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ELECTRICAL POWER AND ITS ENGINEERING FOR THE TWO-MILE LINEAR ELECTRON ACCELERATOR AT THE STANFORD LINEAR ACCELERATOR CENTER *

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The Stanford two-mile accelerator is the world's most powerful "electron microscope" and the longest linear accelerator machine. Accelerators today are many and of various types. Circular machines swing "rocks on strings" many times around their centers; an individual circularly accelerated particle may have a track length travel of hundreds to thousands of miles. Necessarily a linear accelerator has a track length travel equal to its physical length. In this instance it is two miles.

The Stanford Linear Accelerator Center has evolved from the initial development of klystrons by the Varian brothers, early short accelerators devised by Professor Hansen, and the still much-in-use 300-foot-long Mark III accelerator on the main campus. This tradition will be furthered by the use of the two-mile accelerator for basic research in the area of subatomic nuclear particles.

From the first, the fundamentals of electrical engineering have been emphasized in the development of the Stanford line of linear electron accelerators. The founders of this program considered themselves electrical engineers and physicists. Their successors continue of necessity to be very interested in these fields as the investigation of high energy physics research problems continues.

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The electrical engineering aspects cover almost all subdivisions of the field from house wiring and lighting through engine-driven and battery-powered emergency and control systems, variable voltage substations automatic voltage control, direct current power supplies having voltage control to 1 part in 10,000, pulse forming networks tuned to the maximum accuracy attainable, S-band microwave power, electromagnetism, most known methods of communication, programmed control systems into the nano-second class of instant precision, and the latest developments in computers and data processing in order to bring out the results of project activity in a usable form and within reasonable time limits.

During 1966 the two-mile accelerator electron gun will be producing pulses of 10 to the twelth power of electrons at 60, 120, 180, or 360 pulses per second. These electrons travel through a 4-inch-diameter copper pipe inside a two-mile long concrete "accelerator housing" located 25 feet underground. The electrons are propelled forward to higher and higher energies by means of traveling radio waves introduced into the accelerator pipe at regular intervals along the machine. The traveling waves are provided by 240 high power klystron amplifier tubes located in a two-mile long "klystron gallery" on the surface, 25 feet above the accelerator. Interconnections from the klystron to the accelerator are through penetrations in the separating earth. The two-mile long double structure has been divided into 30 sectors, numbered from the injector end.

The klystron output radio waves are at a frequency of 2856 mc/sec. These waves appear in pulses, switched by a high power "modulator." There is one modulator for each klystron. The modulator converts ac electric power to 270 KV dc pulses to switch the klystron on.

When the accelerator beam emerges after its two-mile run, it enters a 1000-foot long "beam switchyard" (BSY) where it can be directed into either of two large "target buildings" or "end stations" in a huge research end station area. Here the beam is used as a probe to explore the structure of the atomic nucleus.

Most experiments require monoenergetic particles to a tight tolerance so that the beam switchyard is crammed with magnets and coils for focussing and steering as well as mechanical devices which chop unwanted lower energy portions of the beam and thus collimate same. At present we are completing the construction of the two research experiment buildings prosaically called "A" and "B." In "A" the beams will be received and analyzed and experiments will be essayed using huge spectrometers covering the three ranges: 1.8 GeV, 8.0 GeV and 20 GeV. At "B" the beams will strike targets and secondary strange particles will be collected, eliminated, sorted, studied,treated and/or mistreated by investigating physicists using spark chambers, bubble chambers and their associated equipment.

Before delving into the electrical systems aspects of supplying power to the two-mile accelerator, it should be noted that the project is a national facility for scientific research. In addition to Stanford scientific teams, there will be similar teams from other institutions who may proceed to initiate and carry out experiments at the Stanford Linear Accelerator Center. It is anticipated that this factor will result in unforeseen requirements for the expansion, conversion or change in emphasis of power usage at the two-mile accelerator.

The two-mile accelerator project as now installed has a connected load of 105 MVA. The peak demand this year is expected to be 45 MVA. The demand is expected to triple within the next five years.

Sources of Electrical Power

The major source of power to supply these loads is a new six-mile long 220 KV-transmission tap line installed to connect with the Pacific Gas and Electric

Company double circuit 220 KV transmission line between their Monte Vista and Jefferson Substations. This primary supply will have a 300-MVA capacity and will be a single circuit with 1272 MCM aluminum conductors installed on post insulators attached to tapered steel poles. The line was carefully designed to blend into the terrain and also meet strict radio interference and corona loss requirements since the two-mile accelerator is located westerly of another Stanford research group which operates a 142-foot diameter radioscience dish antenna. At present this primary source of power is feeding a 80 MVA 220-12.47 KV transformer bank for the entire project power supply.

A secondary source of power to supply loads during the construction period and serve as a backup to the 220 KV tap line is an existing 60 KV tap line connecting to the existing 60 KV system which serves Stanford University. It is available presently at up to 18 MVA for initial testing of systems and equipment of the two-mile accelerator. Its ultimate capacity is 30 MVA which is sufficient to maintain a minimal experimental program in event of outage of the primary source.

Both these primary and secondary tap lines terminate at a single master receiving substation having 12.47 KV secondary distribution located at the geographic center of project electrical loads. The 12.47 KV was selected to match standard Pacific Gas and Electric Company practice and thus enhance possibility of obtaining temporary replacement transformers in event of project equipment failure.

All secondary distribution feeders within the project are run either underground or in enclosed cableways. The 12.47 KV feeder cables are provided between the master substations which provide 4160-volt or 480-volt power to loads at various points or in a few cases directly to very large experimental magnet loads. The power in most cases is connected to three-phase, four-wire

480 volt systems with 277-volt service for lighting use. In many cases special shielded three-phase 480 volt transformers are furnished to provide the 208-volt three-phase and 120-volt single-phase loads where noise and harmonic problems on instrument circuits are critical. In view of the large system short circuit capacity available and the overall economics of 480 volt power distribution the average size of the sixty six (66) 480 volt transformer banks in about 1250 KVA. The power requirements for the four basic project areas may be summarized as follows:

1. Accelerator

The two mile accelerator is served by thirteen 12.47 KV feeder cables installed on the south side of the accelerator. There are thirty (30) unit substations, located 333 feet apart in alcoves along the Klystron Gallery which transforms the 12.47 KV primary power down to the utilization voltage required. Fifteen of the substations are used to supply the continual power requirement of 480 volts. The other 15 substations supply the power the klystrons need. Each substation generally serves two sectors of the Klystron Gallery (666 feet). In addition, there are two substations serving the two cooling towers which dissipate heat from the machine cooling water systems.

a. Auxiliary Services - Distribution System

The main power source for auxiliary services is one 480 volt, 3-phase, 4-wire, 750-KVA substation which serves two 333-foot sectors. Distribution of these auxiliary services is on a per sector basis. Each sector receives two main 480-volt, 3-phase power circuits from the substation, one for the machine cooling water pumps, and the other for modulator auxiliaries, vacuum, instrumentation and control, trigger, microwave, and support and alignment services. Power is subdivided by means of standard industrial circuit breaker panelboards. The

480-volt power is distributed along the sector by means of plug-in bus ducts. Services which require 208 Y/120-volt power are served by local panels each with its step-down transformer served at 480-volts. The electrical load requirements of the 480-volt, 3-phase and 208 Y/120 volts, 3-phase, 4-wire systems are:

	Under Present Design		Under Possible Expansion	
Installed Transformer Capacity - kVA	Demand	Conn.	Demand	Conn.
14,000	9,000	17,200	12,500	21,000

b. Modulator Variable Voltage - Distribution System

There are fifteen substations to furnish variable voltage ac (260-600 volt) services to modulators. These are located in alcoves adjacent to the auxiliary services substations. Each substation is rated at 1750 kVa, 260-600 volt ac and basically serves two sectors (16 modulators at 109 kVa each). The substation serving the first two sectors also serves the main injector klystron modulator and is a double-ended design (two 1750 kVA transformers). One 1750 kVA transformer serves the main injector klystron modulator and the first three modulators in sector 1; the other serves the remaining seven modulators in sector 1 and the eight modulators in sector 2. Subsequent substations serve sixteen modulators (eight per sector) and have only one 1750 kVA transformer. Each modulator is supplied by a separate circuit breaker in the distribution section of the substation.

Summary of Variable Voltage Load Requirements (at 20 GeV beam energy)

Installed Transformer Capacity - kVA	kW Demand at 60 PPS	kW Demand at 360 PPS
28,000	5,250	26,250 kW

c. Positron Source

At a point one-third of the way down the accelerator, a device has been installed to permit the conversion of the electron beam to a positron beam. The positron source power supplies, klystron modulators, and auxiliaries are served by a 1500 kVA, 480 v, 3-phase, 4-wire substation. This substation is located at sector 10.

d. Stand-By Power

Stand-by power, consisting of a second feeder, energized from an adjacent sector substation, is provided only for the vacuum and the beam guidance systems. This will allow two sectors to act as a drift tube in the event of a substation failure and will allow continued machined operation, although at a lower beam energy output.

e. Regulation

Voltage regulation for 480 volt and 208 Y/120 volt services (maintained respectively at 460 and 117 volts) is plus or minus five percent. Design regulation from local substation terminals to the individual device within the Klystron Gallery will be plus or minus three percent. Variable voltage services are designed for one percent regulation.

f. Radio Frequency Interference Reduction

208 Y/120 volt circuits for electronic equipment originate at shielded transformers. Modulator auxiliary services are segregated. Variable voltage substations furnishing modulator power services are designed for 24 phase dispersion overall.

g. Lighting

Design intensity is 20 foot candles in the Klystron Gallery and 10 foot candles in the Accelerator Housing and all circuits are panel controlled.

h. 12.47 KV Cable System

To meet the above accelerator load requirement and the temperature limit of cable under emergency loading conditions, the following 15 KV paper insulated lead covered three conducter power cables are installed on the south side of the accelerators.

Conventional Substation Cable
(In Thousands of Circular Mils)

	No. 1	No. 2	No. 3	No. 4	No. 5	No. 6
Master Substation to Sectors 30 to 28	600	600	600	600	250	250
Sectors 28 to 26	500	500	500	500		
Sectors 26 to 24	500	500	500	400		
Sectors 24 to 22	500	500	500	250		
Sectors 22 to 20	600	600	600	No. 0		
Sectors 20 to 18	400	250	400			
Sectors 18 to 16	400	250	400			
Sectors 16 to 14	250	250	250			
Sectors 14 to 12	250	250	No. 0			
Sectors 12 to 10	250	250	No. 0			
Sectors 10 to 8	250	No. 0	No. 0			
Sectors 8 to 6	No. 0	No. 0	No. 0			
Sectors 6 to 4	No. 0	No. 0				
Sectors 4 to 2	No. 0	No. 0				

Variable Substation Cable
(In thousands of Circular Mils)

	No. 1	No. 2	No. 3	No. 4	No. 5	No. 6	No. 7
Master Substations to Sectors 30 to 28	600	600	600	600	600	250	250
Sectors 28 to 26	600	600	600	600	500		
Sectors 26 to 24	600	600	500	500	250		
Sectors 24 to 22	500	500	500	500			
Sectors 22 to 20	600	600	600	500			
Sectors 20 to 18	400	400	400	250			
Sectors 18 to 16	400	400	400				
Sectors 16 to 14	400	400	250				
Sectors 14 to 12	400	400	No.0				
Sectors 12 to 10	400	400					
Sectors 10 to 8	400	250					
Sectors 8 to 6	250	250					
Sectors 6 to 4	No. 0	No. 0					
Sectors 4 to 2	No. 0	No. 0					

2. Beam Switchyard (BSY)

The electrical system for BSY is served by four 12.47KV - 480/277 V three-phase four-wire transformer banks located in BSY as listed below:

Capacity (KVA)	Services:
1,000/1,333	Power supplies for pulsed magnets. "A" bending magnets, "B" magnetic slit pulsed magnets and steering magnets.
1,000/1,333	Power supplies for "B" bending magnets and "A" quadropoles.
1,500/2,000	"A" dump magnets, photon quadropoles and bending magnets, heat exchanger No. 1 and No. 2, and ac distribution switchboard in Data Assembly Building.
1,500/2,000	Cooling tower fans and pumps, LCW pumps, magnet power supply, heat exchangers, and miscellaneous ac power.

Electrical services are also available inside of the BSY upper housing as follows:

480 volt 100 amp 3-phase power outlets on 100 foot centers,

120 volt receptacles on 30 foot centers.

An emergency generator, 150 KW 480/277 volts, provides emergency ac service to the material handling system in the BSY, to BSY and End Station exhause fans and to miscellaneous research-area power requirements through an automatic transfer switch.

3. Experiment Stations

There are four 12.47 KV underground circuits provided between the Master Substation to the Research Area End Substation, having a capacity of 30 MVA available for experimental use. Five transformer banks are installed to provide the 4160 V and 480 volt services whenever is needed.

The large power requirements for the experimental use such as the spectrometers, bubble chamber and spark chambers, the dc power supplies are served directly by the 12.47 KV system. Most of the magnet power supplies are served at 480 volts except for a group of 567 KW dc power supplies which are fed from 4.16 KV services because of the confined cost economy.

The following listed experiment loads are scheduled for fiscal year 1967 and/or 1968 operations:

End Station A

20 Bev. Spectrometer	5.0 MW
8 Bev. Spectrometer	3.8 MW
1.8 Bev. Spectrometer	1.5 MW
2 Meter Spark Chamber	6.0 MW

End Station B

40" Hydrogen Bubble Chamber	3.4 MW Magnet .3 MW Auxiliary
82" Hydrogen Bubble Chamber	2.5 MW Magnet .5 MW Auxiliary
Spark Chamber Magnet	3.0 MW
Positron Annihilation Beam	1.5 MW average to 2.0 MW
Separated K-Beam	1.4 MW
Mu Beam	.7 MW minimum to 4.8 MW maximum.

Triplexed armor shielded 15 KV and 5 KV 90°C cross-linked polyethylene insulated power cables and 90°C hyperlon 600 volt triplex power cable are used to feed the power from the substation to the experiment magnet power supplies via the underground cableways (see typical section of cableways). The cableways inter-connect the Research Area Substation to Underground Utility Vaults "A" and "B" at the End Stations for the ac power feeds. The same Utility Vaults "A" and "B" inter-connect to the tunnels built in the End Stations for connecting the dc power cables and low conductivity water to the magnets and power devices.

4. Laboratory and Buildings Load

12 KV underground feeders and its associated unit substations are provided for

the following permanent buildings which have a connected load of 9800 KVA:

Test Laboratory (41,000 sq. ft.)--klystron, microwave engineering and modulators test stand,

Electronic Building (26,000 sq. ft.)--electronic design and maintenance,

Heavy Assembly Building (32,000 sq. ft.)--final assembly in construction of large experimental equipment,

Fabrication Building (27,000 sq. ft.)-- machine, pipe, sheet metal, welding, brazing, electroplating and cleaning shops,

Control Building (13,000 sq. ft.)--central control of accelerator in operation,

Central Laboratory (50,000 sq. ft.)--director's office, physics offices and laboratories, library,

Administration and Engineering Building (44,000 sq. ft.)--associated directors, personnel, accounting, budgets, contract, engineering and the Palo Alto area office of the U. S. Atomic Energy Commission,

Cafeteria and Auditorium (10,000 sq. ft.)--dining facilities for 150 persons and meeting facilities for 300 persons,

Data Assembly Building (5,000 sq. ft.)--control of Beam Switchyard and end station beam transport equipment,

End Station "A" (25,000 sq. ft.)--target building where the electron beam and spectrometers will be used,

End Station "B" (11,000 sq. ft.)--target buildings where the electrom beam will be used to create secondary "strange" particles,

Cryogenics Facility Building (8,000 sq. ft.)--low temperature gas and high conductivity experiments.

Miscellaneous Power Supplies

There are thirty-two (32) 24-volt direct-current battery systems each with an average capacity of 200 ampere hours installed to furnish power emergency and control systems plus two (2) permanent connected internal-combustion-engine-driven alternating-current 480-volt generators for emergency use. These tertiary backup sources of power are small in magnitude and are not necessarily indicative of the attention paid to many electrical features of the machine systems. The need for this type of power source has been somewhat overlooked in the accelerator field and when needed is often met by using a surplus diesel-engine drive generator set which can arrive on-site at the earliest date. In general the emergency power sources serve instrumentation and control systems, cryogenic system equipment as well as emergency lighting and fire alarm circuits.

Coordinated Engineering Efforts

It is evident that there is a continuing demand for electrical engineering efforts in building and using large High Energy Physics Laboratories such as SLAC. Procuring power from the PG&E and Bureau of Reclamation, based on the two existing power contracts, for optimum operation of the accelerator represents an annual power cost of over one million dollars. Electrical engineering work now being performed on the project is categorized as follows:

1. AC and DC Power Systems

   220-60-12 kv systems

   Load forecast and cost of optimum operation

   Energy conversion system

   System operation and modification

   Cableway system (underground, overhead)

   Substation control and monitoring system

   Station and cable loadings

Radiation resistance insulated cable and terminating equipment

Development work on superconducting magnets at cryogenic temperatures

2. <u>Instrument and Control System</u>

Instrumentation and control schematics

Electronic equipment rack programs

Cable plants

Computer programs for storing data pertaining to wire lists and tables

Computer and counter circuitry

Inspection and testing

Radiation monitoring system

3. <u>Communication</u>

Service channels, public address system

Telephone and intercommunication system

Radio

Closed circuit television

4. <u>Safety</u>

Machine and personnel protection systems

Safety of electrical installations and grounding

Fire detection and alarm systems

5. <u>Estimates and Cost Control</u>

Cost estimated on new and modified installations

Cost data relating to power forecasts

In the rapidly advancing world of the electrical industry, developments in the accelerator field may be so revolutionary as to make the past 75 years of electrical research seem slow. Perhaps one of the significant side achievements we can expect out of the federally supported basic research in this high energy physics laboratory is that, through coordinated effort, we can establish as effective mechanism of putting the new knowledge gained in our electrical engineering research activities into deliberate industrial and commercial use.

LIST OF FIGURES

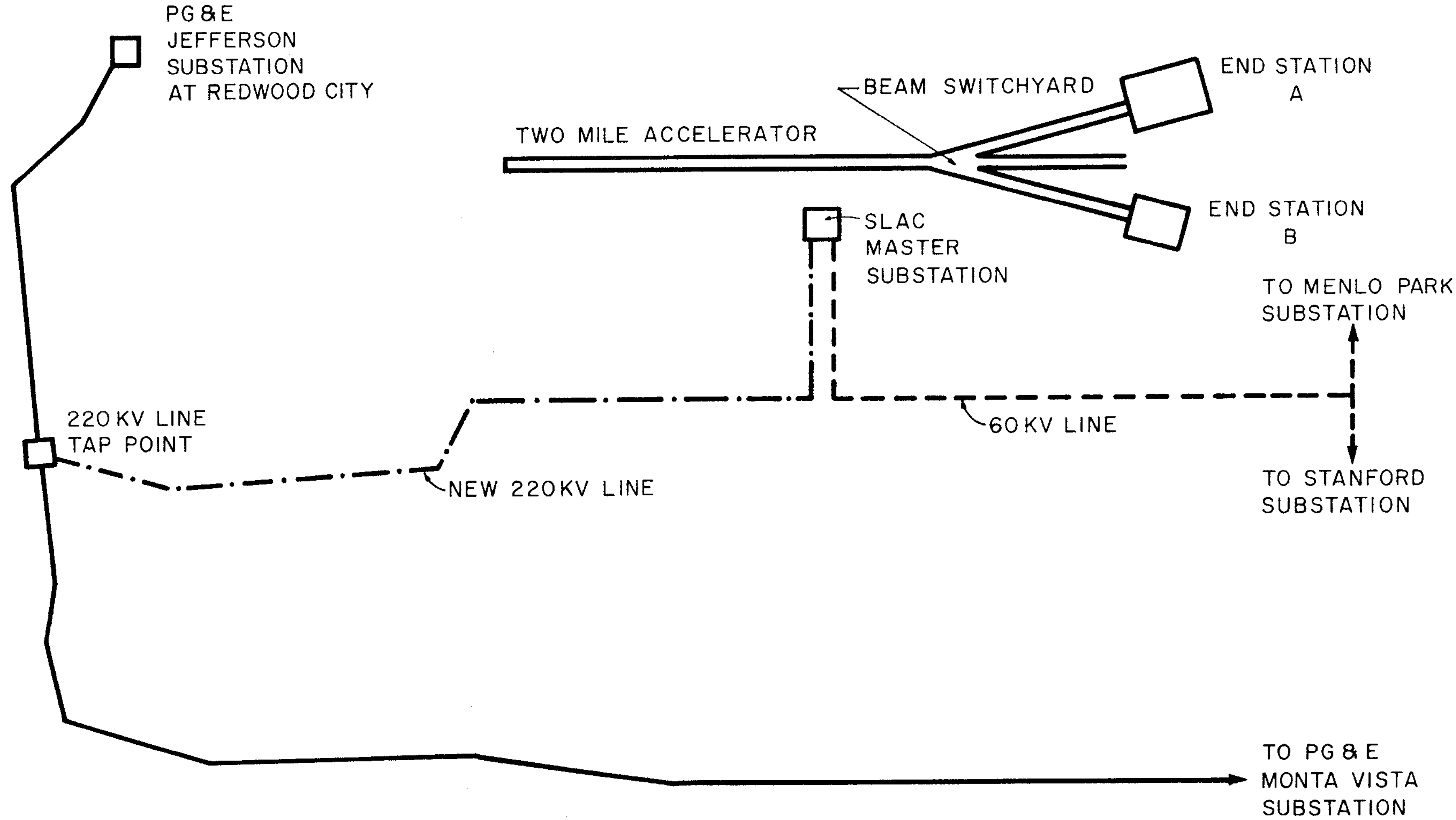

PG&E
JEFFERSON
SUBSTATION
AT REDWOOD CITY
BEAM SWITCHYARD
END STATION
A
TWO MILE ACCELERATOR
END STATION
B
SLAC
MASTER
SUBSTATION
TO MENLO PARK
SUBSTATION
220KV LINE
TAP POINT
60KV LINE
NEW 220KV LINE
TO STANFORD
SUBSTATION
TO PG&E
MONTA VISTA
SUBSTATION

FIG. 1

531-1-B

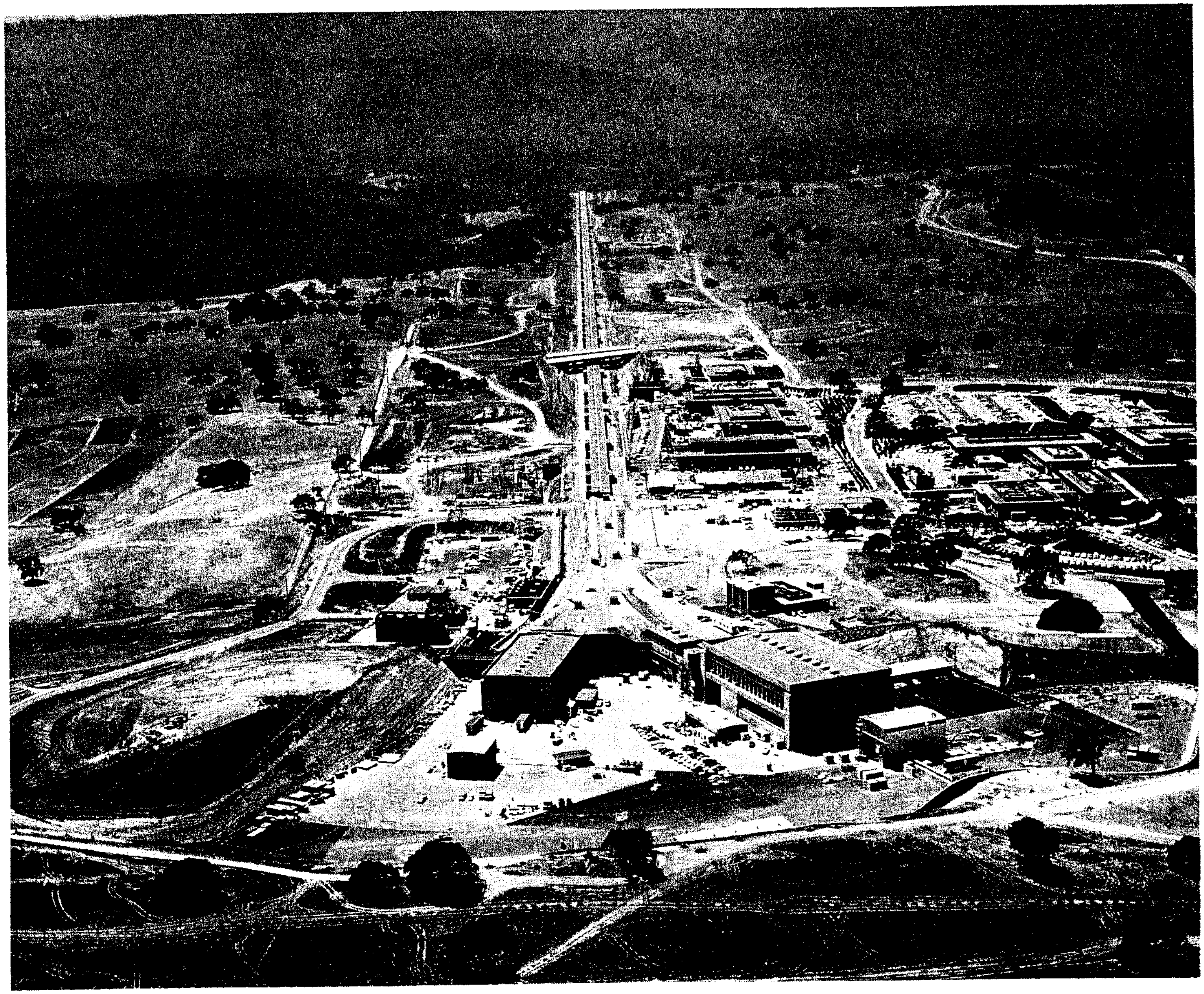


Fig. 2

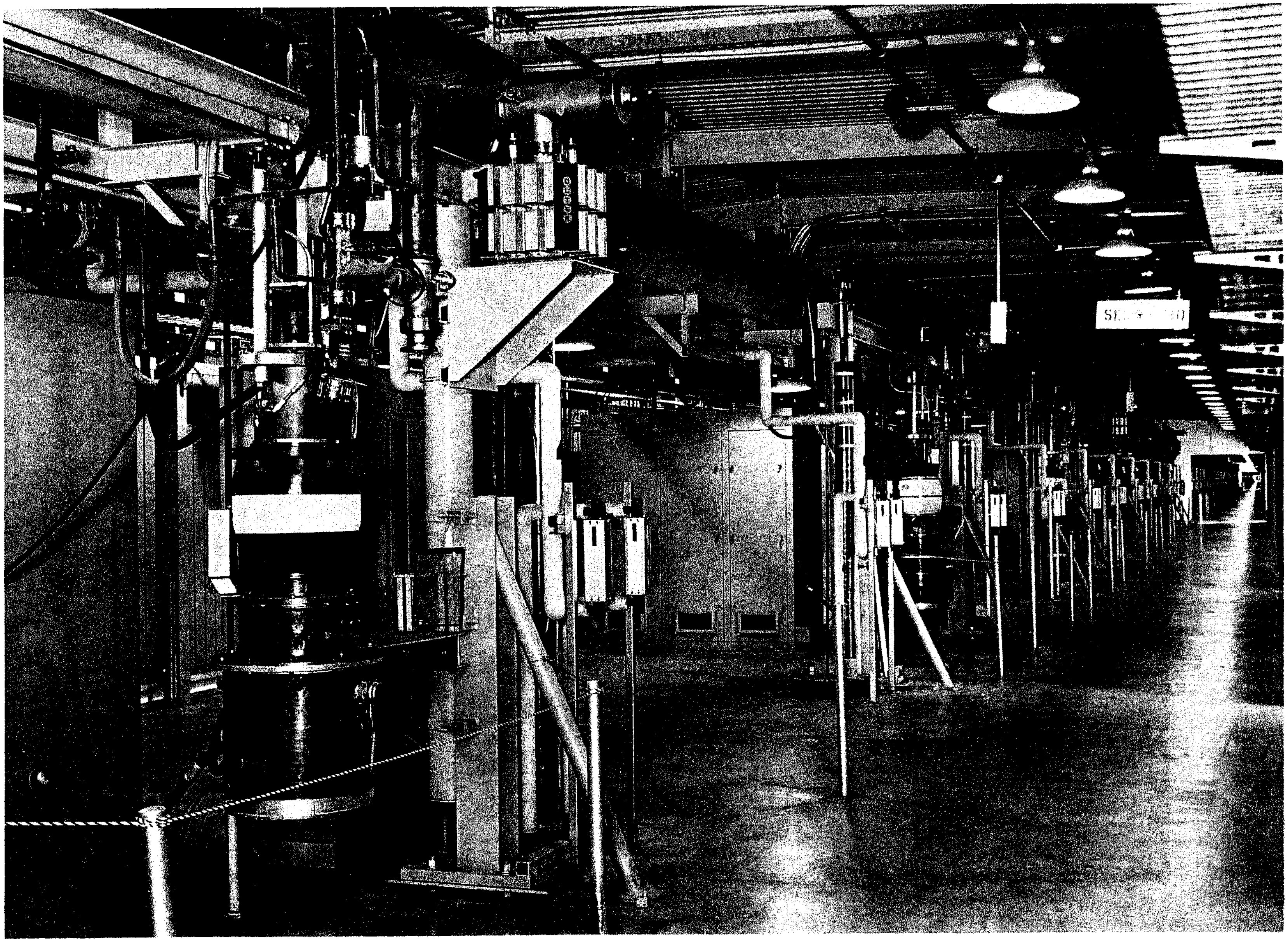


Fig. 3

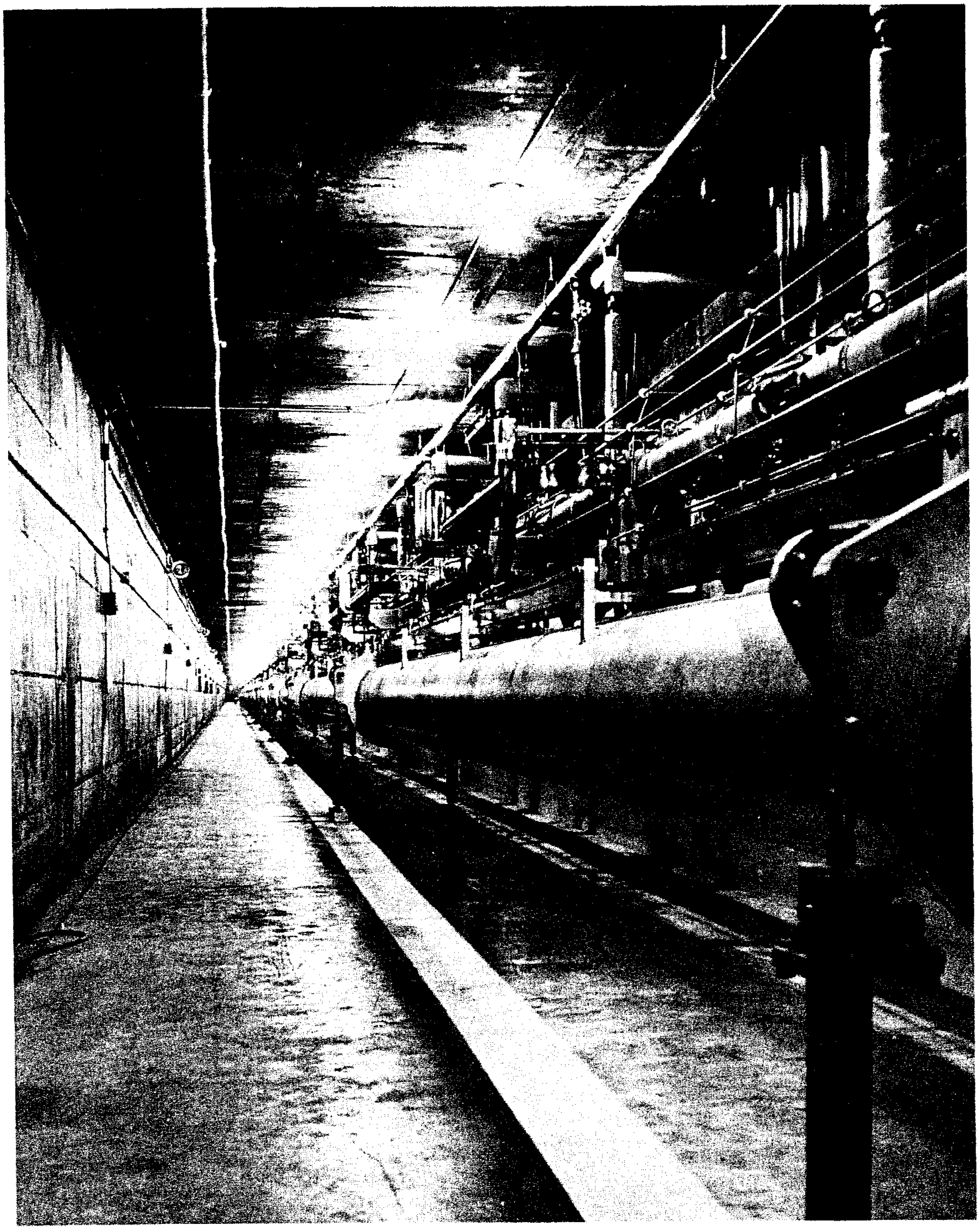


Fig. 4

151M35 Frame 1

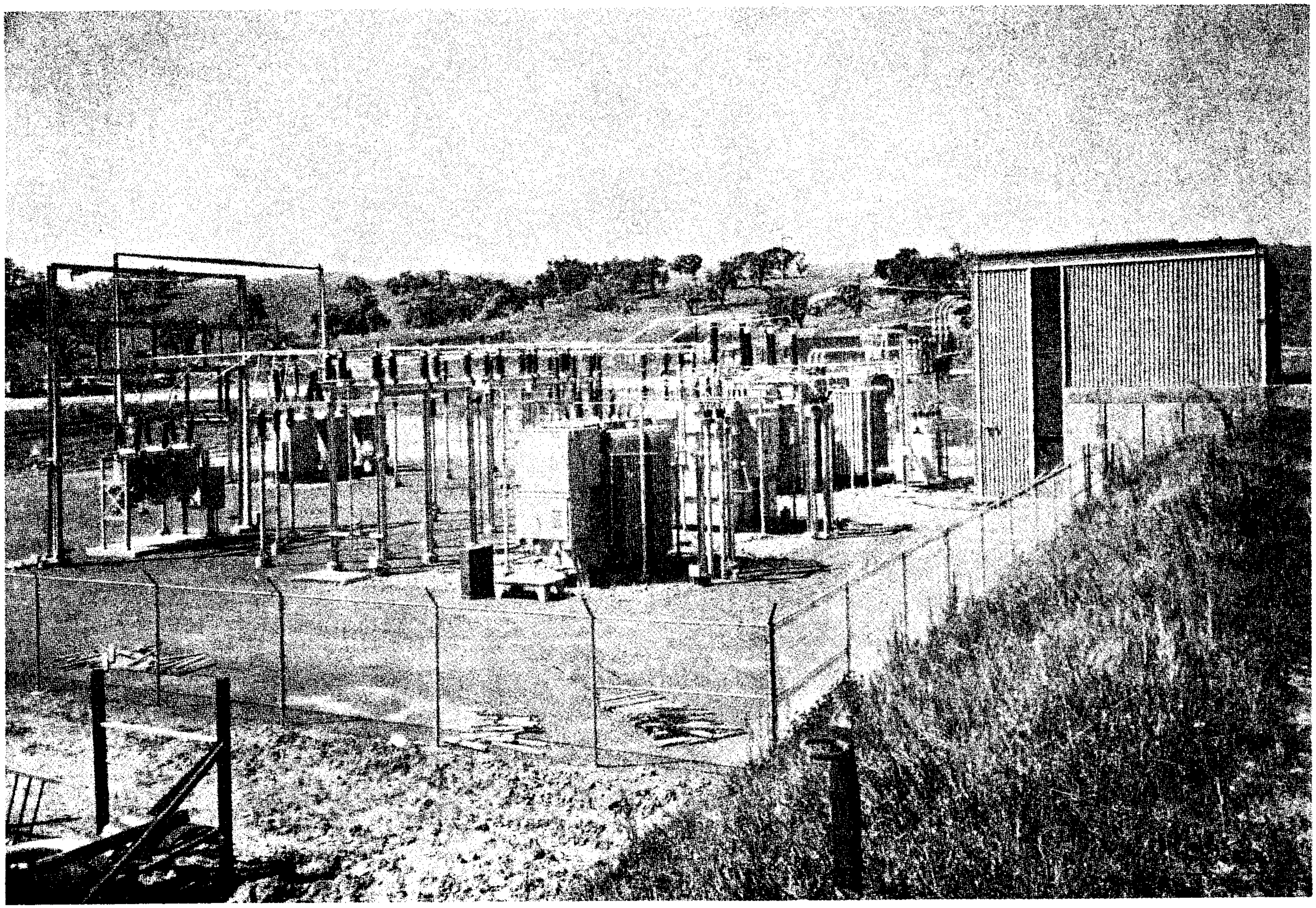


FIG. 5

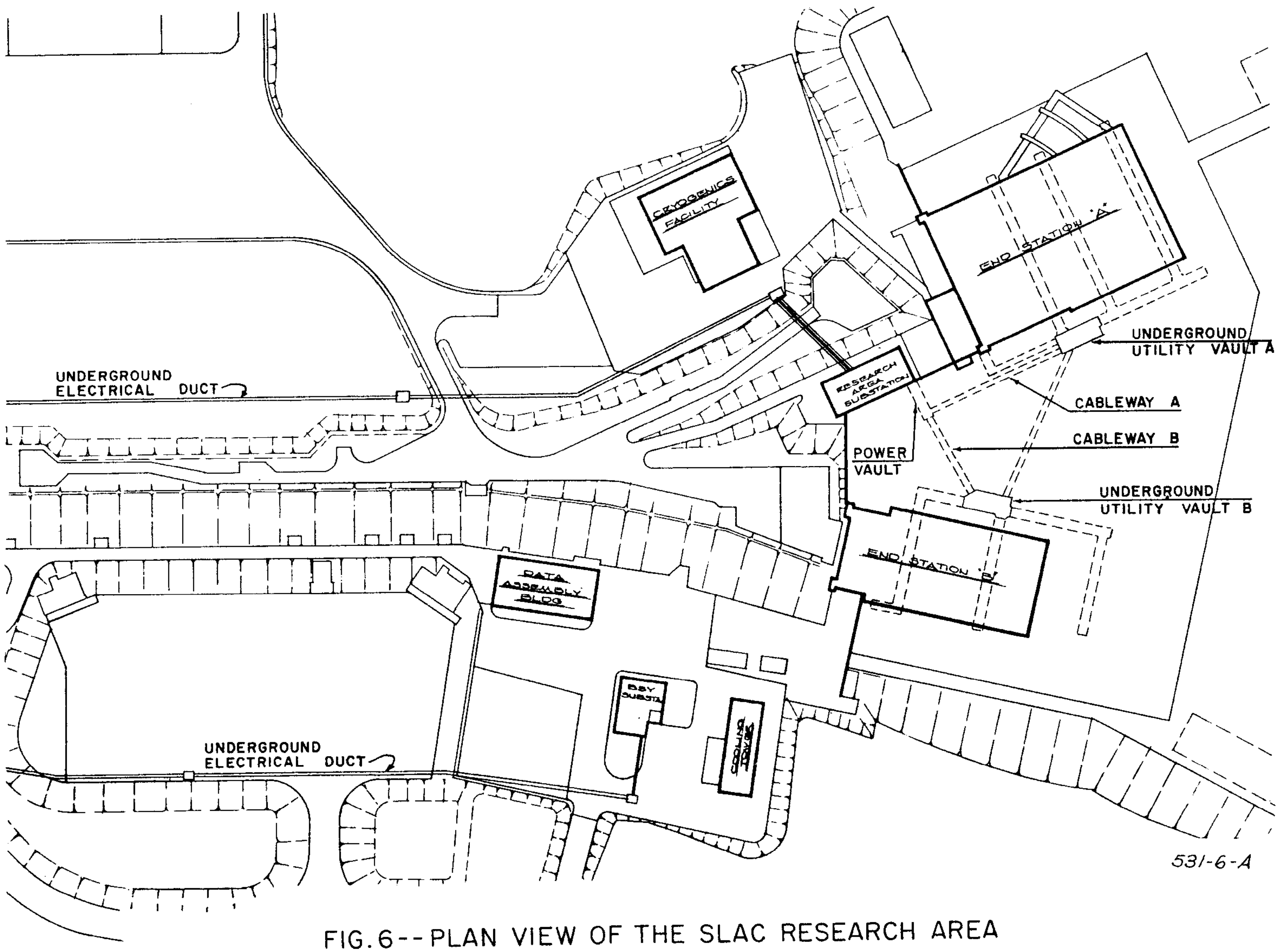
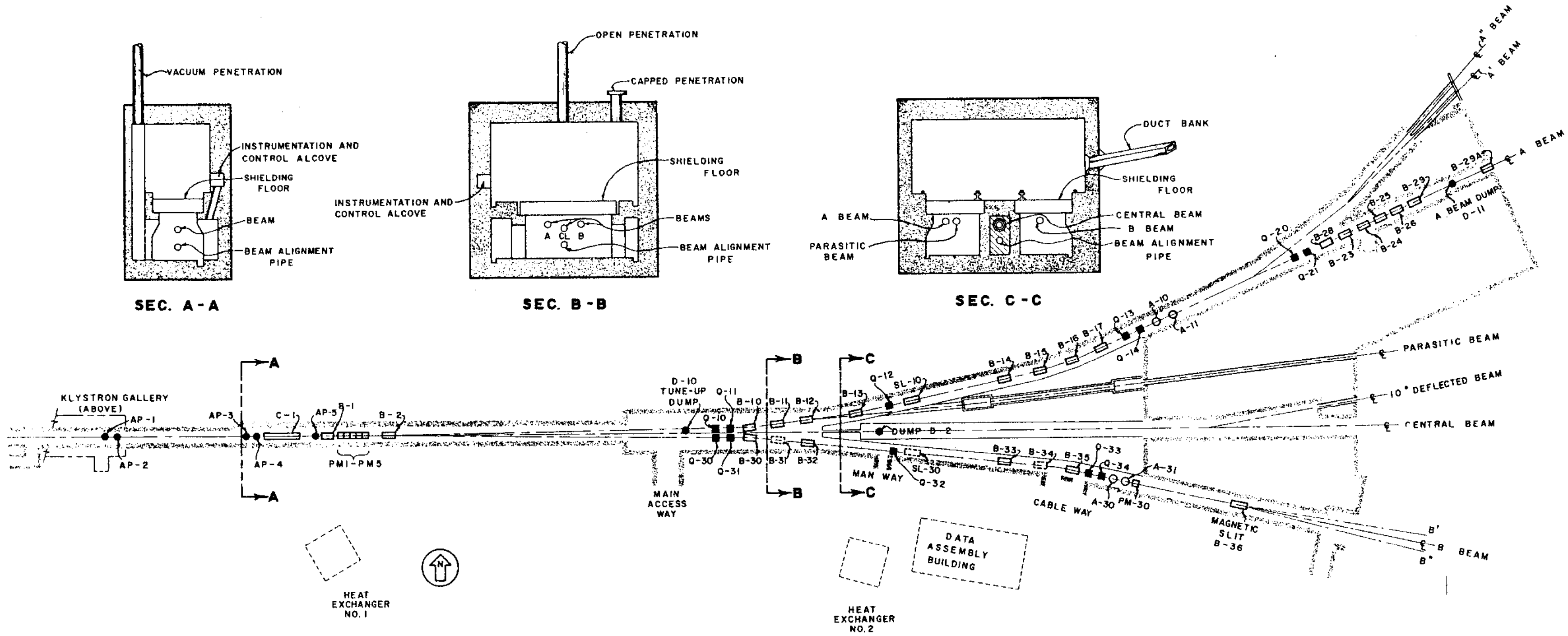


FIG. 6--PLAN VIEW OF THE SLAC RESEARCH AREA



AP - Pulsed Steering Magnet
C - Collimator
B - Bending Magnet
PM - Pulsed Magnet

D - Beam Dump
Q - Quadrupole
SL - Energy Defining Slit
A - DC Steering Magnet

353-10-A

Fig. 7

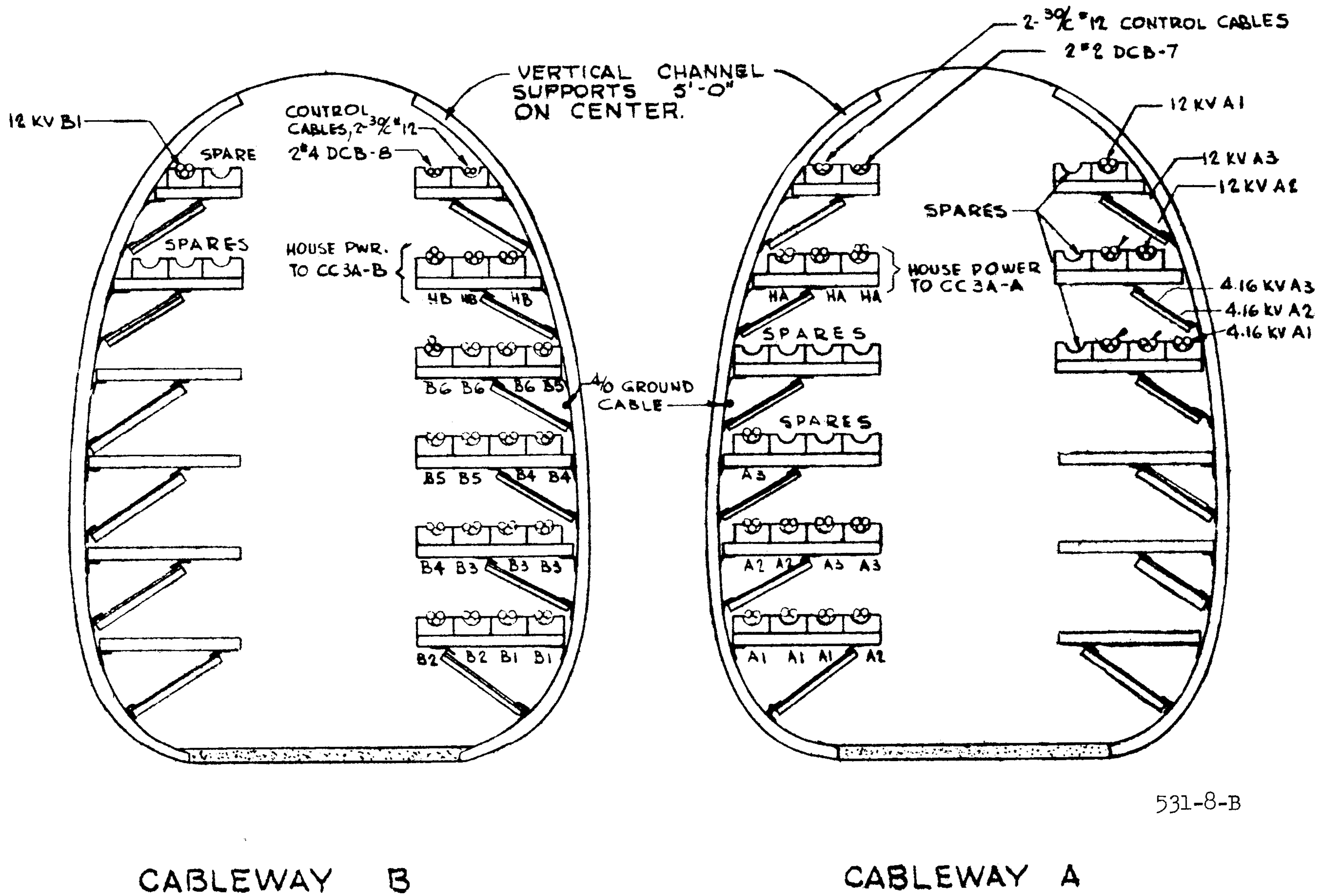

12 KV B1
SPARE
CONTROL CABLES, 2-3/C #12
2#4 DCB-8
VERTICAL CHANNEL SUPPORTS 5'-0" ON CENTER.
SPARES
HOUSE PWR. TO CC3A-B
HB HB HB
B6 B6 B6 B5
4/0 GROUND CABLE
B5 B5 B4 B4
B4 B3 B3 B3
B2 B2 B1 B1
2-3/C #12 CONTROL CABLES
2#2 DCB-7
12 KV A1
12 KV A3
12 KV A2
SPARES
HOUSE POWER TO CC3A-A
HA HA HA
4.16 KV A3
4.16 KV A2
4.16 KV A1
SPARES
SPARES
A3
A2 A2 A3 A3
A1 A1 A1 A2
531-8-B
CABLEWAY B
CABLEWAY A

Fig. 8

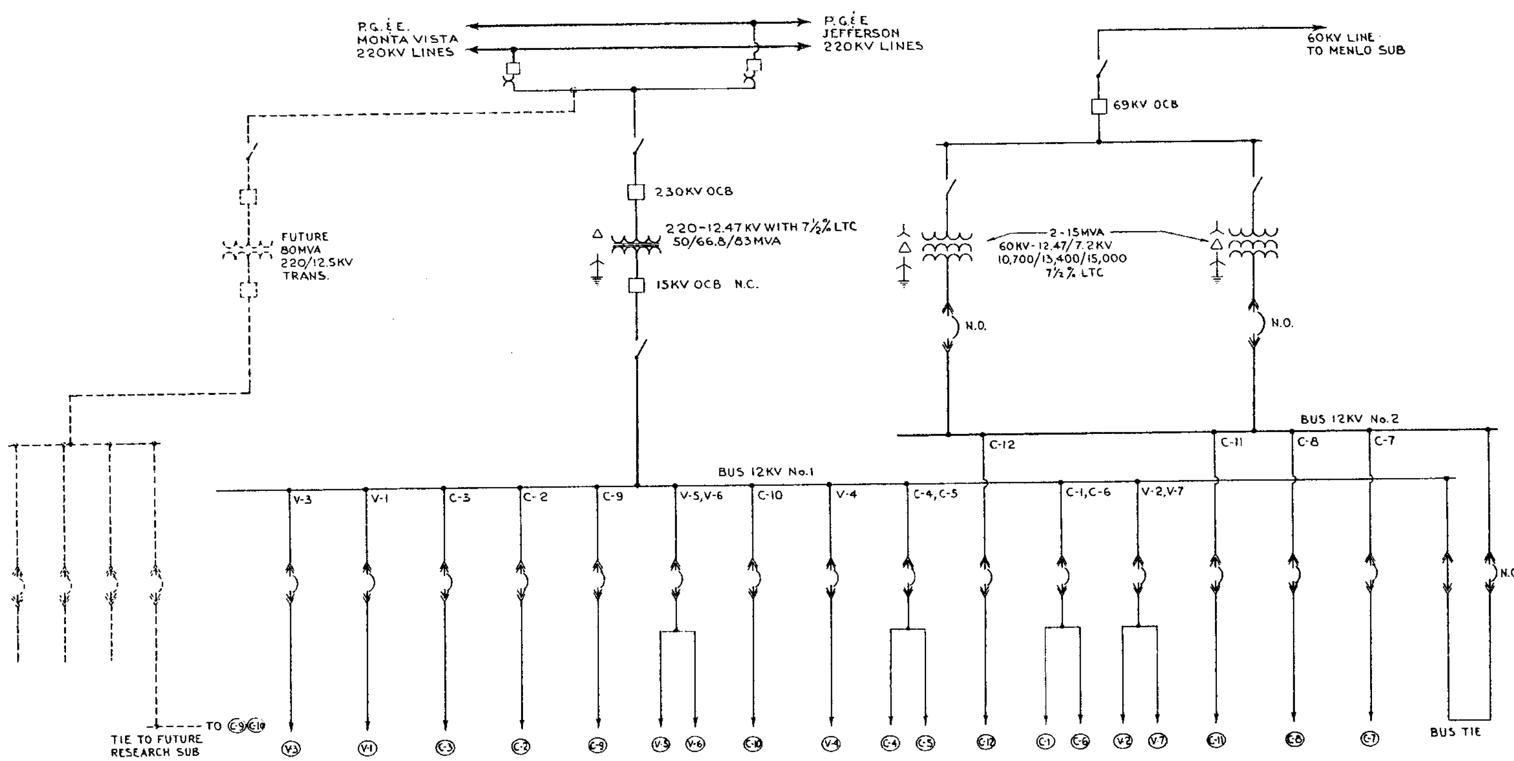

P.G.&E.
MONTA VISTA
220KV LINES
P.G.&E.
JEFFERSON
220KV LINES
60KV LINE
TO MENLO SUB
69KV OCB
230KV OCB
220-12.47KV WITH 7½% LTC
50/66.8/83MVA
15KV OCB N.C.
FUTURE
80MVA
220/12.5KV
TRANS.
2-15MVA
60KV-12.47/7.2KV
10,700/13,400/15,000
7½% LTC
N.O.
BUS 12KV No.1
BUS 12KV No.2
V-3
V-1
C-3
C-2
C-9
V-5,V-6
C-10
V-4
C-4,C-5
C-12
C-1,C-6
V-2,V-7
C-11
C-8
C-7
BUS TIE
TIE TO FUTURE
RESEARCH SUB
TO C-9 C-10

Fig. 9a

531-9-A

V-3

VV6(N), VV7(N), VV8(N), VV11(E), VV13(E)

V-1

VV1A(N), VV1B(E), VV2(N), VV3(N), VV4(E), VV5(E), VV8(E), VV9(E)

C-3

K3(E), K4(E), K5(E), K6(N), K7(N), K8(N), K9(N), K14(E)

C-2

K1A(E), K1B(N), K2(E), K5(N), K6(E), K9(E), K10(N), K13(E), CT1(N), CT2(N), PS1(N)

C-9

RA1(N), RA2(E), RA3B(N), RA3A(E), RA4(N), 5.8-MW Spark Chamber, 1.59-MW Spectrometer, North Staging Area

V-5, V-6

VV12(N), VV13(N), VV14(N), VV15(N)

C-10

RA1(E), RA2(N), RA3B(E), RA3A(N), RA4(E), 1.59-MW Spectrometer, 5.0-MW Spark Chamber

V-4

VV9(N), VV10(N), VV11(N), VV14(E)

C-4, C-5

K10(E), K11(N), K12(N), K13(N), K14(N), K15(N)

C-12

3A-CWP(E), 3B-CWP(N), PNL4A(E), PNL4B(N)

LEGEND

VV = Variable Voltage Substation
K = Conventional Substation
CT = Cooling Tower
RA = Research Area Substation
CWP = Circulating Water Pump
PNL = Beam Switchyard Panel
PS = Positron Source
(N) = Normal Supply
(E) = Emergency Supply

C-1, C-6

K1A(N), K1B(E), K2(N), K3(N), K4(N), K7(E), K8(E), K11(E), K12(E), K15(E), CT1(E), CT2(E)

V-2, V-7

VV1A(E), VV1B(N), VV2(E), VV3(E), VV4(N), VV5(N), VV6(E), VV7(E), VV10(E), VV12(E), VV15(E)

C-11

3A-CWP(N), 3B-CWP(E), PNL4A(N), PNL4B(E)

C-8

Fabrication Bldg. (1000/1333 KVA), Heavy Assembly Bldg. 5B-W (750/1000 KVA), Test Laboratory IB-E (2000/2667 KVA, 12.47 KV, 480 V) and 4B-E (750/1000 KVA, 12.47 KV, 480 V), and Electronics Bldg.

C-7

Heavy Assembly Bldg. 5A-E (750/1000 KVA), Test Laboratory 1A-W (2000/2667 KVA, 12.47 KV, 480 V), Central Laboratory 4A-W (750/1000 KVA, 12.47 KV, 480 V), Construction Office (250 KVA), and Crafts Shop (500 KVA)

FIG. 9b

Variable Voltage Substations (W):

1750 KVA, 12.47 KV, 250/610 V

Conventional Substations K1A, K1B, K2, K3, K4, K6, K7, K8, K9, K11, K13, K15:

750/1000 KVA, 12.47 KV, 480/277 V

Conventional Substations K5, K10, K14:

1000/1333 KVA, 12.47 KV, 480/277 V

Conventional Substation K12:

500 KVA, 12.47 KV, 480/277 V

Cooling Towers (CT):

500 KVA, 12.47 KV, 480/277 V

Positron Source (PS):

1500/2000 KVA, 12.47 KV, 480/277 V

Research Area Substation RA1:

5000/6667 KVA, 12.47/4.16 KV

Research Area Substations RA2, RA3A, RA3B, RA4:

2500/3300 KVA, 12.47 KV, 480/277 V

Circulating Water Pumps (CWP):

1500/2000 KVA, 480 V

Beam Switchyard Panels (PNL):

1000/1333 KVA, 480 V

FIG. 9c