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HUMAN FACTORS EVALUATION OF THE ENGINEERING TEST REACTOR CONTROL ROOM

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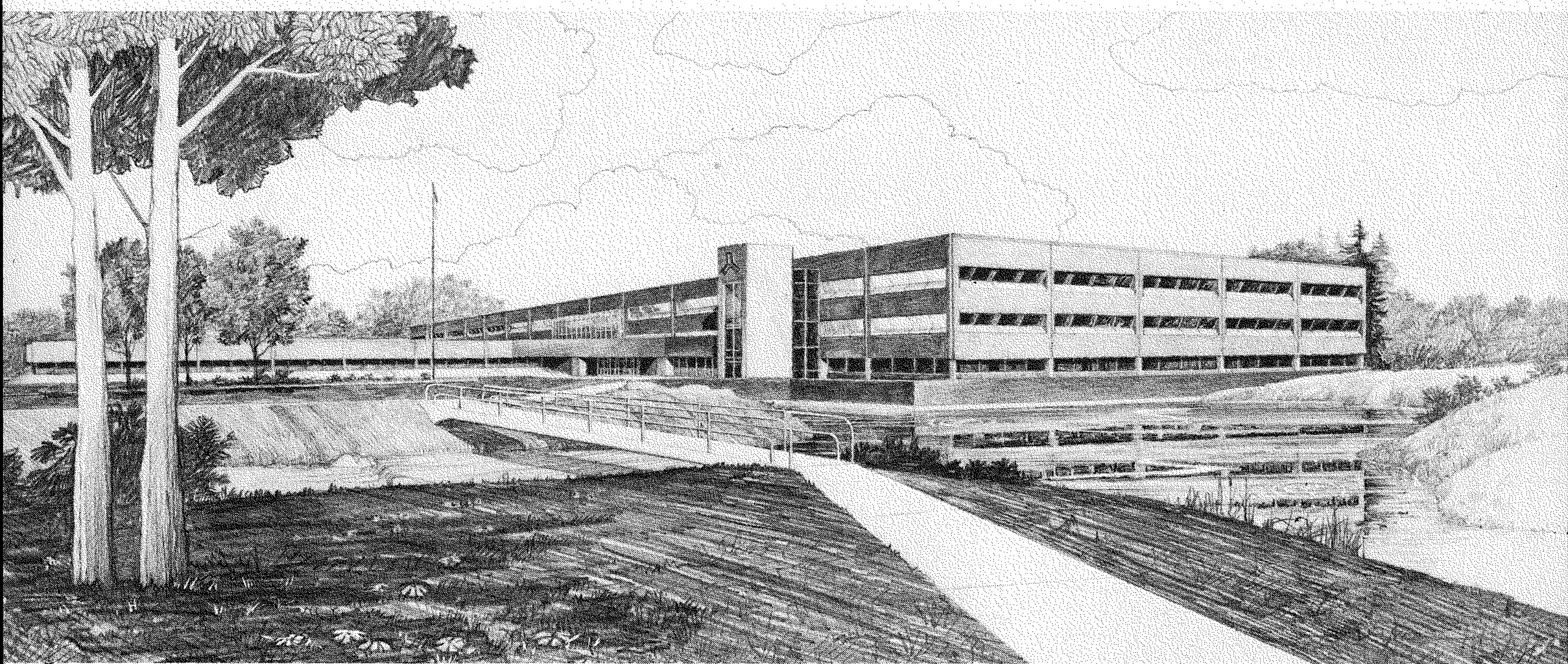

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ABSTRACT

The Reactor and Process Control Room at the Engineering Test Reactor were evaluated by a team of human factors engineers using available human factors design criteria. During the evaluation, ETR equipment and facilities were compared with MIL-STD-1472-B, Human Engineering Design Criteria for Military Systems. The focus of recommendations centered on: (a) displays and controls; placing displays and controls in functional groups; (b) establishing a consistent color coding (in compliance with a standard if possible); (c) systematizing annunciator alarms and reducing their number; (d) organizing equipment in functional groups; and (e) modifying labeling and lines of demarcation.

ACKNOWLEDGMENTS

The authors wish to extend their sincere appreciation to the Operations and Experiments personnel at the Engineering Test Reactor without whose assistance this report would have been difficult to produce. Particular appreciation is given to Dave Schoonen, Doug French, Dennis Suthers, Dave Sheldon, Glen Merrill, Max Killian, and Del Vanorden.

CONTENTS

INTRODUCTION

The information presented here represents findings and recommendations related to improving controls and displays within the Engineering Test Reactor (ETR) Control Room. Although some of the problems examined in this report have been identified previously by ETR Operations personnel, the systematic approach used in this investigation produced additional insights, and revealed new problem, and suggested new solutions.

The purpose of the study was to:

- Identify existing and potential design problems at the man/machine interface of the ETR Control Room
- Provide recommendations to lower the probability of human error
- Provide recommendations which improve overall system and human performance
- Provide recommendations which may correct suboptimal procedures and/or control/display features
- Provide a documented, systematic method which incorporates both a quantitative and qualitative medium for evaluation.

The major thrust of this evaluation focused on the Reactor Control Room and Process Control Room. The specific items addressed in this report include:

- Shim-Rod Subsystem
- Motor-Operated Rheostat
- Auxiliary Power System

- Flux-Run System
- Emergency Subsystem
- Strip Chart Instruments
- Annunciator Subsystem
- Regulating-Rod System
- Pressure and Flow Indicators
- Manual Controls
- Primary Coolant System
- Radiological Instrumentation.

Each problem area was specifically identified and recommendations for corrective action were made to upgrade Human Engineering Design quality.

The problems described and the recommendations made must now be evaluated with respect to their influence on nuclear and process control operators. The priority for adopting the recommendations should be established by a joint group consisting of people from operations, experiments, engineering physics, and human factors.

CONTROL DISPLAY INTEGRATION

The issues addressed in this section concern:

- o Ways to make relationships between controls and associated displays immediately apparent and unambiguous to operators.
- o The functional grouping of controls and displays.
- o The direct and predictable response of a display indication to control activation.

Specific areas of concern and suggestions for enhancement of these areas are discussed below.

Reactor Control Room

Shim-Rod Subsystem

1. The shim rod withdrawal rotary select switch, located on the lower section of Panel R-11, functions to allow the shim rod to be withdrawn using the withdraw/insert switch on Panel R-13 (see Figure 1). Position feedback from the rotary switch is obtained by observing an unlabeled indicator light associated with each shim rod. It is difficult for an operator to determine quickly which shim rod is selected due to the placement of the selected indicator lights in an array of other similar-sized lights (high visual noise). Additionally, four of the rod select positions on the rotary switch are located on another panel 66 inches away (Panel R-15). It is recommended that the shim rod withdrawal control indicator lights and withdraw/insert switch be located in a functionally designated group. Another recommendation is to replace the rotary switch with lighted push buttons in a configuration that mimics the actual physical arrangement of the shim rods. The activated push buttons should

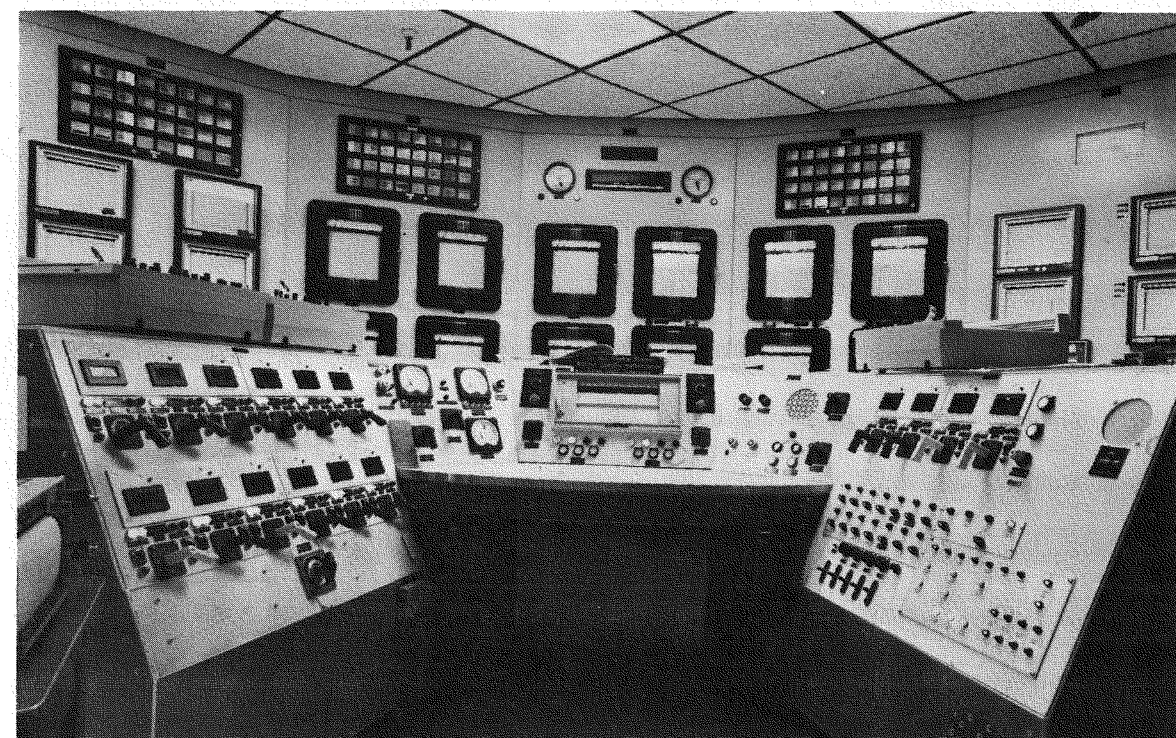

Figure 1. Reactor Console. 1) The shim rod insert withdraw/insert select switch, "A", is separated from the shim rod rotary-withdraw-switch, "B" by 38 inches. They should be grouped together. 2) The placement of the withdraw-selected lights, "C", in a field of similar lights makes them difficult to discriminate. 3) Shim-rod controls are separated into two groups on separate panels. They should be in one functional group.

be back-lighted to indicate that a shim rod is available for withdrawal. If all the shim controls were placed on the same panel, and arranged by group, the push-button matrix could be designed similar to that shown in the table below. Additionally, the lighted push buttons should be color coded by group in a manner consistent with the shim groups. For example, BROWN could be used for Group 1, BLACK for Group 2, and GREY for Group 3.

While it would be desirable to have Group I, II, and III shim rod withdraw controls consecutively numbered instead of numbered in the out-of-sequence progression below, the sequence shown below is compatible with the wiring. During modification, wiring and controls should be revised to normal sequence.

SHIM ROD WITHDRAWAL					
1	2	7	10		
3	4	11	13	6	12
5	9	14	15	8	16

Another approach to shim rod control layout would be to place them within a graphic layout of the core. Operators could then relate to flux shape and shadowing. Some testing is necessary to determine which approach is more effective in improving operator performance.

2. The movement relationship between the withdraw/insert switch and the intermediate/high withdraw switch causes some operator confusion (see Figure 2). The intermediate/high switch must be turned clockwise to withdraw the shim rods at high speed, while the withdraw/insert switch must be rotated counterclockwise to withdraw.

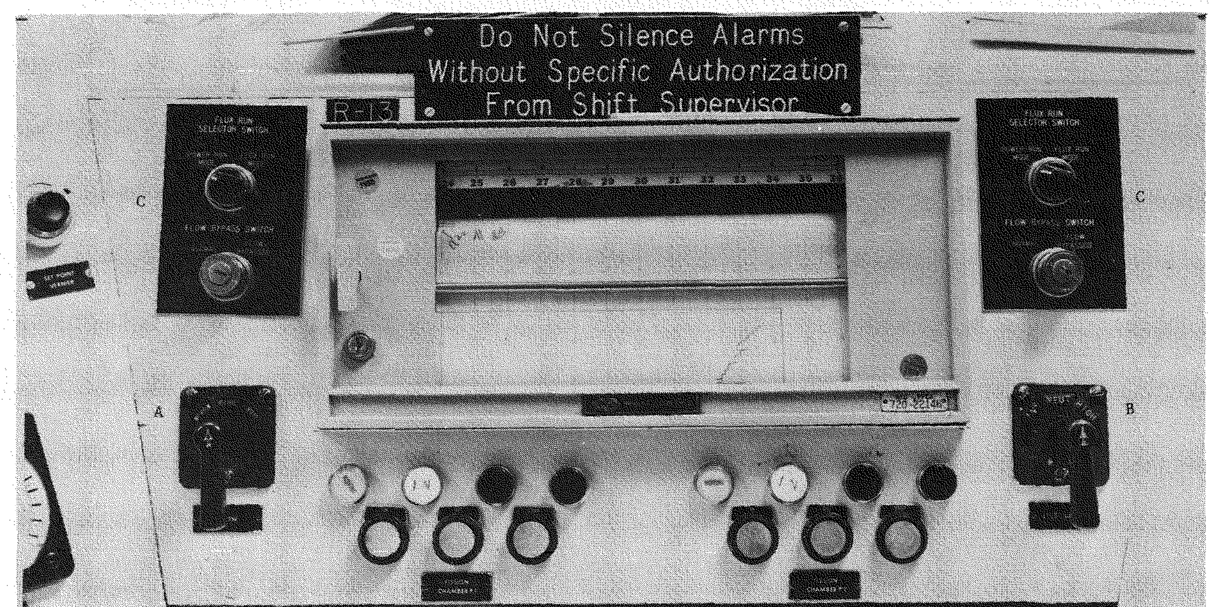

Figure 2. Panel R-13. A counterclockwise rotation of switch "A" causes the shim rod to withdraw. A clockwise or counterclockwise rotation of switch "B" causes the shim rod to withdraw. The flux-run selector switches, "C", are used only once prior to reactor start-up. The regulating rod position recorder uses only one pen at a time. The second pen could be used selectively to monitor one neutron level channel.

Normally, when using the intermediate/high withdraw switch, it is operated in the "high" position. A selector switch used in conjunction with the withdraw/insert switch to select single, intermediate, or high rates of withdrawal would be beneficial and eliminate the need for two separate pistol-grip switches. However, an engineering analysis is necessary to determine if a single switch can meet the single failure analysis criteria and if it can be used effectively in rapid power recoveries.

Motor-Operated Rheostat

1. The flux-level set point and the vernier set point (both located on Panel R-12) function to control power. Two of the displays used in conjunction with above controls are the water-power meter (located on Panel R-9) and the percent-pile-power meter (located on Panel R-7). It is recommended that these controls and associated displays be located in a functional group together and bounded by demarcation lines (see Figure 3). The new servo system to be installed at ETR could incorporate these suggestions.

Process Control Room

1. Emergency valve display indicator lights do not provide information to the operator regarding the percent any valve is open or closed (see Figure 4). The operator has only three indications: open, closed, and intermediate. This could be a particularly serious problem for flow-control valves. An operator does not know from console instruments the degree to which a valve is open or the direction it is traveling. In order to get this information, one must visually inspect the valves which are outside the control room (see Figure 5). It would be advantageous if this information were displayed directly to the operator on the control console. This could be accomplished through a syncro-servo system run directly from the valve into the control room.

2. The diesel RPM controller used to match commercial bus power is separated by over 6 feet from the power breaker C-E bus tie (see Figure 6). Because of this, it takes two people to match diesel with commercial power. It is suggested that these control/meters be located next to each other.

3. The MG 1 Speed Control Panels and the MG 1 Main AC Machine current panel oftentimes must be accessed concurrently but are separated by over 50 feet (see Figure 7). By combining the controls and meters necessary to operate the system on one console, or providing duplicate meters, this problem would be eliminated.

4. If commercial power is inadvertently lost because panel vibration initiates a power bus relay to open, Annunciator Point A-3-4 in the Process Control Room will be activated. This point simply indicates that "electrical building trouble" exists. This annunciator point does not specify which relay is responsible for the alarm condition and hence the process control operator must visually inspect five different areas within the building in order to identify the specific relay which is in the "open" condition.

It is recommended that separate annunciator points be provided in the Process Control Room to specifically identify which relay has opened, and hence direct the operator to the exact trouble.

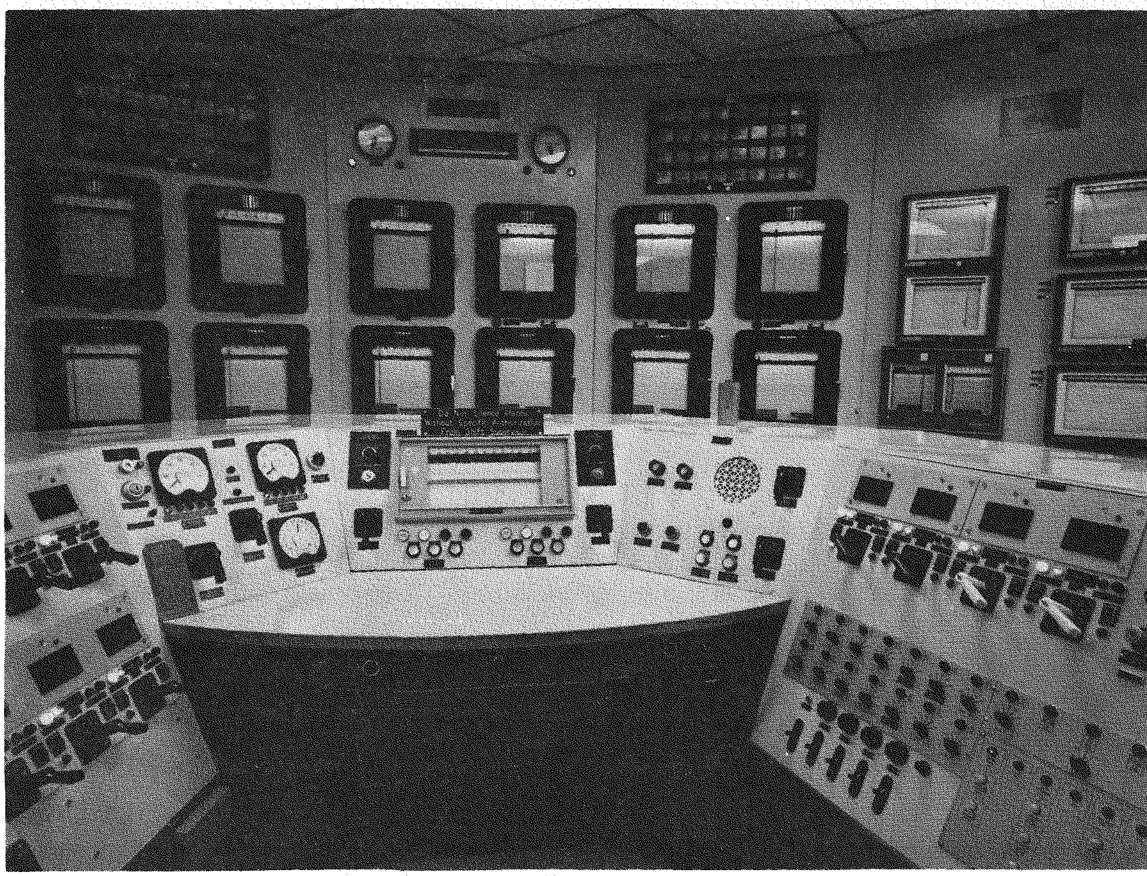

Figure 3. Panel R-12, R-7, and R-9. The water-power meter, "A" and the percent-pile-power meter "B", are used in conjunction with the flux-level set point switch "C", and the set point vernier, "D". These controls and displays should be grouped together.

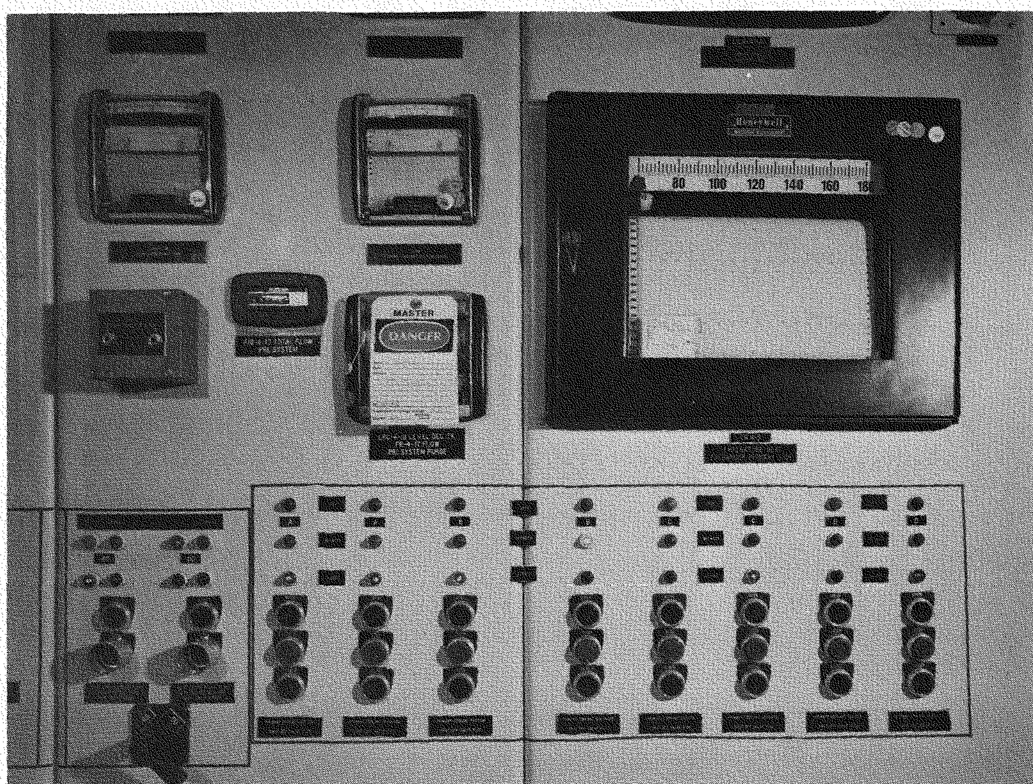

Figure 4. Emergency valve display indicator lights. The arrows are pointing to: (a) "open" indicator light, (b) "closed" indicator light, (c) "intermediate" indicator light. No information as to percent "open" or "closed" is given, nor is there any means to show the direction of valve travel.

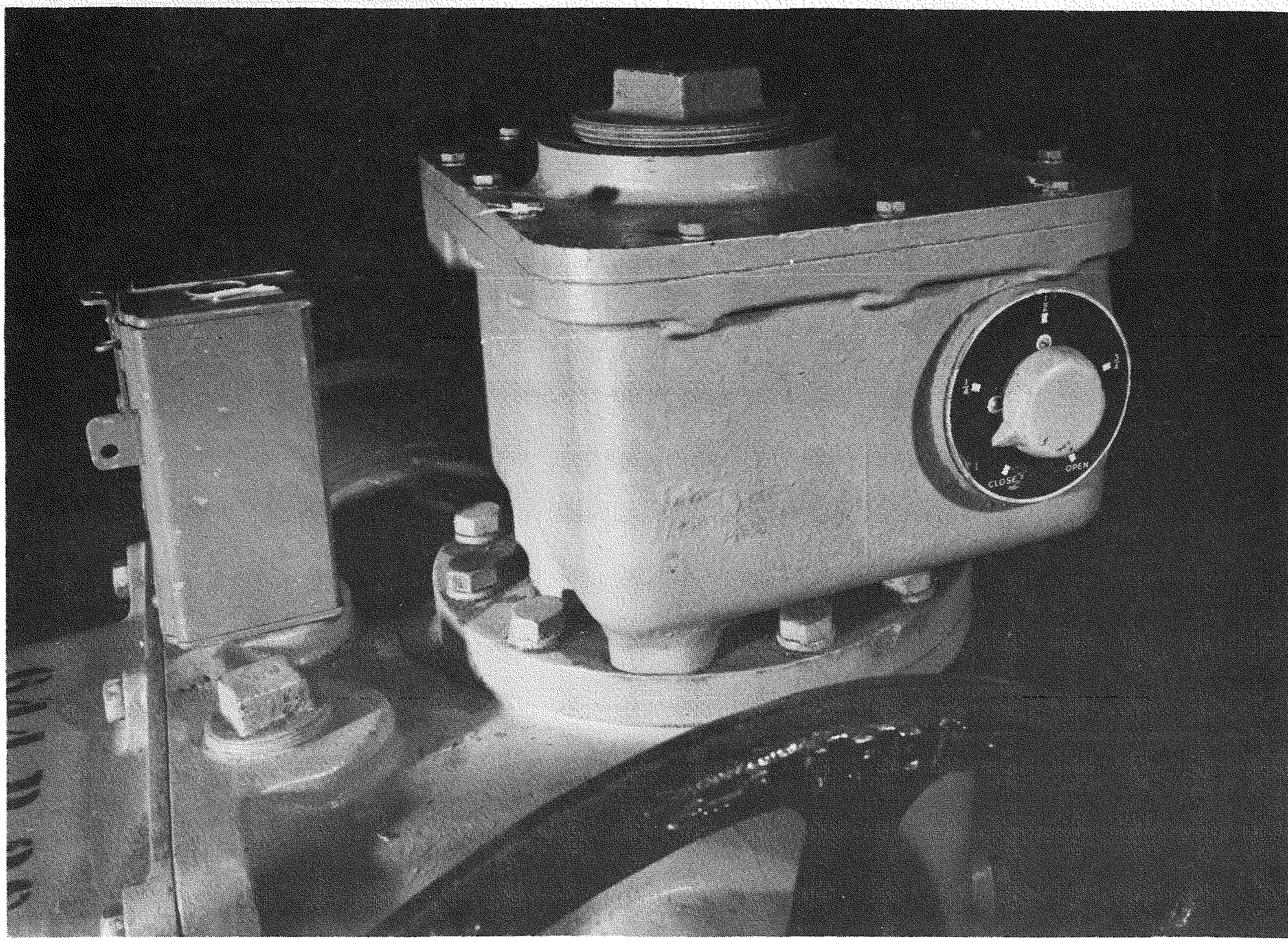

Figure 5. Emergency valves. Visual inspection of valves is required to gain information concerning "percent" open/closed and direction of valve travel in closing or opening.

Figure 6. The diesel RPM controller "A" and power breaker CE bus tie "B." They should be closer together for ease of reading and operation.

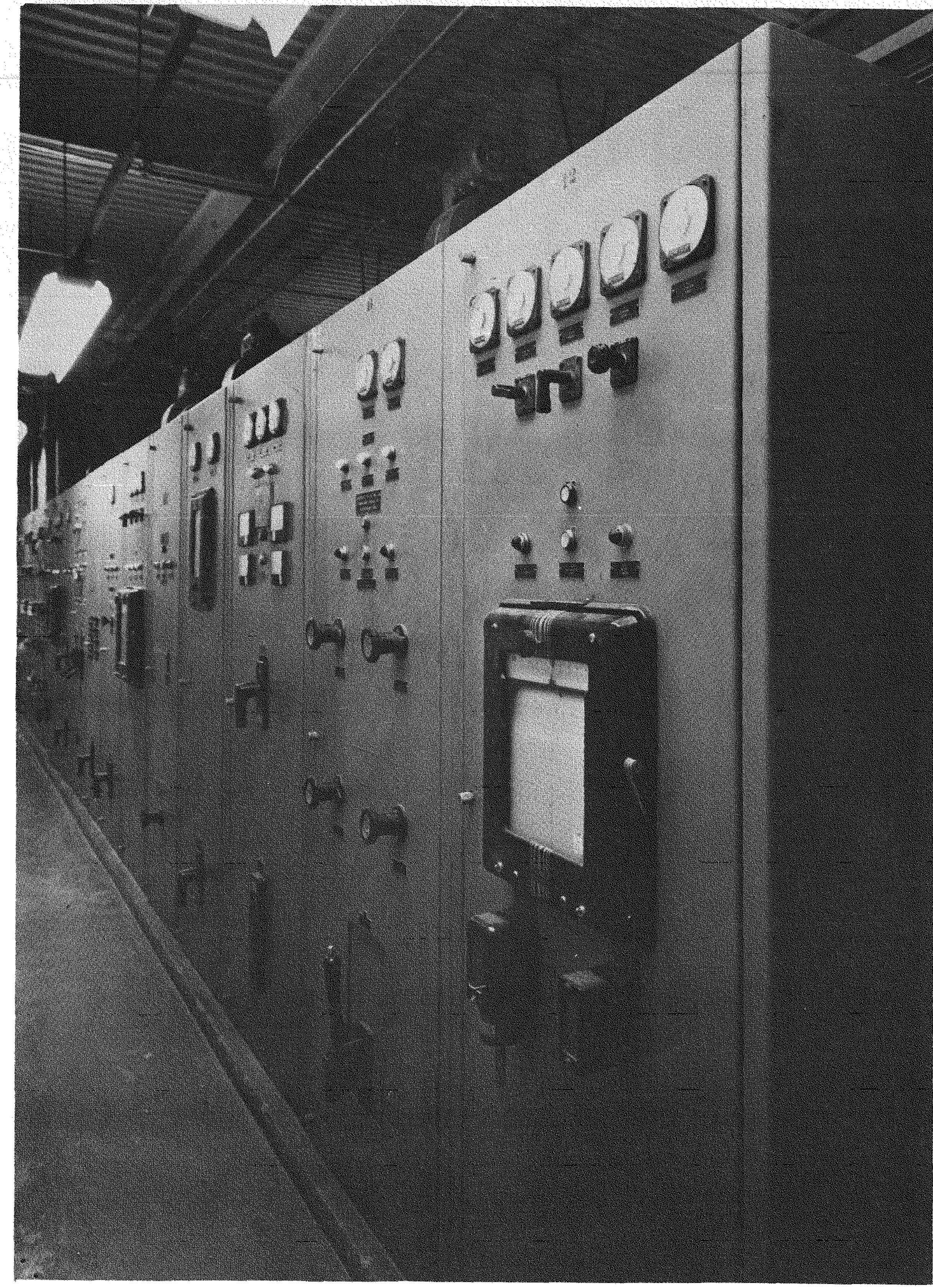

Figure 7. MG-1 Speed Control Panel (Arrow) scale range is inadequate and distance from other associated controls, too far.

CONTROLS

The issues addressed in this section concern:

- o Optimal control layout to conform with operators' reach envelopes
- o The direction of control movement
- o Functional grouping of controls
- o Prevention of unintentional control activation
- o Control accessibility.

Specific areas of concern and suggestions to correct these probelems are discussed below

Reactor Control Room

Shim-Rod Subsystem

1. The shim rods are grouped on two separate panels, R-15 and R-11 (see Figure 1). Rods 1-4 are on Panel R-15 and Rods 5-16 are located on Panel R-11. The control rods are classified into three separate groups--Group I, II, and III. Group III is further subdivided into three groups--IIIA, IIIB, and IIIC. All of Group I controls are used at the same time. However, the individual controls which comprise Group I are not placed together in a manner which makes it obvious that these controls are all Group I. Group II and III controls have the same grouping problem. The lack of grouping by function is a particular problem when attempting to maintain the Group III control rods to within 1 inch of each other. The current layout, grouping, and color-coding scheme is shown in Figure 8.

Key	Group Number Color of Control Grip Rod Number

Panel R-15

I Red 1	I Red 2	II White 3	II White 4

Panel R-11

IIIB Black 5	IIIA Black 6	I Red 7	IIIC Black 8	IIIB Black 9	I Red 10
II White 11	IIIA Black 12	II White 13	IIIB Black 14	IIIB Black 15	IIIC Black 16

Figure 8. Current arrangement of shim rod controls. The controls are spread over two panels.

It is recommended that all controls for the shim rods be placed on the same panel and that they be organized by functional group. A suggested layout is shown in Figure 9. The major feature of the layout is that all Group I, Group II, and Group III shim rods are respectively grouped together. Which rods are in which group, however, depends on the flux shape needs of the experiment and are subject to change from one experiment to another. It will be necessary to provide funds to change the behind-the-panel wiring in such a way that the functional groups are kept intact, regardless of the experimental flux requirements.

Panel R-5

Group 1					
1	2	7	10		
Group 2				Group 3A	
3	4	11	13	6	12
Group 3B				Group 3C	
5	9	14	15	8	16

Figure 9. A proposed layout of the shim-rod controls for the Engineering Test Reactor

2. The shim rod "raise-normal" switch located on Panel R-14 is used normally during shutdown for maintainance purposes only (see Figure 10). It is recommended that Panel R-14, because of its optimal visual position (within the operator's best field of view), be used only for those controls or displays which are used most frequently or are considered to be most important to reactor operation. The raise switch is not as important as other controls and, therefore, should be moved to a position of lower visual prominence.

Flux-Run Selector Switches

The two flux-run selector switches and flow-bypass selector switches located on Panel R-13 are normally used only once for "pre-positioning" prior to reactor start-up and are not used again for quite some time (see Figure 2). Because of this relatively low frequency of use, it is recommended that these controls be placed in a position removed from the operator's console. The operator's console should contain only controls with relatively high importance and/or frequency of use.

Emergency Reactor Shutdown Controls

The two manual reactor shutdown controls, the Manual Scram push button (Channel A and B) and the Manual Rundown pistol-grip switch are located on Panel R-14 (see Figure 10). The current reactor control circuitry is such that the initiation of either will cause a shutdown of the reactor. Both manual scram switches are protected by raised rings; however, the manual rundown switch is a pistol-grip control identical in size and shape to 21 other controls on the reactor console. It is recommended that the rundown activation switch be treated and protected in the same manner as the manual scram controls. Additionally, it is recommended that some form of protection be used to protect all emergency reactor shutdown controls from inadvertent activation. This protection should not interfere with intentional activation.

Emergency Equipment

It is recommended that all the emergency controls and displays discussed below be grouped together in one place with a boundary line separating the functions of these devices from other functional groups and placed at a height no greater than 73 in. (183.3 cm) (this is the overhead reach height of a fifth percentile woman).[a] All the emergency controls should be protected by a single plexiglass shield: this would eliminate the need for individual protective covers to prevent inadvertant activation.

1. The emergency evacuation controls on Panel R-2 are located 83-inches high, measured from the floor (see Figure 11). Personnel shorter than 5 ft 5 in. would require some elevation aid to assist them in operating these controls. It is recommended that these controls be repositioned within the reach envelop of the shortest person required to operate this system. More specifically, controls should be situated where the 5th percentile (height) operator can easily reach them. Relocation of these controls could be performed when the new continuous air-monitoring system is installed.

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a. MIL-STD-1472-B (Notice 2, 10 May 1978) Table XVII.

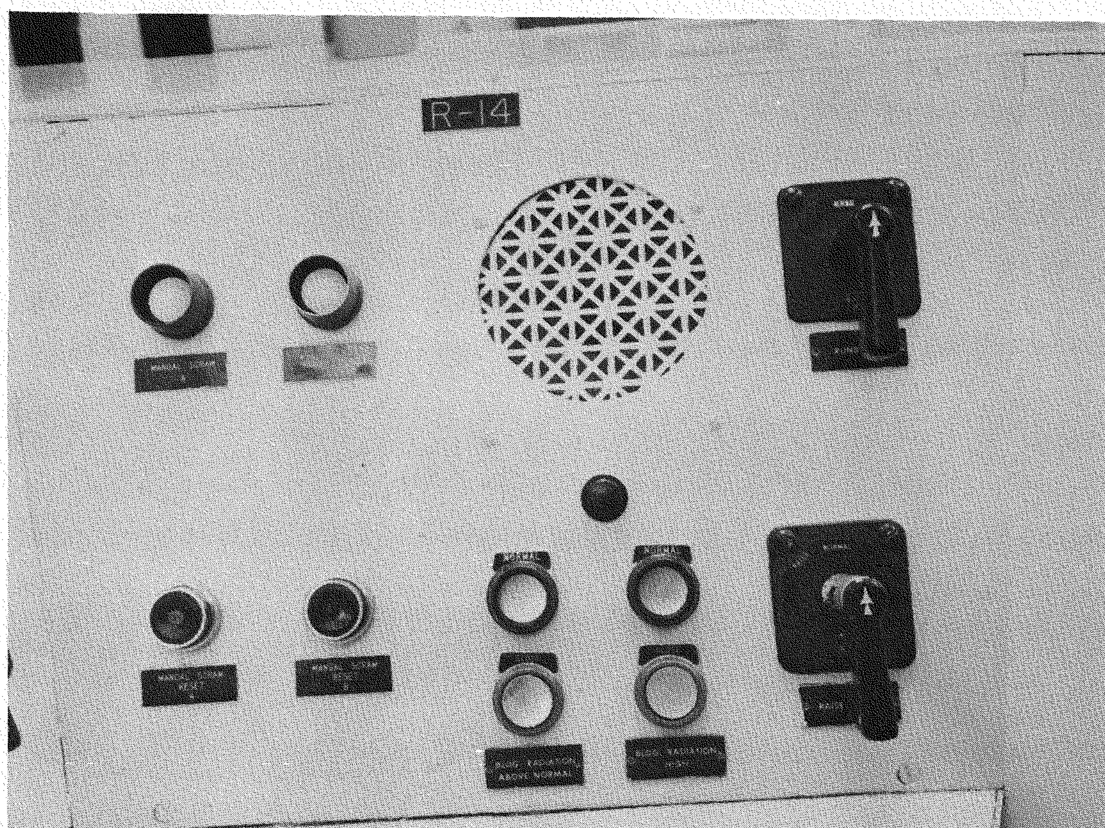

Figure 10. Panel R-14. 1) The raise-normal switch, "A", is used for maintenance only and should be in a less prominent position. 2) The manual rundown switch, "B", is not protected from accidental activation. 3) The Building air-seal switches, "C", are emergency control switches not used during normal reactor operation and should be functionally grouped with all other emergency controls. 4) The intercom volume control switch, "D", is not labeled.

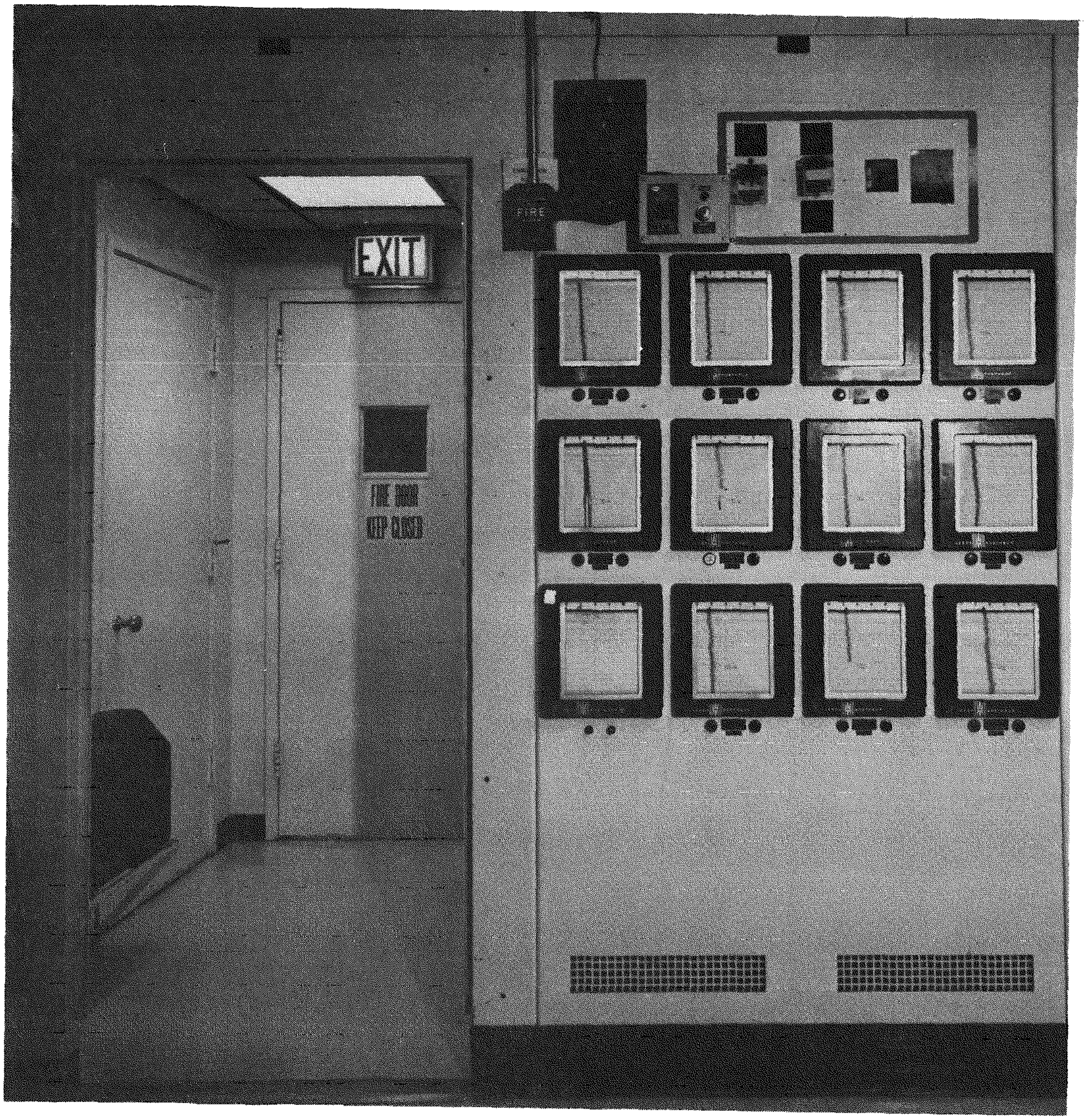

Figure 11. Emergency Controls on Panel R-1. All of these controls are located about 80 inches from the floor. They should be repositioned to be within the reach envelop of each operator.

2. The fire alarm control is located 81 inches from the floor and would prohibit people shorter than 5 ft 2 in. from reaching and activating this device.

3. The evacuation phone is located 87 inches from the floor and requires a person to be taller than 5 ft 5 in. in order to make a call. It is recommended that this phone be repositioned to a height within the reach of the shortest person required to operate it (73 in. from floor).

4. The wind speed and direction indicators and the evacuation route-direction switch are located 25 feet from each other (see Figure 12). Since the wind direction indicator information would be required before deciding on the correct position of the evacuation route select switch, it is suggested that these controls/meters be moved closer to each other, perhaps side by side.

5. The four building seal controls located on Panel R-14 are used only in the event of an emergency and not during normal plant operation (see Figure 10). It is recommended that these controls be removed from the reactor console and functionally grouped with other emergency instruments, e.g., the Evacuation Alert Panel. It is recommended that indicators be provided to indicate which controls have been activated.

6. The emergency radio is located adjacent to instrument Panel R-10, which is in the most remote corner from the exit (see Figure 12). Since this radio should be carried from the building in the event of an evacuation, it is recommended that it be positioned closer to the exit and made an integral part of the emergency control panel suggested above. The radio has, in the past, interfered with the evacuation Remote Air Monitoring system when the two were in close proximity to each other. Engineering solutions to eliminate this interference should be provided in conjunction with the radio relocation.

7. In the case of accidental activation of the Halon Fire Suppression System, the present manual inhibit switch must be depressed continuously

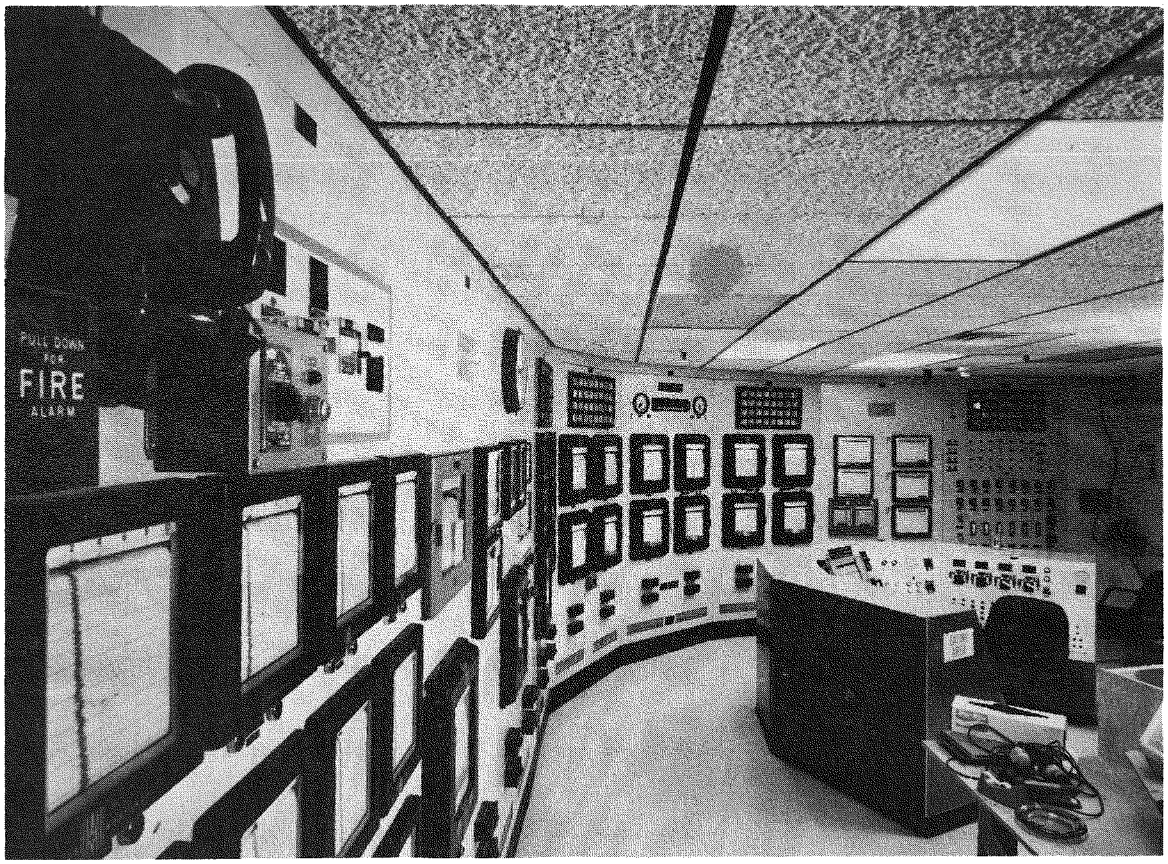

Figure 12. The evacuation route select switch, "A", and the wind speed/velocity indicator, "B", must be used together. It is recommended they be grouped together. The warning communication center radio, "C", should also be grouped with the other emergency controls.

until a key can be obtained to deactivate the control circuitry (see Figure 11). The height of this control (6 ft 7 in.) precludes people shorter than 5 ft 2 in. from reaching it. Additionally, the current control height could cause rapid hand/arm fatigue for these people, if they were required to continually depress the inhibit switch. It is suggested that this device be lowered to accommodate the shortest operators reach envelope (70 inches from floor). In addition, it might save time in an emergency if the reset key was suspended nearby via 5-pound safety wire so that the key could be easily located and used when needed. Another suggestion related to the Halon Fire Suppression Button would be to employ an activation device that need only be depressed once to inhibit the system instead of requiring continuous[a] control depression.

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a. It is not possible (physiologically) to maintain manual depression on a continuous basis. After a time, the control will begin to "chatter" as muscle strength ebbs. It can be assumed to be possible to maintain reliable manual depression no longer than 30 seconds.

VISUAL DISPLAYS

The issues addressed in this section concern:

- o Display illumination and glare
- o The format and precision of displayed information
- o The location and arrangement of displays.

Specific areas of concern are discussed below.

Reactor Control Room

Pen Recorders

1. The strip-chart recorders e.g., neutron-level indicators, have no operating range demarcation lines on the scales to project normal system operation profile goals (see Figure 13). If the glass faces of these instruments were marked with thin red strips of tape which corresponds to 100 $\pm$ 2% power, it could substantially aid operators in identifying quickly and accurately deviation from goal profiles without mental interpolation and reliance on memory alone. As an alternative, premarked chart paper could be used.

This approach is also recommended for period recorders, TRA-4-2B, DPRA-4-3A, and DPRA-4-3B.

The use of marker tape could be applied also to strip-chart recorders that require operators to detect and respond quickly to a system-limit condition as well as any anomalous operating profile.

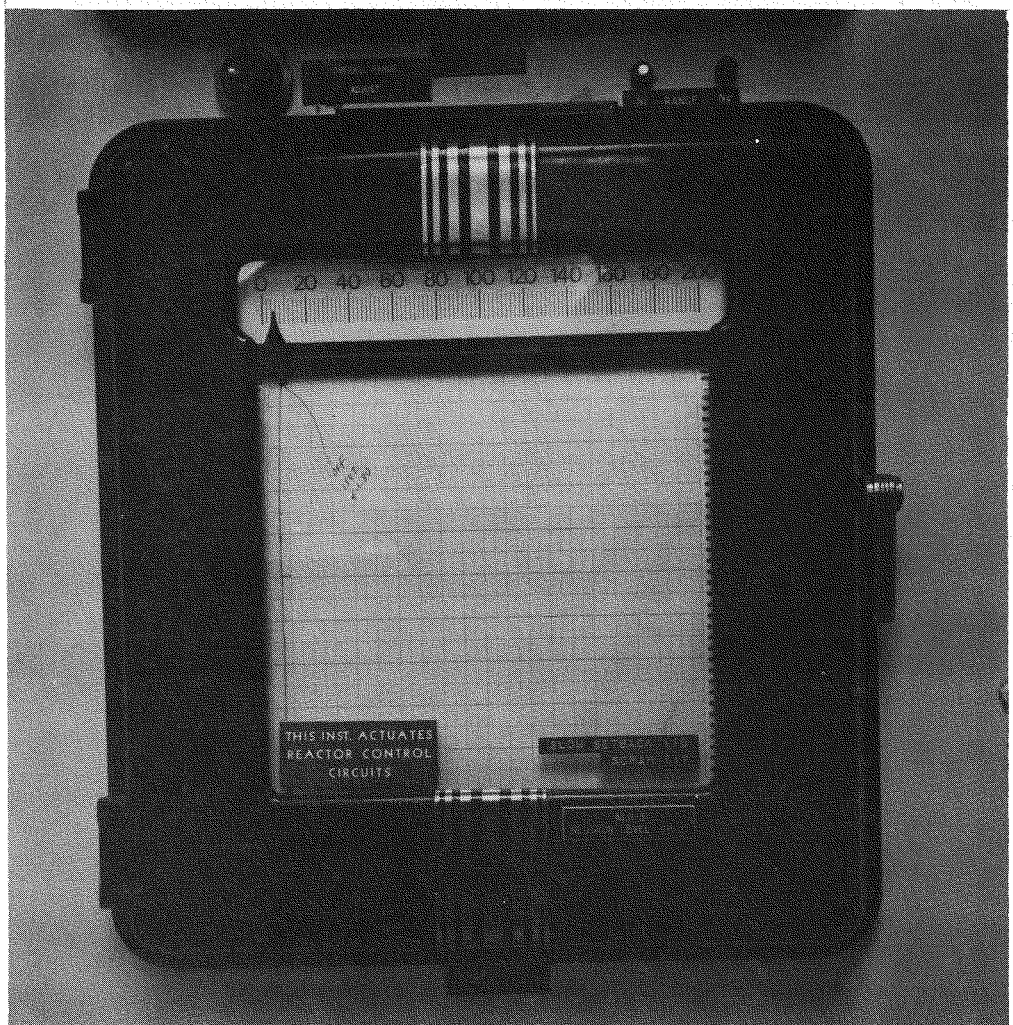

Figure 13. Neutron-level Recorder. An indication of the normal operating range of this meter would help the operator to determine when a deviation occurs.

2. The units of measure for the health physics strip-chart recorders RR-1A and RR-1B were not easily discernable due to the fact that they were handwritten with a grease pencil and partially hidden from view behind the meter cover (see Figure 14). Although this condition may seem minor, it should be corrected.

In the case of the stack monitor strip chart, there was no indication as to the units of measure associated with the display. Clearly labeling the units of measure on these displays is suggested.

3. In general, many of the strip chart recorders were not arranged by sequence of use. For example, the three meters required for the calculation of power (see Figure 15), i.e., differential pressure, differential temperature, and flow were physically separated by over 15 ft. Although these instruments are used as a secondary or backup means of calculating power, it might be advantageous to move these three separate groups of displays physically closer, using boundary markings to visually separate them. This would aid operators who often must examine these three displays and integrate the readings. The ultimate criteria used for instrument location should of course be human visual performance.

4. From the operators console position, it is difficult to clearly read the data which stems from the differential temperature and water-power strip charts. It is suggested that a digital display of water power be incorporated into the reactor control console, with numerals large enough to be easily readable by the operator.[a]

5. Scale graduations on meter PRA4-1C progress in units of 30. Therefore, it is difficult to determine accurately what numeric scale value the pointer is indicating in intermediate positions (see Figure 16). Scale graduations should progress by 1, 2, 5, or decimal multiples thereof.

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a. See details for recommendations under "Annunciators," Page 49, and Table 1, Page 53.

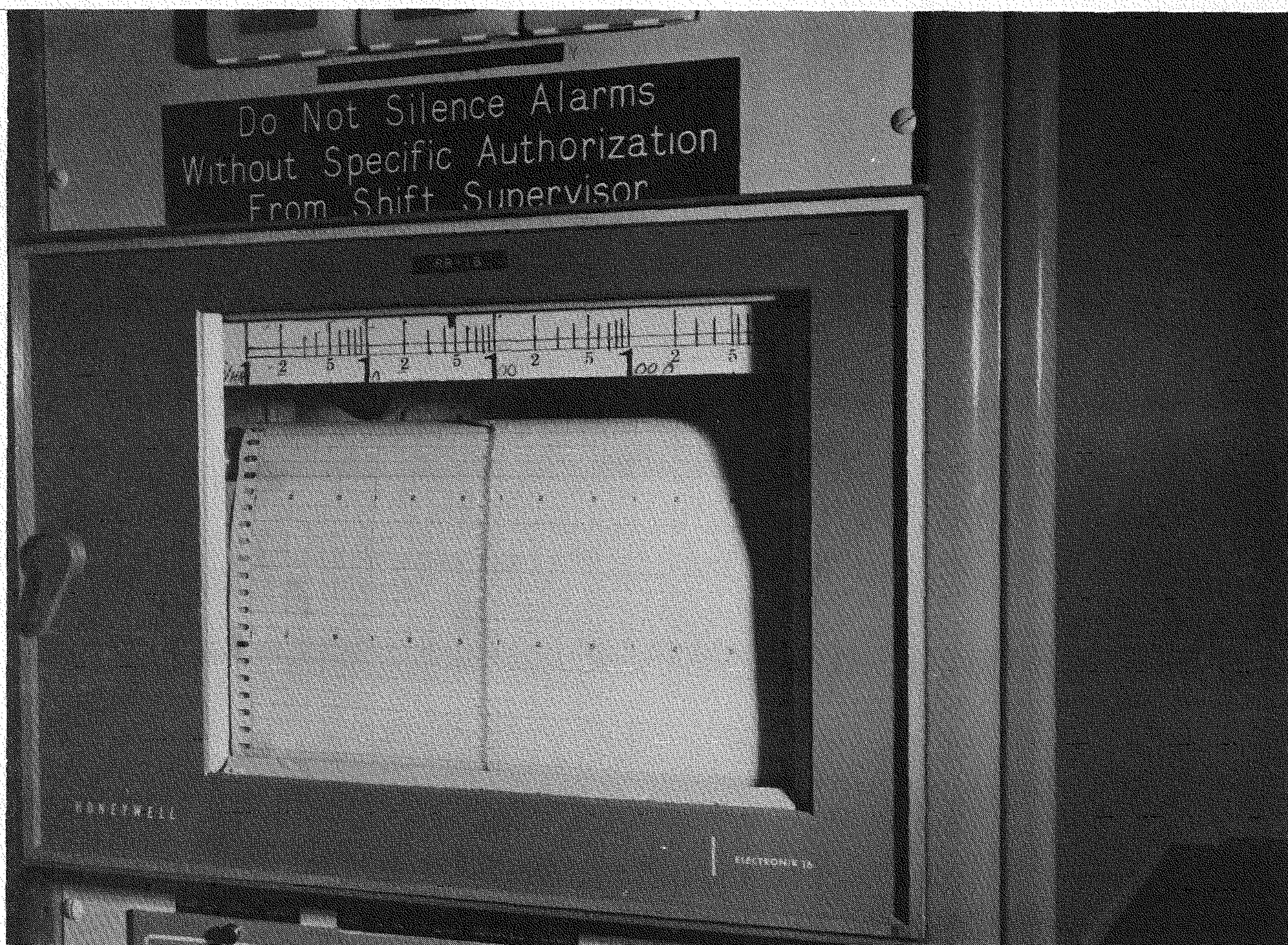

Figure 14. The units of measure on the Health Physics strip chart recorder RR-1A and RR-1B are written with a grease pencil and are partially obstructed by the meter cover.

Figure 15. Three meters--differential temperature, differential pressure, and flow must all be used to calculate water power. They should be grouped together.

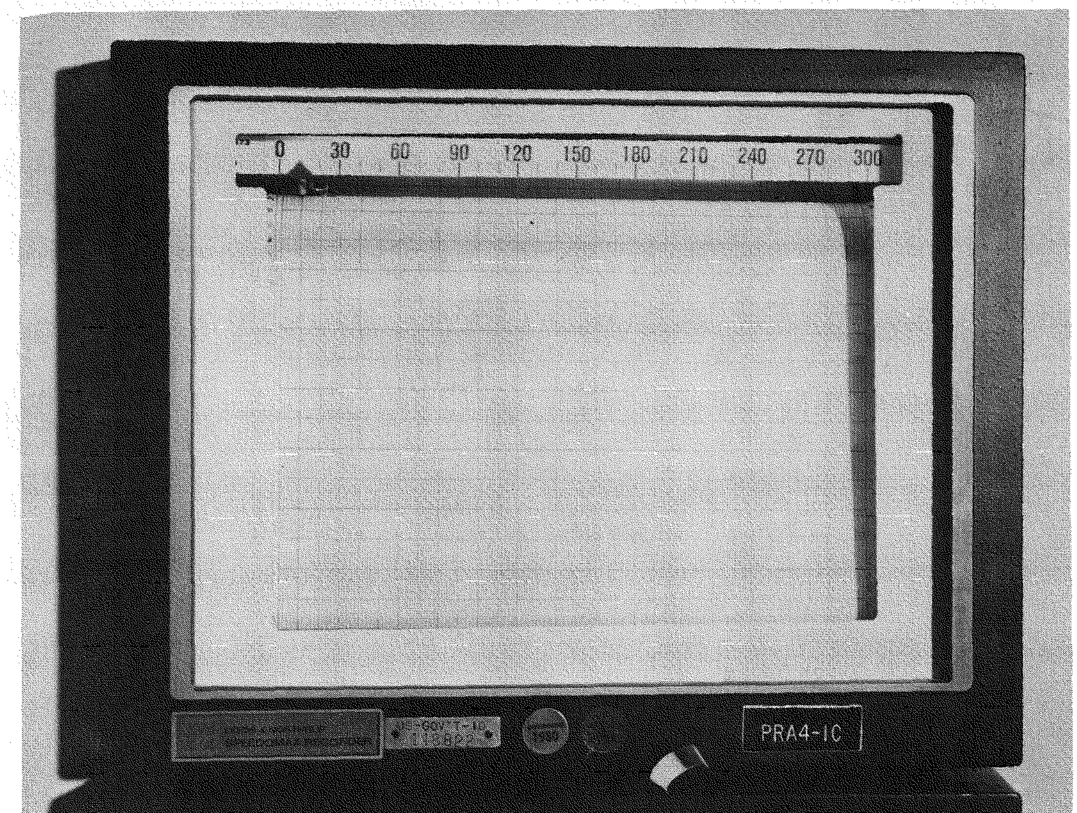

Figure 16. The scale graduations of PRA4-1C progress in units of 30. Scale graduations should progress by 1, 2, or 5 units or decimal multiples thereof.

6. The Westronics two-pen strip-chart recorder located on Panel R-13 monitors both regulating rods (see Figure 3). However, because only one regulating rod is used at a time, one pen always draws a straight line while the other records the position of the regulating rod. In essence, only one pen is giving useful information. Consideration should be given to presenting some additional information on the strip-chart recorder, such as neutron level to more effectively utilize the display. If the neutron level is presented on the console strip-chart recorder, a selector switch should be incorporated that will allow the operator to select between Channel A, B, C, or a position that will automatically choose the highest neutron level.

7. Adequate space has not been provided for the transient plotters. When used in the control room, they are set up on the top portion (flat surface) of the console. In this position, certain meters are obstructed from view. It is suggested that a more stable dedicated space be provided for these instruments.

Annunciators

1. Very poor contrast was observed between the black characters and ambient light source behind the display element on annunciators. Larger[a] characters with greater contrast are recommended to improve this condition.

2. Another problem noted with the annunciators relates to variation in element luminance. Due to inconsistencies in bulb elements, there is a rather diverse set of luminance levels in the annunciators. This condition causes visual noise and could be corrected by selecting lamps of equal wattage.

3. It was noted that 34 annunciator elements were marked with 1/4-in. red tape to indicate priority shutdown alarm conditions (see Figure 17). These

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a. See details of recommendations, Page 49 and Table 1, Page 53.

34 annunciator elements so marked were randomly scattered throughout Panel R-5, R-6, R-8, and R-10 annunciator displays.

To improve visual access and enhance alarm identification, it is recommended that all of these priority shutdown annunciators be grouped together on one centralized display panel. This would allow the operators to quickly detect a priority shutdown alarm without the degree of visual searching currently required, and also eliminate the need for makeshift tape markings. Another drawback to the current use of red tape is that one-half of the light source on the annunciator element is red. Therefore, a red-on-red (low contrast) visual condition exists which is more difficult to visually detect than red-on-white, for example.

An upgrade of the ETR annunciator system should include consideration of video graphics as a means of indicating anomalous conditions.

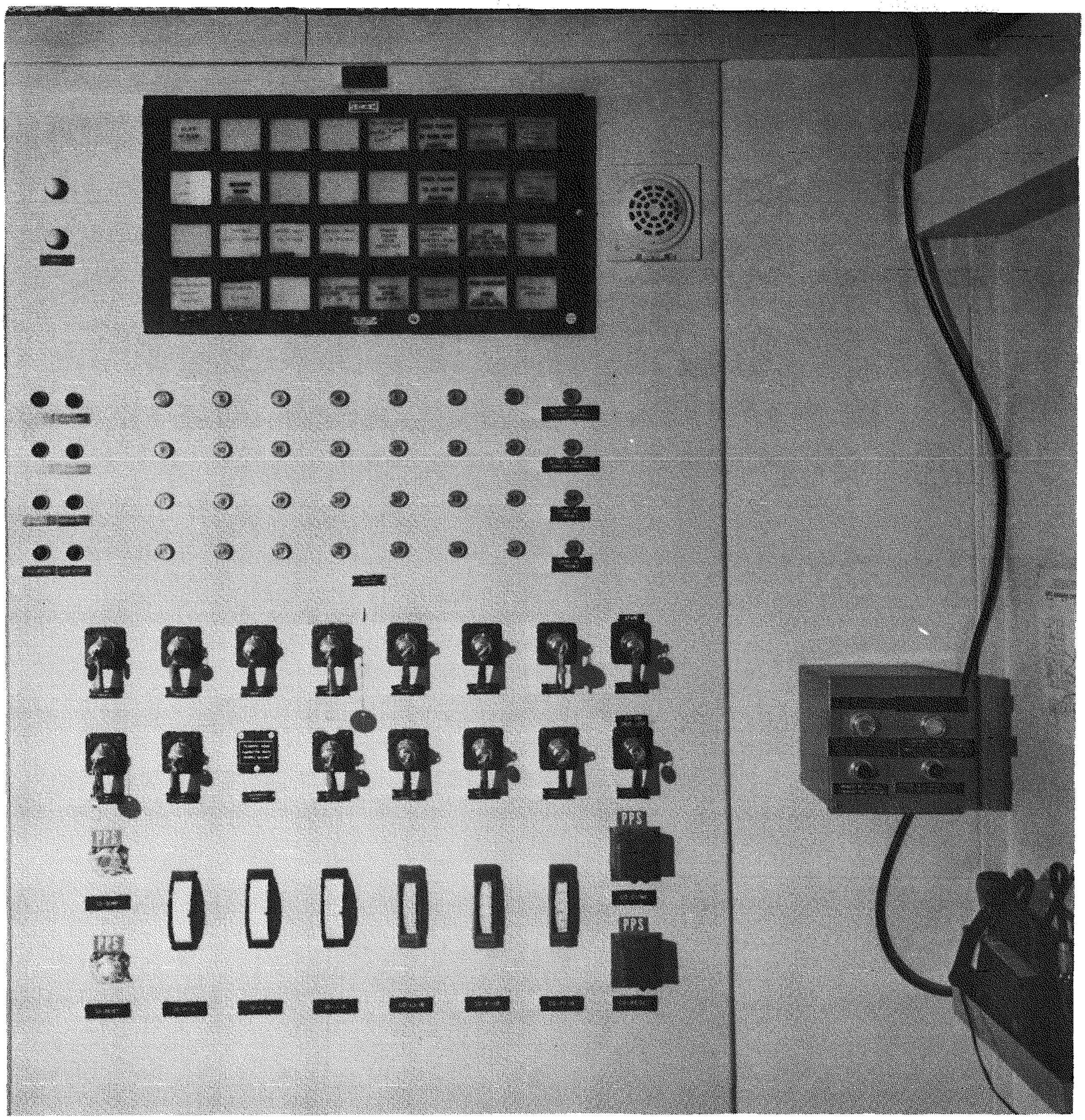

Figure 17. Panel R-10. 1) There are 34 annunciator elements marked with red tape to indicate their importance during shutdown. It is recommended these elements be grouped together. Many of the annunciator elements are very difficult to read from the reactor console. 2) Nonfunctional water loop W switches. These controls have been nonfunctional since 1970 and should be removed.

Indicator Lights

1. The seat and clutch indicator lights associated with each shim rod are very difficult to distinguish among the array of other lights on Panel R-15 and R-11. Because these lights are not used directly with either the shim-rod selector switch or the shim-rod position digital display, it is recommended that the seat-indicator lights be grouped together in one array, and that the clutch-indicator lights be grouped together in a separate array. The simple indicator lights should be converted to legend lights and be grouped in an array that mimics the arrangement of the shim rods. A suggested arrangement for the seat indicators is shown in Figure 18. A similar arrangement is recommended for the clutch lights.

			SEAT		
	Group 1				
1	2	7	10		
	Group 2			Group 3A	
3	4	11	13	6	12
	Group 3B			Group 3C	
5	9	14	15	8	16

Figure 18. A suggested arrangement for the seat and clutch indicator lights

2. There is no redundancy in the light bulb filaments for the incandescent displays. It is recommended that either dual-element light bulbs be used, or the indicator displays use two light bulbs.

3. There is no master test switch to check the lamps in the display. A master test switch should be incorporated to test the lamps. Also, there should be an indication or maintenance label to tell what kind of lamp needs to be used for replacement if a bulb burns out. Two types of light bulbs are used; short and long. If a short bulb is accidently placed in a socket requiring a long bulb, the short bulb can be removed only with great difficulty using a pair of tweezers and much patience.

4. Simple indicator lights are used throughout the control in the place of legend lights. It is recommended that each of the simple indicator lights be replaced with a legend light.

5. The preferred insert and shim-rod withdrawal select indicator lights are very difficult to read because of their close proximity to each other. Demarcation boundaries would aid the operators to discriminate between these two sets of lights.

Regulating-Rod Indications

1. There are three meters which display the regulating-rod position. The fixed-scale moving pointer circular meter on Panel R-12 and the strip-chart recorder on Panel R-13 both show the position of the regulating rod in its normal operating range (see Figure 19). The digital display for shim rod No. 1 and 10 (the regulating rods) serves as a third indicator. It is recommended that the shim-rod digital displays be used as a backup indication of the regular rod position, and the fixed-scale moving pointer displays be eliminated from the panel. An indication of the "percentage pile power" and a digital display of the water power could be substituted for these two meters.

2. The pointer on the servo indicator located on Panel R-12 can cover the numeral value it is pointing to. This is also true for the regulating-rod meters No. 1 and 2, also located on the reactor control console (R-12). Pointers should not obscure the numerals and scales on the meter face.

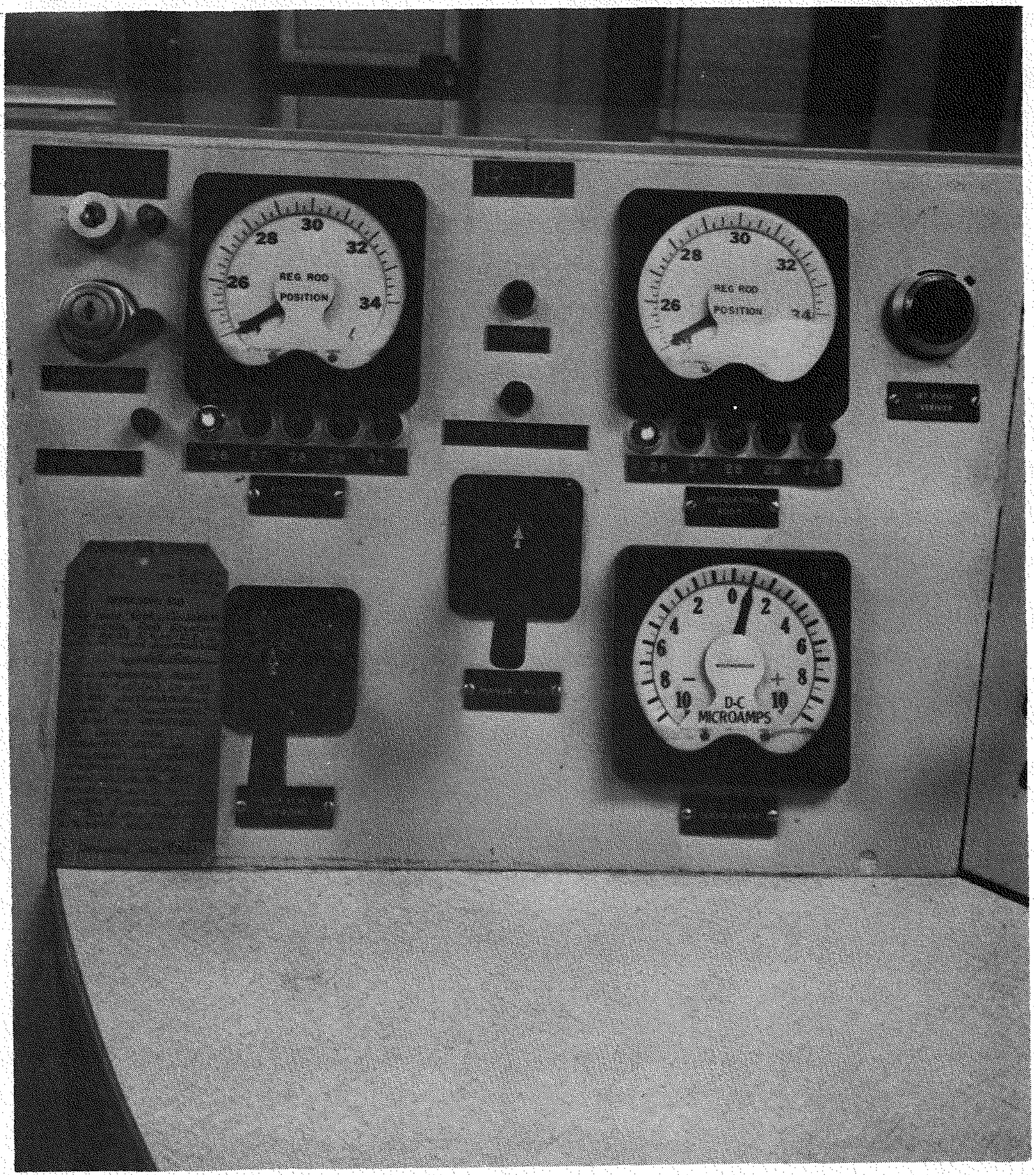

Figure 19. Panel R-12. 1) The two regulating rod-position indicators, "A", and "B" can be eliminated from the panel. There are two other meters which show the same information. 2) The simple indicator lights, "C", which warn the operator when the regulating rod position is out of the operating range should be replaced by legend lights.

3. The shim-rod digital meters are not labeled with any units of measure. It is recommended that all meters indicate the units that are being measured.

Annunciators

1. The annunciator acknowledge and test buttons were located too high and distant from the operators' central desk in the Process Control Room (see Figure 20). These buttons were not positioned appropriately in relationship to their relatively high frequency of use by the operators. It is suggested that all bulkhead-positioned annunciator acknowledge and test buttons be mounted on a unit which can be operated from the operators' desk. This should improve ease of access and reduce the level of irritation currently associated with these controls.

2. The primary loop emergency low flow annunciator element is presented only in the Reactor Control Room. Reactor Operators (ROs) transmit this emergency information to the Process Control Room via telephone where the Process Control Operators (PCOs) take appropriate action. For a short period of time after shutdown, the PCOs must continue to maintain flow; it is possible that during this period of time the ROs may not be in the control room to receive the emergency signal (they are not required to stay in the control room after a shutdown). For this reason, it is recommended that this specific annunciator element also be presented directly to the PCOs in the Process Control Room.

3. The core-deluge annunciator acknowledge and reset buttons are not in plain view, but are covered by a blackboard (see Figure 21). To access these buttons, one must reach around behind the blackboard and it is difficult to see what you are activating. These buttons should be relocated to the PCOs desk if the blackboard is not removed.

4. On pre-1975 annunciators, when a set-point value is momentarily exceeded, the red alarm light may go on and off before a PCO can detect which particular annunciator element alarmed. There should be some means of presenting information which allows the PCO to know what element entered into the threshold range. It is recommended that once an alarm has been sounded, a signal should persist until the operator acknowledges the

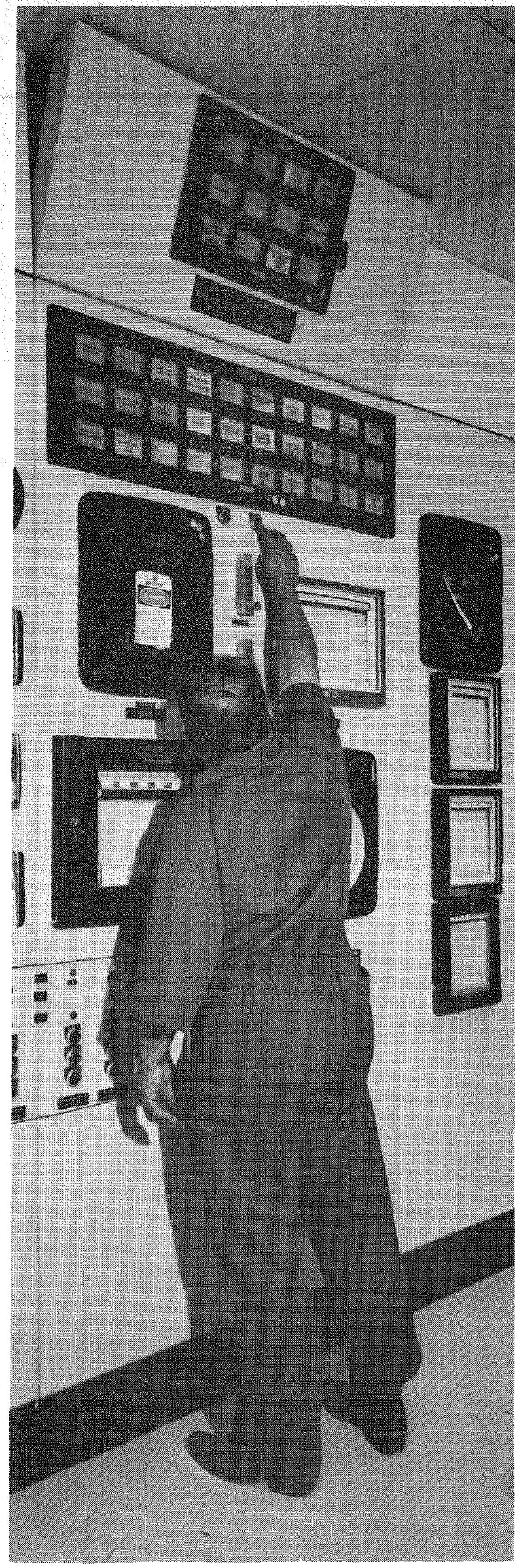

Figure 20. Annunciator Acknowledge and Test Buttons. Note height and location. These items should be repositioned.

Figure 21. Core deluge annunciator acknowledge control. Access blocked by permanent blackboard which precludes direct visual and hand access.

alarm. This will allow the operator to make an accurate determination of what system malfunction caused the alarm without the repeated interference of the horn.

5. Another problem noted was that during shutdown, once a set-point value is exceeded, the horn will occasionally continue to alarm after the acknowledge button is released. Because this situation requires an operator to continually hold the acknowledge button in a depressed position, it would be beneficial if the audible alarm was designed to cease after the acknowledge button is depressed the first time and not sound again until the alarm-indicating light is reset.

6. Display instruments and controls related in function were not close together and marked in a manner which made it easy to see functional relationships. It is suggested that functionally related displays and controls be moved closer to each other, and bounded by demarcation lines. Furthermore, there was considerable variability in location and arrangement of displays which indicated that new equipment was placed on the panel using "space available" as a placement criterion rather than Human/System performance.

7. Since all records throughout the entire facility (plant) are kept using military time, it is recommended that a 24-hour clock be installed in the Process Control Room.

Display Grouping

1. Instruments, such as emergency flow rate, Channel A, B, and C, are widely separated (over 12 ft) on the panel (see Figure 22). It usually makes good design sense to group instruments with common or similar functions relatively close to each other; then surround the area with demarcation lines which visually separate common instruments from other non-related instruments (see Figure 23 and 24). Other sets of instruments that could be rearranged for better functional grouping include:

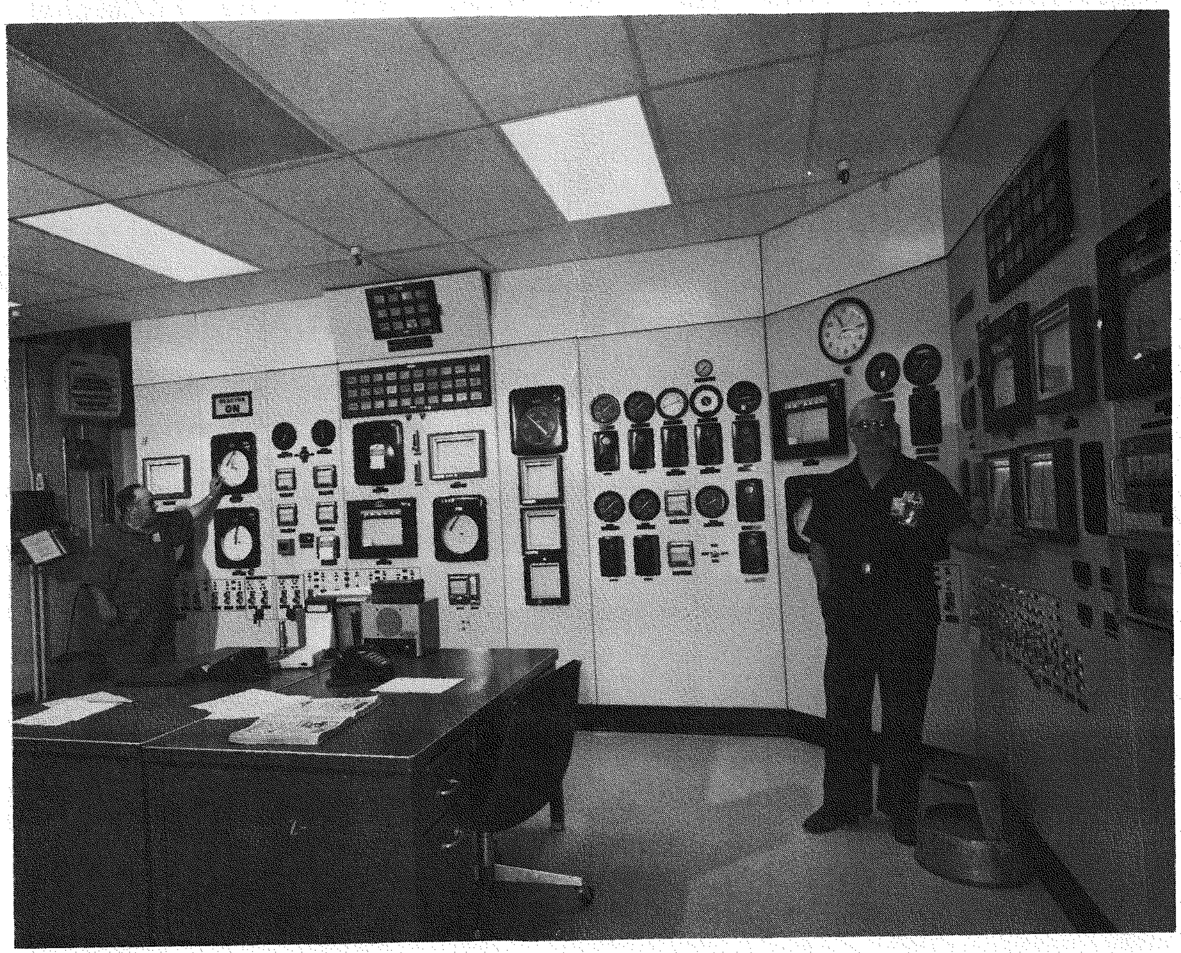

Figure 22. Relative location of emergency flow rate channels A, B, C. This is an example of poor functional grouping.

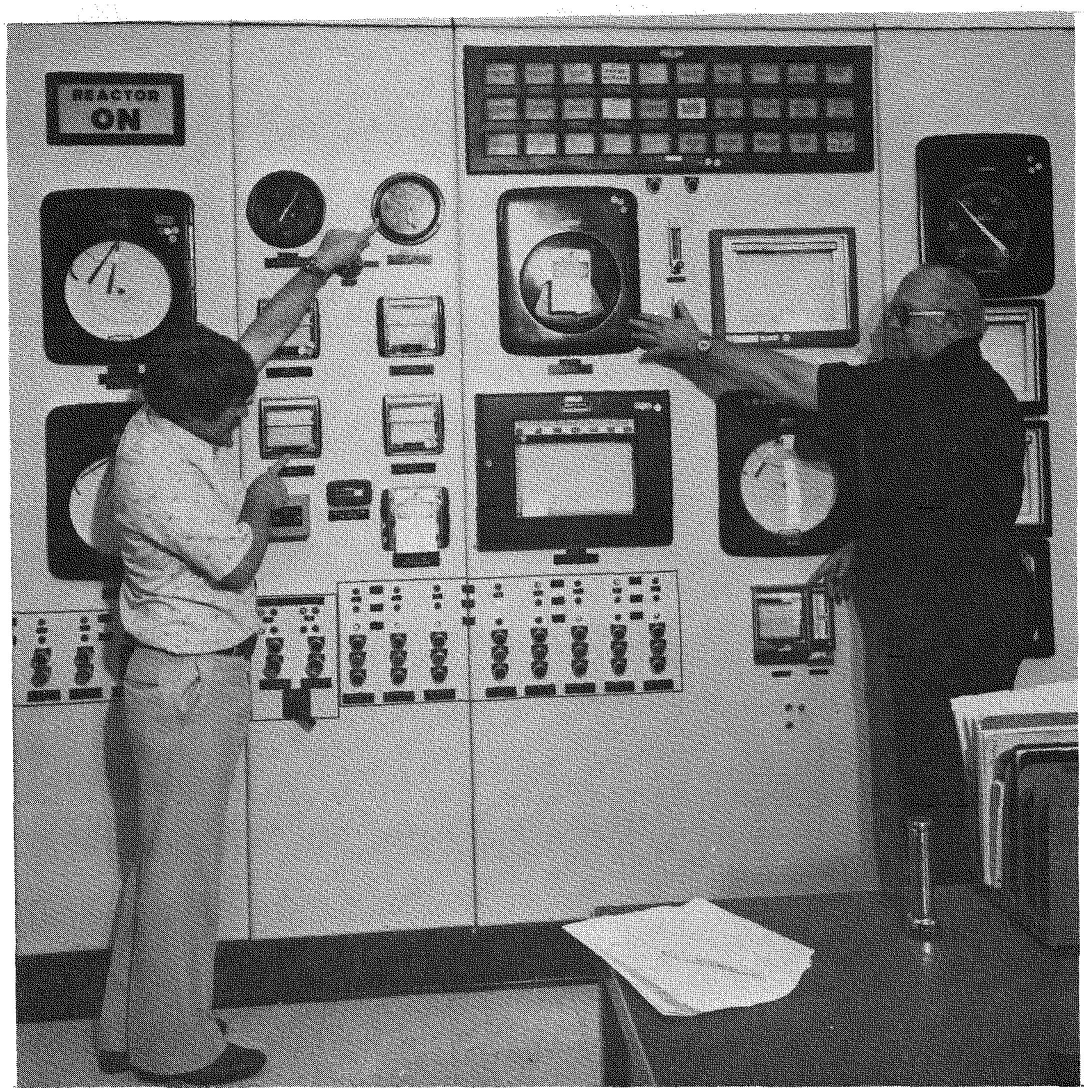

Figure 23. Example of poor functional grouping of degassing tank indicators. (People point to different, but functionally related displays.)

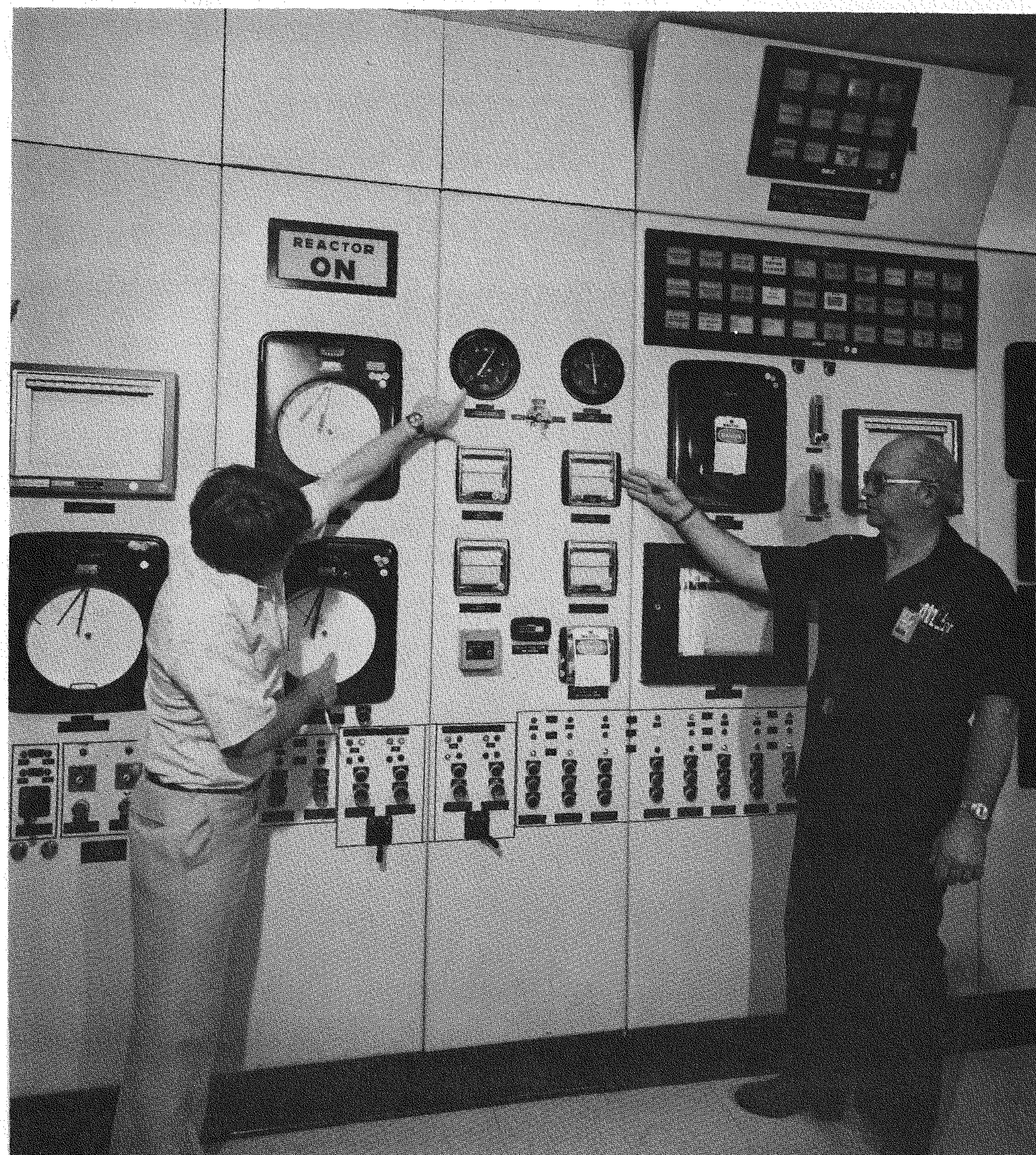

Figure 24. Example of poor functional grouping of pressure indicators. (People point to different, but functionally related displays.)

Degassing-Tank Indicators	Pressure Indicators
o LICA-4-1A	o PRC-4-3
o FR-4-15	o PR-4-2
o LRC-4-1B	o DPR-4-4
o FR-4-18	o PIA-7-4
o LIC-4-1A	

1. Figure 25 shows an example of how the primary coolant subsystem in the Process Control Room could be reconfigured to more adequately conform to MIL-STD-1472-B. Note that all functionally related flow, temperature, pressure, and level indicators are grouped together with appropriate labels and units of measure. In addition, each set of displays is configured according to function, sequence of use, and importance. For example, displays on the top of the console are more important than displays situated on the lower portion of the panel. Likewise, those instruments located on the left would hypothetically be used first, and those displays on the right side of the panel are accessed last when logging data.

2. Panel separation lines were found to interfere with demarcation strips (see Figure 26). If possible, all panel separation sections should be unobtrusive to the eye. Flat panel surfaces are preferred, with no sloping at the edges to create obtrusive panel lines.

3. Multifunction or dual-scale instruments such as TRCA-4-1, FPRC-4-2, and FRA-4-14A should be replaced with modern single-function displays, e.g., digital or Foxboro small strip chart (electronics) (see Figure 26). Dual-scale instruments can cause a higher error rate in reading and longer visual examination time required for extracting correct information.

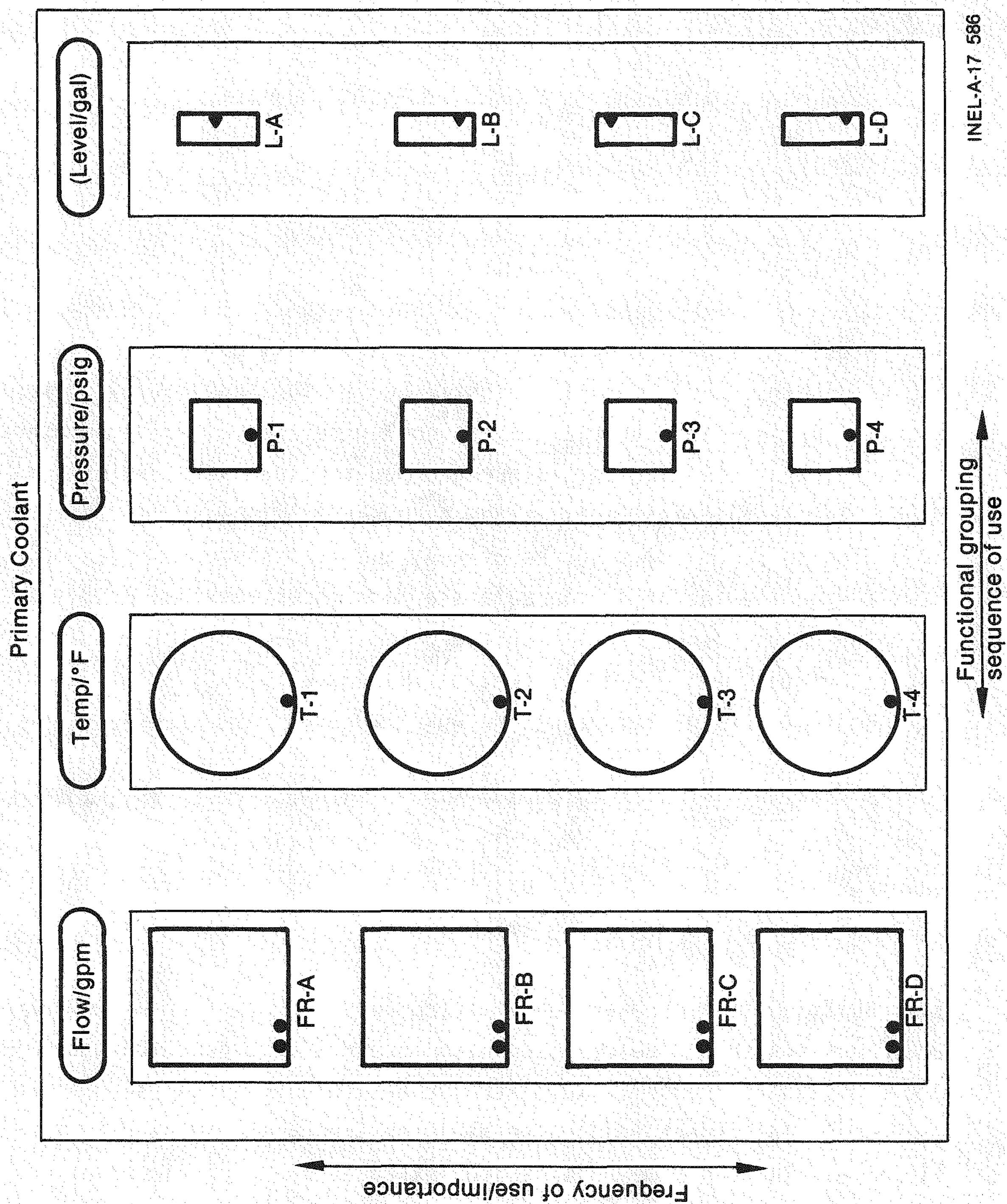

Figure 25. Hypothetical Display Layout which conforms to Human Factors Design Principles.

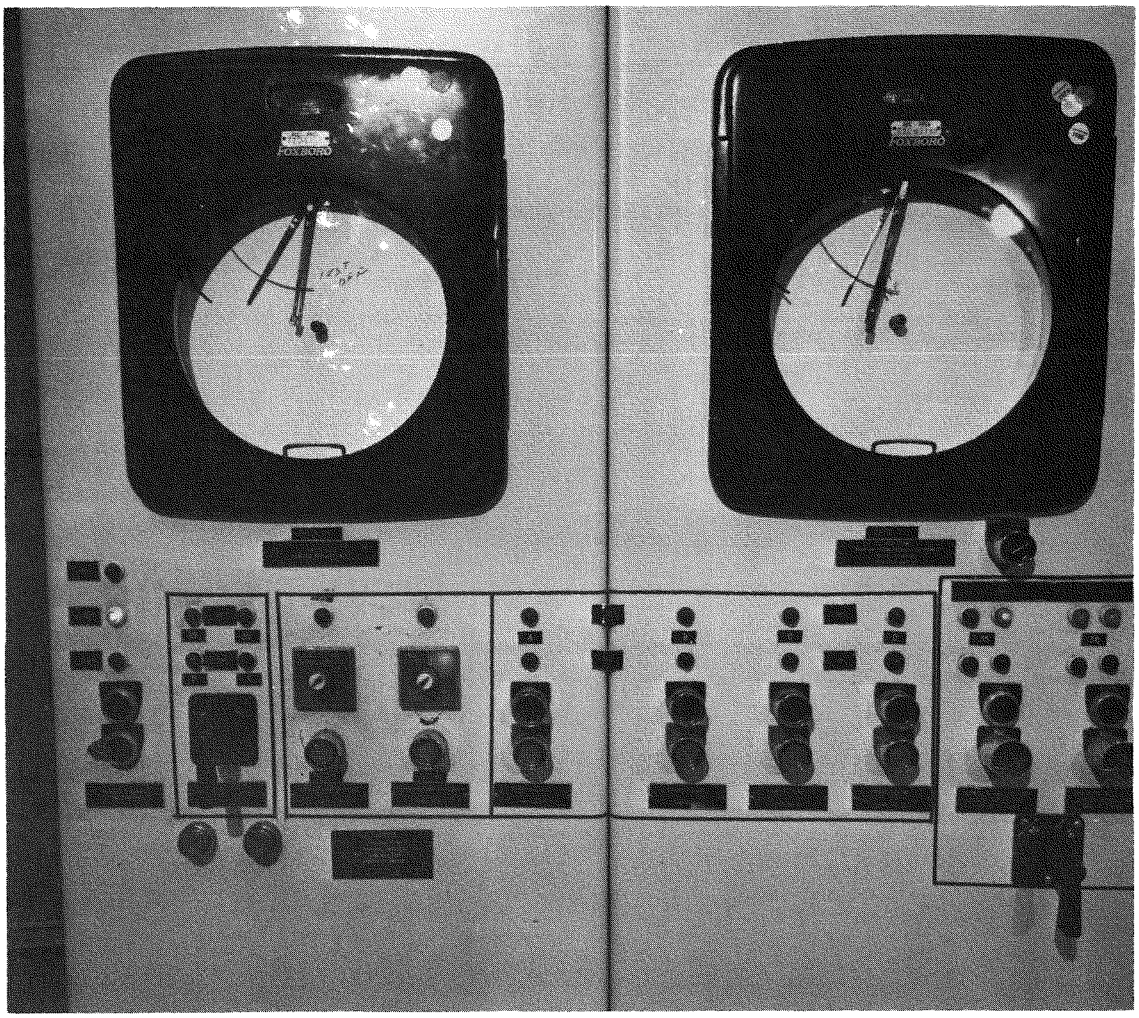

Figure 26. A. Example of visual interference caused by panel separation lines which intersect functional grouping demarkation lines.

B. Example of dual-scale function indicator (TRCA-4-1). These types of indicators should be replaced with single-function displays to minimize errors in reading.

4. Operators indicated that there are a number of display instruments that are normally never read but used only as a backup if the primary display instrument fails. There are two acceptable philosophies utilized in addressing this situation.

a. Place all backup instruments in a lower-priority position relative to primary displays; or,

b. Place all redundant backup displays adjacent to the primary instrument.

The following list of instruments were designated as serving as secondary functions with very low frequency of use:

- o FR-4-15
- o FR-4-16
- o FR-84
- o LRA-4-2B and FR-4-18
- o LIC-4-1A and FR-4-1A

5. Readings taken with F1.4-10 (flow indicator) never move outside the range of 0 to 50 gpm (see Figure 27). However, the indicator scales indicate 0 to 300 gpm. Due to the wide range of scaled values on this instrument, it is sometimes difficult to determine values falling between 0 and 150 gpm. It is recommended that this gage be replaced with another instrument which reads between the range of 0 and 160 gpm, and that the 0-300 gpm indicator be used only during core clean-up.

6. Another similar problem exists with PHRA 4/1 (reactor cooling). The actual operating ranges fall between 5.4 and 5.7; however, the range of scale values goes from 0.4 to 9.0. It is, therefore, difficult to read precisely. It is recommended that the scale-values range be changed to fall between 1.0 and 6.0, or a digital readout device be provided.

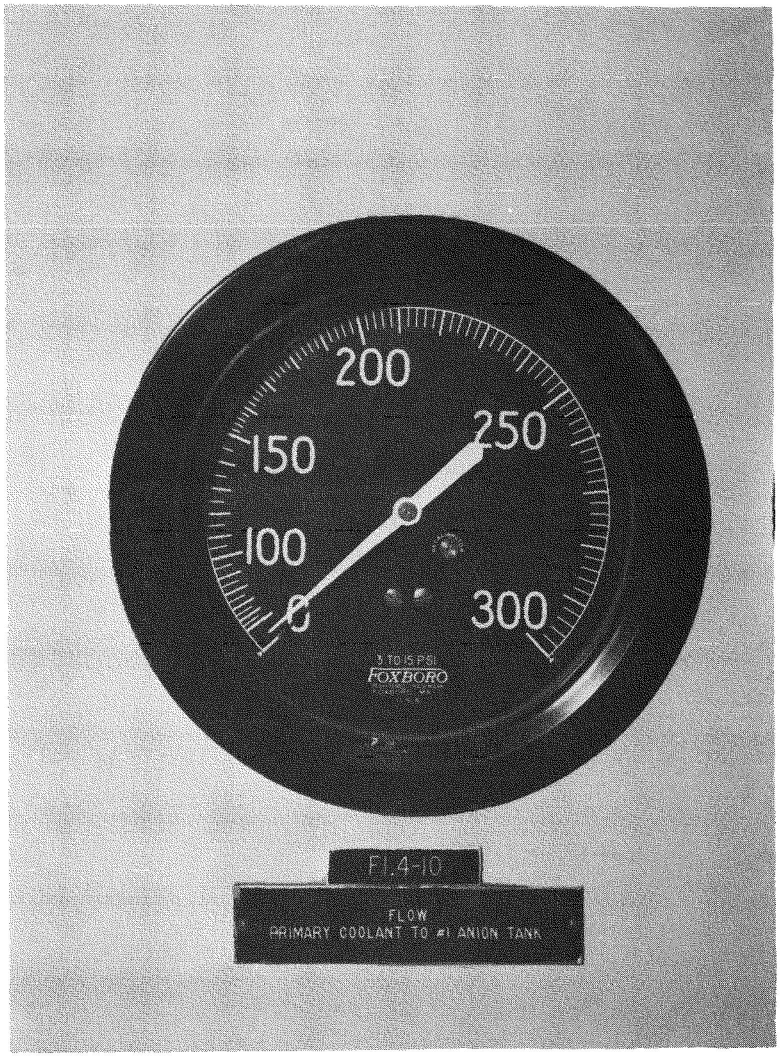

Figure 27. Example of a flow indicator (F1.4-10) showing a scale range of 0 to 300 gpm; the actual flow rates never exceeds 150 gpm. This instrument is over scaled by a factor of 2 which causes degraded precision in interpolation and reading.

The issues addressed in this section concern:

- o The placement of labels above controls and displays so that they may be rapidly and accurately identified and used
- o The legability and size characteristic of labels
- o The orientation of labels.

Specific areas of concern and suggestions to enhance the displays are discussed below.

Reactor Control Room

Annunciators

1. In general, we found the annunciator system to have inadequate labeling relative to the criteria of rapid and accurate reading (see Figure 17). From the operator's seated position, it is difficult to read the imprinted black characters clearly. This is due partially to the fact that suboptimal height, width, stroke width, and spacing between characters was noted. In addition, poor contrast exists between the lettering and the background found on the annunciator panels. Since the annunciator panel is considered to be extremely important to the operator, the following recommendations are suggested:

- o Letter width should be at least 3/5 of the letter height, with the exception of the letter "T" which should be one-stroke width wider, and the "M" and "W" should be at least 4/5 of the letter height.
- o Character spacing should be a minimum of one-stroke width.

- Height and width of letters and numerals should be determined from Table 1.

2. The annunciator acknowledge and reset buttons had no label to indicate the function of individual buttons. It is recommended that these components be clearly labeled (see Figure 28).

Health Physics Continuous Air Monitoring Instruments (Scales)

1. Strip-chart instruments No. RR-4-5 through RR-4-11 were labeled in such a manner that from the standing positions, one could not clearly read all of the label information. This is due to the fact that the bottom portion of these strip charts protrudes from the wall approximately 1.25 in., just enough to obscure portions of the function labels. If these labels were removed from the wall and placed directly on the bottom portion of the strip-chart recorder covers, this minor problem would be eliminated.

2. There was no functional label placed on the Quintector, Mark 2, No. F-2 so as to discern the use of this instrument. It is used as a radiation frisker and should be so marked.

3. MIL-STD-1472-B (9.5.5.3.3.) specifically states that irrelevant information, e.g., trade names, should be omitted from display equipment. Approximately 75% of all meter displays contained the manufacturers' name and model number on the front display panels (see Figure 29). In many instances, the letters comprising the manufacturers' name were more legible than the function label.

Figure 28. Annunciator Acknowledge and Reset Control. Notice the absence of labels.

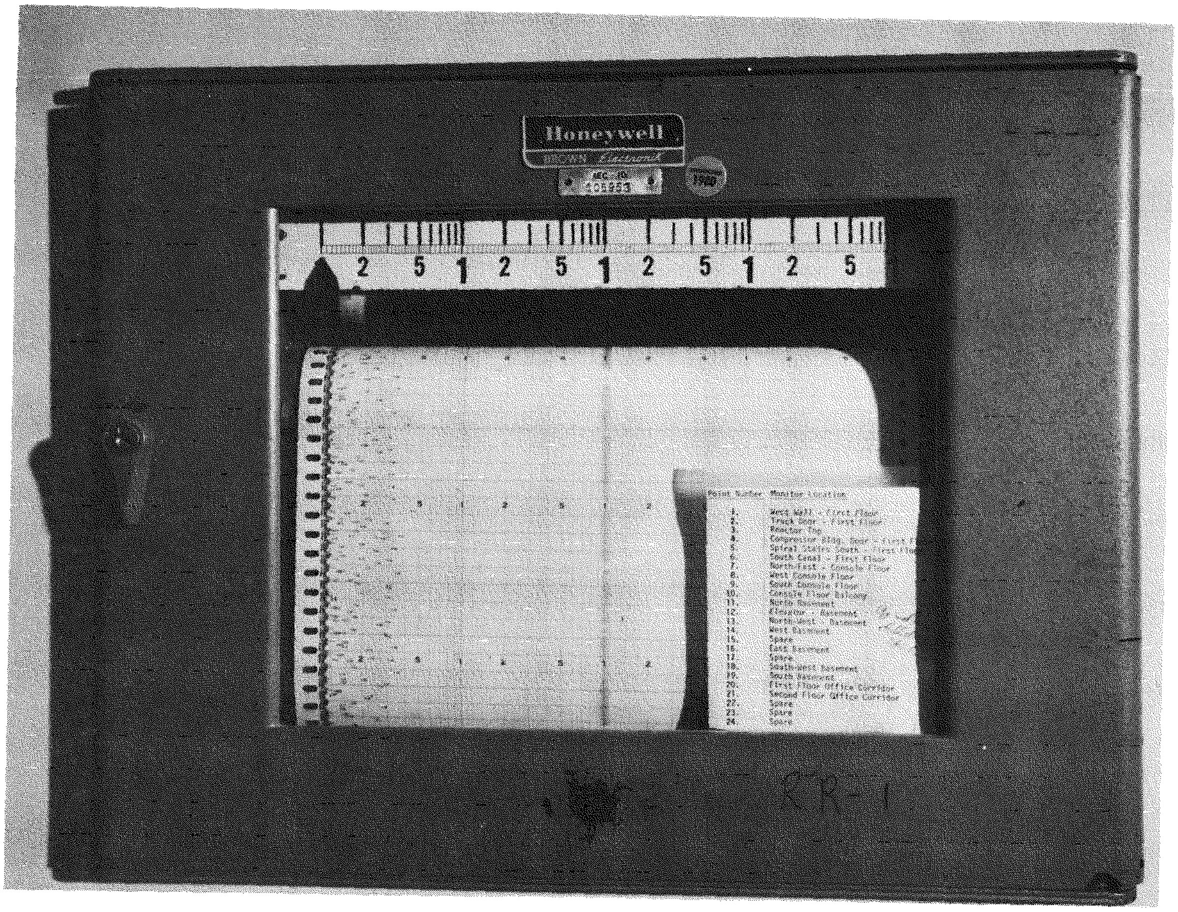

Figure 29. Example of a display which carries highly visible manufacturers label.

TABLE 1.[a] LABEL SIZE VERSUS LUMINANCE

Markings	Height[b] Below 1 ft-L ($3.4\ cd/m^2$)	Above 1 ft-L ($3.4\ cd/m^2$)
For critical markings, with position variable (e.g., numerals on counters and settable or moving scales)	0.20-0.30 in. (5-7.5 mm)	0.12-0.20 in. (3-5 mm)
For critical markings, with position fixed (e.g., numerals on fixed scales, controls, and switch markings, or emergency instructions)	0.15-0.30 in. (3.8-7.5 mm)	0.10-0.20 in. (2.5-5 mm)
For noncritical markings (e.g., identification labels, routine instructions, or markings required only for familiarization)	0.05-0.20 in. (1.3-5 mm)	0.05-0.20 in. (1.3-5 mm)

a. Table 1 taken from MIL-STD-1472-B, 1974.

b. Values assume a 28-in. (710-mm) viewing distance. For a distance, D, other than 28 in. (710 mm), multiply the above values by D/28 in. (D/710 mm).

4. The following controls or displays have no labels on them at all. It is recommended that each be clearly labeled.

Display or Control	Location
Intercom volume control switch	Panel R-14
Radio volume control switch	Panel R-15
Reg Rod 1 and 2 upper-limit indicators	Panel R-7
Reg Rod 1 and 2 lower-limit indicators	Panel R-7
Shim Rod 1-4 Preferred insert indicator	Panel R-15
Shim Rod 1-4 Withdraw selected indicator	Panel R-15
Shim Rod 5-16 Preferred insert indicator	Panel R-11
Shim Rod 5-16 Withdraw selected indicator	Panel R-11

Shim Rod

1. There are no overall labels to indicate the function of the shim rod group. No size coding is present to indicate hierarchy.

2. There are no boundary markers to identify the components which constitute a functional group. It is recommended that boundary markers with large, easily readable headings be placed around each of the functional groups. The degree of redundancy observed on a number of labels can be reduced by the use of one major label instead of multiples. Subgroups within the functional groups should also be separated by lines and labeled. A boundary line drawn around Shim Rods 5-16 on Panel R-11 and labeled, "shim rod" would eliminate the need to have the words "shim rod" on each label. An additional border surrounding each shim-rod group would make the individual control groups much more visible. The core-position labels associated with each shim rod are larger than the name label. Because the name label is more important than the core-location label, it is recommended the name label be made the larger of the two labels.

Motor-Operated Rheostat

The regulating-rod position indicator lights currently placed directly beneath the regulating-rod position markers on Panel R-12 correspond to a number of reactor set points and enable switches (see Figure 19). The indicator lights are named, color coded, and used to mean the following:

Label Name	Lens Coloring	Meaning
26	Red	The MOR goes out of servo control
27	Amber	An automatic rundown is initiated
28	Amber	The shim rod which has been selected to preferred insert will begin to insert
29	Amber	No shim rods can be withdrawn
34	Green	The control rod is at its upper limit

In reality, the relevant information being transmitted to the operator is not the regulating-rod position, but what the system is automatically doing to compensate for the fact that the regulating rod has driven in to a certain point in the core.

It is recommended that the simple indicator lights be replaced with legend lights that are color coded and labeled as follows:

Recommended Label Name	Recommended Color of Lights
34-Upper Limit	Amber
29-Withdrawal Inhibit	Red
28-Preferred Insert	Red
27-Rundown	Red
26-Servo-Limit Position	Red

Process Control Room

The most important controls in the Process Control Room were not labeled or marked in a significantly different manner so as to easily identify the dimension of relative importance, e.g., PCS Valves P11, P12, primary pumps, emergency and shutdown pumps (see Figure 30). Furthermore, the following components were not functionally labeled:

- o APR-4-1A
- o DPR-4-4
- o TIA-4-6
- o FR-4-18
- o CR-4/1.

Many labels used abbreviations such as DBR, APR, etc., which do not convey any standard meaning.

Numerous examples were found where manufacturers' names appeared on display cases. Where possible, manufacturers' names should be removed from the front display faces.

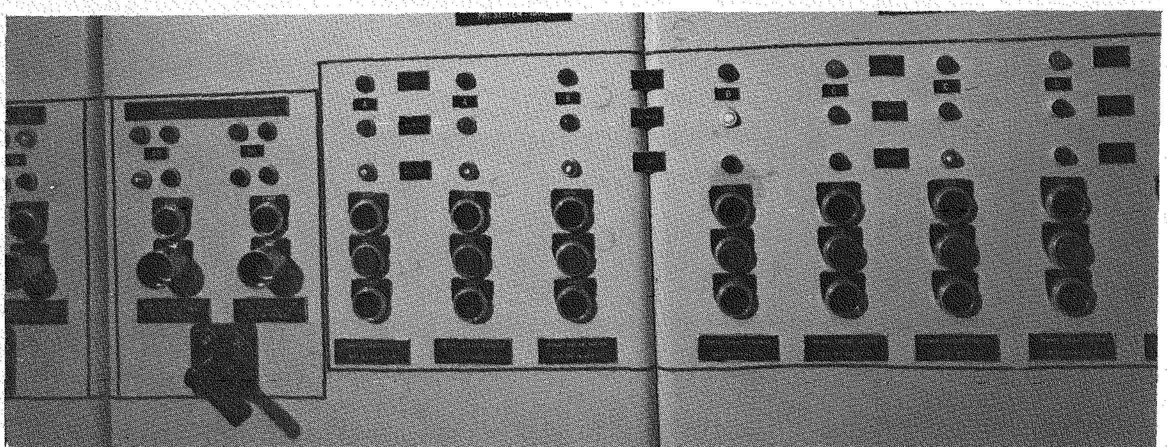

Figure 30. Example of very important primary cooling system valves P_{11} and P_{12} which failed to be differentially or specially treated from other less important valves, requiring more visual search and discrimination time from operators. The separation line also causes some operator confusion.

COLOR CODING

The issues addressed in this section concern the use of color to convey specific meanings. The color meanings used as basis for this analysis are:

- RED shall be used to alert an operator that the system, or any portion of the system, is inoperative, or that a successful mission is not possible until appropriate corrective or override action is taken. Examples of indicators which should be coded RED are those which display such information as "no-go," "error," "failure," "malfunction," etc.

- FLASHING RED shall be used only to denote emergency conditions which require operator action to be taken without undue delay to avert impending personnel injury, equipment damage, or both.

- AMBER shall be used to advise an operator that a condition exists which is marginal. AMBER shall also be used to alert the operator to situations where caution, recheck, or unexpected delay is necessary.

- GREEN shall be used to indicate that the monitored equipment is in tolerance or a condition is satisfactory and that it is all right to proceed (e.g., "go-ahead," "in-tolerance," "ready," "function activated," "power on").

- WHITE shall be used to indicate system conditions that do not have "right" or "wrong" implications, such as alternative functions (e.g., reg rod No. 1 selected for control) or transitory conditions (e.g., action or test in progress, function available), provided such indication does not imply success or failure of operations.

o. BLUE may be used for an advisory light, but preferential use of BLUE should be avoided.

Specific suggestions to correct observed variances from this standard are discussed below:

Reactor Control Room

1. In the reactor control room, the colors RED, AMBER, BLUE, GREEN, and WHITE were used to convey the following meaning, depending, of course, on which subsystem a particular color was used:

Color	Current Meaning(s)
RED	Alarm, abnormal Caution Group 1 control handles Shim rod being withdrawn
AMBER	Caution Abnormal condition ON Failure Normal Preferred Selected High Low 1% 100%
BLUE	Abnormal (clutch disengaged)
GREEN	Incoming call Power on Shim rod being inserted
WHITE	ON-Activated

From the preceeding list, it is apparent that there is no consistent meaning for the use of the Amber color. According to MIL-STD-1472-B, AMBER should be used only to advise an operator that some marginal system or component condition, recheck, or an unexpected delay is necessary.

Some operators commented specifically that due to the profusion of lights (amber), it is difficult sometimes to quickly and accurately discern which shim rod has been selected for operation. It is recommended that consistent meanings color-code practices be established for standardizing the general meanings of colors. These standard practices should be formulated using military standards in conjunction with operator testing and training.

2. It is recommended that wherever it is necessary to indicate conditions such as "On" or "Selected" that do not have "right" or "wrong" implications, WHITE legend lights should be employed. If this recommendation is adopted, at least 16 Amber lights may be eliminated from the panel.

3. Each of the shim-rod groups (handles) are color coded. While this is a good first step, this could be improved upon by color coding in conjunction with shape and functional grouping. This would aid subgroup identification. The colors chosen for each group should be consistent with the meaning of colors throughout the reactor plant. Currently, Red is used for the Group I shim rods. Red as used here does not mean emergency. Brown, Grey, or White would be much more appropriate colors as they do not denote the meaning "emergency".

4. All displays which relate directly to a control should be color coded in the same manner as the control. The shim-rod position meters should be coded the same color as the shim-rod control switches.

Process Control Room

The following presents a summary of the different uses of color meanings within the Process Control Room.

Subsystem	RED	BLUE	GREEN	AMBER
Valves	Closed		Open	Intermediate
Pumps	ON		OFF	
Emerg Pumps[a]	ON	Standby	ON	
Fans	Reverse		OFF	Forward
Health Physics	High			Low
	Selected			

a. The Green lights associated with the emergency pumps should be eliminated, since the two colors are confusing and redundant in meaning, e.g., both Red and Green mean "ON."

MISCELLANEOUS

Reactor Control Room

Reactor Console

Although ample space has been provided for books, schematics, etc., on top of the operator's console, there is no plastic guard or water-tight lip to prevent objects, such as books or coffee cups, from falling onto the actual meters and controls. Such situations have been known to occur on other similar consoles and, for this reason, it is recommended either a barrier be provided to prevent objects from falling onto the face of the console or the top of the console be angled in such a manner as to preclude the placement of objects on it. (Note that if the angle alternative is chosen, additional work space may need to be provided.)

Glare

When control room overhead lights are turned on, glare from these lights is reflected by the MOR Meters No. 1 and 2 and by the R5 and R6 annunciator panels. However, during operational conditions, these overhead light are turned off; hence, the violation is of little or no consequence, except when tours come through that require the lights to be turned on.

Nonfunctional Equipment

The Water Loop W Switches located on Panel R-10 have not been in use since 1970, 10 years ago, (see Figure 17). It is unlikely that these controls and meters will ever be used again, primarily because the involved circuits do not conform to current standards (RDT-26T). For this reason, and also because of the potential gain of an additional 9 to 12 square feet of panel space, it is recommended that all nonfunctional equipment related to this system be physically removed from the main control room.

The Sound Powered Phone Volume Switches located on Panel R-15 underneath the intercom are nonfunctional and should be removed from the panel.

Sufficient funding should be provided in the budgets for new equipment to remove obsolete or unused equipment.

Process Control Room

Nonfunctional Equipment

The following nonfunctional equipment should be removed from the display panels, since they serve only to take up space and create additional visual noise:

- Compressor Annunciator
- TRA-5-7
- OCD Phone (sound powered) and jacks
- Air heater firing-sequence system
- Thermocouple auto reference
- Remote set-point system
- OCD A&P compressor panel.

Vibration-Sensitive Equipment

During the course of our evaluation, a power breaker CE bus opened in response to a cabinet door being closed. The power relay was positioned in the cabinet door and the closing action produced vibration of sufficient magnitude to trip out the relay.

It took approximately 13 minutes to recover the relay and properly set the appropriate syncro controls. Had the reactor been at power, there is an excellent chance that a scram would have occurred with scram recovery unlikely due to the length of time it took to reset the appropriate controls and meters. Having the opportunity to actually witness this condition, the following comments are made:

1. Sources of vibration should be inspected to reduce the possibility of inadvertent reactor scram, relay trip, etc.

2. Recovery controls for a relay trip out are placed too far apart (50 feet) and should be moved closer together.

3. The operator (if alone) has to run back and forth (100 feet round trip) from the RPM controller to the power-breaker circuit.

4. The 24GH Tie Breaker Syncro is an extremely poor control in that a full 10 minutes elapsed before this instrument responded to the operator's control actions.

APPENDIX A

CRITERIA SELECTION

Figure 31 presents a graph of the theoretically based rationale used in developing measures for the evaluation of reactor control rooms. By using a multidimensional approach to criteria selection, we attempted to maximize criterion relevance in the identification of problems most related to system and human performance.

MIL-STD-1472-B

Military standards were reviewed and incorporated into an appraisal checklist for human factors evaluators to use in the field. The items chosen to be incorporated into the checklist were reviewed by at least three human factors specialists to make certain that each standard included was relevant to nuclear control room layouts. This Appendix contains the checklist document used in the evaluation.

Operator Appraisals

Equipment/control operators are quite frequently a valuable data source used in identifying design problems and inadequacies. For this reason, each of the seven operators was interviewed using a structured format to ascertain:

- the function of each control subsystem
- the conditions under which the control subsystem is utilized
- the frequency of use
- the consequence of human error

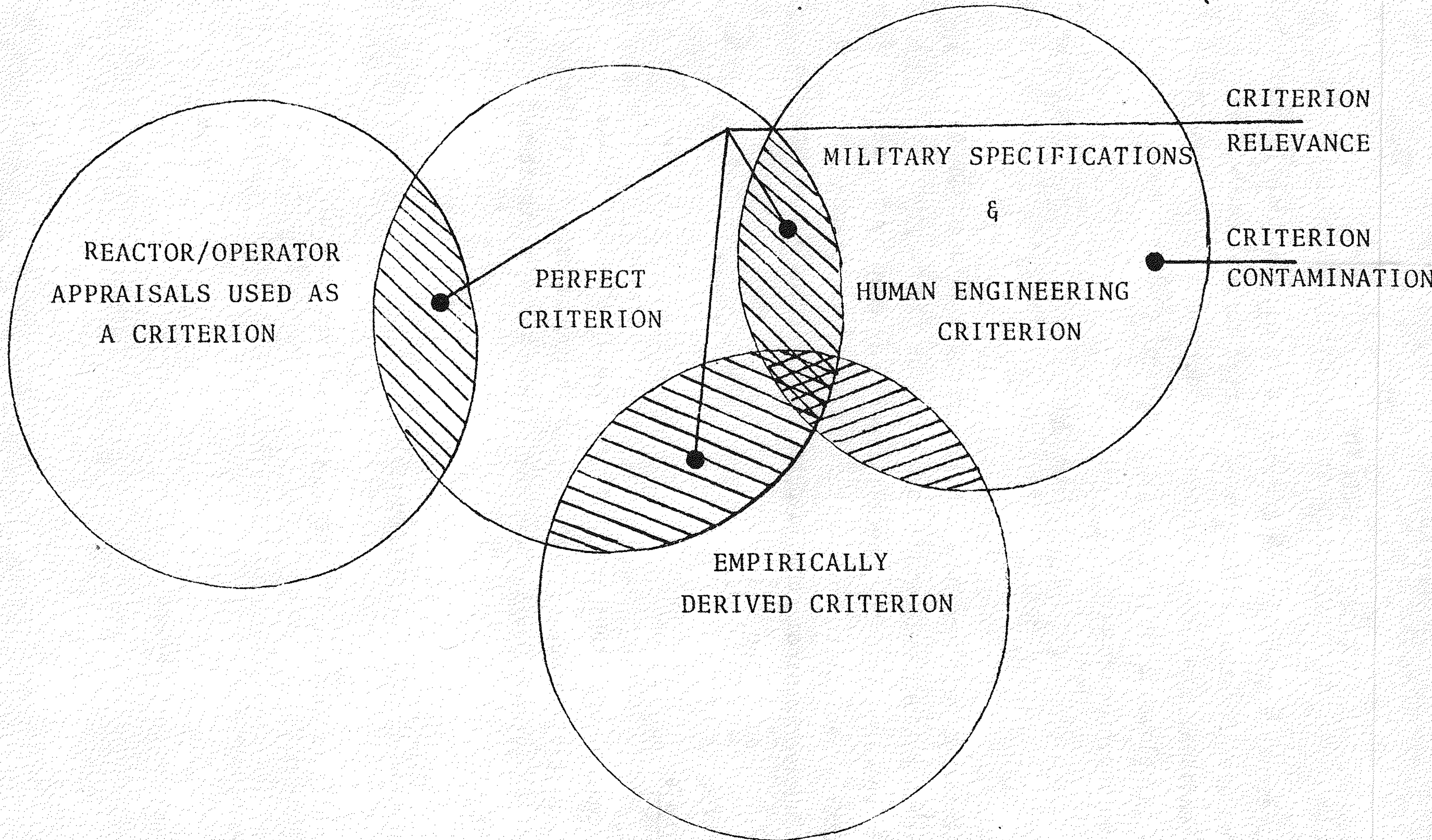

Figure 31. Theoretically Based Criterion Rationale

o what could be changed or eliminated to make their tasks

a) more efficient

b) more comfortable

c) and lower the perceived P (error).

APPENDIX B

METHODOLOGY

Tools

The measurement instruments used during the course of our evaluation consisted of the following:

1. Dividers (4-in.)--manufactured by B and S Manufacturing Company, Providence, R.I.

2. Measuring Tape (12 ft)--Lufkin 1/2-in. roll ruler

3. Ruler (12 in.)--Westcott Model R501-12 Wooden ruler with metal edge

4. Outside calipers (6 in.)--manufactured by the L. S. Starrett Company, Athol, Mass.

5. 35 mm camera--Canon F1 with 50 mm cannon f-1.4 lens

6. Film--Kodak Veri Color II; ASA-100

Procedures

Figure 32 depicts the procedure flow utilized by our evaluation team. Upon the completion of our MIL-STD-1472-B checklist form, two investigators were informally briefed regarding nuclear power plant operations at ETR. Other briefing interviews were scheduled with shift supervisors in order to gain permission to collect the necessary data and to ask specific and general questions about the reactor system and its operation.

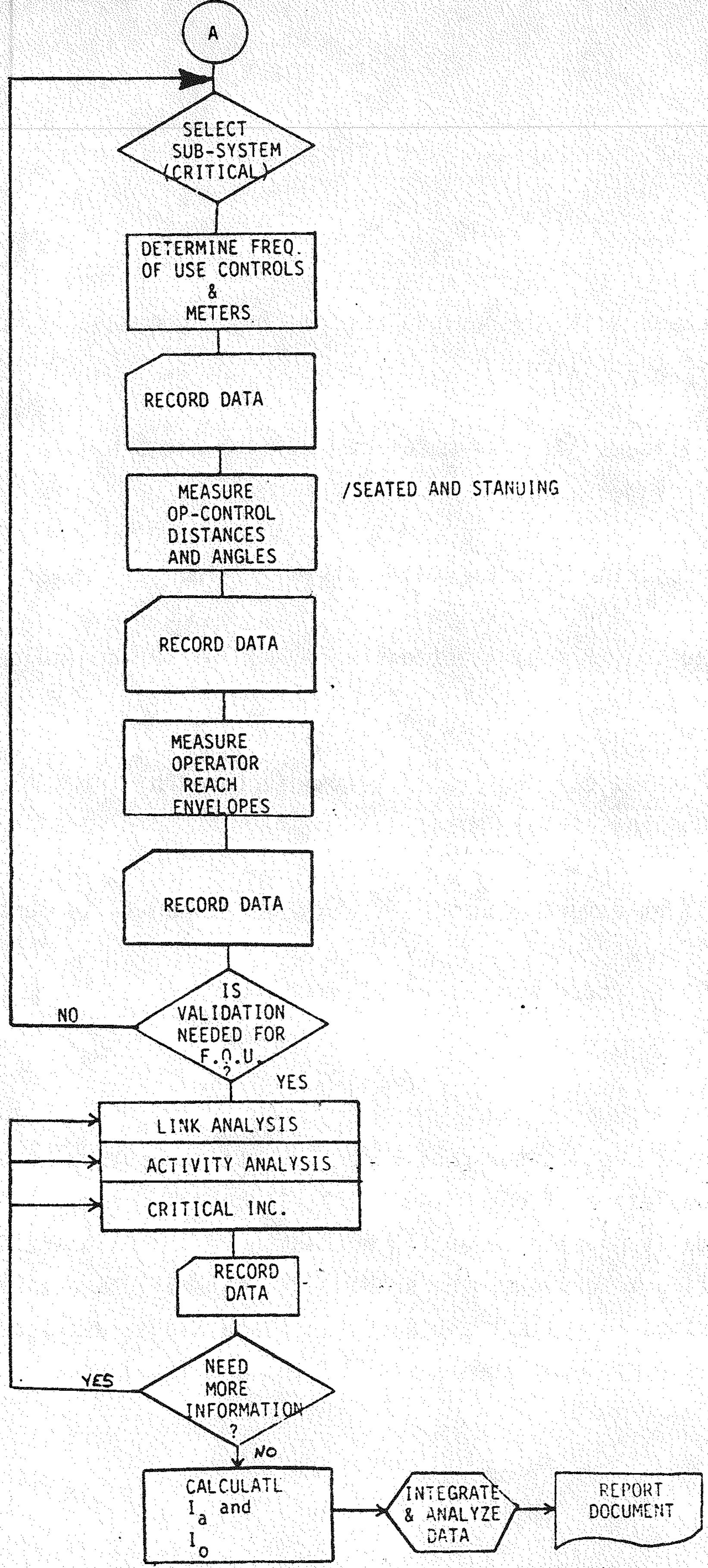

Figure 32. Procedure Flow Chart.

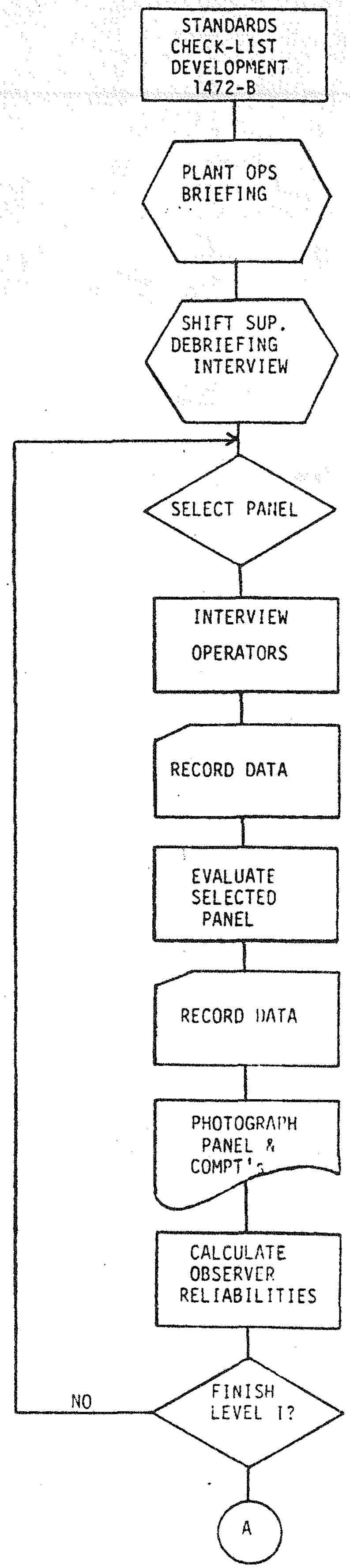

Figure 32. Procedure Flow Chart (Continued)

Photographs

Each component and subsystem was photographed to document problems or deficiencies as they were uncovered. ASA 100 Veri Color II (KODAK) film was used for this purpose.

Operator Interviews

Each operator was interviewed (concurrently when possible with the MIL-STD-1472-B evaluation) in order to obtain the following information:

- o Subsystem functions
- o Estimated control frequency of use
- o Subjective opinion of control design
- o Error consequence
- o Most frequently occurring errors
- o Equipment reliability.

Each interview was conducted either in the Reactor Control Room or the Process Control Room. Interview time varied between 0.5 and 1.3 hours, depending on the particular operator who was being interviewed.

Observer Reliabilities

In order to make certain that an infraction of any Military Standard was reliably observed, two independent observations with different observers were recorded and scored for the Main Control Console. Although this subsystem was not selected on a "random" basis, it was felt that a high interrator reliability score on this subsystem would tend to reflect the overall reliability of observed violations throughout the entire system. A violation was scored as 10, and compliance was scored as 01. For example, if observer A (0_A), and observer B (0_B) were in complete agreement, we would have the following:

$0_A = 10;\ 0_B = 10$

$0_A = 1;\ \ 0_B = 1$

If disagreement was observed, then one of the following relationships would hold.

$0_A = 10;\ 0_B = 1$

$0_A = 1;\ \ 0_B = 10$

From this dummy coding scheme, a correlation r_{AB} is calculated which reflects the degree of observational consistency between A and B observers. This interrator-reliability coefficient is calculated:

$$\underline{r}_{AB} = \text{COV}\ (A, B)\ /S_A^2 \times S_B^2 \qquad (1)$$

In this instance, $\underline{r}_{AB}$ was found to be 0.916 (N = 30, P<.01) regarding observational consistencies across two subsystems.

Accessability Index

In order to provide a more quantitative appraisal of the general relationship between controls and their associated displays, a general accessability index was calculated for the Reactor Control Room console.

$$\underline{I_A} = \text{COV}\ (d,f)/s_j^2 \times s_j^2 - \frac{\sum_{i=1}^{n} f_i'}{\sum_{i=1}^{N} f_i} \qquad (2)$$

where

I_A = is the accessability index,

$\underline{d}$ = is the linear distance of each control measured in inches from the control to the seated operator's sternum (xiphoid process),

f = is the ranked frequency of use for each control

f' = is the ranked frequency of use, for controls falling outside the operator's reach envelope;

n = is the total number of controls falling outside the operator's reach envelope,

N = is the total number of all controls. Intuitively, the index reflects the degree of relationship present between frequently used controls and their relative location to the operator. A weighted negative value based upon the ratio of components outside the operator's reach envelope to the total frequency-of-use rankings for all controls is subtracted from r_{df}, automatically adjusting I_A to account for highly used controls that are beyond the operator's reach envelope.

The index of accessibility was calculated for the control console using Equation (2) and found to be:

$$I_A = 0.69$$

This value was .03 units greater (better) than the value obtained from the Advanced Test Reactor Control Room, (Report EGG-SSDC-5288). However, the optimal value should approach 1.0.