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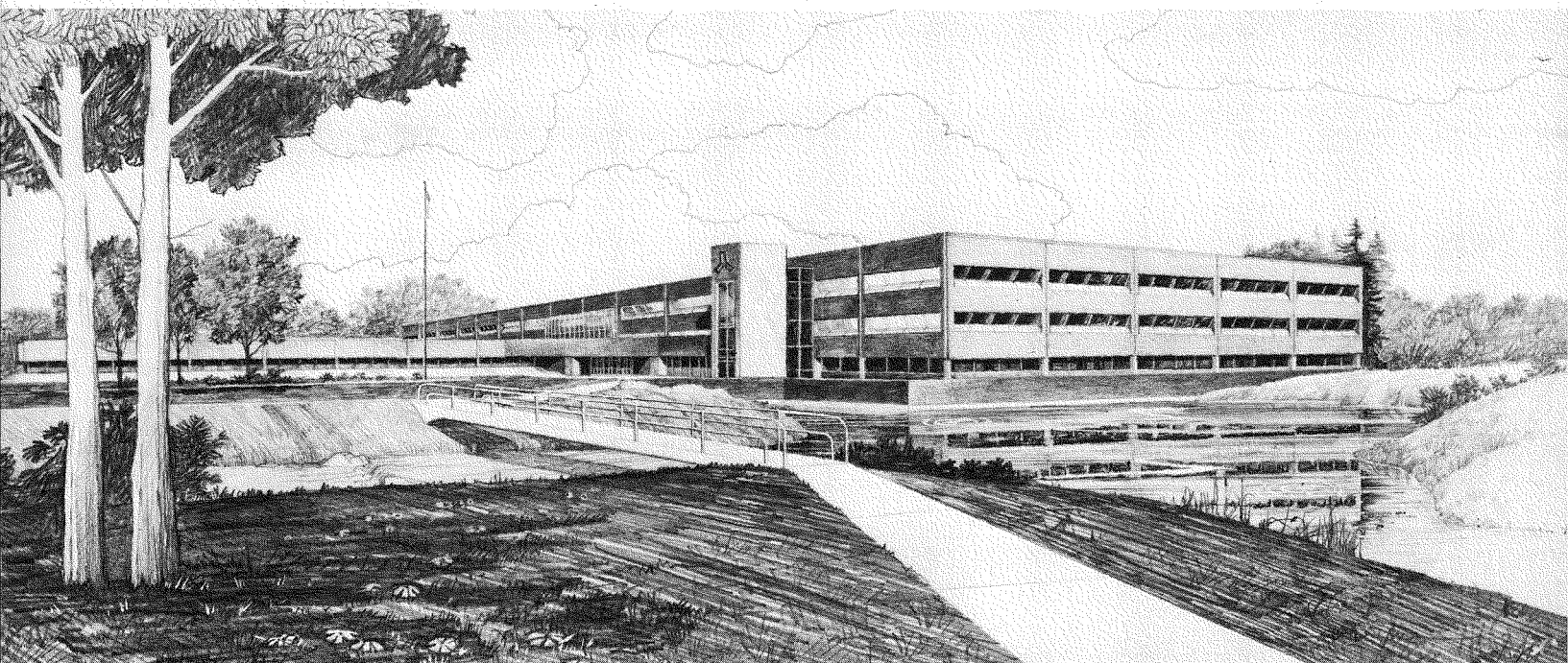
December 1980

HUMAN FACTORS ENGINEERING EVALUATION OF  
THE ADVANCED TEST REACTOR CONTROL ROOM

**MASTER**

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EXECUTIVE SUMMARY

Preliminary results of an ongoing human engineering evaluation of the Advanced Test Reactor (ATR) Control Room led to the following recommendations:

Immediate Implementation

- Emergency Controls (ATR Evacuation Switches) should be repositioned within the reach envelope of all qualified operators.
- A standardized color-code scheme needs to be adopted for control room displays which is consistent with military and industrial color meanings.
- Extensive relabeling is required to eliminate inconsistencies, replace temporary-tape labels and incorporate legible characters.
- All nonfunctional controls, switches, meters, and lights should be physically removed from the control console.
- A system of demarcation lines is needed to visually separate different subsystems from each other.
- Communications equipment should be physically consolidated at one or two stations.
- All broken control handles, pointers, and heat-warped indicator lenses should be repaired.
- Meters which have high-density scales (busy) should be replaced with easier-to-read instruments.

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- Digital displays should be used to replace the displays in the Process Control Room that are read inconsistently by different operators.
- Continually analyze change itself to minimize errors due to change.

#### Downstream Recommendations

Redesign the control room to:

- Take advantage of modern control technology
- Locate items of most frequent use in the operator's immediate reach envelope
- Provide more directly usable abnormal condition indications
- Replace all instruments which require operators to convert or transpose data, with conversion-free instrumentation.

The problem areas described, and the recommendations made must now be evaluated with respect to the influence they will have on reactor and process control operations. The priority for adopting the recommendations should be established by a joint group consisting of people from operations, experiments, engineering physics, and human factors.

## FOREWORD

The contribution of unsystematic error variance into experimental data is the bane of any experiment. Historically, little formal or historic attention had been paid to control of experimental error variance emanating from the operator/control interface at ATR. The design of control rooms, meters, and control instruments may introduce a relatively large degree of procedure variation between and within ATR control operators. Since operators vary considerably in their physical characteristics, it is logical to assume that the physical location and design of controls will statistically interact with operator characteristics to produce differential procedure variations between operators (however slight). The purpose of the scientific method is to eliminate completely, control, or minimize the influence of extraneous variables so that dependent measures are influenced solely by the experimentally manipulated independent variables. An interesting theoretical and practical question becomes what percent of the total experimental variance in a criterion phenomena is directly attributable to procedural and control variation among ATR operators? This question is currently unanswered; however, it is known that a well-designed control room and corresponding instrumentation from a human engineering perspective will substantially minimize operator/procedure variability and help eliminate the possibility that operator actions will influence experimental test results.

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## INTRODUCTION

The information presented here represents preliminary findings related to an ongoing human engineering evaluation of the Advanced Test Reactor (ATR) Control Room. Although many of the problems examined in this report have been previously noted by ATR operations personnel, the systematic approach used in this investigation produced many new insights.

While many violations of Human Engineering military standards (MIL-STD) are noted, and numerous recommendations made, the recommendations should be examined cautiously. The reason for our suggested caution lies in the fact that many ATR operators have well over 10-years experience in operating the controls, meters, etc. Hence, it is assumed adaptation to the existing system is quite developed and the introduction of hardware/control changes, even though the changes enhance the system, may cause short-term (or long-term, depending upon the amount of operator experience and training) adjustment problems for operators adapting to the new controls/meters and physical layout.

The purpose of the study was to:

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

A detailed description of the multidimensional method used during the course of evaluation is found in Appendix M of this report.

## REACTOR CONTROL ROOM

### Annunciator Display System

#### General

There are seven separate annunciator displays in the Main Control Room. Facing the control room instrument panel and proceeding from left to right in a clockwise manner, these panels are labeled: PPS, 7, 9, 10, 11, 13, and 8.

The major function of the annunciator system is to transmit trouble or malfunction conditions to the operator. Each annunciator panel is designed as a matrix or multiple element display with the number of elements varied on each display. Virtually all of the annunciator displays contained blank or nonfunctional elements. The percentage of these nonfunctional elements ranged from 5 to 45%, depending on the annunciator panel. Table 1 shows the number of windows used.

TABLE 1. THE NUMBERS OF ANNUNCIATORS IN THE ATR REACTOR CONTROL ROOM

	No. of Elements Used	No. of Blank Elements	Total Number of Elements	% of Blank Elements
Panel No. 7	41	14	55	25%
Panel No. 8	66	4	70	6%
Panel No. 9	52	3	55	5%
Panel No. 10	44	6	50	12%
Panel No. 11	22	18	40	45%
Panel No. 13	30	10	40	25%
PPS	71	29	100	29%
TOTAL	326	84	410	20%

From a human-factors viewpoint, these nonfunctional elements constitute visual noise, take-up space, and provide no direct positive assistance to operators. An examination of Figure 1, for example, shows Panel No. 7 to have 14 blank or nonfunctional elements.

Only one annunciator grouping was totally integrated by function, i.e., the PPS annunciator. The PPS annunciator panel grouped together all common elements that could potentially scramble the reactor. All other annunciator panels were not completely grouped by any common function or rationale, and none of these were labeled with any text or symbol which might aid in identifying some common function or classification. Figure 1 shows two separate annunciator panels. The arrow points to the PPS panel on the left. Note the dark border around the PPS and the total absence of any distinguishing border on the No. 7 annunciator panel. A trainee, or operator under stress, might assume the No. 7 annunciators are all directly related to the process control strip-chart meters located directly underneath the No. 7 annunciator panel. Such, however, is not the case; a border demarcation would visually separate these two distinct systems. It is recommended that the annunciators be located in such a manner that they are associated with the other meters on the panel. Lines of demarcation and clear labeling are also needed.

#### Specific Problems and Recommendations

Valid Information. Figure 2 depicts annunciator No. 10 in a cluster. It was noted during our evaluation that the data system alarm element (shown by the arrow) can be "cleared" with the acknowledge button, but in reality the problem which caused the alarm is not cleared. We recommend the visual (not auditory) alarm stay on the board until the condition has actually cleared.

Physical Control Layout and Grouping. The annunciator reset button is physically separated from the annunciator acknowledge button by approximately 33 in. (see Figure 3). Operators indicated that both of these devices are functionally related to the annunciator system and that there was no specific rationale which justified the degree of physical separation present. It was also noted that operators often inadvertently press the reset switch when

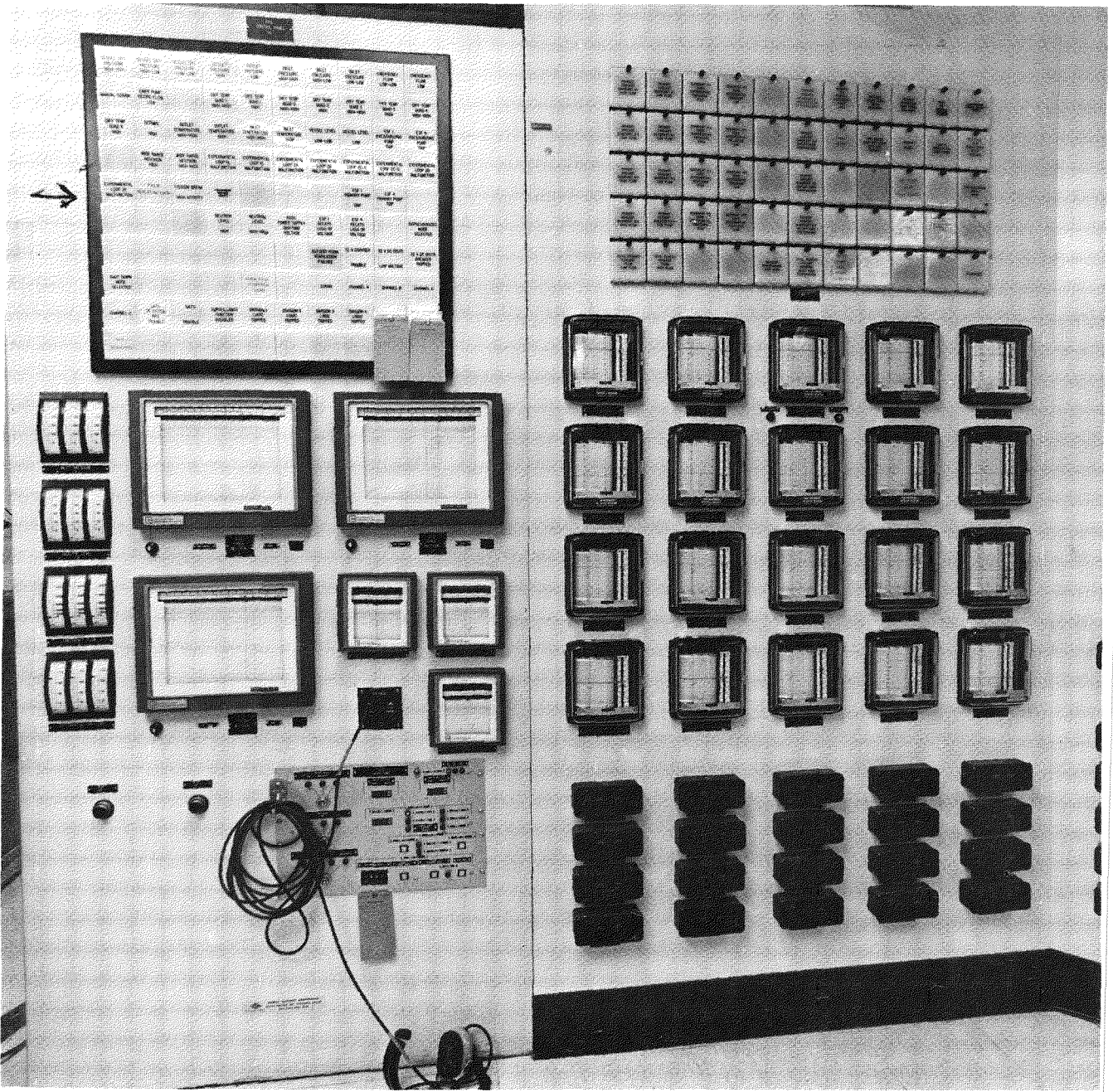


Figure 1. PPS control panel and process instrumentation.

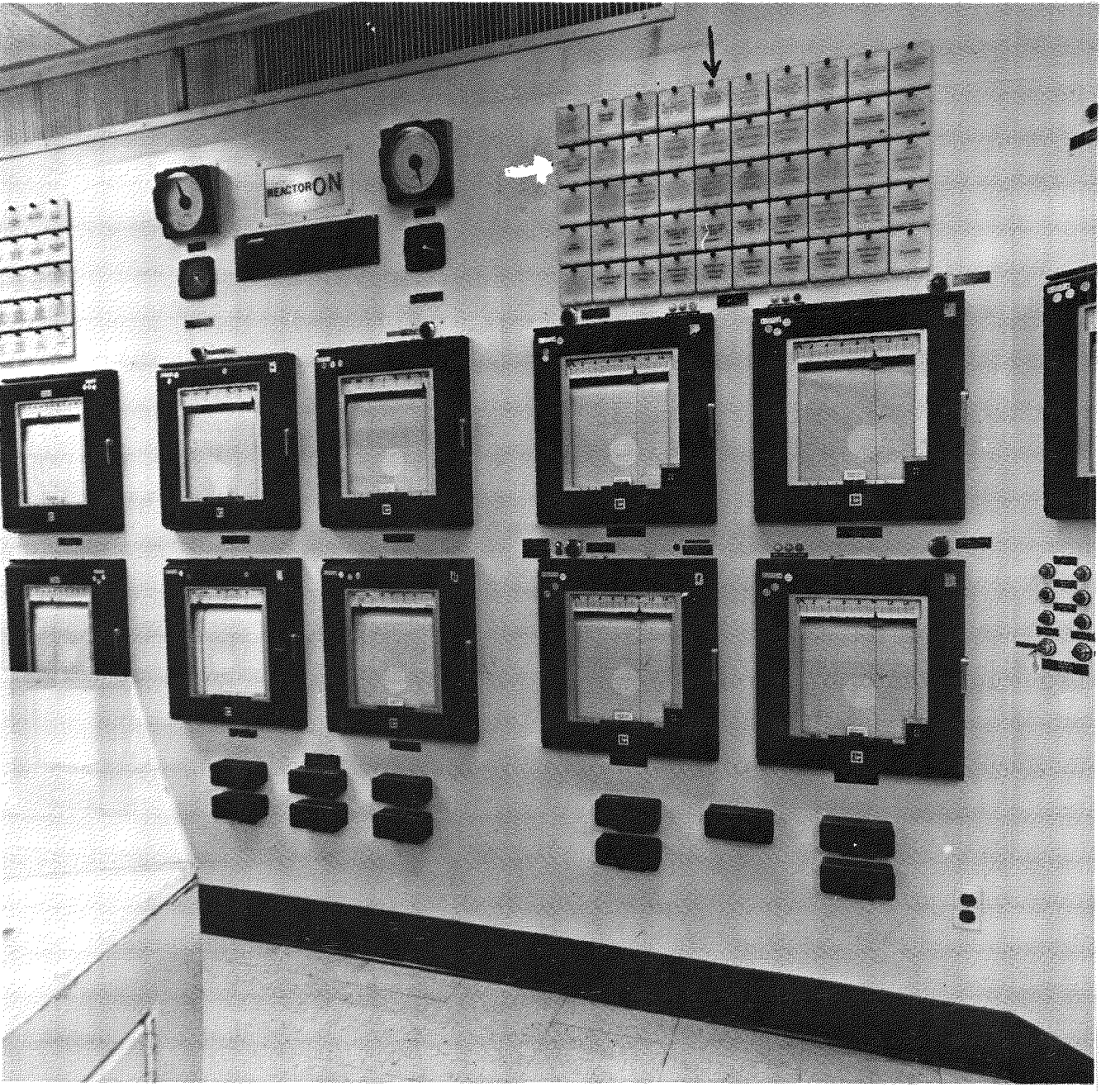


Figure 2. Data System Alarm. (Note the varying contrast of different windows.)

attempting to acknowledge an alarm because they expect the acknowledge switch to be on their right. It usually makes extremely good design sense to group these controls together and clearly label them since they are functionally related. We recommend the annunciator acknowledge switch be located adjacent to, and to the left of, the annunciator reset button. We also suggest the push-buttons be shape-coded so tactile feedback on the switch being pushed will be given to the operator.

Task Loading. The automatic resetting feature of the PPS panel can cause an audible alarm to sound repeatedly, thus distracting operators during times when their attention is directed toward other activities. The PPS annunciator logic is designed in such a way that each time a set point is exceeded, both a visual and audible alarm are initiated. Often, a condition will vacillate around a set point, going below and above the set point every few seconds. Each time such a vacillation occurs, the audible alarm is sounded. Normally, operators are fully aware the alarm condition exists; however, they must continue to push the acknowledge button to silence the horn each time the set point is exceeded.

During a scram recovery, this problem is particularly noticeable. The continuous sounding of the horn ceases to provide operators with additional information and instead, adds unnecessarily to their attention task load. A design, which permits the horn to be silenced after the acknowledge button is pushed, and not to resound for that particular alarm until the reset button is pushed, is recommended. More hysteresis in the set point should also be considered.

Questionable Alarm Disabling Procedure. During the course of our evaluation, we observed a paper clip being inserted into the annunciator acknowledge button. The reactor was down and the operators were going through their normal PM inspection lists. We inquired about the paper-clip procedure and was told the clip was used to prevent the audible alarm from sounding. During shutdown, many set points are readjusted. The readjustment causes an audible and visual alarm in the control room. These alarms are not always

meaningful and are considered by some operators to be distracting. If these alarms are going to continue to be locked out, a more formalized engineering procedure needs to be established (see Figure 3).

Color Coding. For Panels 7, 8, 9, 10, 11, and 13, within the annunciator system, a RED element display means that the operator must respond only when the reactor is ON. A GREEN color indicates that the operator must respond immediately, regardless of reactor state. A WHITE element indicates that a problem or malfunction has been cleared. According to MIL-STD-1472-B, the use of green in this instance would be unacceptable since its standardized meaning is GO or an OK condition. Green would be more appropriate as an indication of a CLEARED condition for new operators. However, if a 15-year veteran operator is to operate the system with a new or reversed color code, an adjustment by the operator may be necessary due to negative transfer of training effects, at least over the short run.

Labeling and Readability. Consistent placement of labels in relationship to controls and meters is essential to minimize display/function confusion for operators. The first-out reset, test, acknowledge, and reset buttons were all labeled in a different manner with differences in label type, lettering, and contrast. We recommend that consistent labeling-type letters, and letter contrast be employed, and that labels be placed ABOVE controls and displays.

With regard to the lettering on the annunciators, letter height was 1/4 in. and letter width was 1/8 in. For a viewing distance greater than 10 ft (operator-to-annunciator distance is greater than 12 ft), it is recommended that letters be between 0.68 and 1.13 in. in height and have a width at least 3/5 of the letter height. For the letter "M", the width should be 4/5 of the height.

All letters, numerals, and symbols on annunciator elements should have the same contrast ratio when visually examined. Four different levels of contrast (figure to background) were noted on the present annunciator elements. Examples of this may be seen by examining Panel No. 10 (see Figure 2) and the following elements:

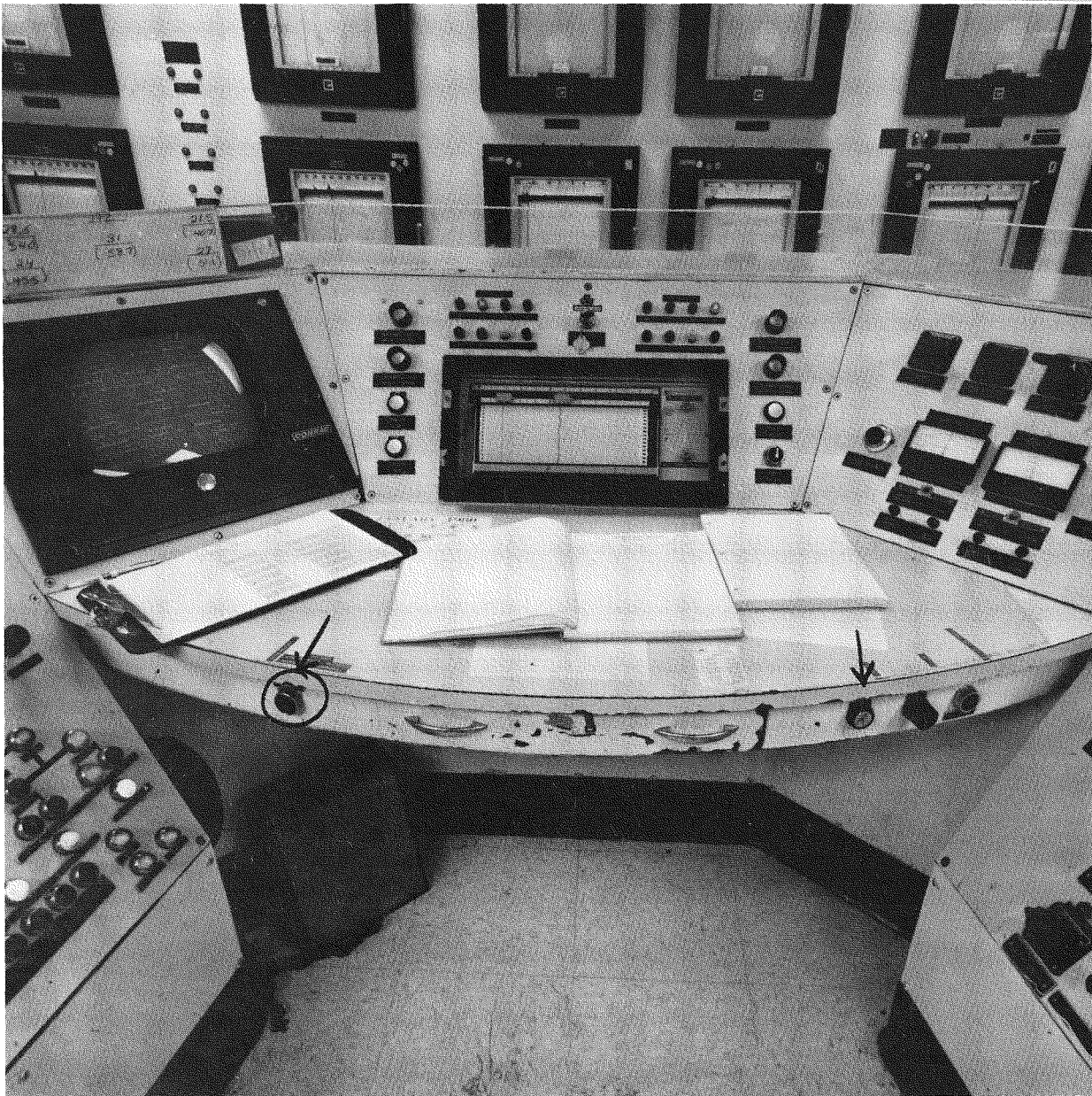


Figure 3. Position of annunciator acknowledge switch

- Evacuation system loss of failure-free power
- Reactor period channel No. 4 less than 15 sec.
- Channel No. 4 trouble
- Channel No. 1 trouble

It is recommended that only one character size and contrast ratio be used on the annunciator panel. The luminance-contrast ratio should be at least 85%.<sup>a</sup>

Physical and Visual Accessibility. The ATR evacuation and evacuation directions switches are out of the reach envelope of at least one operator. The switches are respectively 7-1/2 ft and 7 ft from the floor. Because these controls function to provide emergency information to site workers, they should be in the physical reach envelope of all qualified operators. Figure 4 shows the relative position of these switches. It is recommended that these instruments be moved so that they are within the standing reach envelope of the shortest operator.

Three of the seven operators we informally interviewed stated that they have difficulty in reading the top scale of the log-N overall range adjust vernier (Channel 4 and 5) control (see Figure 5; circles). An incorrect adjustment here would result in an improper set point and would, therefore,

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a. "Luminance contrast" refers to the difference in luminance of the features of the object being viewed; in particular, the feature to be discriminated by contrast with its background (for example, an arrow on a direction sign against the background area of the sign). The luminance contrast is expressed by the following relationship:

$$\text{Contrast} = \frac{B_1 - B_2}{B_1} \times 100$$

in which  $B_1$  = brighter of two contrasting areas  
 $B_2$  = darker of two contrasting areas

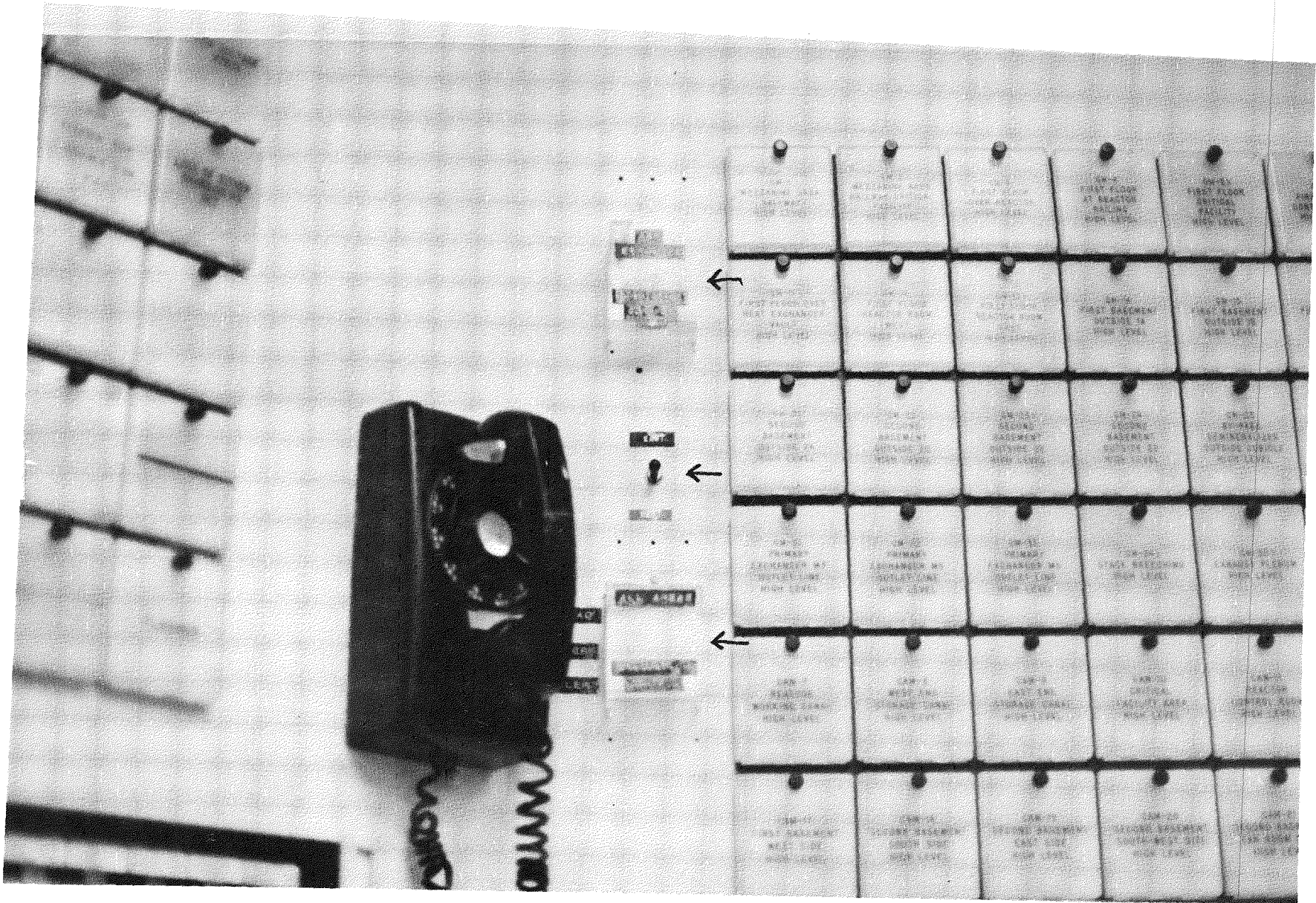


Figure 4. ATR evacuation and evacuation direction switches.

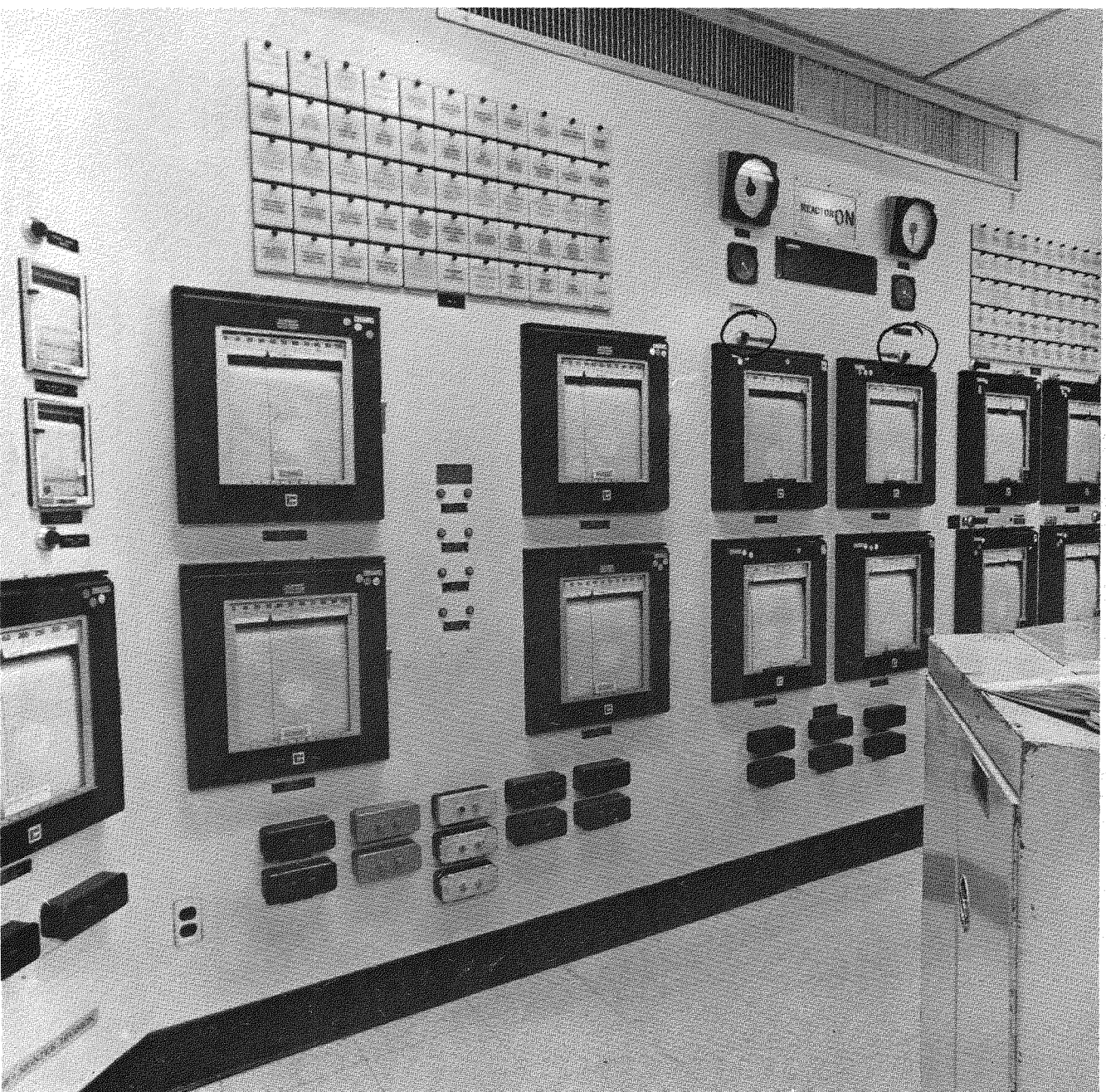


Figure 5. Channel 4 and 5 overall range viewers.

give misleading readings of  $N_L$  and  $N_F$ . This would also incorrectly set the threshold-activation point for the annunciator element and result in a false alarm or missed alarm signal.

Therefore, it is recommended that the log-N overall range adjust be repositioned by at least 8 in. to a lower point on the control panel.

### ATR Communications System

#### General

Eight different phones were situated throughout the control room. Only two or three of these phones were in easy reach of the operators while the rest were well beyond their reach when seated at the console. We recommend that a centralized communications console be incorporated in the control room with all the important and frequently used phones placed where operators can use them without leaving their seat or standing observation station.

One solution might be a nine-position communications select switch with the operator wearing a trans/receive head set. This would allow ease of access, reduce or conserve control space, and allow the operator to change communication lines in less than 0.5 seconds. Multiple jacks with selection switches would also give flexibility in locating communication stations in the neighborhood of other personnel and equipment. A formal study needs to be performed to determine the functional requirements of the communication system.

#### Specific

Phone No. 1, Emergency Evacuation Phone. This phone is located next to the emergency evacuation switches near annunciator panel No. 13 (Figure 6). The evacuation phone is used to coordinate evacuations with the control room at the Engineering Test Reactor (ETR). When picked up, it immediately rings in the ETR Control Room. The phone is not distinguished in any specific

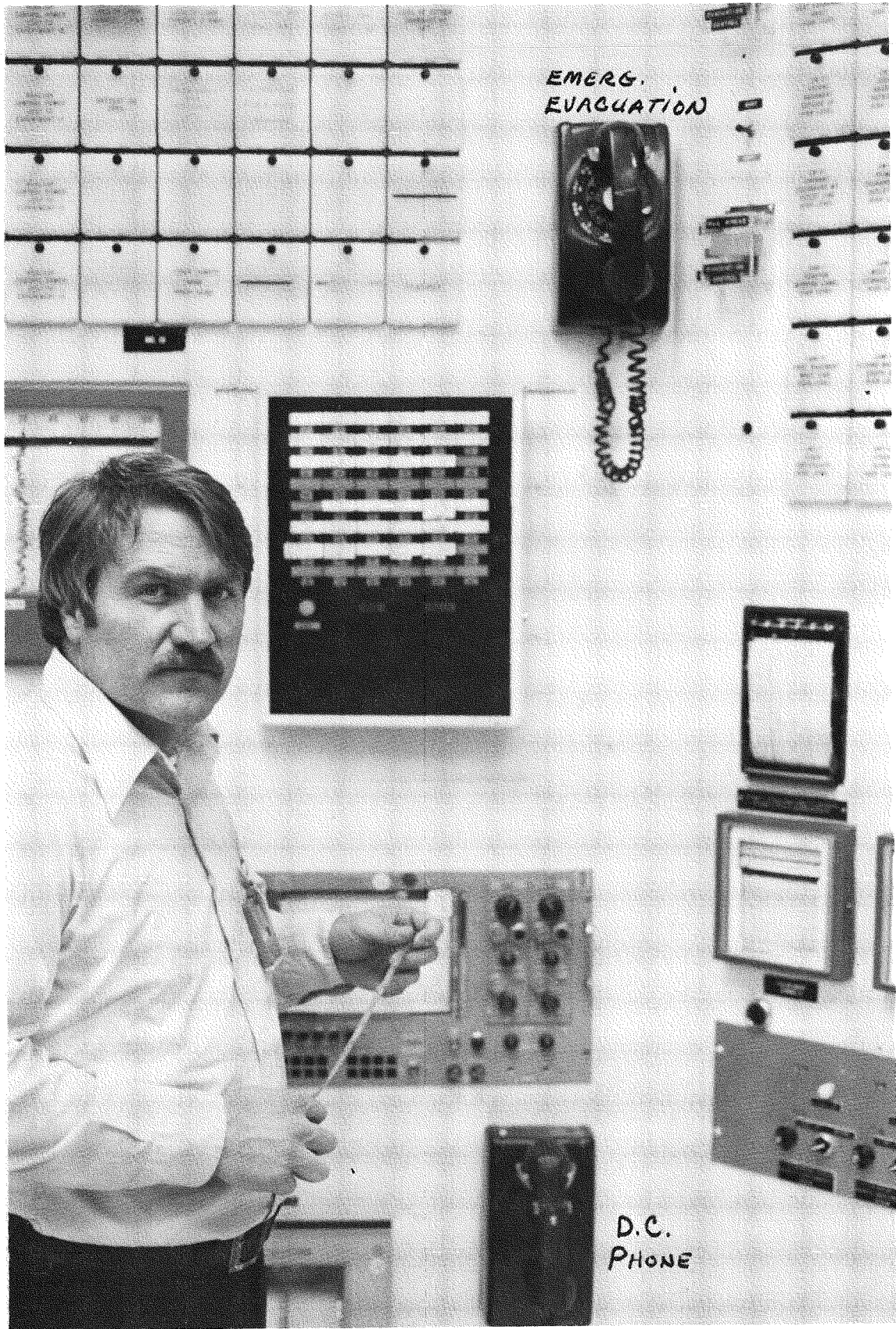


Figure 6. Evacuation and DC phones.

manner. It is recommended the phone be RED because it is used only under special circumstances, such as emergencies or the coordination of power breakers, and not for routine messages.

Because of the instrument's physical (height) placement, one of the shorter operators might experience problems in using the phone without the aid of a chair to stand on. We recommended that if the phone is to remain near the wind-direction indicators, it be lowered in height to 180 cm or lower<sup>b</sup> (this is the reach height of a fifth percentile woman).

Phone No. 2 DC Phone. This phone is used for coordination within the plant (Figure 6). The DC phone can be connected to a number of different stations within the plant. It is located 12 ft from the control console seat; however, it has a very long cord which is normally stretched to the control-console seat. The DC phone is used primarily when the reactor is up in power, though at times is used during other reactor states. Interconnections are made outside the control room with a patch panel. The patch panel (Figure 7) allows operators to connect into a number of stations in other parts of the building. There is the potential for connecting to 80 different stations; however, only 75 stations are currently used. Technical specifications prohibit an operator from leaving the control room during reactor operation; therefore, the patch panel cannot be accessed unless two operators are in the control room. It is recommended the DC phone be integrated into a comprehensive communication center on the reactor console and the patch panel be included as an integral part in the immediate control room. Solid-state switching can be used to miniaturize the size of the panel.

Phone No. 3, Page Phone. The page phone is located at the end of the reactor console to the operator's right when facing the front of the room (Figure 8). The page phone is physically located 5 ft 1 in. from the center of the operating area. A red button is pushed from the top of the page phone in order to call. Discussions can then take place over a telephone-type

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b. Applied Ergonomics 1979 10.4 2150223 "Fitting the Job to the Woman: A Critical Review."

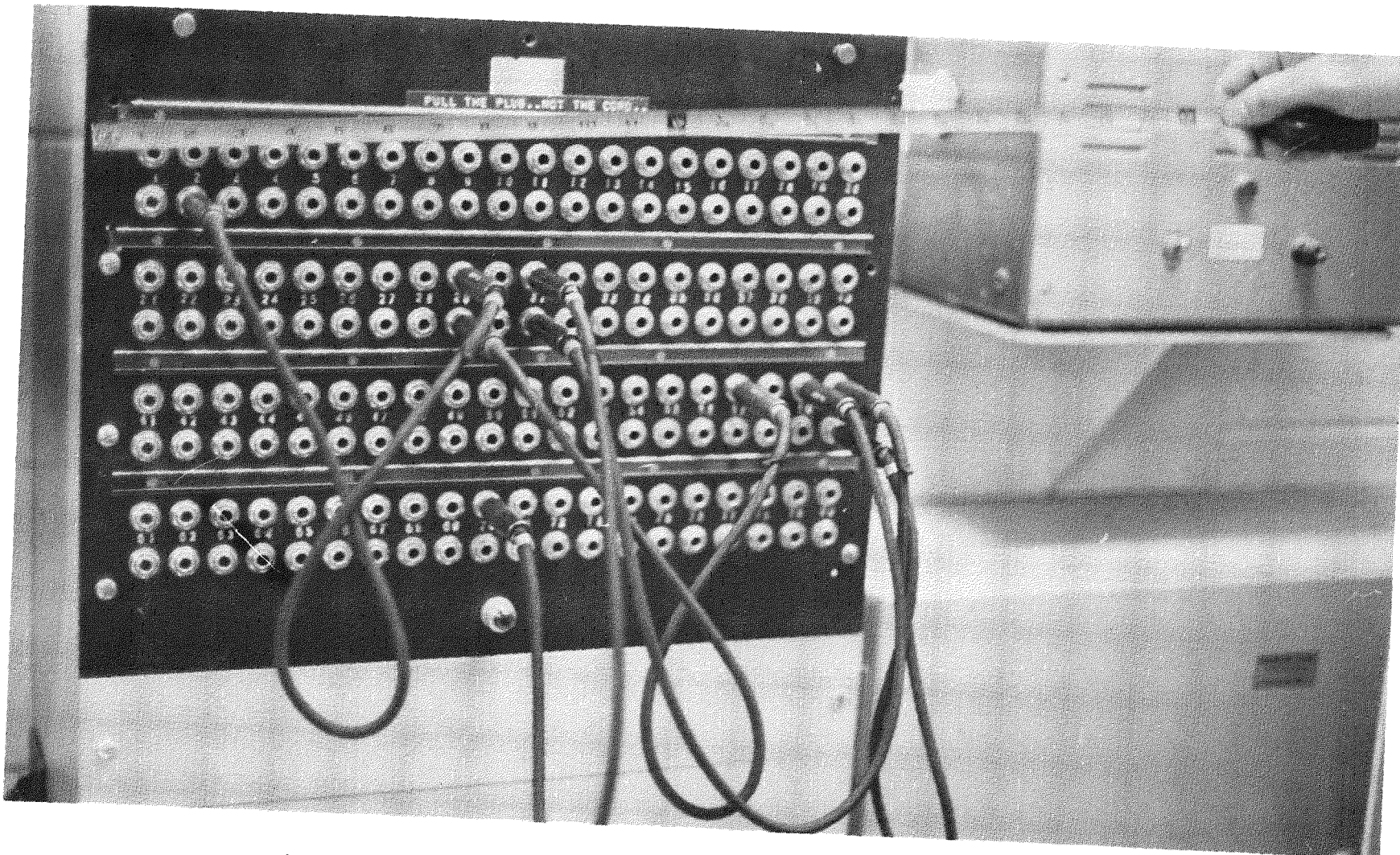


Figure 7. DC phone patch panel located outside nuclear control room.



Figure 8. Evacuation, DC, Page, and Bell phones.

receiver/sender. Speakers, located throughout the building, are loud enough to be heard everywhere and can be used to call anyone. The volume of the page call appears to be proportional to the loudness with which one speaks into the phone. Often, the page-phone speaker in the control room is loud enough to interfere with other verbal communications in the control room. It is recommended that a volume-limiting device be placed on the control room page-phone speaker.

Phone No. 4, Bell Telephone. The Bell telephone is located on the reactor console 12 in. to the left of the operator's seat. Loop operators normally call the reactor operator on this Bell phone, and operators also use this phone for making calls. During sequences where an operator needs to use both hands simultaneously, this phone can tie up one of his/her hands. A head set would eliminate the need to hold the phone.

Phone No. 5, (another Bell telephone system phone). This phone is located on the desk inside the control room directly adjacent to the deck scope and is often used by personnel inside the control room (see Figure 8).

Phone No. 6, (Altec-intercom phone--Nonfunctional). Intercom Number 6 is a Bogan push-button intercom located on the left-hand console panel. The operator can contact anyone of 20 other areas within the plant. Other areas can contact the operator by pushing an intercom switch in their respective areas. This system should be removed from the control panel (see Figure 9).

Phone No. 8, (second DC phone). This phone is located on the PPS panel and is a voice-actuated phone that is used to talk to the other PPS rooms and transmitter. The phone is hard-wired into all locations. It is used primarily when testing PPS division logic systems. The PPS DC head set is located 13 ft from the chair in the console (see Figure 10).

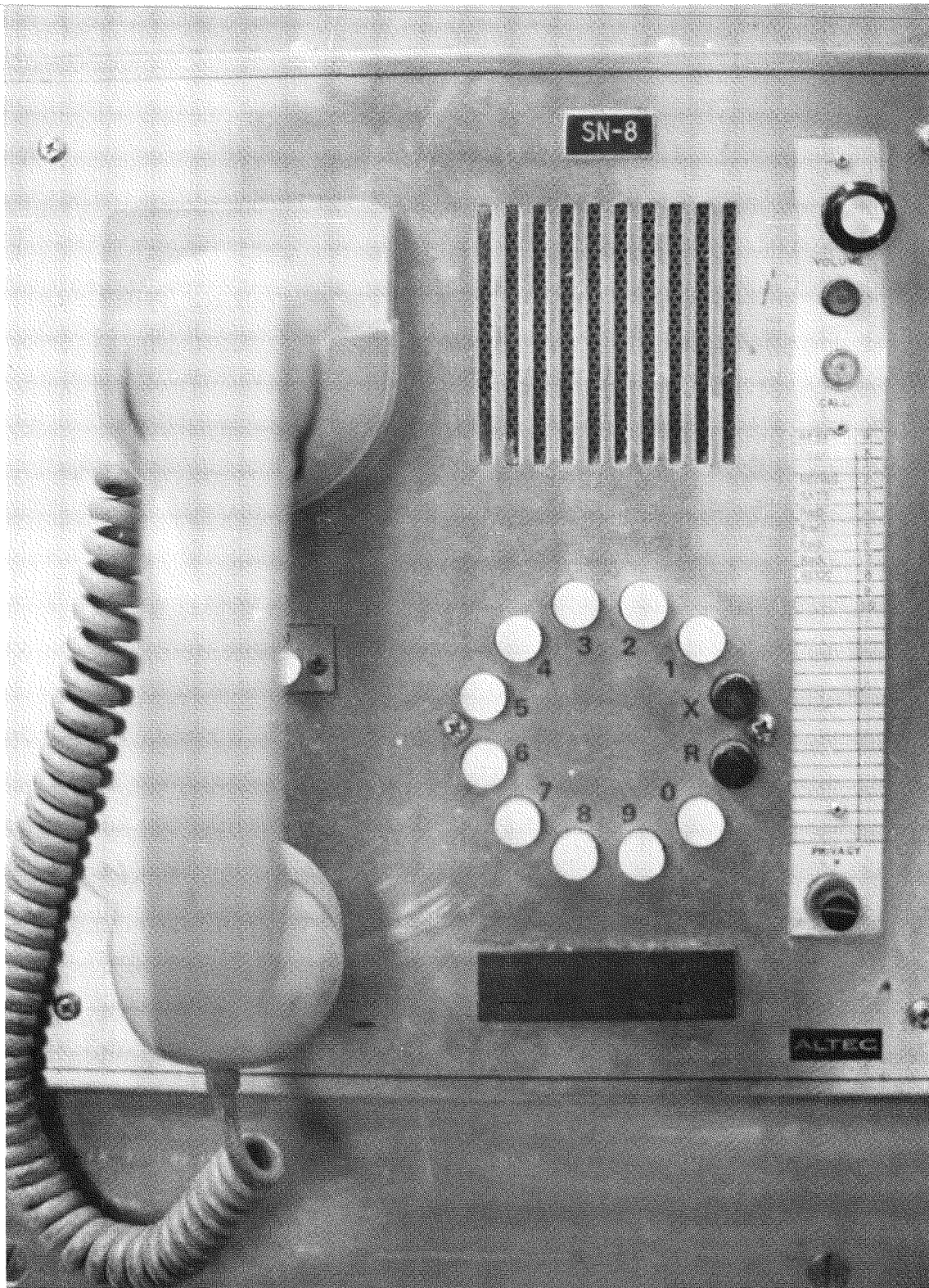


Figure 9. Nonfunctional Altec phone.

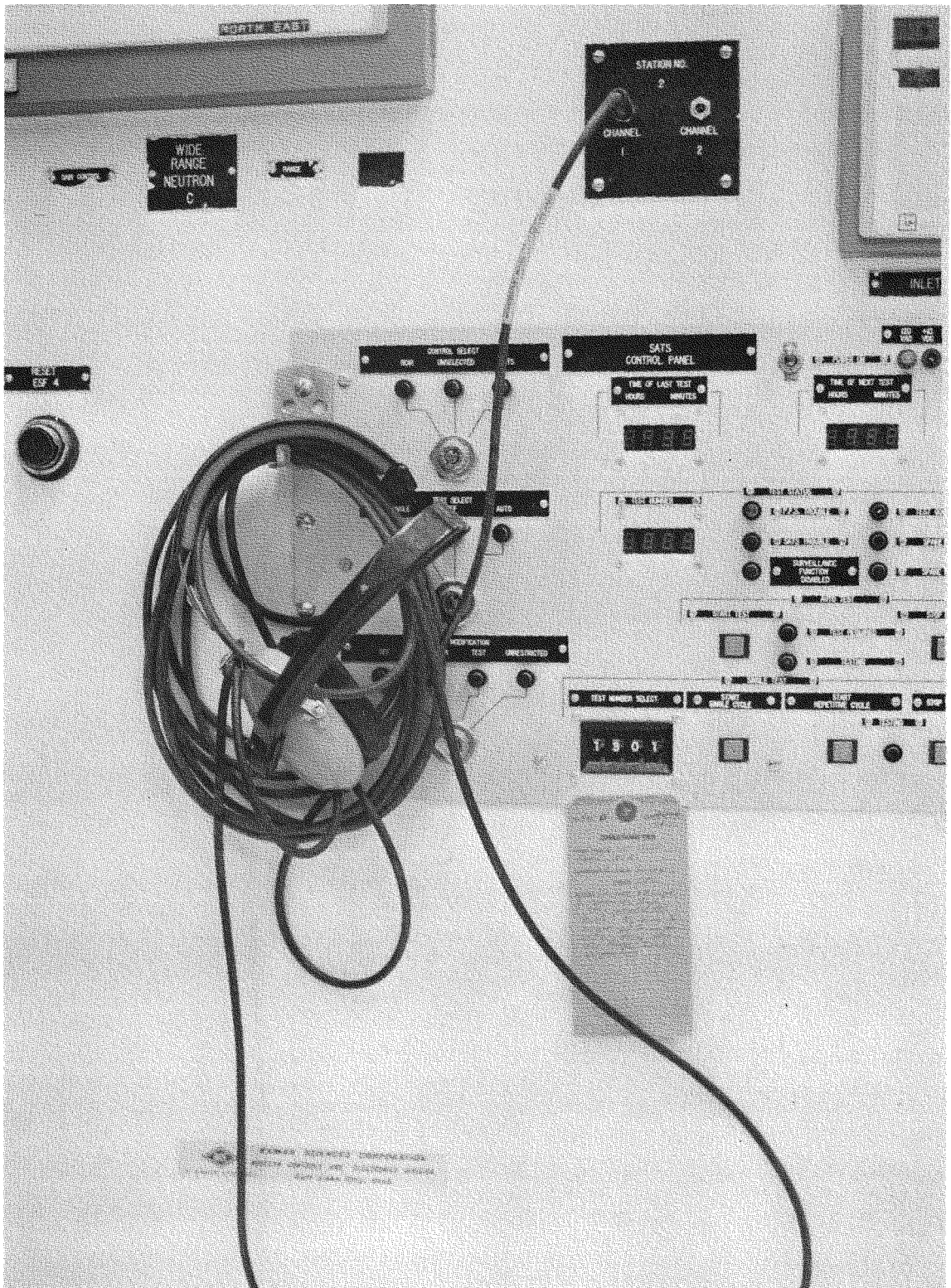


Figure 10. DC PPS phone.

## Cathode-Ray Displays

### Specific Problems and Recommendations

#### Power Split Display.

Contrast Ratios--Very poor contrast ratios of luminance existed for numbers and letters on the CRT. The ambient illuminance is too high in relation to screen illuminance and should not contribute more than 25% of screen brightness through diffuse reflection. Figure 11 shows the reflectance of the lights on the CRT screen. It is recommended that a display be selected which will minimize reflectance. The spacing distance between alpha-numeric symbols was minimal and made the display more difficult to read relative to an optimal separation distance which would equal one half the symbol width. The height-to-width ratio was less than 1:1, and in general, the numbers and letters appeared to be too small. It is our understanding that a color CRT is being ordered to replace the dedicated power split display.

Refresh Time--The CRT update or refresh time was 60 seconds. This often caused the operator to wait for the new information or visually scan other instruments to extract current data. It is recommended that update times be decreased to less than 5 seconds during normal operating conditions and to 2 seconds or less during power changes. If this approach is not feasible, then perhaps a "demand mode" can be incorporated into the display software so that operators can "demand" data updates by pressing a demand button or return key. This demand mode would cause a hardware interrupt and give the operator a priority for updated information.

Quadrant Demarcation--Another problem noted with the CRT display was the inconsistent and poorly illuminated delineation lines (boxes) placed around the numeric data. During some presentations, these lines are broken. It is recommended that the delineation lines be made brighter by a factor of 1, and that the width of these lines be increased by a factor of 1.5. Further, it is suggested that the inconsistency in solid lines be eliminated via a software patch in the format. It is suggested that the boxes be printed only once rather than every time a data update takes place.

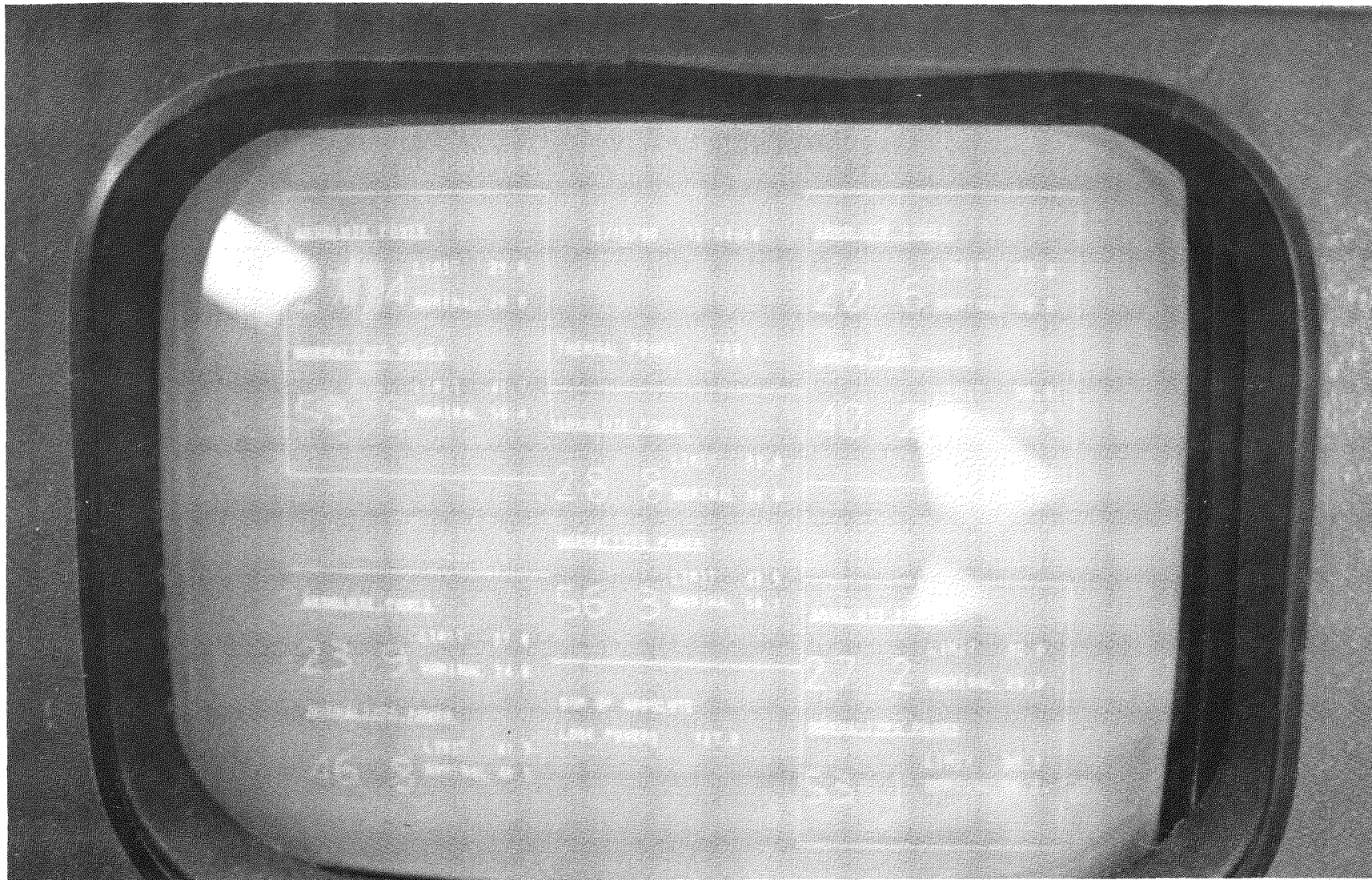


Figure 11. Dedicated power split display (note glare).

Cosmetic Appearance--Maintaining the correct power split is primarily a matching task--matching the desired power levels written on the plexiglass spill guard with the actual power levels shown on the CRT. Although the grease pencil on plexiglass is a good "quick fix," a more permanent method of displaying the desired power should be considered (see Figure 12, Arrow/Circle).

#### Cathode-Ray Tube Display.

Location--The cathode-ray tube (CRT) display located on a desk in back of the reactor console (see Figure 13) can be used to access any of the programs in the ATR computer. The information most often requested by operators concerns temperatures, pressures, and flows of the loops. The tables of information about each loop are used in conjunction with the console-mounted power split display by operators to more accurately determine what reactor power changes need to be made. A marked increase in the use of the CRT display has been noted when two operators are in the control room. Interviews with the operators revealed that the reason a single operator does not make full use of the display is because it is physically separated from the reactor console. It is, therefore, recommended that a display which gives the same information as shown on the CRT display be integrated into the reactor console due to the importance of the loop information, particularly during start-up. The CRT on the reactor console could be used as a dual-function display showing either the power split or any other desired information. An analysis of the amount of time operators use the dedicated power split display could determine the advisability of modifying the dedicated displays in such a way that it becomes a multifunction CRT. If such a modification is not feasible, two displays should be considered.

#### Motor-Operated Rheostat Subsystem (MOR)

##### General

The MOR system permits the operator to control reactor power levels. There are two modes of operation for MOR: manual and automatic. Under manual control, the operator directly controls the physical positioning of control

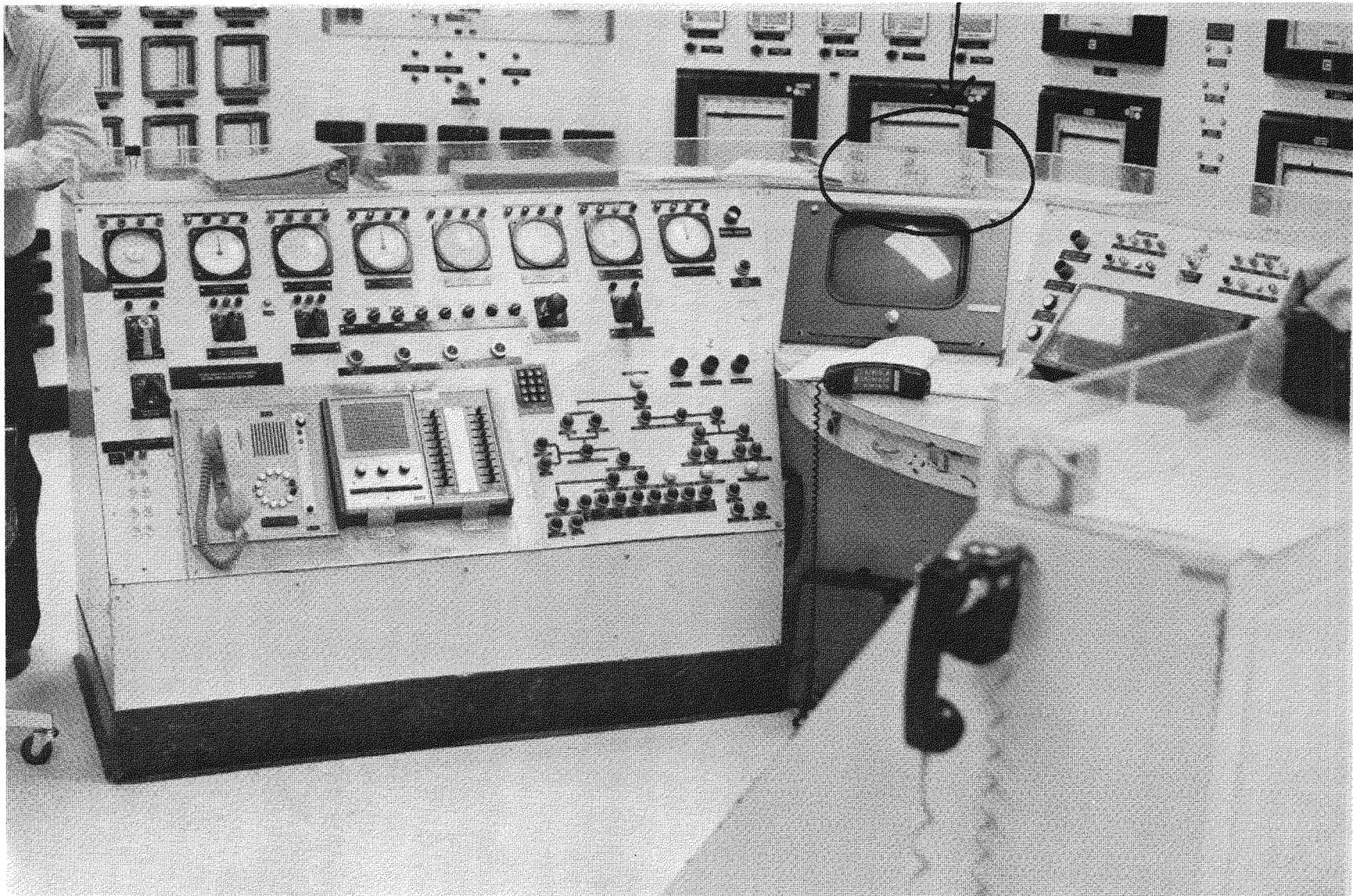


Figure 12. Desired power split written in grease pencil (circled).

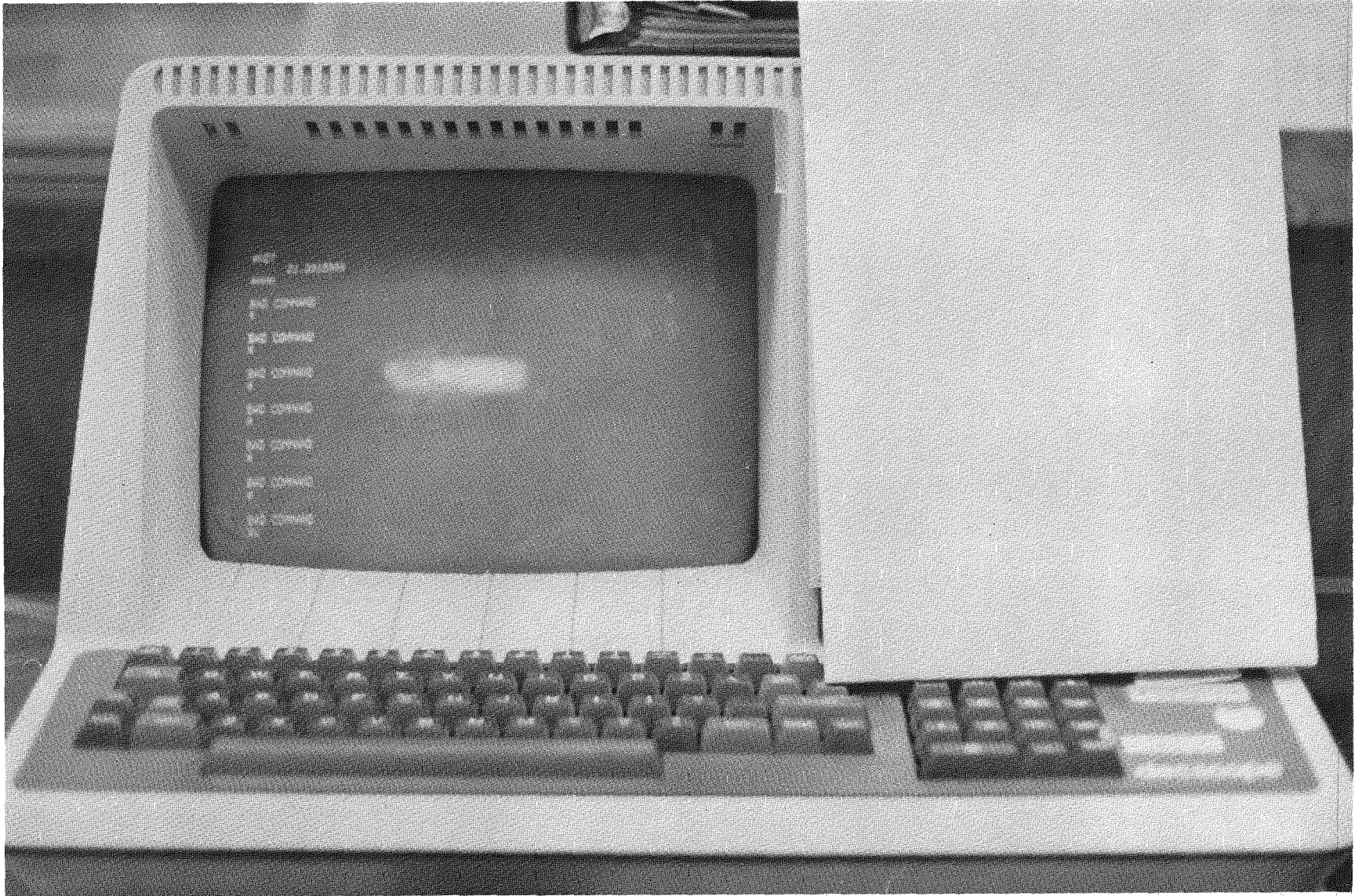


Figure 13. Cathode-Ray tube display located behind reactor console.

rods in the reactor. When switched to automatic mode, a system of synchro-servo motors maintains reactor power by automatically adjusting control rods to manipulate power levels.

In general, inconsistent display control relationships and poor labeling are the main problems associated with the MOR. Appendix A of this report provides a detailed listing of all MIL-STD-1472-B violations noted, along with appropriate comments.

### Display Location

When operating under the automatic mode using the motor-operated rheostat, a number of possible conditions can cause the MOR to enter a manual mode without adequate warning to the operator. The first signal presented to the operator is a change in state of the GREEN "Auto" MOR light: the light will go out. Since this light is located near the seated operator's left knee (see Figure 14, Arrow), there is a high probability the condition will go undetected until the operator perceives "Drift" in the regulating rod script-chart recorder.

To enhance the operator's performance, it is recommended that this light be resituated above the MOR reg rod manual/auto hand control since (a) it is functionally related to this control, and (b) it would be easier and faster for the operator to detect a mode change. It is further recommended that WHITE lights be used to indicate the mode of operation. Since Auto Mode is used more frequently, it might be better to inform the operator only when the system is in manual mode by having a WHITE light come on instead of having a GREEN light go out.

### Display Specificity

Figure 15 shows the two visual demand meters located on the operator's immediate console. After specific questioning, operators informed us that they only monitor the "Directional Movement of the Pointer." They do not

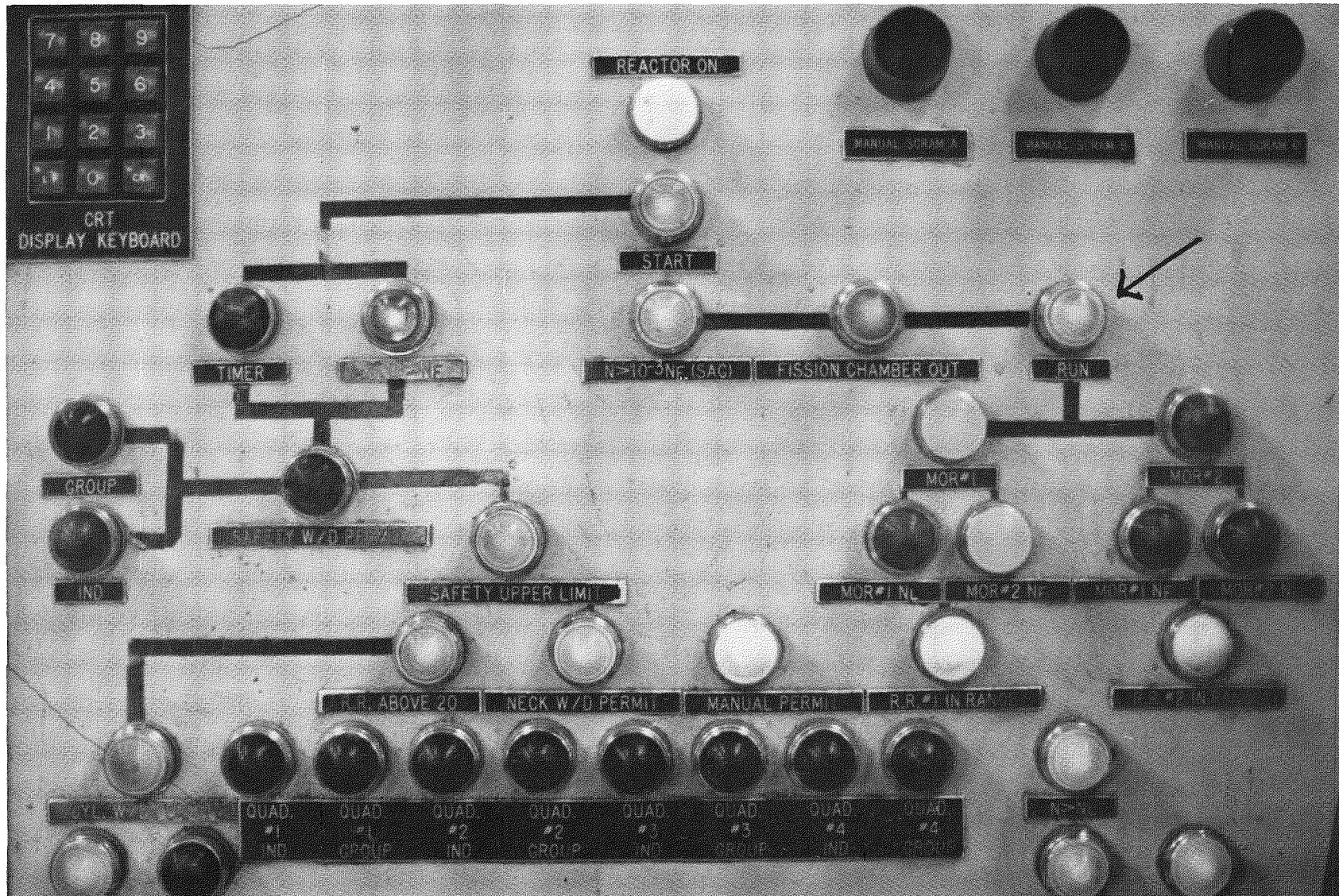


Figure 14. Procedure panel. (Arrow points to "MOR automatic" light.)

take numeric readings from the scales. It is recommended that information be displayed to the operator only to the degree of specificity and precision required for the operator to perform his/her job. Additional information serves only as a distraction and is nonfunctional and nonproductive.

Another problem noted with these demand meters concerns the withdraw/insert toggle switch situated directly underneath the meters. When this switch is placed in the left position, the pointer on the scale reads withdraw voltages to the left-of-center scale. When the toggle switch is placed in the right position, voltages are read to the left-of-center scale. Readings should always be consistent. The left-of-center should always refer to the same voltage, either insert or withdraw, but never used as both. This can cause confusion which, in an emergency condition, can significantly degrade operator decision and action quality.

The reg rod position meters are not located near, or grouped with, their corresponding manual controls. These meters are too densely graduated and scales are too small relative to the actual viewing distance (over 12 ft) used in the control room (see Figure 16). It is recommended that these meters be (a) replaced with similar meters that are better scaled and easier to read, or (b) moved closer to the operators by placing them on their immediate control console in a position which is more closely related to their relatively high frequency of use. In general, controls and meters which are used most frequently should be placed so that the operator has optimal visual and physical access, relative to instruments with relatively low frequency of use.

### Labels

During our observational analysis, we noted numerous examples of labels constructed with plastic tape. These labels were difficult to read, and in some instances, "dog eared", and ready to fall off. It is recommended that all jury-rigged temporary labels be replaced with sturdy, standard-size labels consistent in color and letter height and located above the appropriate control or display. All labels on the main console should be clearly

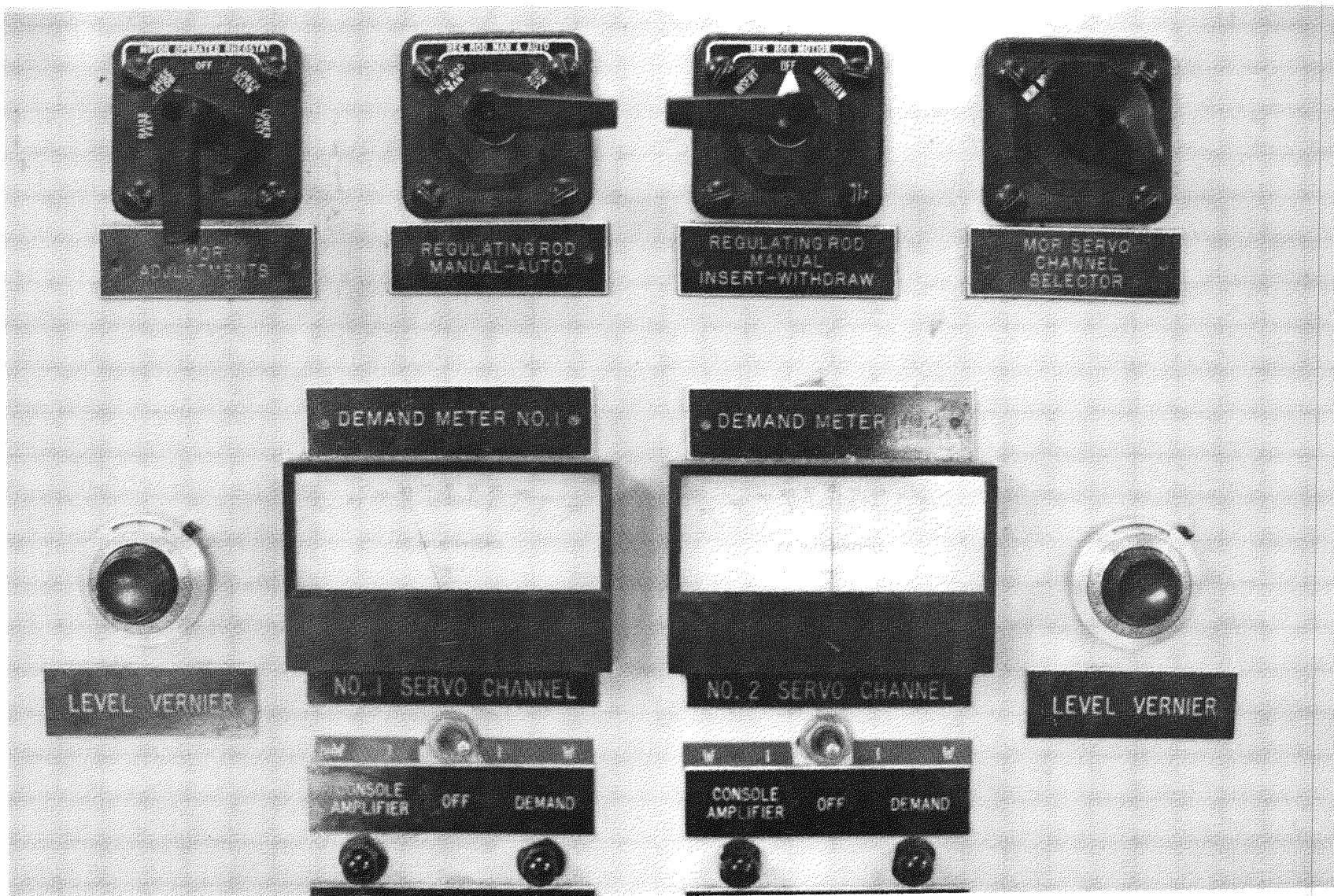


Figure 15. MOR demand meters.



Figure 16. Regulatory rod position meters.

legible from a viewing distance of at least 4 ft, and labels on the forward control panel legible from 14 ft.

Inconsistent labeling practices were noted between demand meters and hand controls. Meter labels were on top of the instruments, but for hand controls, labels were on the bottom. We recommend labels be located consistently above displays and controls.

Letter height for regulating rod position meters at a viewing distance of 78 in. should be at least 0.68 in.; however, the actual letter/numeral height was found to be 0.187 in.

There should be a clear delineation of the functionally related elements so that this subsystem is visually separated from the components not related to the MOR subsystem.

#### Pointer

Broken pointers (triangles) were found on the MOR servo channel select, and other hand controls (see Figure 16A). We recommend that all broken pointers be repaired.

#### Nonfunctional Equipment

Two servo demand indicator lights were found to be electrically disconnected and thus nonfunctional. It is recommended that all nonfunctional or unused components be physically removed from the console. This will reduce visual noise, visual search time, conserve priority space, and improve operator performance under high-anxiety (emergency) conditions.

#### Summary

While MIL-STD-1472 is not obligatory or contractual for DOE/NRC, noncompliance with the standard and/or other design criteria was noted in 46 instances.

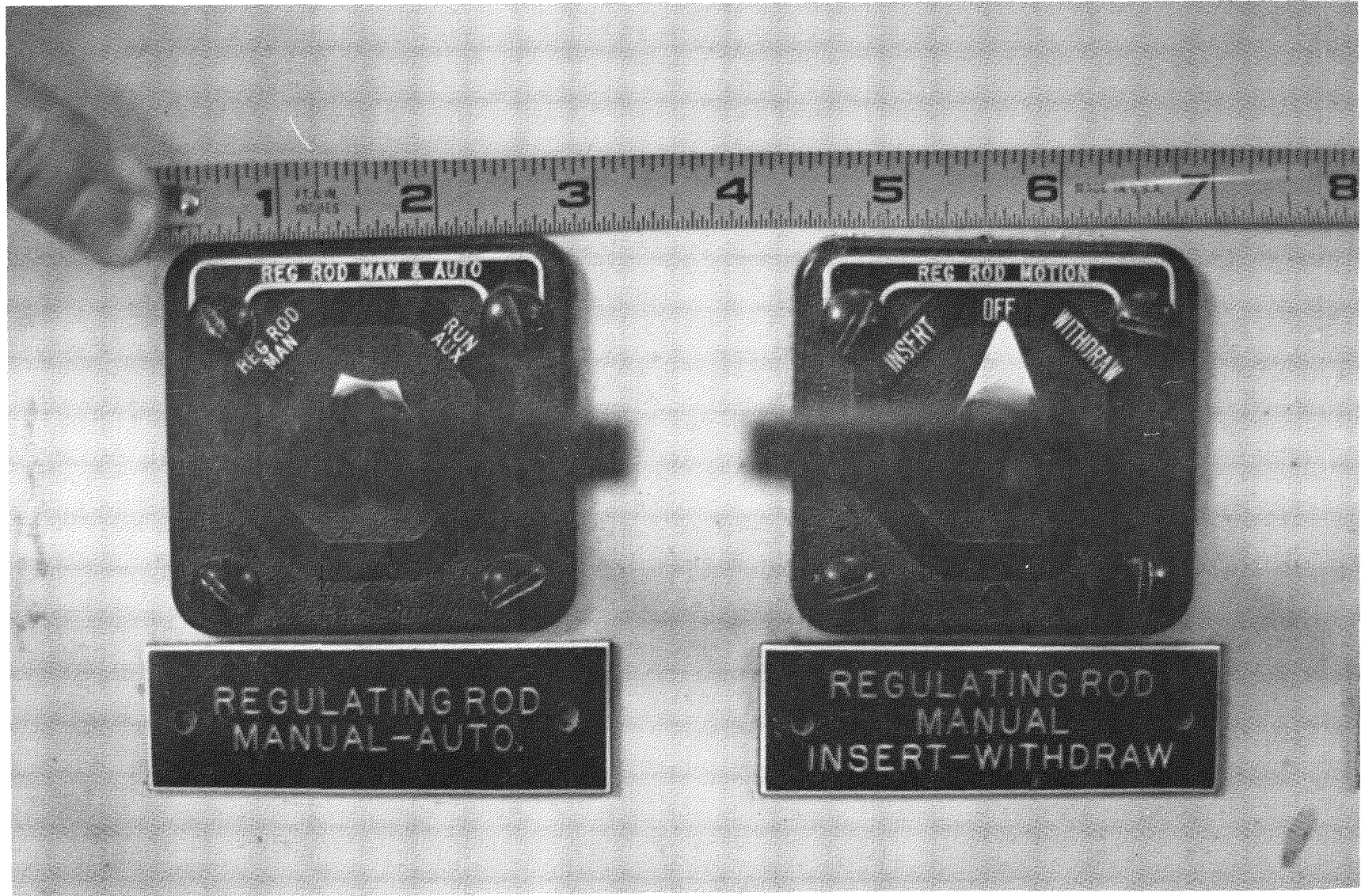


Figure 16 A. Broken pointer on regulating rod manual/auto switch.

## Safety-Rods Subsystem Panel

### Specific Problems and Recommendations

Labeling. There were no distinguishing boundaries between the Safety-Rod Subsystem and other subsystems (Figure 17). It is recommended that these boundaries be incorporated into the system.

Repetitive and inconsistent labeling practices were found. It is recommended that one "general" label for each delineated system be used with each element in the system labeled for component specificity (see Figure 18).

All manufacturers' names should be physically removed from display meters, e.g., "Scientific Atlanta" appears on safety-rod meters.

Display Control Relationships. There was no clear relationship between the safety-rod select switch and its associated visual display. The select points (positions) on the safety-rod hand controller did not directly correspond with the appropriate display, e.g., the north rod is perceived as No. 1, but is physically located in the No. 8 position. This should be corrected if possible.

Glare. The physical distance between safety-rod meters and corresponding control should be decreased to less than 28 in.

The safety-rod meters have convex face covers which increase or contribute to overhead glare on the meter face (Figure 18). It is recommended that these displays be either (a) canted inboard toward the operator, (b) shielded, (c) a nonconvex or concave lens face be used, or (d) dull finish lens face be used.

If a light bulb is not inserted correctly in the exact position (indicator lights), all of the related lights will fail due to this single short or a blown fuse. It is recommended that this condition be corrected so that either (a) only the improperly inserted bulb will fail, or (b) the bulb holder be redesigned so that the bulb cannot be inserted incorrectly.

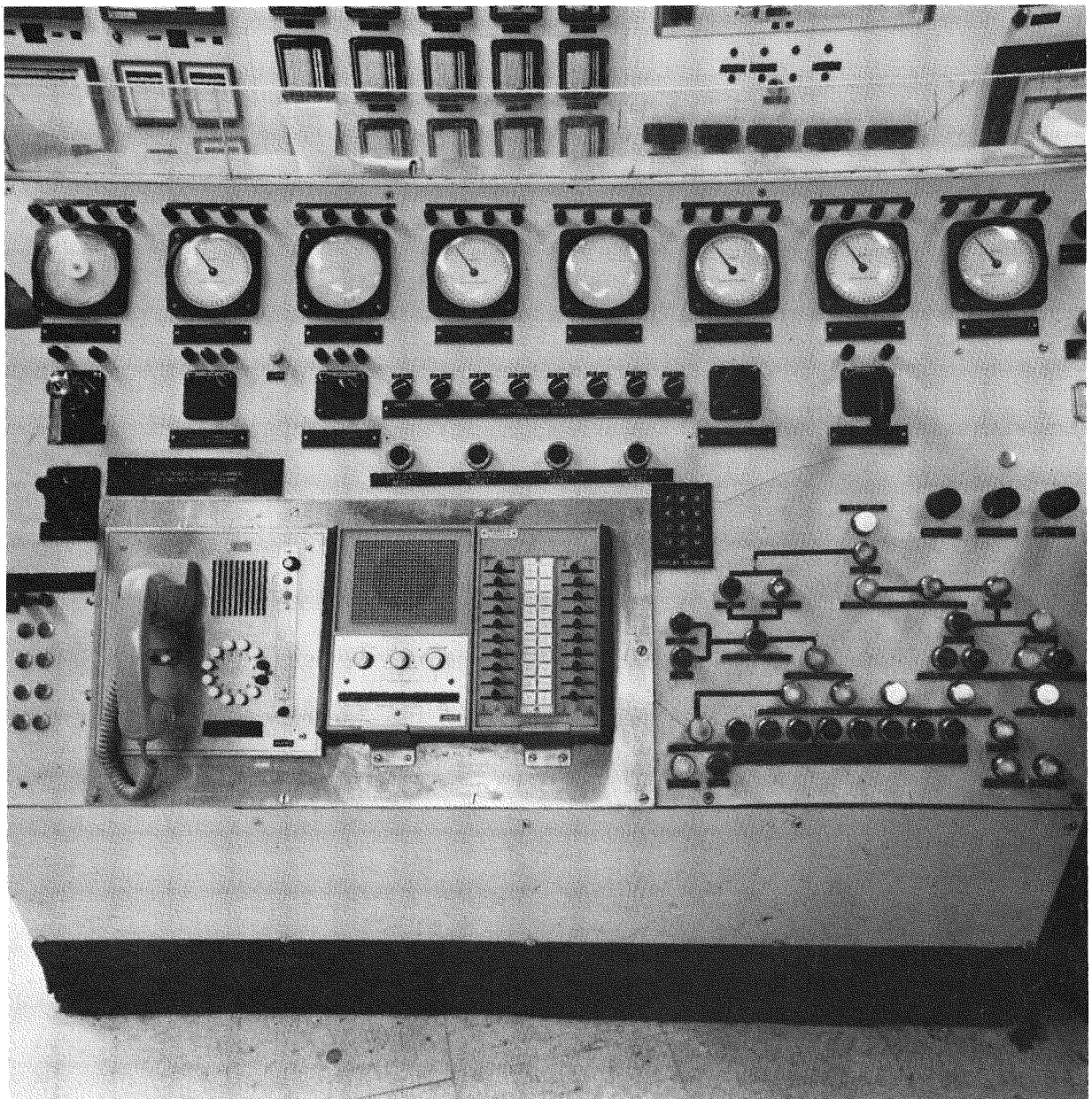


Figure 17. Safety rod subsystem. (A common border would reduce the information needed on each label.)

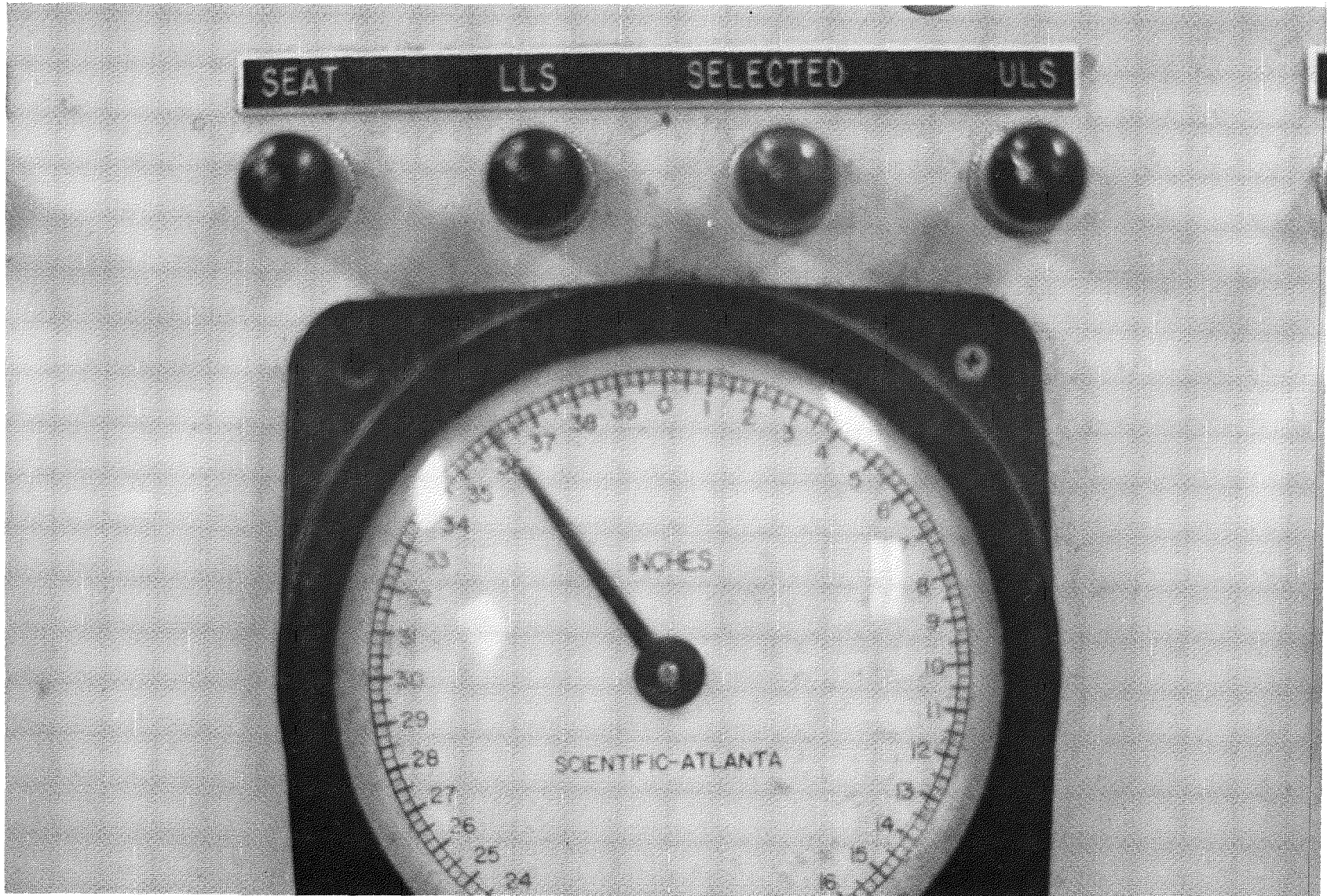


Figure 18. Safety rod meter. (The convex meter face causes glare.)

Color Coding. Color coding was found to be inconsistent and thus confusing. The color RED, for example, was used to denote "upper limit" and "withdraw" simultaneously. In other subsystems, the color RED was used to denote Withdraw/Insert, Danger, Warning, Power On and Outer Limit, 48 inches withdrawn and 1st out. It is recommended that standardized meanings of colors be adopted and implemented throughout the control room.

Legend lights could be used to eliminate multicolor indicator lights.

Appendix B contains a summary of all MIL-STD violations related to this subsystem along with other relevant data.

### Neck Shim Control Subsystem

#### Specific Problems and Recommendations

Poor display/control correspondence between the neck shim rod region select and associated meters was observed. It is recommended that all controls and corresponding meters be integrated into tight physical packages (with boundaries) providing clear visual correspondence between each control and its associated meter.

Display Configuration. There should be some degree of symbolic association between the display and the actual physical phenomena represented. For example, it might be possible to have a subconsole display designed graphically in the form of the four core lobes with the safety-rod controls placed in their actual relative positions on the console in order to mimic the actual hardware configuration.

Since the numeric data displayed in inches on the neck shim meters is often inaccurate, has missing numbers, and is hard to detect (see Figure 19) due to low contrast luminance ratios, these meters should be either (a) replaced, or (b) eliminated. We discovered that only "direction" of shim movement and "relative" location/position of shims is important to operators. If this is the actual case, then numeric information is unnecessary and should be eliminated.

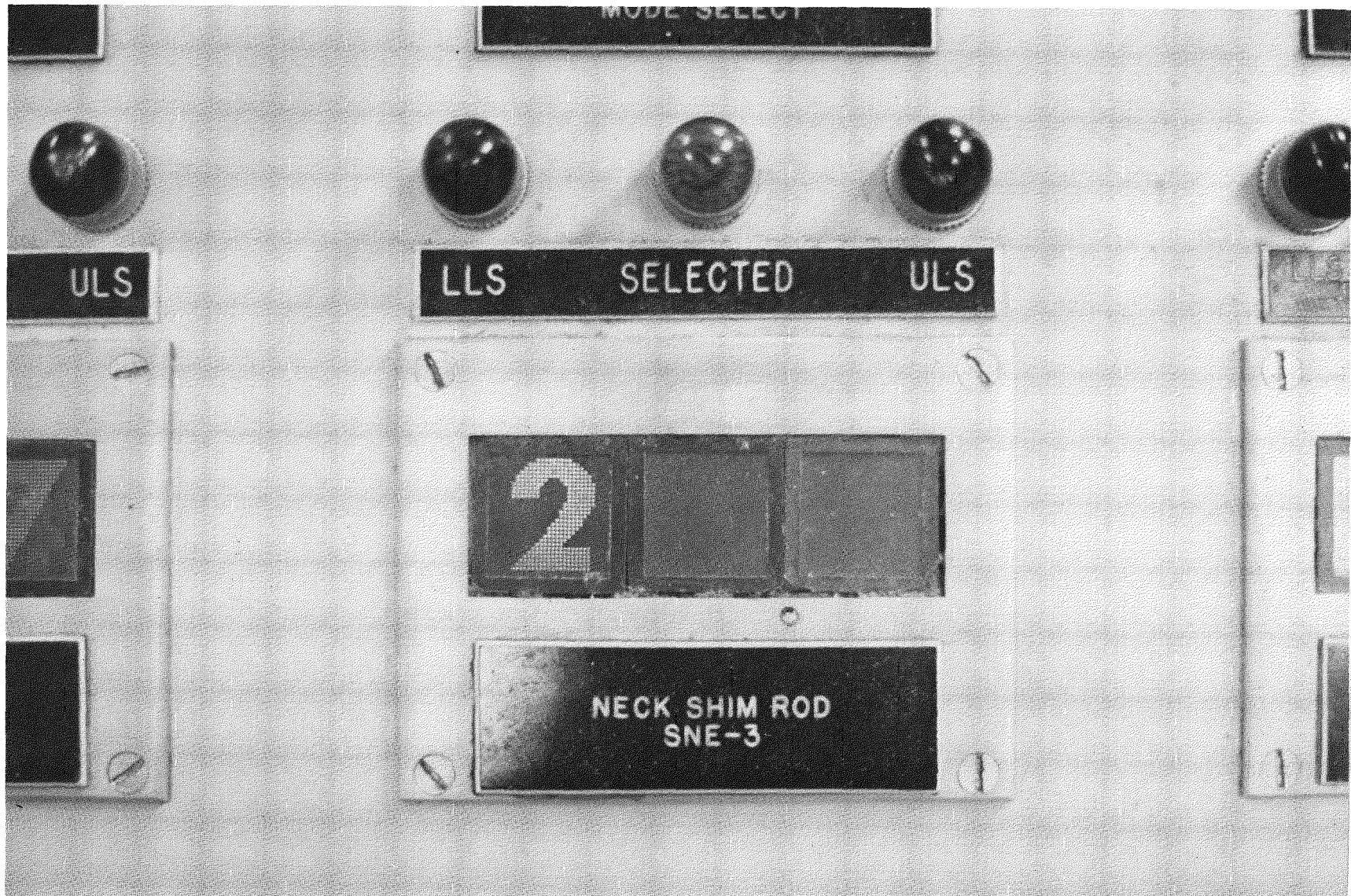


Figure 19. Neck shim rod indicators. (Note the missing numbers.)

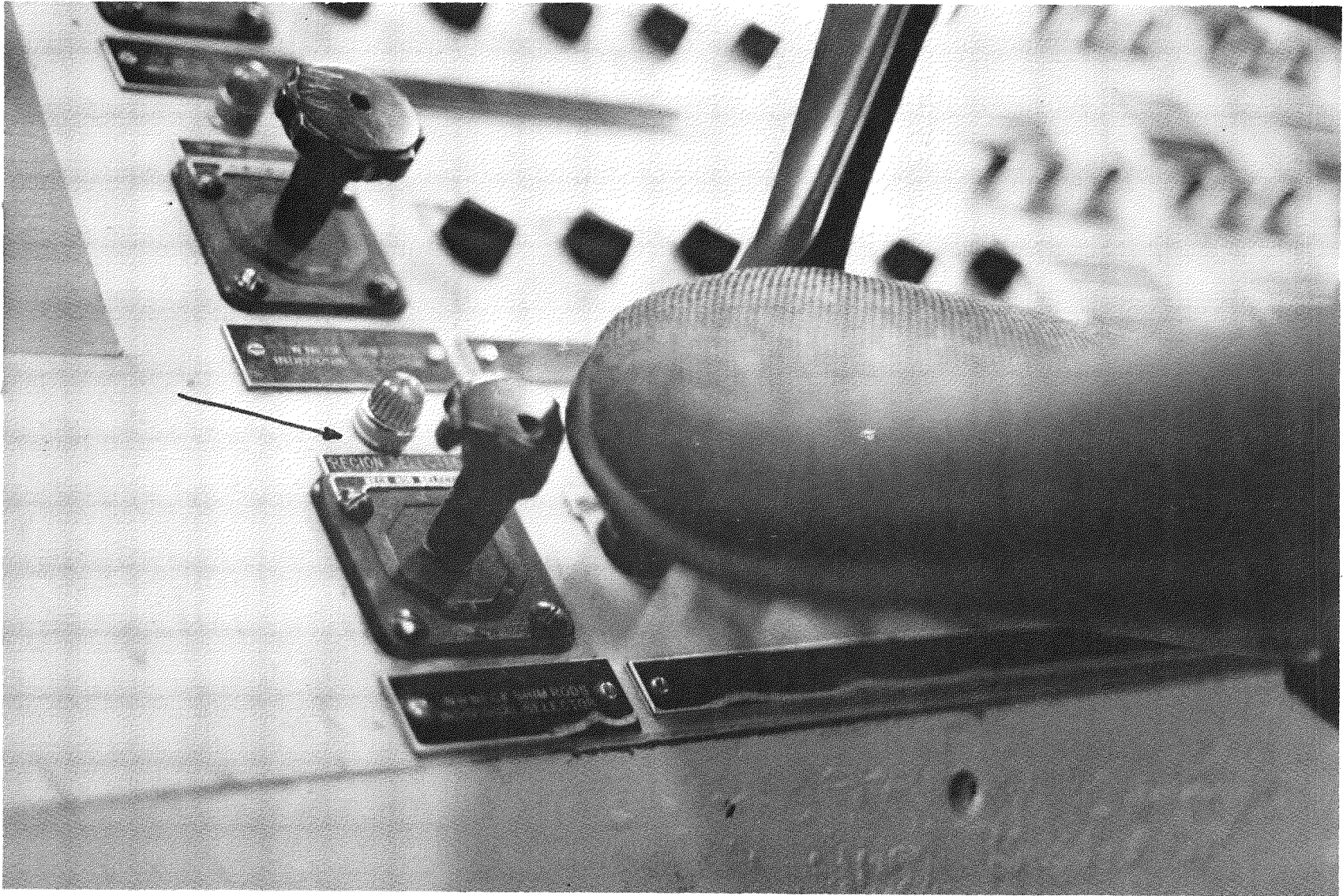


Figure 20. Broken neck shim cylinder select switch.

The indicator lights and digital meters provide overlapping information (redundant for upper and lower limit conditions). This degree of redundancy may not be actually needed, hence another means of displaying this information might be in order.

Damaged Equipment. Numerous pointers on controls were found to be broken, e.g., Neck Shim Rod Region Select. Parts should be replaced or new controls installed with sturdier pointers. One region select switch is located at the same height as the operator's chair and as a result, has been broken by the chair moving against it (see Figure 20).

Labeling. Inconsistent placement of labels and varied letter sizes are used.

The labeling symbols around the shim rod hand controls are almost illegible. They appear to be hand inscribed (see Figure 34). Labels with clear legible characters should be replaced above the controls.

Operator Reaching Limits. During SCRAM recovery, the safety-rod insert/withdraw switch must be operated simultaneously (at times) with the MOR adjust control which is 5 ft 8 in. away. A few operators cannot physically perform this maneuver alone. The distance between these controls should be decreased.

### Summary

Noncompliance with MIL-STD-1472 and other human factors criteria reached 24 for this subsystem (see Appendix C).

### Outer Shim Cylinder Control Panel

#### Specific Problems and Recommendations

Labeling. No boundaries are present to visually isolate the subsystem from other non-related controls and meters. We recommend (a) a boundary be

drawn around the outer shim cylinder panel, and (b) an identification label be mounted at the top of the boundary. Delete redundant labels.

The tape code for showing paired relationships between displays is inadequate. We recommend meter pairs be enclosed by a boundary.

The outer shim cylinder meters are presented without units of measure and decimal points. We recommend units of measure be incorporated in the display.

All plastic labeling (temporary) should be removed and replaced with permanent labels.

Handwritten numbers with poor legibility were found on instruments. We recommend the handwritten labels be replaced with clear, concise labeling, considering size of alpha-numerics, contrast ratios, etc. (see Figure 21).

Color Coding. The Christmas-Tree philosophy used with regard to indicator lights (Figures 22) should give way to legend lights or an off-normal philosophy, where indicator lights are used only when legend lights are not feasible. Inappropriate use of green, red, and amber lights was observed, and it is recommended that the color code requirement of MIL-STD-1472-B be adopted and used consistently throughout the system.

Nixi-Tube Displays. On the outer shim drive display, some of the numbers on South 3 and 4 controller have shifted down 1/8 in. These are old Nixi-tubes displays and are not current state-of-the-art. It is suggested that modern, smaller meters replace the current meters in order to save space, maintenance costs, and present enhanced visual data, e.g., higher contrast ratios.

Technical specifications require that pairs of outer shim cylinder displays be kept within a maximum of 3 degrees of each other. Hence, control actions could be simplified if each pair of displays were combined into a single display with appropriate control modifications, e.g., two pairs of shims could be yolked together and would require only one display per four

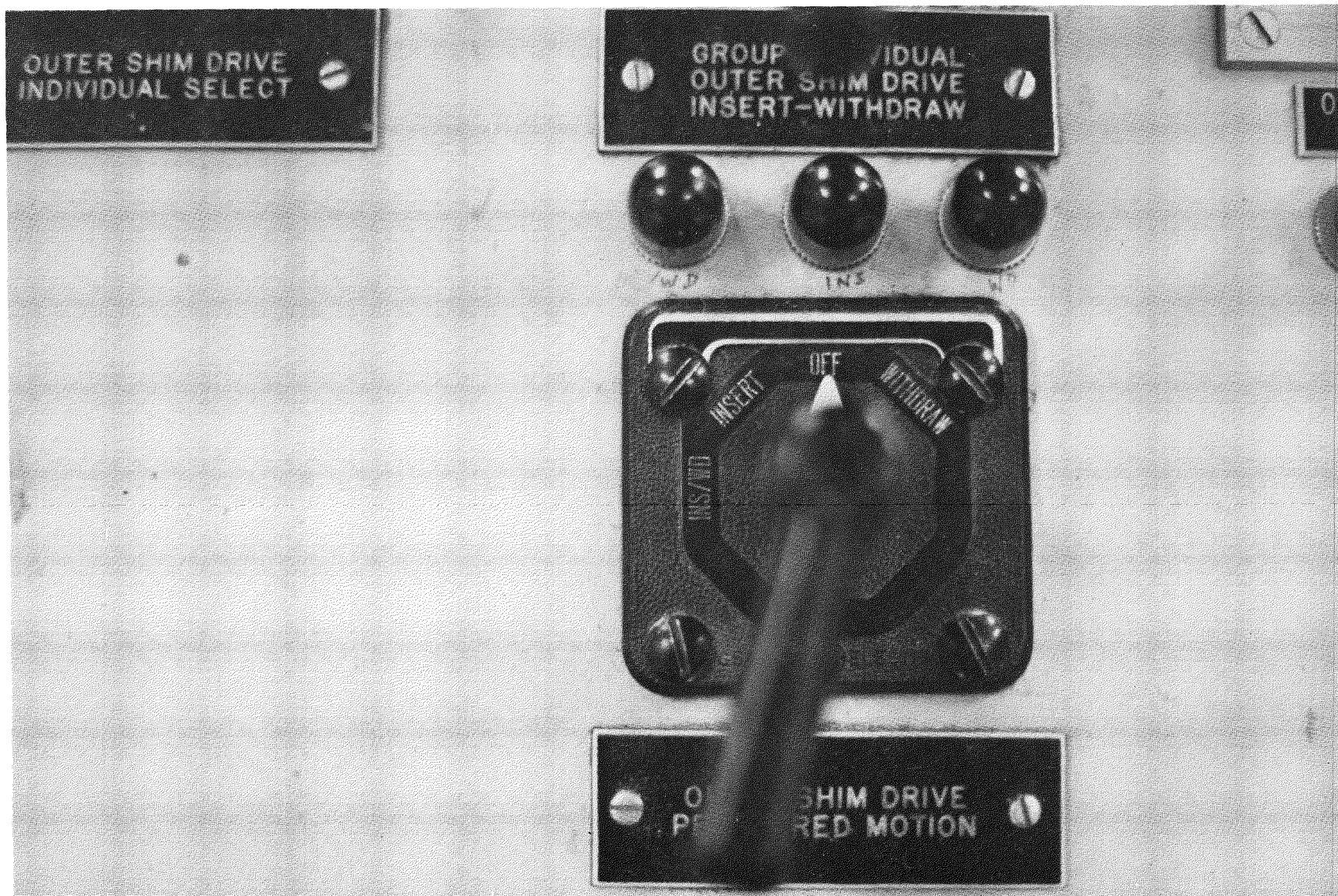


Figure 21. Hand-labeled indicator lights.

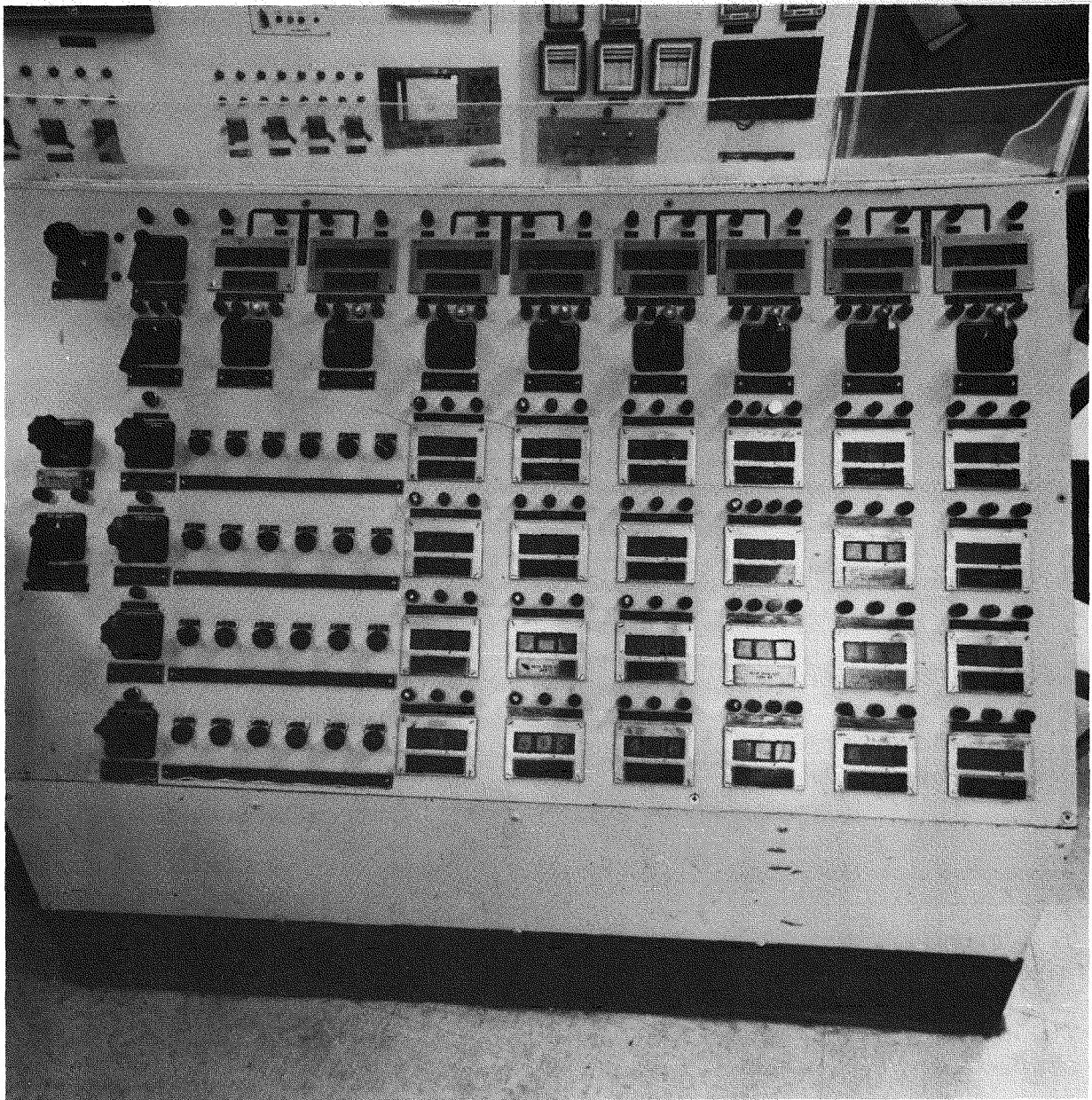


Figure 22. Outer shim and neck shim subsystems.

shims, instead of one display for two shims. This would net a savings in 50% space, hardware, dollars, and time to extract information. Engineering, of course, would be involved in implementation of such a hardware modification.

Control Display Relationship. The relationship between control rotation and metering of outer shim individual select is reversed, e.g., the control reads clockwise; A, B, C, D; but the meters read from left to right; D, C, B, A. This is confusing and should be changed.

Cosmetic Appearance. There is extensive cracking of the main console lamination. Cosmetic appearance of console could be improved if this was repaired/replaced.

### Summary

Noncompliance with MIL-STD-1472 and other human factors design criteria was noted in 15 cases (see Appendix D).

### Miscellaneous Subsystems

#### Manual Scram Switches

The protective covers on the manual scram switches could act as a catch basin for anything inadvertently dropped over the console. If something were dropped onto the manual scram switch, the object would be difficult to retrieve without scrambling the plant. We recommend a spring-return toggle switch (with a rounded or non-flat surfaced plexiglass hood) as an alternative manual scram switch (see Figure 23). The time required to activate the manual scram switch should be kept to a minimum.

#### Process Instrumentation Test Blocks

The labels on the process instrumentation test blocks are located beneath the test blocks and are very difficult to read. Additionally, the position of

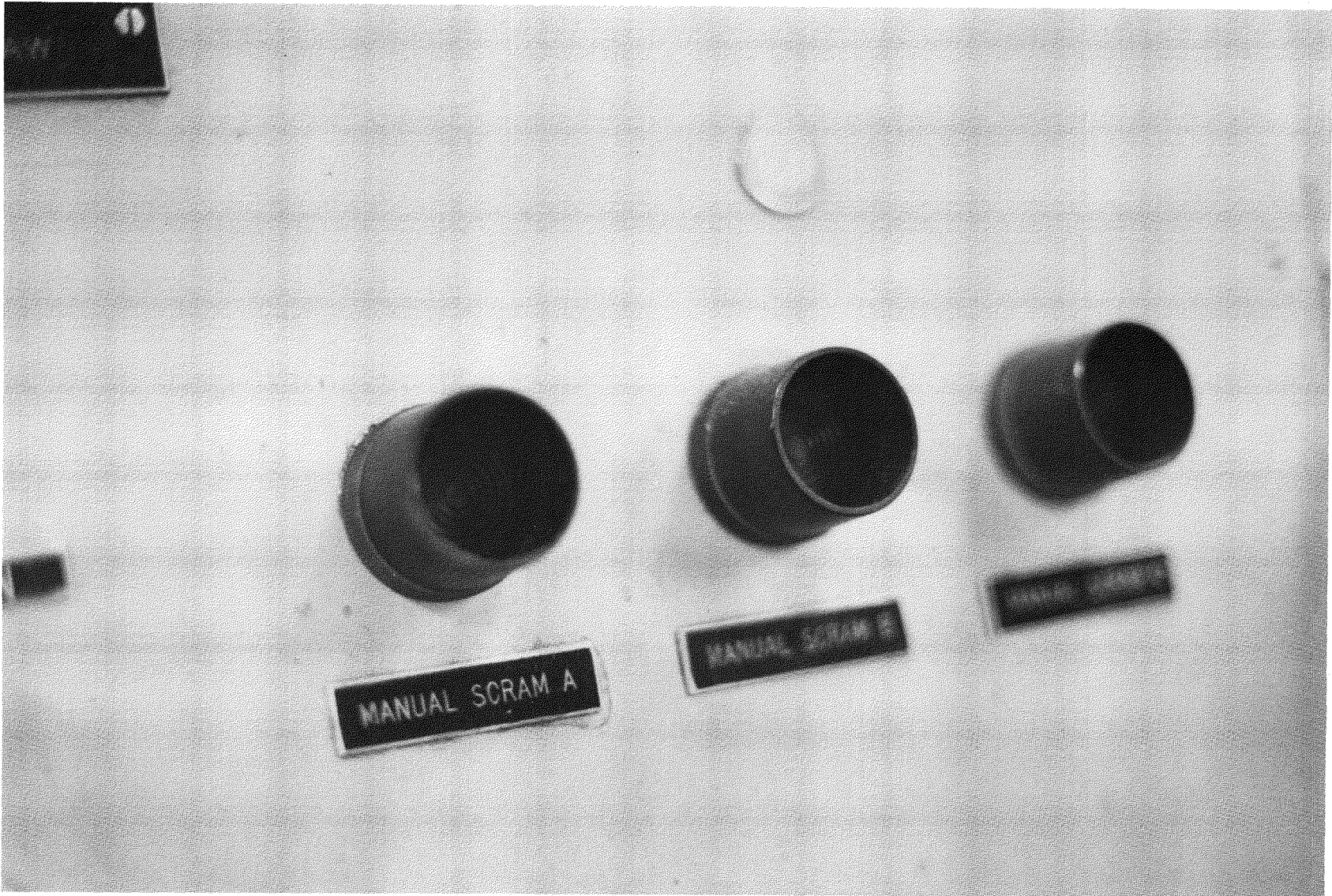


Figure 23. Manual scram switches.

the blocks is not consistent with the meters. We recommend the labels be placed on top of the test blocks and the test blocks arranged in the same manner as their corresponding instrument (see Figure 24).

#### Seat Switch Select and Redundant Safety-Rod Lights Subsystem

The reverse timers, the seat switch select subsystem, and a press to test circuit continuity check meter are all located behind locked plexiglass doors. There is no apparent rationale for specifically protecting any of these devices. On the contrary, the instruments behind the locked doors are used very infrequently, yet they occupy a place on the panel which is within the optimal-viewing range of a seated operator. We recommend items which are used much more frequently, e.g., the channel A, B, and C power-level meters, be located in the space currently occupied by the plexiglass box (see Figure 25). This should be considered simultaneously with total panel assessment modification.

#### Nonfunctional equipment

The CRT display keyboard (Figure 26), and ion chamber insert/withdraw switch (Figure 27), were found to be electrically disconnected and non-functional. It is recommended that all nonfunctional or unused components be physically removed from the console. This will reduce visual noise, visual search time, conserve priority space, and improve operator performance in high workload or emergency situations.

#### Summary

Six items noted in this section did not comply with human factors standards/design criteria.



Figure 24. Process control test blocks.

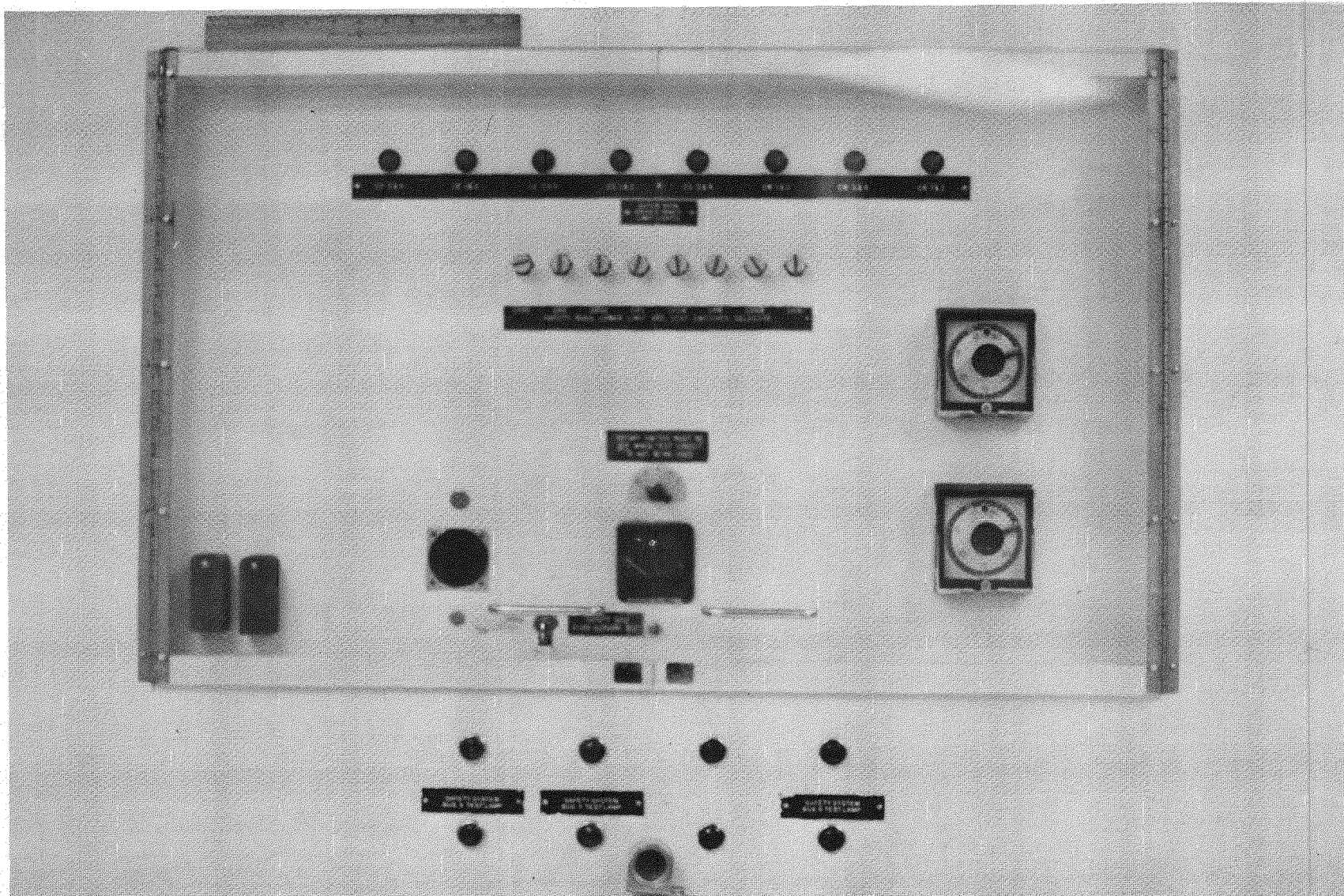


Figure 25. Plexiglass enclosure for reverse timer.



Figure 26. Nonfunctional CRT display keyboard.

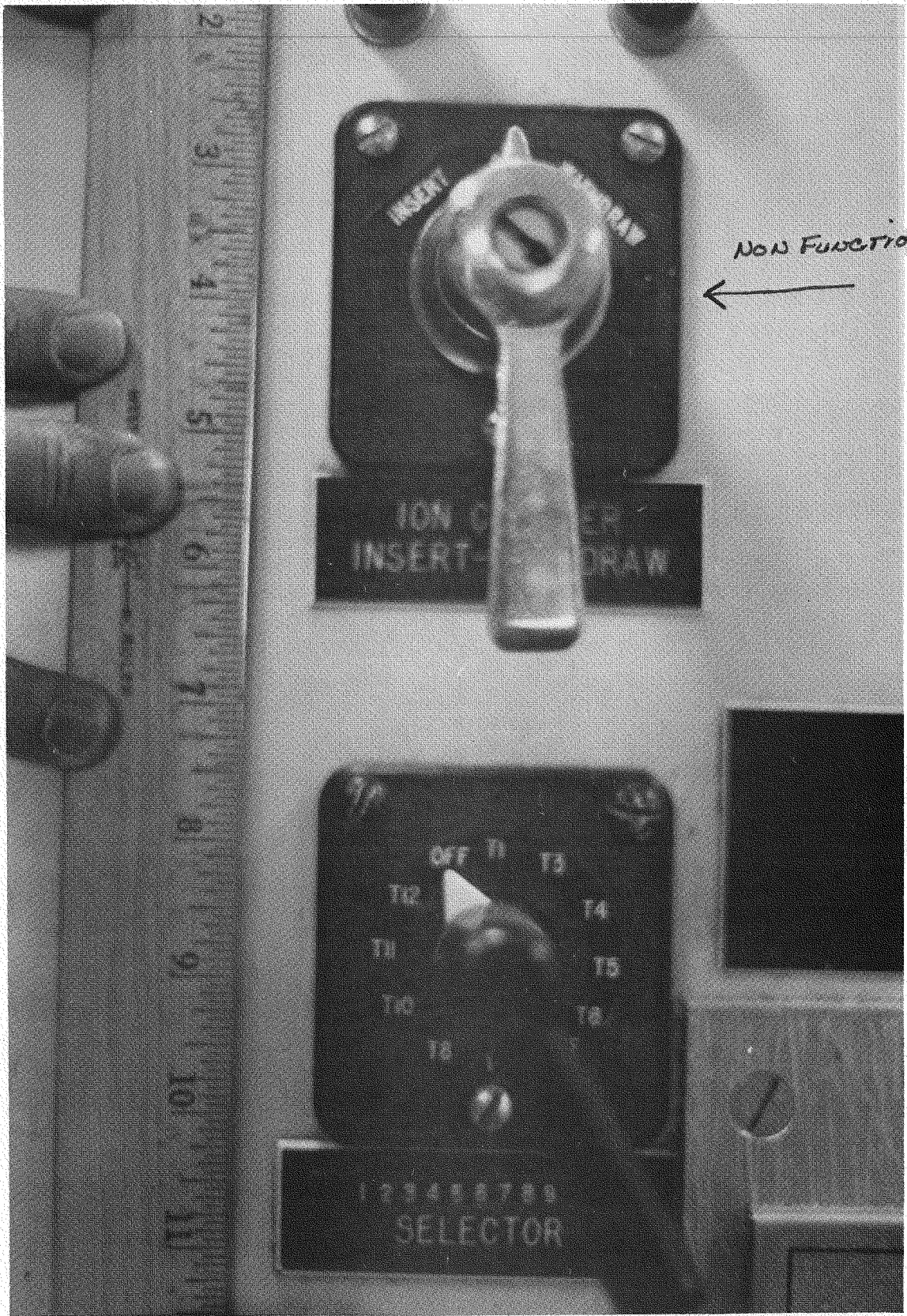


Figure 27. Nonfunctional ion chamber insert-withdraw switch.

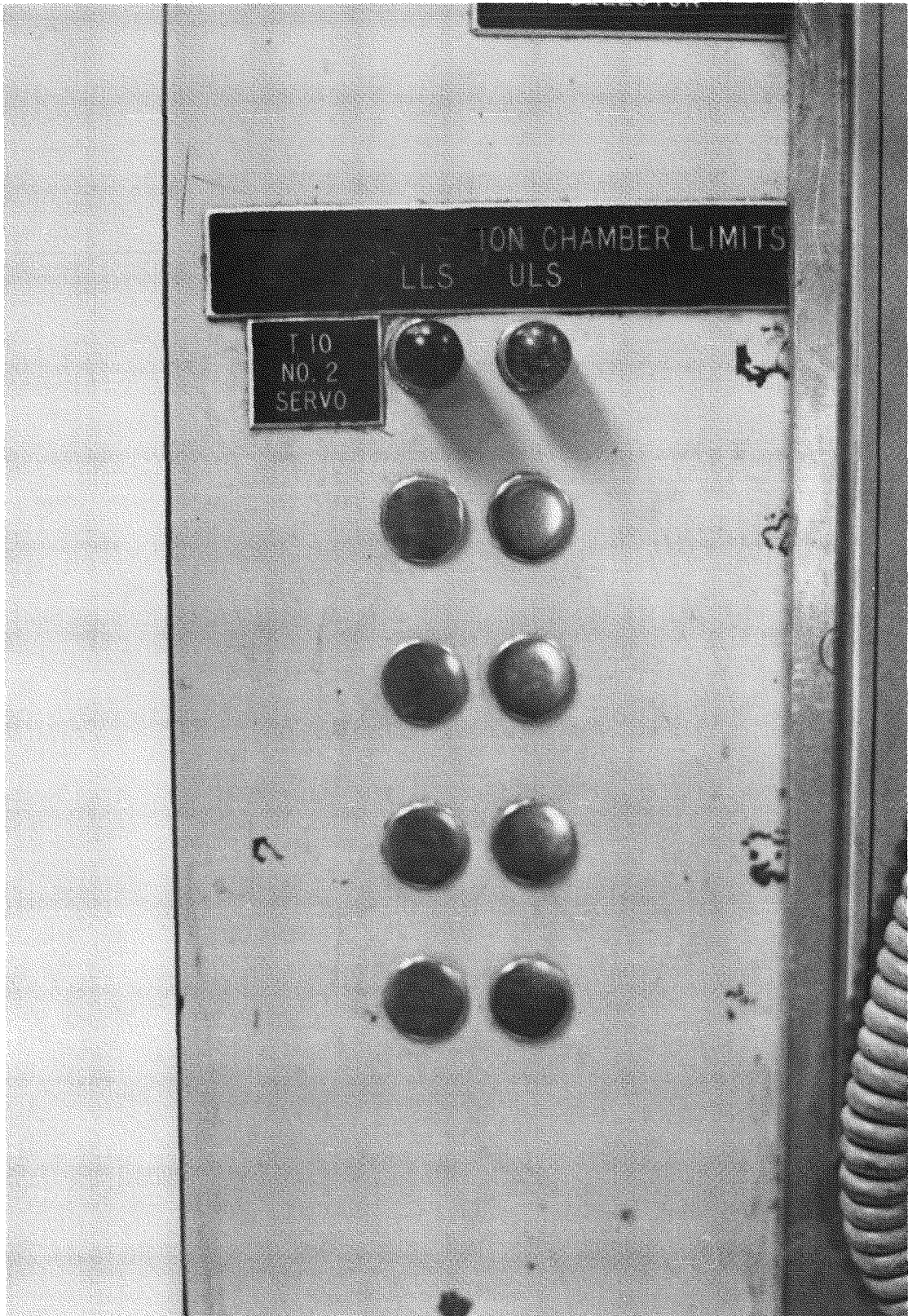


Figure 28. Nonfunctional ion chamber limit lights.

## PROCESS CONTROL ROOM

### General

The Process Control Room monitors and controls both the primary and secondary cooling (water) systems. Instrumentation and controls for wastewater treatment and water purification are also in the Process Control Room. The inability of operators to accurately read some instruments and the need for interpolating data are the most obvious problems in the Process Control Room. In general, we found that the vast majority of meters did not conform to the maximum viewing distance (MIL-STD-1472-B-5.2.1.3.10) of 28 in. usually set for critical or the most important instruments. Nor did the meters comply with (MIL-STD-1472-B-5.2.3.2.3.6) which states that gage pointers should not cover the numerals on the scale. Likewise, not all functionally related groups of controls were set apart with contrasting lines, and it was clearly not evident in the general control layout what systems were the most critical or frequently used, i.e., which groups of controls were designated to control important function processes.

### Specific Problems and Recommendations

#### Feedback

There is no feedback to the operator regarding physical opening of valves used during primary anion regeneration. When the anion regeneration cycle is initiated, a light indicates the regeneration cycle has started. The light does not inform the operator that the valves necessary for the operator are actually opened but only that the control has been activated. We recommend that valves be directly instrumented to give accurate feedback concerning their position (see Figure 29).

#### Conversion

The degassing tank drain flow indicator, secondary makeup and blowdown valve, and watt power meter do not provide operators with conversion-free

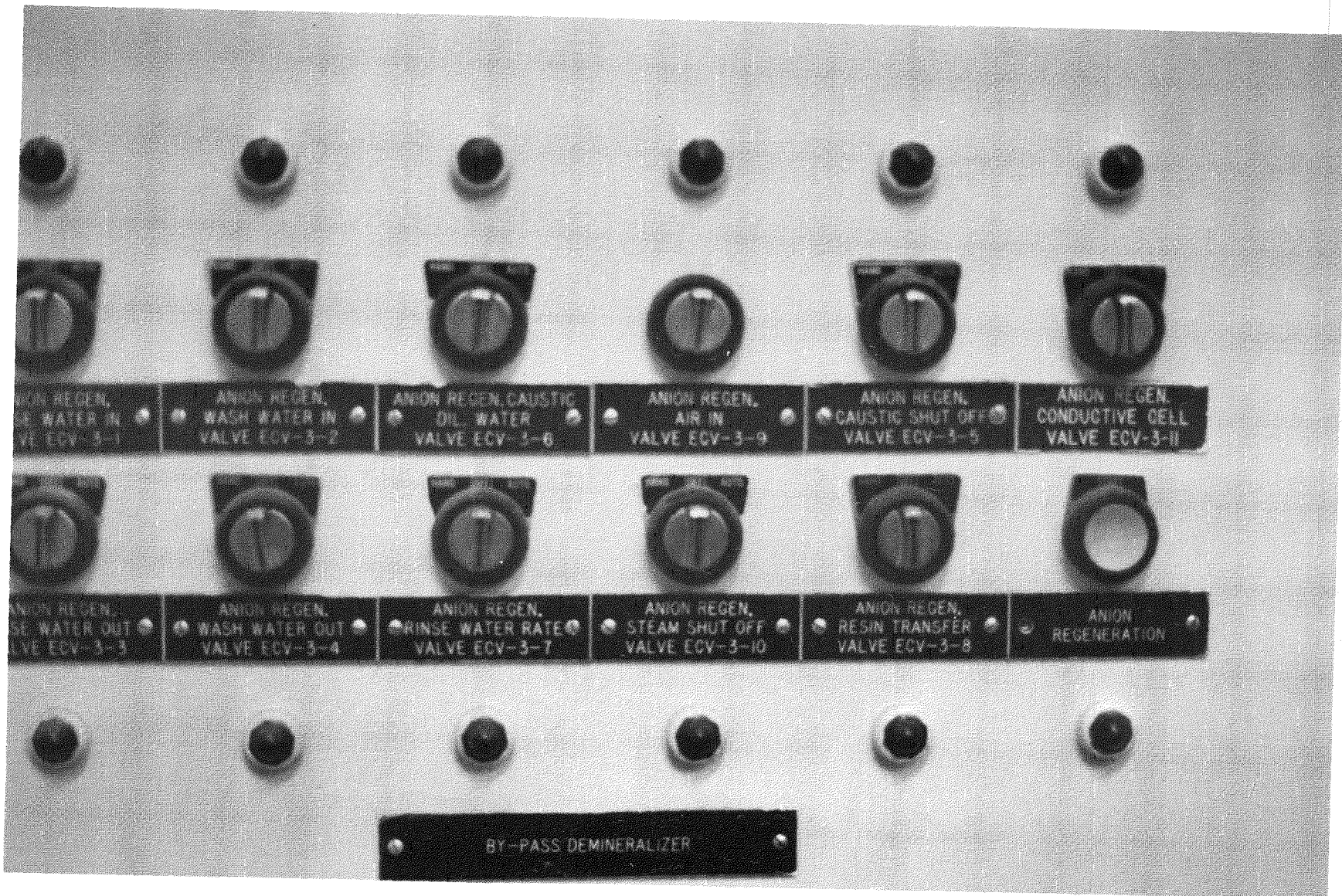


Figure 29. Anion regeneration system. (The indicator lights show circuit activation; not valve opening.)

data. Operators must first read the data and then use a conversion chart before they can interpret what the information means and take appropriate action (PR-1-16). We recommend that indicators be provided that do not require conversion charts and give the desired information directly (see Figure 30 for illustration of watt power indications).

### Reliability

During the course of our evaluation, it was learned that the bearing temperature displays require finger tapping by the operators in order to obtain accurate readings. Needle pointers were said to jump between 1/16 and 1/8 in. after tapping. We recommend that the bearing temperature indicators be replaced with instruments that have higher reliability and of a design that does not require finger tapping (see Figure 31). Digital readouts may satisfy these criteria, and can be used where relative scale, position, and/or trend information is not essential.

Another problem, related to precision of information, was also noted. Operators find the degassing, demineralized water, and kilowatt (power output) meters difficult to read reliably. The scales on these instruments create a high degree of variability between different operator reports of the same information. A digital display would eliminate this unwanted variance in operator interpretation of display information. (Again, these are useful indicators when operators do not need relative scale, position, or trend information.)

There were a few instruments, such as the total secondary coolant flow indicator and FR-1-9, that were not currently used by operators. We recommend any nonfunctional equipment, or nonutilized systems be physically eliminated from the main control/monitor console. Nonfunctional instruments will usually increase operators visual search time and increase visual complexity. Increased visual complexity has a greater chance of impinging on operator performance and should be kept to an absolute minimum.

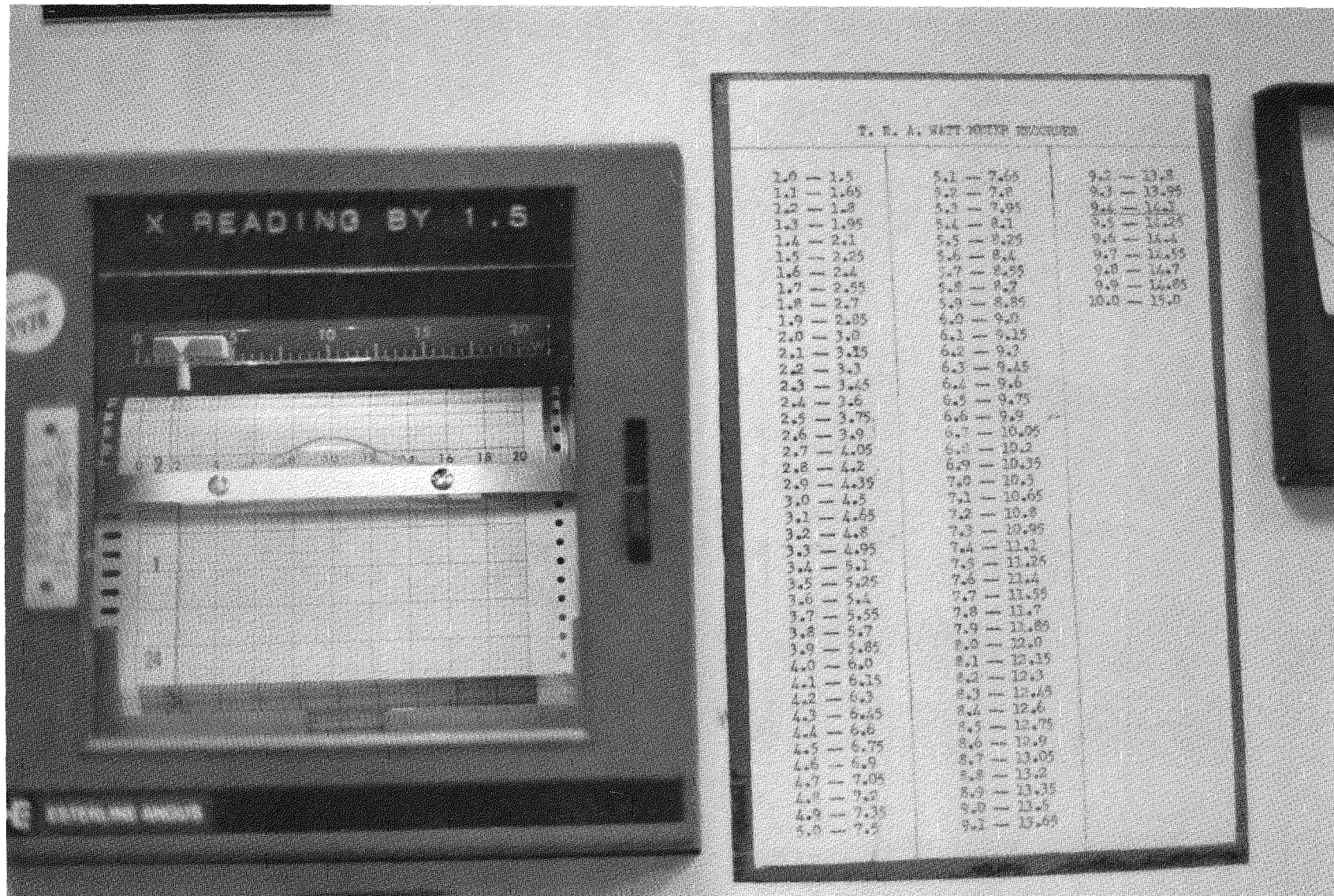


Figure 30. Conversion chart necessary to interpret meter indications.

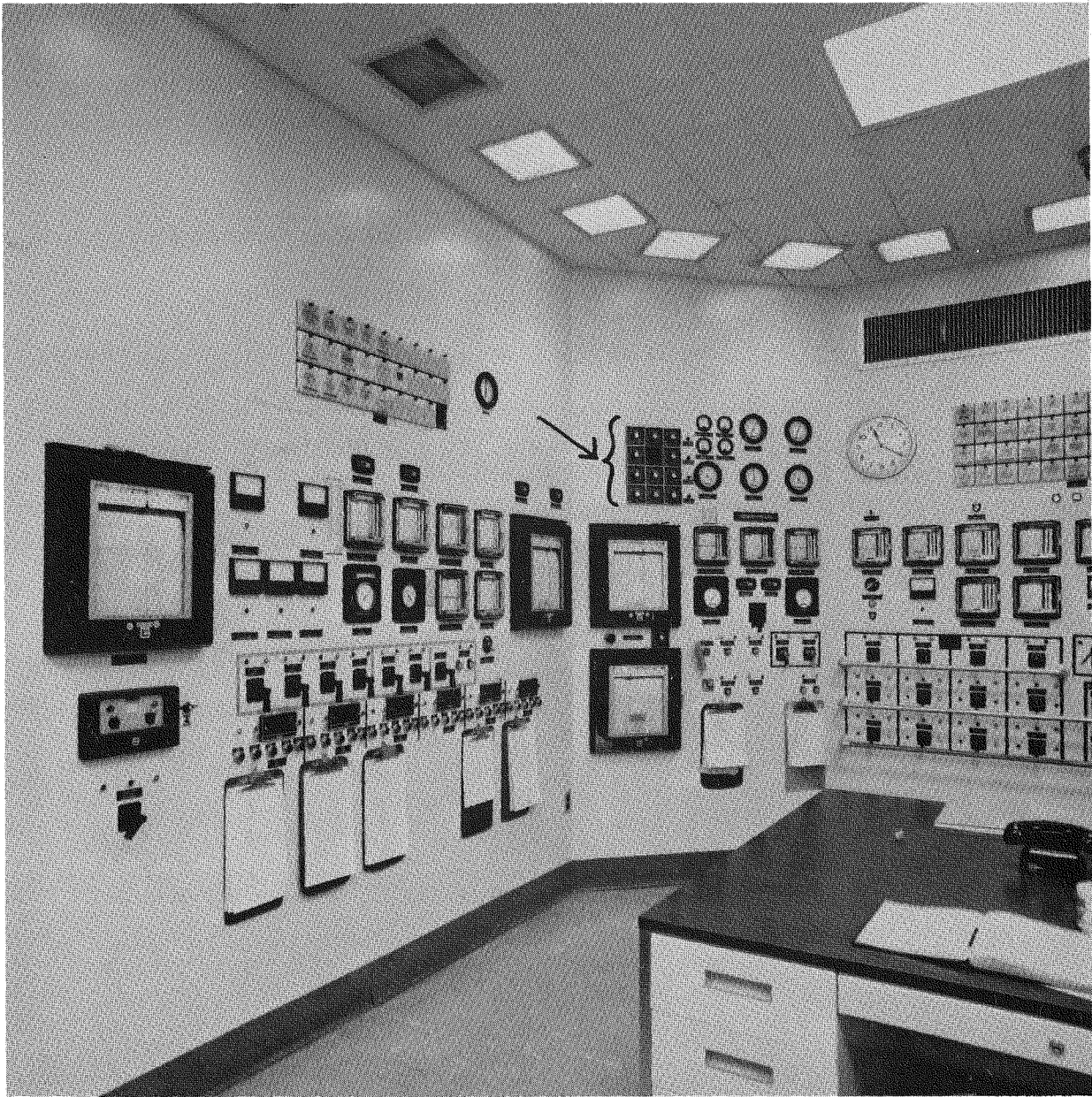


Figure 31. Pump bearing temperature indicators.

### Accuracy

The scales on the acid-level indicator do not accurately indicate the true level of the acid tank. The reading is given in percent; however, when the meter reads approximately 75%, the tank is actually full (100%). Operators have attempted to compensate for the meter error by placing a piece of sticky tape on the meter glass (see Figure 32). The tape reads "1300 gal" and is placed on the meter glass at approximately the 72% mark (when the acid tank is actually full). The tape obscures the meter numbers and dial indicator. We recommend the meter or instrumentation be adjusted so that the meter reads correctly and the tape be removed.

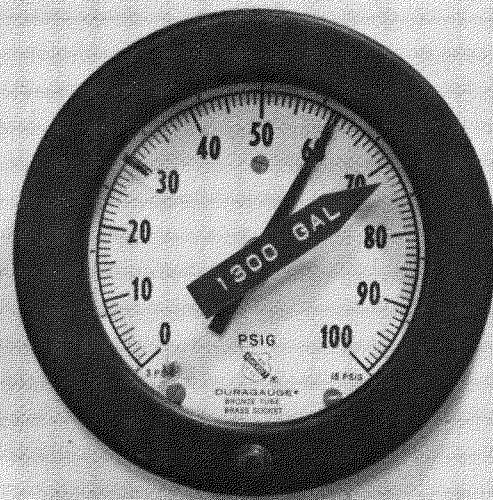
### Additional Information Desired

Information related to the emergency-power diesel engine, such as oil pressure or temperature, is not available to operators in the control room. Operators must leave the control room and physically examine gauges located on and around the diesel engine. This process, as it currently exists, is time consuming and would be unnecessary if appropriate instrumentation were to be provided in the Process Control Room.

### Readability/Access

The primary pump suction pressure, primary coolant pump pressure, hot waste, warm waste, and acid-level meters are situated at a height greater than 6 ft 5 in. and are difficult to read primarily due to the viewing angle, although parallax is also present (see Figure 33). Since these meters are used quite frequently, it is recommended that they be either:

- Repositioned to enhance the viewing angle and more appropriately positioned to correlate with their relative frequency-of-use, or
- Canted downward to increase viewing angle.



LI-II-1B

Figure 32. Acid level indicator. (The tank is actually full when the meter reads 72%.)

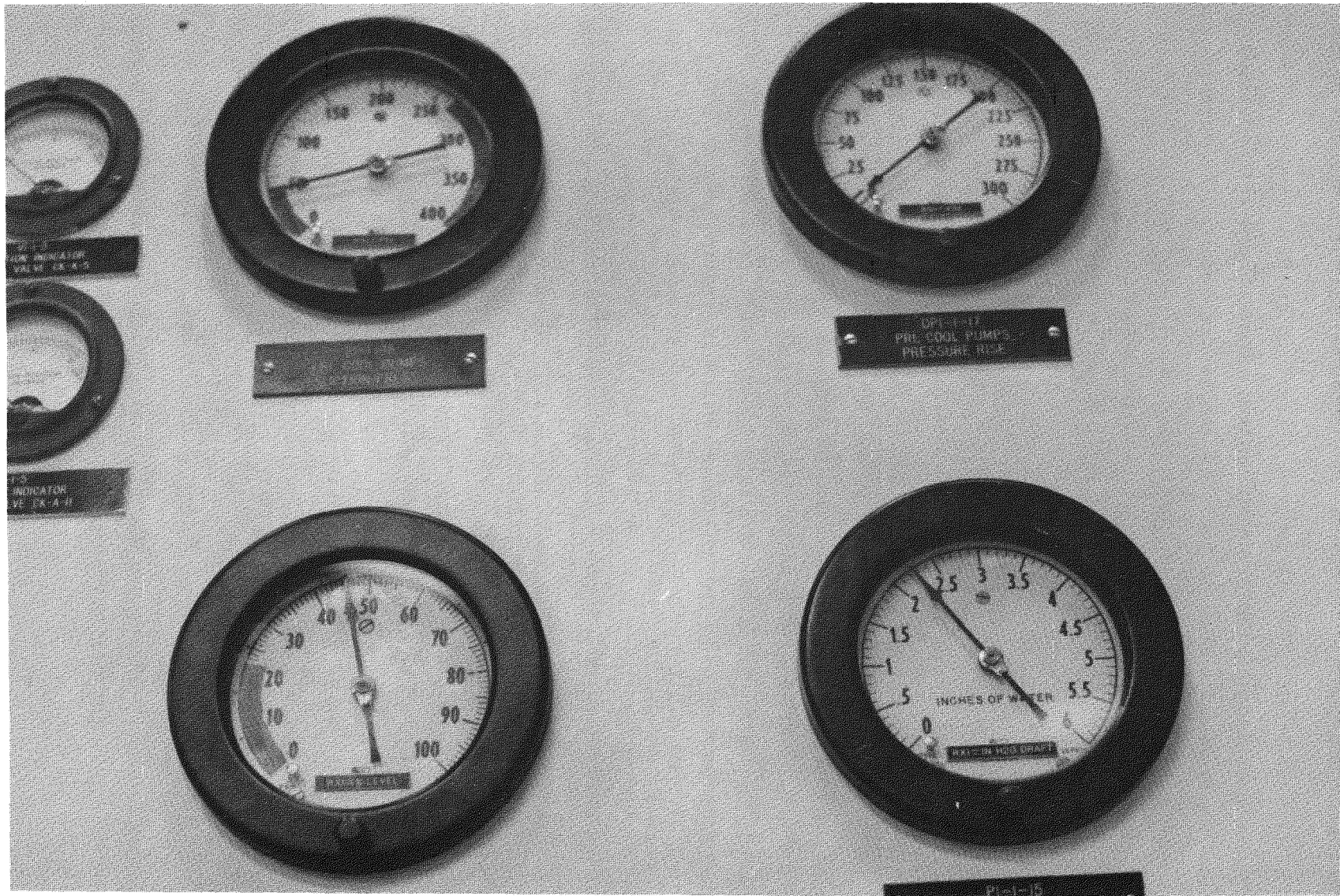


Figure 33. Primary pump suction pressure, primary coolant pump pressure, hot waste and warm waste meters. (There is a parallax problem in reading each of these meters.)

## Nonfunctional Equipment

There is a two-mode (WRC-2-1) butterfly hand switch (see Figure 34) which is part of the secondary coolant (water) system. The extreme left position for this switch is never used. In fact, if the switch were placed in this position, either accidentally or intentionally, a SCRAM would occur. Since this particular element is never used and offers undesirable potential, it should be electrically blocked from the system and the switch removed from the panel.

## Color Code

Color-code practices in the instrumentation in the process and reactor control systems were as follows: BLUE and YELLOW lights were used to indicate a "lower limit" in the Process Control Room. However, YELLOW was also used to indicate an "off" condition. In the Reactor Control Room, GREEN was used to indicate a lower-limit condition and YELLOW was used to denote a "selected" condition. It is recommended that consistent color-code practices be established for standardizing the general meanings of colors. Table 2 presents MIL standards for color use which might assist in selecting colors with standard meanings.

## Confusion

The auto-sump pump switch (see Figure 35) which is part of the heat-exchange system gives the impression of being a four-position selector, but is a two-position control. The upper-right quadrant of the switch is for the "off" position and the left-lower quadrant is used as a name label. The operation of the switch involves a pulling-and-turning motion simultaneously. Single-motion switches are preferred to multimotion, except where the likelihood of inadvertent operation is high and consequences are serious.

Poor functional relationships between controls and corresponding meters were observed within the hot and warm waste flow systems as well as the hot and warm experimental waste holding tank systems. Each control for pump

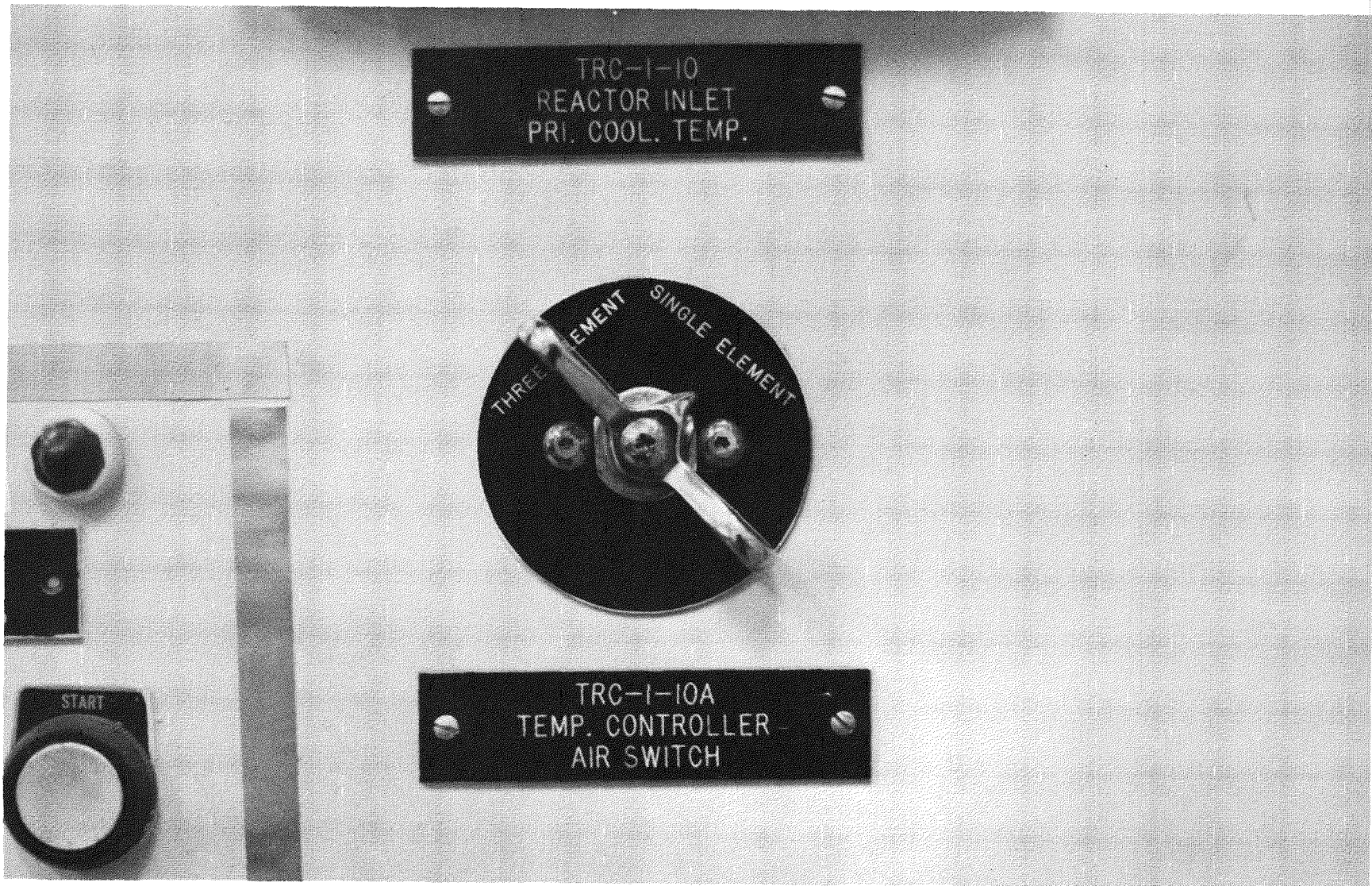


Figure 34. Temperature mode select switch. (If this switch is moved to the three-element mode, it may possibly scram the plant.)

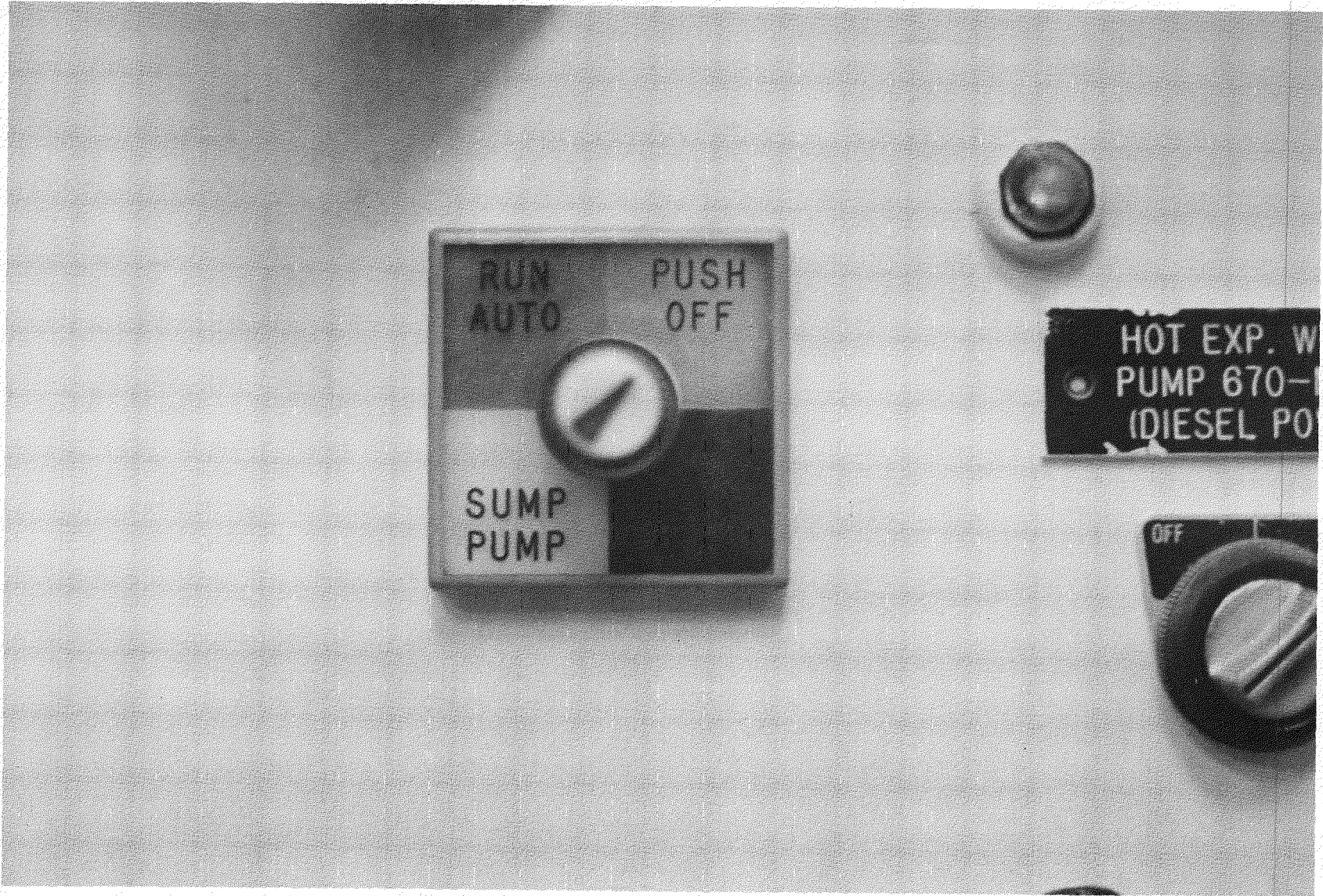


Figure 35. Auto sump switch.

function (on-off, etc.) should be situated in relationship to its associated display so there is no confusion as to which control goes with which display.

TABLE 2. CODING OF SIMPLE INDICATOR LIGHTS  
(Color)

Red	Yellow	Green	White
Malfunction; action stopped; failure; stop action	Delay; check; recheck	Go ahead, in tolerance; acceptable; ready	Functional or physical position; action in progress
Master summation (system or subsystem)	Extreme caution (impending danger)	Master summation (system or subsystem)	
Emergency condition (impending personnel or equipment disaster)			
Out-of-Spec Limits			

NOTE: When color standards are introduced in operating systems, we recommend it be done with assistance from human factors specialists who will work to minimize adaptation problems.

Labeling

During our observational analysis, we noted numerous examples of labels constructed with plastic tape. These labels were difficult to read, and in some instances, "dog eared", and ready to fall off. It is recommended that all jury-rigged temporary labels be replaced with sturdy, standard-size labels consistent in color and letter height, and located above appropriate controls or displays. All labels on the main console should be clearly legible from a viewing distance of at least 4 ft and labels on the forward control panel legible from 14 ft.

The primary pump bearing temperature gauges are poorly labeled (Figure 13) and are positioned in such a manner that they are difficult to read. The layout could be improved by canting the displays forward towards the operator.

The labeling of the secondary cooling fan controls is confusing (see Figure 14). The word "fast" is used to mean increase fan speed, "slow" is used to mean decrease fan speed. The words "increase" and "decrease" would be more appropriate. But a more pressing problem than the labeling is the push-button controls themselves. Fan speed (Figure 14) is difficult to control using the push-buttons. When a control button is pushed, the fan will often increase or decrease in speed more (overshoot) than is desired by the operator. We recommend that the rheostat which controls the speed be equipped with a rotary knob and located on the panel face. This would allow the fan speed to be controlled with much more precision.

An additional improvement could be made in the way the fan direction is displayed. Currently, the fan direction is displayed by an indicator light. Incorporating the fan direction into the rpm indicator would make the direction more obvious. The reverse direction could be indicated by a negative (-) sign on the digital display.

#### Summary

Noncompliance with human factors criteria/MIL-STD-1472 was noted in 18 instances.

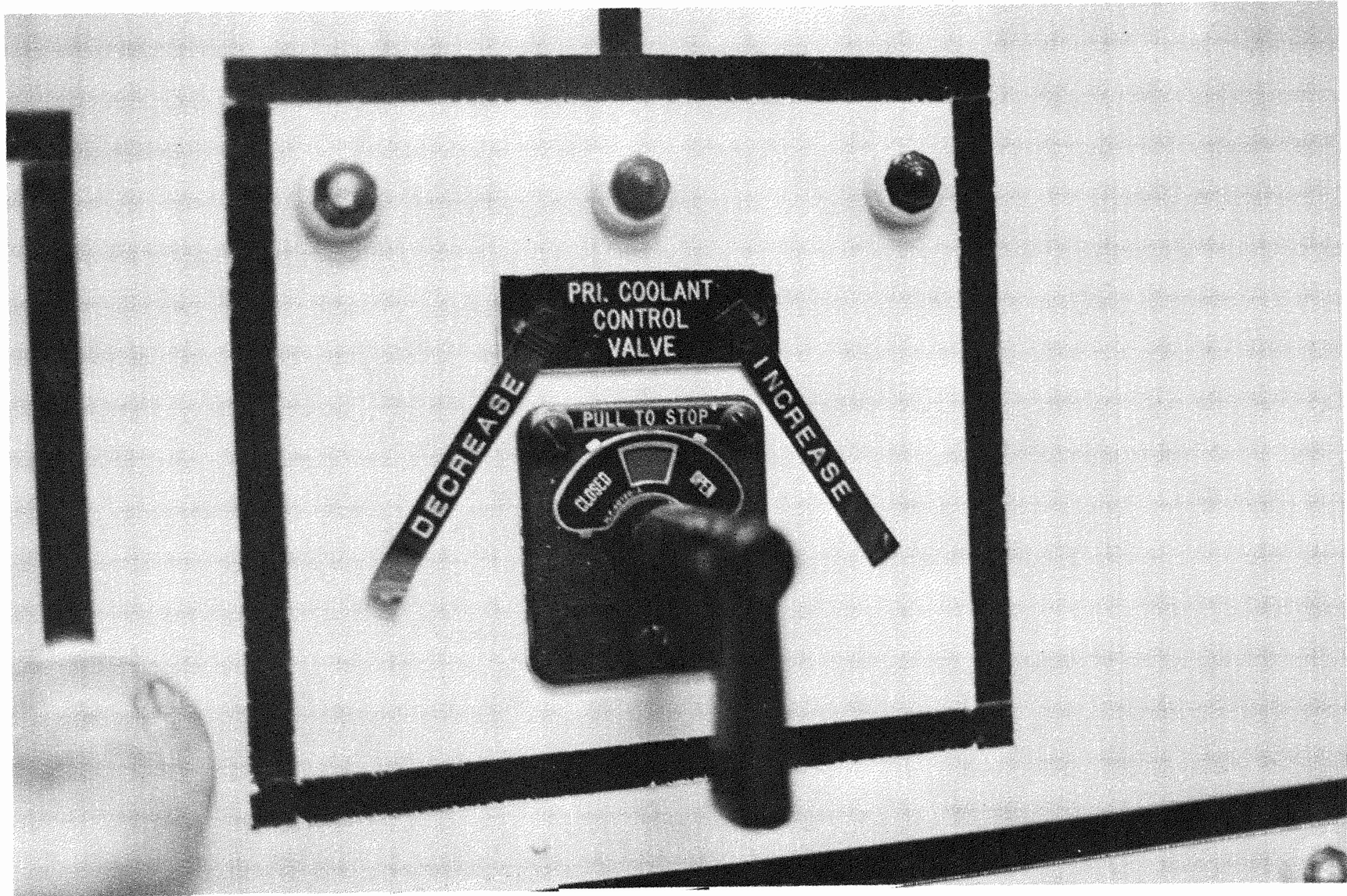


Figure 36. Primary coolant control valve. (More professional labeling should be applied.)



Figure 37. Pump bearing temperature indicators. (Forward canting of these meters would improve their visibility.)

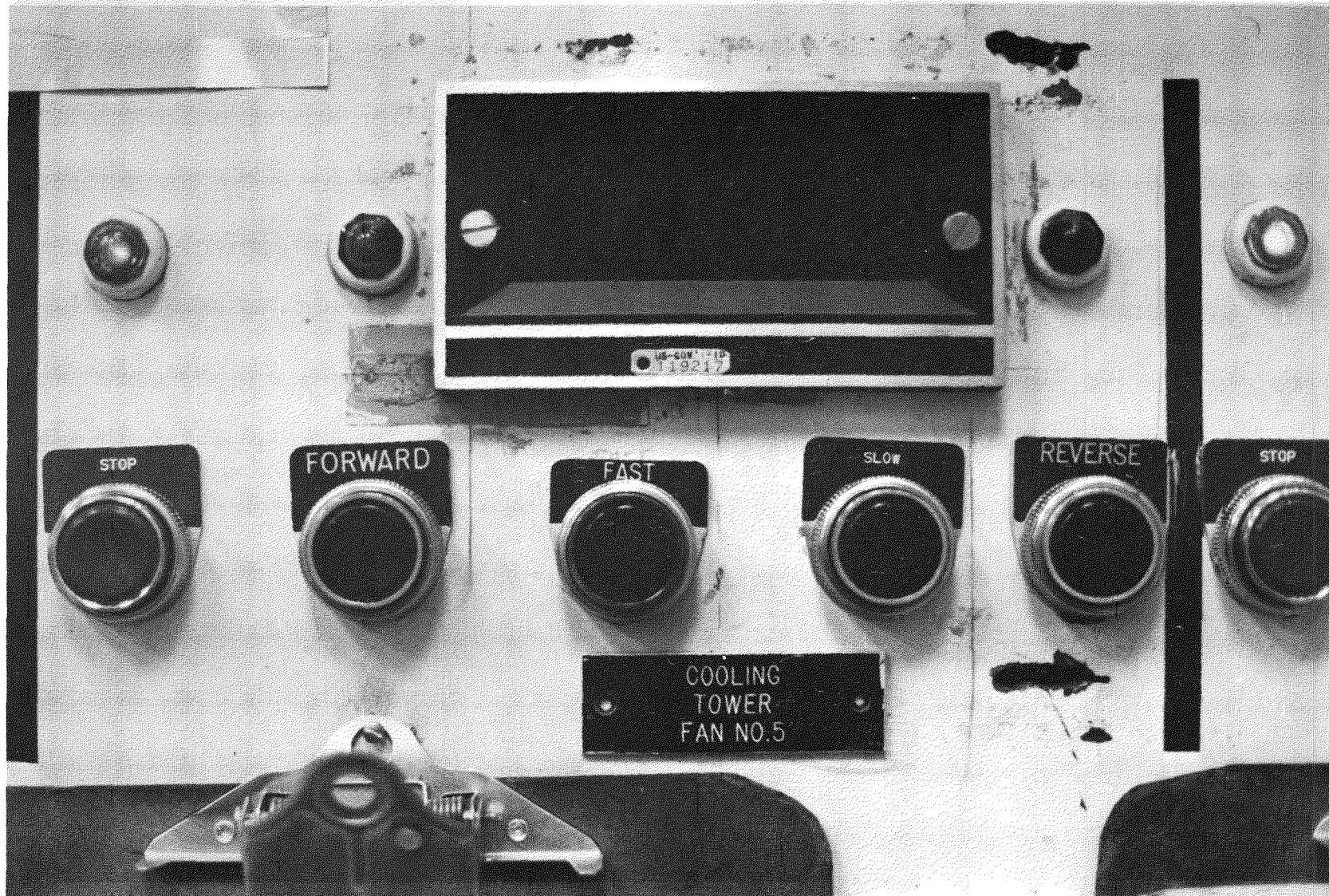


Figure 38. Cooling tower fan controls. (The labels "fast" and "slow" are misleading. "Increase speed" and "decrease speed" would be more appropriate.)

*Blank*

APPENDIX A

NAME: Motor-Operated Rheostat Subsystem Panel (MOR)

FUNCTION: The MOR system permits the operator to establish and control reactor power levels. There are two modes of operation for MOR: manual and automatic. Under manual control, the operator directly controls the physical positioning of all control rods in the reactor. When switched to the automatic mode, a system of synro-servo motors maintains reactor power by automatically manipulating the regulating rod to establish and control the desired power level.

COMPONENTS: (5) Hand Controls (6) Meters  
(2) Switches (5) Indicator Lights

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Noncompliance  
with

MIL-STD-1472-B

Comment

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5.2.1 If the system changes to manual mode, the first signal presented is likely to be missed (a green light goes out) since it is not located in a visually desirable position (near operator's left knee).

5.2.1.2.1 On two visual demand meters, the operator cues only on direction of the pointer. Scales are not needed since the operator does not use numbers on scales.

5.2.1.2.2 Same Reg comment as 5.2.1.2.1.

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Noncompliance  
with

MIL-STD-1472-B

Comment

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- 5.2.1.2.6            The only change of state information presented is that a green light goes from "on" to "off" when auto mode fails.
- 5.2.1.3.0            The regulator-rod meters are not located near their corresponding manual controls and are too densely or over-graduated to be of value to operator.
- 5.2.1.2.8            The manufacturer's name "Simpson" is clearly visible on demand meters No. 1 and No. 2.
- 5.2.1.3.3            The visual angle is 20 degrees above the normal line of sight.
- 5.2.1.3.9            The regulating-rod meters are too far away from their  
5.2.1.3.10           corresponding manual controls. Both operators on duty  
5.2.1.3.11           confirmed this.  
5.2.1.3.12
- 5.2.2.2.1            Legend lights could have been used in lieu of indicator lights.
- 5.2.2.2.4            The operators used plastic "sticky" tape labels on the demand console amplifier switch.

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Noncompliance

with

MIL-STD-1472-B

Comment

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5.2.2.3

5.2.3.1.2

All indicators

5.2.3.1.3

5.2.3.1.4

The No. 1 and No. 2 MOR position indicator meters were found to have log scale presentations.

5.2.3.1.5.2

Regulator position indicators

5.2.3.1.7

Regulator Rods Nos. 1 and 2; MOR position indicators; demand meters.

5.2.3.1.7.2

Regulator Rods No. 1 and No. 2.

5.2.3.1.7.3

5.2.3.1.10.1

5.2.3.1.10.2

5.2.3.1.10.3

5.2.3.2.1

5.2.3.2.2

5.2.3.2.1

Noncompliance  
with  
MIL-STD-1472-B

Comment

5.2.3.2.3.2 (b)  
5.2.3.2.3.3  
5.2.3.2.3.6 a and b  
5.2.4.3 a, c, d  
5.2.4.8 (g) Demand Meters

Miscellaneous Comments

One operator indicated that the key switch (on the center of console) needs a protective cover to prevent the possibility of inadvertent activation.

5.4.2.1.2 Broken pointers were also noted on the MOR servo channel select hand control.

5.4.2.1.3

5.4.2.1.1.6 Broken pointer on the MOR servo channel select.

5.4.3.1.3.1 Console amplifier demand switch.

5.5.1.1 Numerous instances of poor and inconsistent labeling practices and the use of plastic tape as a temporary "fix."

Noncompliance

with

MIL-STD-1472-B

Comment

- | MIL-STD-1472-B | Comment   |
|----------------|---|
| 5.5.2.3        | Labels for demand meters are on top of the meters, but labels for hand controls and other panel meters are on the bottom.                       |
| 5.5.3.2        | "Console amplifier demand switch" labels used plastic tape with "I" and "W" to indicate insert and withdraw respectively.                       |
| 5.5.5          | Plastic temporary tape used.  |
| 5.5.5.13       | Letter height for Reg Rods at a viewing distance of 78 in. should be at least 0.68 in.; however, actual letter height was found to be 0.187 in. |



APPENDIX B

NAME: Safety-Rods Subsystem Panel

FUNCTION: Emergency shutdown of the reactor: The safety rods are inserted via two modes: automatically or manually. This system is also utilized during specific maintenance and reactor testing protocols; hence, subfunction is for maintenance testing

COMPONENTS: (2) Hand controls (8) Meters (9) Buttons  
(8) Switches (34) Indicator lights

---

Noncompliance  
with

MIL-STD-1472-B

Comment

---

5.1.2.1.1.3 No distinguishing delineation boundaries between Safety-Rod Subsystem and other control systems.

5.1.2.2 No clear direct functional link between safety-rod select switch and its associated display (meter) was also noted. A discrepancy between the select points (positions) on the safety-rod hand controller and the positions correspondent with the appropriate display, e.g., north rod is perceived as No. 1, but is physically placed in the No. 8 position.

5.2.1.2.6 Not obvious for failure-mode condition.

5.2.1.2.8 The manufacturer's name "Scientific Atlanta" appears on the meter face.

5.2.1.3.4 Safety-rod meters have convex face covers which add to the glare reflected by overhead lights.

Noncompliance

with

MIL-STD-1472-B

Comment

5.2.1.3.11	Exceeds 28 in., the maximum distance between safety-rod meter and corresponding control.
5.2.2.14	
5.2.2.1.13	Single bulbs--no test.
5.2.2.1.14	
5.2.2.1.15	If a light bulb is not inserted in "exact" position, all related lights will extinguish due to a blown fuse.
5.2.2.1.17	
5.2.2.1.18	(a, b, c, d, e,) color coding is not consistent ... red can mean "upper limit" and/or "withdraw". Red color has multiple meanings. The same is true with green and amber.
5.2.2.2.1	Legend lights could replace same indicator lights.
5.2.2.3.1	
5.2.3.1.10.1	
5.2.3.2.3.3	No break at 12 o'clock.
5.2.3.2.3.5	Pointers are at 10:30 or 45 degrees from 9:00.
5.2.3.2.3.6	
5.4.2.1.1.1	
5.4.2.1.1.3	

Noncompliance

with

MIL-STD-1472-B

Comment

Labeling

5.5.2.2

General inconsistent labeling; some indicators have labels on top, others have labels on bottom.

5.5.4.1

Unnecessary repetitive labeling when one "master" label for a delineated system would suffice.

5.5.5.1

5.5.5.11



## APPENDIX C

NAME: Neck Shim Rod Control Subsystem

FUNCTION: This system is used primarily to compensate for power loss associated with fuel consumption and to adjust and maintain a desired power split in lobe power.

COMPONENTS: (6) Hand Controls (24) Meters  
(24) Switches (76) Indicator Lights

---

Noncompliance

with

MIL-STD-1472-B

Comment

---

- 5.1.1.1 Poor correspondence between the master neck shim rod region select and corresponding meters. This is also true for the neck shim rod insert/withdraw switch and associated displays.
- 5.1.2.1.1.3 There is no symbolic association between display and physical phenomena represented, i.e., configuration of reactor lobes (safety rod position/activation).
- 5.2.1.1
- 5.2.1.2.1 Only "Direction" and configuration of shim movement and location are important to the operator. The numeric data displayed is in inches and is often inaccurate and numbers missing.
- 5.2.1.2.4 Indicator light and digital information are redundant regarding both upper- and lower-limit condition.

---

Noncompliance

with

MIL-STD-1472-B

Comment

---

5.2.2.1.10

5.2.2.1.13

5.2.2.2.13

5.2.2.1.15

5.2.2.1.17

5.2.2.1.18

5.2.2.1.18

Different color-code meanings for the same colors within a system.

5.2.2.3.1

5.2.2.3.2

5.2.2.3.3

5.2.6.2.1

5.2.6.2.4

5.4.2.1.1

5.4.2.1.1.3

Some hand controls, e.g., neck shim rod individuals and region select, are not bar shaped or even consistent in "L" shape.

5.4.2.1.1.4(a)

5.5.1.1

5.5.2.2

Labeling symbols around the shim rod hand control are almost indistinguishable; many pointers are broken on the neck shim rod region select controls.

Noncompliance

with

MIL-STD-1472-B

Comment

5.5.2.3 . Some labels above, some below (inconsistent).

5.5.6.2.3 (a), (b), (c)

5.5.6.2.5 No graduation

NOTE: During SCRAM recovery, the safety rod insert/withdraw switch must be operated simultaneously (at times) with the outer shim cylinder control. Only operators with an arm span greater than 6 ft 2 in. can do this maneuver.

Blank

APPENDIX D

NAME: Outer Shim Cylinder (OSC) Control Panel

FUNCTION: The OSC control panel is used to control reactor power distribution and compensate for fuel burnup by adjusting the rotation angle of the shim cylinders, which in turn control neutron deflection or absorption.

COMPONENTS: (11) Hand Controls (8) Meters  
(0) Switches (53) Indicator Lights

---

Noncompliance  
with

MIL-STD-1472-B

Comment

---

5.1.2.1.1.3 No delineation or separation boundaries between outer shim drive controls and other controls/meters.

5.1.3.2 When changing outer shim drive control, there is a one-minute time lag between the control initiated display information (power levels) presentation.

5.2.1.4.1 (a) The code for showing paired relationships between displays is inadequate.

5.2.2.1.11

5.2.2.1.13

5.2.2.1.14

5.2.2.1.16

5.2.2.1.17

5.2.2.1.18

5.2.2.3.1

5.2.6.2.2

Noncompliance  
with

MIL-STD-1472-B

Comment

- 5.4.2.1.1.2      The pointers of the hand controls (outer shim drive)
- 5.4.2.1.1.3
- 5.4.2.1.1.5      On the outer shim drive display, some of the numbers on the South 3 and 4 control have shifted down approximately 1/8 in. These are nixi-tubes displays and have some disadvantages relative to state-of-the-art displays today, e.g., light-emitting diodes.
- 5.4.1.2            The relationship between control rotation of the outer shim individual select knob and arrangement of corresponding display is reversed, e.g., there is a similar problem of inconsistency regarding CRT core representation and outer shim drive meter display.
- 5.5.1.1
- 5.5.2.1
- 5.5.2.3
- 5.5.3.1            No units of measure given.
- 5.5.4.3            (c) Plastic tag label.
- 5.5.5.1
- 5.5.6.2.3          (A) Every label on outer shim cylinders.
- 5.5.6.2.4          (B) Shim-drive meter repeats.
- (D) Could be said once on a master. In some instances, hand-written numbers were found as well as extensive lamination cracking on panel.
- 5.5.6.2.5

## APPENDIX E

### GROUND WORKSPACE DESIGN

---

Noncompliance

with

MIL-STD-1472-B

Comment

---

- 5.7.11 Kick space was not provided on vertical panels.
- 5.7.1.2 Loop-control handles protruded from Panel No. 11 greater than 1 in. Also on Panel No. 8 (under annunciator), the GM monitor patch panel wires protruded 7.25 in. into the work space. It was further noted that only 3-1/2 ft.
- 5.7.1.3 of work space is provided in front of the reactor console.
- 5.7.3.6 (B and C)
- 5.7.3.9 One control select switch for the N.W. neck shims was broken due to previous impact with the operator's swivel chair. This control was placed below the seated level of the operator at (shin level).
- General Numerous components were found to be nonfunctional or nonessential, but were still maintained on the operator console, e.g., fission chamber I/W switch.
- 5.8.2 Items (b and c) glare from overhead lights was observed on safety-rod withdraw meters. Glare was also found to be present on MOR Nos. 1 and 2 position indicators.
- 5.8.3 Normal voice communications in the control room is impossible at times when the paging system is activated.

---

Noncompliance

with

MIL-STD-1472-B

Comment

---

There is a total of seven phones with some of the phones possessing redundant functions. Each of the seven phones is separately located with no common physical link (access point). All operators (3) questioned indicated a preference for a common communications panel. Noted also was the fact that phone patch apparatus for the D.C. phone is physically out of the control room; hence, an operator cannot patch phone links because he/she is not allowed to leave the control room.

5.13.2.7

There were no fire extinguishers in the "immediate" control room for small localized fires, e.g., waste basket.

APPENDIX F

NAME: Log N Channel Recorders (2)

FUNCTION: Displays to operator in strip-chart form information concerning power levels of core measured in % power output (log scale).

COMPONENTS: (2) meters (strip charts)

---

Noncompliance

with

MIL-STD-1472-B

Comment

---

- 5.2.1 No indication as to what chart speed is on Channel 5.
- 5.2.1.3.4 Inconsistent placement of vernier control relative to script
- 5.2.1.3.10 (minor problem).
- 5.4.1.3.1 No subgroup markings to indicate physical system separation.
- 5.5.4.1(b) Redundancy in labeling, e.g., Log N channel No. 5 appears under meter and on glass face simultaneously.
- 5.6.1(a) Also Log N channel No. 5 overall range adjust vernier (top scale) cannot be read easily by operators below 5 ft 7 in., since it is 71.5 in. off the deck in height.

---

Noncompliance

with

MIL-STD-1472-B

Comment

---

5.2.1.2.8           Manufacturers' names appears on front panel

NAME:               Period Recorders (2)

FUNCTION:           Indicates to operator the rate of power change in seconds to  
change the power by a factor of e.

5.4.1.3.1

5.2.1.2.8

5.5.4.3             Poor labeling: small letters and low contrast in marking for  
5.5.5.4             power and on/off line switches.

5.2.1               No indication as to chart speed on Channel No. 5 period  
indicator (one has to open the panel to read speed).

5.2.1.3.10         Inconsistent indicator-light configuration over channel  
No. 8 normal and intermediate indicator lights.

5.6.1 (a)          Vernier ADJ to high for reading 71.4 in.

APPENDIX G

NAME: Neutron Level Recorders

FUNCTION: The neutron level meters indicate power level in the four lobes of the reactor.

COMPONENTS: (4) Script meters (11) Indicator Lights  
(8) Toggle Switches (4) Vernier Adjust Knobs

---

Noncompliance  
with

MIL-STD-1472-B

Comment

---

5.5.5.12 "Startup" labels too small and poor contrast

5.5.5.4

5.5.4.5

5.5.4.3

5.2.1 Chart-speed indicator can be assessed only by opening the meter face cover and swinging out the package to the rear.



APPENDIX H

NAME: Count Rate Meters

FUNCTION: Indicates to operator, during startup and shutdown, neutron populations used in conjunction with fission chamber-- insert/withdraw

COMPONENTS: (4) Script meters (11) Indicator Lights  
(8) Toggle Switches (4) Vernier Adjust Knobs

---

Noncompliance  
with

MIL-STD-1472-B

Comment

---

5.1.1.2 (A)(B) Poor correspondence between meter and controls.

5.1.1.3

5.2.1.2

5.1.2.1.1

5.1.2.2

APPENDIX I

NAME: Pneumatic Irradiation Status System

FUNCTION: Transmits to operator status on rabbit capsule inpile operation.

COMPONENTS: 2 amber lights (ready)  
2 red lights (capsule inpile)  
2 green lights (interlock-off)  
2 Keys - Lockout

Noted that lens covers had heat damage from hot bulbs, probably due to wrong bulb used in socket.

Again, color code inconsistency with red, amber, and green in relationship to other subsystem color codes.

NAME: Look Isolation Controls ("W" switches)

FUNCTION: Allows operator to isolate loop during shutdown.

---

Noncompliance  
with  
MIL-STD-1472-B

Comment

---

- 5.4.2 (b) Loop control OFF position is 45 degrees (2:00) to right. No pointer arrows other than L-shaped hand controls which have OFF position at 90 degrees or 12 o'clock (This is inconsistent).
- 5.1.2.1.1.3 No Delineation or boundary marks.
- 5.5.1 No labels on fuses and poor relationship to hands.



APPENDIX J

NAME: Evacuation Control Subsystem

FUNCTION: The evacuation control switches are use to alert ATR or area personnel that an evacuation is necessary.

COMPONENTS: (2) Strip-Chart Recorders (1) Telephone  
(3) Switches

---

Noncompliance

with

MIL-STD-1472-B

Comment

---

5.1.2.1.1.2  
5.6.1

The phone and evacuation switches are too high. The ATR - Evacuate/Alert switch is 7 ft 4 in. off the deck.

5.5.1.1  
5.5.21 (a)

The labels on the ATR evacuation switch are on the box protective cover. When the cover is lifted, the labels are not visible, sticky tape is used as labels.

5.5.1.2 (e)

Color coding is inconsistent; red means "east" and "evacuation control", yellow means "west".

5.1.2.1.3

There is no delineating boundary surrounding the evacuation controls.

---

Noncompliance

with

MIL-STD-1472-B

Comment

---

NAME: Battery Backed BR-16-69

FUNCTION: Provides strip-chart historic graphs of power supply. Operator logs readings every eight hours.

PROBLEMS: Physically located too low on console (operator must squat in order to read). The instrument has a relatively low frequency of use, yet it is located on a major control panel. The instrument is not clearly labeled and delineated. The instrument is usually not used as the primary display. The operators prefer to get their readings from a redundant digital display behind the main console.

APPENDIX K

NAME: Power Deviation Brush Recorder

PROBLEM: This instrument is nonfunctional and hence should be physically removed from the instrument panel.



## APPENDIX L

### CRITERIA SELECTION

Figure 39 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 in the checklist were reviewed by at least three human factors specialists to make certain that each standard included was relevant to reactor control room layouts.

#### 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:

- o the function of each control subsystem
- o when the control subsystem is utilized
- o how frequently it was used
- o the consequence associated with human error
- o what could be changed or eliminated to make their tasks

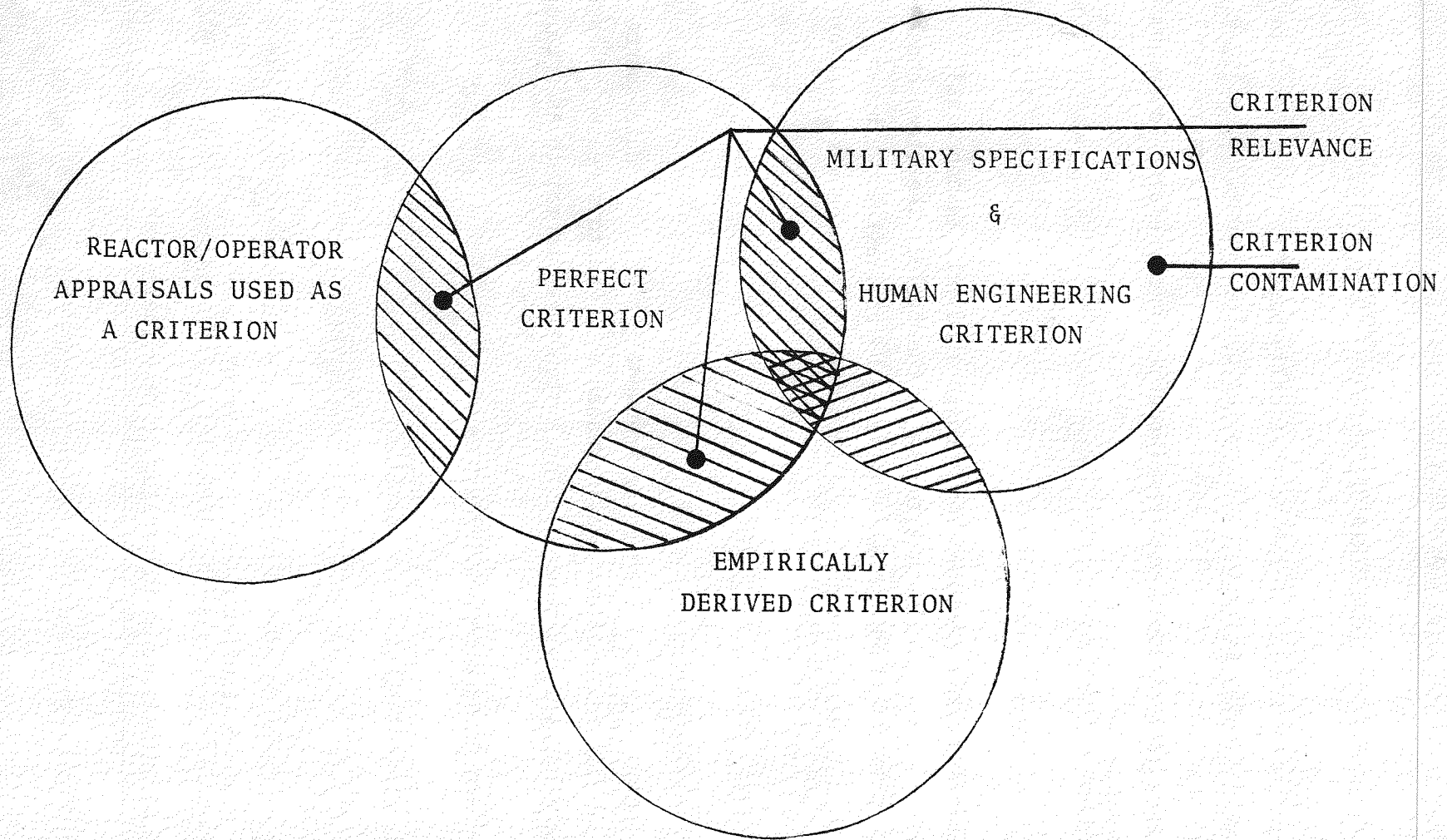


FIGURE 39. Theoretically based rationale for the evaluation of the ATR Control Room.

- a) more efficient
- b) more comfortable
- c) and lower the perceived P (error).

### Empirical Data

Due to the fact that there is a certain degree of unique system specificity at ATR with regard to control instrumentation, design, and layout, we felt it necessary to collect data using video-taped recordings of operator behavior. This was accomplished to provide information concerning actual frequency-of-use measures for each of the 10 most frequently used controls on the main control console. We adopted this strategy since time and money constraints placed limits on the number of controls we could examine using this method.

Blank

## APPENDIX M

### METHODOLOGY

#### Tools

The measurements 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. Video camera - Model No. G-71USJ manufactured by JVC Corporation, Serial Number 09413809 - camera was equipped with 6:1 ratio zoom, lens Model No. CV-L617AM, AMS
6. Video recorder - RCA time-lapse video recorder, Model TC 3250 with time/date generator, Serial Number 121315
7. 35-mm camera - Canon F1 with 50-mm cannon f-1.4 lens
8. Film - Kodak Veri Color II; ASA-100

#### Procedures

Figures 40 and 41 depict the procedure flow utilized by our evaluation team. Upon the completion of our MIL STD 1472-B checklist form, two

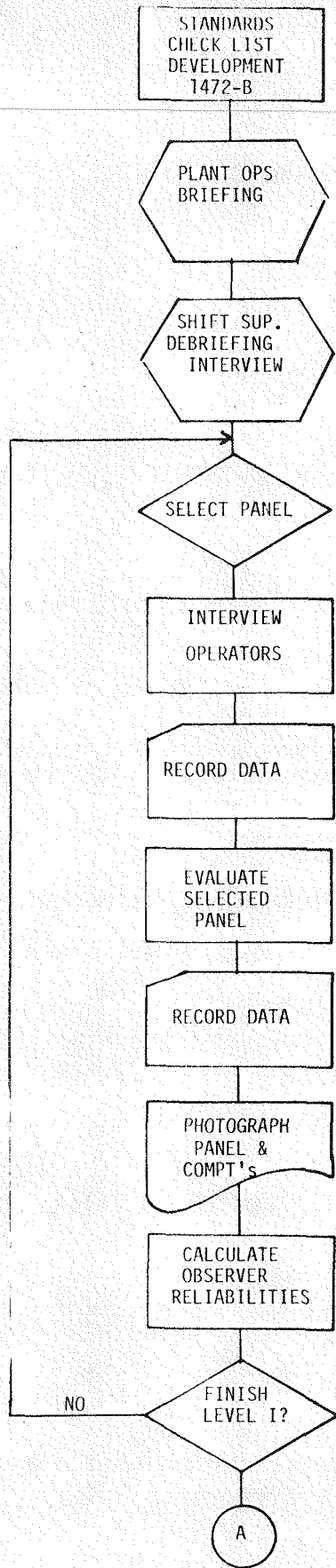


FIGURE 40

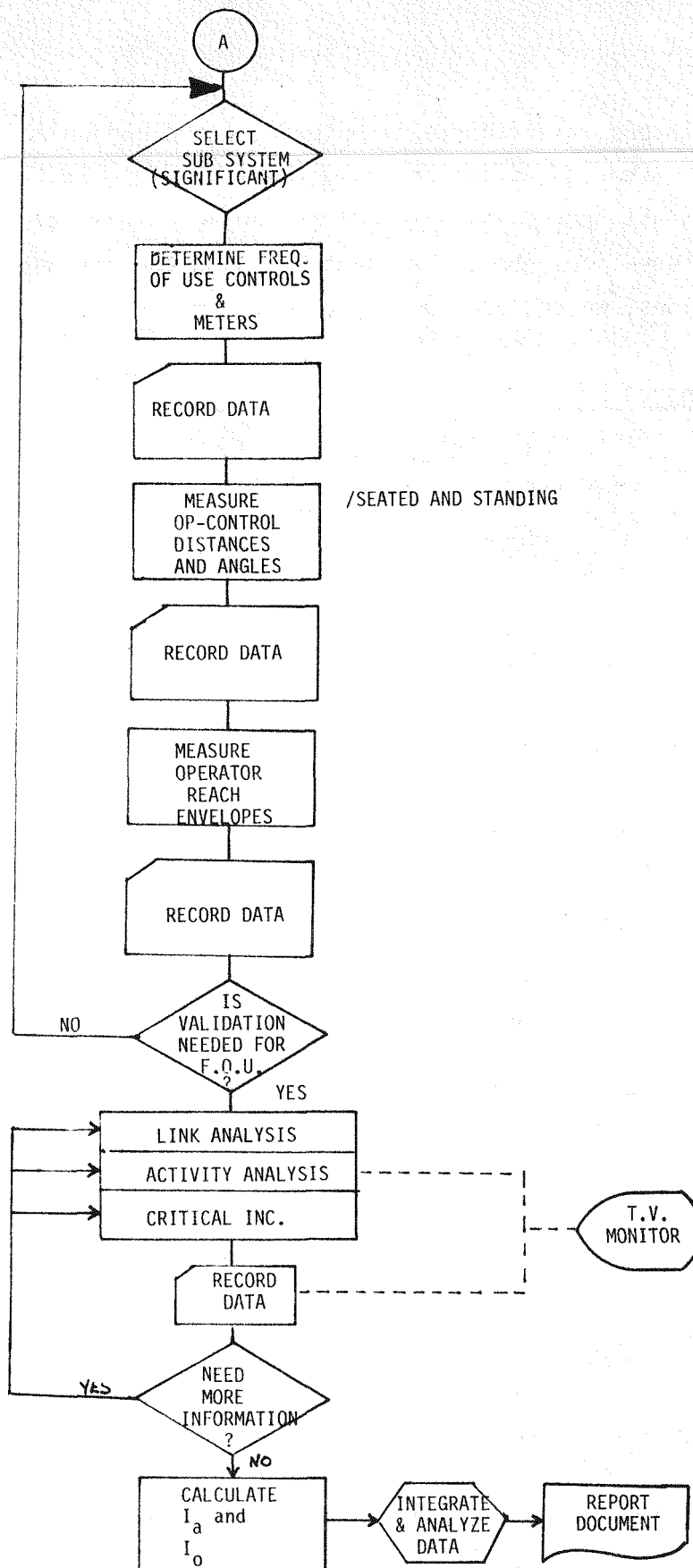


FIGURE 41

investigators were informally briefed regarding nuclear power plant operations at ATR. 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. From these discussions, we decided to evaluate the subsystems in the following order.

Main Control Room

1. Motor-operated rheostat subsystem
2. Log N channel recording subsystem
3. Period-recording subsystem
4. Safety-rods subsystem
5. Work-space design
6. Neck shim control subsystem
7. Outer shim cylinder control panel
8. Neutron level recording subsystem
9. Count-rate subsystem
10. Pneumatic irradiation status subsystem
11. Loop-isolation subsystem
12. Evacuation-control subsystem
13. Battery-backed VR-16-69

14. Power deviation recording subsystem

15. Radiation-monitoring system

16. Fission break sensor subsystem

17. Annunciator system

### Process Control System

#### 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:

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

Each interview was conducted either in the Reactor Control Room or the Process Control Room. Interview time varied between 1 and 4.5 hours, depending on the particular operator who was being interviewed.

### Video-Tape Recordings

The camera speed was set at 2 frames/second and run continuously for 60 hours during an actual reactor start-up and power-distribution activity. The film was later monitored and frequency-of-use observations scored for all hand controls, switches, etc. Activity patterns were also observed to establish operator movement requirements and boundary limits for movement.

### 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 motor-operated rheostat and neck shim control subsystems. Although these subsystems were not selected on a "random" basis, it was felt that a high interrater reliability score on these subsystems would tend to reflect the overall reliability of observed violations throughout the system. A violation was scored as 10, and compliance was scored as 01. For example, if observer A ( $O_A$ ), and observer B ( $O_B$ ) were in complete agreement, we would have the following:

$$O_A = 10; O_B = 10$$

$$O_A = 01; O_B = 01$$

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

$$O_A = 10; O_B = 01$$

$$O_A = 01; O_B = 10$$

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

$$r_{AB} = \text{COV} (A, B) / \sigma_A^2 \times \sigma_B^2$$

In this instance,  $r_{AB}$  was found to be 0.981 (N = 116, p .001) regarding observational consistencies across two subsystems.

#### Accessibility Index

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

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

where:

$I_A$  = is the accessibility 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 1.1 and found to be:

$$I_A = 0.65$$

Interrater reliabilities were calculated in order to evaluate the degree of consistency between two operators and their perception of frequency-of-use estimates using a Pearson  $r$  correlation coefficient

$$r_{AB} = .92 (p < .05)$$

$I_A$  was calculated referencing only steady-state operations since steady state is the primary mode of operation.

TABLE M-1. STEADY STATE

Frequency-Of-Use Ranked Data		Physical Control Location (inches)	Component/Control Name
Operator A	Operator B		
1	2	30	Annunciator Acknowledge
1	2	30	Annunciator Reset
1	1	34	Communications (Intercom)
2	1	40	Outer Shim Drive Group/Individual Select
3	5	48	MOR Level Vernier Adjust
5	4	37-50	Neck Shim Insert/Withdraw
8	6	51	MOR Adjust
4	3	48	Outer Shim Drive Preferred Motion
6	8		Test Blocks
10	10	45	Reg. Rod Manual - Insert/Withdraw
9	9	50	Reg. Rod Manual - Auto

$$r_{AB} = .92$$

$$r_{BL} = .58$$

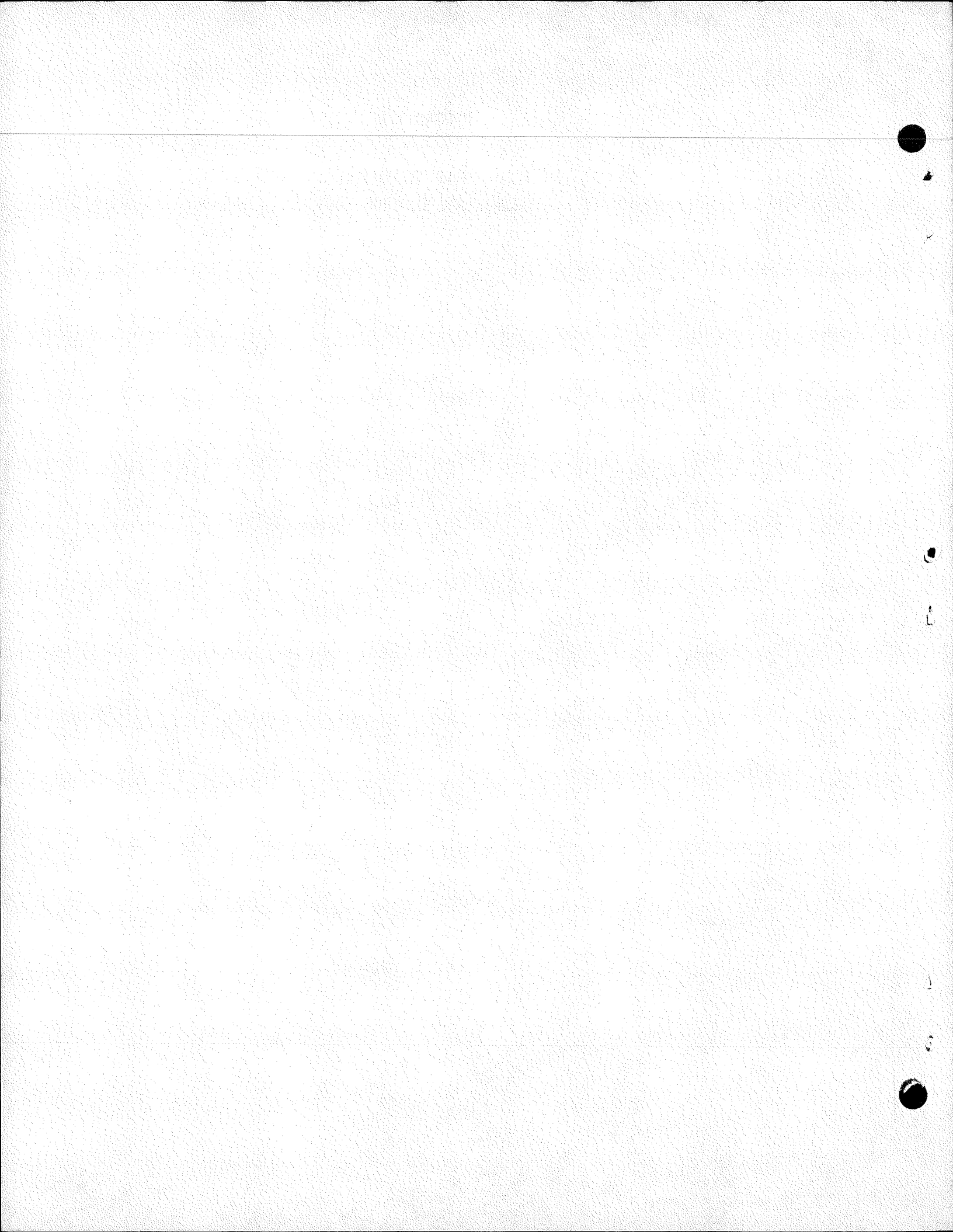
$$r_{AL} = .72$$

$$I_a = .65 = \left( \frac{2}{\sum_{i=1}^2 r_i} \right)$$



APPENDIX N

SHORT-TERM HUMAN FACTORS EVALUATION  
OF THE ATR CONTROL ROOM



**ENGINEERING DESIGN FILE**

PROJECT/TASK ATR CONTROL ROOM UPGRADE

DATE November 25, 1980

SUBTASK HUMAN FACTORS EVALUATION

EDF PAGE NO. 1 OF 4

SUBJECT

Short-Term Human Factors Evaluation of the ATR Control Room<sup>a</sup>

ABSTRACT

Define: Short term human factors upgrades are those which can be accomplished during the next two years using operations personnel and/or minimal engineering support (technical advice) within the existing personnel availability and budget.

A meeting was held with ATR operations personnel on November 21, 1980 to determine which human factors problems could be addressed on a short-term basis. At this meeting, it was agreed that the items on the attached list would be pursued and could be accomplished on a short-term basis. This list of items is a subset of the items addressed in the Human Factors Study of the ATR Control Room (JEB-7-80). The following were in attendance:

M. P. Boone	System Safety Division
J. E. Byrd	Circuits & Components Branch
R. L. Copyak	P&CB - TRTSD
J. H. Faller	P&CS
D. E. Hubbell	ATR Operations
S. E. Lewis	ATR Operations
J. L. Morrison	Circuits & Components Branch

a. More extensive changes are planned during design modification work in FY-83 based on findings of this report.

DISTRIBUTION (COMPLETE PACKAGE):

A. E. Arave	R. L. Copyak	K.S. Dawson	D.E. Hubbell	D.J. Morken
W. C. Banister	J. M. Daniher	J.H. Faller	A.L. Kologi	J.L. Morrison
<del>M. P. Boone</del>	R. C. Davies	J.A. Hong	S.K. Merrill	M.S. Vargo

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J. W. Grace

AUTHOR <i>J.W. Grace</i>	DEPT. <i>NECS DIV.</i>	REVIEWED <i>J. L. Morrison</i>	DATE <i>26 NOV 80</i>	APPROVED <i>W.C. Banister</i>	DATE <i>11-26-80</i>
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Human Factors Item	Response	Action	Comments
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MOTOR OPERATED RHEOSTAT SUBSYSTEM PANEL

Broken pointers on MOR servo channel select	Replace broken pointers		
Console amplifier demand switch wiring inconsistent for reading insert and withdraw voltages	Rewire to cause the insert voltage to be read to the left and the withdraw voltage to the right		
Many examples of poor, inconsistent, and temporary labeling	Relabel components with consistent labeling. labels will be located above the component		

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SAFETY RODS SUBSYSTEM PANEL

No delineation boundaries between systems	Establish boundaries between systems		
General inconsistent labeling practices	Establish consistent labeling		
Unnecessary repetitive labeling	Delete repetitive labels		

Human Factors  
Item

Response

Action

Comments

LOG N CHANNEL RECORDERS

No subgroup  
markings to  
indicate  
physical  
separation

Establish needed markings

Redundant  
labeling

Install proper label above  
recorder. Remove excess  
label from glass

PERIOD RECORDERS

Poor labeling

Install STD label above  
recorders

POWER DEVIATION RECORDER

This instrument  
is nonfunc-  
tional

Has been removed

Human Factors  
Item

Response

Action

Comments

NECK SHIM CONTROL SUBSYSTEM

Some hand controls are not bar shaped or consistent with "L" shape

Replace with pointer-shaped controls or assure directional indication

Labeling around shim rod hand control is poor and many pointers are broken

Install new standard labels above the component.  
Replace broken pointers

Broken hand controls

Replace broken components

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OUTER SHIM CYLINDER (OSC) CONTROL PANEL

The pointers on G hand controls (outer shim drive)

Repair broken pointers

On the outer shim drive display, numbers on the south 3 and 4 displays have shifted down

Restore displays to original position