SAN ONOFRE NUCLEAR
GENERATING STATION, UNIT 1

REPORT ON CABLE FAILURES—1968

SAN ONOFRE

NUCLEAR GENERATING STATION

UNIT 1

REPORT ON CABLE FAILURES—1968

SOUTHERN CALIFORNIA EDISON COMPANY
SAN DIEGO GAS & ELECTRIC COMPANY

SAN ONOFRE

NUCLEAR GENERATING STATION

UNIT 1

REPORT ON CABLE FAILURES - 1968

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SECTION 1

SUMMARY

1.1.0 PURPOSE

This report was prepared to inform the Atomic Energy Commission of two incidents at the San Onofre Nuclear Generating Station Unit 1: a cable failure adjacent to containment penetration EPC4 which occurred on February 7, 1968, and a cable failure in the No. 2 480-volt switchgear room on March 12, 1968.

After extensive investigations by the Southern California Edison Company, NUS Corporation, Westinghouse Electric Corporation, and the Bechtel Corporation, the findings as well as the detailed analysis and safety evaluation leading to these findings are presented in the body of this report. Also included is a detailed description of the incidents and extensive action taken to avoid a recurrence.

It has been concluded that the most probable mechanism leading to both incidents is traceable to a common cause, thermally overloaded 480-volt conductors. For this reason, this summary and the report which follows concerns itself primarily with the March 12 incident.

1.1.1 DESCRIPTION OF THE INCIDENTS

A. February 7, 1968

At 4:45 p.m. on February 7, 1968, while operating at 380 MWe (net), several alarms were annunciated in the control room and a loud noise was heard from the plant area. Immediately thereafter, a fire was observed in the cables leading to sphere penetration EPC4. The fire was promptly extinguished. Due to concern for containment integrity, unit load reduction was initiated at 4:50 p.m. and the reactor and turbine tripped by 5:10 p.m., with reactor cooldown initiated at 5:25 p.m.

The subsequent inspection revealed that the outer bulkhead of the penetration had been forced from the canister shell. Also, the 65 cables leading to this penetration, outside of the sphere, had been damaged by fire. Eleven cables leading to penetration EPC9, located directly above EPC4, were also slightly damaged. Six of the male connectors of the EPC4 canister were discovered pulled out of the inside bulkhead. Inside the sphere all cables at both penetrations were undamaged.

It was noted that of the cables leading to this penetration, forty-five serve pressurizer heaters which had been energized continuously for 96 hours prior to the incident. During the shutdown following the incident, there were no operational difficulties experienced. A subsequent review of circuits disabled by the fire indicated that the ability to maintain a safe shutdown was not impaired. An investigation was immediately initiated to establish the cause of the fire.

During the course of investigations and thermal loading tests of a similar penetration (WPC7) following the February 7, 1968 incident, it had been concluded that the thermal overloading of the cables was due primarily to restricted ventilation with the weather protective cowling at the cable entry to the penetration. Since tests indicated that the cable temperature was well within the manufacturers rating with the cowling removed, it was decided to operate without the cowling until an outage that was planned for April. During the outage, improved cowlings were to be installed and the remaining pressurizer heater cables would be replaced with larger conductors.

The failed pressurizer heater cables leading to EPC4 were replaced with larger size conductors, the penetration canister was repaired, and the unit was returned to service on February 19, 1968. It appeared that the failure was due to a localized problem and it was not suspected that a similar cable failure was imminent elsewhere in the plant. However, the investigating group continued its work to determine the exact cause of failure. Based on subsequent information, it is recognized that the thermal overloading of these conductors was a general condition due to their sizing and was not restricted to localized heating in the penetration cowling.

B. March 12, 1968

On March 12, 1968, at 12:25 a.m. while operating at 380 MWe (net), smoke was observed coming from the No. 2 480-volt switchgear room. It was determined that the smoke was due to a fire confined to cable tray sections 39C3, 39C4, and 39C5 in this room.

After appraisal of equipment conditions in the No. 2 480-volt switchgear room and of the problems associated with the No. 2 480-volt bus and control room intelligence, the reactor was manually tripped at 12:34 a.m. During the course of the fire, feeder cables from the diesel generator to the No. 2 480-volt bus in tray 39C5 were burned and grounded. This circuit was cleared by relaying the entire No. 2 480-volt bus.

In accordance with station fire protection procedures, assistance was requested from the Marine Corps fire fighting unit. Station personnel proceeded to fight the fire with portable equipment and, together with the Marine Corps unit, extinguished the fire by 1:00 a.m. By this time, other station supervisory personnel had arrived at the site.

Actions to proceed with the cooldown were initiated at 1:10 a.m., March 12. The Atomic Energy Commission Compliance Inspector was notified of the incident at 2:50 a.m. and was informed that the plant was being brought to cold shutdown conditions.

Because power had been lost to the Boric Acid Injection Pump, it was decided that boron would be injected as necessary through the use of the Boric Acid Transfer Pump. Also, a Primary Plant Makeup Pump was operated to maintain proper reactor coolant water inventory. At approximately 5:00 a.m., the cooldown was stopped when the Chemical Technician reported that the boron concentration was being reduced rather than increased. An assessment was then made by the Plant Engineer (SRO) and it was concluded that a shutdown margin in excess of 1.0% Δ K/K was available. (Subsequent calculations indicated that the minimum amount of shutdown reached during the incident was 2.8% Δ K/K.)

At that time, lack of boration was attributed to the higher than normal volume control tank pressure exceeding the discharge capability of the transfer pumps. Subsequent investigations, however, have established the actual cause as blockage of transfer pump flow due to accumulation of boric acid crystals. During the cooldown higher than normal pressures were noted in the volume control tank and radwaste systems.

Boration was then accomplished by manually closing the volume control tank outlet valve and by gravity feed from the refueling water storage tank to the suction of the charging pumps. Thereafter, cooldown proceeded without any further boron injection problems.

The fire was confined to three overhead cable trays stacked one above the other in the No. 2 switchgear room. The cables in these trays were badly burned for a length of 15 feet. There were 185 electrical circuits in these trays including the leads from the pressurizer heaters. The fire was of such a limited nature that there was no overheating to the grating and beams or the air intake located 38 inches above the trays.

The plant equipment is arranged such that the major redundant equipment in the plant is duplicated on the No. 1 and No. 2 480-volt buses with some additional duplication and miscellaneous loads on a third bus. For this reason, although the No. 2 bus was deenergized, the redundant equipment on the No. 1 bus was available for service.

The No. 2 480-volt bus was cleared of faulted cables and reenergized by 9:45 a.m. and undamaged equipment such as the boric acid heaters and heat tracing were returned to service from this source. The cooldown was completed at 10:00 p.m. March 12, 1968.

1.1.2 INVESTIGATIVE ORGANIZATION

As a result of the March 12 incident, three principal Task Forces were organized to perform the following:

Conduct a safety review and recommend corrective measures.

Investigate the cause of the failure and recommend corrective action.

Restore the unit to a proper operating condition.

All recommendations by the Task Forces whether of a mechanical, electrical or operational nature, have been presented for approval by the On-Site Safety Review Committee,by the Nuclear Safety Audit and Review Committee and the Safety Control Board.

The applicable sections in the San Onofre Unit 1 Final Engineering Report and Safety Analysis, will be revised, as required, to reflect the equipment modifications which resulted from this investigation.

1.1.3 SAFETY EVALUATION AND CORRECTIVE ACTION

A. The principal responsibilities of the Task Force to Conduct a Safety Review and Recommend Corrective Measures were:

1. A post-incident reconstruction of events and operational difficulties.

2. Recommendations to prevent or minimize the recurrence and consequences of a future similar failure.

3. As part of Item 2 above, analysis and recommendations as to the degree of physical separation of electrical circuits in order to meet the objectives of (1) minimum consequences and (2) assured safe shutdown.

B. A summary of specific areas of review, the conclusions reached, and the action taken by this Task Force are as follows:

1. Plant Design Items

a. During the March 12, 1968 incident, redundancy of plant equipment proved adequate to bring the reactor to a safe shutdown condition. However, analyses have been made to investigate the safety implications of the cable failure and to demonstrate that the required redundancy exists to accomplish a safe shutdown and to minimize the consequences of another similar incident. Cable has been relocated as necessary to meet this objective.

b. The amount of inoperative equipment could have been reduced if provisions had existed for separation of the faulted diesel feeder from the No. 2 480-volt bus. To improve bus isolation, power circuit breakers have been installed in the feeder cables to the 480-volt buses.

c. The Volume Control, Flash, and Waste Gas Surge Tanks were overpressurized due to inoperative equipment and to insufficient relieving capacity for conditions of this incident. The integrity of the tanks has been verified by measurement, hydrotests, dye penetrant checks, and ultrasonic inspection. These investigations have been confirmed by a Consultant Metallurgist. To prevent further overpressurization, relief valves sized to accommodate the maximum flow of 180 gpm have been installed.

d. Flooding of the Flash Tank resulted when the Flash Tank bypass valve remained in the normal rather than the bypass position coupled with loss of power to the Flash Tank discharge pumps. To guard against undue over-pressurization modifications have been made such that the Flash Tank bypass valve fails bypassing the Flash Tank on loss of power or air.

e. Other operating difficulties experienced during cooldown will be prevented in the future by the addition of a magnetic flowmeter, with control room indication, in the boric acid transfer pump discharge line.

2. Operating Procedures

a. Reactor trip and hot shutdown were performed without difficulty.

The decision to initiate a cold shutdown was appropriately based on the uncertainties regarding the continued availability of equipment and the knowledge that significant plant repairs would have to be implemented.

In this instance, there was improper operator action since the applicable station operating instructions, which require boration of the reactor coolant system prior to initating the cooldown, were not followed. Plant conditions did not indicate that such an action was necessary.

Dilution of the boron resulted due to (1) not borating the reactor coolant system to the cold shutdown condition prior to initiating the cooldown, (2) insufficient follow-up with respect to verifying that boration was actually taking place by a boron analysis and boric acid storage tank level checks.

b. The inadvertant boron dilution of the Reactor Coolant System was detected in sufficient time to maintain a minimum shutdown margin of 2.8% Δ K/K. The equipment necessary for the reactor cooldown was available and was either automatically or manually operable.

c. Additional operator training has been conducted to stress the importance of (1) adhering to normal and emergency operating instruction, and (2) placing sufficient emphasis on the evaluation and assessment of plant condition prior to initiating a cold shutdown.

d. The operational instructions have been amplified to assure that the cooldown will not be initiated prior to verification of the appropriate boron concentration and all operating personnel will be trained to take a boron sample for analysis.

1.1.4 ELECTRICAL SYSTEM INVESTIGATION AND CORRECTIVE ACTION

A. The investigation of the cable tray failures was conducted by the Task Force to Investigate Cause and Recommend Action. The work of this committee was supplemented in the area of cable and tray inspection by the Task Force to Restore the Unit to Service. The group investigated the following areas:

1. Review of the conductor insulation requirements, sizing criteria, and specific sizing of individual conductors.

2. Review of the protection schemes associated with individual circuits.

3. Review of cable tray physical and thermal loading design limits to assure that there is no thermal overloading.

4. Inspection and testing of cables obtained from the circuits involved in the failure.

5. Inspection of all cables in tray systems throughout the plant for any evidence of distress.

6. Simulation testing of tray sections involving the same conductors in similar configuration and with the same loadings as the tray section in which the failure occurred.

7. Thermal analysis and tests of various cable configurations.

8. Analysis and simulation tests relating to the cable failure incident adjacent to containment penetration EPC4 which occurred on February 7, 1968.

B. The extent and thoroughness of the investigation lead to the following conclusions:

1. The No. 6 AWG wire used for the 45 pressurizer heater leads was thermally overloaded for the conditions of tray 39C3.

2. Tray 39C3 was heavily filled to a level above the side rails which impeded heat dissipation and caused heavy pressures on the lower cables with possible deformation of the cable materials.

3. The combination of the above conditions which caused the conductors to operate above their 90°C insulation rating increases their susceptibility to insulation failure with time. Coupled with mechanical damage to the insulation, the susceptibility is further increased.

4. The previous cable failure adjacent to containment penetration EPC4 involved similar No. 6 AWG conductors serving the pressurizer heaters, but which were fed from a different source and tray system. The cables entered the penetration through a weather protective cowling where ventilation was restricted. This resulted in conductor temperatures exceeding 90°C. The lack of support to prevent conductors from bearing heavily against each other contributed to the cable failure.

5. The most probable cause for each of the two cable failures was thermally overloaded pressurizer heater cables coupled with heavy mechanical loading or damage resulting in a phase-to-phase fault condition between two cables of separate circuits.

6. Lack of concurrent three phase clearing permitted low level fault current to continue to flow and resulted in additional faults and heat generation in the tray.

C. Corrective work and modifications resulting from the investigation are as follows:

1. The No. 6 AWG wires in the pressurizer heater circuits have been replaced with No. 4 AWG wires in three-conductor cables. Each group of 15, three-conductor cables has been located in a new separate tray.

2. To reduce the number of circuits carried by each 480-volt penetration and to provide for increased conductor sizes, a portion of the pressurizer heater circuits have been relocated to two additional penetrations.

3. Three-phase tripping devices to replace the fuse-switch devices have been installed on all 480-volt power circuits to provide positive three phase clearing of a circuit in the event of a fault on one phase or an intercircuit fault condition.

4. Cable tray thermal and physical loading has been further reduced so that no thermal overloading exists in any of the cable trays throughout the plant, by the installation of new trays, selective relocation of existing circuits and increase in size of certain conductors.

5. Cable repairs and revisions have been made throughout the plant as recommended by experienced Southern California Edison teams inspecting the electrical systems throughout the plant.

1.1.5 START-UP PROGRAM

The Task Force to Restore the unit to a proper operating condition, in addition to inspecting the cables in the tray systems throughout the plant are doing the following:

A. To verify that the new cable for the three damaged trays is installed properly and the recommendations of the investigative committee are followed, a qualified quality assurance team consisting of Southern California Edison and Bechtel experienced technical personnel is inspecting all repairs and modifications.

B. All repairs and modifications will be thoroughly checked, first, by appropriate electrical testing to demonstrate that the installation is correct and that the various components and systems affected by the incident are in proper working order and function as originally designed.

C. The verification and start-up activities will be coordinated by the Station Chief and his operating staff. All operations will be performed as prescribed by the applicable Operating Instructions and Start-Up Procedure Manuals which are being used as a guide for developing testing procedures.

D. In order to verify that cable locations are within proper operating limits on return-to-service, temperatures will be measured at sixty-eight points. Forty-eight points will be recorded continuously on multipoint strip chart recorders and twenty additional locations will be monitored by means of capillary bulb type temperature indicators. High temperature alarms will be utilized in conjunction with these points.

1.1.6 CONCLUSIONS

Based on the analysis and evaluation described in this report, it is concluded that the actions taken provide for: (1) substantially increased assurance against cable tray failures, (2) earlier detection and quick response to a fire, (3) a smooth safe shutdown with a minimum of operational difficulties in the event of a similar incident, and (4) minimum consequences arising from an incident involving cable trays.

Therefore, based upon the extent and thoroughness of the investigations conducted, the conservatism incorporated in the modifications, and upon completion of the start-up test program presented in Section 6 of this report, the plant can be returned to normal operation with a high degree of confidence in its operational safety.

SECTION 2

SEQUENCE OF EVENTS

2.1.0 PENETRATION FAILURE

A. Introduction

On February 7, 1968, while Unit 1 was operating at 380 MWe (net), penetration EPC4 failed as a result of a cable failure. The fire, observed in the cable tray leading to the penetration was extinguished and a reactor trip and cooldown was initiated. This report describes the events during this incident.

B. Sequence of Events Immediately Before, During and After the Cable Failure

A detailed description of events regarding this incident follows:

Time	Event
Prior to Incident	Core depletion tests were in progress, and all pressurizer heaters had been on for 96 hours.
4:45 p.m.	"Pressurizer high level-heaters on" initiated. Heaters failed to come on. Actual pressurizer level normal.
4:45+ p.m.	480-volt bus ground alarm initiated. 100% ground on No. 1 480-volt bus.
4:46 p.m.	A loud noise heard in control room. Lighting fluctuated in control room.
4:47 p.m.	Security Officer reported a loud noise and fire at Southeast side of sphere. Heating and ventilating alarm initiated.
4:47 p.m.	Transferred No. 1 480-volt bus to No. 3 480-volt bus. Ground indications on No. 1 and No. 3 480-volt buses. Transferred 480-volt buses back to normal. Watch Engineer and PEO investigation revealed fire at EPC4 sphere penetration. Fighting fire with Ansul and CO_2 extinguishers. Fire under control.
4:50 p.m.	Opened 480-volt circuit breakers to isolate ground. Ground cleared when Group C pressurizer heater breaker was opened. Started dropping load to remove unit from line.

Time	Event
5:05 p.m.	Unit load at 20% - control rods on manual control. Transferred No. 1A and No. 1B 4 kV buses to C transformer.
5:10 p.m.	Tripped reactor/turbine by pushbutton. Visual inspection made inside sphere for evidence of fire. No damage found.
5:17 p.m.	ORMS channel R1212 on monitor.
5:25 p.m.	Stopped reactor coolant pumps A and C. Started cooldown of main coolant system.

C. Extent of Damage

The inspection revealed that the outer bulkhead of penetration EPC4 had been forced from the canister shell. Also the 65 cables leading to this penetration, outside of the sphere, had been damaged by fire. Eleven cables leading to penetration EPC9, which is located directly above EPC4, were also slightly damaged by the fire outside the sphere. Six of the male connectors of EPC4 canister were found pulled out of the inside bulkhead. Inside the sphere all cables and connectors at both penetrations were undamaged.

2.1.1 CABLE TRAY FAILURE

A. Introduction

On March 12, 1968, while Unit 1 was operating at 380 MWe (net), a cable failure in cable tray 39C3 occurred and the resultant fire which took place in the No. 2 480-volt switchgear room led to tripping the reactor at 12:34 a.m. This fire resulted in significant damage to conductors in three cable trays. This incident complicated reactor cooldown.

B. Sequence of Events Immediately Before, During, and After the Cable Failure

A detailed description of events regarding this incident follows:

Time	Event
Prior to Incident	Watch Engineer and Plant Equipment Operator were in the 220 kV switchyard. Another Plant Equipment Operator was in the controlled area inspecting equipment. The Control and Assistant Control Operators were in the control room.

Time	Event
12:21 a.m.	"Intake Structure Hi Level" alarm initiated. Assistant Control Operator dispatched to the Intake Structure.
12:21+ a.m.	"'480-volt System Ground', 'Station D.C. Bus Ground or Low Voltage', 'Hydraulic Stop Gate Trouble'" alarms initiated. Control Operator identified a 90% ground on No. 2 480-volt bus and checked equipment fed off this bus in an effort to locate and clear the ground.
12:22 a.m.	"Sphere Heating and Ventilating System Trouble" alarm initiated.
12:22+ a.m.	Control Operator called and ordered the Plant Equipment Operator in the controlled area to return to the control room.
12:23 a.m.	Assistant Control Operator reported from the Intake Structure. Found no reason for the "Intake Structure Hi Level" alarm.
12:24 a.m.	Watch Engineer informed of trouble in the plant.
12:25 a.m.	Lost annunciator panels for turbine-generator first out, auxiliary, and electrical boards.
12:25+ a.m.	Assistant Control Operator observed smoke in the No. 2 480-volt switchgear room and notified the Control Operator by phone. Unable to enter the No. 2 480-volt switchgear room due to the smoke.
12:25+ a.m.	Plant Equipment Operator dispatched from the control room to help the Assistant Control Operator.
12:27+ a.m.	Operators observed blue arcing above the east door window of No. 2 480-volt switchgear room.
12:28+ a.m.	Operators returned to the control room to report on trouble.
12:31+ a.m.	Watch Engineer arrived at No. 2 480-volt switchgear room.
12:32 a.m.	Watch Engineer observed fire in three cable trays above the east door.
12:33 a.m.	Watch Engineer returned to the control room.
12:34 a.m.	Reactor tripped.

Time	Event
12:35 a.m.	Assistance requested from Marine Corps Fire Department.
12:35 a.m.	No. 2 480-volt bus cleared by overcurrent relay operations.
12:36 a.m.	Notified the Dispatcher of unit trip. Watch Engineer and Operators fighting fire.
12:37 a.m. to 12:55 a.m.	Performed operations to shutdown the unit, transfer auxiliary equipment and restart the reactor coolant pumps.
12:45 a.m.	Marine Corps Fire Department arrived.
12:56 a.m.	Fire pumps would not start. Started gasoline engine driven Screen Wash Pump (backup emergency fire pump) and opened intertie between salt water and fire main systems.
1:00 a.m.	Fire declared extinguished.

After the fire was extinguished an evaluation of conditions indicated a plant cooldown should be started. The following are some of the significant events that took place: (Reference should be made to the attached chart of operating parameters.)

Time	Event
1:10 a.m.	Transferred steam dump control from automatic to pressure control. Reactor Coolant System temperature at 540°F. Began preliminary operations to cooldown.
2:15 a.m.	Operated the North Boric Acid Transfer Pump for ten minutes. Started taking hourly Boric Acid Tank temperature readings.
2:30 a.m.	Radiation Chemical-Technician called in.
2:35 a.m.	Started the steam driven Auxiliary Feedwater Pump. Feeding the Steam Generators. Reactor Coolant System temperature 510°F.
2:45 a.m.	Commenced cooldown.
2:50 a.m.	AEC Compliance Inspector notified by Station Chief.
3:00 a.m.	Operated the North Boric Acid Transfer Pump for ten minutes.

Time	Event
3:50 a.m.	Radiation Chemical-Technician in the plant.
4:00 a.m.	Reduced cooldown rate and closed steam dump to condenser.
4:30 a.m.	Reactor coolant system boron sample obtained.
5:00 a.m.	Reactor Coolant System boron concentration determined to be 1638 ppm. Stopped system cooldown at 440°F and 870 psig.
5:00 a.m.	Charging Pump suction transferred to the Refueling Water Storage Tank. Opened MOV 1100B and D.
5:10 a.m.	Reactor Coolant sample boron concentration was 1562 ppm.
5:20 a.m.	Charging Pump suction transferred from the Volume Control Tank. Closed MOV 1100C. Reactor Coolant System temperature 435°F and pressure 860 psig.
6:40 a.m.	Reactor coolant sample boron concentration at 1734 ppm.
7:12 a.m.	Reactor coolant sample boron concentration at 1835 ppm.
7:45 a.m.	North Boric Acid Transfer Pump in service with 12% boric acid solution being added to reactor coolant system.
8:40 a.m.	Reactor coolant system cooldown resumed. System temperature at 400°F and 1200 psig.
9:45 a.m.	No. 2 480-volt bus reenergized.

C. Extent of Damage

The damage attributed to the cable failure consisted of the following:

(1) 185 electrical circuits lying in cable trays 39C3, 39C4, and 39C5 in the No. 2 480-volt room. These circuits were totally burned for 15 feet. Approximately 175,000 lineal feet of conductor will be required to replace these circuits.

(2) Section of cable trays 39C3, 39C4, and 39C5 were warped from the heat.

(3) Eighteen (18) control transformers were damaged in motor control center No. 2.

(4) The knife switches in the pressurizer heater cabinet were found welded together.

(5) Heating and Ventilating Annunciator Panel burned out.

(6) Smoke damage occurred to the following:

(a) Motor control center No. 2.

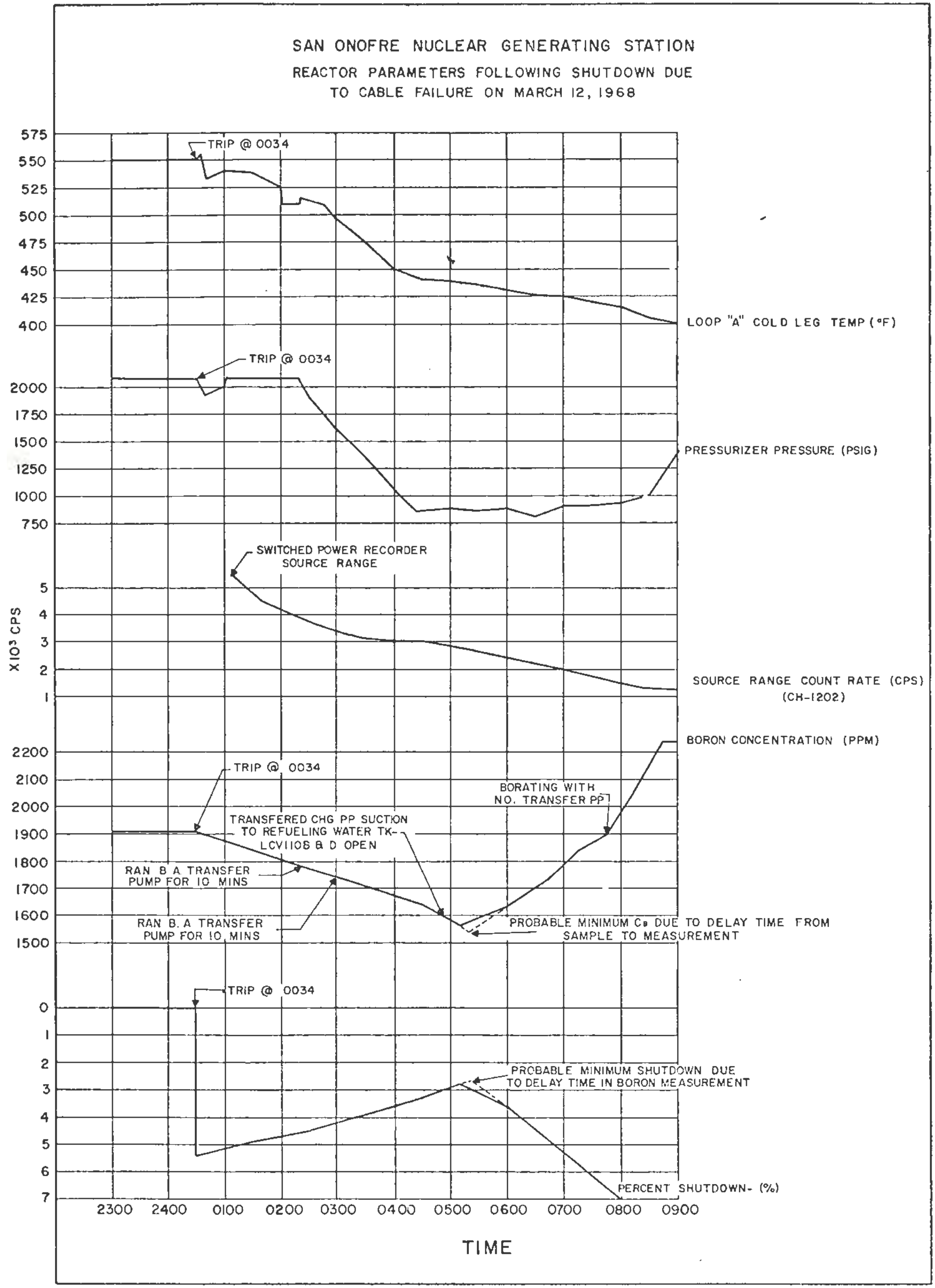
(b) 480-volt switchgear Nos. 2 and 3.

(c) Lighting switchgear.

(d) Pressurizer heater cabinet.

(e) Spent Fuel Building supply for casing and plenum.

(f) Columns, grating, and walls in the No. 2 480-volt room.


SAN ONOFRE NUCLEAR GENERATING STATION
REACTOR PARAMETERS FOLLOWING SHUTDOWN DUE TO CABLE FAILURE ON MARCH 12, 1968
575
550
525
500
475
450
425
400
TRIP @ 0034
LOOP "A" COLD LEG TEMP (°F)
2000
1750
1500
1250
1000
750
TRIP @ 0034
PRESSURIZER PRESSURE (PSIG)
SWITCHED POWER RECORDER SOURCE RANGE
X10³ CPS
5
4
3
2
1
SOURCE RANGE COUNT RATE (CPS) (CH-1202)
2200
2100
2000
1900
1800
1700
1600
1500
BORON CONCENTRATION (PPM)
TRIP @ 0034
BORATING WITH NO. TRANSFER PP
TRANSFERED CHG PP SUCTION TO REFUELING WATER TK-LCV1108 B D OPEN
RAN B A TRANSFER PUMP FOR 10 MINS
RAN B. A TRANSFER PUMP FOR 10 MINS
PROBABLE MINIMUM CB DUE TO DELAY TIME FROM SAMPLE TO MEASUREMENT
0
1
2
3
4
5
6
7
TRIP @ 0034
PROBABLE MINIMUM SHUTDOWN DUE TO DELAY TIME IN BORON MEASUREMENT
PERCENT SHUTDOWN- (%)
2300
2400
0100
0200
0300
0400
0500
0600
0700
0800
0900
TIME

SECTION 3

INVESTIGATIVE ORGANIZATION

3.1.0 PURPOSE

Three principal Task Forces were organized to assure that (1) a thorough investigation of the incident would be accomplished, and (2) to initiate corrective action required to prevent possible recurrence. The responsibilities of the Task Forces were to accomplish the following:

A. Conduct a safety review of the incident and recommend corrective measures.

B. To investigate the cause of the failure and recommend corrective action.

C. To restore the unit to a proper operating condition.

3.1.1 DISCUSSION

The findings, conclusions and all recommendations resulting from the investigations of these Task Forces were submitted for review and approval to the following committees:

A. On-Site Safety Review Committee

B. Nuclear Safety Audit and Review Committee

C. The Safety Control Board

There was a thorough discussion of all recommendations submitted to each of these Committees prior to their approval and implementation of the recommended corrective actions.

A chart outlining the Investigative Organization is attached. Also attached is a chart outlining the Nuclear Safety Committees.

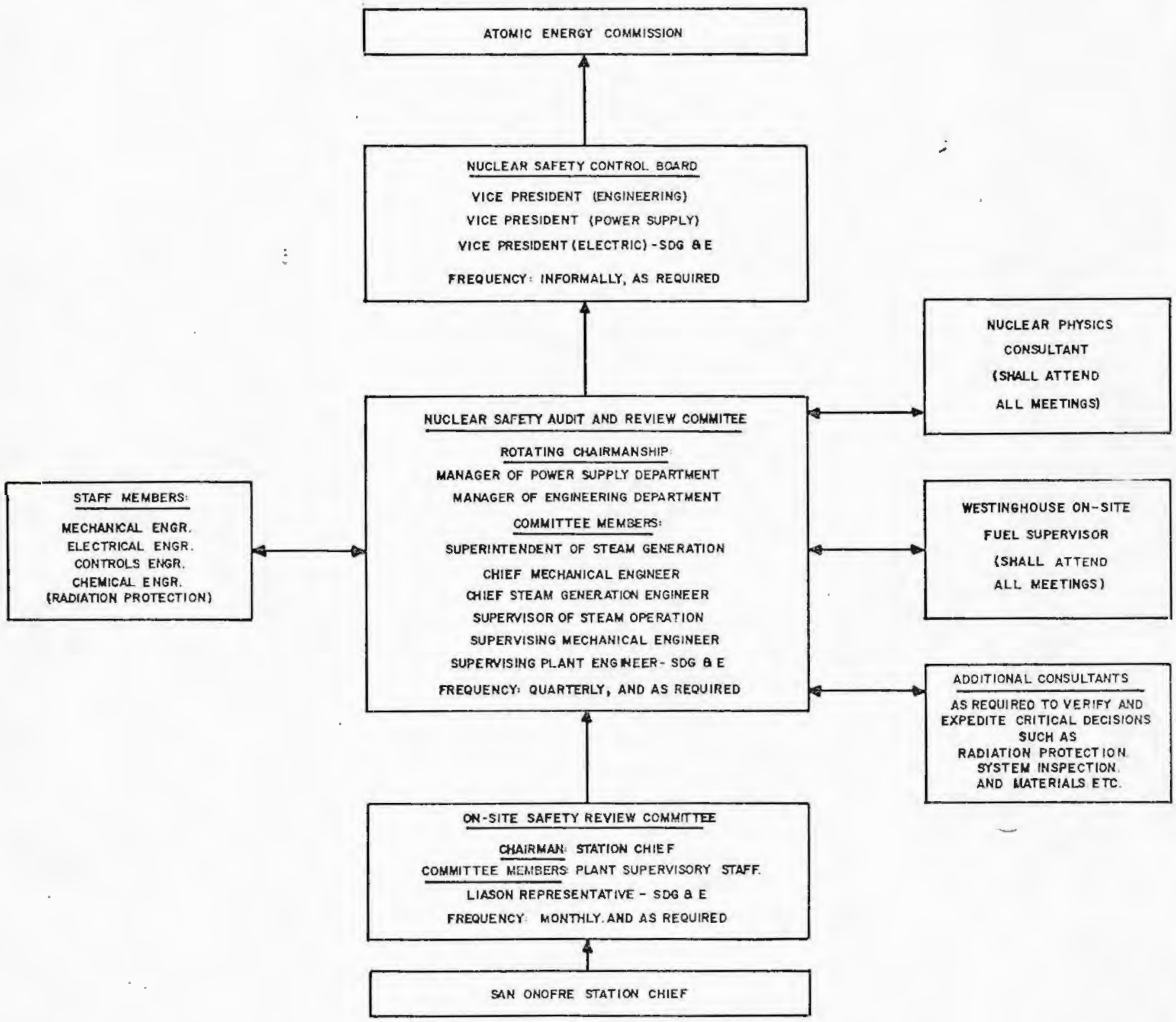
INVESTIGATIVE ORGANIZATION

SAN ONOFRE NUCLEAR GENERATING STATION
CABLE FAILURE INCIDENT - MARCH 12, 1968

SUPERINTENDENT OF STEAM GENERATION

TASK FORCE TO INVESTIGATE CAUSE AND RECOMMEND CORRECTIVE ACTION	TASK FORCE TO CONDUCT A SAFETY REVIEW AND RECOMMEND CORRECTIVE MEASURES	TASK FORCE TO RESTORE UNIT TO SERVICE
CHAIRMAN ASSOCIATE CHIEF ELECTRICAL ENGINEER	CHAIRMAN CHIEF STEAM GENERATION ENGINEER	CHAIRMAN SUPERVISOR OF STEAM OPERATION
UNDERGROUND RESEARCH & DEVELOPMENT SUBSTATION STEAM GENERATION ELECTRICAL ENGINEERING CUSTOMER SERVICE STAFF APPARATUS SYSTEM OPERATION BECHTEL REPRESENTATIVE WESTINGHOUSE REPRESENTATIVE	MECHANICAL ENGINEERING STEAM GENERATION WESTINGHOUSE REPRESENTATIVE NUS REPRESENTATIVE BECHTEL REPRESENTATIVE	STEAM GENERATION SDG&E REPRESENTATIVE MECHANICAL ENGINEERING CONSTRUCTION ENGINEERING BECHTEL REPRESENTATIVE

SOUTHERN CALIFORNIA EDISON COMPANY
NUCLEAR SAFETY ORGANIZATION FOR SAN ONOFRE NUCLEAR GENERATING STATION



RESPONSIBILITIES

ON-SITE SAFETY REVIEW COMMITTEE

1. ANALYZE INSTANCES WHEN TECHNICAL SPECIFICATIONS HAVE BEEN VIOLATED.
2. SUBMIT A FIRST HAND FACTUAL REPORT TO THE AUDIT COMMITTEE IF A TECHNICAL SPECIFICATION HAS BEEN VIOLATED.
3. DETECT POTENTIAL SAFETY HAZARDS BY ANALYSIS OF PLANT ACTIVITIES.
4. REVIEW ALL PLANT PROCEDURES AND CHANGES THERETO.
5. REVIEW ALL PLANT ABNORMALITIES.
6. RECOMMEND MODIFICATIONS TO TECH SPECS.
7. PREPARE REPORTS REQUESTED BY THE CHIARMAN OF THE AUDT COMMITTEE.

NUCLEAR SAFETY AUDIT AND REVIEW COMMITTEE

1. REVIEW AND EVALUATE TECHNICAL SPECIFICATION VIOLATIONS, TAKE APPROPRIATE ACTION.
2. ANALYZE RECOMMENDED CHANGES TO TECH. SPECS. AND PREPARE A REPORT TO THE CONTROL BOARD IF THE RECOMMENDATIONS ARE ACCEPTED.
3. REVIEW AND APPROVE PROPOSED EQUIPMENT REPLACEMENT OR MODIFICATIONS AND PROPOSED SYSTEM CHANGES DOCUMENT REASONS FOR CHANGE AND WHETHER IT INVOLVES AN "UNREVIEWED SAFETY QUESTION".
4. INITIATE ITS OWN RECOMMENDATIONS ON CHANGES TO TECH. SPECS.
5. INITIATE OPERATIONAL IMPROVEMENTS TO PLANT SAFETY WITHIN THE SCOPE OF THE TECH SPECS.
6. REVIEW AND EVALUATE PLANT SAFETY DURING ABNORMAL PLANT CONDITIONS.
7. PERFORM PERIODIC AUDIT OF OPERATION, EQUIPMENT PERFORMANCE, LOGS AND PROCEDURES.

NUCLEAR SAFETY CONTROL BOARD

1. FORMALLY SUBMIT SAFETY ANALYSIS REPORT TO AEC IF A TECH. SPEC. IS VIOLATED.
2. REVIEW AND APPROVE RECOMMENDED CHANGES TO TECH. SPECS.
3. SUBMIT PROPOSED CHANGES TO TECH. SPECS TO AEC FOR CONCURRENCE.
4. MAINTAIN MANAGEMENT CONTROL WITH RESPECT TO NUCLEAR SAFETY IN COMPANY OPERATIONS.

SECTION 4

SAFETY EVALUATION AND CORRECTIVE ACTION

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SECTION 4

SAFETY EVALUATION AND CORRECTIVE ACTION

4.1 SAFETY EVALUATION OF OPERATIONS DURING THE CABLE FAILURE INCIDENT

4.1.0 PURPOSE

The following analysis is made to review the significance of the cable failure of March 12, 1968, including subsequent operation and inoperable equipment as they relate to plant safety. This analysis, which begins with the first observation of trouble, was made in order to determine the problems that developed and their effect on the ability to safely shut down the reactor.

A detailed sequence of events, from the time the first indication of an operating difficulty was received in the Control Room, is given in Section 2 of this Report.

4.1.1 REVIEW OF INCIDENT

A. Equipment Operability

As a result of the cable failure, the reactor was tripped and placed in a hot shutdown condition. Power and/or electrical controls associated with the following plant equipment were damaged as a result of the fire.

1. Stack Discharge Fan A-22
2. Residual Heat Removal Loop Suction Valve, MOV 814
3. Residual Heat Removal Loop Discharge Valve, MOV 834
4. Component Cooling Water Heat Exchanger Outlet Valve (Top), MOV 720A
5. South Primary Plant Make-up Water Pump
6. Power lost to the following Annunciator Panels:
    a. Turbine Generator First Out Panel
    b. Electrical Panel
    c. Auxiliary Panel

In addition, the following equipment which is part of the plant engineered safeguards were electrically inoperative as a result of damaged cables:

1. Safety Injection Recirculation Valves, MOV's 357 and 358

2. West Recirculation Pump and Discharge Valve, MOV 866B

3. Electric Auxiliary Feedwater Pump

4. Safety Injection Train Valves, West Train MOV's 851B, 852B, 853B and 854B

5. Refueling Water Storage Tank Outlet Valve, MOV 883 (normally open)

6. Seal Water Injection Pre-Filter Bypass Valve, MOV 18

7. Refueling Water Pump Discharge Valve to Recirculation System, MOV 880

Safeguard equipment located on other plant buses was operable throughout the incident.

Also, feeder cables from the Diesel Generator to the No. 2 480-volt bus were burned and, as a result, developed phase-to-phase faults. Since the breakers associated with these feeders are located at the Diesel Generator which is remote from the No. 2 480-volt bus, clearing of this circuit could only be accomplished by de-energizing the entire No. 2 480-volt bus. Since this bus had to be de-energized, considerably more equipment became inoperable than would have been the case if breakers had been installed at the 480-volt bus. However, both diesels remained available for service to the No. 1 and No. 3 480-volt buses. Breakers will be added to the 480-volt buses to prevent a recurrence of this problem (refer to the Equipment Addition and Modifications Subsection for detailed discussion).

The following is a list of equipment that became inoperative due to the loss of the No. 2 480-volt bus rather than directly due to fire damage:

1. Battery Charger Set B

2. South Salt Water Cooling Pump

3. South Refueling Water Pump (G-27S)

4. West Residual Heat Removal Pump

5. South Transfer Pump

6. Boric Acid Injection Pump

7. Test Pump

8. Boric Acid Storage Tank Heaters

9. Boric Acid System Heat Tracing

10. South Primary Plant Make-up Pump

11. Waste Gas Compressor

12. Flash Tank Bypass Valve, CV-101

13. East and West Flash Tank Discharge Pumps

14. Center Component Cooling Water Pump

15. Reactor Cavity Cooling Fan A-9S

16. Stack Discharge Fan A-24

17. Motor-Operated Valves

    a. Refueling Water Storage Tank Valve, MOV 1100D

    b. Volume Control Tank Outlet Valve, MOV 1100C

    c. West Residual Heat Exchanger Inlet Valve, MOV 822B

    d. Component Cooling Water Heat Exchanger Outlet Valve (Bottom), MOV 720B

When the No. 2 480-volt bus was restored to service at 9:45 a.m., March 12, all equipment with the exception of that with damaged cables was again available for service.

All redundant components of plant equipment required either for a safe shutdown or safeguard purposes were unaffected and available at all times during the incident, with the exception of the Heat Tracing, and the Boric Acid Storage Tank Heaters.

B. Cold Shutdown Operations

After the reactor was tripped and the fire was extinguished, an evaluation of plant conditions indicated that a reactor system cooldown should be started. Actions to proceed with the cooldown were initiated at 1:10 a.m. March 12.

As a result of the loss of the No. 2 Motor Control Center, the Boric Acid Injection Pump was inoperable. This pump is normally used for borating the primary coolant since metering is provided and preselected amounts of boron can be injected to obtain the desired concentration. Since this pump was not available, it was decided that boron would be injected for a cold shutdown condition through the use of the North Boric Acid Transfer Pump. This pump was operated for two ten-minute periods during the cooldown in order to increase the boron concentration approximately 400 ppm in the Reactor Coolant System. Sufficient quantities of demineralized water were also added to the Reactor Coolant System to make up for system shrinkage as the cooldown proceeded.

The Chemical Technician arrived on site and a primary coolant sample was taken at 4:30 a.m. The results indicated that the required boration was not being accomplished and the cooldown was immediately suspended.

Upon determining that boric acid was not being injected, an alternate means of boration was begun using the Refueling Water Storage Tank. Boration using this tank is accomplished through gravity feed and the closure of MOV 1100C. Because remote operation of MOV 1100C had been lost as a result of the fire, the valve had to be closed manually. Upon closure of this valve, the boron concentration began to increase.

C. Chemical and Volume Control and Radwaste System Operations

During the course of the cooldown, water was being injected with a Primary Coolant Makeup Water Pump into the Volume Control Tank to maintain the primary coolant water inventory.

When it was determined that boric acid was not being injected through operation of the North Boric Acid Transfer Pump, an assumption was made that this transfer pump could not overcome the slightly higher than normal pressure (approximately 40 psig) within the Volume Control Tank. At that time an attempt was made to vent the gases in the Volume Control Tank to the Flash Tank in order to lower this pressure. Venting to the Flash Tank was not effective because the Waste Gas Compressor was inoperable, which resulted in higher than normal pressures in the Radwaste System. It was also not possible to release gases to the stack since the Stack Fans (A-22 and A-24) had also lost their power, and the gas discharge valve (SV-99) which is interlocked with the operation of these fans would not open.

When the Volume Control Tank Outlet Valve (MOV 1100C) was closed in order to utilize borated refueling water, the water level in the Volume Control Tank increased until it reached the level where automatic diversion to the Flash Tank occurred. The Flash Tank Discharge Pumps were inoperative and the level of the Flash Tank increased to the point where the Flash Tank Bypass Valve (CV-101) should have diverted, bypassing letdown directly to the Holdup Tanks. However, CV-101 had failed in the normal position as a result of the loss of power and continued directing water into the Flash Tank. During this period, Volume Control Tank pressure was noted to be above the pressure transmitter range of 100 psig. At this point, the Volume Control Tank as well as the Flash Tank and Waste Gas Surge Tank were water-bound and at pressures above design. To correct this situation the Flash Tank Bypass Valve was manually positioned so that the letdown could flow freely to the Liquid Radwaste holdup tanks.

4.1.2 SAFETY EVALUATION

A. Initial Operator Action

The first indication relative to safety, resulting from the cable failure of March 12, was a ground alarm on the No. 2 480-volt bus. This bus is required for reactor criticality by Technical Specification 3.7. Four minutes later, the Turbine Generator First-Out, Electrical and Auxiliary Annunciators failed. Nine minutes after the annunciator failures the reactor was tripped, and one minute later after tripping the reactor the No. 2 bus relayed.

The loss of any plant annunciation is of operational concern, and, depending upon the degree to which annunciators are lost and what other plant intelligence may be available, may influence operator judgment such that he manually trips the reactor.

It should be noted that at all times during the cable failure all plant vital instrumentation, as well as reactor plant annunciation, remained in service and available for operator surveillance; that is, although some annunciation had been lost, Control Room recorders and other instrumentation monitored by annunciators were displayed in a normal manner to the reactor operator at all times during the cable failure and ensuing fire.

B. Reactor Trip to Hot Shutdown Conditions

Technical Specification 3.7 requires a plant shutdown if the No. 2 480-volt bus cannot be restored to normal service.

When the No. 2 bus was grounded and loss of annunciation occurred, the reactor and turbine generator were manually tripped. The trip was initiated and the plant shut down. All equipment necessary to place the plant in a hot shutdown condition was available and functioned properly.

C. Cold Shutdown Operations

An assessment of the situation resulted in the decision to initiate a cold shutdown which was appropriate. This assessment was based on the uncertainties regarding the continued availability of equipment and the knowledge that significant plant repairs would have to be implemented.

During the course of the cooldown operating personnel believed that more than sufficient boric acid had been added to the Reactor Coolant System for the cold shutdown Xenon-free condition. The first boron sample was obtained at 4:30 a.m. and the analysis completed at 5:00 a.m. This indicated that the coolant concentration had been reduced to 1,638 ppm (from an initial level of approximately 1,911 ppm) and the cooldown was immediately suspended. Plant conditions at this time were 440°F, and 870 psig, and a conservative calculation at that time indicated a shutdown margin in excess of 1% Δ K/K.

A sample taken at 5:10 a.m. showed a further reduction in boron concentration to the minimum value of 1,562 ppm. This further dilution was the result of making up to the reactor coolant system between 4:30 a.m. to 5:00 a.m. when cooldown was stopped. During the entire dilution period source range instrumentation was monitored and the count rate was noted as not increasing. Shortly thereafter MOV 1100C was manually closed and boration was initiated from the Refueling Water Storage Tank. Each sample analyzed thereafter indicated successively higher values of boron.

Subsequent calculations indicate that at the minimum boron concentration (1,562 ppm) the shutdown margin was 2.8% Δ K/K (see Appendix).

Subsequently investigations have established the actual cause as blockage of transfer pump flow due to solidification of boric acid. It was not recognized at the times the Transfer Pump was operated that little or no boric acid was actually pumped and with the addition of demineralized water to maintain reactor coolant inventory, dilution of the Primary Coolant System resulted.

To provide more positive indication of successful boration when employing the boric acid transfer pumps, a flow meter has been installed in the Boric Acid Transfer Pump discharge line, redundancy has been provided in the heat tracing, the Boric Acid Storage Tank Heaters now have separate power supplies and power cable routing, and an additional line section has been traced and insulated (refer to Equipment Addition and Modifications Subsection for detailed discussion).

Existing Operating Instructions stipulate that (1) prior to initiating a cold shutdown, boration to the Xenon-free cold shutdown condition should be accomplished, and (2) verification of the boron concentration in the Reactor Cooling System is to be made by chemical analysis and observation of a decrease in the Boric Acid Storage Tank level. Once this is accomplished, the instructions permit the operator to proceed with the cooldown.

In this instance, there was improper operator action since the applicable station operating instructions, which require boration of the reactor coolant system prior to initiating the cooldown, were not followed. Plant conditions did not indicate that such an action was necessary. Boron dilution resulted from (1) not borating the reactor coolant system to the cold shutdown condition prior to initiating the cooldown, (2) insufficient follow-up with respect to verifying that boration was actually taking place by a boron analysis and boric acid storage tank level checks.

A number of corrective measures regarding operating procedures which are outlined in the Summary of Corrective Action have been taken to avoid a recurrence of this situation.

D. Engineered Safeguards

As noted above, although some components in the Safety Injection, Sphere Spray, and Recirculation Systems were inoperable as a result of the fire, at least one redundant component of all affected equipment in each of these systems remained operable during the cable failure and subsequent fire. Each of these systems would have been capable at all times of performing its design safety function.

In addition, both on-site Diesel Generators were available throughout the subject cable failure and could have been used, if necessary, in conjunction with 480-volt buses No. 1 and No. 3.

E. Chemical and Volume Control and Radwaste System Operation

During the course of events following the cable failure, the Volume Control Tank, Flash Tank and Waste Gas Surge Tank were overpressured due to the inoperability of various pieces of equipment in the Radwaste System. To prevent a future overpressuring of this system, relief valve sizing on the Volume Control and Flash Tanks has been increased and the Flash Tank Bypass Valve (CV-101) changed so that it fails in a position to bypass the Flash Tank (refer to Equipment Addition section for detailed discussion).

In order to determine the highest pressure obtained in these tanks and the Radwaste System, a series of tests were conducted. Inspection of pressure gauges within the Radwaste System indicated that the low pressure range gauges had become distorted due to excessive pressure. Identical gauges were obtained and subjected to a pressure level where similar distortion occurred. The results of this overpressure testing indicated that the Flash Tank and the Waste Gas Surge Tank had reached a pressure of approximately 125 psig.

As a further check, a 0-100 psig pressure transmitter on the Volume Control Tank was inspected in order to determine the extent of distortion; however, no evidence of deformation was noted on this transmitter. Based on the knowledge that this instrument would have been damaged at a pressure level of approximately 150 psig, it was concluded that this was the maximum pressure to which this tank could have been subjected.

To determine the extent of damage, if any, on these three tanks, all were measured for comparison with as-built drawings. These measurements revealed that no distortion occurred. Further confirmation was obtained by conducting dye-penetrant tests on all tank welds. There appeared to be some slight degree of distortion or circumferential expansion on the Flash Tank, which was attributed to initial fabrication. Measurements of the tank shell indicated that this expansion amounted to approximately 0.25 inches beyond design dimensions. Ultrasonic tests in this area were accomplished and verified that this portion of the tank was also sound.

To reinforce the findings with respect to the inspection of these tanks and in particular the slight distortion noted on the Flash Tank, a Consultant Metallurgist was contacted to obtain an independent opinion. Mr. G. M. Butler, Metallurgical Service Laboratories, submitted a report (see Appendix) which confirms Edison's conclusions that these tanks are suitable for continued service.

4.1.3 EQUIPMENT ADDITIONS AND MODIFICATIONS

A. Diesel-Generator Breakers

The cable failure incident indicated that additional power breakers installed between the 480-volt buses and the cable leads to the diesel bus will provide greater 480-volt isolating capability and more operating flexibility in case of a feeder cable failure.

Initially one breaker was provided at the diesel-generator end of each of these cable runs.

In the event of a short circuit in the cable between the 480-volt auxiliary buses and the diesel-generator bus, the additional breakers will automatically open to separate the fault from the auxiliary electric system. This increase in fault clearing selectivity will allow short circuits to be cleared in the cable leads without affecting the continuity of service of other auxiliary system elements.

Therefore, two Westinghouse DB-75, 480-volt, 2000 ampere circuit breakers have been installed between the No. 1 and No. 2 480-volt auxiliary buses and the cable runs to the diesel-generator bus. The interrupting rating of the DB-75 circuit breaker is sufficient to clear faults from the 480-volt bus. These breakers will be controlled at the switchgear with indicating lights and breaker trip alarms in the control room. They are interlocked with the existing breaker so that they cannot be closed unless the breaker at the diesel-generator is open.

B. Provide Magnetic Flow Meter In Transfer Pump Discharge Line

In the course of attempting to borate using the Boric Acid Transfer Pumps, it was necessary to rely on changes in Boric Acid Storage Tank level and chemical analysis of the Primary Coolant to verify that boron was actually being injected.

In order that a more immediate means of determining the rate of boron injection be available to the operator, a magnetic flow meter has been installed in the Boric Acid Transfer Pump Discharge Line and recorded on Control Room instrumentation.

C. Provide Backup Heat Tracing on Boric Acid Lines

Tests indicate that heat tracing on the Boric Acid Lines is important for a long term power loss. Spare heat tracing is provided and has been connected to an alternate power source and arranged so that it will automatically come into service in the event of a failure in the normal tracing system.

D. Separate Boric Acid Storage Tank Heaters

In order to provide complete redundancy within the Boric Acid Storage Tank Heater circuitry, complete physical separation of the two heaters and their power sources is required. The power source to each heater presently comes from separate motor control centers. Power cables have been routed through separate cable trays. Only one heater is required to be in service at any one time and the necessary instrumentation is provided to cause the second heater to begin operating if required.

E. Installation of Additional Heat Tracing and Insulation

In the original station design, no heat tracing nor insulation was provided on the portion of the Boron Injection System Piping between CV-334 and the suction of the charging pumps. It was felt that this was not required since normal operating procedures require that this portion of the line be flushed with primary water after any boration in order to prevent plugging. However, should improper flushing occur, additional heat tracing and insulation will further reduce the possibility of any plugging. Accordingly, heat tracing on this section of line has been provided.

F. Revision of Relief Valve Sizing and Point of Release on Flash Tank and Volume Control Tank

Relief valve sizing on the Volume Control Tank and the Flash Tank has been changed to accommodate the maximum possible amount of letdown of 180 gpm. The original design basis for relief valve sizing on these systems provided that these valves would only be required to accommodate gases. However, as a result of this incident, the relief valve sizing has been increased to accommodate a maximum fluid flow of 180 gpm. In addition, the point of relief valve release from the Flash Tank has been changed to the suction of the Flash Tank Discharge Pumps. The relocation of the relieving point will allow liquid to be selectively relieved from the Flash Tank in order to minimize the amount of gas that would be diverted to the Holdup Tanks during any relief valve operation. The relieving pressure will be approximately 55 psig on the Volume Control Tank and 30 psig on the Flash Tank.

G. Flash Tank Bypass Valve CV-101

During the cable failure, power was lost to control valve CV-101. The normal function of this valve is to bypass the Flash Tank should a high level occur in this tank. The valve was designed to fail in the normal position and allow water to continue to enter into the Flash Tank on loss of power. While this might normally be satisfactory, it did not account for the possibility of a concurrent failure of the Flash Tank Pumps.

Design changes have been developed so that this valve will fail in a position bypassing the Flash Tank and directing all water to the Holdup Tanks as a further means of protecting the Flash Tank from undue flooding. Failure to this new position will occur on loss of power or instrument air.

4.1.4 SUMMARY OF CORRECTIVE ACTIONS

Based on the above safety evaluation, the following recommendations have been implemented:

1. Provide additional operator training to assure that:

   a. The importance of adhering to normal and emergency operating instructions is recognized.

   b. Sufficient emphasis is placed on evaluation and assessment of plant conditions prior to initiating a cold shutdown.

2. Amplify appropriate operating instructions to assure that the proper cold shutdown boron concentration is verified by actual sample analysis before a plant cooldown is initiated.

3. Train all operating personnel to obtain boron samples. Samples will be obtained and analyzed as required during emergency conditions to affirm proper boron concentration.

4. Provide separation with respect to power source, and electrical wiring between redundant components to minimuze the consequences should a similar incident occur.

5. Accomplish equipment additions or modifications as outlined in Paragraph 4.1.3.

4.2 ANALYSIS TO VERIFY ELECTRICAL SEPARATION REQUIREMENTS OF EQUIPMENT

4.2.0 PURPOSE

A study has been made of the electrical separation of redundant plant components to determine whether additional separation may be required. The requirement for equipment to operate under normal and emergency operational conditions has been considered, as well as its relation to other equipment that might perform a similar or redundant function.

The scope of the study includes power sources, and cable tray routing for electrical wiring. Complete electrical separation for duplicate pieces of important equipment was used as a guide for the study even though in some cases this approach goes beyond existing plant design criteria.

4.2.1 DESCRIPTION

A. The following systems were analyzed to assure that the necessary electrical separation exists for redundant equipment desirable for a safe and orderly reactor shutdown under normal and emergency conditions. Recommendations regarding electrical separation were made and implemented for these systems as a result of the analysis.

   Chemical and Volume Control System

   Safety Injection System

   Air-Conditioning System

   Residual Heat Removal System

   Auxiliary Coolant System

   Circulating Water System

   Compressed Air System

   Reactor Coolant System

   Miscellaneous Water System

B. The analysis of the following systems determined that all necessary equipment will perform their safety functions during emergency conditions. No additional action was required.

Containment Isolation

Feedwater and Condensate System

Steam System

C. The following systems were reviewed even though they do not directly relate to the ability to safely shut down the unit. No electrical separation was found necessary.

Turbine Cycle Vents and Drains

Turbine Plant Chemical Feed System

Radwaste System

Turbine System

Turbine Lube Oil System

Miscellaneous System

Turbine Cycle Sampling System

Reactor Sampling System

Sphere Test System

Attached are summaries of the analysis undertaken for each system listed under (A) above and the plans that were developed to assure that the necessary degree of electrical separation exists. Detailed analysis of cable tray routing and power source revealed that in certain instances changes were necessary to accomplish the planned separation. These specific changes are listed at the conclusion of each system analysis.

4.2.2 CHEMICAL VOLUME AND CONTROL SYSTEM

A. System Safety Functions

This system is directly associated with safe operation of the reactor plant and the capability to shut down and maintain control of the reactor in the shutdown condition. Its primary safety function is to regulate the concentration of boron in the primary coolant.

B. Separation Requirements

To accomplish complete redundancy in all functional areas, separation of electrical leads for each of these components and its backup component must exist. In order to provide such separation, verification was required that the electrical leads for the following equipment combinations are routed by completely separate paths from the component in question to its power supply.

EQUIPMENT REQUIRING ELECTRICAL SEPARATION

Power Source 1	Power Source 2	Power Source 3
Boric Acid Injection Pump MOV-1100B	North Boric Acid Transfer Pump MOV-1100C	South Boric Acid Transfer Pump MOV-1100D
North Charging Pump Boric Acid Piping Heat Tracing Boric Acid Heater	Test Pump Alternate Boric Acid Heat Tracing Boric Acid Heater	South Charging Pump

C. Circuitry Revisions

The following circuitry revisions have been accomplished in order to provide the recommended physical separation.

	Equipment	Action Taken
1.	Boric Acid Injection Pump	Electrical leads separated from the South Boric Acid Transfer Pump and the power source relocated to Motor Control Center 3.
2.	MOV-1100D, Refueling Water Storage Tank Outlet Valve	Electrical circuits separated from MOV-1100C and power source relocated to MCC-3.
3.	Test Pump	Rerouted control circuit of the Test Pump to provide isolation of Test Pump, South Charging Pump, North Charging Pump, electrical circuits.

	Equipment	Action Taken
4.	Boric Acid Storage Tank Heaters	Relocated power supply, rerouted power circuit, and removed transfer switch to provide isolation between the two storage tank heaters.
5.	Boric Acid Piping Heat Tracing	Provided new power source for spare heat tracing elements. Power circuits between the two heat tracing systems will be physically separated.

4.2.3 SAFETY INJECTION SYSTEM

A. System Functions

The Safety Injection System provides protection against the consequences of reactor coolant blowdown in the event of rupture of the primary coolant pressure boundary. The design criteria of the Safety Injection System stipulates its satisfactory operation with "second order mechanical equipment failures." Compliance with these criteria if the Safety Injection System were called upon in the event of a loss-of-coolant accident is demonstrated in Section 10 of the FERSA.

B. Separation Requirements

A coincidental occurrence of a fire and requirement for initial safety injection is not considered credible and separation of safety injection circuitry would therefore not be required on that basis.

The credibility of a plant fire, however, increases as time elapses following an assumed DBA. Accordingly, prudent judgment points to the desirability of having separate control and power circuits to at least redundant components of the spray and recirculation systems. Since major cable revision work is underway, the scope of electrical cable separation has been extended to the Safety Injection System.

To accomplish complete redundancy, physical separation of electrical cables for each component and its backup component must exist. The overall system review indicated the following requirements shall be verified.

Equipment Requiring Separation From Each Other With Respect to Electrical Wiring

Injection:

Power Source 1	Power Source 2
East Safety Injection Pump	West Safety Injection Pump
East Feedwater Pump	West Feedwater Pump
MOV 854A MOV 853A MOV 852A	MOV 854B MOV 853B MOV 852B
MOV 851A	MOV 851B

Cable Route 1	Cable Route 2	Cable Route 3
MOV 850A	MOV 850B	MOV 850C

MOV 850A, B & C each have two separate power supplies, motor control centers 1 and 2.

Recirculation and Spray:

Power Source 1 North Refueling Water Pump	Power Source 2 South Refueling Water Pump
East Recirculation Pump	West Recirculation Pump
MOV 866A	MOV 866B
MOV 1100B	MOV 1100D
North Charging Pump	South Charging Pump
MOV 18	MOV 19

Power Source 1	Power Source 2	Power Source 3
MOV 356	MOV 357	MOV 358

C. <u>Circuitry Revisions</u>

The following circuitry revisions were accomplished in order to provide the planned physical separation.

	Equipment	Action Taken
1.	Safety Injection Recirculation Valve MOV 358	Rerouted electrical cables and relocated power source to MCC-3 to provide isolation from MOV's 356 and 357.

Equipment	Action Taken
2. Seal Water Injection Pre-Filter Bypass Valve MOV 18	Rerouted electrical circuits to provide isolation between MOV's 18 and 19.
3. Group I East Safety Injection Pump East Feedwater Pump MOV-851A MOV-852A MOV-853A MOV-854A Group II West Safety Injection Pump West Feedwater Pump MOV-851B MOV-852B MOV-853B MOV-854B	Rerouted electrical cables to provide isolation between the equipment in Group I from that in Group II.
4. MOV-850A, B & C	Rerouted electrical cables to provide isolation of MOV-850A, MOV-850B, and MOV-850C from each other.
5. East Recirculation Pump and MOV-866A	Rerouted electrical cables to isolate the East Recirculation Pump and MOV-866A from the West Recirculation Pump and MOV-866B
6. North Refueling Water Pump	Rerouted electrical cables to isolate the North Refueling Water Pump from the South Refueling Water Pump.

4.2.4. AIR-CONDITIONING SYSTEM

A. System Functions

The air-conditioning system, although not strictly related to the capability to shut down and maintain control of the reactor in the shutdown condition, is desirable to provide air flow in the following safety-related equipment areas:

1. Stack - For controlled release of radioactive gaseous wastes (Fans A-22 and A-24).

2. Reactor Cavity - For cooling of nuclear instrumentation (Fans A-9 and A-9S).

3. Control Rod Drive Space - To limit temperature of control rod drive operating coils (Fans A-8, A-8S, and A-8SS).

B. Separation Requirements

Assure that the electrical supplies to the fan motors in Column 1 below are routed separately from those listed in Column 2.

Column 1	Column 2
A-22	A-24
A-9	A-9S
A-8	A-8S

A-8SS separated from items listed in both columns.

C. Circuitry Revisions

The following circuitry revisions have been accomplished in order to provide the planned physical separation.

	Equipment	Action Taken
1.	Spent Fuel Building Exhaust Fan A-24	Rerouted electrical circuits and relocated power supply to MCC-1 to isolate from Fan A-22.
2.	Reactor Cavity Cooling Fans	Rerouted electrical circuits to provide isolation between Fans A-9 and A-9S.
3.	Control Rod Drive Space Cooling	Rerouted circuits to isolate Fans A-8, A-8S, and A-8SS from each other.

4.2.5 RESIDUAL HEAT REMOVAL SYSTEM

A. System Functions

The residual heat removal system is normally required for cooling down the reactor coolant system once the pressure and temperature are less than 400 psig and 350°F, respectively. This is accomplished by the residual heat removal pumps circulating reactor coolant through the residual heat loop and the reactor. Each of the residual heat removal pumps assures that pumping capacity is only partially lost if one pump fails or becomes inoperative. This system is also required during refueling operations.

B. Separation Requirements

The following electrical separation requirements for the residual heat removal system shall be verified.

1. Confirm that electrical cables for one residual heat removal pump are physically separated from its companion pump.

2. Assure complete physical separation for electrical leads for the motor operated valves (MOV 822A and B) on the inlet of the residual heat exchangers.

3. Confirm that the residual heat exchanger cannot be overpressurized due to an inadvertent valve operation by verifying that the electrical wiring is physically separated between MOV-834 and MOV-833 and also between the valve groups MOV-813 and MOV-814.

C. Circuitry Revisions

The following circuitry revisions have been accomplished in order to provide the planned physical separation.

	Equipment	Action Taken
1.	Residual Heat Removal Loop Suction Valve	Rerouted circuits to isolate MOV 813 to MOV 814.
2.	Residual Heat Removal Loop Discharge Valve	Rerouted circuits to isolate MOV 833 from MOV 834.
3.	Residual Heat Exchanger Outlet Valve	Rerouted circuits to isolate MOV 822A from MOV 822B.
4.	Residual Heat Removal Pump	Rerouted circuits to separate the East and West Residual Heat Removal Pumps.

4.2.6 AUXILIARY COOLANT SYSTEM

A. System Functions

The Auxiliary Coolant System performs functions that, although not relating directly to safety, are important to orderly operations. One Component Cooling Pump will supply cooling for the Residual Heat Removal System, Safety Injection Recirculation Heat Exchanger and Spent Fuel Pit. Component cooling is generally required for an orderly plant shutdown, and control of the plant after a shutdown.

B. Separation Requirements

In order to provide backup in the event of equipment failure, physical separation of electrical leads shall be verified between each of the three Component Cooling Pumps.

C. Circuitry Revisions

The following circuitry revisions have been accomplished in order to provide the planned physical separation.

Equipment	Action Taken
North Component Cooling Water Pump	Rerouted the electrical circuits to provide separation of the three component cooling water pumps.

4.2.7 CIRCULATING WATER SYSTEM

A. System Functions

The Circulating Water System provides the source of cooling for the Auxiliary Coolant System. Therefore, components that interrelated with the Auxiliary Coolant System are also generally required for an orderly plant shutdown and for control of the plant after a shutdown.

B. Separation Requirements

Two Salt Water Cooling Pumps are provided to supply circulating water to the Component Cooling Water Heat Exchangers. One of these two pumps shall be operable at all times and physical separation with respect to electrical cables shall be assured.

C. Circuitry Revisions

The following circuitry revisions were accomplished in order to provide the planned physical separation.

Equipment	Action Taken
North Salt Water Cooling Pump	Separated electrical circuits to provide isolation of the North and South Salt Water Cooling Pumps.

4.2.8 COMPRESSED AIR SYSTEM

A. System Functions

The compressed air system is designed to supply air for pneumatic instrument operation and control. An emergency compressor and receiver is provided to furnish compressed air for emergency instrument service which is sufficient to accomplish an orderly plant shutdown and maintain control of the plant after shutdown.

The emergency air compressor or one main compressor can be run from a diesel generator. Each main compressor is supplied from a separate 480 volt bus, and the emergency air compressor is supplied from a motor control center.

B. Separation Requirements

It shall be verified that the electrical supply to the main compressors is physically separate from the electrical supply for the emergency compressor.

C. Circuitry Revisions

The following circuitry revisions were accomplished in order to provide the planned physical separation.

Equipment	Action Taken
Emergency Instrument Air Compressor	Separated the electrical circuits of the Emergency Instrument Air Compressor from the other Air Compressor circuits.

4.2.9 REACTOR COOLANT SYSTEM

A. System Functions

Plant safety associated with the Reactor Coolant System is directly related to the various trips and interlocks initiated by the following instrument channels:

1. Pressurizer Pressure
2. Pressurizer Level
3. Reactor Coolant Flow
4. Reactor Coolant Temperature
5. Nuclear Instrumentation
6. Turbine Auto Stop Oil Pressure
7. Loss of Feedwater

B. Separation Requirements

All of the Reactor Protection System is of a "de-energize to trip" design. While this is in the safe direction, a loss of power may result in a loss of indication and control which is undesirable when proceeding with a plant shutdown. Therefore assurance shall be made that cables from the inverters to the automatic transfer switches are run separately from the source cables for the 37.5-kVA transformer to maximize the availability of power to the instrument channels. Also, electrical wiring has been separated to assure that at least one of all the redundant instrument channels will be available for indication.

C. Circuitry Revisions

The following circuitry revisions were accomplished in order to provide the planned physical separation.

Equipment	Action Taken
Power Supply to Vital Bus	Provide separation of inverter leads from alternate source in cable trays.

4.2.10 MISCELLANEOUS WATER SYSTEMS

A. System Functions

This system is not directly related to the ability to accomplish a safe plant shutdown or to maintain the plant in a safe shutdown condition. It does supply water to the fire system and as such is necessary in the event of a fire. Both fire pumps, however, have backup from two service water pumps and two screen wash pumps, one of which is driven by a gasoline engine.

B. Separation Requirements

Physical separation of the electrical cables to the two fire pumps is not considered necessary; however, since these cables were damaged by the fire, it is planned that they be physically separated in the course of their renewal.

C. Circuitry Revisions

The following circuitry revisions were accomplished in order to provide the planned physical separation.

	Equipment	Action Taken
1.	North Service Water Pump	Reroute electrical circuits to provide isolation of the North and South Service Water Pumps.
2.	West Fire Pump	Reroute electrical circuits to provide isolation of the West and East Fire Pumps.
3.	South Primary Plant Make-up Water Pump	Reroute electrical circuits to provide isolation of the North and South Primary Make-up Water Pump circuitry.

4.3 FIRE FIGHTING EVALUATION

4.3.1 PURPOSE

The purpose of this evaluation is to determine if chánges to fire fighting equipment and/or procedures are required as a result of the experienced gained during the incident.

4.3.2 DISCUSSION

The cable failure occurred in a closed room which filled with smoke. With visibility obstructed, detection of the fire source was hindered, thus delaying fire fighting activity.

Operating personnel notified the Marine Corps Fire Department as they combatted the fire with a 150# Ansul and 50# carbon dioxide extinguishers. The fire was temporarily arrested but not contained, since the electrical circuits involved could not immediately be de-energized. The Marine Corps fire fighting personnel entered the switchgear room and sprayed water using fog nozzles on the cable trays. This response from the Marine Corps Fire Department was prompt and in accordance with established station emergency procedures.

Alerting of the Marine Corps Fire Department was in accordance with established station fire protection procedures. However, the procedure should have provided that the Marine Corps Fire Department be alerted as soon as the emergency was determined, rather than waiting until a fire is identified.

Relationship between the Marine Corps Fire Department and the San Onofre Nuclear Generating Station personnel is one of close liaison. Fire Department personnel frequently visit the plant to familiarize their personnel with the location of fire fighting apparatus and hydrants. They attend the Station's Fire Fighting Practice demonstrations. It is intended that this relationship will continue.

4.3.3 CORRECTIVE ACTION

1. To assist in rapid detection of future fires, smoke detectors with alarms in the control room have been installed in various locations to provide early warning.

2. The matter of notification of the Marine Corps Fire Department has been reviewed, and the appropriate procedures have been revised to require prompt notification.

4.4 FIRE AND SMOKE DETECTION AND ALARM SYSTEM

4.4.0 PURPOSE

A fire and smoke detection system is desirable to provide prompt detection and identification of fire and/or smoke in various areas of the plant. The system will provide the control room with means to monitor areas of the plant containing equipment and cables required for the operation and control necessary for the safe and orderly shutdown of the unit.

4.4.1 DISCUSSION

The decision to install a fire and smoke detection system is a part of the overall effort to augment plant fire protection and to improve early detection of an incipient fire condition.

Leading manufacturers of fire and smoke detection systems have demonstrated that the most sensitive and reliable manner to promptly detect fire or smoke is by means of sensing the products of combustion.

A "Pyr-a-larm" fire and smoke detection system, using sensing and alarm equipment manufactured by Pytronics, Inc. has been installed at San Onofre Nuclear Generating Station.

The sensing element uses the ionization chamber principle wherein products of combustion entering the detector cause a change in current flow across the ionization chamber. This change in current flow is used to operate the trigger electrode of a cold cathode tube, causing it to operate and activate an alarm in the control room of the plant. Because the detector contains no moving parts, it has proven to be extremely reliable in its operation and has been used extensively throughout this continent for the past 12 years.

4.4.2 CORRECTIVE ACTION

The system is designed to detect smoke or fire in separate areas of the plant. The monitored areas of the plant have been divided into eleven (11) zones as follows:

1. Diesel-generator and motor control center No. 3 area.
2. 4160-volt switchgear room.
3. No. 2 and No. 3, 480-volt switchgear room.

4. Inverter and d-c switchboard room and battery room.
5. The cable gathering area below the turbine front standard.
6. Control room area.
7. Communications room.
8. Administration Building.
9. 220-kV relay house.
10. Reactor auxiliary building.
11. Containment vessel strategic cable areas.

Approximately 110 ionization detectors have been installed to cover the eleven (11) zones listed above. Separate annunciation is provided for each zone to permit quick identification. The detection system for each zone is completely independent such that short circuits, failure of a detector, or any other type of malfunction in any one zone will not affect the satisfactory operation of the detection system in the other zones. The detection system is continuously electrically supervised for power supply low voltage, breaks in wiring or grounds. These problems will be immediately annunciated in the control room and identified by zone.

The wiring for this detection system has been run in a new and separate metal conduit system.

An operating instruction has been written for the fire and smoke detection and alarm systems which sets forth the procedure to be followed by the operators in responding to alarms in the system. These procedures consist of directions such as dispatching personnel to the areas, to evaluate the condition and report their findings. In addition, it outlines directions to be followed in the event areas are inaccessible due to a fire, with specific instructions to take emergency procedures such as de-energizing equipment located in rooms and references to applicable fire fighting procedure.

4.5 OPERATING-SHUTDOWN PROCEDURES

4.5.1 PURPOSE

A review has been made of existing Station Operating Instructions and emergency shutdown procedures to determine where changes are required as a result of the incident.

4.5.2 INTRODUCTION

The initial procedures followed by Station personnel during the incident were to determine the cause of the alarms received. Once the source of the alarms was found and it was established that a fire existed, a proper attempt was made to isolate and clear the 480-volt bus ground condition. When it was determined that the effect of the loss of the No. 2 480-volt bus would result in exceeding a limiting condition of the Technical Specification, the reactor was tripped.

4.5.3 DISCUSSION

A. Electrical Fault Clearing Operating Instructions

Operating Instruction S-6-23 — "4160 Volt Feeder Faults" describes the procedure for clearing electrical faults and is applicable to this incident. The operator's actions to clear the fault were in accordance with this procedure and were effective. Therefore, no revision to this Operating Instruction is necessary.

B. Fire Fighting Operating Instructions

Station Order S-A-2, "Fire Protection" describes the responsibilities and fire fighting procedures to be followed. Experience gained during the fire has been incorporated into the Station Order as follows:

1. The procedures to be followed when a fire is in a switchgear room and involves the safety of personnel or equipment have been revised. The new procedures require the operator to promptly call for emergency assistance.

2. A new section has been added for procedures to be followed in the event of an alarm from the area smoke detector system. These procedures require the control room operator to dispatch another operator to investigate the area in which the alarm originated and determine the problem and action required. These procedures also require the operator to request emergency assistance from the proper agency.

Operating Instructions S-7-1, 2 and 3, "Fire Pumps and Water Systems, Dry Chemical Fire Extinguishers, Carbon Dioxide Fire Extinguishers," have been reviewed and are proper. The Control operator responded correctly and placed the engine-driven screen wash pump (emergency fire pump) into service for fire fighting upon loss of the two station electric-driven fire pumps.

C. Shutdown Operating Instructions

Operating Instructions S-3-1.5, 2.5 and 5.2, "Plant Hot Shutdown to Cold Conditions," "Chemical Shim Control and Emergency Boration of the Reactor Coolant System," have been revised to further emphasize the importance that the concentration of boron in the primary system shall be determined by chemical analysis before a cooldown is started. All other applicable Operating Instructions have been reviewed and found adequate.

D. Additional Changes

1. A series of check cards have been prepared to aid the operator in his response to emergency situations. These cards contain a broad outline of each of the emergency operating instructions listing the major automatic and manual actions that must take place.

   The check cards also contain a reference to the appropriate operating instructions that provide more detailed instructions. The check cards will be kept in an indexed file on the Control Operator's desk where they will be readily accessible. By use of the applicable cards, the operator will be able to monitor the control boards and make notes of the events that have or have not occurred and take action accordingly.

2. All operating personnel have been trained to obtain boron samples. Samples will be obtained and analyzed as required during emergency conditions to affirm proper boron concentration.

SECTION 5

ELECTRICAL SYSTEM INVESTIGATION AND CORRECTIVE ACTION

5.1 CABLE FAILURE AND CORRECTIVE ACTION

5.2 TESTING RESULTS

5.3 CABLE TRAY LOADING

5.4 INSPECTION OF CABLES AND TRAYS

SECTION 5

ELECTRICAL SYSTEM INVESTIGATION AND CORRECTIVE ACTION

5.1 CABLE FAILURE AND CORRECTIVE ACTION

5.1.0 PURPOSE

The purpose of this analysis is to determine the causes of cable failures for each of the two incidents that occurred at San Onofre. The conclusions are based upon the investigative work of the Task Force to Investigate Cause and Recommend Corrective Action which included the testing program outlined in Subsection 5.2 and given in detail in the Appendix. In addition, recommended modifications to electrical equipment to prevent the recurrence of cable failures due to any of these probable causes are presented.

5.1.1 CAUSE OF CABLE FAILURE AND RESULTANT FIRE IN COWLING OF PENETRATION EPC4 ON FEBRUARY 7, 1968

On February 7, 1968, a cable failure occurred within the weather protective cowling of penetration EPC4 on the exterior of the containment.

This penetration had 65 conductors ranging in size from No. 1/0 AWG to No. 6 AWG copper wires. At the time of the failure, the 45 No. 6 AWG conductors supplying the pressurizer heaters had each been loaded at approximately 46 amperes for 96 hours. (See Figure 1 showing Pressurizer Heater Wiring Arrangement.)

The most probable cause for the failure in the cowling of EPC4 was the use of No. 6 AWG copper wire in the 45 pressurizer heater cables which were grouped in bundles restricting ventilation. Heating due to power losses of these conductors under the cowling caused the 90°C rated insulation on these conductors to be subjected to elevated temperatures, which accelerated aging of the insulation.

In addition, the following two factors could have contributed to the failure:

A. Lack of supports allowed conductors to bear heavily against each other and thus contributing to causing a phase-to-phase fault.

B. Development of tracking currents and the subsequent flow of fault current between 480-volt pins on the exterior face of the penetration due to moisture.

The exterior face and areas between the conducting pins on these penetrations were filled with an RTV (room temperature vulcanizing) silicon rubber which could have permitted the entrance of moisture, leading to eventual electrical breakdown at the exterior face of the penetrations.

Circuit protection for the pressurizer heaters consisted of fused disconnect switches for the 30 three-phase circuits.

The use of individual fuses to provide for the clearing of faults on three-phase 480-volt circuits which were involved in the fire resulted in single-phase operation as shown on Figure 2. This permitted low level fault current to continue to flow causing additional faults and heat generation at the outside face of the penetration.

Heat from the resulting fire traveled through the pins to the inside of the canister. The heat caused the insulating materials inside the canister to decompose, forming gases which generated sufficient pressure to expel the outside bulkhead from the canister.

5.1.2 CAUSE OF CABLE FAILURE AND RESULTANT FIRE IN CABLE TRAYS ON MARCH 12, 1968

On March 12, 1968, a cable failure occurred and the resultant fire damaged cable trays 39C3, 39C4, and 39C5. It is significant to note that, as in the February 7 incident, all of the pressurizer heaters had also been in service with each of the 45 No. 6 AWG conductors serving these heaters, loaded to approximately 46 amperes. In this case, the heaters had been in service for approximately nine hours prior to the failure. The pressurizer heater cables were located in the lower tray (39C3).

The most probable cause was the use of No. 6 AWG copper wire in the 45 pressurizer heater conductors in a heavily filled cable tray restricting ventilation. Heating due to the power losses caused these conductors to operate above their 90°C insulation rating, causing accelerated aging.

The following factors coupled with the overheating could have contributed to the failure:

A. The tray was heavily filled to a level above the side rails, causing heavy loading on the lower cables and possible deformation or flow of insulating materials. This loading or other mechanical damage in combination with thermal overloading of cables, contributed to a phase-to-phase fault condition between two separate 480-volt circuits setting the insulation on fire in the tray.

B. Several cable-to-tray ties using No. 12 TW wire, rather than nylon, were found holding power cable in position in the steel trays. These were suspected of possible heating due to transformer action. A wire tie, which had burned apart, was found at the point of most severe damage in tray 39C3.

C. Defective cable.

D. Damage during installation.

The large initial short circuit current was cleared by the fuses in the faulted phases. However, the currents in the unaffected phase was below the fuse continuous rating. (See Figure 2.) Current was subsequently back fed through the pressurizer heaters into the short circuited cables, supporting the combustion of adjacent cable insulation.

Lack of three phase clearing permitted low level fault current to continue to flow and sustain the fire causing additional faults and heat generation in the tray.

5.1.3 REPLACEMENT CABLE INSULATION

The existing single-conductor No. 6 AWG butyl rubber insulated neoprene jacketed cables, originally utilized for pressurizer heater circuits, were replaced with three-conductor No. 4 AWG cables rated at 90°C conductor temperature. The three-conductor No. 4 AWG cables are also insulated with butyl and jacketed with neoprene with an overall jacket of polyvinyl chloride.

The butyl rubber ozone resistant insulation, with a neoprene jacket, is used external to the sphere for 600-volt power and control circuit cables at San Onofre as well as other Company installations. This complies with Southern California Edison Material Standard No. 225 which is included in the Appendix. Suppliers under this standard are limited to a carefully prequalified group.

"Vulkene" cross-lined polyethylene insulated conductor was selected for use within the sphere due to its radiation resistive properties.

In evaluating and selecting the desired cable insulation system, it is normal practice to consider environmental exposure. As in all Southern California Edison applications, the power and control cable provided at San Onofre was selected on the following bases:

A. Southern California Edison's experience at other system locations.

B. Experience of other Utility Companies in the United States.

C. Established national standards.

D. Southern California Edison's Specifications.

E. Manufacturer's specifications and test data.

F. Manufacturer's reputation.

G. Environmental conditions.

5.1.4 CORRECTIVE ACTION

A. The existing single-conductor No. 6 AWG butyl rubber insulated neoprene jacketed cables, originally utilized for pressurizer heater circuits, were replaced with No. 4 AWG three-conductor cable. This will provide for more orderly arrangement of the cable in the trays, and will tend to keep related conductors in a single-circuit adjacent to each other.

B. The remaining damaged power and control cables, which vary in size from 500 MCM to No. 12 AWG, were replaced with cable of the same type as that previously installed as specified in Southern California Edison Material Standard 225.

C. Three-phase circuit breakers have been used to replace the fused devices as short circuit and overload protection on all 480-volt circuits, including the pressurizer heater circuits. This type of breaker has several modes of protection, each of which provides three-phase tripping. The modes are as follows:

1. Magnetic coil contact opening for medium to low magnitude fault protection is used in all breakers.

2. Thermal element contact opening for overload protection is used in all breakers.

3. Current limiting fuses for high magnitude fault protection have been provided with the larger three-phase breakers. The breakers were tested at the Southern California Edison's High Current Testing Facility. The test results indicated the breakers to be highly satisfactory. A copy of the test data on the breakers is included in the Appendix.

   The closed, open, or tripped condition of these breakers is indicated by the position of the breaker operating handle. This visual indication allows Operating Personnel to verify an abnormal condition on the pressurizer heater and on other 480-volt circuits on their regularly scheduled inspection tours through the plant.

D. To reduce the number of circuits and the total conductor power losses carried by each 480-volt penetration, and to provide for the increased conductor sizes, four existing canisters are being modified and replaced, and two existing spare penetrations are being equipped with new canisters. All 480-volt circuits entering the containment will utilize these modified penetrations. Supports are also being provided at the penetrations to prevent cables from being directly supported by their terminals.

E. To reduce physical loading in cable trays, existing cables are being relocated to new trays as required.

F. Throughout the plant, cable tray thermal loading was reduced by relocating existing circuits to new trays, and by changing conductor sizes where required. The pressurizer heater circuits were relocated to new separate trays. (See Subsection 5.3)

G. All cable in trays was inspected for mechanical or heating damage. Replacements or repairs were made as required. (See Subsection 5.4.)

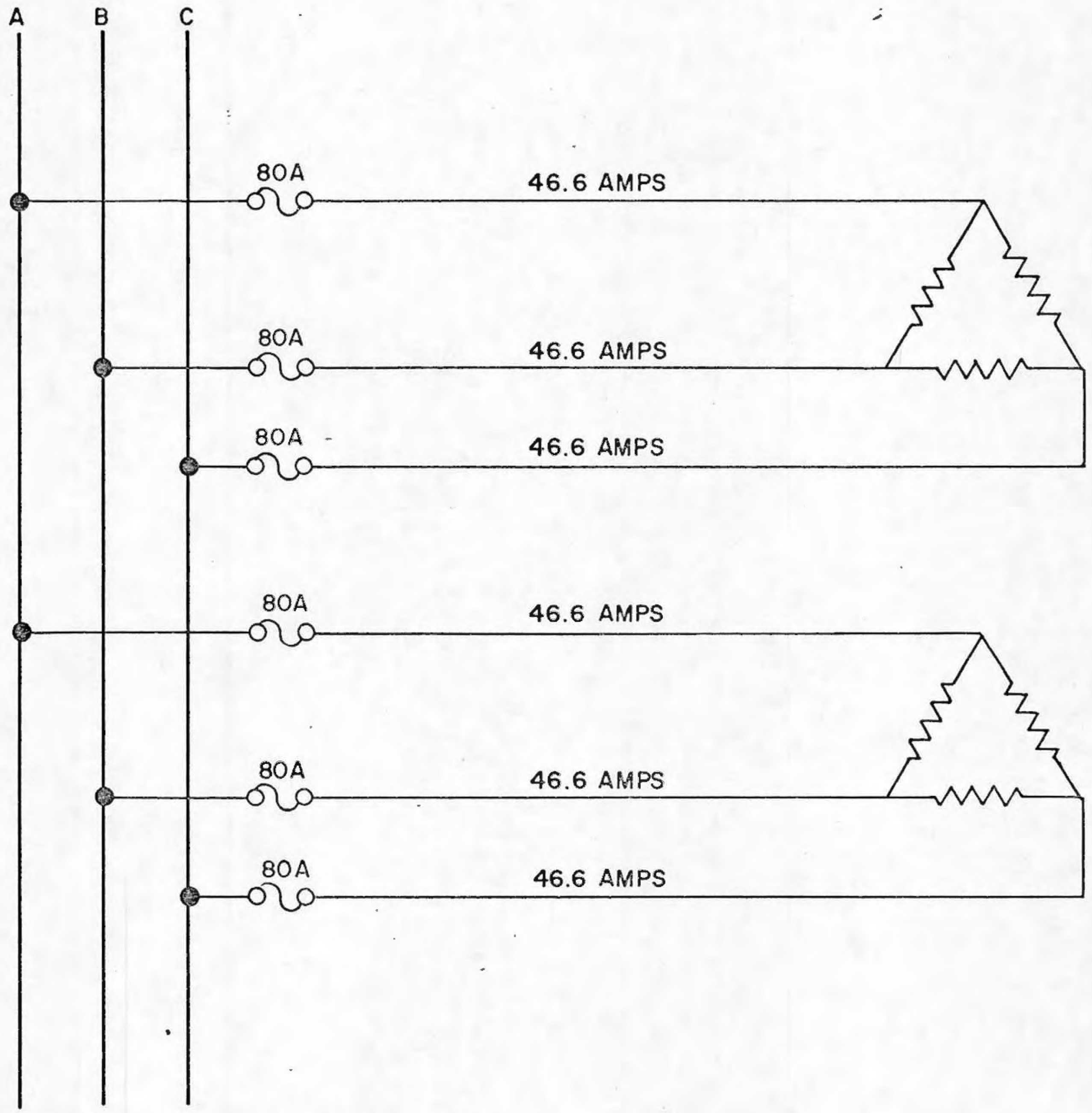
H. All TW wire ties were removed from cable trays.

I. To prevent the possible entrance of moisture to the face of the low voltage power and control penetrations, all existing and new penetrations were equipped with weatherproof enclosures which completely cover and protect the penetration terminations. All exterior enclosures were provided with thermostatically controlled heaters to maintain a temperature above the dewpoint.

5.1.5 CONCLUSIONS

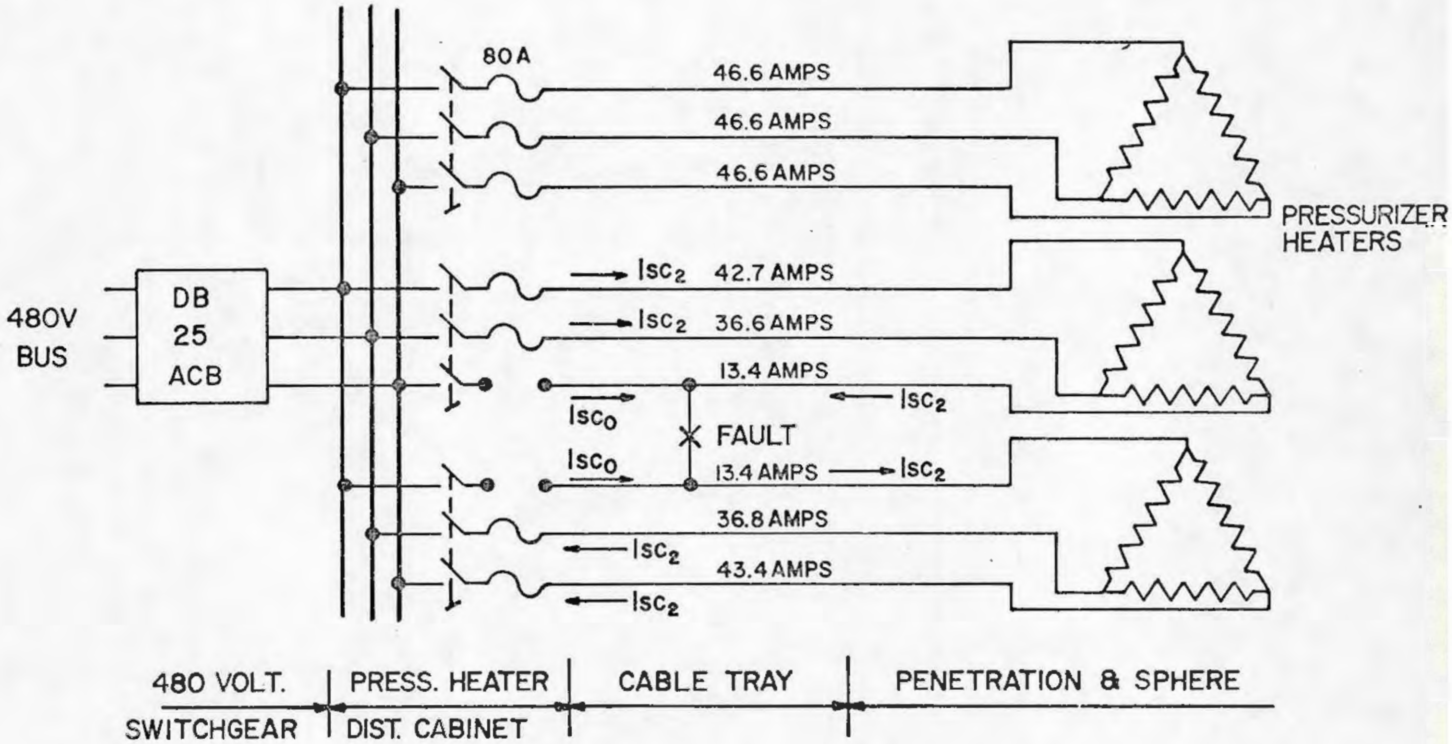
The most probable common cause for the two cable failures was overheating of the pressurizer heater cables coupled with mechanical loading or damage. In addition, other factors have been identified which could have contributed in various degrees to the principal cause of failure. To preclude any future similar incident which could be caused by any of these factors, corrective actions have been performed as outlined in Paragraph 5.1.4.

SAN ONOFRE NUCLEAR GENERATING STATION



480 VOLT PRESSURIZER HEATER CIRCUITS
NORMAL OPERATION

FIGURE 1



Isc_0 = INITIAL SHORT CIRCUIT AFTER CABLE FAILURE

Isc_2 = SUBSEQUENT SHORT CIRCUIT CURRENT BACK FED THROUGH HEATERS

THE PORTION OF Isc_2 PASSING THROUGH UNBLOWN FUSES IS BELOW FUSE CONTINUOUS RATING

SIMPLIFIED THREE - LINE WIRING DIAGRAM OF PRESSURIZER HEATERS

FIGURE 2

5.2 TESTING RESULTS

5.2.0 PURPOSE

This section summarizes the tests conducted to evaluate the existing electrical equipment, cable trays and sphere penetration. Details of test reports are attached in Section 7, Appendix.

5.2.1 TESTS ON ELECTRICAL EQUIPMENT AND CABLE TRAYS

A. Pressurizer Heater Control Unit

The Pressurizer Heater Control unit varies the supply voltage to a portion of the pressurizer heaters. Operational tests on in-service equipment at San Onofre showed no characteristics detrimental to cables or equipment.

B. Thermal Loading Test on Tray 39C3

A cable tray loaded with energized cable similar to the one involved in the failure at San Onofre was subjected to temperatures similar to the condition at the time of the incident. Temperatures in the cable tray were found to be dependent on such factors as spacing, cable configuration, compaction, thermal loading and ambient temperature. The cable temperature was found to vary significantly within short distances for different cable configurations. Cable temperatures as high as 158°F were obtained which exceeded the manufacturer's 90°C rating of the cable insulation.

C. Cable Tray Short Circuit Simulation Test

A test was performed to determine if a cable fire could be initiated and sustained by a momentary short circuit followed by low level current feeding into the fault.

A cable tray was loaded similar to cable tray 39C3 and an intentional phase-to-phase short circuit was initiated between opposite phases of two adjacent three-phase, 480-volt, delta-connected circuits. After the fuses in the faulted phases had cleared, the two phases in each circuit which remained energized, backfed to the fault through the pressurizer heaters. The intense heat created by the sustained phase-to-phase arcing, ignited the cable insulation. Additional electrical faults followed and the fire proceeded at a rapid rate.

This test demonstrated that a cable tray fire could be initiated and sustained in the manner described above.

D. Pressurizer Heater Cable Bundle Overheating Tests

A 45-conductor bundle of No. 6 AWG wires was loaded to 48 amperes to approximate the heater current.

Currents for the 30 pressurizer heaters at San Onofre vary between 45 amperes and 48 amperes, depending upon 480-volt bus voltage, length of supply circuits, and variations in individual heaters.

Temperature measurements were obtained with:

1. The bundle in air.

2. The bundle wrapped in two layers of control cables.

3. The bundle insulated with fiberglass.

Temperatures varied from 85°C for the bundle in air, 135°C wrapped in two layers of cables, in excess of 250°C for the bundle insulated with fiberglass. Cases 2 and 3 exceeded the manufacturer's 90°C rating of the cable insulation.

E. Pressurizer Heater Cable Oven Tests

Sections of Simplex 600-volt No. 6 copper anhydroprene-xx cable (1965) were subjected to heat in an oven at various temperatures and lengths of time until damaged. The appearance of the San Onofre sample showed jacket deterioration similar to cables subjected to oven temperatures of 170 to 200°C for 8 hours.

F. Pressurizer Heater Cable - Voltage Breakdown Tests

Various lengths of No. 6 AWG pressurizer heater cables, showing cracked, overheated jackets were overvoltage tested under water. All of the cable samples passed the 10.8-kV five-minute test, and all but one cable passed the 41-kV d-c test. The normal test voltage for this size cable is 25-kV d-c.

G. Pressurizer Heater Cable Test by Simplex on Physical Condition of Insulation

Simplex Wire and Cable Company tested samples of pressurizer heater cables obtained from between the point of failure and the sphere and the point of failure and the source. These tests indicated that the cable had overheated.

H. Westinghouse 600-Volt Switchgear

1. Pressurizer Heater - Fused Disconnect Switch

Fault interruption tests were made on the original Westinghouse type FDP switch with FRS-80 dual-element and KTS-80 current limiting fuses. The switch performed satisfactorily with KTS current limiting fuses. Fault tests using FRS dual element fuses which were in service at the time of the cable failure caused the switch contacts to weld closed.

2. Westinghouse Tripac Circuit Breaker

Fault interruption tests on the Tripac Type FA, 70-A circuit breaker showed the unit performed very well with no visible distress and very little contact erosion. This device has been installed on all 480-volt circuits and will be utilized to replace the Westinghouse type FDP fuse-switch device for the pressurizer heaters.

I. Existing Penetration Cowling - Cable Heat Run

A bundle of cable, representative of the cable under the cowling of Penetration EPC4 or WPC7 was assembled and loaded to determine internal temperatures. An actual cowling (WPC7), removed from San Onofre, was used. Temperatures up to 109°C were recorded in the center of the bundle. This temperature exceeds the manufacturer's 90°C rating of the cable insulation.

5.3 CABLE TRAY LOADING

5.3.0 PURPOSE

This section summarizes the investigations performed to determine the extent of physical overloading and thermal overloading of the tray sections involved in the fire. The investigation was divided into two major categories:

A. Tray Physical Loading

B. Tray Thermal Loading Limits

5.3.1 TRAY PHYSICAL LOADING

When the trays were investigated to determine physical loading, it was found that some cable trays were filled above the level of the side rails. As a result of replacing and relocating fire damaged cables, relocating redundant circuits, resizing of conductors for circuits, and removal of power cable resulting from thermal analysis described in Paragraph 5.3.2, many of the overfilled tray conditions were corrected. Physical unloading of the remaining trays has been accomplished to reduce the cable fill to the level of the side rails.

A scale model of the cable tray system was developed to facilitate design of new cable trays used for physical separation and cable tray unloading.

5.3.2 TRAY THERMAL LOADING LIMITS

The investigation of the thermal overloading included an analysis of the amount of current carried by each of the conductors in every tray section, the loading criteria to be established and the action to be taken to correct tray overloading.

A. In the investigation of thermal overloading, the full load current of every cable in a tray throughout the plant (926 tray sections) was compared with the manufacturer's allowable current ratings for insulated copper conductors and 90°C conductor temperature. Power cables supplied by motor control centers are sized for 125% minimum of load nameplate current rating. Cables fed from the 480-volt switchgear are sized to provide 150% minimum of the load nameplate current ratings. Any cable not adhering to these minimum criteria was replaced or paralleled with another conductor of the same size. A total of 1200 engineering man-hours was expended on this circuit and tray thermal loading analysis. The cables in each tray were considered to be grouped in the most adverse thermal arrangement, that is, all power conductors tightly grouped and surrounded by a blanket of control cables. Where groupings were found which could produce calculated conductor temperatures in excess of 90°C, power cables were removed from these trays until the 90°C criteria was met.

The detailed analysis techniques used to determine if temperatures would exceed 90°C in the center of the conductor grouping are presented in the Appendix.

B. Corrective recommendations to provide for a safe thermal loading limit in each tray required determining the following for each existing tray in the plant:

   1. The existing tray physical fill.

   2. The ratio of the total area of power and control cable to the total area of power cable.

   3. The total power losses generated in the tray.

C. The following criteria were established for the thermal loading analysis:

   1. An average ambient temperature of 30°C, (86°F).

   2. The assumption that control cables consisted of 100% high thermal resistivity butyl.

   3. The assumption that normal operating conditions prevailed for cable loading and, as a limiting check, the assumption that no diversity existed (all connected load in operation).

      In the case of the pressurizer heater circuits, it was assumed that they operated continually.

   4. The assumption that cables were installed in the most adverse arrangement. For analysis, a circular cross-sectional bundle of cables was assumed for each tray. All loaded power cables were assumed to be at the center of the bundle, with all control cables in the tray placed uniformly around the power cables. By these criteria, higher conductor temperatures resulted than would be actually experienced when the cables were spread in a shallow layer across a 24-inch cable tray.

The maximum conductor temperature in the actual cable tray configuration where cables are not arranged in a circular bundle with all heat producing conductors in the center, but are spread across a 24-inch wide tray, is expected to be substantially less than 90°C as a result of this unloading.

5.3.3 CORRECTIONS AND CONDUCTOR TEMPERATURE MONITORING

A. New tray thermal loading schedules were developed based on results of a computer analysis which considered all of the above conditions for every cable in every tray. The schedules listed 51 circuits in a total of 49 different tray combinations that required relocation to new or unloaded trays to accomplish this thermal unloading.

The cable tray thermal overloading investigation included an analysis of the amount of current carried by each of the conductors in every tray section. As a result of this investigation, 42 circuits required the use of larger conductors or installation of conductors in parallel to increase the circuit capability.

Actual maximum conductor temperatures during either start-up or normal operating conditions will be far below the temperatures calculated since the most adverse cable arrangement and operating conditions were assumed. It was also assumed that total connected load was in service at all times.

B. Temperature monitoring devices have been installed throughout the plant to confirm that conductor temperatures are below the allowable conductor temperature ratings permitted by cable manufacturers.

C. An analysis of the 15 three-conductor replacement cables for the pressurizer heater circuits placed in new separate 24-inch cable trays indicates that the maximum conductor temperature is not expected to exceed 50°C in a 30°C ambient.

5.4 INSPECTION OF CABLES AND TRAYS

5.4.1 PURPOSE

A detailed inspection of cables in all trays was considered necessary to verify that the cables remaining in service did not evidence signs of overheating or other physical damage.

Quality assurance teams consisting of qualified Southern Edison and Bechtel personnel are following all repair and modification work to assure that specifications are met and good construction practices are followed.

5.4.2 INSPECTION

In order to perform a detailed examination of the remaining station cables, 17 inspection teams were utilized, consisting of qualified and experienced Southern California Edison supervisors and accompanied by contractors' journeymen. Each team consisted of one Southern California Edison supervisor and one or two journeymen electricians. The electricians removed individual cables from the cable tray and the inspector flexed and inspected each cable to determine if prolonged overheating damage or other physical damage existed.

If damage or distress conditions were discovered, the cable or tray was tagged and the location noted on record sheets. A team of Southern California Edison engineers then determined whether the cable should be removed or repaired, and, if repaired, how the repairs were to be effected.

All the cables in trays throughout the plant, which involved more than 15,000 lineal feet of cable tray, were inspected and reports from the inspectors were reviewed, evaluated, acted upon, and then filed for reference.

An estimated 500 man-days of effort by Electricians, Riggers, and Laborers were required to carry on the inspection assignment, and 530 man-days of supervisory work to inspect the cables.

The total cost of the inspection effort is estimated at $107,000.

5.4.3 RESULTS OF INSPECTION

It is very significant that no evidence of damage due to overheating was found on any of the cables remaining in service. Evidence of jacket deterioration due to overheating was found on seven pressurizer heater cables after they were removed from the trays.

Corrections were made to cables where mechanical damage resulting from installation was found. Such mechanical injuries are usually caused by pulling techniques, manner of tying cables, etc. The cables provided are protected by a protective jacket for this purpose.

The results of inspecting the power and control cables throughout the plant are as follows:

A. No signs of cable insulation damage by overheating was found on any of the remaining wire.

B. Nine hundred and ninety-nine cases of damage to cable have been found and corrected as required.

C. Five cases of improper pulling of 220-kV switchyard control cable were found. These cables were replaced.

D. The short lugs used originally for connecting the 480 volt motor leads in sixty-nine motors were replaced with a more satisfactory and longer lug.

E. Three hundred and thirty-nine 4-kV terminations were untaped and refinished in accordance with procedures developed and approved by the cable manufacturer and by Southern California Edison engineers. The jackets on the original 4-kV terminations were improperly finished and resulted in corona problems and high noise interference with other sensitive systems.

F. One hundred and thirty cases of improper cable tray installation have been found and corrected.

SECTION 6

START-UP PROGRAM

6.1.0 PURPOSE

Because of the magnitude of repairs and modifications made following the cable failure incident, it is necessary to verify that all components and systems affected by the incident are in proper working order and function as originally designed prior to restoring the unit to service.

6.1.1 ORGANIZATION

The verification and start-up activities will be coordinated by the Station Chief (who holds a current SRO license) and through his operating staff. Start-up teams from the contractors will also assist him with the preparation and execution of the start-up activities. The Watch Engineer for each shift is a qualified Senior Reactor Operator, and will supervise the step-by-step operations during and after the start-up.

The following components were modified or repaired and verification of proper operation will be demonstrated:

A. Electric Motor Heaters:

Thirteen motor heater circuits to be proven.

B. Pumping Components:

Reactor Coolant System Drain Tank. Pump G20-B
West Sphere Sump Pump
West Reheater Pit Sump Pump
West Feedwater Pump Lube Oil Pump
Reactor Cavity Sump Pump
East Sphere Sump Pump
East Intake Sump Pump
"A" Reactor Coolant Pump. Lube Oil Pump
West Fire Pump
West Recirculation Pump
West Residual Heat Removal Pump
North Service Water Pump
West Feedwater Pump
West Feedwater Pump. Lube Oil Pump.
Refueling Water Filter Pump
South Refueling Water Pump
Auxiliary Feedwater Pump
Reactor Coolant Pump "B"
South Primary Plant Makeup Pump
East Recirculation Pump
Turbine Auxiliary Oil Pump
Condenser Vacuum Pump

South Flash Evaporator Feed Pump
West Flash Evaporator Condensate Pump
Flash Evaporator Recirculation Pump North
Flash Evaporator Recirculation Pump South
Reactor Cavity Dewatering Pump

C. Motor Operated Valves:

MOV-822-B
MOV-814
MOV-834
MOV-866-B
MOV-348
MOV-357
MOV-720-A
MOV-852-B
MOV-854-B
MOV-880
MOV-853-B
MOV-851-B
MOV-883
MOV-19

D. Cooling and Ventilating Systems:

Cooling Fan A-5-S
Cooling Fan A-6-S
Cooling Fan A-7-S
Fan A-3
Fan A-22
Fan A-23
Auxiliary Cooler Fan No. 1
Auxiliary Cooler Fan No. 2
Sphere Circulating Fan A-12

E. Miscellaneous Components:

Main transformer cooling equipment
Three (3) power receptacles
Center Instrument Air Compressor
Motor control Center No. 3 supply
Dumb Waiter
Pressurizer Heater Groups "B" and "D"
Communications Circuits
New ACB & Tripac Breakers

6.1.2 VERIFICATION PROCEDURES

Before a component or system is put in service, the following steps will be taken:

A. A quality assurance team consisting of Southern California Edison and Bechtel experienced technical personnel are following all repair and modification work to assure that specifications are met and good construction practice is achieved.

B. Electric circuitry and component and system controls will be checked as follows when required:

1. Control circuitry will be checked and verified.
2. Protective relaying will be verified.
3. Interlocking circuits will be verified.
4. Power circuitry will be verified.
5. Component will be operated separately.
6. System protective and interlocking circuitry will be verified.
7. System control circuitry will be verified.
8. System will be operated manually.
9. System will be operated automatically.

C. A detailed description of the procedures to be used in putting station back in operation has been prepared as a separate document and is described in the following pages. The Start-up Procedure Manual is divided into nine sections:

1. Delineation of Work will consist of a general statement concerning objectives, typical work and equipment functions.

2. Administration, Clearance Procedures and Records will discuss general responsibilities for administration, clearance procedures and record keeping.

3. Electrical Testing covers the responsibilities of the various parties and groups involved in electrical test and start-up until optimum operation of the unit is established.

4. Instrument Testing and Calibration will outline those instrument tests and calibrations required as equipment is returned to service and reactor start-up is initiated.

5. Sequence of Operations will be a tabulation of order in which equipment affected by the cable failure will be returned to operation.

6. Auxiliary Equipment, this section describes the checks necessary before equipment and preliminary operations are started to achieve safe operation. A verification that proper system alignment has been checked, lubrication, cleanliness and adjunct services are available and in service shall be made.

7. Precritical Tests will be outlined and referenced to applicable procedures and operating instructions. The following dynamic tests and/or operations shall be performed as required by the Technical Specifications and/or before reactor start-up:

a. Operate Chemical and Volume Control System equipment required by Technical Specification 3.2.

b. Operate Safety Injection System equipment required by Technical Specification 3.3.1.

c. Verify that the Safety Injection System and Containment Spray System will respond promptly and properly as required by Technical Specification 4.2, I, A and B and II B. (Follow Operating Instruction S-3-3.4, Cold Operational Test of the Safety Injection System and Containment Sphere Spray System and Operating Instruction S.3.3.3, Hot Operational Test of the Safety Injection System.)

d. Operate the electric drive auxiliary feedwater pump required by Technical Specification 3.4, (Operating Instruction S-2.13.)

e. Verify operability of Auxiliary Electrical Equipment required by Technical Specification 3.7.

f. Test the Emergency Power System required by Technical Specification 4.4 A and B. Follow Operating Instructions S-2-11, Diesel Generator Test (Weekly Interval) and S-2-12, Diesel Generator Test (Refueling Interval).

g. Test operation of the hydraulic stop gates. Follow Operating Instruction S-2-14.

h. Test all Reactor Trip Circuits to ensure that signals are received at the trip breakers.

i. Test all Turbine Trip Circuits to ensure that signals are received at the trip solenoid.

j. Complete sphere penetration leak rate tests after penetrations are installed and before sphere integrity is required. b

k. After sphere integrity is established perform a Hydrostatic Test of the Reactor Coolant System, follow Operating Instruction S-3-1.8.

l. After the Reactor Coolant System has been heated to operating temperature and pressure perform control rod drop time tests.

8. <u>Sequence of Start-up Operations</u> will include a copy of the reactor precritical check list, turbine-generator pre-operational check list and the unit start-up Operating Instruction.

9. Cable Temperature Monitoring

In order to verify that cable temperatures throughout the plant are within proper operating limits on return-to-service, temperatures will be measured at 68 selected locations.

Initially each temperature sensor will be attached to a cable located near the center of the test tray cross section. The cables at the test locations will be checked periodically throughout the test and the sensors relocated as necessary to assure that the sensor is attached to the cable operating at the highest temperature in the tray.

The manufacturers' allowable conductor temperature (on a continuous operation basis) for the 600-volt cables installed at San Onofre is 90°C.

To assure that the 90°C conductor temperature is not exceeded, the surface temperature of the cable must be limited to 85°C to allow for an approximate 5°C temperature drop through the electrical insulation of the cable.

The selection of cables to be monitored will be on the basis of highest expected temperature; however, the recorder alarm points will initially be set at a value to allow for the possibility that the point of measurement may produce values somewhat less than the maximum.

Recorded temperatures will be monitored until after the Unit output reaches 450 MWe gross and records will be retained at San Onofre for reference. Indicated temperatures will be logged once per shift for two weeks following return-to-service then once per day for one month and following this, once per week until 450 MWe loading is accomplished.

The above schedule is predicated on satisfactory temperature levels at the points measured.

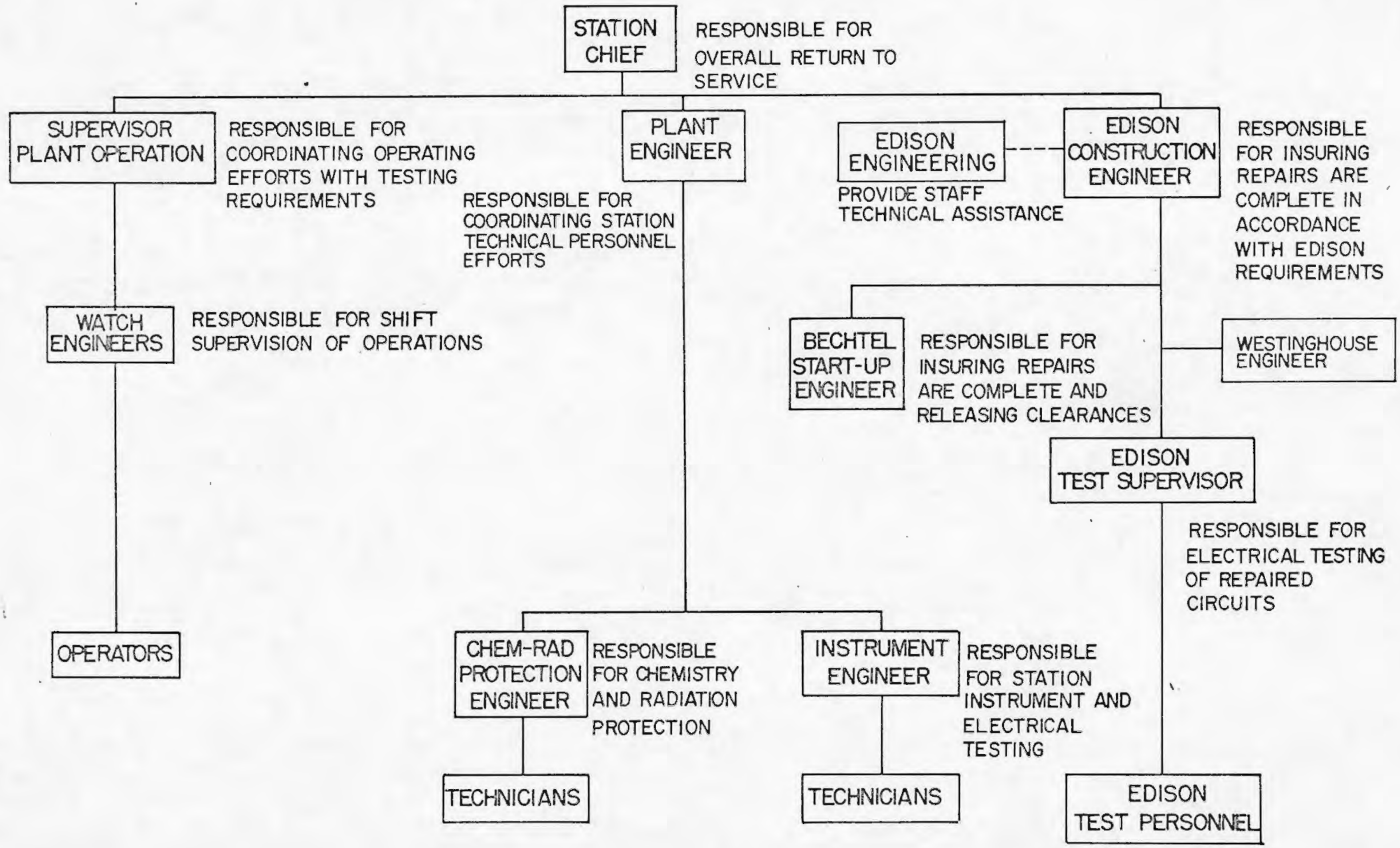
Measurements will be discontinued upon verification that all temperatures are within design values at maximum load ratings.

6.1.3 CONCLUSIONS

In order to verify plant circuitry and system operations after changes have been completed, test teams of Edison and contractor forces have been organized. These teams will coordinate their testing with the operating staff. The operations will be performed as prescribed in the applicable operating Instructions and in accordance with the Start-up Procedure Manual which includes all the applicable operating instructions and orders required to accomplish the work in an orderly and safe manner and it has been prepared as a separate volume. Volume I, Start-Up Procedures, San Onofre Nuclear Generating Station, was used as the basis and guide for preparing the above-mentioned Start-Up Plan.

The results of the testing will be tabulated and will be made part of the permanent plant records along with the initial start-up records.

TESTING COORDINATION FOR RETURNING TO SERVICE
SAN ONOFRE NUCLEAR GENERATING STATION
1968



SECTION 7

APPENDIX

7.1 TEST REPORTS

7.1.0 Thermal Loading Test on Tray 39C3

7.1.1 Duplication of Sustained Combustion Resulting From Pressurizer Heater Cable Short Circuits - Tray 39C3

7.1.2 Existing Penetration Cowling - Cable Heat Run

7.1.3 New Cable Tray Thermal Loading Criteria - Heat Run

7.1.4 Westinghouse 600-Volt Switchgear Test

7.1.5 Boric Acid Crystallization Study

7.1.6 Chemical and Volume Control and Radwaste System Tank Overpressure Investigation

(A) Metallurgist Analysis

(B) Hydrostatic Test of the Volume Control, Waste Gas Surge and Flash Tanks

7.2 PREVIOUS DESIGN BASIS FOR CABLE SIZING

7.3 CABLE

7.3.0 Material Specification No. 225

7.3.1 Simplex 600-Volt Cable Test

7.4 CABLE TRAY THERMAL LOADING ANALYSIS

7.5 SHUTDOWN MARGIN ANALYSIS AT MAXIMUM DILUTION

7.6 DAMAGED CABLE TRAY PICTURES

7.7 DRAWINGS

7.7.0 Chemical and Volume Control System

7.7.1 Safety Injection System

7.7.2 Radioactive Waste Disposal Systems

7.7.3 Additional Cable Tray Location (Model and Drawing)

7.7.4 Smoke Detection System Location

7.1.0 THERMAL LOADING TEST ON TRAY 39C3

REPORT OF THERMAL LOADING TEST
TRAY 39C3
SAN ONOFRE NUCLEAR GENERATING STATION

PURPOSE

The purpose of this test was to determine the maximum temperatures that might develop in tray 39C3 as it was loaded prior to the cable failure, under conditions of normal operation, and under the maximum credible current loading. A series of tests as outlined below were conducted during May 1968.

DISCUSSION

The lists of circuits to be tested under concurrent and maximum credible current operation and the currents at which they were operated were provided by the Bechtel Corporation.

Due to the large number and variation of circuit currents, average values of load current were selected for duplication purposes. The levels to which the circuits were loaded for this test are as follows:

1. CONCURRENT LOAD

Circuit	No. of Conductors and Size	Actual Load Current/ Conductor (Amps.)	Test Load Current/ Conductor (Amps.)
Residual Heat Removal Pump B	3-#1/0	71.0	71.0
Pressurizer Heater Leads	45-#6	46	46
Reactor Control Rod Cooling System	3-#4	48.5	46
Auto. Transfer Siren	3-#6	20	20
Flash Evaporator Condensate Pump - West	3-#10	18.7	20
Flash Evaporator Feed Pump - SW	3-#10	18.7	20
Communications Power Panel	3-#12*	6.3	20
Sphere Fan A3	3-#8	11	11
Sphere Fan A4	3-#8	11	11
Reactor Cavity Water Pump	3-#12*	12.5	11

*Indicates multiconductor cable.

1. <u>CONCURRENT LOAD</u> - Cont'd

Circuit	No. of Conductors and Size	Actual Load Current/ Conductor (Amps.)	Test Load Current/ Conductor (Amps.)
Reheater Sump Pump West	3-#12*	10.2	11
Sphere Pump G21E	3-#12*	6.5	7
Reactor Bldg. Fan A12	3-#12*	6.7	7
Reactor System Drain Tank Pump	3-#12*	18.7	4

2. <u>MAXIMUM CREDIBLE LOAD</u>

Circuit	No. of Conductors and Size	Actual Load Current/ Conductor (Amps.)	Test Load Current/ Conductor (Amps.)
Fire Pump West	3-#4/0	143	142
Fire Pump East or Power Recpt.	3-#4/0	143	142
Main Transformer Feeder #2 Cooling Equipment	3-#2/0	112.8	113
Residual Heat Removal Pump B	3-#1/0	71	71
Pressurizer Heaters	45-#6	46	46
Reactor Control Rod Mechanism Cooling System	3-#4	48.5	46
Reactor Cooling Fan A5S	3-#8	35.7	36
Reactor Cooling Fan A6S	3-#8	35.7	36
Reactor Cooling Fan A7S	3-#8	35.7	36
Sphere Cooling and Filtering Fan A3	3-#8	25	25
Sphere Cooling and Filtering Fan A4	3-#8	25	25
Flash Evap. Recirc. Pump NW	3-#10	24.5	25
Flash Evap. Recirc. Pump SW	3-#10	24.5	25
Auto. Transfer Switch (Emerg. Siren)	3-#6	20	20

*Indicates multiconductor cable.

2. MAXIMUM CREDIBLE LOAD - Cont'd

Circuit	No. of Conductors and Size	Actual Load Current/ Conductor (Amps.)	Test Load Current/ Conductor (Amps.)
Service Water Pump North	3-#10	19.5	20
Flash Evap. Cond. Pump West	3-#10	18.7	20
Flash Evap. Feed Pump SW	3-#10	18.7	20
Communica. Power Dist. Panel	3-#12*	6.3	20
Refueling Water Filter Pump	3-#12	14	14
Reheater Pit Sump West - G55B	3-#12*	10.2	11
Reactor Bldg. Circ. Fan A12	3-#12*	6.7	7
Pump G21B Sphere Sump	3-#12*	6.5	7
Lifting Frame	3-#12*	7.0	7
Turbine Lube Oil Transfer Pump	3-#12*	4.5	4
Reactor Cooling System Drain Tank Pump	3-#12*	18.7	4
Air Comp. Motor Heater - K1B	3-#12*	.4	1
Aux. Cool. Water Pump Motor Heater	2-#12	.4	1
Motor Heater - G36B	2-#12	.33	1
Motor Heater - G14B	2-#12	.57	1
Reactor Cavity Sump Pump	3-#12*	1.7	1
Salt Water Cool. Pump Motor Heater	3-#12*	.3	1

*Indicates multiconductor cable.

A 15-foot section of cable tray 39C3 containing its complement of wires, including the burned sections, was sent to Edison's Shop and Test Division at Alhambra, California. Personnel from Edison's Apparatus, Engineering, Power Supply and Shop and Test Departments emptied tray 39C3 wire by wire, recording the description and position of each within the tray. Three complete cross-sectional unloading profiles were drawn during this procedure. From these tray profiles, Profile #3 representing the cross-section six inches from the point of failure and most severe burning was selected as the model to most closely approximate the cable arrangement for the reloading of the tray. A quantity of undamaged cable which ran from the fire area to the switchgear, plus some additional used cable, was sent from San Onofre and used to reload the tray. The tray was set on steel supports which made point contact with its bottom.

Cable was loaded into the tray, wire by wire in accordance with a cable loading diagram developed from the selected Profile #3. Cable lengths used were approximately 40 to 45 feet each to allow splicing and connections away from the tray area. For the initial test, 23 thermocouples were strategically located in four anticipated hot spot areas in the tray. These locations were at 30 inches, 60 inches, 90 inches, and 120 inches from one end of the tray. Additional thermocouples were placed beneath the tray to record the ambient temperature. A 24-point Esterline Angus chart type temperature recorder was used to record the temperature pattern in the tray.

To connect cables for current loading and to facilitate testing, all conductors carrying the same test currents were connected in series by splicing ends beyond the tray, resulting in six energized series circuits for normal (concurrent) loading. Current values used were 71A, 46A, 20A, 11A, 7A and 4A.

Power was obtained from a three-phase 240-volt fused distribution box, and fed to a 3 kVA, 240-120/240-volt transformer. In the last of the five tests performed, a 10 kVA transformer was used to separately supply the heater cable circuits. In all tests, current control was obtained by using 240V and 120V variacs, power stats, and transtats in conjunction with loading transformers connected to the individual circuits.

A clamp-on ammeter was used for metering load currents. At the primary source a wattmeter was permanently installed measuring total watts to the transformers and loads. Calculations were made to determine watts lost in the cables under test.

TEST 1 - CONCURRENT LOADING

For this test the lower half of the cables in the tray were tied with TW insulated wires while the upper layers were laid in untied.

Ambient temperatures ranged from 22°C to 28°C.

Maximum temperature readings were obtained at two locations. Recorded temperatures varied considerably between thermocouples at each location.

Readings for each of the two groups of thermocouples showing maximum temperatures were as follows:

Test 1

Thermocouple No.	Temperature, °C	
1	54)	
6	29)	This group located 60 inches
9	32)	from load end of tray.
18	73)	
17	33)	
23	39)	
4	38)	
8	30)	This group located 120 inches
12	32)	from end of tray.
14	72)	
13	36)	
21	38)	

Time to reach the above levels was 320 minutes. Both ambient and tray thermocouple readings then started to decrease after 320 minutes' elapsed time.

TEST 2 - CONCURRENT LOADING

For this test all cables were securely bound with TW insulated wire in order to reduce ventilation. Several thermocouples were relocated within their group location to anticipated areas of high temperature. Two thermocouples were relocated, one to the center of the pressurizer heater wire bundle at each end outside of tray. At these points fiberglass insulation was wrapped about the exposed cables to reduce the heat loss at the tray ends.

The ambient temperatures varied from 21°C to 29°C. Maximum temperatures were recorded at two locations.

Watts lost in the test cables were calculated to be 2076 watts. Watts lost per foot of tray were 52 watts.

Readings for each of the two groups of thermocouples showing maximum temperatures were as follows:

Test 2

Thermocouple No.	Temperature, °C	
1	38)	
6	28)	This group located 60
9	33)	inches from end of tray.
18	79)	

Test 2 - Cont'd

Thermocouple No.	Temperature, °C	
17	32	)
23	74	)
4	50	) This group located 120
8	29	) inches from end of tray.
12	31	)
14	79	)
21	78	)

Time to reach the above levels was 390 minutes.

TEST 3 - CONCURRENT LOADING

For this test the 46 ampere pressurizer heater circuits were operated at 48 amperes. Heat lamps were used to hold the ambient constant at 30°C.

The ambient temperatures varied from 20°C at the beginning to 30°C at the end.

Watts lost in the test cables were calculated to be 2240 watts. Watts lost per foot of tray were 56 watts.

Readings for each of the two groups of thermocouples showing maximum temperatures were as follows:

Test 3

Thermocouple No.	Temperature, °C	
1	46	)
6	33	) This group located 60
9	39	) inches from end of tray.
18	85	)
17	37	)
23	80	)
4	53	) This group located 120
8	33	) inches from end of tray.
12	35	)
14	86	)
21	85	)

Time to reach the above levels was 1025 minutes.

TEST 4 - MAXIMUM CREDIBLE LOAD

For this test additional circuits were energized. Current values used were 142, 113, 71, 46, 36, 25, 20, 14, 11, 7, 4 and 1 amps.

The ambient temperatures varied from 24°C to 33°C. Maximum temperatures were recorded at two locations. Heat lamps were used to hold the ambient temperature at 31°C.

Watts lost in the test cables were calculated to be 3596 watts. Watts lost per foot of tray were 90 watts.

Readings for each of the two groups of thermocouples showing maximum temperatures were as follows:

Test 4

Thermocouple No.	Temperature, °C.	
1	50	)
6	43	) This group located 60
9	47	) inches from end of tray.
18	90	)
17	54	
23	91	
4	56	)
8	48	) This group located 120
12	47	) inches from end of tray.
14	87	)
21	93	)

Time to reach the above levels was 390 minutes.

TEST 5 - MAXIMUM CREDIBLE LOAD

For this test the 46 ampere pressurizer heater circuit current was raised to 52 amperes. Two additional thermocouples were installed in the hot spot area, one touching a #6 pressurizer heater conductor through a slit in its insulation, the other taped to the surface of the jacket on the same conductor. Current values used were 142, 113, 71, 52, 36, 25, 20, 14, 11, 7, 4, and 1 amps.

The ambient temperatures varied from 28°C to 33°C. Heat pumps were used to hold the ambient constant at 33°C.

Watts lost in the test cables were 4000 watts. Watts lost per foot of tray were 100 watts.

Readings for each of the two groups of thermocouples showing maximum readings were as follows:

Test 5

Thermocouple No.	Temperature, °C.	
1	54	)
6	43	)
9	49	) This group located 60
18	102	) inches from end of tray.
17	54	)
23	101	)
25	103	) Touching conductor.
26	102	) Touching jacket.
4	60	)
8	49	) This group located 120
12	48	) inches from end of tray.
14	97	)
21	102	)

Time to reach the above levels was 330 minutes.

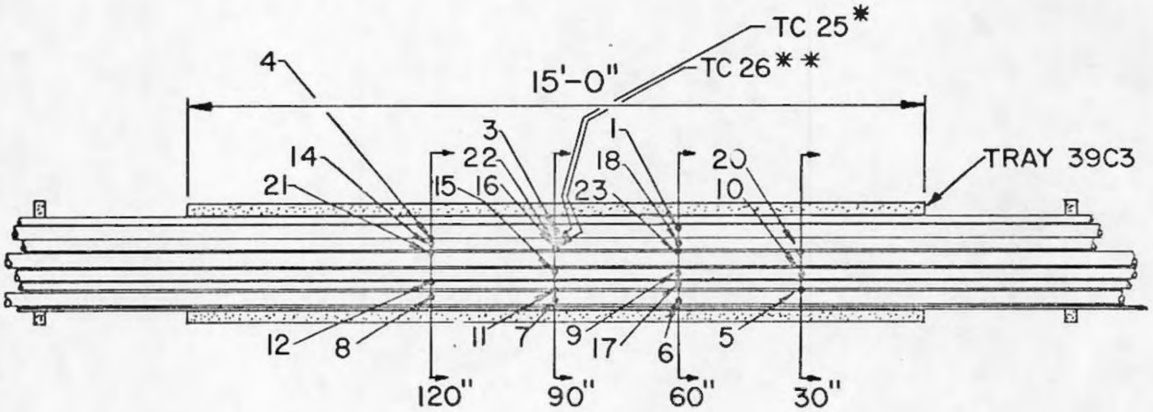
CONCLUSIONS

1. Temperatures in the cable tray were found to depend on a combination of factors. These include cable spacing, configuration, compaction, current loading, number of cables, and ambient temperatures.

2. Temperatures vary radically within short distances in the tray for different cable configurations and compactions.

3. During normal operation, temperatures within this cable tray probably exceeded the manufacturer's rating of the cable insulation.

J. L. Cohon
Apparatus Engineer

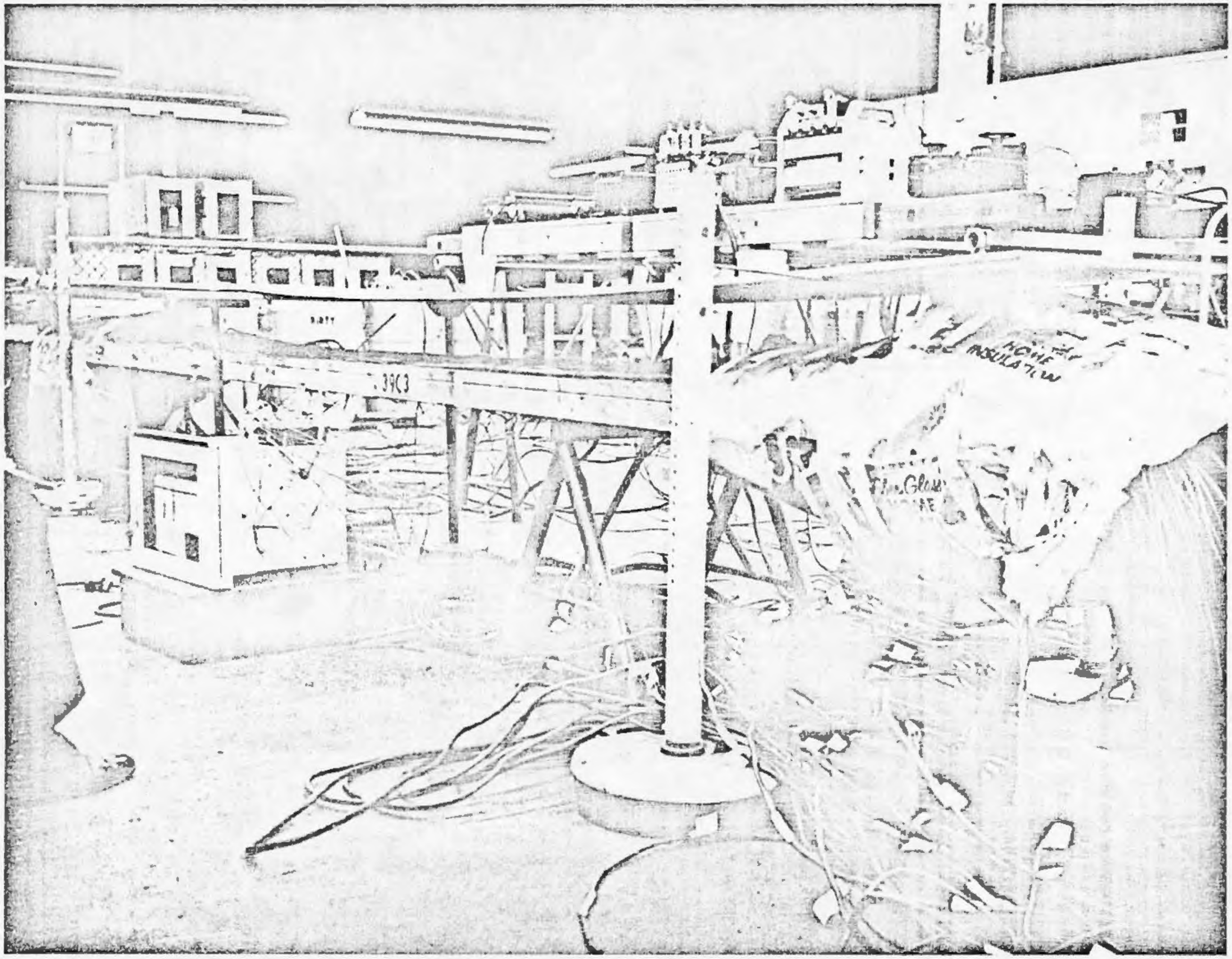


* RECORDING TEMPERATURE OF #6 CONDUCTOR TEST 5 ONLY

** RECORDING TEMPERATURE OF #6 JACKET TEST 5 ONLY

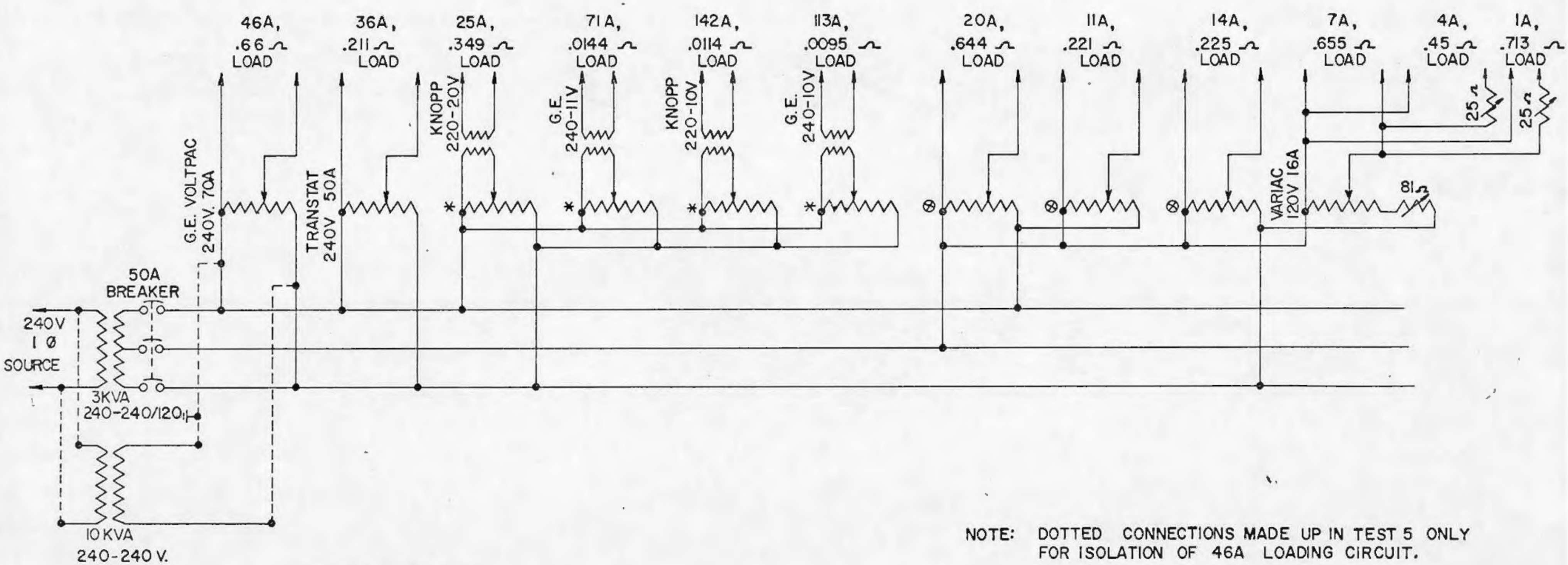
TRAY SIMULATION TEST - PLAN VIEW
SHOWING THERMOCOUPLE LOCATIONS FOR
TESTS 2 THRU 5

5-10-68



THERMAL LOADING TEST ON SIMULATED TRAY 39C3

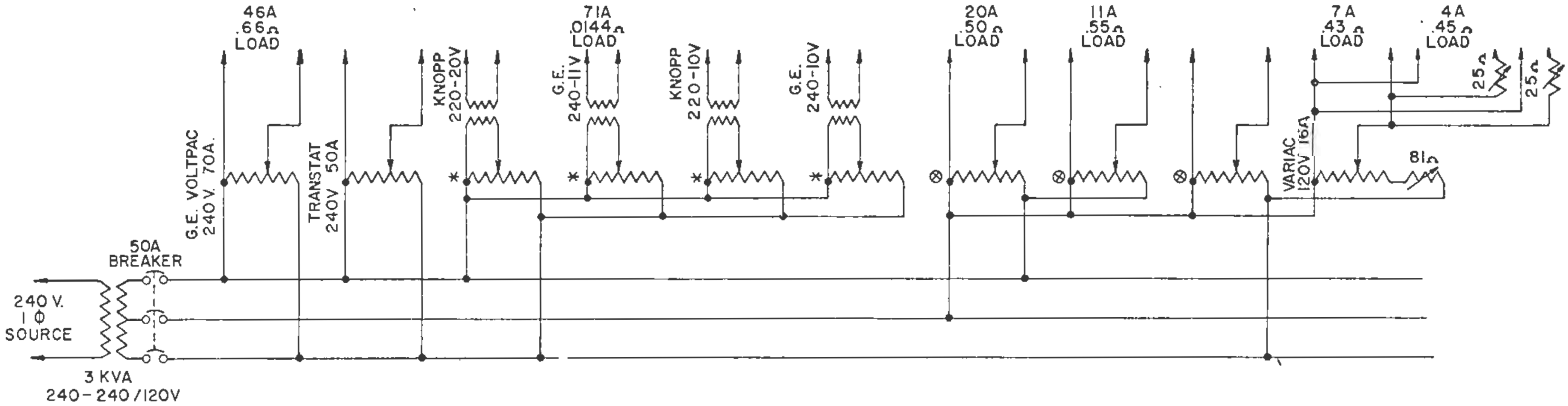
WIRING DIAGRAM FOR SIMULATION
OF TRAY 39C3
MAXIMUM CREDIBLE LOAD



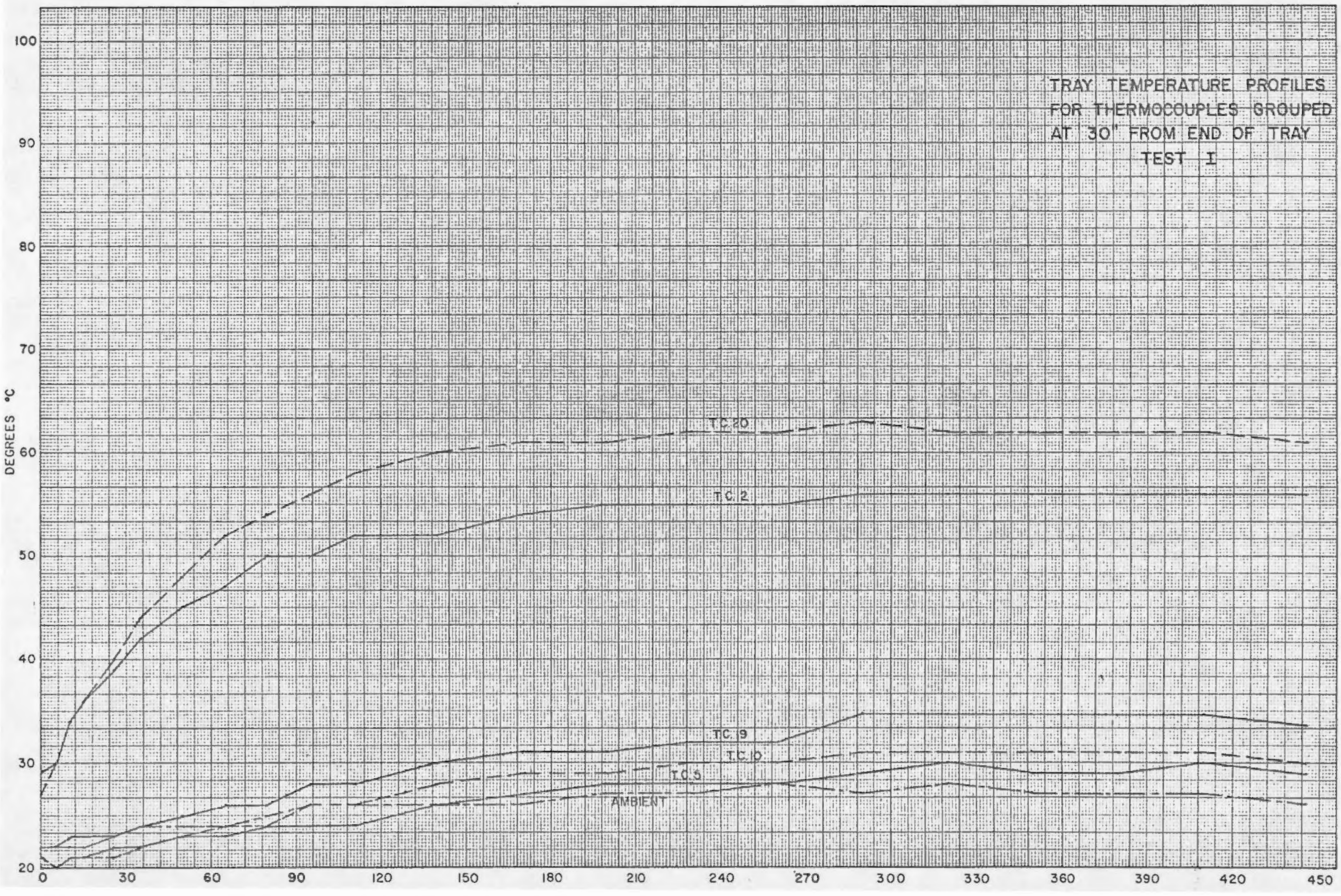
* VARIPAC 240V, 9A
⊗ POWERSTAT 120V, 20A

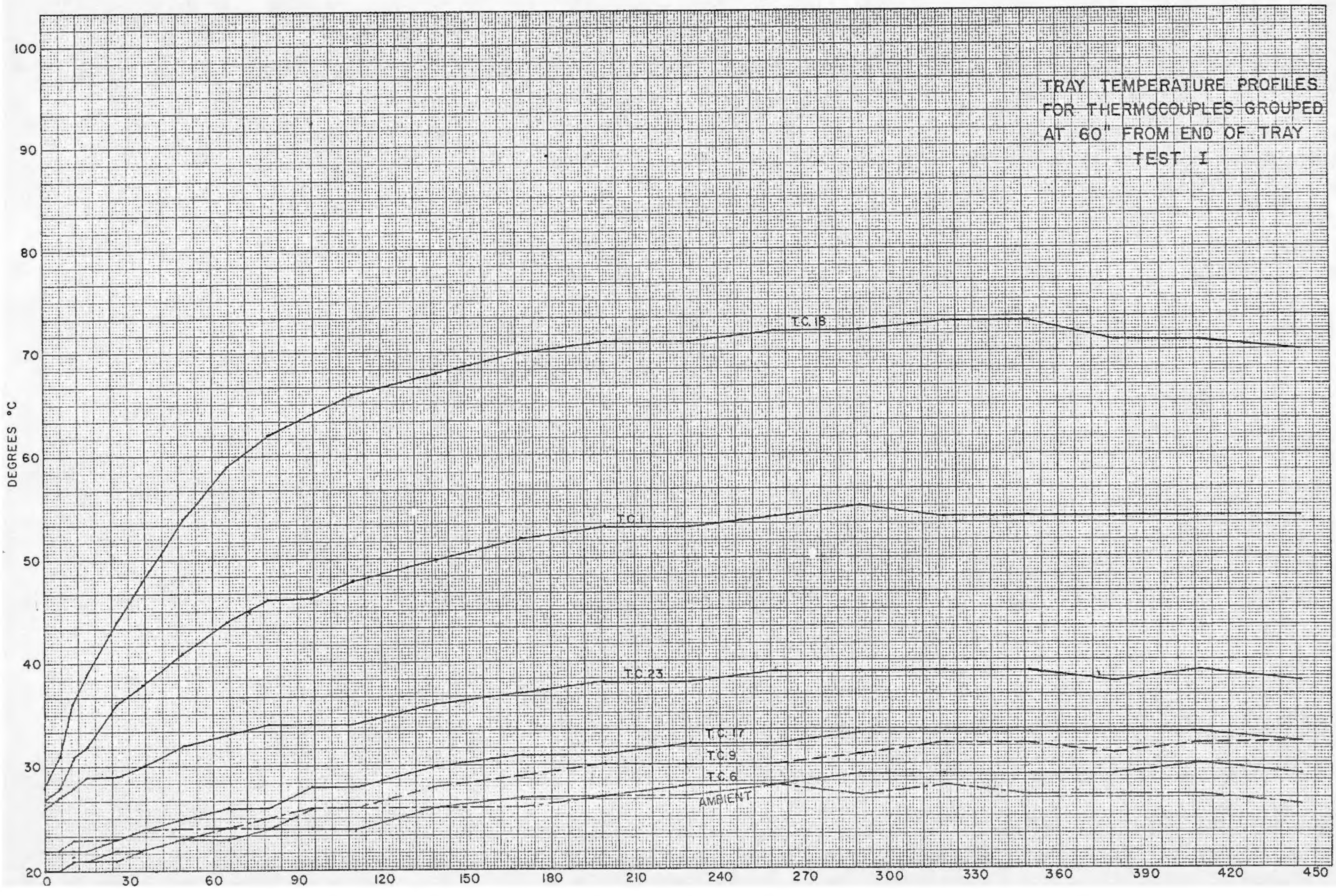
NOTE: DOTTED CONNECTIONS MADE UP IN TEST 5 ONLY FOR ISOLATION OF 46A LOADING CIRCUIT.

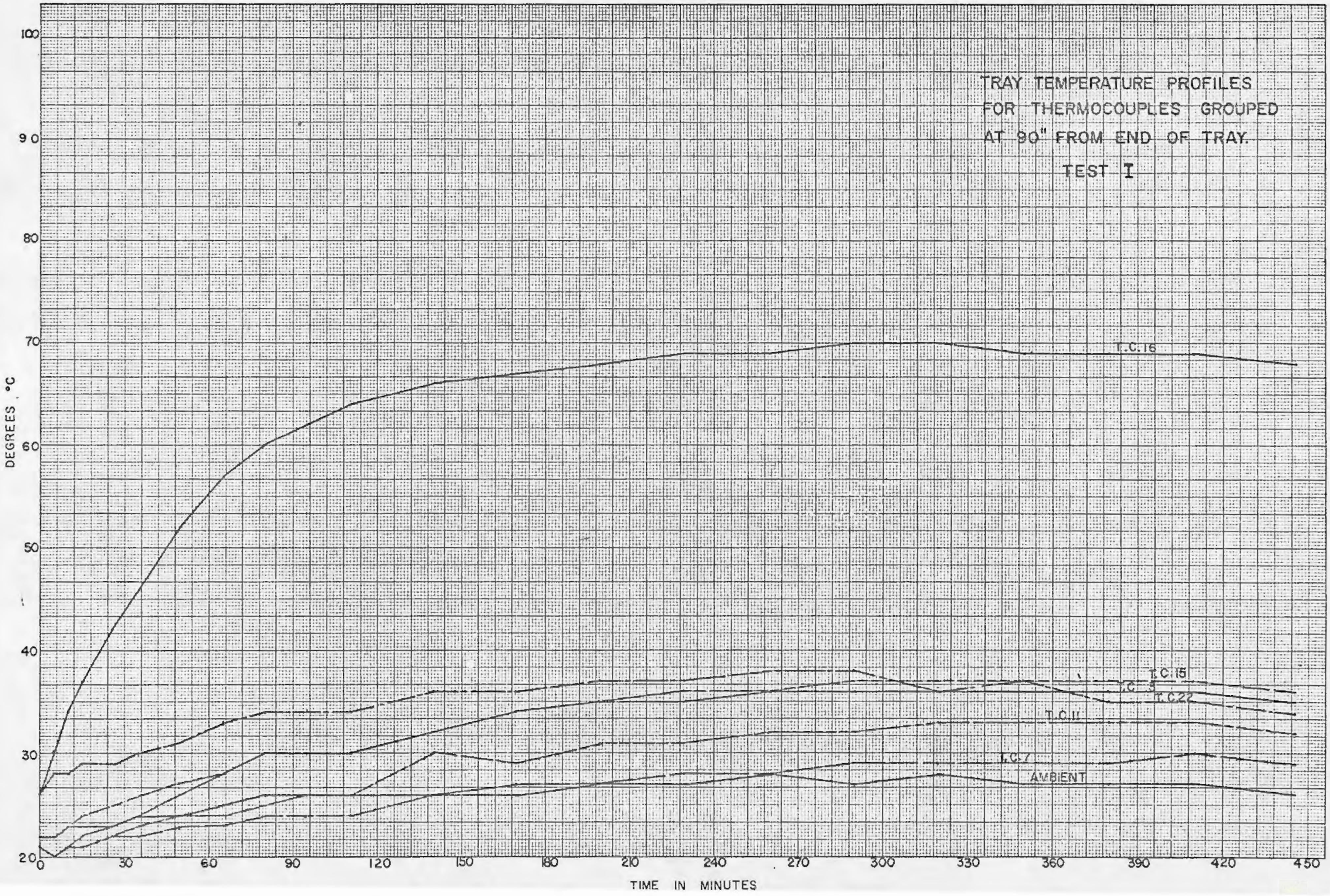
WIRING DIAGRAM FOR SIMULATION
OF TRAY 39C3
CONCURRENT LOADING

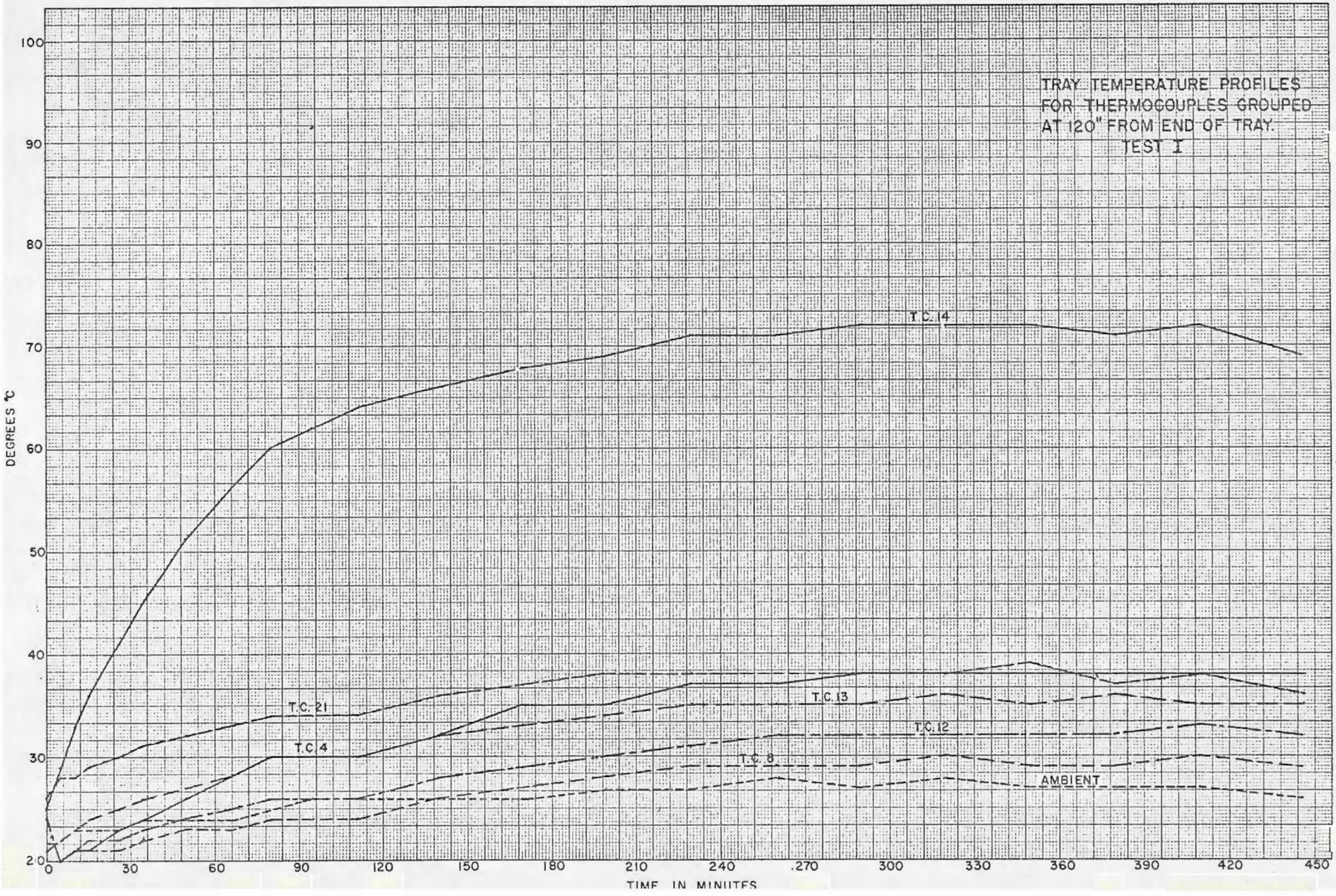


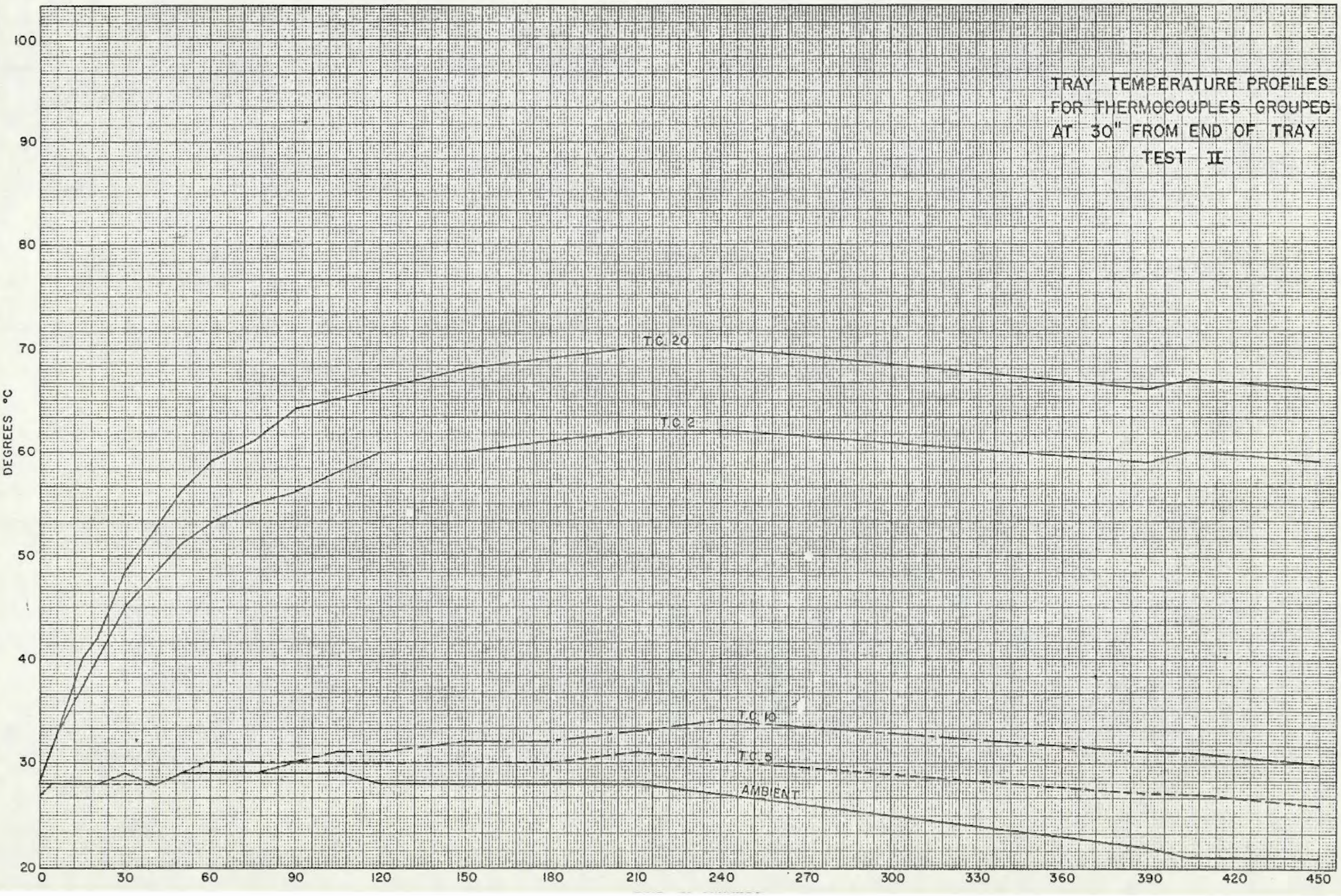
* VARIPAC 240V, 9A
⊗ POWERSTAT 120V, 20A

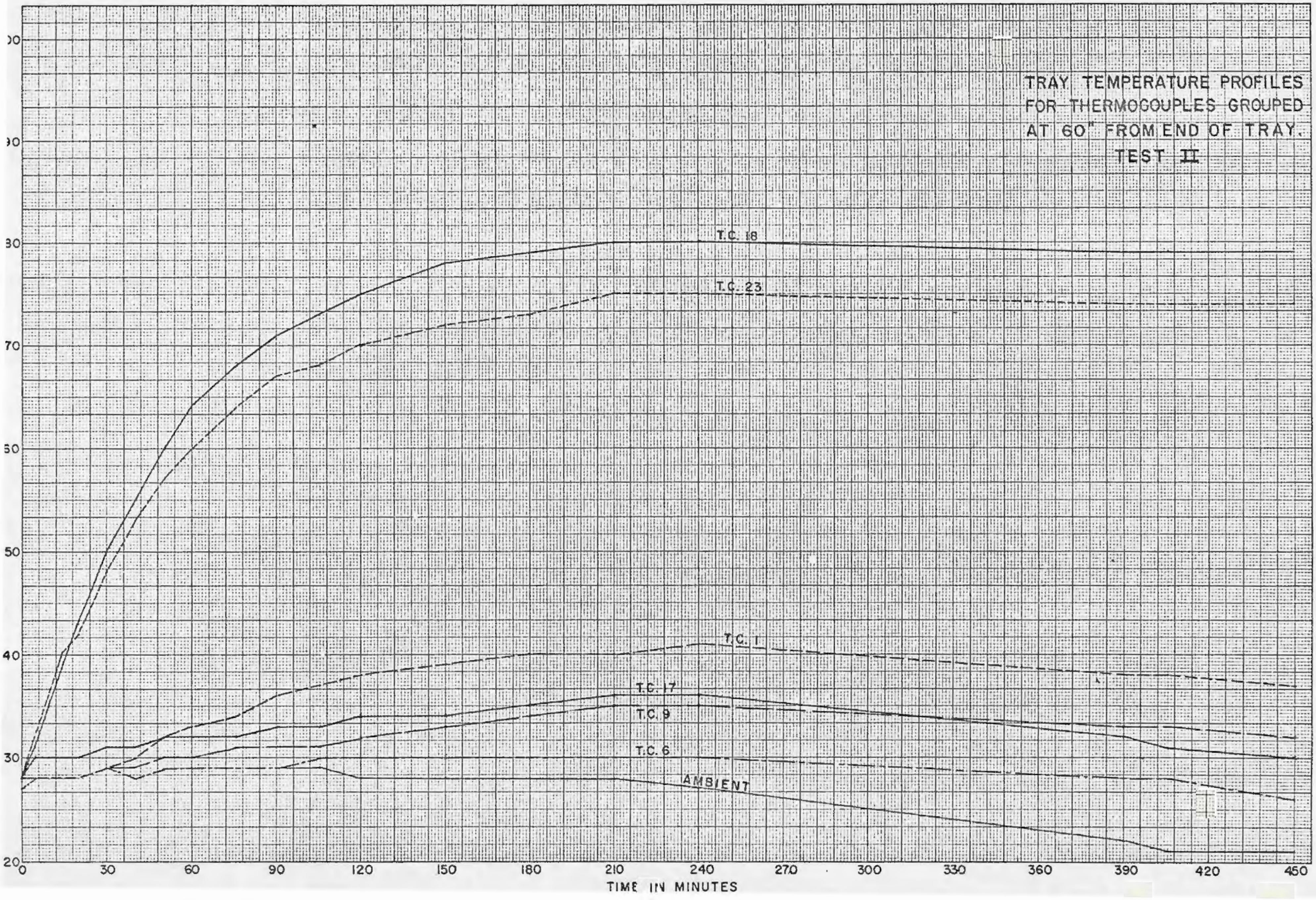

TRAY TEMPERATURE PROFILES
FOR THERMOCOUPLES GROUPED
AT 30" FROM END OF TRAY
TEST I
DEGREES °C
100
90
80
70
60
50
40
30
20
0
30
60
90
120
150
180
210
240
270
300
330
360
390
420
450
T.C. 20
T.C. 2
T.C. 19
T.C. 10
T.C. 5
AMBIENT

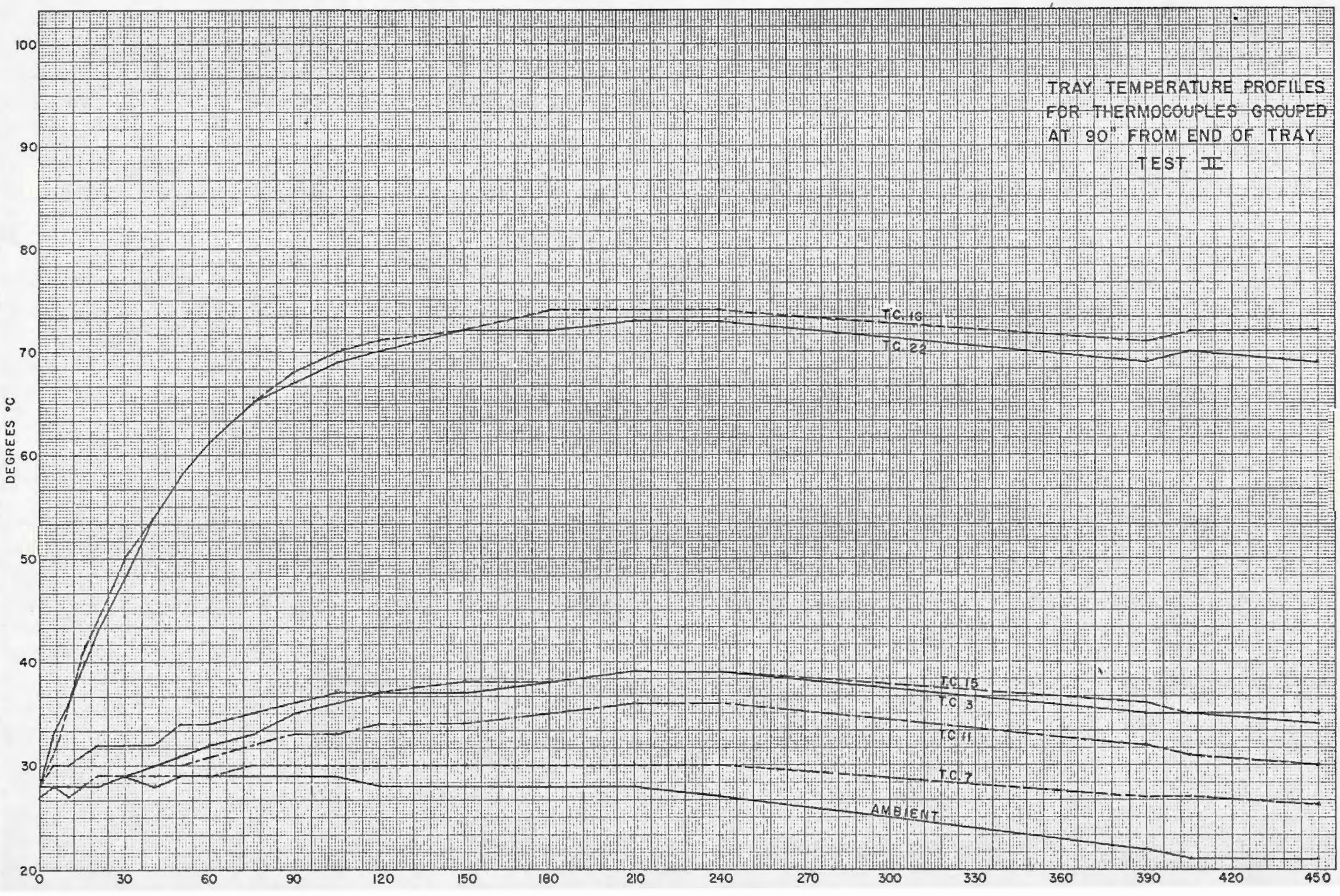

TRAY TEMPERATURE PROFILES
FOR THERMOCOUPLES GROUPED
AT 60" FROM END OF TRAY
TEST I
DEGREES °C
T.C. 18
T.C. 1
T.C. 23
T.C. 17
T.C. 9
T.C. 6
AMBIENT
100
90
80
70
60
50
40
30
20
0
30
60
90
120
150
180
210
240
270
300
330
360
390
420
450

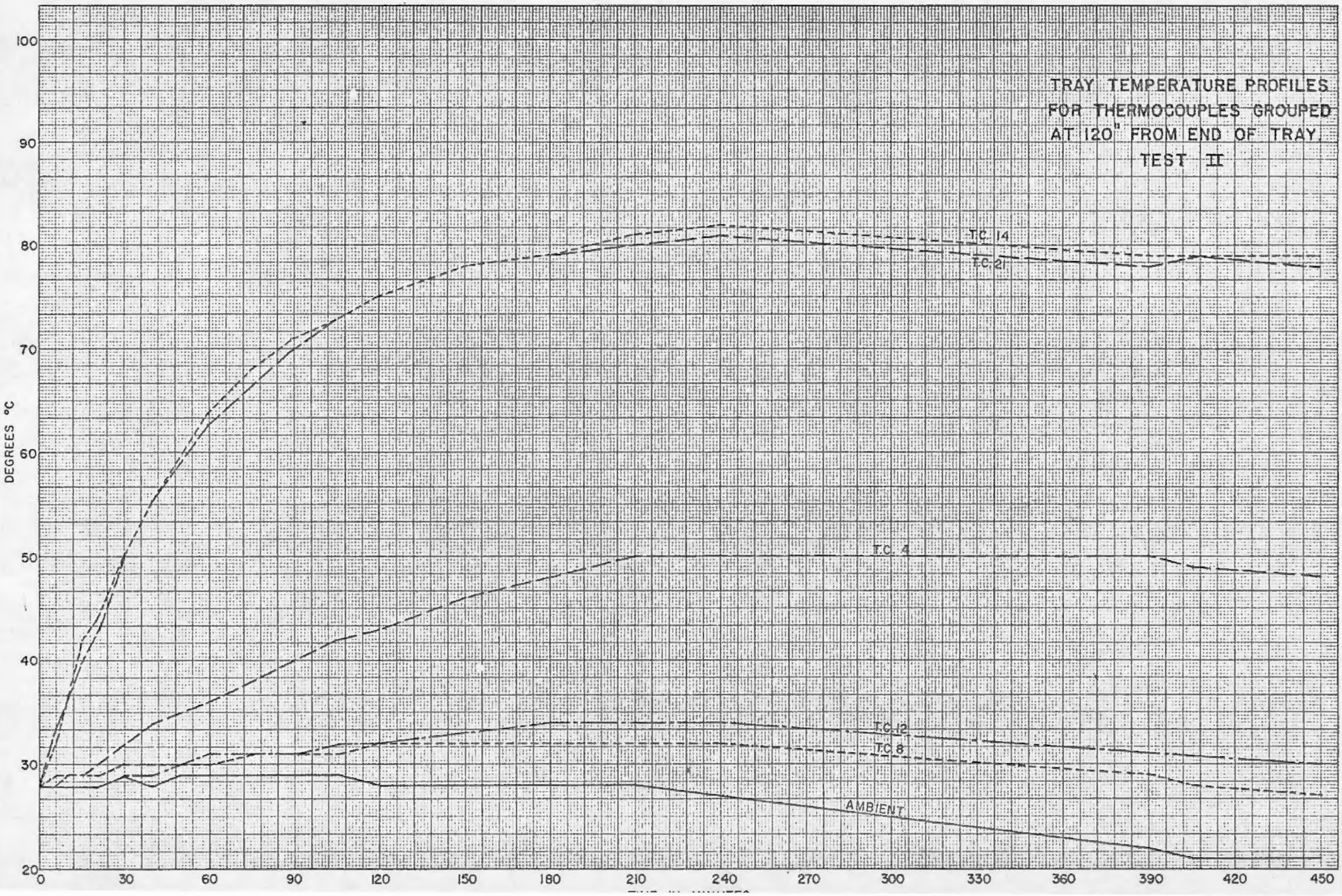

TRAY TEMPERATURE PROFILES
FOR THERMOCOUPLES GROUPED
AT 90" FROM END OF TRAY.
TEST I
DEGREES °C
TIME IN MINUTES
T.C.16
T.C.15
T.C.22
T.C.11
T.C.7
AMBIENT
20
30
40
50
60
70
80
90
100
0
30
60
90
120
150
180
210
240
270
300
330
360
390
420
450

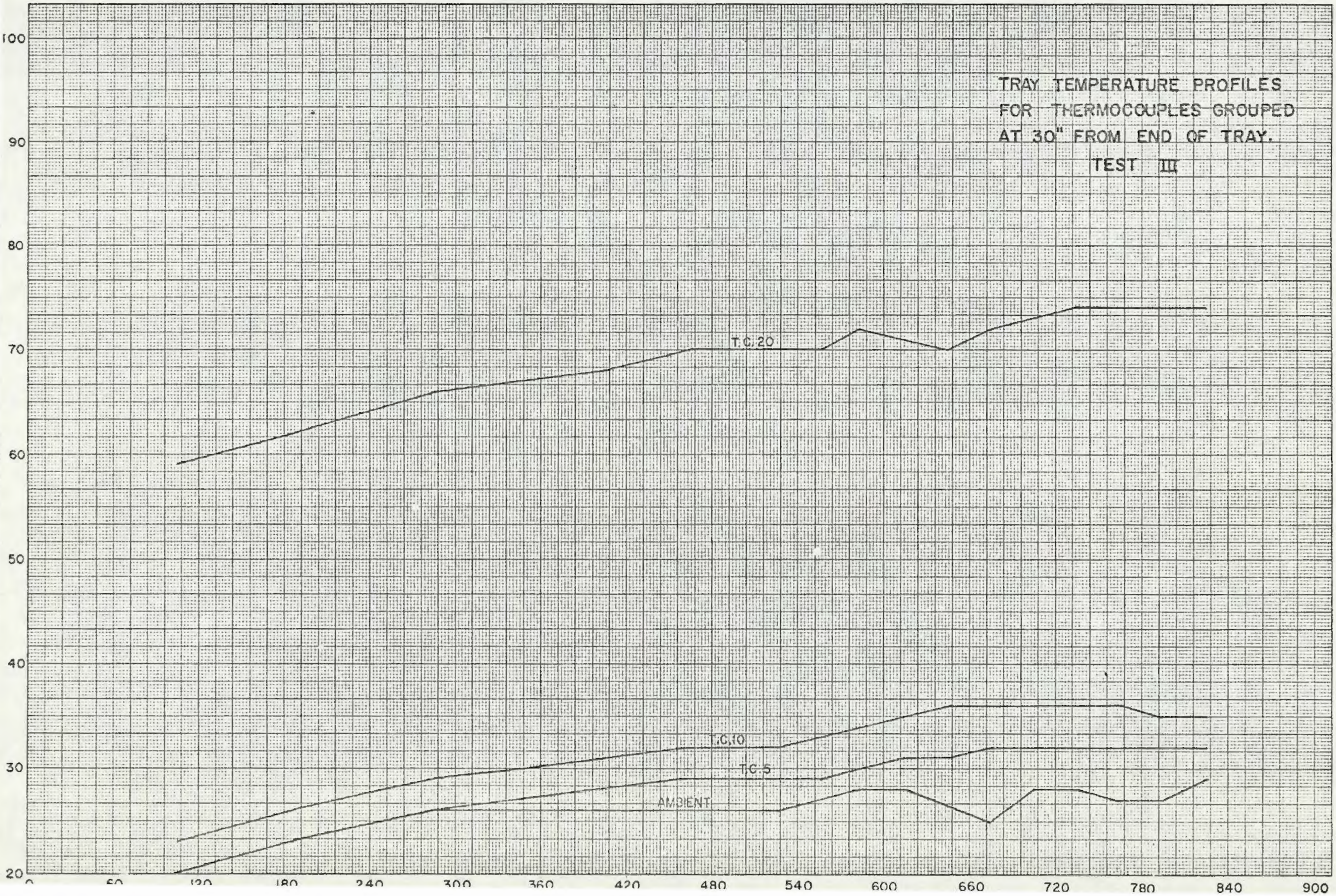

TRAY TEMPERATURE PROFILES
FOR THERMOCOUPLES GROUPED
AT 120" FROM END OF TRAY.
TEST I
T.C. 14
T.C. 21
T.C. 4
T.C. 13
T.C. 12
T.C. 8
AMBIENT
DEGREES °C
100
90
80
70
60
50
40
30
20
0
30
60
90
120
150
180
210
240
270
300
330
360
390
420
450
TIME IN MINUTES


TRAY TEMPERATURE PROFILES
FOR THERMOCOUPLES GROUPED
AT 30" FROM END OF TRAY
TEST II
DEGREES °C
T.C. 20
T.C. 2
T.C. 10
T.C. 5
AMBIENT
100
90
80
70
60
50
40
30
20
0
30
60
90
120
150
180
210
240
270
300
330
360
390
420
450

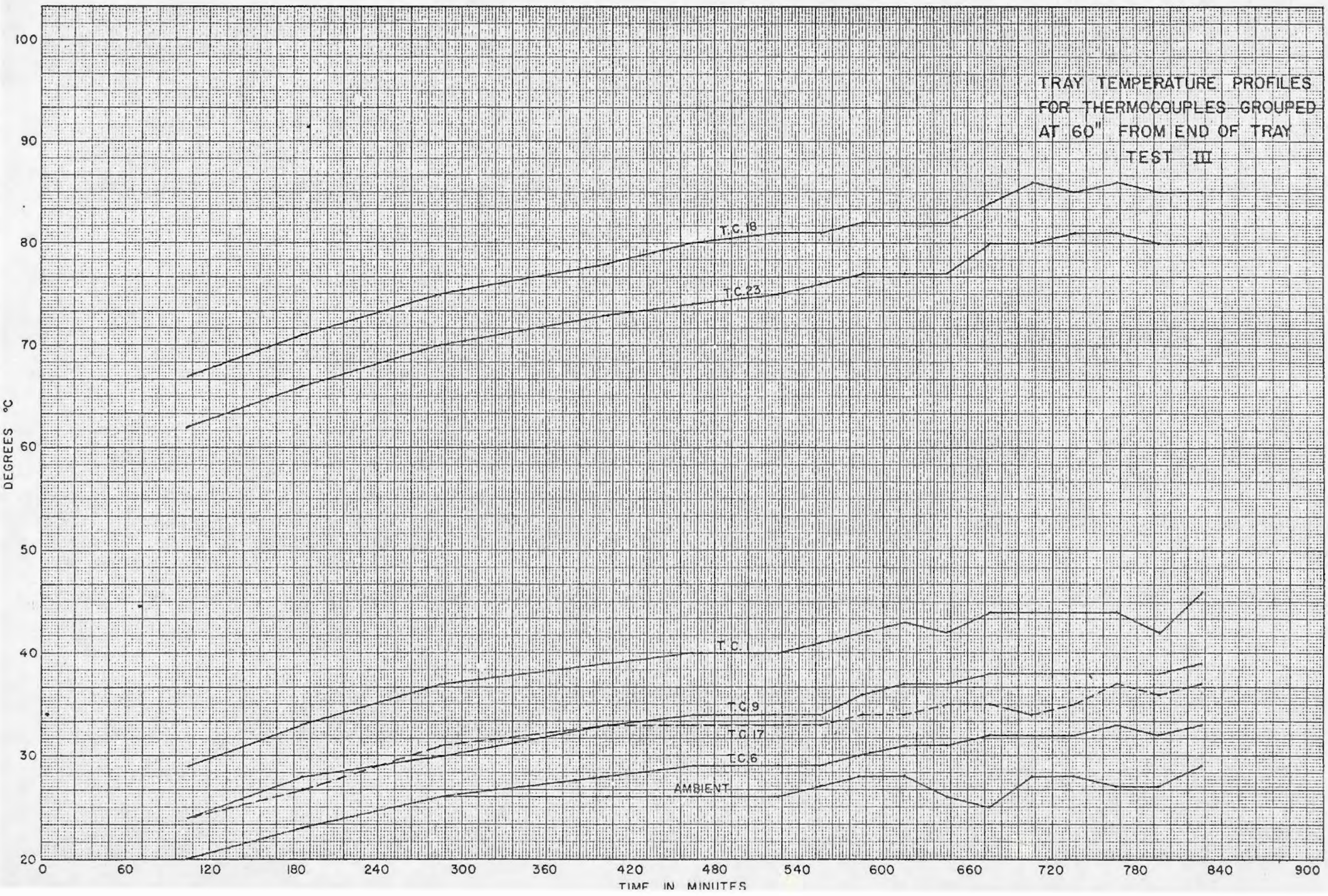

TRAY TEMPERATURE PROFILES
FOR THERMOCOUPLES GROUPED
AT 60" FROM END OF TRAY.
TEST II
T.C. 18
T.C. 23
T.C. 1
T.C. 17
T.C. 9
T.C. 6
AMBIENT
20
30
40
50
60
70
80
90
0
30
60
90
120
150
180
210
240
270
300
330
360
390
420
450
TIME IN MINUTES


TRAY TEMPERATURE PROFILES
FOR THERMOCOUPLES GROUPED
AT 90" FROM END OF TRAY.
TEST II
DEGREES °C
100
90
80
70
60
50
40
30
20
0
30
60
90
120
150
180
210
240
270
300
330
360
390
420
450
T.C. 16
T.C. 22
T.C. 15
T.C. 3
T.C. 11
T.C. 7
AMBIENT

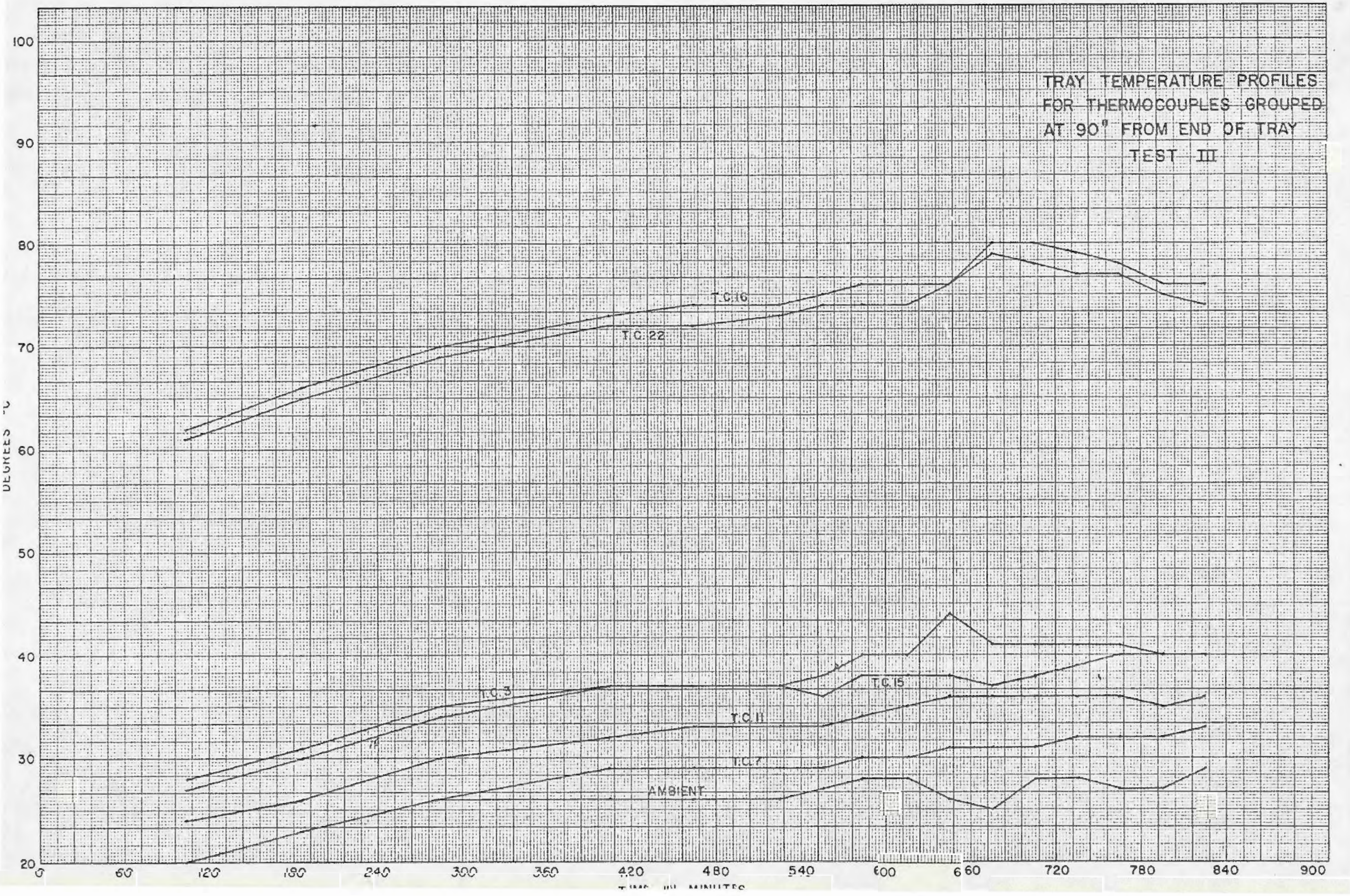

TRAY TEMPERATURE PROFILES
FOR THERMOCOUPLES GROUPED
AT 120" FROM END OF TRAY
TEST II
T.C. 14
T.C. 21
T.C. 4
T.C. 12
T.C. 8
AMBIENT
DEGREES °C
100
90
80
70
60
50
40
30
20
0
30
60
90
120
150
180
210
240
270
300
330
360
390
420
450



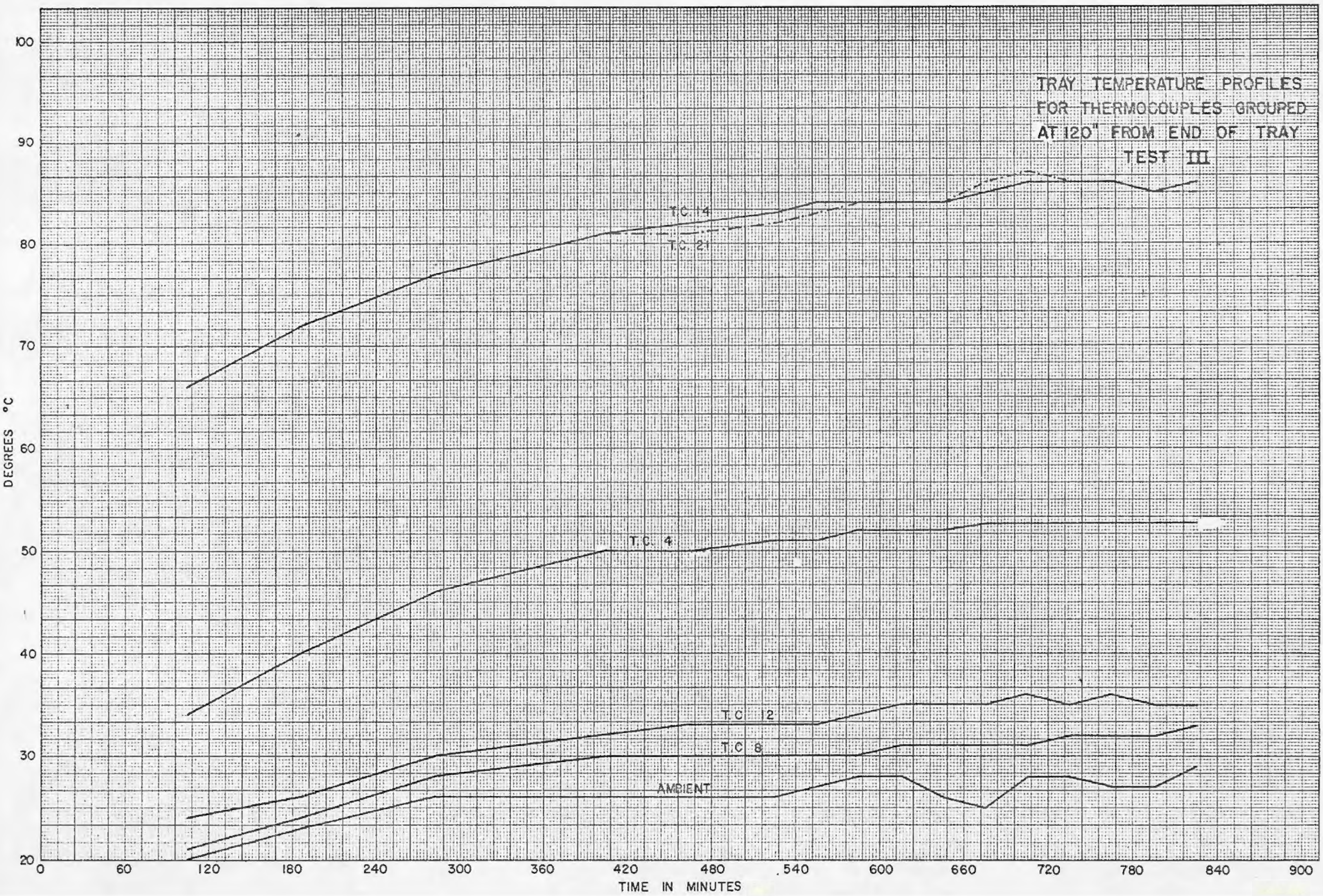
TRAY TEMPERATURE PROFILES
FOR THERMOCOUPLES GROUPED
AT 30" FROM END OF TRAY.
TEST III
T.C. 20
T.C.10
T.C.5
AMBIENT
100
90
80
70
60
50
40
30
20
0
60
120
180
240
300
360
420
480
540
600
660
720
780
840
900

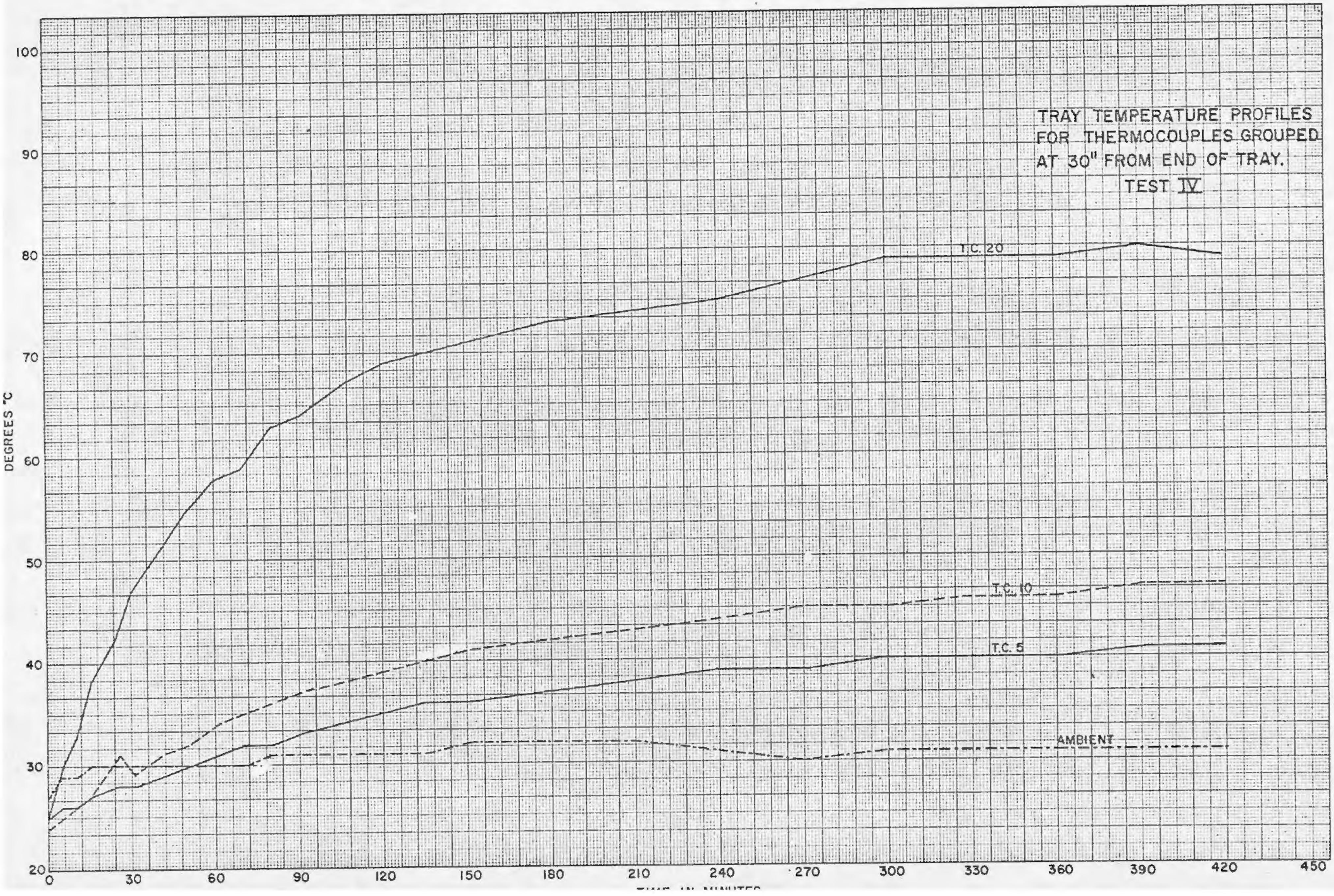


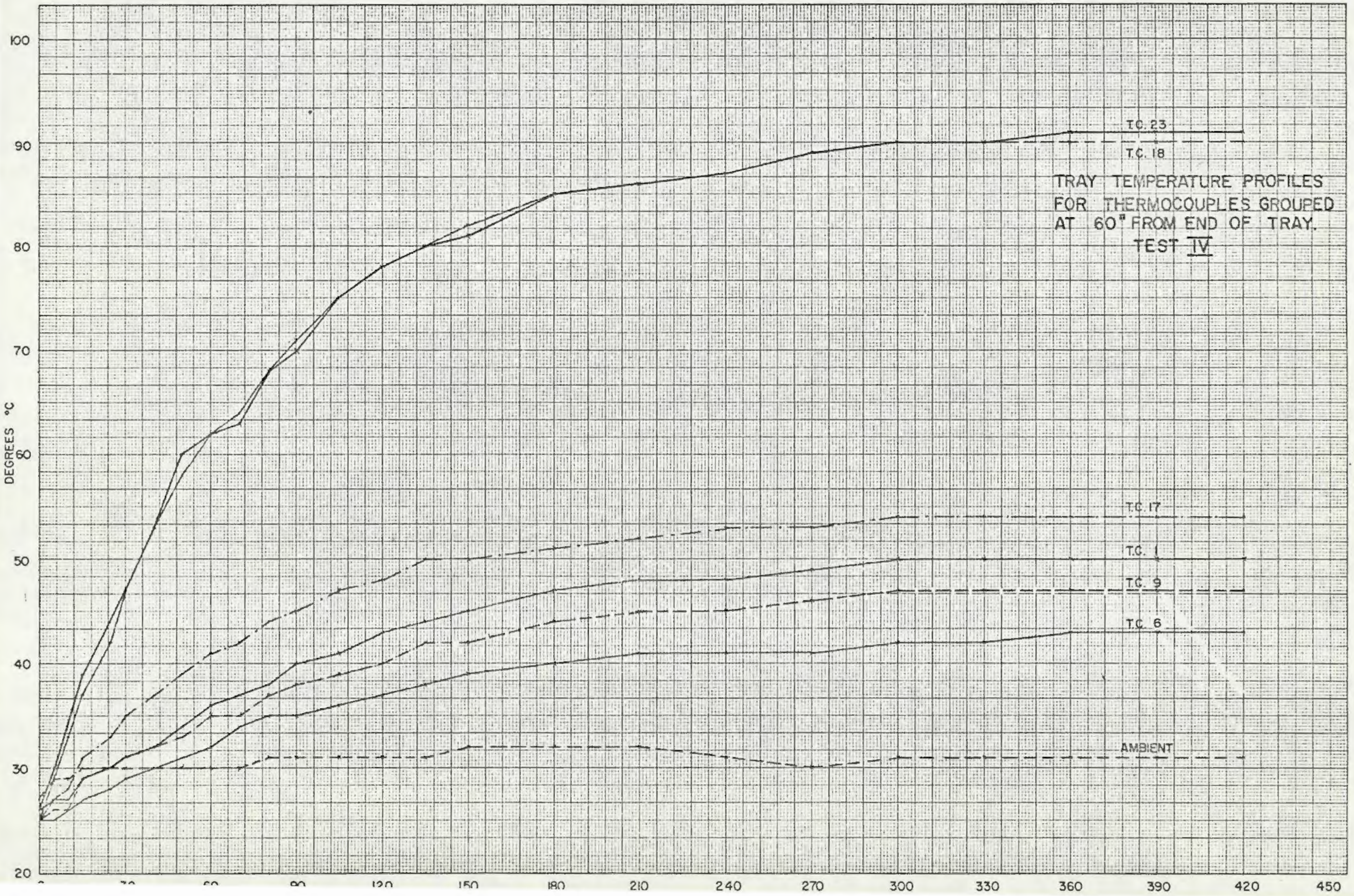
TRAY TEMPERATURE PROFILES
FOR THERMOCOUPLES GROUPED
AT 60" FROM END OF TRAY
TEST III
T.C.18
T.C.23
T.C.
T.C.9
T.C.17
T.C.6
AMBIENT
DEGREES °C
100
90
80
70
60
50
40
30
20
0
60
120
180
240
300
360
420
480
540
600
660
720
780
840
900
TIME IN MINUTES



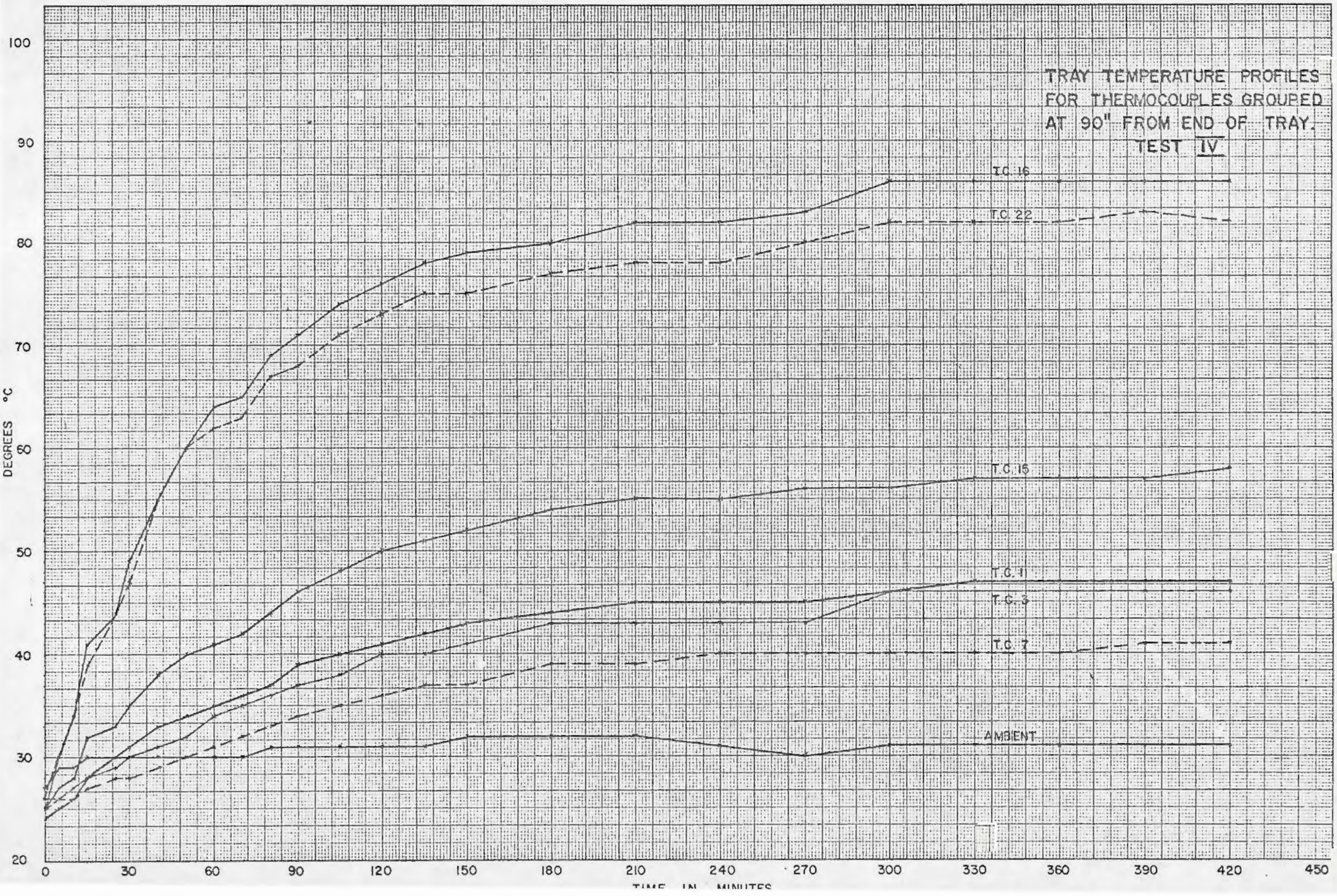
TRAY TEMPERATURE PROFILES
FOR THERMOCOUPLES GROUPED
AT 90" FROM END OF TRAY
TEST III
T.C.16
T.C.22
T.C.3
T.C.15
T.C.11
T.C.7
AMBIENT
100
90
80
70
60
50
40
30
20
0
60
120
180
240
300
360
420
480
540
600
660
720
780
840
900

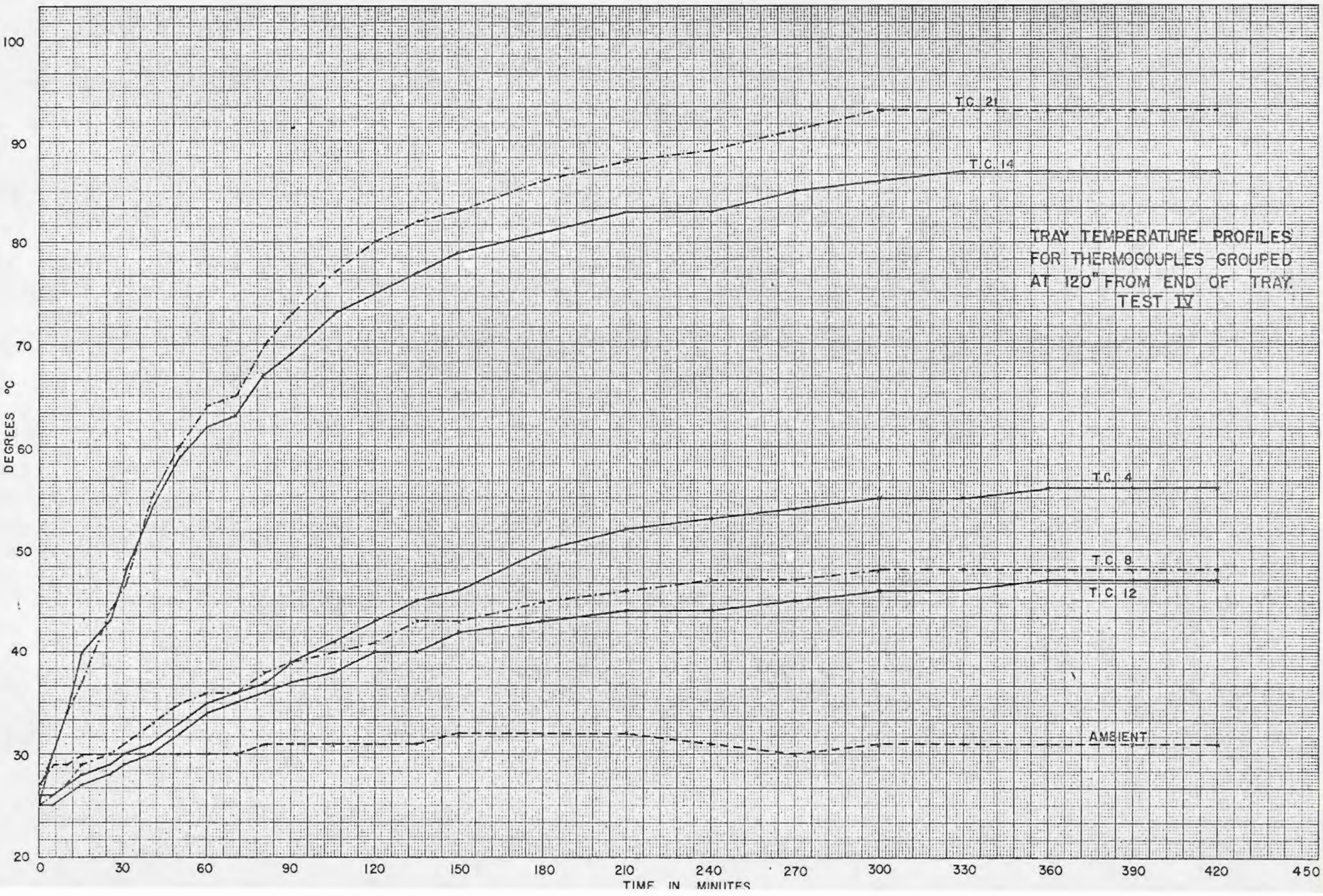

TRAY TEMPERATURE PROFILES
FOR THERMOCOUPLES GROUPED
AT 120" FROM END OF TRAY
TEST III
T.C. 14
T.C. 21
T.C. 4
T.C. 12
T.C. 8
AMBIENT
DEGREES °C
100
90
80
70
60
50
40
30
20
0
60
120
180
240
300
360
420
480
540
600
660
720
780
840
900
TIME IN MINUTES


TRAY TEMPERATURE PROFILES FOR THERMOCOUPLES GROUPED AT 30" FROM END OF TRAY.
TEST IV
T.C. 20
T.C. 10
T.C. 5
AMBIENT
DEGREES °C
100
90
80
70
60
50
40
30
20
0
30
60
90
120
150
180
210
240
270
300
330
360
390
420
450

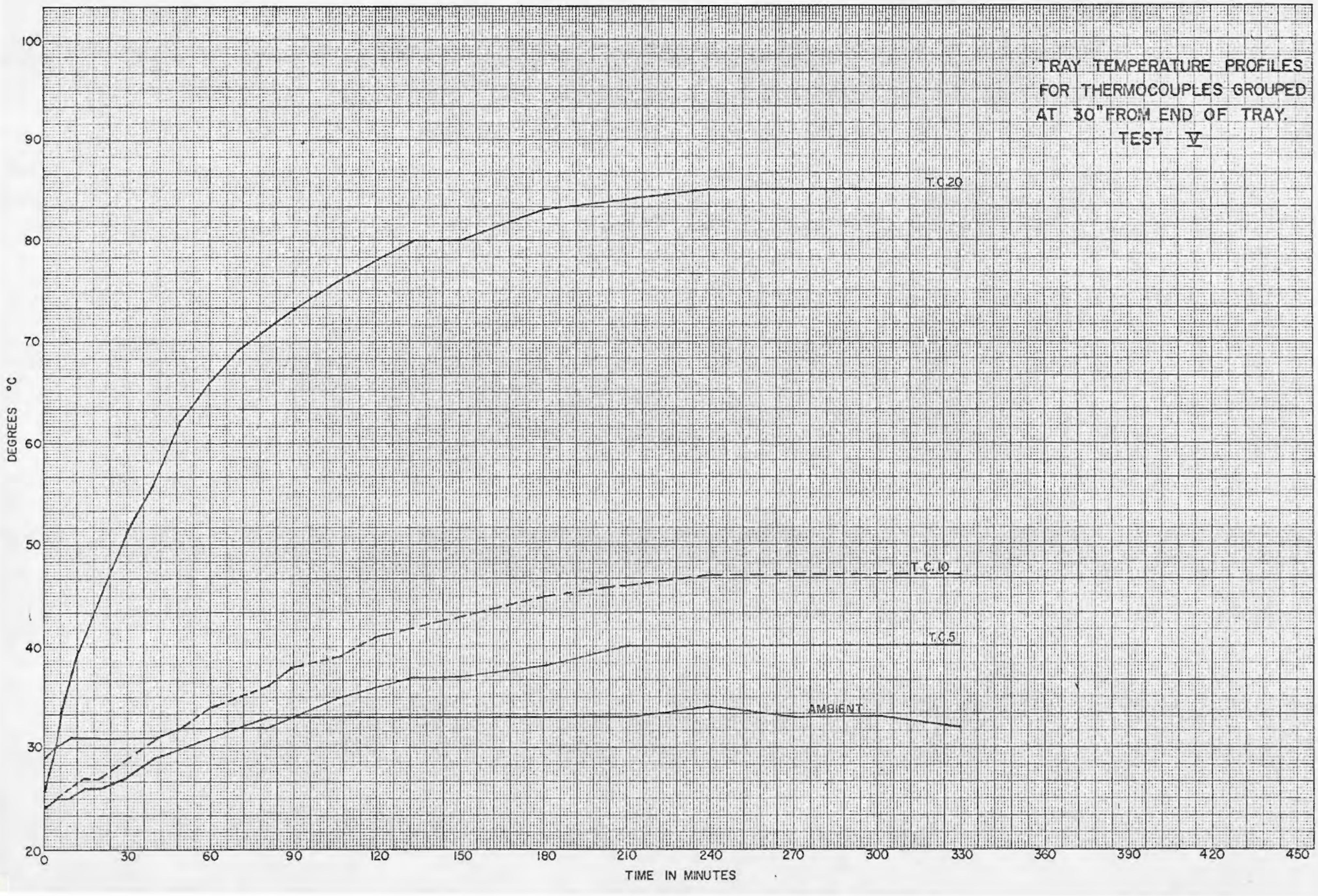


TRAY TEMPERATURE PROFILES FOR THERMOCOUPLES GROUPED AT 60" FROM END OF TRAY.
TEST IV
T.C. 23
T.C. 18
T.C. 17
T.C. 1
T.C. 9
T.C. 6
AMBIENT
DEGREES °C
100
90
80
70
60
50
40
30
20
120
150
180
210
240
270
300
330
360
390
420
450

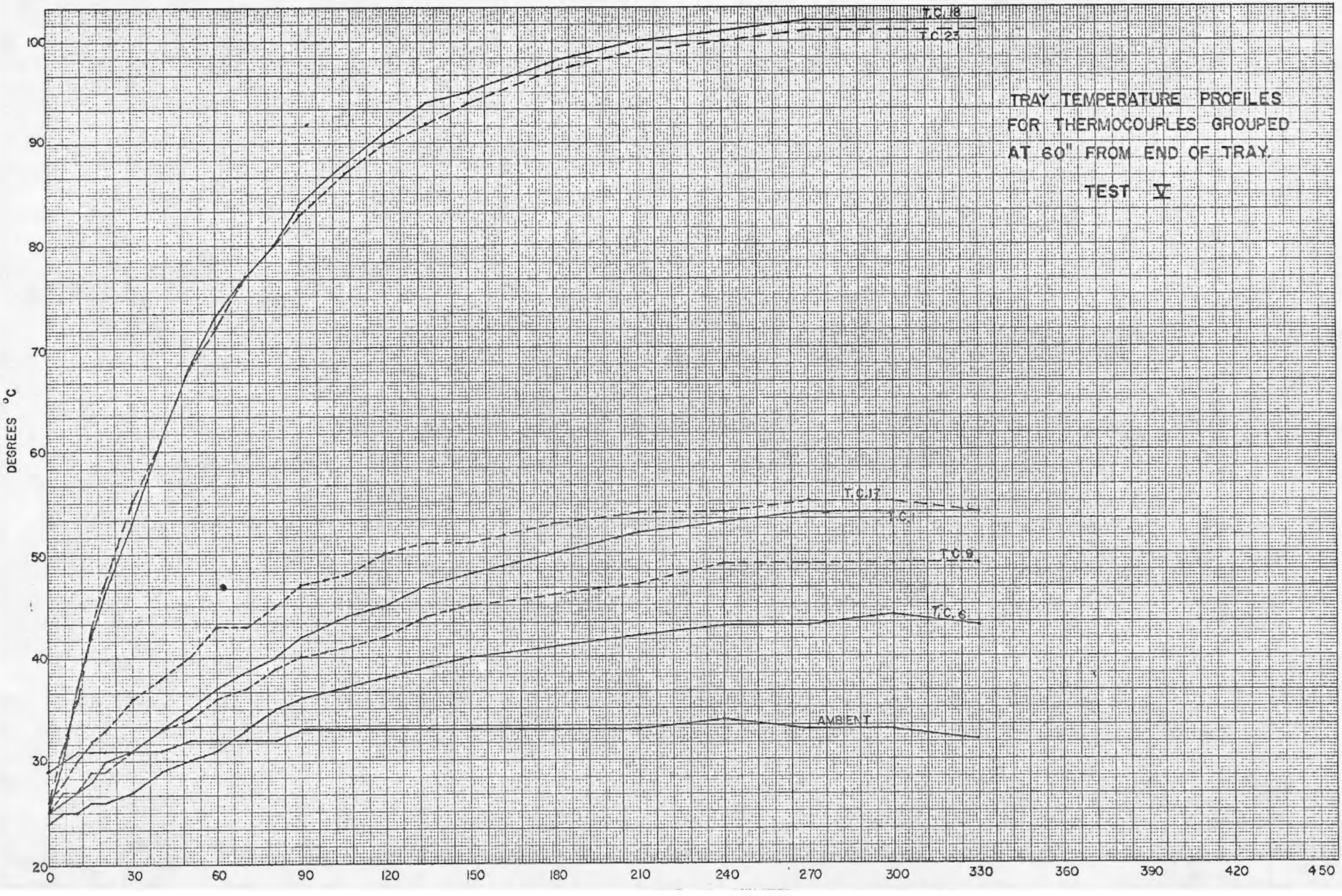

TRAY TEMPERATURE PROFILES FOR THERMOCOUPLES GROUPED AT 90" FROM END OF TRAY. TEST IV
T.C. 16
T.C. 22
T.C. 15
T.C. 1
T.C. 3
T.C. 7
AMBIENT
DEGREES °C
100
90
80
70
60
50
40
30
20
0
30
60
90
120
150
180
210
240
270
300
330
360
390
420
450
TIME IN MINUTES



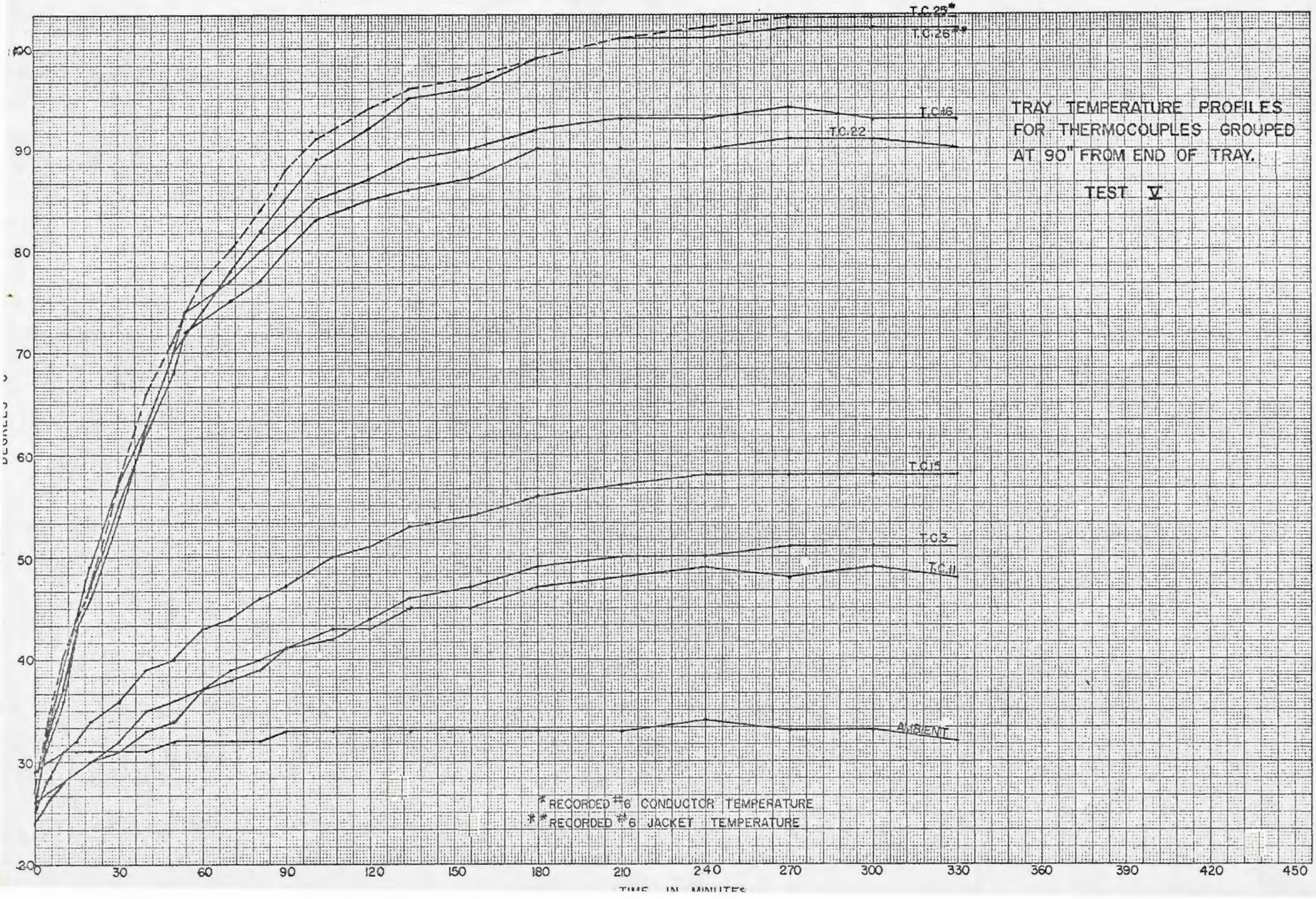
TRAY TEMPERATURE PROFILES
FOR THERMOCOUPLES GROUPED
AT 120" FROM END OF TRAY.
TEST IV
T.C. 21
T.C. 14
T.C. 4
T.C. 8
T.C. 12
AMBIENT
DEGREES °C
TIME IN MINUTES
100
90
80
70
60
50
40
30
20
0
30
60
90
120
150
180
210
240
270
300
330
360
390
420
450



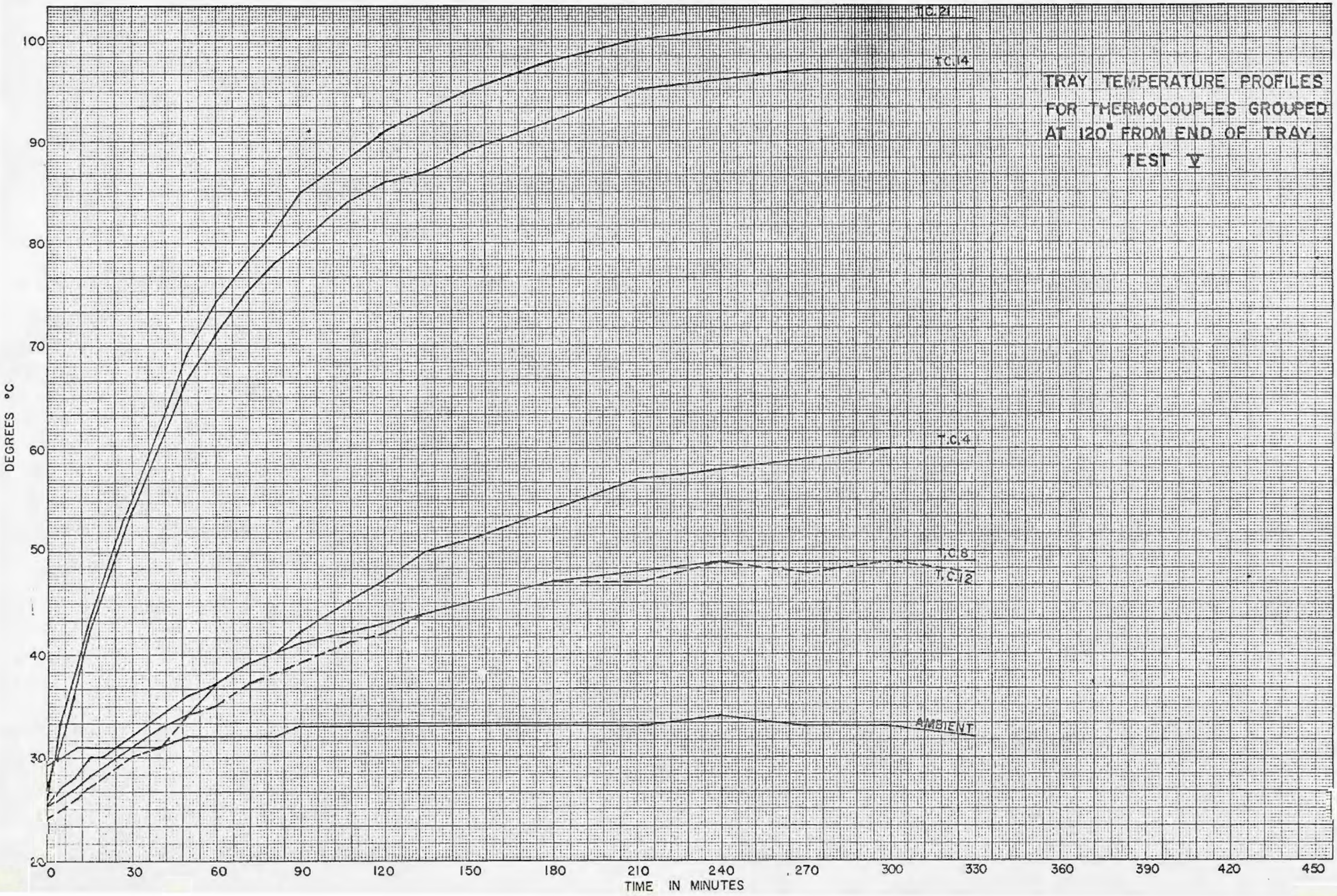
TRAY TEMPERATURE PROFILES
FOR THERMOCOUPLES GROUPED
AT 30" FROM END OF TRAY.
TEST V
T.C.20
T.C.10
T.C.5
AMBIENT
DEGREES °C
100
90
80
70
60
50
40
30
20
0
30
60
90
120
150
180
210
240
270
300
330
360
390
420
450
TIME IN MINUTES



TRAY TEMPERATURE PROFILES
FOR THERMOCOUPLES GROUPED
AT 60" FROM END OF TRAY.
TEST V
T.C. 18
T.C. 23
T.C. 17
T.C. 1
T.C. 9
T.C. 6
AMBIENT
DEGREES °C
20
30
40
50
60
70
80
90
100
0
30
60
90
120
150
180
210
240
270
300
330
360
390
420
450



TRAY TEMPERATURE PROFILES FOR THERMOCOUPLES GROUPED AT 90" FROM END OF TRAY.
TEST V
T.C.25*
T.C.26**
T.C.16
T.C.22
T.C.15
T.C.3
T.C.11
AMBIENT
* RECORDED #6 CONDUCTOR TEMPERATURE
** RECORDED #6 JACKET TEMPERATURE
TIME IN MINUTES



TRAY TEMPERATURE PROFILES FOR THERMOCOUPLES GROUPED AT 120" FROM END OF TRAY.
TEST V
T.C.21
T.C.14
T.C.4
T.C.8
T.C.12
AMBIENT
DEGREES °C
100
90
80
70
60
50
40
30
20
0
30
60
90
120
150
180
210
240
270
300
330
360
390
420
450
TIME IN MINUTES

7.1.1 DUPLICATION OF SUSTAINED COMBUSTION RESULTING FROM PRESSURIZER HEATER CABLE SHORT CIRCUITS - TRAY 39C3

DUPLICATION OF SUSTAINED COMBUSTION RESULTING FROM PRESSURIZER HEATER CABLE SHORT CIRCUITS - TRAY 39C3

PURPOSE OF TEST

This test was made to demonstrate that a phase-to-phase fault between opposite phases of two adjacent three-phase 480-volt, delta connected cable circuits is likely to result in a cable fire and sustain the fire if each phase is protected by individual fuses rather than by an automatic breaker, which provides three-phase clearing for a single-phase fault.

A cable tray carrying power and control cables with the same configuration as the cables in tray 39C3 was utilized for these tests.

Representative pressurizer heater loads were supplied through the tray from individual FRS-80 fuses connected to a 480-volt three-phase source from the original pressurizer heater switchgear cabinets which had been removed from San Onofre.

An additional test was performed using three-phase circuit breakers to clear a fault in the cable tray.

RESULTS OF TEST

1. A cable fire was initiated after an intentional phase-to-phase short circuit was cleared by FRS-80 fuses. The fire was sustained because only the faulted phase were cleared by the fuses. This allowed a current flow and voltage to develop at the fault by "feedback" from the load due to the two phases remaining energized in each of the two three-phase delta circuits.

   The "feedback" current at the fault is limited by the load impedance to a value much smaller than load current and, consequently the fuse on each remaining energized phase does not clear the circuit. In this particular circuit the "feedback" current is limited to 14 amperes if the faulted phases retain good contact after the initial short circuit current or if the short circuit current blows the faulted phases open (the more usual case), an open circuit "feedback" voltage of 240 volts exists. The cable insulation system near the phase-to-phase fault is carbonized to varying degrees of electrical resistance by the previous short circuit current. Therefore, it is possible to develop, at the phase-to-phase fault, various feedback current and voltage magnitudes within the limits of 240 volts open circuit and 14 amperes at full short. Under the proper conditions, small "feedback" leakage currents develop in the carbonized cable insulation over a long period of time and arcing eventually occurs between the faulted phases.

   In an auxiliary test, several trial runs with two short cables demonstrated that sustained arcing was easily obtained. The sustained arcing between the cable conductors is similar to the sustained arc in arc welding. The intense temperature of the sustained phase-to-phase arc starts the cable insulation system burning. The undamaged energized cables in the tray surrounding the sustained arcing starts burning which causes additional electrical faults and more cable fires. Once sustained arcing is achieved the fire proceeds at a rapid rate.

2. The two cables intentionally short circuited were burned and charred in the short circuit area, but little or no damage occurred to the adjacent cables from the short circuit current itself, but rather from the continuous feedback into these circuits.

3. In two test runs, two Westinghouse "Tripac" units interrupted satisfactorily all phases of two three-phase circuits having a single phase-to-phase fault.

CONCLUSIONS

1. The voltage and current "feedback" to a previously cleared phase-to-phase fault of an independently fused, two-circuit, three-phase, delta connected system can cause a fire.

2. The Westinghouse FDP fused load break switches are not satisfactory for this application for two reasons:

   A. The breaker contactors do not meet the momentary current ratings required.

   B. Each phase is independently fused.

METHOD OF TEST

The three 100-kva, 2400/480-volt single-phase transformers were connected in delta and the 480-volt low side was connected to the three-phase buses running down the middle of the two Westinghouse FDP fused load break switch panels. Cables were connected as shown in Figure 1. As noted some of the cables were energized with the far end taped, some were used to circulate current to heat the cables in the tray and six three-phase circuits were under full load conditions. The six circuits were connected to the Rama Resistance Loading Elements. The heat dissipated from these elements was blown by fans through a tunnel of fire resistant material and canvas to heat the cables in the tray to 90°C before making short circuit tests.

Instrumentation was installed to record:

A. Each phase voltage at the low side of the transformers.

B. Current in one phase of the phase-to-phase fault.

C. "Backfeed" current from the load to the fault.

D. Voltage appearing across the phase-to-phase fault.

An intentional fault was made between cables No. 424 and No. 411 at about the center of the tray run before each test. Several techniques of faulting were tried in an attempt to duplicate actual conditions. Both cables insulation systems were cut away on one side to expose the conductor. Carbonized particles obtained from heating cable insulation of identical cables were placed between the cables at the bared conductor. The cables were over-layed with the carbonized particles of cable insulation in place.

Two Westinghouse "Tripac" units were installed in place of the FDP fused load break switches in heater circuits No. 1 and No. 2. These were the two three-phase circuits that contained the phase-to-phase fault. The "Tripac" unit opens all three-phases of a circuit when any type fault occurs. Two tests were made and the "Tripac" units operated as expected in both cases.

The "Tripac" units were removed and FDP fused load break switches were wired to heater circuits No. 1 and No. 2. These FDP fused load break switches failed because of insufficient momentary current rating in the breaker contacts. After this incident, all FDP fused load break switches were removed and each individual circuit was connected to the 480-volt bus through a FRS-80 fuse to complete the test.

Before the final test run in the cable tray, leads were extended from cables No. 424 and No. 411 which were disconnected at the bus end. This permitted several demonstrations of how "feedback" current and voltage from the load were able to start "stabilized-arcing" and, consequently, cable insulation fires.

The final short circuit test was made with the intentional phase-to-phase fault made on cables No. 424 and No. 411. The resistance between the fault phases was adjusted to 5000 ohms. The faulted cables were placed in the fourth level of cables from the top of the tray and the other four three-phase circuits were in close proximity. A thermocouple placed on the outside of one of the faulted cables indicated the cables and tray in the fault area had been heated to 85°C just prior to the application of the short circuit. The canvas tunnel covering the cable tray was removed. The backup breaker on the 2400-volt side was de-energized and the faulted circuits were connected to the 480-volt bus through fuses. The backup breaker was then closed and the faulted phases were instantaneously cleared by the fuses. The short circuit current caused some noise and arcing at the fault, but no sustained fire resulted. However, the "feedback" voltage and current existed, and by moving the faulted cables slightly a sustained arcing was achieved at the fault. The resulting fire caused multiple electrical faults on surrounding cables which were cleared by the FRS-80 fuses.

After 19 of 54 fuses had blown the fire was extinguished. The fire had spread over an area of several square feet at this time and would have continued to involve the majority of the cables in the tray.

EQUIPMENT USED

1, Three 100-kva 2400/480-volt single-phase transformers.

2. One panel containing 12 three-phase Westinghouse FDP fused load break switches. One panel containing six three-phase Westinghouse FDP fused load break switches. This equipment was removed from the San Onofre Nuclear Generating Station to Alhambra Shop for this test.

3. A replica of the cables and cable tray which were destroyed by fire on March 12, 1968, at San Onofre Nuclear Generating Station. A replica cable tray was 24 inches wide by 3 inches deep and 12-1/2 feet long. The material was galvanized steel. The cable tray was loaded with 234 cables of various sizes as shown on the cable tray profile diagram shown under the cable tray heat run test. The cables were of three types:

   A. Simplex Butyl insulated with neoprene jacket.

   B. General Electric cross-linked polyethlene.

   C. Communication cables.

4. A Rama Industrial Company Resistor Assembly and Support type IH-6557. The assembly consists of 54 individual hairpin elements each rated 5 kva at 480-volts which results in a total load factor of 270 kva at 480-volts. The elements are bussed in groups of three in a single phase. There are six three-phase circuits.

5. Instrumentation

   Minneapolis Honeywell Oscillograph
   Current Transformers
   Potential Transformers
   Shunts
   Ammeters

6. Miscellaneous

   Three propeller type fans
   Fire extinguishers
   Insulating material, canvas and steel horses
   Heating lamps
   Loading transformers
   Thermocouples
   Potentiometer

H. M. Stone
Apparatus Engineer

FIGURE 1

WIRE CONNECTIONS FOR ENERGIZED CONDUCTORS

CABINET NO. 1

					Heater No.
(#12) 1/C #6	A 401 - 429		423	B	#1
	B 402 - 430		425	B	
	C 403 - 431		424	C	
(#10) 1/C #6	A 404 - 440		Short 411	A	#2
	B 405 - 441		414	B	
	C 406 - 442		432	C	
(#8) 1/C #6	A 407 - 443		415	A	#3
	B 408 - 444		416	B	
	C 409 - 445		420	C	
(#11) 1/C #6	A 410		413	A	#4
	B 412		433	B	
	C 417		434	C	
(#9) 1/C #6	A 418		439	A	#5
	B 419		437	B	
	C 422		438	C	
(#7) 1/C #6	A 426	361	421	A	#6
	B 427	367	435	B	
	C 428	363	436	C	

WIRE CONNECTIONS FOR ENERGIZED CONDUCTORS

CABINET NO. 2

#14					#13 Compartment
1/C #12 3/C #12	75, 45, 48, 8, 103	A	A	51, 54, 57, 60, 138	1/C #12 & 3/C #12
	76, 46, 49, 9, 103	B	B	52, 55, 58, 61, 138	
	77, 47, 50, 10, 103	C	C	53, 56, 59, 62, 138	

#16					#15
1/C #8	351, 354, 357	A	A	63, 66, 69, 72, 102	1/C #12 & 3/C #12
	352, 355, 358	B	B	64, 67, 70, 73, 102	
	353, 356, 359	C	C	65, 68, 71, 74, 102	

NONE					NONE

FUSE CONDITIONS AFTER TEST FIRE

CABINET NO. 1

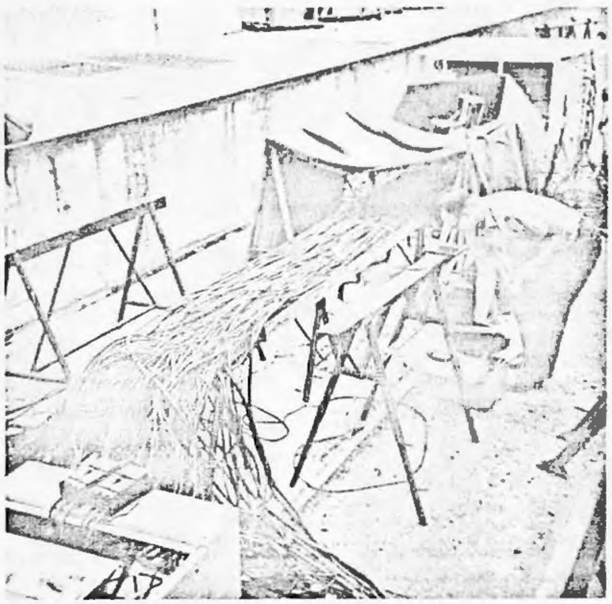
401, 429	- OK	A Phase	423	-	OK
402, 430	- OK	B	425	-	NG
403, 431	- OK	C	424	-	NG
404, 440	- NG	A Phase	411	-	NG
405, 441	- OK	B	414	-	NG
406, 442	- OK	C	432	-	NG
407, 443	- OK	A Phase	415	-	NG
408, 444	- OK	B	416	-	NG
409, 445	- OK	C	420	-	NG
410	- OK	A Phase	413	-	OK
412	- OK	B	433	-	NG
417	- OK	C	434	-	NG
418	- OK	A Phase	439	-	NG
419	- OK	B	437	-	NG
422	- OK	C	438	-	NG
426, 361	- OK	A Phase	421	-	OK
427, 367	- NG	B	435	-	NG
428, 363	OK	C	436	-	NG

CABINET No. 2

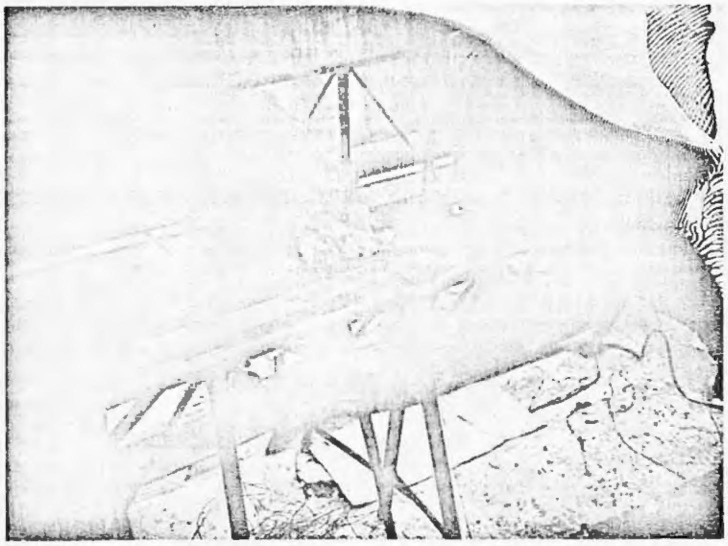
75, 45, 48, 8, 103	- OK	A Phase	51, 54, 57, 60, 138	-	NG
76, 46, 49, 9, 103	- OK	B	52, 55, 58, 61, 138	-	NG
77, 47, 50, 10, 103	- OK	C	53, 56, 59, 62, 138	-	OK
351, 354, 357	- OK	A Phase	63, 66, 69, 72, 102	-	OK
352, 355, 358	- OK	B	64, 67, 70, 73, 102	-	OK
353, 356, 359	- OK	C	65, 68, 71, 74, 102	-	OK

POSSIBLE ELECTRICAL CONDITIONS
@ PHASE TO PHASE SHORT

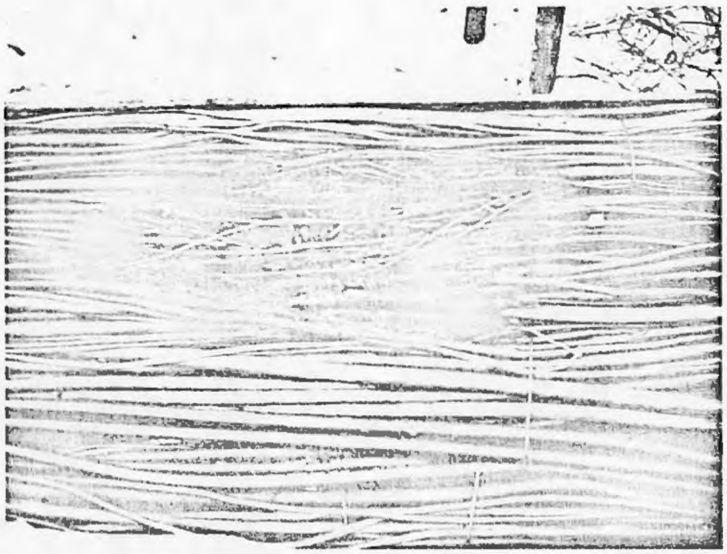
	Watts	Amps	Volts	Resist.
Short	0	14.8	0	0
	860	6.0	138.5	23.2
Max.	880	7.2	119	16.6
	800	10.0	80	8.0
	760	12.0	46	3.85
	220	14.0	14	1.0
	880	7.2	119	16.6
Open Circuit	0	0	234	∞



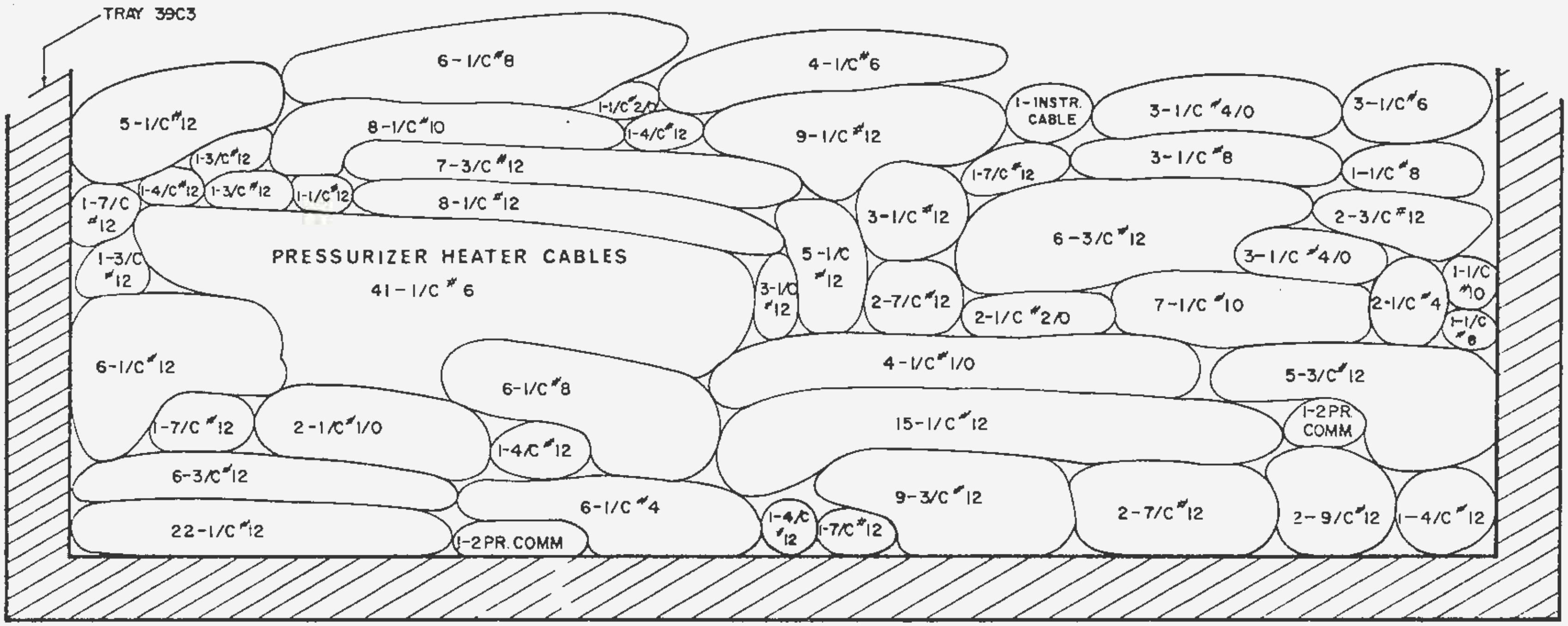
39C3 CABLE TRAY SIMULATION
PRIOR TO SHORT CIRCUIT TEST



SUSTAINED COMBUSTION
RESULTING FROM PRES-
SURIZER HEATER CABLE
SHORT CIRCUITS



RESULTS OF CABLE
SHORT CIRCUIT TEST



CROSS SECTION OF CABLE TRAY
39C3

7.1.2 EXISTING PENETRATION COWLING - CABLE HEAT RUN

REPORT OF THERMAL LOADING TEST ON CABLE UNDER COWLING FOR CONTAINMENT SPHERE PENETRATION EPC4-WPC7

The purpose of this test was to determine the possible maximum temperature within the cowlings mounted on containment sphere penetrations EPC4 and WPC7.

In order to perform this test, it was necessary to reproduce the physical and electrical conditions as they existed during actual service.

Penetration cowlings EPC4 and WPC7 were identical with regard to the number and size of conductors carried into the aluminum housings. The normal load current for WPC7 (which is slightly higher than the EPC4 load current) was used in the simulation.

The Bechtel Corporation provided a cable schedule and current loading values for these penetrations.

The test was conducted in two stages at Edison's Shop and Test facilities at Alhambra, California. Participating in these tests were representatives of Edison's Apparatus, Engineering, Power Supply, and Shop and Test Departments.

A cable bundle was assembled, consisting of six lengths of 1/c #1/0, six lengths of 1/c #2, and 54 lengths of 1/c #6 butyl insulated, neoprene jacketed control cable. Each piece was approximately 6' in length within the cable bundle. These pieces of cable were connected in series groups in accordance with the current loading schedule provided by Bechtel. One end of the cable bundle was secured with plastic electrical tape and a thermocouple #19 inserted at the center of the bundle, one inch from the end. This end was then packed with "Duxseal" compound to simulate the "RTV" silicone rubber compound which was used to seal the penetration face and cable ends against moisture at the San Onofre Nuclear Generating Station. A second thermocouple #18 was taped to the top of the cable bundle, one inch from the end. A third thermocouple #13 was taped to the bottom of the cable bundle at the 90° bend within the cowling.

Other thermocouples used were #3 taped to the top of the cowling, #20 taped to the underside of the cowling, and #1 mounted below the 90° elbow for ambient temperature measurement.

A 90° elbow and two straight sections, one non-ventilated and one ventilated, were shipped from San Onofre to be assembled as complete cowlings for these tests.

A 1/2" thick wooden plug was inserted at the end of the straight section of the cowling for the tests to simulate the penetration face. The cable bundle was inserted into the cowling touching the plug. Several cables protruded through holes provided in the plug for connection to loading transformers. This test was performed in two parts, the first using the non-ventilated straight section of cowling and 90° elbow, and the second using the ventilated straight section of cowling and 90° elbow.

Power was obtained from a 3-kVA 240-240/120-volt single-phase distribution transformer. Four individual series circuits in the cable bundle were loaded as follows: 142 A, 71 A, 46 A, and 12.5 A. Current control was obtained by use of 240-volt variacs. A clamp-on ammeter was used to check currents periodically.

For recording temperatures an Esterline-Angus chart type temperature recorder was used.

The circuits duplicated for these tests were as follows:

Circuit	No. & Size of Conductor	Actual Load Current/Conductor (Amps.)	Test Load Current/Conductor (Amps.)
Recirc. Pump B	3-#1/0	142	142
Residual Heat Removal Pump B	3-#1/0	71	71
Pressurizer Heaters	45-#6	46	46
Reactor Control Rod Mech. Cooling System Fan A8S	3-#2	48.5	46
Fan A1	3-#6	12.5	12.5
Fan A3	3-#6	12.5	12.5
Emergency Lighting Panel	3-#6	-	-
Not Allocated in WPC7	3-#2	-	-

RESULTS:

Test #1 - Non-Ventilated Cowling

Maximum temperatures were as follows:

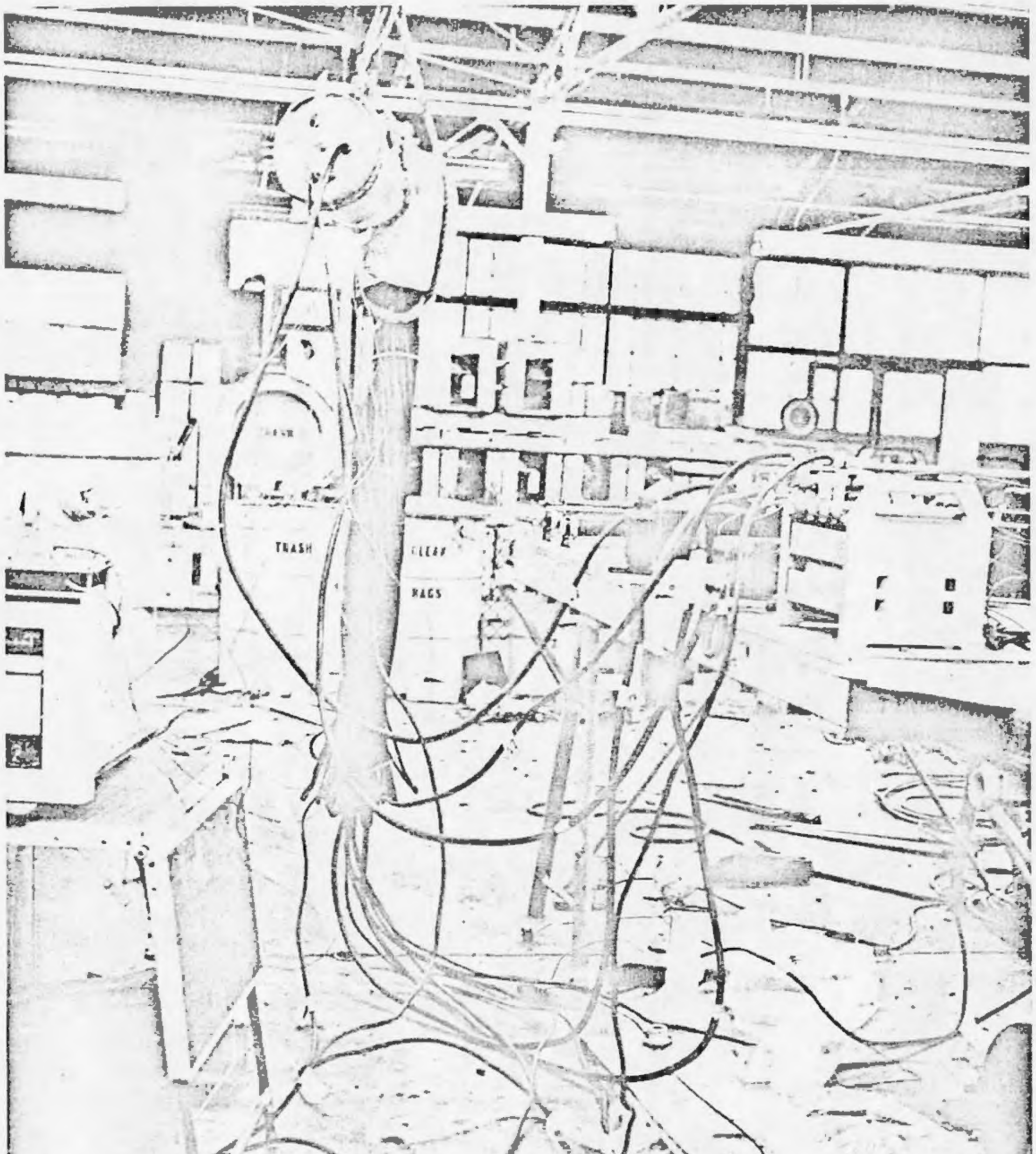
Thermocouple #	Max. Temp.	Location
19	106°C.	Center of cable bundle.
18	85	Top of cable bundle.
13	65	90° bend in cable.
3	46	Top of cowling.
20	40	Bottom of cowling.
1	22	Ambient.

Test #2 - Ventilated Cowling

Thermocouple #	Max. Temp.	Location
19	109°C.	Center of bundle.
18	85	Top of cable bundle.
13	50	90° bend of cable.
3	50	Top of cowling.
20	40	Bottom of cowling.
1	28	Ambient.

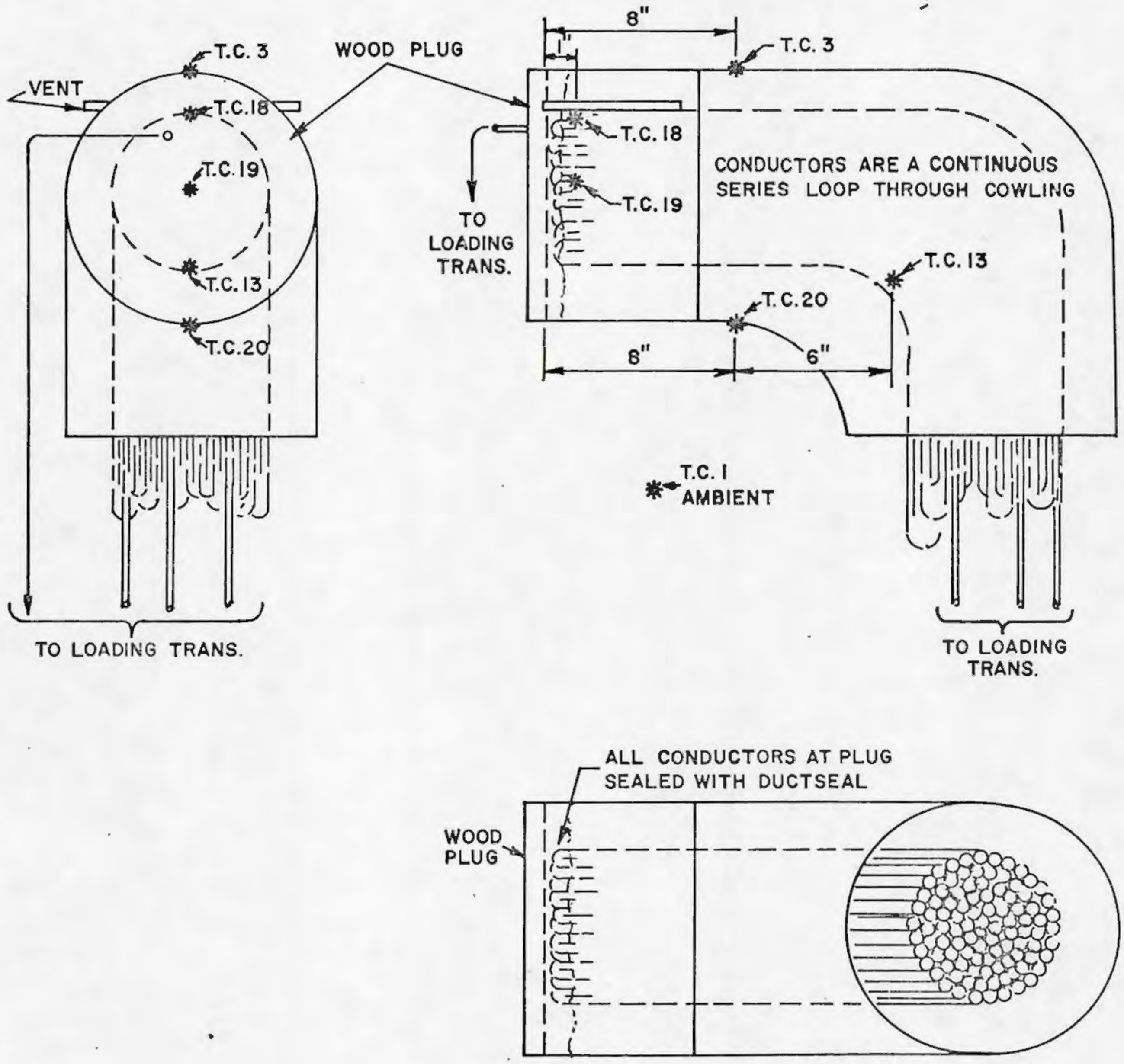
It is concluded that under conditions of high ambient temperatures exceeding those encountered during these tests, cable temperatures could rise to levels above the cable insulation rating, resulting in damage to the cables.

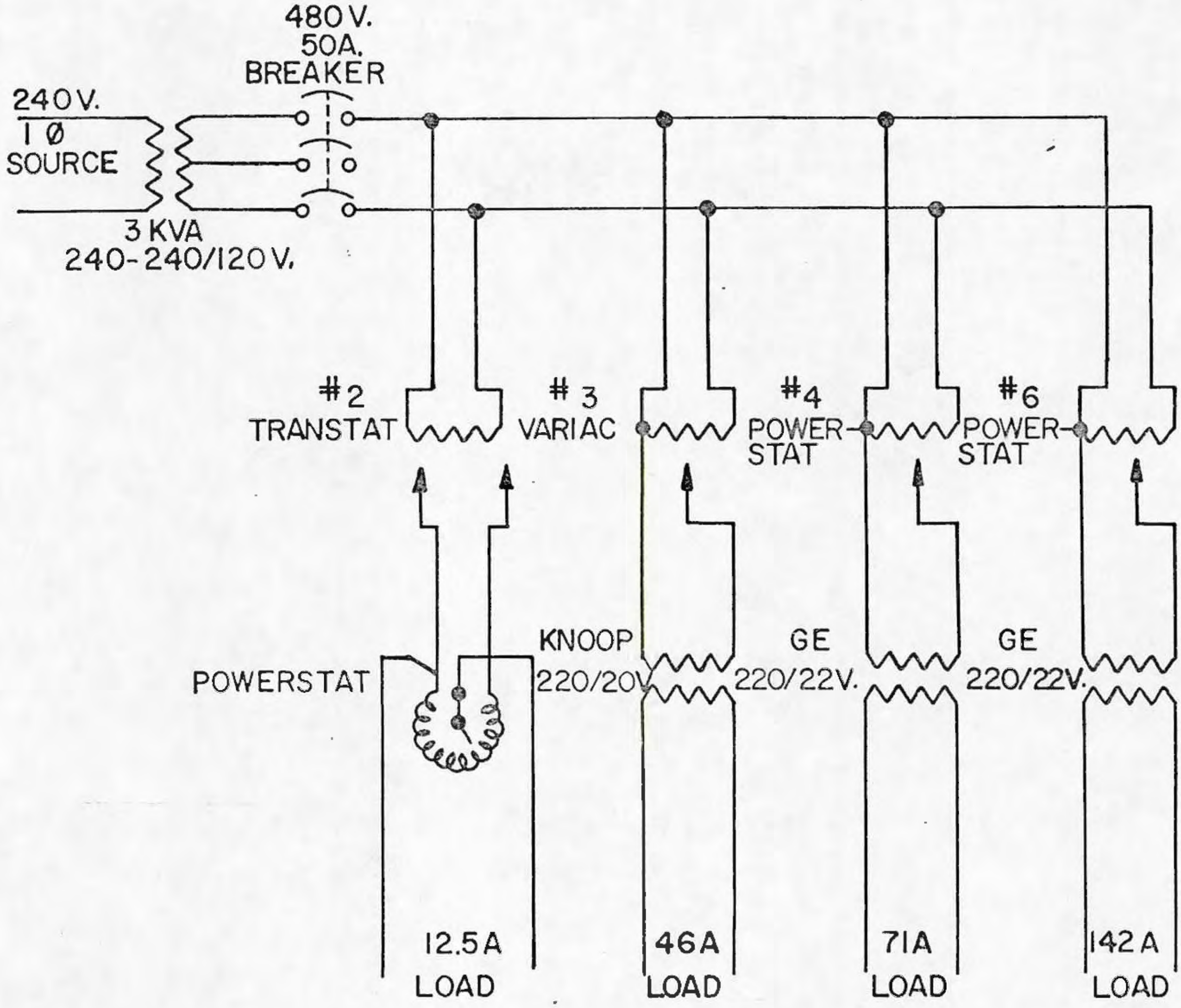
J. L. Cohon
Apparatus Engineer



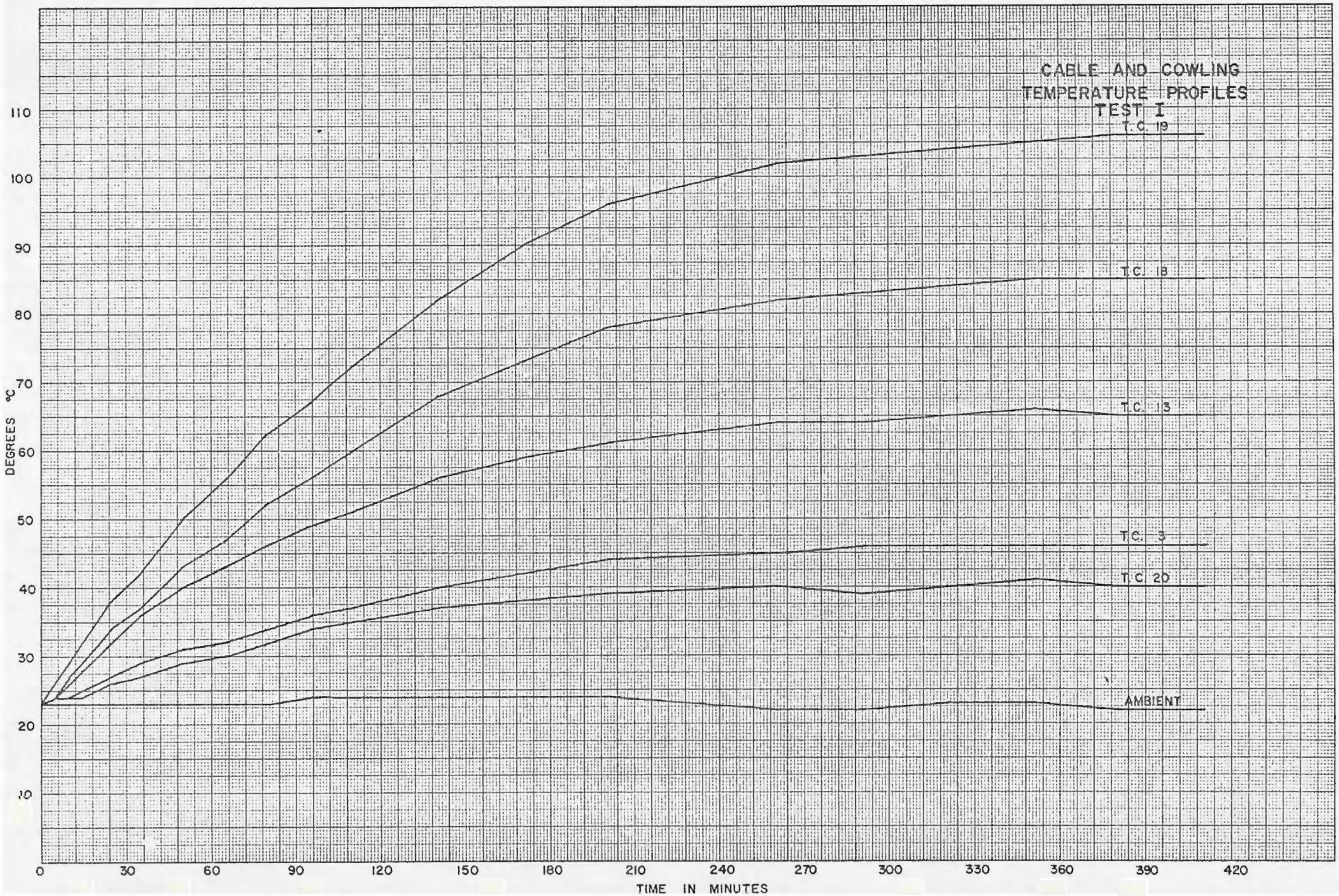
EXISTING PENETRATION COWLING – CABLE HEAT RUN

COWLING DIAGRAM SHOWING CONDUCTOR LAYOUT AND THERMOCOUPLE LOCATIONS FOR HEAT RUN TESTS

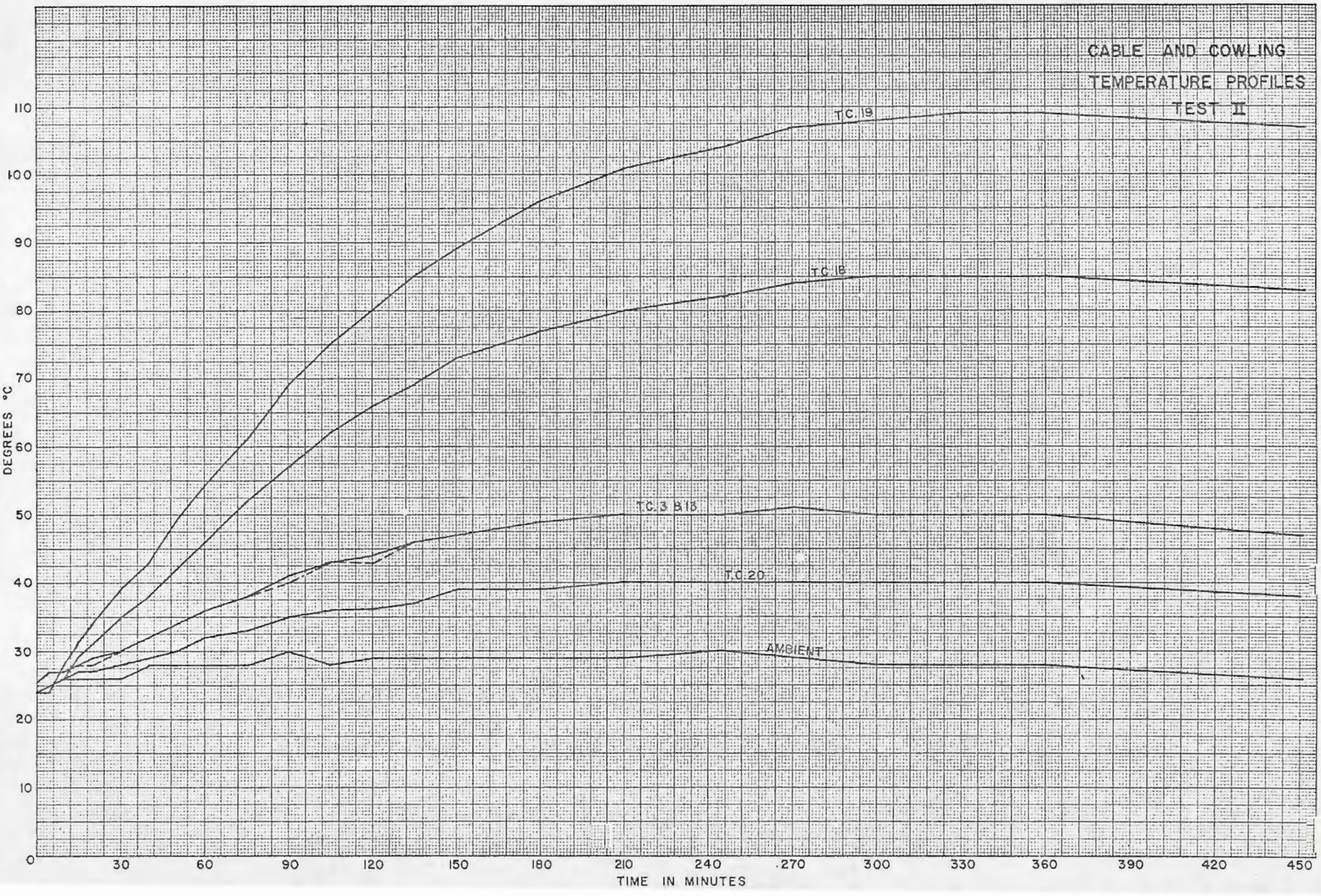




WIRING DIAGRAM FOR COWLING
HEAT RUN TEST



CABLE AND COWLING
TEMPERATURE PROFILES
TEST I
T.C. 19
T.C. 18
T.C. 13
T.C. 3
T.C. 20
AMBIENT
DEGREES °C
110
100
90
80
70
60
50
40
30
20
10
0
30
60
90
120
150
180
210
240
270
300
330
360
390
420
TIME IN MINUTES



CABLE AND COWLING
TEMPERATURE PROFILES
TEST II
T.C. 19
T.C. 18
T.C. 3 & 13
T.C. 20
AMBIENT
DEGREES °C
0
10
20
30
40
50
60
70
80
90
100
110
30
60
90
120
150
180
210
240
270
300
330
360
390
420
450
TIME IN MINUTES

7.1.3 NEW CABLE TRAY THERMAL LOADING CRITERIA - HEAT RUN

TEST REPORT

NEW CABLE TRAY THERMAL LOADING
PRESSURIZER HEATER CABLE - HEAT RUN

PURPOSE

A test was conducted on May 12, 1968, utilizing a model of the new #4 AWG pressurizer heater cables in their new cable tray configuration. The purpose of the test was to determine the maximum temperature that could be expected in these cables under normal full load, 46 amps, and overload condition, 52 amps.

DISCUSSION

To simulate conditions to be found at San Onofre Nuclear Generating Station, two 12-foot lengths of 24" x 3" expanded metal, steel, cable trays and a reel of 3/C #4 AWG 600 volt control cable was sent to Edison's Shop and Test facility at Alhambra, California. This material is identical to that presently being installed at San Onofre Nuclear Generating Station.

The two lengths of tray were bolted together to form a single 24-foot length which was then mounted on 2-foot high steel horses. Only point contact was made between the bottom of the tray and the horses.

The cable used for these tests was supplied by the Okonite Company. It consisted of three 1/C #4 AWG 600 volt butyl (Okonex) rubber insulated, neoprene (Okoprene) jacketed conductors, cabled together with jute fillers, bound with mylar tape and jacketed with "Okoseal" polyvinylchloride compound.

A single length of cable was looped through the tray to form fifteen 40-foot lengths with 24 feet of each in the tray. Including connecting lengths running outside the tray to the power supply, the total length of cable was 650 feet. The three conductors in the cable were connected in series to form a continuous circuit. The fifteen parallel lengths were placed within the tray in a single layer, starting at the edge of the tray with no separation between cables. The cables did not fill the bottom of the 24-inch tray, leaving 7 inches of exposed tray.

Each end of the tray was wrapped with fiberglass insulation to limit the heat loss.

Nine, 250-W., equally spaced, heat lamps were directed at the concrete floor beneath the tray to maintain a constant ambient temperature in the area.

To monitor temperatures, fourteen thermocouples and an Esterline-Angus chart type temperature were installed. The location of these thermocouples are as follows:

#1 - 4'-4" from end of tray.

#2 - 8'-3" from end of tray.

#3, 4, 5, 6, 7, 8 - 12' from end of tray.

#9 - 16' from end of tray.

#10 - 20'-3" from end of tray.

#21 - "Tray Temperature" - 11'-10" from end of tray.

#22 - Ambient beneath the tray and 12' from the end.

#23 - Outside tray beneath fiberglass insulation, 6" from T.C. #1 tray end.

#24 - Outside tray beneath fiberglass, 7" from T.C. #10 tray end.

Thermocouples 1, 2, 5, 9, and 10 were placed into the center of the middle cable in the layer. The outer PVC jacket was slit to permit entry of each thermocouple and then taped with PVC tape.

Thermocouples 3 and 7 were inserted into the center of other cables in a similar manner.

Thermocouples 4, 6, and 8 were taped to the surface of the outer jacket and placed between adjacent cables. Thermocouples 23 and 24 were taped to the top of the middle cable beneath the fiberglass, outside the tray.

Power was supplied from a 240-volt source through a 240-240/120 isolation transformer. For Test 1 a variac and loading transformer was used. For Test 2, a transtat was used. A wattmeter, voltmeters, and ammeters were used to measure power input.

Test #1 -

For this test a current of 46 amperes was circulated through the cable. This provided a total calculated loss of 1086 watts in the cable and 25.2 watts/foot in the tray. Maximum thermocouple readings were:

T.C. #	Temp. °C	
1	39	Maximum readings were obtained after 270 minutes.

Test #1 (cont.)

T.C. #	Temp. °C
2	41
3	40
4	40
5	40
6	39
7	39
8	39
9	39
10	39
21	26
22	24
23	38
24	44

Test #2 -

After terminating Test #1, Test #2 was immediately begun. For this test the current circulating through the cable was increased to 52 amperes. This provided a total calculated loss of 1404 watts, and 32.4 watts per foot of tray. Maximum thermocouple readings were:

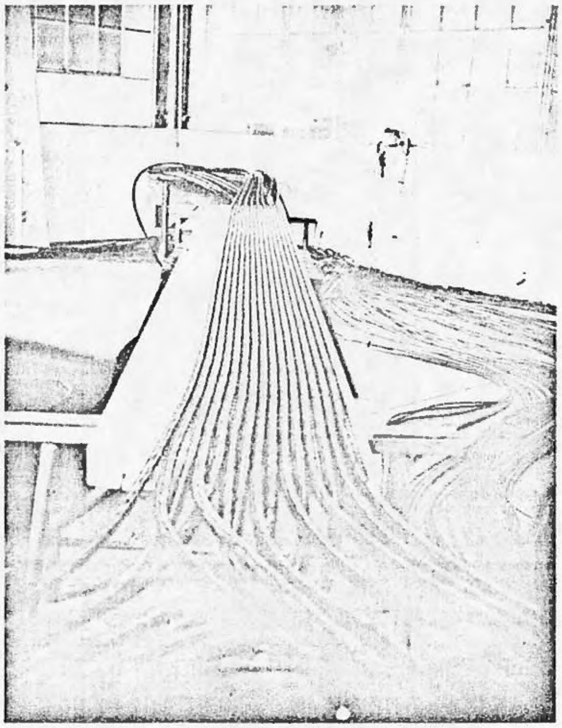
T.C. #	Temp. °C
1	44
2	46
3	44
4	44
5	44
6	44
7	44
8	44
9	44
10	44
21	28
22	26
23	43
24	46

Maximum readings were obtained after 135 minutes.

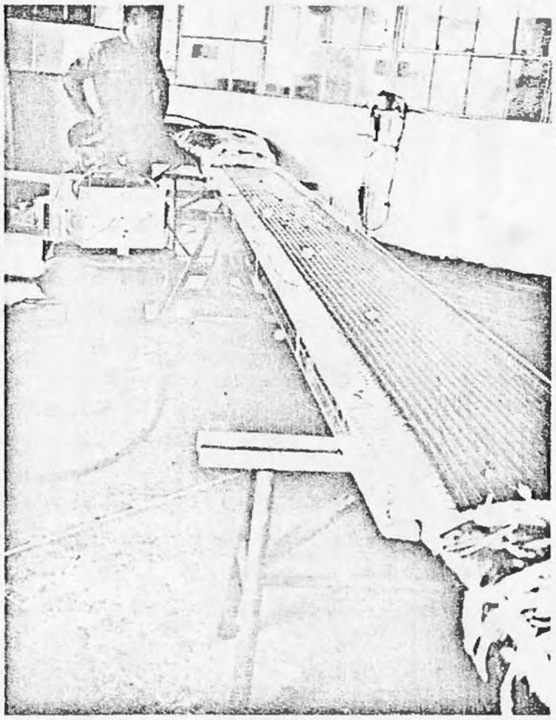
CONCLUSIONS

It was concluded from analysis of this data that the 3/C #4 AWG pressurizer heater cables will experience a maximum temperature rise of approximately 20°C in their new cable tray installation. This temperature rise is well within the temperature limit of this insulation.

J. L. Cohon
Apparatus Engineer



CABLES INSTALLED IN TRAY
BEFORE INSULATING ENDS



TEST IN PROGRESS
ENDS INSULATED

7.1.4 WESTINGHOUSE 600-VOLT SWITCHGEAR TEST

ACCEPTANCE TEST - WESTINGHOUSE 600-VOLT SWITCHGEAR TRIPAC TYPE FA CIRCUIT BREAKER SHORT CIRCUIT INTERRUPTION TEST

PURPOSE OF TEST

This test was conducted on March 23-24, 1968 to verify the acceptability of the Tripac circuit breaker as a substitute for the existing Westinghouse FDP fused load breaker switches.

The suitability of three-phase tripping devices was investigated in order to develop a replacement tripping device that would provide positive three-phase clearing of a circuit in the event of a fault on one phase or on an inter-circuit fault condition.

CONCLUSIONS

The Tripac three-phase tripping units performed satisfactorily in all respects and their installation will provide an improvement in circuit-clearing capability.

600-VOLT SWITCHGEAR COMPONENT TEST PROGRAM (REVISED)

CENTER TEST STATION — MARCH 22, 23 & 26, 1968 — 8:00 A.M.

TEST NO. 352

WESTINGHOUSE 600-VOLT SWITCHGEAR
FUSED DISCONNECT & MOLDED CASE BREAKER

GROUP	A	B	C
"A" BANK	3A	3A	3A
"C" BANK	2C	2C	2C
TEST BANK	#2	#2	#2
69 KV BUS KV	69	69	69
TEST BUS KV	17.1	17.1	17.1
REACTOR OHMS/φ	[illegible]	4.02	4.02
RESISTANCE OHMS/φ	10	10	10
TEST VOLTS	480	480	480
AMPS. (RMS SYM)	20000	17,400	12,000
TYPE OF FAULT	3φ [illegible]	φ-φ [illegible]	φ-φ [illegible]
SERIES	"a"	"a"	"a"
1. Molded Case Breaker TRI-PAC, Type F 600v, 70A.	X	X	
2. Molded Case Breaker TRI-PAC, Type F 600v, 70A.	X		X
3. Fused Disconnect Type FDP, 600v, 100A, with Fuse No. KTS-80	X	X	X
4. Fused Disconnect Type FDP, 600v, 100A, with Fuse No. FRS-80	X		X
BOLTED FAULT	X	X	X

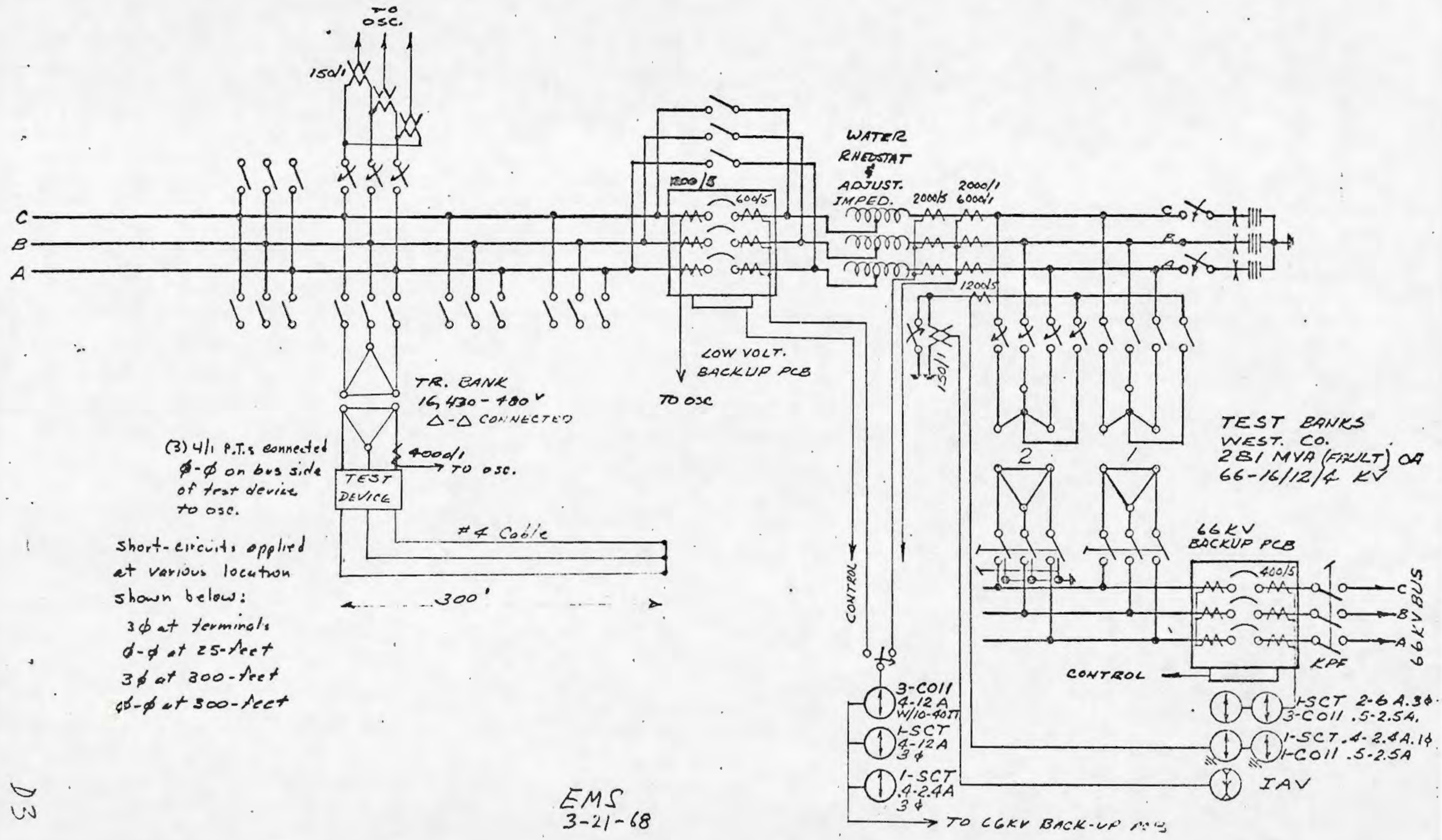
NOTES: "a" = open operation by circuit breaker or fuse. More tests may be performed if deemed necessary.

REF.: Dispatchers' Inst. Bul. I.B No. 1076. APPROVED [signature] OLR CMC CAP / EMS

TEST NO. 352

600-VOLT SWITCHGEAR COMPONENT TESTS

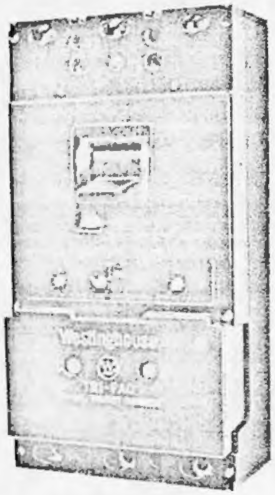
NOTE: TEST BANKS, REACTORS, AND TEST GROUNDING CONDITIONS TO BE SET AS SHOWN ON THE TEST PROGRAM



EMS
3-21-68

D3

TRI-PAC breakers



availability: TRI-PAC types F through L

application

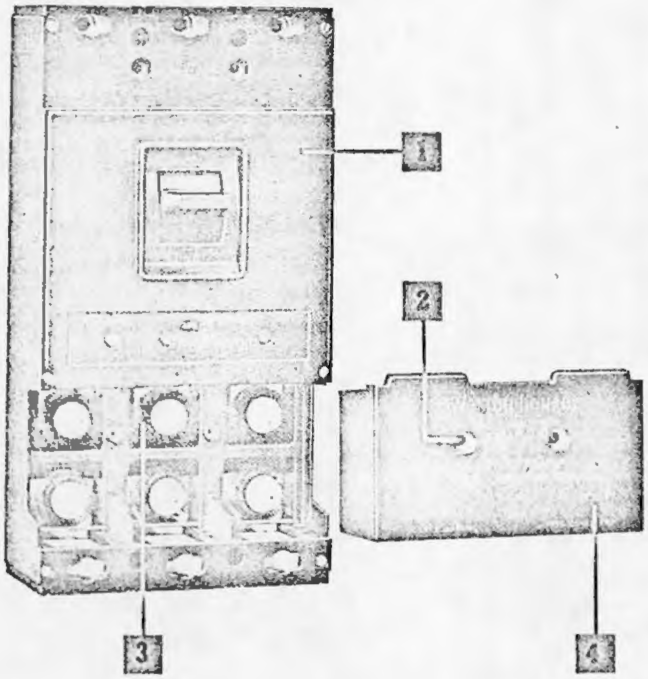
The TRI-PAC breaker is essentially an AB De-ion circuit breaker incorporating a current-limiting device which enables it to be used on distribution systems where fault currents up to 100,000 symmetrical rms amperes are available.

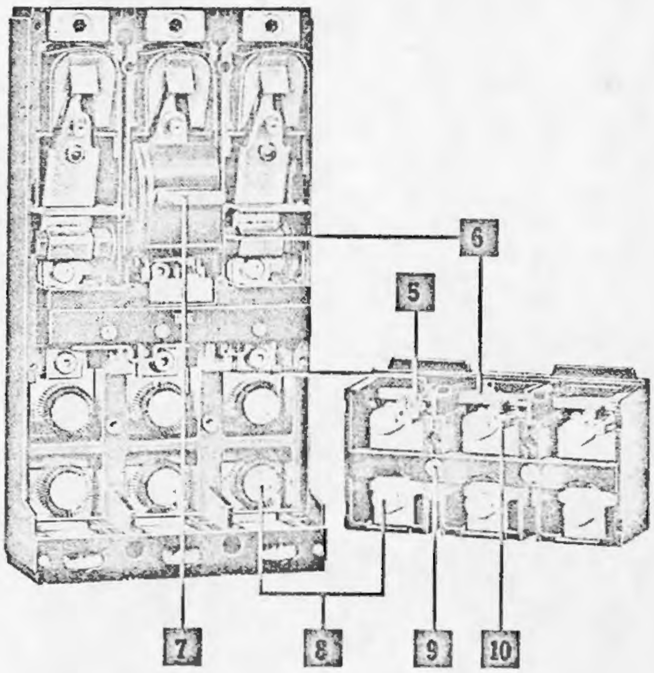
As the name implies, it is a TRIple PACkage of protection—(1) time delay thermal trip, (2) instantaneous magnetic trip, and (3) current limiting protection—combined and coordinated in a single compact and economical device.

TRI-PAC breakers are used on low voltage distribution systems when the available fault current is above the interrupting ratings of standard molded case breakers but does not exceed 100,000 symmetrical rms amperes.

They are designed for use in switchboards, control centers, panelboards, combination starters, bus duct plug-in units and separate individual enclosures. In addition, they are suitable for application as main breakers and for protection of branch and feeder circuits and connected apparatus. When properly applied, TRI-PAC breakers may also be used for the back up protection of standard molded case breakers.

general design features





1 **retain all features of standard AB De-ion circuit breakers:** TRI-PAC breakers are built to the same exacting design standards and by the same methods as conventional Westinghouse molded case circuit breakers. They retain all the features of standard breakers including: De-ion arc quenchers, nonwelding silver alloy contacts, common trip and Moldarta® and/or glass polyester cases.

2 **compact, easy-to-remove current limiter housing:** Current limiters are contained in a single, compact Moldarta housing. It is front removable for easy access to current limiters when replacement is necessary. Limiters are correctly aligned and held in place by a retaining bar so that when the housing is pulled out all are disengaged from their receptacles simultaneously.

3 **limiter housing safety interlock:** When the limiter housing is removed a safety interlock trips the breaker before the limiter stabs disengage. Therefore, these terminals are never required to interrupt current. This interlock also prevents closing of the breaker while the limiter housing is removed so that it is impossible to come in contact with "live" parts.

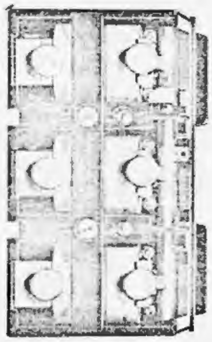
4 **visible disconnecting means:** Removal of the limiter housing simultaneously removes the limiters. With the limiters removed it can be readily observed that the limiter contacts are open and that the circuit is disconnected.

5 **specially designed current limiters:** When a high fault current causes one or more limiters to function, a spring-loaded plunger is instantly ejected from the end of the limiter. The plunger strikes a trip bar which causes the breaker contacts to open the instant the fault occurs.

An extended plunger on any limiter indicates, at a glance, on which phase the fault has occurred so that testing of limiters is unnecessary. Presence of an extended plunger also prevents relatching of the breaker. Thus, "good" limiters must be used or the breaker cannot be operated. These limiters are not affected by the overloads or normal short circuits cleared by the thermal-magnetic action of the breaker, and unless they have cleared a high fault current, as evidenced by an extended plunger, they may be used without question.

Since these limiters are designed for use only with TRI-PAC breakers, safe, proper coordination is assured.

6 **coordinated common trip to prevent single phasing:** When a current limiter operates, the ejected plunger causes instant release of a common tripping bar. All poles are opened simultaneously, eliminating the possibility of single phasing.



7 **positive trip indication:** When a breaker trips, the handle always moves to the center "trip" position. In addition, the cause of tripping is indicated in the following ways:

- If the breaker cannot be reset immediately after tripping but can be reset after a short period it indicates thermal tripping due to an overload or high resistance fault.
- If it can be reset immediately a "normal" fault current has been interrupted by instantaneous magnetic action.
- If the TRI-PAC cannot be reset, high fault interruption by the current limiter has taken place.

8 **plug-in type limiter terminals:** Studs on each current limiter engage "tulip" type connectors in the breaker base. Since the limiter housing provides perfect alignment this arrangement assures positive connection and easy removal of the limiters.

9 **easy replacement of limiters:** Loosening of two screws releases a retaining bar in the limiter housing and permits removal of limiters.

10 **missing limiter interlock:** This interlock, in the limiter housing, prevents the housing from being replaced unless all limiters are in place. Thus accidental single phasing is prevented, since the breaker cannot be reclosed when a limiter is missing.

choice of three terminal connections: TRI-PAC breakers are available with front connected pressure type terminals, bolted rear-connected mounting studs and plug-in terminal mounting blocks.

accessories: TRI-PAC breakers accommodate many standard AB breaker accessories including: shunt trip, undervoltage trip and auxiliary contacts. Application of other accessories should be reviewed with Westinghouse.

TEST 352 - TEST DATA

Westinghouse 600 Volt Switchgear
Tri-Pac Type FA 70 A. &
Fused Disconnect Type FDP w/ FRS 80 & KTS 80 Fuses

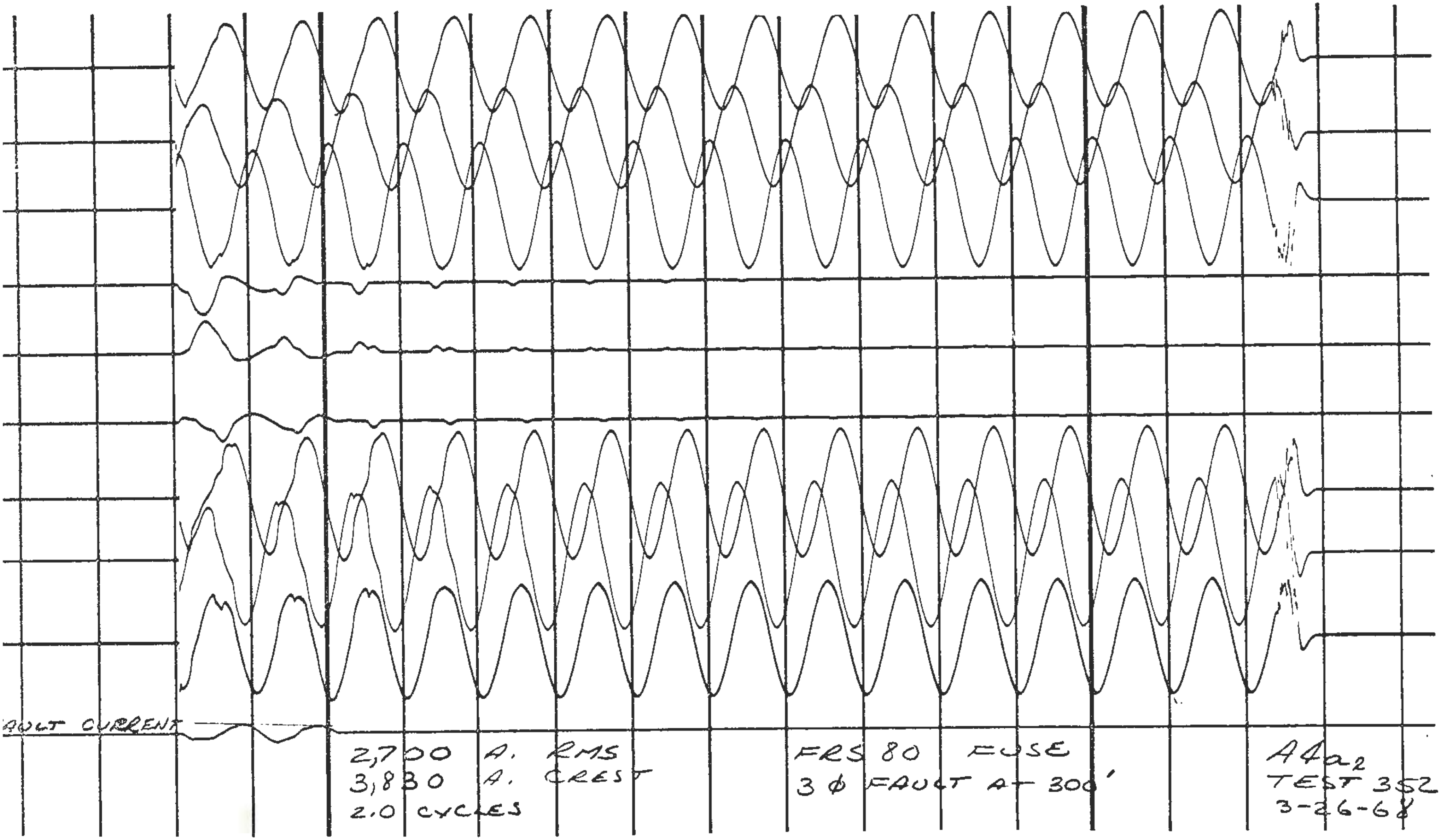
Center Substation
March 23 & 26, 1968

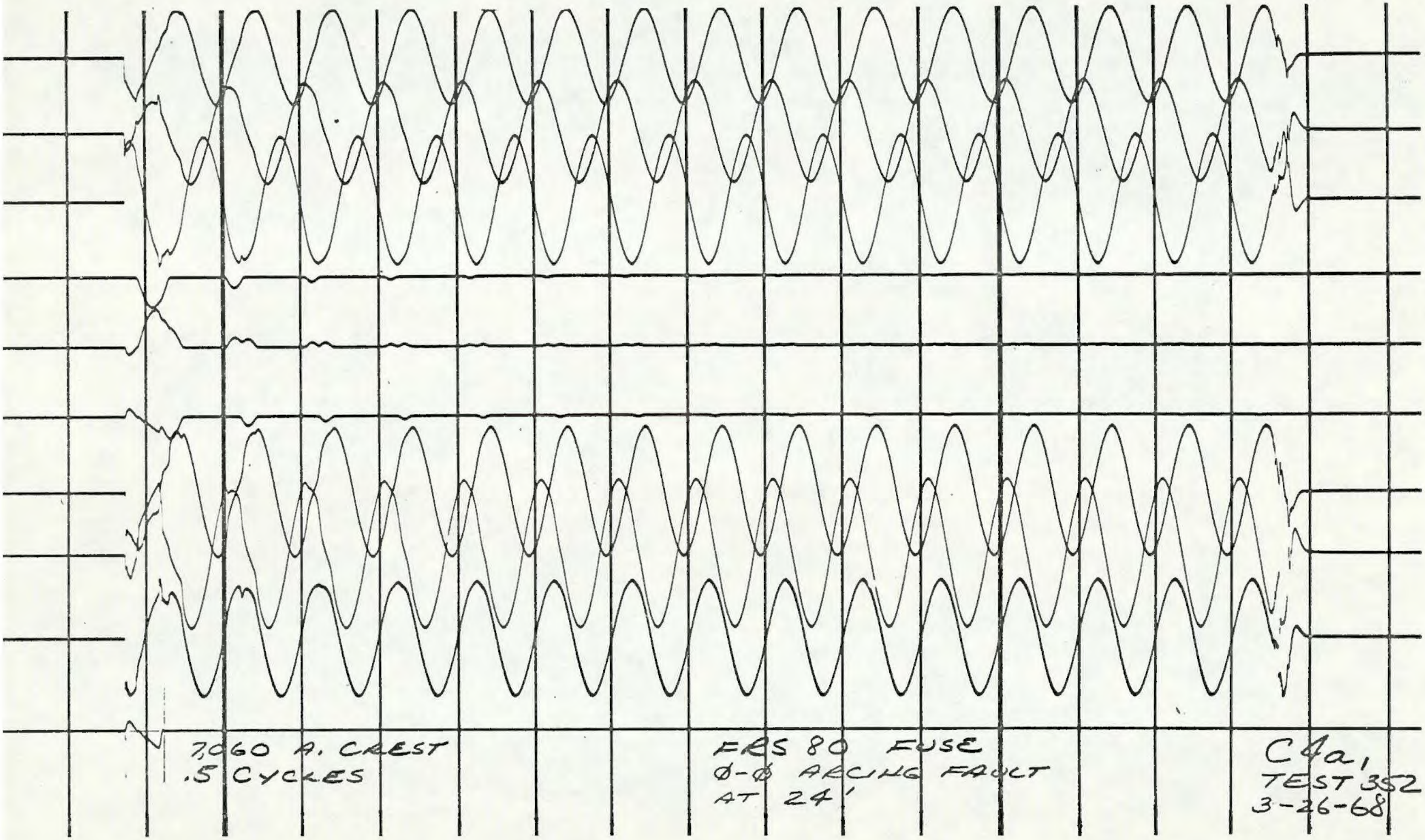
Test No.	(1) Type & Location of Fault	Phase-to-Phase Voltage (RMS Volts)	(2) Available Fault Current (RMS Amps)	(2) Available Fault Current (Crest Amps)	(3) Peak let Through Current (Crest Amps)	Total Clearing Time (Cycles)	Remarks
			TRI-PAC, TYPE FA, 70 A.				
Alal	3Ø at 300'	475	2900	4160	3540	0.40	Breaker tripped, fuses did not blow.
Blal	Ø-Ø at 300'	475	2500	3540	3240	0.85	Breaker tripped, fuses did not blow.
C2al	Ø-Ø arcing at 24'	475	12,300	17,700	-	-	Fault current not of sufficient magnitude to measure. Small wire used for the fault burned and opened the circuit.
C2a2	"	475	12,300	17,700	7060	0.47	Breaker tripped, fuses did not blow.
A2al	3Ø at 0'	475	24,900	33,400	11,200	0.40	A & C phase fuses blew. Breaker tripped.
			FUSED DISCONNECT, TYPE FDP, 100 A. WITH FRS 80 DUAL ELEMENT FUSES				
A4al	3Ø at 0'	475	24,900	33,400	15,800 (RMS)	-	All fuses blew but internal 3Ø fault started and extensively damaged the switch. New switch obtained for remainder of tests.
A4a2	3Ø at 300'	475	2900	4120	3830	2.0	Two fuses blew & switch contacts welded where fuses were blown. Third fuse not blown but contact badly eroded.
C4al	Ø-Ø arcing at 24'	475	12,300	17,700	7060	0.5	Both fuses blew, switch contacts not welded.

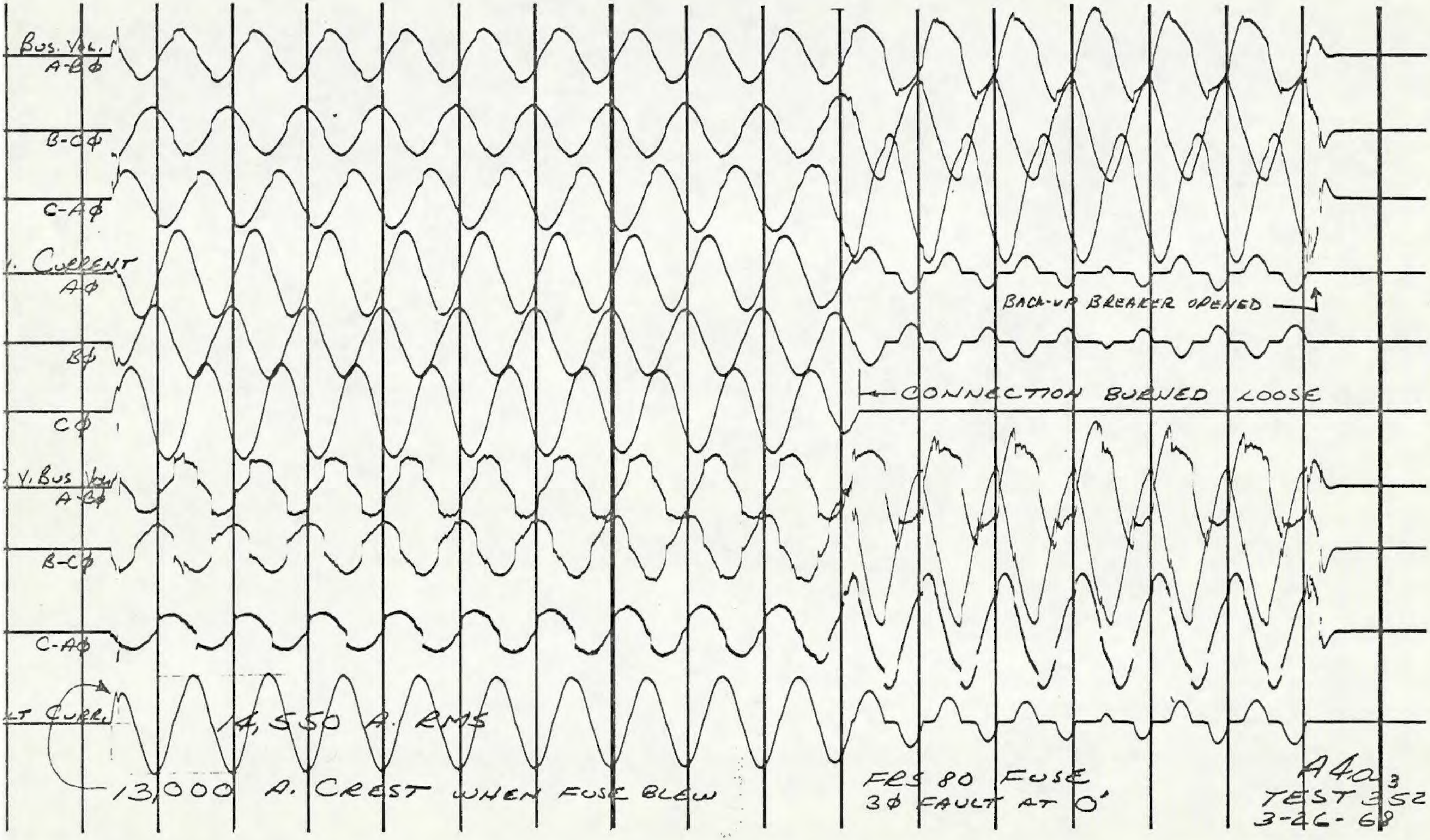
Test No.	Type & Location of Fault[1]	Phase-to-Phase Voltage (RMS Volts)	Available Fault Current (RMS Amps)[2]	Available Fault Current (Crest Amps)[2]	Peak let Through Current (Crest Amps)[3]	Total Clearing Time (Cycles)	Remarks
(Continued)							
A4a3	3Ø at 0'	475	24,900	33,400	14,550	-	Two fuses blew but internal 3Ø fault occurred similar to previous test of same magnitude. Contacts not welded but internal bus destroyed. New switch used for remainder of test.
	FUSED DISCONNECT, TYPE FDP, 100 A. WITH KTS 80 CURRENT LIMITING FUSES						
A3a1	3Ø at 300'	475	2900	4120	1770	0.10	Two fuses blew.
B3a1	Ø-Ø at 300'	475	2500	3540	2060	0.10	Both fuses blew.
C3a1	Ø-Ø arcing at 24'	475	12,300	17,700	2940	0.04	Both fuses blew.
A3a2	3Ø at 0'	475	24,900	33,400	4120	0.05	Two fuses blew.

(1) The location of the fault indicates the length of a #4 cable run between the load terminals of the test device and the fault.
(2) The available fault current is that current which would flow if not interrupted by the test breaker of fuse. The measured current, on most tests, was less than the available current due to current limiting action of the breaker or fuse.
(3) The peak-let-through current is the maximum measured current that flows through the test device. This value can be less than the available current due to current limiting action of the breaker or fuse.

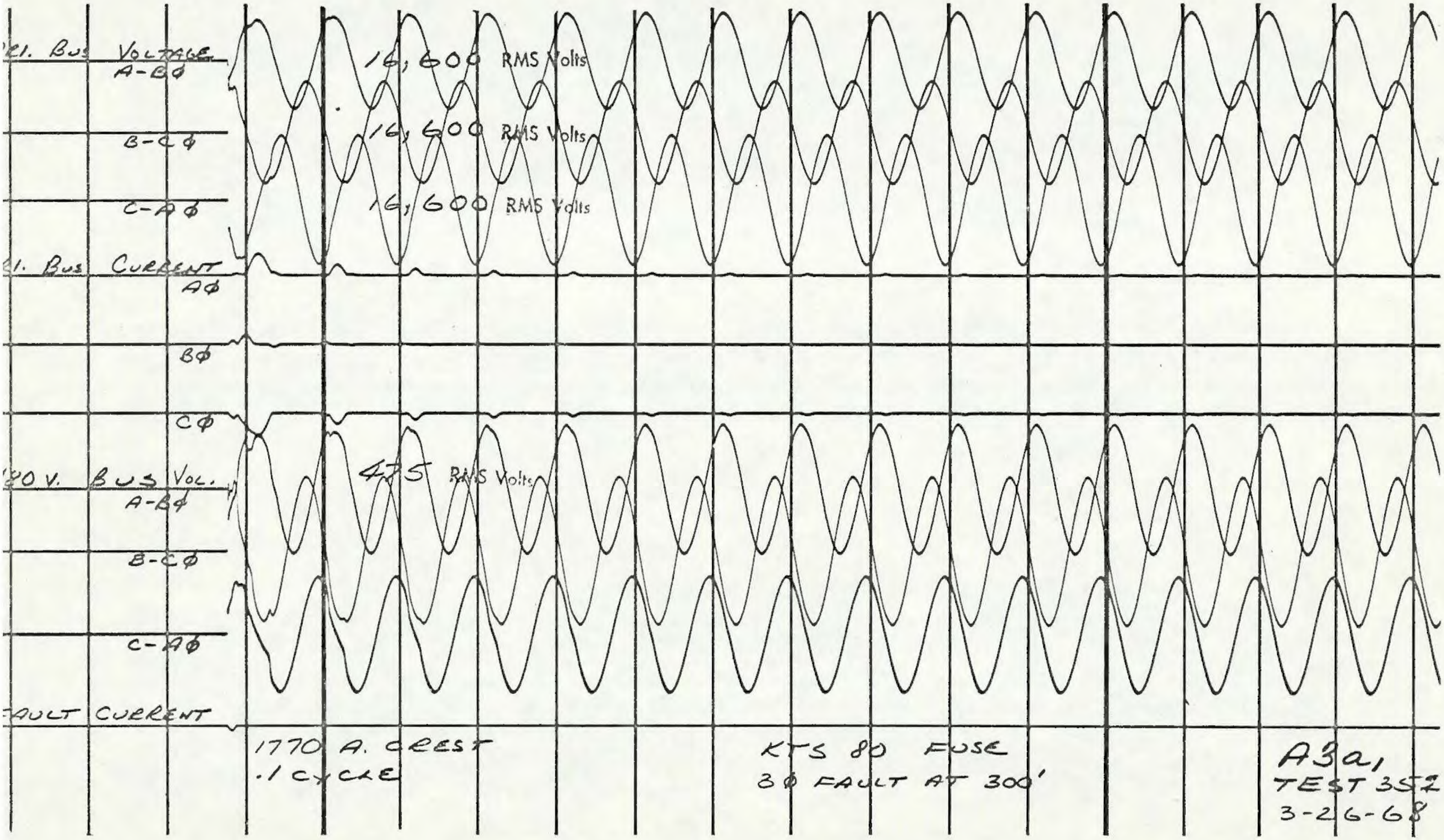
P. L. Wheeler
Assistant Apparatus Engineer


AULT CURRENT
2,700 A. RMS
3,830 A. CREST
2.0 CYCLES
FRS 80 FUSE
3 φ FAULT AT 300'
A4a2
TEST 352
3-26-68

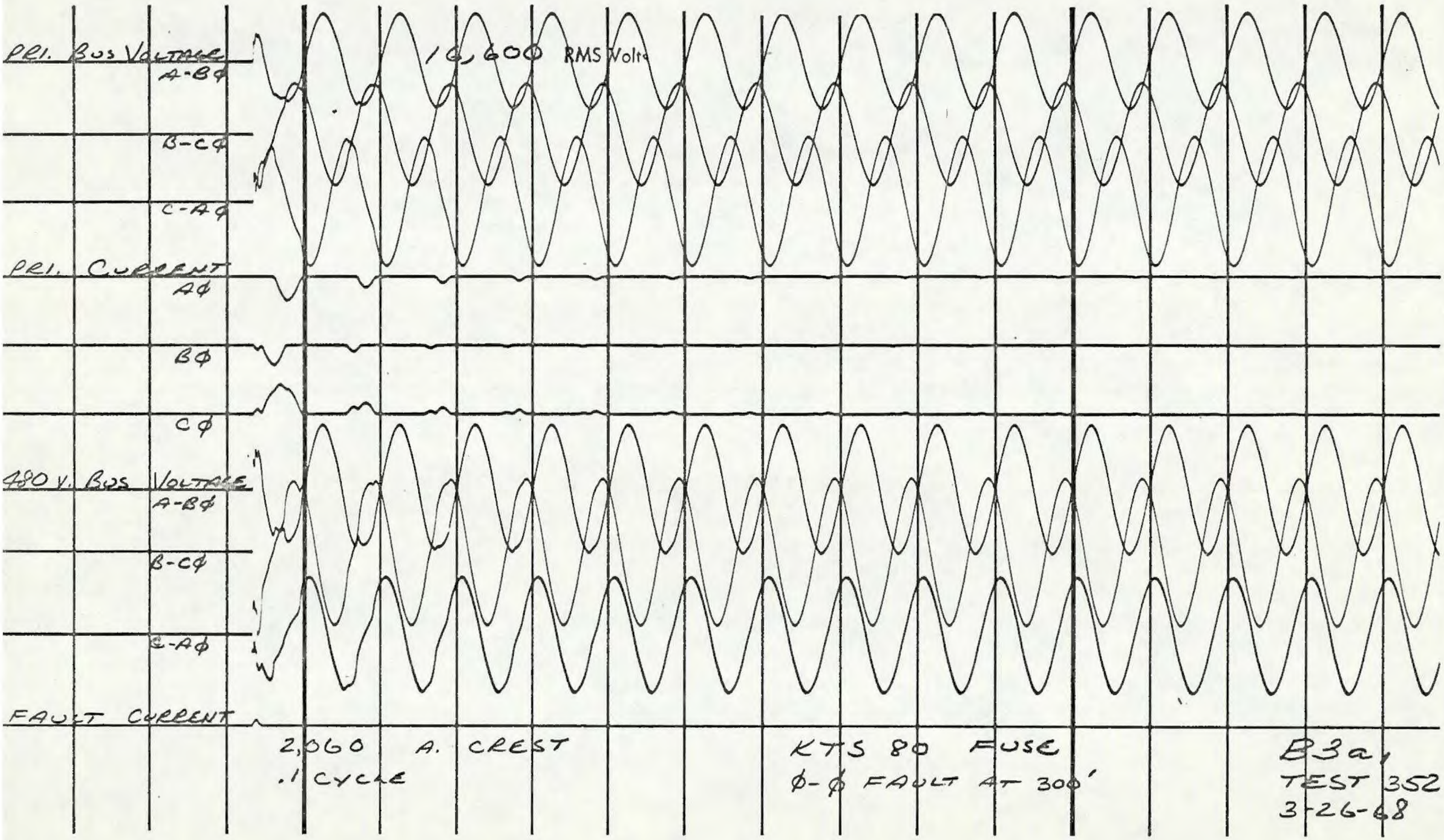

7,060 A. CREST
.5 CYCLES
FRS 80 FUSE
Ø-Ø ARCING FAULT
AT 24'
C4a,
TEST 352
3-26-68

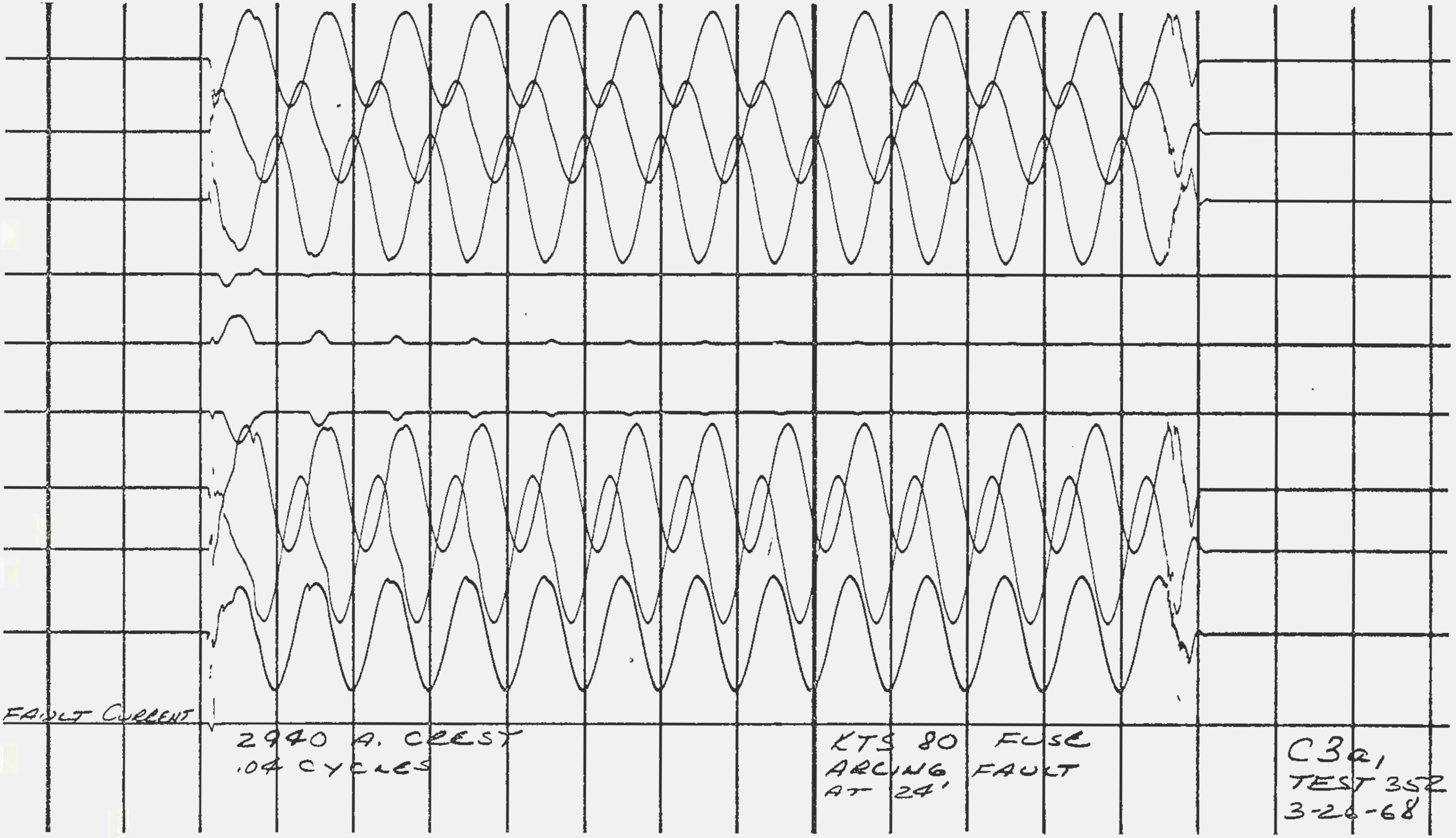


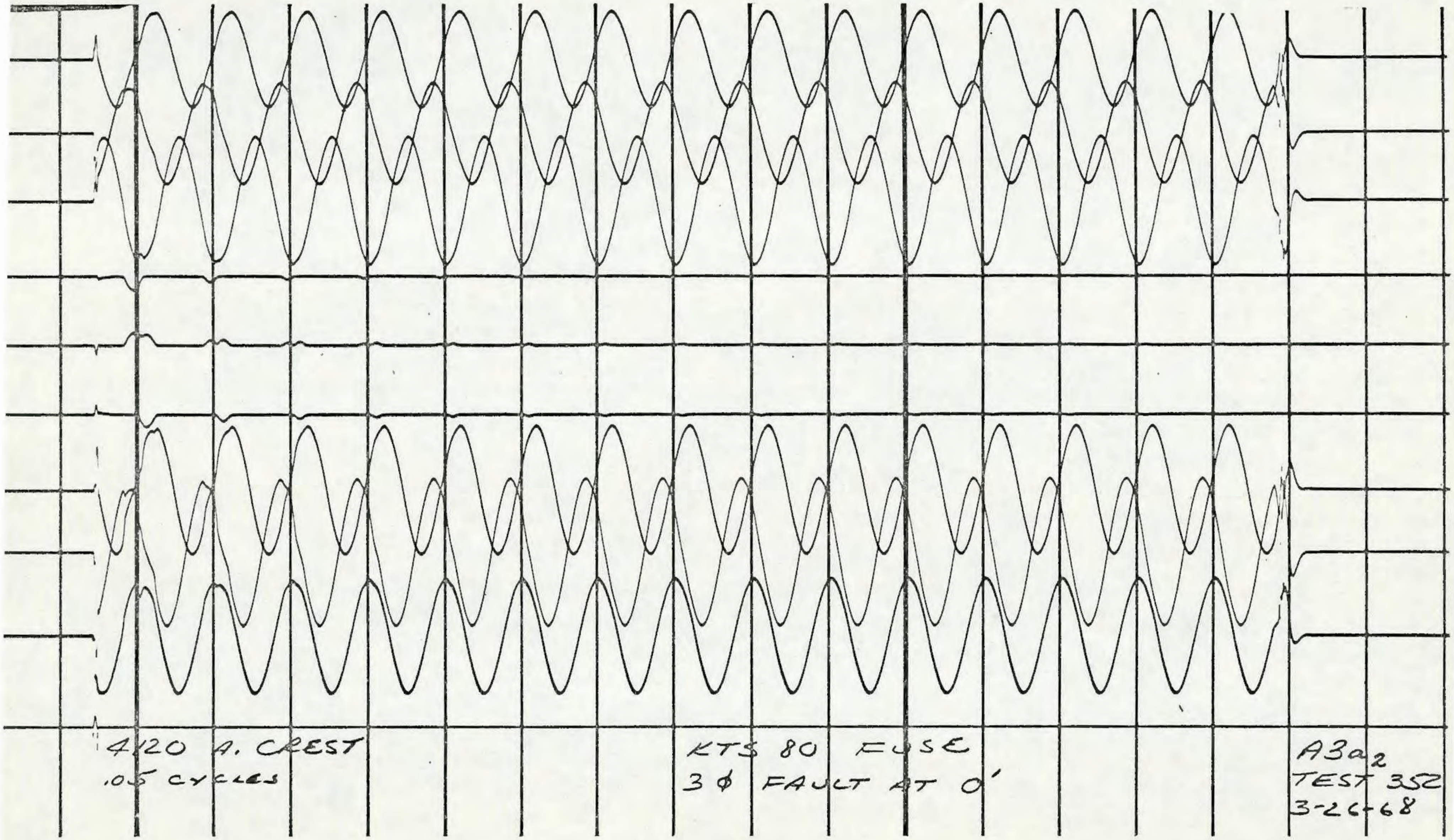
Bus. Vol. A-B ϕ
B-C ϕ
C-A ϕ
Current Aϕ
Bϕ
Cϕ
Bus Vol. A-Bϕ
B-Cϕ
C-Aϕ
Curr.
14,550 A. RMS
13,000 A. Crest when fuse blew
Back-up breaker opened
Connection burned loose
FRS 80 Fuse
3ϕ Fault at 0°
A4a 3
Test 352
3-26-68

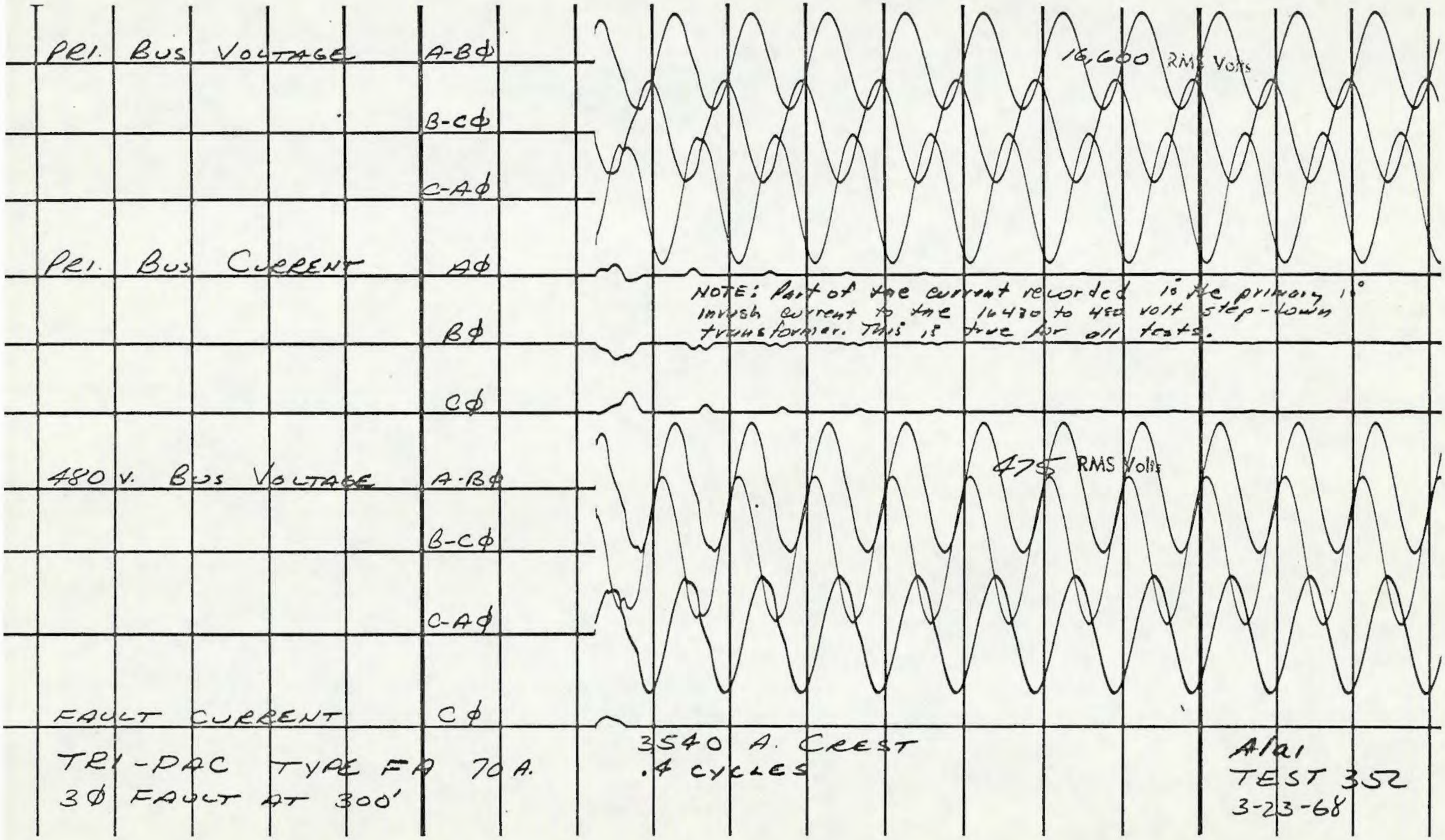


Pri. Bus Voltage
A-Bϕ
16,600 RMS Volts
B-Cϕ
16,600 RMS Volts
C-Aϕ
16,600 RMS Volts
Pri. Bus Current
Aϕ
Bϕ
Cϕ
480 V. Bus Vol.
A-Bϕ
475 RMS Volts
B-Cϕ
C-Aϕ
Fault Current
1770 A. Crest
.1 Cycle
KTS 80 Fuse
3ϕ Fault at 300'
A3a,
Test 352
3-26-68

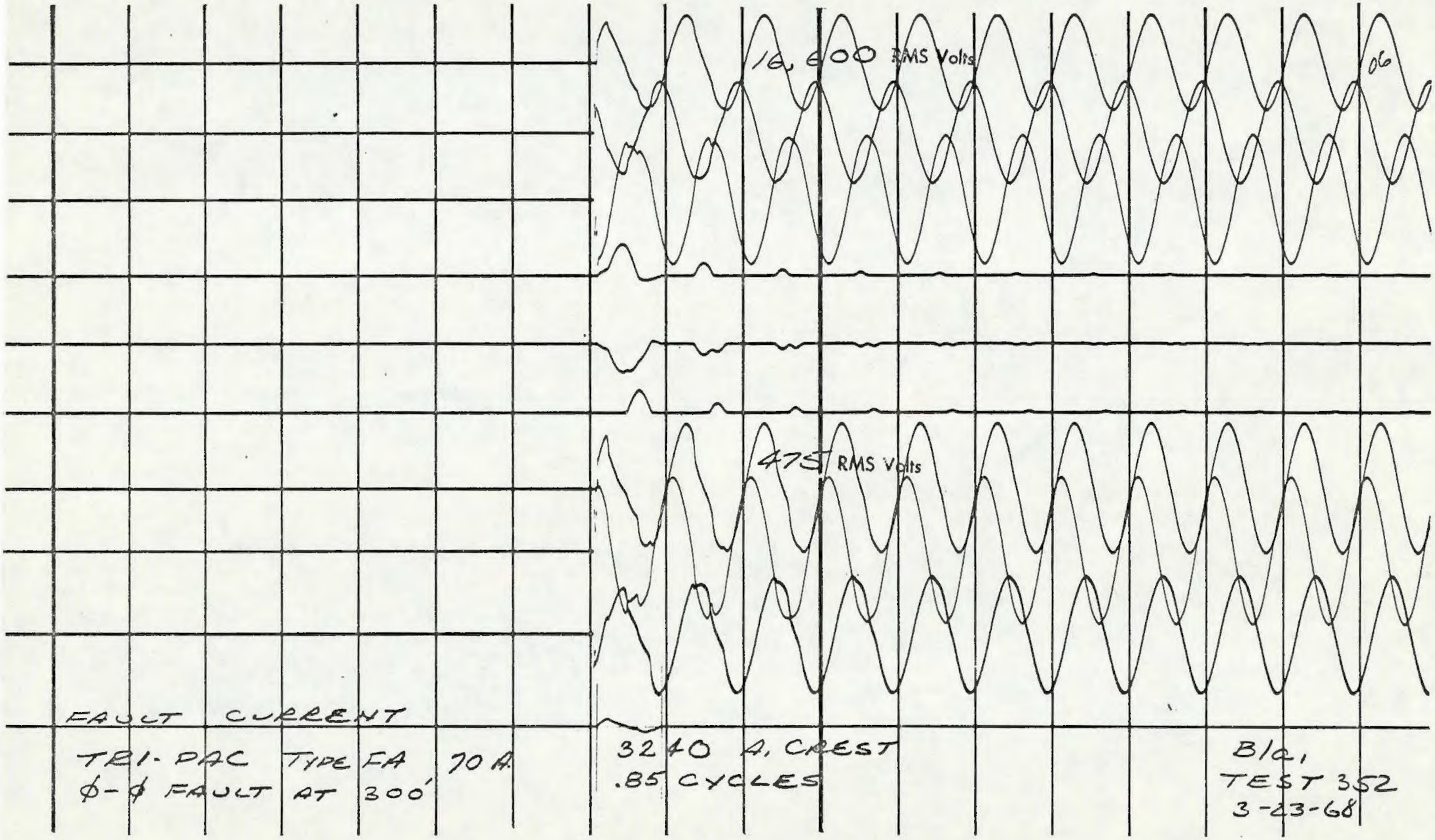

PRI. BUS VOLTAGE
A-BΦ
B-CΦ
C-AΦ
16,600 RMS Volts
PRI. CURRENT
AΦ
BΦ
CΦ
480 V. BUS VOLTAGE
A-BΦ
B-CΦ
C-AΦ
FAULT CURRENT
2,060 A. CREST
.1 CYCLE
KTS 80 FUSE
Φ-Φ FAULT AT 300'
B3a,
TEST 352
3-26-68

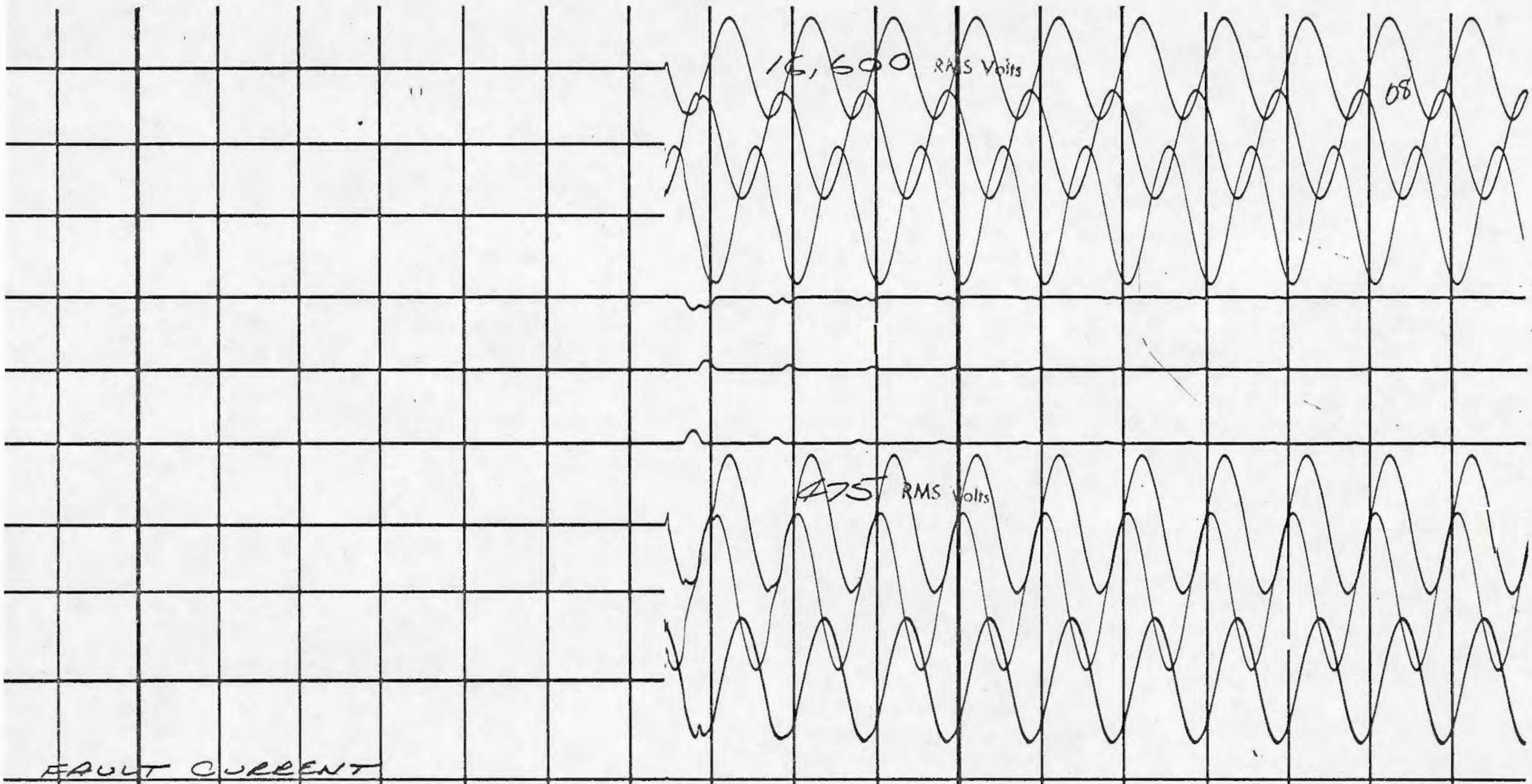

FAULT CURRENT
2940 A. CREST
.04 CYCLES
KTS 80 FUSE
ARCING FAULT
AT 24'
C3a,
TEST 352
3-26-68


4120 A. CREST
.05 CYCLES
KTS 80 FUSE
3φ FAULT AT 0'
A3a2
TEST 352
3-26-68



PRI. BUS VOLTAGE
A-Bϕ
B-Cϕ
C-Aϕ
16,600 RMS Volts
PRI. BUS CURRENT
Aϕ
Bϕ
Cϕ
NOTE: Part of the current recorded is the primary 1° inrush current to the 16430 to 480 volt step-down transformer. This is true for all tests.
480 V. BUS VOLTAGE
A-Bϕ
B-Cϕ
C-Aϕ
475 RMS Volts
FAULT CURRENT
Cϕ
TRI-PAC TYPE FA 70 A.
3ϕ FAULT AT 300'
3540 A. CREST
.4 CYCLES
A1a1
TEST 352
3-23-68

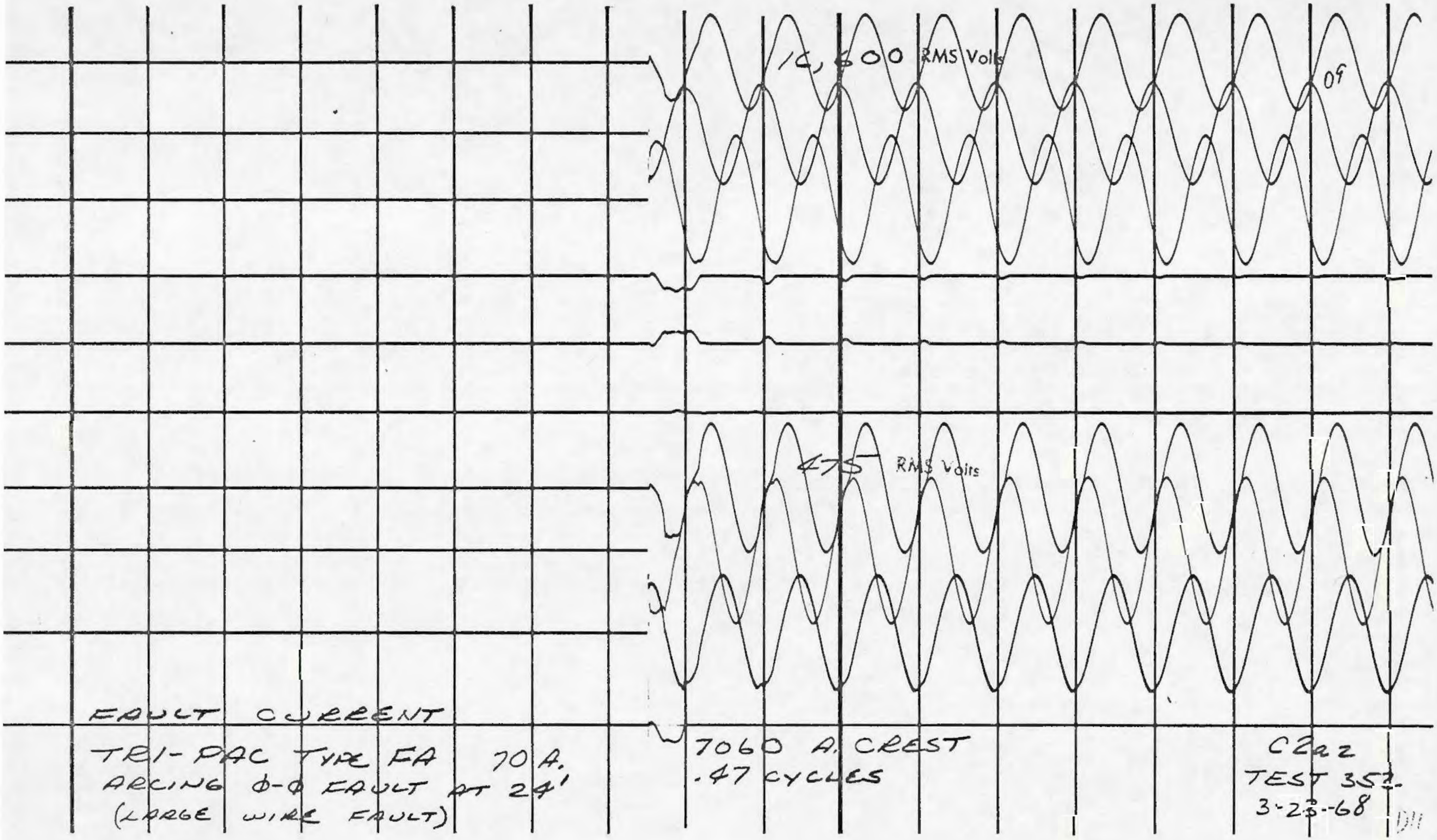

16,600 RMS Volts
06
475 RMS Volts
FAULT CURRENT
TRI-PAC TYPE FA 70 A.
φ-φ FAULT AT 300'
3240 A. CREST
.85 CYCLES
B1a,
TEST 352
3-23-68

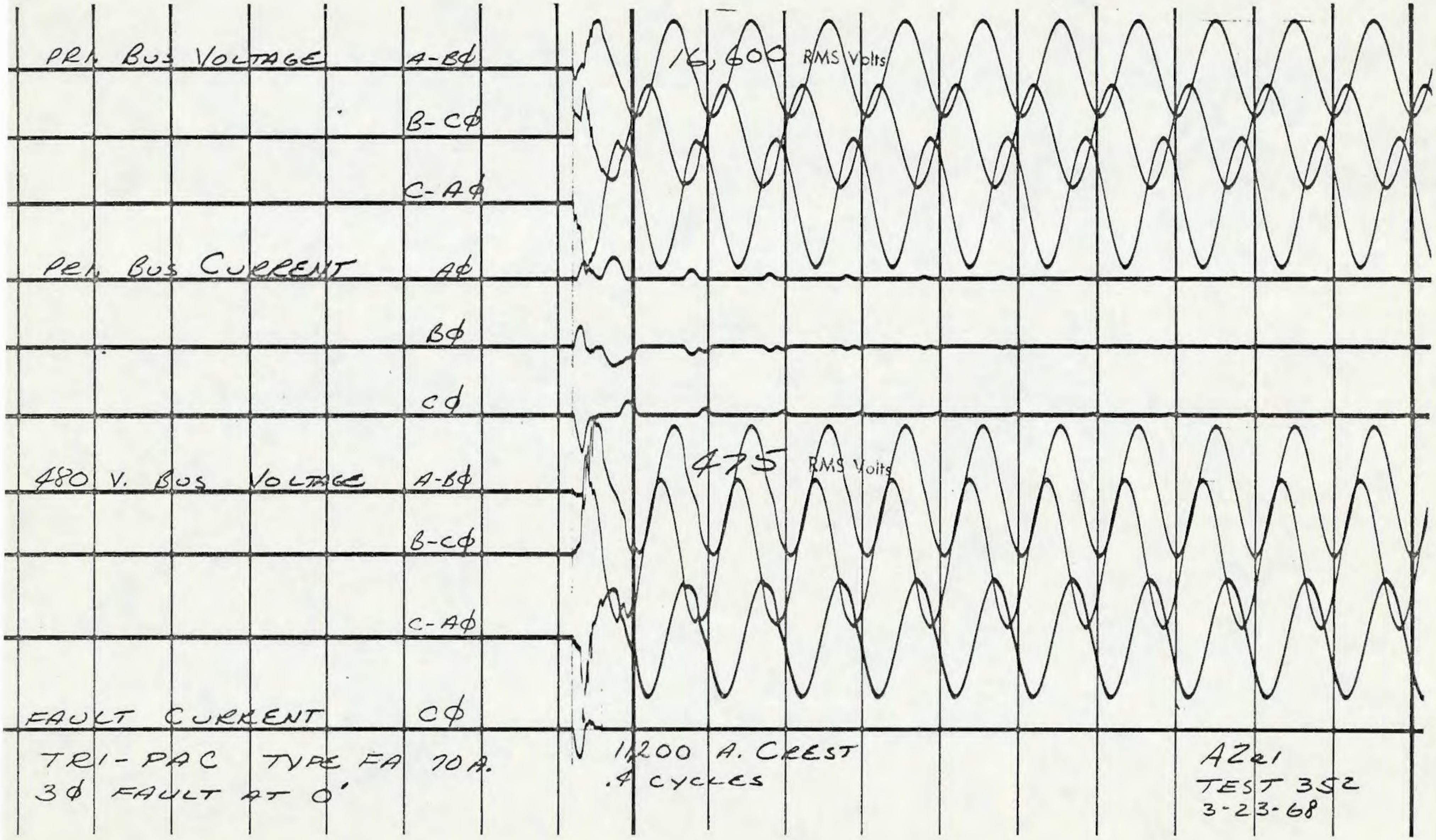


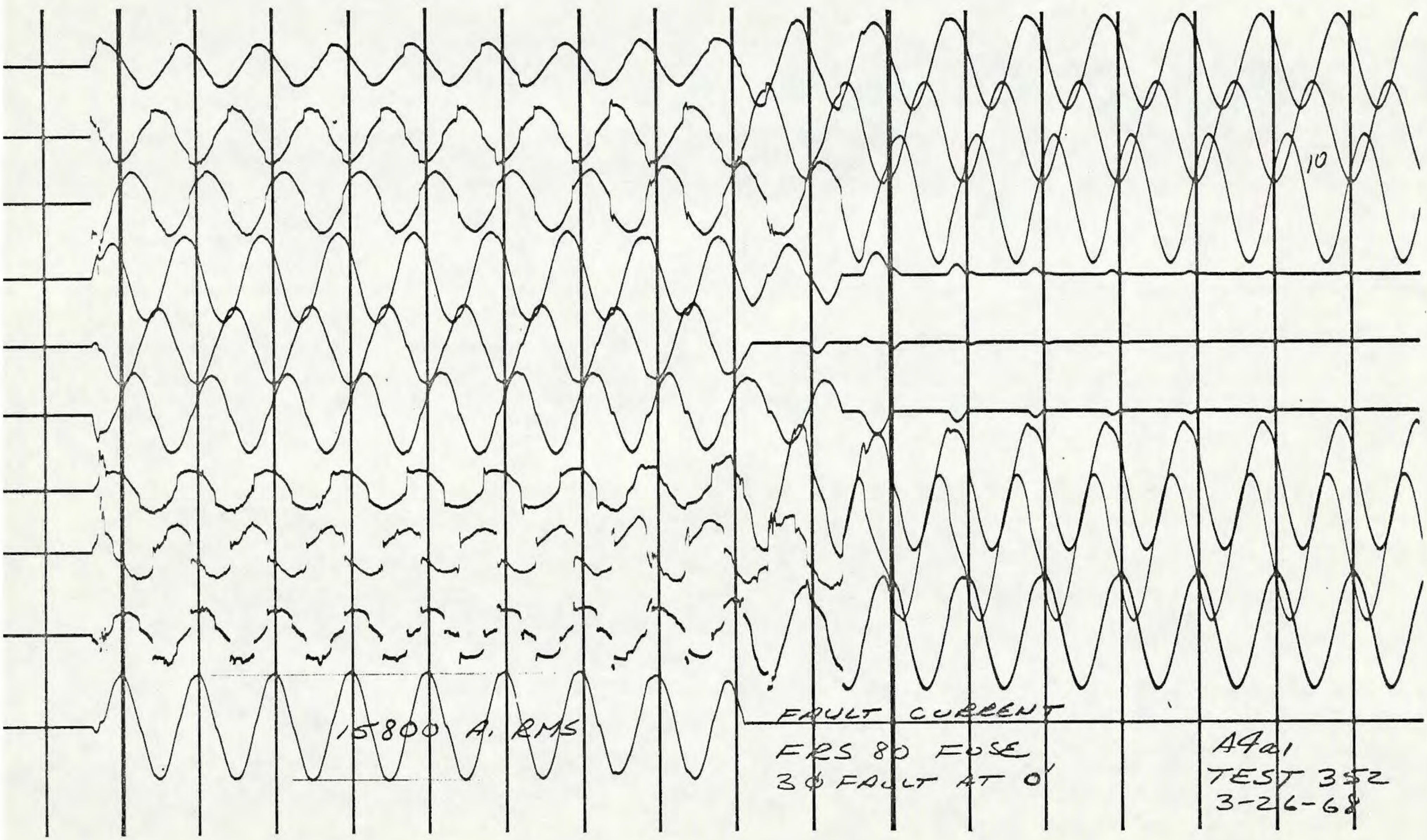
TRI-PAC TYPE FA 70 A.
ARCING φ-φ FAULT AT 24'
(SMALL WIRE FAULT)

CURRENT NOT OF SUFFICIENT MAGNITUDE TO BE MEASURABLE

CZ21
TEST 352
3-23-68


16,600 RMS Volts
475 RMS Volts
FAULT CURRENT
TRI-PAC TYPE FA 70 A.
ARCING Φ-Φ FAULT AT 24'
(LARGE WIRE FAULT)
7060 A. CREST
.47 CYCLES
TEST 352
3-23-68


PRI. BUS VOLTAGE
A-Bϕ
B-Cϕ
C-Aϕ
16,600 RMS Volts
PRI. BUS CURRENT
Aϕ
Bϕ
Cϕ
480 V. BUS VOLTAGE
A-Bϕ
B-Cϕ
C-Aϕ
475 RMS Volts
FAULT CURRENT
Cϕ
TRI-PAC TYPE FA 70 A.
3ϕ FAULT AT 0'
1,200 A. CREST
.4 CYCLES
AZel
TEST 352
3-23-68


10
15800 A. RMS
FAULT CURRENT
FRS 80 FUSE
3φ FAULT AT 0'
A4a1
TEST 352
3-26-68

7.1.5 BORIC ACID CRYSTALLIZATION STUDY

BORIC ACID CRYSTALLIZATION STUDY

At 12:31 a.m., March 12, 1968, a fire in the 480-volt switchgear room at San Onofre Nuclear Generating Station resulted in a power loss to the heat tracing on the boric acid injection system. At the time of the failure the average temperature of the injection system was 175°F.

During this period two unsuccessful attempts were made to inject boric acid into the reactor coolant system using the North Transfer Pump which did not sustain a power loss. The attempts were made at 2:15 a.m. and 3:00 a.m.

Power was restored to the system at 10:10 a.m., on the same day. The heat tracing system recorder indicated that the injection system temperature had decayed in two distinct groups to temperatures of 150°F and 120°F. Due to the fact that the heat tracing system recorder was not operating during the power loss the temperature decay rate could not be determined. It was, therefore, assumed that the decay rate was linear. See attachment.

An inspection of the system revealed that the Boric Acid Storage Tank recirculation line located between the tank and CV 333 is inadequately heat traced. It was observed that when the system was put on recirculation, a cloud of boric acid crystals was pumped out of the recirculation line into the storage tank. Those crystals passed as a cloud through the tank and out the bottom of the tank thus introducing boric acid crystals into the piping system.

The experiments conducted in the laboratory were based on the assumption that at 2:15 a.m. when the first attempt was made to inject boric acid using the North Transfer Pump, boric acid crystals had already formed in the system restricting the transfer pump suction. Therefore, the experiments were conducted with boric acid crystals present in the system. However, it does not seem possible that the system would cool sufficiently in the 1-3/4 hour period between the power failure and the first attempt to inject boric acid to cause the restriction.

The same basic laboratory setup that was used in the previous boric acid crystallization study was used in this study but with two modifications. First, the pump discharged to the top of the ten-foot vertical stand of pipe and second, a one-inch I.D. plastic pipe was inserted at the discharge line to the stainless steel drum from the two-inch I.D. pipe.

As a result of the experiments conducted the following observations were made:

A. Boric acid crystals in the stagnant system that is near its saturation point do not tend to dissolve. If heat is lost on that system, these crystals become the sites at which the precipitation of the boric acid in the system is initiated. This condition can be related to the boric acid crystals which originate in the Boric Acid Storage Tank recirculation line and are injected into the system whenever the system is recirculated.

B. The application of heat by means of heat tracing to a system where boric acid crystals have formed on the walls of the piping in that system results in the boric acid crystals breaking away from the walls of the piping and going into suspension. If the liquid in the system is then pumped, the crystals are carried along with the liquid until they come up against a restriction in the system. At this point they begin to accumulate, gradually shutting off the flow through the restriction.

This occurred in the laboratory at both the pump suction and at the point where the system piping was reduced from two-inch I.D. to one-inch I.D. The capacity of the pump used in the experiment was two gpm. Had a pump with a capacity equivalent to the transfer pump's, 45 gpm, been used the overall effect of the migration and packing would have been greatly magnified.

It is noted that before the North Transfer Pump became operable it was necessary to flush the pump suction. Therefore, the application of the above observation to the existing system is obvious.

The following conclusions are made based on laboratory observations and the inspection of the boric acid injection system.

A. Due to the cold Boric Acid Storage Tank recirculation line, boric acid crystals are probably present in the system at all times.

B. In a system where boric acid crystals have formed as a result of the loss of heat on that system, the reapplication of heat to the system will result in the crystals going into suspension.

C. Boric acid crystals in suspension will migrate with the flow of the fluid in that system.

D. A restriction in the system will result in the accumulation of boric acid crystals at the point of the restriction.

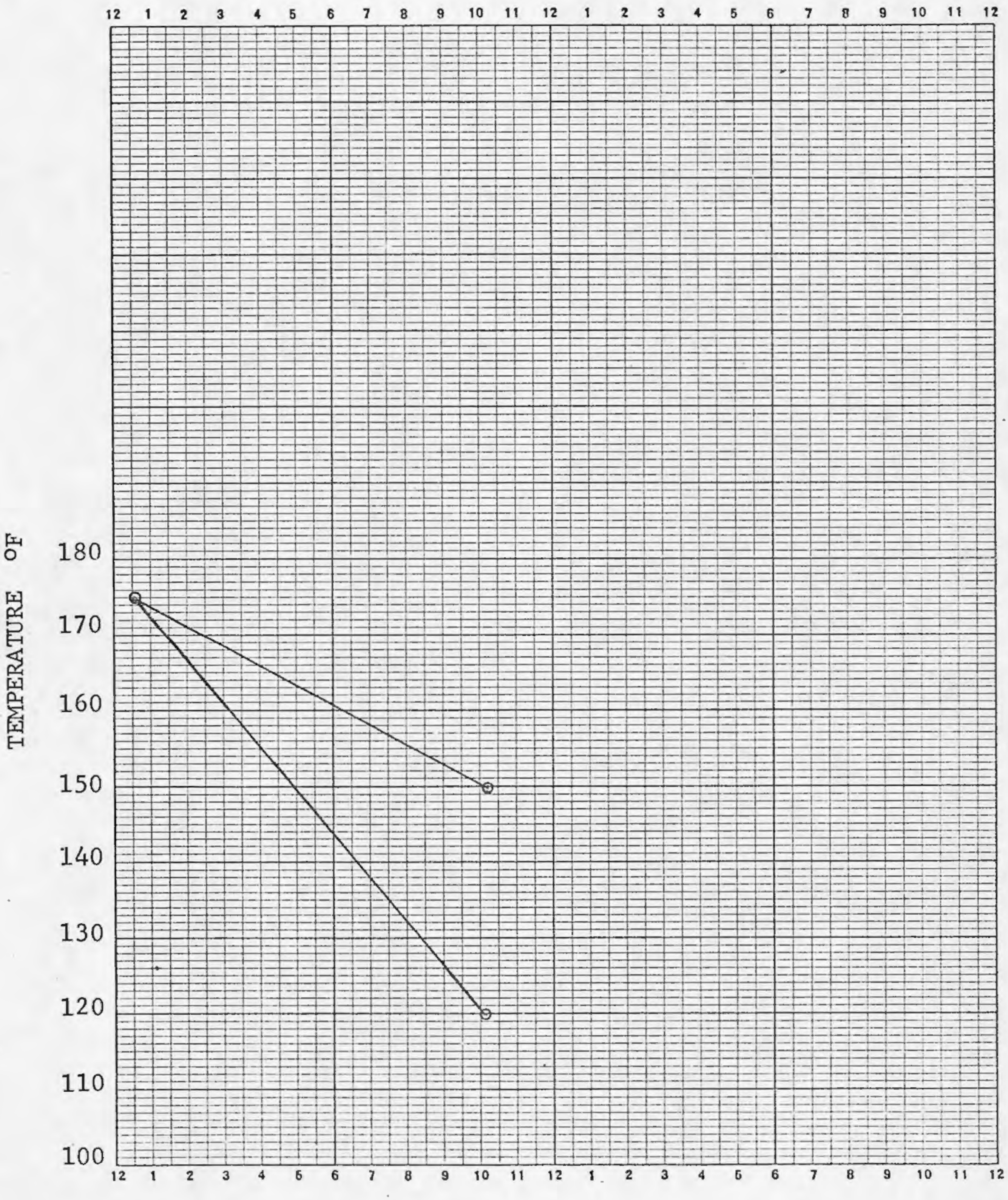
E. The inadvertent injection of boric acid crystals into a system introduces crystal growth sites in the system in the event that heat on the system is lost.

It is not readily apparent how the transfer pump suction was plugged in the short time between the loss of power and the time the North Transfer Pump was operated. However, if it is assumed that boric acid crystals were already present in the suction line followed by a loss of heat tracing, the possibility of rapid crystal deposition exists even though the temperature of the line was above 150°F.

The laboratory experiments have demonstrated the severe packing tendency of the boric acid crystals once they begin to form in a pipe. Thus, if crystals are present in a line the chance of plugging is very high.

R. D. Britt
Chemical Engineer

TEMPERATURE DECAY RATE



7.1.6A CHEMICAL AND VOLUME CONTROL AND RADWASTE SYSTEM TANK OVERPRESSURE INVESTIGATION - METALLURGIST ANALYSIS

METALLURGICAL SERVICE LABORATORIES
division of
TESTING ENGINEERS, INC.
11008 S. NORWALK BLVD. SANTA FE SPRINGS, CALIF. 90670
(213) 723-8541 & 941-3291

LOS ANGEL
SAN DIEG
OAKLANI
SAN JOSE

Date: 4-19-68
P.O. No. T-7747
Lab. No. 18145

SOUTHERN CALIFORNIA EDISON CO.
Division Chemical Section
P.O. Box 392
Redondo Beach, California 90277
Attn: Mr. R. D. Britt

REPORT ON THREE OVERSTRESSED VESSELS IN SAN ONOFRE NUCLEAR STATION

INTRODUCTION

On April 2, 1968, at the request of Mr. R. D. Britt, an examination was made of a flash tank, a waste gas surge tank, and a volume control tank at San Onofre to determine whether possible metallurgical damage had been caused by overstressing to an estimated 125 psi as the result of a power failure.

Mr. R. M. Banister, assistant engineer, assisted in the examination. Mr. Hans Ottoson, station chief, and Mr. J. C. Haynes, chief engineer, were also contacted.

1. FLASH TANK

Per specification book: Length 10'6", O.D. 4'0"; wall thickness of dished heads and of shell 0.140". Material 304 S/S. Per nameplate, tested to 69 psi. Orientation vertical.

This tank showed slight bulging. This was most easily seen at a circumferential weld about 2/3 of the way up the tank. The weld metal, being thicker, had not expanded as much (if at all) as the adjacent metal above and below the weld. Similar constraint against expansion was caused by a horizontal pipe near the top, below which bulging could be seen, and by a large manhole on the side near the top.

No measurements of the tank dimensions after overstressing were available. Therefore, the tank was carefully examined. Observations and checks of the distortion of tank walls indicated that at no point was bulging beyond original dimensions greater than one-quarter of an inch.

EFFECT OF BULGING

Bulging, or circumferential expansion, results in plastic flow of the metal shell, which causes both wall thinning and cold working of the metal. An estimate of the amount of circumferential expansion or stretch of the shell allows judgment as to the effect of such stretch.

Radial expansion of 0.25 inch corresponds to diameter increase of 0.5 inch. This in turn corresponds to a circumferential increase of 1.57 inches. In this 48 inch diameter shell (circumference 151 inches), this equals an elongation of slightly over 1% in the shell plate as a result of the over-stress.

The shell metal, annealed 304 stainless steel, has high ductility and no sharply-defined elastic limit. In conventional tensile testing, it will elongate over 40% before breaking. During this elongating, it is work-hardening. Its "yield point" is being increased by this cold-working.

The effect of a 1% elongation upon the mechanical properties will be slight. The yield point will be slightly raised, so that subsequent overpressure up nearly to the level of the first excursion will cause no further bulging. The wall thickness will be reduced by about 1% - but this amount, 0.0014 inch, is within the manufacturing tolerance for the plate.

It is concluded that the measured bulging has had no harmful effect on the general shell.

Metal immediately adjacent to the welds may have stretched somewhat more, due to local bending. Such local elongation cannot have exceeded 3%. This is much less than the deformation capability of sound welds in 304 stainless.

SUGGESTED FURTHER EXAMINATION

Because of the very slight possibility that local stretching in the welds may have caused incipient cracking at or near a weld, non-destructive testing along circumferential welds was suggested. External testing by ultrasonic techniques was subsequently performed. No indications of cracks were reporte

Since no cracks were revealed by this inspection method, it is concluded that the tank can safely be used at pressures up to that to which the overpressure subjected it.

2. WASTE GAS SURGE TANK

Per specification book: Length 10'7"; O.D. 4'6"; wall thickness of shell and heads 0.375". Material A285C steel, which is straight carbon steel. Per nameplate, tested to 88 lbs. Orientation vertical.

Careful examination of all sides disclosed no hint of a bulge, either at the welds or elsewhere.

CONCLUSION
It is concluded this tank, with much heavier walls, was undeformed. Therefore there is no possibility of any damage having occurred due to the overstressing, and no need for further inspection.

3. VOLUME CONTROL TANK
Per specification book and nameplate: 11'7" long, 5'0" O.D., heads 0.241" thick; shell 0.250" thick. Material 304 S/S. Tested to 75 lbs. Orientation horizontal.

Careful examination disclosed no bulging or distortion beyond normal fabrication limits. Shell and welds were straight and regular.

CONCLUSION
Same as for waste gas surge tank; no damage and no need for further inspection.

4. SUMMARY
The flash tank was bulged very slightly, by an amount far less than its capacity to resist. Because local stretch due to bending at girth welds may have exceeded overall stretch, non-destructive examination of weld areas was recommended. Subsequent ultrasonic inspection was reported to have shown no suspicious indications.

Based on our examination and the ultrasonic testing, we conclude that the flash tank was undamaged and fit for service.

The other two tanks were found to be undamaged and to have experienced no possibility of damage.

G. M. Butler
Metallurgical Engineer
California Reg. No. 454

7.1.6B CHEMICAL AND VOLUME CONTROL AND RADWASTE SYSTEM TANK OVERPRESSURE INVESTIGATION - HYDROSTATIC TEST OF THE VOLUME CONTROL, WASTE GAS SURGE AND FLASH TANKS

HYDROSTATIC TEST OF THE CHEMICAL AND VOLUME CONTROL, WASTE GAS SURGE AND FLASH TANKS

As a result of the apparent over-pressurization, hydrostatic pressure tests were conducted to further affirm that these tanks were suitable for continued service. The pressure testing of these tanks was accomplished satisfactorily on April 29-30, 1968. No leakage was observed from the tanks.

Results are tabulated as follows:

Tank	Test Pressure	Pressurizing Medium	Design Pressure
Chemical and Volume Control	75 psig	Water and Nitrogen	75 psig
Flash Tank	30 psig	Nitrogen	30 psig
Waste Gas Surge Tank	30 psig	Nitrogen	30 psig

7.2 PREVIOUS DESIGN BASIS FOR CABLE SIZING

PREVIOUS DESIGN BASIS FOR CABLE SIZING

INTRODUCTION

The criteria for wire and cable size and for determining electric cable tray loading used in Southern California Edison power plant design is established to accomplish the following:

A. Power Wire and Cable Size

1. To carry load currents with conductor temperatures remaining within the limit established by the wire and cable manufacturer to obtain full expected cable insulation life.

2. To carry fault current until interrupted by primary protection and have the conductor temperature rise remain within the manufacturer's specified temperature limits.

3. To limit circuit voltage drop to three percent.

4. To provide a margin for an increased expected wire and cable life. This is to be accomplished with the conductor temperature remaining below the manufacturer's established rated temperature for the majority of the generating plant operating time.

B. Control Wire Size

Control wire to be sized to provide mechanical strength. This results in the current carrying capacity of the conductors being oversized with respect to actual current which must be carried.

C. Insulation for Wire and Cable

The insulation to meet requirements of environment and service.

D. Electric Cable Tray Fill

The cable tray not to be overfilled with cable. Tray deflection not to exceed 1/360 of the span. Tray designed to carry 50 pounds per foot of wire and cable and a 200-pound live load anywhere along the span between supports such as would be imposed by a man.

DESIGN GUIDES

Design guides and practices which have been employed to accomplish the requirements of the above criteria are as follows:

A. Sizing Power Wire and Cable

1. Conductor size is established by first multiplying the rated or load current by a size increasing factor then selecting a conductor rated by the manufacturer to carry this larger current. The multiplying factor used is 1-1/2 for loads fed from switchgear and 1-1/4 for loads fed from motor control centers. The wire and cable ampacity table used is from Insulated Power Cable Engineers Association (IPCEA) for

"Three Circuits in a Duct" or Triplex Cables in a Circuit." Incorporated in this table are factors to be used for varying conditions of design temperature. The design temperature used depends on plant location and on the specific application within the plant. The 5-kV power cables supplying power from the unit and start-up transformers to the 4160-volt switchgear are rated to carry peak start-up load current. This normally exceeds the transformer full load rating. In addition, the cables are placed in a single layer in the tray with space between cables.

2. Cables also are sized to carry fault current within the manufacturer's limit for total conductor temperature (usually about 200°C). This requirement, many times, results in cables being sized larger than required for current carrying requirements as stated in Section A above.

3. Cable conductors are sized to operate with less than three percent voltage drop for full load current operation. This also may result in cables being sized larger than required for the current carrying requirements.

4. Increased cable life is expected, as the above factors provide for wire and cable operating at conductor temperatures less than the maximum allowed by the manufacturer. Experience gained from previous plants bears out the fact that when these design guides are followed, cables operate at less than maximum allowable temperatures.

B. Electric Cable Tray Fill

Cable tray supports designs are established to meet the tray loading requirements of 50 pounds per foot of wire and cable and of a single 200-pound live load anywhere along the tray span between tray supports. The 50-pound per foot of wire or cable is considered conservative. (As a measure, a heavier cable such as three conductor, 5-kV armored 750 MCM weighs 11.5 pounds per foot. A more commonly used single conductor 4/0 cable weighs 0.85 pound per foot.)

Cable tray fill is reviewed when the cross sectional area of the cables approach 30 percent and is limited to 40 percent when running a large variety of cables. The review point is established to equalize loading between trays. Computer programs are to be utilized to control the tray fill.

EXAMPLES OF CABLE SIZING AND APPLICATION IN EXISTING EDISON PLANTS

Each of the following examples are for existing 480-volt circuits either in motor control centers, or in switchgear.

Cable sizing as to ampacity is taken from IPCEA Table VIII, and Page 309 for 40°C ambient and 90°C conductor temperature for 1000 volts.

A. 480-Volt Switchgear Sources

1. Redondo Generating Station

Seal Water Injection Pump - rated 100 HP, three-phase, 119 amperes full load current.

Cable used - three NO 2/0 copper IPCEA rating - 215 amperes

Calculations - 1.5 X 119 = 180 amps. (well within 215 ampere rating)

2. Redondo Generating Station

Main Turbine Auxiliary Pump - rated 150 HP, three-phase, 176 ampere full load current.

Cable used - three NO 4/0 copper IPCEA rating - 287 amperes

Calculations - 1.5 X 176 = 264 amperes (falls within the 287 ampere rating)

B. 480-Volt Motor Control Center Source

1. Redondo Generating Station

Furnace TV Blower - rated 15 HP, three-phase, 19.2 amperes full load current.

Cable used - three NO 10 copper IPCEA rating - 40 amperes

Calculations - 1.25 X 19.2 = 24 amperes (well within the 40 amperes rating)

2. El Segundo Generating Station

Air Preheater Rotor Drive Motor - 15 HP, three-phase, nameplate data - 20.1 amperes full load current.

Cable used - three NO 8 copper IPCEA rating - 59 amperes

Calculations - 1.25 X 20.1 = 25 amperes (well within 59 amperes rating)

7.3.0 MATERIAL SPECIFICATION NO. 225

SOUTHERN CALIFORNIA EDISON COMPANY

LOS ANGELES, CALIFORNIA

MATERIAL STANDARD NO. 225-63
(Revision of M.S. 225-61)

SPECIFICATION

FOR

600-VOLT RUBBER-LIKE-INSULATED CONTROL CABLES

January 10, 1963

MATERIAL STANDARD NO. 225-63
(Revision of M.S. 225-61)

SPECIFICATION FOR 600-VOLT RUBBER-LIKE-INSULATED CONTROL CABLES

PART 1.00

INTRODUCTION

1.01 INTENT

1.01.01 It is the intent of the Southern California Edison Company to obtain apparatus which meets all of the requirements set forth in the paragraphs which hereinafter follow.

1.02 INSTRUCTIONS TO BIDDERS

1.02.01 As noted elsewhere, this Specification (M.S. No. 225-62) is the revision of Material Standard No. 225-61. Bidders are advised to read this Specification (M.S. No. 225-62) in its entirety.

1.02.02 Wherever used in this Specification the word "Edison" shall mean the Southern California Edison Company, and the word "Manufacturer" shall mean the successful bidder on this Specification. The word "apparatus" is used herein to include apparatus, equipment, materials, supplies, or whatsoever may be purchased hereunder with all the usual and appropriate fittings, attachments, appurtenances, and appliances.

1.02.03 Arrows shown on the right of the pages which make up this Specification are for Edison's use when preparing a Quotation Request. Insofar as the Manufacturer is concerned, the arrows in no way alter the meaning or intent of any paragraph or portion thereof; therefore, they shall in no way relieve the Manufacturer of his obligations.

1.02.04 Bidders shall quote on 600-volt rubber-like-insulated control cables which may be required by Edison exactly as specified herein. The general and technical requirements of the cables are set forth in Part 3.00 of this Specificatio

1.02.05 Paragraph 2.03.03.c of this Specification does not apply.

1.02.06 Additional instructions to Bidders, if any, will be specified in the Quotation Request.

PART 2.00

CONTRACT CONDITIONS

2.01 CHANGES IN SPECIFICATIONS

2.01.01 No changes shall be made in this Specification or referenced Edison Specifications unless authorized by Edison through its Purchasing Agent. Should any conflict prevail between this Specification (or referenced Edison Specifications) and the Manufacturer's Proposal, this Specification (or referenced Edison Specifications) shall prevail. Edison shall have the right to make reasonable changes at any time to the aforesaid Specifications including drawings which are a part thereof or made a part thereof by reason of the changes. Should such changes increase or decrease the amount due or in the time required for performance, an equitable adjustment will be made.

2.02 COMPLIANCE WITH CODES AND STATUTES

2.02.01 The Manufacturer's Apparatus shall comply with the applicable requirements of all statutes, ordinances, codes, and standards of legally constituted authorities having jurisdiction. The Manufacturer shall obtain certificates of compliance where required.

2.03 WORKMANSHIP AND MATERIAL

2.03.01 The intent of this Specification is to secure for Edison Apparatus of first class workmanship in all respects. All components shall be manufactured, fabricated, assembled, and finished with workmanship of the highest quality throughout, and in accordance with the best recognized correct practice.

2.03.02 All materials shall be new, of first class quality, and suitable for the conditions specified.

2.03.03 Unless specified elsewhere in this Specification:

a. All materials used in the manufacture of the Apparatus shall conform to the latest standard of the American Society for Testing and Materials.

b. All electrical design, materials, tests, and construction shall conform to the latest applicable standards of the United States of America Standards Institute (formerly American Standards Association), the Institute of Electrical and Electronics Engineers, and the National Electrical Manufacturers Association, unless specifically excepted by this Specification. In case of conflicting requirements of these standards, they shall apply in the sequence that they are here listed.

c. All structural steel design shall conform to the latest standards of the American Institute of Steel Construction, Inc.

2.03.04 If the Manufacturer has any reason for deviating from the above standards, he shall state in his Quotation exactly the nature of the change and his reasons for making the change.

2.03.05 The finished product shall be complete in all respects and shall fully conform to the description thereof set forth in this Specification and in the covering Purchase Order.

2.04 INSTALLATION

2.04.01 Said Apparatus will be installed by and at the expense of Edison unless otherwise specified in the Quotation Request.

2.05 INSPECTION, TESTS, AND EXPEDITING

2.05.01 Edison shall be allowed access to the Manufacturer's shops and also to those of the Manufacturer's suppliers to inspect the Apparatus and workmanship, to witness tests, and to obtain other desired information. Inspectors representing Edison shall be given every facility to inspect the work during all stages of manufacture, testing, and shipment.

2.05.02 Inspection of the Apparatus may be at the Manufacturer's shops and/or those of his suppliers, or upon receipt at destination at the option of Edison. Inspection by Edison at the aforesaid shops will not be made except on special request by Edison's Purchasing Agent. The waiving of inspection thereof shall in no way relieve the Manufacturer of the responsibility of furnishing Apparatus according to this Specification.

2.05.03 The Manufacturer shall inform Edison of the progress of the work and shall give Edison ample advance notice of the appropriate times for inspections and/or tests. Specified tests will be approved and may be supervised by Edison.

2.05.04 When specific inspections and/or tests are required, the work on the Apparatus involved shall not proceed beyond that point until Edison has made or waived such inspections and tests.

2.05.05 If performance tests are to be made in the field, they are to be made at times and under conditions to be mutually agreed upon by Edison and the Manufacturer.

2.05.06 Certified copies of all performance tests shall be furnished to Edison.

2.05.07 The Manufacturer shall furnish to Edison, if so requested and at no additional cost, shop and mill reports when specified.

2.05.08 The costs of all tests made in the shops are to be borne by the Manufacturer.

2.06 ACCEPTANCE

2.06.01 Edison shall not be deemed to have accepted the Apparatus until it has made sufficient tests to enable it to determine that the Apparatus meets all of the requirements of said Specifications. Such tests shall be made within six (6) months from the date the Apparatus is completely installed ready for use. The conditions of any tests shall be mutually agreed upon and the Manufacturer shall be notified of and may be represented at all tests that may be made. If inspection and/or tests show the Apparatus or any part thereof not to be as represented and/or contracted for, Edison may refuse to accept it, but the Manufacturer shall have a reasonable time within which to correct the Apparatus at his own expense.

2.07 WARRANTY

2.07.01 Manufacturer warrants that the Apparatus and all parts thereof to be delivered hereunder shall be of the kind and quality described herein and shall perform in the manner specified in Specifications and no other warranty, except of title, shall be implied. If any failure to comply with said Specifications appears within the period of one (1) year from the date of the commencement of use of the Apparatus but not later than eighteen (18) months from date of delivery, Edison shall notify the Manufacturer thereof immediately, and the Manufacturer shall thereupon correct without delay and at his own expense the defect or defects by repairing the defective part or parts or by supplying a non-defective replacement thereof, but, if the Apparatus is installed or its installation supervised by the Manufacturer, the aforesaid period shall run for one (1) year from the date of completion of installation and acceptance provided same is not unreasonably delayed by Edison. In the event the Manufacturer shall correct any defect as hereinabove provided, then with respect to the Apparatus corrected the aforesaid period shall run for one (1) year from the date of completion of installation of such correction and acceptance thereof provided same is not unreasonably delayed by Edison. The liability of Manufacturer (except on warranty of title and on the liability respecting patents herein set forth) arising out of the supplying of said Apparatus or its use whether on warranties or otherwise, shall not in any case exceed the cost of correcting defects in the Apparatus as above set forth and upon the expiration of said one (1) year, all such liability shall terminate.

2.08 PATENTS

2.08.01 The Manufacturer shall, at his own expense, defend all suits or proceedings instituted against Edison, its officers, agents, or employees, based upon any claim that the Apparatus or any part or use thereof constitutes an infringement of any patent of the United States covering the Apparatus, any part thereof or the process intended to be performed thereby and will pay any and all awards of damages assessed against Edison, its officers, agents, or employees, in any such claim, suit or proceedings, and will indemnify and save harmless Edison against any losses, expenses (other than expenses of Edison's own Law Department), and/or damages resulting from any such claim, suit or proceedings and/or incurred in obedience to a decree resulting from any such claim, suit or proceeding, or pursuant to a compromise thereof approved by the Manufacturer, provided that Edison, promptly upon service of process upon it, gives to the Manufacturer notice in writing, or by telegraph, of the institution of such suit or proceeding, and permits the Manufacturer, through counsel chosen by it, and satisfactory to Edison, to defend the same, and gives the Manufacturer all needed information, assistance and authority to enable the Manufacturer so to do. If in any such suit, a temporary restraining order, or preliminary injunction be granted, the Manufacturer will make every reasonabl effort, by giving a satisfactory bond, or otherwise to secure the suspension of such restraining order or temporary injunction. If, in any such suit, the Apparatus, or any part thereof, or the process performed thereby, be held to constitute an infringement, and its use be permanently enjoined, the Manufacturer will at once make every reasonable effort to secure for Edison a license, authorizing the continued use of the Apparatus, or of such part or process. If the Manufacturer be unable to secure such license within a reasonable time, it will, at its own expense, and without impairing performance requirements, either replace the Apparatus with non-infringing Apparatus, or modify the Apparatus or the process performed thereby to avoid infringement. If unable to do either of the above things, the Manufacturer will remove the Apparatus and refund the money paid therefor, in addition to indemnifying and saving harmless Edison, as aforesaid.

2.09 RIGHT TO USE WORK REQUIRING CORRECTION

2.09.01 If, after the Apparatus has been installed it is discovered that it or part thereof may require correction as herein elsewhere provided, Edison shall nevertheless have the right to use such Apparatus until such time as it is convenient to Edison that such Apparatus be removed from service for correctio

2.10 SHIPMENT, PACKING, AND PIECE MARKING

2.10.01 The Apparatus shall be shipped in assembled units insofar as is consistent with good shipping practice.

2.10.02 The Apparatus shall be carefully packed for shipment and loaded on the cars or docks at the Manufacturer's plant ready for shipment. Machined and other unpainted surfaces shall be fully protected from impact and weather damage. All openings into the Apparatus shall be carefully plugged or covered so as to be fully protected against weather damage. All costs of packing, loading, and blocking are to be borne by the Manufacturer.

2.10.03 When items must be disassembled for shipment they shall be matchmarked. All units and their containers shall be piece-marked and shall show the Purchase Order number. When specified, they shall show the Edison Material Standard number.

2.11 RISKS

2.11.01 The Manufacturer shall not be held responsible or liable for any loss, damage, detention, or delay caused by fire or strike, civil or military authority, or insurrection or riot, or any other cause which is unavoidable or beyond his reasonable control, or in any event for consequential damages.

2.12 INSURANCE

2.12.01 In order to permit Edison, after the Apparatus has been delivered to the Carrier F.O.B. as aforesaid, to maintain upon such Apparatus or part thereof sufficient insurance to protect Edison's interest therein, the Manufacturer agrees immediately to inform Edison's Traffic Department of each shipment, giving detailed information as to car numbers, etc., and of the value of each such carload and shipment to enable Edison to maintain such insurance.

2.13 TITLE

2.13.01 The title to the Apparatus herein specified shall pass at the actual point of shipment at the time such Apparatus shall be delivered by the Manufacturer to the Carrier for transportation as herein elsewhere specified.

MATERIAL STANDARD NO. 225-63
(Revision of M.S. 225-61)

SPECIFICATION FOR 600-VOLT RUBBER-LIKE-INSULATED CONTROL CABLES

PART 3.00

GENERAL AND TECHNICAL REQUIREMENTS

3.01 SCOPE

3.01.01 Specified herein are the general and technical requirements of the 600-volt rubber-like-insulated single-conductor and multi-conductor control cables which may be required by Edison. The cables shall be insulated, jacketed, cabled, and covered, and they shall be suitable for operation under the service conditions specified below.

3.02 SERVICE CONDITIONS

3.02.01 The control cables furnished under this Specification shall be suitable for installation in underground ducts and conduits, cable trenches, trays and racks, underground structures, terminals in buildings, and any outdoor application. If the cable is intended for direct burial or aerial service it will be so stated in the Quotation Request.

3.02.02 The control cables shall be suitable for operating both in wet and dry locations and in installations with alternately wet and dry conditions.

3.02.03 Atmospheric ozone concentrations up to a maximum of one (1) ppm for extended periods during the year may be present in the areas where these cables will be installed.

3.02.04 Operating voltages will be control and supply voltages of not more than 600 volts either a-c or d-c.

3.03 REFERENCE SPECIFICATIONS

3.03.01 The finished cable and its components shall conform as a minimum requirement with the following industry specifications and standards, unless otherwise specified herein:

a. Insulated Power Cable Engineers Association (IPCEA) Standard S-19-81 (Third Edition). This is also NEMA Publication No. WC 3-1959, Rubber-Insulated Wire and Cable for the Transmission and Distribution of Electrical Energy.

3.03.01 (Continued)

b. American Society for Testing Materials (ASTM) Standards D-574-59T. Insulated Wire and Cables, Ozone-Resistant Type Insulation; D-752-60, Heavy Duty Neoprene Sheath for Wire and Cable; D-1352-60, Ozone-Resisting Butyl Rubber Insulation for Wire and Cable.

3.04 CONFORMANCE TO APPROVED MANUFACTURERS' PRODUCT SPECIFICATION

3.04.01 The cable purchased under this Specification shall be insulated, jacketed, and assembled in accordance with the respective Manufacturer's recommendation insofar as it is consistent with this Specification. The following paragraphs which pertain to each respective Manufacturer are a part of this Specification for that respective Manufacturer and list the approved product for use in this Specification. The Manufacturer shall notify Edison of any re-issue or change in the referenced product specification.

*3.04.02 Oil-Base Insulated Control Cables:

a. Kerite Product Specification Reference: Engineering Data on Kerite Insulated Wires and Cables.

1. Single-conductor Cables: The conductors of single-conductor cables shall be insulated with Kerite insulating compound together with tapes and N. S. Neoprene jacket; or, insulated with Kerite insulating compound with combined TP-nylon braid jacket.

2. Multi-conductor Cables: Each conductor of multi-conductor cables shall be insulated with Kerite, after which, the insulated conductors shall be cabled together with jute fillers and the assembly covered either with a N. S. Neoprene jacket or a combined TP-nylon braid jacket.

b. Okonite Product Specification Reference: Okonite Bulletin 1085, dated 1954.

1. Single-conductor Cables: The conductors of single-conductor cables shall be insulated with Okolite insulating compound with a bonded Okoprene jacket.

2. Multi-conductor Cables: Each conductor of multi-conductor cables shall be insulated with Okolite with a bonded Okoprene jacket,

* Part c of this Paragraph has been deleted (Rome Product Specification).

3.04.02 (Continued)

after which, the insulated and jacketed conductors shall be cabled together with rubber-like fillers and the assembly covered with an Okoprene jacket.

3.04.03 Butyl-Base Insulated Control Cables:

a. Anaconda Product Reference Specification: GP CS 147-4 dated July 1958, and GP CS 206-1, dated May 1959.

1. Single-conductor Cables: The conductors of single-conductor cables shall be insulated with Anaconda low-voltage Butyl insulating compound with a heavy duty black Neoprene jacket (IPCEA Standard S-19-81, Paragraph 4.13.3).

2. Multi-conductor Cables: Each conductor of multi-conductor cables shall be insulated with Anaconda low-voltage Butyl insulating compound with a heavy duty black Neoprene jacket (IPCEA Standard S-19-81, Paragraph 4.13.3), after which the insulated and jacketed conductors shall be cabled together with rubber-like fillers and the assembly covered with a heavy duty black Neoprene jacket (IPCEA Standard S-19-81, Paragraph 4.13.3).

b. Okonite Product Specification Reference: Okonite Okonex (Keystone) insulated Cable Bulletin H-463, dated August 1955.

1. Single-conductor Cables: The conductors of single-conductor cables shall be insulated with Okonex Butyl insulating compound with bonded Okoprene jacket.

2. Multi-conductor Cables: Each conductor of multi-conductor cables shall be insulated with Okonex Butyl insulating compound with bonded Okoprene jacket, after which the insulated and jacketed conductors shall be cabled together with rubber-like fillers and the assembly covered with an Okoprene jacket.

3.04.03 (Continued)

c. Rome Product Specification Reference: (Rome Power and Control Cables, Specification No. ROA-2, dated March 1968

1. Single-conductor Cables: The conductors of single-conductor cables shall be insulated with Rozone-A Butyl insulating compound with Roprene jacket.

2. Multi-conductor Cables: Each conductor of multi-conductor cables shall be insulated with Rozone-A Butyl insulating compound with Roprene jacket, after which the insulated and jacketed conductors shall be cabled together with rubber-like fillers and the assembly covered with a Roprene jacket.

d. Simplex Product Specification Reference: Specification No. 1685-F.

1. Single-conductor Cables: The conductors of single-conductor cables shall be insulated with Simplex Anhydrex XX insulating compound with a heavy duty, black Neoprene jacket (IPCEA Standard S-19-81, Paragraph 4.13.3).

2. Multi-conductor Cables: Each conductor of a multi-conductor cable shall be insulated with Simplex Anhydrex XX insulating compound with a heavy duty black neoprene jacket, after which the insulated and jacketed conductors shall be cabled together with rubber-like fillers and the assembly covered with a heavy duty black Neoprene jacket (IPCEA Standard S-19-81, Paragraph 4.13.3).

3.05 INSULATION AND JACKET

3.05.01 The insulating material shall consist of high-quality ozone-resistant-type compounds and shall conform as a minimum requirement to IPCEA Standard S-19-81, Parts 3.14 and 3.15, ASTM Standard D-574-59T or D-1352-60.

3.05.02 The jacket material shall consist of black neoprene compound having characteristics that conform, as a minimum requirement, to IPCEA Standard S-19-81, Paragraph 4.13.3, or ASTM Standard D-752-60 for heavy duty or other approved materials as referred to in Section 3.04 above.

3.05.03 For cables rated at 600 volts, the insulation and jacket thickness shall be in accordance with IPCEA Standard S-19-81, Part 3, Table 12 (insulation), and IPCEA Standard S-19-81, Part 4, Tables 26 and 29 jacket), except that single-conductor cables, No. 9 AWG and smaller, shall have a jacket thickness of not less than 30 mils. However, when specified in the Quotation Request, single-conductor cables No. 4/0 AWG and smaller shall have a jacket thickness of not less than 65 mils.

3.06 FILLERS

3.06.01 Fillers used to seal or fill the interstices between insulated conductors in multi-conductor cables shall not adhere to the jacket over the individually insulated conductors or to the jacket over the cable assembly.

3.07 CONDUCTORS

3.07.01 The Quotation Request will specify if the conductors are to be of aluminum or soft-annealed copper.

3.07.02 Conductors shall be stranded in accordance with IPCEA Standard S-19-81 for Class B concentric-lay stranded conductors.

3.07.03 Each individual strand of a copper conductor shall be coated with lead, lead alloy, or tin. The tensile, electrical, and coating properties of the coated wire shall conform to ASTM Standard B-189-58 or B-33-58.

3.07.04 The individual strands of aluminum conductors shall be uncoated and shall have tensile and electrical properties that conform to ASTM Standard B-262-61 for three-quarter hard-drawn partially annealed aluminum wire (EC-26 or EC-16).

3.08 IDENTIFICATION

3.08.01 Each single-conductor and multi-conductor cable shall incorporate a durable life-time identification which shows the Manufacturer's name, the year of manufacture, and the words "600-volt Control Cable", all at intervals not to exceed three feet. Either of the following methods are acceptable:

a. A legible and durable life-time printed tape placed in the conductor strands, or under the jacket of single-conductor cables; or, in the conductor strands or under the overall jacket of multi-conductor cables.

b. Embossing, engraving, or printing on the surface of the jacket of single-conductor cables and overall jacket of multi-conductor cables.

3.08.02 No conductor coding, either colored, printed, or otherwise, is required.

3.09 TESTS AND TEST REPORTS

3.09.01 Each coil, reel, or length of insulated conductor that is not to be individually covered with a vulcanized rubber-like jacket shall receive and fully withstand after vulcanization, and after immersion in water for at least 6 hours, the application of alternating current voltage equal to or greater than that stated in IPCEA Standard S-19-81 for the appropriate conductor size applicable to cables with a 600-volt rating and insulated with ozone resistant compound. Any insulated conductor individually covered with a vulcanized jacket shall be tested as above after vulcanization of the jacket.

3.09.02 The Manufacturer shall submit, in duplicate with each shipment of cable, his conventional test report normally furnished to Edison which shall provide a certified record of test results together with a statement to the effect that the cables meet the requirements of this Specification.

3.09.03 When specified in the Quotation Request the Manufacturer shall furnish with each shipment of cable the data called for on the accompanying "Special Data and Test Report Tabulation." Edison will furnish the forms to be used for this requirement. For all the test data required, it is desired that the sampling conform to IPCEA Standard S-19-81, Section 6.4 relating to the number of samples for physical tests, except that one sample shall be selected from each order in which the total quantity ordered (regardless of conductor size or number of conductors) is between 2,000 feet and 50,000 feet of cable, and one additional sample for each additional 50,000 feet thereafter.

3.09.04 Edison reserves the right to make any standard dielectric tests on the cable; such tests will conform to IPCEA Standard S-19-81.

3.10 REELING, PACKING, AND SHIPPING

3.10.01 Cables shall be shipped on reels and shall be in a single length per reel with both ends securely fastened to the reel. Cable shall be properly protected to assure delivery without damage during ordinary shipping and handling operations.

3.10.02 Both cable ends shall be taped or otherwise sealed to prevent the entrance of moisture.

3.10.03 Reels shall be of substantial construction, of adequate diameter, and covered or lagged to provide adequate protection for the cable. Care shall be exercised to assure that no nails or foreign objects extend through the covering or lagging which might puncture or penetrate the cable.

3.10.04 All reels shall be plainly marked with the Manufacturer's name, description of the cable including size, conductor material, voltage rating, type and thickness of insulation and jacket, length, gross weight, Edison Purchase Order number, and destination. The reel number shall be shown on the same side as the above information. In addition, the following description shall be plainly marked on the same side as the above information: 600-Volt Control Cable.

NOTIFICATION OF CHANGE NO. 1

TO MATERIAL STANDARD NO. 225-63

SPECIFICATION FOR

600-VOLT RUBBER-LIKE-INSULATED CONTROL CABLES

April 18, 1963

TO: ALL HOLDERS OF MATERIAL STANDARD NO. 225-63, Specification For Rubber-like-insulated Control Cables.

The following change has been approved and is hereby made a part of Material Standard No. 225-63:

Delete the last sentence in Paragraph 3.05.03.

R. M. Taylor

R. M. TAYLOR
Manager of Purchases

FBF:teb

Copies to: Apparatus Division list of holders of M.S. 225-63

MATERIAL STANDARD NO. 225-63
SPECIFICATION FOR
600-VOLT RUBBER-LIKE-INSULATED CONTROL CABLES

DATE ______________

SOUTHERN CALIFORNIA EDISON COMPANY
SPECIAL DATA AND TEST REPORT TABULATION
PHYSICAL DATA

1. Voltage Rating ______________

2. No. of Conductors ____ ____ ____ ____ ____ ____

3. Overall Diameter of Finished Cable ____ ____ ____ ____ ____

4. Weight Per M Feet of Finished Cable ____ ____ ____ ____ ____

5. Wire -

   Size ____ ____ ____ ____ ____ ____

   No. of Strands ____ ____ ____ ____ ____ ____

   Material ____ ____ ____ ____ ____ ____

   Coating (For Copper) -
   Mark One Lead or Lead
   Alloy, Approx. & Lead ______________

   Tinned Yes ______________

6. Insulation -

   Chemical or Type Name ______________

   IPCEA Designation ______________

   Manufacturer's Trade Name ______________

   Insulation Thickness ____ ____ ____ ____ ____ ____

7. Jacket -

   Chemical or Trade Name ______________

   IPCEA Designation ______________

   Manufacturer's Trade Name ______________

   Jacket Thickness Over
   Insulated Conductor ____ ____ ____ ____ ____

   Jacket Thickness Over
   Completed Assembly ____ ____ ____ ____ ____

MATERIAL STANDARD NO. 225-63
SPECIFICATION FOR
600-VOLT RUBBER-LIKE-INSULATED CONTROL CABLE

SOUTHERN CALIFORNIA EDISON COMPANY
SPECIAL DATA AND TEST REPORT TABULATION
PHYSICAL CHARACTERISTICS

GENERAL

Testing Methods, etc., shall conform to the applicable portions of the latest revision of IPCEA Standard S-19-81, Sections 3, 4, and 6.

	INSULATION	JACKET
ORIGINAL		
1. Tensile Strength, psi	______	______
2. Elongation at Rupture, in % (2" gauge)	______	______
3. Permanent Set, in Inches	______	______
4. Tensile Stress at 200% Elongation, psi	______	______
AFTER AGING		
5. Oxygen Pressure or Air Pressure Heat Test	______	______
Tensile Strength, in % of Original	______	______
Elongation at Rupture, in % of Original	______	______
Tensile Stress at 200% Elongation, psi	______	______
6. Air Oven Test		
Tensile Strength, in % of Original	______	______
Elongations at Rupture, in % of Original	______	______
Tensile Stress at 200% Elongation, psi	______	______
7. Ozone Resistance Test (Indicate any Effect)*	______	______
8. Old Immersion Test		
Tensile Strength, in % of Original	______	______
Elongation at Rupture, in % of Original	______	______

* A complete description from the supplier as to method of test and calculations is a requirement herein.

MATERIAL STANDARD NO. 225-63
SPECIFICATION FOR
600-VOLT RUBBER-LIKE-INSULATED CONTROL CABLE

SOUTHERN CALIFORNIA EDISON COMPANY
SPECIAL DATA AND TEST REPORT TABULATION
ELECTRICAL CHARACTERISTICS, INSULATION

GENERAL

Testing methods, etc., shall conform to the applicable portions of the latest revision of IPCEA Standard S-19-81, Sections 3, 4, and 6.

1. Final Factory a-c Test Value, kv ______________ Test Duration ______________ Min.

2. Final Factory d-c Test Value, kv ______________ Test Duration ______________ Min.

3. Short-Time Dielectric Strength Test

   Breakdown Voltage, kv ________________

   Withhold Time During Last Step ________________ Min.

   (Refer to IPCEA Standard S-19-81, Section 6.5)

4. Insulation Resistance ________________________

5. Accelerated Water Absorption*

   (Refer to IPCEA Standard S-19-81, Section 6.9)

	Power Factor Measurement at 80v/mil	SIC
24 hours	______________________%	______
7 days	______________________%	______
14 days	______________________%	______

Stability Factor ____%

* A complete description from the supplier as to method of test and calculations is a requirement herein.

7.3.1. SIMPLEX 600-VOLT CABLE TEST

PHOENIX • SEATTLE • HONOLULU LOS ANGELES • SAN FRANCISCO

GARNETT YOUNG & COMPANY
SUBSIDIARY OF SIMPLEX WIRE & CABLE CO.
2901 E. VAL VERDE COURT, COMPTON, CALIFORNIA 90221
TELEPHONE: (213) 774-3170 TELEX: 67-287

RECEIVED
MAR 29 1968
APPARATUS DEPT.

March 27, 1968

Mr. Jack Cohon
Southern California Edison Company
Post Office Box 351
Los Angeles, California 90053

Subject: Test Data Samples Control Cable
San Onofre Generating Plant

Dear Mr. Cohon:

Please find attached copies of Mr. M. J. Koulopoulos's telexes of March 25 and 26, 1968, in regards to tests made on the two samples of 1/C #6 AWG copper Anhydrex XX Insulation (butyl) neoprene jacket 600 volt cable from job site.

Should you desire additional information or further test data, please advise.

Very truly yours,

GARNETT YOUNG AND COMPANY

M. J. Lumpkin
Sales Manager

MJL:jo

SCADSLOSANGE

SCADS CAMB 3

MARCH 25, 1968
LOS ANGELES
TIME 1610 EST

M.J. LUMPKIN

RE SAN ONOFRE: SAMPLE NO. 1 IDENTIFIED AS BETWEEN FIRE AND SHERE. NO. 2 AS BETWEEN FIRE AND SOURCE. PHYSICALS INDICATE BOTH SAMPLES SUBJECTED TO OVERHEATING CONDITION. NO. 2 MUCH WORSE THAN NO. 1. INSULATION ON BOTH SAMPLES STILL LOOKS OK.

SAMPLE		INSULATION	SPEC	JACKET	SPEC
1	ELONG.	450%	350	225%	300
	TENSILE	950 PSI	600	2460 PSI	1800
2	ELONG.	354		142	
	TENSILE	795		2300	

BOTH SAMPLES PASSED U.L. HORIZONTAL FLAME TEST. GAS FLAME APPLIED 30 SEC THEN REMOVED. FLAME EXTINGUISHED IMMEDIATELY. CHARRED AREA GLOWED 4 MINUTES.

BOTH SAMPLES HEATED TO 200 C BY CURRENT LOADING. BURNER APPLIED ONE MINUTE. LOAD AND BURNER REMOVER AFTER ONE MINUTE. 3 1/2 INCH PROPAGATION 1 MINUTE 25 SECONDS BURNING TIME.

M.J. KOULOPOULOS
MK

(This teletype message has been retyped to permit reproduction.)

MARCH 26
ATTN M LUMPKIN

RE SAN ONOFRE INSULATION UNDER CRACKED NEOP
HAD ELONGATION 287% AND 825 PSI TENSILE. RESULTS INDICATE
INSULATION ONLY VERY SLIGHTLY EFFECTED BY HEAT. TEST ON ONE
FOOT SAMPLE REMOVED FROM TRAY DAMAGED BY FIRE AS FOLLOWS:
INSULATION 325% ELONGATION AND 755 TENSILE. JACKET 100% ELONGATION
AND 2140 PSI TENSILE. INSULATION IS NORMAL. JACKET VERY DEFIN-
ITELY SHOWED HEAT AGING.

M.J. KOULOPOULOS
SCADS CAMB 2

SCADSLOSANGL

(This teletype message has been retyped to permit reproduction.)

TABULATION OF TEST RESULTS OF PHYSICAL PROPERTIES

OF SIMPLEX CABLE INSULATION & JACKETS

	San Onofre Samples #1	#2	New Cable Test Report	Simplex Spec.
Insulation Ten. Str. psi	950 psi	795 psi	1003 osi	600 psi
Insulation Elong. %	450 %	354 %	525 %	350 %
Jacket Ten. Str. psi	2460 psi	2300 psi	2470 psi	1800 psi
Jacket Elong. %	225 %	142 %	425 %	300 %

NOTE: Sample #1 ran from fire area to sphere.
Sample #2 ran from switchgear to fire area, and is in worse condition than #1.

7.4 CABLE TRAY THERMAL LOADING ANALYSIS

ANALYSIS OF CABLE TRAY THERMAL LOADING

PURPOSE

In this appendix the method is explained which was used in the thermal investigation of the cable trays. Using the methods developed below, it is possible to insure that the cables throughout the plant will operate below their recommended maximum temperature under normal plant operating conditions.

INTRODUCTION

The placement of various power and control cables in the cable trays can be best described as random. An analysis of the infinite combinations of cable placement in a cable tray is impossible; therefore, a configuration was chosen which represented the very worst possible arrangement of cables in a tray. This arrangement is one of all the power cables in the tray grouped in a tight circular bundle and the remaining control cables bundled tightly over the power cables. Thus, if the configuration described above can operate at the normal operating temperature recommended by the manufacturer, we are assured that the specific cable tray will be thermally safe.

ANALYTICAL APPROACH

Once the worst possible thermal arrangement has been established, the task is to determine the maximum temperature within the bundle for a given ambient air temperature. Referring to Figure 1, it is seen that three temperature differences must be evaluated, and the sum of the temperature differences is added to the ambient temperature to arrive at the maximum temperature in the center of the power and control cable bunch. The method of calculating the temperature gradient through each medium is explained in detail in the following paragraphs.

The temperature gradient through the power cable bundle (Tp) can be calculated using the equation for the temperature drop in a cylinder which is generating heat uniformly throughout its volume. Holman [1] gives the equation.

$$T_p = \frac{\dot{q}R^2}{4K} \qquad (1)$$

Where T_p = temperature gradient from axis of cylinder to outside surface.

$\dot{q}$ = heat generated per unit volume.

R = radius of cylinder.

K = thermal conductivity of the material.

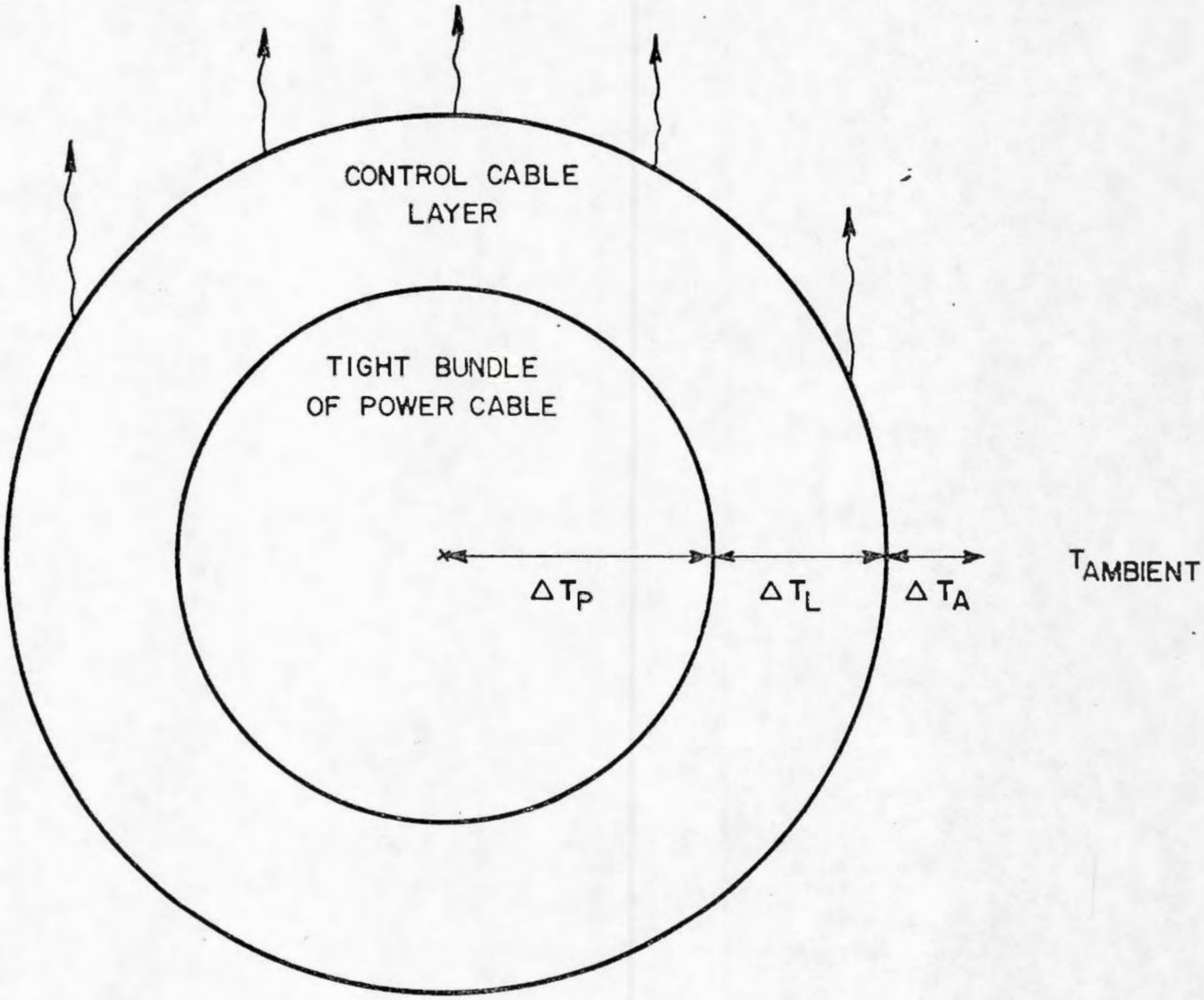


FIGURE 1 - CABLE TRAY CONFIGURATION REFLECTING THE MOST SEVERE THERMAL CONDITIONS POSSIBLE.

Equation (1) can be expressed in terms of the heat generated per unit length by making the substitution

$$\dot{q} = \frac{q}{\pi R^2}$$

to get

$$T_P = \frac{q\rho}{4\pi} \qquad (2)$$

where q = heat generated per unit length.

ρ = thermal resistivity of material.

It is seen from equation (2) that the temperature gradient through a bundle of power cables, each generating uniform heat, is independent of the bundle diameter if the heat loss is expressed in heat per unit length.

In applying this equation to the condition of a nonhomogeneous mixture of power cables, the heat loss must be reasonably uniform over the bundle cross section. If one or two cables have a significantly high heat output compared with the other cables, some appreciable error can result.

The temperature gradient through the control cable bundle (ΔT_L) is calculated by using the familiar form of Fourier's heat flow equation in polar coordinates, namely

$$\Delta T_L = \frac{q\rho}{2\pi} \log_e \frac{D}{d} \qquad (3)$$

where ΔT_L = temperature gradient from the inside of the layer to the outside of the layer.

q = total heat per unit length flowing through the layer.

ρ = thermal resistivity of the layer material.

D = outer diameter of the layer.

d = inside diameter of the layer.

In the above equation it has been assumed that there is no air flow through the bundle of power and control cable and that all heat is transferred by means of conduction. This may or may not reflect the actual average field conditions, but it certainly is the most realistically severe restriction which can be placed on a cable tray configuration.

The temperature gradient of the overall bundle in air (ΔT_A) is obtained from a consideration of both radiation and convection principles. The temperature gradient produced by a flow of heat from the bundle surface is determined by proportioning the amount of heat which flows due to convection and the amount due to radiation.

Considering first the heat which flows due to convection, the basic equation is used

$$q_c = hA\Delta T_A \quad (4)$$

where q_c = heat per unit foot transferred by convection.

h = heat transfer coefficient.

A = bundle surface area per unit length.

ΔT_A = resulting temperature gradient between the bundle surface and ambient air.

McAdams gives the empirical approximation to evaluate the heat transfer coefficient (h) of horizontal cylinders in air as

$$h = .27\left(\frac{T_A}{D}\right)^{1/4} \quad (5)$$

where ΔT_A = the temperature gradient between the bundle surface and ambient air in °F.

D = diameter of the cylinder in feet.

The units of h are expressed in BTU/(hr-ft^2-°F). Equation (5) is from the work of many investigators and its average deviation is considered to be about $\pm$ 10 percent. The equivalent form of [5] in watts/(ft^2-°C) is

$$h = .3\left(\frac{\Delta T}{D}\right)^{1/4} \quad (6)$$

where ΔT is in °C
D is in inches

A simplified form of the Stefan-Boltzmann equation is used to evaluate the heat radiated from a cable bundle

$$q_r = 4\sigma A\varepsilon(Tavg)^3\Delta T_A \quad (7)$$

where q_r = heat per unit length radiated from the bundle.

σ = Stefan-Boltzmann constant.

ε = thermal emissivity of the bundle

Tavg = average absolute temperature of the bundle surface and the surroundings.

ΔT_A = temperature gradient between the bundle surface and the surroundings.

The above approximate equation is very accurate for the small temperature difference encountered in power cable applications.

Equations (4) and (7) are used together, using the fact that the sum of the heat transferred by convection and radiation is exactly equal to the heat generated in the power cables under steady state conditions. Writing the above in equation form we get,

$$q = .3A \left(\frac{1}{D}\right)^{1/4} \Delta T_A^{5/4} + 4\,\sigma\,A'\epsilon\,\left(303 + \frac{\Delta T_A}{2}\right)^3 \Delta T_A \quad (8)$$

The only unknown in equation (8) for a given set of physical conditions is ΔT_A, and the manual solution to equation (8) for ΔT_A is best done using graphical methods.

Finally, the actual temperature in the center of the bundle is obtained by summing ΔT power, ΔT layers, ΔT air, and the ambient air temperature.

This temperature is the highest possible temperature which can be realized in a cable bundle which is tight enough to prevent any air flow through the bundle. If any of the heat is carried out of the bundle by moving air instead of by conduction alone, the temperature calculated using this method will be higher than actually realized. But from a different point of view, one is assured that if a cable tray meets the recommended operating temperature under the conditions imposed above, it will operate at a safe temperature under any conditions which might prevail in a cable tray.

B. Proof of Most Severe Condition

The case of all the cables being bunched in concentric circles is established as the most severe condition possible. This is verified from a somewhat intuitive approach.

Practice has shown that it can be expected that greatest temperatures are produced when several heat sources are brought together instead of spreading them out. This is because the heat is confined to a smaller area and therefore is more intense, and highest temperatures are expected from more intense heat sources. The way to make a given amount of heat most intense is to confine the heat in the smallest area, which is in the shape of a circle. Thus, the analytical investigation has been carried out on circular arrangements of cables.

C. Thermal Analysis of a Given Tray

A systematic approach was taken to analyze each cable tray. A step-by-step analysis of each tray proceeded as follows:

1. Determine the I^2R loss generated in the tray for each cable using the electrical resistance at the normal operating temperature of the cable.

2. Sum the individual heat losses to get the total heat loss for the tray.

3. Determine the cross section area of each power and control cable and add the individual areas to get a total area, in square inches, of both power cable and the area of control cable.

4. The above data is supplied to the computer which uses the equations developed earlier to compute the maximum possible temperature in the assumed bundle configuration.

5. If the temperature is too high, remove heat sources and the associated area from the tray and rerun the data until satisfactory temperatures are reached.

J. Stolpe
Assistant Underground Engineer
Underground Research and Development Division

TRAY THERMAL ANALYSIS

INITIAL INSTALLATION

SWITCHGEAR ROOM NO. 1

04-26-68

TRAY	DT	DP1	QC	RC	TC	DP2	QT	RT	TT
60AC01	34.600	12.400	32.000	1.670	112.591	12.900	39.600	1.638	129.624
60AQ05	31.000	25.300	68.400	1.107	131.233	27.000	76.000	1.072	135.556
60AR02	29.500	6.300	49.200	2.164	190.380	6.300	49.200	2.164	190.380
60AR05	31.000	27.300	68.000	1.066	123.913	28.700	73.000	1.039	125.746
60AS05	31.000	25.000	68.000	1.114	131.724	26.600	73.000	1.080	132.985
60AV03	31.700	8.300	29.000	1.954	117.438	8.300	29.000	1.954	117.438
60AW02	36.700	18.200	58.600	1.420	153.635	18.900	58.800	1.393	151.150
60AW05	37.400	19.300	30.600	1.392	94.048	24.300	38.100	1.241	97.777

REVISED INSTALLATION

SWITCHGEAR ROOM NO. 1

TRAY	DT	DP1	QC	RC	TC	DP2	QT	RT	TT
60AC01	30.200	7.200	14.000	2.048	74.862	8.200	22.500	1.919	97.429
60AQ05	31.000	13.300	17.800	1.527	72.931	15.000	25.200	1.438	86.159
60AR02	34.100	0.900	1.200	5.175	37.186	0.900	1.200	5.175	37.186
60AR05	31.000	15.300	18.100	1.423	70.322	16.700	23.200	1.362	78.593
60AS05	31.000	13.000	17.400	1.544	72.515	14.600	22.400	1.457	80.904
60AV03	32.000	8.000	19.000	2.000	88.982	8.000	19.000	2.000	88.982
60AW02	31.300	12.800	10.600	1.564	56.657	13.500	10.800	1.523	56.392
60AW05	39.000	21.000	25.000	1.363	81.061	26.000	32.000	1.225	85.946

LEGEND:

DT - Area (sq. in.) of total cable bundle.
DP1 - Area (sq. in.) of power cable bundle - maximum operating load.
QC - I^2R (watts/ft.) heat loss - maximum operating load.
RC - Ratio of diameters - total cable bundle to power cable bundle (max. oper.)
TC - Temperature (°C) center conductor of power cable bundle (max. oper.)
DP2 - Area (sq. in.) of power cable bundle total connected load.
QT - I^2R (watt/ft.) heat loss - total connected load operating.
RT - Ratio of diameters - total cable bundle to power cable bundle (tot. conn.)
TT - Temperature (°C) center conductor of power cable bundle (tot. conn.)

REFERENCE LIST FOR APPENDIX 7.4

1. Holman, J. P., "Heat Transfer," McGraw-Hill Book Co., 1963, pp. 23-26.

2. McAdams, W. H., "Heat Transmission," McGraw-Hill Book Co., 1942, p. 241.

3. Neher, J. H. and McGrath, M. H., The Calculation of the Temperature Rise and Load Capability of Cable Systems, AIEE TRANSACTIONS, Vol. 76, Part III, 1957, pp. 752-772.

7.5 SHUTDOWN MARGIN ANALYSIS AT MAXIMUM DILUTION

SHUTDOWN MARGIN ANALYSIS AT MAXIMUM DILUTION - CABLE FAILURE INCIDENT OF MARCH 12, 1968

The minimum shutdown margin occurred at approximately 5:10 a.m. on March 12, 1968. The shutdown calculated at the minimum measured boron concentration of 1562 ppm was 2.8%. The method of calculation was based on reactor conditions immediately prior to the reactor trip as compared to the reactor conditions at the minimum boron concentration following the reactor trip.

Equilibrium Xenon had not been reached at the time of the reactor trip; therefore, xenon concentration calculations were made based on the reactor power for the previous three days. These calculations showed that the equilibrium xenon was worth 1802 pcm at the time of trip and increased an additional 680 pcm by 5:10 a.m.

The power coefficient contributed 1350 pcm at the time of trip.

Since the reactor coolant temperature was reduced to 450°F at 5:10 a.m., the integral rod worth corresponding to this temperature was used. The low power physics total integral rod worth was 5500 pcm @ 150°F and 6800 pcm @ 535°F. Assuming a linear rod worth between the two temperatures gives a total rod worth of 6400 pcm at 450°F. A value of 6360 pcm was used since Control Group II was partially inserted at the time of the trip.

Differential boron worth curves showed the boron worth at an average of 8.2 pcm/ppm. Considering a boron change of 349 ppm, the reactivity change was calculated at 2862 pcm.

The reactivity associated with the temperature change was neglected since the temperature coefficient is very nearly zero.

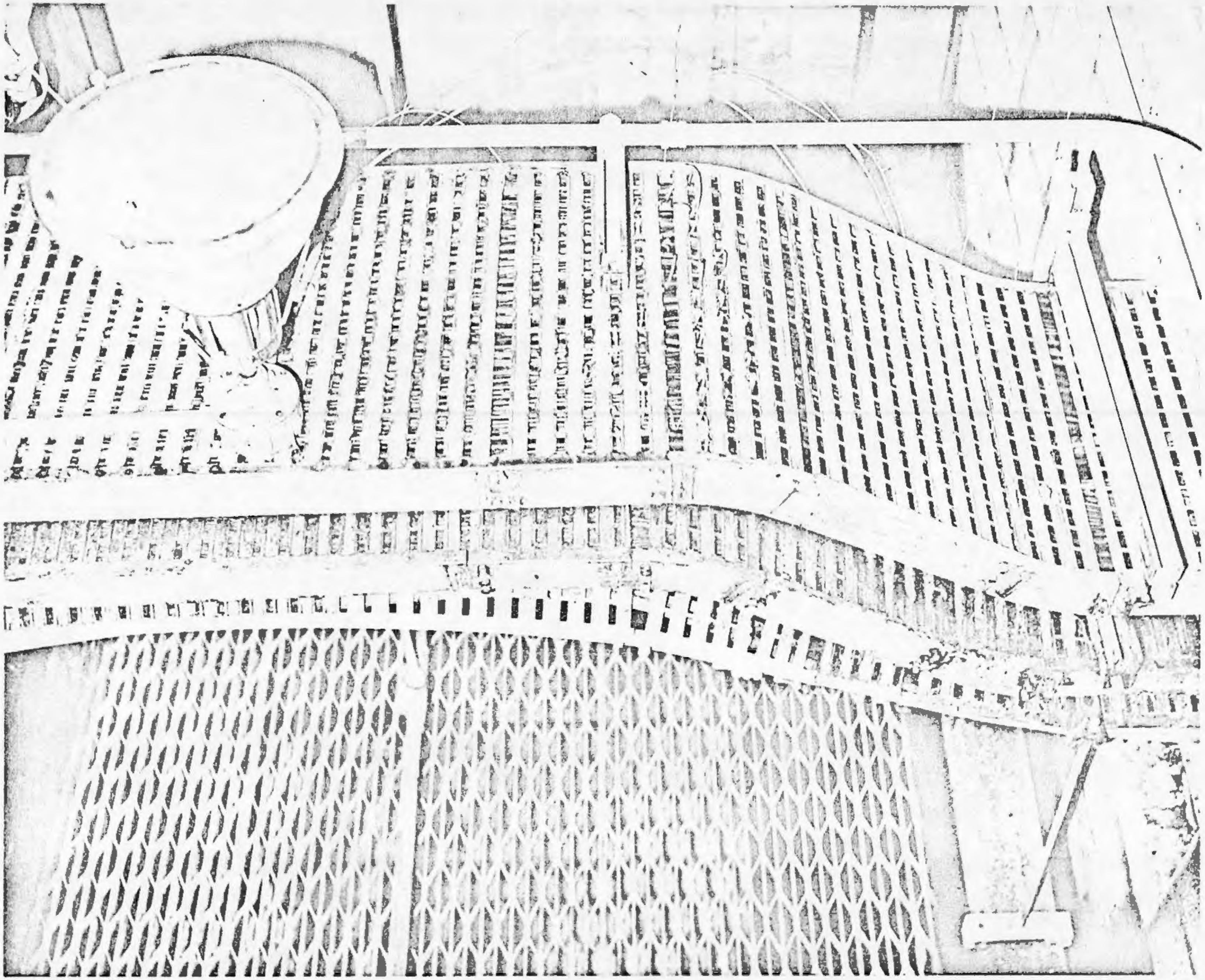
Summary of Calculations

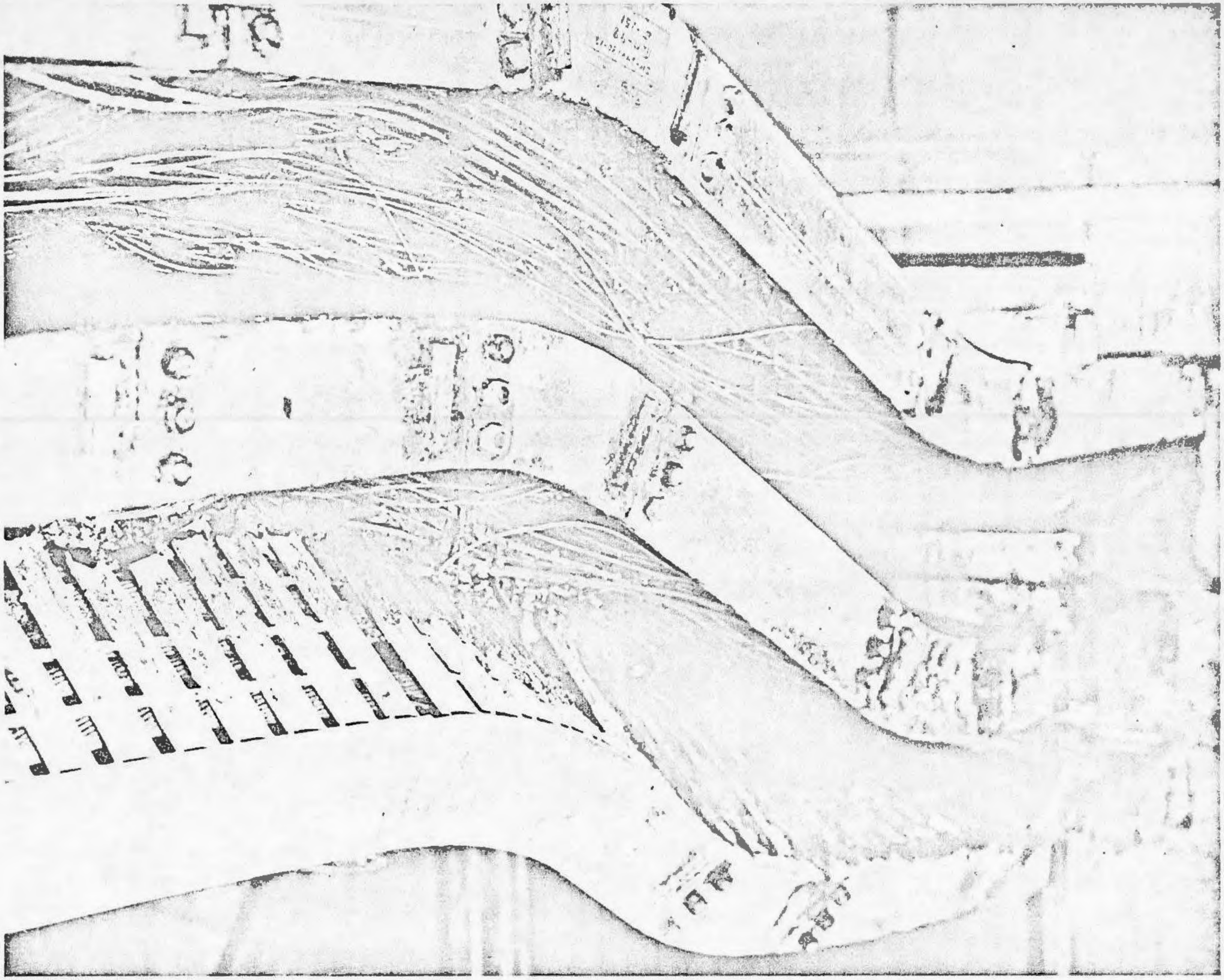
Xenon	-680 pcm
Rods	-6360 pcm
Power	+1350 pcm
Boron	+2862 pcm
Temperature	0 pcm

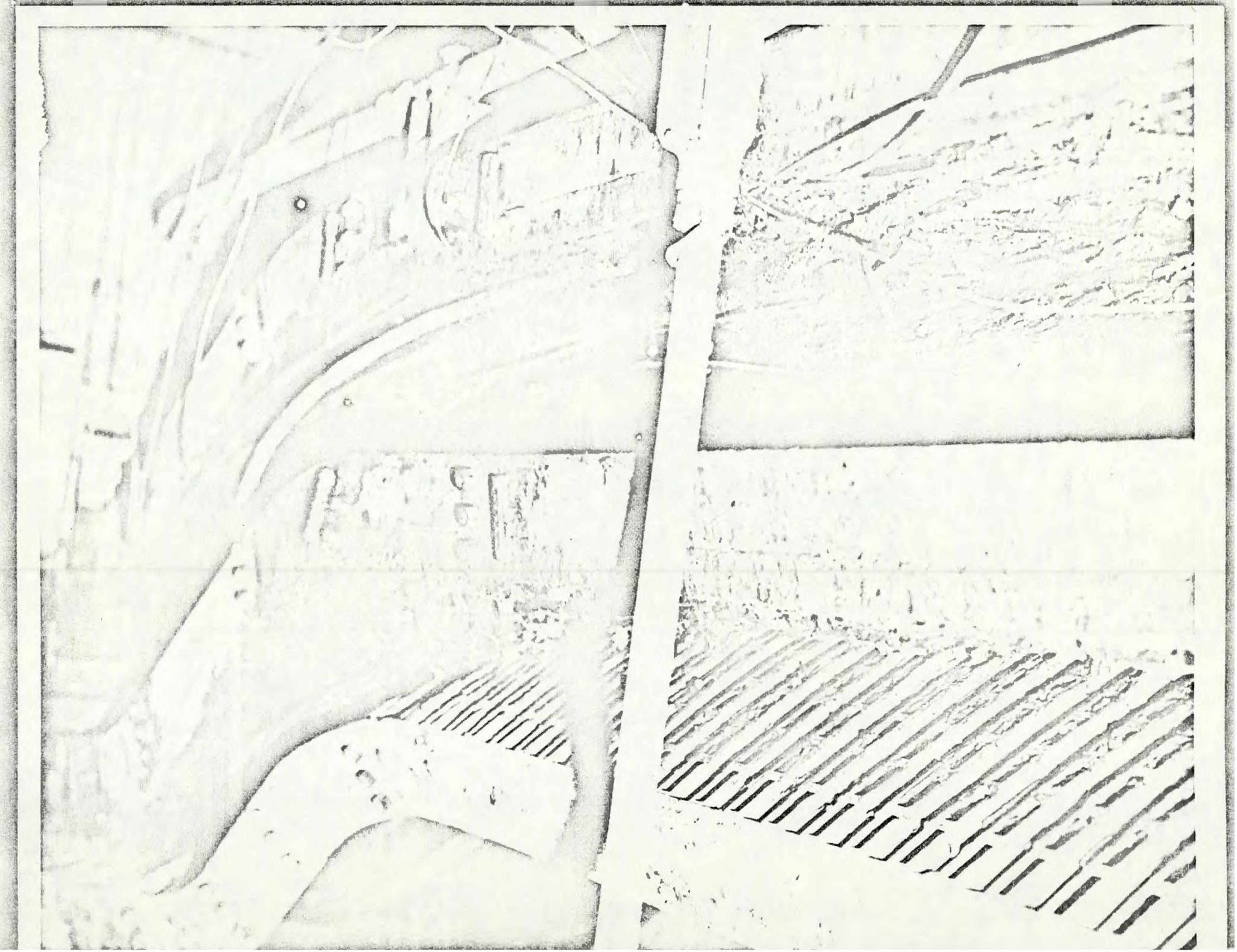
Shutdown @ 5:10 a.m. -2838 pcm

A. J. Girardi
Thermonuclear Engineer

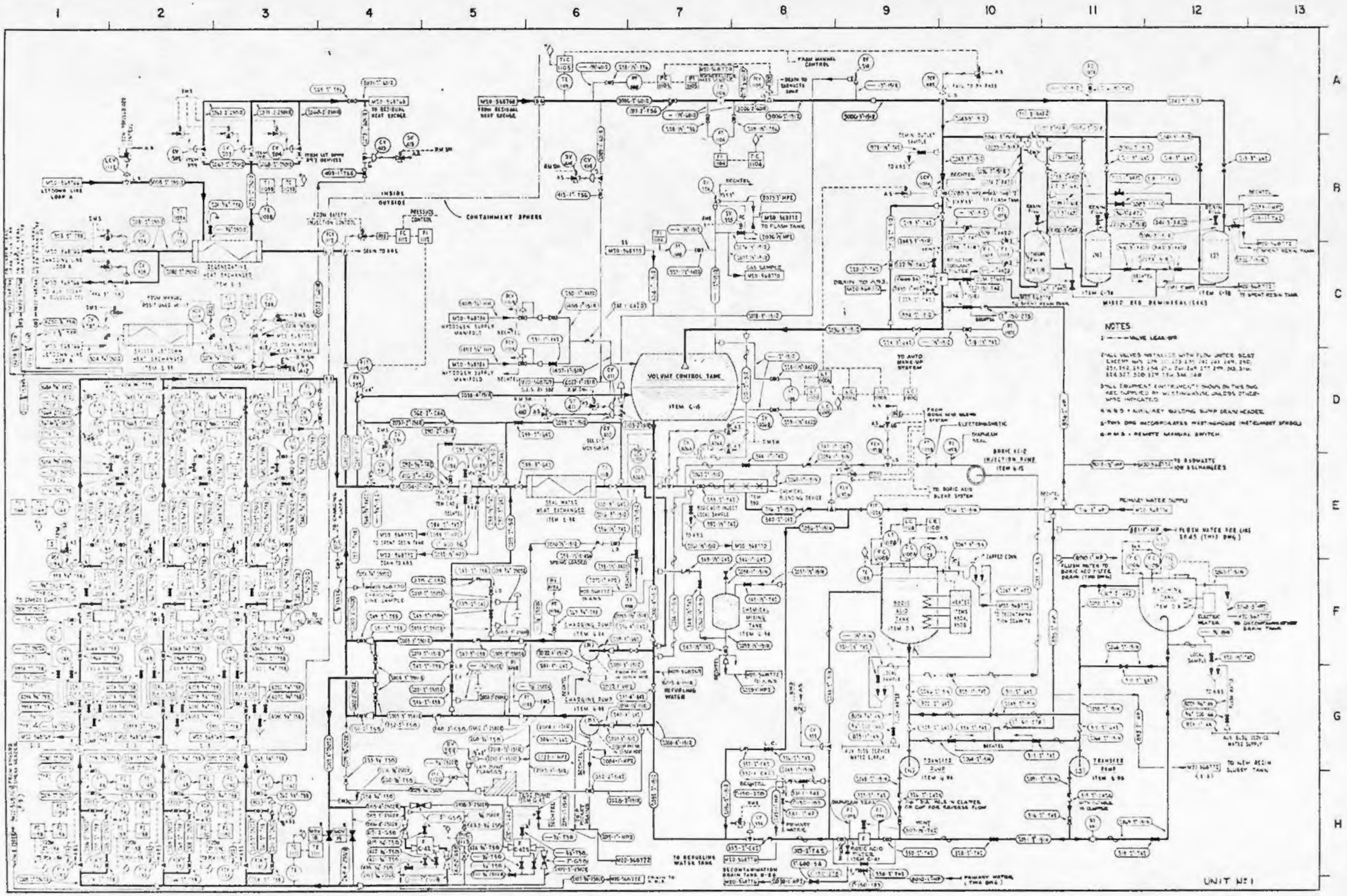
7.6 DAMAGED CABLE TRAY PICTURES



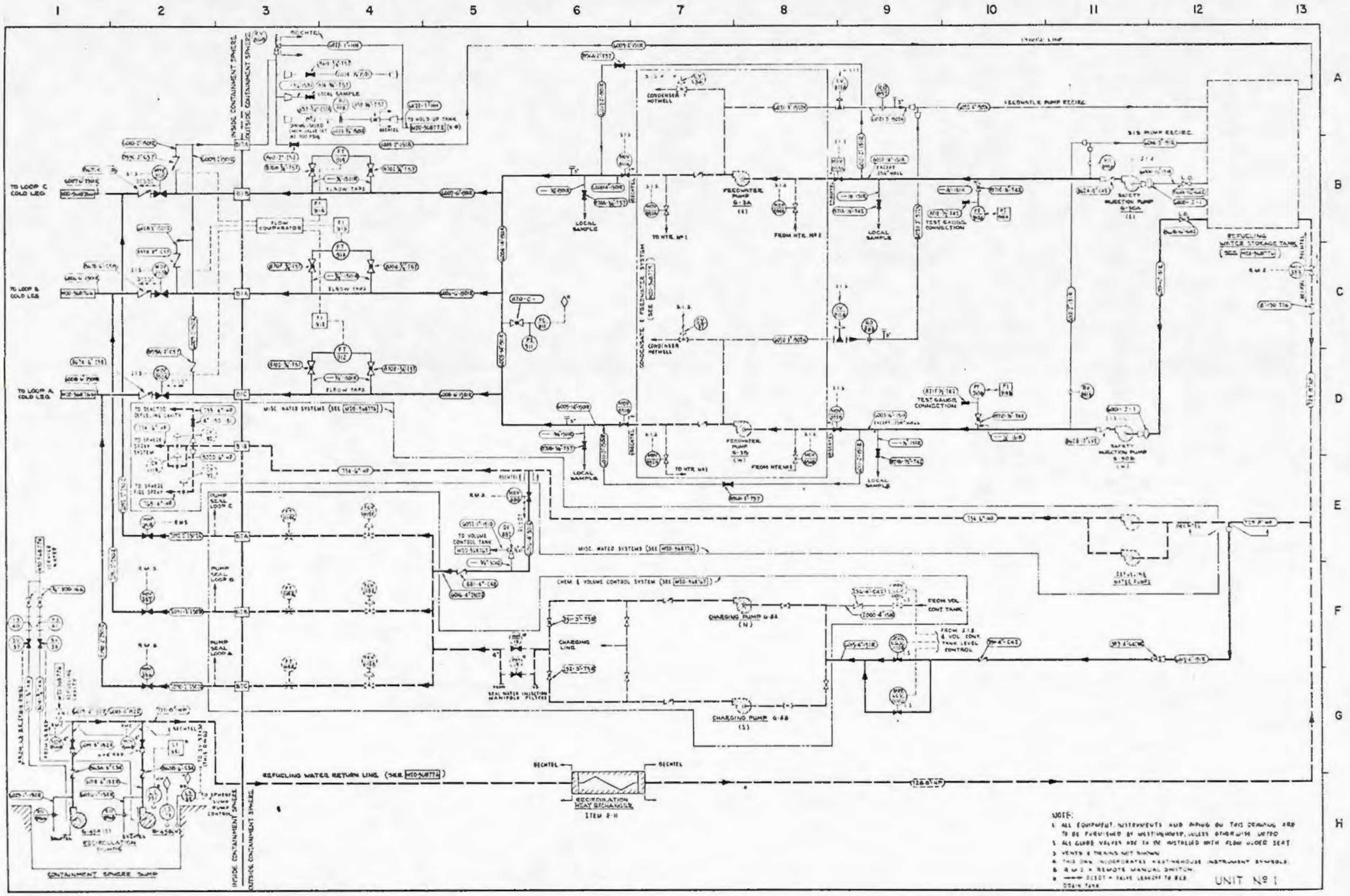




7.7.0 CHEMICAL AND VOLUME CONTROL SYSTEM

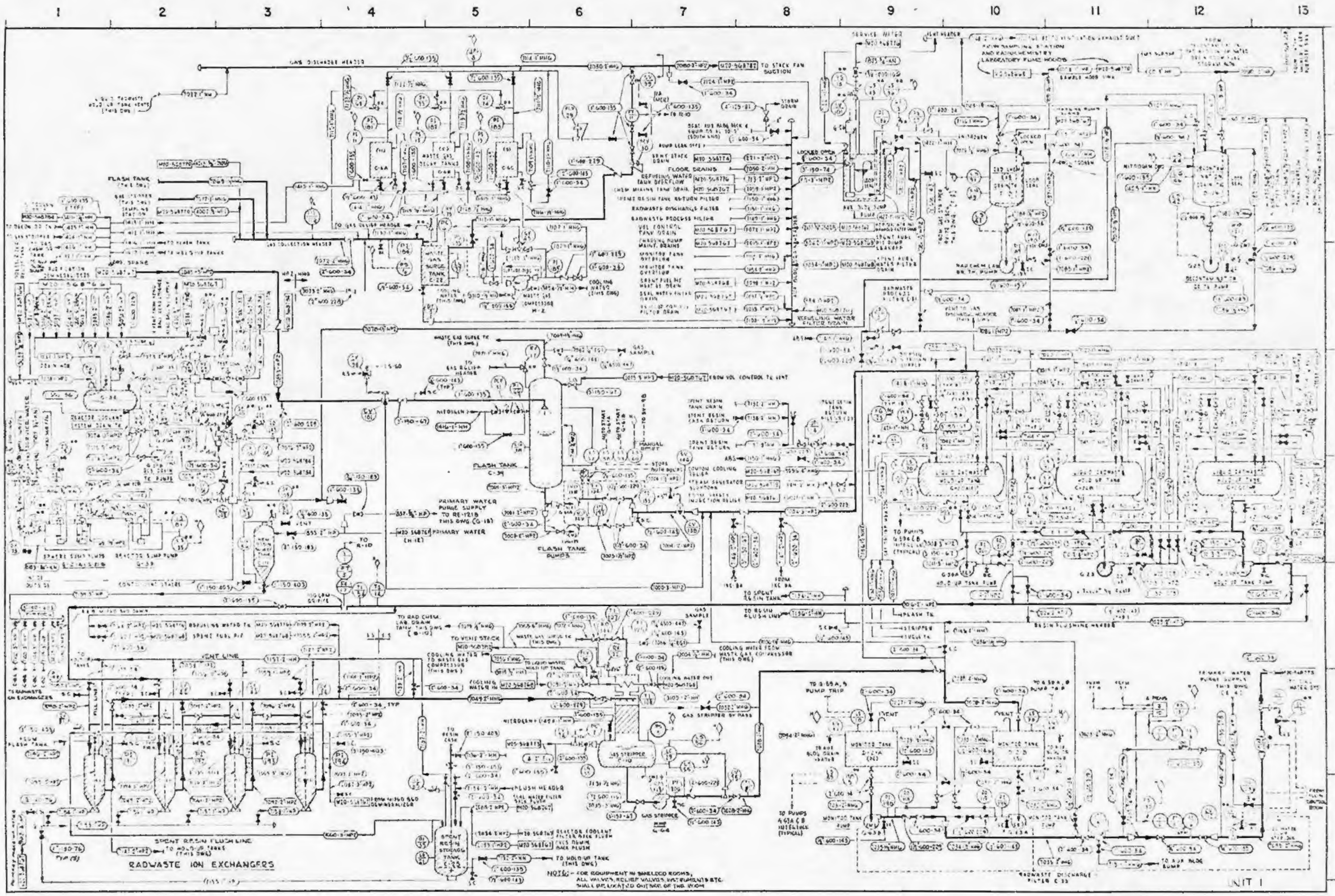

1 2 3 4 5 6 7 8 9 10 11 12 13
A B C D E F G H
CONTAINMENT SPHERE
INSIDE
OUTSIDE
VOLUME CONTROL TANK
SEAL WATER HEAT EXCHANGER
CHARGING PUMP
BORIC ACID TANK
TRANSFER PUMP
NOTES
UNIT No 1

7.7.1 SAFETY INJECTION SYSTEM

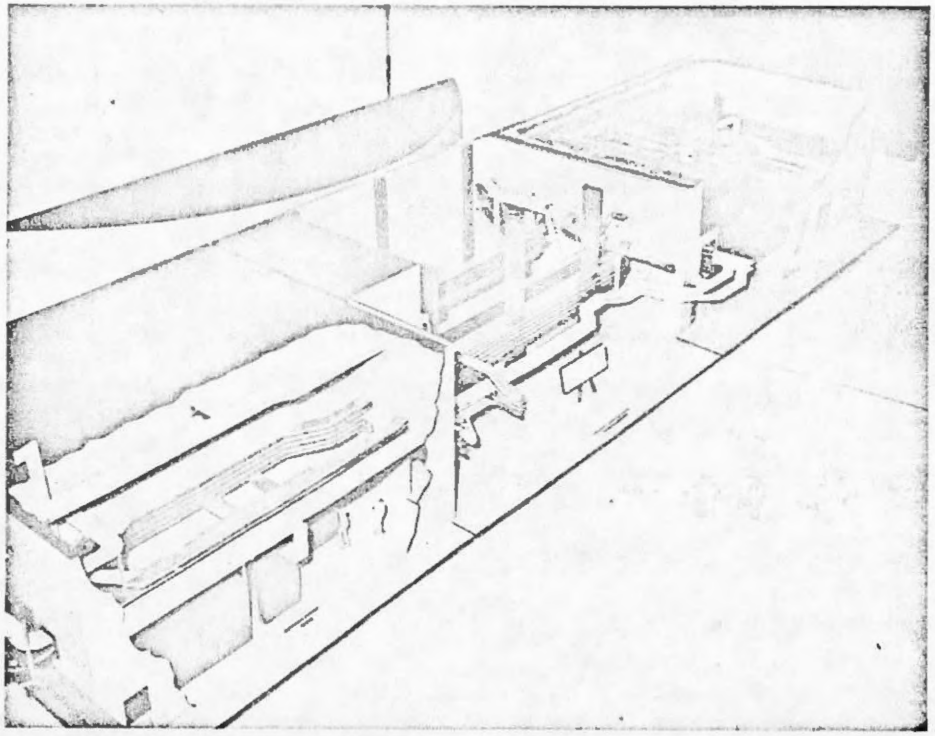


INSIDE CONTAINMENT SPHERE
OUTSIDE CONTAINMENT SPHERE
TO LOOP C COLD LEG
TO LOOP B COLD LEG
TO LOOP A COLD LEG
FLOW COMPARATOR
FLOW TAPS
LOCAL SAMPLE
FEEDWATER PUMP
CONDENSER HOTWELL
CONDENSATE & FEEDWATER SYSTEM
TEST GAUGE CONNECTION
SAFETY INJECTION PUMP
REFUELING WATER STORAGE TANK
PUMP SEAL LOOP C
PUMP SEAL LOOP B
PUMP SEAL LOOP A
MISC. WATER SYSTEMS
TO VOLUME CONTROL TANK
CHEM & VOLUME CONTROL SYSTEM
CHARGING LINE
CHARGING PUMP
FROM VOL CONT TANK
SEAL WATER INJECTION MANIFOLD FILTERS
REFUELING WATER RETURN LINE
BECHTEL
RECIRCULATION HEAT EXCHANGER
RECIRCULATION PUMPS
CONTAINMENT SPHERE SUMP
NOTE:
UNIT Nº 1

7.7.2 RADIOACTIVE WASTE DISPOSAL SYSTEMS

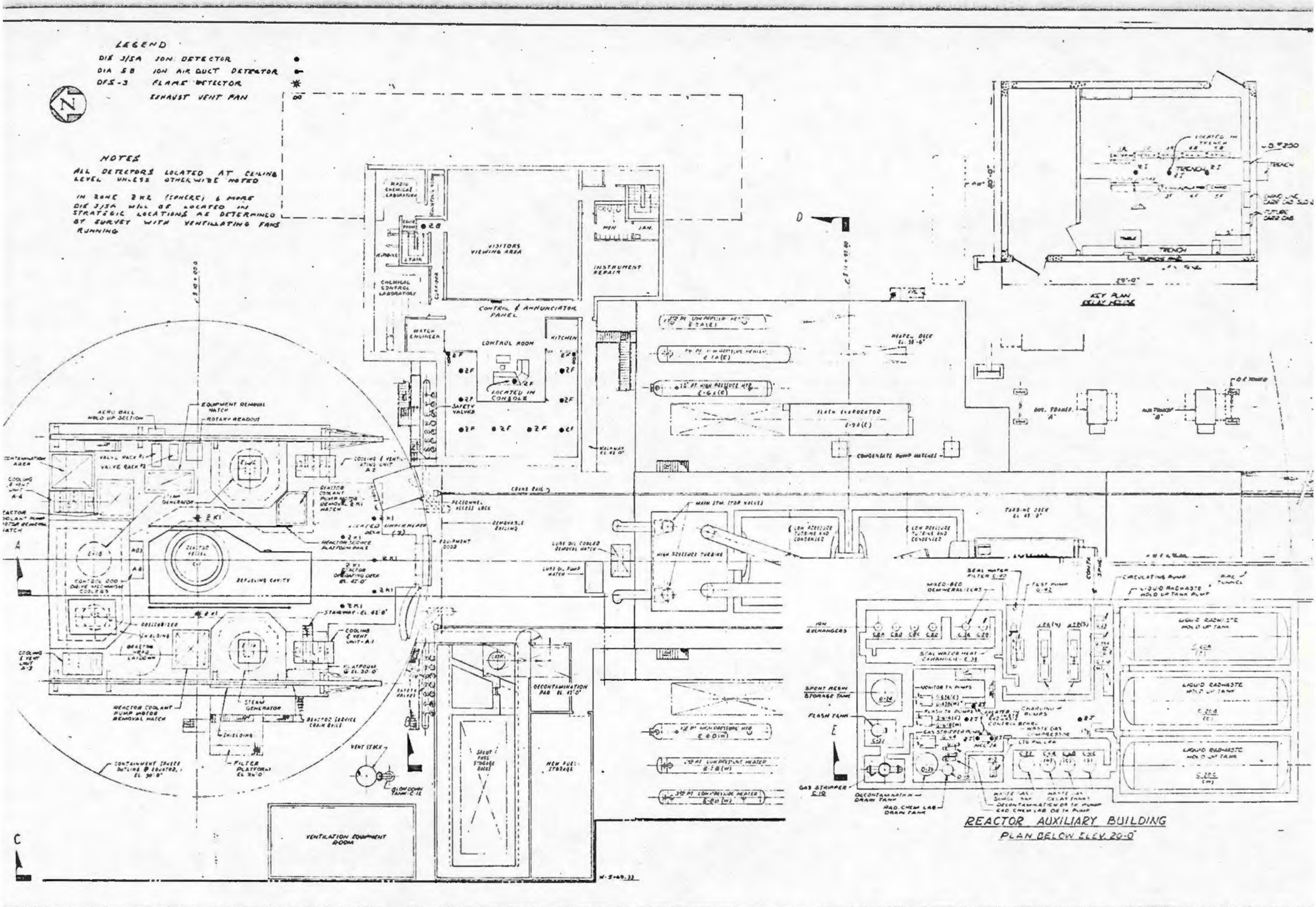

GAS DISCHARGE HEADER
FLASH TANK
C-34
FLASH TANK PUMPS
PRIMARY WATER
FLOOR DRAINS
GAS STRIPPER
SPENT RESIN FLUSH LINE
RADWASTE ION EXCHANGERS
UNIT 1

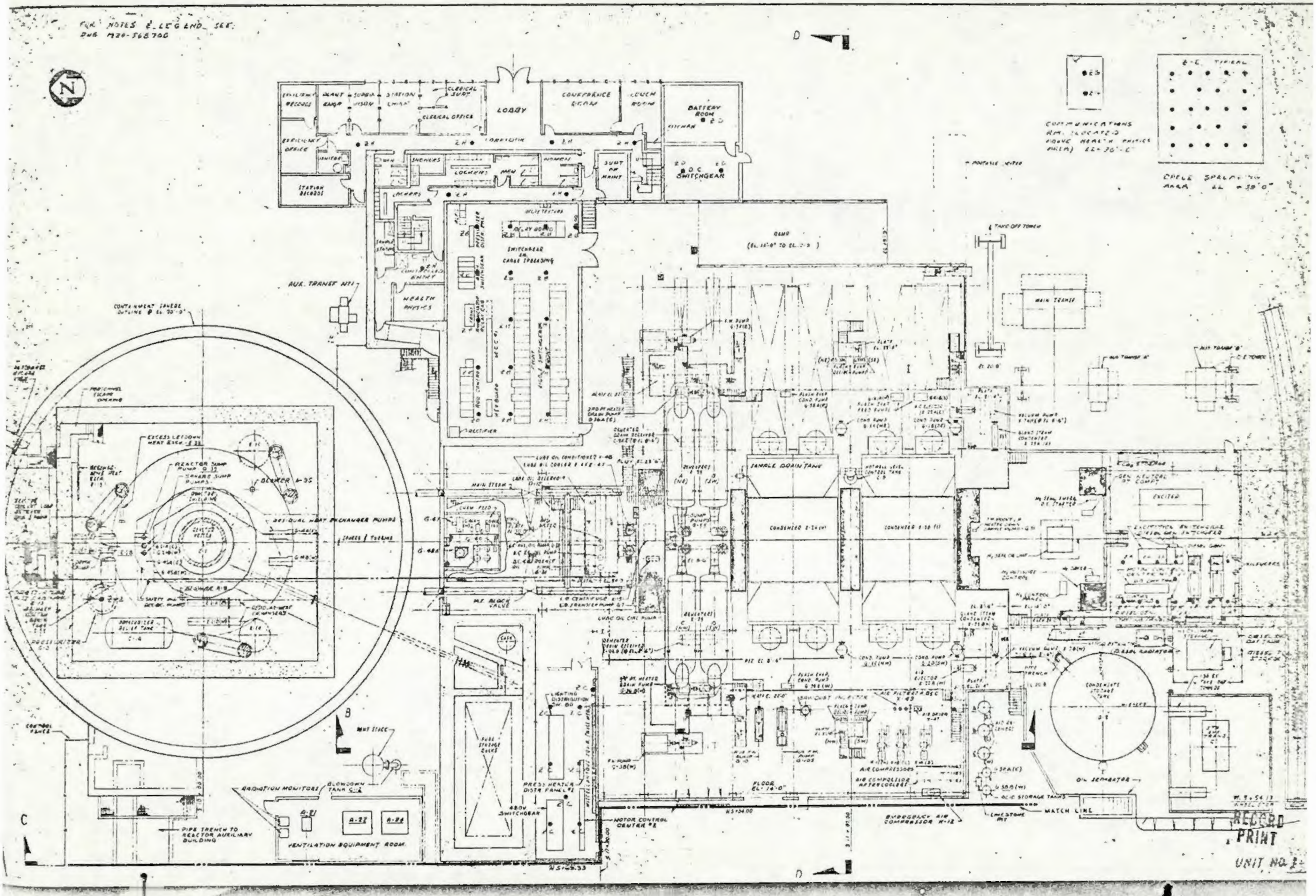
7.7.3 ADDITIONAL CABLE TRAY LOCATION



MODEL SHOWING ADDITIONAL CABLE TRAYS

7.7.4 SMOKE DETECTION SYSTEM LOCATION


LEGEND
DIA 3/5A ION DETECTOR
DIA 5B ION AIR DUCT DETECTOR
DFS-3 FLAME DETECTOR
EXHAUST VENT FAN
NOTES
ALL DETECTORS LOCATED AT CEILING LEVEL UNLESS OTHERWISE NOTED
IN ZONE 2K2 (SPHERE) 6 MORE DIA 3/5A WILL BE LOCATED IN STRATEGIC LOCATIONS AS DETERMINED BY SURVEY WITH VENTILATING FANS RUNNING
VISITORS VIEWING AREA
INSTRUMENT REPAIR
CHEMICAL CONTROL LABORATORY
CONTROL & ANNUNCIATOR PANEL
WATCH ENGINEER
CONTROL ROOM
KITCHEN
LOCATED IN CONSOLE
SAFETY VALVES
MEN
JAN.
FLASH EVAPORATOR
CONDENSATE PUMP HATCHES
CRANE RAIL
TURBINE DECK
HIGH PRESSURE TURBINE
MAIN STM. STOP VALVES
PERSONNEL ACCESS LOCK
EQUIPMENT DOOR
REFUELING CAVITY
REACTOR VESSEL
STEAM GENERATOR
REACTOR COOLANT PUMP MOTOR REMOVAL HATCH
CONTAINMENT SPHERE
DECONTAMINATION PAD
NEW FUEL STORAGE
VENT STACK
VENTILATION EQUIPMENT ROOM
KEY PLAN
DELAY HOUSE
TRENCH
ION EXCHANGERS
SPENT RESIN STORAGE TANK
FLASH TANK
GAS STRIPPER
MIXED BED DEMINERALIZERS
SEAL WATER FILTER
CHARGING PUMPS
CIRCULATING PUMP
LIQUID RADWASTE HOLD UP TANK PUMP
LIQUID RADWASTE HOLD UP TANK
DECONTAMINATION DRAIN TANK
RAD. CHEM LAB DRAIN TANK
REACTOR AUXILIARY BUILDING
PLAN BELOW ELEV 20-0"



FOR NOTES & LEGEND SEE DWG M20-568700
LOBBY
CONFERENCE ROOM
BATTERY ROOM
D.C. SWITCHGEAR
HEALTH PHYSICS
AUX. TRANSF. NO.1
MAIN TRANSF.
SAMPLE DRAIN TANK
RESIDUAL HEAT EXCHANGER PUMPS
PRESSURIZER C-2
RADIATION MONITORS
VENTILATION EQUIPMENT ROOM
PIPE TRENCH TO REACTOR AUXILIARY BUILDING
480V SWITCHGEAR
MOTOR CONTROL CENTER #2
AIR COMPRESSORS
EMERGENCY AIR COMPRESSOR K-12
OIL SEPARATOR
MATCH LINE
RECORD PRINT
UNIT NO. 1