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NS SAVANNAH REPLACEMENT CONTROL
ROD DRIVES
SAFEGUARDS REPORT
VOLUME I

Description

October 1962

RELEASED FOR ANNOUNCEMENT
IN NUCLEAR SCIENCE ABSTRACTS

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AEC Contract No. AT(30-1)-2478

Submitted to
THE UNITED STATES ATOMIC ENERGY COMMISSION

Prepared by
MARVEL-SCHEBLER PRODUCTS DIVISION

Borg-Warner Corporation
Decatur, Illinois

Bound by
THE BABCOCK & WILCOX COMPANY
Atomic Energy Division
Lynchburg, Virginia

NOTE

This report is one of three volumes comprising the safeguards report on operation of the NS Savannah with the replacement control rod drive system:

- VOLUME I NS Savannah Replacement Control Rod
 Drives — Description
- VOLUME II NS Savannah Replacement Control Rod
 Drives — Description of System Modi-
 fication and Hazards Analysis
- VOLUME III NS Savannah Replacement Control Rod
 Drives — Galveston Testing Program

N. S. SAVANNAH
SAFEGUARDS REPORT

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N.S. SAVANNAH

SAFEGUARDS REPORT

1. DESCRIPTION OF REPLACEMENT DRIVE, VESSEL HEAD AND SUPPORT SYSTEMS

1.1 CONTROL ROD DRIVE SYSTEM

The Marvel-Schebler Control Rod Drive System is an electro-mechanical system replacement for the electro-hydraulic system originally installed on the N.S. Savannah. The replacement control rod drive system is manufactured by Marvel-Schebler Products Division, Borg-Warner Corporation, Decatur, Illinois, in accordance with AEC contract AT-(30-1)-2478, dated October 9, 1959.

1.1.1 DESIGN CRITERIA AND GENERAL SYSTEM DESCRIPTION

DESIGN CRITERIA

The design requirements for the replacement control rod drive system are specified in Atomic Energy Commission Specification MRB-MA55/286/10000. Parts of this specification, essential to the design, are abstracted on the following pages. The paragraph numbers refer to the applicable paragraphs in the specification to facilitate further reference to the specification.

GENERAL SYSTEM DESCRIPTION

The replacement rod drive system controls fission by moving preselected groups of control rods and follower rods in the active core of the nuclear reactor in response to signals from the reactor control system. The rod groups are programmed to provide linear output of the reactor in a linearized one rod concept defined and described in paragraph 3.1.2.

The replacement rod drive system provides the means and verification (without moving the control rods) of the rod group programming, however, resolution of the program is the responsibility of the reactor supervisor.

The replacement rod drive system comprises twenty-one mechanisms, power supplies and control circuitry. The leadscrew of each mechanism is mechanically coupled to a control rod and the two parts move in and out of the reactor core as an integral unit.

The rod drive system accepts three external incoming signals:

a. Rod Positioning - The reactor control signal delivers commands to the rod drive system, indicating direction of rod motion and rod speed. The system converts the signal to programmed rod group response.

b. Fast Insertion - Commanded manually by an operator.

c. Scram - Automatically commanded by the Safety System or manually by an operator.

The rod drive system is interlocked with three external systems:

The two roller assemblies (pc. 12) in the lower portion of each segment arm are angular contact bearings, with external lands on the outer race. When the leadscrew is engaged, the rollers contact the leadscrew at four points 90° apart to form a roller nut. Each roller is displaced axially by means of spacers, a distance equal to 1/4 of the leadscrew pitch to permit the roller lands to engage the leadscrew. The rollers are held in the arm by a roller spindle at an angle equal to the helix angle of the leadscrew thread. The roller nut formed by the rollers imparts vertical motion to the leadscrew upon rotation of the rotor assembly. The rollers are designed for long term operation at temperatures up to 300 degrees F.

To limit leadscrew travel at full withdrawal, a rotational stop (pc. 8) is attached to the bottom of one segment arm. The stop rides in the groove of the leadscrew thread until it hits the end of the thread and prevents further rotation of the rotor nut assembly. Continued application of OUT command power to the stator will cause the rotor nut assembly to slip poles. If the stop were not provided, the mechanism ability to scram from the full withdrawal position would be reduced. Programming of the mechanism limits the normal operating withdrawal to 58 inches so that the rotational stop should never be engaged during normal service.

The inner race of the thrust bearing seats on a flange on the bottom of the rotor tube and is held in place by a four section key and capscrews. When the rotor assembly is installed in the motor tube, the outer race of the thrust bearing is held in place with the thrust bearing retainer. The bearing provides support for all vertical loads applied to the rotor assembly as well as radial alignment for the lower portion of the rotor assembly.

The radial bearing of the rotor assembly provides radial support and alignment for the upper end of the assembly when installed in the motor tube. The radial bearing is held on the rotor tube by a lock nut and a cupwasher which locks the lock nut to the rotor tube to prevent it from coming off or loosening. The inner races of the radial bearing and synchronizing bearing are separated by a spacer to permit them to rotate independently.

Figure 1-3 shows two pawls located adjacent to the leadscrew in the area of the motor tube flange, which prevents the leadscrew and control rod from dropping out of the reactor core in the event that the ship capsizes. The tooth pawl is designed to engage the leadscrew at any point of travel. The shape of the tooth pawl permits the leadscrew to scam but will not permit outward motion greater than the distance between threads ($3/8''$). The solid pawl will engage the leadscrew only when it is fully inserted. This pawl is required to absorb the rebound when the buffer piston bottoms in the buffer cylinder. These pawls are spring loaded so that when the rotor nut disengages the leadscrew, the pawls will engage the leadscrew.

Figure 1-4 shows the magnet assembly (pc. 39) used to actuate the rotor motion detector switch described in paragraph 1.1.2.8. The magnet, Alnico V, is hermetically sealed in a 304 stainless steel case and mounted on the segment arm as shown.

FIGURE 1-3A, LEADSCREW CHECK VALVE

4. Capacitors are calculated for a $\pm 20\%$ tolerance and were purchased as 10% components.

5. Modules of the same type are interchangeable without modification and contain no matched or selected components other than as-purchased tolerance.

6. Transistors used are silicon, derated to have adequate power dissipation at 100° C ambient. For design purposes all transistors were considered to have an h_{FE} (current transfer ratio) of not less than 20 (10 for power transistors) or greater than 200. This permits standard commercial transistors to function properly in any application requiring that type of transistor.

7. Military approved components were purchased wherever possible.

8. All component tolerances contributing to possible unsatisfactory performance of a module were combined to represent the worst possible combination and the circuit designed to function under these worst case conditions. All resistors are either carbon film or wire wound. All capacitors are either tantalum or oil. Teflon insulated wire is used throughout the system.

c. Circuit Design

Circuits required for reactor shutdown are redundant to insure shutdown capability for any single circuit failure. Any subsequent single circuit failure can result only in a scram or a stationary rod, withdrawal

is impossible. The system will respond to any legitimate command even though it may be initiated by a malfunction in reactor instrumentation external to the rod drive system. The fault indication circuitry recognizes faults created within the system and the readout locates the fault area. The fault circuits continually monitor the rod drive system.

The system is essentially digital and control levels are not critical. They are either ON or OFF. The exceptions are voltage comparators, pulse generators, and, the dead band of the direction sensor. These circuits contain analog units which are adjusted at the factory and were selected to eliminate expensive precision components, provide easy replacement, and, flexibility of the system.

All relays were selected for reliability. They are the hermetically sealed plug-in type and are used in circuits requiring less than 1/2 of their contact rating. The operate and release times of the relays are not critical and the coil resistances were worst cased to meet temperature requirements. Spare contacts are available in each relay and the plug-in units are securely locked in their sockets.

The patchboards are enclosed in glass covered compartment to permit visual inspection of the programming pattern. The boards are laid out so that the patchcords do not cross one another to facilitate patching and inspection. The patchboard covers are interlocked so that removal of any cover is annunciated on the main annunciator board in the control room.

There are 6 rod position (RPI) patchboards, one rod grouping patchboard (RGP) and one master programmer (MAP) patchboard and the covers are all series interlocked. Another interlock is provided for each motor programmer sequence module to remove logic power to that module before the board can be removed. If the logic power was on and the module removed while the system is in service, false sequence signals would be caused by momentary contact of the connector pins as it is removed from the socket.

Test points are provided for preventive maintenance measurements or trouble-shooting. The test points are isolated from their respective circuits through resistors to eliminate possible circuit malfunctions by inadvertent grounds or cross connection of test leads.

An elapsed time meter located in the system status panel totalizes the operating time of the system.

If it is necessary to operate a single rod for maintenance or other purpose a single rod controller may be patched into the sequence module socket of any motor programmer. The controller permits independent operation of the mechanism including independent rod position readout. Upon returning the mechanism to service the controller and position readout is used to return the rod to its proper position in its group.

1.1.3.3 MOTOR PROGRAMMER (MOP)

The solid state motor programmer latches the motor initially upon command and converts control rod direction and velocity commands into switching operations for sequentially energizing the six stator windings. The motor requires three windings to be energized prior to rotation. This operation (LATCHING) results in the segment arms engaging the leadscrew. Once the motor has been latched, the IN and OUT direction commands select the "firing order" for forward or reverse rotation of the rotor. Each velocity pulse then "fires" a solid state switch that energizes one winding and de-energizes another. As each winding combination becomes energized, the rotor steps or advances 30 mechanical degrees. Figure 1-5 illustrates the front panel of motor programmer drawer.

a. Latch Signals

Prior to latching, the motor programmer is inhibited from sequencing. The latch signal bypasses this inhibit and enters the motor programmer through a separate circuit. When the latch signal is applied to the motor programmer, three motor windings, BB, A and CC are energized, and the sequence inhibit is removed. In Figure 1-5, each circle of lamps is connected to a motor and each lamp is connected to a winding.

The scram SCR driver has a second input, capsize scram, from which the motor may be unlatched. The capsize scram input is grounded during normal operation by contacts of the two capsize scram relays. When capsize scram is commanded, the relays release removing the ground from this line. When the control rod bottoms, the rod bottom proximity switch closes. The switch closure applies +20 vdc through a resistor to the scram SCR to unlatch the motor. During normal operation, the proximity switch may close many times; however, the current passing through the series resistor is shunted to ground through the contacts of the capsize scram relay and never reaches the scram SCR driver.

The unlatching of the motors when the rods bottom is not a requirement as no damage occurs if the motor stalls, nor is there an absolute necessity for conservation of power should the standby battery be in service. Unlatching upon reaching the bottom simply means that less re-charging time will be required should the battery be the source of supply.

j. Fault Indication

1. Motor Programmer Check

A motor programmer check module for each motor programmer provides a signal to inhibit all sequencing should the motor programmer develop a sequencing malfunction. The master fault lamps on the control panel and system monitor illuminate should any motor programmer sequence improperly.

2. Phase Sequence Indicator

Six indicator lamps (Figure 1-5) on the front of each motor programmer indicate which windings of the control rod drive motor are energized. Observing the rotation of the light pattern formed by these lights shows immediately if the programmer is sequencing properly. Since the motor programmer modules are located in the watertight cabinet, the lamps are not visible until the cabinet doors are opened. The lamps are de-energized when the cabinet doors are closed.

1.1.3.4 ROD GROUPING PATCHBOARD

The rod grouping patchboard (Figure 1-6) provides a flexible method of combining 21 motor programmers for group operation. Any number of rods from one to 21 may be patched into a group. The patchboard has 21 sections corresponding to the 21 rods with each section divided into two subsections: one for group selection; and the second for method of latching.

a. Rod Grouping Sub-section

A dual patchcord completes two circuits when patching a motor programmer into one of the available A, B, C, D, E or X groups. One side of the patchcord completes the rod group enable signal from the master programmer to the motor programmer. The other side completes the latch verification circuit between the motor programmer and the latch verification relay driver. Since the B and X groups are latched automatically, latch verification is not available in these two group positions.

b. Latch Sub-section

A patchcord completes the latch circuit from the motor programmer to either the master programmer for automatic latching or control transfer for manual latch at the control panel. Therefore, the method of latch must be selected for each motor programmer prior to system operation.

c. Patchboard Interlock

The patchboard has a removable, glass top cover that serves as: one, a dust cover; and second, as a safety device. When the cover is not in place, the interlock switch completes a circuit which causes an alarm in the control room.

The presence of an X pulse and an IN signal decreases the count one digit.

Only the X pulses are counted during the IN and OUT signals since it was felt that this provided adequate resolution.

4. Pulse Alternator

The X and Y pulses are both required to make the master programmer's performance agree with that of the motor programmers in the use of the velocity pulses. Since the motor programmer requires alternate X and Y pulses for continuous rotation, the master programmer must count alternate pulses. The pulse alternator consists of a flip-flop and diode gating to provide an X pulse only after a Y pulse, thus eliminating any possibility of the master programmer counting transients from external sources. Synchronism between the motor programmers and master programmer is accomplished by the master programmer counting X pulses upon withdrawal and Y pulses upon insertion. The latter function is also performed by the pulse alternator.

5. Fault Indication

The pulse totalizer has a continuous monitoring circuit capable of detecting that the electro-mechanical counter does not step when commanded to do so by the system. Should such a malfunction exist, the fault alarm sounds in the control room; and the fault is indicated on the rod group and fault indication panel (Figure 1-41).

b. Limit Setting Patchboard

The limit setting patchboard (Figure 1-17) is sub-divided into nine major sections. Six of these sections correspond to the six rod groups

2. Master Upper Limit Section

The master upper limit section of the patchboard (colored red) requires dual patchcords for selecting the thousands, hundreds, and tens decades. One side of each dual patchcord completes the circuit to the control panel upper limit digital display which shows the totalized count patched for the master upper limit. The other side of each dual patchcord completes the circuit to the upper limit driver which forms a portion of the internal safety system of the rod drive system.

Should a malfunction occur that resulted in a withdrawal or the operator attempts to increase reactor output beyond the patched upper limit, the inhibit driver (located within the direction sensor) inhibits the OUT command and stops further withdrawal.

To improve reliability of the master upper limit circuit, the signal line from the master programmer to the direction sensor carries a continuous signal for normal operation. If this signal line becomes broken or grounded through a malfunction, the system cannot be withdrawn until a repair has been made. However, this circuit feature does not inhibit normal rod group insertion or the safety modes of FAST INSERTION, CAPSIZE SCRAM or SCRAM.

3. Automatic Latch Section

The automatic latch section (colored green) uses single patchcords for selecting the thousands, hundreds and tens decades.

When the totaled count from the electro-mechanical counter matches the count patched in this section, those rod groups chosen to be latched automatically (B and X) receive the latch signal when the totaled count is increasing.

4. Patchboard Interlock

The patchboards has a removable, glass top cover that is interlocked the same as the Rod Grouping Patchboard (paragraph 1.1.3.4).

c. Group Enable Relays

Six group enable relays corresponding to the groups A, B, C, D, E and X provide the +20 vdc group enable signals to the motor programmers (paragraph 1.1.3.3.c). The six latching-type relays are controlled by solid state logic gates that receive their signals from the limit setting patchboards. When the totaled count reaches the lower limit number in the thousands, hundreds, tens and zero decades, the solid state gates sum the signals and energize the latching-type relay (K16). The next count de-energizes the relay coil; but being a latching-type relay, the relay remains in the latter position completing the rod groups enable circuit. The rod group now withdraws in synchronism with the master programmer's electro-mechanical counter.

1. Rod Group Enable Indicators

Six rod group enable indicator lamps on the system monitor cabinet Rod Group and Fault Indication panel (Figure 1-14) show which groups are enabled. These indicator lamps operate directly from the rod group enable signals and may be tested at any time to establish confidence when not illuminated.

2. Fault Indication

A fault indication circuit is provided for each of the six rod group enable relays and their drivers. The continuous monitoring circuit detects when the relay driver receives a signal to operate the relay and the relay does not respond. Should this malfunction exist, the fault alarm sounds in the Control Room; and the fault is indicated on the Rod Group and Fault Indication panel (Master Programmer Fault Lamp).

d. Automatic Latch Relays

The automatic latch relay operates similar to the rod group enable relays except the latch relay is not the latching-type relay. When the totalized count matches the patched count, the latch relay operates the same as the rod group enable relays, however, the latch signal need only to be momentary as opposed to the rod group enable signals which must be continuous within the range of operation.

2. Flip-Flop

The flip-flop is a bistable transistor circuit that changes state with each oscillator pulse. In one stable state, one side of the symmetrical circuit approaches zero volts while the other side remains at some finite voltage. When a pulse from the oscillator triggers the flip-flop, the finite voltage side now approaches zero volts; and the zero voltage side becomes the finite voltage. The flip-flop circuit will remain in one of the two stable states until triggered by the next oscillator pulse.

An output voltage is taken from each side of the flip-flop which becomes the origin of the X and Y velocity pulse lines. By capacity coupling from each side of the flip-flop to the rest of the generator circuit, a pulse is obtained on each output only when each side changes from zero to a finite voltage. Thus, a pulse appears on the X line when the X side of the flip-flop steps from zero to a finite voltage. The same is true for the Y output taken from the opposite side of the flip-flop. Therefore, the X and Y pulses appear on two separate lines and are staggered in time or, alternated. For example the X pulse is generated with the first oscillator pulse, and the Y pulse is generated with the second generator pulse. The third generator pulse would then provide another X pulse, etc.

3. NOR Elements

Immediately following the flip-flop are two NOR logic elements, one in each of the velocity pulse lines. These elements function as solid state output switches. The output of the NOR elements feed directly into the X and Y line drivers (current amplifiers) for the system. By "grounding" one of the control lines to the pair of NOR elements the output of the velocity pulse generator is withheld from the system, but internally the oscillator and flip-flop continue to function normally. Removing the "ground" basically connects the generator to the system through the X and Y line drivers.

During normal operation in the automatic or manual mode, the automatic/manual generator provides the X and Y pulses for the system. The fixed rate generator's output is inhibited by the NOR elements in that generator. When fast insertion or capsize scram mode is commanded, the automatic/manual generator is disconnected from the system; and the fixed rate pulse generator is connected.

b. Velocity Pulse Line Drivers

Both the X and Y lines leaving the velocity pulse generators control the X-Y line driver amplifiers. The amplifiers are three stage transistor current amplifiers capable of switching the total X-Y currents of the system. The two line drivers are cross-coupled such that the presence of a pulse at the output of one line driver inhibits the output of the other. Should a line driver malfunction such that a constant output was available, the other line driver would not function; thus, preventing simultaneous X and Y pulses.

1.1.3.8 CONTROL TRANSFER

The control transfer sub-system establishes the system operation modes in response to commands originating at the reactor instrumentation or from the control panel. The control transfer, upon command, places the system in the modes of MANUAL, AUTOMATIC, FAST INSERTION, CAPSIZE SCRAM, and SCRAM. Each mode of operation demands a particular group of operating parameters such as rod velocity and rod group insertion-withdrawal patterns. All safety action originates within the control transfer. The components and their functions for each mode of operation is explained in the following sections.

a. Scram Relays

The two scram relay coils (K9A and K9B) are normally energized from the +26 vdc through a series of safety contacts such that the relays' coils will de-energize and cause scram under the following conditions:

1. Loss of either or both of the safety amplifier signal(s) originating in the reactor instrumentation system.

2. Loss of the normal motor voltage (+90 vdc) for the control rod drive motors for a period greater than one to five seconds. The slight delay permits under-voltage transients to occur on the 440 vac busses without resulting in scram. During the momentary period of under-voltage, the standby motor power batteries carry the control rod drive motor load.

3. Loss of the +26 vdc for the system which has a battery backup for the normal regulated power supply. This only occurs upon loss of both the power supply and battery backup.

4. Breaking or "grounding" the line energizing the two relay coils K9A and K9B.

Two relays have been used to improve the reliability of the scram circuit by unlatching 10 motors from K9A and 11 motors from K9B ensuring at least a one-half scram upon failure of either relay to de-energize upon command. Other safety circuits use the contacts of the K9A and K9B relays either in series or parallel depending upon the application. An explanation of the other functions performed by the scram relays is as follows:

1. Scram relays must be energized to manually latch 16 rods initially.

2. Scram relays must be energized to reset the capsized scram relays (K8 and K22).

3. De-energizing K9A or K9B scram relays commands the reset of all rod position indicators.

4. De-energizing the scram relays when all rods are bottomed, inhibits both the IN and OUT command lines.

5. De-energizing the scram relays opens the circuit to the external Auto-Disable Relay "D".

6. De-energizing the scram relays inhibits the OUT command line whether all rods are bottomed or not.

3. Master programmer resets to zero after all rods reach bottom.
4. Each motor unlatches when its own rod reaches bottom.
5. Closes battery ventilation system until all rods reach the bottom to prevent flooding batteries should the vessel capsize.
6. Enables all motor programmers to insert on a non-programmed insertion pattern.
7. The external "Auto Disable D Relay" circuit is interrupted.
8. Annunciates CAPSIZE SCRAM (B&W).
9. Inhibits 16 rod latch until capsize switch relays are reset.

c. Fast Insertion Relays

The two fast insertion relays K7A and K7B perform parallel function for improved reliability. The relay coils are both energized from an external voltage during normal operation. Loss of this voltage de-energizes the fast insertion relays which perform the following functions:

1. Switches the automatic/manual velocity pulse generator "off" of the X and Y velocity lines.
2. Switches the fixed rate pulse generator "on" the X and Y velocity lines thus commanding maximum rod velocity of 13.5 inches/minute.
3. De-energizes the automatic/manual relay (K10) should the system be in the automatic mode when fast insertion is commanded.

4. Enables the IN command line between the line driver and the system.
5. Inhibits the OUT line between the line driver and the system.
6. Annunciates the Fast Insertion (B & W).

During fast insertion the control rods are inserted at 13.5 inches/minute in the pre-programmed pattern which is the reverse of the withdrawal pattern. Re-energizing the fast insertion relays K7A and K7B results in the following action:

1. The fixed rate velocity pulse generator is switched "off" of the X and Y velocity lines.
2. The automatic/manual velocity pulse generator is switched "on" the X and Y velocity lines.
3. Returns the IN and OUT command lines to line driver control.
4. Returns the system to the manual operating mode rather than automatic.

d. Capsize Switch Relays

The two capsizes switch relays K22A and K22B perform parallel functions for improved reliability. Normally these two relays are

The operator may now withdraw rods in the pre-programmed pattern either manually with the IN-HOLD-OUT selector switch or automatically from reactor instrumentation. The system may be advanced to the automatic mode with the spring loaded automatic switch. When the system operates in the automatic mode, the automatic indicator is illuminated. To return the system to the manual mode, the operator rotates the IN-HOLD-OUT switch away from the HOLD position to either IN or OUT which cancels the automatic mode.

The next three indicators are illuminated only when the system advances to one of the safety modes. These indicators are explained as follows:

1. Mechanism Outer Limit - This indicator illuminates should any rod or group of rods exceed the normal programmed travel through a system malfunction. The action originates within the rod position indication equipment and prevents further withdrawal of all rods.

2. Out Inhibit - The out inhibit indicator shows that out motion of the control rods is inhibited. During the period that this indicator is "on" control rods cannot be withdrawn, however, they can be inserted.

3. Capsize Scram - The capsize scram indicator illuminates when the system advances to the capsize scram mode. This safety action is initiated by any combination of roll and pitch in excess of 45° . This indicator remains "on" after all rods bottom until "reset" at the reactor compartment cabinets.

FIGURE 1-9, CONTROL PANEL, REACTOR CONTROL ROOM (C DECK).

1.1.3.10 ROD POSITION INDICATORS

The rod position indicators (Figure 1-10) register the total number of rotor revolutions as a measure of rod position where one revolution of the mechanism rotor represents 0.375 inches of rod travel. Twenty-one electro-mechanical counters totalize the rotor revolutions and provide the digital readout.

As the rotor passes a given point during rotation, a magnetically operated switch provides a signal to the add-subtract counter drivers. In the presence of an OUT system command, each revolution adds a count on the electro-mechanical counter. In the presence of an IN system command counts are subtracted. When the rods are scrambled, the counters are electrically reset to zero by the sequential reset unit.

The electro-mechanical counter not only provides a visual readout of the totalized counts; but also provides a digital output for each count, thus making it possible to have an electrical readout as well. The electrical readout terminates at the rod position limit patchboard (Figure 1-11) where a particular count may be selected as the upper limit for a given rod beyond which the system is inhibited from further withdrawal of any rods. The upper limit for a rod may be selected by placement of patchcords in the patchboard and shall be set above the normal programmed rod travel.

a. Rotor Motion Switch

Detection of rotor motion without penetrating the primary containment is obtained by the rotor motion switch described in paragraph 1.1.2.8. As the permanent magnet on the rotor revolves past the reed switch,

FIGURE 1-10, ROD POSITION INDICATION DRAWER PANELS.

		☐	☐	☐	MODE	☐	☐	☐	
0	☐	☐	☐			☐	☐	☐	0
1	☐	☐	☐			☐	☐	☐	1
2	☐	☐	☐			☐	☐	☐	2
3	☐	☐	☐			☐	☐	☐	3
4		☐	☐				☐	☐	4
5		☐	☐				☐	☐	5
6		☐	☐				☐	☐	6
7		☐	☐				☐	☐	7
8		☐	☐				☐	☐	8
9		☐	☐				☐	☐	9
	HUN	TEN	UNIT						
	ROD X								

1"

FIGURE 1-11, PATCHBOARD FOR ROD POSITION INDICATORS.

FIGURE 1-12, ROD BOTTOM INDICATION DRAWER PANEL.

c. Rod Position Indicator (RPI) Controls

The rod position indicator accumulates counts as the rotor withdraws the control rod. Should the operator wish to scram a single rod with the single rod controller, the rod position indicator would still show the last highest count. However, a rod position indicator reset push button has been provided to reset the RPI to zero after scrambling a single rod.

A detector pulse indicator lamp has been incorporated to indicate each time the rotor motion switch closes which adds or subtracts counts from the rod position indicator. This indicator light serves to: one, provide a means of detecting slip of the rotor as the lamp should light every six counts on the pulse totalizer; and the second to detect if the rotor motion switch is providing the count signal for the rod position indicator.

d. Rod Velocity Control

After the IN-HOLD-OUT switch is placed in the IN or OUT position, the control rod may be withdrawn or inserted at the fixed speeds of 2, 6 or 13.5 inches per minute through three push buttons. It is only necessary to release the push button to stop the rod or change speeds.

The system conditions existant during each of these modes are further outlined as follows:

Preparatory Modes

(a) OFF

1. Logic Power off
2. Standby Logic Power off the line (charging)
3. Normal Motor Power off
4. Standby Motor Power off the line (charging)
5. Battery Ventilation System Operational
6. Rod Drive Motors unlatched

(b) START MODE

1. Logic Power on and System Reset
2. Standby Logic Power on-the-line and charging
3. Normal Motor Power on (two power supplies)
4. Standby Motor Power on the line and charging
5. Battery Ventilation System Operational
6. Rod Drive Motors unlatched

(c) READY MODE

1. Reactor Scram is reset (external to system)
2. Fast Insertion is reset (external to system)
3. High Primary Temperature is reset (external to system)
4. High Neutron Flux is reset (external to system)

5. Filament Failure is reset (external to system)
6. Capsize Scram is reset
7. Rod Drive Motors latched (except B and X groups)

1. The B and X groups are automatically latched at some programmed count of the rod groups withdrawal pattern.

Operational Modes

(d) MANUAL CONTROL

Provides manual selection of control rod withdrawal or insertion with a preselected, group pattern at a fixed, rod velocity.

(e) AUTOMATIC CONTROL

The system responds to the analog reactor demand signals after being manually advanced to the Automatic Mode. The control rods are then withdrawn or inserted with a preselected, group pattern. The direction of travel depends upon the polarity of the analog signal, and the linear velocity is a function of signal magnitude.

Rod groups X and B automatically latch at a predetermined withdrawal level and then travel with groups A, C, D and E as a portion of the preselected, group pattern.

The system returns to Manual Control upon initiation of a manual command of withdrawal or insertion.

Safety Modes

(f) FAST INSERTION

The system responds to a reactor initiated Fast Insertion Command overriding Manual or Automatic Control. The control rods are inserted in the preselected group pattern at 13.5 inches/minute velocity until the Fast Insertion Command ceases. The system then returns to the Ready Mode.

(g) CAPSIZE SCRAM

The system responds to the Capsize Scram Command which overrides the Manual, Automatic, Fast Insertion and Scram Modes. The command is initiated by the Capsize Switch which actuates when the ship's attitude exceeds 45 degrees in roll, pitch or combination thereof. Once the command is initiated, the system remains in the Capsize Scram Mode until manually reset.

All rods, regardless of rod group pattern, insert simultaneously at 13.5 inches/minute rod velocity. As each rod bottoms, the control rod drive motor de-energizes to conserve the Standby Motor Power (Battery) should this be the power source during Capsize Scram.

The battery ventilation system closes during the Capsize Scram period to prevent possible flooding through the ventilation ducting. The ventilation system re-opens after all rods are bottomed if the 115 vac power is on.

After all rods are bottomed, the system resets to zero and returns to the Start Mode.

(h) SCRAM

The system responds to Scram initiated by the following:

1. Reactor Instrumentation (Safety Amplifiers)
2. Loss of Normal Motor Voltage for a period in excess of 1 to 5 seconds.
3. Loss of both Normal and Standby Motor Power.
4. Operator (external to this system).

All rods unlatch and the system resets to zero when all rods bottom. The system returns to the Start Mode.

System Verification Mode

(i) SYSTEM CHECK-OUT

The system check-out mode permits ship's personnel to verify the preselected rod group pattern without rod movement. To insure safety of operation, the control rod drive motors are disconnected from their respective Motor Programmers and "dummy" loads substituted. Both the Normal and Standby Motor Power must be "Off-the-Line" before the system can be advanced to the System Verification Mode.

System may be exercised without control rod movement in the following modes by internal commands:

FIGURE 1-17, RELAY DIAGRAM, FAST INSERTION (K7)

FIGURE 1-19, RELAY DIAGRAM, SCRAM (K9)

FIGURE 1-29, RELAY DIAGRAM, SAFETY AMPLIFIERS (K23, K24)

FIG. -34 1-159

The prototype spring moment at land-on-land is 762 lb-in and at latched it is 1675 lb-in. Figure 2-9 illustrates these rotor-leadscrew relations.

c. Segment Arm Bending Tests

Segment arm bending tests were performed to justify the peak holding moments obtained for the radial moment exerted by the stator as determined in later tests. The test also ascertained whether the arms would bend under the forces applied and affect roller adjustment. Two shims were placed on each side of the rotor assembly between the upper end of the segment arms as shown in Figure 2-10. Equal and opposite forces were applied to the lower ends of the segment arms with the adjusting screw. The deflection (for both arms) was equal to the gap measurement under load minus the initial gap. The gap between the arms was the same as the gap measured before testing started which indicates that the range of moment applied by the stator would not give the arms a permanent deformation. The spring moment proved to be as high as other types of mechanisms and therefore, no trouble was expected with roller adjustment as was borne out by the subsequent actual roller adjustment.

h. Capsize and Bounce Latch Strength Tests

The bounce and capsize latches must be capable of stopping the leadscrew rebound without damage following a scram. From scram tests run in an autoclave it was determined that when the buffer piston (on the leadscrew) bottoms in the buffer cylinder (in the motor tube extension), the leadscrew could rebound 0.187 inches (upper bounce limit including standard deviation from arithmetic mean). From a 10 to 1 drawing layout, 0.871 inches was found to be the maximum distance between the capsize latch and leadscrew thread before they come into contact. Under normal circumstances the bounce latch and capsize latch do not come into contact with the leadscrew after a scram because of the dampening effect of water in the system and relative location of the latches. However, if the reactor is partially empty and a scram occurs, or a capsize condition exists; then the capsize and bounce latches should prevent the outward motion of the control rod when the mechanism rotor nut is not engaged with the leadscrew. Therefore, the design objective of the latches was determined as follows. Both latches, individually, should take a force exerted on them approximately twice the weight of control rod and leadscrew assembly (dry) dropped from a height of .871 inches.

The tests were performed by installing the mechanism upside down in an air test stand and an adapter loaded the leadscrew with dead weights ranging from 540 to 840 lbs. The leadscrew was raised 0.871 inches and dropped against the capsize latch. The first ten drops used a 540 lbs. weight. In the following nine drops the weight was increased in 25 lb. increments to 815 lbs. Eleven additional drops were made with an 850 lb. weight. There was no indication of damage or malfunction of the capsize latch during this test.

Since the bounce latch was stronger due to its physical shape it was decided to start with 850 lb. weight dropped from .871 inches. At the end of ten drops there was no damage or malfunction of the bounce latch. Therefore, the design of the latches was more than adequate.

45° attitude. Scram commands may be initiated by the reactor operator or automatically by the reactor instrumentation. Within the rod drive system a scram will be caused by loss of normal motor voltage for a period greater than five seconds.

Each mechanism has its own scram circuits initiated by a common command. Power for the scram circuit is obtained directly from the same source used to energize the stator. The scram circuit is therefore safe because failure of the scram circuit power would also be failure of stator power and result in a scram anyway. Any power failure to the stator causes the mechanism to scram.

Parallel power sources limits this type failure to individual cable failures and/or individual stator failures. Another inherent feature of the mechanism is that a scram will also result if, by some remote possibility, the frequency of the input power could increase to the equivalent of 24 inches per minute rod speed (hot).

The thermostat within the stator assembly initiates an over-temperature alarm but does not disable stator power.

Rod drive motor power is supplied by two transformer-silicon rectifier type power supplies connected in parallel so that both are on the line continuously, each one capable of carrying the entire load.

Power for the logic portion of the system is provided by two sets of transformer-silicon rectifier type regulated power supplies operated from separate 110 vac sources and a set of standby batteries.

Only one power supply is in service at a time. Failure of the one in service puts the system on battery power and annunciates an alarm. The operator then manually switches to the alternate power supply without interruption of service.

When a scram occurs the buffer piston on the top end of the leadscrew limits the bottom impact to between 4 and 6 g's.

The mechanism is not expected to ever withdraw the lead-screw as high as it can go (72 inches), however, a rotational stop is provided on the rotor assembly to insure that the leadscrew can be scrambled from this point.

1.1.5.4 CAPSIZE SCRAM

If the ship attitude exceeds 45° in any combination of roll or pitch a capsized scram command is automatically initiated which overrides the manual, automatic, fast insertion and scram modes to simultaneously insert all rods at 13.5 inches per minute. Upon failure of the normal power supplies, motor power or logic power, a standby battery system automatically furnishes power to drive the rods in. Watertight integrity insures that capsized scram can be accomplished even if the reactor compartment is flooded. The watertight cabinets and cable assemblies permit safe operation for a minimum of 10 minutes while subjected to 186 psig inside the containment vessel or while submerged under a 20 foot head of water outside the containment vessel. This is adequate time for the capsized scram mode to drive all rods in from 60 inch withdrawal (5 minutes). When the mechanisms are operating in the capsized scram mode the scram circuit is inhibited to insure that the rods will be driven into the core.

Whenever stator power is off, intentionally or accidentally, the leadscrew is automatically engaged by pawls which limit outward motion of the control rod to 3/8 inches maximum (the lead of one thread). The pawls always engage the leadscrew regardless of ship attitude when stator power is off. When stator power is on, engagement of the rotor with the leadscrew prevents inadvertent motion of the leadscrew.

1.1.5.5 ROD POSITION

Rod bottom indication by the proximity switch and rod position indicated by the rotor motion switch are directly actuated by movement of the leadscrew and rotor respectively. The proximity switch assembly contains a second switch which can be used to verify the switch in service (or replace a faulty switch) by interchanging connections at an external junction box.

The upper limit of rod travel is controlled by two separate subsystems. The master counter (pulse totalizer) is programmed to stop the system at some predetermined count. The individual rod position indicators are programmed for a maximum withdrawal of their respective groups. Any one rod in any group progressing beyond the programmed limit will annunciate an alarm and stop withdrawal of all rods.

1.1.5.6 FAST INSERTION

Fast insertion commands override manual or automatic control. The control rods are inserted in the preselected group pattern at 13.5 inches per minute for as long as the fast insertion command exists.

The electrical system is designed such that any critical component failure will cause the affected rod or rod group to hold or scram. In no case will the affected rod or rod group be caused to move out without a valid OUT command.

All major units of the electrical system are monitored for proper operation. All faults which may occur in the system are indicated by a panel lamp on the main control panel and by an audible alarm. The operator localizes the fault by observing the system status indicators in the cabinets located in the equipment space of the reactor compartment.

Most circuit components of the electrical system are mounted on plug-in circuit boards so that any faulty unit may be operable by merely plugging in replacement circuit boards. Wherever a unit function is critical to the reliability of system operation two or more components are used to duplicate the function for reliability.

A fault in a motor programmer will stop the affected rod but does not affect the ability to scram. However, it is possible that the fault would cause a scram. A fault causing one or more rods to progress above the upper limit inhibits the entire system. Any other fault does not affect the system operation.

The maximum permissible rate of buffing of the leadscrew/control rod is 16g. The buffer on this mechanism provides less than 6g decelerating force, however, 6g is used for calculation. Maximum stress occurs at a point in the leadscrew just below the buffer piston assembly. Using a conservative yield point for 17-4 PH Stainless Steel at 650°F, the safety factor is 8.4; the minimum for any point in the assembly. Stress in the leadscrew coupling due to buffing was calculated for the worst alignment condition (minimum overlap of male and female halves). The factor of safety is 9.6 based on ultimate strength of 304 stainless steel at operating temperature.

Contact stresses for the rollers in the rotor nut and the leadscrew were computed for the most extreme condition of axial loading (stuck rod condition). The rollers have a 6.6 factor of safety and the leadscrew tooth stress, 4.2.

The leadscrew assembly has limited lateral freedom at the control rod coupling and at the upper end of the leadscrew extension which permit only concentric loads on the extension. However, the leadscrew proper sees eccentric loads when there is misalignment with the control rod. Calculations for maximum assumed misalignment and maximum axial load indicate the factor of safety is 5.8.

h. Stellite

1. Haynes Alloy No. 3 (bearing balls leadscrew check valve ball).
2. Haynes Alloy No. 6 (pawls, leadscrew connector).
3. Haynes Alloy No. 19 (bearing races, bushings, pivot pins).
4. Haynes Alloy No. 25 (bearing races, synchronizing pins).

The design lifetime of parts used in the mechanism is 10 years which is expected to equal the lifetime of the reactor. Similar parts have been in service in operating pressurized water reactors for over five years and there is no record of failure, appreciable wear or corrosion during this time. Improvements in raw material, quality control and welding techniques plus extensive testing are expected to further extend the life of the mechanisms now being built.

Marvel-Schebler's past experience with ARMCO 17-4 PH Stainless Steel in control rod drive mechanisms has been good. Leadscrews of 17-4 PH stainless have been used in all mechanisms of this type manufactured by Marvel-Schebler with no failure or trouble reported to date.

The 17-4 PH stainless steel was selected as being the best material to resist corrosion, retain strength at elevated temperatures, maintain consistent hardness (does not work harden), and is not notch sensitive. For mechanism applications, no deviations in chemistry are permitted and ultrasonic testing is performed during manufacture to insure sound material. The 17-4 PH stainless steel material is an age hardenable modification of the standard 18% chromium, 8% nickel corrosion

resistant steel. The modification consists of replacing 1/2 of the nickel with copper and the addition of columbium and titanium to produce stability of material. All 17-4 PH material used in the Savannah mechanism was age hardened at 1050°F for 20 hours, 16 hours more than normal, to relieve residual stresses and reduce the danger of stress corrosion cracking.

The choice of 403 and 410 stainless steel is based on the fact that they are heat treatable and also magnetic. They are tempered above 1110°F which is the minimum tempering temperature for best corrosion resisting properties.

The 302 and 304 stainless steels are standard 18% chromium, 8% nickel and are outstanding for corrosion resistance. The materials are used in the annealed condition, free of precipitated carbides and should not be subject to inter-granular corrosion.

Inconel "X" is an age-hardenable alloy developed for high temperature use up to 1500°F where it has good fatigue and tensile properties, together with resistance to corrosion and oxidation.

Carpenter No. 10 is an alloy used for bolts, rivets, etc. that is highly corrosion resistant and well suited for its intended use.

Generally the Haynes Stellite cobalt-base alloys have excellent properties of hardness and abrasion resistance, as well as resistance to galling and erosive wear. They also have good impact and thermal shock

resistance. All of the Stellite metals used in the mechanism are recommended for bearing applications by the Corrosion and Wear Handbook for Water Cooled Reactors published by the United States Atomic Energy Commission.

1. 1. 6. 3 GALVANIC CORROSION

Galvanic corrosion should be very limited because of the similarity of materials used in the primary water environment.

1. 1. 6. 4 TRANSITION WELDS

Transition welds used in fabrication of the motor tube are made under carefully controlled conditions and have been proved satisfactory by test and service. Several hundred are now in service on pressurized water reactors including Shippingport.

In March of 1960, a thermal cycling test was performed to determine the adequacy of the welded areas in a motor tube having transition welds similar to the Savannah motor tube. Testing was divided into three phases. The first phase consisted of 1000 cycles of variable temperature (70 to 225°F) and pressure (0 to 2500psi) with three emergency cooling cycles (410° to 225°F) at the end. The second phase consisted of 500 cycles at constant pressure (2500 psi) and variable temperature (70 to 225°F) with three emergency cooling cycles at the end. The third phase was the same as the second except six emergency cooling cycles were run at the end. The test proved the adequacy of the four welded areas and contributed data concerning shrinkage and misalignment during welding.

2.2 QUALIFICATION AND EXPERIENCE

Marvel-Schebler, a division of the Borg-Warner Corporation, began manufacture of rod drive mechanisms and construction of test facilities in 1956. The following is a summary of experience since then:

a. Design and manufacture of five types of drive mechanisms for pressurized water reactors. Several hundred of these mechanisms have been manufactured and are in use.

b. Manufacture of two other types of mechanisms for pressurized water reactors which were designed by other companies.

c. Manufacture of the original Shippingport PWR mechanisms, design and manufacture of mechanisms for second core for Shippingport PWR, including means for electrically indicating leadscrew position.

d. Design and manufacture of semi-automatic seal welding machines, seal weld cutting tools and tooling for reshaping seal weld lips for rewelding.

e. Design and manufacture of prototype static power supply for military application.

f. Mechanism decontamination and refit for pressurized water reactors.

g. Design and manufacture of prototype two and three inch valves for nuclear application and a complete valve test loop.

Personnel with extensive experience in missile, aircraft, and ordnance systems were responsible for developing the Savannah electrical system to meet the rod operation requirements specified by Maritime Administration, AEC.

Special purpose devices for fuel handling, remote coupling, and remote controlled electro-mechanical manipulators complete with television monitors are other nuclear products independently developed by Marvel-Schebler. The facilities of the Borg-Warner Corporation Research Center are available to Marvel-Schebler for any problems encountered.

The test facility in Decatur has four complete mechanism test loops for simulated service testing of reactor components in a pressurized water environment at temperatures up to 600°F and pressures to 2500 psi. Each high pressure test loop contains an electrically heated stainless steel autoclave approximately 10 inches in diameter and 16 feet deep. Three of the autoclaves are mounted vertically and the fourth is mounted on journals for mechanism operation at any fixed angular position from vertical to 60° from vertical. All four autoclaves are equipped with automatic pressure and temperature controls.