THE MARVEL-SCHEBLER CONTROL ROD
DRIVE SYSTEM DESIGN REVIEW

FINAL REPORT

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ABSTRACT

A design review of the Marvel-Schebler control rod drive system was conducted by The Babcock & Wilcox Company. This review included studies of mechanical design, electronic and electrical circuitry, component reliability, system reliability, system logic, component and logic failures, and system relationship to reactor safety. Work was not completed on the fault analysis, system packaging, and test recommendations.

CONTENTS

	Page
1. INTRODUCTION	1
2. REVIEW STATUS	2
3. RELIABILITY STUDY	3
3.1. General Reliability	3
3.2. Component Reliability	4
3.3. System Reliability	7
4. MAINTENANCE	12
4.1. Maintenance of Modules	12
4.2. Fault Detection System	12
4.3. Maintenance Aboard Ship	13
5. CONCLUSIONS	14
5.1. Good Features	14
5.2. Bad Features	14
5.3. Incomplete Areas of Review	15
6. SYSTEM LIMITATIONS	16
6.1. Fault Detection System	16
6.2. O-Rings	16
6.3. Lead Screw Latches	17
6.4. Trapped Gas	17
6.5. Rod Drive Rotor Assembly	17
6.6. Master Programmer	17
6.7. Rod Group Control	18
7. RECOMMENDATIONS	19
8. TEST PROGRAM	22

1. INTRODUCTION

The Babcock & Wilcox Company (B&W) was requested by the Atomic Energy Commission to review the Marvel-Schebler (M-S) control rod drive system, because as the original designers of the NS Savannah's reactor plant, B&W was well qualified to examine the relationship between the M-S system and the remainder of the plant. The review conducted to reveal any weaknesses in the design of the system included workmanship, quality of components, packaging, installation arrangement, analysis of each circuit, effects of component and unit failures, rod drive materials, and mechanisms of the drive. Special emphasis was placed on electronic circuitry upon which the system logic and intelligence depends, because the complexity of the system offers a fertile field for "sneak" circuits and false logic. Resources of previous reports, consultation with personnel at Galveston and Marvel-Schebler, and data supplied by component manufacturers were used by the design reviewers. An attempt was made to factor in all changes now being made to the system. This report applies to the system as it existed on April 22, 1963.

The M-S control rod drive system consists of a collapsible rotor mechanism driven by stepping motors. The stepping motors are controlled by an electronic system based largely on the use of solid state components. The system provides for programming of the control rods so that, at any time in life, the operator simply pushes a lever in one direction to increase reactivity and in the opposite direction to decrease reactivity. The operator does not need to be concerned with the position of individual rods or rod groups.

The results and conclusions obtained from this review are presented in the following pages of this report.

2. REVIEW STATUS

Review of the mechanical design and the electronic circuits included the following:

1. Component selection and reliability.
2. System reliability.
3. Correctness of the stated logic.
4. Susceptibility to false signals or logic.
5. Presence of false logic.
6. Consequences of component failures.
7. Consequences of unit or regional failures.
8. Reactor safety requirements.
9. Operation and materials.

A review of the systems packaging was not completed since study could not be undertaken until after installation of the system in the new mockup area at Galveston. The packaging review was designed to uncover any physical aspect of the equipment that might affect operation or maintenance.

The individual circuits and units were examined for failures that might affect the safety of the reactor and the performance of the system logic; however, a fault analysis of the system as related to damage or destruction of the system was not completed. The objective of the fault analysis was to find ways and means for short circuiting heavy currents through the system by way of the ship's hull or other common tie. The source of destructive currents might be the normal ship's power distribution system, the standby power within the M-S system, electromagnetic radiation, or static discharge. This analysis could not be separated from the review of the system packaging and installation.

In summary, the report covers the review of design and design principles, but does not include review of final circuitry and as-built hardware. The review was sufficiently detailed, however, to give the reactor design agency confidence that the system can be operated safely.

3. RELIABILITY STUDY

3.1. General Reliability

One of the major requirements of this system is its dependability to perform intended functions under design conditions for a specified period of time. Reliability of a system is the summation of the individual component reliabilities determined for the specific design application and environment in which the components are to be employed; otherwise, the reliability figure has no meaning. When the reliability of a system has been calculated or determined by operation, the chances of success for continuous operation within a given period can be predicted. For example, a system whose reliability is 99% for 100 hours operation would have to have an average failure rate of less than one in 10,000 hours. Reliability is statistical; a given system may operate successfully for years while its twin may suffer frequent failures.

No attempt has been made to determine the numerical reliability of the M-S system since a great amount of work would be required. Instead, the system has been reviewed for techniques and designs known to produce highly dependable systems. This review has examined the practices employed in design and component selection and found them to be excellent in most cases. Briefly, the design criteria for reliability is based upon a generous derating of circuits under "worst-case" conditions and the selection of only those components known to be reliable.

As a standard procedure, all circuits were worst-case designed (all component tolerances were assumed to work in the worst direction while at the same time system supply voltages, signals, and temperatures assumed their worst values). In essence, each component or circuit was designed to operate satisfactorily for the worst case possible within the latitude of component and environment variations.

3. 2. Component Reliability

No statistical failure rates or confidence figures have been established for the system; therefore, reliability will be presented in terms of designer practices. These practices relating to components are discussed in the following paragraphs.

3. 2. 1. Motor Silicon Controlled Rectifiers

The motor silicon controlled rectifiers (SCR) are rated for 50 amps of continuous current and 1000 amps of surge current. Normal motor current is less than 10 amps for a current derating of 5 to 1. Back electromotive force is almost nonexistent due to the unusually small motor inductance of 100 millihenrys; hence, the peak reverse voltage (PRV) limitations of the SCR present no problem. Oscillographic records show that the surge current never exceeds 12 amps.

The present SCR's are Westinghouse Type WX809H. This type has now been superseded by a direct replacement, Type 2N1916, which is rated for 70 amps. Therefore, SCR's replaced in the future will have a current derating of 7 to 1 or better.

The SCR's are rated for a maximum forward gate voltage of 10 volts and will gate somewhere between 0.3 and 3 volts, depending on the particular SCR. Gating current ranges from 1 to 60 ma. Maximum allowable gating current at 20° C is 70 ma for continuous current and 2 amps for surge current. To prevent firing at low levels and to assure cutoff, the circuit design provides a bias to hold the trigger to -1.4 volts. The maximum trigger voltage is limited to 8 volts by a pair of Zener diodes. Gating current is approximately 50 ma. These circuit parameters represent a good compromise between a hard-driving signal and ample derating for long life and reliability.

3. 2. 2. Logic and Transistor Bias Diodes

The logic and transistor bias diodes are Type 1N645. These diodes are rated 400 ma maximum and have a 1-cycle surge current rating of 10 amps and a maximum PRV rating of 225 volts. With proper derating, these diodes are designed to operate up to 175° C. As applied in this system, the motor programmer gating logic diodes may experience 150-volt surges, while other logic diodes will never be

subjected to voltages higher than the logic supply voltage (20 to 26 volts) and only small currents. The derating ratios vary, but all are good.

3.2.3. Transistors

Transistors are used in this equipment primarily in switch applications. All transistors are conservatively rated. A permissible and widely used practice in transistor switching circuits allows the maximum rated peak dissipation of the transistor during switching to be momentarily exceeded, provided the on and off points are within the rated values. In a typical case the transistor may be operating at 10 times its rated dissipation value during the switching transient. Transistor switching circuits designed to briefly exceed their maximum dissipation ratings are common in a number of commercially available systems. There are many undesirable features accompanying this practice: component failure, power supply voltage shift, or the chance of a maintenance man probing the system with a voltmeter may shift the normal operating point into the maximum dissipation region and destroying the transistor. In addition, circuit elements and tolerances become more critical.

The M-S system does not follow the above design practice. Transistor circuit values have been chosen so that the maximum dissipation at any time does not exceed 50% of the continuous power capability of the transistor. Derating transistors in this manner increases reliability, reduces the chance of damage during maintenance, and provides a system that is not sensitive to changes in component values, voltages, or signals. For example, the stated limits of operation are based upon a $\pm 10\%$ change in supply voltage; however, it appears that the system logic may function properly without damage for supply variations as great as 40% and certainly within $\pm 20\%$.

3.2.4. Master Programmer Counter

The master programmer counter is a 4-decade stepping switch having count readout. This is an electromechanical device capable of adding and subtracting pulses as well as resetting to zero. A solid state (semiconductor) system could have been substituted for the counter; however, the complexity and magnitude of such equipment is not economically or technically justifiable. The mechanical counter has a

lifetime rating of 5×10^7 unit counts—the equivalent to daily cycling the control rods over their full stroke for 30 years.

3.2.5. Relay Circuits

Relay circuits, used in some instances despite the semiconductor nature of the over-all system, are also worst-case designed. Relays are designed for 125° C continuous operation. Contacts are silver plated and the units are sealed for reliable service. Contact current densities are well within design limits, showing no tendency to weld.

3.2.6. Bias Diodes

The bias diode used in each transistor logic element is a protective device. The voltage limiting characteristic of the diode is applied between the base and the emitter to limit the reverse bias voltage and to improve the circuit cutoff characteristics. This technique provides an extra measure of circuit protection and stability.

3.2.7. Isolation Diodes

The isolation diode in the scram SCR circuit has a continuous rating of 1.2 amps and a PRV of 300 volts. The 1-cycle surge rating is 15 amps. As applied in the circuit, the diode will experience surge currents of approximately 8 amps for approximately 100 microseconds. A first look would indicate that the surge current derating is insufficient, but this is not the case. Standard time for a surge rating is 8.3 milliseconds and since the rating is a local heating problem, it is a function of the electrical heat I^2t (resistance is essentially constant). The diode derating is the ratio of $(15)^2 \times 0.0083$ to $(8)^2 \times 0.0001$ or approximately 200 to 1.

The consequences of an isolation diode failure were examined. There are 21 scram SCR's, each having three isolation diodes for a total of 63 diodes. These diodes, designated D7, D8, and D9 in the circuit diagram, transmit the quench signal to the motor SCR's. An open diode would prevent rod motion because it would de-energize one of the affected drive's three motor windings. A shorted diode would probably not affect the operation. Multiple diode failures in a given motor circuit would result in improper stepping or failure to step. Isolation diode failures do not present serious problems since they do not lead to uncontrolled rod motion nor affect the scram ability of the rod.

3.2.8. Solid Tantalum Electrolytic Capacitors

Solid tantalum electrolytic capacitors are employed in the logic circuitry where bypassing or filtering requires high capacitance. Based on military failure data, solid tantalum capacitors have failure rates five times greater than general purpose silicon transistors and ten times that of metal film resistors; however, they are the most reliable capacitors available for the size and capacity range needed in the M-S circuits.

The reliability of solid tantalum capacitors may be improved by voltage derating. This is not true of ordinary electrolytic capacitors. Marvel-Schebler has in some cases derated these capacitors by about 40% for 100°C operation. Solid tantalum capacitors are also sensitive to charge rate. Their life expectancy is decreased when the series impedance is 3 ohms or less. Although complete and final diagrams were not available to examine all circuits using tantalum capacitors, there is reasonable evidence that they are properly applied. If multiple failures show up in service records, the particular application should be reviewed in detail for proper derating.

3.3. System Reliability

Reliable components alone do not prevent circuits and components from failing. The system must also have inherent characteristics designed to promote reliability, safety, self-protection, and stable operation. Provided that component failure cannot be prevented but only minimized, redundancy and failure monitoring techniques may be employed, as they have in this system to prevent failures from affecting the system's vital functions and reactor safety.

3.3.1. High-Level Logic

High-level logic, one of the inherently reliable features of this system, requiring signals of several volts, rather than millivolts or microvolts. In general, this permits discrimination against any signal below a certain level (only signals that exceed a given threshold voltage are passed). In addition, as previously mentioned, switching transistors are reverse-biased to assure good cutoff characteristics. The high-level logic is permitted by the use of saturated switching

circuits whose advantages are (1) low transistor dissipation, (2) relative insensitiveness to transistor characteristics, (3) good temperature stability, (4) relative immunity to noise and stray pickup, and (5) relative insensitiveness to circuit voltages. The disadvantages usually discouraging the use of saturated switch designs have been turned into advantages, such as slow switching speed and the need for high-level switching signals. Slow switching speed is of no consequence in the M-S system.

3.3.2. Pulse Generating Complex

The pulse generating complex is made up of two nearly identical pairs of pulse generators. One pair operates at a fixed rate corresponding to the maximum rod speed and is held exclusively for fast insertion or capsized scram. A second pair of generators operate at a variable pulse rate for automatic or manual control.

All pulse generators run continuously, allowing their output to be continuously monitored. Failure of a variable rate generator produces an alarm. The operator can switch from the defective unit to the good unit by means of a transfer switch. Failure of one of the fixed pulse rate generators results in an alarm and automatic bypassing of the defective generator.

The generators are relaxation oscillators in which the pulse repetition rate (PRR) is determined by a resistor capacitor (RC) network. Marvel-Schebler has elected to hold the PRR of each generator to an accuracy of $\pm 2.5\%$ for 1% power supply changes at the oscillator over a temperature range of from 25 to 100 C. To maintain this accuracy, temperature compensation consisting of a resistor-thermistor network is employed. Component values for this network must be selected and usually cannot be replaced in the field. The network compensates for temperature changes in the frequency determining capacitor. The replacement of any of the frequency determining components will upset and destroy the compensation and accuracy of the oscillator, causing an approximate 15% change in the PRR for a temperature rise from 25 to 100 C.

This represents an extreme in temperature changes since the temperature will remain relatively constant once the plant is in operation. The PRR would, in practice, very likely be maintained at $\pm 5\%$ or

better. Voltage regulation circuitry for each oscillator is contained on the oscillator module. The voltage regulators are transistorized series regulators in which the output is 20 volts $\pm 1\%$ for logic power variations of 26.2 to 23.3 volts representing 1-1/2 hours of operation on the logic battery.

3.3.3. Direction of Rod Motion

The direction of rod motion as commanded by the operator is determined by the direction sensing logic. The function of the logic is to determine whether proper conditions have been satisfied before allowing rod motion in a given direction. In addition, the logic prevents the splitting of an X or Y pulse. Without this logic, it would be possible for the operator to change the rod motion command out of synchronism with the pulse generators stepping the motor but losing one count.

The "OUT" direction logic is double-tracked in such a way that two nearly identical sets of logic must agree that (1) an OUT movement of rods has been requested; (2) an "IN COMMAND" does not exist through a fault or otherwise; and (3) the upper limit status as determined by the master programmer is correct for the desired motion. The output of one of these OUT direction sensors is called "OUT ENABLE". This signal is transmitted to the individual motor programmer or motor logic by a private line that is not shared by any other motor or unit. The output of the other OUT direction sensor is called "OUT COMMAND" and is transmitted to the individual motor logic in a similar fashion. The loss of either an OUT ENABLE or an OUT COMMAND line to any motor logic prevents the OUT movement of that rod. Failure of one of the OUT direction sensors cannot produce rod motion since both sensors must agree on the direction of motion.

The "IN" direction sensor is not double tracked. The design is justifiable on the grounds that an IN COMMAND always overrides an OUT COMMAND and that there are three independent ways of moving rods IN: (1) normally, by the operator's IN-OUT switch, (2) by the operator's election to fast insert, (3) by the operator's manual scram. Failure of the IN-direction sensing logic will either prevent normal IN motion via the IN-OUT switch or produce a continuous IN COMMAND.

Rod motion commands and signals consist of X and Y pulses, IN COMMAND, OUT COMMAND, and OUT ENABLE. These

signals originate in the pulse generators and direction sensing units. They go directly to the individual motor logics, bypassing the master programmer.

3.3.4. Master Programmer

The master programmer has the function of keeping track of the commanded movement of the rods and assuring that the programmed sequence of rod motion is followed. The rod program is established by manually patching or plugging individual rods into rod groups and patching in the desired sequence of group withdrawal. Once the program has been patched into the system, the system logic will follow the program.

The heart of the master programmer is the Neuron counter, which is basically a 4-decade stepping switch. This counter counts alternate pulses transmitted to the rod-drive motors. A monitoring circuit checks the electrical output of the counter's unit's wheel against the add-subtract input. Failure of the unit's wheel to respond to an input signal initiates a fault indication to the operator.

As rod motion proceeds and a count is reached corresponding to the full programmed stroke of a rod group, that group is deprived of its motor logic power. The converse is also true; when the program requires an initial movement of a rod group, motor logic power is supplied enabling the rods in the group to accept movement commands. Hence, it is not merely the absence of a signal that stops motion, but rather the absence of circuit power. Failure of the master programmer cannot produce rod motion. Failure will either "freeze" the program (prevent the program from advancing), or stop rod motion.

3.3.5. Motor Programmer

The motor programmer logic units and power switching SCR's are independent and separate for each of the 21 drives. Each motor requires 6 SCR's and each SCR is controlled by an independent logic unit. The failure of a single element or a complete motor has no effect upon any other motor. The malfunction of a motor programmer logic driver could fire an SCR at the wrong time or in the absence of a command. If this occurs, the affected rod will either step a fraction

of a turn or hold its position. In no case has it been possible to devise a fault that could lead to anything greater than a fraction of an inch of rod motion other than scram.

3.3.6. Capsize Scram

A capsized scram is a fast insertion or power rundown of the rods if the attitude of the ship should exceed 45 degrees. Upon initiation of a capsized scram the following takes place: ability to scram is blocked; automatic and manual control is blocked; rod speed is controlled by the fixed rate (high speed) pulse generator; the master programmer is bypassed; and all motors are enabled and receive continuous IN motion power. Capsized scram signals are transmitted on 21 lines to the individual rods, bypassing the systems normal logic and programming equipment. Motor logic is so arranged that capsized scram signals override all other logic inputs or commands.

3.3.7. Scram

Scram is commanded by the safety system. The scram network, like the capsized scram, is independent of the system's normal logic and program. A scram command is transmitted along 21 lines to the individual rods. Upon initiation of a scram, a command signal is sent directly to the 21 motor programmers or motor logic where the first action is to inhibit or stop commanded rod motion for 1 to 5 milliseconds before firing the 21 scram SCR's. The independence, isolation, and redundancy of the scram and capsized scram circuits assure positive, safe, and reliable action.

3.3.8. Battery Power Systems

The standby battery power systems are basically sound in principle and conceptual design. Battery charger equipment and normal power supplies require additional review when detail plans are available; however, it appears that design review and operational testing will be required to establish reliability and confidence.

4. MAINTENANCE

4.1. Maintenance of Modules

The modular design and standardization of modules in the M-S system provide for easy maintenance. Correcting a fault may be accomplished by substituting spare modules until the fault is cleared. The defective module may be put aside and repaired at a later date. (See Section 6 for a discussion of substitution maintenance limitations.)

A module tester, built by Marvel-Schebler as an aid to manufacture, will test any of the system modules by means of patch cords, multiple switches, variable external power supplies, and both internal and external meters. It enables a checker to run an individual module as if it were operating in the system. On the surface the tester appears to be usable as a maintenance tool; however, it was designed to be used as an engineering tool. The information developed from the tester requires interpretation and a detailed knowledge of the circuit being tested. A mistake in programming the tester may result in destruction of the module. As an engineering tool, the device may be used to check design values, voltages, and signal limits under varying operating conditions. It is definitely not suitable for maintenance work in the same way in which a technician uses a tube checker or transistor checker. It should be retained for use by the shop charged with the responsibility of module maintenance. A GO-NO-GO type of module tester can be designed specifically for maintenance. The need for such a device may be best established after the system is placed in operation and experience has been gained as to the needs and frequency of servicing.

4.2. Fault Detection System

The fault detection system is an important aid to trouble shooting. The system monitors important functions and announces a failure in that function. This scheme is a real aid for isolating trouble so that module substitution can be quick and effective.

The pulse nature of the system would also allow the use of signal tracing techniques that locate a fault with a suitable test device by listening to the system's command pulses at key points. A standard volt-ohm-meter may also be used for trouble shooting.

4.3. Maintenance Aboard Ship

Shipboard maintenance based on module replacement rather than component replacement reduces the need for highly specialized test equipment. The system's conservative design removes much of the danger of damaging the semiconductors during trouble shooting. Less conservative semiconductor circuitry may be easily damaged when a voltmeter or an ohmmeter is applied to the wrong points.

5. CONCLUSIONS

Conclusions drawn from the design review of the M-S control rod drive system are presented in the following paragraphs.

5.1. Good Features

The M-S system has some very favorable features, such as those listed below:

1. Good concept.
2. Apparent infallible logic.
3. Easy operability and good human engineering features.
4. Good circuit design.
5. Wise component choice.
6. Incorporation of factors promoting reliability.
7. Effective noise immunity characteristics.
8. Good serviceability design.
9. Good power supplies (particularly the redesigned logic power supplies).
10. No serious limitations.
11. Compatible with reactor plant.

5.2. Bad Features

Although there are several weak points in the M-S system, they can be easily corrected. These weaknesses are as listed below:

1. Improper consideration given to principles of electric circuit protection for between cabinet cabling.
2. Inadequate monitoring of power sources.
3. Contemplated changes not justifiable, such as follows:
 - (1) Individual rod group control.
 - (2) Out inhibit functions.

5.3. Incomplete Areas of Review

Areas not complete and, hence, not fully endorsed include the following:

1. Safeguards Report, Volumes 1 and 2 are accurate for the original system, but must be revised to incorporate system changes already accomplished and those not yet resolved. Refer to the Appendix for a summary of these items.

2. The final drawings of the equipment were not available, hence, the review is based on the original system. The design principles and general system design is endorsed; however, this does not constitute endorsement of exact details of final circuitry.

3. The equipment was not available for a review of the as-built hardware, except for some of the modules. Therefore, the review does not necessarily endorse internal physical arrangement design or workmanship.

6. SYSTEM LIMITATIONS

6.1. Fault Detection System

The fault detection system indicates the general area in which a fault may lie. Since the system does not always pin point a faulty module or component, locating a fault within the limits of the fault detection system may require more effort than is first supposed. A more refined maintenance philosophy than the general one stated previously (substituting spare modules until the fault is found) will be required and should be developed through experience. This philosophy oversimplifies the situation leading to the impression that the skill and knowledge of maintenance personnel need not be too high. A good basic knowledge of electronics and a reasonable knowledge of the system are still required.

An example of the kind of problems one may become involved in is the location of a fault occurring between modules or cabinets. If one assumes that the fault lies in the modules and follows the substitution scheme of fault location, one or more spare modules may be damaged in the process before it is realized that the fault is external to the modules. The development of maintenance philosophy and trouble shooting schemes will require careful study practice to avoid such pitfalls.

6.2. O-Rings

The O-rings used as the primary seal in the rod closure are considered a limitation in view of experience and Marvel-Schebler's statement that the rings must be changed once a year or following a temperature excursion. The O-rings are rated for 1-year continuous service at 300 F. Since the closure is not temperature monitored, Marvel-Schebler defines a temperature excursion as being anytime stator cooling is lost. Loss of stator cooling is indicated through stator high-temperature monitoring. There is no relation between stator temperature and O-ring temperature; however, the stator represents the only

element in the drive monitored for temperature. This is a questionable area that may be resolved by a more careful study of the O-ring characteristics.

6.3. Lead Screw Latches

Lead screw latches have been limited by the manufacturer to a lifetime limit of 500 latches. Test data indicates that this is a conservative figure and will not impose an undue limitation upon the system.

6.4. Trapped Gas

Trapped gas in the top of the drives has serious consequences if it extends below the top step of the buffer cylinder. Gas below this point destroys the action of the buffer piston and leads to a dry scram. A dry scram will seriously damage the mechanism and possibly shear off the latch pawls. Any gas in the upper section of the rod produces excessive wear in the torque restrainer. Gas may accumulate in the upper drive section from degassing of the primary water cooling in the top of the drive. Although degassing may take place, the rate and amount of gas accumulating may be insignificant. A routine venting of the drives may establish whether or not gas accumulation is a problem; however, the venting arrangement as presently designed may not be suitable for frequent venting.

6.5. Rod Drive Rotor Assembly

Assembly or disassembly of the rod drive rotor must not be attempted by untrained personnel having no knowledge in the special techniques required. This will probably limit inspection and repair of the rotor assembly to M-S factory trained personnel.

6.6. Master Programmer

The master programmer limits rod withdrawal to a sequential program; the first rod group OUT is the last rod group IN. In effect, one may consider the reactor as being controlled by one long rod group. The system does not allow for the control of a single group independent of the program sequence. This is not an operational limitation.

6.7.. Rod Group Control

Individual rod group control is not provided in the M-S system. This does not impose any operational or safety limitations, but it does mean that rod worth determinations may no longer be made by the differential movement of rod groups. Rod worth determinations were originally made by differential rod worth methods and were adequate for the needs of the time even though they were subject to errors arising from the interaction between groups. Future rod worth measurements may be made without resorting to individual group control by using other more accurate methods of measurement. It is, therefore, concluded that the lack of individual group control does not impose a limitation on the system.

7. RECOMMENDATIONS

Recommendations for improving the M-S control rod drive system are listed as follows:

1. Positive battery monitoring is required to show the state of the standby battery power complex beyond that presently provided. Blown-fuse monitoring and indication is required in any situation where loss of a fuse affects a battery or power supply's capability. An example is loss of an individual motor fuse, which automatically places the motor on battery power. A fault of this kind may lead to discharge of the battery without the knowledge of the operator. Metering the charge rate of the battery is not considered an adequate monitor. A safe and reliable means of indicating, locating, and replacing motor fuses is also needed. The 50-amp motor power fuses are the cases to be considered. A minimum acceptable monitor is a battery current discharge meter. A further improvement would be to provide blown fuse indicators.

2. The ship's electric power serving the M-S system has a history of wide voltage swings due to transients introduced by heavy machinery on the line. The system's logic circuits are capable of satisfactory operation even when there are wide swings in power supply voltage. It is not evident that the system's power supplies will withstand repeated line-voltage variations, especially shipboard observed transients of short duration and high amplitude. Tests that simulate expected line conditions are recommended.

3. An external power supply is required to power the backup relays for the operator's reactor control switch and the manual fast insertion relays during normal operation. Loss or momentary interruption of this power would result in a rod run in. The reliability of this external power source must be of a high order. It is recommended

that if and when control room individual rod position indication is incorporated in the system, a reliable power source capable of satisfying the requirements of the position indicators, the control backup relays, and the fast insertion relays be supplied as one unit. Consideration should be given to using the battery-backed instrumentation bus as the primary source of power.

4. Electrical noise immunity should be demonstrated. The system appears to be immune to stray electrical noise unless the noise is capable of inducing 3 to 5 volts at several milliamperes into the low impedance switching circuits. Ordinary sources of noise are not capable of inducing interference of this magnitude. Feed through of line voltage transients from the ship's normal power bus could cause trouble if the system's main power supplies are not capable of withstanding and arresting these transients. It is recommended that tests be devised that will realistically demonstrate the ability of the system to withstand line noise and transients. (The system has been operated satisfactorily in Galveston from what is believed to be poor quality shore power. Similar operation with data taking is desirable.)

5. Annunciation of scram is provided by a set of relay contacts shared with the auto-disable Relay D. The nature of the annunciator circuitry will not allow this arrangement. Contacts required for annunciation cannot be shared with any other device. This is a general rule intended to prevent interactions and cross connecting of a-c circuits. In the K8-K9 annunciator, Relay D circuit, there is every opportunity for interaction between these devices as well as possible cross connecting of a-c circuits. It is recommended that annunciation circuits operate independent of all other circuits. The auto-disable relay should also operate from an independent contact network. The M-S equipment will not require modification provided annunciation of scram from the Relay D is acceptable to the operator. This means that capsized scram or relay failure will also trip the annunciator.

6. The solid tantalum capacitors are cause for some concern. The system reviewers are not satisfied that all solid tantalum capacitors have been sufficiently derated nor that their series circuit

impedance limitations have been observed. In view of this component's relatively high failure rate history, it is recommended that additional time and study be given to the application of this type of electrolytic capacitor in the M-S system and that careful service records be maintained.

7. Remote single rod position indication near the operator is desirable, although the question of necessity may be debatable. The most direct and simplest method for attaining remote indication is the use of a low-power relay repeater system terminating in a position counter. It is understood that Marvel-Schebler is proposing a similar scheme.

8. Electrical interference to the nuclear instrumentation may be generated by the installation of counter type, individual rod position indication equipment in the control room. It is recommended that noise suppression techniques be employed on any counter type equipment designed for position indication within the control room.

8. TEST PROGRAM

The test program conducted on shore should establish reliability, uncover false or unexpected logic behavior, and reveal any wiring or circuit faults. Shipboard tests should be directed toward proving the correctness of the installation, the compatibility of all interconnecting systems, and establishing that the system performs as desired.

Shore testing should emphasize operation of the system under both realistic and extreme conditions over a relatively long period of time. A long-term record of successful operation will build up confidence.

The test program should include provision for operationally testing all spare logic boards and other spare units.

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