BASIS FOR

CABLE SYSTEM DESIGN

POWER GENERATING STATIONS

Public Service Electric and Gas Company
Newark, New Jersey
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INDEX

I. INTRODUCTION

For over 50 years we have followed a consistent approach in the design of cable systems for power generating stations. We have used high grade rubber insulated cable purchased from reliable manufacturers and have installed it following conservative design and installation practices. This approach has resulted in a sound cable system with a proven 40 year minimum life.

We have realized that the cable system is a very important factor in the overall reliability of operation in generating stations. Although the cable system is a relatively small part of the total cost of a generating station, cable failures can result in costly repairs and outages.

Cable insulation is the foundation of the cable system. It must be a good dielectric material capable of withstanding the rigors of installation in a power generating station where it is subjected to high temperatures, water, surface contamination, fire, and in nuclear stations, radiation. High grade rubber insulation has been proven to be capable of 40 years life under such conditions.

Although we have followed a consistent basic policy for 50 years, we have made many improvements in our cable design during those years. We have participated actively in changes in the cable insulation field and in 1966, after extensive testing in our own laboratory, we became one of the first utilities to use ethylene propylene rubber (EPR) insulation. EPR was found to be superior to the natural rubber insulation that we had been using and also superior to the other thermosetting and thermoplastic insulations tested. Recently, we have made changes in our overall cable construction to obtain greater fire resistance.

Until the 1940's most utilities used high grade rubber insulation. From 1940 to 1965 many utilities switched to the newer insulations: PVC, polyethylene, butyl, and cross-linked polyethylene. These utilities changed not because of poor service with the high grade rubber insulation, but rather for short term economic gains. The newer insulations had a lower initial cost. Since 1965, with the greater concern for fire and radiation resistance, many utilities have switched back to high grade rubber insulation. During the time that the newer insulations were being used in generating stations, a number of failures were reported in technical magazines and surveys.

In 1964 as an owner in Keystone Generating Station we tried to convince the other owners that the additional cost for high grade rubber insulated cable was worthwhile because of its excellent characteristics, which included flame resistance. None of the other owners agreed with us and polyethylene-PVC cable was purchased for the Keystone Generating Station.

In 1967, after the utility industry had experienced a number of serious fires, we had no trouble convincing the other owners of Conemaugh Generating Station that it was worthwhile to buy a superior cable. After extensive fire tests and evaluation of cable characteristics, the owners of Conemaugh Generating Station decided on EPR insulated cable as we had recommended.

Although the cable construction is of prime importance in cable system design, there are other factors which must be considered in order to design a sound, trouble-free cable system. These factors are cable inspection, cable derating, cable overload protection, cable run design, and cable identification and installation control. These factors, together with cable construction, will be discussed in detail in the remainder of this report.

II. CABLE CONSTRUCTION

Rubber was first used as an insulation in 1811. Since that time many improvements have been made in rubber technology. In the early 1920's, with new chemicals, particularly antioxidants and organic accelerators, improvements were made in rubber insulation to the point where it had excellent electrical characteristics as well as good physical properties. Neoprene was introduced in 1931 as a jacketing material for rubber insulation to provide protection from flame, oil, and chemicals. The combination of Neoprene jackets and rubber insulated cables became the industry's standard.

Polyvinyl chloride, the first modern thermoplastic wire insulation, was introduced in 1930. It has been used for interior wire, control cable, and as a jacket for rubber insulated power cables. It provided adequate electrical characteristics for indoor applications, but it does not have the characteristics required for a high grade insulation for use in generating station applications.

Polyethylene was developed in 1933 and was first used as insulation for high frequency cables. It has been used in recent years for communication wire, medium voltage cable, and control cable. Polyethylene has excellent electrical characteristics and low water absorption, but it lacks flame resistance and has a low melting point.

A popular control cable design during the 1960's has been the polyethylene-PVC cable. It was thought that for control cable applications, the low melting point of PVC and polyethylene would not be a factor and that the PVC would provide adequate flame protection for the polyethylene. After several serious fires, it was demonstrated that the PVC did not provide the required flame protection for polyethylene because it melted when subjected to flame; thereby, exposing the polyethylene to the flame.

Butyl was offered as a cable insulation in 1946. Its prime characteristic was its 90°C rating. Many utilities switched to butyl insulated power cables in order to obtain the higher ampacity ratings that were available because of the 90°C insulation rating. Testing that had been done by the manufacturers failed to discover that butyl reverted to a soft compound when subjected to high temperatures, as occurred during short circuits. Also, butyl was found to be a very difficult material to manufacture.

In the 1960's cross-linked polyethylene was developed as a cable insulation and provided almost the same electrical characteristics as polyethylene, but was a thermosetting compound rated at 90°C. It, like polyethylene, has a very poor fire resistance. Cross-linked polyethylene has been used mainly as a power cable insulation.

In 1965, when the utility industry became concerned about fire resistance, a flame retardant cross-linked polyethylene was

developed. It was thought that this type of insulation, which did not require a jacket for flame resistance, would be superior to high grade rubber insulation with Neoprene jackets. The flame retardant cross-linked polyethylene is compounded by adding antimony oxide to regular cross-linked polyethylene. This addition changes the electrical and water absorption characteristics of the insulation. It no longer has the excellent characteristics of polyethylene.

In 1966 ethylene propylene insulation was first offered as a replacement for the high grade natural rubber insulation, which was in short supply. EPR insulation like rubber insulations is a compound of elastomers, antioxidant, and stabilizers. The compound that was offered for cable insulation was the result of 10 years of laboratory investigation. EPR insulation offers excellent electrical and water absorption characteristics and, in addition, has a 90°C rating. Although EPR will burn, it can be protected by a thermosetting Neoprene jacket and has passed all known flame tests.

Although up until 1966 we used natural rubber insulation, we did analyze new insulations as they were introduced; we found no reason to switch from the high grade rubber insulation with which we had had an excellent service record. In 1966 we instituted an extensive testing program in our own laboratory in order to analyze the characteristics of various commercially available cable insulations. In addition to testing new insulations, we also tested the natural rubber insulation of which we had been using for 45 years. We used the characteristics of the natural rubber insulation as a benchmark. To our knowledge no one in the cable industry has been able to determine any single characteristic of an insulation which can be used to project long service life. Therefore, we considered the overall balance of characteristics to be of prime importance. Both standard and special tests were used. The standard tests were basically ASTM tests with modifications to use the same test conditions for thermosetting and thermoplastic compounds. The special tests were developed to simulate possible field conditions which were not adequately covered by standard tests and to determine the long time aging characteristics of the insulations. Following is a list of the tests that were performed:

Tests	Test Methods
Dimensions	ASTM D 470
Tensile Strength	ASTM D 470
Elongation	ASTM D 470
Aging Test	
Air Oven-121C, 168 hrs.	ASTM D 573
Air Pressure-121C, 48 hrs., 80 psi	ASTM D 454
Oxygen Pressure-70C, 96 hrs., 300 psi	ASTM D 572
Oil Immersion-ASTM#2, 121C, 18 hrs.	ASTM D 470
Ultraviolet Aging	ASTM D 2244

Tests	Test Methods
Heat Distortion-121C, 1 hr.	ASTM D 2633
Heat Shock	ASTM D 2633
Cold Bend	ASTM D 2633
Water Absorption	
Electrical Method	ASTM D 470
Gravimetric Method	ASTM D 470
Electrical Characteristics	
Dielectric Constant	ASTM D 150
Power Factor	ASTM D 150
Insulation Resistance	ASTM D 257
Insulation Resistance Constant	
Dielectric Strength	ASTM D 149
Alternating AC-DC Test	(see below)
Ozone Resistance	ASTM D 1149
Compression Cut Test	(see below)
Flame Tests	
Horizontal	ASTM D 470
Vertical	ASTM D 2633
Electroendosmosis Test	(see below)
Thermal Endurance	(see below)

Alternating AC-DC Test

Ten foot specimens of the control cables were immersed in tap water at ambient temperature for 16 hours. A potential of 3500 Volts AC was applied to the conductors and maintained for 5 minutes, followed immediately by a potential of 9000 Volts DC, maintained for 10 minutes. If the cables withstood these potentials, the AC was increased in increments of 1000 Volts and the DC in increments of 2500 Volts and maintained for 5 and 10 minutes respectively. The test was terminated when the insulation failed electrically or a potential of 19,500 Volts AC and 49,000 Volts DC was attained.

Compression Cut Test

A twelve inch specimen of cable was formed into a loop with the ends twisted together. A 2.5 pound weight was suspended on the looped cable with a short section of #20 AWG bare copper wire. The assembly was placed in an air oven and maintained at an elevated

temperature for 24 hours. The specimen was allowed to cool to ambient temperature and then electrically proof tested with a potential of 5.0 kV for 5 minutes between the cable conductor and the #20 AWG bare copper wire with the weight still attached. If the cables sustained the 5.0 kV for 5 minutes, they were then tested to electrical failure. Each type of cable was subjected to several different elevated temperatures.

Electroendosmosis Test

Ten foot specimens of the cables were immersed in tap water maintained at 75C. A negative 600 Volt direct current potential was maintained on the cables continuously, except when the following tests were conducted:

1. Maintain 5 kV AC for 5 minutes
2. Power factor, 60 Hertz
3. Dielectric Constant, 60 Hertz

The tests values were determined at the start of immersion and weekly thereafter for three months.

Thermal Endurance

Thermal endurance of the cable insulations was determined by aging the insulation at various temperatures until a loss of 40% elongation was determined.

The insulations tested, in addition to natural rubber, were ethylene propylene rubber, two flame retardant cross-linked polyethylenes, and two polyvinyl chlorides. Since 1966 we have also performed tests on silicone and teflon insulation and additional tests on different suppliers of EPR, flame retardant cross-linked polyethylene, and PVC insulations. Polyethylene was not tested because of its poor fire resistance and low melting point, and butyl insulation was not tested because of its reversion at high temperatures. EPR insulation was found to be the best insulation of all those we have tested. It has the excellent balance of characteristics which natural rubber has and, in addition, a much improved long time aging characteristic. The only characteristic

where EPR is inferior to natural rubber is in initial tensile strength, but since it was found to be very stable during long time aging tests, this characteristic was not considered a serious deficiency. In addition, the Neoprene jacket provides the mechanical strength required for installation.

Our tests substantiated the deficiencies which were mentioned earlier concerning PVC and flame retardant cross-linked polyethylene. These insulations do not remain stable when immersed in water for long periods of time. Since wet conditions are found in generating stations, we considered this characteristic to be important.

In the last few years cable manufacturers supplying EPR insulation have performed extensive radiation tests. EPR insulation has been proven to be serviceable after being subjected to a pre-aging equivalent to a 40 year life, 1 X 10^8 RADS radiation, and then 350°F in a steam autoclave at 60 psig for 10 hours.

In the last 5 years many utilities who had switched away from high grade rubber insulation are changing back to high grade insulation and are using EPR insulation. The use of PVC-polyethylene cable has virtually disappeared in the utility industry. Most utilities are now using either flame retardant cross-linked polyethylene or EPR insulation. Those who favor flame retardant cross-linked polyethylene do so because it offers a smaller size cable since a jacket is not required on single conductors. EPR insulated cables, although larger in size, have superior electrical and water absorption characteristics. For power cables, EPR and regular cross-linked polyethylene are the insulations used in most generating stations. For power cable applications, EPR offers much better corona resistance, higher physical strength at operating temperature, and it is more flexible and easier to handle.

The overall cable construction is important because it protects the insulation during installation and provides fire, oil, and chemical protection. Until 1957 we used lead outer covering on control cables. At that time we changed the outer covering to incorporate a 5 mil corrugated bronze tape and a PVC outer jacket, which we felt offered the same protection as the lead but at a lower cost. In 1968, after performing many fire tests, we decided to change the PVC outer jacket to Neoprene to provide improved fire resistance. In 1970 we added an asbestos mylar tape under the corrugated bronze tape to provide additional fire protection. The additional fire resistance added by changing the outer covering of the cable in no way changes the excellent electrical and water absorption characteristics of the insulation.

In our 5 kV power cables until 1970 we used a non-shielded construction. From 1966 to 1969 we used an EPR insulation with oil added, which provided greater corona resistance. We experienced problems with this insulation in areas where the cable was alternately wet and dry. We worked closely with the cable manufacturer and discovered that the problem could not be corrected. We then started using straight EPR cables for 5 kV applications and decided to use a shielded construction with Neoprene outer jackets. We decided after a careful analysis that the shielded construction, terminated properly, would offer a safer installation than non-shielded cable and would also have greater fire resistance.

The changes mentioned previously in overall cable construction to effect greater fire resistance were made after performing an extensive amount of fire testing. A separate section of this report will discuss in detail the fire testing which we have performed.

The cable construction for the 5 kV power, 600 Volt power, and 600 Volt control cables for nuclear generating stations are similar to those we have used for past stations. The following is a brief description of each type of cable.

1. <u>5 kV Power Cable</u>

    Copper conductor
    Strand shielding
    Ethylene Propylene Rubber Insulation
    Semi-conducting shielding
    Flat copper shielding tape
    Neoprene jacket

2. <u>600 Volt Power Cable</u>

    Copper conductor
    Ethylene Propylene Rubber Insulation
    Neoprene jacket

3. <u>600 Volt Control Cable</u>

    Copper conductor
    Ethylene Propylene Rubber Insulation
    Neoprene jacket
    Outer coverings:
        Asbestos-Neoprene tapes
        Asbestos Mylar tape
        Corrugated bronze tape
        Neoprene jacket

III. FIRE TESTING

Since no industry test exists for determining acceptable degrees of fire resistance for completed cables, a number of fire tests have been developed by utility companies and manufacturers. The greatest cable fire hazard in the generating stations exists in exposed tray systems, and a vertical tray fire propagation test has been accepted by many companies. The vertical tray runs represent the greatest hazard because "chimney" action will spread the products of combustion to a large area.

In 1968 we suggested that the owners of Conemaugh Generating Station form a task force to establish criteria for acceptable fire resistant control cable. Criteria established specified that the cable had to be fire resistant and also maintain circuit continuity without short circuiting during the fire test. In addition, the electrical, mechanical, and water absorption characteristics of the cable had to be suitable for a 40 year life in a generating station. The vertical tray fire propagation test was chosen by the task force as the test to use to evaluate different cable constructions. The test procedure used was as follows:

1. Erect an 8 foot high, 6 inches wide metal tray vertically. Protect tray from wind by installing in an enclosure.

2. Load tray with one level of test cable, of one type, allowing one-half diameter space between cables.

3. Make electrical connections to check continuity and energize circuit.

4. Insert crumpled 2 foot x 2 foot burlap previously soaked in transil oil, into vertical tray approximately one foot above lower cable ends. Hold burlap in place with loose metal band.

5. Ignite the oil-soaked burlap.

The cable fails this test if a self-sustaining, propagating fire results or one electrical circuit breaks down during the fire.

Each supplier on the bidders' list was requested to submit 100 foot samples of 7 conductor, #12 control cable before the due date for proposals. By requesting all samples to be the same size and number of conductors, the possibility of conductor size affecting the test results was eliminated. All fire resistance testing was performed at Public Service Electric and Gas Company's Maplewood Testing Laboratory.

The task force decided, based on consideration of insulation characteristics and our experience in many installations, to specify a control cable construction consisting of EPR insulation and Neoprene jacket on single conductors, cabled together with an asbestos tape and an overall jacket of Neoprene. Since the task force realized that all the manufacturers could not conform to this specified construction, alternate constructions were invited. All manufacturers were requested to send data on insulation characteristics in addition to samples for fire resistance testing. In addition to the specified construction, four other constructions were submitted for the task force's consideration.

1. EPR-Neoprene on 1/C, Asbestos Tape, and PVC overall.

2. Hypalon on 1/C, Asbestos Tape, and Neoprene overall.

3. XLPE on 1/C-Silicone Glass Tape, Asbestos Tape, and Neoprene overall.

4. PVC-Nylon on 1/C, Asbestos Tape, and Neoprene overall.

All the above constructions passed the fire propagation part of the test but alternate constructions No. 1 and 4 failed on electrical continuity by shorting between conductors. Figures 1-4 show a typical sequence of before, during, and after the test for cables that passed the fire propagation part of the test.

The polyethylene-PVC control cable construction used at Keystone was also subjected to the test. It failed both criteria and continued to burn until all the polyethylene-PVC was burned off the wires for the entire length of the sample (Figure 5).

As a result of all the fire tests, the task force concluded that PVC was not acceptable as an insulation on single conductors because it flowed from the wires and exposed a greater length of conductor. During the test, the wires shorted. It was also decided that even though cables with an overall PVC jacket passed the fire propagation part of the test, PVC was not acceptable as an overall jacket because the cables with PVC jackets burned for a greater length and emitted more smoke during the test than corresponding cables with Neoprene jackets. Therefore, alternate 1 with the overall PVC jacket and alternate 4 with the PVC insulation were eliminated.

Since it was decided at the beginning of the investigation that an acceptable control cable construction had to be not only fire resistant but also had to have characteristics suitable for a forty-year life in a generating station where it may be subjected

to water and heat, each manufacturer was asked to state that his cable could operate satisfactorily in this environment. The manufacturers who offered cable constructions with Hypalon insulation did not recommend using it in a wet environment. Hypalon was therefore considered unacceptable and alternate 2 was eliminated.

Based on fire resistance testing and consideration of electrical, mechanical, and water absorption characteristics, the task force concluded that two of the cable constructions submitted were acceptable for use in open trays in generating stations, the specified construction and alternate 3:

1. EPR-Neoprene on 1/C, Asbestos Tape, Neoprene overall.

2. XLPE on 1/C-Silicone Glass Tape, Asbestos Tape, Neoprene overall.

EPR was preferred over XLPE because of its superior electrical characteristics; bids were received on both constructions and EPR was selected.

The task force did not agree that a corrugated bronze tape was required on control cable in the generating station. They felt that the overall Neoprene jacket was more important for fire resistance than the bronze tape. As a result of our participation in these tests, we changed the outer jacket of our control cable to Neoprene but retained the use of the corrugated bronze tape. This tape offers additional fire resistance and also provides excellent mechanical protection to the single conductors.

Our power and control cables have passed both the Bureau of Mines and the UL Vertical Flame Test for single conductors. The results of the vertical tray flame propagation test were given to NEPIA for their consideration in our appeal to their requirements for a water spray system over cable trays. NEPIA felt the vertical tray fire propagation test in partly loaded trays was not sufficient and they suggested a test be made to check fire propagation between horizontally stacked trays filled with cables.

In order to test our cables in fully loaded trays stacked one above another, we developed a test procedure and had tests performed by the Okonite Company at their Fire Test Building in Passaic, New Jersey. Several tests were performed to determine the effectiveness of tray spacing in preventing propagation between trays.

The test procedure, results, and conclusions are as follows:

Test Procedure

1. Erect two 6' long by 24" wide ladder-type aluminum cable trays horizontally with provisions to space the trays at 12" and 18", tray bottom to tray bottom.

2. Three tray tests are to be performed:

   A. Trays separated 12" and no asbestos barrier.

   B. Trays separated 12" and an asbestos barrier in the bottom of the upper tray.

   C. Trays separated 18" and no asbestos barrier.

3. Load each tray with six cables of each type of control cable supplied by Public Service. This loading will result in 40% fill by cross sectional a area. The cable lengths shall be 10' long, 6' of which is in the tray with 2' overhanging on each end for connection to test leads. Connect conductors in every other cable in the lower layer of each tray to a 120/240 Volt 3 wire test circuit as follows:

   A. Connect center conductor, bronze shielding tape, and tray to neutral of test circuit.

   B. Group conductors into two groups with alternate conductors in each group. Connect groups to test circuit with a lamp in each circuit to indicate conductor shorting.

4. Locate six thermocouples as follows: At the bottom of the lower tray, at the center of the fire, and to the side - 12" and 18" from the center of the fire and at the bottom of the upper tray directly above the center of the fire and 12" and 24" to the side.

5. An Ellipse wheel gas burner with a 14" outer diameter shall be used as the source of fire. The burner shall be located below the center point lower tray and shall be adjusted to produce a temperature of 1500°F at the point of impingement with the cables. (See Fig. 6)

6. The burner shall be ignited for 15 minutes. Record all thermocouple readings every 2 minutes. Note propagation of fire and observe lamps for conductor shorting. Time shall be recorded for any cables which short. After completion of the tests, the damaged area of cable in each tray shall be measured.

7. During the test, photographs shall be taken at 2 minute intervals. After the test, close-up photographs shall be taken of the damaged areas.

8. The above test procedures shall be followed for each of the 3 tests required.

Public Service provided one 2,000 foot reel of each of the following cable constructions for the tests: T-201, T-401, T-901, T-214, T-414, T-914, T-1914. Also provided were four aluminum trays and two asbestos boards.

Test Results

General

The complete test data for all the tests is given in tables attached to this section. The gas burner was adjusted prior to the tests to 1500°F at the hottest part of the flame. It was noted that when the thermocouple was moved away from the hottest part of the flame, the temperature dropped off rapidly. During the tests the thermocouple directly above the burner never read above 1060°F because it was not possible to position the thermocouple in the hottest spot. During the test the temperature decreased because of movement of the cables and tray caused by the extreme heat.

Test No. 1 - 12" Separation, No Barrier

Prior to the start of the test the set-up was checked and even though the tray was filled with cables, there were spacings between the cables (See Fig. 8-12). At 11.5 minutes conductors in a T-201 cable shorted. Two minutes later it was observed that the flame had surrounded the bottom tray along the lateral edges. At 15 minutes conductors in a T-214 cable shorted See Fig. 13-15). At this time the burner was turned off. Most of the flame extinguished immediately, but a small flame continued to burn until 7.5 minutes after the burner was turned off (See Fig. 16-18). The cables in the upper tray with stood the entire test without a failure. The burned area in the cables in the lower tray was no greater than the area that the

burner flame contacted. There was no horizontal or vertical propagation of the fire.

Test No. 2 - 12" Separation, Asbestos Barrier

This test was cancelled because the results of Test No. 1 proved that flame propagation between trays with a 12 inch separation was negligible without a barrier. The asbestos barrier would have completely blocked both flame and heat from the upper tray.

It was decided to perform Test No. 3 in order to compare temperatures at the bottom of the upper tray for 12 and 18 inch separation.

Test No. 3 - 18" Separation, No Barrier

Prior to the start of the test, the test set-up was inspected and spaces were observed between the cables in both fully loaded trays (See Fig. 19). About 7.5 minutes after the flame was applied conductors in a T-214 appeared to short, but then the indicating lamp turned off, indicating that the short had cleared. At 10 minutes the flame broke around the edges of the lower tray. At 12.5 minutes conductors in both a T-414 and a T-214 cable shorted. Since the flame had not broken through the cables in the lower tray at the end of 15 minutes, the test was continued for 5 more minutes (See Fig. 20-23). The burner was turned off at 20 minutes and there was no major afterburn (See Fig. 24).

Close inspection after the test revealed the cables in the lower tray had swelled during the test and bonded together to form a tight barrier which prevented the main flame from breaking through the cables. The maximum temperature of the cables in the upper tray was 190°F (See Fig. 20).

The "bonded" cables in the lower tray were separated to allow air to circulate and the test was continued for 10 more minutes. The flame broke through immediately towards the upper tray. Five more cables failed in the lower tray during this additional test, But there were no cable failures in the upper tray. Flame concentration was within twelve inches above the lower tray with the cables in the upper tray subjected to flame intermittently (See Fig. 26-29).

This additional test of 10 minutes added to the original test of 20 minutes subjected the same cables to 30 minutes of flame. This combined test was much more severe than any test that we or Okonite were aware of.

Test No. 4

A special test using oil as a source of flame in place of gas was performed because we felt that since NEPIA is used to fire testing with oil, they might want to be able to compare the results of an oil fire with the results of a gas fire. In order to save time and expense, it was decided to use the same cables that were used in Test No. 2. Since the cables in the upper tray were not damaged in that test, the oil fire was set up under that tray. An oil pan with a quarter of an inch of turbine lubricating oil was used. The oil was added to the pan by pouring it over the cables to simulate an oil spray.

The oil was very difficult to ignite, but once ignited it burned readily. Again, as in Test No. 3, the cables in the tray blocked the flame from going through, and the flame went around the sides of the tray. The fire lasted about 10 minutes. Three minutes after the oil was consumed, all flames were out. There were no failures of cables (See Fig. 30-32).

Conclusions

1. There was no propagation of the fire from the lower to the upper tray with either 12" or 18" spacing with no barriers used in either tray. At the start of each test there were spacings between the randomly laid cables, but after the fire started the cables expanded and closed the openings, thereby restricting the fire from breaking through the cables. In the first test the fire broke through in 7 minutes and in the second test there was no breakthrough after 20 minutes of burning. The cable damage was primarily limited to the lower cables in the bottom tray.

2. There was no propagation of the fire horizontally outside the immediate area of the gas burner in any of the tests. The main part of the fire extinguished immediately when the gas burner was shut off. In several tests a small flame continued to burn after the burner was shut off. The maximum after burn time was 7 minutes.

3. The 18 inch separation provided greater protection than the 12 inch separation for the cables in the upper tray, although the cables in the upper tray were not damaged in either case. The maximum temperature at the bottom of the upper tray was 190°F for 18 inch separation and 520°F for 12 inch separation.

4. The vertical tray fire propagation test with a partially loaded tray appears to be more severe than a horizontal test with fully loaded trays. The vertical tray test is also simpler and less expensive to perform and therefore is much better suited as a qualification test than the horizontal test.

5. There were no conductor shorts during the first 11 minutes, after which there were several shorts in the lower cables in the bottom tray. This time is more than adequate to allow proper operation of the control circuits.

6. The fire produced by the gas burner was more severe than that produced by the oil fire. No circuits shorted during the oil fire.

7. The test result of the horizontal tray fire propagation tests confirm our findings from previous fire tests that our control cable construction does not propagate fire either vertically or horizontally and does provide adequate circuit integrity. The test results also prove that 18 inch vertical separation between trays provides adequate protection from fire propagation when fire resistant cables are used.

PUBLIC SERVICE ELECTRIC AND GAS COMPANY
ELECTRIC ENGINEERING DEPARTMENT

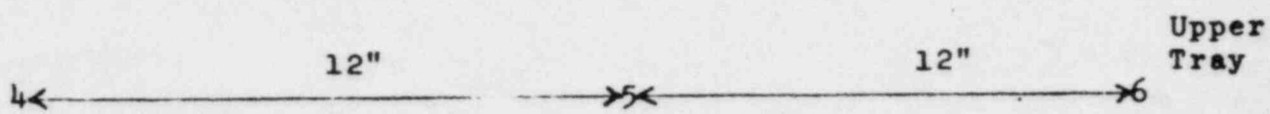
TABLE 1
HORIZONTAL TRAY FIRE PROPAGATION TEST
12" SEPARATION - NO BARRIER
2/12/71

THERMOCOUPLE READING °F

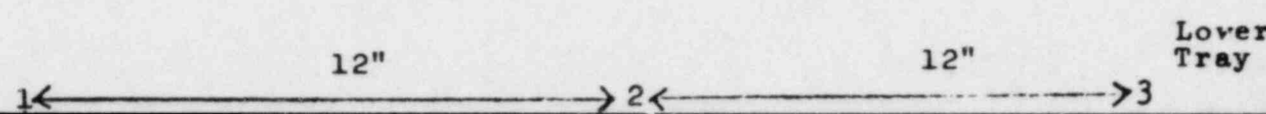
TIME	1	2	3	4	5	6	NOTES
1	1000	80	70	130	90	70	
2	1050	80	70	120	90	80	
3	970	80	70	120	100	80	
4	960	100	80	120	100	80	
5	950	130	80	130	100	80	
6	940	150	80	140	100	80	
7	910	150	80	200	120	80	Flame broke through lower tray
8	900	140	80	350	140	90	
9	900	130	80	440	160	100	
10	910	130	80	460	180	100	
11	900	140	80	480	180	100	T-201 failed at 11' 30"
12	900	140	80	500	200	110	
13	930	140	80	510	220	120	Flame broke around tray front and back
14	930	150	90	540	220	120	
15	920	160	90	520	220	120	T-214 failed at 15' Flame out at 15'
18	650	120	80	240	160	110	
20	610	120	80	210	150	110	
22	590	110	80	200	150	110	Final flame out at 22' 35"
24	570	110	80	200	140	100	
26	540	110	80	180	140	100	
28	500	110	80	180	140	100	
30	480	110	80	170	140	100	

THERMOCOUPLE LOCATIONS

Center of Tray



Center of Tray



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ELECTRIC ENGINEERING DEPARTMENT

TABLE 2
CONTROL CABLE
HORIZONTAL TRAY FIRE PROPAGATION TEST
18" SEPARATION - NO BARRIER
2/17/71

TIME	THERMOCOUPLE READINGS °F 1	2	3	4	5	6	NOTES
1	1360	80	80	90	80	80	
2	1350	90	90	100	90	80	
3	1280	100	100	110	100	80	
4	1260	120	100	120	100	80	
5	1200	130	100	120	100	80	
6	1130	140	110	130	100	90	
7	1100	150	110	140	110	80	T-214 failed at 7' 30"
8	1060	140	110	140	110	80	
9	1030	150	110	160	120	80	Flame broke around tray front and back
10	1020	160	110	160	120	80	
11	1000	160	110	160	120	90	
12	920	180	120	180	130	100	T-914 failed at 12' 25" and T-414 failed at 12' 35"
13	900	180	120	180	130	100	
14	900	180	120	200	140	100	
15	940	200	120	190	140	100	
16	960	210	120	200	140	100	
18	940	240	120	200	140	100	
19	940	260	130	200	140	100	
20	960	220	130	190	140	100	Flame turned off - No major afterburn
21	680	200	120	150	120	100	
22	580	200	120	130	120	100	
23	520	190	120	120	110	90	
24	480	180	120	120	100	90	
26	430	180	120	110	100	90	
28	390	170	120	100	100	80	
30	360	160	120	100	100	80	

THERMOCOUPLE LOCATIONS

Center of Tray — 4 ←12"→ 5 ←12"→ 6 — Upper Tray

Center of Tray — 1 ←12"→ 2 ←12"→ 3 — Lower Tray

Center of Burner (at 1)

PUBLIC SERVICE ELECTRIC AND GAS COMPANY
ELECTRIC ENGINEERING DEPARTMENT

TABLE 3
HORIZONTAL TRAY FIRE PROPAGATION TEST
18" SEPARATION - NO BARRIER
2/17/71

TEST CONTINUATION AFTER CABLE SEPARATION

THERMOCOUPLE READING °F

TIME	1	2	3	4	5	6	NOTES
1	450	140	180	360	160	100	
2	580	140	80	510	200	110	
3	600	170	80	630	240	120	
4	730	190	90	630	280	140	
5	760	240	100	620	330	140	
6	760	260	100	510	320	140	
7	740	320	100	510	320	150	
8	760	340	100	500	340	160	T-914 failed at 8' 0"
9	780	340	110	520	330	160	
10	780	340	110	540	360	170	T-901 failed at 11' 0"
12	790	270	110	380	280	150	Flame out at 11' 30"
14	780	200	100	320	280	140	
17	740	160	90	250	200	130	
20	700	140	90	220	180	120	
23	690	130	80	190	170	120	
26	620	140	80	200	170	120	
30	600	120	80	190	150	120	T-1914 failed at 27' 0"

THERMOCOUPLE LOCATIONS

Center of Tray — 4 ←12"→ 5 ←12"→ 6 — Upper Tray

Center of Tray — 1 ←12"→ 2 ←12"→ 3 — Lower Tray

↑ Center of Burner (at 1)

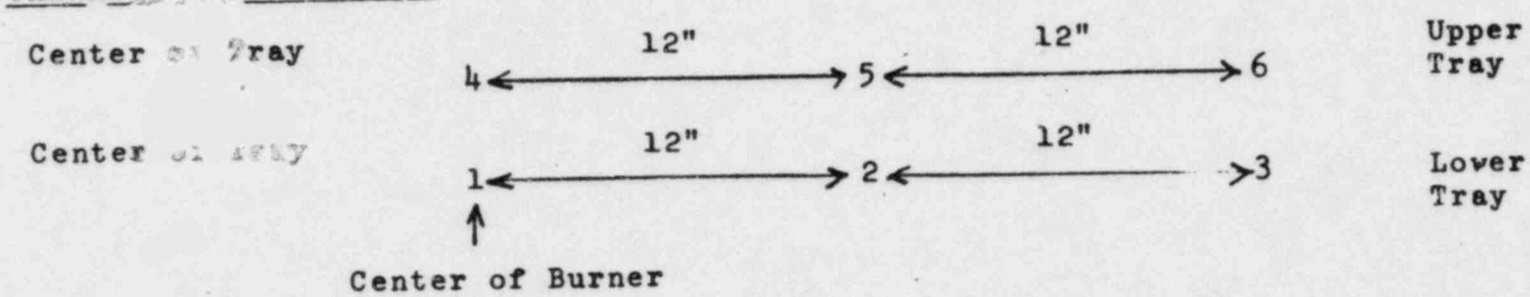
RWM/vh

PUBLIC SERVICE ELECTRIC AND GAS COMPANY
ELECTRIC ENGINEERING DEPARTMENT

TABLE 4
CONTROL CABLE
HORIZONTAL TRAY FIRE PROPAGATION TEST
OIL FIRE TEST
2/17/71

TIME	1	2	3	4	5	6	NOTES
1			400	140	100		
4			480	140	100		
5			1160	220	120		
6			1140	320	120		
7			1080	300	130		Flame surround cable tray at 7'
8			1020	300	130		
9			990	360	140		
10			1000	300	140		Fire out in oil pan at 10'
11			960	360	140		
12			850	240	130		All flames out at 12'

THERMOCOUPLE LOCATIONS



RWM/vh
6/1/71

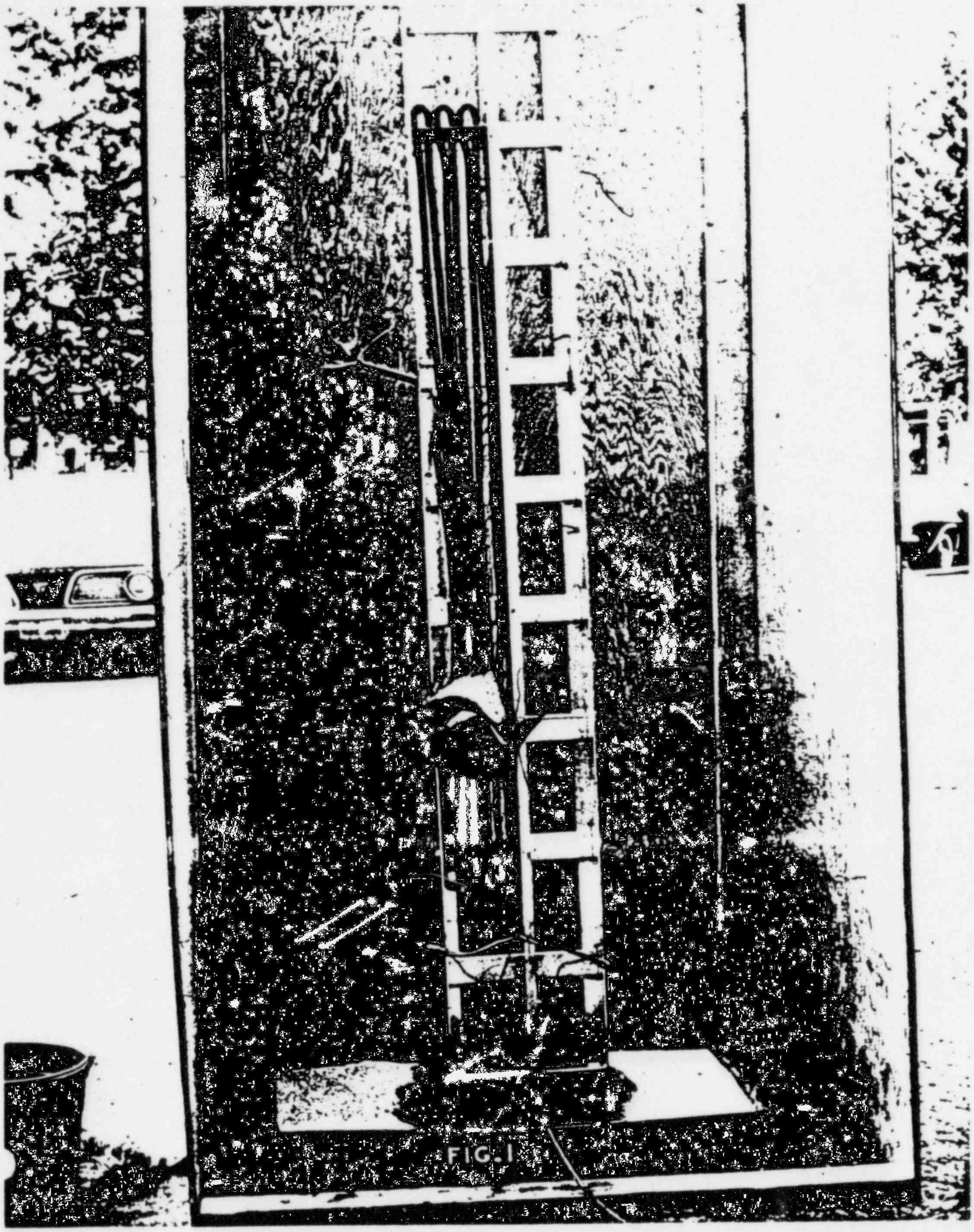


FIG. 1

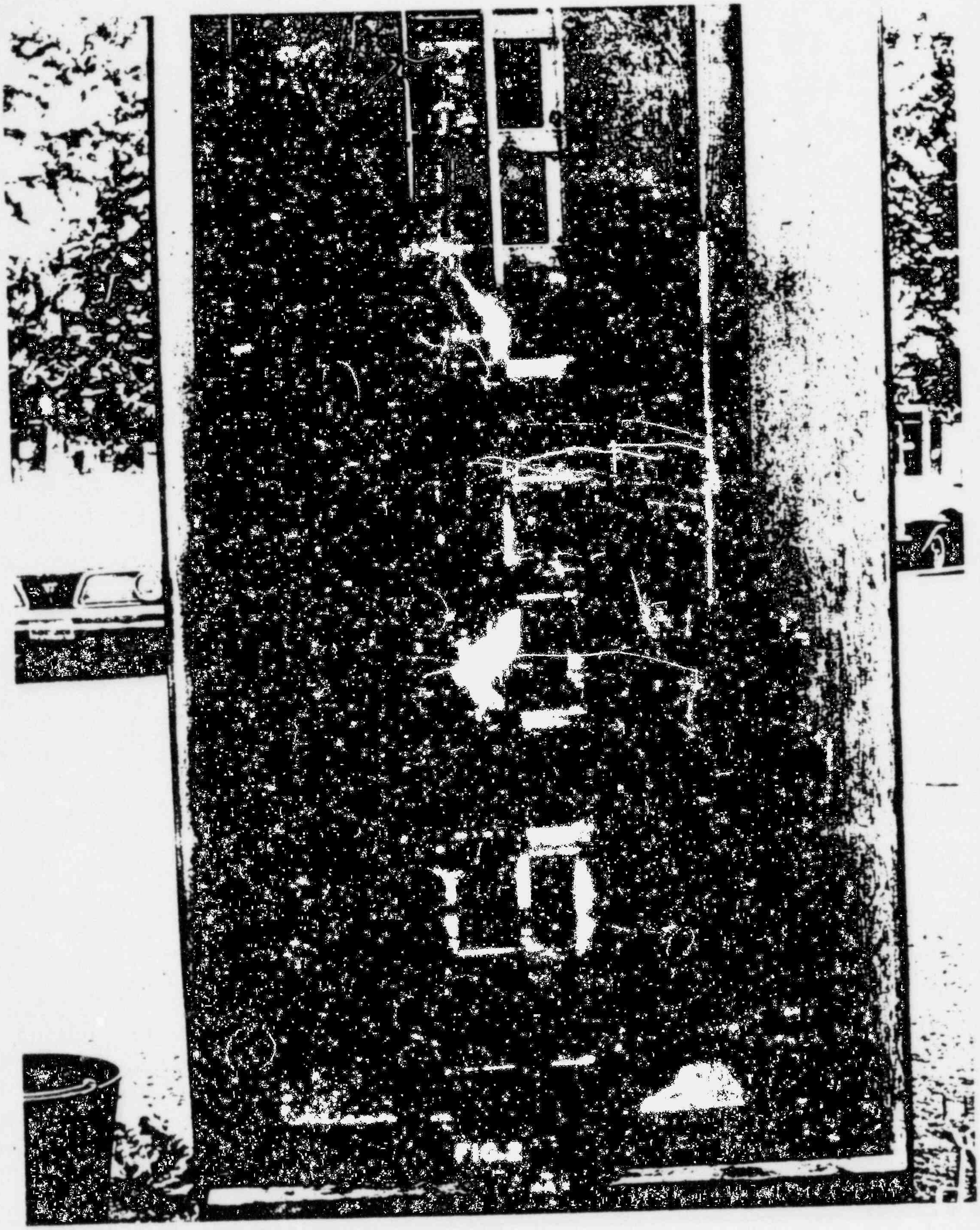
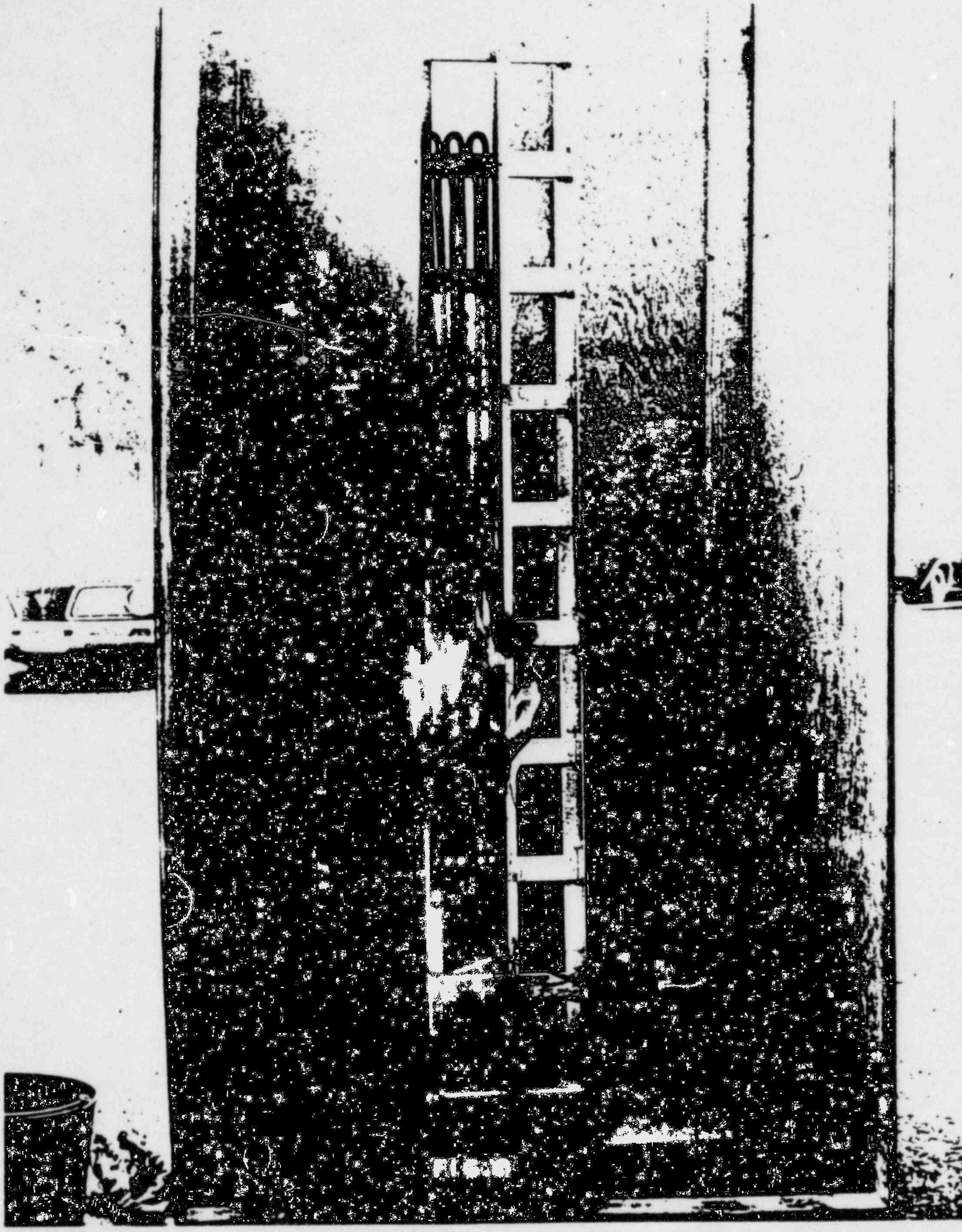


FIG.2



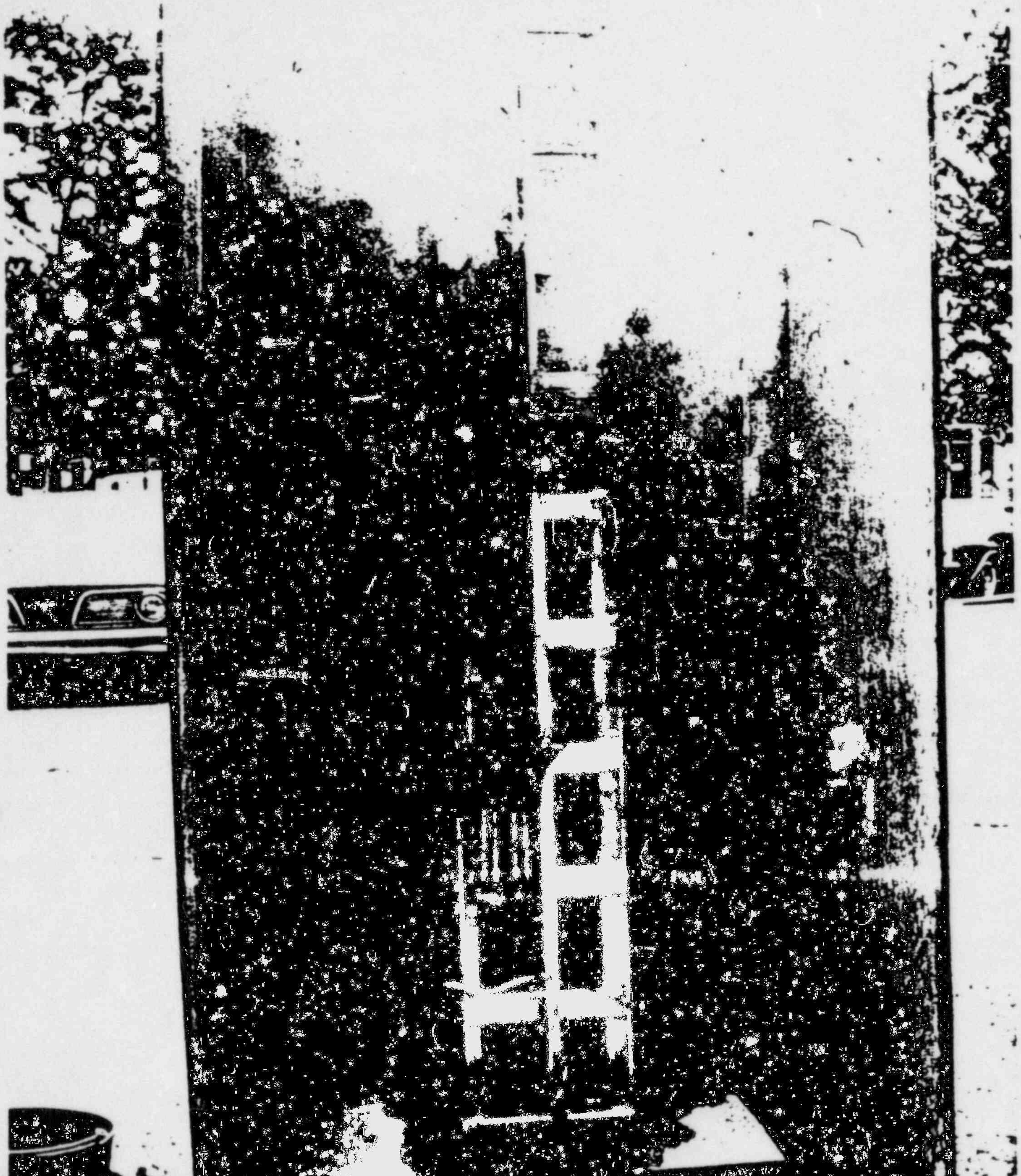


FIG. 9

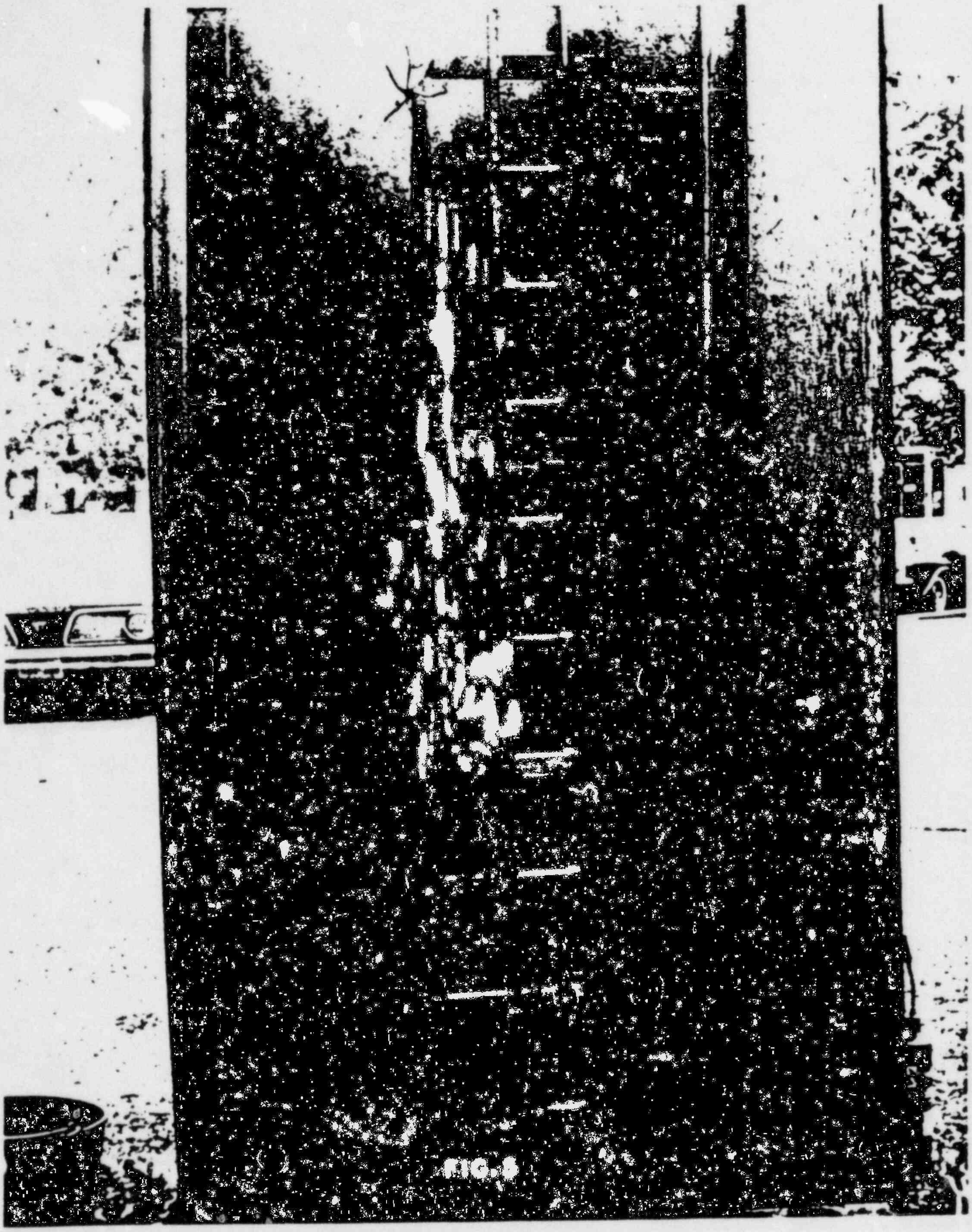
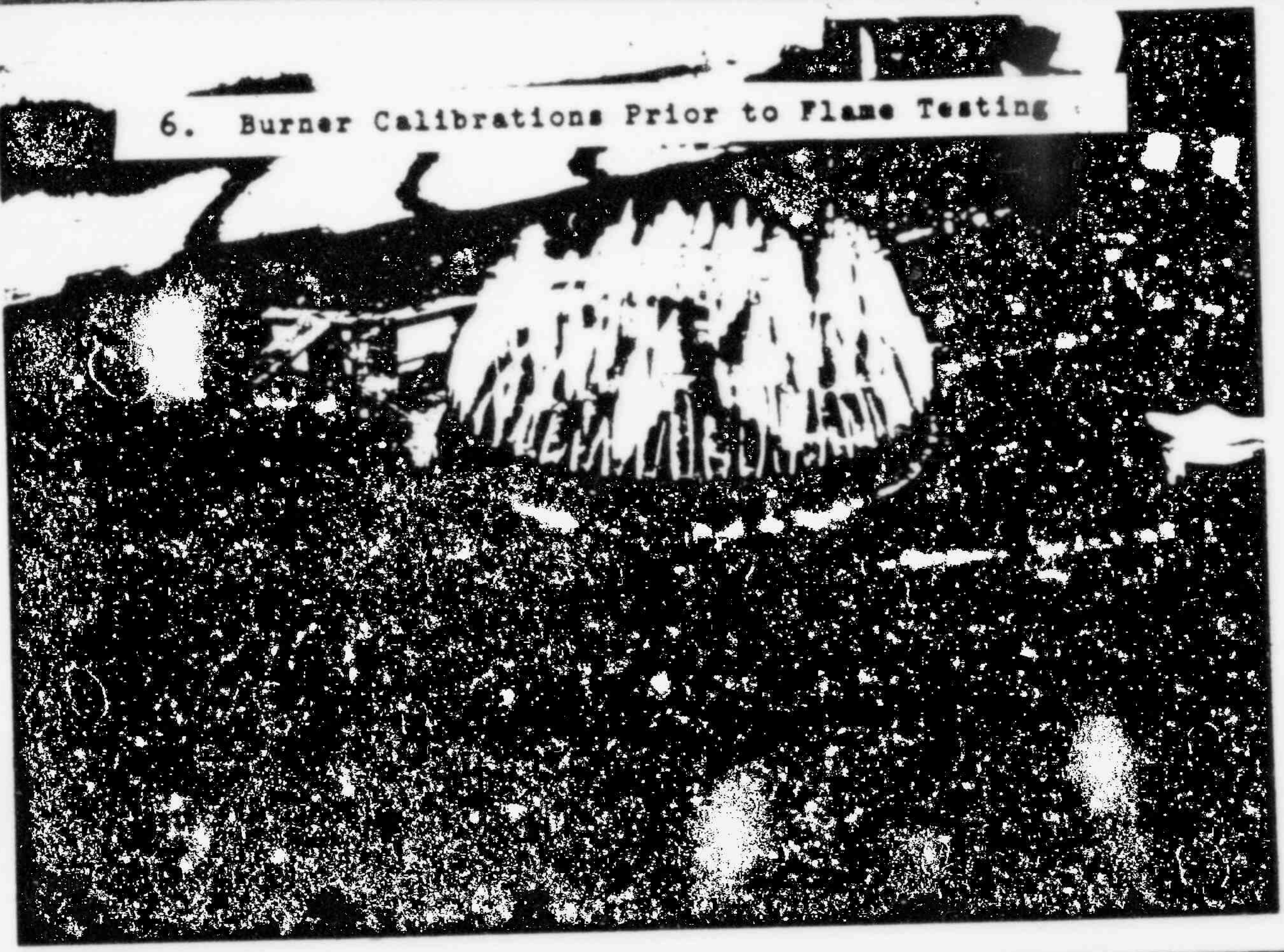
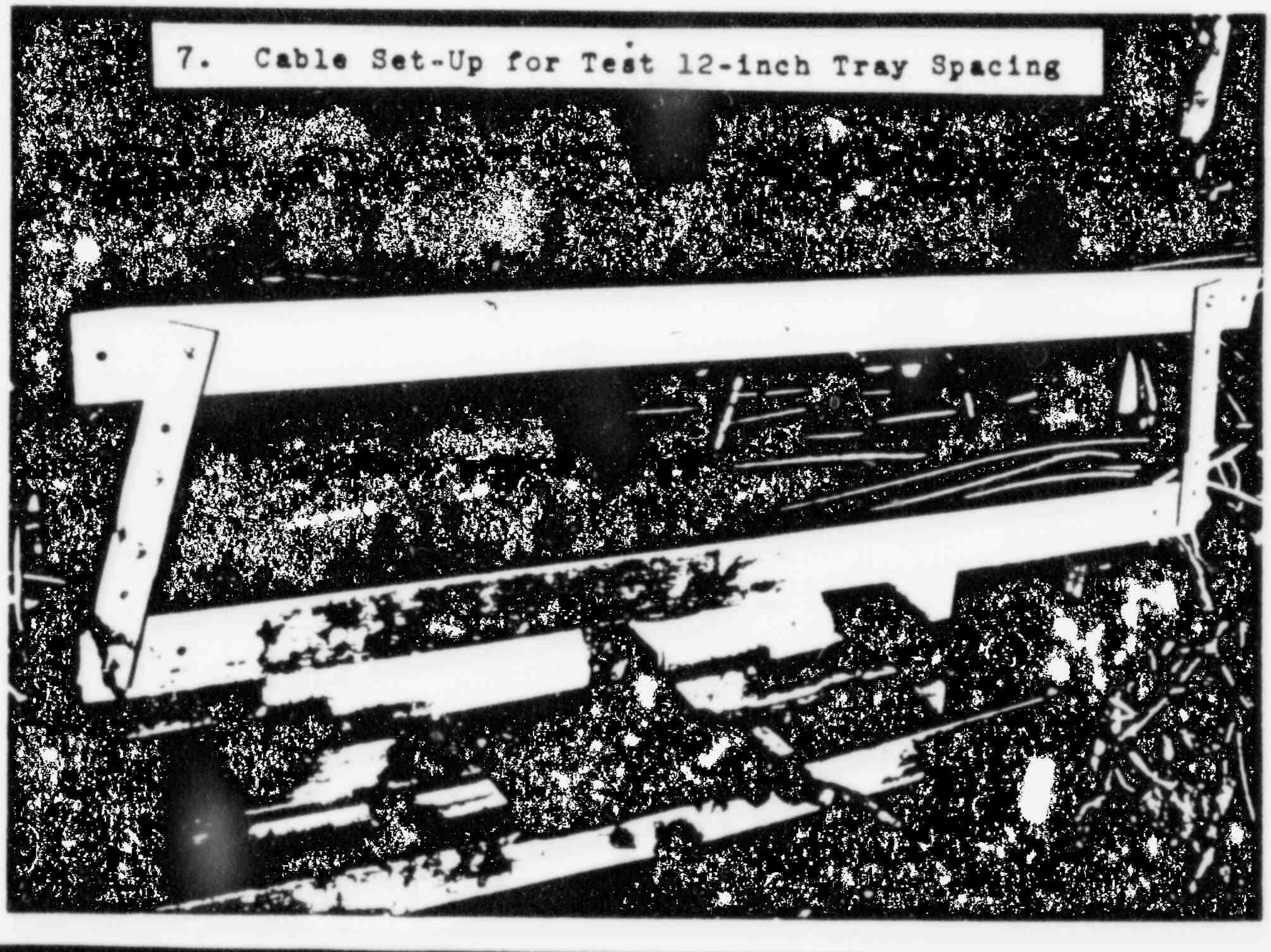


FIG. 6



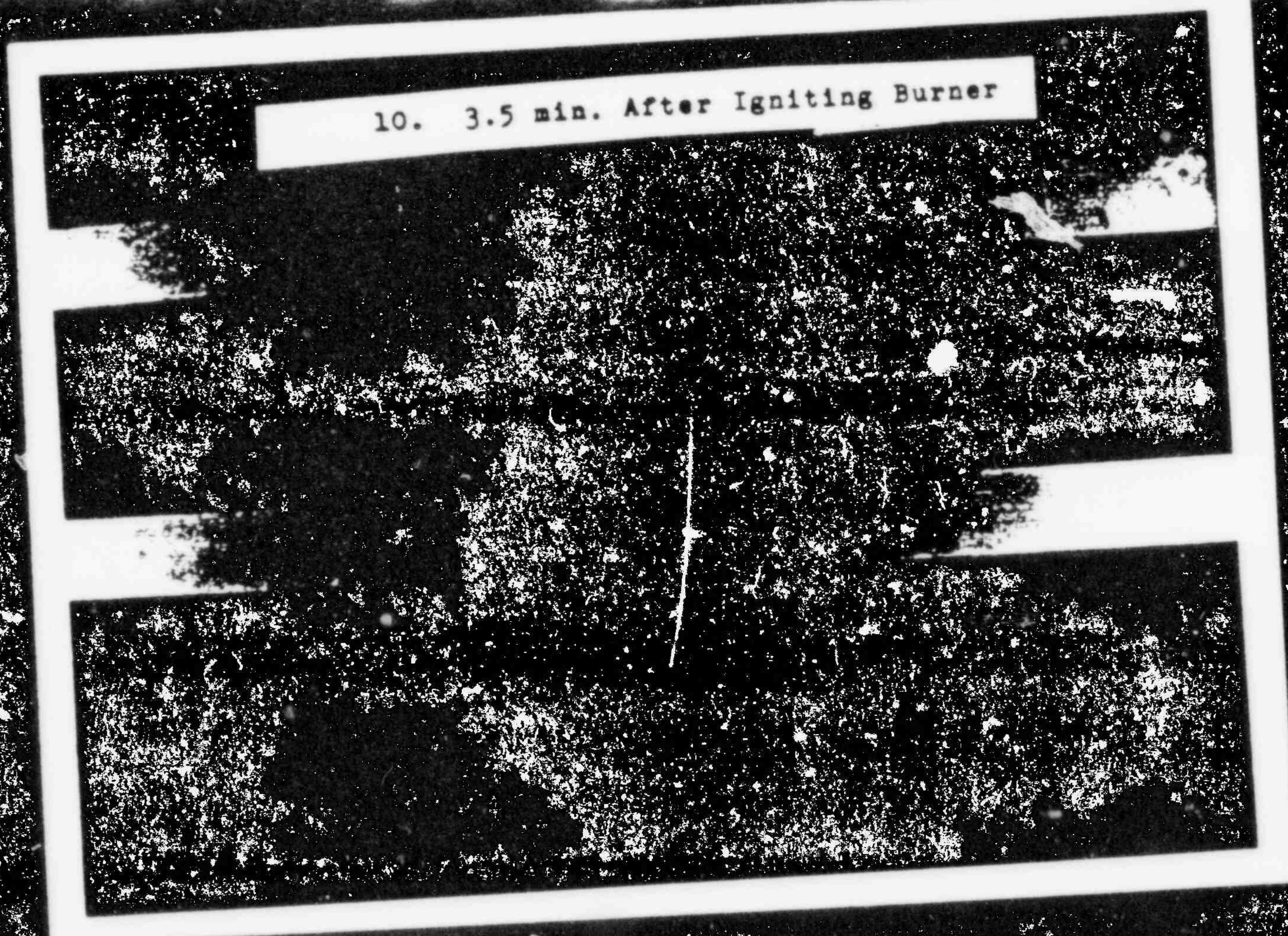
6. Burner Calibrations Prior to Flame Testing

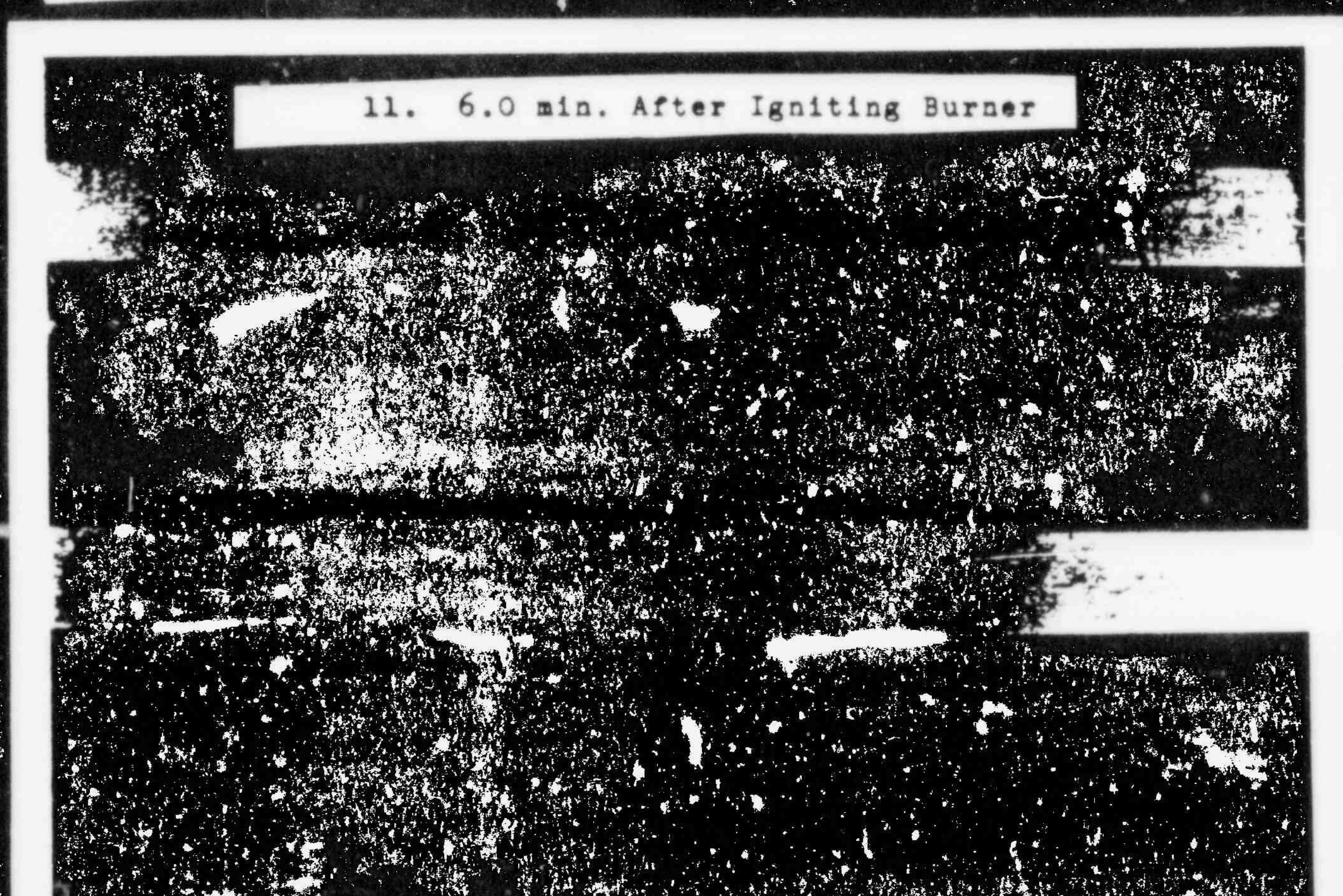


7. Cable Set-Up for Test 12-inch Tray Spacing

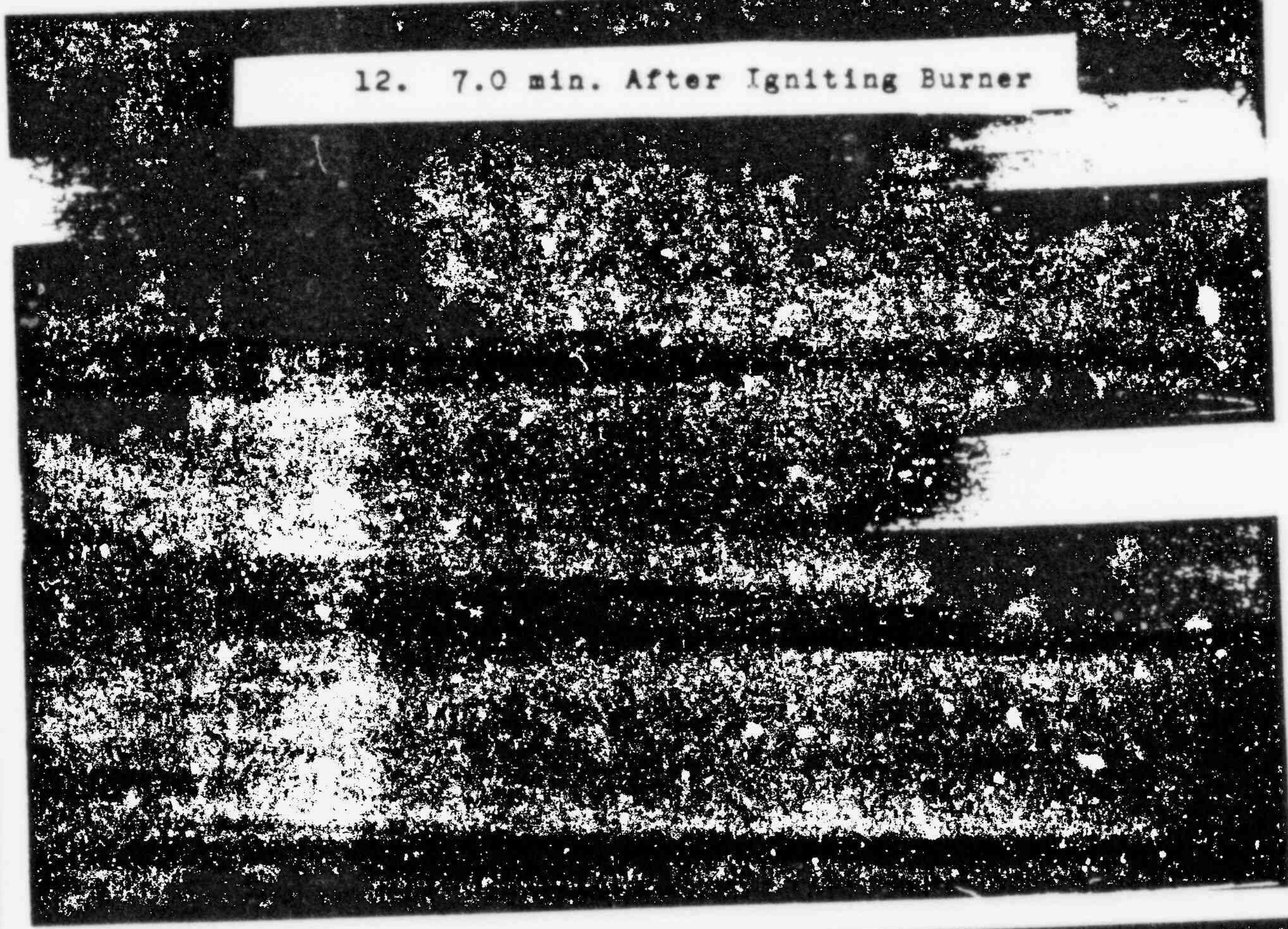
8. 1.5 min. After Igniting Burner

9. 2.5 min. After Igniting Burner

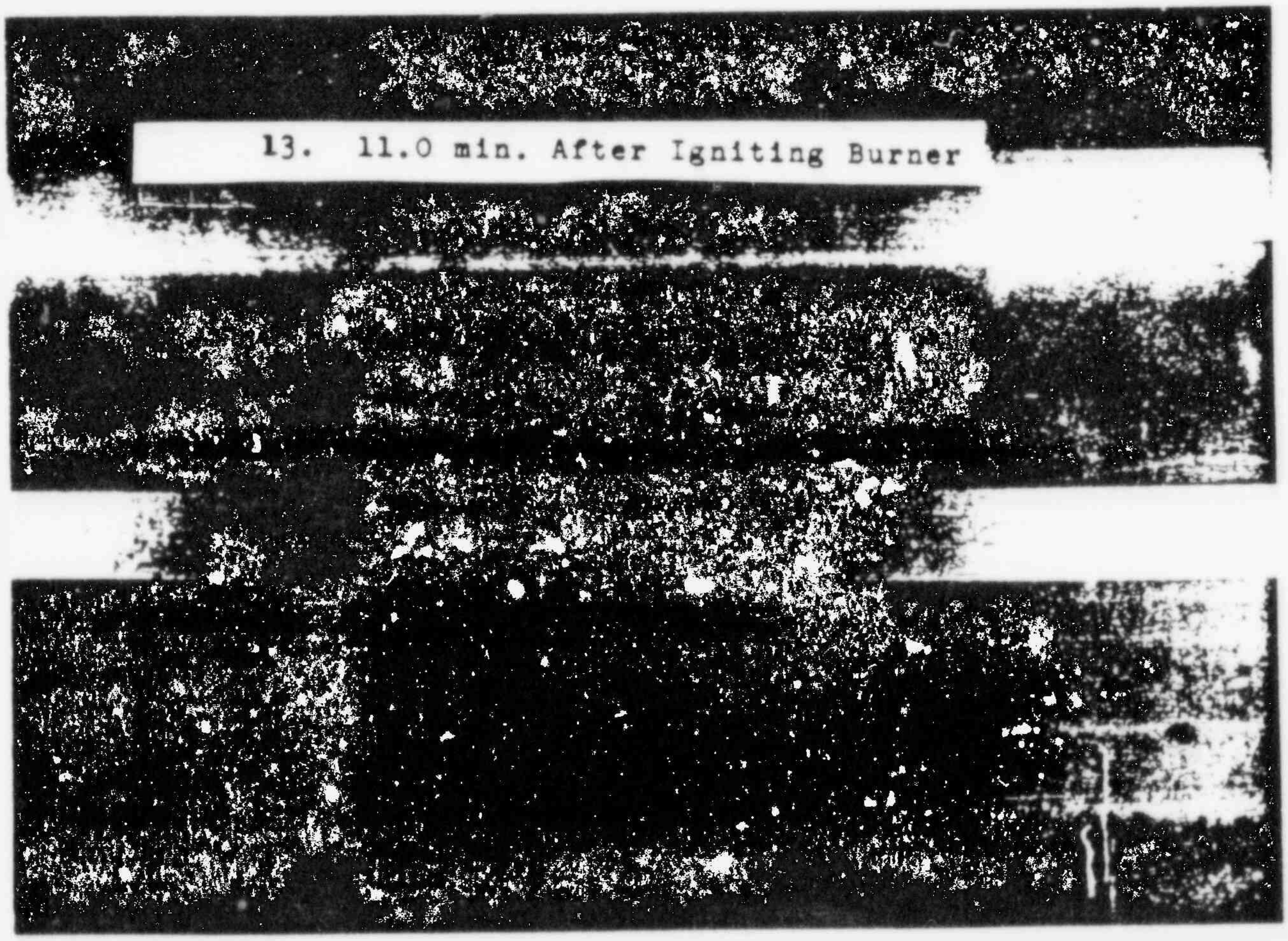

10. 3.5 min. After Igniting Burner


11. 6.0 min. After Igniting Burner

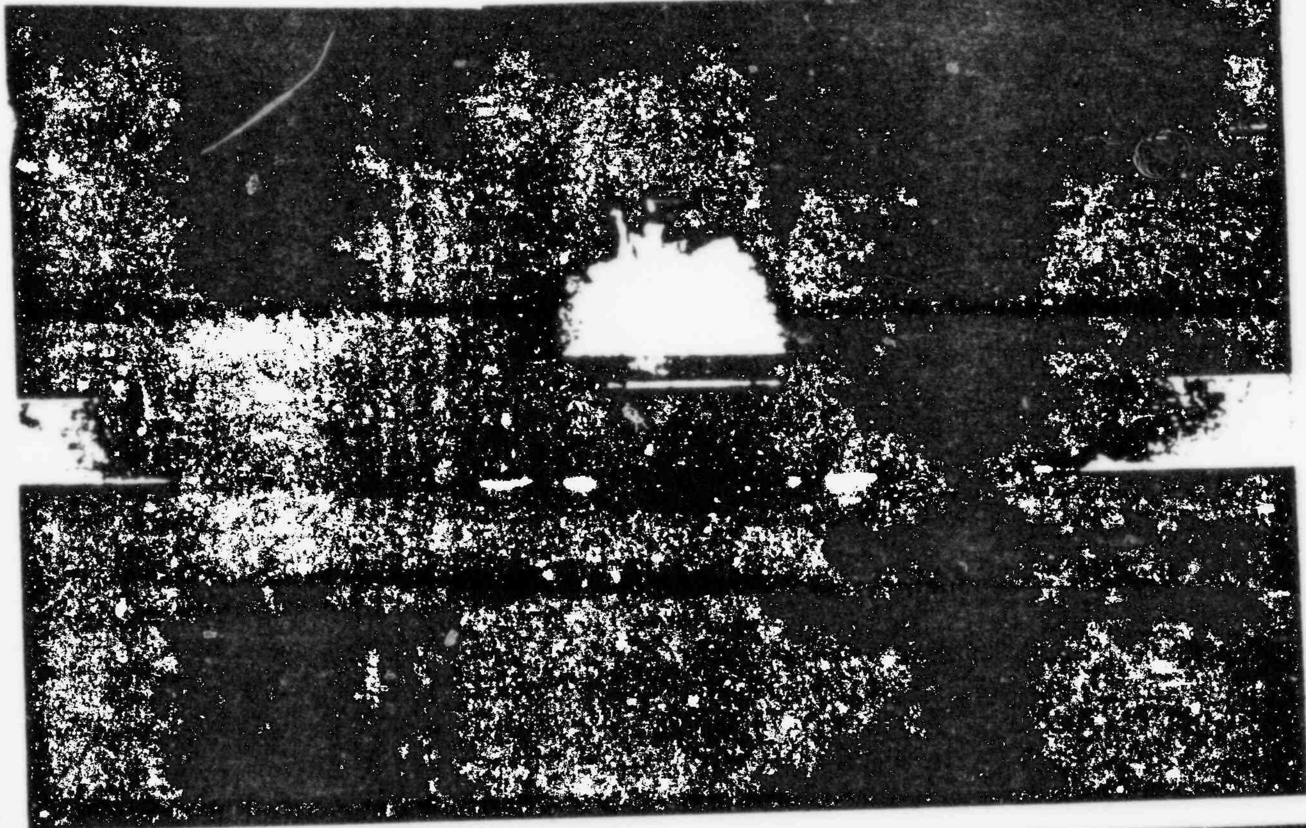
12. 7.0 min. After Igniting Burner



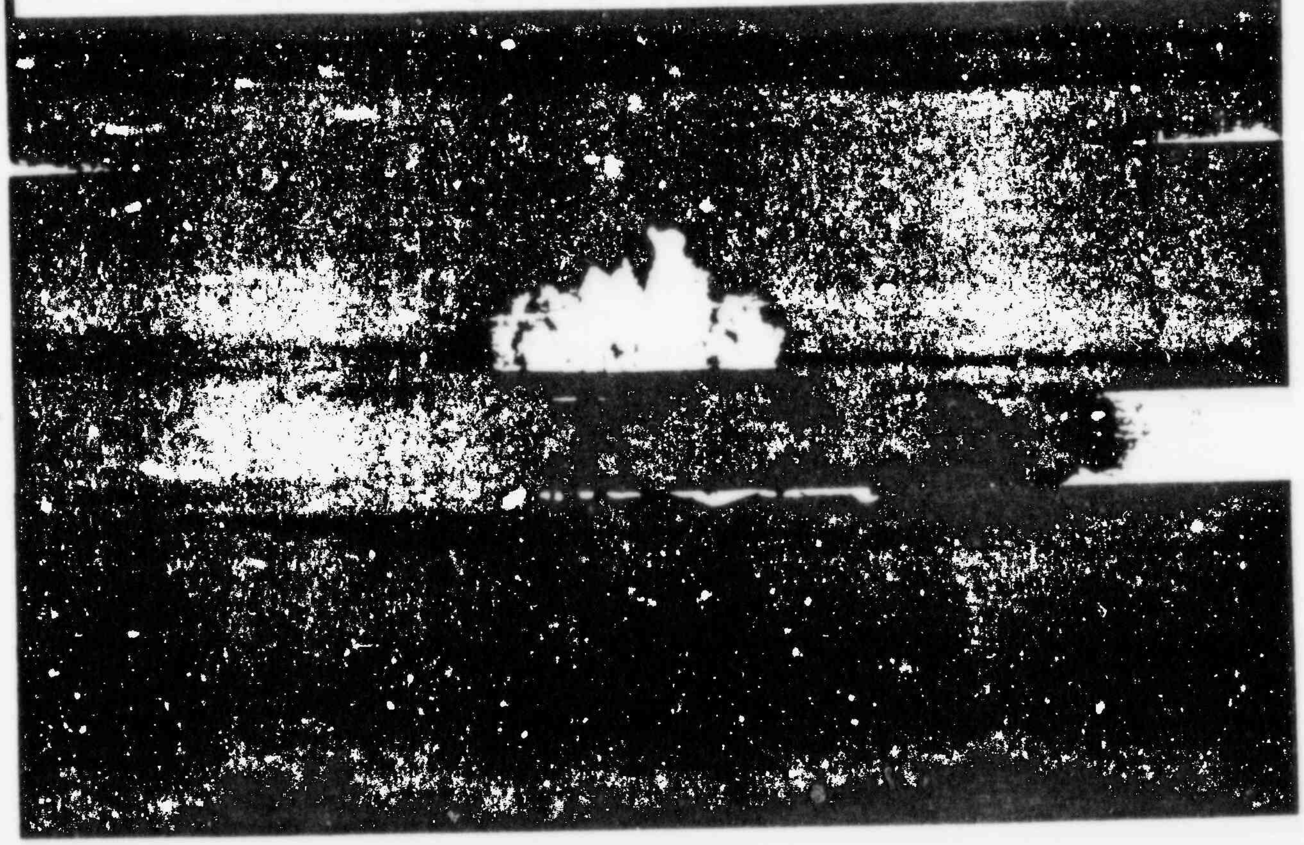
13. 11.0 min. After Igniting Burner



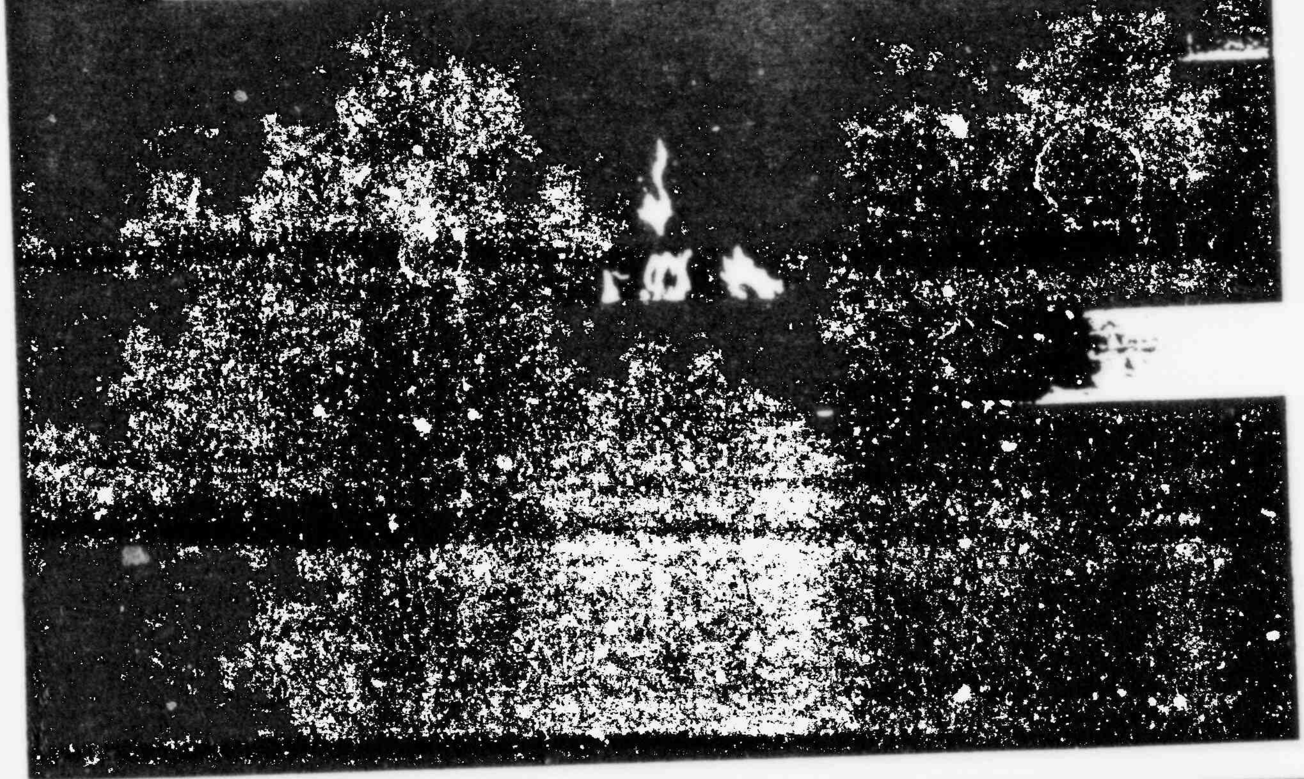
14. 14.5 min. After Igniting Burner Flame Around Back of Tray



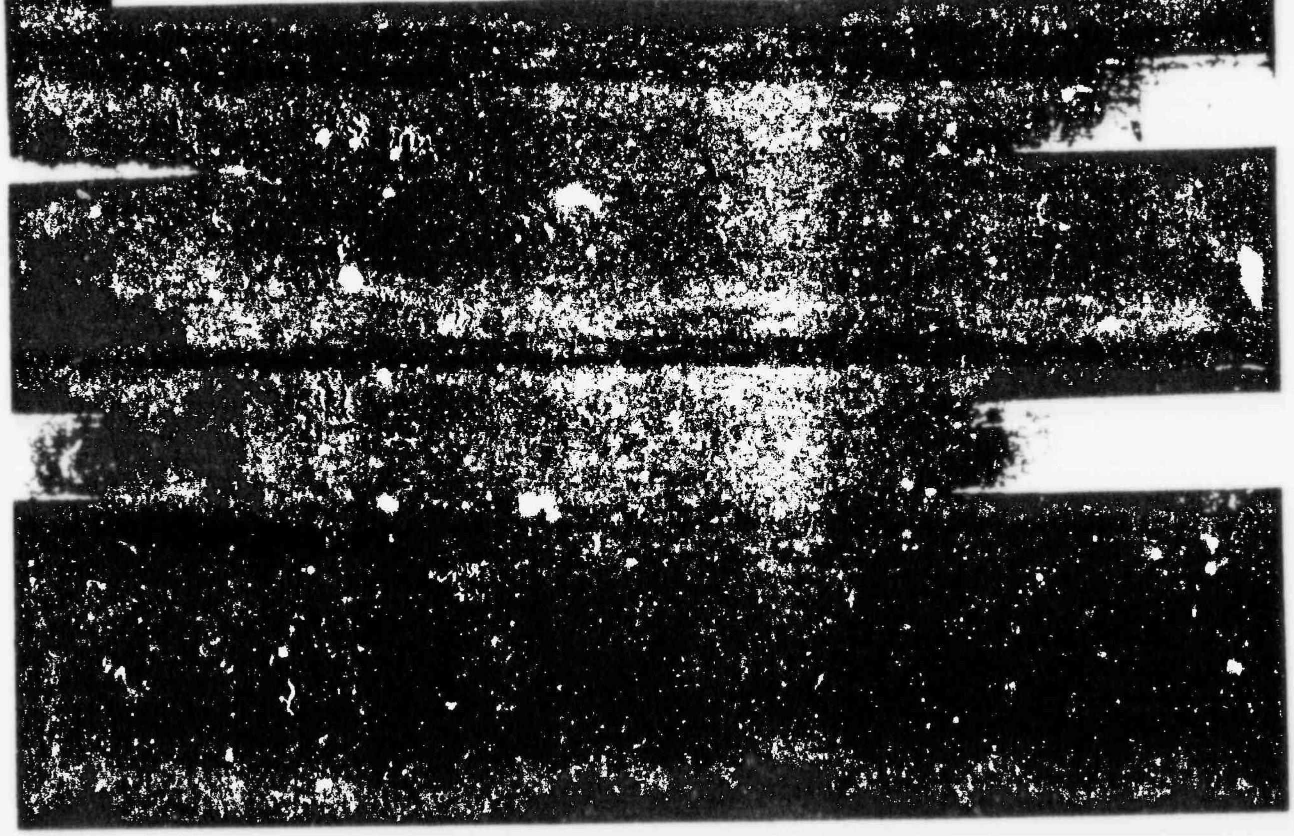
15. 15.0 min. After Igniting Burner Flame Around Back of Tray



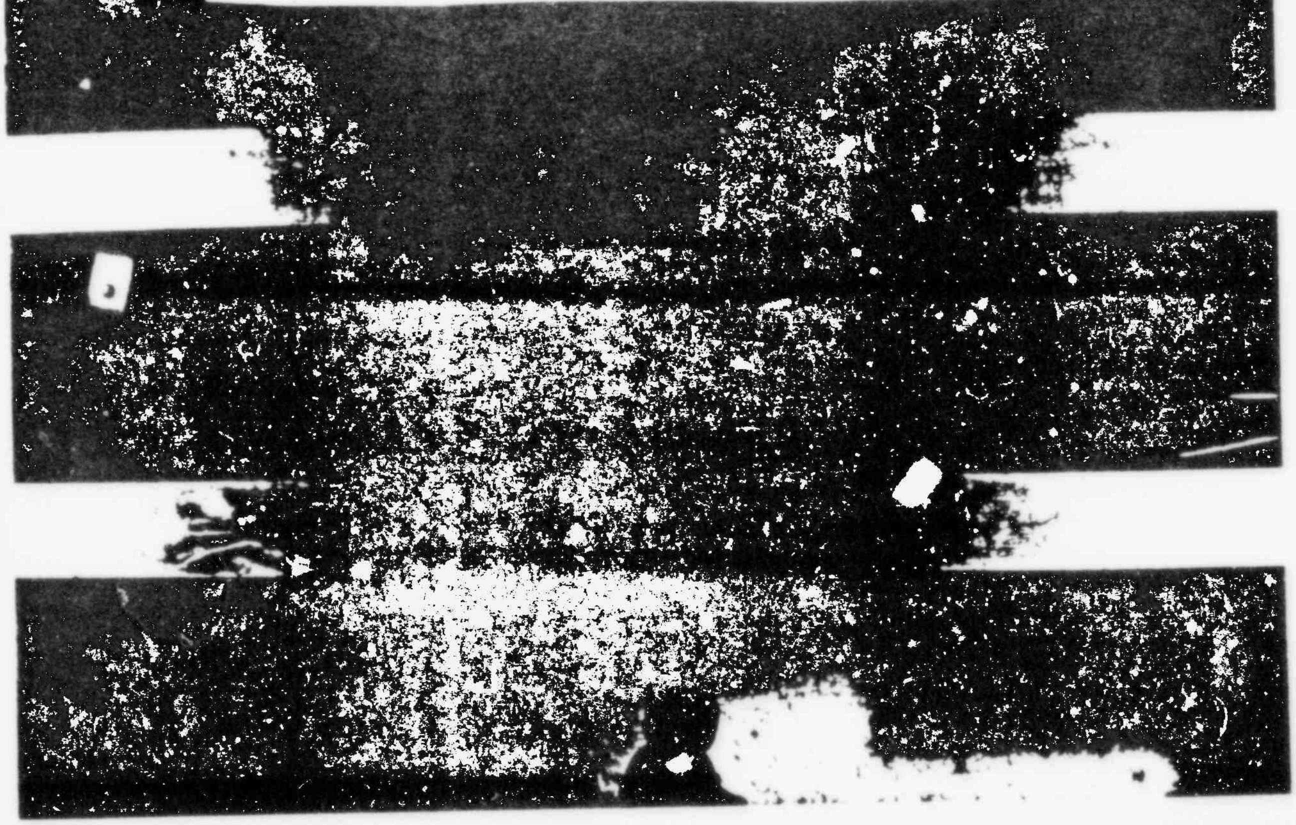
16. 30 seconds After Flame Turned Off



17. 7 min. 20 secs. After Flame Turned Off

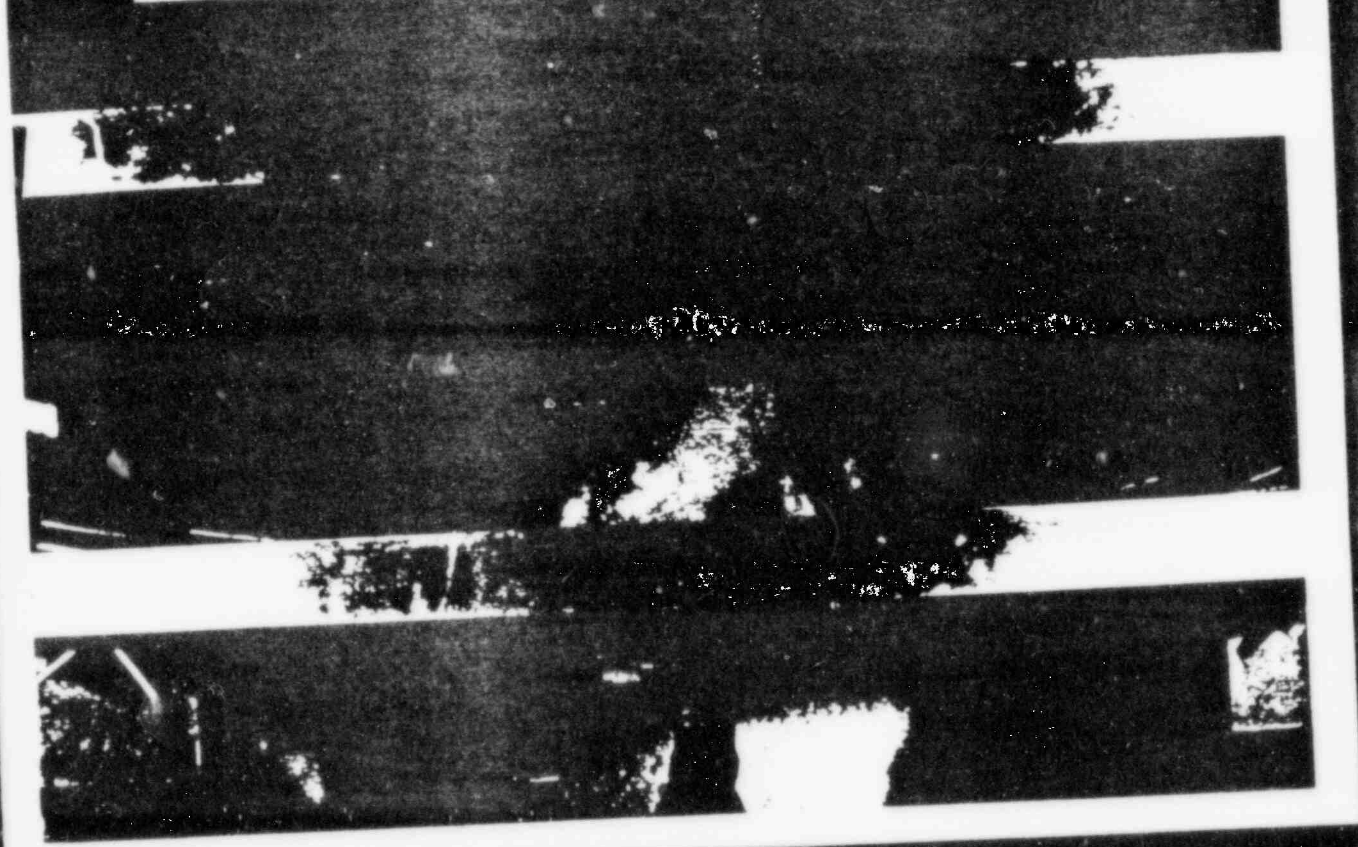


18. 22 min. 35 secs. Flame Out



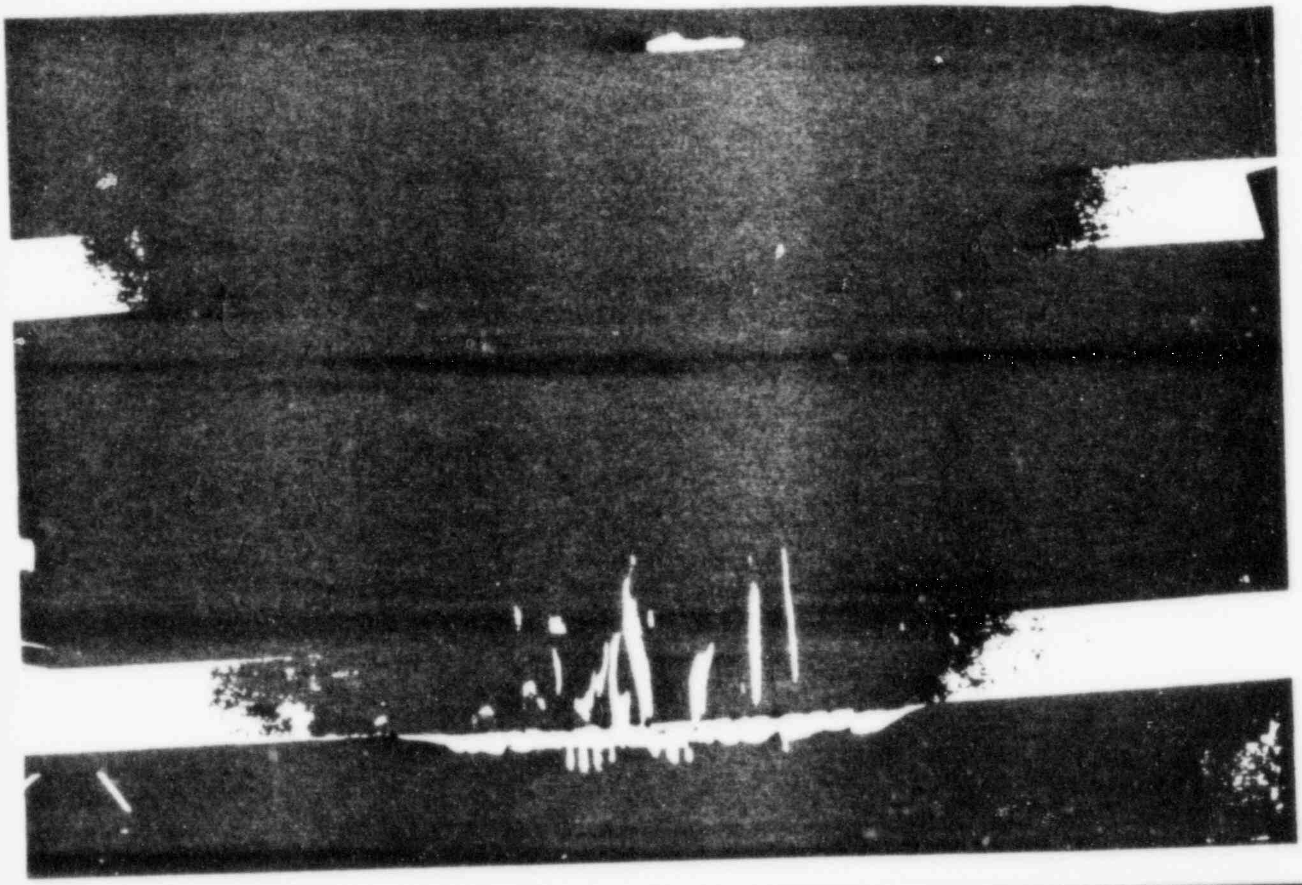
19. Test Set-Up 18" Tray Spacing

20. 40 sec. After Ignition Tray Spacing

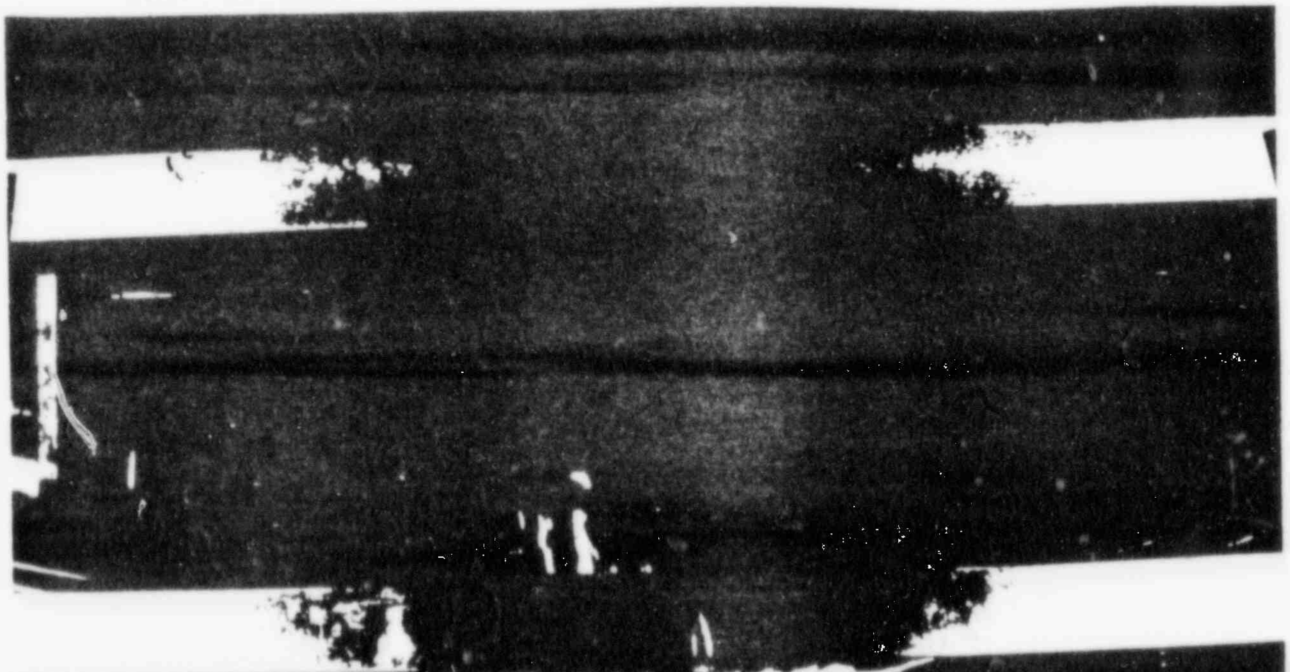


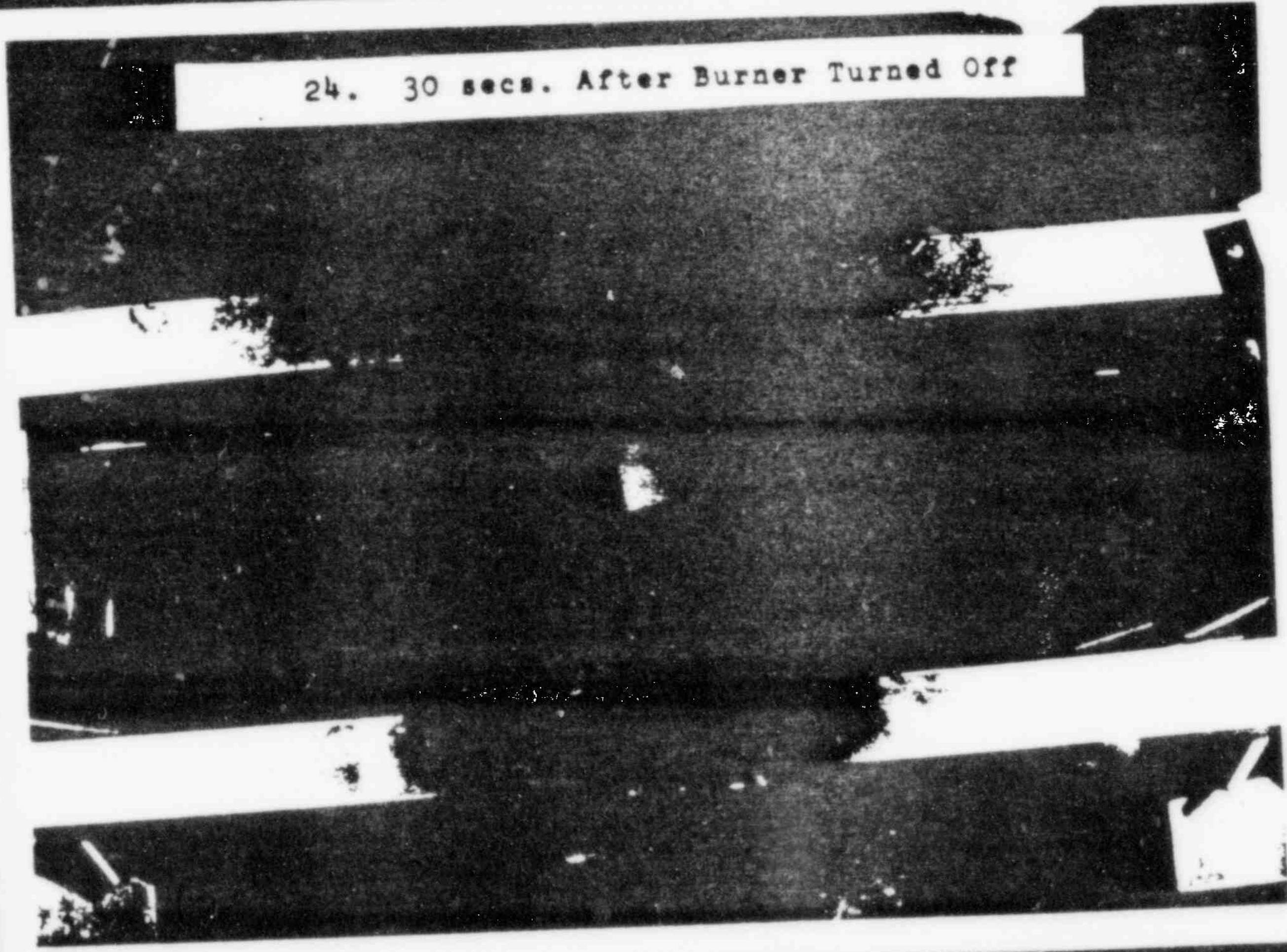
21. 3 min. After Ignition Flame Around Outside of Tray

22. 10 min. 20 secs. After Ignition Flame Around Outside of Tray



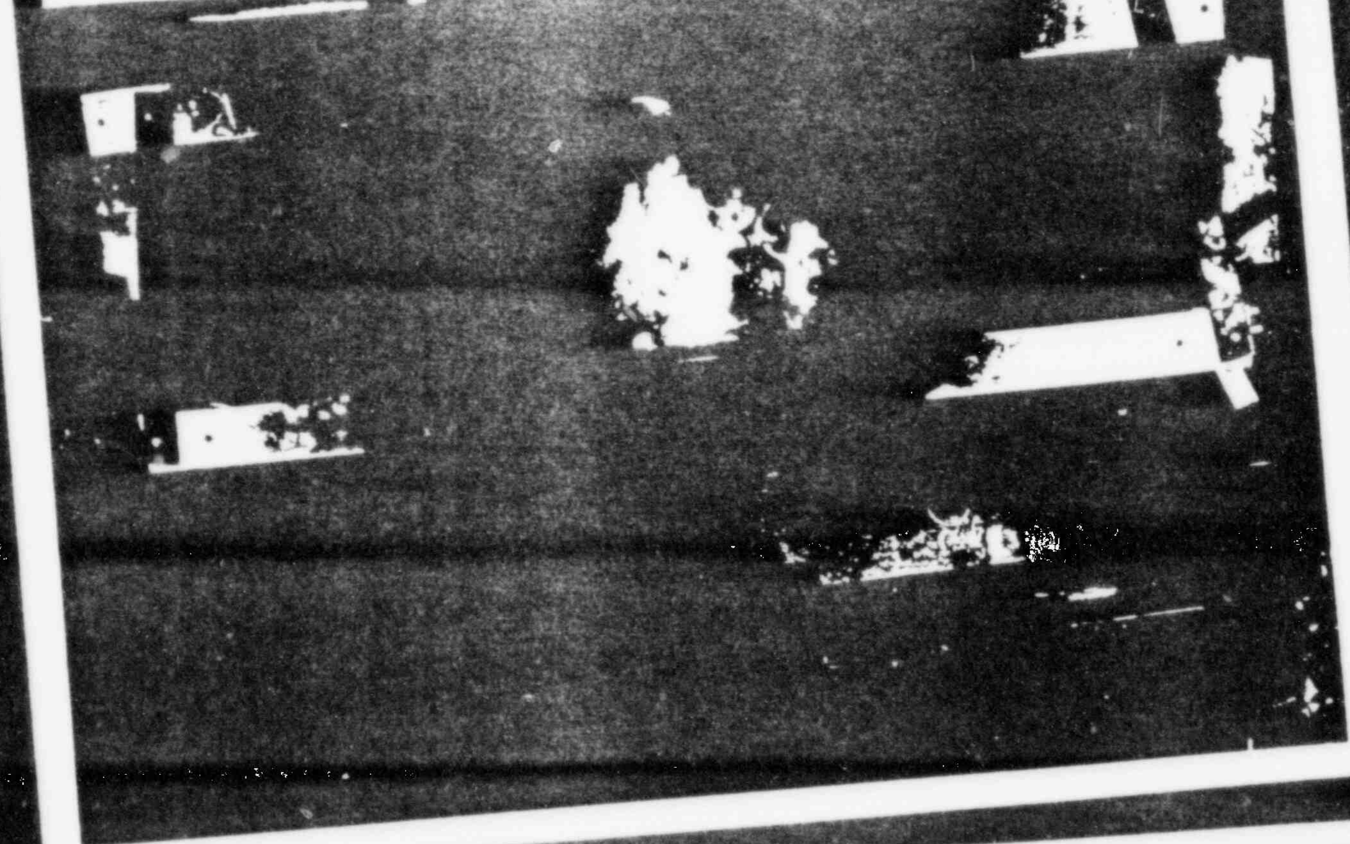
23. 17 min. After Ignition Flame Around Outside of Tray



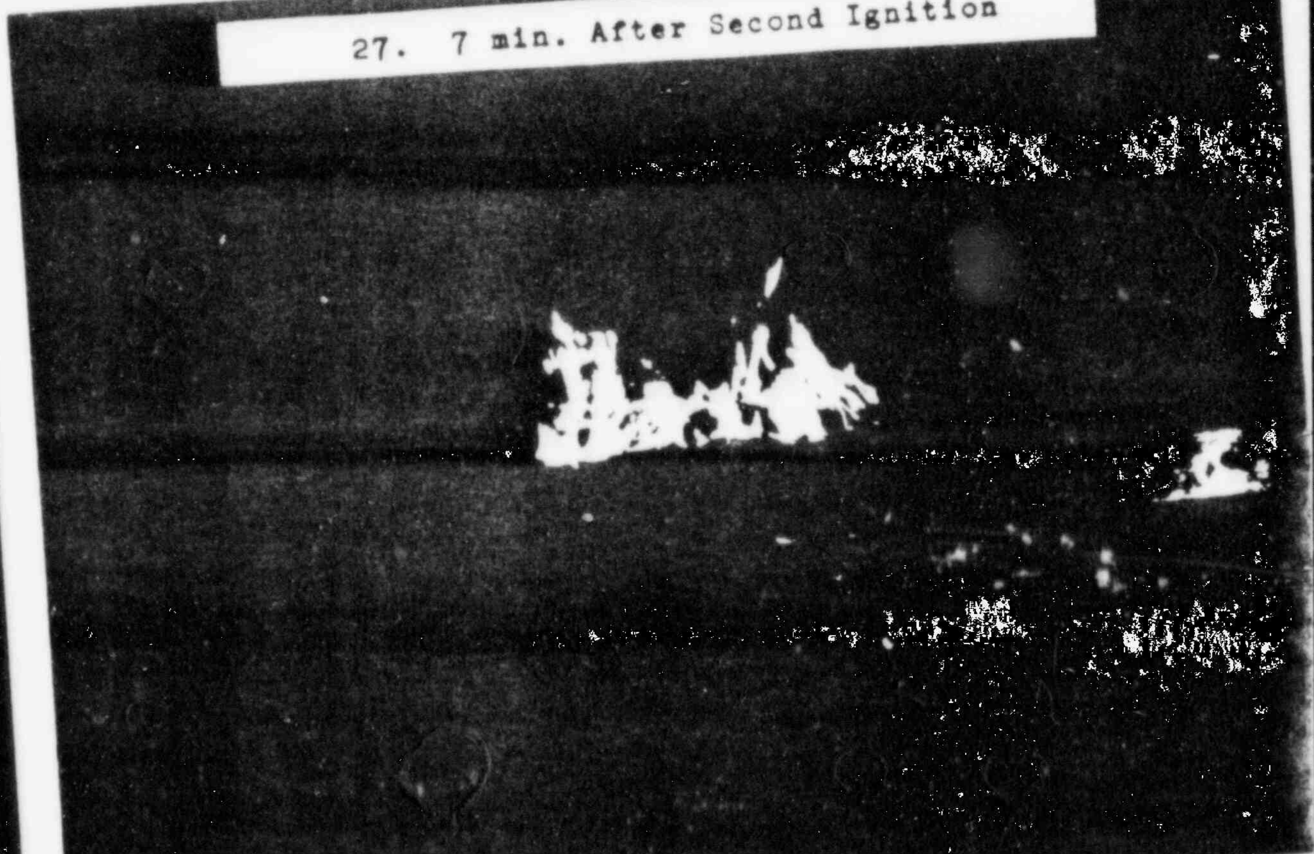


24. 30 secs. After Burner Turned Off

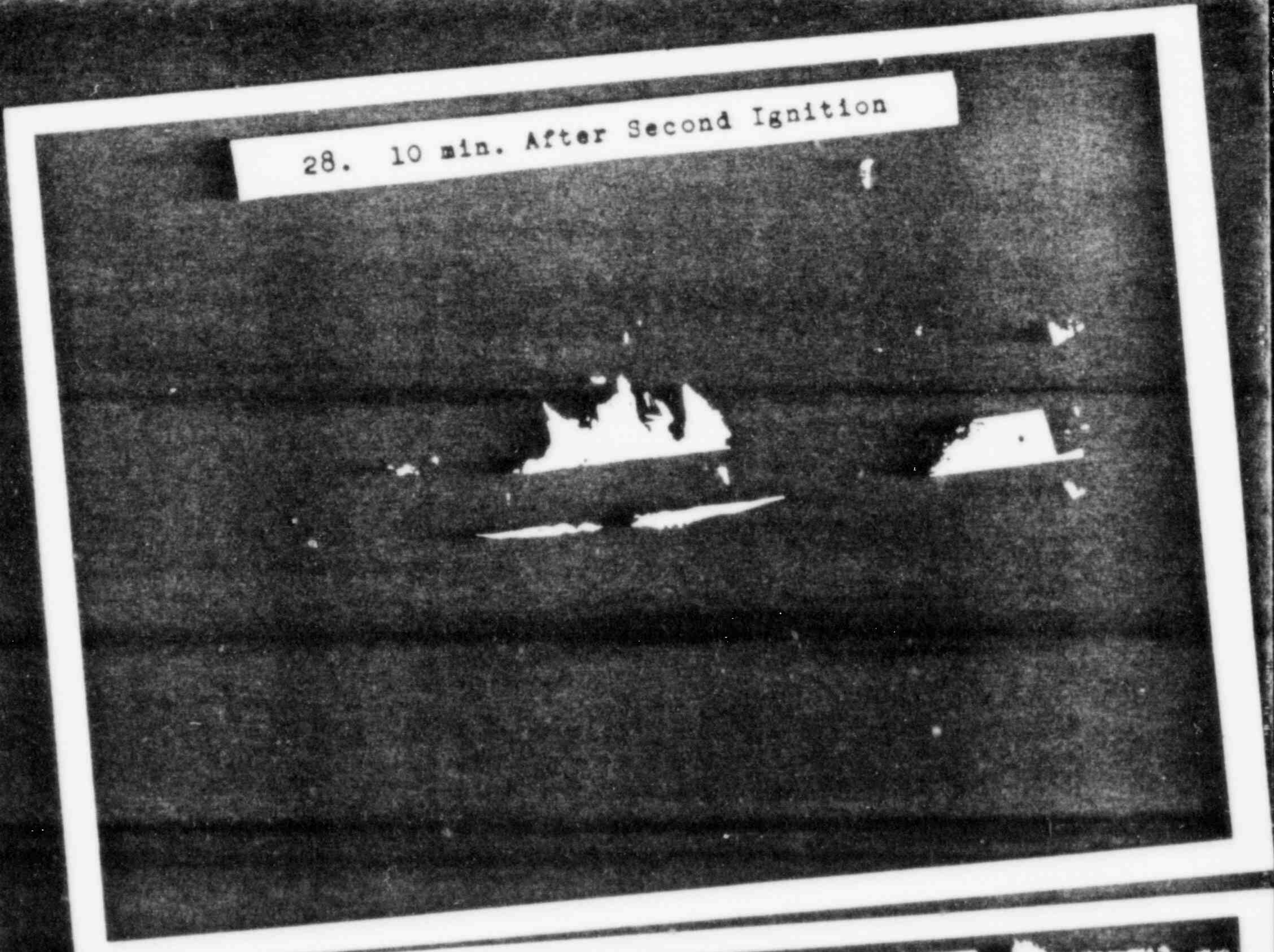
25. Observation of Top of Bottom Tray After Test



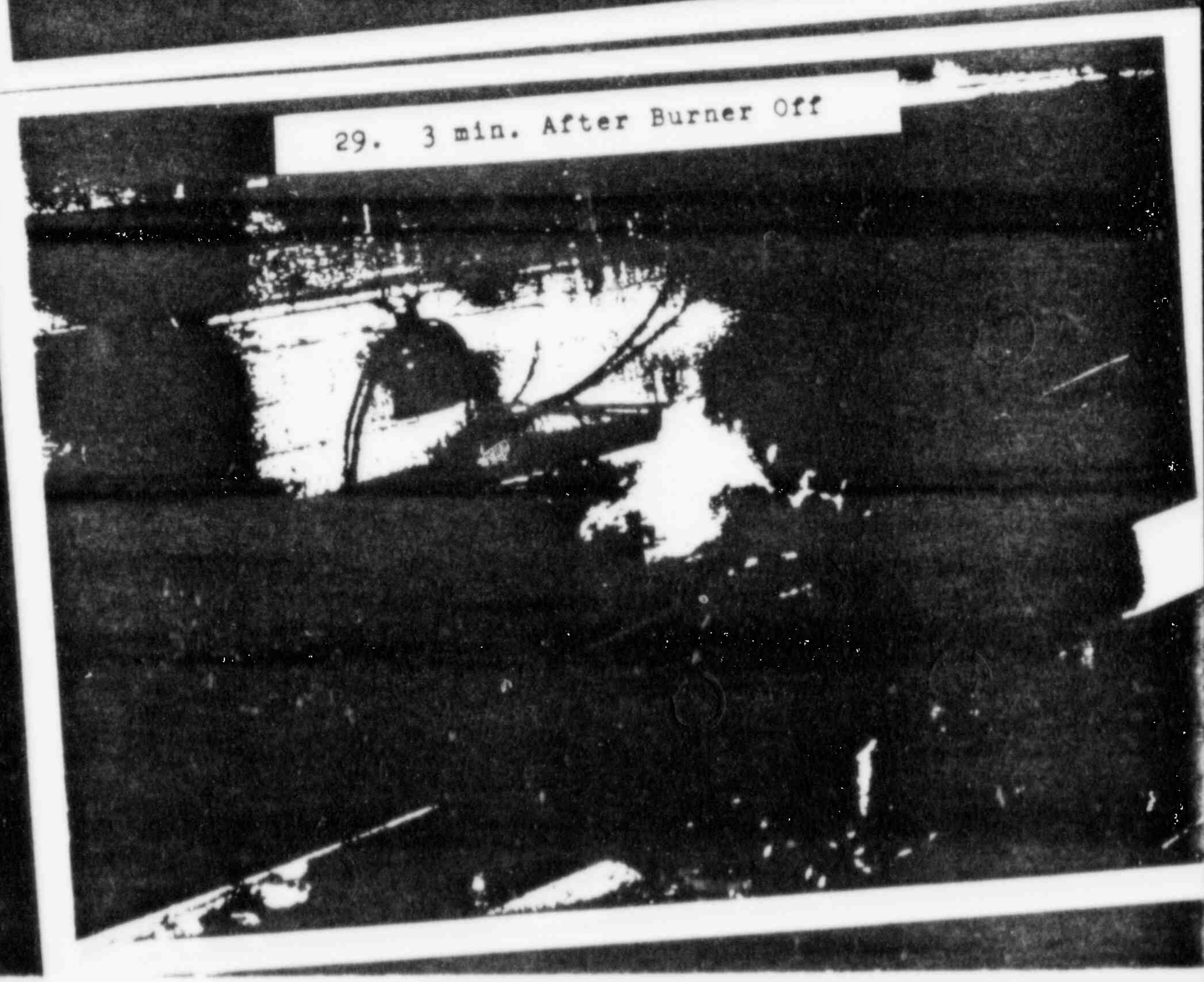
26. Cable Spread to Allow Flame to Extend Through



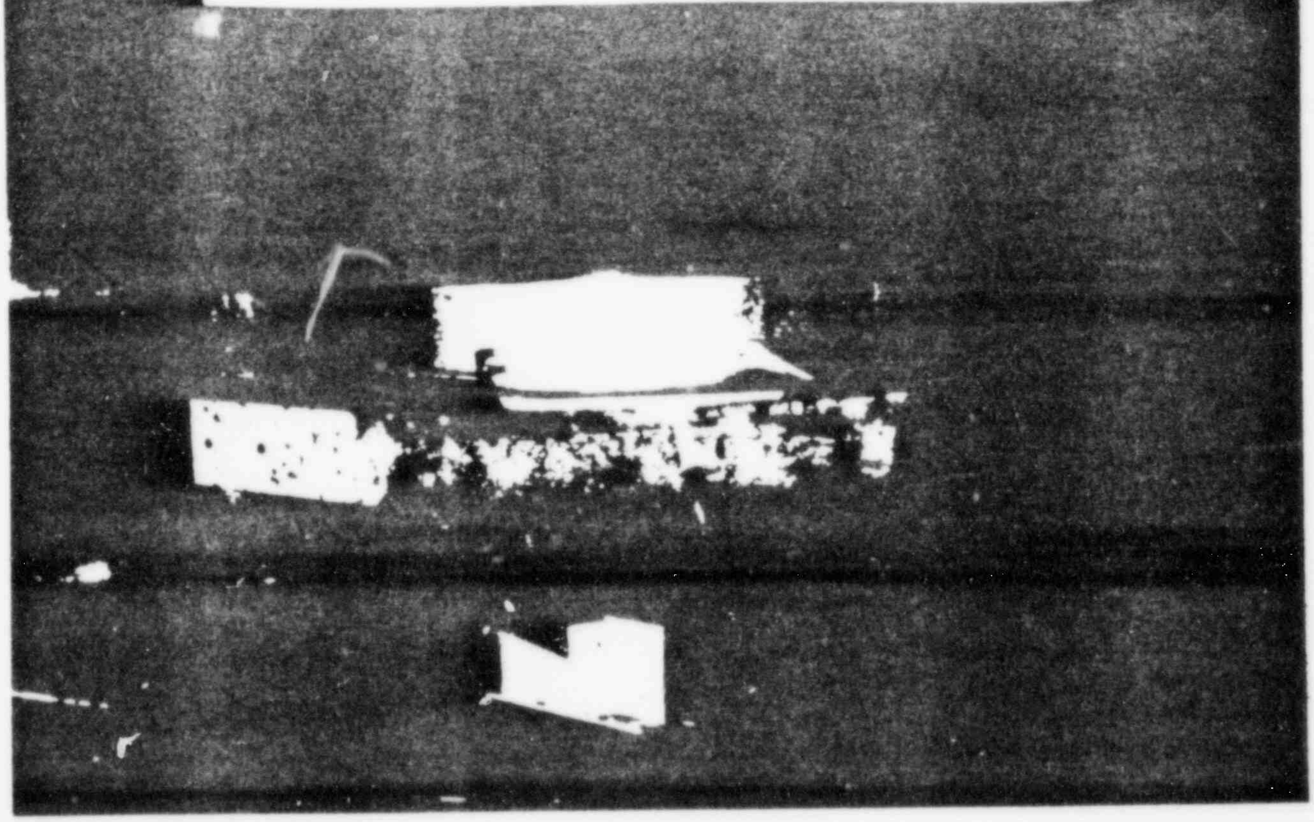
27. 7 min. After Second Ignition



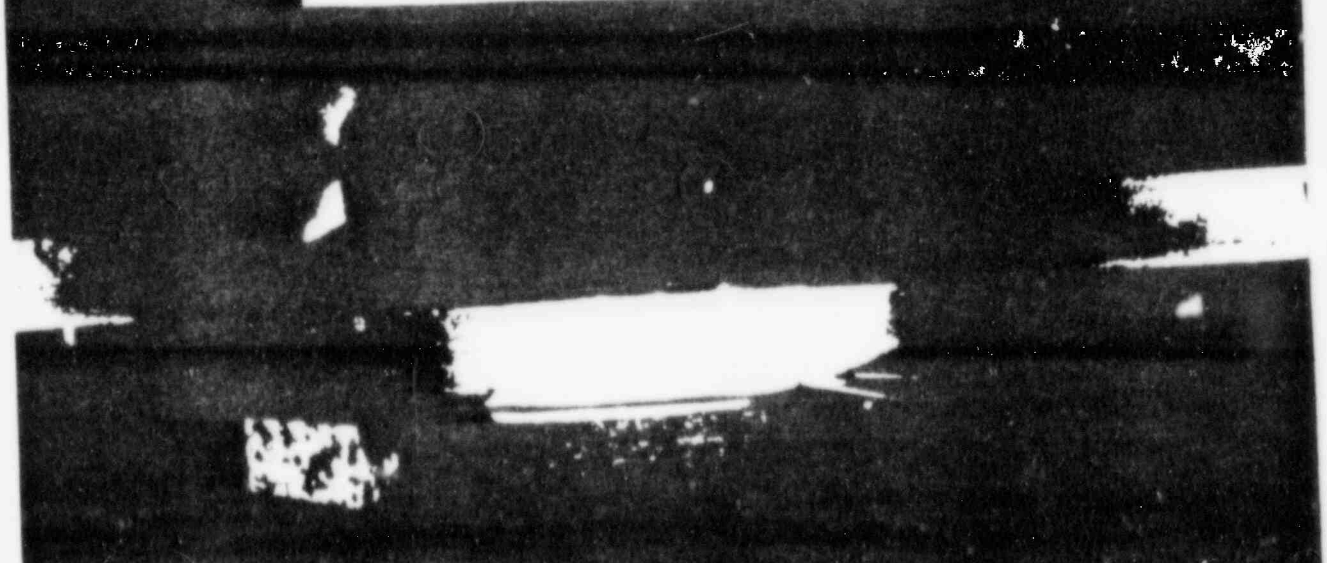
28. 10 min. After Second Ignition



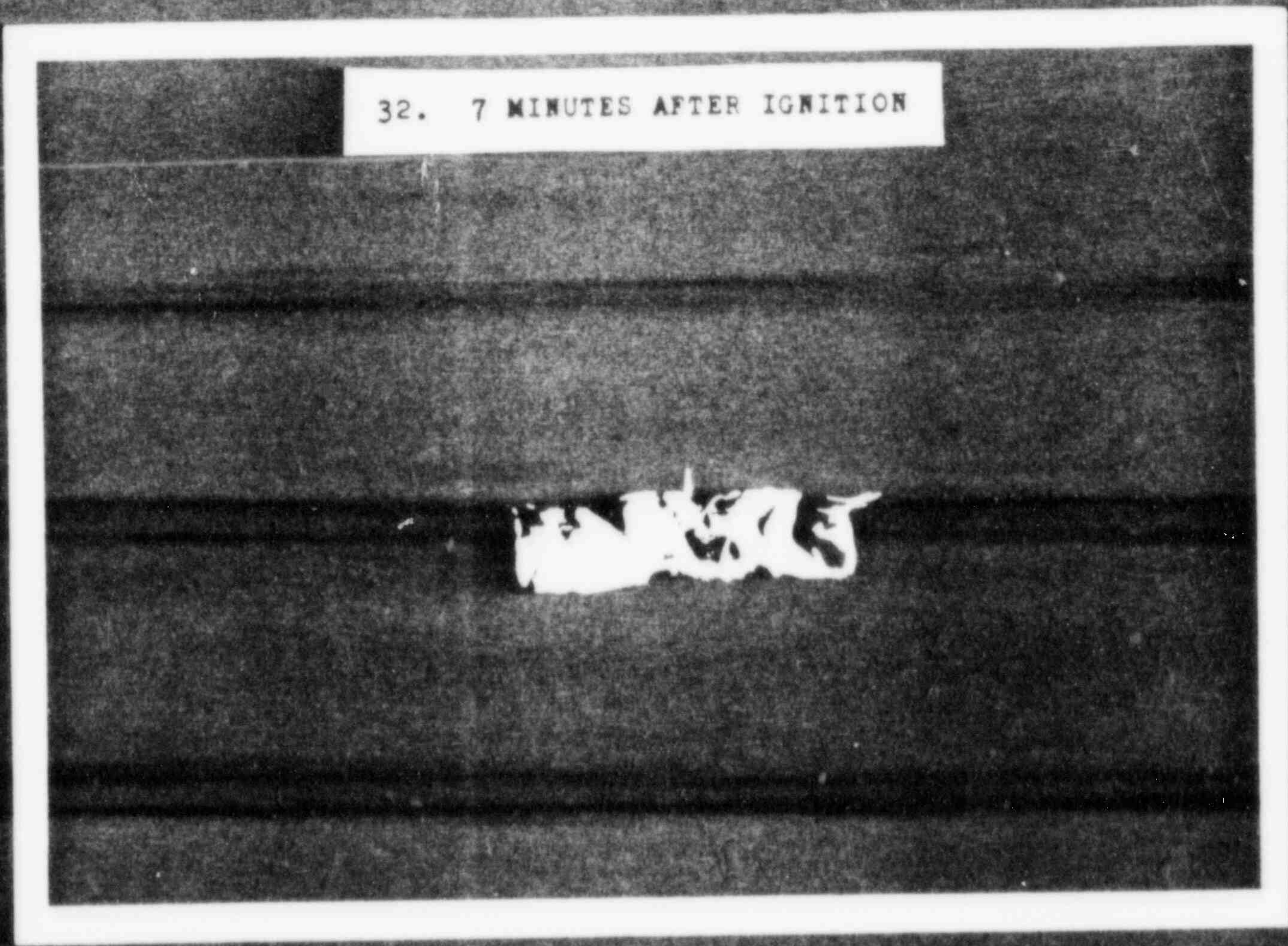
29. 3 min. After Burner Off



30. LIGHTING OF OIL - OIL FIRE TEST



31. 4 MINUTES AFTER IGNITION



32. 7 MINUTES AFTER IGNITION

IV. CABLE INSPECTION

As has been our long standing policy all cable for generating stations is checked by one of our qualified cable inspectors in the factory for compliance with our specifications. The cable manufacturer is required to provide certified test reports of all tests required in our specifications and the IPCEA Standards. Our inspectors check that all required tests are performed and verify that the test results meet the characteristics required in our specifications.

Detailed inspection reports are issued by our inspectors for each inspection. Control cable inspection reports contain the following information:

Our inspector's report on single conductors includes the following:

1 - Test report number

2 - Date

3 - Station name

4 - Reel number

5 - Conductor size

6 - Length on reel

7 - Conductor outer diameter

8 - Insulation thickness

9 - Jacket thickness

10 - Centering of conductor

11 - AC and DC tests - record voltage, time and pass or fail

12 - Insulation Resistance

13 - Conductor Resistance

14 - Indicate quantity accepted and rejected

15 - Inspector's signature

For Items 7-13 the specified and the observed values are included in the report. The inspector also takes one three foot sample from each reel of single conductor back to the laboratory for testing of physical characteristics. Each sample is tagged with the reel number, date, station name and test report number.

Our inspector's report on finished cables includes the following:

1 - Test report number

2 - Date

3 - Station name

4 - Reel number of finished cable

5 - Reel numbers of single conductor which made up finished cable

6 - Type of cable

7 - Length on reel

8 - Cable outer diameter

9 - Painting on single conductors for numbering and readability

10 - Footage marker tape

11 - Bedding Tapes (2) - thickness and lap

12 - Asbestos Mylar Tape - thickness and lap

13 - Corrugated Metal Tape - thickness and lap

14 - Outer jacket thickness

15 - AC and DC tests - record voltage, time and pass or fail

16 - Indicate quantity accepted and rejected

17 - Inspector's signature

For Items 8 and 11-15 the specified and the observed values are included in the report. The inspector also takes one, one foot sample of finished cable from every other reel back to the laboratory for testing of physical characteristics. Each sample is tagged with the reel number, date, station name and test report number.

Inspection reports similar to the above are also issued for power cables.

Cable Derating

The normal current rating assigned to power cables is limited to that continuous value which does not cause excessive insulation deterioration from heating. The current ratings listed in "Power Cable Ampacities," published by the Insulated Power Cable Engineers Association (IPCEA-IEEE) are derated for the specific application of grouped conductors in tray or conduit and then is further derated 10% to provide a margin of safety. It is assumed in these calculations that all conductors are carrying rated current continuously. We believe this method of calculating current ratings is conservative because the number of different conductor sizes is limited and the chance that a group of conductors will all be carrying full normal rated current is remote.

The following table and notes indicate the step by step procedure used in calculating the normal current ratings for generating station power cable applications.

Voltage Class	Cond. Size	In Tray		In Conduit	Normal Rating
	Note 5	Note 1	Note 2	Note 3	Note 4
5 kV	2/0	257	211	221	189
	350M	467	383	387	344
	500	578	474	473	425
	750	728	596	579	520
600	12	36	27	30	24
	6	89	66	75	60
	2	158	117	130	105
	2/0	247	183	204	165
	350M	464	342	384	308
	500	580	430	477	387
	750	747	552	598	497

Note 1 The figures indicated in this column are from the published IPCEA ampacities for 90°C total temperature, three single 5 kV shielded and 600 V. to 5 kV non-shielded conductors in air.

Note 2 The figures indicated in this column have been obtained by multiplying the figures in the column under Note 1 by the following derating factors:

(a) For 5 kV cables a derating factor of 0.82 which represents the derating factor to be applied per IPCEA for a single, spaced layer of cable in tray.

(b) For 600/1000 Volt cables a derating factor of 0.74 which represents the standard derating factor to be applied per IPCEA for two layers of cable in tray.

Note 3 The figures indicated in this column are from the published IPCEA ampacities for three single conductors in one isolated conduit.

Note 4 The figures indicated in this column have been obtained by multiplying the lowest of the ampacity figures in the columns under Note 2 and Note 3, by an additional derating factor of 0.90. These final ampacity figures are used to determine conductor sizes for all generating station power cable applications.

Note 5 The minimum cable size to be used for each application is 2/0 for 4160 Volt, #6 for 460 Volt and #12 for 230 Volt. These cable sizes are the smallest that can carry the available short circuit current without overstressing the insulation.

Cable Overload Protection

All power cable circuits are protected by circuit breakers with thermal or magnetic overload devices. The current-time interrupting characteristic settings for these protective devices are chosen for each cable size so as not to exceed the published allowable short circuit current duration for the associated cables. The selection of the settings is subject to independent review to assure the proper setting is selected.

Prior to installation, breakers are tested at the generating station to assure that the settings are correct. Periodic maintenance checks are also made.

Cable Rur Design

The design of cable runs within nuclear generating stations follow our long established practices for fossil stations which are:

1. No intermixing of 4160 Volt cables with 460 Volt cables. Separate tray systems are used for each of these voltages.

2. No intermixing of above power cables with 230 Volt power control and instrumentation cables.

3. Tray loadings in trays are limited to: one layer for 4160V power cables, two layers for 460V power cables and 50% fill by cross-sectional area for 230V power, control and instrumentation cables.

4. Physical separation, routing or barriers are used to assure

isolation between 4160 Volt, 460 Volt and other cable trays.

5. Where physical limitations prevent the above, rigid conduit is used.

6. Where vertical shafts are used between elevations, the same philosophy of separation is followed. In addition, all cable openings between elevations are sealed.

7. All cables entering the relay room and control room areas and interconnecting cables between these two rooms are sealed to insure the integrity of each area.

In addition to the above practices, the following separation requirements are followed for Class I Electrical Systems cable runs:

1. Physical separation of cable runs is provided for redundant cables so that no single credible event can damage cables or redundant counterparts.

2. Large distances or alternate routing, and the utilization of walls and other natural barriers inherent in the station design, are used as means of providing physical separation of redundant cables. The routing of redundant cables in a tiered tray arrangement is avoided.

3. If situations occur which involve crossing redundant trays or short runs of tiered redundant trays in non-hostile areas, a minimum vertical separation of 18" is provided. Where trays containing redundant cables have less than 18" vertical separation, a fire resistant barrier is provided.

4. The minimum horizontal distance between trays containing redundant counterparts is 12". If this is unattainable, a fire resistant barrier is provided.

5. When non-Class I electrical cables are run with Class I electrical cables, the cable run will not violate the above four requirements.

6. The grouping of penetrations at the containment wall follow the above requirements.

Cable Identification and Installation Control

A computer assisted cable control system is used by engineering, design, and field personnel as an aid for assuring proper separation of redundant circuits and to monitor and document the installation of these circuits. All cables are assigned an identifying mark consisting of a combination of letters and numbers. These marks appear on permanent cable identification tags. All cables associated with Class I Electrical Systems have marks indicating their safety-related group. For example, power cable marks are a series of alphanumeric digits indicating in order: unit number, bus letter or equipment letters, number or position, and voltage (D-4160V, X-460V, Y-230V). A cable identified with the mark 1A4D-A originates at the No.1 unit, A bus, 4th position, 4160V and is in the A separation group. All trays, shafts, and conduits are also assigned an identifying mark consisting of letters and numbers. All wireways containing safety related cables are distinctly identified as such. These designations are used by designers when routing cables. This routing information is provided as input to the computer system which controls the generation of cable pulling and connecting cards. These cards and the appropriate reference drawings are used by the field as specific instructions and become documentation for all cable installation work.

The Cable Control System was developed as an extension of the computerized Cable and Conduit List used for previous generating station projects. Modifications were made to this system to simplify the input procedure, provide additional information on each cable (route, reel, number, etc.), assure tighter administrative control over the system, provide additional reporting functions such as installation reports, cost reports, etc., and utilize the data base to control and check field installation.

The following is a description of how the system operates. A comprehensive operating manual is given to the field and engineering coordinators covering card loading, filing, error routines, etc.

Design Input

Four stages of design input are made to the system:

> Termination and cable data - from, to, cable type, wiring diagram information, etc., is prepared from controls wiring diagrams and entered onto termination input sheets. This information is checked

by the Design Division coordinator and forwarded to the Electrical Division coordinator for entry into the computer.

Prior to preparing the cable pulling schematic for an area, the responsible designer prepares a traymark ordering sheet. This sheet lists the vital and non-vital tray identifications which are used in a particular area.

Routing data - the cable mark, estimated length, and route of all cables is to be entered onto routing input sheets by each designer at the time the cable pulling schematic is being prepared. These sheets are forwarded to the Electrical Division coordinator for entry.

Updating - the Design Division coordinator checks each issue of the Cable Control Report, notes the required changes on the master copy and forwards it to the Electrical Division coordinator for updating.

Field Operation

The assigned field coordinator is responsible for assuring that all cable installation documentation operations are performed in accordance with this document and related field directives. The field portion of the system operates in the following manner:

Each cable reel containing permanent power, control and instrumentation cable will be assigned a reel number at the time of delivery. This reel number, the type and amount of cable, and the manufacturers coil number will be recorded on a cable stock card and filed in the cable stock file.

Before any cable is pulled in an area, all trays and shafts must be marked with tray identification markers.

The field coordinator will distribute pulling and connecting cards at the beginning of each working day. He then assembles all cards which were distributed the previous day. The cards which show work completed are placed in the card transport box and sent to the Electrical Division coordinator in Newark. The remaining cards are returned to the appropriate working card file. Cards received from the Electrical Division coordinator each day are to be filed in the appropriate card file immediately.

The foreman of each pulling or connecting gang is responsible for assuring that all work is performed in accordance with cable pulling schematics and the pulling or connecting cards and referenced documents. After the pull is completed, the foreman fills in the required information on the card and signs his name, the cable is then identified at frequent and significant intervals along its route. At the completion of the days work, the foreman returns <u>all</u> cards to the field coordinator for filing.

<u>Electrical Division Operation</u>

Each day the Electrical Division coordinator keypunches any design input and the previous day's field input. He then loads this input into the local terminal. The program updates the file and generates new pulling and connecting cards (two copies). Two security tapes are made of the entire data and program files and notification is received on the terminal that all operations have been completed successfully.

After running the program, the operator files all design input cards and the duplicates of the new pulling and connecting cards. The originals of the pulling and connecting cards are placed in a transport

box and sent to the field coordinator.

Cable Control Reports

The program which generates the major Cable Control Reports will be run by the Electrical Division coordinator on a weekly basis. The reports will be printed on the 1108 high speed printer and to the site and Newark by messenger.

Special reports such as file searches, installation reports, and system reports can be generated by the Electrical Division coordinator on demand. The method of running these programs will be similar to the running of the daily report program, i. e., the necessary input will be keypunched, placed between the control cards, and loaded into the terminal. During the running of any of these programs, the security tapes will be in a "read only" mode to prevent damage to the mail file. Specific instructions covering the necessary input for these functions will be added to the operating manual as the functions are developed.

VI. SUMMARY

We have followed a consistent basic policy for over 50 years in the design of cable systems for power generating stations. High grade rubber insulation has been the foundation of our cable system.

Fire resistance is obtained by protecting the insulated conductors with coverings rather than changing the insulation. Extensive fire testing has been performed which prove that 18 inch vertical separation between trays provides adequate protection from fire when fire resistant cables are used.

In addition to using high grade rubber insulated cable with proven fire resistance, we follow conservative application and installation practices. This approach has resulted in a sound cable system with a proven 40 year minimum life.

OFFICE FILE

RRB
SHB 10/28
RHM 10/29

Salem
Electrical Division
File # 18 Item # 3805

September 22, 1971

Memorandum to the Chief Electrical Engineer

600 VOLT POWER CABLE
HORIZONTAL TRAY FIRE PROPAGATION TESTS
OKONITE TEST BUILDING - PASSAIC, NEW JERSEY
SALEM NUCLEAR GENERATING STATION
AUGUST 3, 1971

INTRODUCTION

In a memorandum to the Chief Electrical Engineer dated September 20, 1971, we reported on the results of a horizontal tray fire propagation test with trays filled with 600 Volt power cables with 12" vertical separation between trays. Since then, we have performed the same test with 600 Volt power cables with 18" vertical separation between trays. The results of this test is reported in this memorandum.

TEST PROCEDURE

1. Erect two 6' long by 24" wide ladder type aluminum cable trays horizontally with a 18" spacing from tray bottom to tray bottom. The trays are erected in a building free from drafts and wind.

2. Load each tray with cables supplied by PSE&G to a 40% fill by cross-sectional area. The cable lengths shall be approximately 7 feet. Twenty three test circuits shall be used: 20 sets of 120/240 Volt 3-wire leads, and 3 sets of 220/440 Volt 3-wire leads. (See Table -1 for cable type and test lead set-up).

3. Locate six thermocouples as follows: At the bottom of the lower tray, at the center of the fire, and to the side - 12" and 18" from the center of the fire and at the bottom of the upper tray directly above the center of the fire and 12" and 24" to the side (See Fig. 1).

4. An Ellipse wheel gas burner with a 14" outer diameter shall be used as the source of fire. The burner shall be located below the center point lower tray and shall be adjusted to produce a temperature of 1400 F at the point of impingement with the cables.

5. [illegible] burner shall be ignited for 15 minutes. Record all thermo[illegible] every minute. Note propagation of fire and observe [illegible] conductor shorting. Time shall be recorded for any cables which short. Upon completion of the test, the damaged area of cable in each tray shall be measured.

6. During the test photographs shall be taken at one minute intervals. After the test, close-up photographs shall be taken of the damaged areas.

PSIAG provided the following cable constructions for the test: Triplexed 500 MCM, 350 MCM, #2 AWG, #2/0 AWG, and #6 AWG, and 3/C #12 AWG cable.

TEST RESULTS

The complete test data is given in Tables 1 and 2 attached to this memorandum. The gas burner was calibrated prior to the test to 1400°F at the hottest part of the flame. The cable constructions and sizes used in this test were the same as those used in the previous test except 3/C #12 AWG cable was used in place of triplexed #12 AWG; 3/C #12 AWG is our standard construction for #12 cable.

The flames did not break through the cables immediately as in the previous test. At 4'30" into the test a # 6 AWG cable in the lower tray failed. About 45" later the flames broke through the cables in the lower tray. At 7' 45" a #2 AWG cable in the lower tray failed. The flames were about the same intensity as they were in the previous test with 12" separation, but the flames did not touch the cables in the upper tray with 18" separation. The maximum temperature of thermocouple #4, which was located directly above the burner under the upper tray, was 280°F. At 15' the Ellipse Burner was turned off.

Within 15" after the burner was extinguished, all flames went out, but 1' 30" later they suddenly re-ignited. The flames were only a fraction of the flames which occurred when the burner was on. At 20' two 350 MCM cables in the lower tray failed. At 32' a 500 MCM cable in the lower tray failed. At 49' the two remaining small flames went out and then re-ignited 2' later. Finally at 65' all flames were out. A visual inspection was then made which revealed that no damage occurred to the cables in the upper tray (See Figures 3 - 17).

CONCLUSIONS

1. There was no propagation of the fire from the lower to the upper tray. The maximum temperature in the upper tray was 1100°F

lower [illegible] previous test with 12" separation. The trays were filled to [illegible] by cross-sectional area as specified and the cables provided greater blanketing of the flames during the first 5' of the test. No cable was damaged in the upper tray.

2. There was no propagation of the fire horizontally outside of the immediate area of the gas burner. The main part of the fire extinguished immediately when the gas burner was shut off. Small flames continued to burn for 50' after the burner was shut off. The afterburn was 30' longer than the previous test with 12" separation. We believe the longer afterburn was the result of the blanketing which occurred during the first 5' of the test. When the burner was shut off at 15' there was a larger amount of insulation that had not burned. The heat retained in the copper conductors was hot enough to re-ignite the fire.

3. The only cables that failed during the 15' that the burner was turned on were a #6 AWG and a #12 cable. The #12 cable which had failed within a few minutes in the previous test did not fail during this test because its construction was changed from a triplex to a 3-conductor cable. In order to assure that 600 Volt power cable will have the same degree of fire resistance as control cable, the Neoprene jacket thickness should be increased 15 mils for single conductor and triplex cables, and for the smaller size cables (#2, #6, #12) a three conductor cable construction should be used with a 15 mil increase in Neoprene jacket on individual conductors and a minimum 60 mil overall Neoprene jacket.

4. This test proves that 18 inch vertical separation between trays provides adequate protection from fire propagation when fire resistant cables are used.

5. Additional fire tests will be performed when samples of the new 600 Volt power cable constructions are available.

RJK/vh

PUBLIC SERVICE ELECTRIC AND GAS COMPANY
ELECTRIC ENGINEERING DEPARTMENT

TABLE NO. 1
TEST LEAD SET-UP AND CABLE TYPE

Set No.*	Position	Cable
1	Top-end	3/C #12 AWG
2	Bottom-end	#6 AWG
3	Bottom-end	350 MCM
4	Bottom-center	350 MCM
5	Bottom-end	#2 AWG
6	Bottom-end	#2/0 AWG
7	Bottom-end	#6 AWG
8	Bottom-center	500 MCM
9	Top-center	#2 AWG
10	Top-end	#2/0 AWG
11	Top-center	#2 AWG
12	Top-center	3/C #12 AWG
13	Top-end	#2 AWG
14	Top-end	#2 AWG
15	Top-end	#2 AWG
16	Top-center	#2 AWG
17	Top-center	500 MCM
18	Top-center	500 MCM
19	Top-end	#2/0 AWG
20	Top-end	3/C #12 AWG
1A' 1B'	Bottom-center	500 MCM
2A' 2B'	Top-end	#2/0 AWG
3A' 3B'	Bottom-center	500 MCM

*NOTE: Set 1-20 - 120/240V
Set 1A' 1B' - 220/440V
2A' 2B' - 220/440V
3A' 3B' - 220/440V

RJK/vh
9/22/71

PUBLIC SERVICE ELECTRIC AND GAS COMPANY
ELECTRIC ENGINEERING DEPARTMENT

TABLE NO. 2

Cables installed in trays in triplex configuration
Upper and lower tray contain the following:

2 - 3/C #12 AWG

2 - #6 AWG

2 - #2 AWG

3 - #2/0 AWG

4 - 350 MCM

4 - 500 MCM

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9/22/71

PUBLIC SERVICE ELECTRIC AND GAS COMPANY
ELECTRIC ENGINEERING DEPARTMENT

TABLE NO. 3
HORIZONTAL TRAY FIRE PROPAGATION TEST
18" SEPARATION - NO BARRIER
AUGUST 3, 1971

Thermocouple Readings °F

Time	1	2	3	4	5	6	Notes*
1	1480	180	90	260	100	100	
2	1500	190	90	230	100	100	
3	1520	380	80	220	100	100	
4	1550	400	60	210	110	100	#2 failed @ 4'30"
5	1540	390	60	210	110	100	Flame Brake Through @ 5'15"
6	1520	400		210	120	100	
7	1520	420	Ther-	210	120	100	#5 failed @ 7'45"
8	1460	420	mocou-	220	120	110	
9	1400	430	ple	240	120	120	
10	1390	430	insert-	240	120	120	
11	1320	440	ed wrong	260	120	120	
12	1300	450		260	130	120	
13	1310	460		260	130	120	
14	1340	470		270	130	130	
15	1320	480		290	140	120	
16	920	460		250	140	120	
18	820	420		220	140	120	#4 failed @ 19' 15"
20	840	410		210	140	120	#3 failed @ 21' 35"
22	860	400		220	140	120	
24	880	400		240	140	120	
26	850	390		270	140	120	
28	840	390		280	140	120	
30	830	390		280	140	120	
32	780	400		280	140	120	#1A' failed @ 33'
34	740	420		280	140	120	
36	680	420		260	140	130	
38	600	420		240	140	130	
40	560	430		230	140	130	
42	520	430		240	140	130	
44	490	430		260	140	130	
45	460	440		300	150	130	
48	420	440		260	150	130	
t							
h							
r							
u							
65	All flames out						

RJK/vh
9/22/71

FIGURE 1

POSITION OF THERMOCOUPLES AND TEST LEAD SET-UP

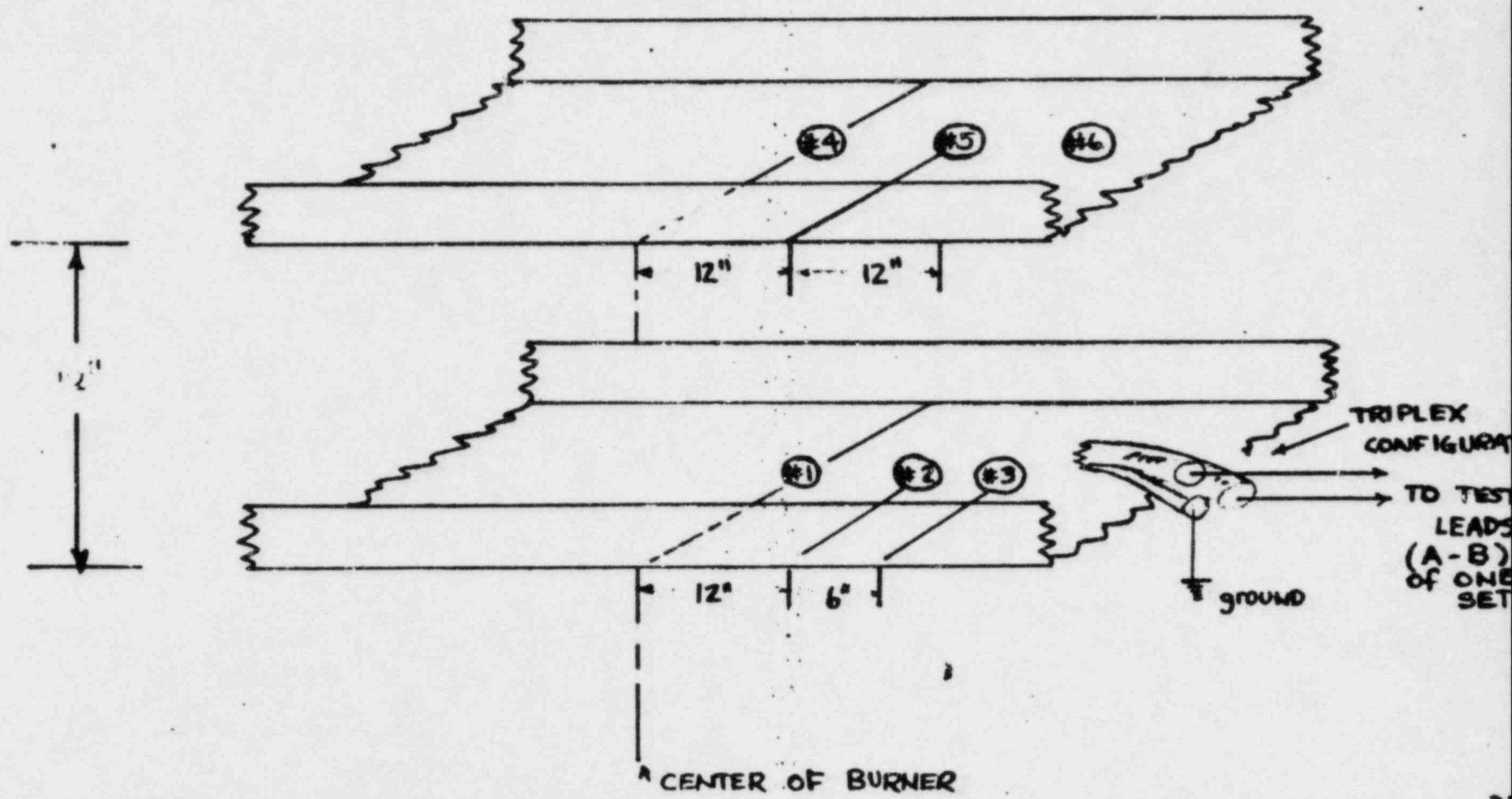
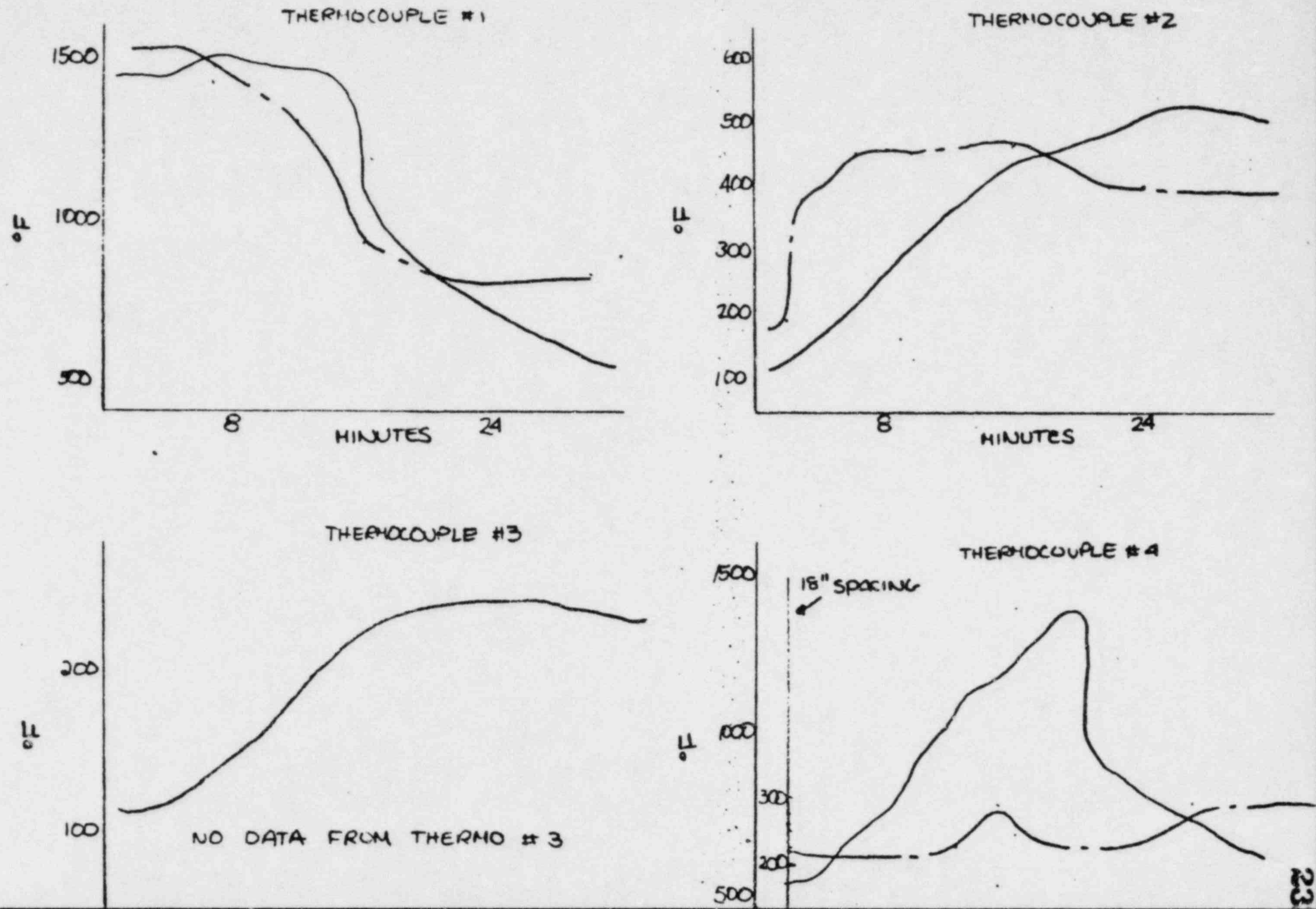
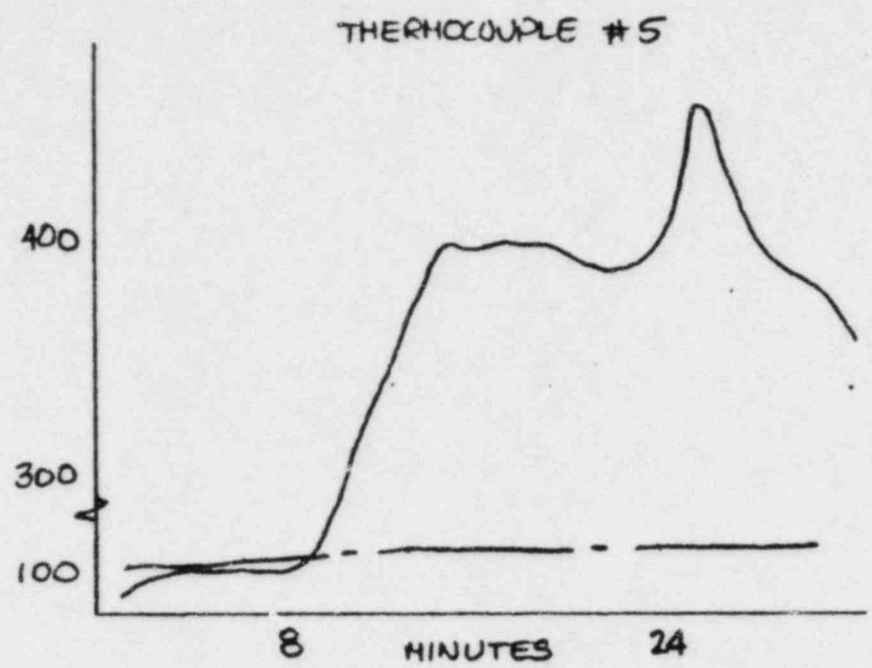
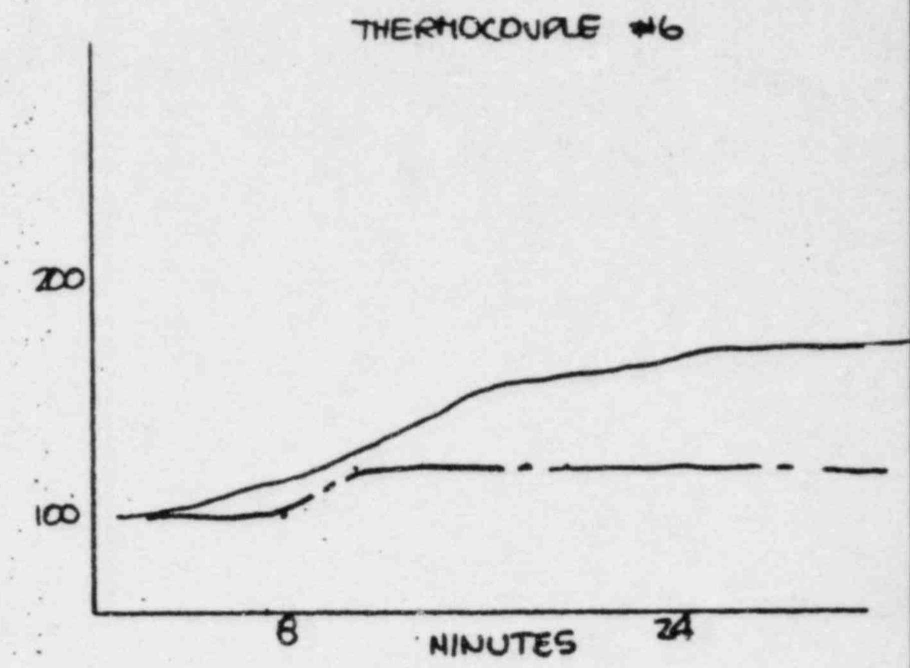


FIGURE 2

FIRE TEST COMPARISON OF 600 VOLT POWER CABLE AT 12" and 18" SEPARATION







NOTE ——12"—— TRIPLEX CONFIGURATION

——18"—— 600V POWER CABLE (SPACING)

RTK 8/5/71

OFFICE FILE

GWS 10/

Salem
Electrical Division
File # 18 Item # 3800

September 20, 1971

Memorandum to the Chief Electrical Engineer

600 VOLT POWER CABLE
HORIZONTAL TRAY FIRE PROPAGATION TESTS
OKONITE TEST BUILDING - PASSAIC, NEW JERSEY
SALEM NUCLEAR GENERATING STATION
JULY 28, 1971

INTRODUCTION

In a memorandum to the Chief Electrical Engineer dated June 21, 1971, we reported on the results of horizontal tray fire propagation tests with trays filled with control cables. Since then we have performed the same tests with trays filled with 600 Volt power cable. The results of a test with 12" vertical separation between trays is reported in this memorandum.

TEST PROCEDURE

1. Erect two 6' long by 24" wide ladder type aluminum cable trays horizontally with a 12" spacing from tray bottom to tray bottom. The trays are erected in a building free from drafts and wind.

2. Load each tray with cables supplied by Public Service Electric and Gas Company to a 40% fill by cross-sectional area. The cable lengths shall be approximately 7 feet long. Twenty-three test circuits shall be used: 20 sets of 120/240 Volt 3-wire leads and 3 sets of 220/440 Volt 3-wire leads. (See Table #1 for cable type and test lead set-up.)

3. Locate six thermocouples as follows: At the bottom of the lower tray, at the center of the fire, and to the side - 12" and 18" from the center of the fire, and at the bottom of the upper tray directly above the center of the fire and 12" and 24" to the side (See Fig. 1).

4. An Ellipse wheel gas burner with a 14" outer diameter shall be used as the source of fire. The burner shall be located below the center point lower tray and shall be adjusted to produce a temperature of 1400°F at the point of impingement with the cables.

[redacted]

[redacted] shall be ignited for 25 minutes. Record all therm[redacted] every minute. Note propagation of fire and observe lamps for conductor shorting. Time shall be recorded for any cables which short. Upon completion of the test, the damaged area of cable in each tray shall be measured.

6. During the test photographs shall be taken at one minute intervals. After the test, close-up photographs shall be taken of the damaged areas.

Public Service provided the following triplex cable constructions for the test: 500 mcm, 350 mcm, #2 AWG, #2/0 AWG, #6 AWG, and #12 AWG.

TEST RESULTS

The complete test data is given in the tables attached to this memorandum. The gas burner was calibrated prior to the test to 1400°F at the hottest part of the flame. The flames broke through the cables immediately. Within a few minutes the #12 triplex cable in the lower tray shorted. The extreme heat destroyed the relatively thin jacket and insulation. As the test continued, the flames constantly lapped the upper tray. At 10' 15" a #2 AWG cable in the lower tray failed and 20 seconds later, a #12 AWG cable failed in the upper tray. The flames had now propagated to the upper tray. At 15 minutes the Ellipse burner was turned off. Just prior to extinguishing the burner, a #2/0 AWG failed in the bottom tray. About 30% of the visible flame went out when the burner was extinguished. At 16 minutes, during afterburn, two more conductors failed in the lower tray. At 23' a #2 AWG in the upper tray failed. Finally, at 35' 10" into the test the last flame went out, and a visual inspection was made of the damaged area (See Figures 3 - 17).

CONCLUSIONS

1. There was propagation of the fire from the lower tray to the upper tray with 12" tray spacing. During installation of the triplex cable, it was noticed that there was a large amount of space between the cables. Also the trays were not filled to 40% fill by cross-sectional area as specified. Due to the triplex construction and spaces between cables, the fire broke through immediately after the burner was ignited. There was no blanketing effect as noted during the same test with control cables. Cable was damaged in both trays.

2. There was no propagation of the fire horizontally outside of the immediate area of the gas burner. The main part of the fire extinguished immediately when the gas burner was shut off. Small flames continued to burn until 20 minutes after the burner was shut off. The afterburn was longer than for control cables due to the larger amount of insulation.

3. The temperatures at all thermocouple locations were hotter than during [illegible] test using control cables. Figure 2 presents a comparison of the temperatures at each thermocouple location.

4. In order to assure that 600 Volt power cable will have the same degree of fire resistance as control cable, the Neoprene jacket thickness should be increased 15 mils for single conductor and triplex cables. For smaller sized cables (#2, #6, #12 AWG), a three conductor cable construction should be used. This construction should include a 15 mil increase in Neoprene jacket on individual conductors and a minimum 60 mil overall Neoprene jacket.

5. On August 3, 1971, we will conduct a horizontal tray fire propagation test using 600 Volt power cables with 18" separation.

RJK
RJK/vh

PUBLIC SERVICE ELECTRIC AND GAS COMPANY
ELECTRIC ENGINEERING DEPARTMENT

TABLE NO. 1
TEST LEAD SET-UP AND CABLE TYPE

Set No.*	Position	Cable
1	Top-center	#2 AWG
2	Top-end	500 mcm
3	Top-end	#2 AWG
4	Top-end	#2/0 AWG
5	Top-center	#2/0 AWG
6	Top-center	#12 AWG
7	Top-center	500 mcm
8	Top-center	#2 AWG
9	Top-center	#2/0 AWG
10	Top-end	500 mcm
11	Bottom-end	#2 AWG
12	Bottom-end	500 mcm
13	Bottom-center	#6 AWG
14	Bottom-end	#2/0 AWG
15	Bottom-end	#12 AWG
16	Bottom-center	500 mcm
17	Bottom-center	500 mcm
18	Bottom-end	350 mcm
19	Top-center	#2 AWG
20	Top-center	#12 AWG
1A' 1B'	Bottom-end	#2/0 AWG
2A' 2B'	Bottom-end	500 mcm
3A' 3B'	Top-end	#2/0 AWG

NOTE: Set 1 - 20-120/240V
Set 1A' 1B' - 220/440V
2A' 2B' - 220/440V
3A' 3B' - 220/440V

RJK/vh

9/7/71

PUBLIC SERVICE ELECTRIC AND GAS COMPANY
ELECTRIC ENGINEERING DEPARTMENT

TABLE NO. 2
CABLES INSTALLED IN TRAYS IN TRIPLEX CONFIGURATION

Lower Tray	Upper Tray
4 - 500 mcm	3 - 500 mcm
2 - 350 mcm	2 - #12 AWG
1 - #12 AWG	1 - #6 AWG
3 - #6 AWG	4 - #2/0 AWG
2 - #2/0 AWG	3 - #2 AWG
1 - #2 AWG	

RJK/vh

9/7/71

PUBLIC SERVICE ELECTRIC AND GAS COMPANY
ELECTRIC ENGINEERING DEPARTMENT

TABLE NO. 3
HORIZONTAL TRAY FIRE PROPAGATION TEST
12" SEPARATION - NO BARRIER
JULY 26, 1971

Time	Thermocouple Readings °F 1	2	3	4	5	6	Notes*
1	1430	110	100	420	130	100	
2	1430	130	110	530	150		#15 failed at 2'
3	1440	140	110	490	160	100	
4	1420	150	120	510	170	110	
5	1430	180	120	640	200	110	
6	1500	210	130	700	220	120	
7	1500	240	140	740	240	120	
8	1490	270	140	710	260	120	
9	1460	290	150	750	260	130	
10	1470	320	160	900	290	130	#11A failed at 10' 15
11	1460	330	170	1000	320	140	#20AB failed at. 10' 3
12	1440	350	180	1040	360	140	#14A & 11B failed at
13	1430	370	200	1160	400	150	
14	1420	410	210	1120	400	150	
15	1420	420	220	1120	390	160	Flame out at 15'
16	1000	430	220	1120	400	160	#13A & 19AB failed at 15' 35"
17	940	440	220	1300	400	160	#4B failed at 17'
18	900	460	230	1370	390	160	#4A & 5A failed at 18' 30"
19	890	460	230	1380	390	160	#1B & 3A failed at 19
20	860	470	230	1380	390	160	
21	840	470	230	890	390	160	
22	810	480	230	860	380	160	
23	780	490	240	820	390	160	#3B failed at 23' 40"
24	750	500	240	810	400	160	
25	730	510	240	790	440	170	
26	710	530	240	760	410	170	
27	680	530	240	730	390	170	
28	660	520	240	710	380	170	
29	640	520	230	680	380	170	
30	620	500	230	640	370	170	
31	590	500	230	620	360	170	
32	570	490	230	600	360	170	
33	550	490	230	570	360	170	
34	540	470	230	540	360	170	
35	520	470	230	520	350	170	All flames out at 35' 10"

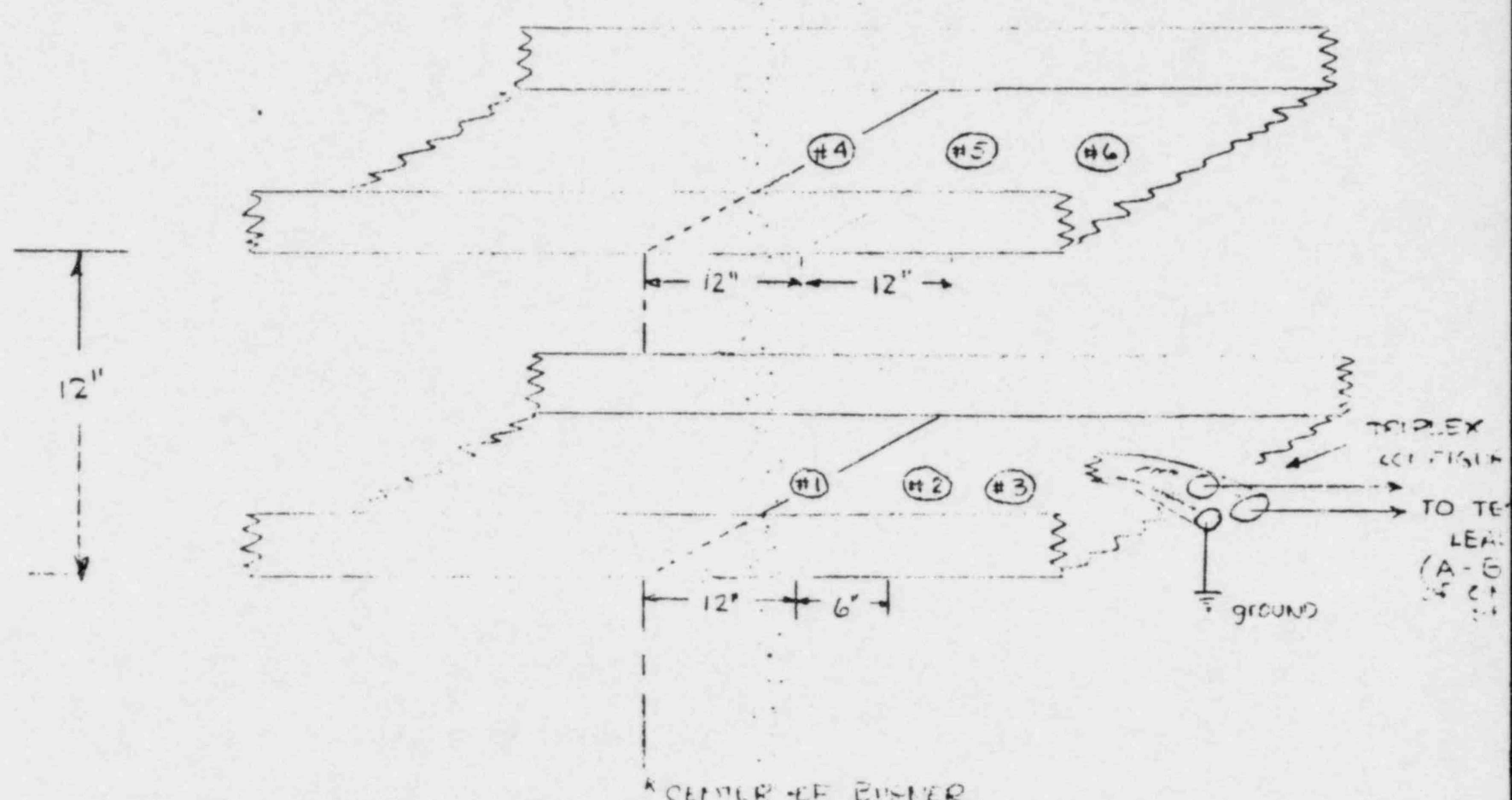
* Refer to Table No. 1 for cable type.

RJK/vh

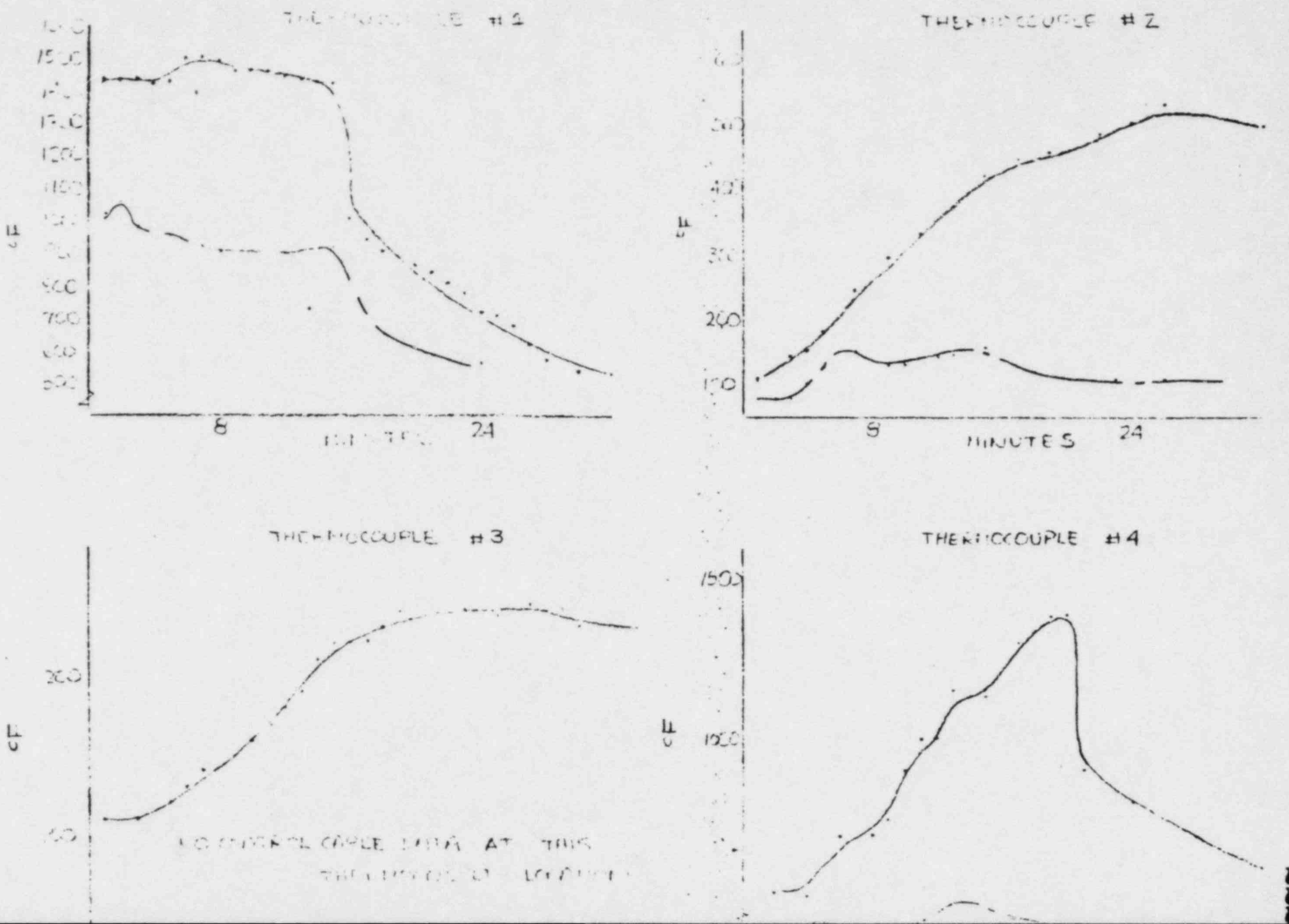
9/7/71

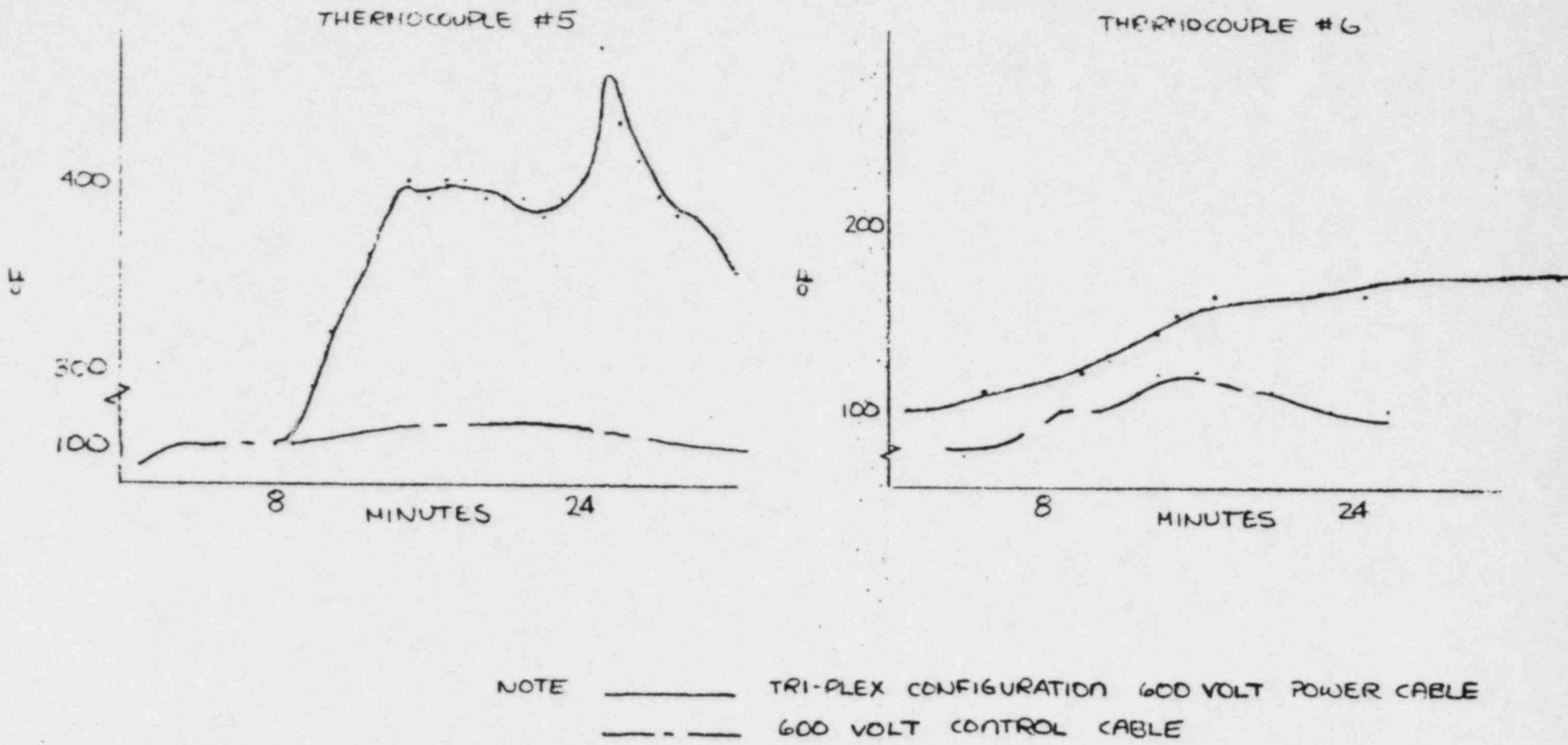
FIGURE 2

POSITION OF THERMOCOUPLES AND TEST LEAD SET-UP



AND 600 VOLT ... CABLE (...) AT 12" TRAY SEPARATION




THERMOCOUPLE #5
400
300
100
°F
8
MINUTES
24
THERMOCOUPLE #6
200
100
°F
8
MINUTES
24
NOTE
TRI-PLEX CONFIGURATION 600 VOLT POWER CABLE
600 VOLT CONTROL CABLE

December 14, 1976

THE OKONITE COMPANY
Ramsey, New Jersey

ENGINEERING REPORT NO. 289

Public Service Electric and Gas Horizontal Cable Tray Fire Tests

INTRODUCTION

Fully loaded horizontal cable tray fire tests were conducted for Public Service Electric and Gas Co. of New Jersey. These tests were designed by PSE&G to determine the fire characteristics of various cable constructions in horizontal fire tests. PSE&G also investigated the spacing required between trays and conduits to prevent propagation. Propagation for these tests was defined as causing the cable in the upper tray or conduit to burn to short circuit.

SUMMARY

A twelve inch spacing between horizontal trays did prevent propagation during the fire test designed by PSE&G when 600 V, 7 C #12 EPR-Hypalon control cable was exclusively utilized for testing.

An eighteen inch spacing did not prevent propagation from one tray to the next when 600 V, 7/C, #12 polyethylene-polyvinylchloride (non-flame retardant) control cable was utilized for testing.

The coaxial and instrumentation cable tested created a large enough fire in the bottom tray to propagate the fire to the lower row of EPR-Hypalon cable in the upper tray.

An asbestos thermal blanket prevent damage to the EPR-Hypalon cables during a twelve inch spacing fire test. Without the blanket, some damage occurred. The thermal blanket is effective, but it reduces the inside volume of the cable tray.

PROCEDURE

Tests 1-6, 9-11:

Two 12 x 2-1/2 inch horizontal trays were utilized for these tests. The bottom tray was placed three inches above the 105,000 BTU/hr. (calculated value), 13-1/4 inch commercial gas burner. The top tray was spaced 18iinches above the top of the bottom tray for Tests 1-6 and 9. The spacing was reduced to 12 inches for Tests 10 and ~~10~~ 11.

Each tray was loaded with two tightly packed regimented rows of cables. Each cable was approximately 68 inches long. The lower row of the top tray was electrified (120/240 volts) to determine time to short circuit should the fire propagate to the top tray. Cable construction varied. Table I lists the constructions utilized.

A temperature profile of the fire was recorded throughout each test. Thermocouples were located as shown in Ill. 1.

Copper mirrors were hung approximately two feet above the top tray to determine the presence of corrosive off gases. This procedure was discontinued after the fourth test.

Tests 7 and 8:

The bottom tray was kept identical to the bottom tray described in the procedure above. The top tray was removed. Two 2-inch steel conduits were placed above the bottom tray. Both conduits were 66 inches long. One conduit was placed three inches above the top of the cable tray. The remaining conduit was placed six inches above the cable tray. A temperature profile was obtained throughout the test, also. (See Ill. 2)

EPR-Hypalon cable was used in the bottom tray for both tests. Test 7 had one electrified length of EPR-Hypalon cable in each of the conduits. An electrified coaxial and instrumentation cable were placed in each of the conduits for Test 8. The burner application time for each test was fifty minutes.

Tests 1-12:

Time to short circuit, afterburn, and maximum jacket damage were recorded for each test. Films were taken of each test by PSE&G personnel.

DISCUSSION

Initially, the PSE&G test program had four objectives. These objectives were (1) comparison of various materials, (2) performance of fire-proof coatings on cables, (3) performance of thermal blankets inside trays, and (4) performance of cable inside conduit in horizontal tests.

Tests 1 through 6 were designed to compare the various cable materials. The fire source was applied for twenty minutes during Tests 1, 2, and 3 at a rate of 105,000 BTU/hr. The first three constructions did not demonstrate fire propagation. However, the polyethylene/PVC construction was beginning to propagate the fire when the burner was extinguished.

If the fire source was allowed to burn longer, the polyethylene/PVC would have propagated the fire to the upper tray.

The 105,000 BTU/hour burn applied for twenty minutes is considered to be a severe fire. However, twenty minutes was not long enough time period to differentiate the various cable methods when the samples were tightly packed in the tray. Therefore, PSE&G decided to increase the length of time until they felt the fire in the lower tray had reached its maximum intensity.

Tests 4 and 5 are an example of different fire characteristics encountered. Test 4 had EPR-Hypalon control cable in the bottom tray and coaxial and instrumentation cable in the top tray. Throughout the 46 minute fire source application to the EPR-Hypalon cable, propagation did not occur. However, when the trays were reversed, the coaxial and instrumentation cable created a large enough fire to propagate to the EPR-Hypalon cable in the top tray.

The CMO construction (Test 6) performed similar to the EPR-Hypalon tests. A longer afterburn was experienced due to the greater amount of fuel (EPR) and the corrugated bronze shield tape. The helically wrapped tape did not allow the gases from the core to escape easily. Pressure was created and caused a more intense fire. This characteristic of helically wrapped metallic tape constructions has been observed in vertical cable tray fire tests, as well.

Test 9 illustrated the flamability of polyethylene/polyvinylchloride control cable. The PVC was not the flame retardant type. This construction does not burn similar to EPR-Hypalon. The PVC does not swell as does the Hypalon. When the Hypalon swells as it ashes, it acts as a heat shield to the remaining unburned portion. The polyethylene/PVC melts then flows and burns. As it burns, it exposes more flammables.

The cables in the upper tray began to melt due to the heat generated from the lower cables. Several short circuits occurred prior to ignition of the top tray of cables. The top tray took only five minutes before it was totally engulfed with flames on the bottom row. The preheating and melting of the top tray of cables caused the rapid propagation of fire.

Tests 7 and 8 were designed to determine the performance of cables in conduit in close proximity of cable tray fires. The EPR-Hypalon in the bottom tray did not create as severe a fire as would polyethylene/PVC. Therefore, the cables in the conduit did not experience the worst conditions. However, this test was designed to simulate a possible cable tray/conduit arrangement PSE&G would encounter in their nuclear stations where they using EPR-Hypalon or neoprene cables, not polyethylene/PVC.

The samples in the conduits were slightly damaged. Maximum jacket damage is shown in Table II. The cores of all the test samples experienced minimal surface damage. No short circuits occurred. It was unknown which cables, if any, ignited since they could not be seen while inside the conduit.

Tests 10 and 11 were designed to determine the performance of thermal blankets inside trays. A 0.1 inch thick woven asbestos blanket was placed in the bottom and up the sides of the tray in Test 11. Test 10 was identical to Test 11 except for the blanket. The blanket reduced the tray capacity by two samples. Tray spacing was reduced to 12 inches to typify PSE&G cable tray spacings where cable trays cross. (Thermal blankets are being used at these crossings.)

The thermal blanket did prevent damage to the upper tray in Test 11. Fourteen inches of damage was measured in Test 10. No short circuits occurred in either test. It is important to note that even with the reduced tray spacings, EPR-Hypalon still did not propagate the fire in Test 10.

PSE&G decided not to test fire-proof coatings. This decision was based on the good performance of the EPR-Hypalon and CMO constructions tested.

Copper mirrors were utilized during the first four tests. Slight traces of copper remained on the glass after completion of the first two tests. After Test 3, no copper remained. Again no copper was found after Test 4.

The disappearance of copper signified the emission of a halogen compound (HCl) from the burning cable. The disappearance was expected since Hypalon and PVC have chlorine atoms in them and a great deal of smoke is generated during the lengthy tests.

The PSE&G fully loaded horizontal cable tray fire tests were not the worst case conditions. Tightly reigmented samples in cable trays will not burn as quickly or with the same intensity as randomly placed samples. Also, except for the coaxial and instrumentation cable tests, homogeneous cable constructions were used for each test. PSE&G was aware of the discrepancies however, they felt that the cable selection and placement in the test trays best typified their present nuclear installations.

Prepared by: J. R. Cancelosi /row
J. R. Cancelosi

Approved R. G. Feller /row
R. G. Feller

JRC/row

DISTRIBUTION:

Messrs. J. S. Lasky
R. G. Feller
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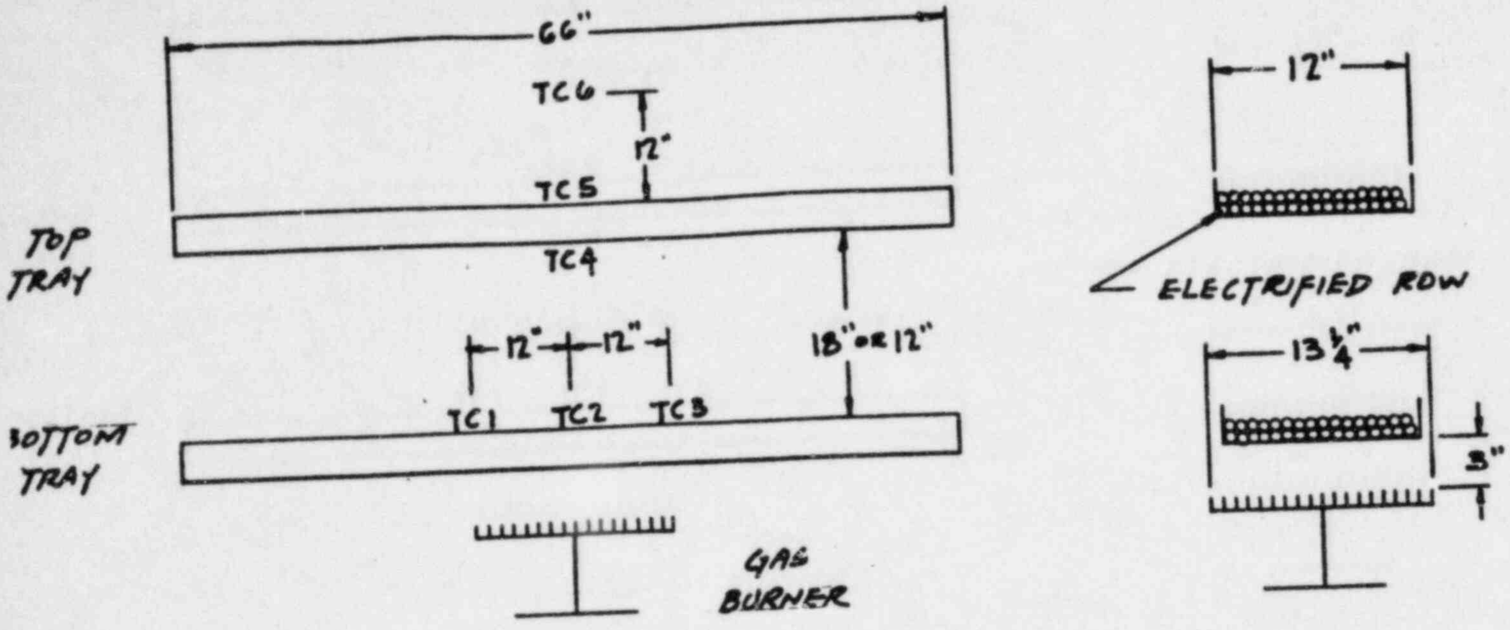
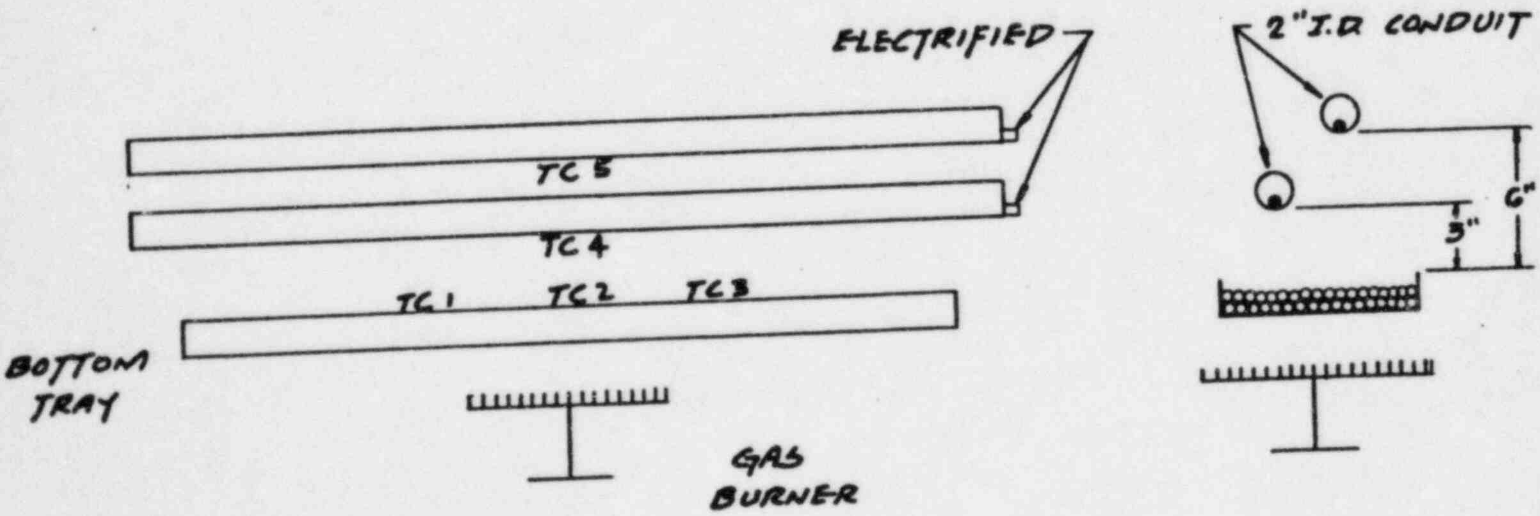

66"
TC6
12"
TC5
TOP TRAY
TC4
12"
12"
18" OR 12"
TC1
TC2
TC3
BOTTOM TRAY
GAS BURNER
12"
ELECTRIFIED ROW
13 1/4"
3"

ILL. 1


ELECTRIFIED
2" I.D CONDUIT
TC5
TC4
TC1
TC2
TC3
BOTTOM TRAY
GAS BURNER
6"
3"

ILL. 2

TABLE I

CABLE CONSTRUCTIONS

EPR-Hypalon (Okonite)

FO-70651 - 7/C #12 7X TC, .030" Okonite, .015" Okolon, .020" extruded fill, .065" Okolon jacket OD = 0.760"

FMR X-Olene; Flame and moisture resistant crosslink polyethylene (Okonite)

EO 96517, 7/C, #12 7X TC, .035" FMR X-Olene, .035" extruded fill, .065" Okolon jacket OD = 0.700"

P-30; Polyethylene-Polyvinylchloride (Okonite)

SO 3-17539 - 7/C, #12 7X BC, .020" Okolene, .010" Okoseal, .012" binder tape, .065" Okoseal jacket OD = 0.650"

Coaxial (Boston Insulated Wire)

7 strands of #21 BC, .120" insulation, .008" BC braid, .001" heat barrier tape, .005" asbestos-glass tape, .010" BC braid, .001" Mylar tape, .045" thermost jacket OD = 0.500"

Instrumentation (American Insulated Wire)

7 pair #16 7X .020" EPR, .017" neoprene, #18 7X TC drain wire, .002" aluminum Mylar shield, cabled with .008" asbestos-glass tape, .002" Mylar tape, .095" neoprene jacket OD = 0.910"

CMO (Okonite)

4/C, #10 19X TC, .055" Okonite, .021" Okoprene, 5 rubber fillers, 2 - .015" Okoprene tapes, .006" glass reinforced asbestos Mylar, .005" corrugated bronze shield, .110" Okoprene jacket OD = 0.930"

TABLE II

TABLE OF RESULTS

Test #	Burner Application (min)	Tray or Conduit Spacing	Construction			Maximum Damage			Propagation	Time to Short Circuit (min)	Afterburr (min : se
			Bottom Tray	Top Tray	Conduit	Bottom Tray (in.)	Top Tray (in.)	Conduit (in.)			
1	20	18	EPR-Hypalon	EPR-Hypalon	---	35/24 (1)	None	---	No	None	1 : 30
2	20	18	FMR X-Olene	FMR X-Olene	---	36/26	None	---	No	None	None
3	20	18	Poly/PVC	Poly/PVC	---	46/32	15/None	---	No	None	Not record
4	46	18	EPR-Hypalon	Coax., Instr.	---	36/29	Coax. Blisters	---	No	None	10 : 30
5	35	18	Coax. Instr.	EPR-Hypalon	---	38/29	28/None	---	Yes	28 (3)	12 : 30
6	50	18	CMO	CMO	---	33/27	17/None	---	No	None	32 : 20
7	50	3; 6 (2)	EPR-Hypalon	---	EPR-Hypalon	48/33	---	8; 7 (2)	No	None	12 : 00
8	50	3; 6	EPR-Hypalon	---	Coax. Instr.	47/33	----	6; 2	No	None	10 :00
9	50	18	Poly/PVC	Poly/PVC	---	48/45	{68/68 (total)}	---	Yes	34 (4)	46 : 15
10	50	12	EPR-Hypalon	EPR-Hypalon	---	47/35	14/None	---	No	None	8 : 10
11	50	12	EPR-Hypalon	EPR-Hypalon w/asbestos thermal blanket	---	46/35	None	---	No	None	11 : 40

(1) Bottom layer of cable/top layer of cable

(2) Lower conduit; upper conduit

(3) Four of fifteen cables short circuited

(4) All fifteen cables short circuited

May 2, 1977

THE OKONITE COMPANY
Ramsey, New Jersey

SECOND
ADDENDUM TO
ENGINEERING REPORT NO. 289

SUBJECT: Public Service Electric and Gas Company, Horizontal Cable Tray Fire Tests

An additional fire test was performed at the request of PSE&G. PSE&G utilizes asbestos blankets in horizontal trays which are spaced less than 18" from each other. It becomes necessary to slit the blankets in order to secure them to the trays. The NRC had questioned PSE&G on the possibility of propagation of fire from one horizontal tray to the next through these slits.

PSE&G designed the following test: Two horizontal trays were placed 12 inches apart. The bottom tray was filled with two layers of 4/C #9 19X CMO-E cable. The top tray had a thermalon blanket placed in the bottom of the tray with four 4 to 5 inch slits cut in it. Two slits were directly above the burner and two were just outside the perimeter of the burner. The bottom layer of the top tray was filled with CMO-E cables and electrified. The top layer was filled with CMO-E cables. As in all previous horizontal PSE&G tests, the 100,000 BTU/hr. circular burner was utilized. The burner was applied for fifty minutes. Temperatures at six locations were monitored and photographs were taken.

At no time were flames observed in the top tray. Short circuits did not occur to any of the cables in the top tray. However, the bottom layer did experience some jacket damage. The core was in good condition. The slits in the thermalon blanket probably allowed more hot air to filter through the top tray. Damage was not concentrated directly above the slits. The entire area on the bottom of the lower layer of cable above the burner was damaged.

SUMMARY OF RESULTS

Burner Application (min)	50
Tray Spacing (inches)	18
Construction	CMO-E
Propagation	No
Time to Short Circuit (min)	No Shorts
Afterburn (min)	39

J. R. Cancelosi

J. R. Cancelosi

JRC/jsg

THE OKONITE COMPANY
Ramsey, New Jersey 07446

Work Performed - May 1977
Work Reported - March 27, 1979

THIRD ADDENDUM
to
ENGINEERING REPORT NO. 289

P. S. E. & G. HORIZONTAL CABLE TRAY FIRE TESTS

Four additional fire tests were designed by and performed for P. S. E. & G. P. S. E. & G. 's purpose for these tests was to justify their cable construction selection and cable system design. These tests also allowed for motion picture filming by a professional film crew.

The first two tests were repeats of Tests 6 and 9 of Engineering Report No. 289. These two tests were performed mainly to demonstrate a good flame retardant construction versus a poor flame retardant construction in P. S. E. & G. 's cable system. As expected, the CMO-E construction (Test #14) did not propagate the fire to the upper tray. The polyethylene-polyvinylchloride construction (Test #15) did propagate the fire. Short circuits in the upper tray occurred approximately $3\frac{1}{2}$ minutes prior to visual observance of flames in the tray. This indicated that the polyethylene and PVC materials were melting due to the heat generated in the lower cable tray. The fire did not have to propagate from the lower tray to the upper tray in order to interrupt electrical integrity.

Since these two tests were performed for motion picture filming and are repeats of Tests 6 and 9, actual length of damage measurements were not recorded but can be seen in the movie. Damage to the CMO-E construction wasy very similar to the damage observed in Test #6. Damage to the polyethylene - PVC construction was severe, however, the entire upper tray was not completely damaged as in Test #9. A summary of these two tests appear in Table 1.

The last two tests requested by P. S. E. & G. involved an elaborate cable tray configuration as shown in the attached diagram. The cable trays were of the same type as used in the previous tests. Rungs were spaced 9" apart center to center. The bends in the "S" trays were closed on the inside of the tray. The two horizontal trays were in contact with the "S" trays. The burner was centered directly beneath the lower "S" tray as shown in the diagram. The burner was applied for 50 minutes. Ten cables in the upper "S" tray and five in the lower horizontal tray were energized to measure time to short circuit. Temperatures were measured at various locations as indicated on the diagram.

Each cable tray was filled with two layers of the cables described below:

"S" Trays

Test #16 7/C #12 (7 X) BC, .020" Okolene, .020" Okoseal, .012" binder tape, .065" Okoseal jacket OD - 0.650"

Test #17 4/C #9 (19 X) TC, .055" Okonite, .020" Okoprene, 5 rubber fillers, 2 - .015" Okoprene tapes, .006" glass reinforced asbestos-Mylar, .005" corrugated bronze shield, .110" Okoprene jacket OD = 0.930"

Horizontal Trays

Tests #16 and 17 - 7/C #12 (7 X) TC, .030" Okonite, .015" Okolon, .020" extruded fill, .065" Okolon jacket OD = 0.760"

During the first 40 minutes of the Poly/PVC test, the fire in the lower horizontal section of the "S" tray continued to spread. At approximately 40 minutes the fire creeped around the corner of the tray and during the next three minutes propagated up the vertical section of the tray. At the 60 minute mark (10 minutes after the burner was turned off), the fire spread to the upper horizontal section of the lower "S" tray. The first short circuit in the upper "S" tray occurred at approximately $61\frac{1}{2}$ minutes. Flaming ashes fell into the horizontal trays but extinguished within ten minutes. No shorts were observed in the two horizontal EPR-Hypalon trays. At the 100 minute mark the test was discontinued and the fire was extinguished with water.

The CMO-E test (Test #17) had completely different results. Damage was confined to only the lower horizontal section of the lower "S" tray. Overall damage was less than 40 inches. No short circuits occurred in any of the cables energized. Afterburn lasted for 35 minutes. A comparison of Tests 16 and 17 are shown in Table 1.

After the above test was completed and the cables cooled down to room temperature, the burner was moved to the left so that the flames impinged on the cable just as they entered the lower curve of the "S" tray. The flame was reapplied for 50 minutes. The fire did not burn past approximately two-thirds the way through the bend. Afterburn lasted 34 minutes.

This additional fire application was not photographed or witnessed by P.S.E. & G. but was done by Okonite to determine if the cable would propagate up the vertical section if the flame source was applied close to it.

TABLE #1

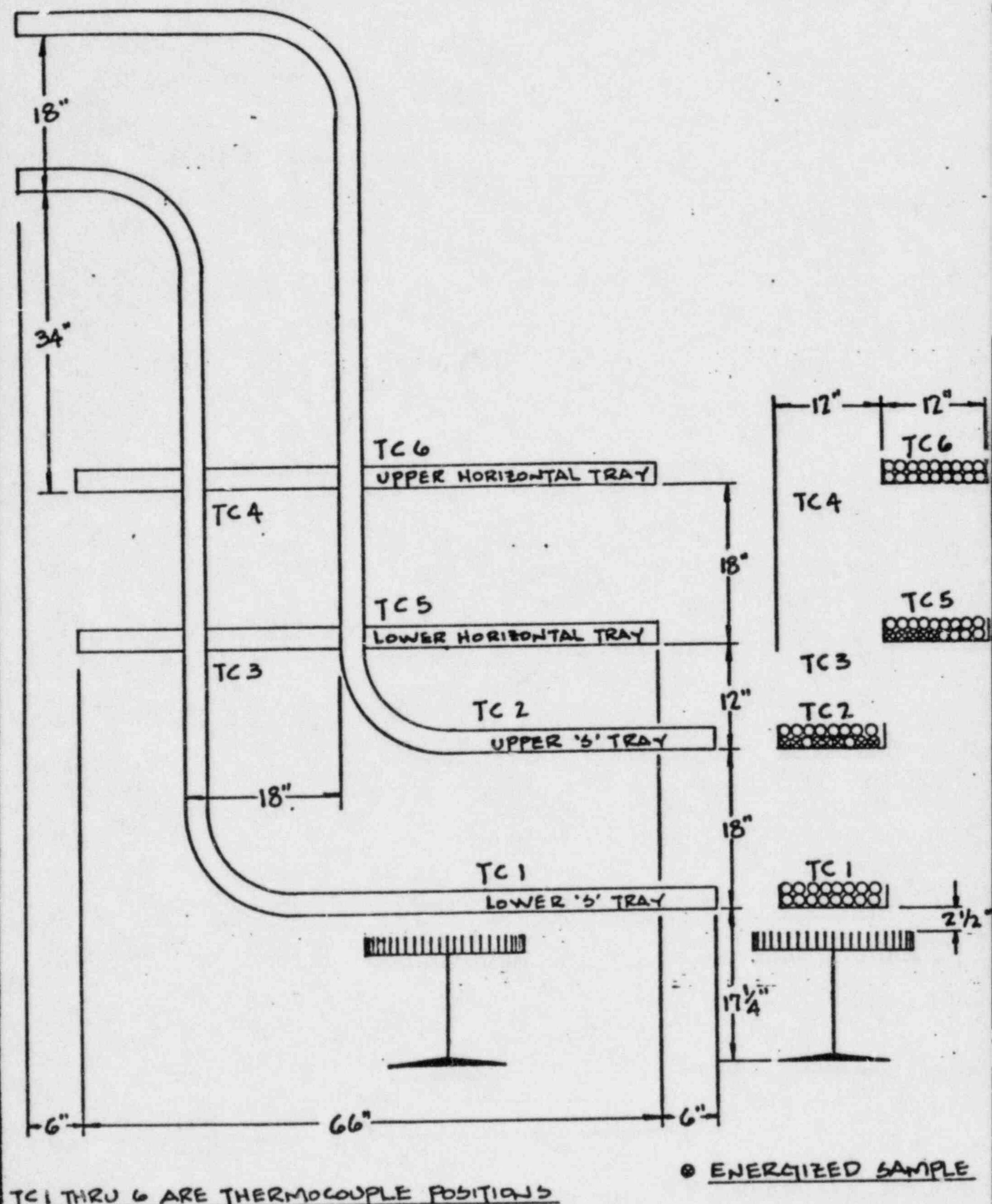
Summary of Results

Test Number		14	15
Burner Application, minutes		50	50
Tray Spacing, inches		18	18
Construction -	Bottom Tray	CMO-E	Poly/PVC
	Top Tray	CMO-E	Poly/PVC
	"S" Tray	-----	-----
Fire Spread to:	Upper Horizontal Tray	No	25:00
Propagation		No	Yes
Time to Short Circuit, min : sec		No Shorts	21:20
Afterburn, minutes		28	49

Test Number		16	17
Burner Application, minutes		50	50
Tray Spacing, inches		See Diagram	
Construction -	"S" Trays	Poly/PVC	CMO-E
	Horizontal Trays	EPR-Hypalon	
Fire Spread to:	Upper "S" Tray, minutes	60:00	No
	Lower Horiz. Tray, min.	Slight Damage	No
Propagation		Yes	No
Time to Short Circuit, min: sec,	"S"	61:20	No Shorts
	Horiz.	No Shorts	No Shorts
Afterburn,		Ext. with Water	35

J R Cancelosi
J. R. Cancelosi

JRC/row



CABLE TRAY CONFIGURATION

THE OKONITE COMPANY RAMSEY. N.J.. U.S.A.	DATE 11-30-77	SCALE NTS	REVISIONS
	DR.	TR.	DRAWING NO.
	CH.	APP. LRC	SK-5701