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CONTROL-CAB DESIGN FOR ML-1A NUCLEAR POWER PLANT: HUMAN ENGINEERING CONSIDERATIONS

B. Lawrence Sova, Jr.

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HUMAN ENGINEERING LABORATORIES

ABERDEEN PROVING GROUND,
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ABSTRACT

This report summarizes the human engineering considerations in the preliminary detailed design of the ML-1A control cab. It discusses the pros and cons of alternate designs for the cab interior and the cab sub-system, with conclusions.

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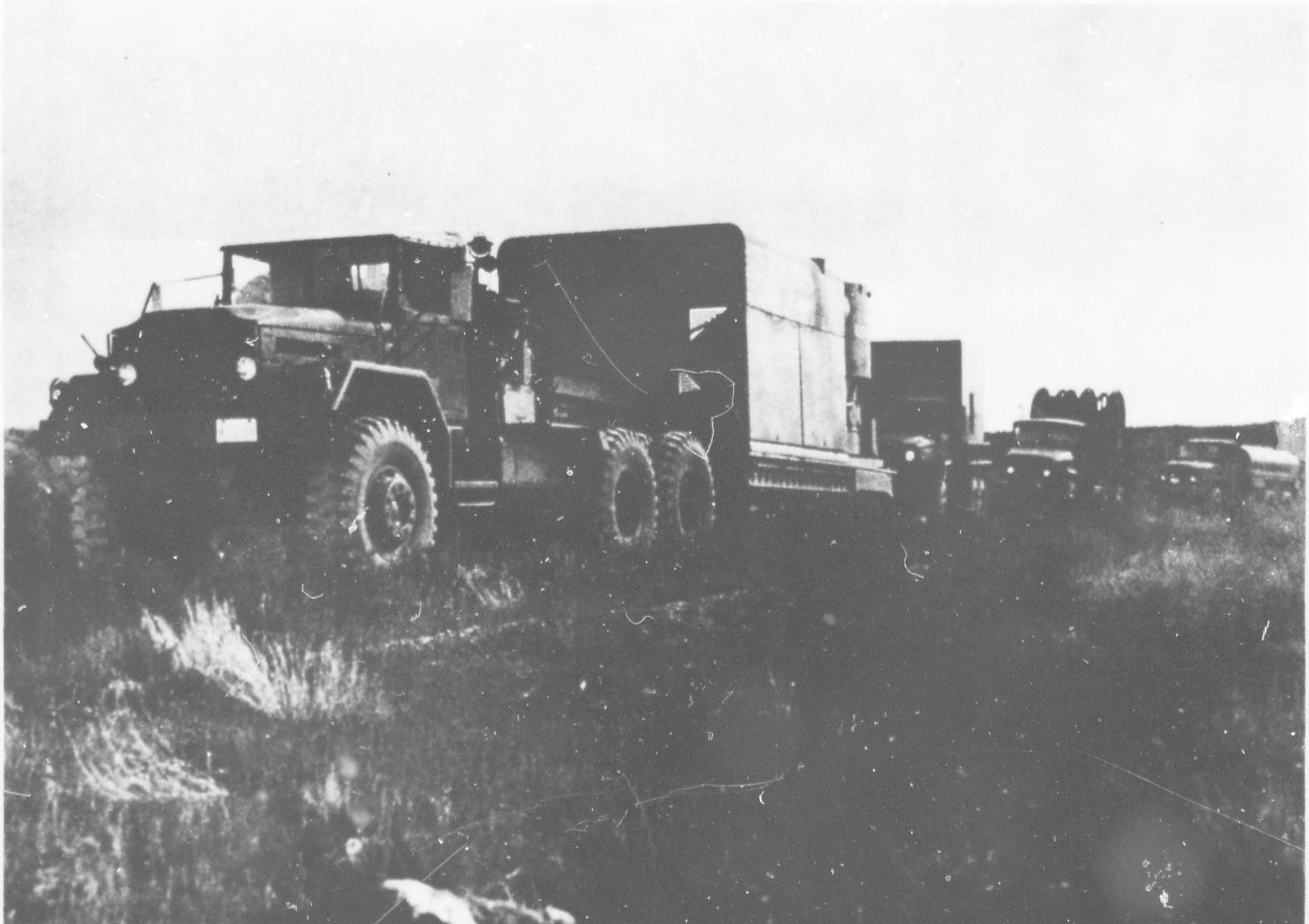

Fig. 1. ML-1 MOBILE LOW POWER NUCLEAR POWER PLANT -- IN TRANSPORT

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CONTROL-CAB DESIGN FOR ML-1A NUCLEAR POWER PLANT:

HUMAN ENGINEERING CONSIDERATIONS

INTRODUCTION

This report continues the human engineering evaluation of the ML-1 Mobile Nuclear Power Plant, which the U. S. Army Human Engineering Laboratories (HEL) conducted at the request of the U. S. Army Corps of Engineers. Two earlier reports (6, 8) covered earlier stages of the HEL evaluation. This report deals with the HEL study, concluded in June 1964, of human engineering considerations in the detailed preliminary design of the ML-1A control cab.

The ML-1A Mobile Low-Power Nuclear Power Plant (Fig. 1) merges a high-temperature, gas-cooled, water-moderated reactor with compact power-conversion equipment. The goal of this closed-cycle, gas-turbine power plant is to generate 300 to 500 kilowatts (kw). The ML-1 is being used to develop an optimum mobile plant for the Army to use in supporting such field operations as tactical missile systems, field hospitals, depot maintenance complexes, and small remote military installations. The plant has four major parts: the nuclear reactor skid, the power conversion skid, the control cab for instrumentation and control, and the auxiliary sub-systems used in start-up and shut-down. The system is designed to have a core life of 10,000 hours and weigh about 40 tons; it is to be transported by C-124, C-130A, or C-133 military transport aircraft, by ship or barge, by railroad flatcar, or by standard Army trailers.

HEL Technical Memorandum 8-62 (6) reported a primarily static evaluation of the control cab. The study revealed numerous human factors shortcomings and made recommendations for resolving them. It also developed detailed operating procedures for the control cab and established human engineering design criteria for future systems.

HEL Technical Memorandum 19-63 (8) gave a simultaneous task analysis of the start-up procedures, and reviewed the major system components, the product improvement program, and the training simulator design. The report included a proposal for an ML-1A control console.

This report discusses the human engineering factors considered in the preliminary design of the ML-1A control cab. In June 1963 the Atomic Energy Commission (AEC) requested the contractor, Aerojet-General Nucleonics (AGN), San Ramon, Calif., to submit a proposed design for an improved ML-1 system, to be designated the ML-1A. The AEC requested HEL to work directly with the contractor during the preliminary design to make sure human factors provisions were incorporated. The preliminary ML-1A design is presented in AGN TM-408 (2). Our report presents supplemental information concerning the human engineering considerations in the design. It should be noted that the conclusions reported here have emerged from the joint efforts of AGN, AEC, and HEL.

This report covers the design of the control cab shelter only, although the other major components -- reactor, power conversion skid, and auxiliary sub-systems -- were also reviewed. Most recommendations in HEL Technical Memorandum 19-63 (8) have been incorporated. Since no unusual problems were encountered during the design, and since the primary HEL effort was centered on the control cab, where man-machine relationships are concentrated, this report does not discuss the other system components.

The ML-1A is a compact, transportable nuclear power plant operating as a conventional Brayton closed-cycle gas turbine plant. The reactor is the heat source, and oxygenated nitrogen (0.5 vol. % O_2 + 99.5 vol. % N_2) is the power-plant working fluid. The power plant is designed to produce electrical power within the range of 300 to 500 kw, in ambient air temperatures ranging from -65 to +100° F.

The power plant consists of two major skid-mounted power-plant packages and a control-cab skid:

a. Reactor skid -- includes the reactor core, shielding, and reactor auxiliaries (Fig. 2).

b. Power-conversion skid -- includes the turbine compressor set, recuperator, precooler, alternator and starting motor, lubrication system, and electrical switch-gear (Fig. 3).

c. Control-cab skid -- includes the instrumentation and control console for remote plant start-up and operation (Figs. 4 and 5).

Auxiliary equipment (cable reel, water-treatment equipment, and equipment for generating and storing gas) is also skid-mounted.

The reactor and power-conversion packages are both on skids with shock mounts. These two packages are coupled rigidly during operation to form a power plant that is complete except for the instrumentation and controls located remotely in the control cab. Each of the packages may be transported separately on its individual skid, or the reactor and power-conversion packages may be coupled and transported in some modes as a single unit. However, the C-124C and C-130A cannot transport the reactor and the power-conversion skids simultaneously.

The control cab, which can be located up to 500 feet from the power plant during operation, is connected to the power-plant skids electrically by four armored control cables. The control cab is an inclosed, compact central control station on skid runners.

The reactor is a heterogeneous, water-moderated type, fueled with fully enriched uranium dioxide (UO_2) and UO_2 in beryllium oxide. The core consists of 61 pressure tubes connecting the inlet (upper) and outlet (lower) plenum chambers. The reactor transfers heat to the working fluid (N_2 with oxygen trace) as it flows through pin-type fuel elements in the pressure tubes. At the ambient design condition of 100° F, the coolant enters the reactor at a nominal 810° F, and leaves at 1225° F. The demineralized-water moderator surrounds the pressure tubes and flows under forced convection counter-current to the gas flow. The core, reflector, and integral lead shielding are inclosed in a tank of borated water during operation,which provides additional shielding.

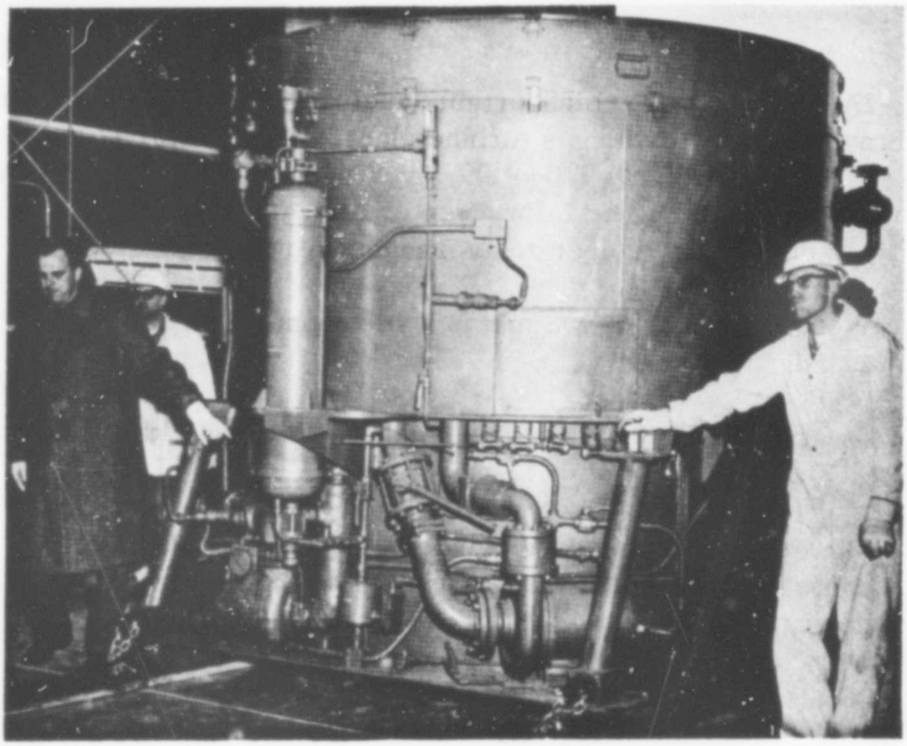

Fig. 2. ML-1 REACTOR SKID

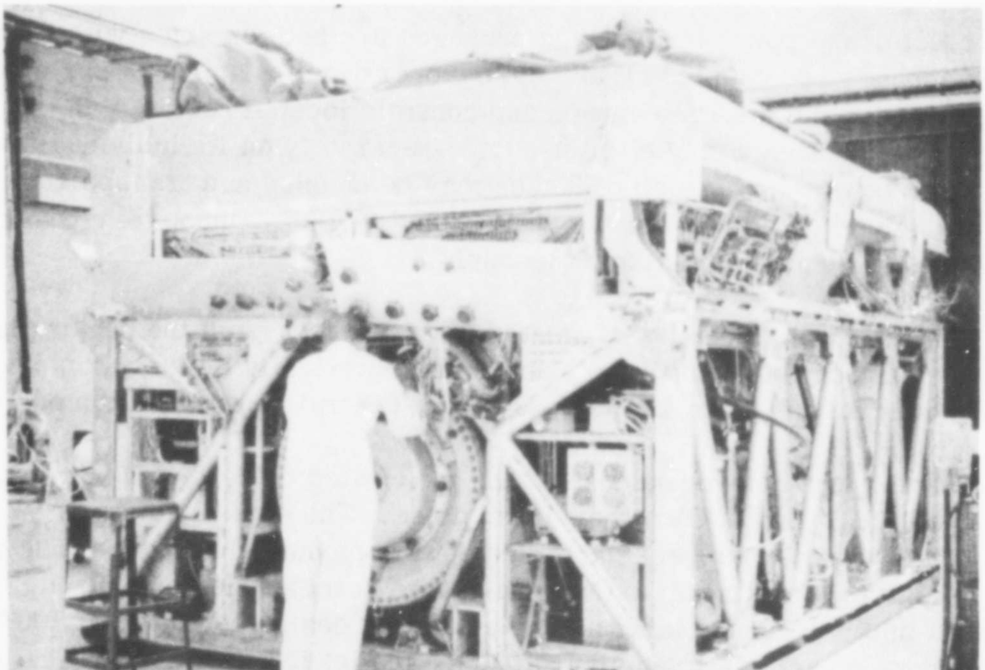

Fig. 3. ML-1 POWER CONVERSION SKID

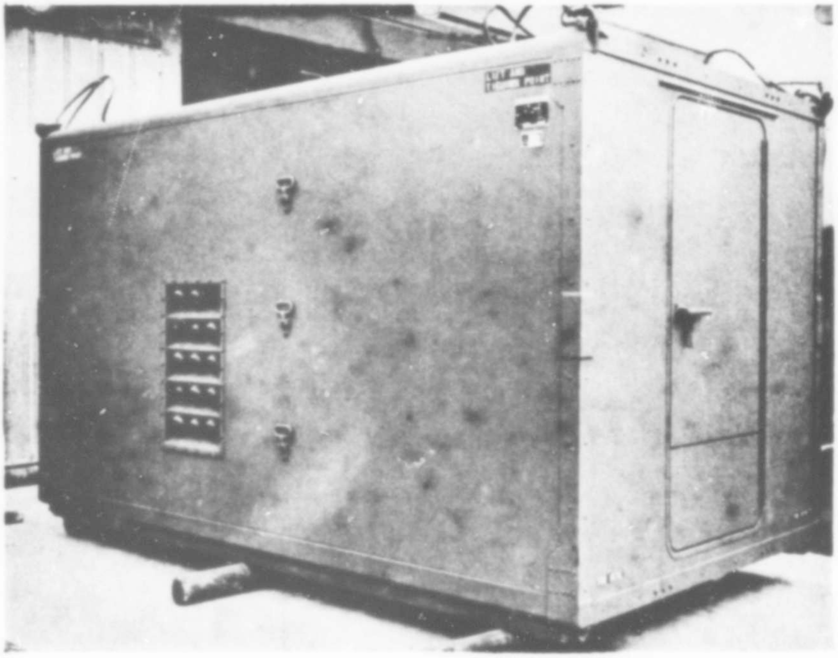

Fig. 4. ML-1 CONTROL CAB -- EXTERIOR

Fig. 5. ML-1 CONTROL CAB -- INTERIOR

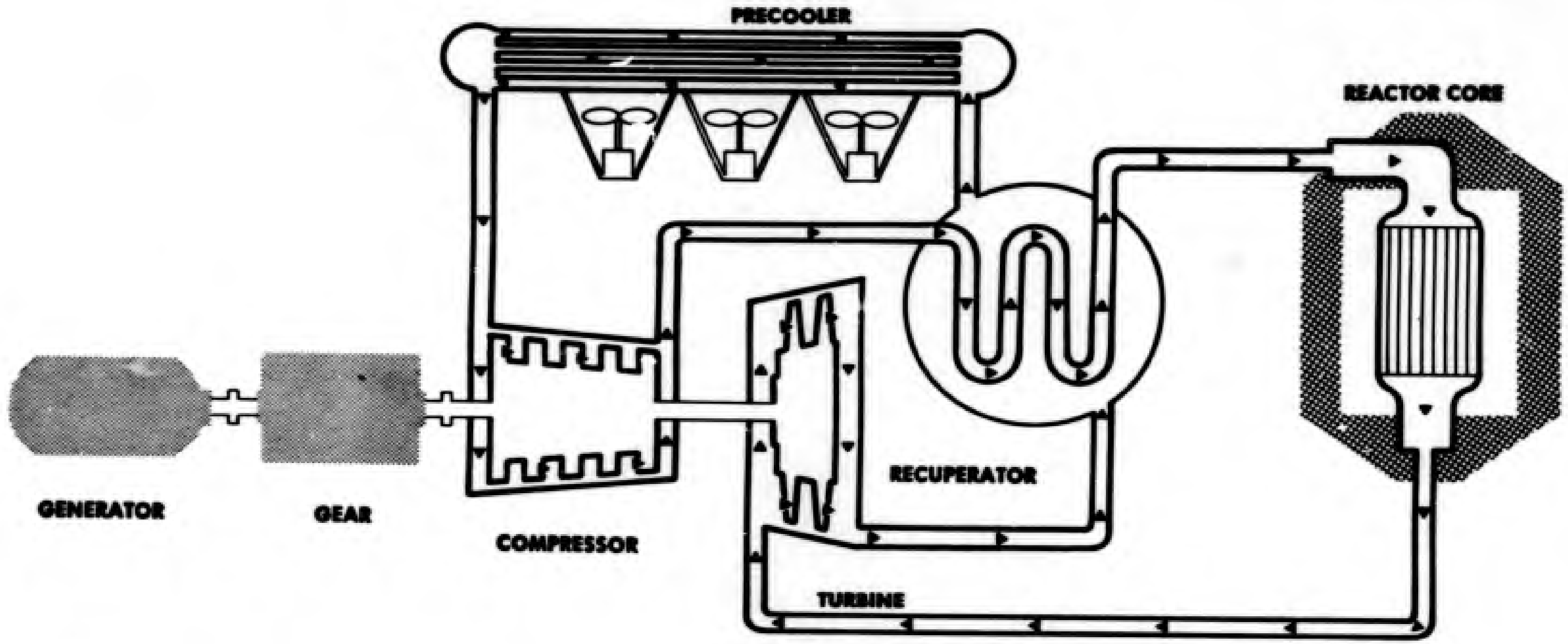

Fig. 6. ML-1/ML-1A POWER CYCLE

Six pairs of semaphore-type control blades (shims) that move in the moderator water and sandwich between the pressure tubes control the reactor. Electro-mechanical devices located in cavities set into the periphery of the shield-water tank operate the blades. Five pairs of blades provide coarse control of the reactivity of the reactor, and one pair allows fine control. Fully inserting all blades "scrams" (shuts down) the reactor in emergency.

Major components of the power-conversion system are a turbine-compressor set and reduction gear; alternator and starting motor; pre-cooler with fans; recuperator; lubrication system; switch gear and connecting piping and valving. The hot gas leaves the reactor at 1225° F (Fig. 6), expands in the turbine, passes through the low-pressure side of a regenerative heat exchanger (recuperator) and through an air-cooled pre-cooler where the waste heat is rejected to the atmosphere. After being compressed in the compressor, the gas is pre-heated to about 810° F as it passes through the high-pressure side of the recuperator. Then it passes through the reactor to the turbine inlet, completing the cycle. Through a gear box, the turbine drives the direct-coupled compressor and the alternator. The net useful output from the turbine shaft drives the rotor of an alternator operating at 1800 rpm. The equipment is mounted on a lightweight, shock-isolated skid. When the sides of the structure are opened during operations, air flows freely through the pre-cooler.

The lifetime of the first ML-1 core loading that had a 1750° F hotspot limit was initially estimated to be about 3000 hours. The current estimate is up to 6000-7000 hours with intermediate reshimming. The goal for the ML-1A core will be to produce 10,000 full-power hours of operation without reshimming. At ambient temperatures less than 100° F, it is possible to achieve rated power output with lower reactor temperatures. At an ambient temperature of 50° F, it is possible to reduce reactor power. When reactor power is reduced, fuel-element temperature drops, corrosion is reduced, and, consequently, core life is increased.

METHOD

HEL coordinated its work closely with AGN design engineers at the contractor's plant throughout the period of preliminary design, and reported its progress to AEC personnel at both Idaho Falls, Idaho, and Germantown, Md. HEL discussed the pros and cons of the new design in detail with each of these agencies. HEL recommendations presented in previous reports were reviewed, and those recommendations found to be appropriate to the new design were incorporated.

DISCUSSION

General Comments

Guidelines that delineated the human engineering design considerations were discussed in detail with personnel from AEC (Idaho and Maryland) to make sure that all agencies concurred in the basic design philosophy. Agreement was reached in each of the areas listed below.

System Requirements

The basic requirements were established in two documents (1, 7).

Human Engineering Criteria

The human engineering criteria for the system are stated in Appendix A of HEL Technical Memorandum 8-62 (6).

System-Use Ground Rules

There was much debate about whether the system will be used as a field plant or as a research plant. It was agreed that the ML-1A should be designed for use as a field plant, but that the first plant will probably be used for research only, so research requirements should be fully considered. Conflicts from attempting to satisfy both field-plant and research-plant requirements were to be resolved as they arose.

In general, there was little difficulty designing for both the field- and research-plant requirements. The only major conflict concerned the scram button's location, which is discussed in detail on page 62.

CONTROL-CAB INTERIOR DESIGN

Since the man and machine interact most in the control cab, the primary HEL effort was directed to the detail design of this cab. The major human engineering design considerations are listed below in detail, with the conclusions deriving from each.

Basic System Requirements

Since the ML-1A system is intended for use as a field plant, the control cab should be designed for use by Field Army personnel. The basic system requirements for field-plant use are:

a. Present information to the operator in directly usable quantities; do not require arithmetic calculations.

b. Minimize occasions when information must be consolidated or integrated from several sources.

c. Locate maintenance controls or adjustments where they are not accessible to the operators.

d. Eliminate any instrumentation that operators do not need.

e. Provide for performing some maintenance on the electronic equipment while the system is in operation.

Number of Operating Personnel

The several documents pertinent to the ML-1A specify the number of crewmen required to operate the power plant:

> This plant will be capable of 24 hour operation by its seven man crew (7, para 2b).
>
> The crew requirement for continuous 24 hour operation will consist of one officer (or non-commissioned officer) in charge and six enlisted men organized in accordance with the TOE 5-500 concept (7, para 12a).
>
> Housed Equipment The control shelter shall house the following equipment:
>
> (j) Sufficient space for full time occupancy by two persons; one of which may be seated at the operating console (1, para 3.3.3.2.1).

To satisfy these requirements, it must be possible to operate the plant with six men and one supervisor (the officer in charge) who would not be on continuous duty. With two men thus available for each eight-hour shift, one man must be able to operate the plant alone while the other attends to maintenance and other duties.

As part of an earlier study (6), HEL made a detailed analysis of the procedures for operating the ML-1 system. The study concluded that, because operations are so complex, it would certainly be desirable to have an assistant for the operator, even though one man can operate the plant.

Since a second man is available and desirable on each shift, there must be sufficient space in the control cab for this man to act as observer, assistant, student or supervisor. Therefore, the cab design should allow for a single operator, but the console should also allow for an assistant.

TABLE 1

Operators' Comments on ML-1A Instrumentation

Instrumentation	Operators[a]			
	A	B	C	D
Compressor Inlet Pressure Meter	+	+	-	+
Compressor Outlet Pressure Meter	?	-	+	-
Reactor Outlet Temperature Meter	+	+	+	+
Reactor Outlet Temperature Error Meter	+	+	-	-
Compressor Inlet Temperature Meter	+	+	+	+
Moderator Reactor Inlet Temperature Meter	+	+	+	+
Moderator Reactor Outlet Temperature Meter	+	+	+	+
Shield Inlet Temperature Meter	+	+	+	+
Moderator Water Level Meter	+	L	L	L
Shield Water Level Meter	+	L	L	L
Moderator Water Conductivity Meter	-	-	-	-
Shield Water Conductivity Meter	-	-	-	-
Lube Oil Pressure Sump Meter	+	+	+	+
Lube Oil Pressure Bearing Inlet Meter	+	+	+	+
Bearing Lube Oil Temperature Meter	+	+	+	+
Bearing Temperature Meter	+	+	+	+
Fast Pressure Loss, Scram	+	+	+	+
Compressor Inlet Pressure Low, Scram	-	-	O	-
Compressor Inlet Pressure Low, Alarm	+	+	O	+
Compressor Inlet Pressure High, Alarm	+	+	O	+
Reactor Outlet Temperature High, Alarm	+	+	+	+
Reactor Outlet Temperature Error High, Alarm	-	-	-	-

[a] Symbols

\+ Function preferred
\- Function not preferred
O Function not discussed
L Lights preferred to meters
? Undecided

Confinement

It is apparent that an operator may sometimes spend his entire shift alone in the cab. Thus it is important to find out whether isolation or the claustrophobic effects of the small cab will degrade the operator's performance.

To reduce performance decrements, there is an auditory alarm to attract the operator's attention whenever a critical parameter is "out of tolerance." In addition, the cab design was intended to create as much subjective volume around the operator as possible to keep him from feeling "closed in."

Instrumentation Review

After the basic design requirements of the ML-1A control cab had been established, it was necessary to define the equipment to be installed in the cab.

HEL reviewed the ML-1A instrumentation with both AGN and AEC. The results of this review are included in AGN TM-408, Vol. III (2), with justifications for changing the ML-1 instrumentation. Since the presentation in the AGN report is rather complete, there is no reason to discuss the instrumentation further in this report. For detailed information, see the AGN report.

As part of the instrumentation review, two military and two AGN operators at the ML-1 plant at the National Reactor Testing Station (NRTS), Idaho Falls, Idaho, were interviewed concerning the instrumentation. This interview tried to capitalize on their experience in operating the ML-1 plant. Their comments were taken into account in designing the ML-1A where possible.

Table 1 shows the operator preferences elicited during these interviews. The table indicates whether given functions were discussed with an operator, whether or not he preferred certain functions, and whether he preferred lights to meters for certain functions.

Two points are evident from Table 1. First, different operators may use different instruments to determine the system's status. Two operators relied on the reactor outlet temperature error meter to note reactor temperature changes; the other two used the reactor outlet temperature meter itself.

Second, operators do not agree on which type of display gives status information best. For example, three operators preferred lights to display moderator water-level information, while one preferred a meter.

Apparently, no one design could satisfy all operators. At any rate, it would take interviews with many operators to obtain a valid consensus on any specific point. Therefore, the entire ML-1A instrumentation was reviewed with only these four operators, but with particular attention to points on which they agreed. Where the operators clearly did agree, their comments were incorporated into the design.

Cab Layout -- General

The documents pertinent to the ML-1A specify a number of requirements relating to the cab layout:

> The control cab weight shall not exceed 2.5 tons (7, para 8a).
>
> The control cab shall be transportable in a standard military 2 1/2-ton cargo truck (7, para 8b4).
>
> Human factors engineering characteristics of the plant will include, but not be limited to, consideration of each of the following, in terms of the intellectual, physical and psychomotor capabilities of the intended user (7, para 10f):
>
> (4) Work space layout.
>
> Size. Size of individual assemblies shall be kept to a minimum and within the limits as established by the required modes of transportation to be used as defined herein. Limiting dimensions for individual assemblies in the transport condition shall be as shown in Table [2] (1, para 3.1.2.1.2.1).
>
> Weight. Maximum weights for individual assemblies in the transport condition shall be as shown in Table [2] (1, para 3.1.2.1.2.2).
>
> Primary mode of transportation. The control shelter shall be transported intact and shall be suitable for both operation from and transport on a standard military 2 1/2-ton cargo truck (1, para 3.1.2.1.3.1).

TABLE 2

Maximum Sizes and Weights for Transporting Power Plant[a]

Assembly	Length in.	Width in.	Height in.	Weight lbs.
Control Shelter	147	84	82	5,000

[a] Ref. 1, para 3.1.2.1.2.2

<u>Space limitations for operation and maintenance</u>. The principles established for human engineering design criteria as defined in U. S. Army Ordnance Technical Memo 8-62, OCMS Code 5010.21.81902, Appendix A, shall be used as a guide in the design of the power plant where human access to components or assemblies for operation and maintenance is necessary (1, para 3.1.2.2.1).

<u>Housed equipment</u>. The control shelter shall house the following equipment (1, para 3.3.3.2.1):

(a) Where applicable, all instruments and operating controls required for startup, self-sustained operation, and shutdown of the power plant.

(b) An air conditioning device to maintain an essentially constant interior temperature and humidity throughout the full range of environmental conditions specified in 3.1.2.1.1.

(c) A battery energized emergency power system.

(d) A malfunction detection system to alert the operator to abnormal plant conditions or incipient faults.

(e) An intercommunication system to provide a communication link between the power plant, control shelter and a minimum of five substations during periods of plant maintenance.

TABLE 3

Control Cab Equipment and Space Requirements

Equipment	Approximate Space Requirements[a]
Console	60"-75" long x 72" high x 25" deep
Electric Power Instrumentation	1 1/2 racks
Process Instrumentation	1 rack
Nuclear Instrumentation	1 rack
Terminal Boards and Circuit Breakers	1 rack
Air Conditioner	3/4 rack
Storage Cabinet	1 rack

[a] One rack space is approximately 20" wide x 72" high x 20" deep.

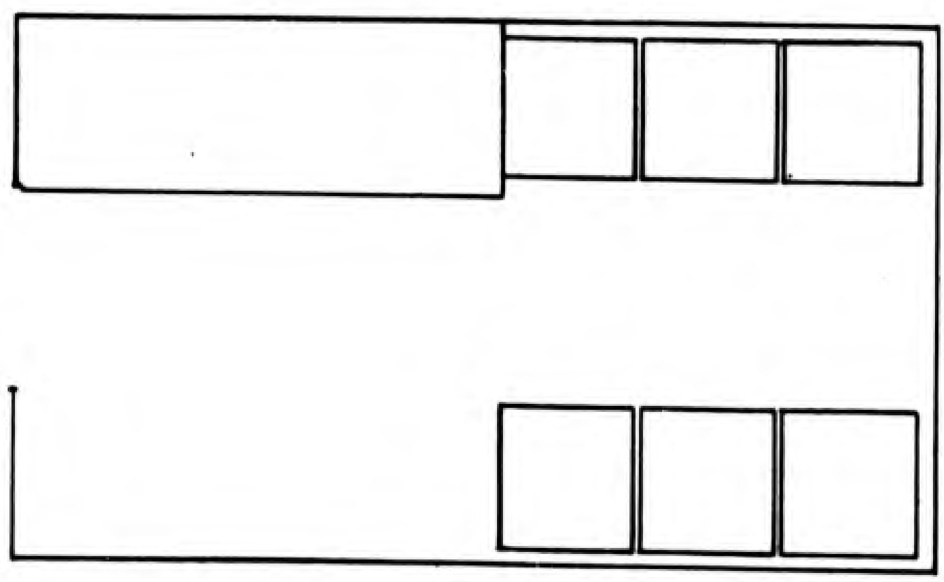

Fig. 7. PRELIMINARY CONTROL CAB #1

(f) A radiological instrumentation system as described in 3.3.3.10.

(g) Storage drawer space for operating manuals, logs, and portable radiological survey instruments.

(h) A coat and rifle rack to accommodate four persons.

(i) A suitable fire extinguisher and fire axe.

(j) Sufficient space for full time occupancy by two persons; one of which may be seated at the operating console.

The shelter chosen to satisfy these requirements was the military standard Shelter, Electrical Equipment, S-141( )/G. This shelter can be transported on a 2-1/2-ton truck, will house the equipment necessary to operate the system, and should meet the weight requirements. The maximum exterior dimensions of this shelter are:

Length -- 142 inches
Width -- 81 inches
Height -- 82 inches

The first step in establishing the control-cab layout is considering the basic design requirements discussed earlier. The layout should allow operation by one man but permit the use of an assistant, avoid a "closed-in feeling," and allow for maintenance while the system is in operation.

Table 3 shows the control cab equipment and space requirements.

HEL tried four approaches in laying out the S-141 shelter to satisfy these equipment and space requirements, as well as the basic design requirements.

The basic layout of the shelter in Figure 7 located the console along the side wall, with the equipment racks to the rear. The main reasons for placing the console there were allowing space around the console for the assistant and giving the operator a broader side view, thus creating greater subjective volume. In this layout, however, the operator's chair obstructed traffic between the outside and the equipment area. Maintenance men entering and leaving the shelter would interfere with system operation, so this layout was unacceptable.

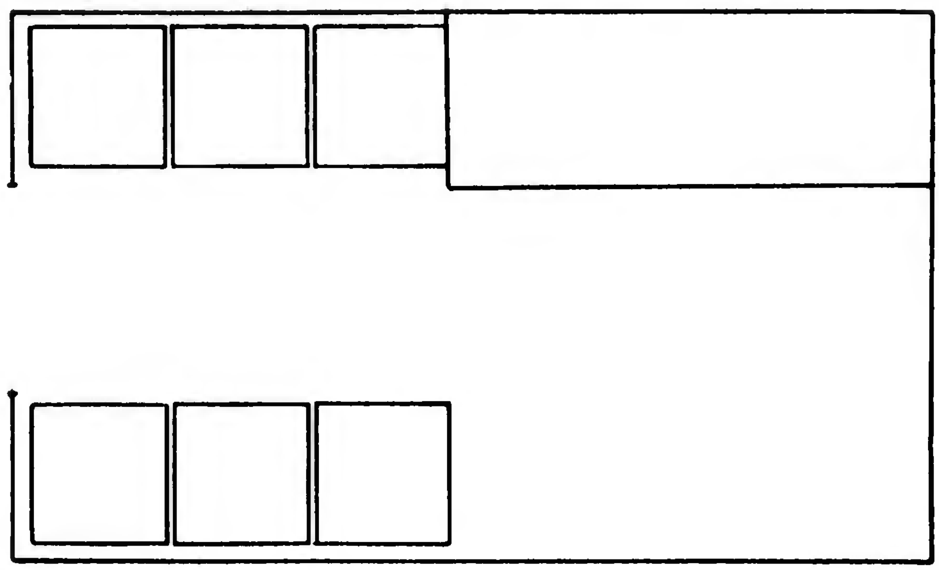

Fig. 8. PRELIMINARY CONTROL CAB #2

The layout in Figure 8 moves the console to the rear and the equipment racks to the front to alleviate the traffic problem. Since this layout would not allow space for possible growth of the console, it was unacceptable.

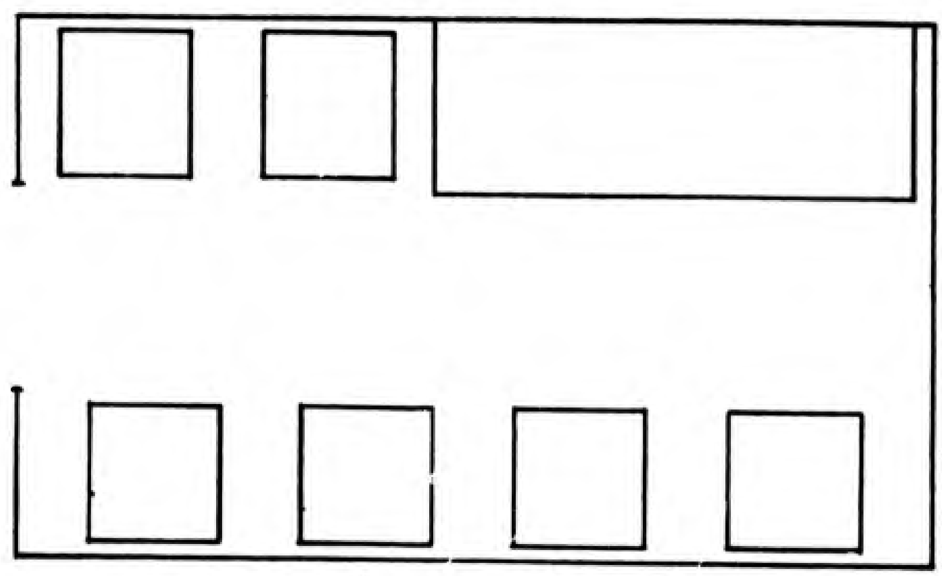

Fig. 9. PRELIMINARY CONTROL CAB #3

The layout in Figure 9 places two of the racks behind the operator. This layout allows the console to grow but does not give the operator enough room. Moreover, the racks behind the operator can not be maintained while the system is in operation. Therefore this layout was also unacceptable.

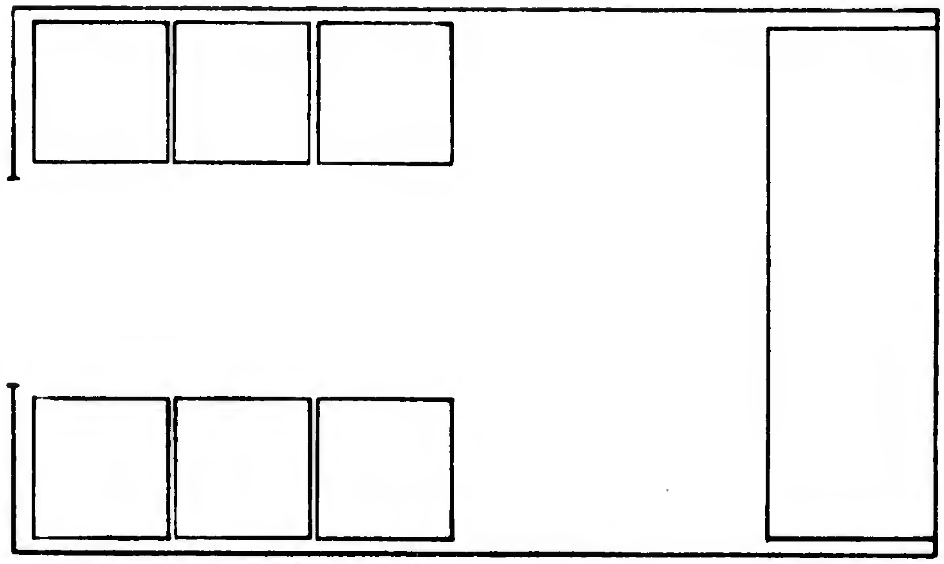

Fig. 10. PRELIMINARY CONTROL CAB #4

Although the layout in Figure 10 is similar to the ML-1 layout, the console area has been changed considerably to allow room for an assistant and to provide a sense of spaciousness. This layout satisfied all of the basic design requirements and equipment and space requirements, so it was adopted.

Rack-Area Layout

The equipment to be mounted in the rack area, with approximate space requirements, is shown in Table 4.

TABLE 4

Rack-Area Equipment and Space Requirements

Equipment	Approximate Space Requirements[a]
Electric-Power Instrumentation	1 1/2 racks
Process Instrumentation	1 rack
Nuclear Instrumentation	1 rack
Terminal Boards & Circuit Breakers	1 rack
Air Conditioner	3/4 rack
Storage Cabinet	1 rack

[a] One rack is approximately 20" wide x 72" high x 20" deep.

Before dealing with the details of the rack-area layout, two maintenance requirements were noted:

a. The need to perform maintenance on the system while it is in operation must be kept in mind in positioning the equipment.

b. In instances where the maintenance man must refer to console displays, the equipment should be close to the console to make it easier for him to read the meters.

The layout of the rack area began with the positions furthest from the console, at the far end of the shelter near the door. These positions are obviously most appropriate for equipment least closely associated with the console. The rack-area items that fall most clearly into this category are the storage cabinet and the terminal boards and circuit breakers.

Although maintenance men will need access to the terminal boards and circuit breakers, they will not need to consult the console while maintaining these elements. In interviews, the NRTS operators felt that the circuit breakers should be located near the console where the operator could monitor and control them, but this feeling apparently derives from their experience with the ML-1 "research plant." During continuous testing with greatly varying loads, the breakers undoubtedly open frequently, irritating the operators, who must rise and walk back to close them. The ML-1A, however, is to be a field plant -- the loads should be better defined and the breakers should not be tripping very frequently. Moreover, making the breakers less handy to the operator means they are less likely to be misused as switches. For all these reasons, the circuit breakers and terminal boards were located just inside the door.

In reviewing the cab and system-site layouts, it appeared that the cable entrance panel behind the terminal-board panel should be on the right side of the shelter. Therefore the terminal boards and circuit-breaker panel were located immediately on the right as the cab is entered, and the storage cabinet on the left.

The electrical-power instrumentation and air conditioner will have high voltage lines coming from the terminal-board panel. Since it is desirable to keep the high voltage lines in the cab as short as possible, the electrical-power instrumentation and air conditioner should be adjacent to the terminal-board panel. The electrical-power instrumentation has a closer association with the main console than the air conditioner has, so it was placed closer to the console.

The other two rack spaces will accommodate the process instrumentation and the nuclear instrumentation. Because the nuclear instrumentation is more closely associated with the console, it is placed nearer the console, and the process instrumentation is located near the storage cabinet (Fig. 11).

According to the space requirements in Table 4, some miscellaneous equipment must still be provided for. There should be enough space below the console to accommodate this remaining rack equipment. Since this space is not easily accessible, only equipment that requires little attention should be located there.

The detailed chassis-by-chassis layouts of the rack area were based on the need for access to given chassis and on the desire to shorten interconnecting cables between associated chassis. No special problems arose in these layouts, and Figures 12 and 13* show the final rack layouts.

* These and other Aerojet-General Nucleonics figures appearing in this report are included by courtesy of Aerojet-General Nucleonics, San Ramon, Calif.

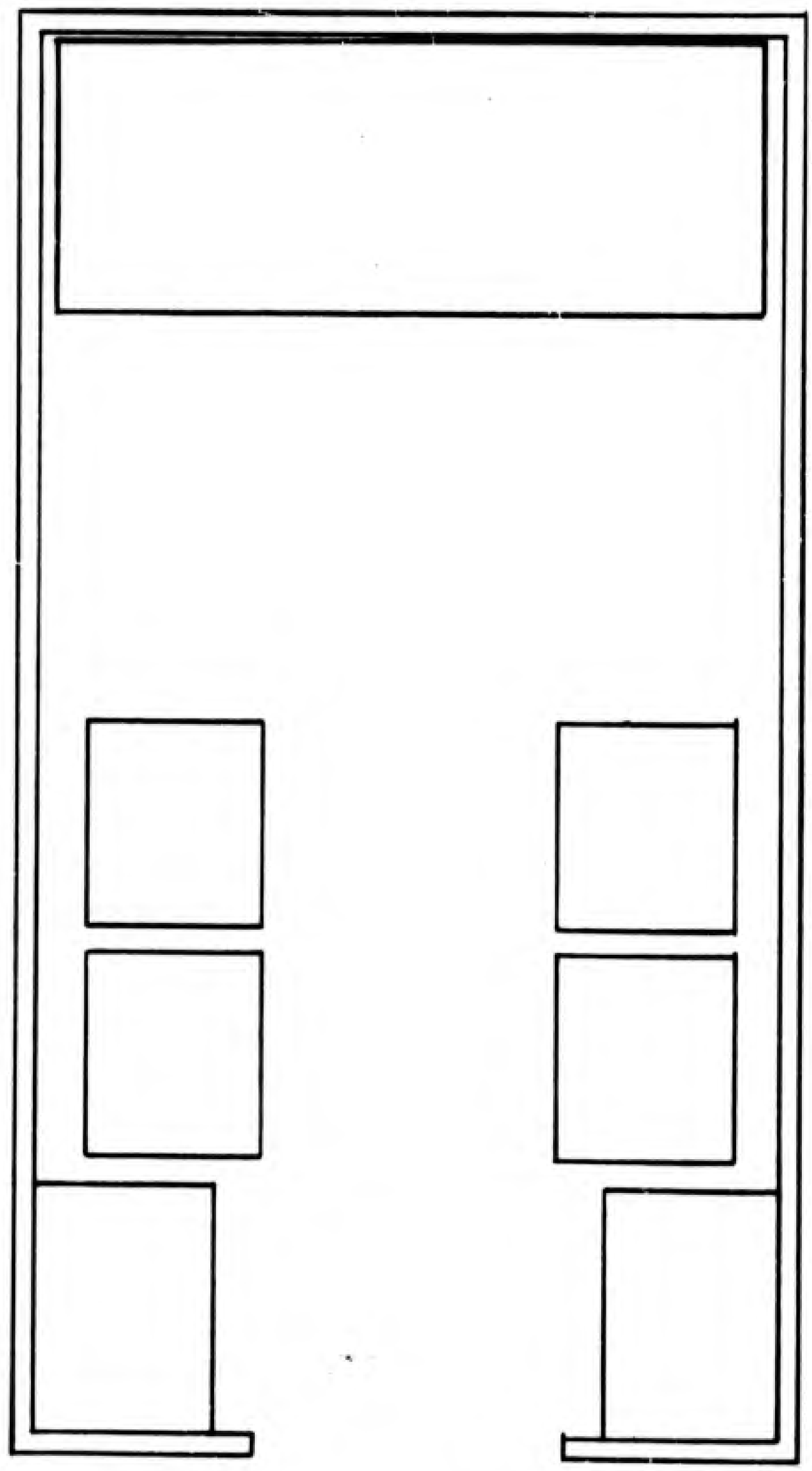

Fig. 11. FINAL RACK AREA

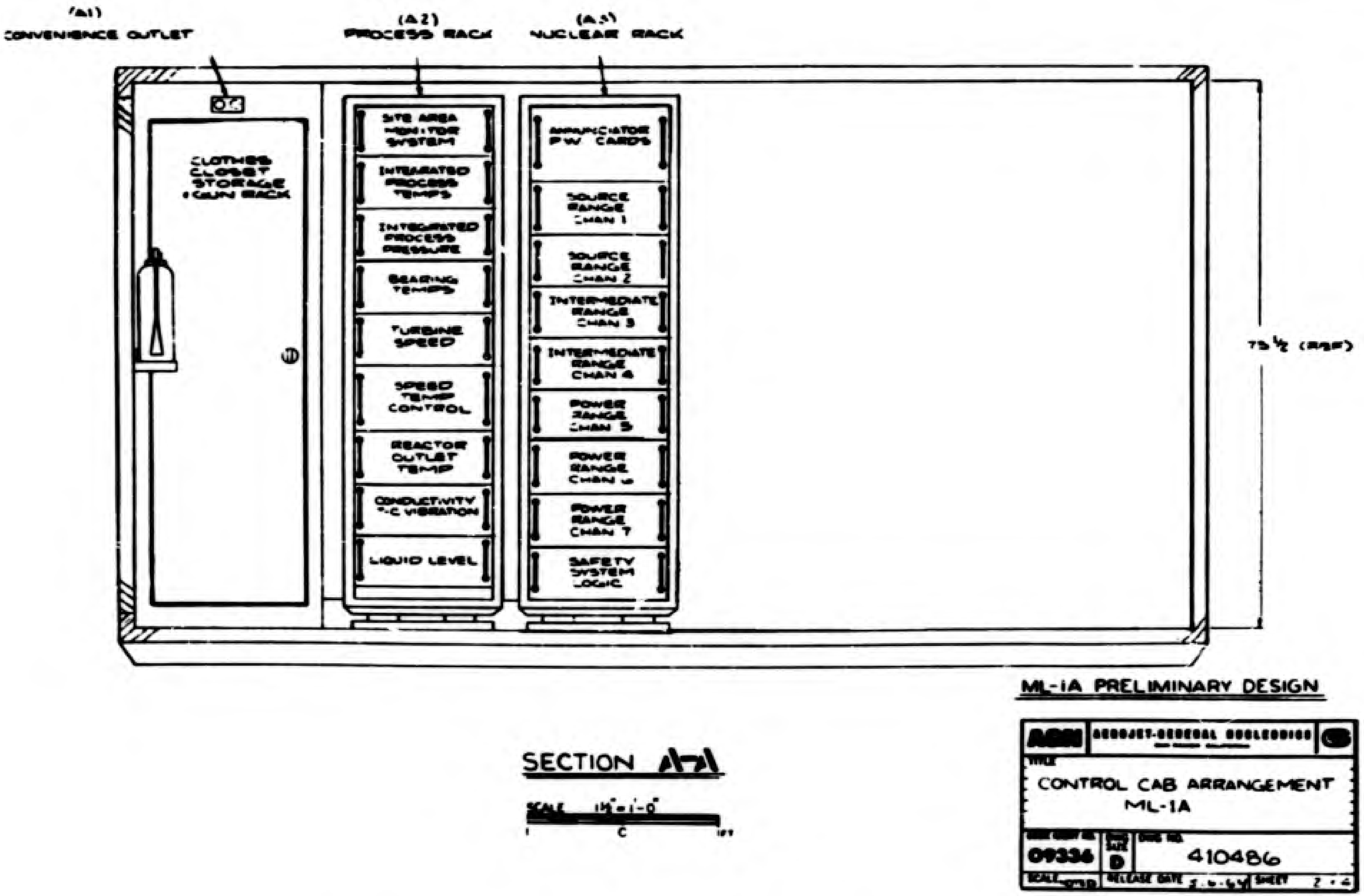

Fig. 12. FINAL RACK LAYOUT -- LEFT SIDE OF CAB

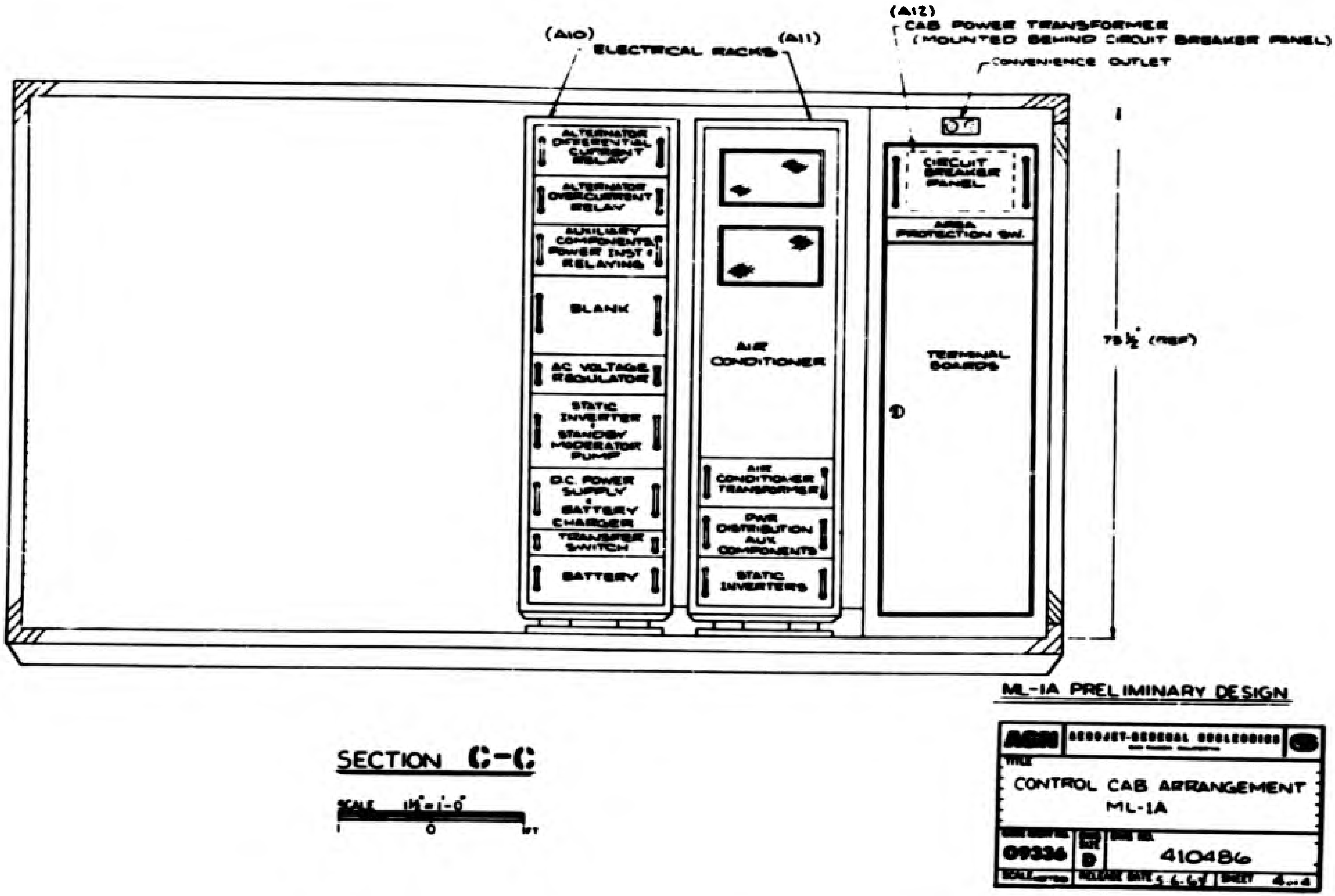

Fig. 13. FINAL RACK LAYOUT -- RIGHT SIDE OF CAB

Console-Area Layout

The primary consideration in laying out the console area was the shape of the console. The flat console recommended in previous HEL studies (8) was considered first. Comparing this console with the results of the instrumentation review (2, Vol. III) revealed that more instrumentation was being considered for the ML-1A. The flat console (8) is the maximum size that a single operator can use conveniently, since the extreme controls are just within his reach. Adding more instrumentation would mean enlarging the console, thus placing some controls beyond easy reach, so the flat console was evaluated as unacceptable.

The U-shaped console used in the ML-1 system would certainly be large enough to hold the planned instrumentation, so this shape was considered next. However, a U-shaped console would certainly make the operator feel more "closed in," so this shape was judged to be unacceptable.

Since both extremes in console shape were unacceptable, a compromise design was adopted: a "wing-shaped" console. This shape makes the console as flat as possible, to give the operator a sense of spaciousness, but it brings the ends of the console slightly inward so the operator can reach all controls conveniently. The shape adopted is shown in Figure 14. This console allows space for all the instrumentation, with easy access to the controls, and it gives the operator as great a sense of spaciousness as possible in the actual space available.

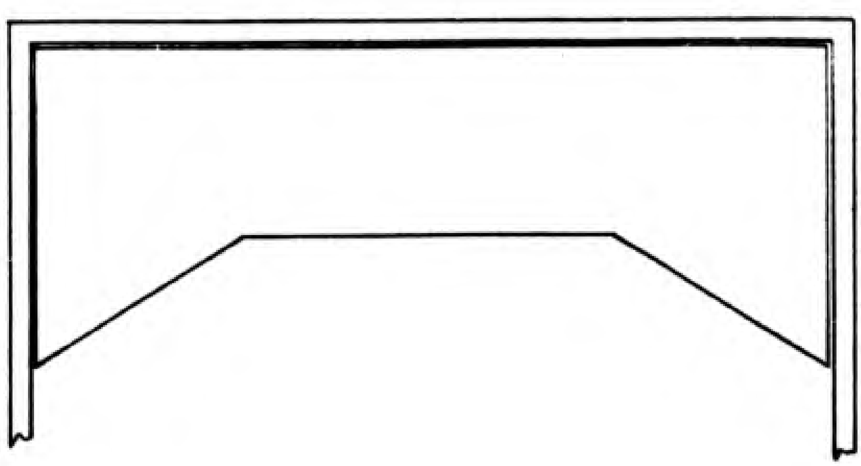

Fig. 14. PRELIMINARY PLAN VIEW OF CONSOLE AREA

When the basic console shape had been established, the layout of the console area continued. The rack-layout study had indicated that there would have to be some space under the console for electronic gear or storage. Since these racks must be 15 inches deep, and since the operator requires an additional 16 inches of knee space, the console's depth from the back wall was established at 31 inches. The side view of the console in Figure 15 shows how these dimensions were established. Combining this console layout with the rack layout adopted previously, produced the overall shelter layout in Figure 16.

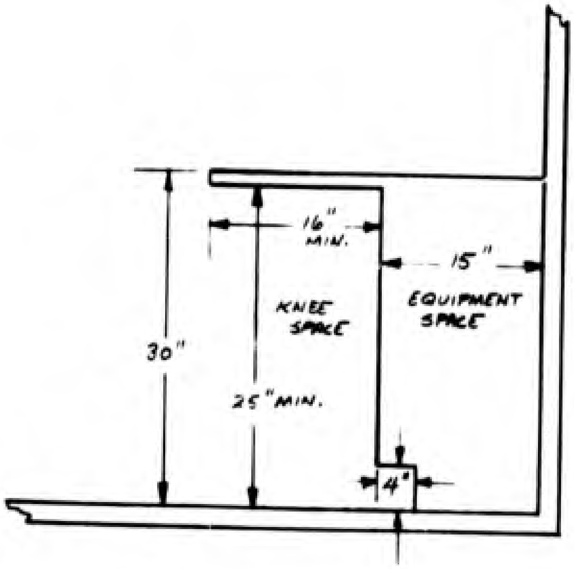

Fig. 15. PRELIMINARY CONSOLE PROFILE

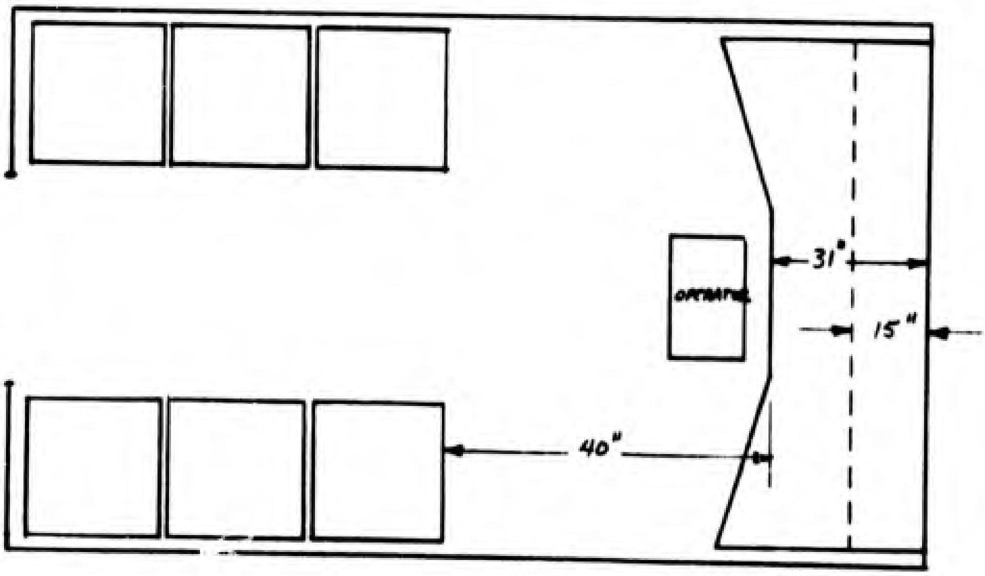

Fig. 16. CONTROL CAB COMBINING RACK-AREA AND CONSOLE-AREA CONCLUSIONS

With a console like the one adopted for this shelter, there should not be desk space in front of the operator. If the operator spreads out books and papers in front of him, he may cover up controls and displays, or even operate a control accidentally. Therefore the desk space immediately in front of the operator was limited to six inches -- room enough to rest his elbows, but not enough to use books and papers. However, the operator does need desk space somewhere so he can complete his check lists and log books; pull-out writing shelves were installed on both sides of the operator's position.

There was room for an assistant on either side of the operator, and he could use either of the pull-outs as a desk. But as the console was finally laid out, the auxiliary electrical controls are on the operator's right, and miscellaneous controls on his left. Since the log books could not operate the miscellaneous controls accidentally, the assistant's position was established at the operator's left, as shown in the final cab layout (Fig. 17).

Viewed in cross-section, the most appropriate console shape would allow the seated operator to view the meters perpendicularly (to avoid parallax) and to reach all controls. Although the ML-1A uses more instrumentation than the ML-1, the basic operations of the two systems are identical. Therefore the basic ML-1 cross-sectional shape was retained (Fig. 19). This shape also resulted in natural breaks between the various functional areas, as indicated in the conclusions about console layout.

The final complete layouts of the ML-1A control cab arrangement are shown in Figures 17-20.

Escape Hatch

In the ML-1A layouts (Figs. 17-20) the console is at the extreme opposite end of the hut from the door. Much equipment (transformer, terminal boards, batteries, air conditioner, etc.) is located directly between the operator's position and the door, and the corridor is very narrow. If there were a fire in the electrical equipment, the operator would find it virtually impossible to escape. Hence an escape hatch was provided.

The escape-hatch dimensions recommended for accommodating the 95th percentile man wearing arctic clothes are a minimum of 20 inches square. Such a hatch was incorporated into the roof of the ML-1A control cab (Fig. 17).

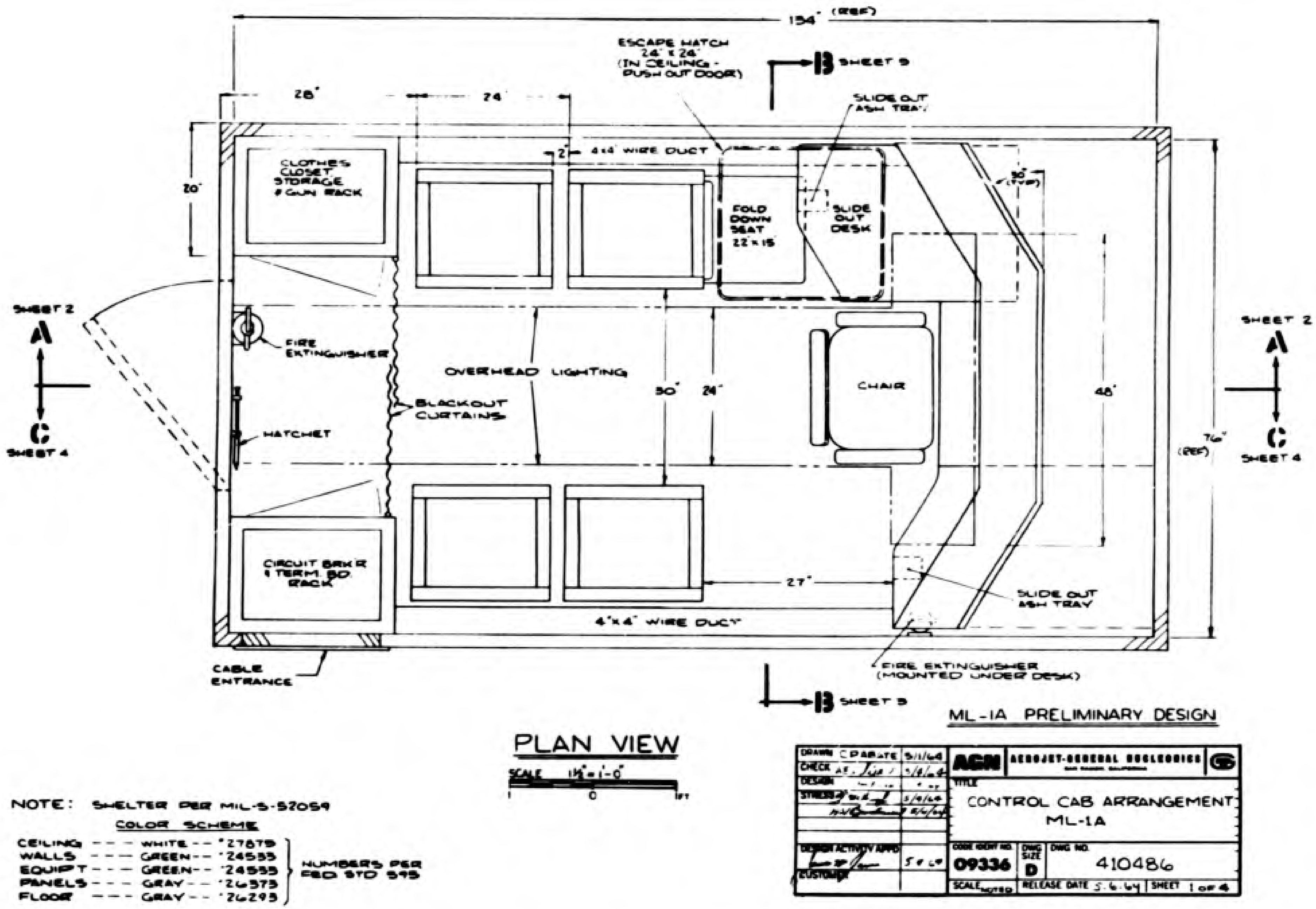

Fig. 17. FINAL PLAN OF CONTROL CAB

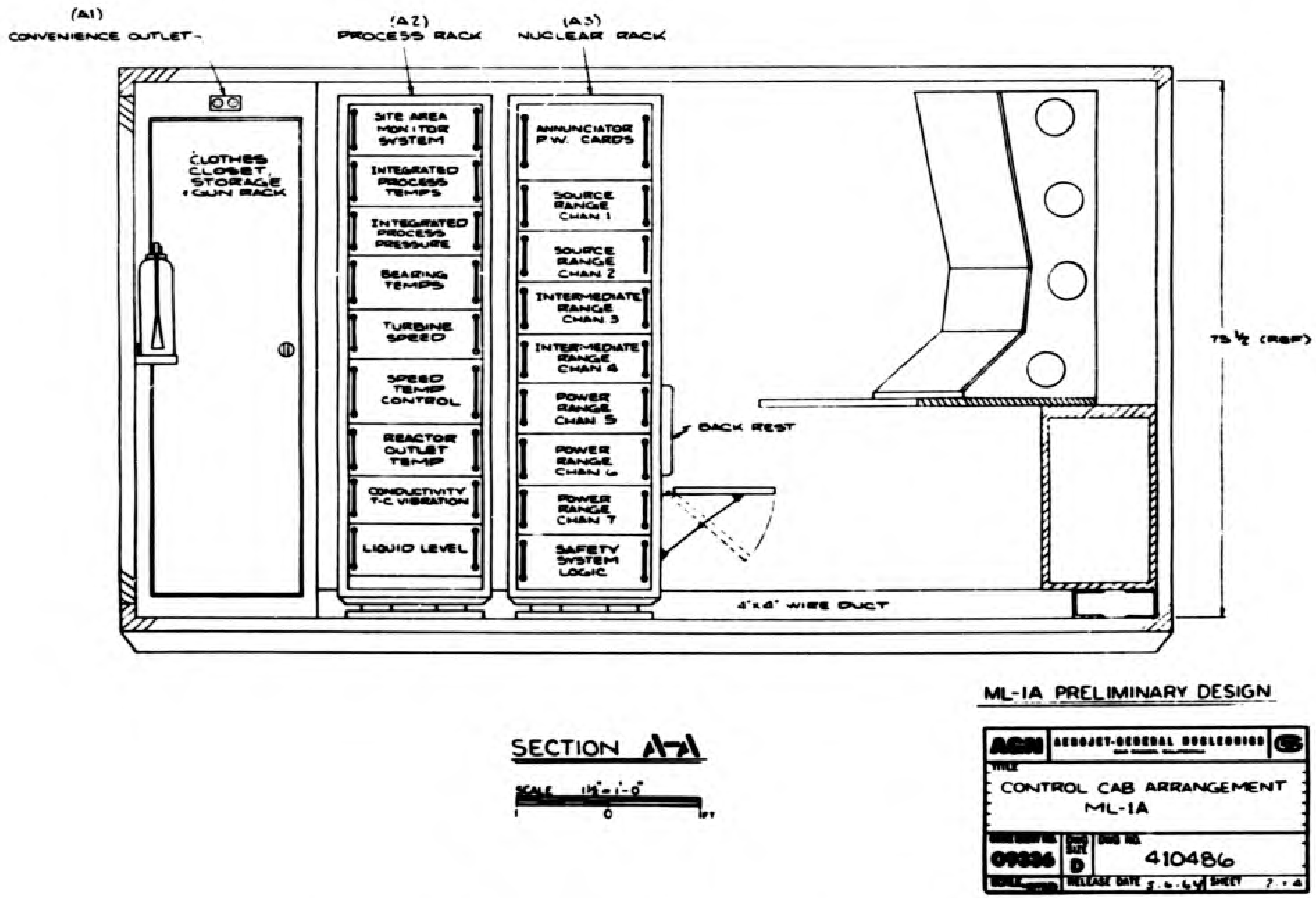

Fig. 18. FINAL CONTROL-CAB LAYOUT -- SECTION A-A

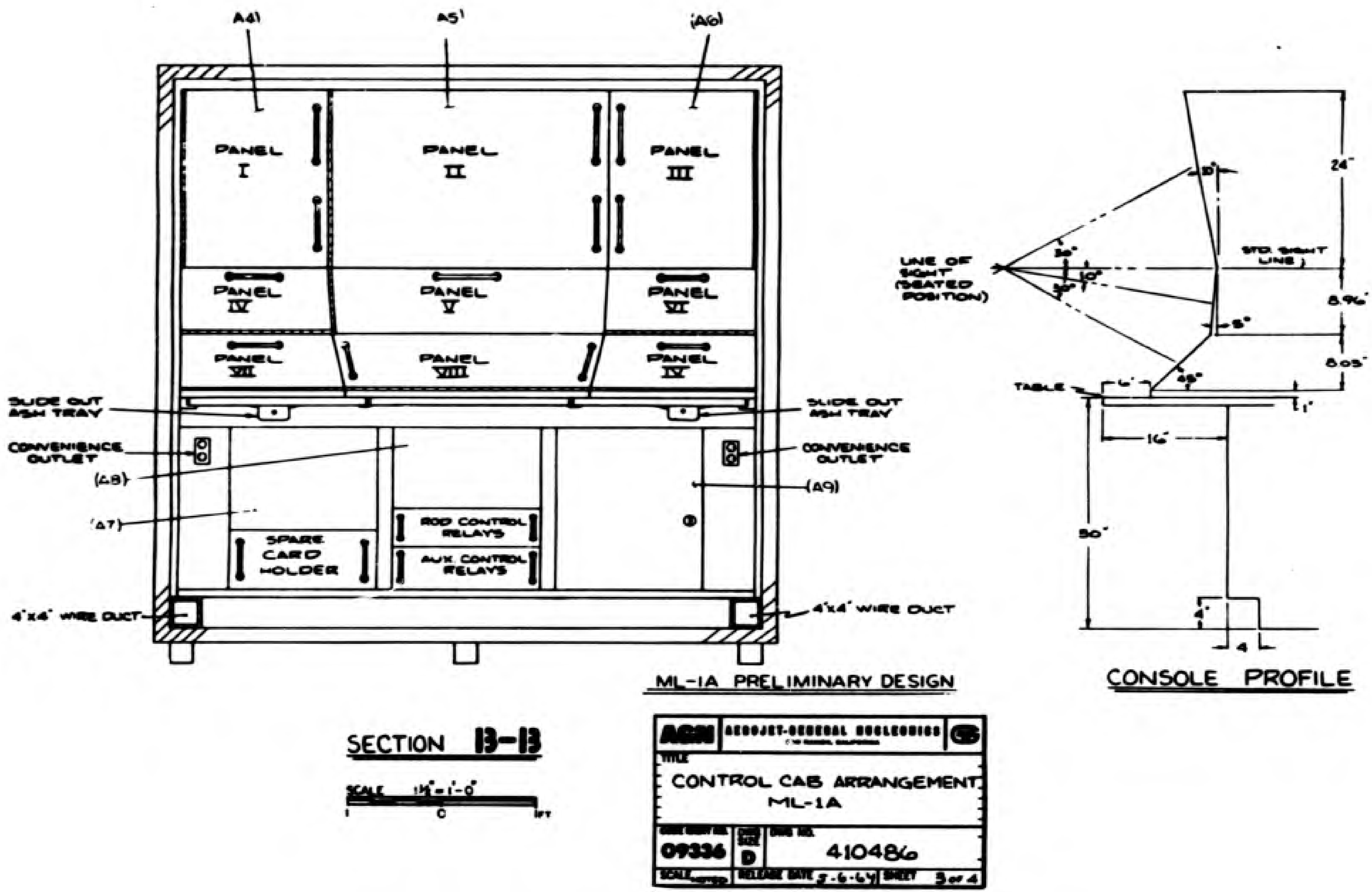

Fig. 19. FINAL CONTROL-CAB LAYOUT -- SECTION B-B AND CONSOLE PROFILE

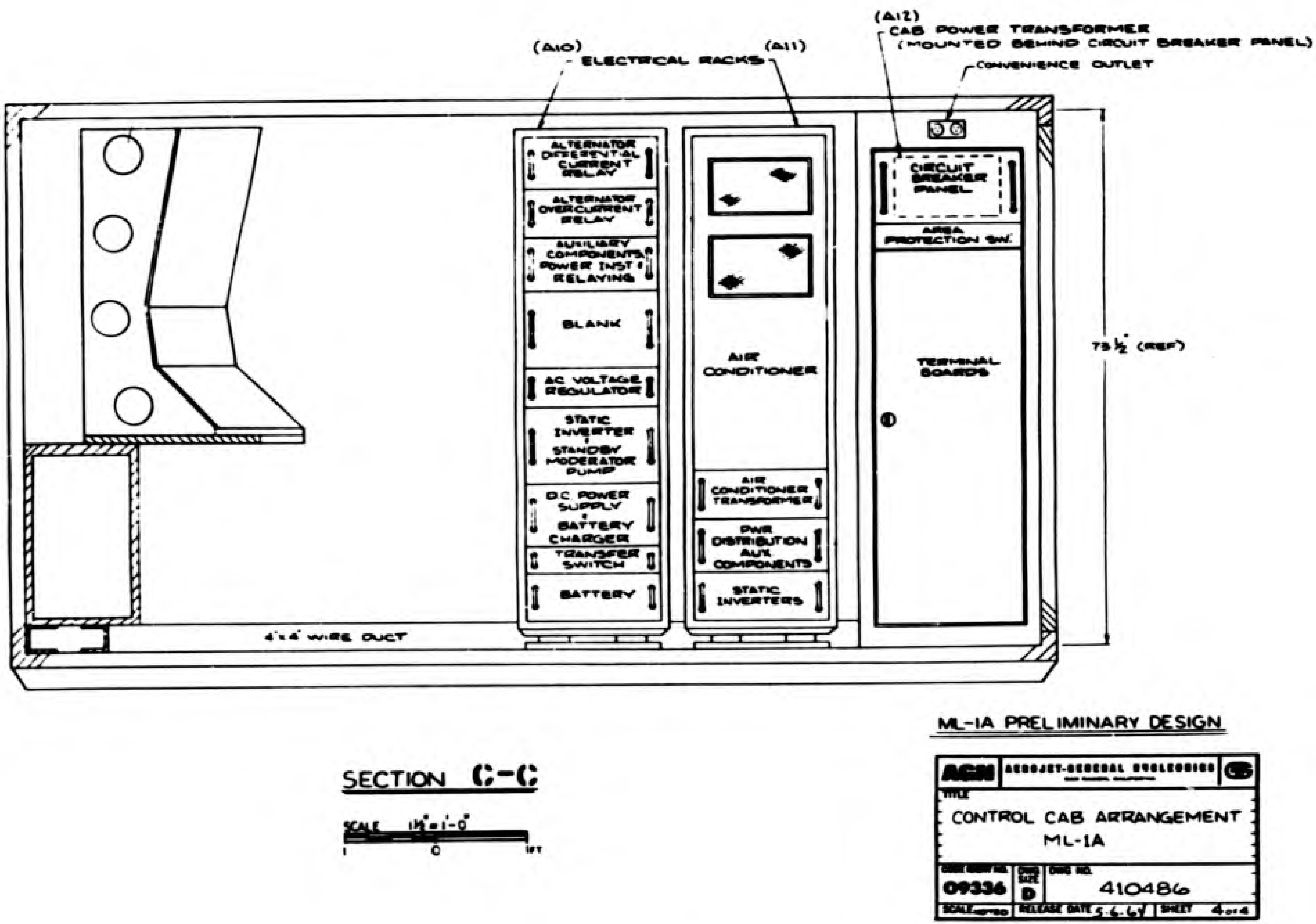

Fig. 20. FINAL CONTROL-CAB LAYOUT -- SECTION C-C

TABLE 5

Paint Colors for Van Interiors[a]

Application	HEL Technical Memoranda 8-62 and 8-63	AR 746-2300-1
Ceiling	27875 White	24533 Green
Walls	24664 Green	24533 Green
Mounted Equipment	24664 Green	24533 Green
Panels	26373 Gray	- -
Floor	26293 Gray	36118 Gray

[a] Color numbers refer to samples shown in Federal Standard 595.

TABLE 6

Recommended Paint Colors for ML-1A

Application	Color[a]
Ceiling	27875 White
Walls	24533 Green
Mounted Equipment	24533 Green
Panels	26373 Gray
Floor	26293 Gray

[a] Color numbers refer to samples shown in Federal Standard 595.

Paint Colors

The paint colors for the interior of the ML-1A shelter were originally discussed with AGN personnel in September 1963. At that time, HEL Technical Memorandum 8-62 (6), HEL Technical Memorandum 8-63 (9), and Army Regulation (AR) 746-2300-1 (3) were applicable. The AR does not specifically cover this type of equipment, i.e., nuclear power plant systems; but since the equipment described in paragraph 8k of this AR is similar to the ML-1A, it seems desirable to adopt the paint colors which are recommended there and which are available through established Government supply channels. Table 5 compares the requirements of these references.

As Table 5 indicates, the references disagree, mostly about the floor and ceiling. The green and gray paints in Reference 3 have low reflectances, which might make it difficult to light the shelter. The other colors do not differ greatly.

To account for various lighting factors, yet take advantage of paints that are available in the military supply, the paint colors shown in Table 6 were recommended for ML-1A (2, Vol. V).

Since the colors in Table 6 were chosen, Reference 4 has superseded Reference 3 and established the requirements shown in Table 7.

TABLE 7

Paint Colors Required by AR 746-5 (4)

Application	Color[a]
Ceiling	27875 White
Walls	24410 Green
Equipment Cabinets	24410 Green
Panels	26492 Gray
Floor	36118 Gray

[a] Color numbers refer to samples shown in Federal Standard 595.

Reference 4 is not specifically intended for this type of equipment (i.e., nuclear power plant systems). However, the paint colors in Table 7 seem quite close to those that were recommended. Since it is desirable to use paints available in the military supply, it is recommended that the final design of the ML-1A use the colors shown in Table 7.

Lighting

HEL Technical Memorandum 13-65 (5) gives a detailed analysis of lighting for the ML-1A shelter.

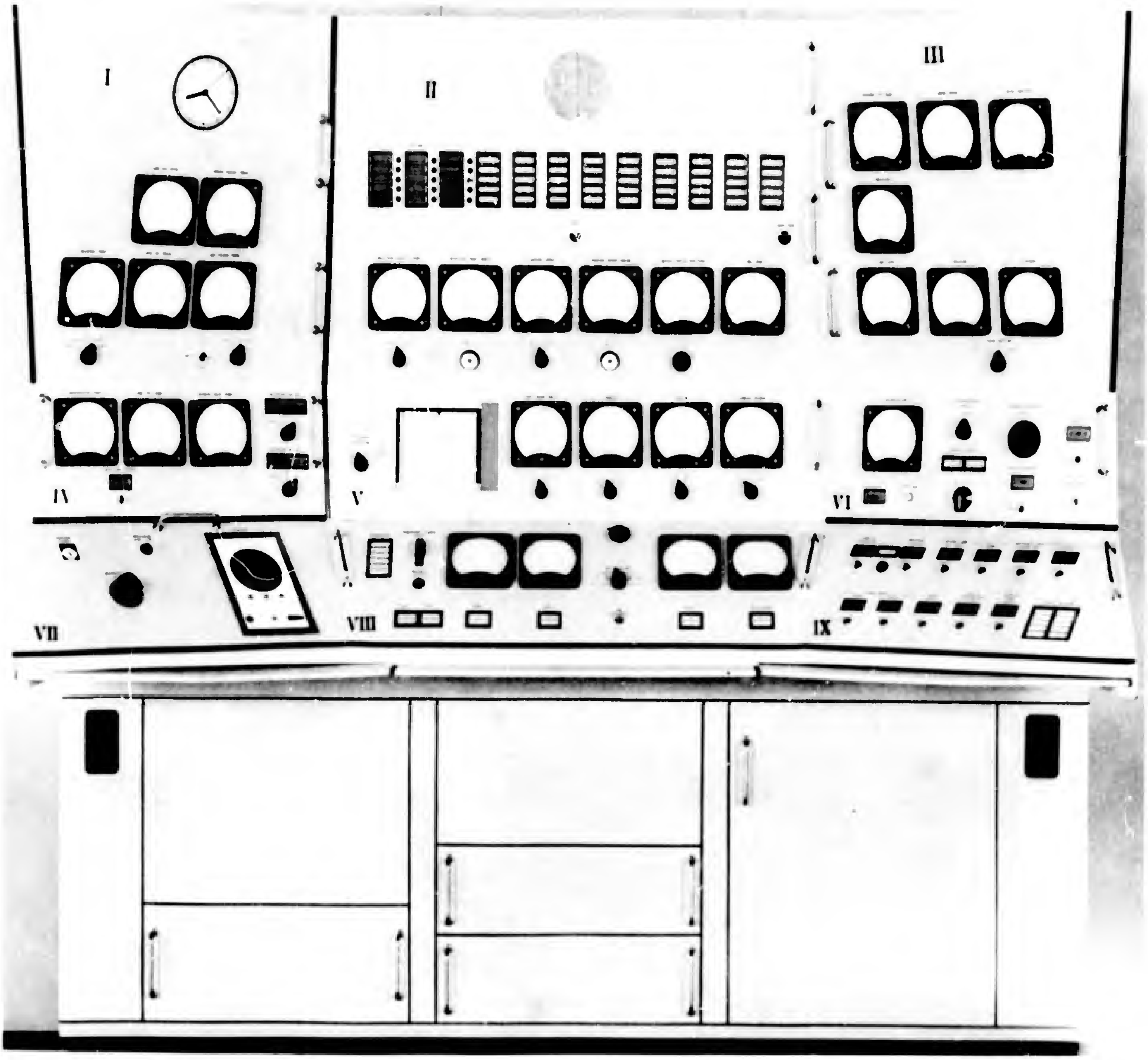

Fig. 21. FINAL ML-1A CONSOLE

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Console Layout -- General

To help the reader follow the discussion of the console layout, a photograph of the ML-1A console as finally laid out (Fig. 21) is provided on the fold-out page opposite.

The first consideration in determining how the console should be laid out was grouping the equipment functionally as follows:

a. Annunciator system

b. Nuclear instrumentation

c. Blade control system

d. Auxiliary electrical controls

e. Paralleling control system

f. Communication system

g. Electrical system

h. Primary process system

i. Secondary process system

j. Miscellaneous (clock, wind speed & direction, air temperature, interlocks, overhead light dimmer, etc.)

This grouping can be divided as follows into instrumentation of primary and secondary importance to the operator:

Primary Instrumentation

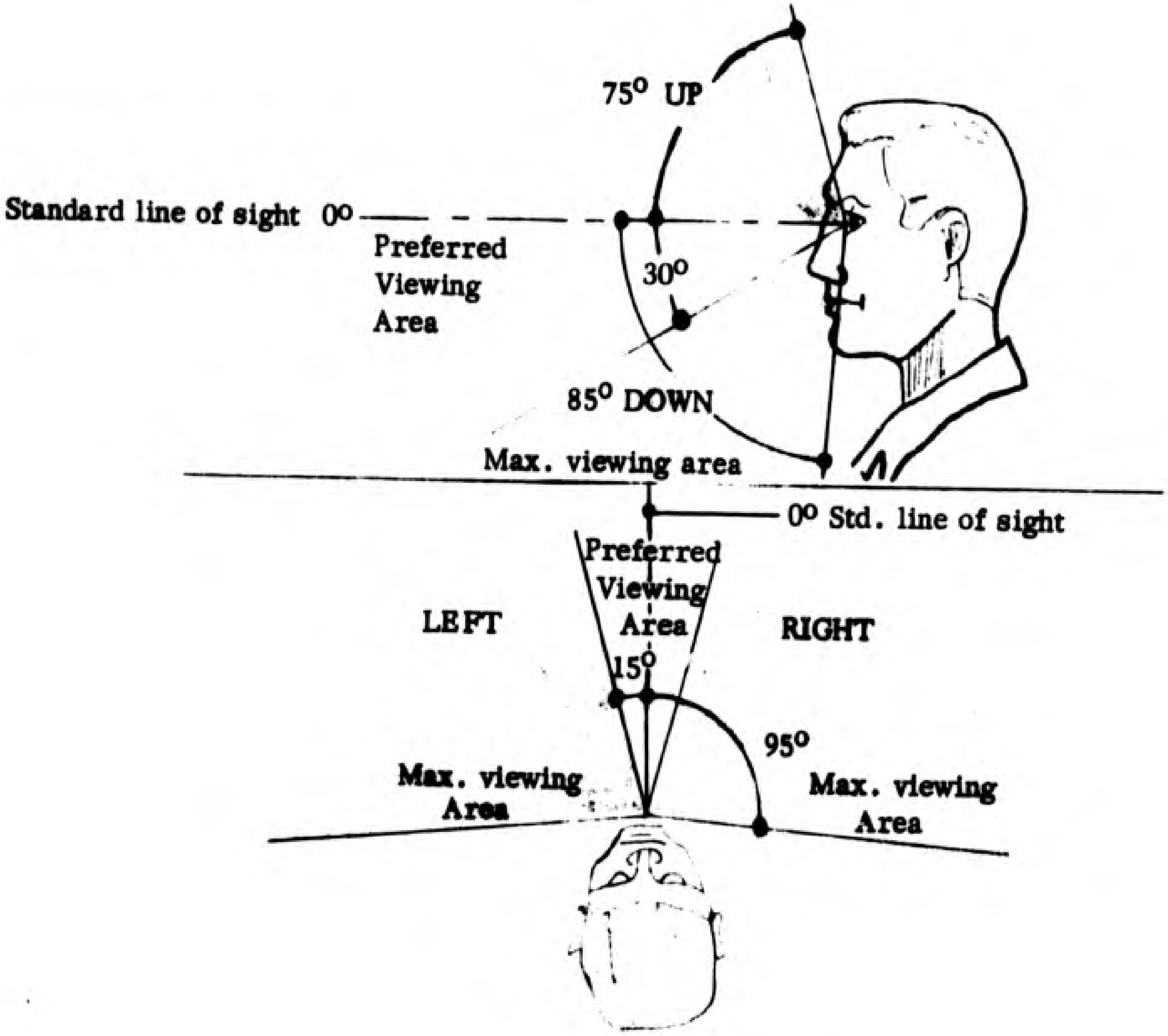
a. Annunciator system

b. Blade control system

c. Nuclear instrumentation

d. Primary electrical system

e. Primary process system



	Preferred[a]	Maximum[a] Eye Rotation Only	Maximum[a] Head and Eye Rotation
Up	0°	25°	75°
Down	30°	35°	85°
Left	15°	35°	95°
Right	15°	35°	95°

[a] Display area on the console defined by the angles measured from the standard line of sight.

Fig. 22. VIEWING AREA

Secondary Instrumentation

a. Secondary electrical system

b. Auxiliary electrical system

c. Paralleling control system

d. Secondary process system

e. Communication system

f. Miscellaneous

Primary instrumentation should be grouped in the center of the console where the operator can see the displays and operate the controls most readily. In the ML-1A, the center of the console includes panels II, V, and VIII (Fig. 19).

The recommended viewing areas shown in Figure 22 should be considered in designing the console. Primary instrumentation should be within the preferred viewing area, and all secondary instrumentation should be within the maximum viewing area. Since it was obvious that all of the primary instrumentation could not be fitted into the preferred viewing area, some compromises were made.

Since the standard 0-degree line of sight was to the center bottom of panel II, the primary instrumentation was extended vertically one-meter-row high on panel II (about 15 degrees above the standard line of sight) and to the bottom of panel VIII (about 40 degrees below the standard line of sight). Horizontally, the instrumentation extended to the edge of the center panel section (about 30 degrees from the standard line of sight).

Since the annunciator is purely a display and has no direct system controls, it was placed at the top of panel II. It extends beyond the limits of the primary instrumentation area, but this position is an acceptable compromise because operators do not look at the annunciator as often as the other primary instrumentation. The blade-control system does have direct system controls, so it was placed on panel VIII where the operator can reach it easily. Since the nuclear instrumentation gives the feedback of nuclear-power level that results from position of the control blades, this instrumentation was placed immediately above the blade-control system on panel V. Finally, in this closed-cycle system, the primary process and electrical output instrumentation are directly related. Since this instrumentation tells the operator the system output, it presents the information that the operator is ultimately most concerned about. Further, this instrumentation is related to the nuclear instrumentation since the nuclear power levels determine the final output, so the primary process and electrical output instrumentation were placed immediately above the nuclear instrumentation on panel II.

The secondary information was allocated to remaining console areas. The auxiliary electrical controls and the paralleling control system contain most of the system's direct controls. These were placed to the operator's right, since more than 90 percent of the population is right handed.

Since the auxiliary electrical controls will be used more often than the paralleling controls, these auxiliary electrical controls were placed on the lower right on panel IX where they are more accessible. The paralleling controls were placed immediately above the auxiliary electrical controls on panel VI. Parenthetically, the electrical-system instrumentation is both primary and secondary. During paralleling operations, the operator needs to refer to the electrical system and to some process instrumentation, so the secondary electrical system was placed immediately above the paralleling controls on panel III, at the same level as the primary process system and primary electrical system.

The secondary process system was placed on panels I and IV to relate it horizontally with the primary process system.

The remaining console space on panel VII was convenient for the intercom, which operators must use quite often.

Miscellaneous controls and instrumentation were located according to availability of space and their relation to other associated equipment; for example, the interlock indicators are related to the blade-control system, since all of the interlocks should be closed before any of the blades are withdrawn.

When the general areas of the console had been allocated functionally, the functional groupings themselves were laid out. The considerations following in order of priority governed the group layouts:

a. Sequence of use.

b. Operational relationships with equipment in other groups or in the same group.

c. Operational importance and (for controls) accessibility.

d. Non-interference in using instruments.

There was rarely any conflict among these four considerations in the actual laying out of any group. Occasionally a choice had to be made between operational relationships and operational importance, but in general one consideration would clearly dominate the others with regard to a given group. The priority above, therefore, reflects primarily the order in which the considerations were applied to each group.

The system may dictate a certain sequence of use for the instruments in a given group.

Related instruments should generally be located as nearly together as possible to reduce operator error. This principle was applied to laying out the functional groups. In some cases, however, the relationship of an instrument in one group to another in a different group took precedence in the layout, since such instruments might otherwise be widely separated.

Some read-outs and controls are more critical to the operation of the system than others, and this relative importance was taken into account in laying out the functional groups: the critical read-outs were displayed as conveniently to the operator as possible, and particular care was taken to make critical controls readily accessible to him.

Using any instrument should not obstruct another instrument that needs to be used at the same time, so instruments were located within the groups to avoid such interference.

Console Layout -- Primary Instrumentation

Annunciator

The system review conducted with AGN personnel indicated that the ML-1A would require about 60 annunciation channels, comprising 15 scrams and 45 alarms. Since equally critical channels should be grouped together so operators can determine an annunciation's importance quickly, the 15 scrams were grouped together and placed arbitrarily on the left. (The exact positioning of the individual annunciator channels was left to the final design, because the channel applications had not yet been completely determined.)

The scram reset buttons were placed to the right of their respective channels (according to the standard control-display orientation) so that right-handed operators can see the channel as they depress the button.

The final layout of the annunciator is shown in Appendix A, Figure 2A.

Blade-Control System

The blade-control system on panel VIII includes six pairs of indicators, four meters, and two switches:

a. SAFE 1 indicators

b. SAFE 2 indicators

c. SHIM 1 meter and indicators

d. SHIM 2 meter and indicators

e. SHIM 3 meter and indicators

f. REGULATING-BLADE meter and indicators

g. ROD SELECTOR switch

h. WITHDRAW-INSERT switch

The location of panel VIII within the overall console layout is shown in Figure 21.

The indicators and meters were positioned on the panel from left to right in order of use (the shim indicators and meters and the regulating blade indicators and meter were considered as single units for placement). SAFE 1 and SAFE 2 were placed to the far left of the panel, followed by SHIM 1, SHIM 2, SHIM 3, and REGULATING BLADE (indicators and meters). The limit indicators were placed below their corresponding meters so that all of the position information would be seen together. The ROD SELECTOR rotating switch and WITHDRAW-INSERT toggle switch were placed in the center to accommodate both right-handed and left-handed operators.

The final layout of the blade-control system on panel VIII is shown in Appendix A, Figure 8A.

Nuclear Instrumentation

The nuclear instrumentation on panel V includes a recorder, four meters, and five selector switches:

a. Single-channel pen recorder and selector switch.

b. LOG COUNT RATE meter and selector switch.

c. PERIOD meter and selector switch.

d. LOG N meter and selector switch.

e. LINEAR POWER meter and selector switch.

Figure 21 shows the location of panel V within the overall console layout.

The nuclear instrumentation was arranged on the panel from left to right, generally in order of use (with each instrument and its associated selector switch taken as a unit). The LOG COUNT RATE, LOG N, and LINEAR POWER meters were placed in that order according to sequence of use, but the PERIOD meter was placed between LOG COUNT RATE and LOG N since the period relates to either readout depending upon switch position.

The recorder should be placed in the position that relates it most centrally to its associated readouts, which include LOG COUNT RATE, LOG N, LINEAR POWER, and REACTOR OUTLET TEMPERATURE. As it will appear later, the REACTOR OUTLET TEMPERATURE meter was placed on the lower left corner of panel II, so the recorder was placed in the most central position available at the extreme left of panel V.

The final layout of the nuclear instrumentation on panel V is shown in Appendix A, Figure 5A.

Electrical and Primary Process Systems

The electrical and primary process systems were planned together since their functions are closely related. (The fact that the electrical system is considered as both primary and secondary instrumentation was also taken into account.)

The plant's mission is producing power, so the operator is vitally interested in obtaining electrical information. Two parameters of electric power are directly under his control -- frequency and voltage -- but he is also interested in the net kilowatt output: the load the plant is delivering. His "mission instrumentation" -- the primary electrical instrumentation -- therefore indicates net kilowatts as well as frequency and voltage.

Since the system is a closed cycle, some of this mission instrumentation is directly related to the primary process instrumentation. A properly designed panel should group all related instrumentation closely together so the operator can make comparisons at a glance without searching the panel.

The primary process system contributes five meters to panel II, and one meter (NET KW) is added from the electrical system (the remainder of which is on panel III):

a. REACTOR OUTLET TEMPERATURE meter

b. REACTOR TEMPERATURE ERROR meter

c. TURBINE SPEED meter

d. TURBINE SPEED ERROR meter

e. BYPASS VALVE POSITION meter

f. NET KW meter

Panel II also contains two switches and three potentiometers from the primary process system:

a. One two-position switch allows the operator to control the reactor outlet temperature by means of the regulating blade either manually or automatically.

b. Another two-position switch allows the operator to control the turbine speed by means of the turbine bypass valve either manually or automatically.

c. One potentiometer adjusts the bypass valve position when the valve is under manual control.

d. A ten-turn TEMPERATURE SET potentiometer sets the desired reactor temperature.

e. A ten-turn SPEED SET potentiometer sets the desired turbine speed.

The remainder of the primary electrical system instrumentation (in addition to NET KW) is found on panel III:

a. FREQUENCY meter

b. VOLTAGE meter

The location of panels II and III within the overall console layout is shown in Figure 21.

The net kilowatt output, a measure of the load being delivered, is closely related to the position of the bypass valve. If the operator wants to supply a greater load, the BYPASS VALVE POSITION meter will tell him if he can deliver it. For any given reactor-outlet temperature -- which the operator determines by the TEMPERATURE SET potentiometer -- the BYPASS VALVE POSITION meter could be calibrated in kilowatts, so that meter and the NET KW meter should be close together.

The frequency of the electrical output is determined by the turbine speed. The operator, therefore, controls the frequency by controlling the turbine speed. The TURBINE SPEED ERROR meter shows the difference between the actual turbine speed and the speed set on the SPEED SET potentiometer, so the SPEED SET, the TURBINE SPEED and TURBINE SPEED ERROR meters, and the FREQUENCY meter should be grouped together as closely as possible.

The TEMPERATURE SET potentiometer controls the reactor-outlet temperature, and the REACTOR TEMPERATURE ERROR meter gives the difference between the desired temperature and the actual temperature. The operator may conserve fuel by adjusting the reactor outlet temperature so that the bypass valve closes almost entirely. But he can set the valve this way only if no load change is expected -- an increase in load would require the valve to close even further. If it is already nearly closed, it would not be able to close further to meet the increased load demand. All this related instrumentation -- the TEMPERATURE SET and the REACTOR OUTLET TEMPERATURE, REACTOR TEMPERATURE ERROR and BYPASS VALVE POSITION meters -- should be placed together as closely as possible.

These considerations, involving both the primary process system and the electrical system, suggest four possible ways of grouping these instruments:

1. VOLTAGE, FREQUENCY, and NET KW.

2. NET KW and BYPASS VALVE POSITION.

3. FREQUENCY, TURBINE SPEED, and TURBINE SPEED ERROR.

4. BYPASS VALVE POSITION, REACTOR OUTLET TEMPERATURE, and REACTOR TEMPERATURE ERROR.

Unfortunately, these groupings are not all feasible, since some of the meters appear in more than one group. Some compromises had to be made.

The console-display design had to meet two basic requirements: (a) the instrumentation had to be arranged into functional groupings, and (b) related instruments in different functional groupings had to be located as near to each other as possible (6). We had to determine, therefore, which meters in the primary process system were most closely related to meters in the electrical system.

The instruments in the first group above -- VOLTAGE, FREQUENCY, and NET KW -- are all related functionally in the electrical system, so we were obliged to accept that group.

Of the remaining groups above, the fourth -- BYPASS VALVE POSITION, REACTOR OUTLET TEMPERATURE, and REACTOR TEMPERATURE ERROR -- seemed the least critical, since these instruments are used together only when no major load changes are expected.

Thus we chose between the second and third groups.

The rationale of the third group -- FREQUENCY, TURBINE SPEED, and TURBINE SPEED ERROR -- is that frequency is determined by turbine speed.

The rationale of the second group -- NET KW and BYPASS VALVE POSITION -- is that net kilowatts is a measure of the load being delivered, and the position of the bypass valve tells the operator if he can deliver more load without changing the reactor temperature. The maximum load that can be delivered depends primarily on ambient temperature, so the operator cannot easily tell if he can deliver a greater load just by looking at the NET KW meter alone; he must also refer to the BYPASS VALVE POSITION meter.

Thus, although frequency and turbine speed are related, the operator need not refer to the two meters simultaneously; both meters convey essentially the same information in different forms. The NET KW and BYPASS VALVE POSITION meters, however, do not convey the same information; the operator must consult both to see if he can deliver more load. These meters, therefore, were placed next to each other. The rest of the electrical system instrumentation was placed on panel III to the right of the NET KW meter, and the rest of the primary process instrumentation was placed on panel II to the left of the BYPASS VALVE POSITION meter.

The primary process instrumentation had already been allocated the area at the bottom of panel II, with the electrical instrumentation at the bottom of panel III. The area at the bottom of panel II can accommodate six meters, but the primary process instrumentation includes only five meters. This area, therefore, can accommodate all of the primary process instrumentation and one meter (NET KW) from the electrical system instrumentation.

The BYPASS VALVE POSITION meter and NET KW meter, side by side, were positioned first, with the NET KW meter at the extreme right of panel II. To complete the first group -- VOLTAGE, FREQUENCY and NET KW -- the VOLTAGE and FREQUENCY meters were located at the extreme left of panel III, next to the NET KW meter. The rest of the primary process instrumentation -- REACTOR OUTLET TEMPERATURE, REACTOR TEMPERATURE ERROR, TURBINE SPEED, and TURBINE SPEED ERROR -- remained to be placed within the panel II area. Obviously, the first two of these should be paired, as should the second two; but we still had to determine which pair should be next to the BYPASS VALVE POSITION meter.

The REACTOR OUTLET TEMPERATURE meter is related to the BYPASS VALVE POSITION and NET KW meters, but it also relates to the secondary process instrumentation, which had been allocated panels I and IV. The operator will have to consult the combination of REACTOR OUTLET TEMPERATURE, BYPASS VALVE POSITION, and NET KW only when considering load changes, but he will have to view the REACTOR OUTLET TEMPERATURE meter and the secondary process instrumentation whenever he wants to know the status of the reactor system, a more critical and more frequent concern. The REACTOR OUTLET TEMPERATURE meter, therefore, was located at the extreme left of panel II, with the REACTOR TEMPERATURE ERROR meter to its right. The TURBINE SPEED and TURBINE SPEED ERROR meters were placed in the remaining space to the right, with the TURBINE SPEED ERROR meter nearest the BYPASS VALVE POSITION meter.

We had now completed the preliminary layout of the primary process and primary electrical instrumentation (Fig. 23). The next step was laying out the rest of the secondary electrical instrumentation.

Console Layout -- Secondary Instrumentation

Secondary Electrical System

The secondary electrical system on panel III includes two meters and one three-position switch:

a. NET VARS meter

b. AMPERES meter

c. PHASE SELECTOR switch

Net volt-amperes reactive (vars) and amperes are termed "secondary" in the electrical system, since vars are of concern only in paralleling (to avoid circulating current) and amperes need only be monitored.

The electrical instrumentation had to be arranged to satisfy two requirements: (a) the mission instrumentation -- NET KW, FREQUENCY, and VOLTAGE meters -- had to be kept close together, and (b) the load instrumentation -- NET KW, NET VARS, VOLTAGE, and AMPERES meters -- also had to be kept close together.

The load on an electrical system is totally described by four parameters -- net kilowatts, net vars, volt-amperes, and power factor -- but any two of these parameters will give an adequate working description of the load. During the instrumentation review (2, vol. III), it had been concluded that the power factor need not appear on the console and that voltage and amperes would be presented by separate meters. Thus, for this system, load will be described by the NET KW and NET VARS meters.

Separating voltage and amperes led to a third requirement for arranging the electrical instrumentation -- the VOLTAGE and AMPERES meters had to be kept close together (where also a single PHASE SELECTOR switch centered below them would allow both to be monitored conveniently for each phase of the three-phase system).

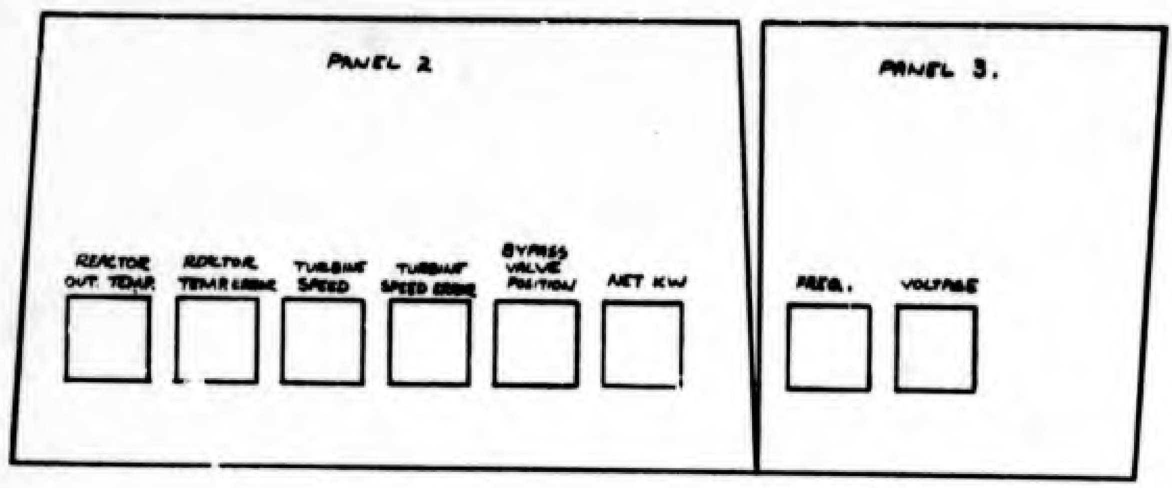


Fig. 23. PRELIMINARY PRIMARY ELECTRICAL AND PROCESS INSTRUMENTATION

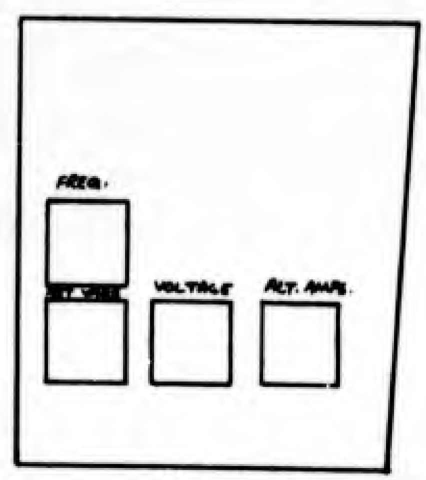


Fig. 24. FINAL ELECTRICAL INSTRUMENTATION

These three sets of requirements obviously could not all be satisfied completely, since they conflict with each other. Again, compromise was necessary.

Placing either the mission or the load instrumentation all together would separate the other. Putting the FREQUENCY and VOLTAGE meters together with NET KW to keep mission information intact would remove NET VARS at least two spaces from NET KW, since VOLTAGE and AMPERES had to be kept together. NET VARS could be placed next to NET KW without separating the mission instrumentation as widely. It was therefore placed there, at the extreme left of panel III, with FREQUENCY immediately above and VOLTAGE and AMPERES in order to the right. This arrangement seemed to most nearly satisfy all the requirements (Fig. 24).

The location of the FREQUENCY meter on panel III violates the earlier intention to keep all primary instrumentation within the preferred viewing area, but the compromise appeared reasonable since the operator can obtain frequency information (deviation from 60 cps) from the TURBINE SPEED meter or TURBINE SPEED ERROR meter, both within the preferred area. The location chosen on panel III keeps the FREQUENCY meter as near as possible to the TURBINE SPEED meter.

Auxiliary Electrical System

The instrumentation for the auxiliary electrical system on panel IX includes 12 controls and associated indicators as well as a group of ten circuit-breaker status indicators:

a. START UP COMPRESSOR switch and indicator

b. SEAL GAS AUTOTRIP RESET switch and indicator

c. EMERGENCY SEAL GAS switch and indicator

d. STANDBY LUBE OIL PUMP switch and indicator

e. MODERATOR WATER PUMP switch and indicator

f. MODERATOR WATER STANDBY PUMP switch and indicator

g. MODERATOR WATER HEATER switch and indicator

h. SHIELD WATER PUMP switch and indicator

i. SHIELD WATER HEATER switch and indicator

j. START MOTOR switch and indicator

k. LUBE OIL REFRIGERATION SYSTEM switch and indicator

l. LUBE OIL SUMP HEATER switch and indicator

m. Ten circuit-breaker status indicators

Figure 21 shows the overall layout of panel IX.

Panel IX will accommodate a row of controls and indicators at the top and another row at the bottom. Seven controls and indicators were placed in the top row and five in the bottom row. The ten circuit-breaker status indicators were also placed in the bottom row, grouped in two vertical columns of five.

The 12 controls might be grouped logically by function as follows: (a) shield-water controls (PUMP and HEATER), (b) moderator-water controls (PUMP, HEATER, and STANDBY PUMP), (c) seal-gas controls (START UP COMPRESSOR, SEAL GAS AUTOTRIP RESET, and EMERGENCY SEAL GAS), (d) lube-oil controls (SUMP HEATER, REFRIGERATION SYSTEM, and STANDBY PUMP), and (e) the starting motor (START MOTOR).

These controls may be actuated in several sequences, depending on the circumstances of a specific mission. However, the START UP COMPRESSOR, STANDBY LUBE OIL PUMP, and START MOTOR controls are interlocked to avoid damage and must be activated in that order. Several other controls should also be activated before the START MOTOR control, even though they are not interlocked, since all sub-systems must be operating before the plant is started: (a) EMERGENCY SEAL GAS, (b) MODERATOR WATER HEATER, (c) SHIELD WATER PUMP, (d) SHIELD WATER HEATER, (e) LUBE OIL SUMP HEATER, (f) LUBE OIL REFRIGERATION SYSTEM, and (g) MODERATOR WATER PUMP.

Two tasks must be performed during the pre-start phase: (a) the sequence above (START UP COMPRESSOR, STANDBY LUBE OIL PUMP, and START MOTOR) must be observed; (b) before the starting motor is activated, the emergency seal-gas device that prevents the mixing of the gas and lubricating oil when the system is idle must be shut off. The emergency-seal device cannot be switched off, however, until there is pressure in the system to maintain the seal. That pressure is obtained from the start-up compressor. These two tasks are therefore related in that both require the start-up compressor to be operating. The controls should accordingly be activated in the following order: START UP COMPRESSOR, SEAL GAS AUTOTRIP RESET (if it needs resetting), EMERGENCY SEAL GAS, and STANDBY LUBE OIL PUMP. The moderator-water, shield-water or lube-oil controls need not be taken in any particular order, so any of them might have been placed next. But since there were three more control spaces in the top row, the three-control moderator-water group was placed there: (a) MODERATOR WATER PUMP, (b) MODERATOR WATER STANDBY PUMP, and (c) MODERATOR WATER HEATER. The heater control might be placed first or last in this group, but the pump and standby-pump controls should be side by side.

The remaining five controls were placed in the second row. The sequence of the controls was arbitrary, except that the START MOTOR control was deliberately placed last: (a) SHIELD WATER PUMP, (b) SHIELD WATER HEATER, (c) LUBE OIL REFRIGERATION SYSTEM, (d) LUBE OIL SUMP HEATER, and (e) START MOTOR.

There was enough space left in the lower right-hand corner of the panel to accommodate the ten circuit-breaker status indicators. They were placed in this position, furthest from the operator, since they are principally monitoring devices.

Appendix A (Fig. 9A) shows the final layout of the auxiliary electrical system.

Paralleling-Control System

The following nine elements, all found on panel VI, will be called the paralleling-control system in this report:

a. SYNCHROSCOPE

b. DARK LAMP indicator

c. CIRCUIT BREAKER switch and indicator

d. POWER TRANSFER switch and two indicators

e. SYNCHRONIZING SWITCH

f. A-B-C PHASE SEQUENCE indicator

g. EXCITER switch and indicator

h. VOLTAGE REGULATOR ADJUST potentiometer

i. PARALLEL OPERATION switch

Figure 21 shows the overall layout of the paralleling-control system.

In paralleling the system, the operator will operate the CIRCUIT BREAKER switch while watching the SYNCHROSCOPE. Since most operators are right-handed, the CIRCUIT BREAKER switch was placed to the right of the SYNCHROSCOPE so the operator's hand would not obscure it, just as the entire panel was placed to the right of the console so the operator could view the remainder of the console while paralleling.

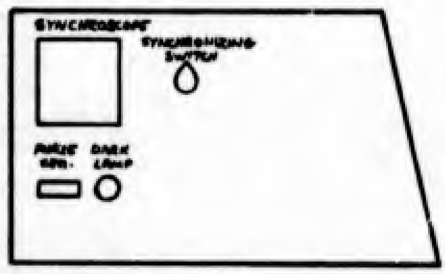


Fig. 25. PARTIAL PARALLELING CONTROL SYSTEM #1

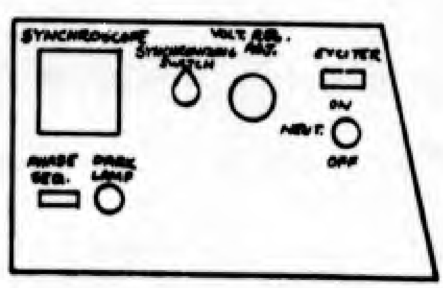


Fig. 26. PARTIAL PARALLELING CONTROL SYSTEM #2

To transfer the plant load from the auxiliary power unit to the plant generator, the operator must again consult the SYNCHROSCOPE while using the POWER TRANSFER switch, so this switch was also placed to the right of the SYNCHROSCOPE.

Since the SYNCHROSCOPE and the DARK LAMP are used together in both paralleling and power transfer operations, the lamp was placed immediately below the SYNCHROSCOPE.

Now the CIRCUIT BREAKER switch and the POWER TRANSFER switch had been placed to the right of the SYNCHROSCOPE, but the SYNCHROSCOPE itself had not yet been positioned on the panel. Since the SYNCHROSCOPE has a normal meter readout, it should be as nearly perpendicular as possible to the operator's line of sight to avoid parallax. On this panel, that position is at the extreme left, so the SYNCHROSCOPE was placed there.

The SYNCHRONIZING SWITCH is used to monitor the output of the auxiliary power unit, the plant itself or the incoming line. The parameters monitored are frequency, voltage, amperes, phase sequence, and synchronization with plant, so the switch should be located centrally among these components. Since the SYNCHRONIZING SWITCH is used with the SYNCHROSCOPE and DARK LAMP, as well as with the FREQUENCY, VOLTAGE, and AMPERES meters on the panel above, the switch was located on the upper part of panel VI, to the right of the SYNCHROSCOPE. The phase-sequence indicator, which is controlled by the SYNCHRONIZING SWITCH and which must be consulted before paralleling, was placed immediately below the SYNCHROSCOPE, just to the left of the DARK LAMP. At this point, the panel appeared as shown in Figure 25.

Next to be located were the EXCITER switch and indicator and the VOLTAGE REGULATOR ADJUST. The exciter must be activated to develop the plant voltage. The operator controls the voltage level by setting the VOLTAGE REGULATOR ADJUST; the plant voltage is then regulated by the voltage regulator. Since the voltage is displayed on panel III above, the VOLTAGE REGULATOR ADJUST was placed on the upper part of panel VI. The EXCITER switch and indicator were also placed on the upper part of the panel, next to the VOLTAGE REGULATOR ADJUST, because the exciter is involved in producing plant voltage. Figure 26 shows the panel with the addition of these two controls.

The POWER TRANSFER switch and CIRCUIT BREAKER switch will both be used in conjunction with the SYNCHROSCOPE, so they were placed as close to it as possible. In the operating sequence, the POWER TRANSFER switch will be used first, so it was placed closest (Fig. 27). (When paralleling, the operator will be adjusting the SPEED SET control to synchronize the frequency of his plant with the frequency of either the auxiliary power unit or incoming line with which he intends to parallel. His left hand, therefore, will be on the SPEED SET, his right hand on either the POWER TRANSFER switch or the CIRCUIT BREAKER switch. This was another reason for keeping the SPEED SET as far to the right on panel II as possible -- to reduce the reach demanded of the operator.)

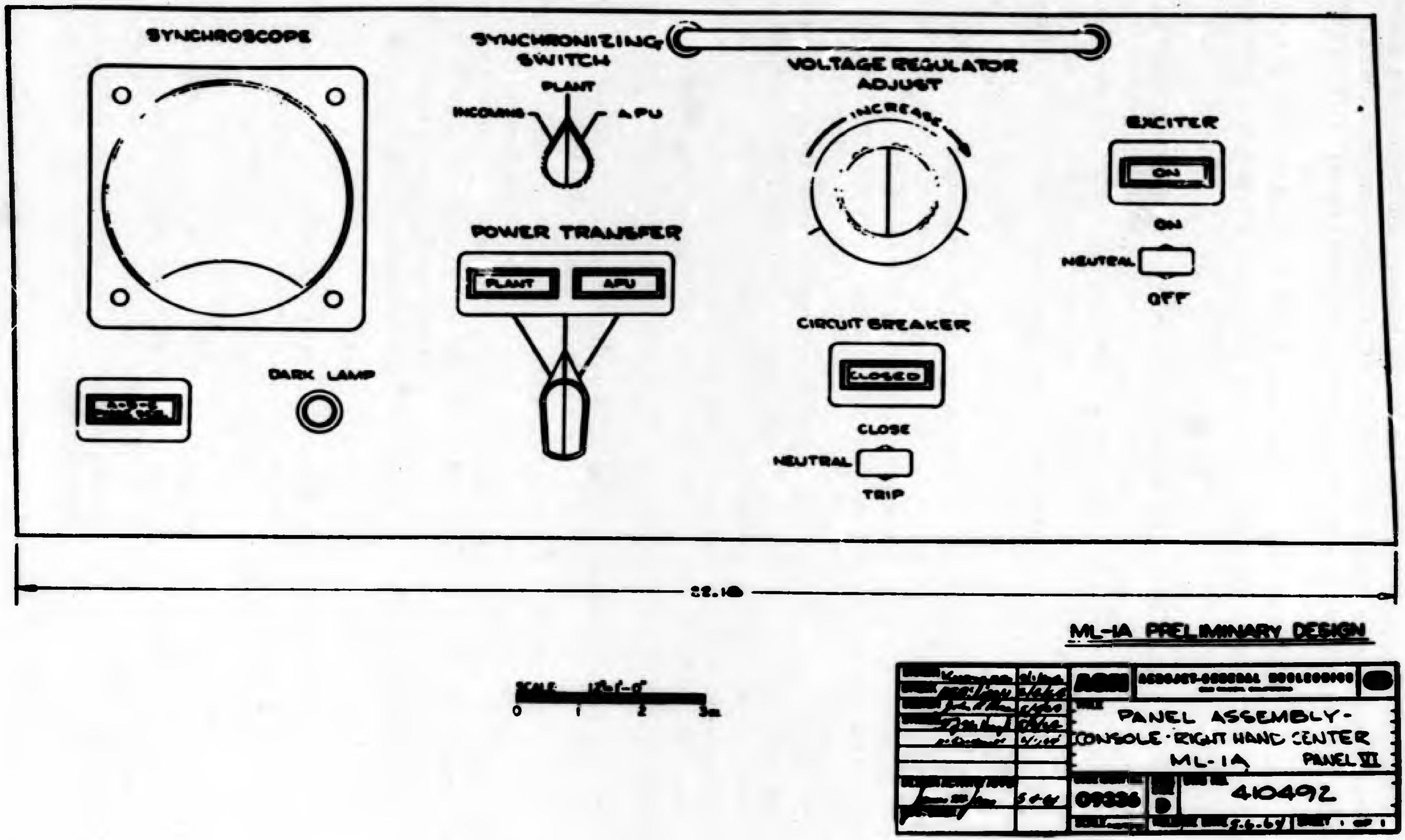


Fig. 27. PARTIAL PARALLELING CONTROL SYSTEM #3

The PARALLEL OPERATION switch actuates circuitry that controls the electrical load assumed by the plant. When the operator throws this switch in paralleling, just after throwing the CIRCUIT BREAKER switch, there is little or no load on the turbine and the turbine speed is synchronous. When stopping paralleling, the operator throws the PARALLEL OPERATION switch after reducing the load on the turbine (the speed, of course, will still be synchronous). In either event, throwing the PARALLEL OPERATION switch causes only negligible changes in the other plant parameters. Since no controls or readouts need be monitored at the moment this switch is thrown, it was placed in the lower right-hand corner of the panel.

The final layout of the paralleling system on panel VI is shown in Appendix A, Figure 6A.

Secondary Process System

The secondary process system on panels I and IV includes eight meters, six switches, and five indicators:

a. LUBE OIL LEVEL meter

b. COMPRESSOR OUTLET PRESSURE meter

c. BEARING TEMPERATURE meter and switch

d. LUBE OIL PRESSURE meter

e. REFERENCE/COMPRESSOR PRESSURE meter and two switches

f. MODERATOR TEMPERATURE meter

g. LUBE OIL TEMPERATURE meter

h. MODERATOR/LUBE COOLER switch and indicator

i. PRECOOLER FAN NO. 1 switch and two indicators

j. PRECOOLER FAN NO. 2 switch and two indicators

Figure 21 shows the final layout of panels I and IV.

The instruments in the secondary process system may be divided into four groups according to the part of the system they refer to: (a) compressor instrumentation (COMPRESSOR INLET TEMPERATURE, REFERENCE/COMPRESSOR PRESSURE and COMPRESSOR OUTLET PRESSURE), (b) lube-oil instrumentation (LUBE OIL TEMPERATURE, LUBE OIL PRESSURE and LUBE OIL LEVEL), (c) moderator instrumentation (MODERATOR TEMPERATURE), and (d) bearing instrumentation (BEARING TEMPERATURE).

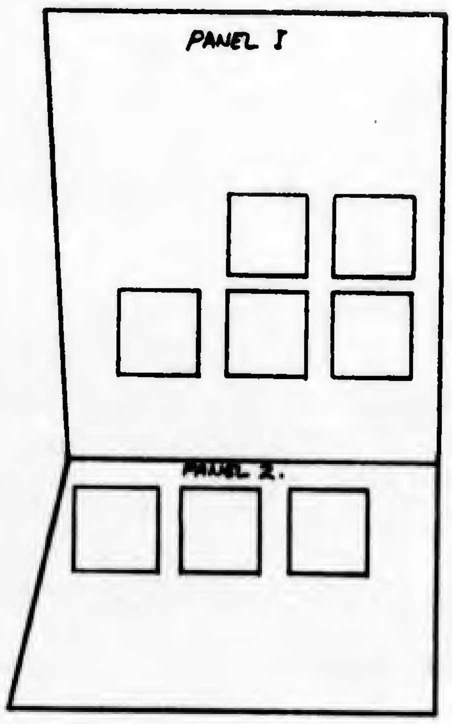


Fig. 28. SPATIAL LAYOUT OF SECONDARY PROCESS INSTRUMENTATION

Or the same instruments may be grouped according to the sort of function they refer to: (a) pressures (REFERENCE/COMPRESSOR PRESSURE, COMPRESSOR OUTLET PRESSURE, and LUBE OIL PRESSURE), (b) temperatures (COMPRESSOR INLET TEMPERATURE, LUBE OIL TEMPERATURE, MODERATOR TEMPERATURE, and BEARING TEMPERATURE), and (c) level (LUBE OIL LEVEL).

The panel space available permitted no more than three meters in any one row. One row of three can be placed on panel IV; three more can go along the bottom of panel I and two at the top, to make up the total of eight (Fig. 28).

The compressor instrumentation should be arranged so the operator can view all of it at once. The temperature and pressure meters should also be arranged for viewing at a single glance.

A further complication in laying out these panels is that five of the eight meters involved are associated with controls:

a. The REFERENCE/COMPRESSOR PRESSURE meter has a fill-vent switch which adjusts the compressor inlet pressure and a two-position meter switch to monitor either reference pressure or compressor inlet pressure.

b. The COMPRESSOR INLET TEMPERATURE meter is associated with the two precooler fans (each with a three-position switch and two indicators) because the fans control the temperature.

c. The MODERATOR TEMPERATURE and LUBE OIL TEMPERATURE meters are associated with the MODERATOR/LUBE OIL COOLER switch (which has an "on" indicator) because both temperatures are controlled by the moderator/lube oil cooler systems.

d. The BEARING TEMPERATURE meter has a four-position switch.

The operator should be able to reach these controls from his seat, so no meter-control combination should be placed in the top row of panel I, which is beyond normal reach. The three most critical or most frequently used meter-control combinations should be located on panel IV, since it is most readily accessible to the operator. The remaining combinations should be placed in the bottom row on panel I.

The layout for these panels that most nearly satisfies all these conditions is the most desirable.

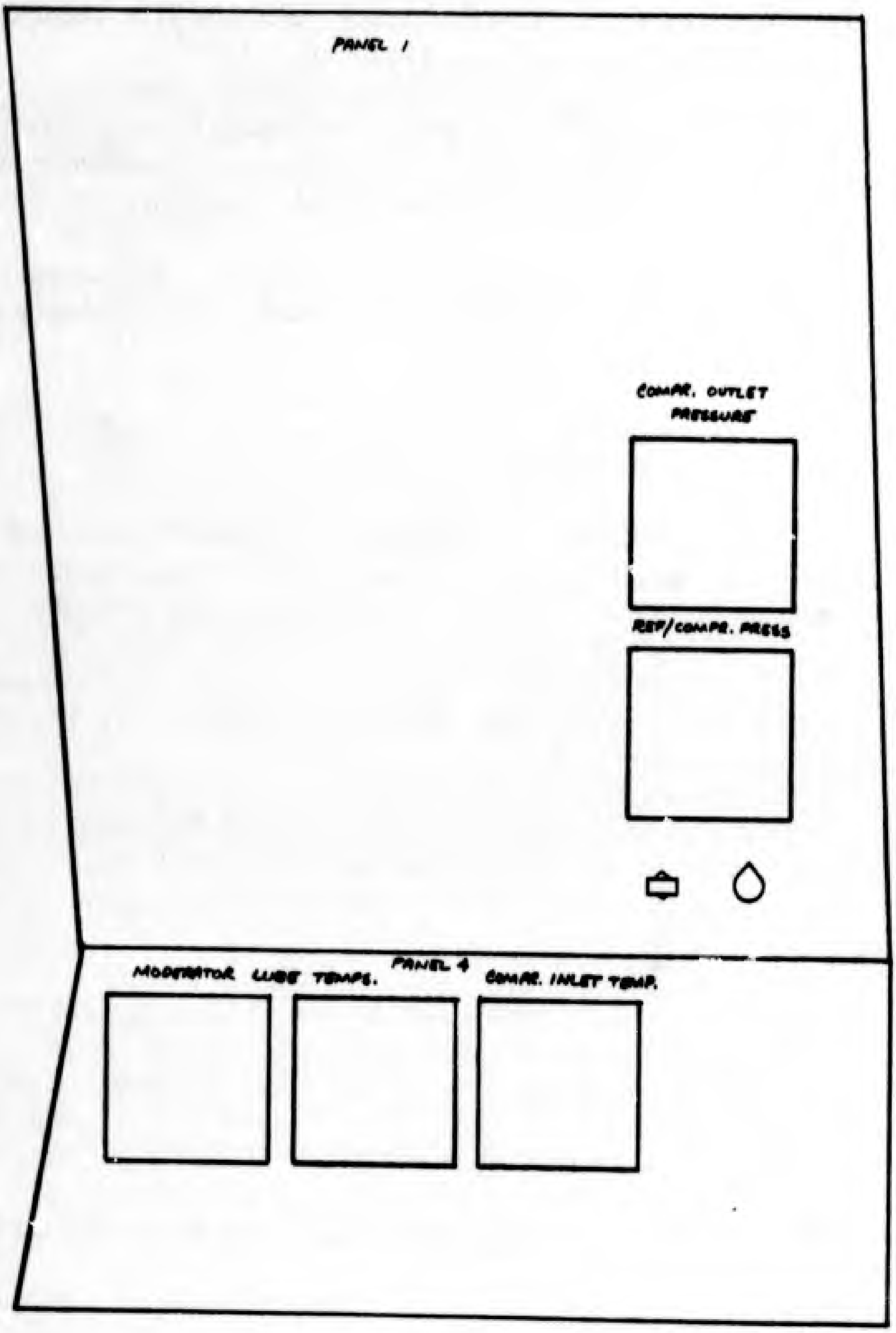


Fig. 29. PARTIAL SECONDARY PROCESS INSTRUMENTATION

Among these eight meters, the one most closely related to the REACTOR OUTLET TEMPERATURE meter is the REFERENCE/COMPRESSOR PRESSURE meter. The operator would probably refer to this meter first if there were any uncertainty in the primary process information. It should therefore be placed near the REACTOR OUTLET TEMPERATURE meter, at the right of the bottom row on panel I.

Since the MODERATOR TEMPERATURE and LUBE OIL TEMPERATURE meters are controlled by the same switch, they should be side by side. There is adequate space for them in the bottom row on panel I, but, since these meters are completely unrelated to the REFERENCE/COMPRESSOR PRESSURE meter already located there, they were placed on panel IV.

The one space remaining on panel IV should be devoted to another meter-control combination, either the COMPRESSOR INLET TEMPERATURE meter and the precooler fan switches and indicators, or the BEARING TEMPERATURE meter and switch. The precooler fans may have to be switched from time to time during the day to adjust the compressor inlet temperature as the ambient temperature changes; the BEARING TEMPERATURE meter is switched only to monitor the various bearings. Thus, the COMPRESSOR INLET TEMPERATURE meter with the precooler fan switches and indicators was given the more convenient location on panel IV. The BEARING TEMPERATURE meter and switch were placed on the bottom row on panel I.

The MODERATOR/LUBE COOLER switch is activated only once, but the precooler fans may be adjusted several times a day, so the compressor inlet-precooler fan combination was placed closer to the operator at the right of panel IV. This position is doubly appropriate, since it places the COMPRESSOR INLET TEMPERATURE meter directly below the REFERENCE/COMPRESSOR PRESSURE meter. Moreover, the compressor grouping was readily completed vertically by locating the COMPRESSOR OUTLET TEMPERATURE meter, which has no associated control, in the top row of panel I directly above the REFERENCE/COMPRESSOR PRESSURE meter (Fig. 29).

Of the three meters still to be located, the one associated with a switch -- BEARING TEMPERATURE -- had to be placed on the bottom row of panel I where the operator could reach it. The LUBE OIL PRESSURE and LUBE OIL LEVEL meters remained, and they could be merged into a lube-oil group by placing them on panel I in line vertically above the LUBE OIL TEMPERATURE meter on panel IV. Of the two, the LUBE OIL PRESSURE meter is probably more important to the operator; in fact, it is probably more important to him than the BEARING TEMPERATURE meter. Therefore, it was given the more viewable of the positions not yet assigned -- the middle of the bottom row on panel I -- with the LUBE OIL LEVEL meter directly above in the top row.

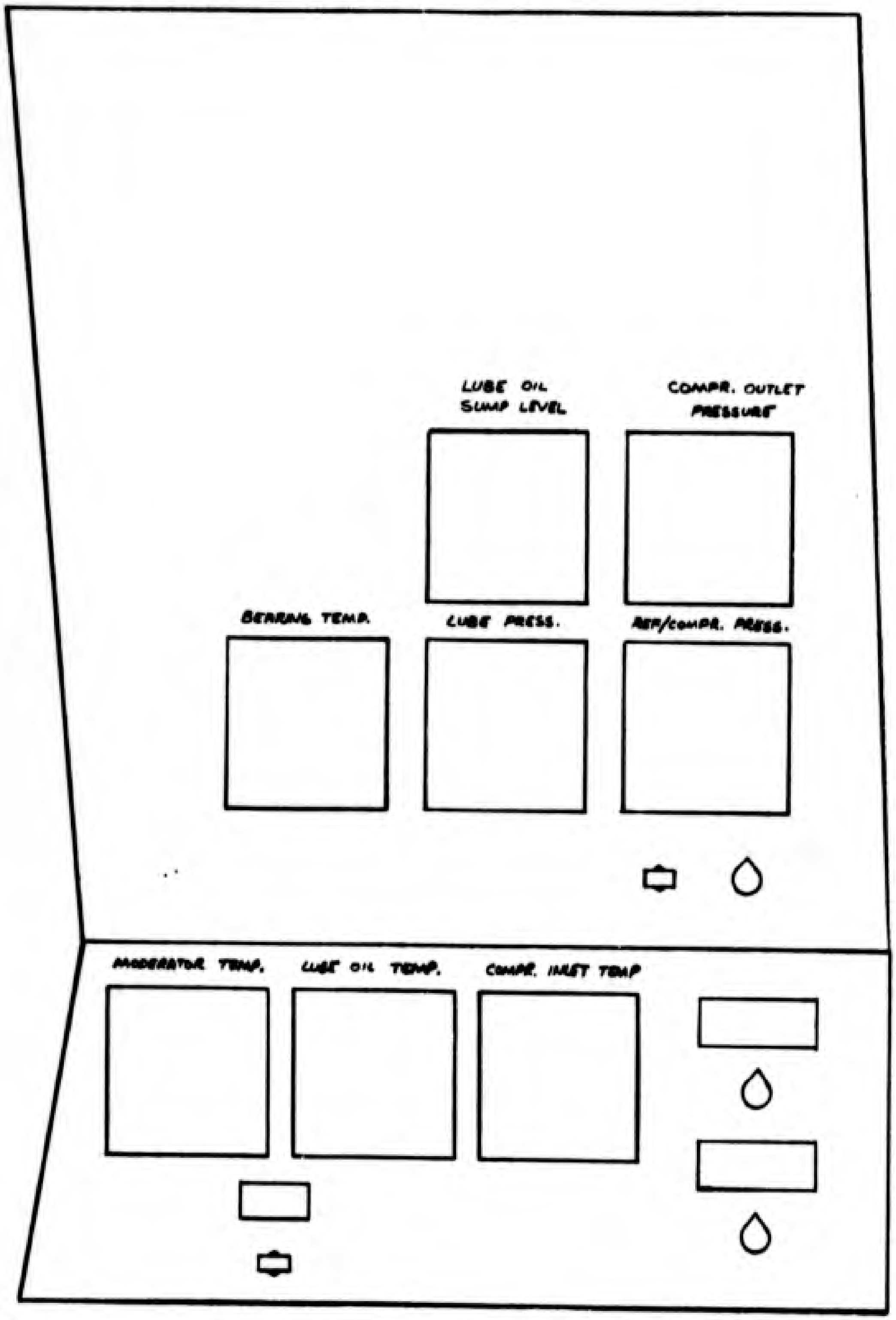


Fig. 30. FINAL SECONDARY PROCESS INSTRUMENTATION

The final layout of the secondary process system (Fig. 30) came close to satisfying the requirements established for it. The compressor and lube-oil groups were arranged vertically. Three of the four temperature meters were grouped horizontally on panel IV, with the one remaining just above on panel I. Two of the pressure meters were side by side on the bottom row of panel I, with the other one just above on the top row. Finally, all of the meters associated with controls were located on panel IV or on the bottom row of panel I, where the seated operator could reach them conveniently.

Communication System

Since the operator uses the communication system continually, it was placed near him on panel VII (Fig. 21).

Miscellaneous Meters and Controls

The miscellaneous meters and controls were located in available space according to their relationships to meters and controls already placed. The miscellaneous category includes the following components:

a. MANUAL SCRAM button

b. ACKNOWLEDGE button

c. Annunciator LAMP TEST button

d. CONSOLE LAMP TEST button

e. Annunciator alarm speaker

f. INTERLOCKS indicators

g. EMERGENCY CLUTCH POWER switch

h. ENERGIZE CLUTCHES switch

i. AMBIENT AIR TEMPERATURE meter

j. WIND SPEED meter

k. WIND DIRECTION meter

l. CONTROL POWER switch

m. OVERHEAD LAMPS potentiometer

n. Clock

The MANUAL SCRAM button should be readily accessible to the operator. In the ML-1 system, this button is in the top center of the lower center panel (equivalent to panel VIII in the ML-1A layout here). HEL has recommended placing this control immediately below the scram section of the annunciator on panel II (6, p 43).

In considering the location of the scram button, it must be remembered that the ML-1 was primarily a research plant, while the ML-1A may become a field plant. Safety is equally important in operating either type of plant, but the two types differ in mission. The mission of a research plant is to produce information; the mission of a field plant is to produce power for a military purpose. Scramming a research plant simply delays its mission; the information will still be obtained. Scramming a field plant deprives some military purpose of the power it requires. In a research plant, therefore, the design and operating procedures can be focussed largely on safety, but a field plant must be designed and operated not only to be safe but also to complete its mission. In a research plant, then, the scram button should be located where it can always be readily pressed when it should be. In a field plant, it should be located where it can be pressed when safety requires it but where hasty or accidental depression cannot interfere with the plant's mission of producing power.

The operator must press the manual-scram button quickly if the automatic circuitry fails to sense a genuine malfunction of the system. But he should press the button only when there is an actual malfunction, not when the instrumentation presents incorrect information or is incorrectly interpreted.

It will take the operator half a second longer to reach the manual-scram button located on panel II, as recommended by HEL, than it would to reach it on panel VIII, where it was located on the ML-1. This delay could result in serious damage to the reactor if the automatic circuitry does not detect certain malfunctions. On the other hand, in a field system, all scram functions should be well defined and provided with adequate automatic back-ups. The manual scram should serve only as a last-ditch emergency control.

Furthermore, putting the manual scram on the more distant panel should help prevent false scrams, because the operator will have to lean forward and rise slightly to reach the button. Since it involves more of his body muscles, this movement may prevent him from reacting too quickly to an incorrect or incorrectly interpreted indication.

Finally, locating the manual-scram button under the annunciator on panel II decreases the possibility of accidental activation. On panel VIII, the ML-1 location, the log book could depress it accidentally.

In discussions with AEC and AGN personnel, it was agreed that some of these considerations might apply to a field plant, but it was also agreed that the ML-1A is not yet a field plant. Since it will function initially as a research plant, we selected the location on panel VIII, which gives the faster reaction time. It was agreed to reconsider the location of the button if the ML-1A becomes a field system.

The ACKNOWLEDGE button is associated with the annunciator, which includes indicators and an alarm. When the alarm sounds and one of the indicators begins blinking, the operator presses the ACKNOWLEDGE button and the blinking indicator light turns to a steady light. Since some of the annunciator lights may already be shining steadily, the operator must look at the panel before pressing the button, so he will know which part of the system is responsible for the malfunction he is acknowledging.

With the ACKNOWLEDGE button located immediately below the annunciator, the operator can hardly avoid looking at the panel when he presses the button. Moreover, the ACKNOWLEDGE button should be readily accessible, and in this location the operator can reach it without rising from his chair.

Two lamp-test circuits were chosen for this console to separate the annunciator-lamp test from the console-lamp test. It is desirable to test the entire alarm circuitry, including the audible alarm, when the annunciator lamps are tested; but it is not necessary to sound the audible alarm each time the regular console lamps are tested.

Since the ANNUNCIATOR LAMP TEST button applies to the annunciator only, it was located in the immediate area of, though still slightly apart from, the annunciator. The CONSOLE LAMP TEST button was placed on panel VII, where there was ample room for it. Testing the console lamps would be one of the first steps during prestart, and this location preserves the generally left-to-right feature of the console.

The annunciator alarm speaker was mounted directly above the annunciator.

The interlock indicators and the controls for applying emergency clutch power and energizing the clutches are all associated with the blade-control system. The blades will not operate until the interlocks are all "made" up, so the operator must check the indicators first: when they are all green, he can energize the clutches and activate the blades. These indicators should be immediately adjacent to the control that energizes the clutches. Since the EMERGENCY CLUTCH POWER control also energizes the clutches, it was placed next to the ENERGIZE CLUTCHES control. To prevent accidental operation, however, the two controls were sharply distinguished by making the energizing control a button and the emergency control a toggle switch. Since the latter control is for emergency use only, the toggle switch was covered, and it should be lock-wired in place.

The AMBIENT AIR TEMPERATURE, WIND SPEED, and WIND DIRECTION meters have been discussed in previous HEL reports (6, 8), and a letter from AEC to AGN, dated 6 April 1964, directed that these indicators must be installed in the ML-1A cab.

There was no room for these meters in the racks, so they were located on the console; but since they are only occasionally monitored, they were not given prime console space. They were placed at the top of panel III, although they might just as well have been placed at the top of panel I.

The control-power switch turns on the power to the console. A lock-switch must be used to prevent unauthorized operation, and the key must remain in the switch while the console power is on. To prevent an oversize key ring or tag from obscuring a meter or interfering with a control, this switch must be kept clear of the rest of the console. Furthermore, since it will be activated before any other control, it should be placed to the extreme left of the console. A location on panel VII satisfied both these requirements.

The OVERHEAD LAMPS control that adjusts the brightness of the overhead lamps should be easily accessible, yet, since it is a secondary control, well out of the way. It was also placed on panel VII.

The clock, another secondary element, was placed in a convenient space on the top of panel I.

The final panel-by-panel layouts of the ML-1A console, as concurred in by AGN, AEC, and HEL, will be found in Appendix A. Interior photographs of the ML-1A control cab and console mock-ups will be found in Appendix B.

CONTROL-CAB SUBSYSTEM DESIGN

During the overall layout of the control cab, it became apparent that human engineering factors were critical for several subsystems and that these areas must be analyzed completely before the subsystems could be designed in detail.

Annunciator Design

The annunciator is a critical information-transfer system, hence an effective annunciator design must consider the man-machine relationships. These relationships vary from system to system, so no single annunciator design can serve all systems. The ML-1A annunciator design had to devote particular attention to three of these relationships.

First, the operator must know when there is a fault within the system. To be sure he cannot ignore them, faults should be signalled both visually and audibly by blinking lights and an alarm.

Next, the fault indicators should blink and the alarm should sound until the operator acknowledges them. In some systems, fault indicators operate for only a certain number of seconds, or they stop operating when the fault clears. Neither feature is desirable in the ML-1A. If a fault indicator stops blinking automatically before the operator can pinpoint it on the annunciator, he has no way of knowing where the fault occurred, unless he can remember the previous status of the panel. Furthermore, even if a fault clears spontaneously, the operator should still know where it occurred; if such a fault occurs repeatedly, it may indicate a potential breakdown in that part of the system. Also, if any indicator signals a fault erroneously, the operator should know which one it is so he can check it. Requiring the operator to positively acknowledge all indications on the annunciator will keep him fully informed on all sources of actual or potential trouble.

Finally, we also had to decide whether a system as relatively small and compact as the ML-1A needs an annunciator "ring back" -- a positive indication to the operator that a fault has been cleared. The power equipment and reactor are only 500 feet from the control cab, and maintenance can hardly be performed without the operator's knowledge. It was concluded, therefore, that no positive "ring back" is required.

All three of these considerations were incorporated into the ML-1A annunciator design.

If a fault occurs, a light will blink and an alarm will sound until the operator acknowledges the fault. When he does acknowledge, the light will change from blinking to a steady glow, and the alarm will stop sounding. If a second fault occurs before the operator acknowledges the first, a second light will begin blinking while the same audible alarm continues unchanged. When the ACKNOWLEDGE button is pressed, both lights will change to steady state. If a further fault occurs after the operator's acknowledgment, a blinking light and the alarm will begin an entirely new cycle as though there had been no previous fault.

If a fault clears before the operator acknowledges, the light will blink and the alarm will sound until he does acknowledge.

When a fault clears after the operator has acknowledged, the steady light will go out altogether with no positive "ring back."

Communications System

The document pertinent to the ML-1A communications system gives the requirements for the system:

> Housed Equipment The control shelter shall house the following equipment:
>
> (e) An intercommunication system to provide a communication link between the power plant, control shelter and a minimum of five substations during periods of plant maintenance (1, para 3.3.3.2.1).

A complete analysis of the ML-1A communications system requires consideration of all the possible communication stations that might be established on the ML-1A site:

a. Officer-in-Charge (OIC) Quarters

b. Control Cab

c. Reactor-Power Conversion Skid (PCS) Area

d. Maintenance Shelter

e. Gas-Generation and Storage Skid

f. Cable-Handling Skid

g. Water Make-Up Area

h. Auxiliary Power Unit (APU)

i. Crew Quarters

Each of these locations was analyzed individually to arrive at the communications requirements of the system as a whole.

Officer-in-Charge Quarters

Communications must be monitored at the OIC station 24 hours a day, and they must be monitored en route as well as on site. Since the OIC must exercise administrative control over the whole site and all personnel, the OIC station must have communication links with all locations within the site. This all-station capability would be especially important in case of emergency.

As commanding officer of the ML-1A unit, the OIC must also have communications with the higher authority to which he is responsible and possibly also with other stations beyond the immediate ML-1A site. To assure the OIC full command of his unit and full information at all times as to its operation, the OIC quarters should be the only station on the site in communication with outside stations.

Control Cab

The control cab is the operational center of the ML-1A site. At various times during prestart, start-up and operation, the operator may need to communicate with each of the other stations within the ML-1A network. During paralleling the operator may also need to communicate with the other power source on the line, but this link should be established through OIC's outside channels, so the operator does not need a direct channel to any outside station.

Although the operator will be linked with all stations at the ML-1A site, his station should be used for operational purposes only. He has been technically trained to operate the ML-1A, and his responsibility is to supply power when it is needed; to avoid interfering with the operator and with the ML-1A's mission, all administrative responsibilities should be handled through the OIC station at all times.

Reactor-PCS Area

During start-up, shutdown, and maintenance, some controls at separate locations within the ML-1A site must be closely coordinated: one operator monitors equipment at the reactor-PCS area while another monitors readouts in the control cab. Achieving this coordination requires communications between the two stations. The reactor-PCS area will also be linked to the OIC station, but there is no apparent need for a link between the reactor-PCS area and any other station.

Maintenance Shelter

Maintenance personnel and equipment will probably be housed in a separate shelter. Although there is little or no requirement for coordination between the cab and this station, the cab operator may need assistance or some piece of equipment from this shelter, so he should have direct contact with the shelter.

The maintenance shelter will also be linked to the OIC station, but not to any other station.

Gas-Generation and Storage Skid

This skid is close to the control cab and is normally unattended after it is started. Controls for this skid are on the skid itself and some readouts are in the cab, but since the skid is normally unattended, there seems to be little reason for communications with other stations. No link has been provided.

Cable-Handling Skid

This skid has not been designed yet, so its precise communication requirements are still unknown. Possibly the skid will be handling cable during prestart and shutdown. If it does, the operator must be linked to it so he can control all aspects of these phases of operation. Since cable-handling may take time, a link with the OIC station may also be required. No other communication needs are apparent.

Water Make-Up Area

Within the present system design, this area is still ill-defined. A communication station might be required to keep the operator fully informed during prestart or shutdown; but since this area should be near the reactor, it might share the reactor's communications. A final conclusion for this area will be postponed until the area is better defined.

Auxiliary Power Unit (APU)

The cab operator must tell the APU operator when power can be applied, and communication might also be required during maintenance, so there should be a communication station here.

Crew Quarters

Communications with the crew's living quarters will be purely administrative, so they can be handled by runner. The crew quarters have not been included in the communication net.

Special Communication Requirements

Noise Levels

Noise levels may be high near the reactor-PCS area because of the precooler fans. These fans will not normally operate during prestart and shutdown, but they will operate during certain maintenance operations, so the noise must be taken into account.

If there is a station on the cable-handling skid, it may be subject to high noise levels when it moves between the cab and the reactor-PCS area, depending on the vehicles used and the location of the phone headset.

Noise levels may also be high around the APU. This noise must also be considered in designing the communication system.

Power

The ML-1A communication net must operate even when no power is being generated -- for example, during prestart, shutdown, maintenance, and emergency. Some alternate power source must be provided.

Types of Communication Systems

When both general and special communication requirements of the ML-1A have been determined more fully, a communication system will be chosen to meet them.

A sound-powered system has been suggested, since it has the advantage that it does not depend on power generated by the ML-1A itself, and could be used at any time. But sound-powered systems also have their disadvantages: poor speech characteristics, poor noise-cancelling characteristics, and no ring circuit (although one could be operated by battery power or switched in when the generator begins operating). Other types of systems can, of course, be tailored to provide better speech and noise-cancelling characteristics.

Final conclusions on the type of communication system to be used for the ML-1A will be reserved until all requirements are better defined.

Parallel Operation

The documents pertinent to the ML-1A establish requirements for parallel operation:

> (Essential) the plant shall operate satisfactorily in parallel with other units built in compliance with Specification MIL-G-10328A (CE) (7, para 7f).
>
> (Desirable) the plant shall operate satisfactorily in parallel with other units built in compliance with Specification MIL-G-14609A (CE) (7, para 7g).
>
> Parallel Operation The power plant shall be capable of satisfactory operation when operated at 60 cycles in parallel with other units operating at 60 cycles and built in compliance with Specification MIL-G-10328 (1, para 3.2.5).

Concerns arose on requirements for paralleling of the ML-1A. The specifications quoted for the ML-1A (MIL-G-10328A and MIL-G-14609A) covered plants with a wide range of output powers. Statements in each of these specifications require only that the corresponding piece of equipment operate in parallel with a unit of identical rating and manufacture. The ML-1A preliminary design provided for paralleling with all plants developed to MIL-G-10328A. AEC considered restricting the ML-1A specifically to paralleling only with other ML-1A's. However, re-evaluation by AEC led to the conclusion that the present requirements, and hence the present controls, are satisfactory and will be retained.

Area-Protection Switches

Area-protection switches assure personnel working around the reactor that it cannot be made critical either accidentally or deliberately from the control cab. When the area-protection switch at the reactor is in the SAFE position, it should be impossible to make the reactor go critical from the cab.

Normal safety procedure around electrical equipment is to use large switches with visible contacts so the operator can check the circuit's condition visually. This procedure seems appropriate for the ML-1A.

In the ML-1 design, the area-protection key switch at the reactor must be thrown to the RUN position before the reactor can be made critical. However, this key switch can be bypassed -- violating good safety practice -- with a jumper at the terminal board in the cab. On the ML-1A, it was recommended that the area protection switch at the reactor should open the circuitry to the blade-driving motors, and that it should be possible to check the circuitry visually. This recommendation was not incorporated into the ML-1A's preliminary design, which does not give detailed circuitry, but AGN stated that it should be incorporated into the final design.

Chemical-Biological-Radiological (CBR) Protection

Statements in QMR suggest that the ML-1A may have to operate under CBR conditions:

> The use of this nuclear power plant should not increase the vulnerability of an installation through enemy action over the vulnerability associated with a similar installation which uses a conventional power plant (7, para 20b).
>
> This mobile nuclear power plant will serve as a primary power source for installations such as tactical operations centers, field army missile defense systems, airhead command and control centers, remote camps or stations, and Strike Force Command Posts (7, para 2a).

Plants providing power to such installations must certainly be considered targets for enemy CBR attacks. Insuring that the ML-1A system would be able to operate during and after a CBR attack required detailed investigation of CBR protection for the crew.

A meeting was held with the Chemical Research Development Laboratories (CRDL), Engineer Research Development Laboratories (ERDL), AEC, and HEL. The discussion developed three approaches to providing a crew with CBR protection:

a. Provide nothing in the control cab and expect each man to use individual protection -- gas masks, gloves, etc.

b. Provide a few sources of pure filtered air within the cab (as, for example, in tanks), with each source sufficient for one man.

c. Provide complete collective protection with a CBR system including filters and, most likely, an entrance air lock into the cab. Such a system would also facilitate maintenance by preventing instrument contamination.

As a result of the meeting, it was concluded that a collective protection system has significant advantages over individual protection measures for three basic reasons:

a. Operators cannot perform effectively for long periods if they must wear individual protection apparatus.

b. CBR agents linger for some time after an attack, and these agents may contaminate the electronic equipment. Maintenance would then be seriously hampered for some time after the attack, because maintenance personnel would have to wear individual protection apparatus.

c. Individual protection can protect men, but not the equipment and gear in the control cab. There is evidence that certain agents can significantly alter the characteristics of electronic equipment and cause malfunctions.

Further discussion indicated that a protective entry system should perhaps be considered. The protective entry system is an area attached to the shelter's door where men can change clothing before entering the cab or don protective clothing before going out into a contaminated area. Such an entrance would prevent operators from carrying agents into the cab and contaminating it. Airborne contamination is continuously swept out of such an entryway by blowing a large amount of filtered air through it.

Therefore, the following provisions were recommended by AEC for CBR protection on the ML-1A:

a. A CBR protection requirement should be added to the ML-1A QMR.

b. Collective CBR protection should be provided, rather than individual protection, since it not only enables the operator to work unhampered but also protects the control-cab instruments.

c. CBR protective hardware is already available (including the protective entry) and requires little or no modification; it should be adopted for the ML-1A.

d. A separate filter unit and entrance should be used so that the ML-1A control cab design, specifically the air conditioning unit, need not be changed.

Air Conditioner

The documents pertinent to the ML-1A establish environmental requirements for the control cab:

> (Essential) the plant shall be capable of operation under the Basic Operating Conditions, Extreme Cold Weather Operating Conditions (with cold weather kit), and Extreme Hot Weather Operating Conditions (at a reduced power level) as established in paragraphs 7a, 7b, and 7c of AR 705-15, and will meet storage and transportation criteria established in paragraph 7d of AR 705-15 (7, para 7k).
>
> (Essential) Human factors engineering characteristics of the plant will include, but not be limited to, consideration of each of the following, in terms of the intellectual, physical and psychomotor capabilities of the intended user (7, para 10f).
>
> (10) Comfort only as required to ensure crew efficiency.
>
> <u>Environmental Conditions</u> Unless otherwise specified herein, the plant shall have the inherent capability of acceptable performance as defined in this specification under the Basic Operating Conditions, Extreme Cold Weather Operating Conditions, Extreme Hot Weather Operating Conditions, and Storage and Transient Conditions as established by Army Regulations AR 705-15 (1, para 3.1.2.1.1).

Housed Equipment The control shelter shall house the following equipment:

(b) An air conditioning device to maintain an essentially constant interior temperature and humidity throughout the full range of environmental conditions specified in 3.1.2.1.1 (1, para 3.3.3.2.1).

The commercial air-conditioning unit in the ML-1 system was too large and had an unnecessarily high rating. Both HEL and AEC recommended that government-furnished equipment (GFE) be used.

The cab must maintain an ambient environment of from 50 degrees to 85 degrees effective temperature when exposed to the temperatures stated in AR 705-15 (-65° F to +125° F with solar radiation of 360 Btu/ft^{2}hr). Calculations show that a GFE air conditioner-heater of 18,000 Btu/hr nominal rating will satisfy these requirements. The unit is described in the ML-1A preliminary design (2, Vol. III).

SUMMARY

This report summarizes human engineering contributions to preliminary design of the ML-1A mobile nuclear power plant -- and especially to the control cab, operator's console, and certain subsystems. It emphasizes the step-by-step procedures used to develop the final cab and console layouts shown. These layouts are, in a very real sense, the conclusions of this human engineering study.

First, the report gives the basic premises that guided the human factors program -- system requirements, human engineering criteria, and ground rules for system use.

The second section demonstrates how basic system requirements dictate the control-cab design. After listing the equipment which must be located within the cab, it discusses the rationale for arranging that equipment efficiently in the available space, while providing adequate lighting and maximum "subjective volume," so operators will not feel "closed in." Human engineering succeeded in developing a flexible console configuration which one man can operate adequately, yet with enough space for a possible assistant operator.

Third, the report gives step-by-step details of how the operator's console was designed. There were three basic considerations: fitting in all of the controls and displays needed in a nuclear power plant for military use, and arranging them in order of operation, while satisfying accepted human engineering requirements for height, reach, preferred viewing areas, and the like. Essentially, the panel components were grouped by functions and assigned panel locations so critical or frequently used functions are most conveniently accessible to the operator. After space had been allotted to each functional group, the group was analyzed so the individual components could be placed appropriately in relation to each other. Some compromises were required where components in different functional groups must be used together. Wherever possible, critical and frequently used components were kept within easily accessible areas.

Finally, the report examines several important subsystems: the annunciator system, which signals system malfunctions; the communication system, special communications problems in noisy areas of the plant, and the sort of equipment which might cope with these problems; air-conditioning equipment for the control cab; and safety provisions, such as area-protection switches and protection against chemical-biological-radiological (CBR) attack.

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APPENDIX A

FINAL PANEL-BY-PANEL LAYOUTS OF THE ML-1A CONSOLE

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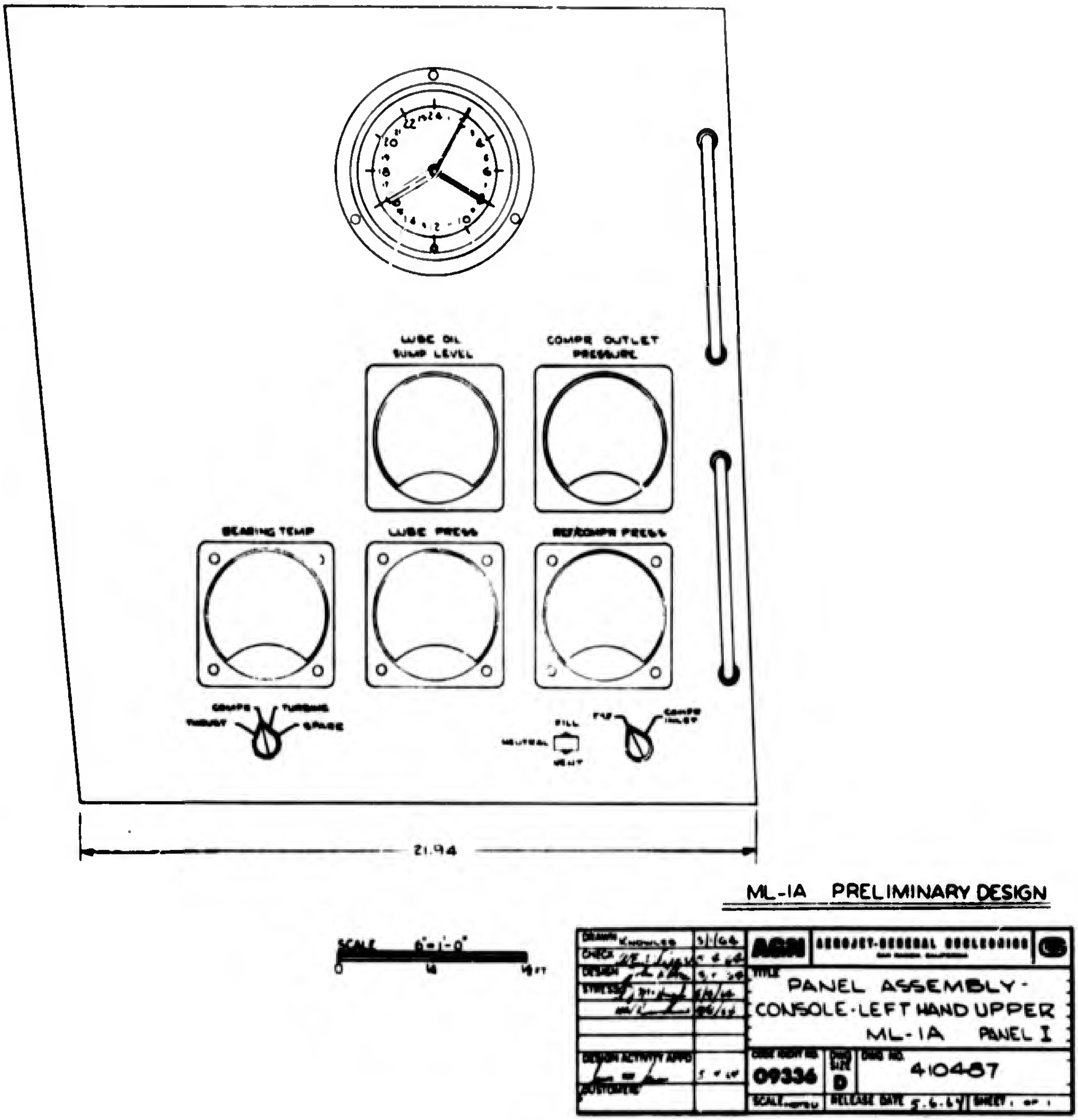

Fig. 1A. FINAL CONSOLE LAYOUT -- PANEL I

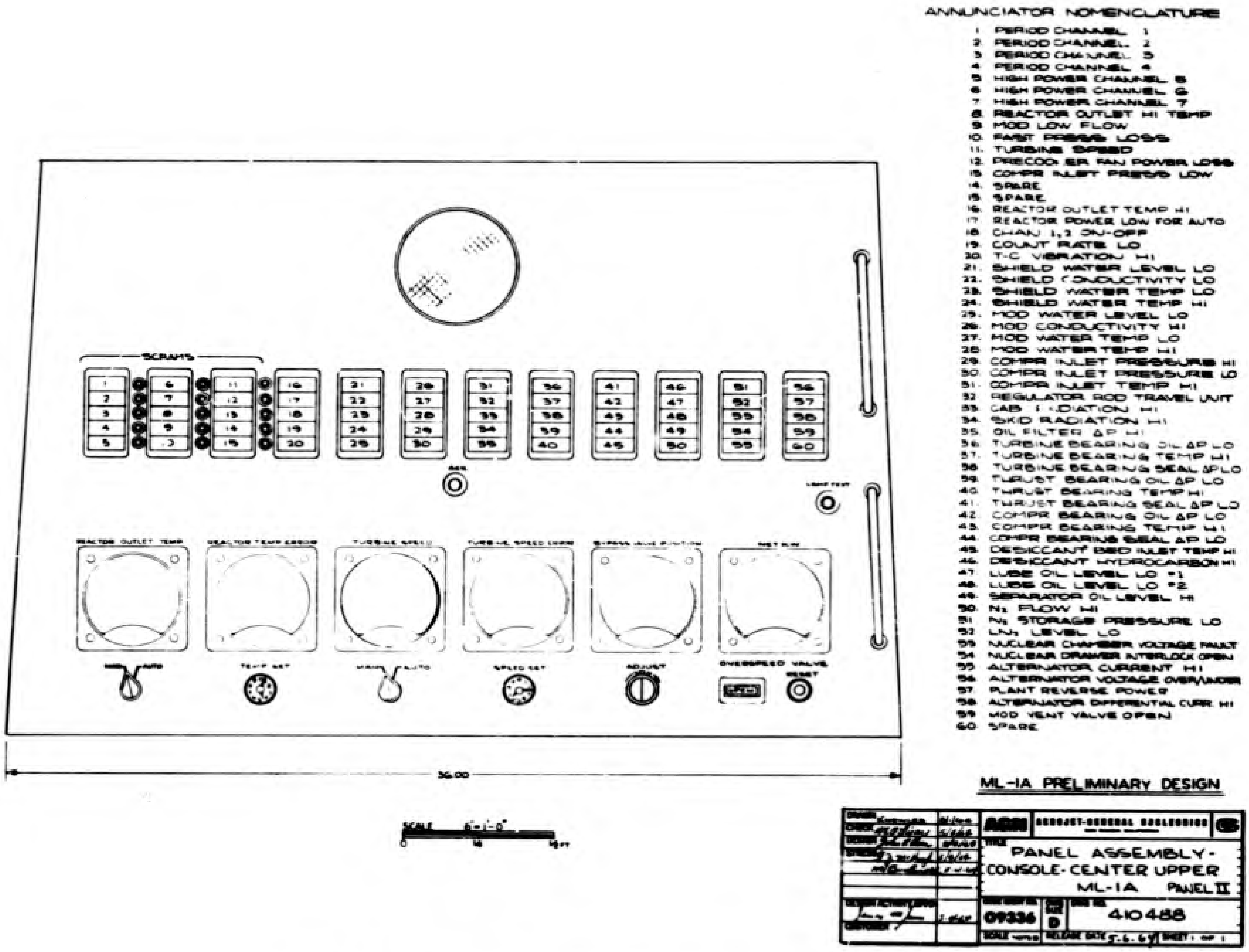

Fig. 2A. FINAL CONSOLE LAYOUT -- PANEL II

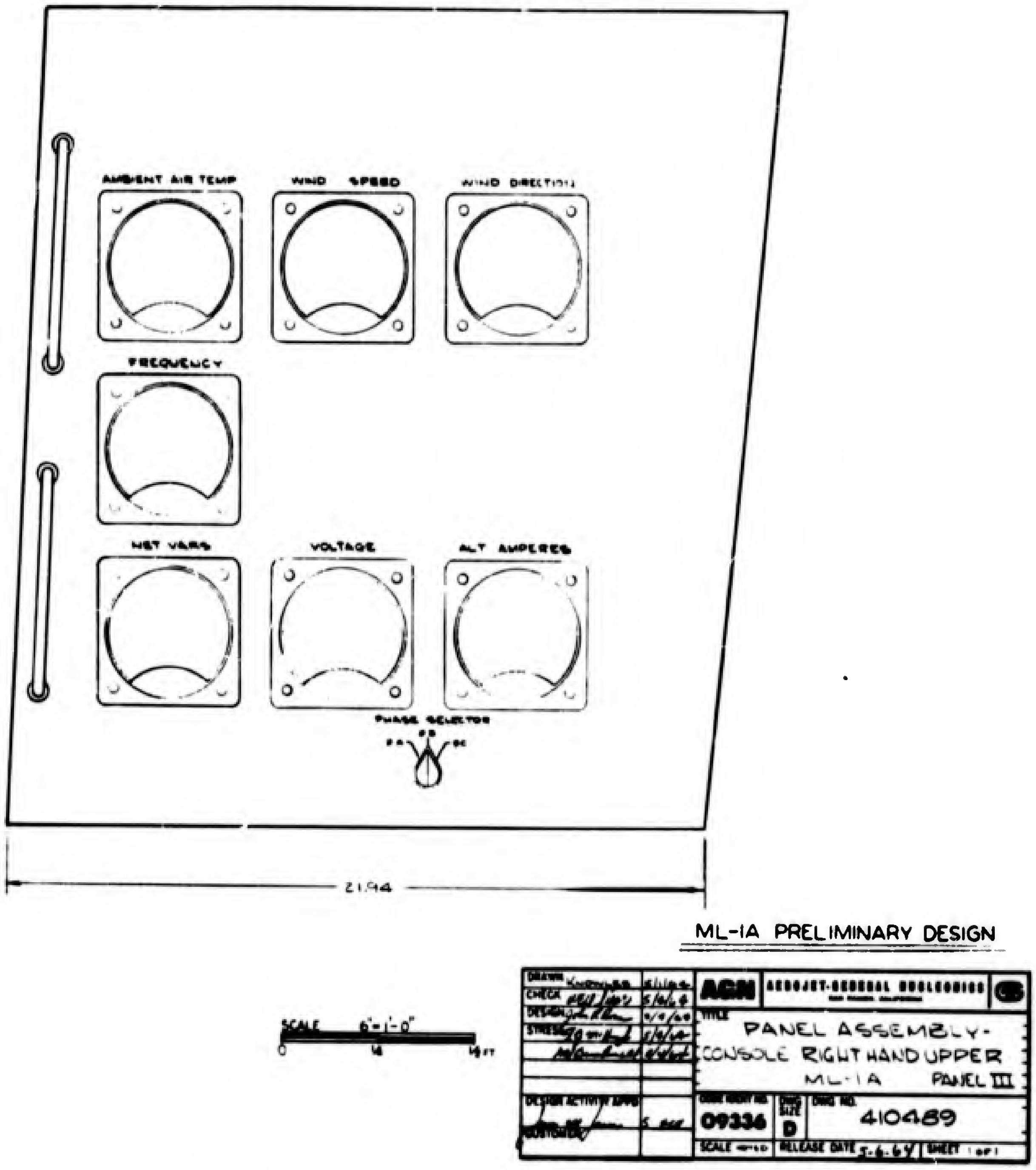

Fig. 3A. FINAL CONSOLE LAYOUT -- PANEL III

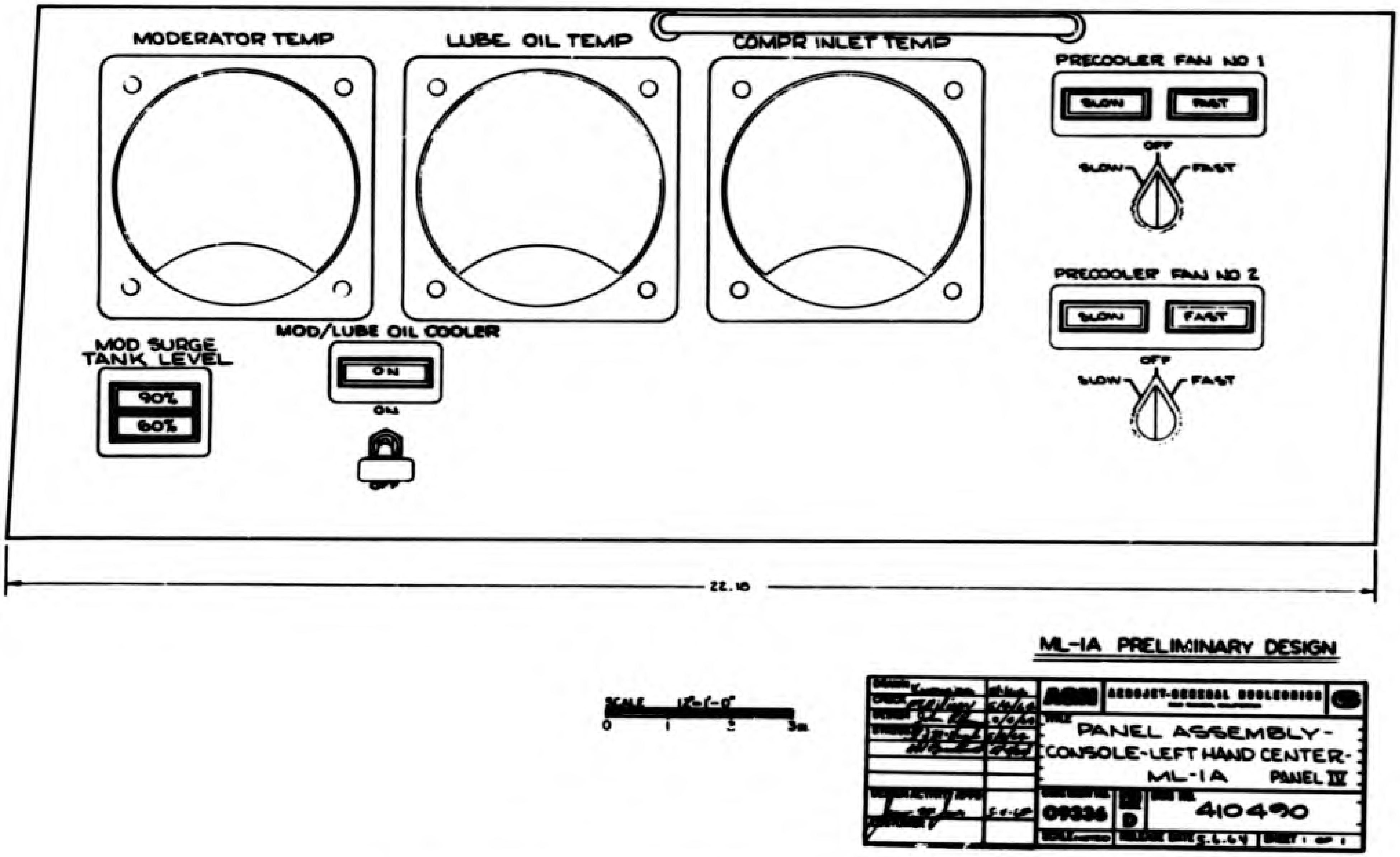

Fig. 4A. FINAL CONSOLE LAYOUT -- PANEL IV

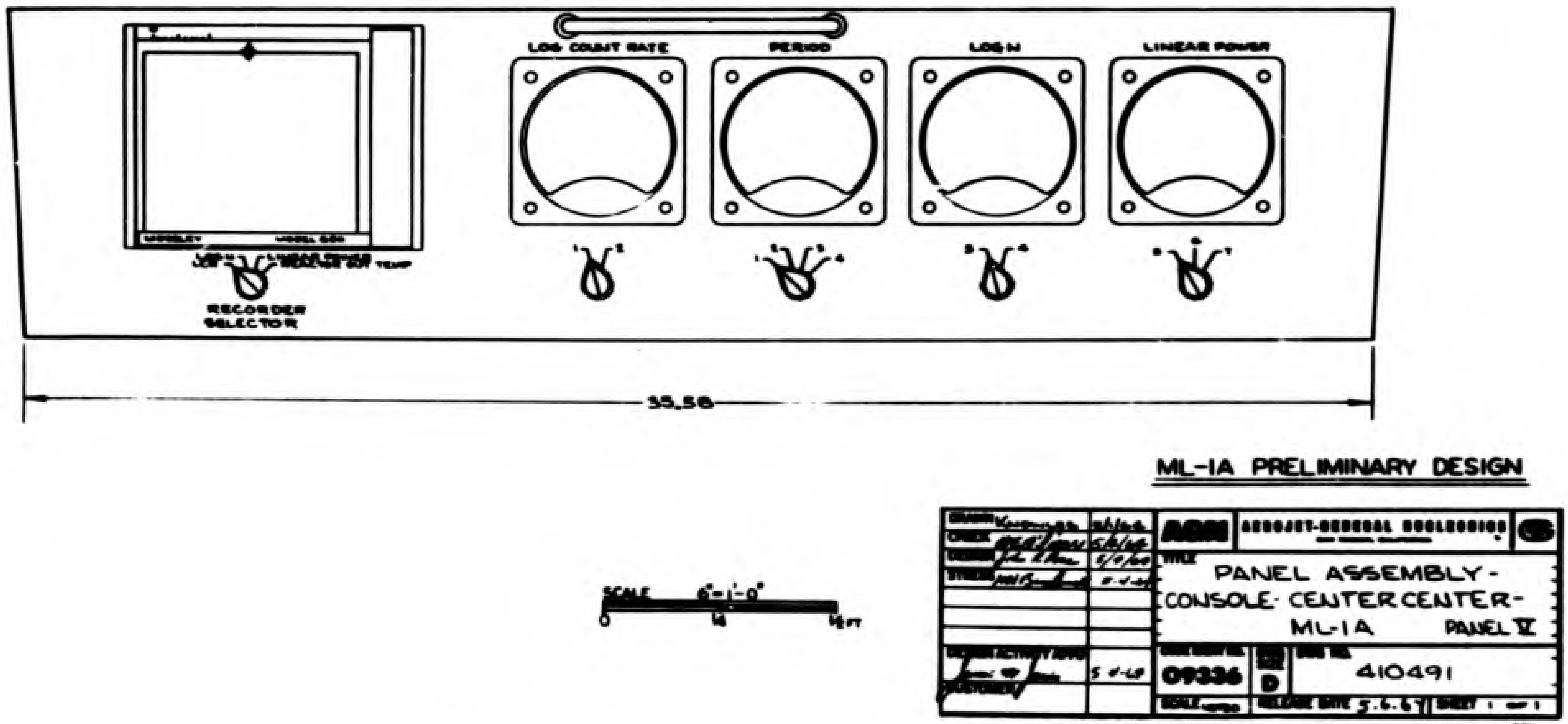

Fig. 5A. FINAL CONSOLE LAYOUT -- PANEL V

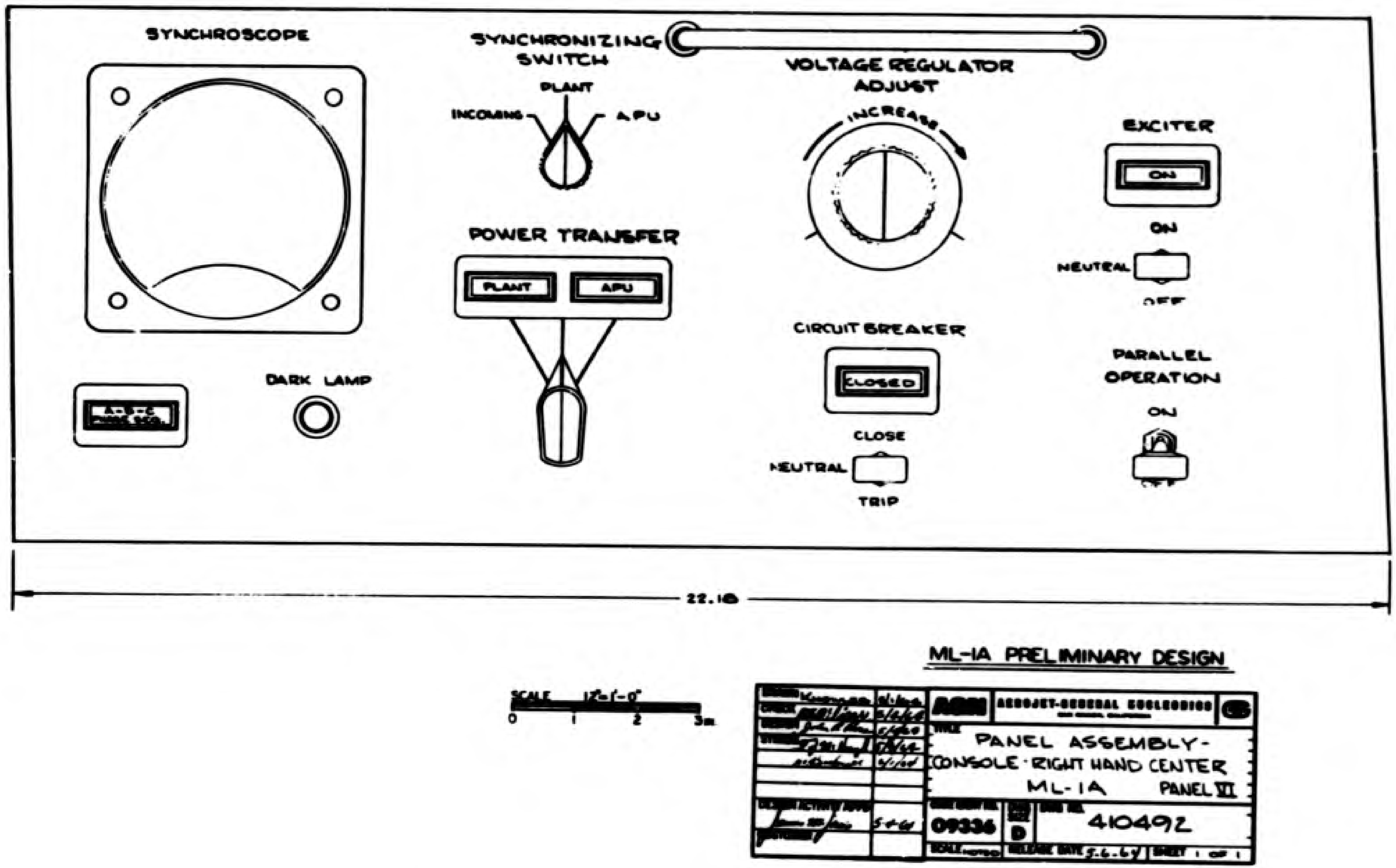

Fig. 6A. FINAL CONSOLE LAYOUT -- PANEL VI

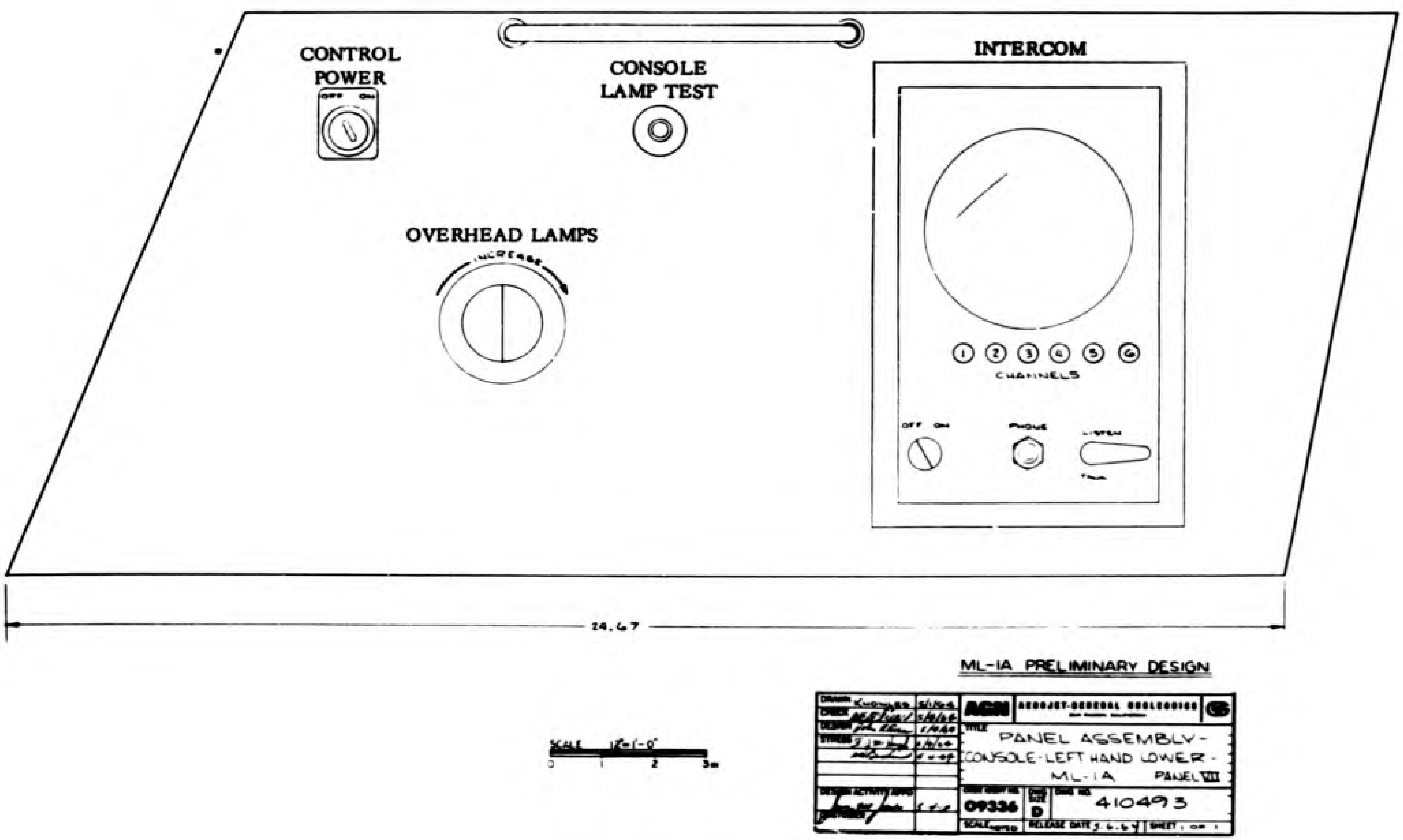

Fig. 7A. FINAL CONSOLE LAYOUT -- PANEL VII

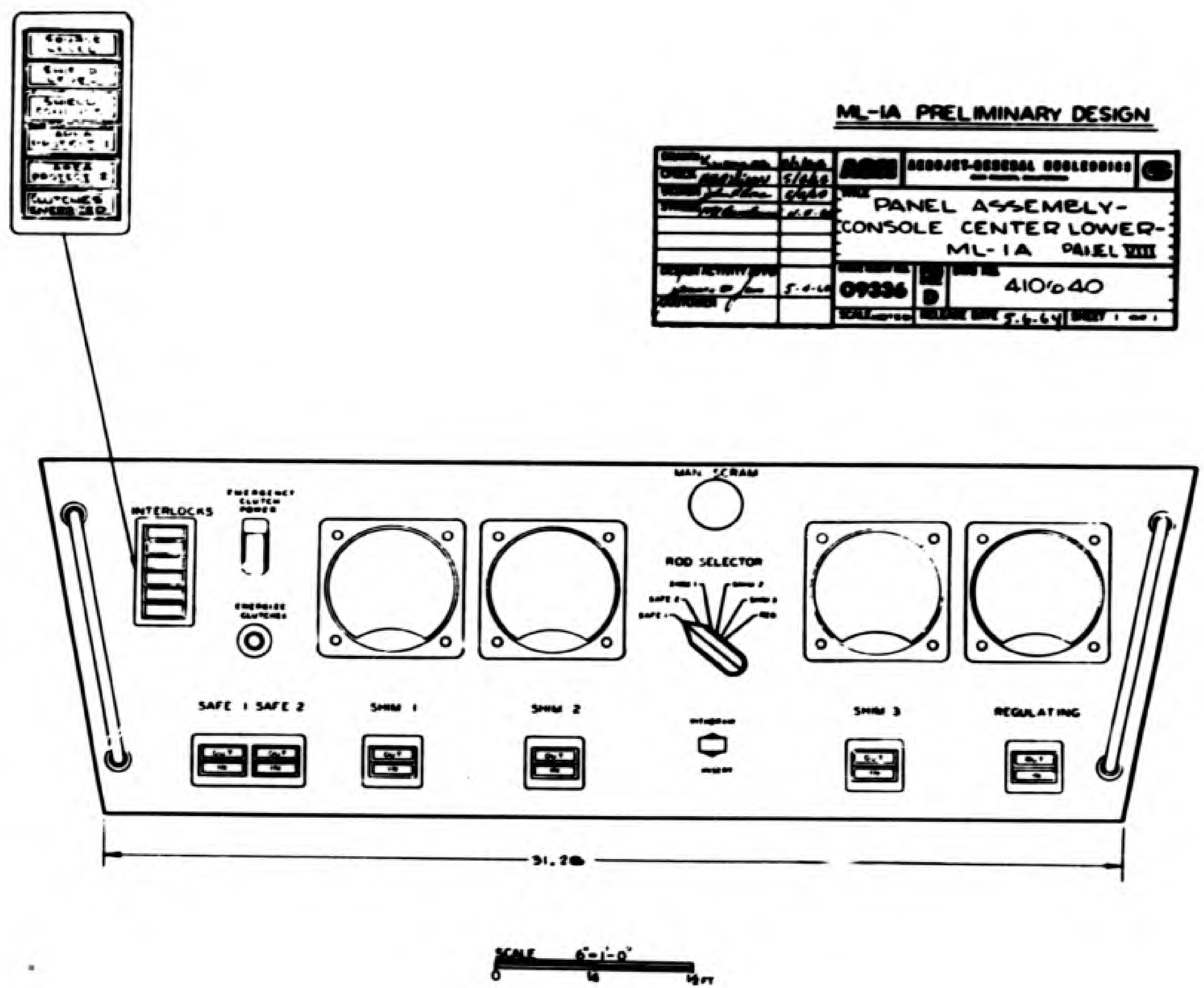

Fig. 8A. FINAL CONSOLE LAYOUT -- PANEL VIII

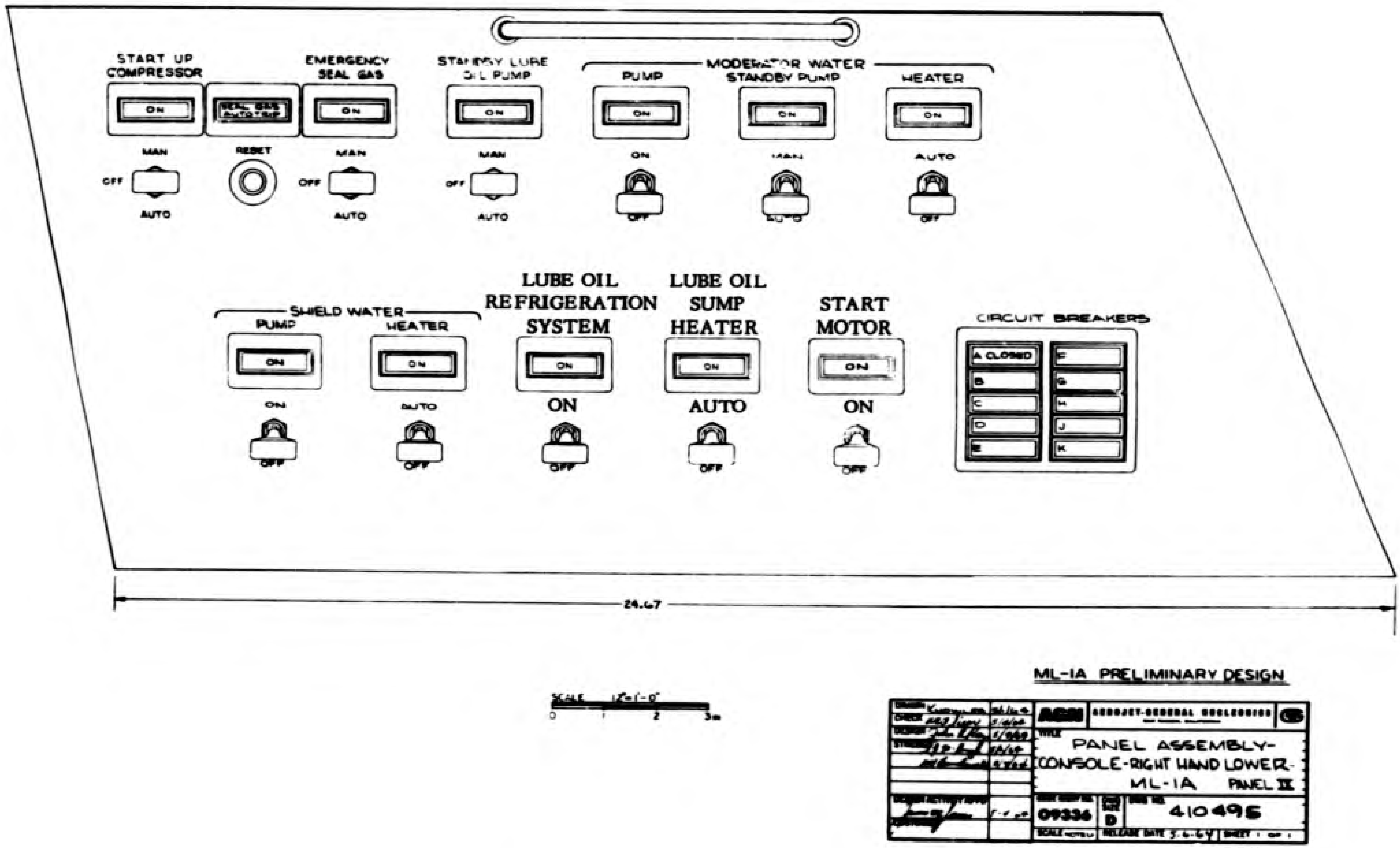

Fig. 9A. FINAL CONSOLE LAYOUT -- PANEL IX

APPENDIX B

INTERIOR PHOTOGRAPHS OF THE ML-1A CONTROL CAB MOCK-UP

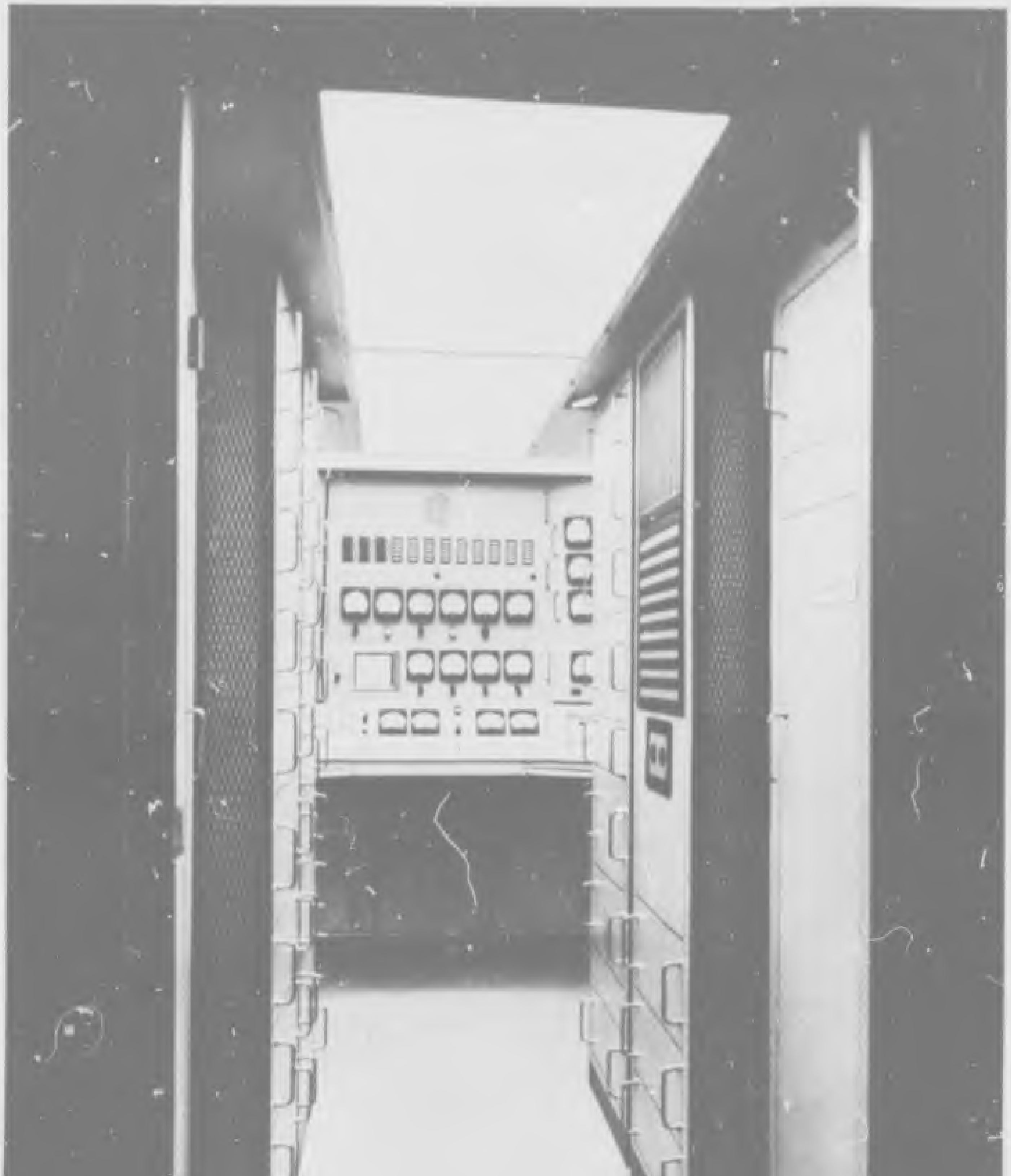

Fig. 1B. ML-1A CONTROL CAB -- INTERIOR

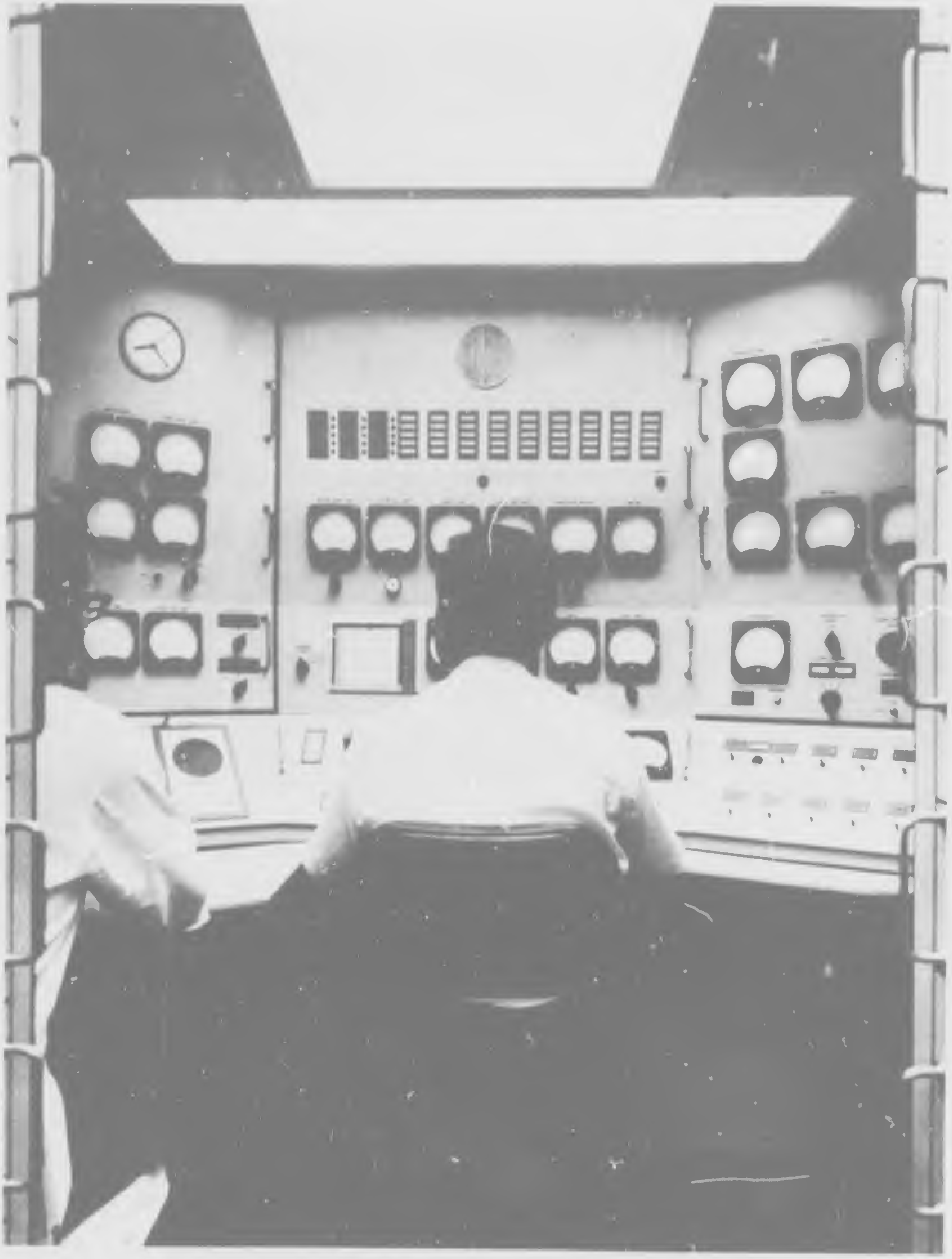

Fig. 2B. ML-1A CONSOLE AREA SHOWING OPERATOR AND ASSISTANT

Fig. 3B. RIGHT REAR OF ML-1A CAB

Fig. 4B. LEFT REAR OF ML-1A CAB SHOWING ASSISTANT'S CHAIR

Fig. 5B. LEFT REAR OF ML-1A CAB SHOWING ASSISTANT'S CHAIR IN STOWED POSITION

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4. DESCRIPTIVE NOTES (Type of report and inclusive dates)

5. AUTHOR(S) (Last name, first name, initial)

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13. ABSTRACT

This report summarizes the human engineering considerations in the preliminary detailed design of the ML-1A control cab. It discusses the pros and cons of alternate designs for the cab interior and the cab sub-system, with conclusions.

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