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STUDY OF INTERFACE CHARACTERISTICS FOR ELECTRONIC EQUIPMENT IN COMMAND AND CONTROL FACILITIES

FOR

THE MITRE CORPORATION

BEDFORD, MASSACHUSETTS

PURCHASE ORDER NUMBER M 20746

AF33(600)-39852

13 APRIL 1962

POPE, EVANS AND ROBBINS

POPE, EVANS AND ROBBINS
CONSULTING ENGINEERS
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13 April 1962

The Mitre Corporation
Box 208
Bedford, Massachusetts

Attention: Mr. J. J. O'Sullivan, Dept. D-23

Subject: The Mitre Corporation
Purchase Order No. M20746
AF33(600)-39852
Electronic Equipment-Facility
Interface Characteristics Study

Gentlemen:

In accordance with subject purchase order, we are transmitting herewith our study report. This report outlines an approach to permit facility design to proceed prior to obtaining final electronic equipment data.

Our study is based on work being done in this field today.

However, during the study it became evident that facility design approaches have not kept pace with modern concepts and needs of superhard command and control facilities. These design areas are in addition to the recognized new concepts of weapons effects and are listed below. Neither time nor scope of contract permitted detailed development of these items.

1. Due to the unusual conditions of below ground construction and operation, as well as "button-up" requirements, all normal design contingencies result in multiplying and compounding cost, space and personnel requirements to an almost intolerable degree. Design criteria must take cognizance of this by being reduced to the minimum level consistent with mandatory operational requirements. Some areas of consideration are:

a. General lighting levels should be the lowest possible (perhaps 5 foot candles rather than the presently specified 40-50) with provision for local and temporary higher levels where and when absolutely necessary.

b. Verification of electronic equipment power and cooling requirements (also power, diversity, demand, load, etc. factors) by actual test rather than the use of catalogue data or "guess-timates."

c. Verification of the electronic equipment support areas (maintenance, test, storage, programming, administration, etc.) to be assured that the space and power requirements reflect actual need rather than guesses that can so seriously penalize a facility.

d. Verification of floor areas and live load requirements.

2. Establish a detailed military specification for electronic equipment for superhard installations based on a completely new look at all areas of design as they affect the facility as a whole. All existing criteria must be either verified or changed, based on a crash program of detailed studies. Just as we demand a new equipment concept for aircraft and submarines, so must a new concept be developed for superhard facilities.

3. Implement a program to increase the reliability level of all direct support equipment and systems to a point approaching, if not equalling, that of the electronic equipment. A mean time between failures (MTBF) of more than 15,000 hours has been attained on the Minuteman program for environmental control equipment. The critical function of this type equipment warrants engineering, specifications, manufacture, installation and checkout with the same thoroughness that is applied to the electronic equipment and systems, rather than being treated as conventional "brick and mortar."

4. Investigate new approaches to environmental control to provide maximum flexibility with minimum space utilization. This might be directed toward separating the dehumdification and the sensible cooling requirements, and accomplishing the

latter with either a grid of water cooled ceiling radiant panels or multiple fan coil units, or a combination of both. The water distribution system could be routed and valved so that changes in load location can be accommodated by valve operation or reconnecting fan coil units. Plug-in type portable dehumidifying and air revitalization systems would complete the environmental control requirements.

5. Develop a new concept in utility distribution space that would permit maintenance and flexibility. Permanent false floors of sufficient depth (maybe 48") to serve both the areas below and above it would eliminate both "floating" type floors and hung ceilings which are both costly and troublesome in a shock environment. This utility space concept should be coordinated with new approaches in heat dissipation and electrical distribution systems.

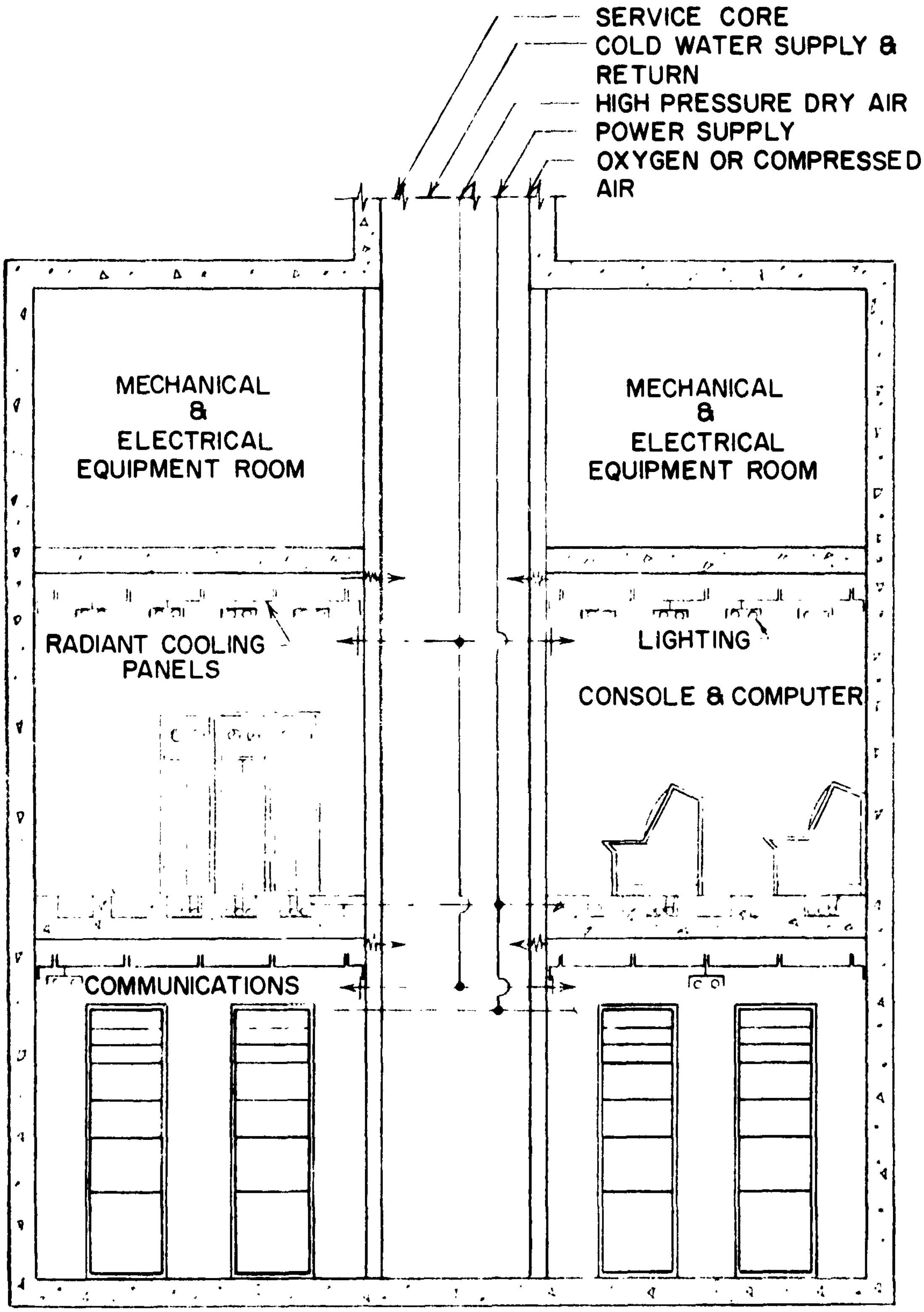
6. Adopt a multi-step criteria, design and construction program that would permit the freezing and implementation of each step of the final facility construction without penalizing the steps that follow. The use of a simplified PERT or critical path scheduling of separable steps would permit an orderly development of the information for the design criteria, subsurface investigation, equipment-facility interface characteristics, tunnelling and shaft construction, facility design and construction, technical area design and construction, equipment design, fabrication, installation and checkout.

We would appreciate the opportunity of discussing this report with you in further detail at your convenience.

Performing this study for The Mitre Corporation has been most challenging and interesting, and we look forward to further association with you.

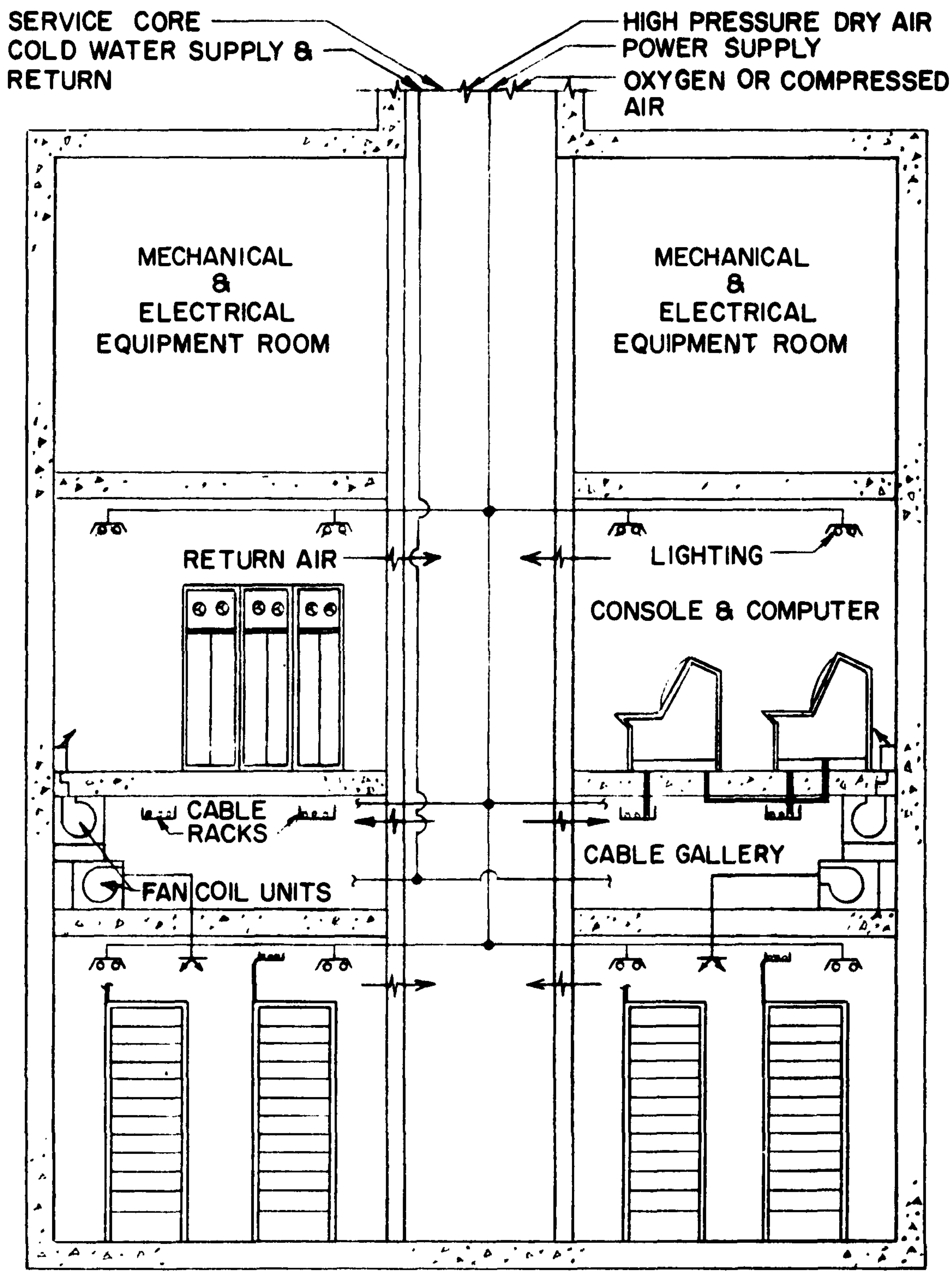
Very truly yours,

Michael Pope



UNDERGROUND FACILITY
CENTRAL CORE WITH RADIANT PANELS
AND TRENCH FLOOR

POPE EVANS AND ROBBINS
CONSULTING ENGINEERS



UNDERGROUND FACILITY WITH
CABLE GALLERY AND FAN COIL UNITS

POPE, EVANS AND ROBBINS
CONSULTING ENGINEERS

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1.0 INTRODUCTION

The mission of a command and control facility is accomplished by a man-machine team whose composition is based on detailed system studies and analyses. By machine we mean computer, display and communications equipment which are the basic tools of command and control.

The team is assembled and housed in a facility which must provide all the necessary services for the team's performance. By services we mean electric power supply, level of lighting, temperature and humidity control and structural support.

The services required by the machine-member of this team is the subject of this study. Specifically, we are concerned with the services required by the electronic equipment to achieve an uninterrupted and satisfactory level of operation with a capability of flexibility and growth. The standardization of these equipment-facility service (inter-face) requirements has been a continuing need in vital command control systems. The need is even more pressing in facilities designed to survive the effects of nuclear weapons where space, power and heat rejection equipment are very costly and relatively inflexible.

Fundamentally, it is the electronic equipment and support services which establish the space requirement in the technical areas of the facility. This space requirement must be translated into building height, shape and area. In extremely hard underground facilities, the building configuration is often dictated by tunnel sizes or structural strength considerations. Rock tunnels have width and height limitations, and buried structures are ideally of cylindrical or spherical shapes. Therefore, equipment layouts must of necessity be dependent upon, and in consonance with, the specially designed "hardened" structures. These special structures have construction lead times that are measured in years, and either equal or exceed equipment lead times. Therefore, we have a condition of concurrency which demands facility finalization long before equipment has been finalized. It has been found that equipment requirements vary with the specific equipment manufacturer (and even with different models of the same manufacturer) and that the interface requirements are rarely available in time to satisfy the facility design schedule. The lack of this information results in an arbitrary estimate of the computer, display and communication requirements, with excessive safety factors, and the subsequent design of a facility which is excessively expensive.

Standardization and definition of the electronic equipment facility interface requirements appears to be the most feasible way of relieving this deficiency. It will simplify the facility design effort, improve the design schedule and introduce the required flexibility at a reasonable cost. This solution will also answer another need of command and control facilities; ... flexibility and growth. Invariably, the facilities design must proceed prior to the completion of the system's concept and its translation into hardware. Also, these systems are usually evolutionary in nature and subject to change due to the results obtained in a test facility or advances in the state of the art between the time originally conceived and the time of equipment installation and operation. The ultimate in flexibility would be to permit full freedom of location, relocation and addition of equipment on an essentially pluggable basis. Although the ultimate may not be reached, the goal of this study will be to develop an approach that will permit the facility design to proceed prior to finalization of electronic equipment selection and provide the required flexibility in the facility.

2.0 CONCLUSIONS AND RECOMMENDATIONS

To bring into being an operational, superhard command control facility, with a 3 - 4 year time period, that will accommodate equipment as well as an operational concept not yet fully developed requires at least the following:

2.1 Adopt standardized electronic equipment-facility interface specifications and criteria to which equipment manufacturers and system designers must conform. Where equipment manufacturers cannot fully conform to the standard specifications, they must detail all deviations at the time of their bids or contract award.

2.2 Establish a three step design and construction schedule which freezes each of the following in a timely manner.

a. Excavation and tunnels.

b. Overall structural enclosure, non-technical support areas and major central power and air conditioning systems.

c. Technical area structural, architectural and electronic equipment-facility interface services.

This study has addressed itself primarily toward the survey of the interface characteristics of computer, display and communications command-control equipment and the preparation of standardized specifications which will satisfy the planning of a superhard facility without imposing undue restrictions on the equipment manufacturers or system designers.

Exhibit I is a proposed standardized equipment specification.

Exhibit II is a proposed three step facility design and construction schedule.

Exhibit III is a summary of the interface characteristics obtained from a representative group of electronic equipment manufacturers.

Section 4 is a discussion of the power, lighting, air conditioning, and structural interface characteristics of command control electronic equipment.

Section 5 contains schematic drawings of typical technical area arrangements.

Command Control Facilities are varied in size, level of hardness, and function. While this report will discuss the general problem of electronic equipment - facility interface, it will deal in part with the specifics of a relatively small, extremely hard, deep underground installation that must continue to operate during and after a major nuclear attack.

3.0 EXHIBITS

EXHIBIT I - STANDARDIZED ELECTRONIC EQUIPMENT - FACILITY INTERFACE SPECIFICATIONS

3.1 Computer

3.11 Size - equipment and carrier shall pass through a 4 foot x 8 foot door opening for initial installation. This door size shall also be adequate for test and maintenance equipment.

3.12 Floor Loading - equipment weight and support area shall be such as not to exceed a maximum floor design live load of 50 pounds per square foot in any 100 square foot equipment layout area and maximum point concentrated live load of 1000 pounds.

3.13 Electrical Service

3.131 Power requirements shall be 120/208 volts, 3 phase 60 cycle, 4 wire. Any other service required shall be transformed or converted by equipment furnished by the computer supplier.

3.132 Minimum tolerances shall be as follows:

Voltage: ± 8%

Frequency: ± 1/2 cycle (steady state)

± 1.2 cycles (normal switching)

± 3.0 cycles (full transients)

Any closer tolerances shall be provided by integral equipment supplied by the computer manufacturer.

3.133 Cabling

All cabling shall be arranged to enter and leave the computer and its auxiliaries from below. The equipment shall be designed for support on a removable panel, free access type, elevated floor whose surface is

12 inches above the surface of the sub-floor with approximately 13 feet clear height between the sub-floor and the underside of the over-head structure. The cabling size and bend radius and the type and location of equipment terminations shall permit the routing of all inter-connecting cabling through this under floor space.

3.134 Lighting

Equipment lighting requirements shall be satisfied by room lighting of 40 foot candles maximum at floor level using direct type fluorescent fixtures. Any other operational or maintenance lighting requirements shall be met by auxiliary lighting provided as an integral part of the computer.

3.135 Grounding

Adequate number, size and type of grounding connections shall be provided at a single point for each frame or chassis to satisfy the supplier's equipment and cabling grounding requirements.

3.14 Air Conditioning Environment

Equipment room conditions of 75° ± 3° DB and 35 to 65% R.H. will be provided by the facility by means of a conventional air conditioning system. Air distribution will be provided through ceiling diffusers or registers uniformly spaced. The air distribution system will be 20 percent oversized for flexibility. The computer equipment shall not require either supply or return ducting. The equipment shall be designed for either ambient cooling or with built-in air fans so that the air temperature rise through it shall not exceed 12° F.

3.15 Equipment Support

The electronic equipment shall be furnished with the necessary hardware and fittings to provide for levelling, support and anchoring in a shock environment of 1 G vertical and 1/2 G horizontal acceleration forces.

3.16 Weapons Effects

The equipment shall be capable of providing continuous and unchanged performance under 1 G vertical and 1/2 G horizontal shock and shall have an RFI susceptibility threshold of 120 db (above 1 microvolt per meter per megacycle) over a range of 0.1 to 10^3 megacycles.

3.2 Display Equipment

3.21 Except for lighting and noxious fumes the size, floor loading, power requirements, cabling, lighting, grounding, weapons effects, air environment and support specifications shall be identical to the computer specifications noted in Section 3.1.

3.22 Lighting

Display equipment shall be capable of full performance and maintenance in a direct fluorescent lighted area with a dimmable light level of 0 to 40 foot candles as measured 30 inches above the floor.

3.23 Noxious Fumes - Corrosive Drains

Generation of noxious fumes or corrosive drains will not be acceptable under normal or shock environment conditions. Release of noxious fumes and/or corrosive liquids shall only be permitted under accidental conditions and the amounts released shall be such that no deleterious build-up will occur in a one (1) air change per minute air conditioned environment. In any event, equipment capable of generating noxious fumes or corrosive drains will not be acceptable unless it is the only practical solution and can be proven to provide significant cost savings.

3.3. Communications

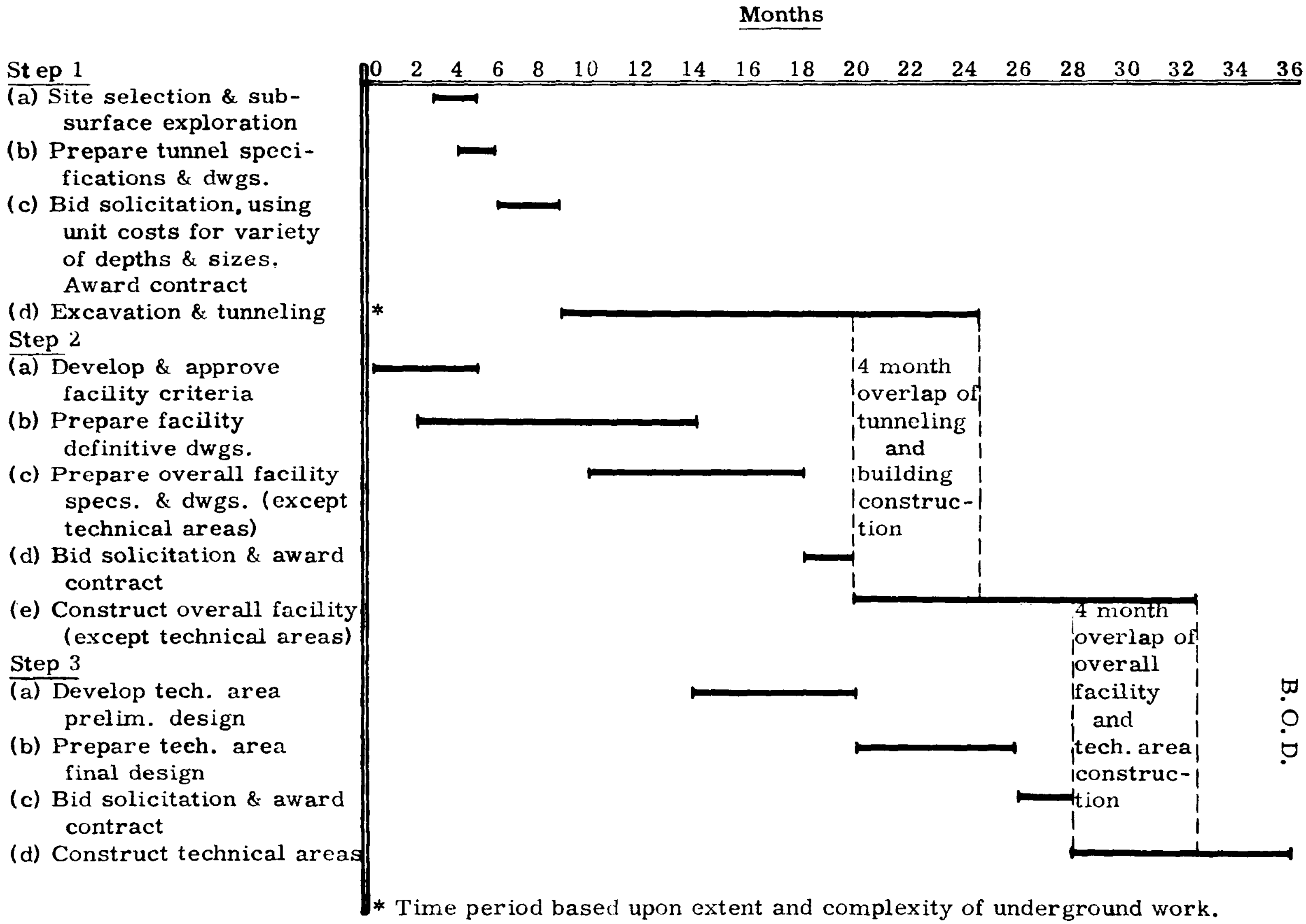
All specifications listed for the computer equipment shall be applicable to the communications equipment except for the following.

3.31 Cabling

All cabling shall be arranged for overhead routing requiring no holes through the supporting floor. The equipment will be located in a room with 13 feet of height between the surface of the supporting floor and the underside of the overhead building structure.

EXHIBIT II

THREE STEP FACILITY DESIGN & CONSTRUCTION SCHEDULE



* Time period based upon extent and complexity of underground work.

EXHIBIT III

The following firms furnished data pertinent to the equipment they would furnish for command and control installations:

Western Electric Company
New York, N. Y.

General Precision Laboratories
Pleasantville, New York

Hazeltine Corporation
Little Neck, New York

Sperry-Rand Univac
Division of Sperry-Rand
New York, N. Y.

I. B. M. -Federal Systems Division
Rockville, Maryland

Philco Corporation
Washington, D. C.

Minneapolis Honeywell Corporation
Pottstown, Pennsylvania

Bendix Computer Division
Los Angeles 45, California

Burroughs Corporation
Paoli, Pennsylvania

Radio Corporation of America
Camden, New Jersey

American Telephone and Telegraph Company
New York, N. Y.

The following sheets summarize the equipment interface data that has been obtained relative to this study. The previous standardized electronic equipment-facility interface specifications differ from the following equipment data in those areas where it is felt that the differences will reduce the cost and simplify the facility design without unduly restricting equipment selection and performance.

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EXHIBIT III

SUMMARY SHEET

ELECTRONIC EQUIPMENT INTERFACE

Item	Maximum Dimensions Inches Side x Height	Kva	Power Factor	Volts	Maximum Cycle Deviation	Air Envi… Temperature °F	Rela… Hum… %
COMPUTER							
RCA - 601	36 x 80	58	.78	208±10%	±1/2	70-80	20-
RCA - 501	31 x 69	15	.87	---	---	70-80	20-
RCA - 301	30 x 74	37	.8	120/208/230	---	70-80	20-
IBM - 701,704,709	37 x 69	85-130	---	208 ± 8%	±1/2	65-80	20-
Remington Rand Univac 1103, 1103A	32 x 69	82	.9	208	---	240,000 Btu/h… 50° chilled wat… ment cooling.	
Remington Rand Univac 1105	32 x 69	175	.9	208	---	420,000 Btu/hr 50° chilled wat… ment cooling. room RH - 60%	
Remington Rand Univac-Solid State	32 x 69	--	---	208/240±10%	±1/2	60-85	30-
Philco - 2000	42 x 72	75	1.0	120/208±10%	±1/2	60-80	45-
Honeywell - 800	36 x 73	57	.8	120/208±10%	±1/2	74max	[illegible]
Honeywell - 1000	36 x 73	110	.86	208		Air conditionin…	unit…
Burroughs - 220	35 x 76	56	.87	208	---	60-80	40-
Bendix G-200	29 x 64	30	.8	115±10%	---	65-80	35-
DISPLAY							
Hazeltine AN/UPA-25	39 x 47	1.83	.85	115±10%	±2	32-122	40-
General Precision (General data)	64 x 83	---	---	---	---	50-100	95% 50° 50% 100
IBM - SAGE	---	1.4	(From computer power module)			ducted 61	50m…
COMMUNICATIONS							
Wes. Elec. "SAGE"	---	---	---	120/208	---	75	50 n…
Am. Tel. & Tel.	23 x 138	---	---	208/240/±10%	±3	80 design	35-

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EXHIBIT III

SUMMARY SHEET

PMENT INTERFACE CHARACTERISTICS

um e ion	Air Environment Temperature °F	Relative Humidity %	Maximum Dew Point °F	Floor Area Sq. Ft.	Ceiling Height Ft.	Lighting Level Ft. Candles 30" above flr	Raised Flr. Required	Maximum Live Load PSF
	70-80	20-65	58	1400	---	------	Yes	---
	70-80	20-65	58	750	---	------	Yes	---
	70-80	20-65	58	----	---	------	Yes	100
	65-80	20-60	--	2000-4000	---	40	Yes	100
	240,000 Btu/hr equivalent as 50° chilled water for equipment cooling.			1800	10	------	Yes	40
	420,000 Btu/hr equivalent as 50° chilled water for equipment cooling. Maximum room RH - 60%			3000	10	------	Yes	47
	60-85	30-60	--	----	10	50	Yes	150
	60-80	45-60	--	1500	---	------	Yes	54
	74max		59 WB Max.	1600	8	40	Yes	75
	Air conditioning integral with unit			4500	8'3"	------	Yes	125
	60-80	40-60	--	1500	---	------	Yes	180
	65-80	35-65	--	2300	---	60	Yes	223
	32-122	40-95	--	----	---	Drk. room Required	---	---
	50-100	95% @ 50° F 50% @ 100° F	--	----	---	2 to 50	Yes	250
le)	ducted 61	50max.	--	----	17	Dimmable 40	Yes	150
	75	50 max.	--	----	15	Integ. with equip.	No	175
	80 design	35-65	--	----	15	Integ. with equip.	No	175

Computer - RCA 601

Electrical -

58 Kva
0.78 pf
208 volts ± 10%
60 cycles ± 1/2 cycle
Cabling routed under elevated floor

Mechanical -

13 tons of air conditioning
Room conditions:
- 70 - 80° FDB
- 20 - 65% R. H.
- 58° F maximum dew point

Structural -

Computer area 1400 square feet
Elevated floor required for cables
Equipment maximum dimensions;
- 80 inches high
- 36 inches deep

Computer - Remington Rand Univac 1103, 1103A

Electrical -

82 Kva
0.9 pf
208 volts, 60 cycles, 3 phase, 4 wire power to motor generator sets.
Cabling routed under elevated floor.

Mechanical -

20 tons of refrigeration supplying 50° F water for equipment cooling.
Room cooling for operator comfort.

Structural -

Computer Area - 1800 square feet
Elevated floor 15-1/2 inches high for cabling
Room height - 10 feet
Floor design live load - 40 psf;
500 pounds maximum concentrated load.

Computer - Remington Rand Univac 1105

Electrical -	175 Kva 0.9 p.f. 208 volts, 60 cycles, 3 phase, 4 wire to motor generator sets. Cabling routed under elevated floor.
Mechanical -	35 tons of refrigeration supplying 50° F water for equipment cooling. Three fan cabinets cool room air and feed a plenum to the equipment. Exhaust air from equipment to the room is 74 - 80° F. Maximum relative humidity is 60%.
Structural -	Computer area - 3000 square feet Room height - 10 feet Floor design live load - 47 psf.

Computer - Remington Rand Univac-Solid State

Electrical -	208 or 240 volts ± 10% 60 cycles ± 0.5% Cabling routed under elevated floor. All equipment grounded to Processor or Synchronizer which are then connected to the facility ground. Lighting - 50 foot candles 30 inches above floor.
Mechanical -	Room cooled equipment with integral fans. Room conditions: 60 - 85° FDB 30 - 60% RH Design for 75° FDB and 50% RH
Structural -	Elevated floor for cabling with a 6 inch bend radius. Floor design live load - 150 psf with 353 pound maximum concentrated load. Equipment size: 69 inches high x 32 inches deep maximum.

Computer - RCA 501

Electrical -	15 Kva 0.87 p.f.
Mechanical -	20 tons of air conditioning. Room cooled equipment. Room conditions: 70 - 80° FDB 20 - 65% RH 58° F maximum dew point
Structural -	Computer area - 750 square feet. Elevated floor required for cabling. Maximum equipment dimensions: 69 inches high, 31 inches deep.

Computer - RCA 301

Electrical -	37 Kva 0.8 p.f. 120/208 volts, 3 phase, 60 cycle, 4 wire or 230 volts to Processor
Mechanical -	10 tons of air conditioning. Room cooled equipment. Room conditions: 70 - 80° FDB 20 - 65% RH 58° F maximum dew point
Structural -	Maximum equipment dimensions: 74 inches high, 30 inches deep Floor design live load - 100 psf

Computer - Philco 2000

Electrical -	75 Kva 1.0 p.f. 120/208 volts, 60 cycles, 3 phase, 4 wire. Voltage tolerance ± 10%. Frequency tolerance ± 1/2 cycle. Separate air conditioning power supply. Cabling routed under floor.
Mechanical -	Room cooled equipment with integral fans. Room conditions: 60 - 80° FDB 45 - 60% RH
Structural -	Computer Area - 1500 square feet Elevated floor 2 feet high for cabling. Maximum equipment dimensions: 72 inches high, 42 inches deep. Floor design live load - 54 psf

Computer - Honeywell 800

Electrical - 57 Kva
0.8 p.f.
120/208 volts, 3 phase, 60 cycles, 4 wire grounded.
Voltage tolerance ± 10%
Frequency tolerance ± 1/2 cycle.
Equipment grounded separately.
Cabling routed under floor.
Lighting - 40 foot candles, 30 inches above floor.

Mechanical - 10 ton air conditioning.
Room cooled equipment - integral fans.
Room conditions:
74° FDB maximum
59° F WB

Structural - Computer Area - 1600 square feet.
Elevated floor 9 inches high for cabling.
Floor design live load - 75 psf;
500 pounds caster load.
Floor to ceiling height - 8 feet.
Maximum equipment dimensions:
73 inches high, 36 inches deep.

Computer - Honeywell Datamatic 1000

Electrical - Computer - 110 Kva, 0.86 p.f.
Built in air conditioning - 60 Kva, 0.82 p.f.
208 volts, 3 phase, 60 cycles.
Cabling routed under floor.

Mechanical - Equipment air conditioning is built into the equipment.
Additional air conditioning required for operator comfort.

Structural - Computer area - 4500 square feet.
Elevated floor required for cabling.
Floor design live load - 125 psf
Floor to ceiling height - 8 feet, 3 inches.

Computer - Burroughs 220

Electrical - 56 Kva
0.87 p.f.
208 volts, 60 cycles, 3 phase, 4 wire.
Cabling routed under floor.

Mechanical - Room cooled equipment.
Room conditions:
60 - 80° FDB
40 - 60% RH
Elevated floor can be used as air plenum.

Structural - Computer Area - 1500 square feet.
Elevated floor 8 inches high required for cabling.
Equipment maximum dimensions:
76 inches high, 35 inches deep.
Floor design live load - 180 psf;
700 pounds concentrated.

Computer - Bendix G-200

Electrical -

30 Kva
0.8 p.f.
115 volts ± 10%, single phase, a.c.
Cabling - 1/2inch - 1 inch - 1-1/4 inch diameter.
Cabling routed on or under floor.
Separate power supply for air conditioning equipment.
Lighting - 60 foot candles, 30 inches above floor.
Fire Detection - smoke and high temperature detectors below floor and above ceiling.

Mechanical -

Room cooled equipment.
Room conditions:
65 - 80° FDB
35 - 65% RH
Design for 72° FDB and 50% RH

Structural -

Computer and support area - 2300 square feet.
Equipment maximum dimensions:
64 inches high, 29 inches deep.
Elevated floor required for cabling.
Floor design live load - 223 psf;
316 psi concentrated.
Equipment can withstand 6 gs of shock acceleration experienced during transportation.

Computer - IBM 701, 704, 709

Electrical - 85 - 130 Kva
208 volts ± 8%, 3 phase, 4 wire
60 ± 1/2 cycle
Cabling under elevated floor.
Lighting - 40 foot candles 30 inches above floor.

Mechanical - Room cooled equipment.
Room conditions:
65 - 80° F (75° F design)
40 - 60% RH (acetate tape)
20 - 60% RH (mylar tape)
20 - 28 tons.

Structural - 12 inches high elevated floor.
Sustained vibration - 0.25 g max.
Maximum dimensions:
37 inches wide x 69 inches high.
Floor design live load:
100 psf and 1,000 lb. caster load.

Computer - IBM - AN/FSQ-7

Electrical -	750 Kw DC Supplies - 480 volts, 0.65 p.f. Induction regulators and power distribution units - 120/208 volts, 1.0 p.f. Lighting - 45 foot candles at floor 8 feet, 3 inches height of fixture. Cabling routed in overhead trays.
Mechanical -	Room cooled equipment: 75° FDB ± 5° 57° F dew point maximum Memories: ducted air at 61° FDB± 4°, 50% RG max. Drum Assembly - 1 scfm of instrument air at 40 - 80 psig.
Structural -	Concrete floor air plenum. Floor design live load - 150-200 psf Floor height - 14 feet, no ceiling. Leveling channels required in floor. Clearance of 10 feet required above vertical drums. Area for duplexed computer and maintenance and programming room - 22,500 sq. ft. Equipment maximum dimensions: 7 feet, 7-1/2 inches high; 4 feet, 4-1/8 inches deep.

Display - IBM AN/FSQ - 7

Electrical - Power supplied from a computer module.
Lighting - dimmable with blue filters on alternate tubes. Fixtures inverted midway between reflective ceiling and honeycomb ceiling with 60° cut-off angle.

Mechanical - Air ducted to and from consoles.
Air supplied at 61° FDB and 50% RH max.
Room maintained at 75° FDB and 50% RH max.

Structural - Special concrete floor for maximum flexibility and relocation.
Floor pierced for cables and air to each console.
Floor design live load - 150 psf.
Height from floor to underside of roof - 17 feet.

Display - Hazeltine AN/UPA - 25

Electrical - 1.83 KVA
0.85 pf
115 volts $\pm$ 10%
60 $\pm$ 2 cps
Lighting: dark room

Mechanical - Room cooled
0 to 50° C DB
40 to 95% RH
Integral ventilating fan

Structural - Equipment maximum dimensions:
47 inches high by 39 inches deep.
Servicing clearance - 2 feet all around.
Equipment bolted to floor.

Display and Data Processing - General Precision's Air Traffic Control Data Processing Central

Electrical -

Three types:

- 400 cycle critical power
- 60 cycle critical power
- 60 cycle non-critical power

Critical power is provided by 100 KVA diesel-motor "no-break" power sets.

Cable bend radius - 10 inches maximum.

Cabling preferred below 8 inches high raised floor.

Can also run overhead.

Separate chassis and signal ground terminals.

Lighting: Cold cathode with U. V. filters.

- Fixture 9 feet above floor.
- Dimmable from 50 to 2 foot candles.
- Luminous ceiling 8 feet above floor consisting of 40 layers of polarizing film between two 1/4 inch plexiglass sheets.

Mechanical -

Room cooled equipment.

50 - 100° F

Max. R. H. - 95% at 50° F; 50% at 100° F.

Equipment cooled by natural convection, induced draft or internal refrigeration.

High temperature protection internal thermostat.

Structural -

Equipment maximum dimensions:

- 83 inches high by 64 inches deep.

Floor design live load - 250 p. s. f.

Communications - Western Electric for SAGE

Electrical -

120/208, 3 phase, 60 cycles power to motor-generator sets.
Battery in motor-generator room.
Cabling and lighting by telephone company.
Cabling in overhead trays.

Mechanical -

Room cooled equipment.
Room conditions:
75° F, 50% RH maximum.
Air blown across room from perimeter registers.

Structural -

Floor design live load - 175 psf.
Height from floor to underside of second floor - 14 feet.

Communications - American Telephone and Telegraph Company

Electrical -

Power supply is 208-240 volts with 460 volt m-g sets or rectifiers for large installations. A. C. power is converted to dc to storage batteries. D. C. power is distributed to the equipment.

For critical a. c. electronic equipment the d. c. is inverted to a. c.

Voltage tolerance is ± 10%.

Frequency tolerance is ± 5%.

Lighting and convenience outlets - one 15 amp 120 volt a. c. circuit per 20' x 20' bay. Lighting fixutres come with the equipment.

Interequipment cabling is furnished with the equipment in overhead racks and braced to the ceiling.

Grounding conductors are installed with the equipment to terminate at the building water service.

Mechanical -

Room cooled equipment.

Mechanical ventilation adequate.

Humidity range 35 - 65% R. H.

Design conditions: 80° FDB and 50% R. H.

Heat Release: 1. 5 - 3. 6 watts per square foot.

Air distribution: blown down equipment aisles.

Structural -

Frame size: 23" wide x 12" deep x 11'6" high.

Electronic switching equipment: 7' to 9' high.

Structural clearance 13'0" to 13'6" high.

Equipment furnished with steel angle supports.

Design live loads:

- Batteries 175 - 300 psf
- Equipment 150 - 175 psf
- Operations 100 psf

Shock mounting and bracing can be added requiring 6 inches more of height.

4.0 Discussion

The goal of this study was to develop criteria to permit the design of the structure and its fixed facility support systems to be finalized prior to the selection of the electronic equipment. The total facility design can be considered to consist of two parts. One part is the primary utility systems and the structural portion of the building. The second part is the secondary utility systems to the points of use, and the interior finish of the structural portions of the building, containing the computer, display and communications electronic equipment. The separation between these two parts can be considered the technical area interface.

It can be safely assumed that the electronic equipment data necessary for the design of the first part (non-technical areas) can be made available, or quite closely estimated, fairly early in the design. The electronic equipment data necessary for the design of the second part is more detailed and more dependent on the specific equipment being supplied. Therefore, it will not be available until more definitive "hardware" type information has been generated.

It appears therefore that the total facility design should be accomplished in two phases, based upon the availability of firm design information. Were it possible to start the electronic systems and equipment design earlier than the facility design, then this two phased approach would not be necessary. However, since the schedules of previous command and control facilities have not been able to accommodate this optimum type of design schedule, the two phased approach appears justified.

Basically, it permits designs based on firm information to proceed, while delaying other designs until adequate information is available. This prevents costly changes during construction, or retrofitting after construction completion. It also permits more flexibility in the selection of electronic systems and equipment, recognizing the evolutionary nature of this type of facility. Depending upon the overall schedule, the delay in a portion of the total design may have very little effect on the facility Beneficial Occupancy Date. This relatively small portion of design and construction can be phased into the total effort such that the final dates for occupancy, installation, checkout, etc., are relatively unaffected. This phased approach to design and construction is not new and has proven to be a very realistic and desirable solution in a situation involving short schedules and concurrent systems and facility designs. This approach is very common even in conventional facilities in order to provide schedule relief. Frequently the substructure design and construction is separated from the balance of the facility and issued at an early date for implementation as a separate work entity. The changes to this initial phase that have been found necessary during the balance of the design and construction have seldom outweighed the schedule and cost improvement that resulted from this course of action.

To implement this phased design approach requires the establishment of complementary facility and equipment criteria. Even with this approach, flexibility for equipment is not unlimited. One very obvious point of restriction would be the floor height required for equipment and services. Therefore, equipment criteria should be established for only those areas which affect the firm design of the primary utility systems and building structure. Too restrictive equipment criteria may affect equipment capability and reduce competition, thereby adding unreasonable cost. Also, a building design based on very restrictive equipment criteria may be too inflexible to accommodate changes in this criteria and in equipment that may be necessary at a later date when building construction is under way or completed. This inflexibility of building and primary utility systems would have great impact on cost, schedule and systems and facility performance, and be in contradiction with the evolutionary nature and rapid advances in the state of the art of command and control.

The facility criteria should consist of establishing and defining the interface location between facility and technical area designs and data necessary for the facility design to proceed. This facility criteria should complement the equipment criteria in that the outside limits for one must be within the inside limits of the other. This should result in fitting the two together as closely as possible without overlap or interference and with a degree of tolerance consistant with the requirements for flexibility. An outline of equipment criteria relative to interface requirements is included in Section 3, Exhibit I.

Specifically, it is intended to establish various interface locations between the facility and technical areas. At these locations, all technical area utility requirements should be furnished as part of the facility design. The quantity and quality of the utilities should be noted by the systems designer for such services as power, fresh air, chilled water, hot water (or steam), instrument air, etc. The technical area design phase should then pick up these utility supplies and distribute them as required for the specific electronic equipment and systems. These interface locations are in essence utility rooms for central location of utility supply, for subsequent distribution to points of use. The location of these utility interface points should be established based on relative locations of the source of utilities and the points of use from the standpoint of cost, performance and reliability. Good engineering practice, modified by special facility and system criteria should be the guide to the selection of the number and location of the interface points.

4.10 Environmental Control

4.11 General

Environmental control is required for all electronic equipment and includes the computer, display and communication components of the Command and Control facility. Although the temperature restrictions of the communications equipment is not as stringent as for the other components, the savings resulting from a separate classification are insignificant and, consequently, no differentiation was made between the communications equipment and the computer and display equipment. Consequently the following discussion applies to all the electronic equipment included in this facility.

4.12 Temperature

Of all the parameters that effect electronic equipment reliability, the most critical is temperature. Variations in temperature may change electrical values which could introduce errors in operation. Since all of the electrical energy input to the equipment appears in the form of heat, this energy must be removed in order to maintain a constant equilibrium temperature. Past experience indicates that a maximum acceptable variance of temperature between components is approximately 10 degrees F.

Another effect of elevated temperature is the shortening of the life of the electronic equipment. Since this equipment contains thousands of components, this is a very important factor from the standpoint of continuity of operation, maintenance cost and space requirements for parts and personnel.

Although personnel comfort cannot be considered as an equipment requirement, it is available as a by-product at very little extra cost and therefore should be considered in the original design. The present trend is to design a combined system which will maintain both a satisfactory environment for human comfort and also maintain the equipment between the prescribed temperature limits.

A survey of the manufacturers of electronic equipment indicates that temperature control of the electronic components is essential. However, the accepted temperature range of satisfactory operations is not too restrictive. Many types of systems have been used to absorb the heat emission of the electrical energy. Forced convection, natural convection, liquid cooling and various combinations of these systems have been used. If the facility design is to proceed concurrently with the electronic equipment design, a standard method for equipment cooling must be selected and the electronic equipment designer must conform to this standard and provide any auxiliary services as part of the electronic equipment.

It is suggested, therefore, that the electronic equipment areas be maintained at a constant year round temperature of 75°F ± 3°F. This temperature can be maintained by a conventional air conditioning system.

All internal cooling of the equipment could be achieved either by forced circulation of room air or by natural convection and radiation to the room surroundings.

Information concerning the estimated heat gains due to electronic equipment must be made available to the designer during the initial phases of design. This information need only be approximate in the initial phase and refined as soon as the type of equipment is selected.

4.13 Relative Humidity

The effect of relative humidity, except for extreme ranges, is generally negligible on the electronic components. Electronic components can be designed to operate satisfactorily in atmospheres where the relative humidity varies between 20 and 80 percent. However, at these extremes, the effect of electrostatic leakage or electrostatic discharge may introduce errors in the computer. In addition, unless mylar tape is used, low relative humidities will effect the tapes used to record information. It is good practice, therefore, to limit the variation in relative humidity between 35 and 65 percent. A range of 35 to 65 percent is easily maintained with standard air conditioning equipment and should impose no hardship on the electronic equipment designer.

To maintain the relative humidity between design limits, the designer should restrict himself to mechanical refrigeration or non-corrosive sprays or drying agents. The use of glycol sprays should be avoided because of the potential corrosive vapor which could, under certain conditions, affect the operation of the electronic equipment.

4.14 Air Cleanliness

The air environment for the electronic equipment must be clean. To achieve this, non-dusting building materials should be specified.

Supply air should be filtered through a high efficiency fabric type filter. Filter efficiency should be not less than 90 percent, as specified by the National Bureau of Standards Discoloration Test using atmospheric dust. To prolong the life of the filters, a prefilter should be used. The choice of a prefilter should be determined by the facility designer, based on an economic study.

In addition to the air filtration system, the building should be maintained at a positive pressure to prevent the infiltration of any unfiltered air.

4.15 Air Distribution

The method of air distribution both internal and external is also a prime consideration in the design of the installation. Systems have been designed in which all the electronic equipment is cooled by forced cool air through the cabinets and others where the elements are room cooled. In addition, combinations of both types of cooling have been employed. In large systems where extensive cooling is required, the electronic equipment cooling system and the building system may be designed as one system with excellent results. However, this is not always possible since the electronic equipment varies among manufacturers and their requirements differ. For most installations, where it is desirable to accommodate any number of types of equipment, it is customary to provide the proper room environment and have the equipment manufacturer design his equipment accordingly. For those pieces of equipment that require forced air cooling, the equipment manufacturer can supply a circulating air system integral with his equipment.

A number of installations have been made employing a closed air system. Cool air is ducted to the unit and the exhaust air is ducted back to the air conditioning unit for recycling. These systems have the disadvantage in that if any of the cabinets require servicing and access panels are removed, the air distribution is upset. Excessive air is delivered to the room upsetting the equilibrium balance and untreated air is drawn into the return system. In addition, leakage through the cabinets even when closed becomes a problem. It has been found that the small savings in refrigeration capacity achieved by this system were more than offset in the complexities and difficulties resulting therefrom.

In addition to the disadvantages indicated above, this system does not provide for room cooling. Therefore, a separate air distribution system with independent air conditioning units must be provided to maintain the required room conditions for personnel comfort.

Pressurized plenum chambers located below the computer floor have also been used to distribute air to the electronic equipment and the room. In this system a plenum, the full area of the equipment room, is pressurized and adjustable presized openings are provided at various locations for the equipment intake. If equipment is relocated, the old opening is closed and a new opening in the new location is installed. This system has been used successfully although it consumes more space and is more expensive than a conventional air distribution system. Disadvantages of this system are the difficulty in maintaining clean plenums and the fire hazard. If an electrical fire should start in the plenum, the fumes and fire would be distributed to the equipment above. For this reason a number of regulating organizations have made it necessary to run the cables in conduit which would nullify much of the advantages of this elevated floor system as a flexible cable raceway.

Since we are assuming that none of the equipment will require ducted air, a conventional low pressure air distribution system should be used. The heat gains due to electronic equipment will be higher per square foot of floor area than the conventional air conditioning system and, consequently, the temperature difference between supply air and room air should be the maximum without causing drafts.

The air distribution system should also take into account the flexibility of equipment location. It is suggested that the supply air be distributed uniformly and sufficient dampers be included so that the air distribution pattern may be changed by as much as 20 percent by merely repositioning dampers. To achieve this result, it would also be necessary to oversize the supply air ducts. The quantity of supply air may require adjustment due to adjustment of the electronic equipment load. Either vortex dampers or throttling dampers should be included with the air conditioning equipment. In addition, variable pitch fan drives should be provided for additional flexibility.

4.16 Other Cooling Media

Some equipment with high heat dissipation densities have been made with liquid cooling. Chilled water is circulated through cold plates within the equipment cabinets and the electronic components are cooled both by convection and conduction from these cold plates.

In this system extreme care must be taken to prevent leakage and in the control of the liquid temperature so as to maintain the surface temperature above the dew point at all times. If this precaution is not taken, condensation will take place with consequential adverse effects on equipment operation. The water chemical composition control is also critical with reference to fouling and corrosion.

Research is also being done on the use of cryogenic fluids and superconductors for electronic equipment. These advances in the state of the art will result in smaller physical size and lower power and heat dissipation requirements for a given equipment capability.

4.17 Reliability

Since the command and control facility must be in continuous operation, the components selected must be rugged, require minimum maintenance, and must be capable of being serviced without shutdown. All parts subject to failure that cannot be repaired within a two-hour period should be duplexed and integrated into the air conditioning system so that the spare component will carry out its function without interruption of service.

To achieve this degree of reliability, all equipment such as bearings and drives should be oversized for long operating life. In addition, all essential components, the failure of which would shut down the air conditioning system, should be duplexed as indicated above. The term duplex as referred to equipment means the installation of a spare component which is ready to operate if a failure of the original component occurs. For example, the failure of fan would result in the complete shutdown of the air conditioning system. The addition of a spare fan connected to the air conditioning system with auxiliary isolating dampers would permit the system to operate while the damaged component is repaired or replaced. Such a system would be known as a "duplex" fan installation. Similarly, this may be applied to coils or complete air conditioning units. Duplexing is required of essential equipment for either maintenance of possible malfunction. Where the failure of a piece of equipment can be easily repaired within a short period and when the breakdown will not effect the operation of electronic equipment during this inoperative period, duplexing is not required and a single piece of equipment may be installed. Duplexing is also not required if the electronic equipment is fully duplexed. In this case, each of the duplexed electronic equipment groupings would be served by its own simplex support system which permits any one of the electronic equipment groups or its support system to fail without degrading the system function. It is expected that the computer would be fully duplexed to insure the continuous availability of the stored data. The time required for reprogramming for new input data collection and analysis is not available in a facility which is expected to have zero-warning time.

4.20 Power Supply

4.21 General

The primary utility requirement of command and control facility equipment is electric power. Electrical power distribution requires much less space, is more resistant to shock and is much more flexible than distribution systems for other power media. However, electrical distribution and generation systems are varied and complicated in their own way and require special design considerations for command and control facilities.

The degree of electric power reliability will be based on the system performance criteria which, in turn, must first be translated into electronic equipment systems and modes of operation. One of the design features of electronic equipment systems which has great impact on the system reliability levels as well as on the method of generation and distribution is duplexing of critical equipment and providing marginal checking equipment to detect deteriorating components, circuit checking and diagnostic programs, pluggable type designs for ease of in-place substitution of faulty components, etc.

Although they are costly, these features are warranted to the extent that they are consistent with permissible downtime of the system. Power generation distribution must therefore back up this high electronic system reliability to the fullest extent.

The power system starts with the generating equipment of which there must be sufficient capacity installed and connected to the buses. Consideration must also be given to the optimum number and size of units to provide an economical design and still satisfy normal maintenance procedures and "spinning" reserve capacity. A utility tie might also fit in with some design concepts as the normal source of power, together with a "no-break" system, to insure continuity of critical power until the standby plant is put on the line. The prime power bus arrangement also requires analysis from the standpoint of both the generation side and the load side. Split buses with and without bus-tie breakers, normally open or closed bus-tie breakers, single bus, etc., all rate consideration on the basis of reliability, performance and cost.

The method of distribution from the load side of the main generation bus to the points of use can be established in different ways. The reliability level required will affect the selection of the number of feeder breakers; the number, size and location of substations and/or motor generator sets; the application of redundancy in duplicate primary feeders, spare substations tied to operational ones; non-essential load shedding; rating of feeders; use of cable versus bus duct; fault clearance methods; etc.

Loss of power results in de-energizing the electronic equipment. After a computer is re-energized, it must be reprogrammed for new input data collection and analysis. Restoration of the computer function may take sufficient time during a critical period to have lost the data processing function entirely for that period. Time for re-synchronizing certain communications equipment is also critical, especially in a facility where communications are a major function.

The power requirements for command and control facilities vary considerably with each installation. The electronic equipment systems criteria is the basis for the total equipment required. Due to the fact that system performance is generally evolutionary in nature and that equipment requirements vary with the make of equipment, the initial design must be based on an educated guess by experienced people. Total power requirement variations can be appreciated by examining the list of computers in Exhibit III. However, for today's command and control facility, we can assume that the electronic equipment power requirements may be in the 300 kw range. As such, the power engineer is dealing with power quantities of reasonable magniture. With a 300 kw electronic load, the total facility generation requirement may be about 1300 kw. This quantity would satisfy all other support requirements as well as dissipating the electronic equipment heat load.

Power to electronic equipment is normally 120/208 volts, 3 phase, 60 cycles, 4 wire. Special requirements are normally provided by equipment included in the electronic modules or by separate motor-generator sets. The motors of these sets would take electrical service at a voltage level normally considered good practice for the rating of the units. The voltage might also be determined by the inrush current characteristics as related to the voltage transients induced on the power system. It is desirable to have one voltage level for all electronic equipment power supplies to facilitate the distribution system design. The generated voltage will generally be at a much higher level so that transformers will be required to bring the level down to utilization voltage.

The power factor applicable to electronic equipment loads generally varies between 0.80 and 1.0 although some units are rated at 0.65. Until such time as specific equipment is selected, the facility design can only proceed on the basis of a conservative best guess. This is also true of load, demand and diversity factors. Many spare electronic units draw full power at all times even though they are not manned or are in a "slave" condition relative to a "master" unit, as in the case of a duplexed computer installation.

Voltage and frequency tolerances are specific to each equipment design. Normally, the power supply to the electronic equipment is subject to all the disturbances that occur to the system by connecting or disconnecting loads either deliberately or accidentally. These disturbances have very little effect on computer reliability if they are of a relatively small magnitude. Also, their effect is very small on equipment with long thermal time constants or large kinetic energy drives. Cathode ray tube-type display equipment is only slightly affected by transients. Minor transients in a computer system may cause a momentary error from which it can quickly recover. Disturbances that can cause equipment damage, normally activate a safety trip to de-energize the electronic equipment. Unlike display equipment which can recover rapidly after re-energizing, the computer requires much more time for reprogramming.

Voltage variations are generally specified for slow load changes, transients and differences between phases. Other specifications relate to voltage drift under steady state conditions, open circuit wave form, exciter response, regulator stability and voltage adjustment. Similar frequency variation specifications are prepared as part of the system's performance criteria. In most cases, the frequently specified tolerance of $\pm 1/2$ cycle on frequency is not too difficult to achieve where the design of the power generation, distribution and control systems are part of the total facility system design.

It is assumed that prime power generation and distribution will be the responsibility of the facility design agency, based on criteria for quantity and quality established by the cognizant agency. In accordance with the design approach established in Paragraph 4.0, the technical area power requirements will be established at one or more interface locations, terminating in an equipment room. Electronic equipment requirements and systems reliability criteria will provide guidance for the design agency in establishing the power distribution systems starting with the main power buses. A generally accepted arrangement for reliability involves two main power buses connected by a bus tie breaker which is normally closed, establishing, in effect, a single bus for normal operation of the facility.

The main power bus arrangement will depend on the nature of the selected power source. In any event it will be necessary to provide multiple units for supplying power to the facility and, based on the strategic nature of the installation, a separate emergency power source capable of sustaining lighting and critical life functions such as oxygen regeneration. The primary source of power must be self-generation by a minimum of 3 prime movers capable of meeting the full critical operational and support electrical loads for the full pre and post attack periods. Where dependable commercial power is available, it may be deemed desirable to tie into the commercial system for at least custodial and or emergency back up power. It should be noted that the term "dependable power" embraces power that is essentially free of interruptions and transient disturbances and meets the voltage and frequency requirements of the equipment supplied.

Each of the independent power sources should be connected to a separate main power bus with a normally closed tie breaker interconnecting the two buses. The switchgear short circuit rating should be such as to interrupt the available fault current without the use of reactors in order to avoid undue voltage fluctuations.

Establishment of the double bus system permits splitting of electronic and essential loads so that a bus fault will not result in a complete shutdown. Further, those loads normally supplied via one bus can be supplied from the other bus using automatic transfer equipment to throw over to the alternate bus in event of bus fault.

Most electronic equipment and their direct support systems will operate at a voltage level lower than that generated in the power generation equipment. Therefore, a number of substations will be required for the necessary voltage transformation. Separate substations for each of the computer, display and communications systems may or may not be provided. Separate substations for lighting and air conditioning equipment is generally recommended for isolation of utility transients, thereby maintaining high reliability and quality of the electronic equipment power. However, since the electronic equipment cannot operate for extended periods without air conditioning, this power system must have a comparably high level of reliability. Another factor bearing on the number of substations required would be the relative sizes of the computer, display and communications loads. This information should be developed prior to the start of facility design so that the method of load distribution can be selected at that time. Typical one-line distribution systems are included in Section 5, showing various arrangements of feeders, substations and loads. In all cases, the facility design agency will provide the power system up to the established interface points.

Service to the electronic equipment will be assumed as 120/208 volts, 3 phase, 60 cycle, 4 wire. It is reasonable to expect that any other requirement will be converted or transformed from this power supply by components that are part of the electronic equipment. The other interface requirement regarding quality of power can be established as a voltage deviation tolerance of ± 8% and frequency deviation tolerance of ± 1/2 cycle, for steady state: ± 1.2 cycles for normal switching and ± 3 cycles for full transients. Again, should the equipment require closer tolerances, it should be the responsibility of the equipment supplier to make provisions for it.

4.22 Distribution

The technical area electrical interface will generally be established at the distribution substations where the primary voltage has been stepped down to use level. The number, size and location of the substations should be included in the technical area criteria. They will be dependent on the size of the electronic load, the distribution of this load, the method of splitting the load to meet reliability requirements, the location of the center of load to shorten secondary feeder runs, and the configuration of the building. Underground facilities are much less flexible and, therefore, more restrictive in the systems possible for consideration. Individual power supplies may be required to most of the equipment modules, or a single power supply may be run to a power module first and subsequent routing included in the interequipment wiring system. Flexibility and low voltage drop can often be realized by use of plug-in bus-duct from the substation secondary connections, and running through the area requiring separate equipment power supplies. Cabling for electronic equipment may be run either below the floor or overhead, depending on the equipment entrance requirements. Appearance has little significance in a military facility. However, in display areas, the space between the floor and ceiling must be as unobstructed as possible for projection, viewing and lighting requirements. Overhead distribution in a system of cable trays is desirable from the standpoint of ease of maintenance, relocation and growth. The cabling is also exposed to an air conditioned space for longer life of insulation and maximum rating. Cabling systems that must pierce a structural floor for access to the equipment are undesirable since they hamper flexibility for relocation and growth, which are normal requirements of today's evolutionary type facilities. The use of the so-called "floating" or "elevated" floor placed several inches above the structural floor provides a cable space for bottom fed equipment and permits relocation and growth without impairing the integrity of the structural floor.

The major volume of cabling is that which interconnects equipment such as the individual computer, communications and display frames. This cabling may either run directly or be routed through junction or distribution boxes for ease of relocating, adding and changing equipment configurations and terminations. The relative location of electronic equipment may best be determined by the routing of services to them. The usual case is to locate display equipment above the computer. Ideally, the building volume above the computer and below the displays acts as a service area common to both systems. Maximum distribution flexibility is also required to minimize and equalize cable lengths as is required for various equipments. This configuration would satisfy a system where the input data is raw and requires processing before display.

The possibility of differential displacements occurring due to ground shock is not too serious a problem since most electrical work is relatively flexible. However, flexible connections must be used when terminating at equipment to account for the different responses between them. Cable trays would require sway bracing to resist the anticipated acceleration forces and the cabling must be connected to the trays so as to transmit their acceleration forces to the tray support and sway brace system.

Distribution of power to the electronic equipment will be part of the Step 3 technical area design based upon specific equipment requirements such as feeding individual modules, power distribution modules, motor-generator sets or other frequency or voltage regulation equipment. These requirements, as well as others, such as voltage deviation tolerances, will also dictate the means of distribution such as by cabling or plug-in bus duct. This phase of the work will be coordinated with the signal cabling requirements between equipment modules and systems. It will therefore involve interface input to the facility design only in the space required for the cabling distribution systems and cable chases through floors and walls. Cable chases cannot be defined until equipment configuration and cabling requirements are more firmly known. Vertical space (height) requirements for cabling distribution can be approximated based upon normal equipment requirements. Using preliminary information on the cabling method, it would be reasonable to establish a modular pattern of inserts to be provided by the facility design agency for subsequent use in designing the technical area cable supports.

4.221 Computer

Computer cabling can be either overhead, below or on the floor. Below the floor cable runs should be the only acceptable method for superhard facilities. An elevated floor whose surface is 12" above the structural floor, allowing at least 10" clear vertical space should be provided for cabling, bend radius and termination requirements. The cabling would not require a cable tray distribution system but can be arranged on the sturctural floor surface, separating signal and power services as required. Floors will be pitched and drained to prevent any accumulation of water on the floor.

4.222 Communications

Communications equipment, in almost all cases, will require overhead cable racks for distribution. The racks are mounted on top of the frames, braced to the ceiling and are furnished together with the cabling, by the equipment supplier. This cabling includes the interconnections between power source, m-g sets or rectifiers, batteries and possibly inverters to change the d.c. back to a.c. for some electronic frames.

4.223 Display

Display equipment will require cabling from below by the very nature of its function and the spaces in which it is located. Cabling requirements are normally such that an elevated floor whose surface is 12" above the structural floor, with 10" clear vertical space, would be adequate. This system would also permit relocation and addition of equipment with minimum cost. The cabling can be arranged on the structural floor surface with the required separation of signal and power and provision for insuring a dry floor.

4.23 Lighting

The lighting requirements of the technical areas of command and control facilities require special consideration only in the display areas. In other areas, good lighting design with some consideration for human factor requirements for underground facilities, and sway bracing and other protection from shock induced accelerations, would be all that is required. The use of incandescent or fluorescent fixtures requires the consideration of the type of lighting and the impact of high wattage and heat dissipation requirements on the facility power and refrigeration plant. Lighting in the telephone areas is normally furnished by the telephone company, connected to a modular system of outlets provided in the facility design.

Display area lighting has been a major problem in the past. The lighting in these rooms must not interfere with reading the console scope, must be adequate to permit the console operator to do limited reading and writing, must be adequate to permit safe traffic through the room, and must minimize operator fatigue. The type of cathode ray tube employed in the display console is a major factor in the lighting system design. The overhead lighting must not be seen as a reflection on the scope face. Also, because of operator fatigue and the need for the display to be viewed simultaneously by more than one observer, hoods or special glasses are not recommended. Group display (screen projection) generally requires different types of lighting during normal operation and during exercises or alerts. Provision must also be made for lighting areas that may be shadowed by different levels of observer positions. The operators must be able to switch conveniently from one lighting system to another. Hallways leading to display areas should have a compatible lighting system to minimize disturbances to personnel entering or leaving the display areas, employing light locks where required for light isolation. The design of the lighting system in areas adjacent to display rooms should consider the possibility of expansion into these areas at a future date. Dimming capability is a feature normally required in display areas to enable establishment of the optimum operational lighting level.

Methods of producing satisfactory lighting are many, ranging from relatively simple to very complex systems. Since the final design will have great impact on power requirements, heat dissipation, cost, building height and excavation height for underground structures, it is recommended that reasonable restrictions be placed on electronic equipment requirements.

The emergency lighting system can be of conventional design using battery lanterns in stairwells, corridors and equipment rooms. Consideration must be given to relatively tall equipment arranged in rows in the computer and communications areas when establishing lantern locations.

4.231 Computer

Computer lighting should be based on 3 watts per square foot of floor area for establishing the load at the interface point. The lighting system will consist of fluorescent fixtures arranged for direct lighting and hung to provide a minimum clearance of 8'-0" from the top of the finished floor to the underside of the fixture. It is assumed that no suspended ceiling will be required so that the fixtures will be pendant type arranged to provide optimum lighting for the computer equipment configuration to satisfy both operation and maintenance needs.

4.232 Communications

Communications equipment area lighting is designed, furnished and installed by the communications equipment contractor. For the purpose of establishing the interface point design load, 3 watts per square foot of floor area should be used. The communications equipment contractor will specify what he requires in the building for his use. This may just consist of fixtures in a modular pattern on the ceiling to which he will connect his equipment, aisle lighting and convenience outlets.

4.233 Display

Display equipment areas are most sensitive to lighting requirements. For the purpose of this study it is assumed that displays will require lighting with wide range dimming capability from the maximum level required during non-operational periods to almost total darkness. It is also assumed that the lighting required at the display console desk surface for reading or writing will be furnished as part of the equipment. On this basis, the interface point design load should be based on 3 watts per square foot of floor area. It is also assumed that display areas will require finished ceilings for lighting diffusion or reflection and sound attenuation. The method of providing satisfactory lighting levels, and not result in distracting reflections on the face of the display scope, will have the greatest impact on establishing the height of the display area structural ceiling. Since this room lighting is so dependent on the type of display equipment selected, it is recommended that the lighting criteria be established by the equipment supplier with the following limitations:

- 0 to 40 foot candles measured 30" above the floor.
- 10 feet of height maximum between the top of the equipment floor and the underside of a reflective acoustic ceiling.

4.24 Fire Detection and Alarm Systems

For the technical areas, it is assumed that this system will be part of the overall facility security system. As such, the facility design agency should be expected to proceed with the non-technical area system and zoning, and provide termination equipment to pick up the technical area circuits at the designated interface points. The technical area system will provide for both manual stations for normally manned spaces, and automatic detectors for any non-manned space or hidden space containing cabling such as elevated floors. Detailed interface requirements must await the assignment of equipment areas, elevated floors and suspended ceilings and the establishment of compatible zones. Until that time, the facility design agency should be made aware of the need for interface point coordination.

4.25 Grounding

Grounding requirements for the technical areas will be part of the overall facility grounding system and will relate to the method adopted for protection from electromagnetic effects of nuclear weapons. In a hardened underground facility, grounding in the conventional sense will be accomplished by embedment of a grid or counterpoise comprised of heavy copper cables in the concrete lining in close proximity to the bed rock; wherever possible, this ground should be supported by connection to water pipes connected to an underground water storage or supply system. A target value of less than 5 ohms resistance to ground should be adopted for the system, but field conditions may be such as to render this value impractical.

The electronic equipment and cable grounding system should be part of the technical area design and should be integrated with the facility grounding system.

4.26 Convenience and Clock Outlets

Convenience and clock outlets will be required throughout the technical areas. The requirements can be established early in the design as soon as the main equipment, maintenance and support areas are defined. A modular pattern can be established and the circuit ratings specified.

4.30 Structural

4.31 General

The command and control facility building serves the traditional purpose of supporting and enclosing the equipment and personnel so that the proper environment and services can be provided and maintained. The structural design of the building will be a function of the dead load, live loads and dynamic loads anticipated. Of major consideration will be the loads imposed by weapons effects such as over-pressure, displacement and free field shock as established for the specified threat.

Certain electronic equipment structural interface data must be made available to the facility design agency early in the schedule. This data will permit them to design the structural shell which will shelter and support the electronic equipment and their auxiliary systems, and to receive the necessary architectural, mechanical and electrical finish for both operational and human factors needs.

4.32 Weapons Effects

This consideration has bearing on the survivability of the man-machine team so that its mission can be performed during and after attack as defined by the system criteria. The degree of survivability will also be defined by the system criteria for post attack requirements. The building is expected to survive the weapons effects imposed and to attenuate them to a level consistent with the fragility characteristics of man and machine. The amount of attenuation required of the building is determined more by the fragility level of man than of the machine since the human operational tolerance level as expressed in "G" or acceleration forces is a fraction of even "unhardened" equipment. Attenuation of weapons effects and fragility levels of man and machine as an operating entity have been under study for the past several years. These studies have been primarily of a theoretical nature with relatively little verification by simulation testing. Inasmuch as this subject has been growing in importance at an ever increasing rate, it is expected that an expanded and accelerated effort will be made to provide more reliable data that can be applied to command and control facility design with the same confidence as more conventional design criteria. The results of today's operational and test experience indicates the desirability of providing an attenuation system to permit a 1/2G man-machine operational environment in critical command control systems.

The assumed threat for the particular facility, and its translation into design criteria, will be the starting point of a building survivability analysis. The weapons effects environment (both shock and electromagnetic) within the building will require detailed analysis by experts in the field and as such will not represent electronic equipment interface data that can be made available early in the design schedule. Survivability data on equipment is relatively unavailable, and what is available varies greatly for different makes and models. It can be expected that, based upon an economic analysis of hardened buildings versus hardened equipment, the optimum level for each will be established as criteria for future facilities. The fragility level of the human operator will also be a factor in this evaluation since command and control facilities are expected to be semi-automatic for some years to come.

4.33 Building Shell

In a weapons effects environment, the building must also serve to some degree as protection from electromagnetic effects. In an underground location, it must support the weight of earth cover, or if located in an excavated chamber, it must support and protect against spalling, debris and water.

The relation between building shell and electronic equipment is primarily electromagnetic shielding and temperature, humidity and dust control. There are plans to test the electromagnetic effects of thermo-nuclear weapons in the very near future. In the absence of firm data, critical facilities have been provided with welded metal enclosures of thicknesses of 1/8" to 3/8" thick and with specially designed penetration shields and grounding devices. The scope of this report precludes dealing in detail with any other structural interface than the environmental control problem.

Environmental control will be achieved by the combined structural and mechanical design. The structural design will provide the optimum conditions relative to:

a. Maintaining positive pressure within the building to prevent infiltration.

b. Use of materials to provide an overall heat transfer coefficient that is lowest and most economical for the design conditions. These could vary considerably for different geographical locations above ground and below ground, with earth cover or in an excavated chamber.

c. Use of a vapor barrier to reduce vapor transmission and facilitate humidity control to satisfy the man-machine environment.

d. Dust control is achieved by maintaining a positive pressure and providing efficient filters in the air distribution systems and the use of materials of construction that are not dust generating.

From the standpoint of electronic equipment interface data required by the design agency for the design of the building shell, environmental control is the only factor exclusive of weapons effects. It can be expected that a competent engineering organization, knowing the function of the facility, will provide in their design for low heat and vapor transmission characteristics of the shell materials, air filtration and use of non-dusting materials and the prevention of uncontrolled infiltration of outside air. Good engineering practice and the use of military and federal specifications and design guides will provide an adequate environment for electronic equipment presently in use.

4.34 Column Spacing

Column spacing is intimately related to the structural integrity of the building, especially under the dynamic loading of weapons effects. Column spacing relates to system requirements as follows:

a. Since the primary function of the building is to house men and equipment to perform a given mission, maximum floor space with minimum obstruction should be the objective. Maximum column spacing will generally result in larger size columns and deeper floor sections which, in turn, would result in a taller building (and higher excavation) for the same clear floor to ceiling height.

b. Column spacing in most areas affects the layout of rooms and equipment within the rooms. Normally, this will have minor impact on initial operational requirements since the design can be built around them. However, it will be a limiting factor in growth and reconfiguration of equipment as dictated by the results of initial test and operation or advances in the state of art.

c. The most critical areas affected by column spacing are group display areas. These areas contain observer-operators seated at desks or display consoles, observers, projection equipment and projection screens. Projection may be either front or rear, requiring a specified clear distance and angle between the projector and the screen. This distance is a function of the screen and image size and type of projection equipment. Advances in projection techniques may result in systems that are radically different from the present ones requiring much shorter clear distances for projection. The observer positions must obviously not be obstructed from the viewing region in front of the screen. Relative elevations of screen and observers will provide the required vertical viewing clearances. This area is also most likely to require changes after initial installation so that maximum flexibility in the design is almost mandatory. This would dictate the complete absence of columns in group display areas.

Electronic equipment interface data relative to column spacing is special only in group display and projection areas. Otherwise, the broad criteria calling for a minimum number of columns in all equipment areas would provide flexibility for both the initial and future configurations, with maximum utilization of the gross building floor area. However, compromise is to be expected in this area of design in view of the critical nature of weapons effects which must be taken into account. No more detailed or restrictive interface criteria can be imposed on the design agency until a review of their preliminary design has been made.

With reference to large group display and projection areas, the complete absence of all obstructions, and the use of two floor heights, is almost mandatory. Since the location and configuration of these operations areas are generally developmental, criteria and guidance for the design agency cannot be expected early in the schedule. Since the structural integrity of the facility is involved, early resolution of this problem is required.

4.35 Structural Floors

The great variety of structural floor designs available for a facility make selection of the optimum one a matter of detailed evaluation of such factors as cost, construction time, flexibility, efficiency, etc. For a command and control facility, the following are some pertinent considerations:

a. Structural integrity, as in any facility, is the prime consideration especially under weapons effects loading.

b. In most of the non-technical areas of a command and control facility, the structural floor will serve as the finished floor with the addition of some degree of finish to suit the functions of the space. However, in the technical areas, the equipment requirements demand reconsideration of the structural floor design as a primary floor or as one to support another so called "false," "elevated" or "floating" floor.

Equipment requirements that have most impact on floor design are electrical and mechanical services, flexibility for changes and additions, and equipment anchorage. Where the first floor is on grade and services must be supplied to the underside of equipment this can be accomplished either by putting them in trenches, or providing an elevated floor above the slab on grade. Trenches in the slab are truly "poured in concrete" with a reduction in flexibility for change or growth. The choice of structural floor design with or without an elevated floor must be based on equipment needs and flexibility with cost kept to a minimum.

Elevated floors are generally considered those furnished as a manufactured product consisting of floor plates and pedestals. For non-combustible construction the floor plates would be aluminum with factory installed floor tile. The pedestal assembly consists of a floor plate, threaded support rod and pedestal head whose height can be adjusted and locked for final leveling of the finished floor. A typical elevated floor system is shown in Section 5. Elevated floor systems weigh about 6 pounds per square foot and a removable 18" x 18" floor plate weighs about 13 pounds and is lifted by means of a suction cup tool. Special floor plates are available for fitting at walls, columns, cable and duct openings, ramps and handrails. These floor systems are gaining very wide use for commercial computer installations, especially in existing buildings, because of their flexibility and independence of the structural floor for anything but support of the pedestals and cabling. However, a weapons effect environment will impose a special requirement on the floor system with regard to shock accelerations, displacement and velocity while providing support and anchorage for equipment with relatively high centers of gravity.

Electronic equipment interface data can be established for the structural floors very early in the design schedule. This data should also be reflected in electronic equipment procurement specifications to insure compatability. At this time, only floor loading values and penetrations can be considered. Floor design live loads should be kept to an absolute minimum due to their effect on floor heights, building weight and shock mounts. Detailed methods of equipment support such as anchors, leveling channels, etc., are not significant in the structural design and must await specific equipment selection.

4.351 Computer

The structural floor design live load for the computer equipment area should be 50 psf, with a provision for a load of 1000 pounds placed on any space 3 inches square wherever this load upon an otherwise unloaded floor would produce stresses greater than those caused by the uniformly distributed load of 50 psf. This value is adequate for almost all of the present computers and would be reasonable for second generation equipment if it is included in the equipment specification as a maximum value. It is recommended that the computer equipment be mounted on an elevated floor approximately 12" above the structural floor. As such, there will be no concentrated loads on the structural floor other than the elevated floor pedestal base plates..

In no case will the equipment require holes in the structural floor under each piece of equipment. The use of an elevated floor will eliminate this requirement. However, there may be a requirement for cable and air duct chases through the floor. This information will not be available early in the design but it should be finalized before the end of design so that its effect on the structure can be analyzed by the design agency prior to construction implementation.

4.352 Display

The structural floor design live load for the display equipment area should be the same as for the computer.

This would also provide the flexibility to permit the use of areas originally assigned to displays, for additional computer space, should the need arise.

The display equipment will be specified as being mounted on an elevated floor so that all cabling can be contained therein. Therefore, concentrated loads on the structural floor will be limited to the elevated floor pedestal base plate.

Just as for the computer equipment, no holes will be required in the structural floor for individual pieces of equipment. Cable and air duct chases may be required as noted for the computer.

4.353 Communications

The structural floor design live load for the communications areas should be the same as for the computer. Just as for the display equipment, this value will provide for the flexibility of using this area for other purposes.

The equipment would be mounted directly on the structural floor and will not require floor holes for individual pieces of equipment but as in the case of computer and display equipment, cable and air duct chases may be required.

The floor design live loads noted above should be verified by the equipment suppliers, requesting detailed substantiation for any higher values required due to the critical impact of this criteria on the entire facility design.

4.36 Room Finish

The importance of this item has grown in recent years as more has been learned about the effect room finish has on the human psychology and functional efficiency. It becomes much more critical with the present underground facilities designed for "button-up" periods of varying durations. Although this phase of the work does not have a major impact on the facility design and schedule, early resolution of the requirements should be made. Some specific items in this category are:

a. Lighting levels for all areas to suit the tasks to be performed within them. Special lighting for individual and group display areas are covered in this study under Power Supply.

b. Paint color and light reflectivity of walls, ceilings and floors as related to human factors considerations.

c. Noise levels and control thereof by reduction in transmission between areas, and attenuation within the space generating the noise. Ceiling, wall and partition materials as well as the air distribution system will be the controlling factors in maintaining a noise level compatible with the operator assignments.

d. Dust control by use of materials and finishes that are non-dust generating to reduce the load on the air circulating system filters.

The electronic equipment interface characteristics in this area of design have very little impact on the facility design. Therefore, these requirements should be assigned to the Step 3 technical area design phase and any coordination required with the facility design can be accomplished at that time. Noise transmission control is probably the area that will require coordination where technical and non-technical areas are contiguous.

4.37 Corridors and Stairs

Corridor and stair systems are designed from a human factors approach based on traffic patterns for normal operation and emergency conditions. Equipment maintenance is often a controlling factor in sizing and location of corridor, stair and elevator systems. Maintenance may consist of in-place checking and repair, partial disassembly, and replacements or complete replacement. Under the latter condition, as well as during initial installation, corridors and doorways must be sized to permit the passage of largest assembly or subassembly. Elevator size and capacity must also be adequate for this purpose.

Opposed to this requirement is the reduction in usable floor space due to partition-defined corridors. This reduction approaches a fairly large percentage in relatively long narrow buildings. For instance, with a 40 foot wide building using a 6 foot wide corridor running the length of the building, 15 percent of the floor space is taken up by corridor. In an underground facility this reduction would appear to be justifiable only on the basis of it being operationally mandatory. Operating and maintenance equipment must be sized so as not to penalize facility floor space by excessive corridor and service space demands. The use of dual purpose corridors is a way of conserving valuable building space. This application is recommended in command and control facilities that must remain "buttoned-up" or enclosed for long periods after an attack or an alert.

Fold-away or pull-down emergency bunks and shelves can decrease the need for large areas of sleeping quarters that are not used except during emergency operations.

The equipment data available indicates that maximum electronic equipment dimensions that must be considered for equipment movement is 84" high by 42" deep. Since a carrier will be used to transport the equipment, clearance of 96" high and 48" wide should be used as a basis for design. It is expected that shipping lengths will be such that the equipment can move around corners in the corridors and be carried between floors by a combination personnel and freight elevator. This should be verified with the equipment supplier prior to the completion of the facility design.

4.38 Room Heights

The vertical space between the top of a structural floor, and the underside of the structure above it, establishes the building height and, therefore, the excavation height for below ground structures. It is evident that this dimension has great impact on design and facility cost. It must, therefore, be established very early in the design schedule to permit the basic facility layout and excavation to proceed.

Vertical space requirements are established by equipment heights, lighting, services and their routing spaces such as elevated floors, suspended ceilings or just overhead space. Since it is mandatory to establish this dimension as soon as possible, it will be necessary to establish it without the benefit of equipment and systems design dimensions. Therefore, it will be established based on previous experience with comparable equipment and systems. A conservative approach in estimating and extrapolating existing data should be used in that once the excavation is made the total building height is firmly established.

4.381 Computer

Computer equipment heights can be limited to 84" without imposing any restriction on the equipment supplier. Cable routing should be located under a 12" high elevated floor. Lighting should be hung with the lowest part of the fixture a minimum of 8'-3" above the equipment floor level. Air conditioning ductwork space should be assigned to the highest level of the room above all other services. Based on the foregoing estimates for equipment and services, a reasonable dimension between the computer structural floor and the underside of the structure above it would be 13 feet.

4.382 Display

Display console height is normally not more than 4 feet and so does not establish room heights. However, consoles generally require special lighting and are also located in group display and projection areas. Vertical clearances for viewing and projecting on a screen vary with the screen size, number of viewers, and type of projection. Therefore, until more definitive operational criteria is available for the specific facility, it would not be reasonable to attempt to establish room heights for large group displays. The use of two floor heights would provide the required vertical space for this function.

Display console area (and possible small group displays) vertical dimensions can be estimated as was done for the computer. However, the lighting requirements may vary excessively and impose an unusual burden on the facility design, or delay it unreasonably. Therefore, it is proposed that the following criteria be imposed on the equipment supplier to satisfy the facility design:

-All cabling shall be routed in a 12" high elevated floor.

-All equipment shall be room air cooled requiring no air ducting to or from the equipment.

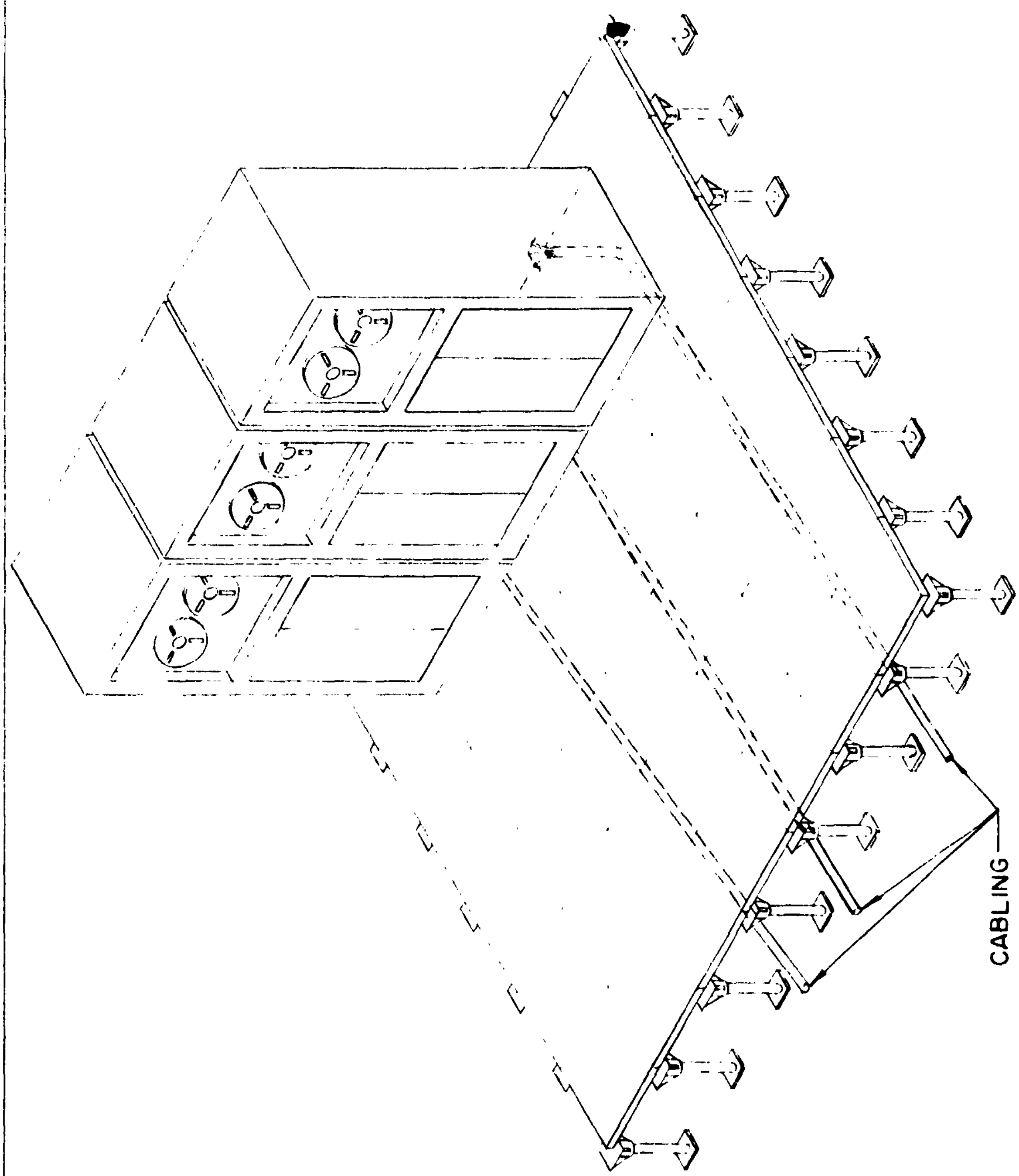
-The lighting system is to be established by the equipment supplier and shall not require more than 10 feet from the top of the elevated floor to the underside of a reflective ceiling.

On the basis of the foregoing, a reasonable dimension from the top of the structural floor to the underside of the overhead structure is 13 feet.

4.383 Communications

Telephone frame areas are similar to computer areas. They contain relatively tall rows of equipment with overhead cabling and lighting and room air conditioning ductwork. Since this equipment has been standardized and is available from a very limited number of sources, firm data should be obtained as early as possible from the communications equipment supplier. Until that time, a design dimension of 13 feet from the top of the

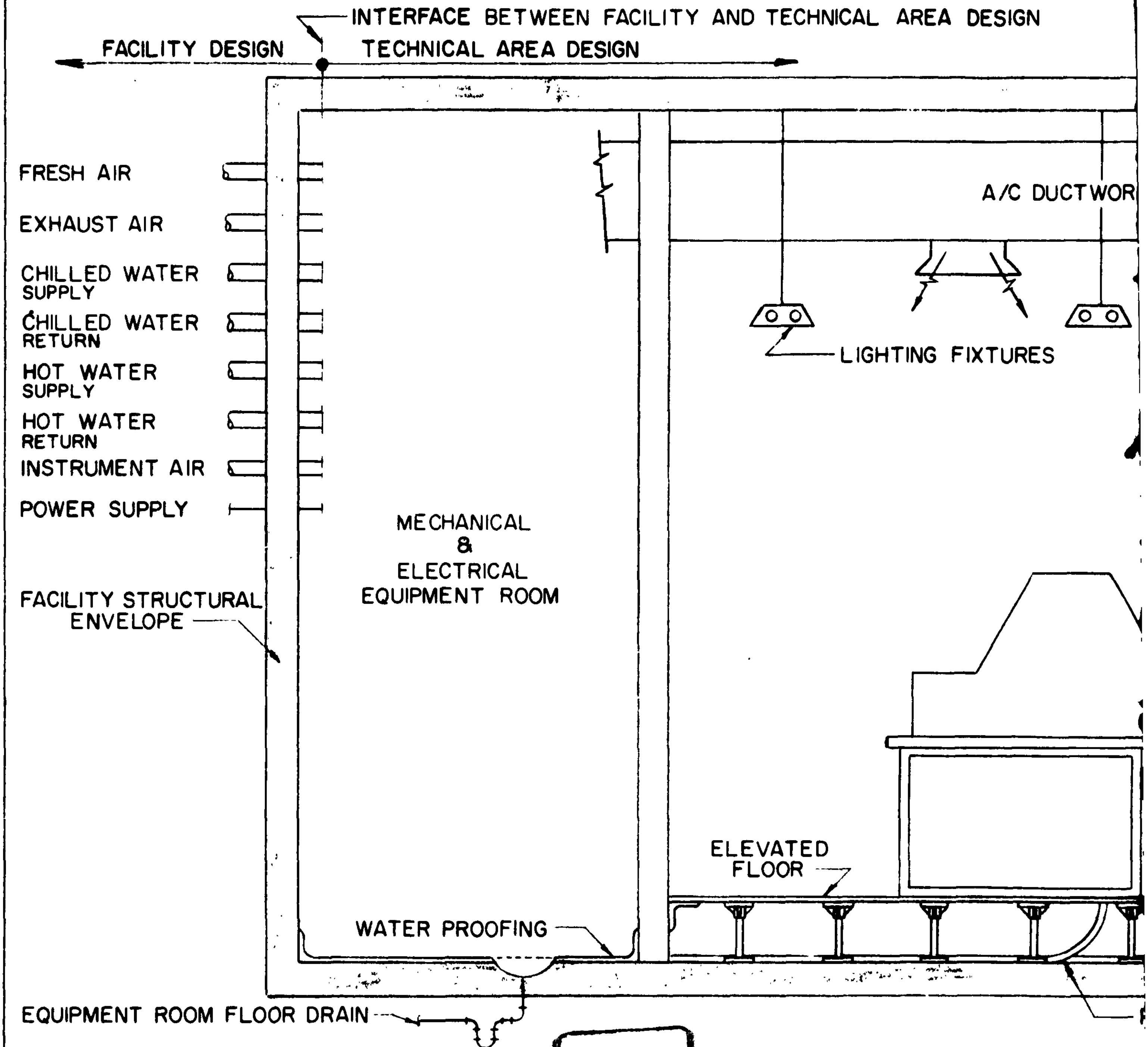
structure would be reasonable. This dimension will permit a standardization of floor heights in computer, display, and communications area, thus providing full equipment location flexibility.



TYPICAL ELEVATED FLOOR SYSTEM

PEDESTAL OR FREE ACCESS TYPE

POPE, EVANS AND ROBBINS
CONSULTING ENGINEERS

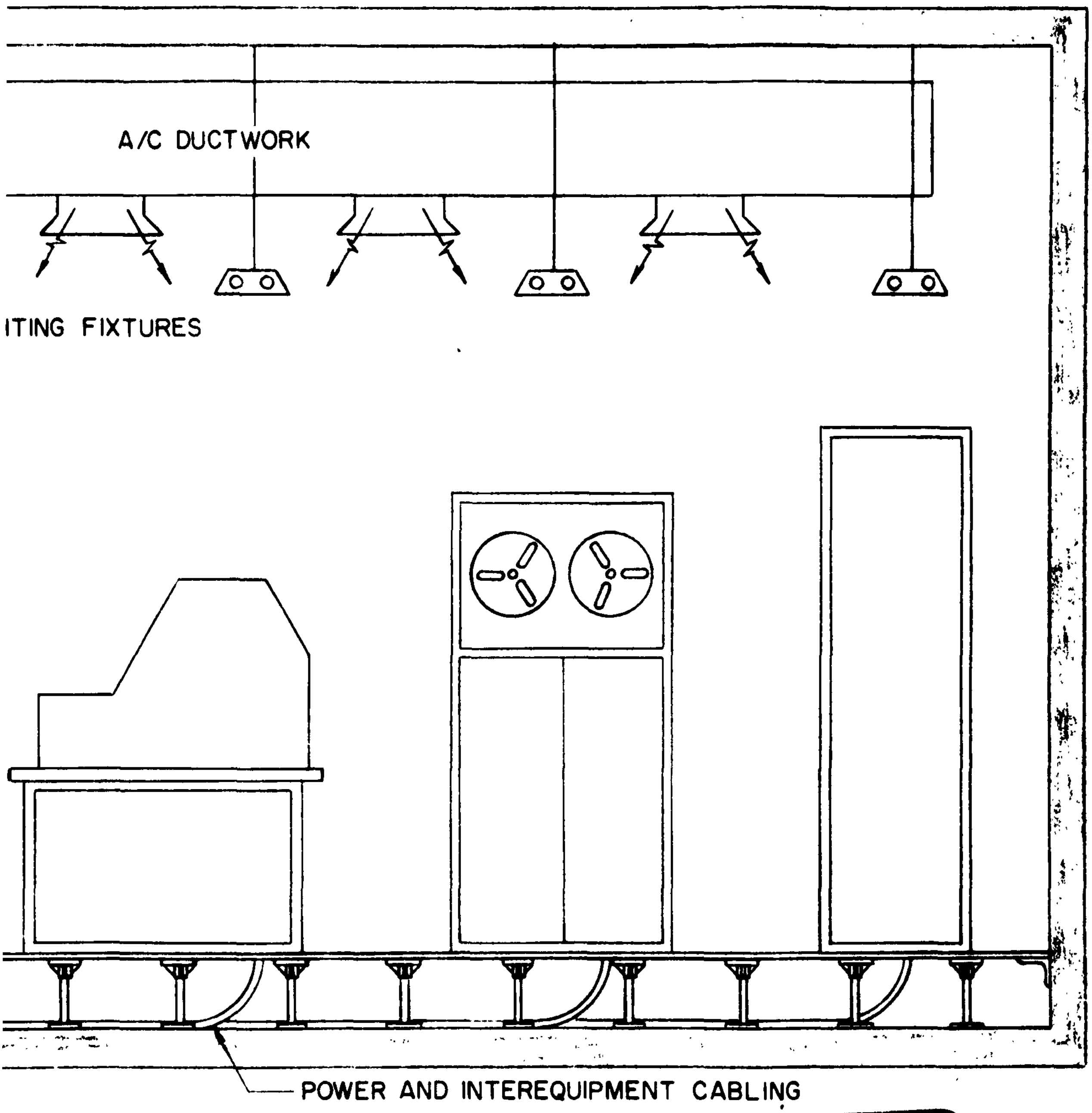


1

TYPICAL COMPUTER

(WITH ELEVATED FL

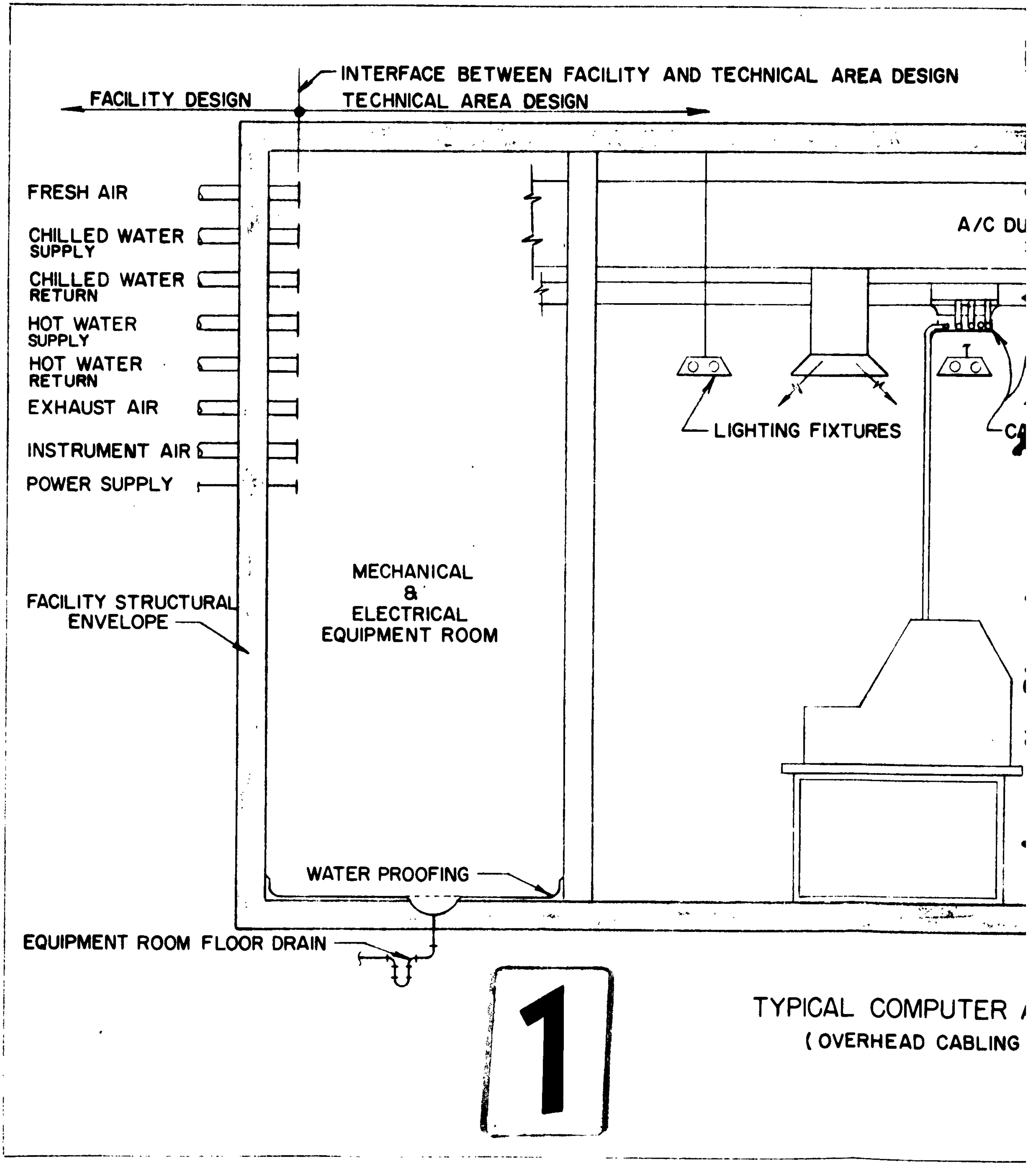
AREA DESIGN



YPICAL COMPUTER AREA
(WITH ELEVATED FLOOR)

2

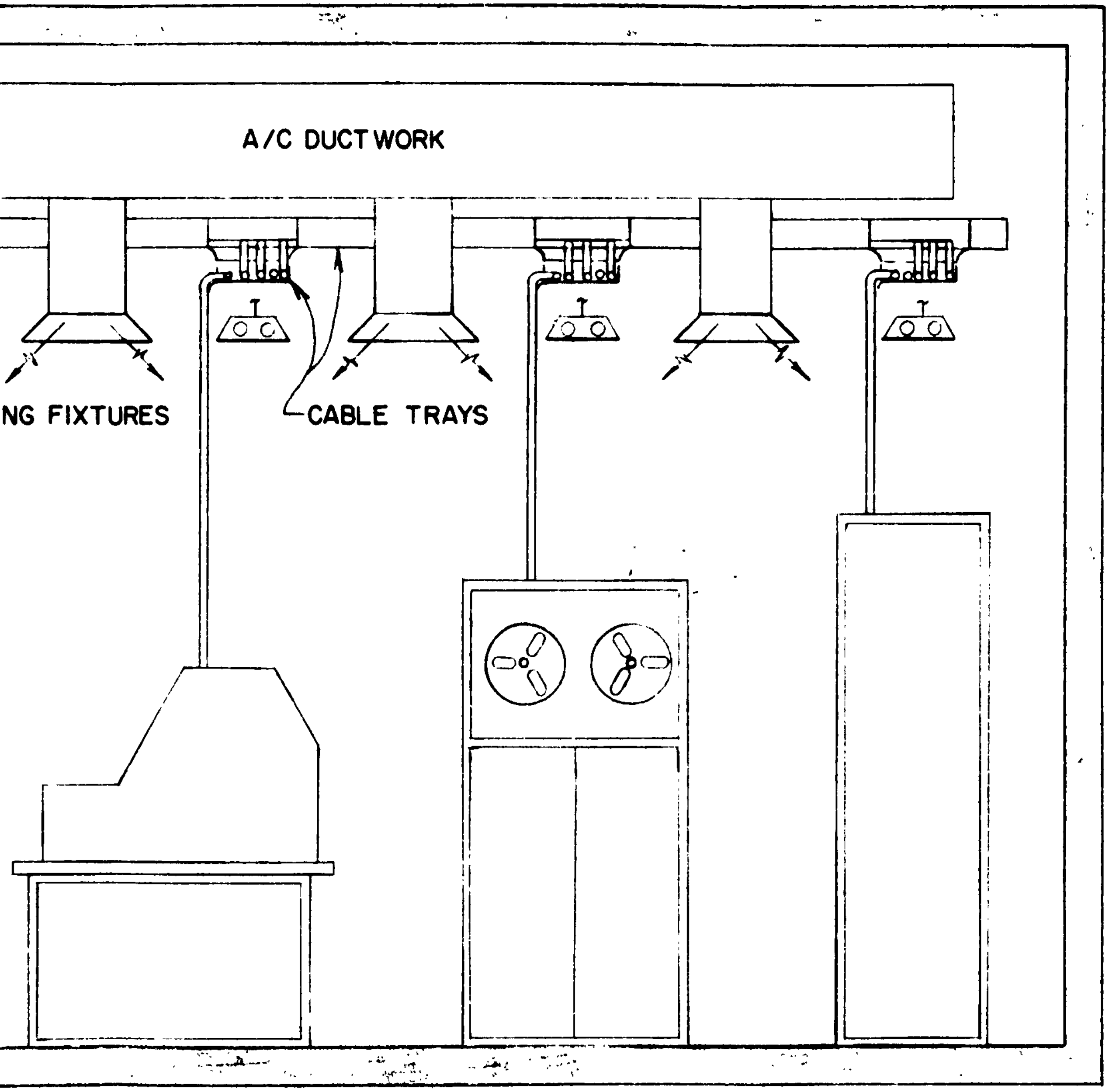
POPE, EVANS AND ROBBINS
CONSULTING ENGINEERS



TYPICAL COMPUTER

(OVERHEAD CABLING

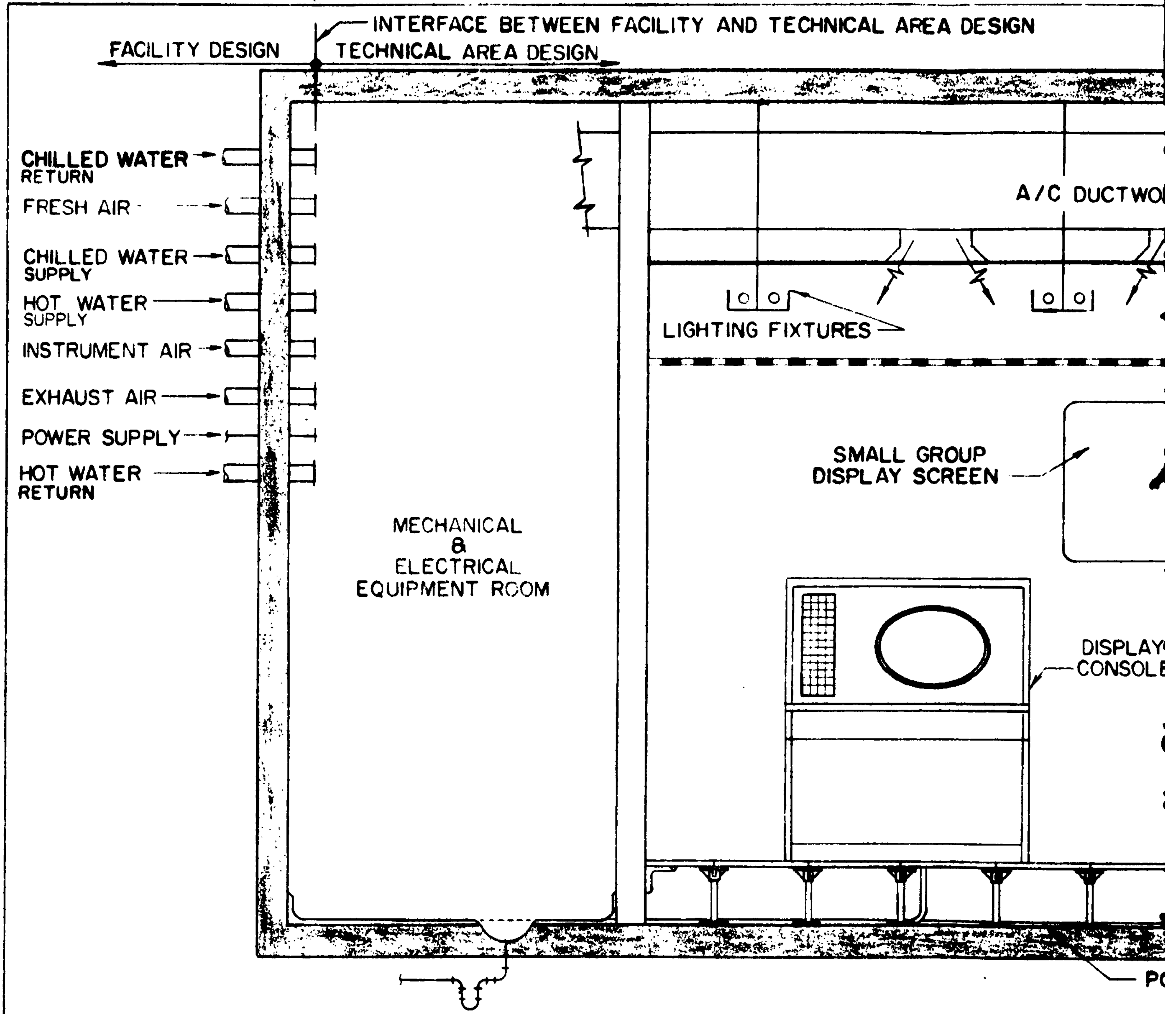
ICAL AREA DESIGN



YPICAL COMPUTER AREA
(OVERHEAD CABLING)

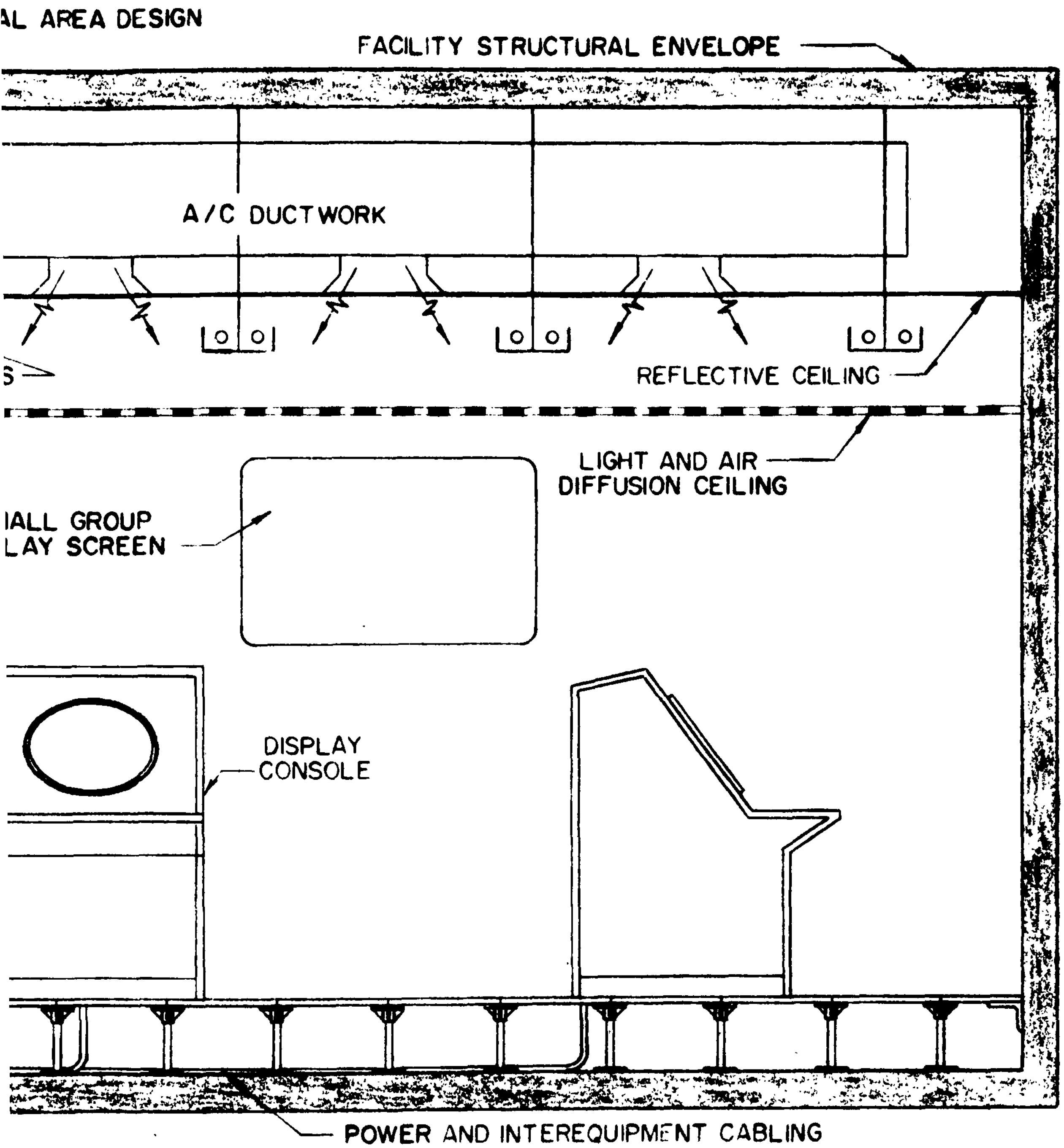
2

POPE, EVANS AND ROBBINS
CONSULTING ENGINEERS



1

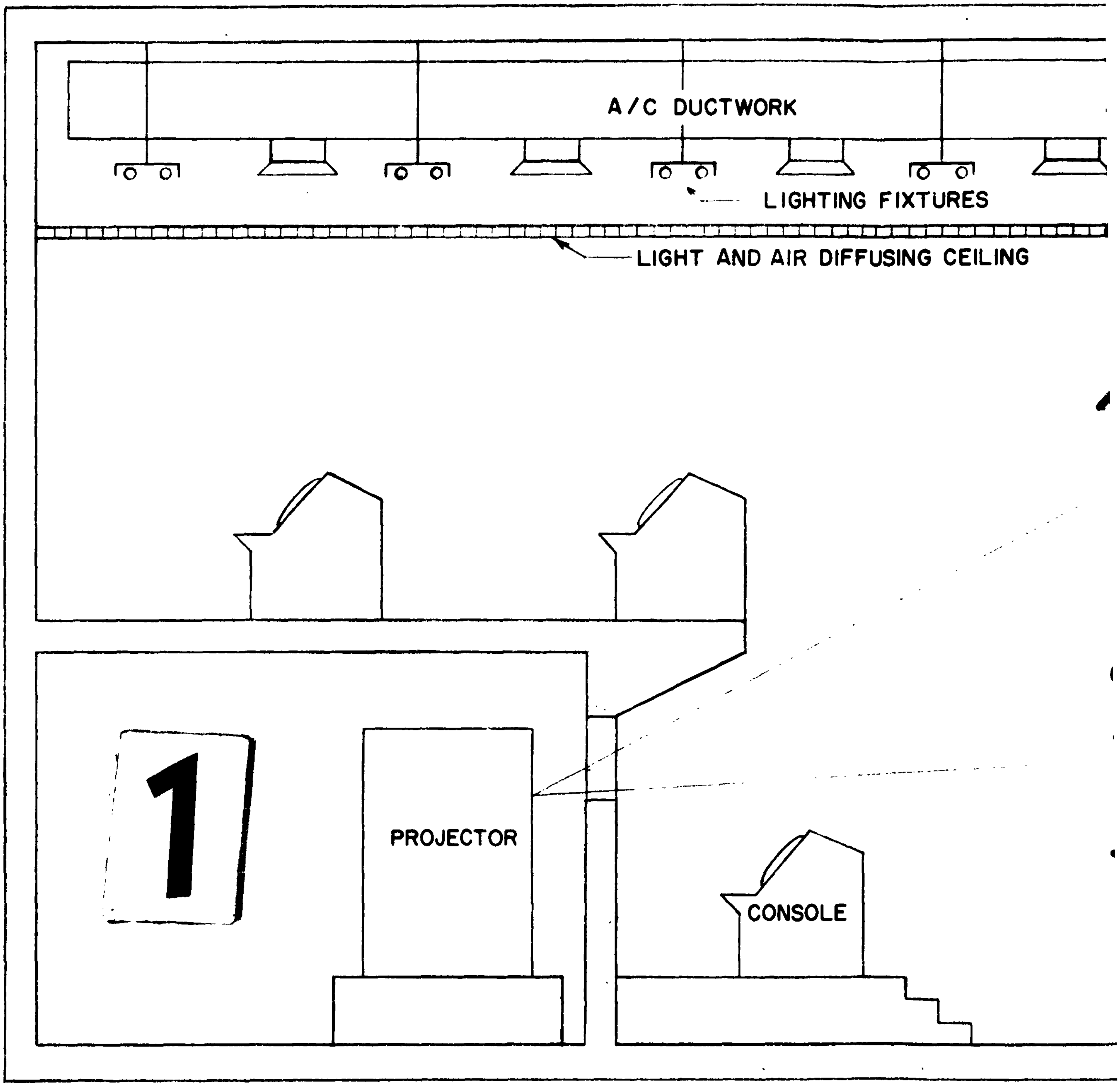
TYPICAL DISPLAY ARE
(SMALL GROUP TYPE DISPLA



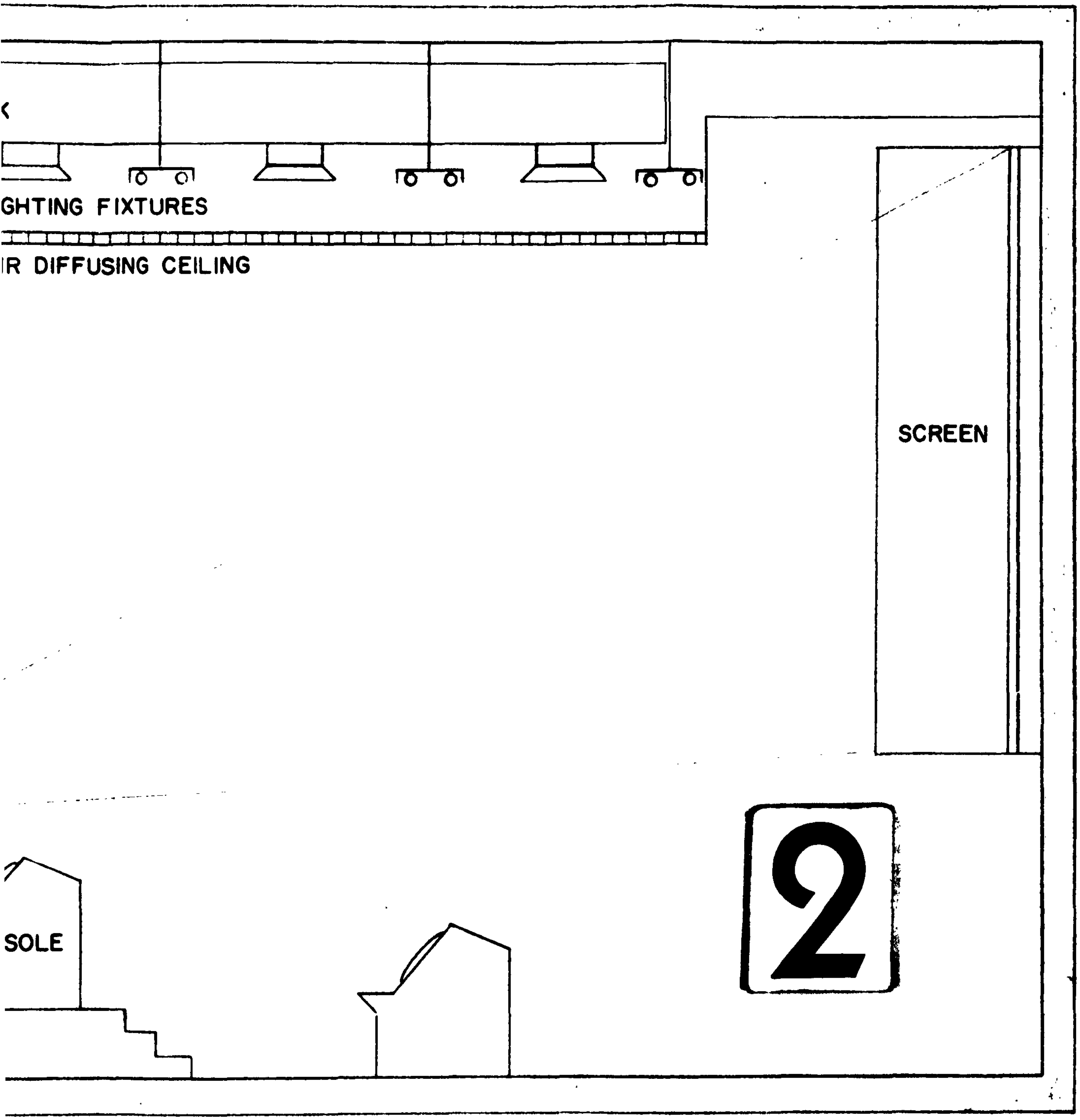
TYPICAL DISPLAY AREA
MALL GROUP TYPE DISPLAY)

2

POPE, EVANS AND ROBBINS
CONSULTING ENGINEERS

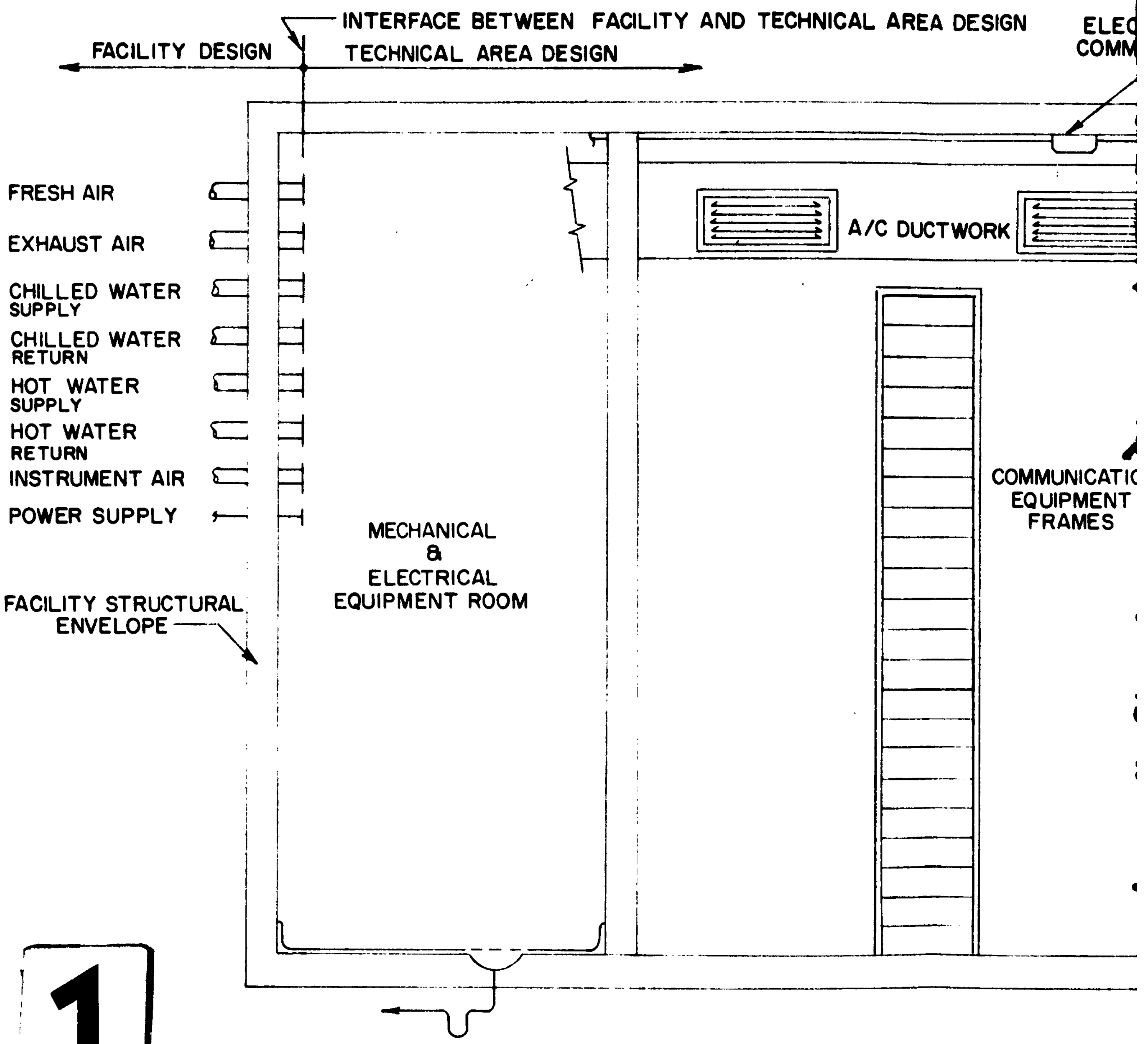


LARGE GROUP DISPLAY



RGE GROUP DISPLAY

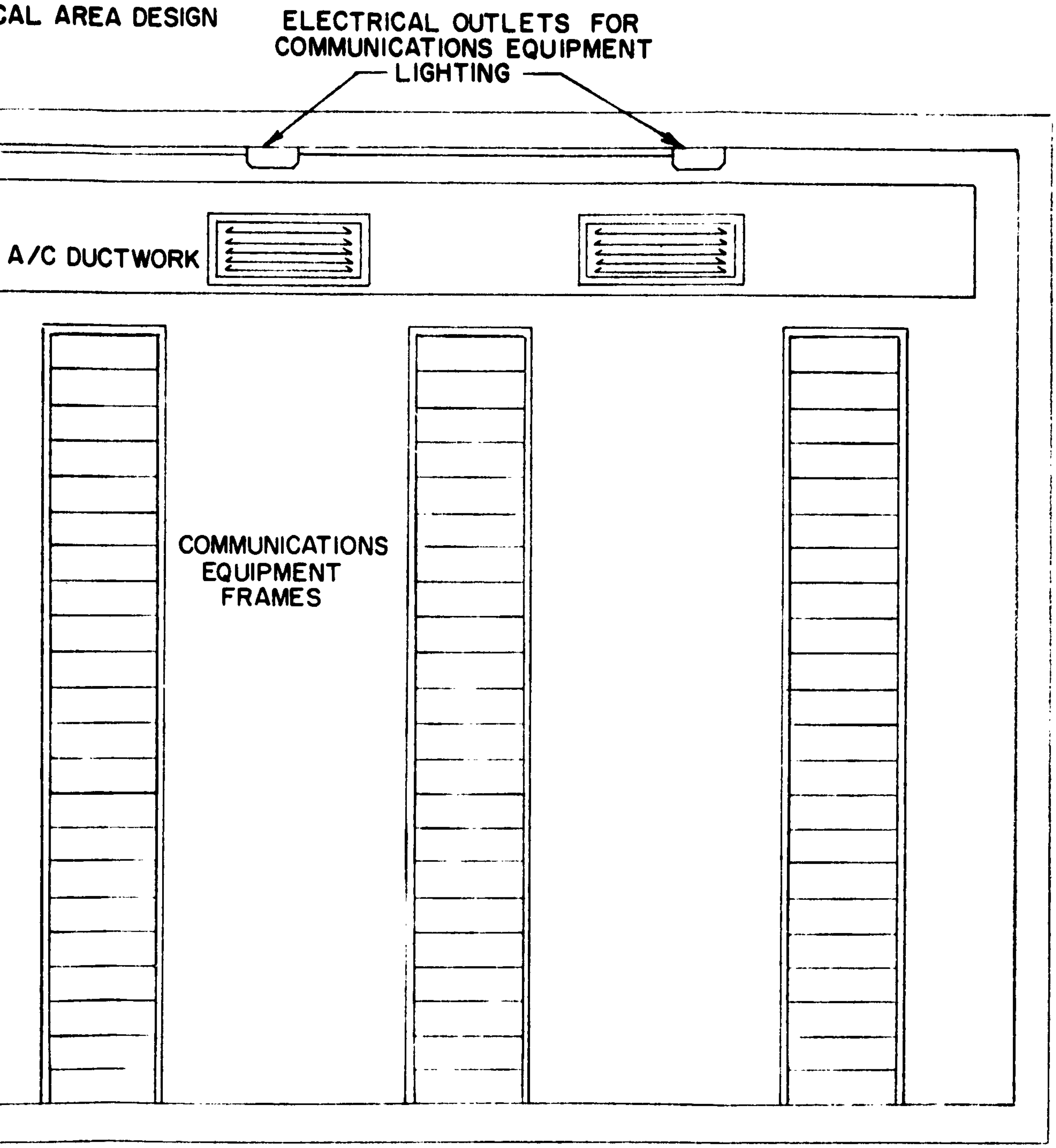
POPE, EVANS AND ROBBINS
CONSULTING ENGINEERS



1

TYPICAL COMMUNICATIONS FRA

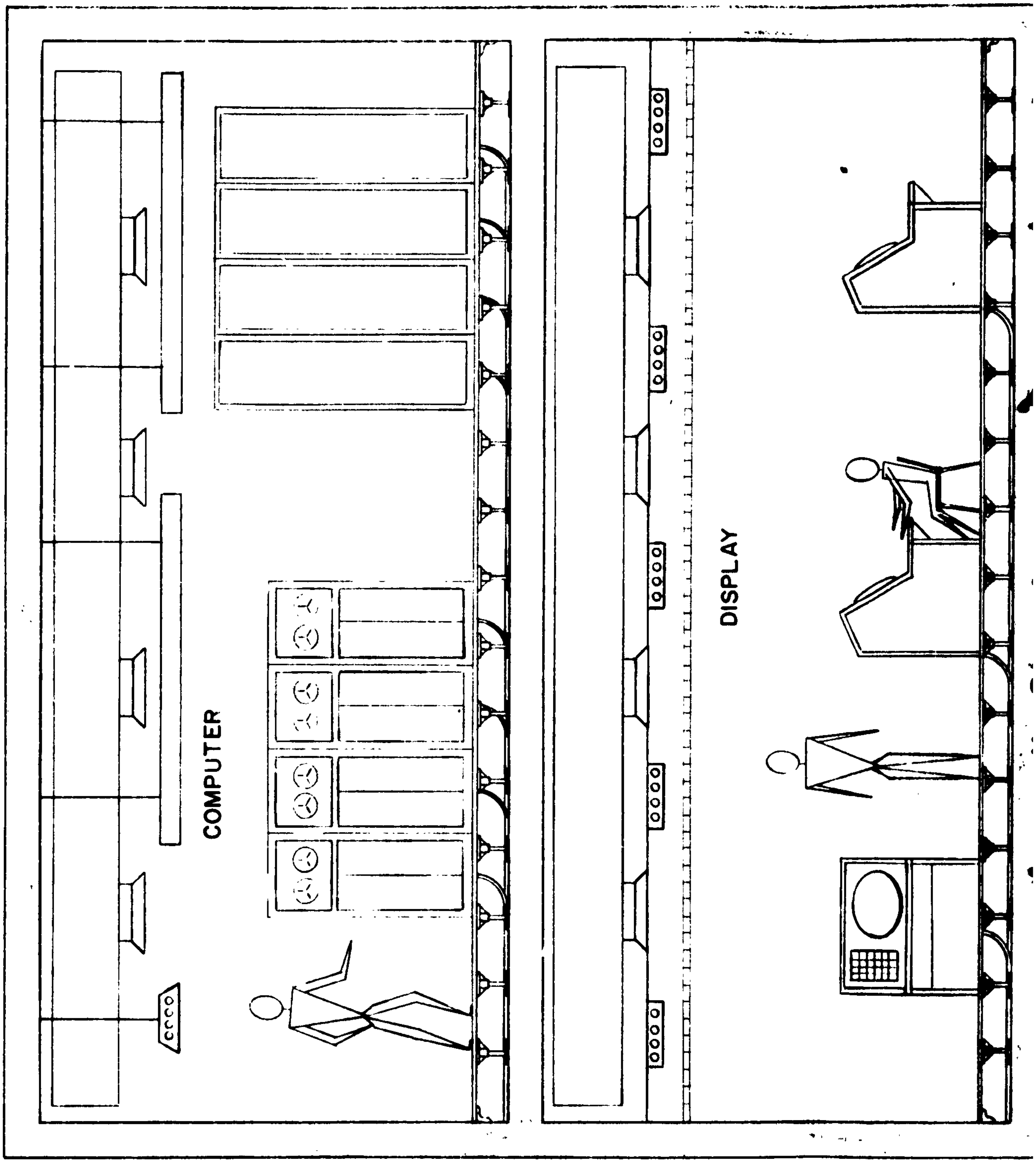
CAL AREA DESIGN



AL COMMUNICATIONS FRAME AREA

2

POPE, EVANS AND ROBBINS
CONSULTING ENGINEERS



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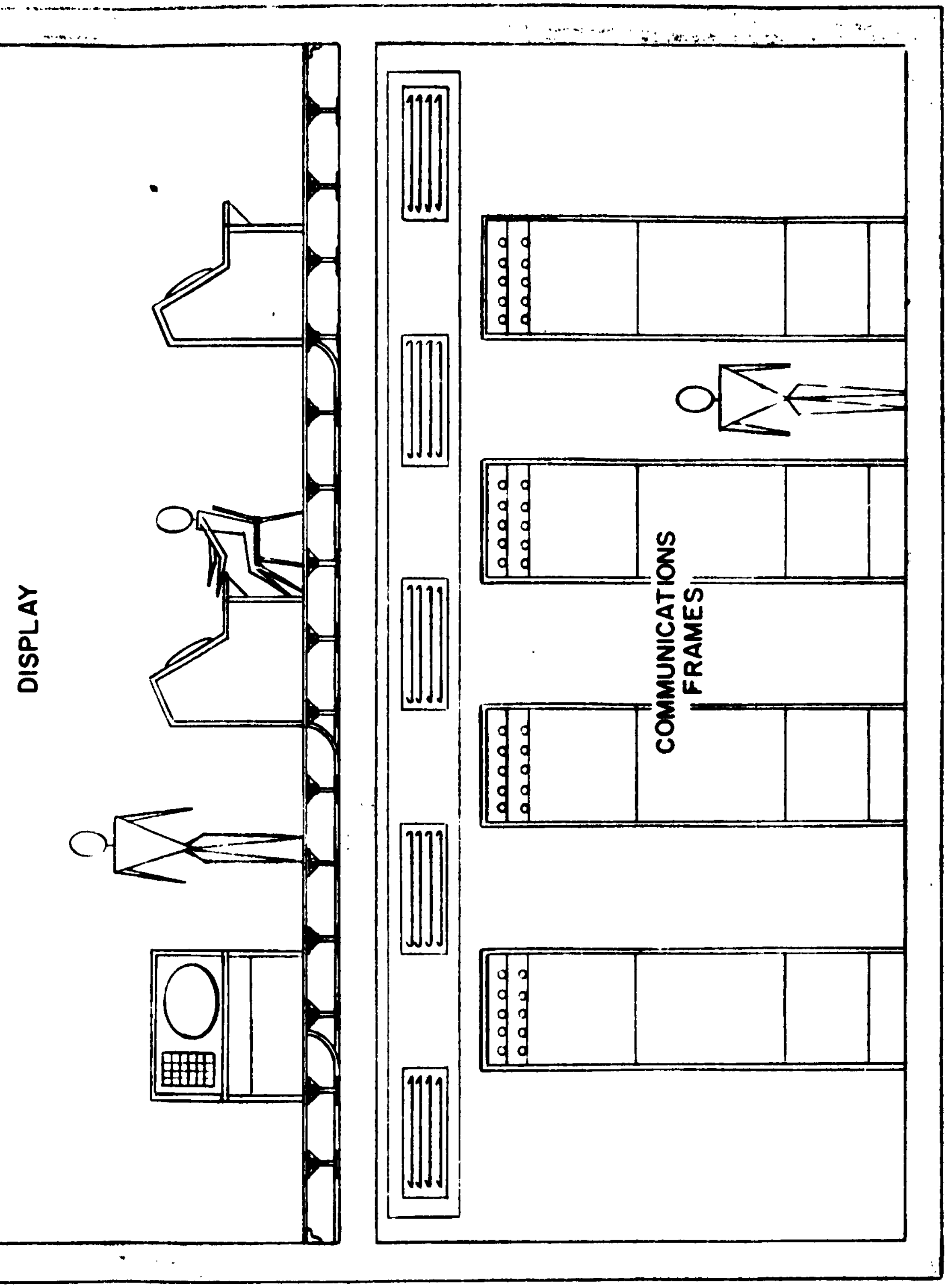
VERTICAL AREA ARRANGME



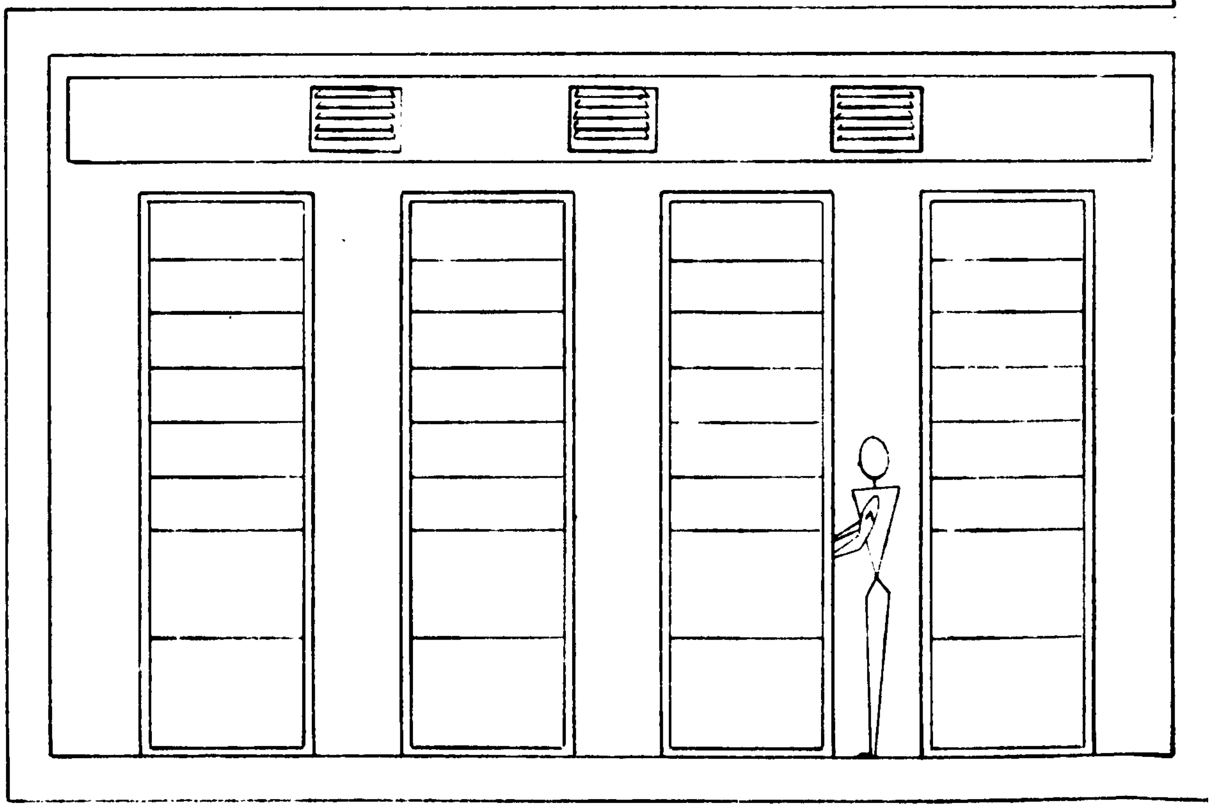
2

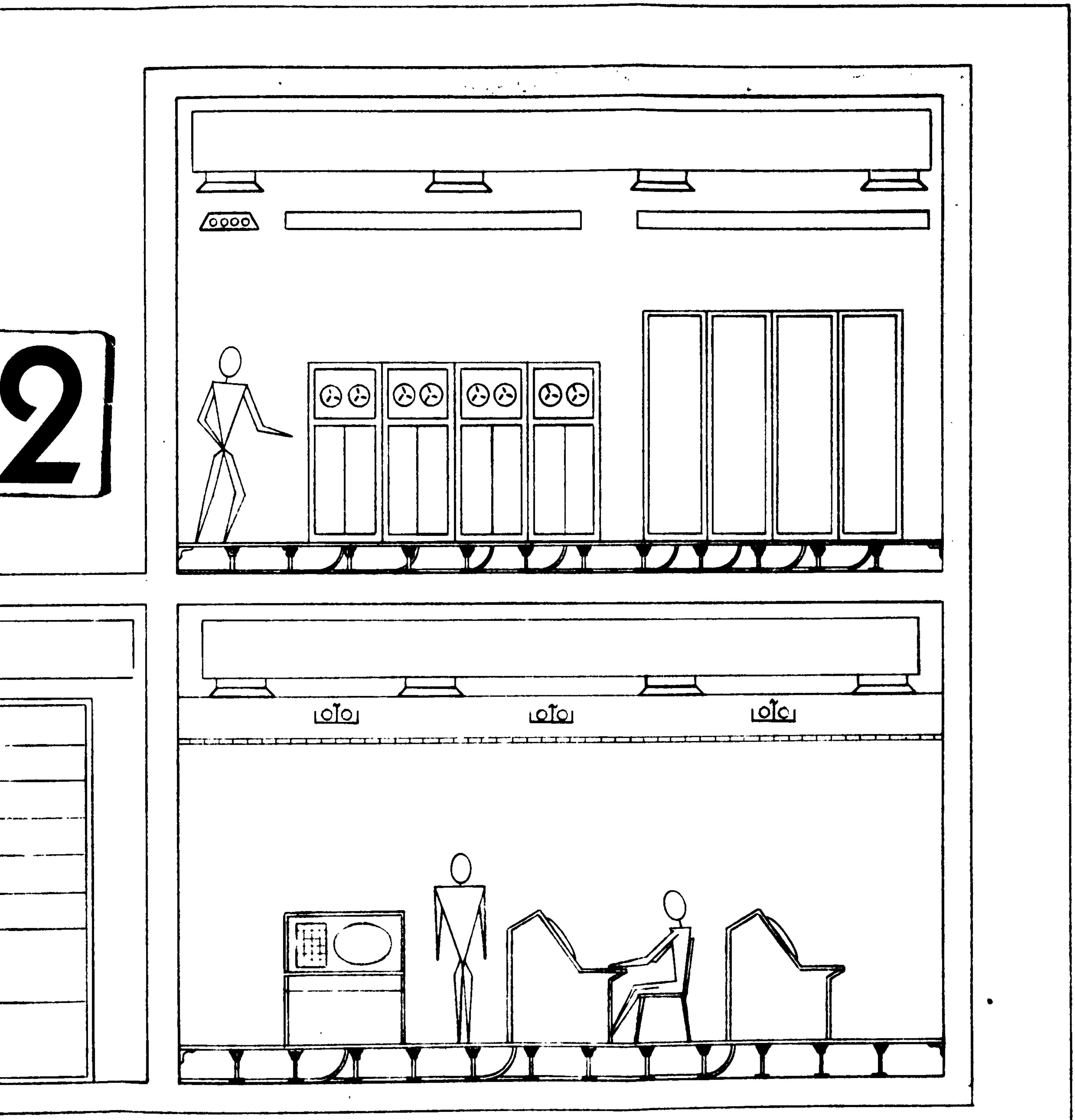
AL AREA ARRANGMENT

POPE, EVANS AND ROBBINS
CONSULTING ENGINEERS

HORIZONTAL AREA ARRANGEMENT

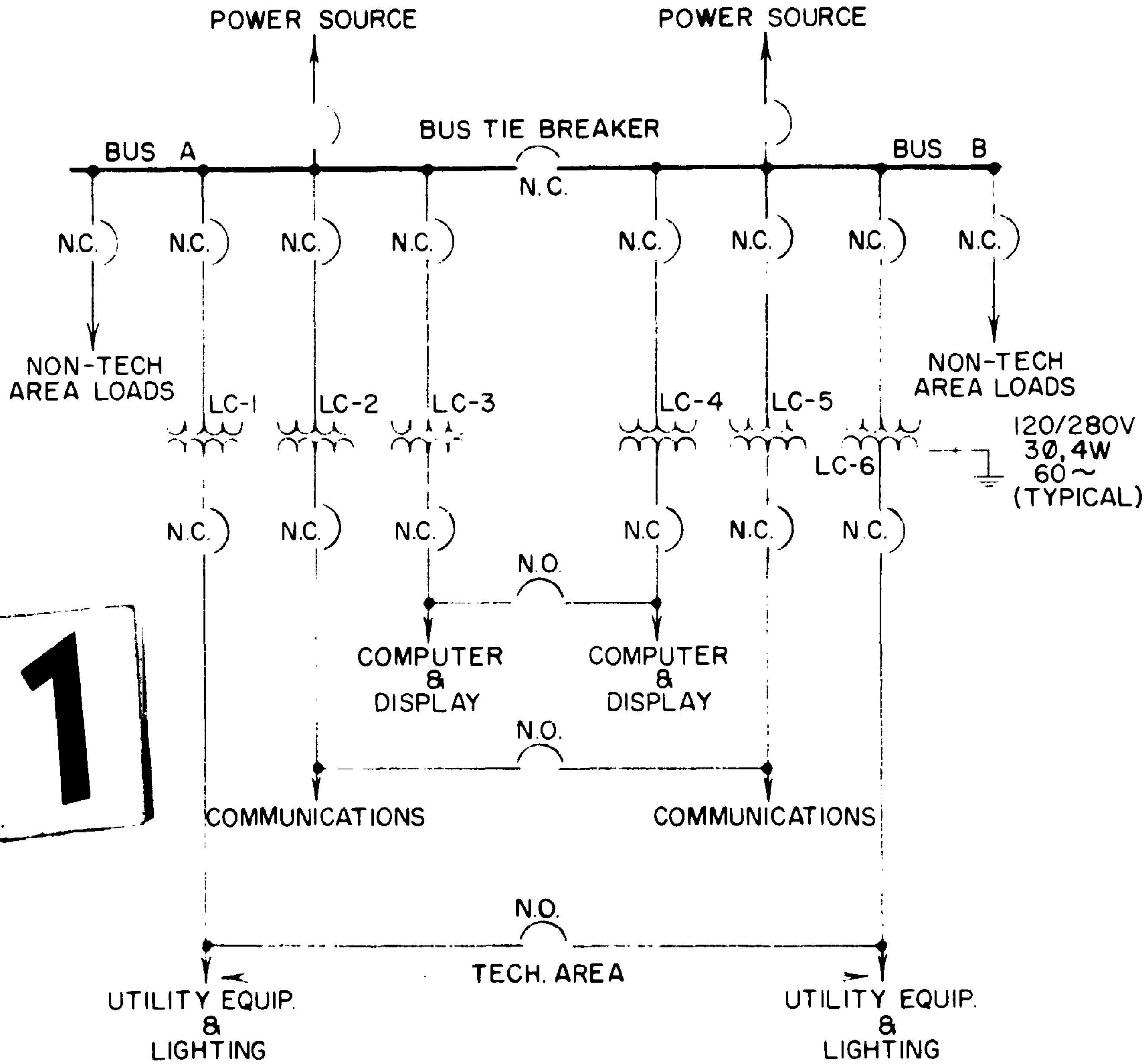
1

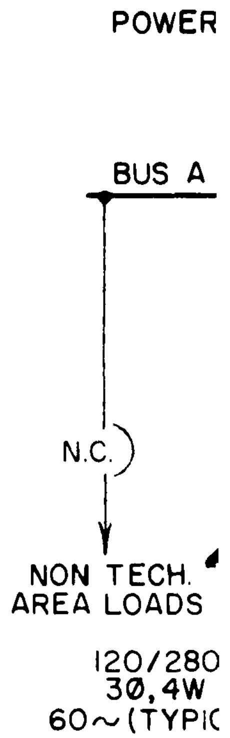




POPE, EVANS AND ROBBINS
CONSULTING ENGINEERS

LARGE SYSTEM





1 LOAD CENTERS (LC-1 THRU LC-6) RATED FOR TOTAL LOAD OF BOTH SIDES SO THAT ONE SIDE CAN CARRY TOTAL LOAD IN THE WORST CASE OF A MAIN BUS FAULT, ASSUMING ADEQUATE GENERATOR CAPACITY IS AVAILABLE ON THAT SIDE.

1. LOW VOL
VOLTAGE

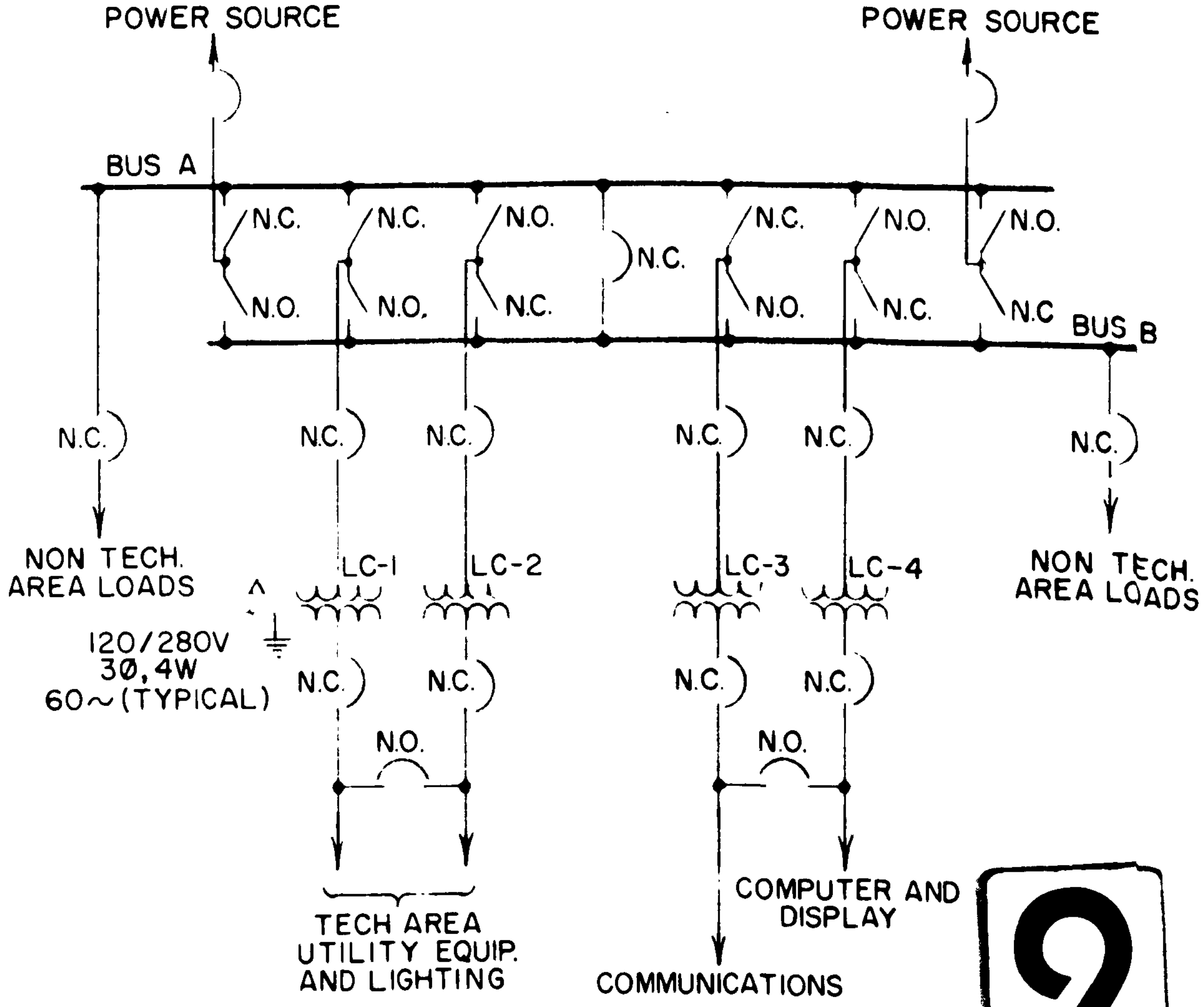
2. LC-1 AND
LIGHTING

3. LC-3 AND

N.O. = NORMALLY OPEN

N.C. = NORMALLY CLOSED

SMALL SYSTEM



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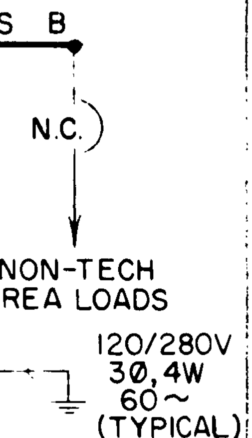

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G

TH SIDES
OF A

1. LOW VOLTAGE TIE BREAKERS CLOSE AUTOMATICALLY ON LOSS OF BUS VOLTAGE NOT DUE TO BUS FAULT

2. LC-1 AND LC-2 EACH RATED TO CARRY TOTAL TECH AREA UTILITY & LIGHTING LOAD.

3. LC-3 AND LC-4 EACH RATED TO CARRY TOTAL ELECTRONIC LOAD