	CSA	ZQJ	EMD	CSA
ZQJ	CSA	ZQJ	FVT	ZQJ	ZQJ
OWR	FVT	OWR	OWR	OWR	OWR
KPB	KPB	KPB	KPB	KPB	KPB
LUH	LUH	LUH	LUH	LUH	LUH

Three of the thermocouples were placed within the transformer oil, 2 in., 4 in. and 6 in. below the oil surface, at the center of the pail. One thermocouple was fixed in position 12 in. above the oil surface on the vertical centerline of the pail. The remaining "roving" thermocouple was affixed to a wand to permit variable probing of the flame. Thermocouple locations are shown in ILL. A2.

Results

Heat Release Rate - The weight loss recorded for the burning transformer oil is shown in ILL. A3. As shown, the burning rate of the transformer oil tended to increase as the burning continued.

Based on the observed rate of weight loss, and the measured heating value of the oil, the apparent heat release rate varied from approximately 100,000 BTU/hr to 150,000 BTU/hr.

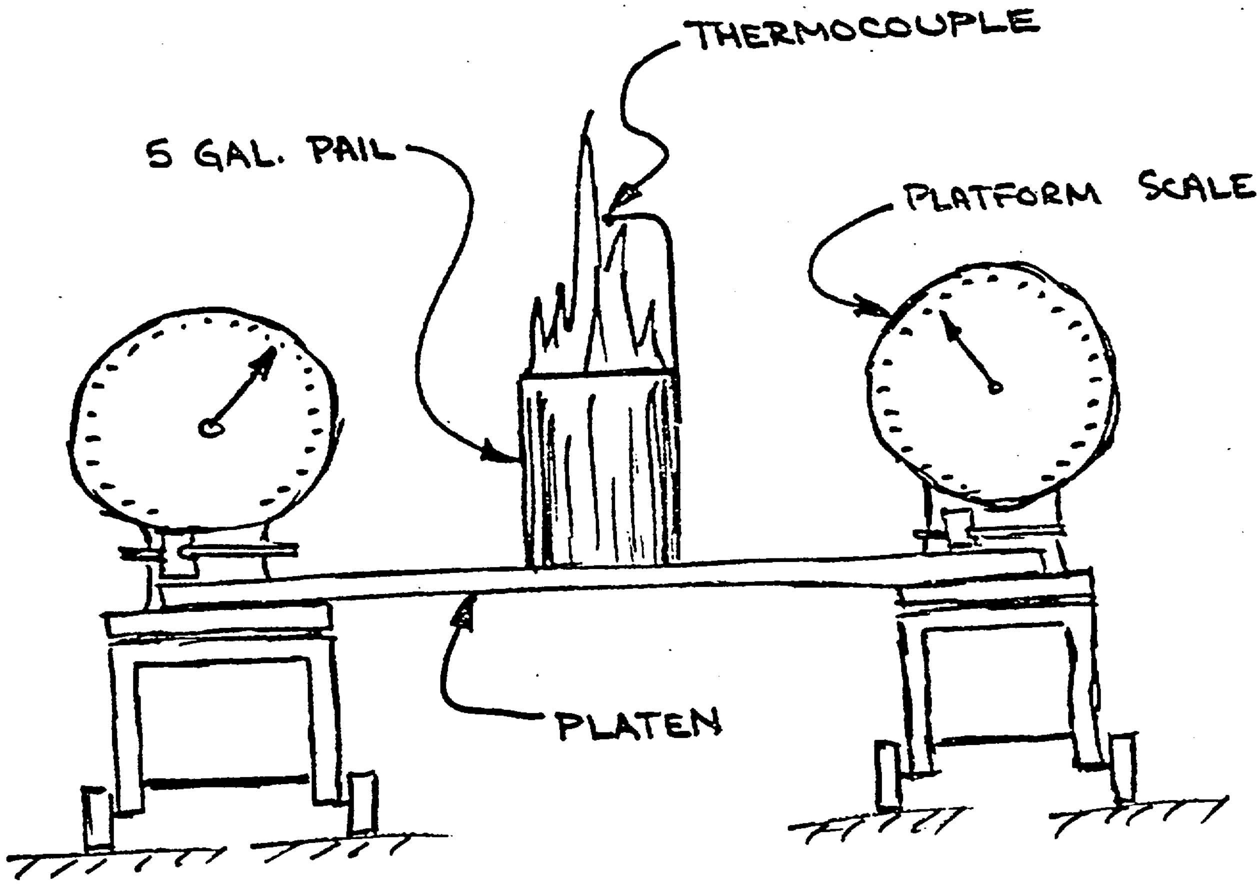
Actual heat release rate is likely somewhat less than the theoretical heat release rate. Incomplete combustion, as indicated by the production of black smoke, does not permit all of the theoretical heat generation to be realized. The degree to which incomplete combustion occurs is not readily determinable and actual heat release rate is likewise not readily determinable.

Temperature - The temperatures recorded by the four fixed location thermocouples are shown in ILL. A4.

Thermocouple Nos. 1, 2 and 3 remained below the surface of the transformer oil throughout the test.

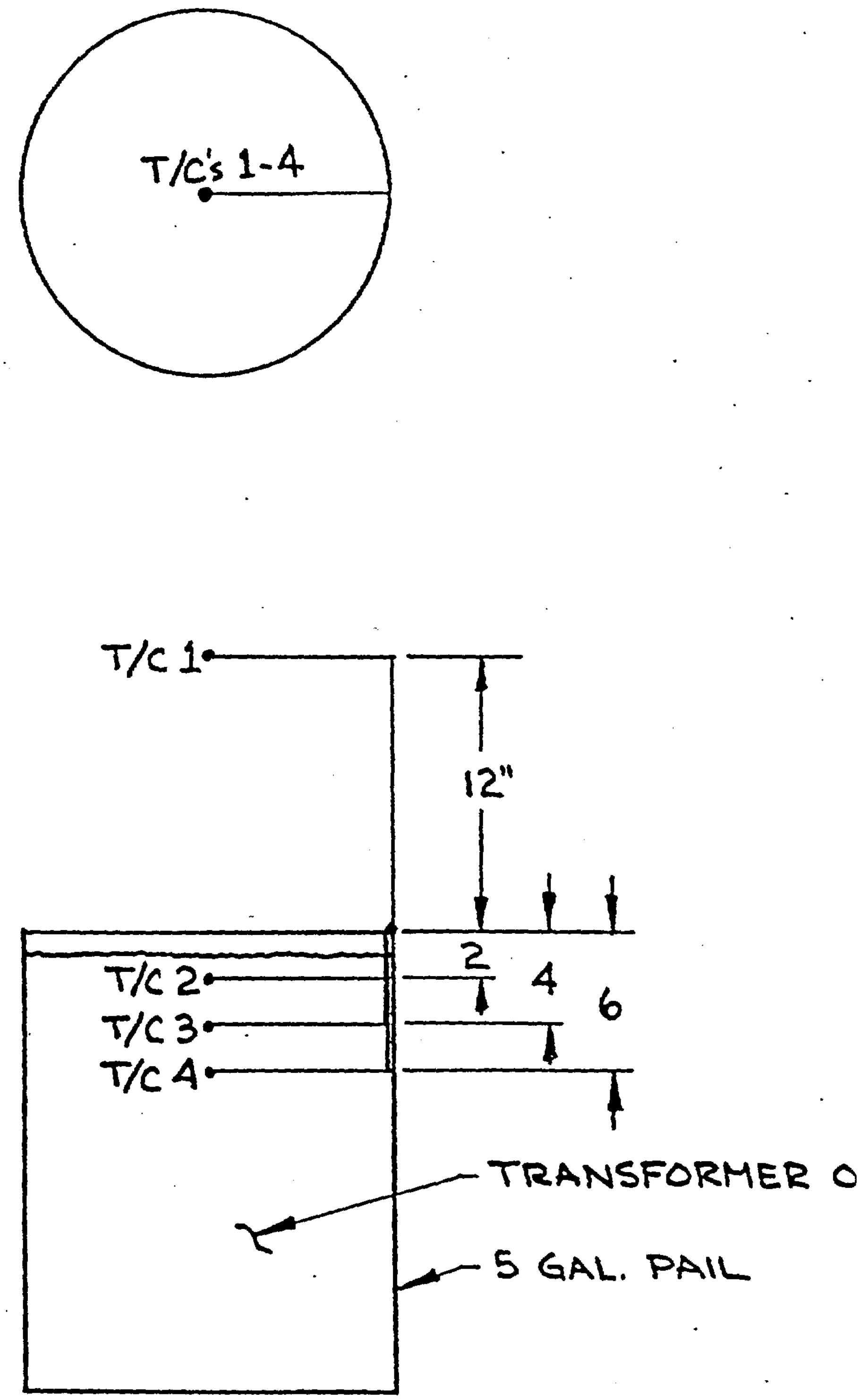
Because the flame fluctuated greatly during the test, and did not maintain a uniform position with respect to thermocouple No. 4 the temperatures recorded ranged from a low of 600 F to a high of 1300 F, generally remaining between 800 F and 1200 F. The temperature shown in ILL. A3 is the maximum temperature recorded during the 5 minute interval indicated.

The roving thermocouple, used to probe the flame, recorded a maximum flame temperature of 1430 F at a distance of 4 in. to 6 in. above the surface of the transformer oil. The flame region 4 in. to 6 in. above the surface of the oil exhibited the highest temperatures, generally ranging from 1200 F to 1430 F throughout the test.



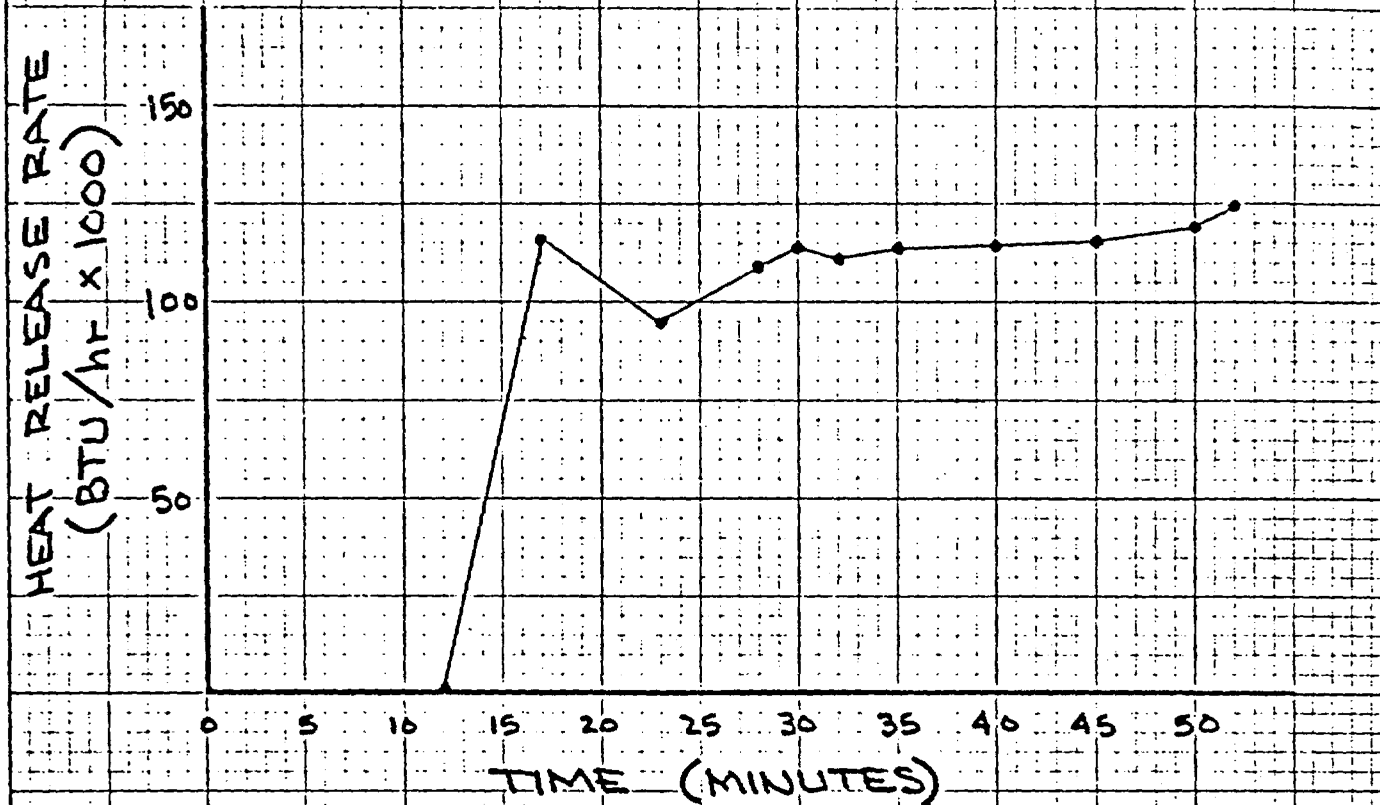
TRANSFORMER OIL BURN TEST

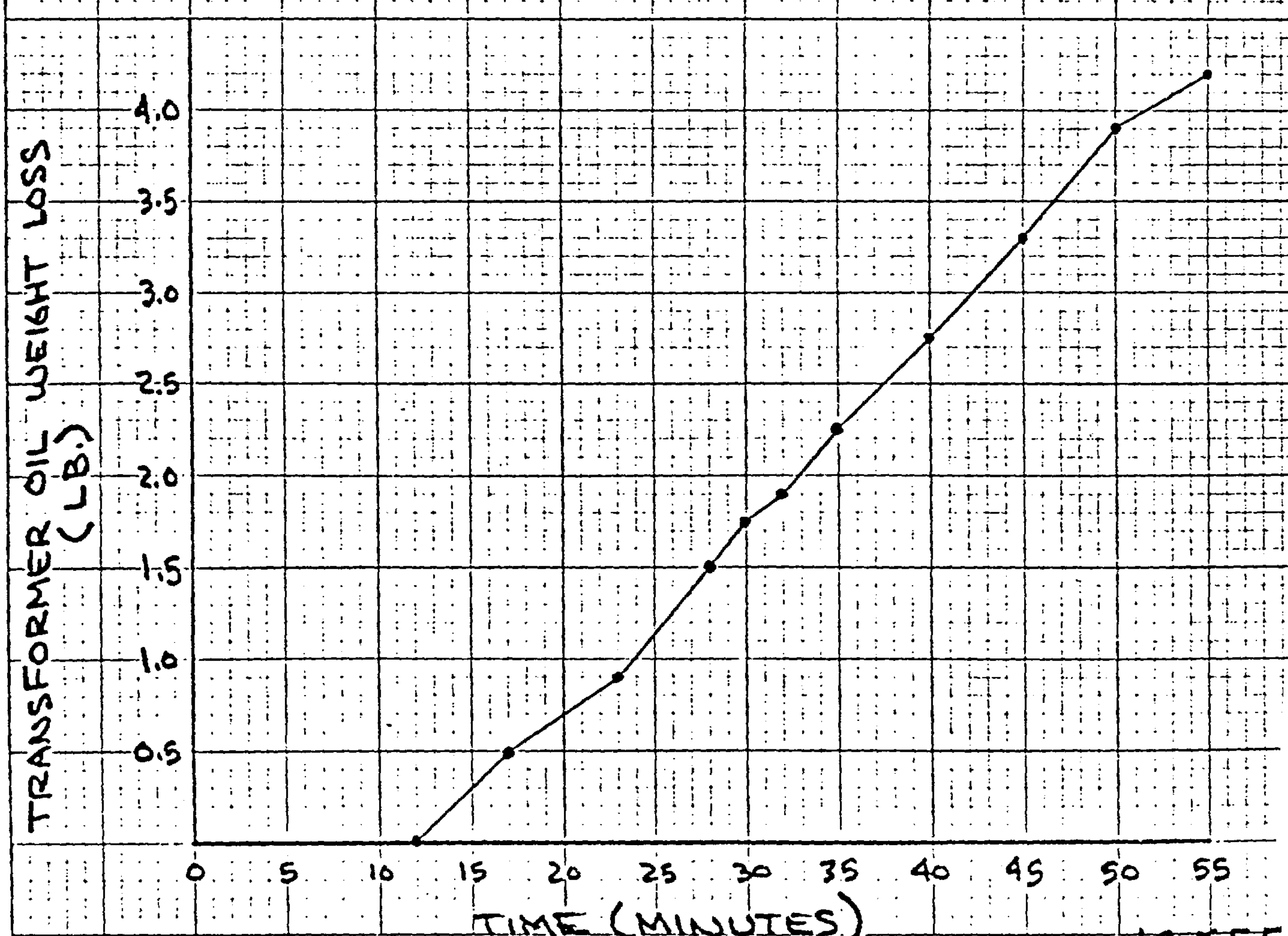
NC555
ILL. A1



FIXED T/C LOCATIONS

NC 555
ILL. A2


HEAT RELEASE RATE
(BTU/hr x 1000)
150
100
50
0
5
10
15
20
25
30
35
40
45
50
TIME (MINUTES)


TRANSFORMER OIL WEIGHT LOSS
(LB.)
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0
5
10
15
20
25
30
35
40
45
50
55
TIME (MINUTES)

NC555
ILL. A

TIME	TEMPERATURE			
	T/C #1	T/C #2	T/C #3	T/C #4
0-12	381	78	78	78
13-17	1126	65	65	65
18-22	1185	65	65	65
23-27	1082	65	65	65
28-32	910	65	65	65
33-37	929	120	80	80
38-42	850	138	82	80
43-47	1300	166	82	80
48-52	1080	212	–	–

FIXED T/C TEMP. DATA

NC 555
ILL. A4