FAILURE MODES AND EFFECTS ANALYSIS FOR THE SAN ONOFRE NUCLEAR GENERATING STATION UNIT-1 ROD CONTROL SYSTEM

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1.0 INTRODUCTION

The analysis in this report was performed to prepare the following information for SEP Topic IV-2, Reactivity Control Systems:

1) Single failures within the systems used for reactivity control which can:

   a) Cause an inadvertant reactivity insertion.
   b) Cause a single or combination of rods to be positioned in other than the design sequence. This included consideration of single rod withdrawal/insertions which can result from a single equipment component failure.

2) Design features which limit reactivity insertion rates and rod malpositions resulting from a single failure.

The results of the analysis show how, and to what extent, the San Onofre Rod Control System will perform its intended reactivity control function accounting for failure of single components.

The type of analysis used to evaluate the Rod Control System is a Failure Mode and Effects Analysis (FMEA). This analysis goes to the replaceable component level (i.e., control rod drive mechanism, contactor, relay, logic gate, etc.) The method used to perform the FMEA is consistent with that described in IEEE Standard 352-1975.

The FMEA considered the essential elements of the Rod Control System and its interface with other plant systems. References to design information used in the analysis are provided in Section 5.0. Results of the FMEA are presented in Appendix A in tabular form for specific component failures. A discussion of the results for functional blocks of components (i.e., sequencing circuitry, master cycler, command circuitry, etc.) is presented in Section 3.0.

2.0 SYSTEM FUNCTIONS AND DESCRIPTION

2.1 General Description

The reactor of a PWR nuclear power plant such as San Onofre Unit 1 is controlled by temperature coefficients of reactivity; by motion of control rods, which is required for load follow transients and for startup and shutdown; and by boron in the form of boric acid which is adjusted in concentration during core lifetime to compensate for such effects as fuel consumption and accumulation of fission products. A description of the control system used for movement and control of the full length control rods is presented in the paragraphs that follow.

2.1.1 System Functions

The Rod Control System (RCS) controls the motion of the drive mechanisms of the full length control rods for rod motion in or out of the reactor core in response to signals initiated by the reactor operator and the Reactor Control System. The control rods are grouped and identified as being used for either shutdown or control. The RCS programs rod motion for reactor control and also provides the operator with information regarding rod motion and rod position. Figure 1 presents a simplified block diagram of the RCS.

2.1.2 Arrangement of Banks and Groups of Control Rods

The drive mechanisms for the full length control rods are divided into symmetrical banks which are further divided into groups as shown in Figure 2. The figure shows that for San Onofre Unit 1 there are two Control Banks each consisting of four groups of mechanisms and one Shutdown Bank consisting of two groups of mechanisms. The mechanisms within a group are paralleled electrically to step simultaneously and the groups within a designated bank are moved sequentially such that the groups in a bank are always within one step of each other.

2.1.3 Control Rod Movement - Plant Operation

Use of the full length control rods for reactivity control varies during plant operation. An example of their use is that of reactivity control during plant startup. Briefly stated, the plant startup sequence for full length control rods consists of the following steps:

1. Shutdown Banks are individually withdrawn to their "FULL-OUT" position under manual operator control.

2. Control Bank 1 is manually withdrawn until the Automatic Rod Control Defeated annunciator window goes off.

3. At this point, the sytem is placed in the automatic mode of operation; rod motion is then controlled by the RCS in response to the analog demand signal from the Reactor Control System.

It should be noted that in the automatic control mode, the control rods are moved in a predetermined, programmed sequence which is controlled by the master cycler and bank overlap circuitry.

2.1.4 Control Rod Speed of Operation

The stepping rate of control rods assigned to Shutdown Banks is fixed at 40 steps per minute (S/M). This corresponds to a bank speed of 15 inches per minute. In the manual mode, the stepping rate of control rods assigned to Control Banks is preset at 40 S/M. In the automatic mode, the Control Bank stepping rate is varied in response to speed signals generated by the Reactor Control System. The rate varies over a range of 1 to 40 S/M depending on demanded speed.

The maximum stepping rate is a function of the maxiumum speed of the motor driven cam limit switches. The output of the motor and associated speed reducer that drives that cam limit switch is 40 RPM. Since the Control Rod Drive Mechanism provides a 3/8 inch step of rod movement, the effective maximum stepping rate is 15 inches per minute.

2.1.5 Sequencing of Groups within Banks of Control Rods

Control rod group movement assigned to a bank assuming four groups for each bank, is sequentially stepped to obtain incremental reactivity changes. When the master cycler receives the first shift pulse from the pulser the first group starts its step. Upon receipt of the second, third, and fourth shift pulses,the master cycler then sequences the second, third, and fourth rod groups for the bank. When a change in direction is called for, the last group that was sequenced is the first group to be moved in the new direction. The rod groups are then sequenced in a reverse order. In this way all of the rod groups of one bank are kept within one step of each other.

2.1.6 Bank Overlap of Control Rods

During the automatic mode, movement of Control Banks is performed in accordance with a predetermined programmed sequence. Control Bank 1 is withdrawn until it reaches the full out position. At this point, Control Bank 2 is moved out as required for reactor control. There also exists the capability to overlap these 2 control banks using thumbwheel switches designed into the RCS equipment. However, this is not normally used at San Onofre Unit 1.

2.2 Description of Equipment

The RCS interfaces with other plant systems (i.e., Reactor Protection System and Reactor Control System) as shown by Figure 1. A brief decription of the essential sub-systems of the RCS is presented in the paragraphs that follow.

2.2.1 Operator Controls and Indicators

All controls used for normal operation of the RCS are located on the main control board. Descriptions of the various indicators, controls, and alarms are provided below.

2.2.1.1 In-Hold-Out Lever

The In-Hold-Out lever is used for manual operation of individual banks of control rods. It is a three-position lever switch which is spring-returned to the "Hold" position. For rod motion, the lever actuates pushbutton contacts to energize control relays in the "In" and "Out" positions.

2.2.1.2 Bank Selector Switch

The Bank Selector switch mounted on the main control board permits selection of either manual control or automatic control from the RCS. In conjunction with the Bank Overlap Cutout switch it also permits selection of individual bank operation. The bank selector switch is interlock wired to protect against simultaneous automatic and manual mode of operation. Four switch positions are provided as follows:

1. Automatic - In this position, the In-Hold-Out lever circuit is disconnected and control rod motion is determined by demand signals from the Reactor Control System. Speed of movement is controlled by a variable stepping-rate control signal generated by the Reactor Control System.

2. Manual - In this position, control banks are moved manually using the In-Hold-Out lever. Rod speed is preset at the maximum stepping rate. Individual control bank motion can be obtained by rotating the Bank Overlap Cutout switch to the desired position.

3. Shutdown Group 1 - Shutdown Group 1 rods are moved manually using the In-Hold-Out lever. Rod speed is preset at the maximum stepping rate.

4. Shutdown Group 2 - Shutdown Group 2 rods are moved as described for Shutdown Group 1 rods.

2.2.1.3 Step Counters

The demand signal for each group of Full Length Control Rods is displayed on the Control Board by a three digit and-subtract Step Counter. The number of step counters required for monitoring demand signal to control rods is as follows:

SHUTDOWN GROUPS	CONTROL GROUPS	TOTAL
2	8	10

2.2.1.4 Rod Position Indication Reset Switch

This pushbutton switch, mounted on the control board, is used to reset the equipment as indicated by the following chart:

EQUIPMENT	LOCATION
1. Full Length Rod Step Counters	Control Board
2. Master Cycler Reversible Counter	Logic Cabinet - LA
3. Bank Overlap Counter	Logic Cabinet - LA
4. Pulse to Analog Converters	Rod Position Indication System

2.2.1.5 Lift-Coil-Disconnect Switches

A lift-coil-disconnect switch is furnished for each control and shutdown control rod drive mechanism. The switches are used in retrieving a dropped rod. By disconnecting the lift coils of all drive mechanisms in the affected bank, except the lift coil of the dropped rod, the dropped rod can be returned to its original position. All lift-coil-disconnect switches are located at the Rod Disconnect Switch panel in the control room and are under administrative control of the reactor operator.

2.2.1.6 Rod Motion In-Out Lights

Rod motion "IN" and "OUT" lamps on the control board indicate that rod motion has been initiated by either the manual In-Hold-Out control lever switch or the Reactor Control System signals when the Bank Selector switch is in the "AUTO" position.

2.2.1.7 1/2 Power Indicator Lights

For each group of rods, one lamp on the control board indiates that 1/2 power resistors have been inserted in series with the movable gripper coils of the Control Rod Drive Mechanism. This is done during a period of no rod motion.

2.2.1.8 Plant Annunciator

The following RCS alarms are displayed on the plant annunciator.

1. Start-up Rate Rod Stop - Indicates that rod motion has been inhibited by the Reactor Control System.

2. Start-up Rate Scram - Indicates that the trip breakers have been opened.

3. Failure Alarm - From master cycler; indicates failure in slave cycler cam switches.

2.2.2 Interlocks and Rod Stops

The RCS interfaces with the Reactor Control System as shown by Figure 1. Commands for both manual and automatic control rod motion must pass through various permissive circuits in the Reactor Control System prior to generating the actual call for rod motion. The following interlocks between the RCS and the Reactor Control System are provided:

1. Stop Manual Rod Withdrawal - Blocks manual rod withdrawal on plant conditons of:

   a. Power Range (High Range) Nuclear Overpower
   b. Intermediate Range Nuclear Overpower
   c. Source Range Nuclear Overpower
   d. Overtemperature ΔT

2. Stop Automatic Rod Withdrawal - Blocks automatic rod withdrawal on plant conditions of:

   a. Power Range (High Range) Nuclear Overpower
   b. Overpower
   c. Overtemperature ΔT
   d. Rod Drop - Nuclear
   e. Rod Drop - Rod Position
   f. Turbine First Stage Pressure

2.2.3 Control Rod Driven Mechanism (CRDM)

The control rod drive mechanism is a three-coil, electromagnetic jack which raises and lowers a drive rod to which are attached the rod control cluster assemblies. The three coils, mounted outside the guide tube, which forms a pressure boundary with the reactor coolant system, actuate armatures continued within a housing attached to the guide tube. The movable and stationary gripper armatures operate latches which grip a grooved drive rod. The movable gripper latches are used to hold the drive rod at a command position. The movable gripper latches, which are raised and lowered by the lift coil armature, are used to raise and lower the drive rod. Each complete sequence step of the drive mechanism moves the drive rod 3/8 inch. The mechanical sequence of operation for one "IN" and "OUT" step is as follows:

1. Mechanical "OUT" Sequence -

   a. Hold on movable gripper.
   b. Stationary gripper off.
   c. Pull up the lift armature, raising the drive rod 3/8 inch.
   d. Latch the stationary gripper.
   e. Unlatch the movable gripper.
   f. Drop the lift armature.
   g. Latch the movable gripper.
   h. Unlatch the stationary gripper.
   i. Repeat steps "c" through "h" for the next 3/8 inch "OUT" step.

2. Mechanical "IN" Sequence -
   a. Hold on movable gripper.
   b. Latch the stationary gripper.
   c. Unlatch the movable gripper.
   d. Pull up lift armature.
   e. Latch the movable gripper.
   f. Unlatch the stationary gripper.
   g. Drop the lift armature, lowering the drive rod 3/8 inch.
   h. Repeat step "b" through "g" for the next 3/8 inch "IN" step.

While at a fixed command position, reduced power is applied to the movable armature. Inadvertent or tripped loss of power to the armature will release the movable latch and the drive rod will drop due to the force of gravity acting upon it.

2.2.4 Sequencing Circuitry

The sequencing circuitry provides the interface between the RCS and the Control Rod Drive Mechanism (CRDM) coils. The circuitry consists of power contactors, 1/2 power resistors and associated relays, arc suppression devices, isolation diodes and fuses. There are three contactors per group of rods, one each for the movable grippers, stationary grippers and lift coils of the CRDMs. Upon receipt of a rod motion signal the 1/2 power resistor relays are de-energized and the normally closed contacts of the relay shunt 1/2 power ressistor connected in series with the movable gripper coils. The coils of the power contactors are then energized by the cam switches in the proper sequence and the rod group completes a step. Voltrap type suppression devices are connected across the CRDM coils to limit voltage transients and reduce arcing on the contactor contacts.

2.2.5 Slave Cycler Circuitry

The slave cycler circuitry processes rod motion signals from the master cycler and sequences the power contactors in the sequencing circuitry through cam limit switches. The circuitry consists of a cam limit switch, clutch, motor, and speed reducer for each group of rods. The output RPM of the motor is reduced to 40 RPM by the speed reducer. The speed reducer is coupled to the cam limit switch through the clutch. When rod motion is called for, an output relay in the master cycler is energized. When a set of contacts in the relay closes, power is provided to the coil of the clutch. The cam limit switch is then rotated by the motor/speed reducer. At a cam switch speed of 40 RPM, the maximum possible stepping rate is 15 inches per minute (based on 3/8 inch per step).

2.2.6 Programming Circuitry

The programming circuitry consists of the Master Cycler assembly, Bank Overlap assembly, and Pulser assembly. Brief descriptions of these assemblies are presented in the paragraphs that follow. Note that these assemblies are related to control rods only and the material that follows does not apply to shutdown rods.

2.2.6.1 Master Cycler Assembly

The master cycler interprets signals from the Pulser assembly, Bank Overlap assembly, and command control circuitry and energizes the slave cycler clutches in the proper sequence to provide control rod bank motion. Another function of the master cycler is to provide fault detection for failures in the slave cycler circuitry.

The master cycler is composed basically of three subsystems consisting of an in-and -out counter, a decoder, and an error detector. The in-and-out counter logic card circuitry is composed of NAND gates formed by discrete components. The counter counts pulses received from the pulser assembly. The direction of the count is determined by the "IN" and "OUT" direction signals from the command control circuitry. The NAND gates in the in-and-out counter circuit are connected to form flip-flop logic. The outputs of the combination logic determine which control rod group is to be actuated by providing signals to the decoder circuit.

The decoder circuit consists of four OR gates, each of which is comprised of three NAND gates. Discrete components are used to form these gates. One OR gate makes up the logic for selecting control rod groups 1 and 5. The other three OR gates make up the logic for control rod groups 2 and 6, 3 and 7, and 4 and 8. To maintain a one step difference between rod groups in the same bank it is necessary to apply the first pulse after a reverse command to the same rod group that was pulsed prior to the command. Via the OR gates,the decoder selects the same rod group after a change in direction command. The output of the OR circuit drives relay drivers. The relay drivers control the master cycler output relays which control the slave cycler clutches and 1/2 power relays in the sequencing circuitry.

The error detection circuitry in the master cycler detects two types of errors; 1) failure of a slave cycler to respond to a move signal, and 2) a failure of a slave cycler to complete a cycle and return to the home position. The error detector uses index contacts on the cam limit switch to energize an alarm relay if an error condition exists. This alarm relay then energizes an ammunciator on the control board. Rod motion in the "OUT" direction is inhibited if the system is in the Auto mode.

2.2.6.2 Bank Overlap Assembly

The bank overlap assemblies process "IN" or "OUT" direction signals from the command control circuitry and engage control rod Bank 1 and/or Bank 2 according to a predetermined overlap program. Normally the Control Banks are not overlapped. However, the banks can be overlapped as described in the next paragraph.

There is one assembly for each control bank. The overlap assemblies are comprised of relays,thumbwheel switches, a digital counter and an AC-DC convertor. The thumbwheel switch is used to select the step desired for overlap initiation and cutoff. A set of normally open contacts in the output relay in the Bank 1 overlap assembly controls the bank motion signal to the master cycler for control Bank 2. Therefore, rod motion for control Bank 2 will be inhibited as long as the output relay in the Bank 1 overlap asembly is de-energized. A set of normally closed contacts in the output relay in the Bank 2 overlap assembly controls the bank motion signal to the master cycler for control Bank 1. Therefore, rod motion for control Bank 1 will be allowed as long as the output relay in the Bank 2 overlap assembly is de-energized. When the count in control Bank 1 has reached the overlap initiation setpoint, the output relay in the bank 1 overlap assembly is energized and the relay contacts close. This action provides a bank motion signal to the master cycler for control Bank 2. Now both control banks are stepped out in unison. When the count in the Bank 2 overlap assembly reaches the overlap cutoff setpoint, the output relay in the Bank 2 overlap assembly is energized and the relay contact open. This action removes the Bank 1 motion signal to the master cycler for control Bank 1. Now only control Bank 2 moves in the out direction. Movement in the "IN" direction is similar to the "OUT" direction except that where Bank 1 was turned off, Bank 2 will be turned on. Also, where Bank 2 was turned on Bank 2 will be turned off.

If motion of an individual control bandk is desired, the overlap cutout switch can be used to select the desired bank.

2.2.6.3 Pulser Assembly

The function of the pulser assembly is to transform a rod speed signal from the Reactor Control System to a pulse rate that is linearly related to the input signal. The pulser assembly consists of power supplies, relays, integrated circuits,and other discrete components such as transistors, resistors, and capacitors. When rod motion is called for, a shift pulse is sent to the master cycler through a set of normally closed contacts from a relay in the pulser assembly. The master cycler then sends a signal back to the pulser assembly that energizes the relay. This action terminates the shift pulse. At the same time an integrator network in the pulser assembly begins to process the rod speed signal from the Reactor Control System. When the integrator reaches a setpoint value the relay is de-energized and a new shift pulse is sent to the master cycler through the normally closed contacts. This operation repeats itself as long as rod motion is called for.

2.2.7 Command Control Circuitry

The command control circuitry provides the interface between the plant operator or Reactor Control System and either the programming circuitry for control bank rods or the shutdown bank slave cycler for shutdown bank rods. The command control circuitry is mostly comprised of relays. The relays are divided into two functional groups, "OUT" directional relays nd "IN" directional relays. When rod motion is called for in either the "OUT" or "IN" direction the appropriate group of relays performs the following functions for the control bank rods.

1. Provides power to the contactor coils in the sequencing circuitry through the cam limit switches.

2. Provides rod direction signal to the master cycler assembly and bank overlap assemblies.

3. Initiates shift pulse to pulser assembly.

4. Provides a circuit path to the neutral bus for the step counters. This allows the step counters to be pulsed when rods are stepped.

Since shutdown bank rods are not affected by the programming circuitry, the shutdown directional relays only perform Items 1 and 4 listed above.

Other functions of the directional relays are to prevent any attempt to move rods in the opposite direction when rods are being stepped and, when control bank rods are being stepped, shutdown bank rods are inhibited from moving and vice versa.

2.2.8 Scram Breaker Circuitry

The purpose of the scram breaker circuitry is to remove power from the Control Rod Drive Mechanism coils when a reactor trip signal is received from the Reactor Protection System. There are two independent and redundant sets of scram breaker circuitry. If one set of circuitry should fail, the reactor trip would be accomplished by the other set of scram breaker circuitry. When the Reactor Protection System sends a trip signal to the scram breaker circuitry, the breakers remove power from the stationary and movable gripper coils of the CRDM. This action causes the gripper latches to fall out permitting the control and shutdown bank rods to fall into the core. The scram breakers can also be opened manually by a switch on the main control board.

3.0 FAILURE MODE AND EFFECTS ANALYSIS

3.1 Scope and Level of Analysis

The breadth and depth to which one performs a failure analysis is a function of the following elements:

a. The complexity of the equipment being studied,

b. The equipment's intended mission and objectives to be met,

c. The system component level selected so as to verify that a mission has been completed and that all stated objectives have been accomplished.

The basic approach to failure analysis in this study is to determine the failure characteristics of the RCS under plant conditions of providing near or full reactor power output. For the shutdown bank rod control circuitry it was assumed that failures occured while shutdown banks were being operated under manual control. The basic failure modes of the RCS are identified; the failure mechanisms attributed to identified failure modes are postulated; the methods used for failure detection upon occurrence of a failure are determined; and the effects of a failure on RCS operation are analyzed. In the paragraphs to follow, the boundaries of the plant control systems that constitute the RCS are defined and the level of analysis is established. The subsystems of the RCS having a failure impact on the uncontrolled withdrawal or misalignment of a bank of control rods are defined, the failure modes of each subsystem are determined, and their effects on system operation are analyzed.

System functions and descriptions of equipment in the RCS were presented in detail in Section 2.0 of this report. With reference to the material presented, functional systems of the RCS may be defined to include:

1. An ac and dc power distribution system consisting of transformers, redundant circuit breakers, and distribution buses.

2. A control board switch arrangement (bank selection switch, IN-HOLD-OUT rod movement switch, etc.) for operator control of rod movement.

3. A visual display system (step counters) for indication of demand rod movement.

4. A control module (logic cabinet) that receives various demand signals, either manual from the operator or automatic from the reactor rod speed control system, and provides the command signals needed to operate the shutdown and control rod groups in a prearranged program.

5. Power modules (cycler cabinets and shutdown/control cabinets) that provide dc currents to the operating coils of the CRDMs.

6. A surge suppression module (suppressor cabinets) which limits voltage transients caused by turning off power to CRDM coils.

7. A Control Board switch arrangement (lift coil disconnect switch panel) used for retrieving dropped rods.

With reference to this study, only four of the above defined systems were considered for analysis. System faults attributable to operator error and anomalies of the visual display system were outside the study. In addition, only functional systems having a potential for a fault that could cause inadvertant withdrawal or misalignment of a control bank were analyzed.

The single failure analysis was conducted for the logic cabinet, cycler cabinets, shutdown/control cabinets, and suppressor cabinet. Consideration was given in the study to failure of a control rod drive mechanism and the results of a brief analysis conducted are included in the report. The FMEA worksheets prepared for the systems analyzed are included in Appendix A. For each system analyzed, the failure modes and mechanisms postulated are presented, the effects of failure on system operation are identified and methods for failure detection are identified. System effects on potential rod movement tend to fall into three basic categories: (a) dropping of rods, (b) blocking of rod movement which results in rod misalignment and (c) erroneous rod insertion or withdrawal.

Diverse means are provided in the design of a Westinghouse NSSS such as San Onofre Unit 1 to detect and/or mitigate the effects of malfunctions within the Rod Control System that include the dropping of rods, rod misalignment and blocked rod movement. A reactor trip or turbine run back by the Reactor Control and Protection System is provided if dropped rods, blocked rod movement, or erroneous rod movement results in established process setpoints being reached.

The Rod Position Indication System provides a visual display at the Control Board of the actual position of all full length rods both in and out of the reactor core. It also provides an alarm with annunciation if a rod is at the bottom of the reactor core during power operation and provides information to a rod insertion monitor which sounds an alarm if rod insertion limits are exceeded.

This system is also programmed to sound an alarm in the event of misalignment of rods assigned to control and shutdown banks used for reactivity control.

The RCS provides visual display at the Control Board for reactor operator surveillance of demand group position of rod banks. Certain faults within the RCS leading to erroneous rod movement are announced at the plant annunciator.

The methods of detection listed on the FMEA worksheets were selected first as being initiated by an alarm condition within the RCS and second by one or more of the other diverse methods stated. It should be noted that because of such a selection technique some of the entries do not include all methods of detection available. The method of detection further assumed that minimum compensating factors were available (i.e., moderator temperature, coolant density, maneuvering band, etc.) for reactor trip and for rod insertion limit alarms.

Administrative procedures for the operation of the reactor at power conditions specify frequent surveillance of the operation of all systems of the RCS. As an example of the surveillance required, rod bank position as indicated by the bank demand step counters of the RCS and the position of rods indicated by the rod position indicators of the Rod Position Indication System shall be verified as being within $\pm$12 steps of indication once every shift.

The surveillance required for reactor power operation was considered in the establishment of analysis bounds and also as a possible method of detection for failure modes postulated for the RCS.

3.2 Control Rod Drive Mechanism

Only a brief analysis was conducted in regards to the control rod drive mechanism (Appendix A, Sheet 1). Since the analysis conducted was oriented towards the electrical and electronic control aspects of the RCS and not to its mechanical operational characteristics, an "in-depth" analysis of the rod drive mechanism was not performed. The analysis conducted on the drive mechanism treats component failures to the extent necessary to show failure.

The FMEA conducted for the control rod drive mechanism revealed no failure modes that could cause inadvertent rod withdrawal. The design of the mechanism makes such an event incredible. As shown by the analysis conducted, the effect of failure of a control rod drive mechanism would be to either drop an individual rod into the reactor core or block movement of a rod. Neither of these events would have much effect on the actual operation of the reactor as the Reactor Control System can compensate for the reactivity deviation. Both events would produce alarms and annunciation at the Control Board that require corrective action to be taken.

3.3 Sequencing Circuitry

Sheets 2 through 16 and 46 through 50 of Appendix A describe the FMEA peformed for the sequencing circuitry. The analysis identified no single component failures that would cause uncontrolled insertions or withdrawals of shutdown or control rods. The analysis substantiates that the design of the sequencing circuitry is "fail-safe" in regards to a rod withdrawal transient, in that if a component fails, the end result of failure is either that of blocking rod movement or that of dropping an individual rod or group of rods. The analysis also revealed that within the sequencing circuitry, no single failure which could cause erroneous rod movement would remain undetected.

3.4 Slave Cycler Circuitry

Sheets 20 through 25 of Appendix A describe the FMEA performed for the slave cycler circuitry. As with the sequencing circuitry the analysis revealed no single component failure that would result in uncontrolled rod bank withdrawals. Again, failures that result in blocking rod movement or dropping of rods will not remain undetected.

3.5 Programming Circuitry

The programming circuitry consists of the bank overlap, pulser, and master cyler assemblies. The FMEA for the bank overlap assemblies is described on sheets 26 through 32 of Appendix A, while the FMEA for the pulser and master cycler assemblies is on Sheets 17, 18, 33, and 51 through 58 of Appendix A. The analysis revealed several component failure modes that could result in erroneous rod insertion or withdrawal if operating in the automatic bank overlap control mode. For most of these failures the rod withdrawal or insertion rate would be limited to the stepping rate called for by the Reactor Control System. However, there are failures in the pulser assembly that could cause the RCS to step rods at a rate that exceeds what is called for by the Reactor Control System. For these failures, the maximum credible stepping rate would be limited to 40 steps per minute by the motion/speed reducer in the slave cycler circuitry. In the unlikely event of such a failure, the reactor would eventually trip and mitigate the consequences of the postulated component failure. The results of the analysis indicate that all failure modes are detectable or are terminated by a diverse means (e.g., reactor trip).

3.6 Command Control Circuitry

The FMEA for the command control circuitry is described on Sheets 34 through 45 of Appendix A. The analysis revealed no failures that would cause uncontrolled insertions or withdrawals of shutdown or control rods. The end result of failures in the command control circuitry is either blocking of rod movement or dropping of a group of rods. The analysis also revealed that within the command control circuitry, no single failure will remain undetected.

3.7 Other Circuitry

A FMEA was not performed for the scram breaker circuitry or the indication circuitry described in Section 2.2. Since the scram breaker circuitry is redundant, a single failure would not prevent the breakers from performing their intended function, which is to trip the plant upon receipt of a manual trip signal or a signal from the Reactor Protection System. Also, since indication circuitry does not effect rod motion it was excluded from the FMEA.

4.0 CONCLUSIONS

The FMEA shows the single component failures for the RCS result in one of three possible events 1) dropping of rods, 2) blocking of rod movement which results in rod misalignment and 3) erroneous rod insertion or withdrawal each of which affects reactor operation. Dropped rods are detected by the Rod Position Indication System which will energize the "Rod Bottom - Rod Drop" annunciator on the control board. If the RCS is in the automatic mode, rod bottom relays in the permissive circuitry will de-energize which prevents further rod motion. Failures which cause rod misalignment are detected by the operator via step counters and the Rod Position Indication System which compares demanded position and actual rod position and initiates a "Rod Deviation" alarm if the difference between demanded and actual rod position exceeds a specified limit. For failures leading to erroneous rod insertion or withdrawal, detection can be made via the Rod Position Indication System or the step counters. The stepping rate for most of the failures analyzed will be defined by the Reactor Control System. Certain failures in the pulser assembly will lead to stepping rates in excess of the rate called for by the Reactor Control System. The maximum credible stepping rate is 40 steps per minute which is defined by the maximum RPM for the motors/speed reducers in the slave cycler circuitry. The reactor would eventually trip and mitigate the consequences of component failures leading to erroneous rod insertions or withdrawals.

In summary, the FMEA performed for the San Onofre Unit 1 RCS shows that most single failures are in the safe direction (i.e., rod movement is blocked or rods are dropped) and that either an alarm is actuated to detect the failure or the reactor is tripped to insure that the reactor core is maintained within safe design limits.

5.0 REFERENCES

1. SCE Rod Control System Technical Manual

2. NOK Rod Control System Technical Manual*

3. CY Rod Control System Technical Manual*

4. SCE Dwg. 1542 Sheets 102-118 (W Dwg. 915E637 Sheets 1-17) Master System Schematic

5. W Dwg. 942H061 Master Cycler Schematic Diagram

6. W Dwg. 939F055 Pulser Assembly Schematic

7. W Dwg. 992D217 Bank Overlap Control Assembly Schematic

* References were made to technical manuals from similar plants for clarification purposes only.

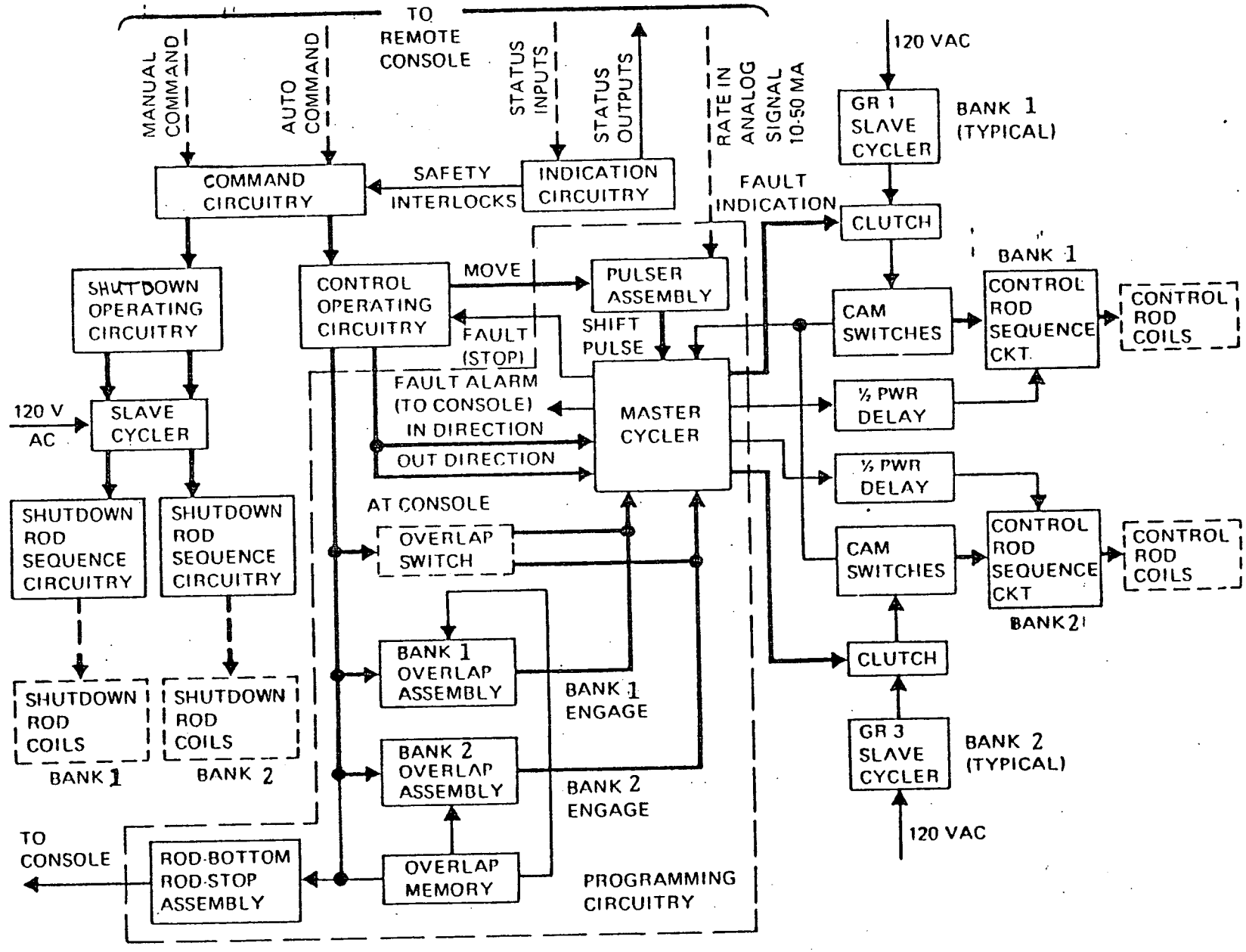

FIGURE 1

ROD CONTROL SYSTEM, FUNCTIONAL BLOCK DIAGRAM

CONTROL BANK 1 -	GROUP 1 - 2 Rods
	Group 2 - 2 Rods
	Group 3 - 4 Rods
	Group 4 - 4 Rods
CONTROL BANK 2 -	Group 5 - 4 Rods
	Group 6 - 4 Rods
	Group 7 - 5 Rods
	Group 8 - 4 Rods
SHUTDOWN BANK 1 -	Group 1 - 8 Rods
	Group 2 - 8 Rods

FIGURE 2

ARRANGEMENT OF CONTROL AND SHUTDOWN BANKS

APPENDIX A

FMEA WORKSHEETS

REFERENCE DRAWING		CIRCUIT FUNCTION CRDM				'E November 30'81
COMPONENT	FUNCTION	FAILURE MODE	FAILURE MECHANISM	EFFECT ON SYSTEM	METHOD OF DETECTION	REMARKS
Control Rod Drive Mechanism.	Moves Control or shutdown rod into or out of the reactor core for negative reactivity control of reactor power.	A. Dropped Rod.	Mechanical failure in stationary or movable latch mechanism. Winding insulation breakdown causes shorted movable coil. Movable coil open.	Tilt in core power due to dropped rod.	Rod Position Indication Sys.(RPIS) will activate "Rod Bottom-Rod Drop" annunciator at the Control Board.	Rod Position Indication Sys. monitors rod position in or out of the reactor core.
		B. Immovable Rod.	Mechanical failure in stationary latch mechanism. Winding insulation breakdown causes shorted lift coil. Lift coil open due to poor connection to coil or material failure of winding wire.	Tilt in core power due to misaligned rod.	RPIS initiates "Rod deviation" alarm.	RPIS is programmed to detect error between rod position and demanded position. A deviation alarm is sounded if a specified error exists between position indicated and demanded bank position.

REFERENCE DRAWING W Dwg. 915E637, Sheet 14, 15, 17		CIRCUIT FUNCTION Control Rod Sequencing Ckt. V, VI; Shutdown Rod Sequencing Ckt. II				TE November 30'81
COMPONENT	FUNCTION	FAILURE MODE	FAILURE MECHANISM	EFFECT ON SYSTEM	METHOD OF DETECTION	REMARKS
Stationary Gripper Fuses 30A CA-FU-25,26 CA-FU-21,16 CA-FU-55,56 CA-FU-46,47 CB-FU-25,26,27,22 CB-FU-21,16,17,18 CB-FU-55,56,57,52 CB-FU-46,47,48,43 Cabinets CC,CD,SA SB contain fuses in similar configuration as cabinets CA and CB	Provides power overload protection to the stationary Gripper coil connected in series with each particular fuse.	Opens prematurely	Material Failure of fuse element. Poor connection to fuse element. Material failure of fuse contact. (clip or holder)	Failure results in an open circuit that blocks flow of current to the stationary coil of a single rod drive mechanism causing erroneous stepping during rod movement allowing release of a rod to drop into reactor core.	The Rod Position Indication Sys. monitors position of all full length rods, in or out of the reactor core. The system activates an annunciator "Rod Bottom Rod Drop" and energizes a "Rod Bottom" indicator light at the control board to alert the reactor operator of a dropped rod.	There are two 30A fuses for each stationary Gripper coil. One up-stream and one down stream of the coil.
Stationary coil power-line fuse 100A CA-FU3,FU30 CB-FU3,FU30 Cabinets CC;CD, SA,SB contain fuses in similar configuration as cabinets CA and CB.	Provides power overload protection for stationary coil power circuitry for single group of rods.	Opens Prematurely	Material Failure of fuse element. Poor connection to fuse element. Material failure of fuse contact. (clip or holder)	Failure results in an open circuit that blocks flow of current to a group of stationary coils. This will cause erroneous stepping during rod movement allowing the release of the rod group to drop into reactor core.	Same as stationary Gripper 30A fuse failure.	Each rod group consists of four rods with the exception of groups in the CA cabinet which consists of two rods and one group in the CD cabinet which consists of five rods.

REFERENCE DRAWING W Dwg. 915E637 Sheet 14,15,17		CIRCUIT FUNCTION Control Rod Sequencing Ckt. V, VI; Shutdown Rod Sequencing Ckt. II				E November 30'81
COMPONENT	FUNCTION	FAILURE MODE	FAILURE MECHANISM	EFFECT ON SYSTEM	METHOD OF DETECTION	REMARKS
Movable Gripper fuses 30A CA-FU-23,24 CA-FU-13,14 CA-FU-53,54 CA-FU-44,45 CB-FU-23,24,19,20 CB-FU-13,14,15,51 Cabinets CC,CD, SA, SB contain fuses in a similar configuration as cabinets CA and CB	Provides power overload protection to the movable Gripper coil connected in series with each particular fuse.	Opens Prematurely.	Material failure of fuse element. Poor connection to fuse element. Material failure of fuse contact (clip or holder).	Failure results in a open circuit that blocks flow of current to the movable coil of a rod drive mechanism causing erroneous stepping during rod movement and loss of holding current to the rod mechanism during time period of no demand for rod movement allowing release of a rod to drop into reactor core.	The rod position indication system monitors position of all full length rods in or out of the reactor core. The system activates an annunciator "Rod Bottom Rod Drop" and energizes a "Rod Bottom" indicator light at the control board to alert the operator.	There are two 30A fuses for each movable Gripper coil. One up-stream and one down-stream of the coil.
Movable coil power-line fuse 100A CA-FU-4,31 CB-FU-4,31 Cabinets CC,CD, SA, SB contain fuses in similar configuration as cabinets CA and CB.	Provides power overload protection for movable coil power circuitry for single group of rods.	Opens Prematurely.	Material failure of fuse element. Poor connection to fuse element. Material failure of fuse contact (clip or holder).	Failure results in an open circuit that blocks flow of current to group of movable coils. This will cause erroneous stepping during rod movement or loss of holding current during period of no demand for rod movement allowing release of the rod group to drop into reactor core.	Same as movable Gripper 30A fuse failure.	Each rod group consists of four rods with the exception of the groups in Cabinet CA which have two rods and one group in cabinet CD which has five rods.

REFERENCE DRAWING W Dwg. 915E637 Sht. 14,15,17		CIRCUIT FUNCTION Control Rod Sequencing Ckt. V, VI; Shutdown Rod Sequencing Ckt. II				D November 30'81
COMPONENT	FUNCTION	FAILURE MODE	FAILURE MECHANISM	EFFECT ON SYSTEM	METHOD OF DETECTION	REMARKS
Lift Coil fuses 60A CA-FU-10,11 CA-FU-37,38 CB-FU-10,11,7,8 CB-F4-37,38,34,35 Cabinets CC,CD,SA, SB contain fuses in similar configuration as cabinets CA and CB	Provides power overload protection to lift coil connected in series with each particular fuse.	Opens Prematurely.	Material failure of fuse element. Poor connection to fuse element. Material failure of fuse contact (clip or holder).	Failure results in an open circuit that blocks flow of current to lift coil of a rod drive mechanism causing erroneous stepping during rod movement which results in misalignment of affected rod with other rods assigned to same group.	A misaligned rod initiates sounding of a rod deviation alarm by the RPIS to alert operator of failure.	RPIS is programmed to defect error between rod position and demanded posistion. A deviation alarm is sounded if a specified error exists between actual and demanded bank position.
Lift coil powerline fuse 150A CA-FU-1,28 CB-FU-1,2,28,29 Cabinets CC, CD, SA, SB contain fuses in similar configuration as Cabinets CA and CB	Provides power overload protection for lift coil circuitry for ½ of a single group of rods.	Opens Prematurely.	Material failure of fuse element. Poor connection to fuse element. Material failure of fuse contact (clip or holder).	Failure results in an open circuit that blocks flow of current to lift coils of two rods causing erroneous stepping during rod movement which results in misalignment of affected rods assigned to same bank.	Same as lift coil 60A fuse failure.	Each rod group consists of four rods with the exception of the groups in cabinet CA which consist of two rods and cabinet CD which has one five rod group.

REFERENCE DRAWING W Dwg. 915E637 Sheet 14,15,17		CIRCUIT FUNCTION Control Rod Sequencing Ckt. V, VI; Shutdown Rod Sequencing Ckt. II				November 30'81
COMPONENT	FUNCTION	FAILURE MODE	FAILURE MECHANISM	EFFECT ON SYSTEM	METHOD OF DETECTION	REMARKS
De-Ion Disconnect switches CA-1CLD1,1CLD2 CA-2CLD5,2CLD6 CB-3CLD1,3CLD2, 3CLD3,3CLD4 CB-4CLD5,4CLD6, 4CLD7,4CLD8 Cabinets CC,CD, SA,SB contain switches in similar configuration as Cabinets CA and CB	Provides for manual disconnect of lift coil from power circuitry during maintenance or rod adjustment operation.	Opens Prematurely.	Mechanical failure of contacts.	Same as failure of 60A lift coil fuse. (See Sheet 4)	Same as failure of 60A lift coil fuse. (See Sheet 4)	There is one disconnect switch per rod.
Isolation Diodes-Stationary Coils UA-D3-CR-1,2,3,4 UA-D14-CR-1,2,3,4 UB-D19-Cr-1,2,3,4 UA-D8-CR-1,2,3,4 UA-D13-CR-1,2,3,4 UB-D30-CR-1	Provides circuit isolation that prevents circulating currents between stationary coils of a given group.	a. Fails Open.	Poor bonding of die or electrode contact causes open junction. Interconnect wire to diode open.	Same as failure of 30A stationary coil fuse. (See Sheet 2)	Same as failure of 30A stationary coil fuse. (See Sheet 2)	
UB-D26-CR-1,2,3,4 UB-D32-CR-1,2,3,4 UA-D1-CR-1,2,3,4 UA-D6-CR-1,2,3,4 UB-D20-CR-1,2,3,4 UB-D25-CR-1,2,3,4		b. Fails Short.	Surface defect causes junction short. Bulk defect in silicon base material causes short. Junction breakdown due to reverse voltage or forward current transient.	Failure could result in improper current levels to a stationary coil for a single rod causing erroneous stepping during rod movement which results in misalignment of affected rod with other rods assigned to same bank.	A misaligned rod initiates sounding of a rod deviation alarm by the RPIS to alert operator of failure.	

REFERENCE DRAWING W Dwg. 915E637 Sheet 14,15,17		CIRCUIT FUNCTION Control Rod Sequencing Ckt. V,VI; Shutdown Rod Sequencing Ckt. II				TE November 30'81
COMPONENT	FUNCTION	FAILURE MODE	FAILURE MECHANISM	EFFECT ON SYSTEM	METHOD OF DETECTION	REMARKS
Isolation Diodes-movable coils UA-D4-CR-1,2,3,4 UA-D15-CR-1,2,3,4 UB-D22-CR-1.2.3.4 UA-D11-CR-1,2,3,4 UA-D16-CR-1,2,3,4 UB-D30-CR-2 UB-D27-CR-1,2,3,4 UB-D33-CR-1,2,3,4 UA-D2-CR-1,2,3,4 UA-D9-CR-1,2,3,4 UB-D21-CR-1,2,3,4 UB-D28-CR-1,2,3,4	Provides circuit isolation during rod stopping and rod holding that prevents interaction between movable coils of rod drive mechanisms for rod in same group.	Fails Open.	Poor bonding of die or electrode contact causes open junction.	Same as failure of 30A Movable coil fuse. (See Sheet 3)	Same as failure of 30A movable coil fuse. (See Sheet 3)	
		Fails Short.	Surface defect causes junction short. Bulk defect in silicon base material causes short. Junction Breakdown due to reverse voltage or forward current transient.	Same as failure of stationary coil isolation diode. (See Sheet 5)	Same as failure of stationary coil isolation diode. (See Sheet 5)	
Isolation Diodes-Lift Coils UA-D7-CR-1,2,3,4 UB-D18-CR-1,2,3,4 UB-D23-CR-1,2,3,4 UA-D12-CR-1,2,3,4 UA-D17-CR-1,2,3,4 UB-D30-CR-3 UB-D31-CR-1,2,3,4 UB-D34-CR-1,2,3,4 UA-D5-CR-1,2,3,4 UA-D10-CR-1,2,3,4 UA-D29-CR-1,2,3,4 UA-D29-CR-1,2,3,4	Provides circuit isolation during rod stepping that prevents interaction between lift coils of rod drive mechanisms for rods in same group.	Fails Open.	Poor bonding of die or electrode contact causes open junction.	Same as failure of 60A lift coil fuse. (See Sheet 4)	Same as failure of 60A lift coil fuse. (See Sheet 4)	
		Fails Short.	Surface defect causes junction short. Bulk defect in silicon base material causes short. Junction breakdown due to reverse voltage or forward current transient.	Same as failure of stationary coil isolation diode. (See Sheet 5)	Same as failure of stationary coil isolation diode. (See Sheet 5)	

REFERENCE DRAWING W Dwg. 915E637 Sheet 14,15		CIRCUIT FUNCTION Control Rod Sequencing Ckt. V, VI; Shutdown Rod Sequencing Ckt. II				E November 30'81
COMPONENT	FUNCTION	FAILURE MODE	FAILURE MECHANISM	EFFECT ON SYSTEM	METHOD OF DETECTION	REMARKS
Voltrap Stationary Coils UA-VR-4,10,23,15, 19 UB-VR-35,45,51 UA-VR-1,9 UB-VR-36,43	Limit transient voltages during rod stepping and reactor trip.	Fails Open.	Poor counter electrode spring contact Interconnect wire to voltrap terminals open.	Degraded circuit protection. No immediate effect on system operation. Possible degradation of contactor contacts.	Detection possible during routine maintenance of cabinet.	High peak voltage transients due to turning off current to stationary coil will accelerate wear on contactor contacts.
		Fails Short.	Bulk defect in selenium layer causes device short. Surface defect in barrier (blocking) layer causes device short. Interconnect wire to voltrap terminals shorted to ground.	Voltrap failing short and resultant line to neutral current path will lead to protection fuse being blown. Effect on system operation is similar to that stated for 100A stationary coil line fuse.	Same as 100A stationary coil line fuse. (See Sheet 2)	
Voltrap movable coils UA-VR-6,10,24,39, 16 UA-VR-20,2,9 UB-VR-46,52,37,44	Limit transient voltages during rod stepping and reactor trip.	Fails Open.	Poor counter electrode spring contact. Interconnect wire to voltrap terminals open.	Degraded circuit protection. No immediate effect on system operation. Possible degradation of contactor contacts.	Detection possible during routine maintenance of cabinet.	High peak voltage transients due to turning off current to movable coil will accelerate wear on contactor contacts.

REFERENCE DRAWING		CIRCUIT FUNCTION				DATE November 30'81
COMPONENT	FUNCTION	FAILURE MODE	FAILURE MECHANISM	EFFECT ON SYSTEM	METHOD OF DETECTION	REMARKS
Voltrap movable coils (cont.)		Fails Short	Bulk defect in selenium layer causes device short. Surface defect in barrier (blocking) layer causes device short. Interconnect wire to voltrap terminals shorted to ground.	Voltrap failing short and resultant line to neutral current path will lead to protection fuse being blown. Effect on system operation is similar to that stated for 100A movable coil line fuse	Same as 100A movable coil line fuse. (See Sheet 3)	

REFERENCE DRAWING W Dwg. 915E637 Sheet 14,15		CIRCUIT FUNCTION Control Rod Sequencing Ckt. V,VI; Shutdown Rod Sequencing Ckt. II				DATE November 30'81
COMPONENT	FUNCTION	FAILURE MODE	FAILURE MECHANISM	EFFECT ON SYSTEM	METHOD OF DETECTION	REMARKS
Voltrap Lift Coils UA-VR-11,12,17,18 UB-VR-33,34,40,41 UA-VR-21,22,3,7 UB-VR-47,48,53,54 UA-VR-13,14 UB-VR-32,42,45,50	Limit transient voltages during rod stepping and reactor trip.	Fails Open	Poor counter electrode spring contact. Interconnect wire to voltrap terminals open.	Degraded circuit protection. No immediate effect on system operation. Possible degradation of contactor contacts.	Detection possible during routine maintenance of cabinet.	High peak voltage transients due to turning off current to lift coil will accelerate wear on contactor contacts.
		Fails Short	Bulk defect in selenium layer causes device short. Surface defect in barrier (blocking) layer causes device short. Interconnect wire to voltrap shorted to ground.	Voltrap failing short and resulting line to neutral current path will lead to protection fuse being blown. Effect on system is similar to that stated for 150A lift coil fuse. (See Sheet 4)	Same as 150A lift coil fuse. (See Sheet 4)	
½ Power Resistor Bank CA-1RES1,2RES2 CB-3RES1,4RES2 CC-5RES1,6RES2 CD-7RES1,8RES SA-1RES1,1RES2 SB-2RES1,2RES2	Reduces power consumed by movable Gripper coil during period of no rod motion.	Fails Open	Interconnect wire to resistor bank open. Material failure of resistance element.	Failure results in an open circuit that blocks flow of current to a group of movable coils. This will cause loss of holding current allowing release of the rod group to drop into reactor core.	The Rod Position Indication System monitors position of all full length rods in or out of the reactor core. The system activates an annunciator "Rod Bottom Rod Drop" and energizes a "Rod Bottom" indication light at the control board to alert operator.	

REFERENCE DRAWING W Dwg. 915E637 Sheet 14,15		CIRCUIT FUNCTION Control Rod Sequencing Ckt. V,IV; Shutdown Rod Sequencing Ckt. II				E November 30'81
COMPONENT	FUNCTION	FAILURE MODE	FAILURE MECHANISM	EFFECT ON SYSTEM	METHOD OF DETECTION	REMARKS
½ Power Resistor Bank (cont.)		Fails Short	Interconnect wire shorted. Insulation breakdown between windings of resistance element.	Degraded circuit protection. No immediate effect on system operation. Possible failure of movable coil due to overheating.	Detection possible during routine maintenance.	

REFERENCE DRAWING W Dwg. 915E637 Sheet 12,14,15,16,17		CIRCUIT FUNCTION Control Rod Sequencing Ckt. III,V,VI; Shutdown Rod Sequencing Ckt. I,II				November 30'81
COMPONENT	FUNCTION	FAILURE MODE	FAILURE MECHANISM	EFFECT ON SYSTEM	METHOD OF DETECTION	REMARKS
Movable Coil ½ Power Resistor Contactor CA-1CK1,2CK2 CB-3CK1,4CK2 CC-5CK1,6CK2 CD-7CK1,8CK2 SA-1SK1,1SK2 SB-2SK1,2SK2	Inserts resistor bank in movable coil power circuit during period of no rod motion. Provides indication via light in control room for status of circuit.	Coil fails open. Contact M fails closed.	Coil winding open due to insulation breakdown. Open interconnect wire to coil. Contacts fused.	Degraded circuit protection. No immediate effect on system operation. Possible failure of movable coil due to overheating.	For coil failure ½ power indicator light will turn off. For contact failure detection possible during routine maintenance.	Aux contact on contactor power ½ power indicator lights. There is possibility of only this contact failing which results in inaccurate information being displayed by indicator lights. For shutdown rods, Aux. contacts from both contactors in either the SA or SB cabinet are connected in series.
		Coil fails closed. Contact M fails open.	Coil winding shorted due to insulation breakdown. Contacts worn or corroded. Mechanical failure in armature switching mechanism. Open interconnect wire to coil or contact terminal.	Failure results in reduced current to the movable coils of a group of rods during rod stepping. This will cause erroneous stepping allowing the release of the rod group to drop into reactor core. If failure is result of coil failing closed, Contact B of contactor will prevent Master cycler from sequencing group of rods. Therefore no erroneous stepping will occur.	The Rod Position Indication System monitors position of all full length rods in or out of reactor core. The system activates an annunciator "Rod Bottom Rod Drop" and energizes a rod bottom indicator light at the control board to alert the operator. For coil failure ½ power indicator light will remain on.	

REFERENCE DRAWING		CIRCUIT FUNCTION				E
W Dwg. 915E637 Sheet 12,14,15		Control Rod Sequencing Ckt. III				November 30'81
COMPONENT	FUNCTION	FAILURE MODE	FAILURE MECHANISM	EFFECT ON SYSTEM	METHOD OF DETECTION	REMARKS
Movable coil ½ Power Resistor Contactor. (Cont.)		Contact B fails open.	Contact worn or corroded.	Failure will prevent master cycler from engaging clutch for sequencing group of rods. This results in misalignment of affected rods with other rods assigned to same bank.	Master cycler failure detector will produce alarm.	Rod motion in out direction will be stopped if system is in auto-mode.

REFERENCE DRAWING 16,17 W Dwg. 915E637 Sheet 10,11,14,15,	CIRCUIT FUNCTION Control Rod Sequencing Ckt. I,II,V,VI; Shutdown Rod Sequencing Ckt. I,II					I 3 November 30'81
COMPONENT	FUNCTION	FAILURE MODE	FAILURE MECHANISM	EFFECT ON SYSTEM	METHOD OF DETECTION	REMARKS
Stationary Coil Contactors CA-1SC1,2SC2 CB-3SC1,4SC2 CC-5SC1,6SC2 CD-7SC1,8SC2 SA-1SS1,1SS2 SB-2SS1,2SS2 Contact M	Receives current orders from slave cycler cam switches and applies 125VDC power across a group of stationary coils.	Fails Open.	Contacts worn or corroded. Mechanical failure in armature switching mechanism. Coil winding open due to insulation breakdown. Open interconnect wire to coil or contact terminal.	Same as failure of 100A stationary coil line fuse. (See Sheet 2)	Same as failure of 100A stationary coil line fuse. (See Sheet 2)	
		Fails Closed.	Contacts fused. Coil winding shorted due to insulation breakdown.	Failure results in stationary Gripper latches being constantly engaged with rod driveline preventing movement of group of rods. This results in misalignment of affected rods with other rods assigned to same bank.	A misaligned rod initiates sounding of a rod deviation alarm by the RPIS to alert operator of failure.	Possible failure of stationary coil due to overheating if current is continuously applied to coil.

REFERENCE DRAWING W Dwg. 915E637 Sh. 10,11,14,15,16,17		CIRCUIT FUNCTION Control Rod Sequencing Ckt. I, II, V, VI; Shutdown Rod Sequencing Ckt. I, II				E November 30'81
COMPONENT	FUNCTION	FAILURE MODE	FAILURE MECHANISM	EFFECT ON SYSTEM	METHOD OF DETECTION	REMARKS
Movable Coil Contactors CA-1MC1,2MC2 CB-3MC1,4MC2 CC-5MC1,6MC2 CD-7MC1,8MC2 SA-1MS1,2MS2 SB-2MS1,2MS2 Contact M	Receives current orders from slave cycler cam switches and applies 125VDC across movable coil.	Fails open.	Contacts worn or corroded. Mechanical failure in armature switching mechanism. Coil winding open due to insulation breakdown. Open interconnect wire to coil or contact terminal.	Same as failure of 100A movable coil fuse. (See Sheet 3)	Same as failure of 100A movable coil fuse. (See Sheet 3)	Aux. contact on contactor powers cycler removal indication relay. There is a possibility of only this contact failing open, which would result in inaccurate information being displayed by indicator lights if cycler removal switches are closed.
		Fails closed.	Contacts fused. Coil winding shorted due to insulation breakdown.	Failure results in movable gripper latches being constantly engaged with rod driveline, preventing movement of group of rods. This results in misalignment of affected rods with other rods assigned to same bank.	A misaligned rod initiates sounding of a rod deviation alarm by the RPIS to alert operator of failure.	

REFERENCE DRAWING W Dwg. 915E637 Sh. 10,11,14.15,16,17		CIRCUIT FUNCTION Control Rod Sequencing Ckt. I, II, V, VI; Shutdown Rod Sequencing Ckt. I, II				D November 30'81
COMPONENT	FUNCTION	FAILURE MODE	FAILURE MECHANISM	EFFECT ON SYSTEM	METHOD OF DETECTION	REMARKS
Lift Coil Contactors CA-1LC1, 2LC2 CB-3LC1, 4LC2 CC-5LC1, 6LC2 CD-7LC1, 8LC2 SA-1LS1, 1LS2 SB-2LS1, 2LS2 Contacts A & B	Receive current orders from slave cycler cam switches and applies 125VDC across a group of lift coils.	Fails open.	Contacts worn or corroded. Mechanical failure in armature switching mechanism. Coil winding open due to insulation breakdown. Open interconnect wire to coil or contact terminal.	Same as failure of 150A lift coil line fuse. (See Sheet 4)	Same as failure of 150A lift coil line fuse. (See Sheet 4)	Aux. contact on contactor powers step counter. There is a possibility of only this contact failing and resulting in a loss of rod motion indication via the step counter.
		Fails closed.	Contacts fused. Coil winding shorted due to insulation breakdown.	Failure results in lift coil being constantly energized, preventing lift coil assembly from stepping rods. This results in misalignment of affected rods with other rods assigned to same bank.	A misaligned rod initiates sounding of a rod deviation alarm by the RPIS to alert operator of failure	Possible failure of lift coil due to overheating if current is continuously applied to coil. Aux. contact on contactor powers step counter. There is a possibility of only this contact failing and resulting in a loss of rod motion indica-

REFERENCE DRAWING W Dwg. 915E637 Sh. 10,11,14,15,16,17		CIRCUIT FUNCTION Control Rod Sequencing Ckt. I, II, V, VI; Shutdown Rod Sequencing Ckt. I, II				E November 30'81
COMPONENT	FUNCTION	FAILURE MODE	FAILURE MECHANISM	EFFECT ON SYSTEM	METHOD OF DETECTION	REMARKS
Lift Coil Contactors (Cont.)						tion via the step counter. For shutdown, step counters contacts from both contactors in SA and SB cabinet must fail closed to lose step counter indication.

REFERENCE DRAWING W Dwg. 915E637 Sh. 7,12		CIRCUIT FUNCTION Control Rod Sequencing Ckt. III, Programming Ckt. II				E November 30'81
COMPONENT	FUNCTION	FAILURE MODE	FAILURE MECHANISM	EFFECT ON SYSTEM	METHOD OF DETECTION	REMARKS
½ Power Resistor Time Delay Relays CA-1TR1, 2TR2 CB-3TR1, 4TR2 CC-5TR1, 6TR2 CD-7TR1, 8TR2	Allows insertion of ½ power resister banks in movable coil power circuitry during a period of no rod motion. Five second time delay allows completion of rod step.	Fails open.	Contacts worn or corroded. Mechanical failure in armature switching mechanism. Coil winding open due to insulation breakdown. Open interconnect wire to coil or contact terminal.	Failure results in a loss of power to ½ power resistor contactors 1CK1, etc. This will result in ½ power resistor bank being bypassed during period of rod holding. No immediate effect on system operation. Possible failure of movable coil due to overheating.	½ power indicator light for affected rod group will turn off.	
		Fails closed.	Contacts fused. Coil winding shorted due to insulation breakdown.	Failure results in ½ power resistor contactor being unable to shunt ½ power resistor bank resulting in reduced current to movable coil during rod stepping. This will cause erroneous stepping allowing the release of the rod group to drop into reactor core.	The rod position indication system monitors position of all full length rods in or out of reactor core. The system activates an annunciator "Rod Bottom Rod Drop" and energizes a rod bottom indicator light at control board to alert the operator. ½ power indicator light for affected rod group will remain on.	

REFERENCE DRAWING W Dwg. 915E637 Sheet 7		CIRCUIT FUNCTION Programming Ckt. II				DATE November 30'81
COMPONENT	FUNCTION	FAILURE MODE	FAILURE MECHANISM	EFFECT ON SYSTEM	METHOD OF DETECTION	REMARKS
½ Power Resistor time delay relay snubber network. CA-1REC-1,2REC-2 3REC-1,4REC-2, 5REC-1,6REC-2, 7REC-1,8REC-2	Limits transient voltages across master cycler output relays K101 through K108 Contact 10 - 11.	Fails Open.	Poor bonding of die or electrode contact causes open junction.	Degraded circuit protection. No immediate effect on system operation. Possible degradation of relay contacts.	Detection possible during routine maintainence of cabinet.	
3A fuses - ½ power resistor time delay relays. CA-FU-32,33 CB-FU-32,33 CC-FU-32,33 CD-FU-32,33	Provides power overload protection for time delay relay coils.	Opens prematurely.	Material failure of fuse element. Poor connection to fuse element. Material failure of fuse contact (Clip or holder).	Same as ½ power time delay relay failing open. (See Sheet 17).	Same as ½ power time delay failing open. (See Sheet 17).	

REFERENCE DRAWING W Dwg. 915E637		CIRCUIT FUNCTION Control Rod Sequencing Ckt. III				B November 30'81
COMPONENT	FUNCTION	FAILURE MODE	FAILURE MECHANISM	EFFECT ON SYSTEM	METHOD OF DETECTION	REMARKS
Step Counter Relay Coil CA-1LCX1, 2LCX2 CB-3LCX1, 4LCX2 CC-5LCX1, 6LCX2 CD-7LCX1, 8LCX2	Provides pulses to step counters for rod group position information.	Fails open or closed.	Contacts worn or corroded. Mechanical failure of armature switching mechanism. Coil winding open or shorted due to insulation breakdown. Open interconnect wire to coil or contact terminal. Contacts fused.	Loss of step counter information for a group of rods.	Step counter information for other group of rods in same bank will indicate correct position for bank.	No effect on rod motion. 1LCX1 contact B and 5LCX1 contact B provide control rod position information to P/A convertor. P/A convertor provides rod position information to bank insertion monitor.

REFERENCE DRAWING W Dwg. 915E637 Sh. 10,11,13,16,17		CIRCUIT FUNCTION Control Rod Sequencing Ckt. I, II, IV; Shutdown Rod Sequencing Ckt. I, II				DATE November 30'81
COMPONENT	FUNCTION	FAILURE MODE	FAILURE MECHANISM	EFFECT ON SYSTEM	METHOD OF DETECTION	REMARKS
Cycler Removal Switches YA-S1,S2,S4,S5 YB-S6,S7,S8,S9 YA-S3	Energizes movable coil to prevent rod drop if cam shaft on slave cycler switches has stalled.	Fails closed.	Contacts fused. Mechanical failure of switching mechanism.	Failure results in movable gripper latches being constantly engaged with rod driveline preventing movement of group of rods. This results in misalignment of affected rods with other rods assigned to same bank.	A misaligned rod initiates sounding of a rod deviation alarm by the R P I S to alert operator of failure.	Local indicator lights turn on when cycler removal switch is closed. It is likely that failure would be detected before any attempt at rod motion is made since switches are only used in maintenance mode.
Cycler Removal Relays YA-BE,BG,BI YB-BE,BG,BH,BI, BJ YA-BA,BB YB-BA,BB	Provides power to local indicator light when cycler removal switches are closed.	Fails open.	Contacts worn or corroded. Mechanical failure in armature switching mechanism Coil winding open due to insulation breakdown. Open interconnect wire to coil or contact terminal.	Loss of indication that cycler has been removed.	Since this is a maintenance mode, detection can be made during maintenance period.	

REFERENCE DRAWING W Dwg. 915E637, Sht. 10,11,17		CIRCUIT FUNCTION Control Rod Sequencing Ckt. I, II; Shutdown Rod Sequencing Ckt. I				DATE November 30'81
COMPONENT	FUNCTION	FAILURE MODE	FAILURE MECHANISM	EFFECT ON SYSTEM	METHOD OF DETECTION	REMARKS
Command Control Relay LB1-SO Contact H LB2-SO Contacts F,G,H LB2-SOX1 Contacts E,F,G LB2-COX2 Contacts E,F	Prevents motion in control group if shutdown group is in motion and vice versa.	Fails open	Contacts worn or corroded. Coil winding shorted due to insulation breakdown.	Failure results in an open circuit that blocks flow of current to lift coil contactor for group of rods. This results in erroneous stepping during rod movement which results in misalignment of affected rods with other rods assigned to same bank.	A misaligned rod initiates sounding of a rod deviation alarm by the RPIS to alert the operator of failure.	These are N.C. contacts. If the contacts fail closed, then a simultaneous failure in other command control relays would have to occur before Control and Shutdown rods are stepped together.

REFERENCE DRAWING W Dwg. 915E637, Sht. 10,11,16		CIRCUIT FUNCTION Control Rod Sequencing Ckt. I,II; Shutdown Rod Sequencing Ckt. I				November 30'81
COMPONENT	FUNCTION	FAILURE MODE	FAILURE MECHANISM	EFFECT ON SYSTEM	METHOD OF DETECTION	REMARKS
Cam Limit Switch YA-TM1,2,3,4 YB-TM5,6,7,8 YA-SGC Contacts SO, SI, MO, MI, LO, LI	Provides sequencing for rod stepping via contactors.	Contacts fail open.	Contacts worn or corroded. Open interconnect wire to contact terminal. Broken return spring.	Failure results in an open circuit that blocks flow of current to either the stationary, movable or lift contactor coils.	See movable, stationary or lift contactor open circuit failure.	
		Contacts fail closed.	Contacts fused. Mechanical failure of cam element.	Failure results in either the stationary, movable or lift contactor coil being constantly energized.	See movable, stationary or lift contactor closed circuit failure.	
		Cam Shaft Assembly failure.	Assembly binds. Cam shaft breaks.	Failure results in loss of sequencing instructions to control rod drive mechanisms for a group of rods. This results in misalignment of affected rods with other rods assigned to same bank.	Failure of Cam switch to make full revolution results in Master Cycler failure detector opening contacts for alarm interlock on Control Board.	Rod motion is stopped if system is in automode.

REFERENCE DRAWING W Dwg. 915E637, Sht. 10,11,16		CIRCUIT FUNCTION Control Rod Sequencing Ckt. I, II; Shutdown Rod Sequencing Ckt. I				DATE November 30'81
COMPONENT	FUNCTION	FAILURE MODE	FAILURE MECHANISM	EFFECT ON SYSTEM	METHOD OF DETECTION	REMARKS
Cam Limit Switch (Cont.)		Snubber network failure.	Material failure of resistance element. Poor connection to resistance element. Dielectric breakdown. Poor connection to capacitor.	Degraded circuit protection. No immediate effect on system operation.	Detection possible during routine maintenance of cabinet.	High peak voltage transients due to turning off contactor coils will accelerate wear on Cam switch contacts.

REFERENCE DRAWING W Dwg. 915E637, Sht. 10,11,16		CIRCUIT FUNCTION Control Rod Sequencing Ckt. I, II; Shutdown Rod Sequencing Ckt. I				E November 30'81
COMPONENT	FUNCTION	FAILURE MODE	FAILURE MECHANISM	EFFECT ON SYSTEM	METHOD OF DETECTION	REMARKS
Command Control Relays LB1-CO Contacts C,D,F,G,H LB1-CI Contacts C,D,F,G,H LB1-COX1 Contacts A,B,E,F,G,H LB1-CIX1 Contacts A,B,E,F,G,H LB1-COX3 Contact E LB1-CIX3 Contact E LB2-CO Contacts C,D,E,F,G,H LB2-CI Contacts C,D,E,F,G,H LB2-COX1 Contacts A,B,E,F,G,H LB2-COX1 Contacts A,B,E,F,G,H LB1-SO Contact B,F,G LB1-SI Contact B,F,G Cam Switch Fuses-10A YA-FU-5,6 YB-FU-5,6 YA-FU-3,4	Provides current path for Cam switches for lift, movable, and stationary contactors. Provides power overload protection to the stationary movable and lift contactor coils.	Contact fails open. Contact fails closed. Opens prematurely	Contacts worn or corroded. Open interconnect wire to contact terminal. Contacts fused. Material failure of fuse element. Poor connection to fuse element. Material failure of fuse contact (clip or holder).	Failure results in an open circuit that blocks flow of current to either the stationary, movable or lift contactors. Failure results in either the stationary, movable or lift contactor being energized out of sequence resulting in erroneous stepping during rod movement. Failure results in an open circuit that blocks flow of current to the movable contactors for 1/2 of the control rods or all of the shutdown rods. This will cause loss of holding current during a period of no demand for rod movement allowing release of the rods to drop into the reactor core.	See movable, stationary, or lift contactor open circuit failure. (See Sheet 13,14 15). See movable, lift or stationary contactor closed circuit failure. (See Sheet 13,14 15). The Rod Position Indication System monitors position of all full length rods in or out of the reactor core. The system activates an annunciator "Rod Bottom Rod Drop" and energizes a "Rod Bottom" indicator light at the control board to alert the operator.	

REFERENCE DRAWING W Dwg. 915E637 Sh. 8, 9		CIRCUIT FUNCTION Slave Cycler Motor Circuitry, Programming Ckt. III				E November 30'81
COMPONENT	FUNCTION	FAILURE MODE	FAILURE MECHANISM	EFFECT ON SYSTEM	METHOD OF DETECTION	REMARKS
Intermittent Drive Unit (clutch) YA-TM1,TM2,TM3, TM4 YB-TM1,TM2,TM3, TM4 YA-FU9,10,12,13 YB-FU14,15,16,17	Connects motor to cam switch to sequence rod group	Motor does not engage cam switch.	Clutch circuit fuse blown. Clutch coil open circuited.	See cam shaft assembly failure. (See Sheet 22).	See cam shaft assembly failure. (See Sheet 22).	
		Snubber network failure.	Dielectric breakdown. Poor connection to capacitor.	Degraded circuit protection. No immediate effect on system operation.	Detection possible during routine maintenance.	
Motor/Motor Starter/Speed Reducer MTR-1,2,4,5,6 7,8,9 YA-MS1,MS3 MS4,MS5 YB-MS7,MS7,MS8, MS9	Rotates cam switch.	Motor stops running. Speed reducer stops.	Motor starter overload trip. Motor starter heater element faulty. Faulty lubrication causes speed reducer seizure.	See cam shaft assembly failure. (See Sheet 22).	See cam shaft assembly failure. (See Sheet 22).	
		Speed reducer slows down.	Gear tooth breaks.	Group of rods sequenced by affected speed reducer does not step at required rate.	Step counter will not be pulsed at required rate.	

REFERENCE DRAWING	CIRCUIT FUNCTION					I November 30'81
W Dwg. 915E637 Sh.6	Programming Ckt. I					
COMPONENT	FUNCTION	FAILURE MODE	FAILURE MECHANISM	EFFECT ON SYSTEM	METHOD OF DETECTION	REMARKS
Bank Overlap Cutout Switch LA-O.C.	Provides for selection of Bank Overlap mode or single bank mode of operation.	Contact A11-B11 fails open or contact A5-B5 fails open when switch is in overlap mode.	Contacts worn or oxidized. Mechanical failure of switching mechanism.	Either DB or DC relay will fail to energize at proper time. As a result of this there will be no bank operation signal to master cycler and the affected bank will not step when required.	The Rod Position Indication System monitors the position of all full length rods in or out of reactor core. Affected bank will not show rod motion in overlap region.	
		Contact A6-B6 or A1-B1 fails closed when switch is in overlap mode.	Contacts fused. Mechanical failure of switching mechanism.	Either DB or DC relay will constantly be energized. As a result of this there will be a constant bank operation signal to the master cycler and the affected bank will step when no motion is required.	The Rod Position Indication System monitors the position of all full length rods in or out of reactor core. Affected bank will show rod motion when out of overlap region.	

REFERENCE DRAWING W Dwg. 915E637 Sh. 6		CIRCUIT FUNCTION Programming Ckt. I				I November 30'81
COMPONENT	FUNCTION	FAILURE MODE	FAILURE MECHANISM	EFFECT ON SYSTEM	METHOD OF DETECTION	REMARKS
Bank 1 Operation Relays LA-DB, DC	Provides bank operation signal to master cycler	Coil fails open when system is in overlap mode.	Coil winding open due to insulation breakdown. Open interconnect wire to coil.	Same as failure of overlap cut-out switch contacts A5-B5 or A11-B11 failing open. (See Sheet 26)	Same as failure of overlap cut-out switch contacts A5-B5 or A11-B11 failing open. (See Sheet 26)	
		Coil fails closed when system is in overlap mode.	Coil winding shorted due to insulation breakdown.	Same as failure of overlap cut-out switch contacts A1-B1 or A6-B6 failing closed. (See Sheet 26)	Same as failure of overlap cut-out switch contacts A1-B1 or A6-B6 failing closed. (See Sheet 26)	
Reset Relay LA-DR	Resets bank overlap counters and master cycler.	Fails open.	Contacts worn or corroded. Coil winding open due to insulation breakdown. Open interconnect wire to coil or contact terminal.	Bank overlap counters and master cycler output relays K101 thru K108 cannot be reset. This could lead to erroneous bank stepping in the bank overlap mode during system startup.	Same as failure of overlap cut-out switch contacts A1-B1 or A6-B6 failing closed. (See Sheet 26)	This relay is energized by a remote switch on control board.
		Fails closed.	Contacts fused. Coil winding shorted due to insulation breakdown. Reset switch on control board shorted.	Master cycler counter circuit is constantly being reset. As a result of this a rod group will step out of sequence with other rods in same bank resulting in rod misalignment.	A misaligned rod initiates sounding of a rod deviation alarm by the RPIS to alert operator of failure.	

REFERENCE DRAWING		CIRCUIT FUNCTION				E
W Dwg. 915E637 Sh. 6		Programming Circuitry I				November 30'81
COMPONENT	FUNCTION	FAILURE MODE	FAILURE MECHANISM	EFFECT ON SYSTEM	METHOD OF DETECTION	REMARKS
Bank Overlap Memory and Count Circuit Relays LA-LR1,2,5,8 LA-LM1,2,3,4 LA-LE1,2	Provides in or out count signal to bank overlap assemblies.	Fails open.	Contacts worn or corroded. Coil winding open due to insulation breakdown. Open interconnect wire to coil or contact terminal. Cam switch TM1-4, 5, 8 contact LRA fails open.	Counter B1 coil in bank overlap control assembly will not receive "add" or "subtract" signals. This will result in control banks not following bank overlap program.	The Rod Position Indication System monitors the position of all full length rods in or out of reactor core. The affected bank will show rod motion when out of overlap region.	If failure is due to cam switch failure then failure detector in master cycler will stop rod motion in out direction if system is in auto mode.
		Fails closed.	Contacts fused. Coil winding shorted due to insulation breakdown of cam switch TM1-4, 5, 8 contact LRA failing closed.	Possibility of erroneous "add" or "subtract" signal to counter B1 in bank overlap control assembly. This will result in control banks not following bank overlap program.	Same as above.	Same as above.

REFERENCE DRAWING W Dwg. 915E637 Sht. 6 992D217 Sht. 1	CIRCUIT FUNCTION Programming Circuitry I				E November 30'81
COMPONENT	FUNCTION	FAILURE MODE	FAILURE MECHANISM	EFFECT ON SYSTEM	METHOD OF DETECTION	REMARKS
Bank 1 (or 2) Overlap Control Assembly						
Relay RE1	Provides circuit path for ADD coil of counter B1. (contact 1-3) Provide circuit path to energize memory relay RE3X when counter setpoint is reached. (contact 6-7)	Fails open or closed when system is in bank overlap mode.	Contacts worn or corroded. Coil winding open due to insulation breakdown. Open interconnect wire to coil or contact terminal. Contacts fused. Coil winding shorted due to insulation breakdown.	Bank 2 Operation Relay DC (or Bank 1 Operation Relay DE) will not be energized at proper time which will result in control bank 1 (or 2) not following bank overlap program.	The Rod Position Indication System monitors the position of all full length rods in or out of reactor core. The affected bank will show no rod motion in the overlap region.	
Relay RE2	Provides circuit path for subtract coil of counter B1 (contact 1-3). Provides circuit path to energize memory relay RE3X when counter is above setpoint.	Fails open or closed when system is in bank overlap mode.	Same as above.	Same as above.	Same as above.	
Relay RE3 RE3X	Provides circuit path to energize memory relay RE3X	Fails open when system is in bank overlap mode.	Contacts worn or corroded. Coil winding open due to insulation breakdown. Open interconnect wire to coil.	Same as above.	Same as above.	

REFERENCE DRAWING W Dwg. 915E637 Sht. 6 992D217 Sht. 1		CIRCUIT FUNCTION Programming Circuitry I				DATE November 30'81
COMPONENT	FUNCTION	FAILURE MODE	FAILURE MECHANISM	EFFECT ON SYSTEM	METHOD OF DETECTION	REMARKS
Relay RE3, RE3X (cont.)		Fails closed when system is in bank overlap mode.	Contacts fused. Coil winding shorted due to insulation breakdown.	Bank 2 (or 1) operation relay DC (or D8) will be constantly energized. This will result in control bank 2 (or 1) not following overlap program.	The affected bank will show rod motion when out of the overlap region.	

REFERENCE DRAWING W Dwg: 915E637 Sht.6; 992D217 Sht.1		CIRCUIT FUNCTION Programming Circuitry I				E November 30'81
COMPONENT	FUNCTION	FAILURE MODE	FAILURE MECHANISM	EFFECT ON SYSTEM	METHOD OF DETECTION	REMARKS
Bank 1 (or 2) Overlap Control Assembly Thumbwheel Switch S1-(1),(10),(100)	Provides overlap set-points for overlap Assembly.	Contact fails open or closed when sys is in bank overlap mode.	Mechanical failure of switch.	Failure results in wrong set-point being used which will result in control bank 2 (or 1) not, following bank Overlap program.	The Rod Position Indication System monitors the position of all full length rods in or out of reactor core. The affected bank will either show rod motion when out of overlap region or show no rod motion when in the overlap region.	
AC-DC Convertor PS1	Provides 96VDC power source for counter B1.	Loss of power supply voltage when system is in bank overlap mode.	Open circuit in AC transformer. Failure in regulation circuit.	Failure results in "ADD" or "SUBTRACT" signals not being recorded which will result in control bank 2 (or 1) not following overlap program.	Same as above.	
Fuse F1-3A	Provides power overload protection to relays RE1,RE2, RE3.	Opens prematurely when system is in bank overlap mode.	Material failure of fuse element. Poor connection to fuse element. Material failure of fuse contact (clip or holder).	Failure results in loss of power to relay RE3X which will prevent control Bank 2 (or 1) from stepping when	The Rod Position Indication System monitors the position of all full length rods in or out of reactor core. The affected bank	

REFERENCE DRAWING Sheet 2 W Dwg. 915E637 Sheet 6 992D217		CIRCUIT FUNCTION Programming Ckt. I				DATE November 30'81
COMPONENT	FUNCTION	FAILURE MODE	FAILURE MECHANISM	EFFECT ON SYSTEM	METHOD OF DETECTION	REMARKS
Fuse F1-3A (Cont.)				called for.	will show no rod motion in the overlap region.	

REFERENCE DRAWING W Dwg. 915E637 Sheet 8		CIRCUIT FUNCTION Programming Ckt. III				E November 30'81
COMPONENT	FUNCTION	FAILURE MODE	FAILURE MECHANISM	EFFECT ON SYSTEM	METHOD OF DETECTION	REMARKS
Cycler Fault Detection Switches TM1 thru TM8 Switch MRCL	Provides fault indication for Master Cycler.	Contact fails open or closed.	Contacts worn or corroded. Open interconnect wire to contact. Terminal contacts fused.	Master cycler will produce false alarm signal.	Rod group associated with faulty switch will step normally when system is in manual mode.	Rod motion in out direction will stop if system is in auto mode.
Carry Over Cam TM1 thru TM7 Switch COC	Interupts power to clutch in between sequencing periods.	Fails open.	Contacts worn or corroded. Open interconnect wire to contact terminal.	Failure results in clutch failing to engage motor to cam switch which results in the loss of sequencing instructions to a group of rods. This will cause a misalignment of affected rods with other rods assigned to same bank.	Failure of cam switch to leave home position results in master cycler failure detector opening contacts for alarm interlock on control board.	Same as above.

REFERENCE DRAWING W Dwg. 915E637 Sheet 2		CIRCUIT FUNCTION Command Control Ckt. I				E November 30'81
COMPONENT	FUNCTION	FAILURE MODE	FAILURE MECHANISM	EFFECT ON SYSTEM	METHOD OF DETECTION	REMARKS
Directional Time Delay Relays LB1-TDO LB2-TDI	Energizes directional relays LB1-CO or LB1-CI. Time delay on de-energization to ensure that directional relays are held in long enough for slave cycler to initiate rotation.	Fails Open.	Contacts worn or corroded. Coil winding open due to insulation breakdown. Open interconnect wire to coil or contact terminal.	Directional relays (either Out or In) will fail to energize resulting in no rod motion when it is called for.	Total loss of rod motion in either the in or out direction.	
		Fails Closed.	Contacts fused. Coil winding shorted due to insulation breakdown.	Directional relays (for either Out or In motion) will only permit rod motion in one direction.	Same as above.	
		Timer failure.	Mechanical failure of timer mechanism.	Possibility of directional relays being de-energized before slave cycler initiates rotation. This could result in a group of rods dropping into Reactor Core.	The Rod Position Indication System will activate "Rod Bottom - Rod Drop" alarm annunciator at the control board.	

REFERENCE DRAWING W Dwg. 915E637 Sheet 2		CIRCUIT FUNCTION Command Control Ckt. I				November 30'81
COMPONENT	FUNCTION	FAILURE MODE	FAILURE MECHANISM	EFFECT ON SYSTEM	METHOD OF DETECTION	REMARKS
Directional Relays LB1-CO (or LB1-CI)	Provides power for Aux. Directional relays and to various cam switches	Coil fails open contact B fails open.	Coil winding open due to insulation breakdown. Open interconnect wire to coil or contact terminal. Contact worn or corroded.	Failure results in loss of power to Aux. Directional Relays. This will prevent rod motion in the out direction. (or in direction).	Total loss of rod motion in one direction.	Failures related to contacts associated with CAM switches are covered on Sheet 21.
		Coil fails closed. Contact B fails closed.	Contacts fused. Coil winding shorted due to insulation breakdown.	Failure results in one set of Aux. Directional Relays being constantly energized which results in rod motion being permitted in one direction only.	Same as above.	
		Contact A fails open.	Contact worn or corroded. Open interconnect wire to contact.	Failure results in Memory Path from cam switch Index "A" opening. This will result in Directional Relays being de-energized before cam sequence is completed. This could lead to rods misstepping or to dropped rods.	A misaligned rod initiates sounding of the Rod deviation alarm by the R P I S For dropped rods the Rod Position Indication System will activate "Rod Bottom - Rod Drop" alarm annunciator at the control board	

REFERENCE DRAWING W Dwg: 915E637 Sheet 2		CIRCUIT FUNCTION Command Control Ckt. 1				November 30'81
COMPONENT	FUNCTION	FAILURE MODE	FAILURE MECHANISM	EFFECT ON SYSTEM	METHOD OF DETECTION	REMARKS
Aux. Directional Relays LB1-COX1,CIX1 LB2-CO,CI LB2-COX1,CIX1	Contacts for these Aux. Directional Relay provide power to various CAM switches. Failures related to these relays are covered on Sheet 21.					
Aux. Directional Relay LB-COX2	Removes shutdown cam switch when control rods are being sequenced to prevent inadvertent movement of shutdown rods.	Coil fails shorted Contacts fail open	Coil winding shorted due to insulation breakdown. Contacts worn or corroded.	Failure results in open circuit path to shutdown rod lift contactor. This will prevent shutdown rod motion.	Total loss of movement for shutdown rods.	
Aux. Directional k ay LA-COX1,CIX1	Provides direction signal to step counters on control board. No effect on rod motion.					

REFERENCE DRAWING W Dwg. 915E637 Sheet 2		CIRCUIT FUNCTION Command Control Ckt. 1				E November 30'81
COMPONENT	FUNCTION	FAILURE MODE	FAILURE MECHANISM	EFFECT ON SYSTEM	METHOD OF DETECTION	REMARKS
Aux. Directional Relay LA-COX2,CIX2	Provides circuit path for Pulser Control Relay DA. Provide circuit path for relays RE1 and RE2 in bank overlap control assemblies.	Fails open.	Contacts worn or corroded. Open interconnect wire to coil or contact terminal. Coil winding open due to insulation breakdown.	DA relay failing to energize results in no shift Pulse to master cycler. This will prevent rod motion.	Total loss of rod motion in one direction.	For failures related to contacts connected to RE1 and RE2 in bank overlap control assemblies see failures for RE1 or RE2 on Sheet 29.
		Fails Closed.	Contacts fused. Coil winding shorted due to insulation breakdown.	DA relay constantly energized resulting in constant shift Pulse to master cycler. This will result in system stepping rods in wrong direction for a few steps when a change of direction is called for.	Rods will be stepping in direction opposite to what is shown by direction indicator light.	
Aux. Directional Relay LA-COX3,CIX3	Provides circuit path for Relays in bank memory and overlap count circuit. Failures would produce effects similar to failures for relays LA-LR1,2,5,8 LA-LM1,2,3,4 (See Sheet 28)					

REFERENCE DRAWING W Dwg. 915E637 Sheet 2		CIRCUIT FUNCTION Command Control Ckt. 1				DATE November 30'81
COMPONENT	FUNCTION	FAILURE MODE	FAILURE MECHANISM	EFFECT ON SYSTEM	METHOD OF DETECTION	REMARKS
Aux. Direction Relay LA-COX4	Provides out direction or in direction signal to Master Cycler.	Coil fails open. Contact A1 fails closed. Contact A2 fails open.	Open interconnect wire to coil or contact A2 terminal. Coil winding open due to insulation breakdown. Contact A1 fused.	Failure results in master cycler constantly receiving In signal. This would result in Group 1 and Group 5 rods (or Group 2-6, 3-7, 4-8) becoming separated from other rod groups in same bank by two steps when a change in direction is called for.	Step counters located on control board will display two step difference for affected rod group and other rod groups in same bank.	
		Coil fails shorted. Contact A1 fails open. Contact A2 fails closed.	Coil winding shorted due to insulation breakdown. Contact A1 worn or corroded. Open interconnect wire to contact A1 terminal. Contact A2 fused.	Failure results in master cycler constantly receiving out signal. This would result in Group 1 and Group 5 rods (or Group 2-6, 3-7, 4-8) becoming separated from other rod groups in same bank by two steps when a change in direction is called for.	Same as above.	

REFERENCE DRAWING W Dwg. 915E637		CIRCUIT FUNCTION Programming Ckt. II				DATE November 30'81
COMPONENT	FUNCTION	FAILURE MODE	FAILURE MECHANISM	EFFECT ON SYSTEM	METHOD OF DETECTION	REMARKS
Pulser Control Relays LA-DA, DAX	Provides circuit path to relay K2 in Pulser Assembly which initiates shift pulse to master cycler.	Fails Open.	Open interconnect wire to coil or contact terminal. Contact worn or corroded. Coil winding open due to insulation breakdown.	Failure results in Pulser not sending shift pulse to master cycler when rod motion is called for. This will result in system not stepping rods when required.	There will be a loss of rod movement with the In Direction or Out Direction lights on control board turned on.	
		Fails Closed.	Coil winding shorted due to insulation breakdown. Contacts fused.	Failure results in Pulser continuously sending shift pulse to master cycler when no rod motion is called for. Master cycler will engage clutch for slave cyclers. Rods will not step since circuit path to lift contactors thru Aux. Relay contact will not be closed.	½ Power Indication lights on control board will turn off during period of no rod movement.	

REFERENCE DRAWING W Dwg. 915E637 Sheet 7		CIRCUIT FUNCTION Programming Ckt. II				DATE November 30'81
COMPONENT	FUNCTION	FAILURE MODE	FAILURE MECHANISM	EFFECT ON SYSTEM	METHOD OF DETECTION	REMARKS
28 VDC Power Supply	Provides power for relay K2 in pulser assembly.	Loss of power.	Transformer failure. Failure in Rectifier circuit.	Relay K2 will fail to energize on signal from DAX relay. Shift pulse will not be sent to master cycler when rod motion is called for. This will result in system not stepping rods when required.	The In direction or Out direction lights on control board will be turned on. However, there will be no rod motion.	
LA-REC 10	Provides feedback path to +28 VDC side of DAX relay. This ensures that DAX relay is held on for full pulse width.	Fails Open.	Poor bonding of die or electrode contact causes open junction. Interconnect wire to diode open.	Failure could result in Master Cycler output relays not being given enough time to energize. Upon receipt of next shift pulse the Master Cycler will change state to pick up next rod group without slave cycler engagement of the previous subgroup ever having occurred.	Rod position as displayed by step counters will be out of sequence by one step for affected rod group	

REFERENCE DRAWING W Dwg. 915E637 Sheet 2		CIRCUIT FUNCTION Command Control Ckt. I				DATE November 30'81
COMPONENT	FUNCTION	FAILURE MODE	FAILURE MECHANISM	EFFECT ON SYSTEM	METHOD OF DETECTION	REMARKS
Cam Switch Index A TM1 thru TM8 Contact 7	Provides memory path to relay LB1-TDO (or LB1-TDI) if Directional signal is removed to assure that last cycle has completed its required shaft rotation.	Contact fails open	Contact worn or corroded Open interconnect wire to contact.	Failure will result in Directional relays de-energizing prematurely if rod motion signal (Rods In or Rods Out) is removed during cycle period. This could result in symptoms similar to failures for directional relays. (See Sheets 34-38)	(See Sheets 34-38)	
		Contact fails closed.	Contact fused. Mechanical failure of cam element.	Failure will prevent Directional Relays from droping out when Directional signal is removed. This will then cause rods to move in one direction whether Rods In signal or Rods Out signal is applied to system.	Rods will only step in one direction despite direction of rod motion signal. If failure is due to cam shaft assembly failure the master cycler failure detector will open contacts for alarm interlock on control board.	Rod motion in out direction will stop if system is in automode.

REFERENCE DRAWING		CIRCUIT FUNCTION				DATE
W Dwg. 915E637 Sheet 2		Command Control Ckt. I				November 30'81
COMPONENT	FUNCTION	FAILURE MODE	FAILURE MECHANISM	EFFECT ON SYSTEM	METHOD OF DETECTION	REMARKS
480V/120V Transformer UA-T1	Provides AC power to control Buss.	Loss of Power.	Material failure of winding wire. Poor connection to primary or secondary winding termination.	Failure results in loss of rod movement when required.	Total loss of rod motion. ½ power indicator lights will turn off.	
Voltrap UA-VR-25	Provides over-power protection to control buss.	Fails short.	Bulk defect in selenium layer causes device short. Surface defect in barrier layer causes device short.	Failure will result in UA-T1 transformer failure.	Same as above.	
Directional Relay Fuses - 10A YA-FU-1,2	Provides power overload protection to Directional Relays and other control circuitry.	Opens Prematurely.	Material failure of fuse element. Poor connection to fuse element. Material failure of fuse contact (clip or holder)	Failure results in loss of rod movement when required.	Same as above.	

REFERENCE DRAWING W Dwg. 915E637 Sheet 3		CIRCUIT FUNCTION Command Control Ckt. II				DATE November 30'81
COMPONENT	FUNCTION	FAILURE MODE	FAILURE MECHANISM	EFFECT ON SYSTEM	METHOD OF DETECTION	REMARKS
Shutdown Rod Directional Relay LB1-SO (or LB1-SI)	Provides circuit path to shutdown cycler cam switch, memory path for Index A, blocks lift circuit for control cam switch TM1 when shutdown rods are in motion.	Fails Open.	Coil winding open due to insulation breakdown. Open interconnect wire to coil or contact terminal.	Failure results in open circuit path to SGC cam switch. This will prevent motion of shutdown rods.	Total loss of shutdown rod movement.	
		Fails Closed.	Coil winding shorted due to insulation breakdown.	No effect on rod motion.	Direction Indication light on control board will be turned on during period of no rod motion.	
Shutdown Rod Directional Relays LB-2-SO (or LB2-SI)	Provides circuit path to carry over cam relay CC, blocks lift circuit for control cam switch TM2 thru TM5.	Fails open. (contact D)	Coil winding open due to insulation breakdown. Open interconnect wire to coil or contact terminal. Contact worn or corroded.	Failure results in open circuit path to relay LB1-CC. This will prevent motion of shutdown rods.	Direction Indication light on control board will turn on but there will be no rod motion.	
		Fails Closed. (contact D)	Contacts fused. Coil winding shorted due to insulation breakdown.	Failure results in cycler clutch being energized when no rod motion is required. The lift circuit for the SGC cam switch will remain open. Therefore, there will be no rod motion.	½ power indicates light will turn off during period of no rod motion.	

REFERENCE DRAWING W Dwg. 915E637 Sheet 3		CIRCUIT FUNCTION Command Control Ckt. II				DATE November 30'81
COMPONENT	FUNCTION	FAILURE MODE	FAILURE MECHANISM	EFFECT ON SYSTEM	METHOD OF DETECTION	REMARKS
Shutdown Directional Relay LB2-SOX1	Blocks lift circuit for control cam Switch TM-6 thru TM-8 when shutdown rods are in motion. Failure of this relay would not affect rod motion since a simultaneous failure would have to occur in the Group Selection switch for control rods to move.	Contact fails Open.	Contact worn or corroded. Open interconnect wire to contact.			
Shutdown cam Switch Index A :C contact 7	Provides memory path to relay LB1-SO (or LB1-SI) if directional signal is removed to assure that cycler has completed its required shaft rotation.	Contact fails open.	Contact worn or corroded. Open interconnect wire to contact.	Failure will result in shutdown rod Directional Relay de-energizing prematurely if rod motion signal is removed during cycle period. This could result in symptons similar to failures for shutdown directional relays. (See Sheet 43)	(See Sheet 43)	

REFERENCE DRAWING W Dwg. 915E637 Sheet 3		CIRCUIT FUNCTION Command Control Ckt. II				DATE November 30'81
COMPONENT	FUNCTION	FAILURE MODE	FAILURE MECHANISM	EFFECT ON SYSTEM	METHOD OF DETECTION	REMARKS
Shutdown CAM switch Index A SGC Contact 7 (Continued.)		Contact fails closed.	Contact fused. Mechanical failure of cam element.	Failure will prevent shutdown Directional relays from dropping out when directional signal is removed. The shutdown rods will continue to step	Rods will continue to move when no motion is called for.	
Carry Over Cam Relay CC	Provides circuit path for cycler clutch circuit.	Fails Open.	Coil winding open due to insulation breakdown. Contact worn or corroded. Open interconnect wire to coil or contact terminal.	This will result in open circuit to shutdown cycler clutch. This will result in system not stepping shutdown rods when required.	There will be a loss of shutdown Rod movement with the In direction or Out direction light on control board turned on.	
		Fails closed.	Coil winding shorted due to insulation breakdown. Contacts fused.	Failure will result in cycler clutch being energized when no rod motion is required. The lift circuit for the SGC CAM switch will remain open. Therefore, there will be no rod motion.	½ power indication light will blink on and off during period of no rod motion.	

REFERENCE DRAWING W Dwg. 915E637 Sheet 16		CIRCUIT FUNCTION Shutdown Rod Sequencing Ckt. I				DATE November 30'81
COMPONENT	FUNCTION	FAILURE MODE	FAILURE MECHANISM	EFFECT ON SYSTEM	METHOD OF DETECTION	REMARKS
Intermittent Drive Unit (Clutch) YA-SGC	Connects motor to SGC cam switch to sequence shutdown rod bank.	Motor does not engage cam switch.	Clutch circuit fuse blown. Clutch coil open circuited.	Failure results in loss of sequencing instructions to shutdown contact This will result in loss of rod motion for shutdown bank.	Shutdown Bank does not step when required.	
		Snubber network failure.	Dielectric breakdown. Poor connection to capacitor.	Degraded circuit protection. No immediate effect on system operation.	Detection possible during routine maintenance.	
Motor/Motor Starter/Speed reducer MTR-3 YA-MSS	Rotates SGC cam switch.	Motor stops running. Speed reducer stops.	Motor starter overload trip. Motor starter heater element faulty. Faulty lubrication causes speed reducer seizure.	Same as failure of intermittent drive unit above.	Same as failure of intermittent drive unit above.	
		Speed reducer slows down.	Gear tooth breaks.	Shutdown bank does not step at required rate.	Step counter will not be pulsed at required rate.	

REFERENCE DRAWING W Dwg. 915E637 Sheet 16		CIRCUIT FUNCTION Shutdown Rod Sequencing Ckt. I				DATE November 30'81
COMPONENT	FUNCTION	FAILURE MODE	FAILURE MECHANISM	EFFECT ON SYSTEM	METHOD OF DETECTION	REMARKS
Shutdown Group selection relays SA-1G1, 2G1 Fuses - 10A YA-FU7,FU8	Provides for selection of shutdown banks 1 or 2.	Coil fails open. Contact B fails open. Fuse opens prematurely.	Coil winding open due to insulation breakdown. Open interconnect wire to coil or contact. Contact worn or corroded.	Failure results in loss of rod motion for selected shutdown bank.	Total loss of rod motion for selected bank. Opposite bank will operate normally.	
		Coil shorted Contact B fails closed.	Coil winding shorted due to insulation breakdown. Contact fused.	Failure results in open circuit path to opposite shutdown bank selection relay. This will result in loss of rod motion for opposite shutdown bank when required.	½ Power Indicator light for bank in which failure ocurred will remain off when no shutdown rod motion is called for.	
		Contact C or D fails open.	Contact worn or corroded. Open interconnect wire to contact.	Failure results in open circuit to movable or stationary gripper contactor during period of rod motion resulting in shutdown bank released and dropped into reactor core.	The Rod Position Indication System motiors position of all full length rods in or out of reactor core. The system activates an annunciator "Rod Bottom, Rod Drop" and activates a "Rod Bottom" indicator light at control board to alert operator.	

REFERENCE DRAWING W Dwg. 915E637 Sheet 16		CIRCUIT FUNCTION Shutdown Rod/Sequencing Ckt. I				DATE November 30'81
COMPONENT	FUNCTION	FAILURE MODE	FAILURE MECHANISM	EFFECT ON SYSTEM	METHOD OF DETECTION	REMARKS
		Contact A fails open.	Contact worn or corroded. Open interconnect wire to contact.	Failure results in open circuit to lift coil contactor during period of rod motion resulting in a loss of rod motion for selected shutdown bank.	Total loss of rod motion for selected shutdown bank.	
Shutdown Group Selection Relays SA-1G1, 2G1	Provides for selection of shutdown banks 1 or 2.	Contact H fails open.	Contact worn or corroded. Open interconnect wire to contact.	Failure results in open circuit to movable gripper contactor which results in loss of holding power to selected shutdown bank during period of no rod motion. This will cause the shutdown rod bank to fall into reactor core.	Same as contact C or D failing open. (See above).	
		Contact G fails open.	Contact worn or corroded. Open interconnect wire to contact.	Failure results in open circuit to shutdown selection relay which results in loss of rod motion for selected shutdown bank.	Same as contact A failing open. (See above).	

REFERENCE DRAWING W Dwg. 915E637 Sheet 16		CIRCUIT FUNCTION Shutdown Rod Sequencing Ckt. I				DATE November 30, 1981
COMPONENT	FUNCTION	FAILURE MODE	FAILURE MECHANISM	EFFECT ON SYSTEM	METHOD OF DETECTION	REMARKS
Shutdown Group Selection Relays SA-1GX1, 1GX2	Opens lift circuit to opposite shutdown bank to prevent inadvertant rod motion.	Coil fails open. Contact fails closed.	Coil winding open due to insulation breakdown. Open interconnect wire to coil. Contact fused.	No effect on rod motion. A simultaneous failure in relays SA-1G1 or 2G1 would have to occur to affect rod motion.	Detection possible during routine maintenance.	
		Coil fails closed. Contact fails open.	Coil winding shorted due to insulation breakdown. Contact worn or corroded. Open interconnect wire to contact.	Failure results in open circuit to lift contactor of opposite shutdown bank resulting in loss of rod movement for affected bank.	Total loss of motion for selected shutdown bank. Direction indication light on control board will remain on.	
Cam Switch Index A SGC contact 8	Provides memory path to selection relays SA-1G1, 2G1 if directional signal is removed to assure that cycler has completed its required shaft rotation.	Contact fails open	Contact worn or corroded. Open interconnect wire to contact.	Failure will result in selection relays de-energizing prematurely if rod motion signal is removed during cycle period. This could result in symptons similar to failures for selection relays. (See Sheets 47-78)	(See Sheets 47-48)	

REFERENCE DRAWING W Dwg. 915E637 Sheet 16		CIRCUIT FUNCTION Shutdown Rod Sequencing Ckt. I				DATE November 30'81
COMPONENT	FUNCTION	FAILURE MODE	FAILURE MECHANISM	EFFECT ON SYSTEM	METHOD OF DETECTION	REMARKS
Cam Switch Index A SGC contact 8 (continued)		Contact fails closed.	Contact fused mechanical. Failure of cam element.	Failure will prevent selection relays from dropping out when directional signal is removed. Relay will remain locked up until bank selector switch is rotated. No effect on rod motion unless a simultaneous failure occurs in bank selector switch.	½ Power Indicator light for affected bank will remain off during period of rod holding.	

REFERENCE DRAWING W Dwg. 915E637 Sheet 7 939E055 Sheet 1		CIRCUIT FUNCTION Programming Ckt. II				E November 30'81
COMPONENT	FUNCTION	FAILURE MODE	FAILURE MECHANISM	EFFECT ON SYSTEM	METHOD OF DETECTION	REMARKS
Pulser Assembly Relay K1	Converts signal from Pulser control relays DA, DAX to pulse train by using feedback signal from master cycler to control integrator circuit in pulser assembly.	Fails Open	Coil winding open due to insulation breakdown. Contacts worn or corroded. Open interconnect wire to coil or contact. Transistor Q2 collector Emitter junction fails open. Transistor Q1 collector Emitter junction fails closed. Diode CR7 fails open. Loss of voltage from PS1 or PS2.	Failure results in shift pulse not terminating. This will prevent master cycler counter circuit from sequencing rod group in proper order. Failure results in loss of shift pulse to master cycler. This will prevent system from stepping rods. Failure results in pulser continuously sending shift pulse to master cycler when no rod motion is called for. Master cycler will engage clutch for slave cyclers. Rods will not step since circuit path to lift contactor thru aux. control relay contact will not be closed.	Error detection circuitry in master cycler will provide alarm for an unterminated shift pulse. Total loss of rod motion with the in direction or out direction indicator light on control board turned on.	Rod motion in out direction will be inhibited if system is in auto mode.
		Fails closed.	Coil winding shorted due to insulation breakdown. Contact fused. Transistor Q2 collector Emitter junction fails closed. Transistor Q1 collector Emitter junction fails open.			

REFERENCE DRAWING W Dwg. 915E637 Sheet 7 939F055 Sheet 1		CIRCUIT FUNCTION Programming Ckt. II				E November 30'81
COMPONENT	FUNCTION	FAILURE MODE	FAILURE MECHANISM	EFFECT ON SYSTEM	METHOD OF DETECTION	REMARKS
Pulser Assembly Relay K2	Energizes relay K1 via contacts from relay K109 in Master cycler.	Fails open.	Coil winding open due to insulation breakdown. Contact worn or corroded. Open interconnect wire to coil or contact.	Failure results in Pulser not sending shift pulses to master cycler when rod motion is called for. This will result in system not stepping rods when required.	There will be a loss of rod motion with the in direction or out direction indicator light on control board turned on.	
		Fails closed.	Coil winding shorted due to insulation breakdown. Contacts fused.	Failure results in Pulser continuously sending shift pulses to master cycler when no rod motion is called for. Master cycler will engage clutch for slave cyclers. Rods will not step since circuit path to lift contactors thru Aux. Control relay contact will not be closed.	½ Power indicator lights on control board will turn off during period of no rod movement.	

REFERENCE DRAWING W Dwg. 915E637 Sheet 7 939F055 Sheet 1		CIRCUIT FUNCTION Programming Ckt. II				DATE November 30'81
COMPONENT	FUNCTION	FAILURE MODE	FAILURE MECHANISM	EFFECT ON SYSTEM	METHOD OF DETECTION	REMARKS
Pulser Assembly Integrator/Amplifier circuit G1, G2	Transforms current level from Foxboro signal in Reactor Control system to pulse rate that is linearly related to the input current.	Pulse rate exceeds input required by reactor control system.	Failure of reference diodes CR1 or CR2 Resistor R3 or R8 shorts	Failure results in pulse rate to master cycler that exceeds rate required by reactor control system. Maximum stepping rate will be limited to 40 steps per minute which is the maximum speed of motors in slave cycler circuits.	Step counters on control board will not be stepped at required rate.	

REFEREN DRAWING W Dwg. 915E637 Sheet 7,8 942N061 Sheet 1		CIRCUIT FUNCTION Programming Ckt. II, III			TE November 30'81	
COMPONENT	FUNCTION	FAILURE MODE	FAILURE MECHANISM	EFFECT ON SYSTEM	METHOD OF DETECTION	REMARKS
Master cycler Assembly Output Relays K101 thru K108	Provides circuit paths to slave cycler clutch circuit, fault detection circuit and ½ power time delay relays.	Fails open.	Coil winding open due to insulation breakdown. Open interconnect wire to coil or contact terminal. Contact worn or corroded. Diode CR127-CR130, CR133-CR136, CR 139-CR142, CR145-CR148 fails open. Relay Driver CD111 or CD112 fails open.	Failure result in open circuit path to slave cycler clutch for group of rods energized by affected relay. This will cause loss of rod motion for one group of rods resulting in misalignment of affected rods with other rods assigned to same bank.	A misaligned rod initiates sounding of a rod deviation alarm by the RPIS to alert operator of failure.	
		Fails closed.	Coil winding shorted due to insulation breakdown. Contacts fused. Diode CR126, CR131, CR132, CR137, CR138, CR143, CR144, or CR149 fails short.	Failure results in slave cycler clutch for affected relay being constantly energized. This will cause rod group to step out of sequence resulting in misalignment of affected rods with other rods assigned to same bank.	Same as above.	

REFERENCE DRAWING W Dwg. 910E637 Sheet 7,8 942H061 Sheet 1		CIRCUIT FUNCTION Programming Ckt. II,III				E November 30'81
COMPONENT	FUNCTION	FAILURE MODE	FAILURE MECHANISM	EFFECT ON SYSTEM	METHOD OF DETECTION	REMARKS
Master cycler Assembly Counter circuit CD101-1 CD102-3,4,5,6,7,8 CD103-1,2,3,4 CD104-1,2,3,4 CD104-5,6,7,8 CD105-1,2,3,4	Provides signals to energize Master cycler output relays in proper sequence	Gate fails high or low.	Transistor collector emitter junction fails open or closed. Diode fails open or closed. Open interconnect wire to logic card. Loss of supply and bias voltages.	Failure results in wrong signals being sent to decoder circuit resulting in master cycler output relays being energized out of sequence. This will cause rod group to step out of sequence resulting in misalignment of affected rods with other rods assigned to same bank.	A misaligned rod initiates sounding of a rod deviation alarm by the RPIS to alert operator of failure.	

REFERENC DRAWING W Dwg. 915E637 Sheet 7,8 942H061 Sheet 1		CIRCUIT FUNCTION Programming Ckt. II, III				E November 30'81
COMPONENT	FUNCTION	FAILURE MODE	FAILURE MECHANISM	EFFECT ON SYSTEM	METHOD OF DETECTION	REMARKS
Master cycler assembly Decoder Circuit. CD-106-3,7 CD-107-3,7 CD-106-4,8 CD-107-4,8	Decodes signals from master cycler in and out counter and energizes appropriate master cycler output relay.	Nand gate fails high.	Diffusion defect in element junction. Element junction breakdown due to switching transient.	Failure results in master cycler output relay failing to turn on for rod motion if the failure is in gate 3 or 7, or failing to turn on for rod motion in the in direction if the failure is in gate 4 or 8. This results in loss of rod motion in either the in or out direction for a group of rods.	Loss of rod motion in one direction for a group of rods. Rod group will become misaligned with other rods in same bank.	
		Nand gate fails low.	Loss of supply and bias voltages. Poor lead bonding to metallization pad of junction element or to package terminal post. Bulk defect in silicon substrate material.	Failure results in gates CD-106-5, 106-6, 107-5, or 107-6 remaining high. See failure of CD106-5,6 - CD107-5,6 on sheet 57.	See Sheet 57.	

REFEREN - DRAWING W Dwg. 915E637 Sht. 7,8 942H061 Sht. 1		CIRCUIT FUNCTION Programming Ckt. II, III				DATE November 30'81
COMPONENT	FUNCTION	FAILURE MODE	FAILURE MECHANISM	EFFECT ON SYSTEM	METHOD OF DETECTION	REMARKS
Master Cycler assembly decoder circuit CD106-5,6 CD107-5,6	Decodes signals from master cycler in and out counter circuit and energizes appropriate master cycler output relay.	Nand gate fails high.	Diffusion defect in element junction. Element junction breakdown due to switching transient.	Failure results in slave cycler clutch being constantly energized thru master cycler output relay powered by affected gate. This will cause rod group to step out of sequence resulting in misalignment of affected rods with other rods assigned to same bank.	A misaligned rod initiates sounding of a rod deviation alarm by the R P I S to alert operator of failure.	
		Nand gate fails low.	Loss of supply and bias voltages. Poor lead bonding to metallization pad of junction element or to package terminal post. Bulk defect in silicon substrate material.	Failure results in open circuit path to slave cycler clutch for group of rods energized thru master cycler out put relay powered by affected gate. This will cause loss of rod motion for one group of rods resulting in misalignment of affected rods with other rods assigned to same bank.	Same as above.	

REFERENCE DRAWING W Dwg. 915E637 Sheet 7,8 9424061 Sheet 1		CIRCUIT FUNCTION Programming Ckt. II, III				DATE November 30'8
COMPONENT	FUNCTION	FAILURE MODE	FAILURE MECHANISM	EFFECT ON SYSTEM	METHOD OF DETECTION	REMARKS
Master cycler assembly relay K109	Interfaces with relay K1 in pulser assembly to terminate shift pulse. Provides +28 VDC to output relays K101 thru K108.	Fails open.	Coil winding open due to insulation breakdown. Contact worn or corroded. Interconnect wire to coil or contact open. Ground path thru relay driver CD111-5 open. Diode CR153 fails open.	Failure results in unterminated shift pulse. This will prevent system from stepping rods.	Error detection circuitry in master cycler will provide alarm for an unterminated shift pulse.	
		Fails Closed.	Coil winding shorted due to insulation breakdown. Contact fused.	Failure results in master cycler output relays K101 thru K108 not dropping out when direction signal is removed and slave cycler has completed its rotation. This will cause rod group to step out of sequence resulting in misalignment of affect rods with other rods assigned to same bank.	A misaligned rod initiates sounding of a rod deviation alarm by RPIS to alert operator of failure.	