APPENDIX R
MULTIPLE HIGH IMPEDANCE CABLE FAULT
FLAME TEST REPORT

MAY 27, 1988

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Revision Record

| Revision | Page | Section | Description | Date |
|---|---|---|---|---|
| 0 | All | All | First Issue | May 27, 1988 |

Approvals

| Revision | Date | Prepared By | Reviewed By | Approved By |
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NOTE

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## 1.0 Objective

This test report presents the test results of three separate energized cable flame tests. The tests were performed to: (1) determine the characteristics of fire induced cable insulation failures as they relate to leakage current through insulation degraded by fire, (2) determine the effect on a common power supply where multiple individually fused cables are installed in a manner simulating typical power plant practice and are subjected to a fire source. The results will be used to consider the effects of fire related simultaneous high impedance faults in compliance with 10CFR50, Appendix R.

## 2.0 Summary

Generic Letter 86-10 "Implementation of Fire Protection Requirements" (April 24, 1986), Enclosure 2 Item 5.3.8 requires consideration of simultaneous high impedance faults for all common bus associated cables located in a fire area.

A series of energized cable flame tests were conducted in order to address the concerns identified in the generic letter. The tests included a simulated 120 VAC distribution panel arrangement with coordinated supply circuit breaker and fused load circuits. The results of this test will be used to consider simultaneous high impedance faults for specific common bus arrangements.

This report describes the test specimen selection, the test set-up and procedure and presents the test results and conclusions.

## 3.0 Conclusions

The cable flame tests reported upon herein were conducted by Philadelphia Electric Company to provide data which supports the premise that simultaneous high impedance faults from fire damage do not occur in a manner such that electrical coordination of power sources (as designed for PECo nuclear facilities) is jeopardized. The test results confirm the premise as stated.

Supporting evidence from Tests 1 and 2 includes the following:

1. The time to failure varies randomly within ranges which are dependent on proximity to flame source and number of intervening cables between a subject cable and the flame source.

2. The failure mode consists of an initial period of transient insulation breakdown which is very current limited as opposed to approaching the trip threshold of fuse or breaker sizes used in power distribution panels.

3. The insulation resistance or alternatively the leakage current during the initial insulation breakdown transient has a waveform with alternating peaks and valleys.

4. The period of initial transient high impedance insulation breakdown is generally enveloped within a 1 minute duration.

In addition to fully supporting the results of Tests 1 & 2, Test 3 provides the following:

5. Failure of insulation after the initial transient breakdown, cascades to a very low insulation impedance within less than 1 second.

6. The electrical protection device actuation will be principally influenced by the high current during the cascading insulation breakdown as opposed to the lower initial transient leakage current. The fault during the cascading insulation breakdown is less than 1 second in duration.

4.0 Introduction

The PBAPS Safe and Alternative Shutdown System Analysis evaluated each plant fire area to determine the affects of an Appendix R fire on the ability to achieve safe shutdown. For analysis, fire damage to electrical power, control and instrumentation cables was defined as short, ground, open or hot short circuits. Associated circuits (safe shutdown or non-safe shutdown) were considered those i.e. circuits that have a common power source or common enclosure with the active safe shutdown equipment.

A 10CFR50, Appendix R Electrical Coordination Study was performed for PBAPS safe shutdown electrical buses from 4.16KV to 120VAC and including the 125/250 VDC System.

The coordination study determined that the existing design is coordinated and that faults on associated circuits due to flame damage, of the type analyzed, are not a concern. Also, fault current available at all distribution levels is adequate for the proper operation of the current actuated protective devices.

In 1986 the NRC issued Generic Letter 86-10 (April 24, 1986) "Implementation of Fire Protection Requirements". Enclosure 2 of this letter provided NRC responses to questions raised by the industry during a series of NRC Regional Workshops. Question 5.3.8" Short Circuit Coordination Studies," asked if high impedance faults should be considered in the coordination studies. The NRC response requires that simultaneous high impedance faults (below the trip point for the breaker of each individual circuit) for all associated circuits located in the fire area, should be considered in the evaluation of the safe shutdown capability.

During the NRC review meeting on PBAPS Appendix R held, July 30, 1987, PECo responded to questions regarding multiple high impedance faults stating that the prospect that they occur on associated circuits in a fire area is very low because the raceway system is solidly grounded and nuclear grade cable is used.

A subsequent review of NUREG-0050 and 0061 associated with the Browns Ferry Fire was conducted. The fire damage resulting to cables installed in cable tray and conduit was reported to be caused by flame and temperature. The loss of control circuit function associated with these cables was reportedly due to short circuits. Evidence of high impedance faults or tripping of related upstream protective device trips was not found in these reports.

Nuclear Industry cable suppliers were contacted as well as PECo cable test experts to gain insights related to their experience with failure modes of cable during flame testing. Significant flame testing to IEEE 383-1974 has been performed on 600 Volt multiconductor nuclear grade cables. The acceptance criteria used in these tests has been: (1) time to short circuit, (2) flame propagation and (3) char distance. Testing was conducted on energized cables using indicating lights to signal when conductor to conductor or conductor to ground insulation breakdown occurred.

This test report presents the results of three separate flame tests on energized cables, the purpose of which was to collect data on high impedance faults. The tests were performed using high speed recording analyzers and data loggers to measure transient changes in cable insulation resistance and leakage current at time intervals as low as 0.5 milliseconds.

The first two tests were conducted on a 120 VAC energized multiconductor power cable circuit. Insulation leakage current resulting from flame damage was measured using a high speed recording analyzer. The recorder was automatically triggered at a low insulation resistance value. The third test was run using a coordinated 120 VAC circuit breaker and fuse arrangement. Current through each fuse was measured using transducers and recorded by an IBM-PC and data logger. These tests were not terminated until a time after the energized cables developed short circuits, in order to verify coordination.

In considering typical power plant voltage levels, testing was performed at 120VAC because 120VAC buses are the more numerous, share more of the associated cable loads and are considered more susceptible to high impedance faults. Testing at 120VAC is conservative since at higher voltages, additional voltage stress adds to cable flame damage and cable short circuiting. Protective device clearing levels will occur quicker than at lower voltage levels.

## 5.0 Test Simulation

Testing was performed in the PECo test laboratories. A room in the Material Testing Laboratory measuring 19.5 X 10.5 X 12 feet with a glass observation window was used. The room was ventilated by means of two exhaust hoods, used to clear the smoke and fumes produced from the flame test.

The cable, cable tray and the flame source were located in the test room. Electrical connections to the cables, gas piping to the burner and other instrumentation were routed outside the room through sealed penetrations.

### 5.1 Flame Source

A 70,000 BTU per hour ribbon gas burner using commercial grade propane as the fuel was used for the flame. The flame source and set-up met the requirements of IEEE 383-1974, Section 2.5 Flame Test, and Regulatory Guide 1.131, Issued for comment August 1977.

This arrangement was chosen since it represents a recognized industry standard and the flame test is repeatable.

Commercial grade propane and air were premixed using a venturi mixer and supplied to the gas burner. The propane flow rate corresponded to a heat input rate of approximately 70,000 ± 1600 BTU per hour based on the gross heating value of propane, and the supply airflow of 163 ± 10 standard cubic feet per hour. Flow rates were monitored using two calibrated rotameters. The set-up for the flame source is shown in Figures 1 and 2.

### 5.2 Cable and Cable Tray

The cable and cable tray arrangement was set up to simulate field installed conditions and facilitate the testing within the confines of the test facility.

A horizontal tray configuration was used. It was loaded with single and multiconductor cables typically used in 120VAC power and control circuits.

The test tray used was open ladder steel construction, 4 foot long, 6 inches wide and with 3 inch siderails.

The single and multiconductor cables were installed in a loop with both ends exiting the same end of the tray to facilitate electrical connections. The percent fill of cable tray was 28.5%. The cable installation approximated three (3) levels of cables in the tray (bottom-middle-top), as shown in Figures 4 and Picture 3.

The cables used in the test were procured under PECo Specification 125-P-7 for PBAPS. The cables were obtained from PECo stores by material code number. The following cables were used:

| PECo Material Code | Manufacturer | Description |
|---|---|---|
| 125-09508 | Brand-REX | 1/C #12, Copper conductor, 600 Volt cross-linked polyethylene insulation. |
| 125-09512 | Rockbestos | 4/C #12, Copper Conductor, 600 Volt cross-linked polyethylene insulation with an overall black flame retardant neoprene. |
| 125-09516 | Brand-REX | 2/C #10, Copper Conductor, 600 Volt cross-linked polyethylene insulation with an overall black flame retardant neoprene. |

Each flame test was conducted using randomly looped lengths of the above cable installed per Section 6.2. The following is a summary of the numbers and types of cables used in each test:

12-Cables - 2/C #10 (Code 125-09516)

12-Cables - 4/C #12 (Code 125-09512)

6 -Cables - 1/C #12 (Code 125-09508)

The cables have the following construction:

| | Conductors | | | Thickness-MILS | | O.D. Inches | |
|---|---|---|---|---|---|---|---|
| Code No | No. | KCMIL(AWG) | Strands | Insulation | Jacket | Min. | Max. |
| 125-09508 | 1 | 12 | 7 | 30 | None | 0.152 | 0.167 |
| 125-09512 | 4 | 12 | 7 | 30 | 45 | 0.475 | 0.522 |
| 125-09516 | 2 | 10 | 7 | 30 | 45 | 0.460 | 0.506 |

5.3 Test Circuit

5.3.1 Test-No.1

A recording analyzer measured the voltage across a resistance load box which was proportional to the leakage current caused by insulation flame damage to a 4/C #12 energized cable test specimen located in the cable tray. Two (2) conductors of the test specimen were electrically connected together and tied to the line side of the power supply through the resistive load box as shown in Figure 3. All other cable conductors in the tray were electrically connected to the steel tray which was tied to the neutral side of the power supply. The steel tray and supports were isolated from ground. With the circuit energized in the initial condition prior to applying the flame source, there was no current flow in the circuit. The current path due to cable insulation degradation would be from the energized conductors across the insulation to a neutral connected conductor or to the cable tray. This current would be a direct result of the cable/conductor insulation flame damage and leakage current. Pictures 1, 2 and 3 show the test set-up and instrumentation.

A 120VAC test lab power supply, capable of providing 50 amperes, was connected through a supply circuit breaker to the test set-up. Since there was no load current on the energized cable, the measured current was purely leakage.

The recording function of the analyzer was automatically triggered when the leakage resistance dropped to (reached) 200 ohms. The trigger had a 400 millisecond (ms) preset, so that 400 ms of data prior to trigger was recorded. The recorder took sample readings each 0.5 millisecond for a 4 second period (or 8000 data points). Each sample data point consisted of a reading of the power supply voltage and the voltage across the fixed resistance load box. Using these values, the analyzer was set-up to calculate the leakage resistance and leakage current. Figure 5 shows the range, trigger and program used by the recording analyzer for these calculations.

The data is displayed in graph form or digitized in tabular form. A permanent hard copy of the digitized data was made for documentation retrieval.

5.3.2 Test No.2

The test set-up and methodologies were the same as for test No.1 except the recording analyzer was triggered at ohms of insulation leakage resistance instead of 200 ohms. Also the recording time was increased from 4000 milliseconds to 8000 milliseconds. Data points were measured and recorded each millisecond. This second test was performed to confirm the results and repeatability of the first test.

5.3.3 Test No.3

This test was conducted using the same flame source and cable tray arrangements as the first two tests. Eight (8) circuits representing 66% of the cables were energized at 120VAC and fault current was monitored during the entire duration of the test as shown in Figures 10 and 11. Power for each circuit was supplied through individual fuses which were fed from a common circuit breaker simulating a coordinated common bus arrangement. The flame test was run until after either the breaker tripped or the fuses blew, in order to test for high impedance fault effects on electrical coordination.

The following circuit breakers and fuses were obtained from the PBAPS Storeroom for use in the test:

| Type | Manufacturer | Description |
|---|---|---|
| Circuit Breaker | Westinghouse | Type EB, TM 30A @120VAC |
| Fuse, 10A | Bussmann | Type KTK |
| Fuse, 30A | Bussmann | Type KTK |
| Fuse, 30A | Bussmann | Class RK5, Type FRN |

Six (6) of the energized circuits were fused with Bussmann, Type KTK, 10 Amp. fuses. The remaining two (2) circuits were fused with Bussmann, Type KTK and FRN 30 Amp. fuses, as shown in Figure 10 and Picture 11.

The current through the main supply circuit breaker and each fused circuit was monitored and recorded.

A calibrated current transducer was used to monitor current through the fuses. The output of each transducer was connected to a Fluke 2280 B Data Logger. The current supplied through the circuit breaker was monitored by the logger.

The test measured and recorded the leakage current through the circuit breaker and each individual fused circuit as a function of time. Each current data point was scanned and recorded once a second.

The test data shows the time when leakage current started to flow and the point at which the fuse failed. Continuity checks were made after the test to confirm that the fuses had failed.

The data logger interfaced with a RS232 interface modem to an IBM-PC, so that the data was stored on a floppy disc as shown in Figure 11. The data was then printed and plotted

## 6.0 Test Procedure

### 6.1 Flame Source Preparation

The same flame source set-up was used for all three (3) tests. The ribbon burner, air-gas venturi mixer, air and gas rotameters and 20 lb. commercial propane gas tank were all connected per Figure 2. All connections were sealed and the completed installation was checked for leaks with gas sniffing devices.

The temperature of the flame source was checked prior to running the test. After the flame source was ignited, the rotameters were adjusted by needle valves for 70,000 BTU/HR. The temperature was measured using a type "K" thermocouple, located in the flame, 3 inches above the top of the burner face. The temperatures were in the range of 1500 °F to 1600 °F, during the tests.

The thermocouple remained in place and was used to monitor the temperature during all three tests.

6.2. Cable Tray Preparation

The same cable tray arrangement and cable loading was used for all three (3) tests. Suitable lengths of the specified types of cable were individually randomly laid in a loop configuration, inside the 4 foot long cable tray. Both ends of each cable exited from the same side of the tray to facilitate electrical connections.

For tests 1 and 2, the non-energized cable conductors were connected together to the steel cable tray and tied to the power supply neutral. The cable tray was supported horizontally over the flame source (burner) using a four legged frame. The frame was isolated from ground using insulators under each of the four legs, as shown in Picture 3.

In both tests a 4 conductor cable was energized and monitored for leakage current. Two (2) of the conductors were connected together and tied to the line side of the power supply. The other two (2) conductors were tied to the non-energized conductors, cable tray and neutral side of the power supply. Any leakage current between the line side conductors and other conductors or cable tray was measured and recorded.

For test number 3, eight (8) cables were energized with 120 VAC and monitored (4-2 conductor and 4-4 conductor cables). Two (2) of the conductors of the 4 conductor cable were tied together and connected to the line side of the power supply. The other two (2) conductors were tied to neutral along with all non-energized cables and the cable tray. One (1) conductor of the 2-conductor cable was tied to line and the other to neutral, as shown in Figure 10 and Picture 12.

6.3 Test Room Preparation

Only the ribbon gas burner, cable tray and cable and thermocouple were inside the test room. All piping, electrical and instrumentation connections exited the room via sealed penetrations. All room openings were sealed with the exception of a louvered opening on the main door to the room.

During the test two exhaust hood ventilation fans were kept running, which kept the room at a slight negative pressure with respect to the rest of the test laboratory area. This caused air flow from the test laboratory area to the test room, via a 2' X 2' louvered opening in the door. The smoke was exhausted to the outside through the main building ventilation system and ductwork (a smoke detector in the main ventilation ductwork was bypassed to avoid automatic shutdown of the ventilation system). The volume of the room is 2457 cubic feet.

Each of the three tests were video taped using a camcorder located outside the test room. The filming was performed through glass observation windows in the test room.

6.4 Power Supply

The capability of the 120 VAC, 60 HZ. power supply was checked by connecting a direct short circuit across the power supply and measuring the momentary short circuit current. The current was recorded at 49.9 amperes using a Hioki Digital Tong Set.

The power supply to the test specimen was connected through a circuit breaker to protect the test laboratory instrumentation. The cable lengths were short (less than 10') and therefore cable resistance had negligable effect on the current supply.

6.5. Test Circuit Connection

The circuit connections for tests numbers 1 and 2 are shown in Figure 3. The basic circuit is a voltage divider network. Two (2) resistances are in series. One (1) resistance is a fixed value resistance load, which provides two functions:

1) Voltage input to the analyzing recorders

2) Limits the fault current to below 50 amperes

The voltage input to the recorder was proportional to the current flow through the circuit. Initially there was no current flow due to the series resistance of the undamaged cable insulation, which is on the order of a hundred megohms. As cable insulation flame damage occured and the resistance dropped, a voltage proportional to leakage current through this resistance developed across the fixed resistance load box.

Resistance values of the load box were set and measured prior to the test along with megohmmeter measurements of the cable insulation resistance. All connections were made and checked including operation of the analyzer prior to the test.

After the data from the test was collected and analyzed, manual calculations were performed to verify the internal program used to calculate leakage resistance and current.

The circuit connections for test number 3 is shown on Figures 10 and 11. The test circuit was set-up to simulate a coordinated breaker and fuse panel arrangement. Each of eight (8) energized cables were separately fused and all were supplied through a common circuit breaker.

A current-to-millivolt transducer was wired in series with each circuit and used to measure leakage current due to cable insulation damage from the flame source. The output from each transducer was connected to a data logger. Total current through the circuit breaker was measured with a clamp on ammeter and connected to the data logger. The Data Logger had a scan rate of 10 channels/second.

The Data Logger was connected via an RS232 interface modem interface to an IBM-PC. Data from the test was a floppy disc, through this interface and stored for future analysis.

Data was collected at a 1 second scan rate from the beginning of the test to the conclusion. The test was concluded after the majority of the circuits shorted and their fuses failed as a result of flame damage.

6.5 Test Sequence

Test monitoring and data collection for the three flame tests was automated. The only manually recorded data was the following:

1. Test room ambient temperature
2. Resistor load box value
3. Time required to trigger analyzer (Only for Tests 1 and 2)
4. Total flame test time

During each test the temperature of the flame source was observed continuously along with the power supply line voltage.

For test number 1 and 2, the following sequence was used:

6.6.1 Record the ambient room temperature.

6.6.2 Measure the resistance of the load box.

6.6.3 Connect the test specimen to the power supply voltage source.

6.6.4 Check all connections of the test circuit and inputs to the analyzing recorder.

6.6.5 Energize and adjust the analyzing recorder and check the trigger set points.

6.6.6 Close the power supply breaker and measure the voltage, using the voltmeter.

6.6.7 Ignite the flame source and adjust the rotameters to supply 70,000 BTU's per hour. At this point the timer is started at T=0.

6.6.8 Monitor the flame test and flame source temperature until the analyzing recorder triggers.

6.6.9 Record the time to trigger from the start of the test (T=0).

6.6.10 After the recorder is triggered, continue the test for approximately 15 seconds, while data is being recorded.

6.6.11 Shut down the flame source and open the voltage supply circuit breaker.

For test number 3 the following sequence was used:

6.6.1 Record the ambient room temperature.

6.6.2 Check the test specimen connections to the transducers and data logger.

6.6.3 Close the common power supply circuit breaker.

6.6.4 Ignite the flame source and adjust the rotameters to supply 70,000 BTU's per hour. At this point the timer is started at T=0.

6.6.5 Start the data logger at T=0.

6.6.6 Monitor the flame test and flame source temperature until, either the circuit breaker trips or the fuses fail.

6.6.7 Shut down the flame source, open the voltage supply circuit breaker and stop the data logger.

7.0 Test Results:

7.1 Test No.1

The analyzer triggered at 10 minutes from the start of the test. The analyzer was triggered at a cable insulation resistance value of 200 ohms between the energized conductors and neutral. Eight thousand data points were recorded during the four (4) second period. Figure 6 shows a graph of the cable insulation leakage resistance versus time for the recording period. The energized cable did not experience a short circuit. During the recorded period the maximum insulation leakage resistance between the energized conductor and neutral was 272 ohms which occurred at 601 MS and the minimum resistance was 18.57 ohms which occurred at 3752 MS. The maximum and minimum currents recorded were 5.508 Amps and 0.416 Amps. The following is a listing of various maximum and minimum points recorded.

| Points | Time (Milliseconds) | Insulation Leakage Resistance (OHMS) | Current (AMPS) |
|---|---|---|---|
| 1 | 451 | 168.5 | 0.659 |
| 2 | 601 | 272.0 | 0.416 |
| 3 | 994.5 | 183.8 | 0.614 |
| 4 | 110.3 | 214.7 | 0.526 |
| 5 | 1831.5 | 128.0 | 0.877 |
| 6 | 1947 | 165.0 | 0.683 |
| 7 | 2202 | 116.0 | 0.966 |
| 8 | 2468.5 | 201.7 | 0.560 |
| 9 | 3752 | 18.57 | 5.508 |
| 10 | 3834 | 188.2 | 0.599 |
| 11 | 3918.5 | 21.2 | 4.880 |
| 12 | 3994 | 215.7 | 0.524 |

Figure 7 is a graph of the current through the energized conductor into the high impedance fault as a direct result of the cable flame damage to the insulation. The average current is 1.009 Amperes for the 4 second period. The maximum current peak of 5.508 Amps occurs at 3752 MS. and reaches that peak from an initial value of 2.055 Amps in 6.18 cycles. The peak then drops to 0.7310 Amps in 2.97 cycles demonstrating the transient nature of the fault resistance.

Pictures 4 to 7 show the extensive cable insulation damage in the lower portion of the tray which is to be expected since they were closest to the flame source. In many cases the bare conductors were exposed. The top most cables experienced minor visible damage which is attributed to the non-propagating and flame retardant properties of the nuclear grade cable being tested.

Picture 5 shows the location and condition of the energized 4/C #12 cable. Careful inspection of the cable in the flame area did not reveal bare conductor. It is therefore concluded that the leakage current occurred between the conductors of the same cable.

In summary, the test data shows that short circuit leakage current of a limited magnitude, as measured, occurs due to insulation flame damage. The leakage current is limited to very low values by the high impedance of the fault and does not reach a sustained valve for the range and test period measured. Test results show there was no distinct pattern to the fluctuations in leakage current during the period, except that they were transient.

7.2 Test No.2

A second test was conducted using the same arrangement as test 1 to support and confirm the results. Two minor modifications were made.

The changes from test no. 1 were:

1) Since the cables were randomly installed, the position of the energized cable in the cable tray flame area was different. This resulted in different times to trigger, supporting the hypothesis that cable damage is a function of position relative to the flame source.

2) The recording analyzer was set to trigger at 75 ohms instead of 200 ohms. The scan rate and recording time were increased from 0.5 milliseconds and 4000 milliseconds to 1.0 millisecond and 8000 milliseconds.

The analyzer triggered at 8 minutes and 5 seconds from the start of the test. Eight thousand data points were recorded during the eight (8) second interval after the analyzer triggered. Figure 8 is a graph of the cable insulation leakage resistance versus time. The energized cable did not experience a total short circuit.

During the recorded period the maximum insulation leakage resistance was 4969 ohms which occurred at 6146 MS and the minimum was 21.34 ohms which occurred at 7085 MS. The maximum and minimum insulation leakage currents were 4.893 amperes and 0.023 amperes. Although the following listing is not all inclusive it represents a large sample of maximum and minimum points.

| Points | Time (Milliseconds) | Resistance (OHMS) | Current (AMPS) |
|---|---|---|---|
| 1 | 885 | 33.50 | 3.220 |
| 2 | 1449 | 1140.00 | 0.100 |
| 3 | 1619 | 68.83 | 1.618 |
| 4 | 1889 | 1961.00 | 0.058 |
| 5 | 2210 | 32.81 | 3.286 |
| 6 | 2633 | 2540.00 | 0.045 |
| 7 | 3249 | 2852.00 | 0.040 |
| 8 | 3333 | 71.41 | 1.561 |
| 9 | 3600 | 3558.00 | 0.032 |
| 10 | 3697 | 115.6 | 0.974 |
| 11 | 3841 | 4111.00 | 0.027 |
| 12 | 6786 | 4710.00 | 0.016 |
| 13 | 4992 | 146.10 | 0.774 |
| 14 | 5191 | 3422.00 | 0.033 |
| 15 | 5774 | 90.12 | 1.245 |
| 16 | 6146 | 4969.00 | 0.023 |
| 17 | 7085 | 21.34 | 4.893 |

Figure 9 is a graph of the insulation leakage current through the energized conductor into the high impedance fault as a result of the cable flame damage. For the recorded duration, the average current is 0.7525 amperes for the 8 second period. The maximum current is 4.893 amperes which occurs at 7085 MS.

Pictures 8 to 10 show the cable insulation damage to cables in the lower portion of the tray, closest to the flame source. The damage is very similar to that of test no. 1. As expected the top most cables experienced minor visible cable insulation damage which can be attributed to the non-propagating and flame retardant properties of the nuclear grade cables being tested. Conclusions resulting from the first test were supported by this test.

7.3 Test No.3

This test was performed with the same tray, cable and flame source configuration as the first two (2) tests. Eight (8) cables were energized and each was separately fused as shown in Figure No. 10. The current through each fuse was monitored as well as the total current through the supply circuit breaker. Other non-energized cables in the tray were connected to neutral.

The test was stopped after 15 minutes due to excessive smoke in the room. At that time six (6) of the eight (8) circuit fuses had failed thereby clearing short circuits on the individual energized cable to which they were connected.

Pictures 13 to 18 show the cable damage in the fire area. As in the first two tests, the cables in the bottom of the tray had much more damage than the cables at the top.

The cables were carefully removed from the tray and damage in the fire area was photographed for each separate cable. The relative position of the cable in the fire area was noted along with the channel number, cable type, fuse size and type, time until fuse failed and failure sequence. This information is shown in Figure No. 14.

Fuses associated with cables on Channel 13 and 18 did not fail. Figure 14 shows that these cables were located in the top most part of the tray. The cable damage to these circuits is shown in Pictures No. 25 and 26. All energized cables located in the bottom and middle sections of the tray blew their fuses and sustained major cable flame damage as can be seen in Pictures 19 to 24.

The results of test number 3 confirm the results of the first two tests and also conclude:

1) The occurrence of cable faults in a common tray are not simultaneous. Cables nearest the flame source develop flame damage related short circuits before cables further away. As a result, with the exception of cables 11 and 16 no simultaneous faults occurred during the test. Faults occurred simultaneously on cables 11 and 16 which were side by side in the bottom of the cable tray closest to the flame source as can be seen in Figure No. 14 "Cable Location In Flame Area Vs. Time To Blow Fuse".

2) The cable fault short circuit characteristic has a high impedance period followed by a transition to low impedance, which results in fault clearing. During the high impedance period the current is limited to very low values which do not effect electrical coordination. As shown in the table below the longest short circuit high impedance period was 54 seconds for cable 16. During this period the recorded current was limited to a maximum valve of 1.901 ampers by the impedance of the fault in cable 16.

| Chan. No. | Fuse | Start of Leakage Current From T=0 (Sec's.) | Fuse Melt Clearing Time (Sec.) | Transient Fault Duration (Sec.) Until Clearing | Maximum Leakage Current Recorded (AMP) |
|---|---|---|---|---|---|
| 10 | 10A, KTK | 428 | 477 | 49 | 5.136 |
| 14 | 10A, KTK | 535 | 546 | 11 | 0.540 |
| 15 | 10A, KTK | 559 | 609 | 50 | 5.260 |
| 11 | 10A, KTK | 601 | 651 | 50 | 9.310 |
| 16 | 30A, KTK | 624 | 678 | 54 | 1.901 |
| 12 | 10A, KTK | 679 | 687 | 8 | 4.758 |

For the common bus configuration tested, the bus supply circuit breaker did not trip. The breaker is a Westinghouse, 120VAC Type EB, 30 amperes rated with thermal and magnetic trip elements. The maximum recorded current through the breaker was 14.56 amperes. While the 14.56 amperes peak value transient occurred for less than 1 second, the breaker trip requirement for this short time period is on the order of 220 amperes.

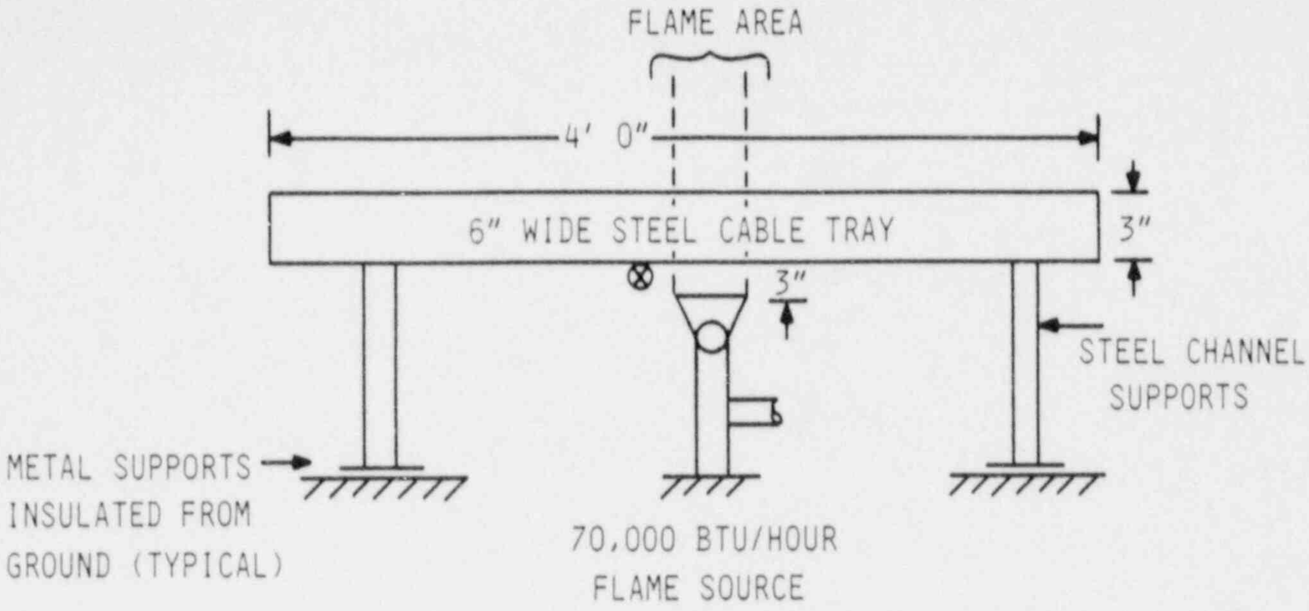
Alternatively, the average current for the longest high impedance fault period of 54 seconds was 2.256 amperes which included fault current from cables 11 and 16. The sustained current required to trip the circuit breaker for a 54 second time period is 50 amperes.

As can be seen from Figure No. 12 "Total Supply Breaker Current Vs. Time During Flame Test" the circuit breaker was not in jeopardy of tripping due to cable fault high impedance short circuit currents. The current through the supply breaker was a combination of the fault current contributions from each of the energized cables.

As shown in Figure No. 13 "Load Supply Fuse Current Vs. Time During Flame Test", the short circuit characteristic of each cable fault was similar. A high impedance fault period followed by a transition to low impedance and then fuse fault clearing. The fuses used were type KTK, non-time delay fast acting which provided high speed of response above the 1000 second rating of the fuses. Under all cases the high impedance short circuit peak current recorded was below the lowest fuse rating of 10 amperes. At the transition to low impedance the fuse failed immediately. The transition to low impedance was caused by conductor to conductor contact.

Section 8.0

Figures




⊗ INDICATES LOCATION OF FLAME SOURCE THERMOCOUPLE

NOTES

1.0 BURNER FACE IS 3" FROM BOTTOM OF HORIZONTAL TRAY.

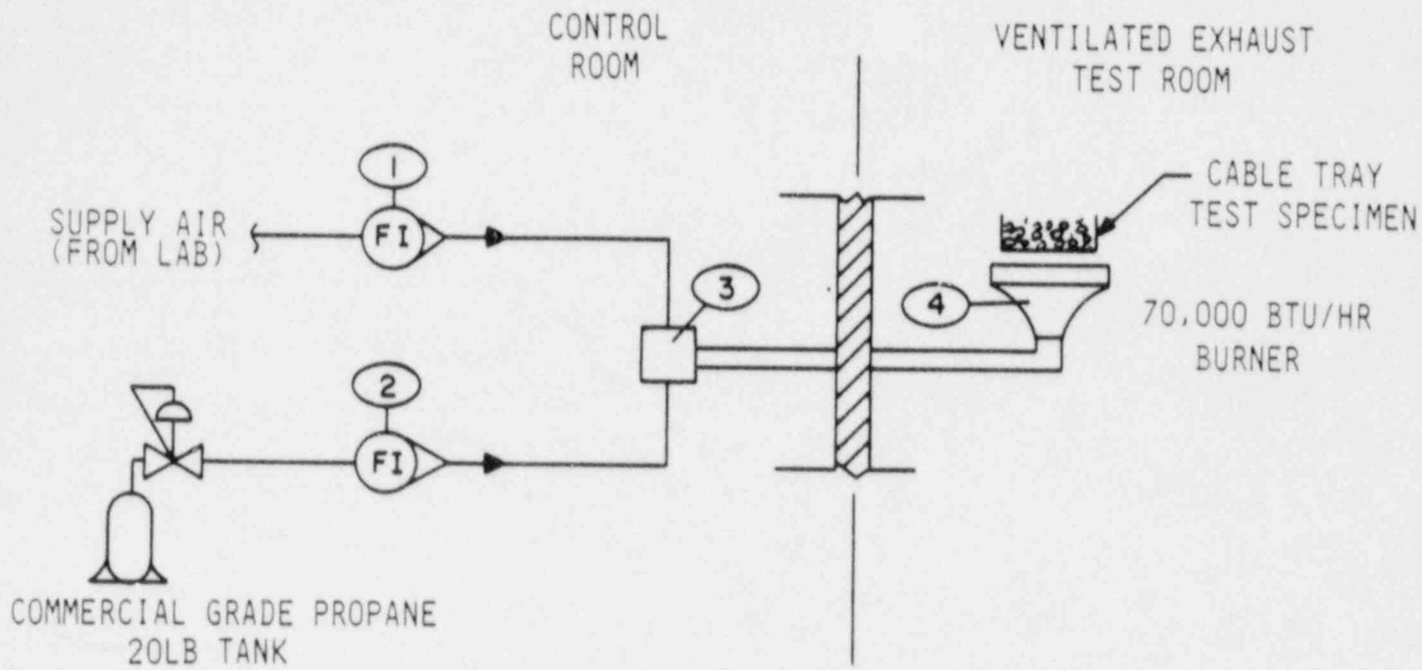
2.0 BURNER LOCATED SO THAT FLAME IMPINGES ON BOTTOM LAYER OF CABLES MIDWAY BETWEEN TRAY RUNGS.

3.0 THERMOCOUPLE LOCATED IN FLAME, CLOSE TO BUT NOT TOUCHING CABLES.

FIGURE NO. 1

TEST NO. 1 , 2 , AND 3

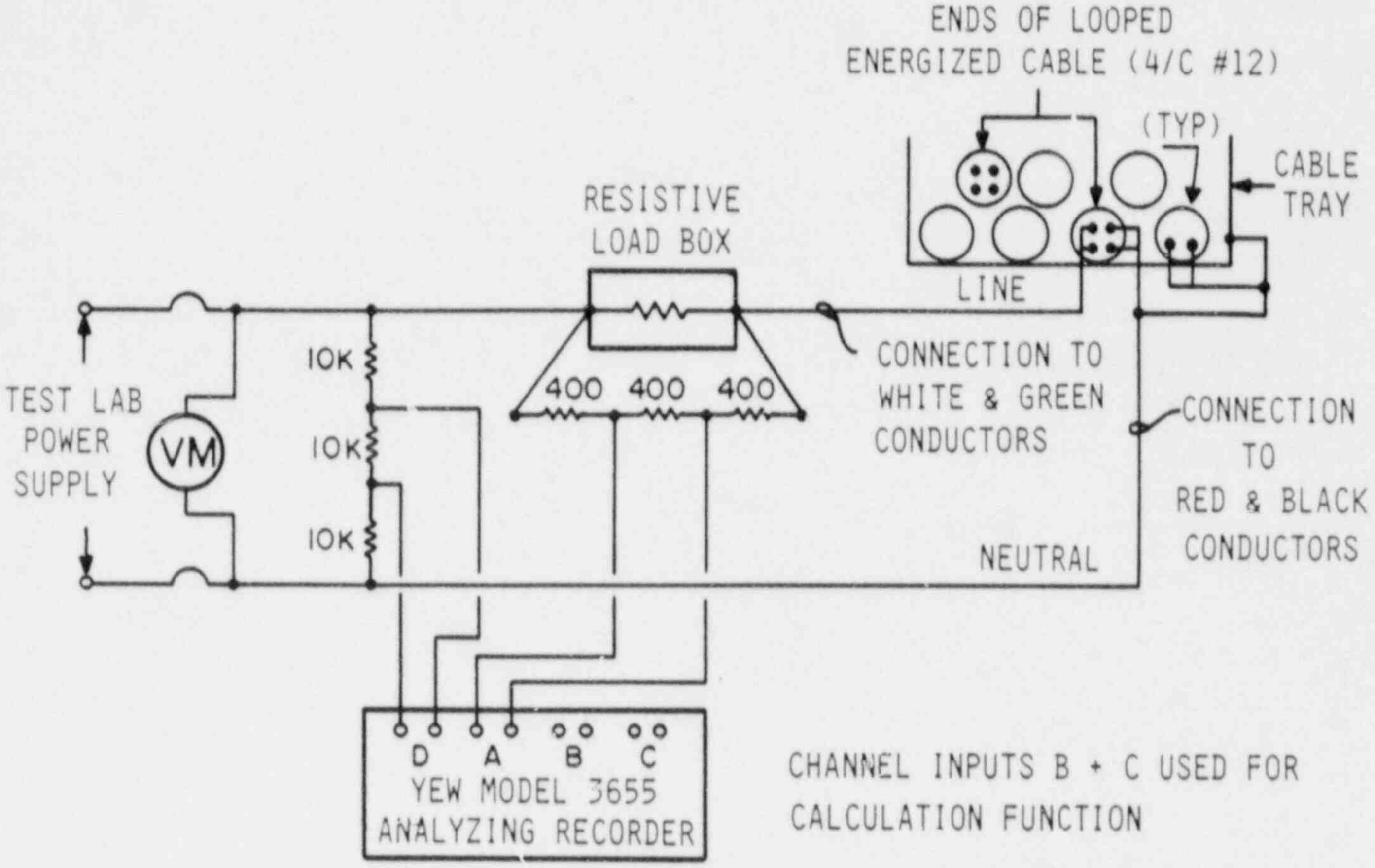
CABLE TRAY AND FLAME BURNER ARRANGEMENT




| ITEM NO. | DESCRIPTION |
|---|---|
| 1. | ROTAMETER FOR SUPPLY AIRFLOW, SET AT 163± 10 SCFH |
| 2. | ROTAMETER FOR FUEL INPUT RATE, SET AT 70,000± 1600 BTU PER HOUR |
| 3. | AIR-GAS VENTURI MIXER, MFGRD. BY AMERICAN GAS FURNITURE CO., CAT NO. 14-18 (2 LB /IN2 MAX GAUGE PRESS.) |
| 4. | RIBBON BURNER, MFGRD. BY AMERICAN GAS CO., 10", CAT. NO. 1614 |

FIGURE NO 2
TEST NO. 1, 2, AND 3

FLAME SOURCE CONNECTIONS
70,000 BTU'S PER HOUR




NOTES:

1.0 FIXED RESISTOR VOLTAGE DIVIDERS USED TO REDUCE VOLTAGE INPUT TO RECORDER.

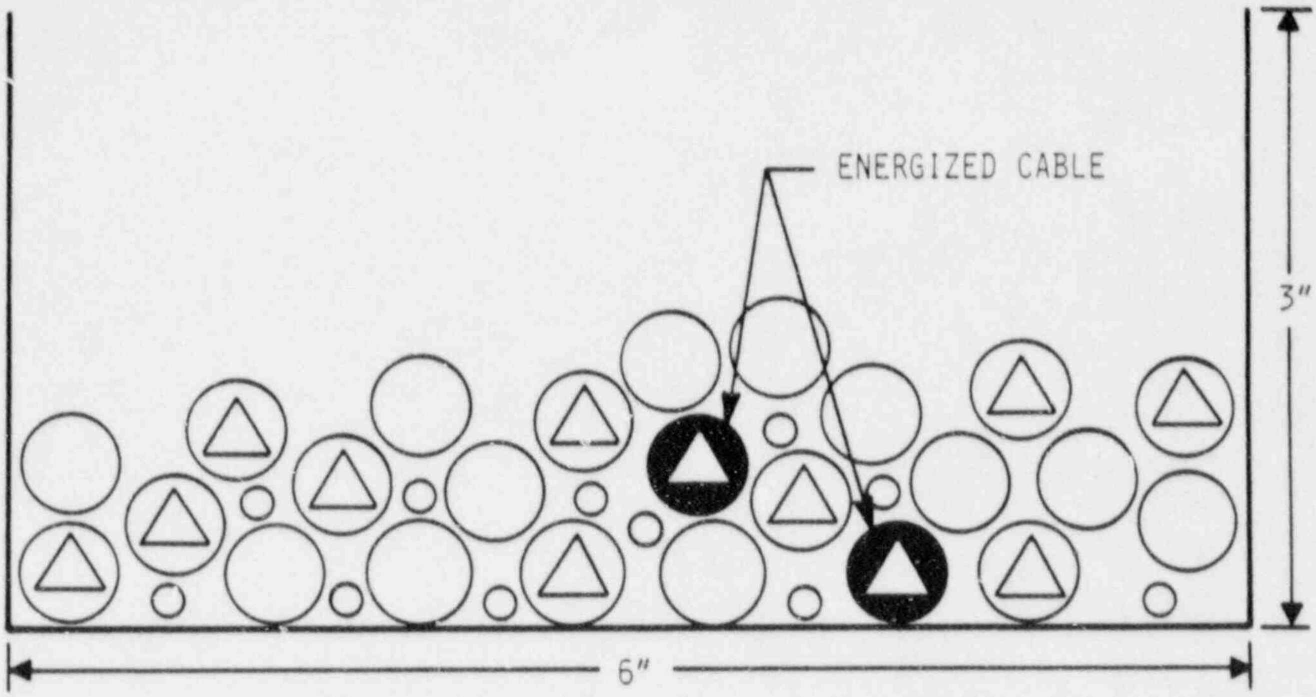
2.0 ALL CONDUCTORS OF UNENERGIZED CABLES ARE TIED TO NEUTRAL

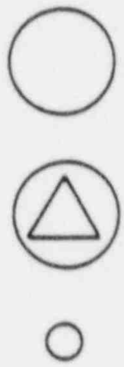
3.0 TEST LAB POWER SUPPLY WAS NOMINAL 115VAC WITH A 50 AMPERE CAPACITY

FIGURE NO. 3

TEST NO.1 AND 2

CIRCUIT CONNECTIONS



2/C #10 (CODE 125-09516)

4/C #12 (CODE 125-09512)

1/C #12 (CODE 125-09508)

NOTE:

1.0 CABLES ARE RANDOMLY INSTALLED IN THE TRAY TO SIMULATE FIELD CONDITIONS.

2.0 CABLE IS LOOPED IN THE TRAY, SO THAT BOTH ENDS OF THE CABLE ARE ON THE SAME SIDE OF THE TRAY.

3.0 PER CENT TRAY FILL IS 28.5%.

FIGURE NO. 4

TEST NO. 1 AND 2

CABLE INSTALLATION AT FLAME AREA

MODEL 3655 LIST

MODE: MEMORY

SAMPLE RATE: 1.00 ms (Test 2)

0.50 ms (Test 1)

****** SET RANGE ******

| CH. | INPUT | RANGE | FILTER |
|---|---|---|---|
| A | AC | 60V | OFF |
| B | OFF | | |
| C | OFF | | |
| D | AC | 60V | OFF |

****** SET TRIGGER ******

| | | |
|---|---|---|
| TRIGGER LEVEL | : | 6% (Test 2) 2% (Test 1) |
| TRIGGER SOURCE | : | A |
| TRIGGER SLOPE | : | POS |
| PRE TRIGGER | : | 10% |
| SAMPLE CLOCK | : | INT |
| BUFFER MEMORY | : | 8000 |
| AVERAGING | : | OFF |

****** SET PROGRAM ******

PROGRAM : ON

| | UNIT | LOW | HIGH |
|---|---|---|---|
| Y1 = H*(SQR(MEAN(A*A))) | SV | 0.000 | 180.0 |
| Y2 = (H*(SQR(MEAN(A*A))))/F | I | 0.000 | 60.00 |
| Y3 = (G/((H*(SQR(MEAN(A*A))))/F))-F | R | 0.000 | 300(Test 1) 3000(Test 2) |
| Y4 = I*(SQR(MEAN(D*D))) | LV | 0.000 | 180.0 |

| | | | | |
|---|---|---|---|---|
| F = 2.165 (Test 1) 2.120 (Test 2) | G = 114.8 | H = 3.010 | I = 2.994 | J = 0.000 |
| K = 0.000 | L = 0.000 | M = 0.000 | N = 0.000 | O = 0.000 |
| P = 0.000 | Q = 0.000 | R = 0.000 | S = 0.000 | T = 0.000 |

****** SET DISPLAY FORMAT ******

DISPLAY MODE: SINGLE

1: Y1 - SHUNT VOLTAGE

2: Y2 - LEAKAGE CURRENT

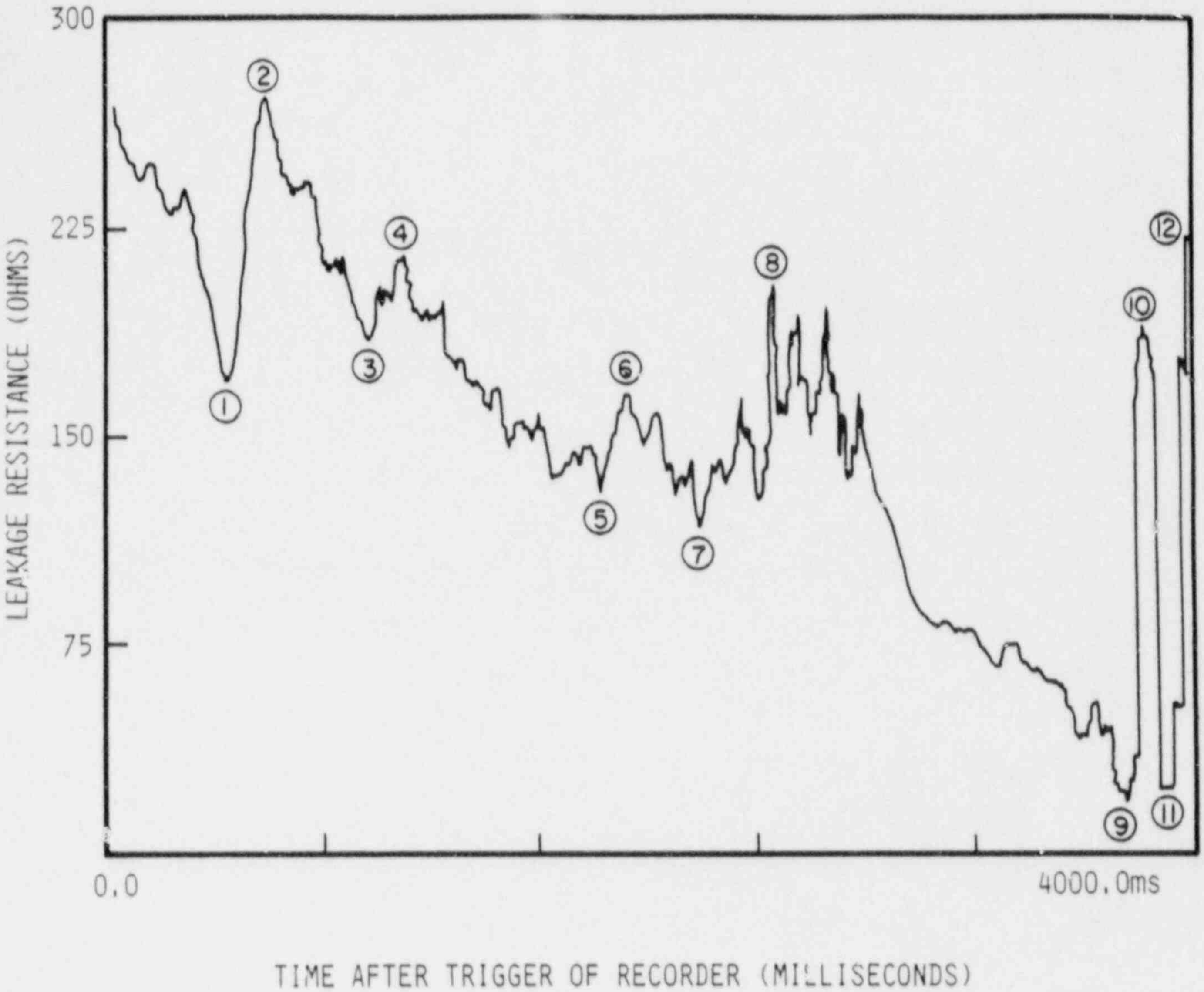
3: Y3 - LEAKAGE RESISTANCE

4: Y4 - LINE VOLTAGE

FIGURE NO. 5

TEST NO. 1 AND 2

ANALYZING RECORDER PROGRAM

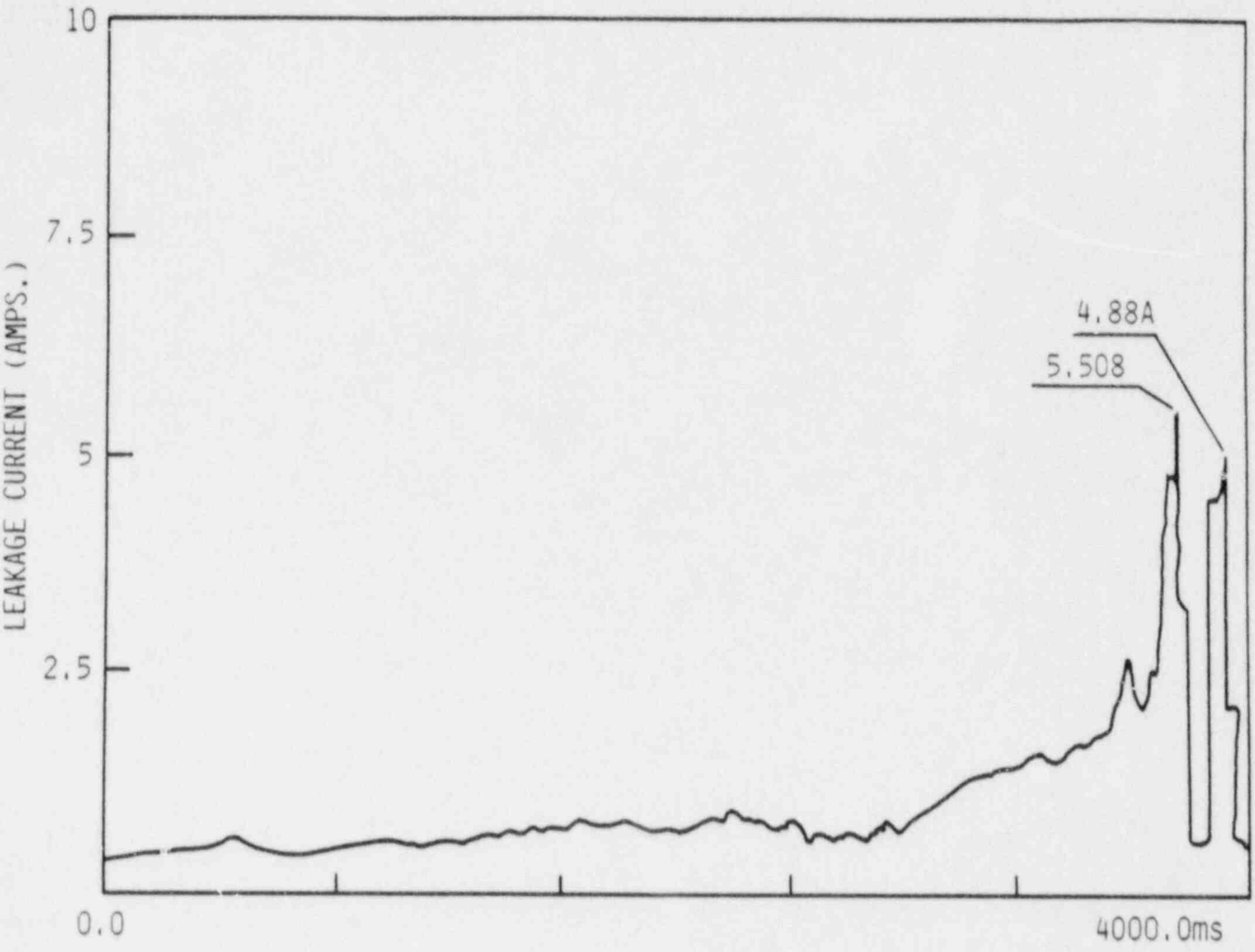



SCAN RATE: 0.5 MILLISECONDS

TRIGGER TIME: 10 MINUTES

(1) - EXTREME POINTS, SEE REPORT SECTION 7.1 FOR VALUES

FIGURE NO. 6
TEST NO. 1
CABLE INSULATION LEAKAGE RESISTANCE
VS. TIME (AFTER TRIGGER)




TIME AFTER TRIGGER OF RECORDER (MILLISECONDS)

SCAN RATE: 0.5 MILLISECONDS

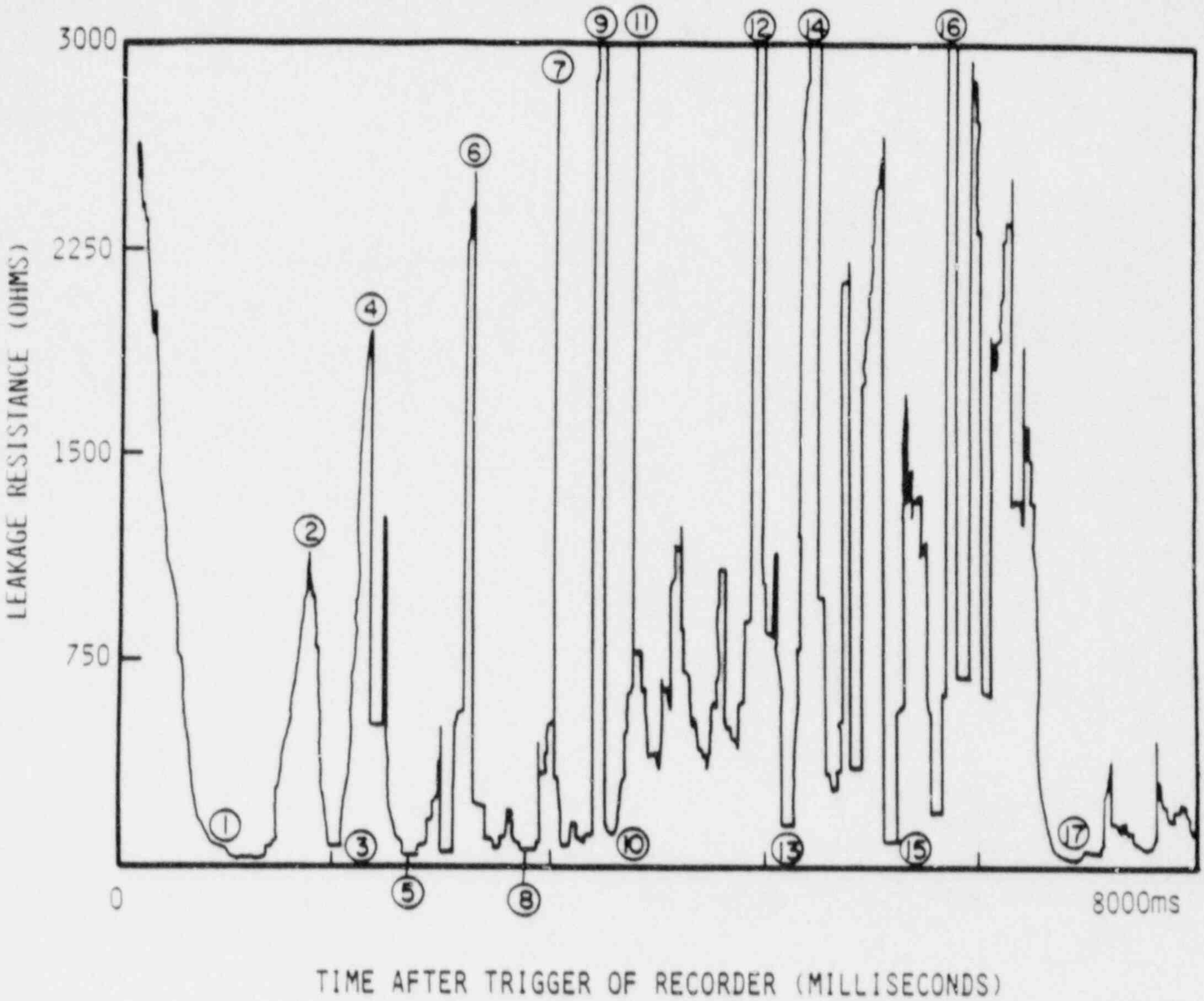
TRIGGER TIME: 10 MINUTES

FIGURE NO. 7

TEST NO. 1

CABLE INSULATION LEAKAGE CURRENT

VS. TIME (AFTER TRIGGER)




SCAN RATE: 1.0 MILLISECONDS

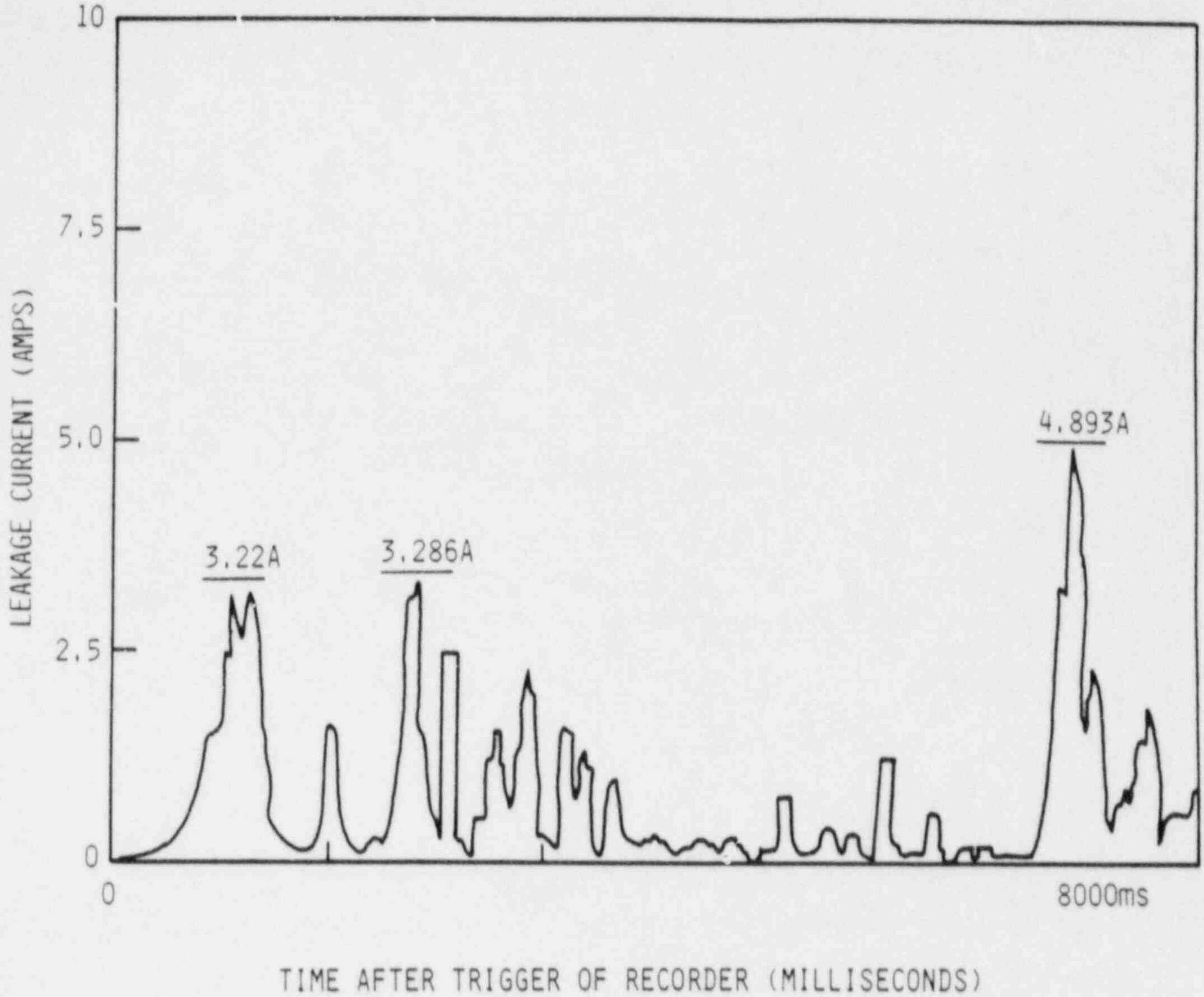
TRIGGER TIME: 8 MINUTES 5 SECONDS

① - EXTREME POINTS, SEE REPORT SECTION 7.2 FOR VALUES

FIGURE NO. 8

TEST NO. 2

CABLE INSULATION LEAKAGE RESISTANCE
VS. TIME (AFTER TRIGGER)




SCAN RATE: 1.0 MILLISECOND

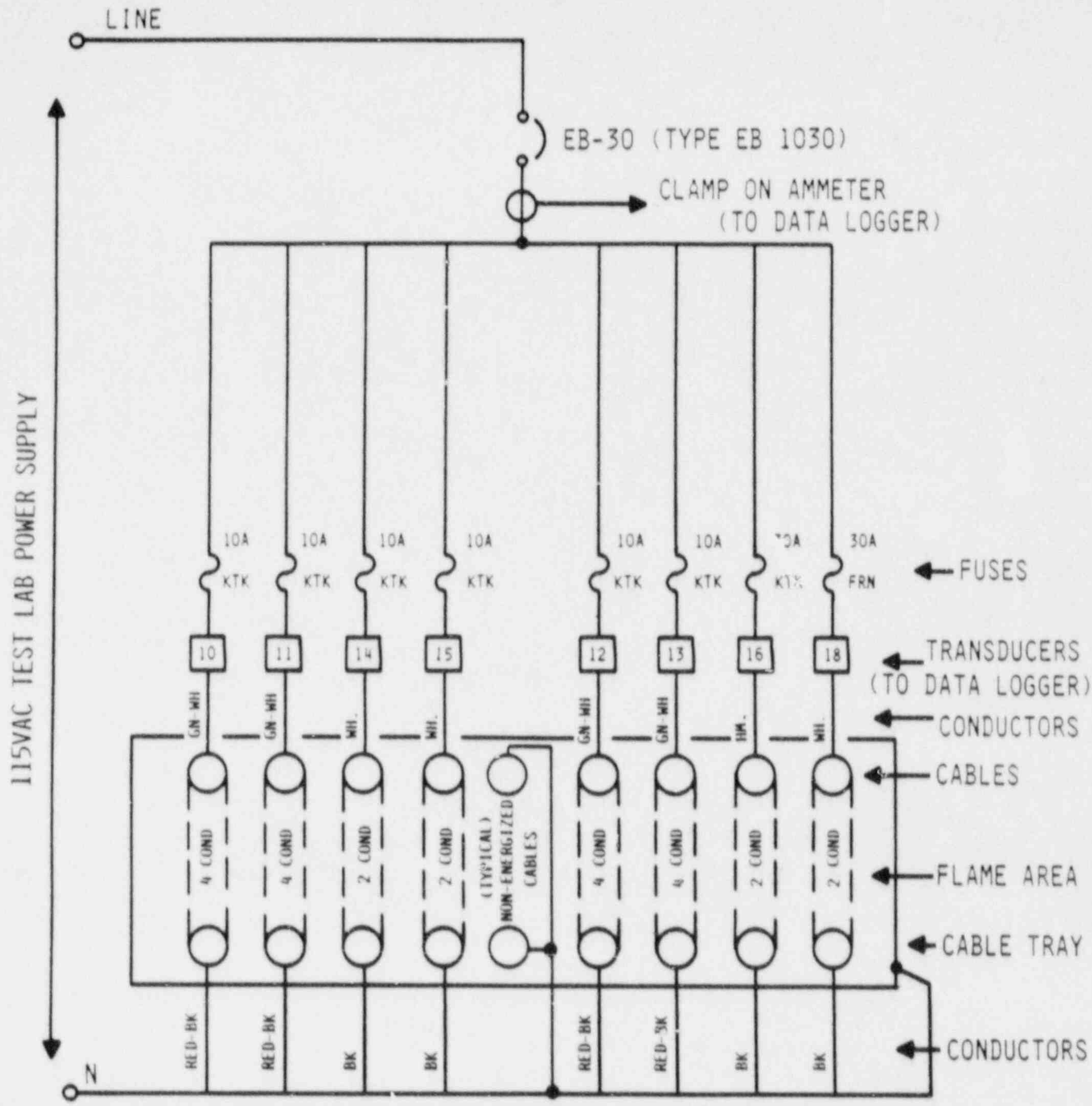
TRIGGER TIME: 8 MINUTES 5 SECONDS

FIGURE NO. 9

TEST NO. 2

CABLE INSULATION LEAKAGE CURRENT

VS. TIME (AFTER TRIGGER)




NOTES:

1.0 [10] - INDICATES 5 AMPERE TRANSDUCER TO DATA LOGGER NUMBER INDICATES CHANNEL INPUT.

FIGURE NO. 10
TEST NO. 3
CIRCUIT CONNECTION

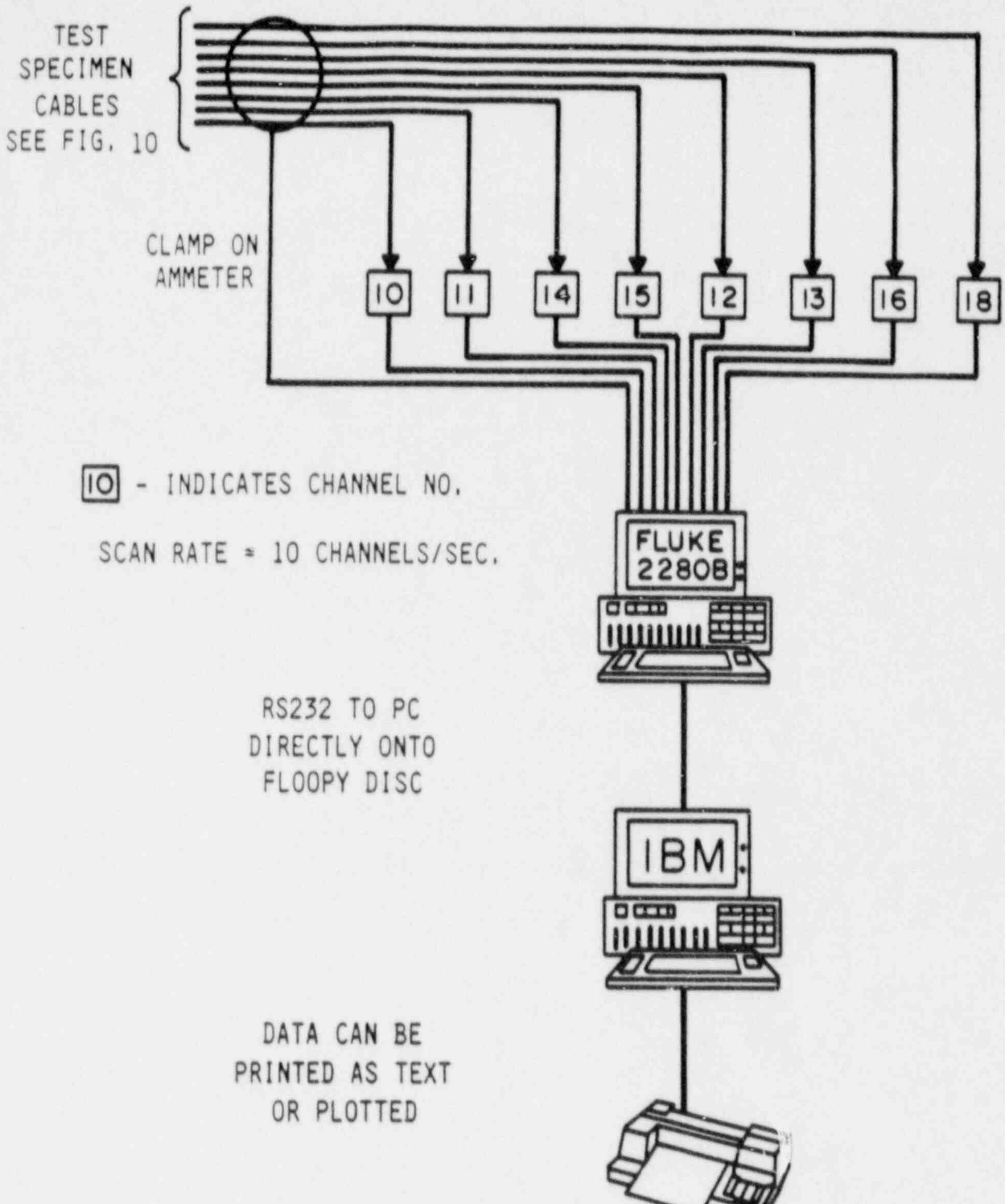
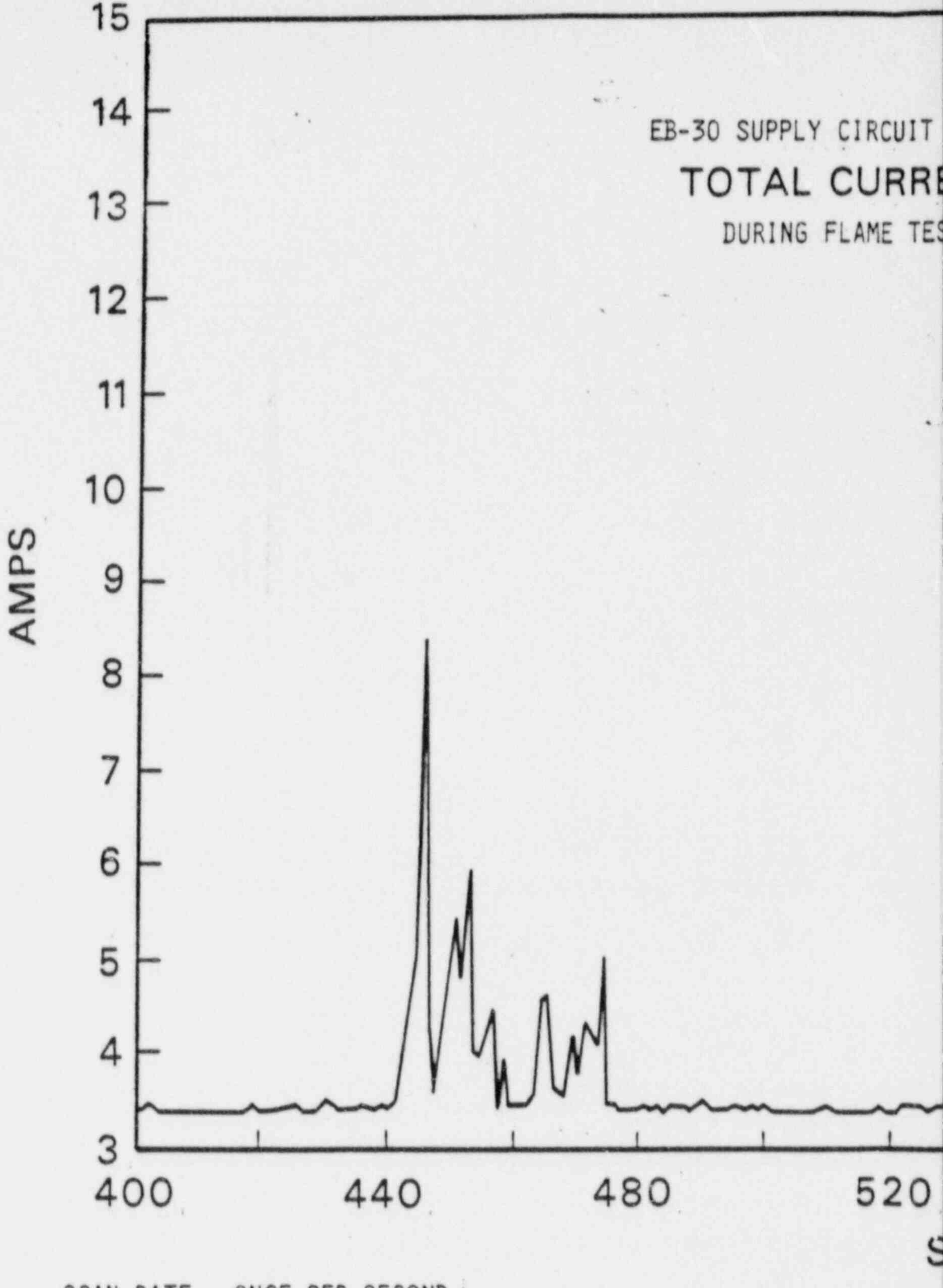



FIGURE NO. 11
TEST NO 3
DATA LOGGER INTERFACE



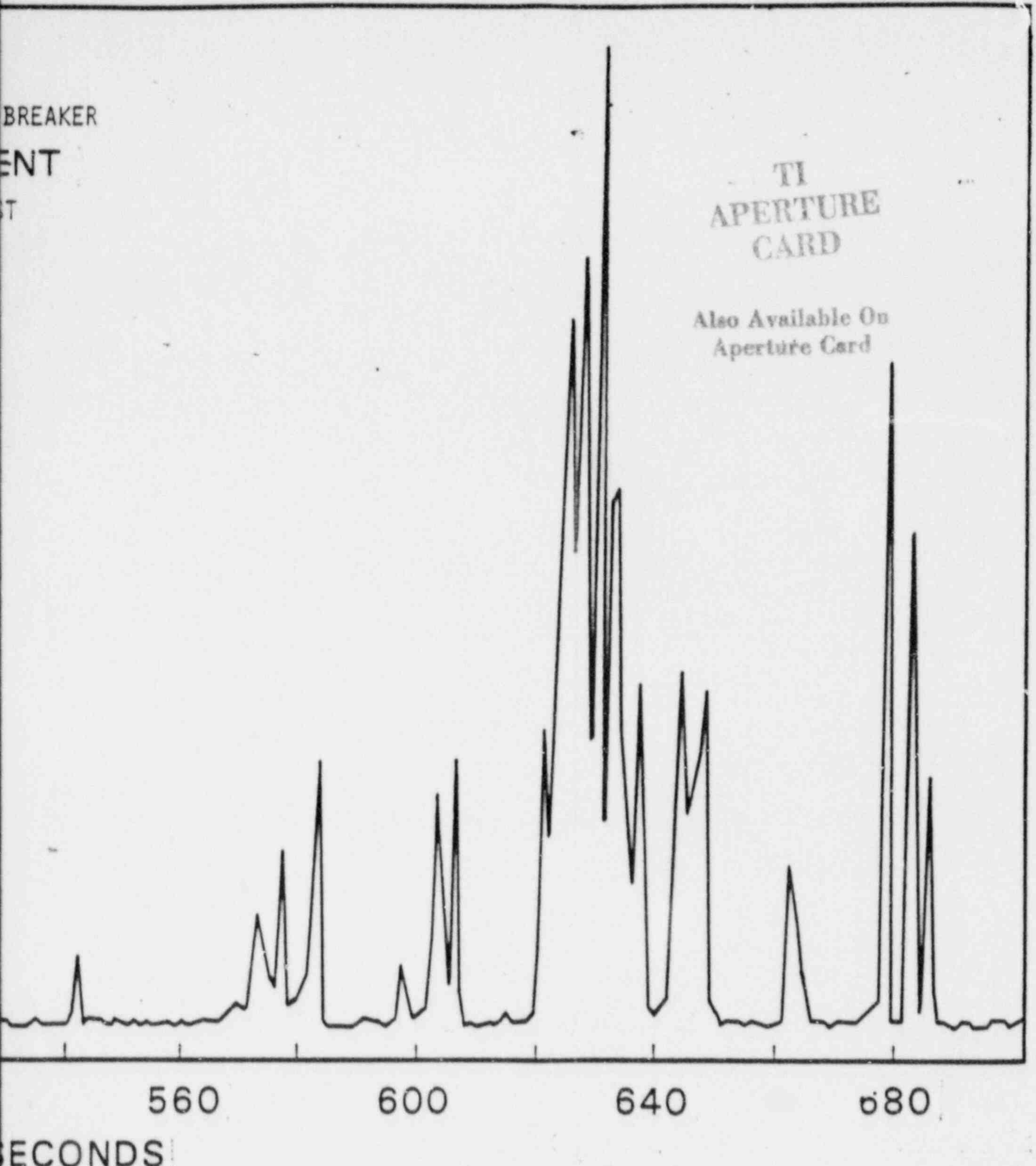

SCAN RATE - ONCE PER SECOND

NOTE: TIME SCALE IS SECONDS AFTER START OF FLAME SOURCE.

F

TOTAL SUPPLY

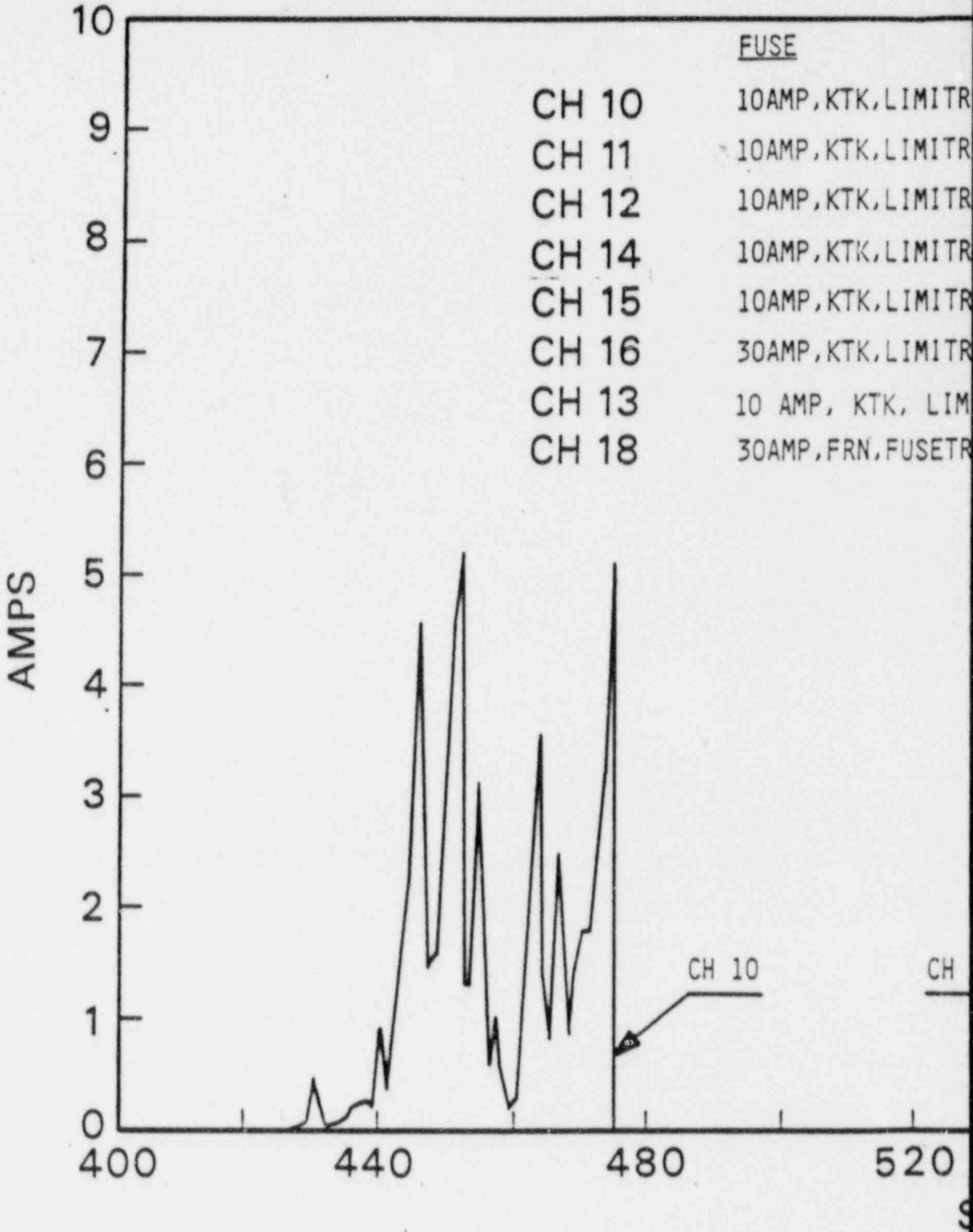
DUR






IGURE NO 12
TEST NO 3
BREAKER CURRENT VS. TIME
ING FLAME TEST

8806210052-01




SCAN RATE: ONCE PER SECOND

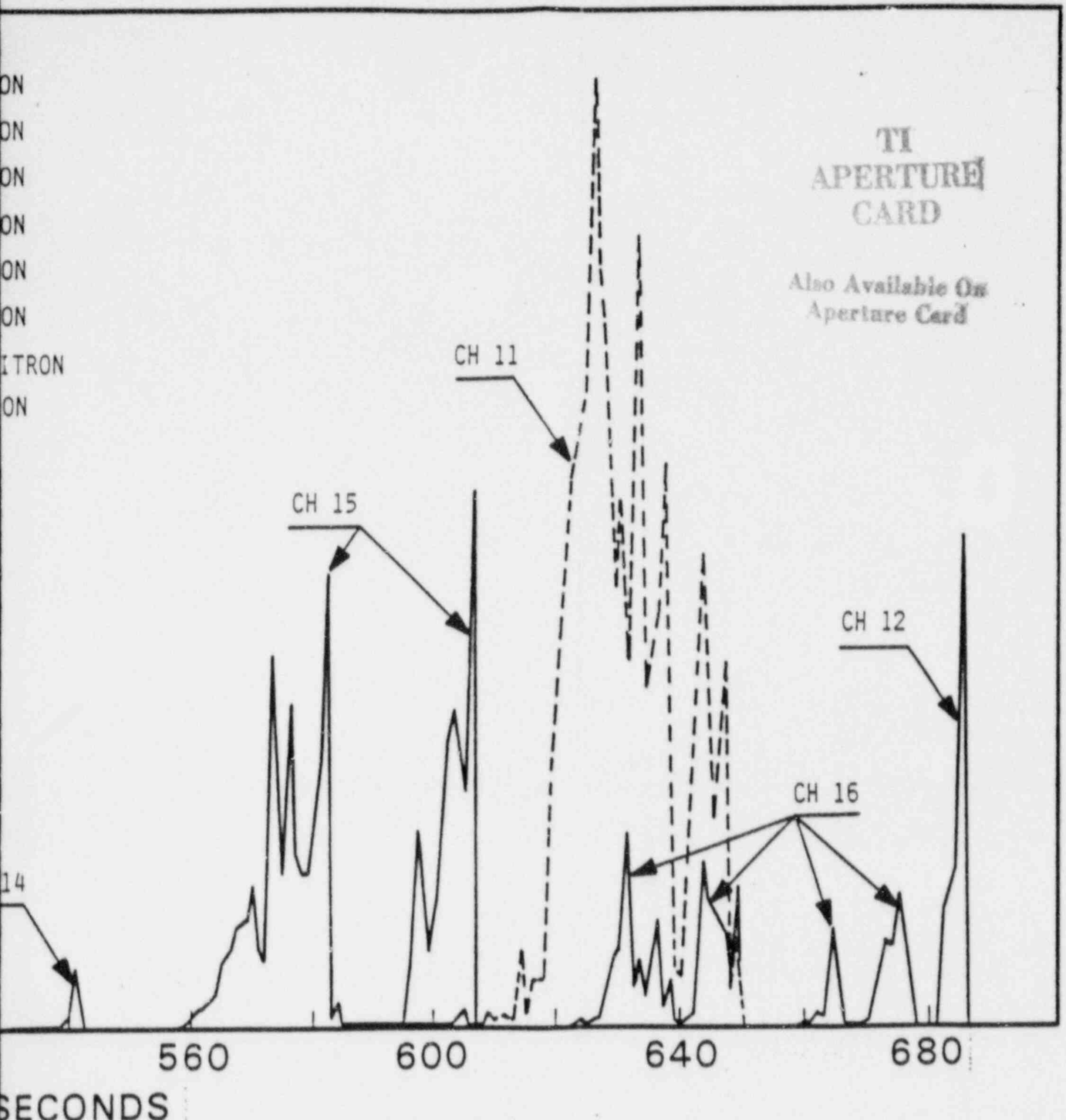
NOTE: 1.0 TIME SCALE IS SECONDS AFTER START OF FLAME SOURCE

2.0 NO LEAKAGE CURRENT RECORDED FOR CHANNELS 13 & 18

FI

LOAD SUPPLY

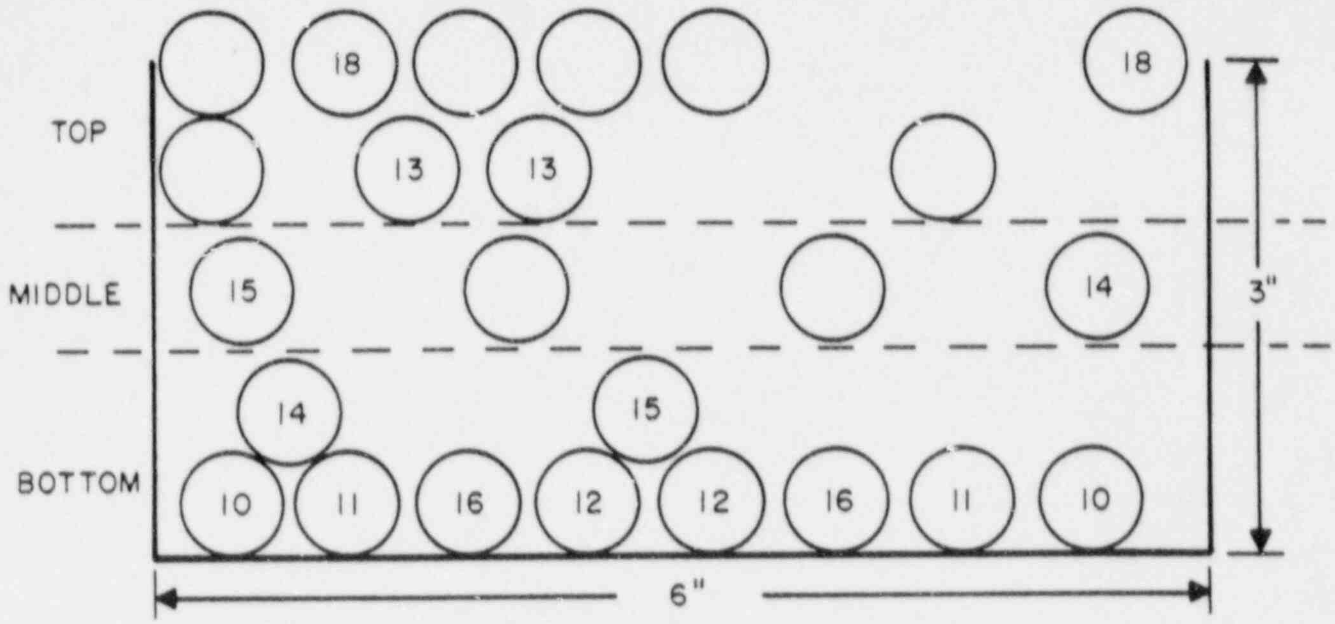
DURI






GURE NO 13
TEST NO 3
FUSE CURRENT VS TIME
NG FLAME TEST

8806210052-02




| CHANNEL # | CABLE TYPE | FUSE | FROM START OF FLAME TIME TO BLOW FUSE (SEC) | FAILURE SEQUENCE |
|---|---|---|---|---|
| 10 | 4/C #12 | 10A, KTK | 477 | 1 |
| 14 | 2/C #10 | 10A, KTK | 544 | 2 |
| 15 | 2/C #10 | 10A, KTK | 609 | 3 |
| 11 | 4/C #12 | 10A, KTK | 652 | 4 |
| 16 | 2/C #10 | 30A, KTK | 679 | 5 |
| 12 | 4/C #12 | 10A, KTK | 688 | 6 |
| 13 | 4/C #12 | 10A, KTK | DID NOT BLOW | NO FAILURE |
| 18 | 2/C #10 | 30A, FRN | DID NOT BLOW | NO FAILURE |

NOTE: (10) - INDICATES ENERGIZED CABLE AND DATA LOGGER CHANNEL NO. INPUT

( ) - INDICATES UNENERGIZED CABLE, ALL CONDUCTORS AND TRAY CONNECTED TO NEUTRAL.

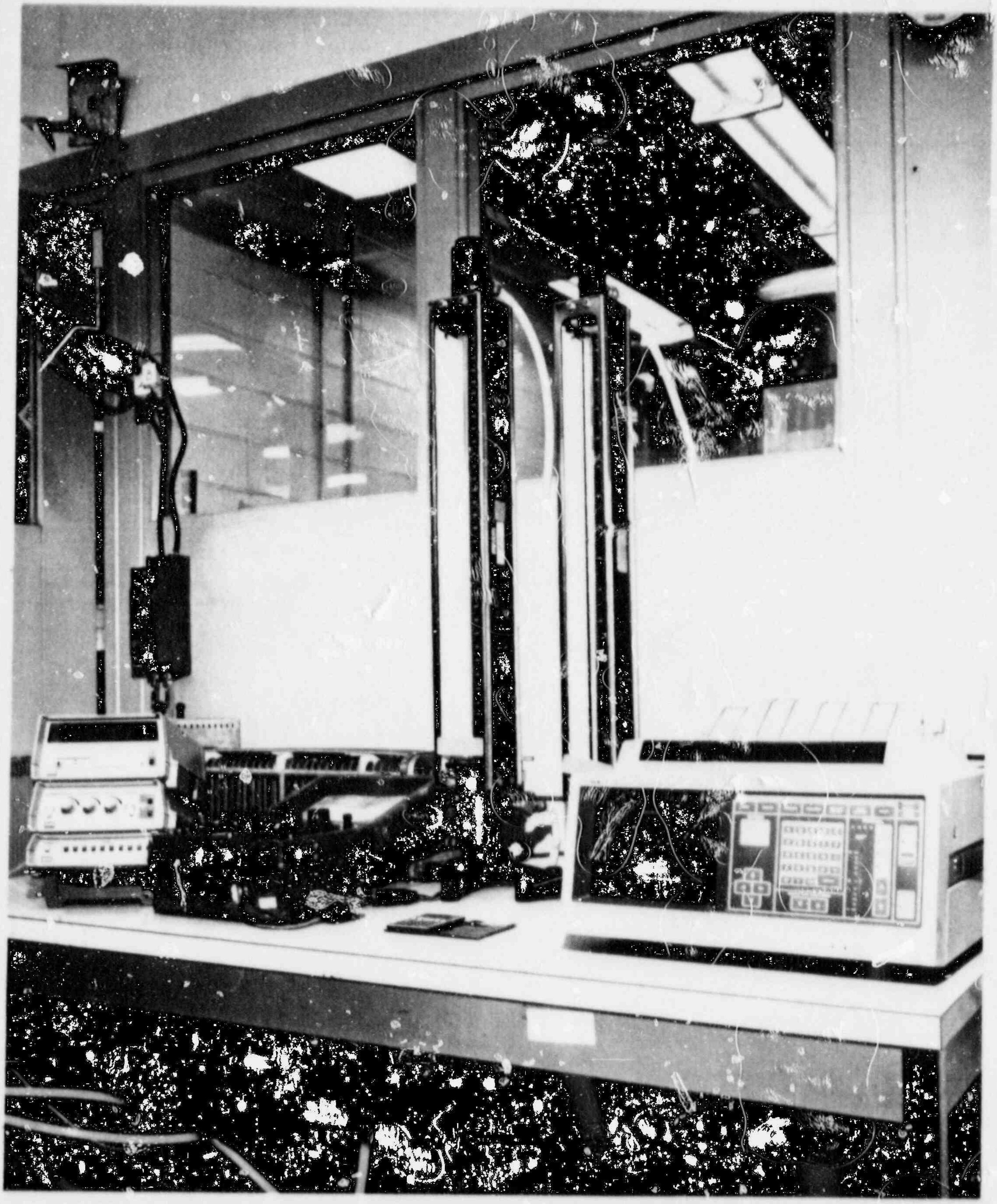
FIGURE NO. 14

TEST NO. 3

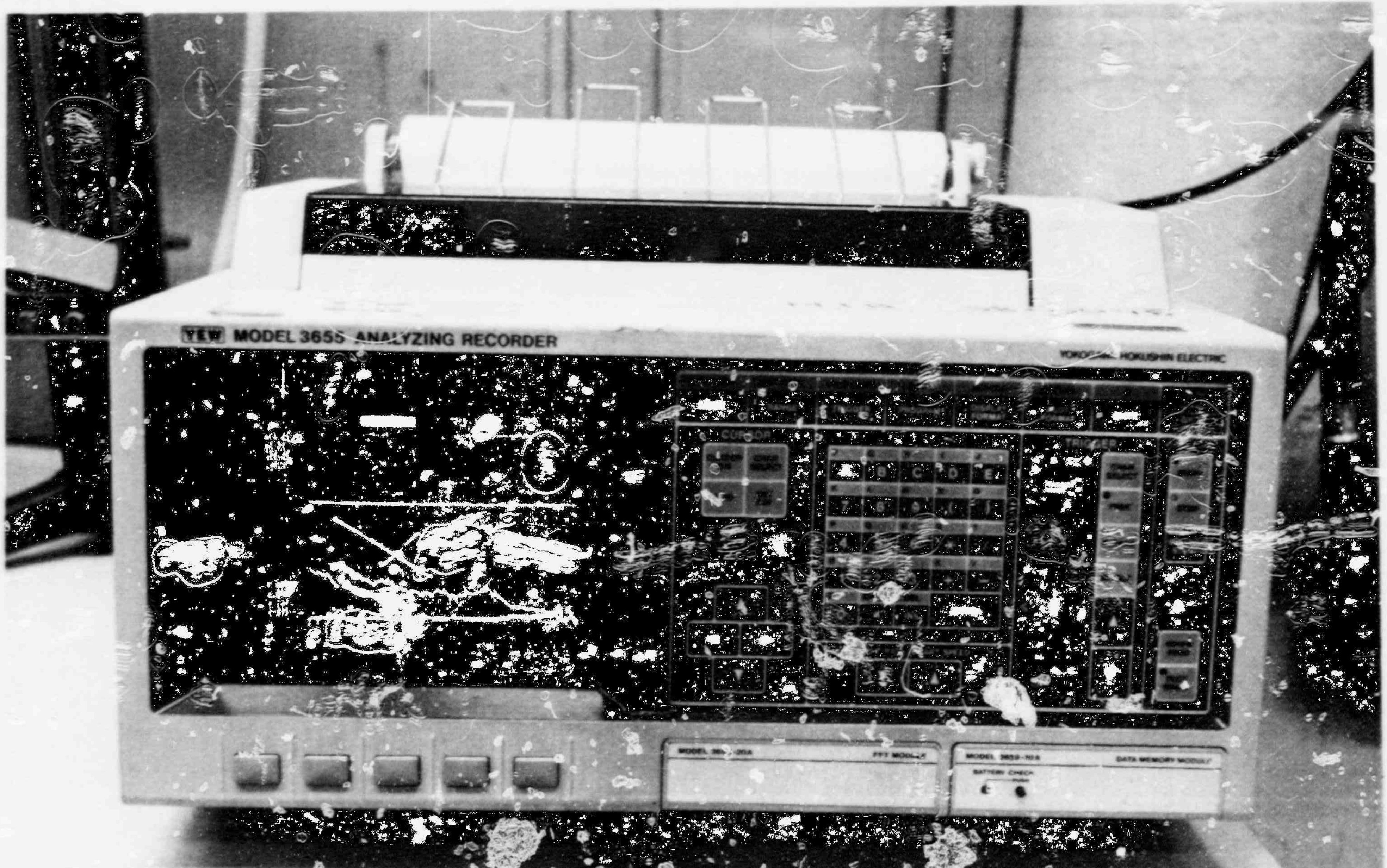
CABLE LOCATION IN FLAME AREA VS. TIME TO BLOW FUSE

## Section 9.0

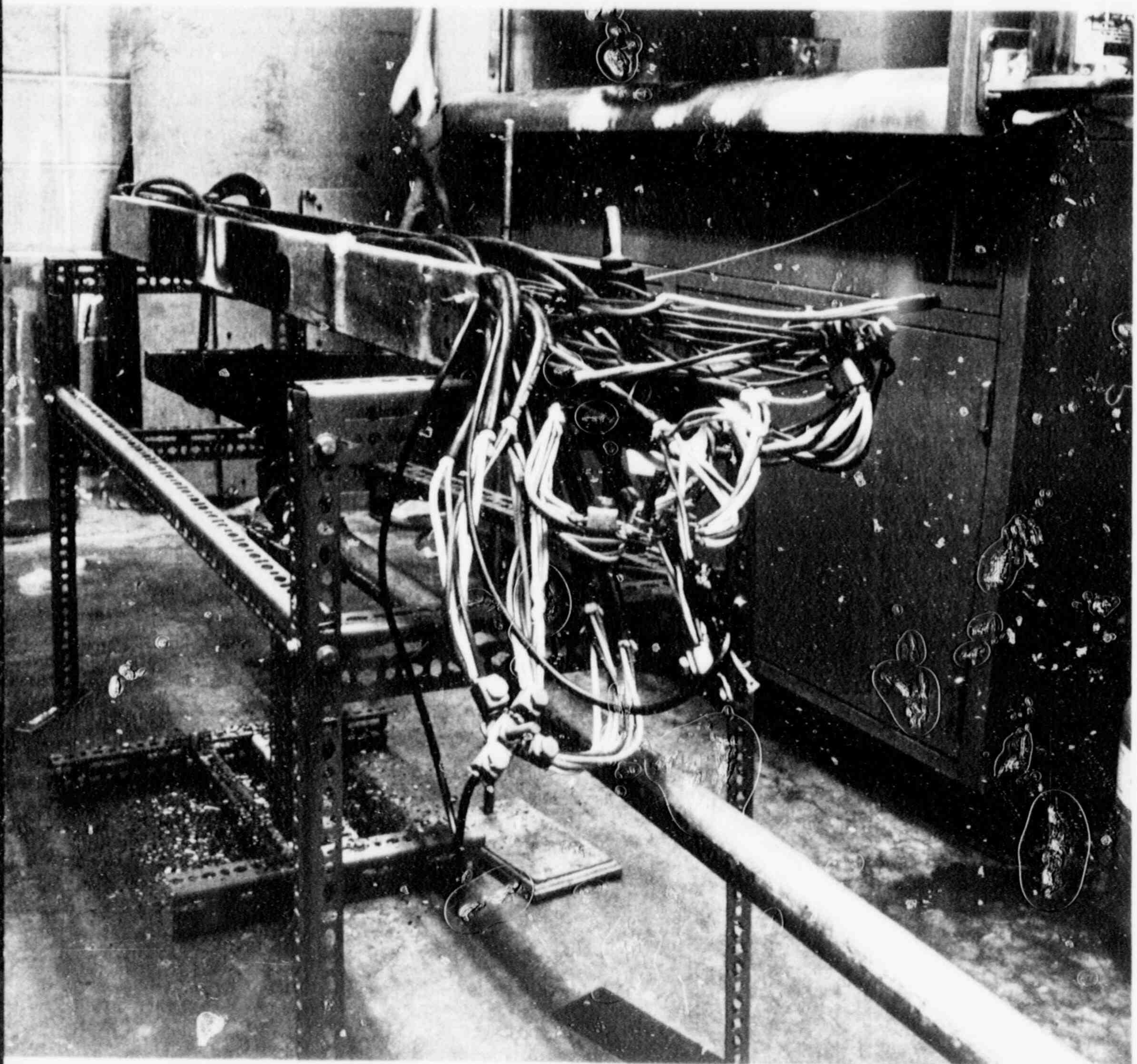
## Pictures



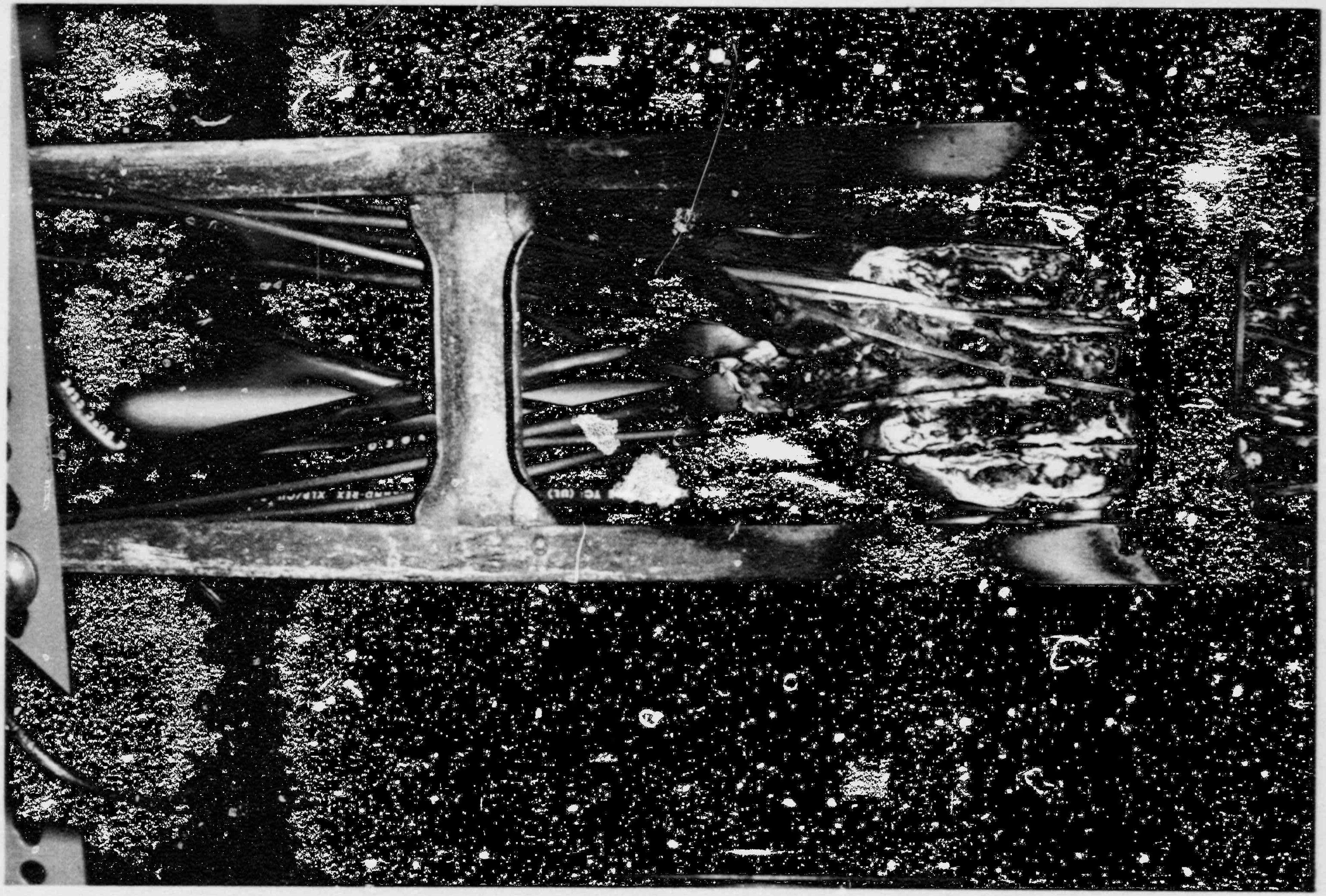
PICTURE NO. 1
Test No. 1 and 2
Control Room Instrumentation
Rotameters, Load Box, Analyzing Recorder



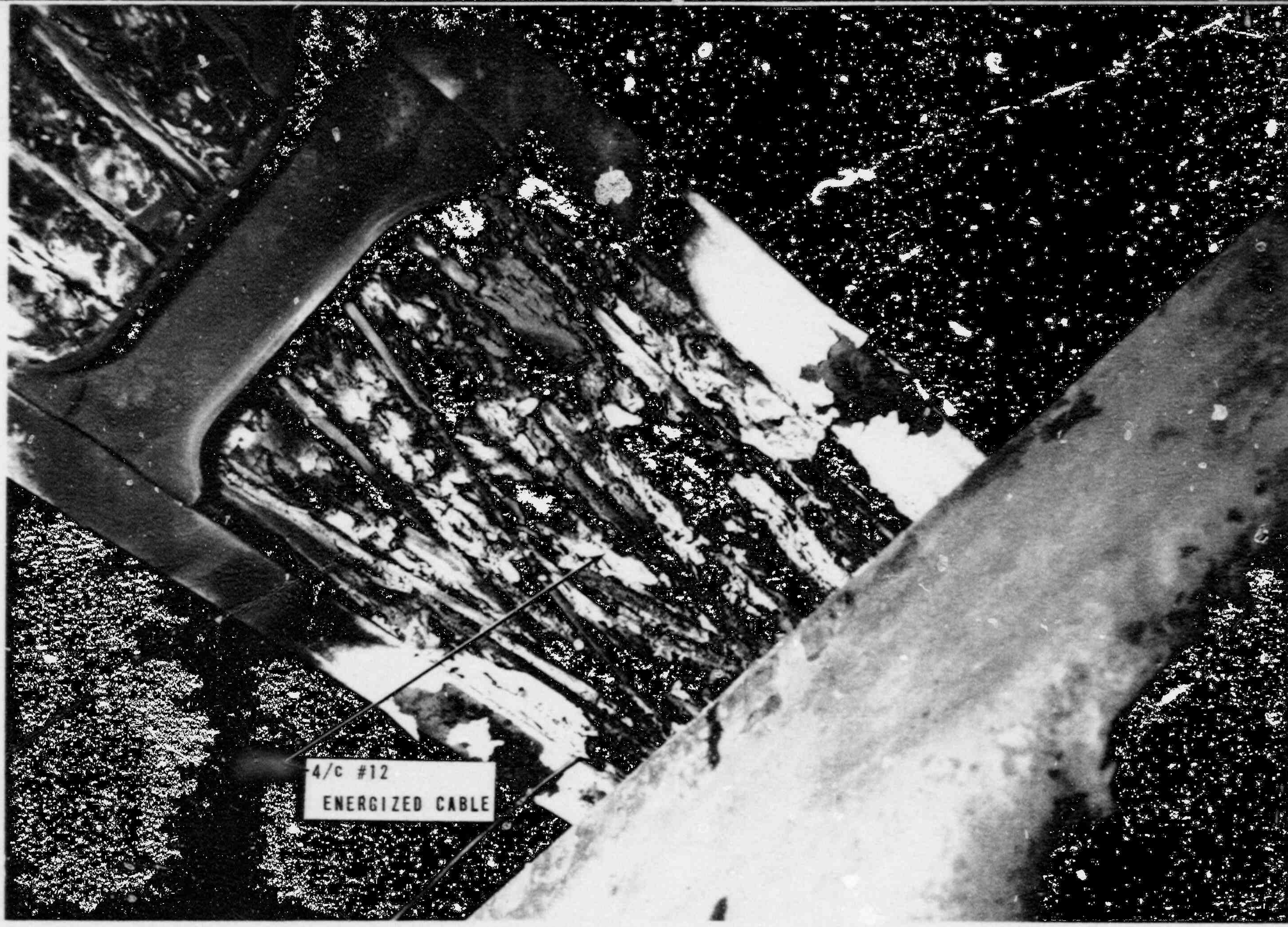

PICTURE NO. 2
Test No. 1 and 2
YEW Model 3655 Analyzing Recorder



PICTURE NO. 3
Test No. 1 and 2
Flame Source, Cable Tray and Cable Connections

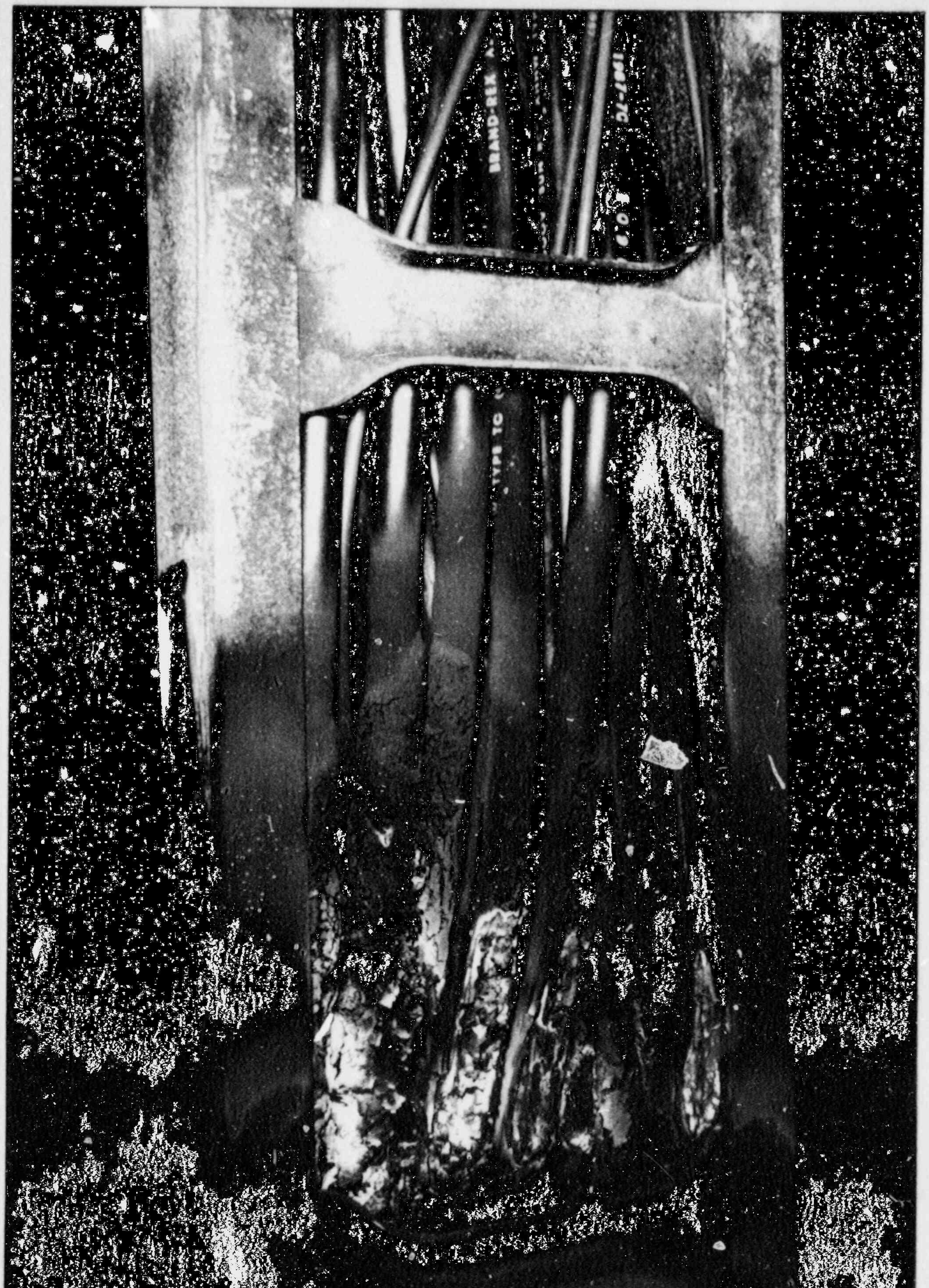


PICTURE NO. 4
Test No. 1
Cable Damage

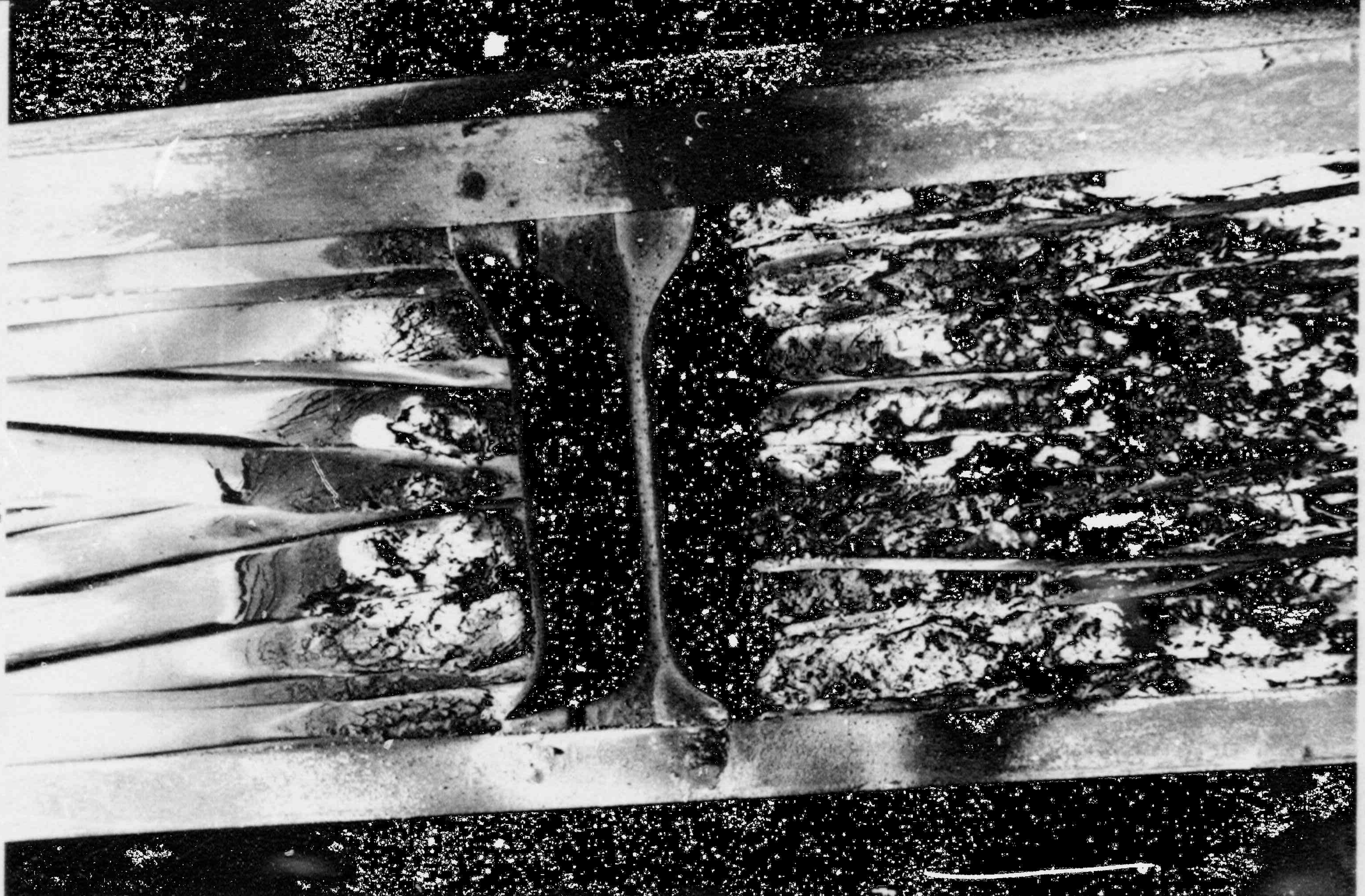



PICTURE NO. 5
Test No. 1
Cable Damage, Burner and Thermocouple Wire

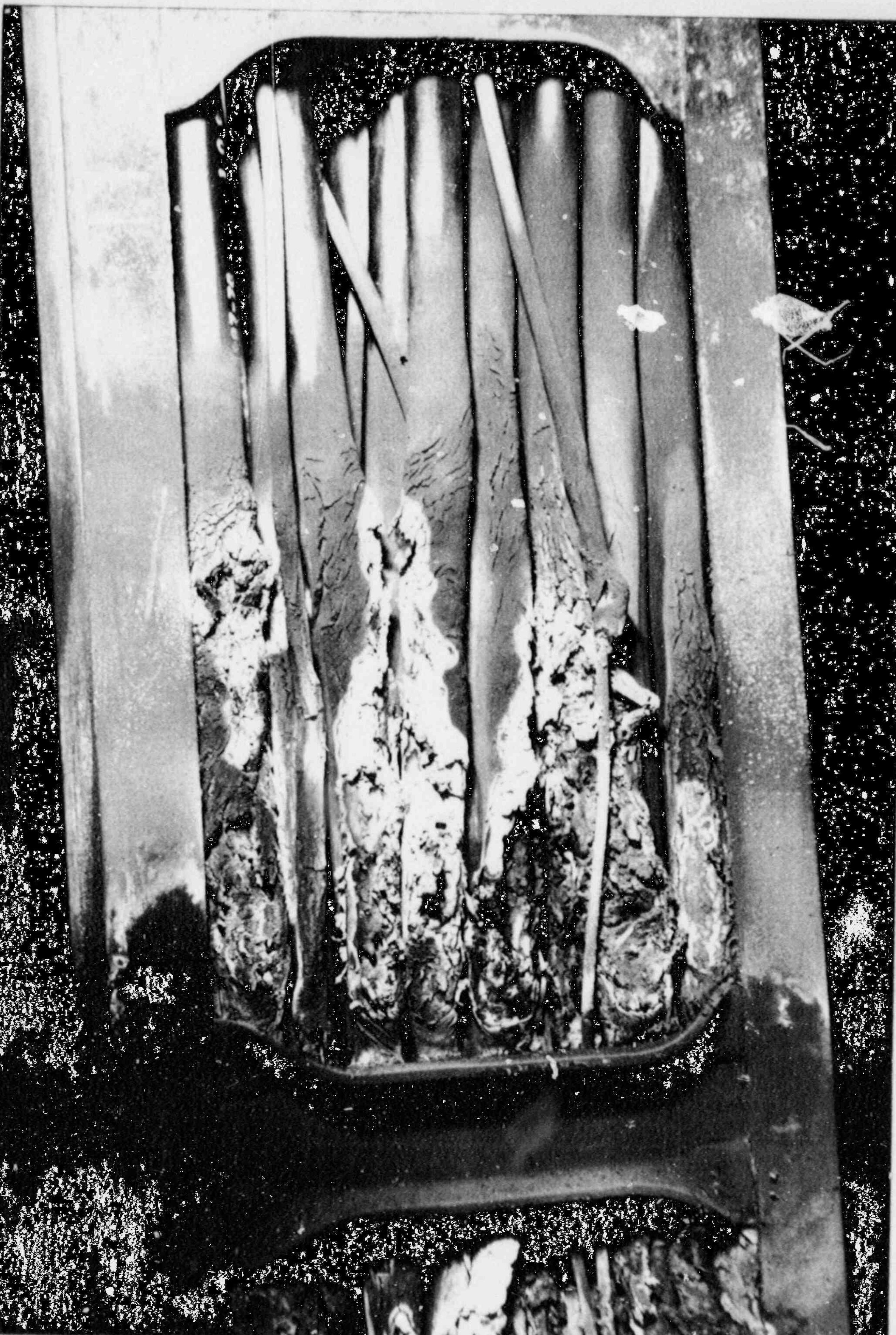
PICTURE NO. 6
Test No. 1
Cable Damage, Burner and Thermocouple Wire




PICTURE NO. 7
Test No. 1
Cable Damage

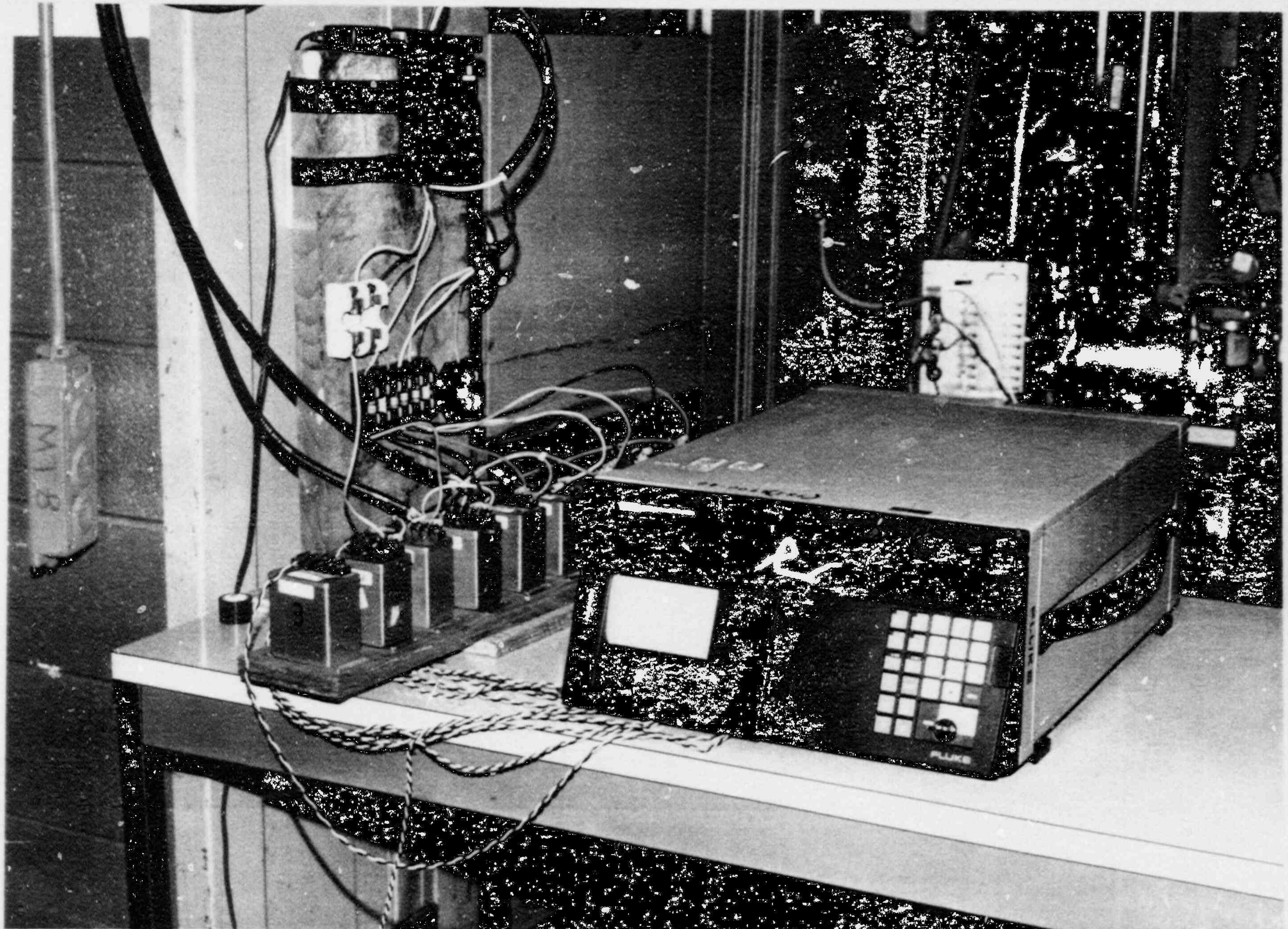


PICTURE NO. 8
Test No. 2
Cable Damage

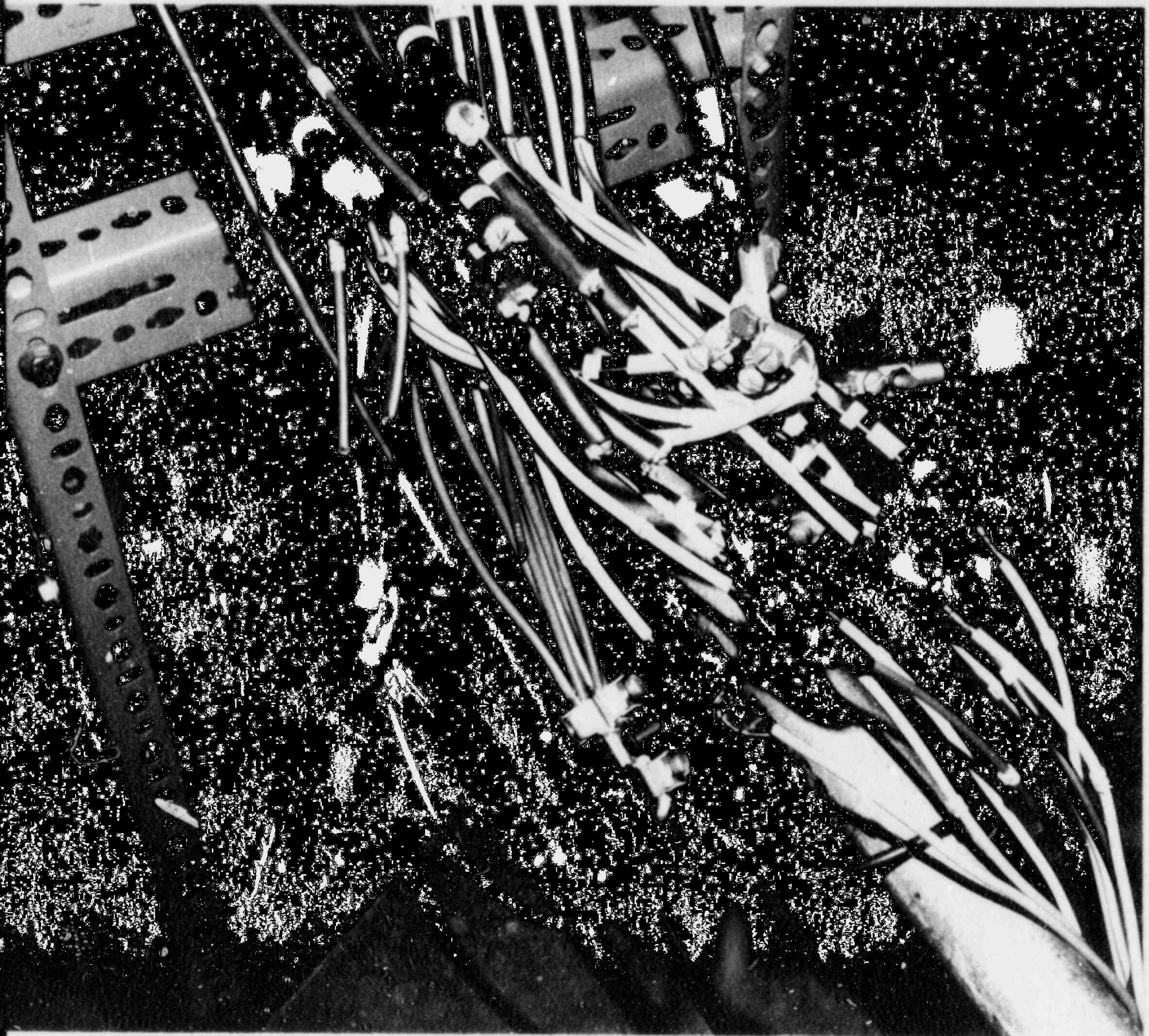


PICTURE NO. 9
Test No. 2
Cable Damage

PICTURE NO. 10
Test No. 2
Cable Damage



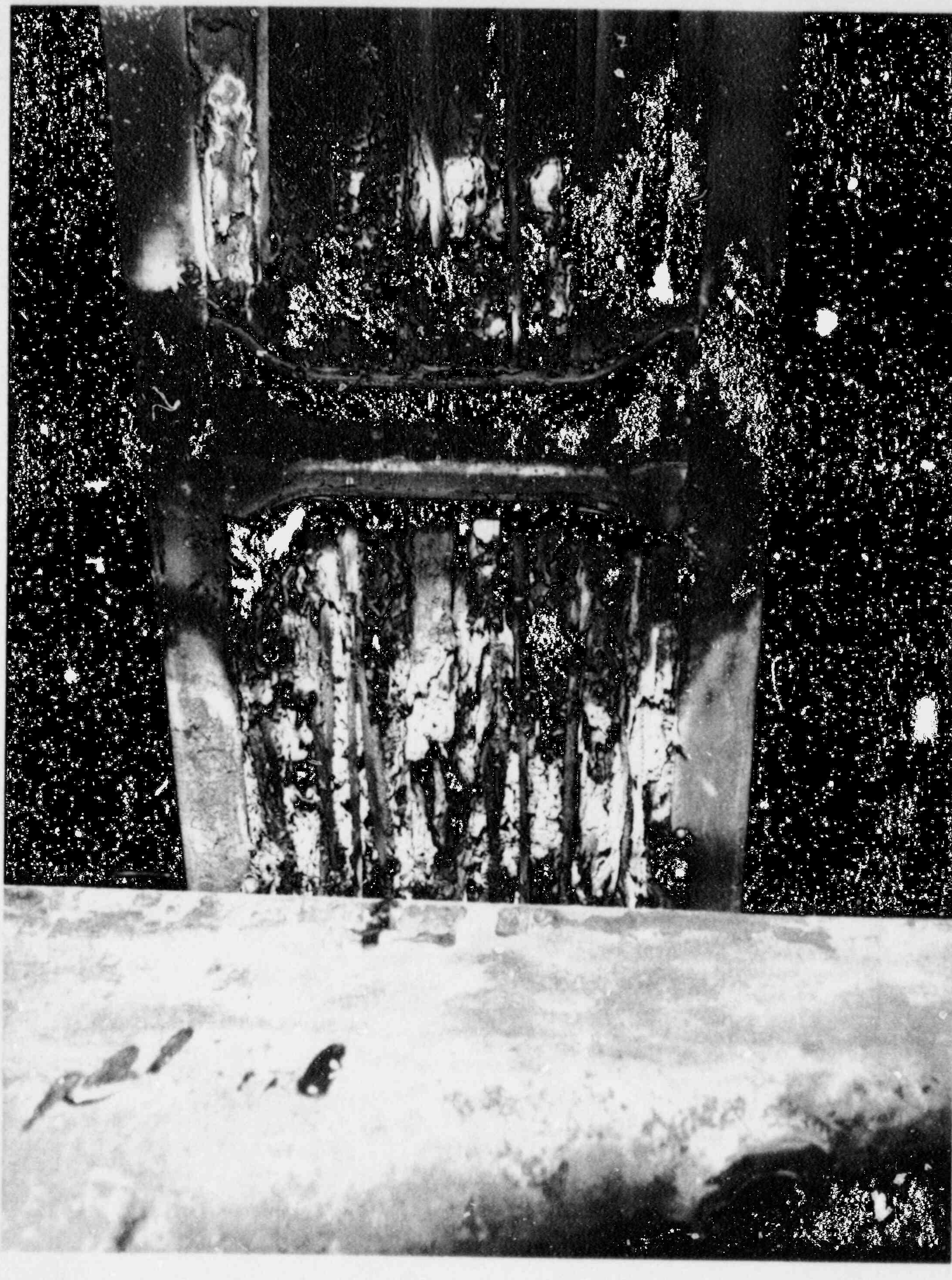

PICTURE NO. 11
Test No. 3
Circuit Breaker, Fuses, Transducers
and Fluke Data Logger



PICTURE NO. 12
Test No. 3
Electrical Cable Connections
At Cable Tray

PICTURE NO. 13
Test No. 3
Cable Damage in Flame Area
Top of Tray

PICTURE NO. 14
Test No. 3
Cable Damage

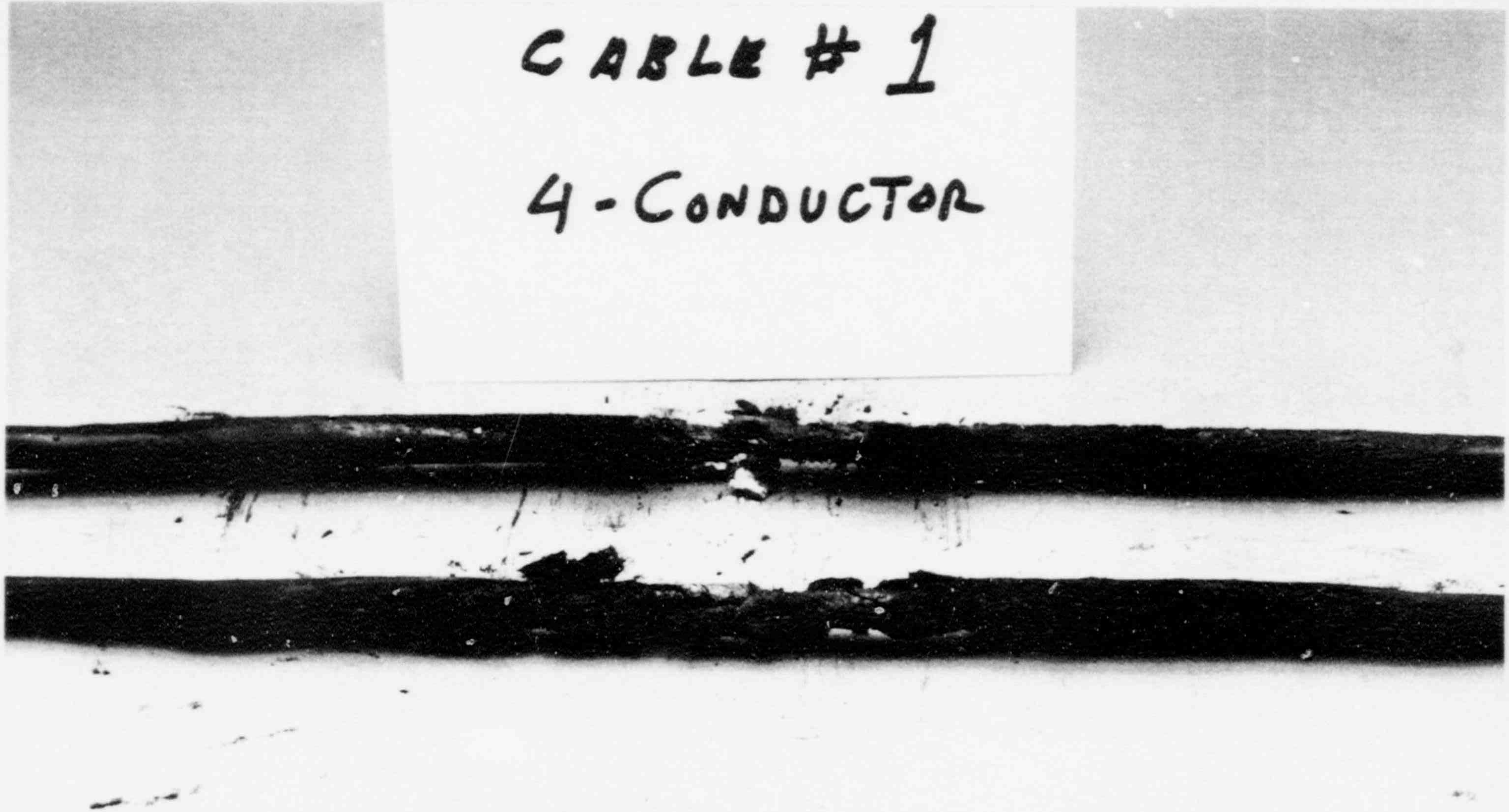


PICTURE NO. 15
Test No. 3
Cable Damage and Burner

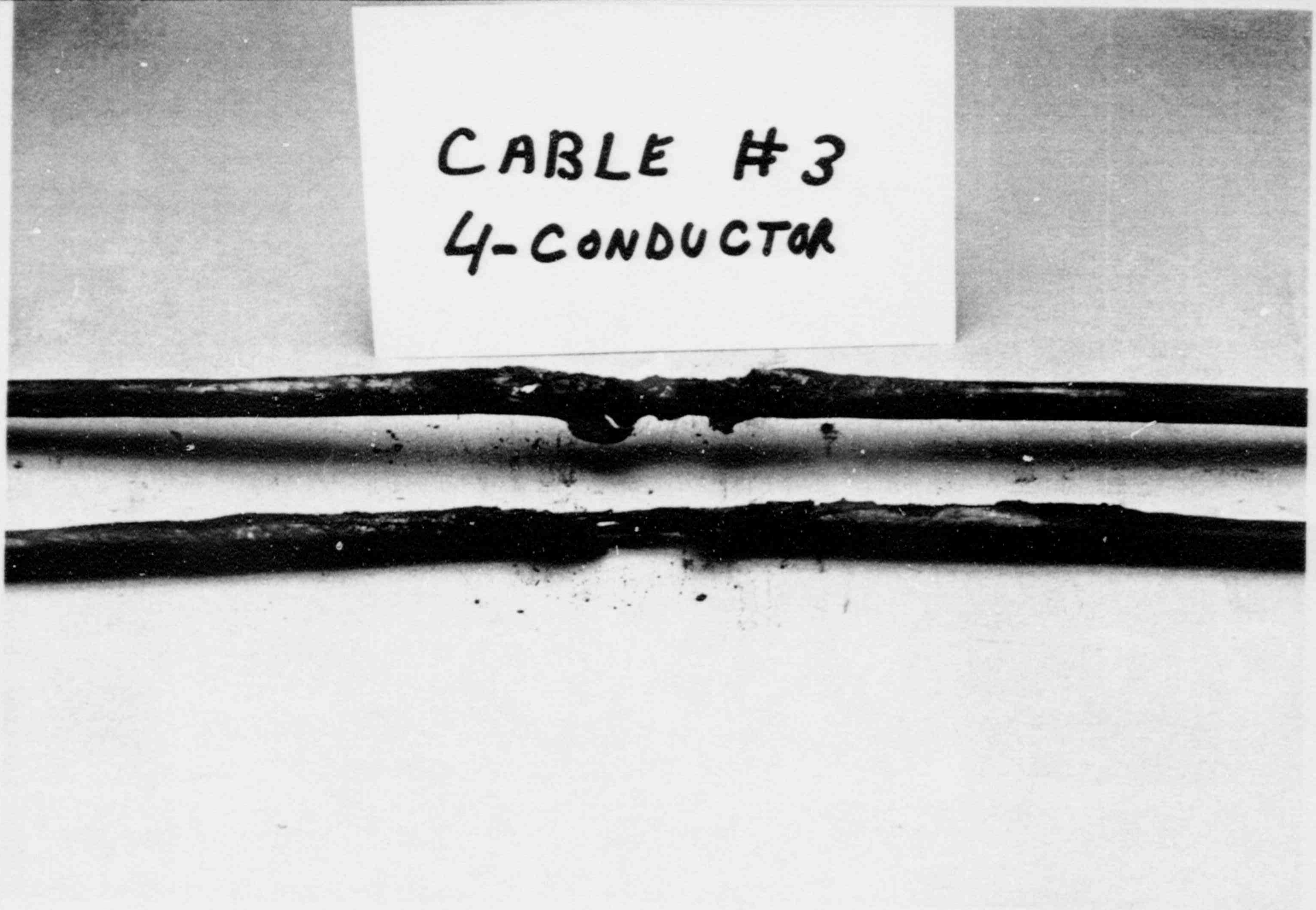
PICTURE NO. 16
Test No. 3
Cable Damage and Burner

PICTURE NO. 17
Test No. 3
Cable Damage

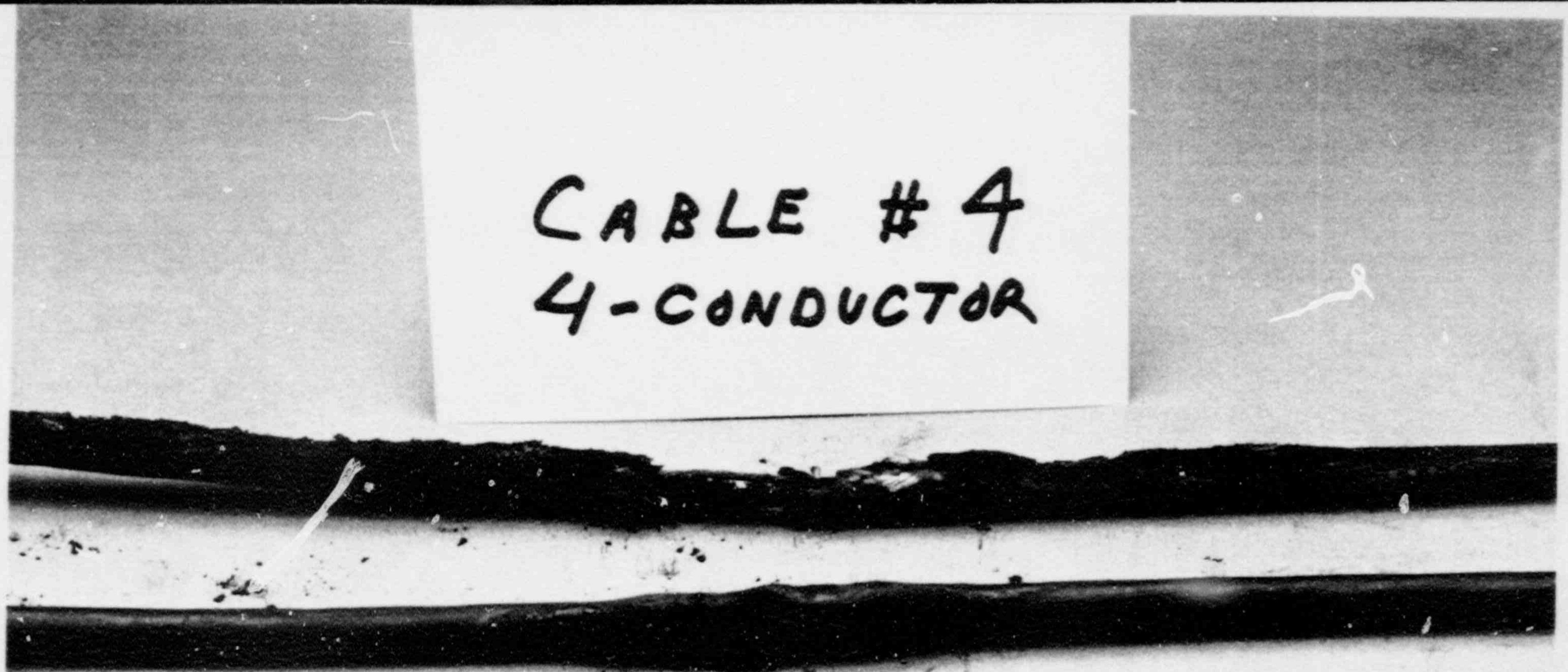
PICTURE NO. 18
Test No. 3
Cable Damage, Burner and
Melted Conductor



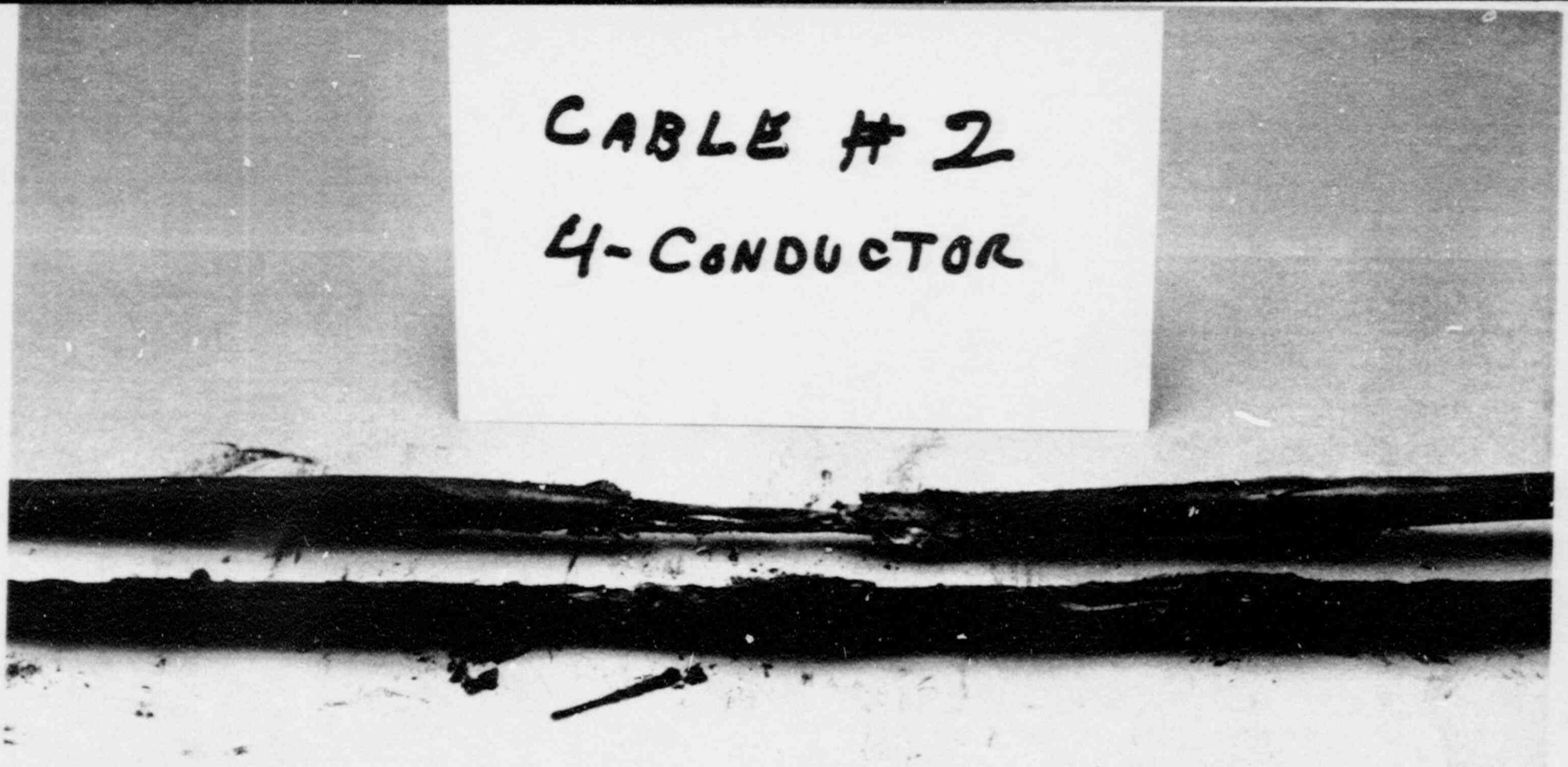

PICTURE NO. 19
Test No. 3
Channel #10



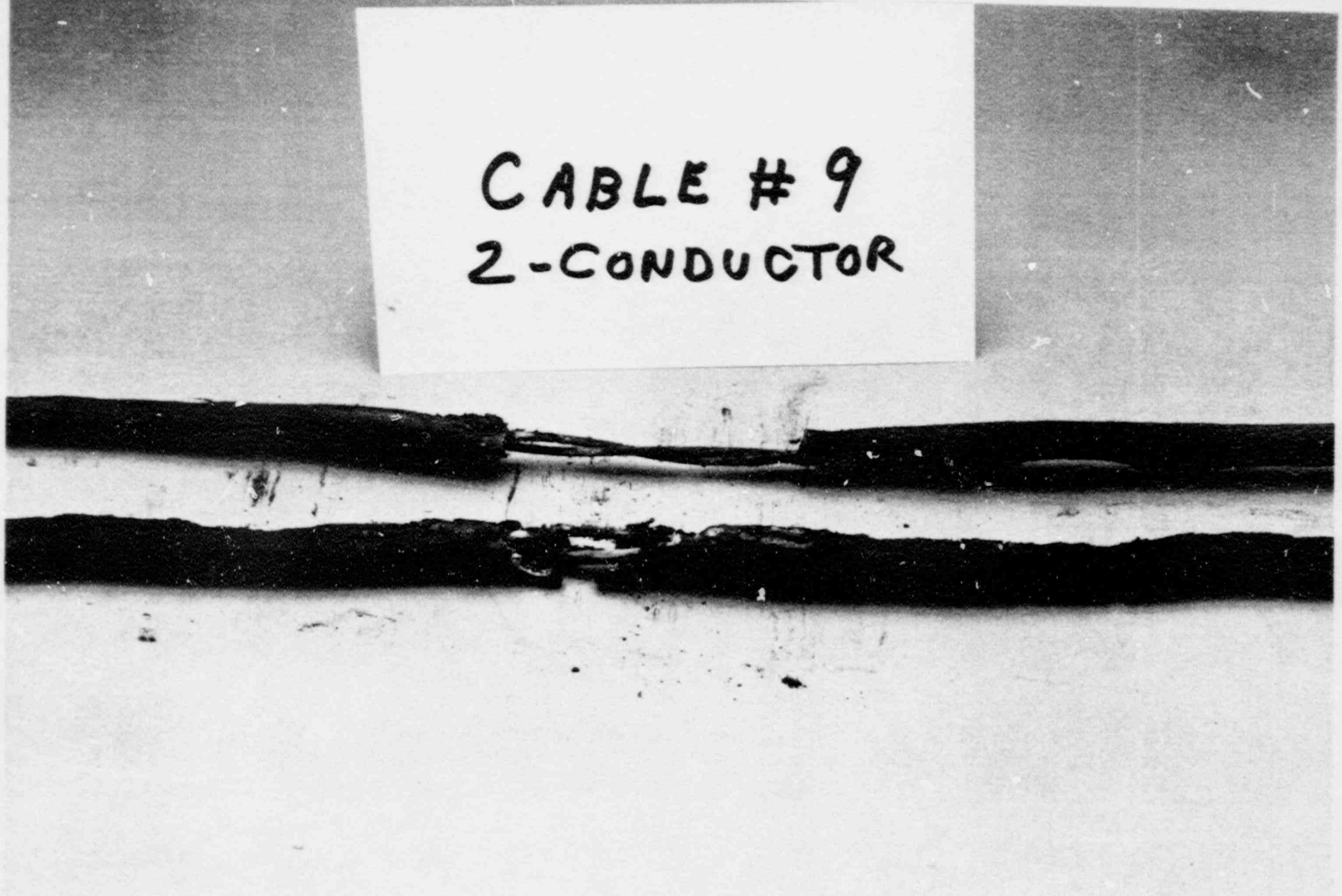

PICTURE NO. 20
Test No. 3
Channel #14




PICTURE NO. 21
Test No. 3
Channel #15

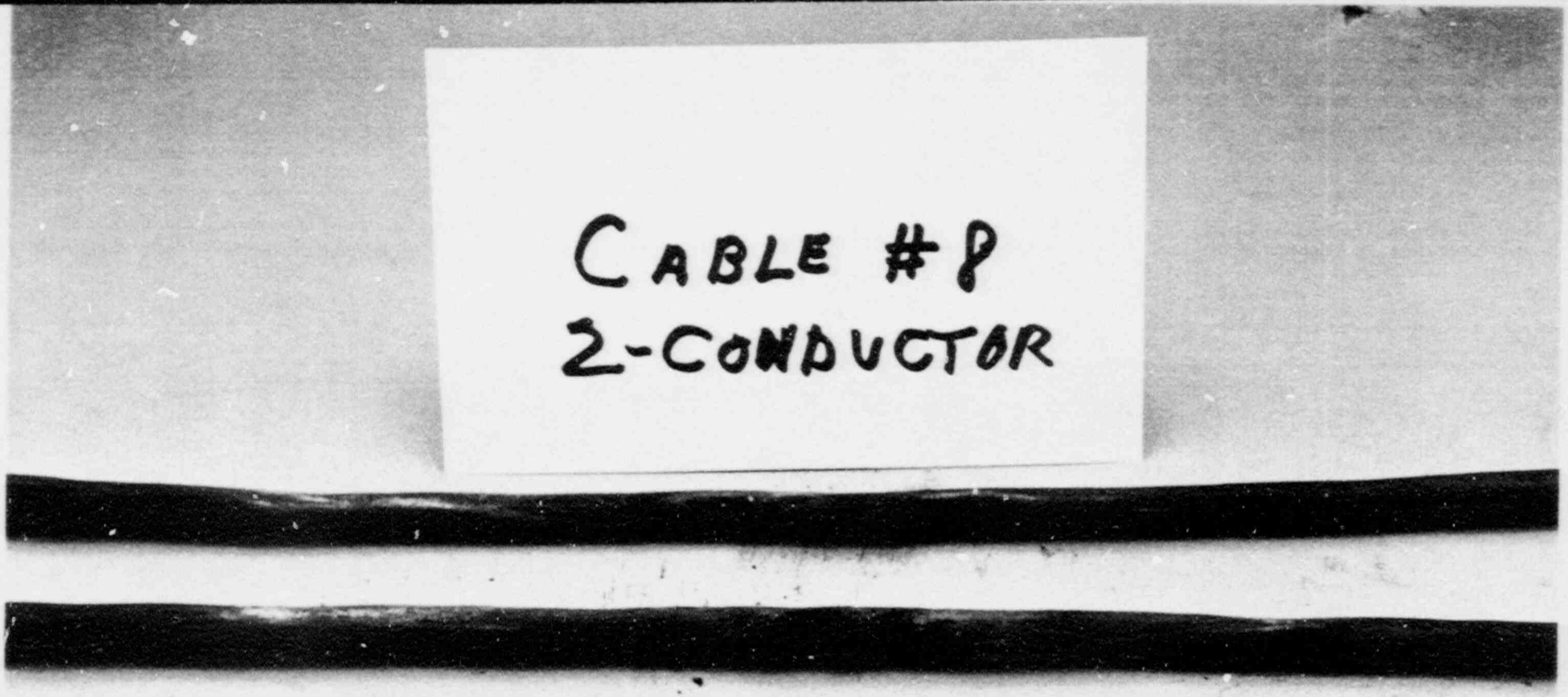



PICTURE NO. 22
Test No. 3
Channel #11

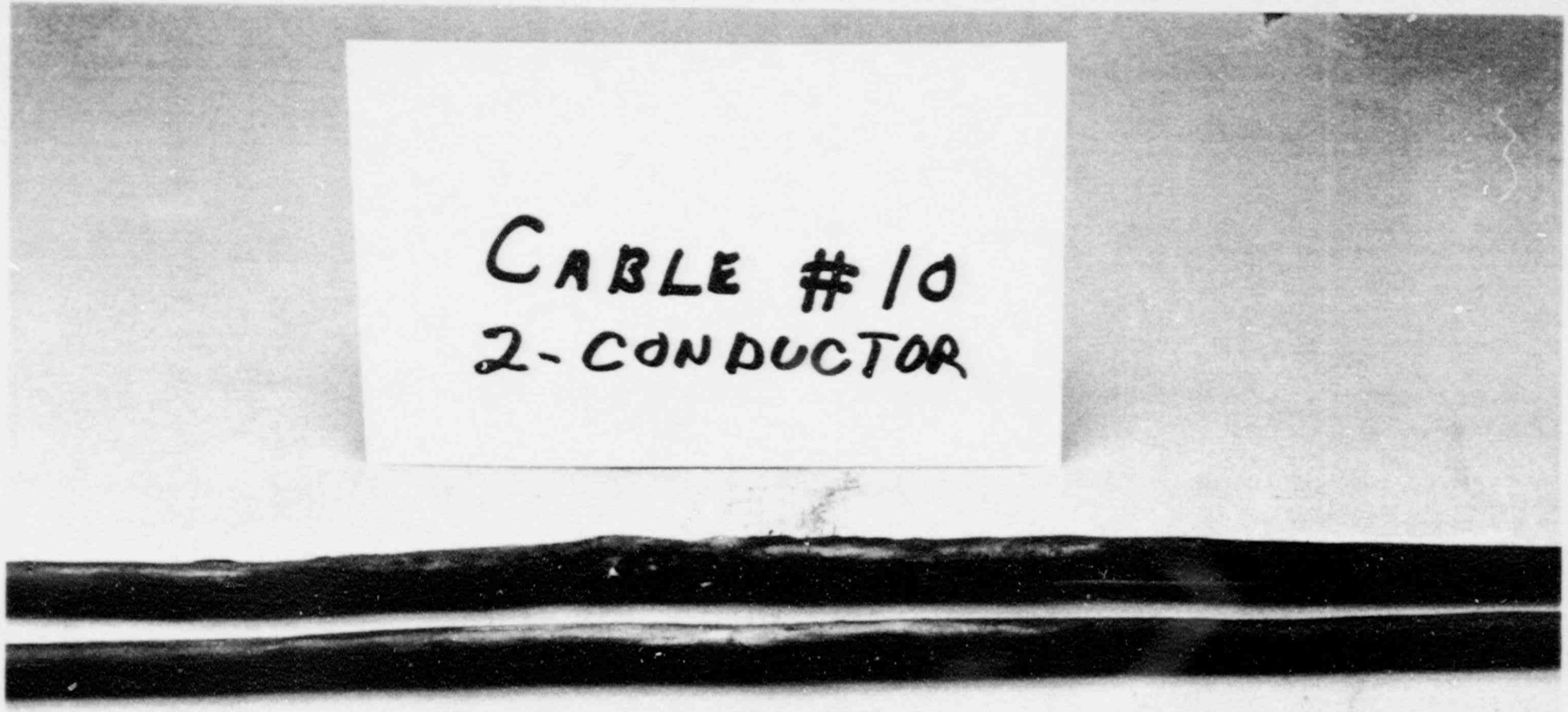



PICTURE NO. 23
Test No. 3
Channel #16


PICTURE NO. 24
Test No. 3
Channel #12




PICTURE NO. 25.
Test No. 3
Channel #13




PICTURE NO. 26
Test No. 3
Channel #18

## Section 10.0

## List of References


1. IEEE Standard 383-1974, "IEEE Standard for Type Test of Class IE Electric Cables, Field Splices, and Connections for Nuclear Power Generating Stations".

2. USNRC Generic Letter 86-10 (April 24, 1986) "Implementation of Fire Protection Requirements".

3. PBAPS 10CFR50, Appendix R Electrical Coordination Study (August, 1986).

4. USNRC Regulatory Guide 1.131, "Qualification Tests of Electric Cables and Field Splices for Light - Water - Cooled Nuclear Power Plants", Issued for Comments August 1977.


RBR/ss/05208801

## Section 11.0

### List of Data Acquisition Instruments

| Equipment | Manufacturer | Model No. | ID No. | Range | Accuracy | Cal. Expire |
|---|---|---|---|---|---|---|
| Rotameter (Gas) | Brooks | 1110-08D2ALQ | 21-0173 | 0-286,000 BTU/HR. | ± 2% RDG | 10-6-88 |
| Rotameter (Air) | Brooks | 1110-09K3ALQ | 21-0174 | 0-650 SCFH | ± 2% RDG | 10-6-88 |
| Air-Gas Venturi Mixer | American Gas Co. | 14-18 | - | 216/1N2 Max. Guage Press | - | - |
| Ribbon Burner | American Gas Co. | 1614 | - | 10" | - | - |
| Analyzing Recorder | YEW | 3655 | 38-0078 | See Manual | ± 0.25% FS | 5-4-88 |
| Digital Thermometer | Fluke | 2190A | 52-2086 | See Manual | ± 0.25% FS | 2-16-88 |
| True RMS Multimeter | Fluke | 8060A | 57-5946 | See Manual | ± 0.5% + 10 counts | 6-15-88 |

## Section 11.0

### List of Data Acquisition Instruments

| Equipment | Manufacturer | Model No. | ID No. | Range | Accuracy | Cal. Expire |
|---|---|---|---|---|---|---|
| Megger | Biddle | - | 32-1953 | 50,000 MEGOHM | ± 1 Div. | 11-8-87 |
| Digital Tong Set | Hioki | 3206 | 01-0131 | See Manual | See Manual | 2-25-88 |
| True RMS Multimeter | Fluke | 8062A | 57-5943 | See Manual | ± 0.5% + 10 Counts | 4-4-88 |
| True RMS Multimeter | Fluke | 8060A | 57-5946 | See Manual | ± 0.5% | 6-15-88 |
| Data Logger | Fluke | 2280B | 24-0064 | See Manual | Loop Calibrated 11-9-87 | 3-9-88 |
| Resistive Load Box | States Co. | 33536 | 33871 | 120-240 VAC 7200 Watts | By Resistance Measurement | - |
| Resistance Bridge | L+N | 5300 | 09-1917 | .001-1 MEG. | ± 0.15% RDG. | 6-23-88 |
| Digital Thermometer | Fluke | 2190A | 52-2086 | See Manual | ± 0.25°F | 2-16-88 |