NUREG/CR-3754

Failure Evaluation of General Electric SB-1 and SB-9 Reactor Mode Switches

Prepared by V. P. Bacanskas

Franklin Research Center

Prepared for
U.S. Nuclear Regulatory Commission

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Prepared by
V. P. Bacanskas

Franklin Research Center
20th and Race Streets
Philadelphia, PA 19103

Prepared for
Division of Emergency Preparedness and Engineering Response
Office of Inspection and Enforcement
U.S. Nuclear Regulatory Commission
Washington, D.C. 20555
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1. SUMMARY

As a result of reactor mode switch malfunctions at operating nuclear power plants (IE Information Notice 83-42), the U.S. Nuclear Regulatory Commision (NRC) requested that Franklin Research Center (FRC) per. ·m a failure evaluation of the General Electric (GE) SB-1 reactor mode switch. The objectives of the program were to identify the failure mechanisms for the SB-1 switch and to determine if the failure mechanisms were the result of age-related conditions, defects of a particular switch, or design. In addition, the vendor-proposed SB-9 replacement switch was evaluated for susceptibility to similar failure mechanisms.

The SB-1 reactor mode switch that malfunctioned at Quad Cities Unit 1 was evaluated along with new SB-1 and SB-9 switches. The SB-1 reactor mode switch malfunctions were most probably the result of the switch being placed in a false detent position (an intermediate switch position just prior to the actual detent position), which allowed several of the contacts required to be closed to remain open. The false detent noted in the SB-1 switch operation is a result of the indexer mechanism design and not age-related conditions or a defect of a particular switch. The indexer mechanism for the SB-9 switch is of a different design and is not susceptible to a similar failure mechanism.

2. INTRODUCTION AND BACKGROUND

The NRC requested that FRC perform an analysis on a GE SB-1 switch that malfunctioned while in service at Quad Cities Unit 1. Dresden Unit 2 reported a similar malfunction and also uses an SB-1 switch; therefore, the results of the analysis are considered to be applicable to both plants. On June 23, 1983, the NRC Office of Inspection and Enforcement (IE) issued IE Information Notice 83-42 [1] entitled "Reactor Mode Switch Malfunctions." The Information Notice discussed the mode switch malfunctions at Dresden Unit 2 and Quad Cities Unit 1.

On October 4, 1983, NRC IE personnel visited FRC and delivered the Quad Cities Unit 1 reactor mode switch. In addition, the following verbal description of the events at the two plants was provided:

- Dresden Unit 2 - With the reactor at approximately 0.6% rated power, and the reactor mode switch in the start-up/hot-standby position, a Group 1 isolation occurred when the main steam line pressure dropped below 850 psig. The Group 1 isolation resulted in a reactor scram.

- Quad Cities Unit 1 - The control room operator was in the process of moving the reactor mode switch from the run to the shutdown position when a Group 1 isolation occurred as a result of main steam line low pressure. The unexpected isolation complicated the normal shutdown recovery.

At both Dresden Unit 2 and Quad Cities Unit 1, the reactor mode switch bypasses the main steam line low pressure trip signal in all switch positions except the run position and the intermediate position between run and start-up/ hot standby.

3. SCOPE OF EVALUATION

The following specific tasks were performed for this evaluation:

- Examination of the malfunctioning Quad Cities Unit 1 SB-1 reactor mode switch to determine if any design or manufacturing defects contributing to switch failure exist.
- Determination of points of wear critical to proper operation of the SB-1 switch.
- Testing of the Quad Cities Unit 1 reactor mode switch to determine if any abnormal operation or contact misalignment exists.
- Similarly, testing and evaluation of a new SB-1 reactor mode switch to determine if the malfunction was wear- or design-related.
- Comparison of the two SB-1 switches with a new SB-9 reactor mode switch to determine if the SB-9 switch is susceptible to a similar malfunction.
- Determination of whether the design changes incorporated into the SB-9 switch could result in failure modes not identified for the SB-1 switch.

4. TECHNICAL EVALUATION

4.1 DESCRIPTION OF DEVICES

Three reactor mode switches were evaluated during this task. Each switch was assigned a number for ease of identification. Switch 5896-1 is the reactor mode switch that was in service at Quad Cities Unit 1 during the event described in IE Information Notice 83-42 [1]. Switch 5896-2 is a replacement SB-1 reactor mode switch that was in spare parts stock at the Quad Cities plant and was provided by Commonwealth Edison for this effort. Switch 5896-3 is an SB-9 reactor mode switch that was purchased from the General Electric Nuclear Energy Business Operations in San Jose, California specifically for the evaluation reported herein.

4.1.1 Switch 5896-1

Switch 5896-1 (Figure 1) is a GE Type SB-1, 10-stage, 2-bank, gear-driven tandem switch. The switch has 20 contacts on each bank. The GE drawing number on the tag affixed to the rear of the switch is 0226A9653G1X2. This switch is the original reactor mode switch from Quad Cities Unit 1 and was in service for more than 10 years.

4.1.2 Switch 5896-2

Switch 5896-2 (Figure 2) is a GE Type SB-1, 10-stage, 2-bank, gear-driven tandem switch. The switch has 20 contacts on each bank, and was supplied with a keylock handle, escutcheon plate, and two keys. The GE drawing number on the tag affixed to the rear of the switch is 226A9859G1X2. The switch was purchased as a replacement part for Quad Cities Units 1 and 2 by Commonwealth Edison and had been in storage since January 1978.

4.1.3 Switch 5896-3

Switch 5896-3 (Figure 3) is a GE Type SB-9, 8-stage, 4-bank, gear-driven tandem switch. The switch has 16 contacts on each bank for a total of 64 contacts. The GE drawing number on the tag affixed to the rear of the switch is 262A6750P001. The switch was purchased from GE and was received on December 19, 1983.

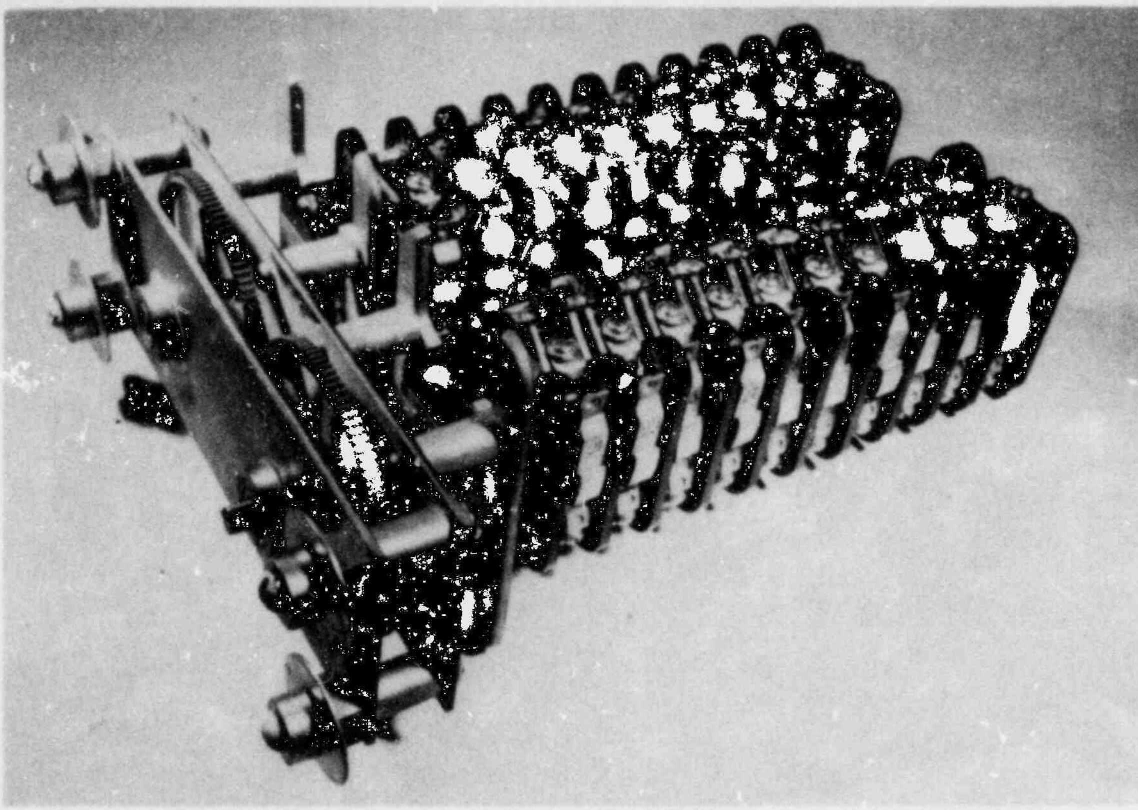

Figure 1. Switch 5896-1

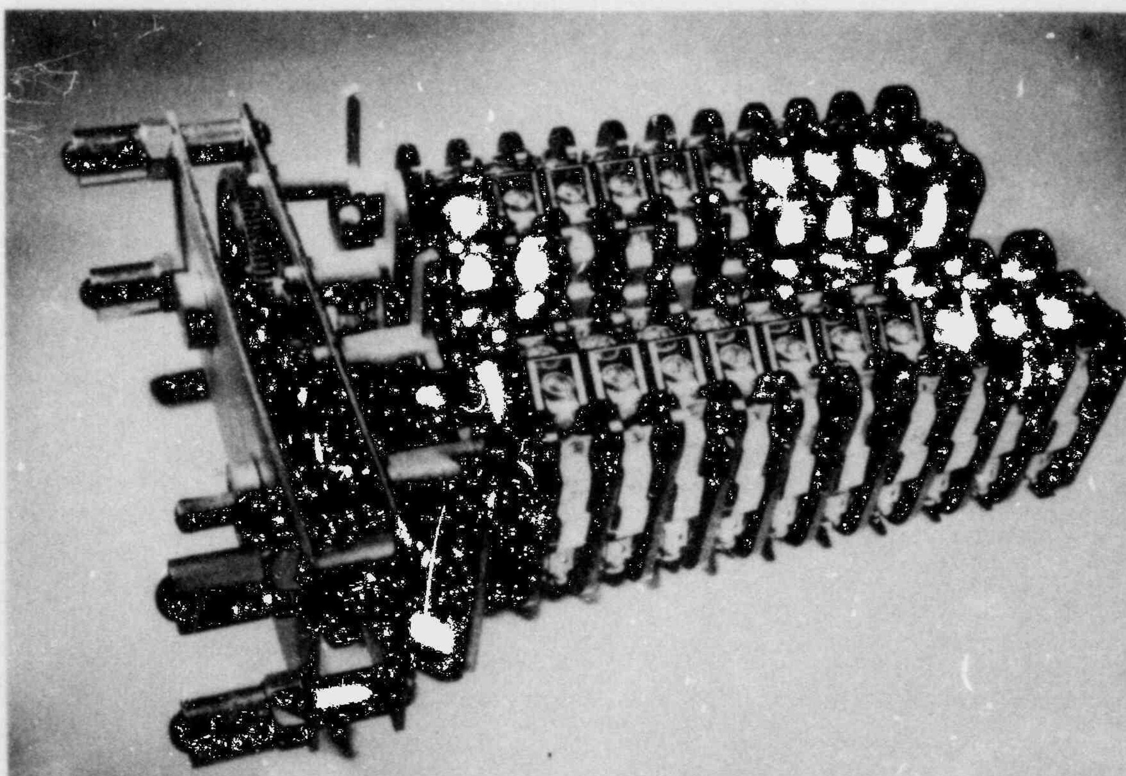

Figure 2. Switch 5896-2 with Terminal Covers Removed

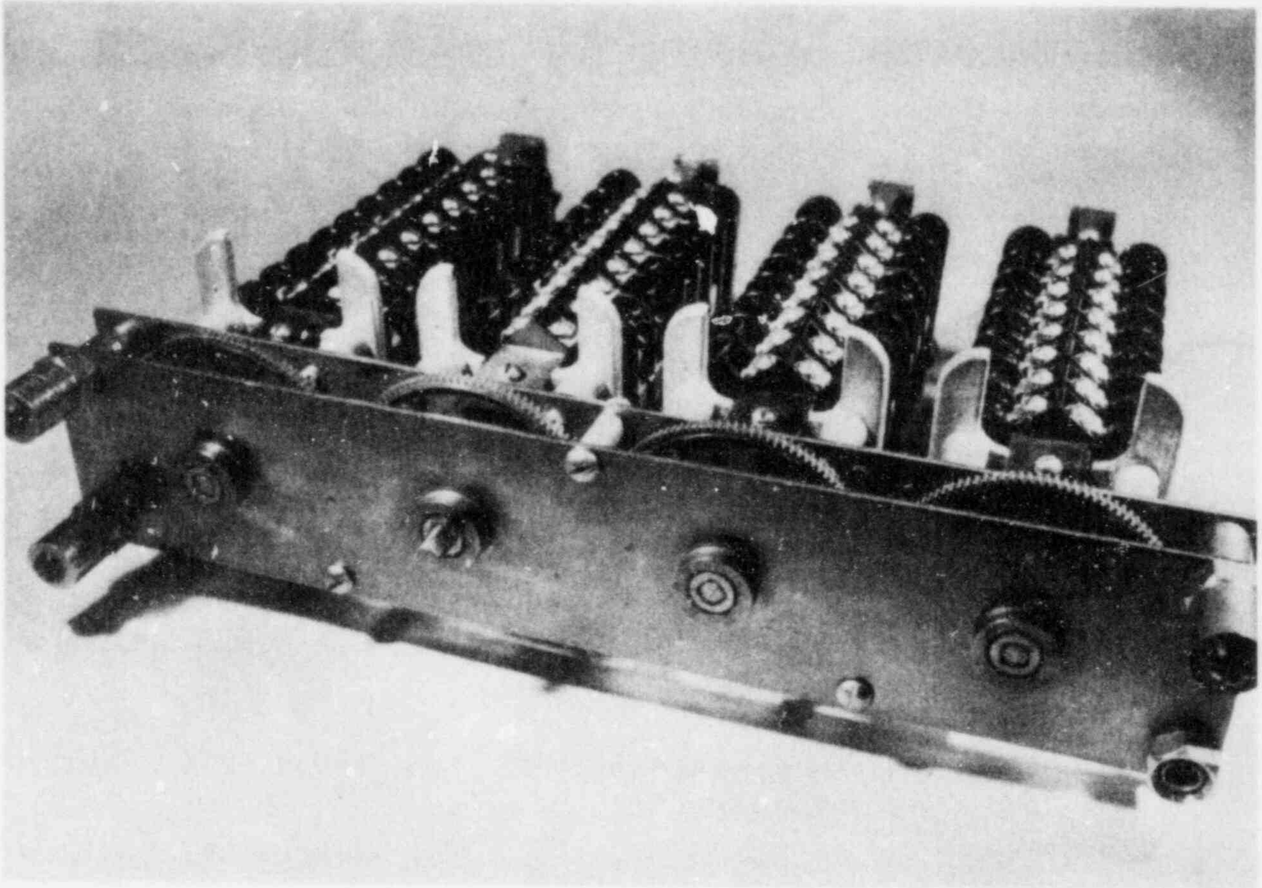

Figure 3. Switch 5896-3 with Terminal Covers Removed

4.2 TESTING OF REACTOR MODE SWITCHES

Upon receipt, each reactor mode switch was visually inspected and then subjected to a series of tests to determine functional abnormalities, if any, prior to disassembly and internal visual inspection. The methods used and the results for each step of the evaluation are detailed in the following paragraphs.

4.2.1 Receipt Inspection

Switch 5896-1 was inspected on October 4, 1983. The switch was received without the switch handle and the NEMA 1* terminal covers. There was no sign of any external damage to the switch. There was, however, a buildup of dust on the phenolic blocks separating each pair of contacts. The dust was evident only on the face of the phenolic separator facing the control board surface. As explained by Commonwealth Edison personnel, the reactor mode switch is mounted in a manner such that the switch stages hang vertically. Thus, the single surface experiences the dust buildup as the opposite face of the preceding phenolic separator is directly above it. Wire identification tags made of cloth and numbered 1 and 2 were found underneath the contact terminal screws on contacts 1 and 2. The brass inserts in the final stage directly behind the cam shaft were not threaded, indicating that the NEMA 1 terminal covers could not be secured in place.

Switch 5896-2 was received and inspected on October 20, 1983. The switch was in a "like-new" condition and free from any dust buildup. Two differences were noted from Switch 5896-1. The cam shaft extension that mates to the switch handle was more than two times as long as that of Switch 5896-1. Also, the brass insert in the final stage was threaded for securing the NEMA 1 terminal covers in place. The switch was received with the NEMA 1 terminal covers in place.

Switch 5896-3 was inspected on December 20, 1983. The switch was received in a "like-new" condition but without a switch handle, and one of the mounting screws and spacers was missing. The switch was received with all four NEMA 1 terminal covers in place. Unlike the terminal covers from Switch

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*National Electrical Manufacturer's Association.

5896-2, a 1-1/2-in-diameter hole was stamped in the rear of the terminal covers for wiring access from the rear of the switch. The detent mechanism for the SB-9 switch is markedly different from that of the SB-1 and is located at the rear of the switch. This difference is discussed in more detail in Section 5.2 of the report.

4.2.2 Contact Resistance Measurements

Each reactor mode switch was prepared for contact resistance measurements by connecting a No. 10 uninsulated terminal lug to each of the terminal screws to facilitate connection of the measuring device. A John Fluke Manufacturing Company Model 8800A digital multimeter was used with four-wire resistance-compensated test leads.

For Switch 5896-1, 35 of the 40 contacts had resistances of less than 5 milliohms, and the remaining five had resistances of less than 30 milliohms. Measurements were made at 200 millivolts dc.

With the exception of contact 21, all contacts on Switch 5896-2 had a resistance of less than 5 milliohms at 200 millivolts dc. Contact 21 originally read 371 milliohms, but began to drop immediately and dropped to 3 milliohms within a few seconds. No switching was performed until the resistance had dropped. It is believed that the initial high resistance was a result of a buildup of oxides on the contact surface which were subsequently burnt off during the test. Such a condition would be of no consequence during operation at the expected service voltage.

All contacts from Switch 5896-3 had a resistance of less than 5 milliohms at 200 millivolts dc.

4.2.3 Contact Arrangement Development

Visual inspection was used to develop the contact arrangement for each of the reactor mode switches. Each switch was moved from position to position while the status of each contact in that position was recorded until the development was completed. Tables 1, 2, and 3 provide the contact development for Switches 5896-1, 5896-2, and 5896-3, respectively.

Review of Tables 1 and 2 shows that the switch developments for contacts 19 and 20 differ from Switch 5896-1 to Switch 5896-2. Discussions with

Commonwealth Edison personnel revealed that Switch 5896-2 would have been modified with a kit supplied by GE prior to its use so that Contacts 19 and 20 would agree with the developments shown on Reference 2.

It should be noted that the contact arrangement shown in Table 3 is markedly different from those of Tables 1 and 2. This is a direct result of the fact that Switch 5896-3 was the only SB-9 reactor mode switch available for procurement. The original intent of the project was to obtain an SB-9 switch that was a direct replacement for the Quad Cities SB-1 switch; however, the long lead time for construction of an SB-9 switch made this impossible. The different contact development has little bearing on the conclusions drawn concerning the SB-9 switch because the evaluation was restricted to the functional components of the switch, which are similar for all SB-9 switches regardless of contact development.

4.2.4 Reactor Mode Switch Functional Testing

To accomplish functional testing, each switch was wired to a light board with an indicating lamp wired to each switch contact. The switch was powered with a 120-volt ac power source. The switch handle was placed in the run position, and the numbers of the closed contacts indicated by illuminated lamps were recorded. The switch handle was then rotated approximately halfway between the run and start-up/hot-standby position and the closed contacts were recorded. This process was repeated until each intermediate and full-travel position through shutdown was recorded. (Switch 5896-3 could not be maintained in an intermediate position; therefore, only full-travel positions were recorded.) The switch handle was then rotated to the run position and the process repeated. This sequence was repeated until five complete cycles of the switch were recorded.

During the functional testing, Switches 5896-2 and 5896-3 performed repeatedly with no deviations from the contact developments noted in Tables 2 and 3; however, abnormalities were noted in the operation of Switch 5896-1.

While the handle of Switch 5896-1 was being moved, it appeared that there were two detents at each switch position; the second detent (false detent) was more noticeable when changing between the run and start-up/hot-standby positions from either direction than between any of the other positions.

Table 1. Contact Development for Switch 5896-1

Contact	Handle Position[a] 1	2	3	4	5	6	7	Contact	Handle Position 1	2	3	4	5	6	7
1	O	O	O	O	O	O	X[b]	21	O	O	O	O	O	O	X
2	O	O	X	X	X	O	O	22	O	O	X	X	X	O	O
3	X	O	O	O	O	O	O	23	X	O	O	O	O	O	O
4	X	O	O	O	O	O	O	24	X	O	O	O	O	O	O
5	O	O	X	X	X	X	X	25	O	O	X	X	X	X	X
6	X	O	O	O	O	O	O	26	X	O	O	O	O	O	O
7	X	O	O	O	O	O	O	27	X	O	O	O	O	O	O
8	O	O	O	O	X	X	X	28	O	O	O	O	X	X	X
9	X	X	X	X	X	O	O	29	X	X	X	X	X	O	O
10	O	O	X	X	X	X	X	30	O	O	X	X	X	X	X
11	O	O	X	X	X	X	X	31	O	O	X	X	X	X	X
12	O	O	X	X	X	X	X	32	O	O	X	X	X	X	X
13	X	O	O	O	O	O	O	33	X	O	O	O	O	O	O
14	X	O	O	O	X	X	X	34	O	O	O	O	X	O	O
15	X	X	X	O	O	O	O	35	X	X	X	O	O	O	O
16	X	O	O	O	O	O	O	36	X	O	O	O	O	O	O
17	O	O	X	X	X	O	O	37	O	O	X	X	X	O	O
18	O	O	X	X	X	X	X	38	O	O	O	O	O	O	X
19	X	O	O	O	O	O	O	39	X	O	O	O	O	O	O
20	O	O	X	X	X	X	X	40	O	O	X	X	X	X	X

a. Handle Position:
- 1 = Run
- 2 = Intermediate
- 3 = Start-up/hot standby
- 4 = Intermediate
- 5 = Refuel
- 6 = Intermediate
- 7 = Shutdown

b. X = Denotes contact closed in this position.
O = Denotes contact open in this position.

Table 2. Contact Development for Switch 5896-2

Contact	Handle Position[a] 1	2	3	4	5	6	7	Contact	Handle Position 1	2	3	4	5	6	7
1	O	O	O	O	O	O	X[b]	21	O	O	O	O	O	O	X
2	O	O	X	X	X	O	O	22	O	O	X	X	X	O	O
3	X	O	O	O	O	O	O	23	X	O	O	O	O	O	O
4	X	O	O	O	O	O	O	24	X	O	O	O	O	O	O
5	O	O	X	X	X	X	X	25	O	O	X	X	X	X	X
6	X	O	O	O	O	O	O	26	X	O	O	O	O	O	O
7	X	O	O	O	O	O	O	27	X	O	O	O	O	O	O
8	O	O	O	O	X	X	X	28	O	O	O	O	X	X	X
9	X	X	X	X	X	O	O	29	X	X	X	X	X	O	O
10	O	O	X	X	X	X	X	30	O	O	X	X	X	X	X
11	O	O	X	X	X	X	X	31	O	O	X	X	X	X	X
12	O	O	X	X	X	X	X	32	O	O	X	X	X	X	X
13	X	O	O	O	O	O	O	33	X	O	O	O	O	O	O
14	X	O	O	O	X	X	X	34	O	O	O	O	X	O	O
15	X	X	X	O	O	O	O	35	X	X	X	O	O	O	O
16	X	O	O	O	O	O	O	36	X	O	O	O	O	O	O
17	O	O	X	X	X	O	O	37	O	O	X	X	X	O	O
18	O	O	X	X	X	X	X	38	O	O	O	O	O	O	X
19	O	O	O	O	O	O	X	39	X	O	O	O	O	O	O
20	X	X	X	X	X	O	O	40	O	O	X	X	X	X	X

a. Handle Position:
1 = Run
2 = Intermediate
3 = Start-up/hot standby
4 = Intermediate
5 = Refuel
6 = Intermediate
7 = Shutdown

b. X = Denotes contact closed in this position.
O = Denotes contact open in this position.

Table 3. Contact Development for Switch 5896-3[a]

Contact	Handle Position[b] 1	3	5	7	Contact	Handle Position 1	3	5	7
1	O	O	O	X[c]	17	O	O	O	X
2	O	X	X	O	18	O	X	X	O
3	X	O	O	O	19	X	O	O	O
4	X	O	O	O	20	X	O	O	O
5	X	O	O	O	21	X	O	O	O
6	O	X	X	X	22	O	X	X	X
7	O	X	X	X	23	O	X	X	X
8	O	O	X	X	24	O	O	X	X
9	X	X	X	O	25	X	X	X	O
10	O	X	X	X	26	O	X	X	X
11	X	O	O	O	27	X	O	O	O
12	X	O	O	O	28	X	O	O	O
13	X	X	O	O	29	O	O	X	O
14	X	O	O	O	30	X	O	X	X
15	O	X	X	O	31	O	X	X	X
16	X	O	O	O	32	O	X	O	O
33	O	O	O	X	49	O	O	O	X
34	O	X	X	O	50	O	X	X	O
35	X	O	O	O	51	X	O	O	O
36	X	O	O	O	52	X	O	O	O

a. The SB-9 switch by design cannot be maintained in an intermediate position unless specifically constructed to do so.

b. Handle Position:
   1 = Run
   3 = Start-up/hot standby
   5 = Refuel
   7 = Shutdown

c. X = Denotes contact closed in this position.
   O = Denotes contact open in this position.

Table 3 (Cont.)

Contact	Handle Position[(b)] 1	3	5	7	Contact	Handle Position 1	3	5	7
37	X	O	O	O	53	X	O	O	O
38	O	X	X	X	54	O	X	X	X
39	O	X	X	X	55	O	X	X	X
40	O	O	X	X	56	O	O	X	X
41	X	X	X	O	57	X	X	X	O
42	O	X	X	X	58	O	X	X	X
43	X	O	O	O	59	X	O	O	O
44	X	O	O	O	60	X	O	O	O
45	O	O	X	O	61	X	X	O	O
46	X	O	X	X	62	X	O	O	X
47	O	X	X	X	63	O	X	X	O
48	O	O	X	O	64	O	O	O	X

Further testing of Switch 5896-1 revealed that a false detent did exist approximately 5 to 10 degrees before the full-travel position (arrival at next detent position). It was noted during evaluation of the false detent that several of the contacts required to be closed in the full-travel position were not closed in the false detent position. The open contacts included two contacts used for the main steam line low pressure bypass interlock. It should also be noted that the handle from Switch 5896-2 was used to perform the testing. With the switch in the false detent position, the switch handle could not be locked and the key could not be removed. (See Section 5.1 for further discussion.) After further evaluation of the false detent noted in Switch 5896-1, Switch 5896-2 was tested under similar conditions to determine if the false detent was related to the indexer design and not to age-related conditions or uniqueness of a particular switch. The detent spring adjustment screws on Switch 5896-2 were repositioned to replicate the as-received position of the detent spring adjustment screws on Switch 5896-1. Functional testing was then repeated on Switch 5896-2. The false detent was also noted on Switch 5896-2; similar contacts remained open, indicating that the false detent was related to the indexer mechanism design.

4.2.5 Switch Handle Torque Measurements

In order to limit subjectivity in the discussion of the false detent, torque measurements were made while moving switch 5896-1 from position to position. The measurements were made with the detent spring adjustment screws showing approximately three threads, which would represent a loose detent (Figure 4). The reproducibility of this testing is limited by the accuracy in repositioning the adjustment screws; however, the test results indicate the existence of the false detent.

The measurements were made by moving the switch from the run position to the false detent and from the false detent to the start-up/hot-standby position. In terms of the mechanical aspects of the switch, this entails moving the ball bearing out of the machined slot on the indexer (as shown in Figure 4) to the flat in-between positions, and then from the flat to the next machined slot. It was found during the testing that a torque of 16 in-lb was required to move the switch from the run position to the false detent, and a torque of 19 in-lb was required to move the switch from the false detent to

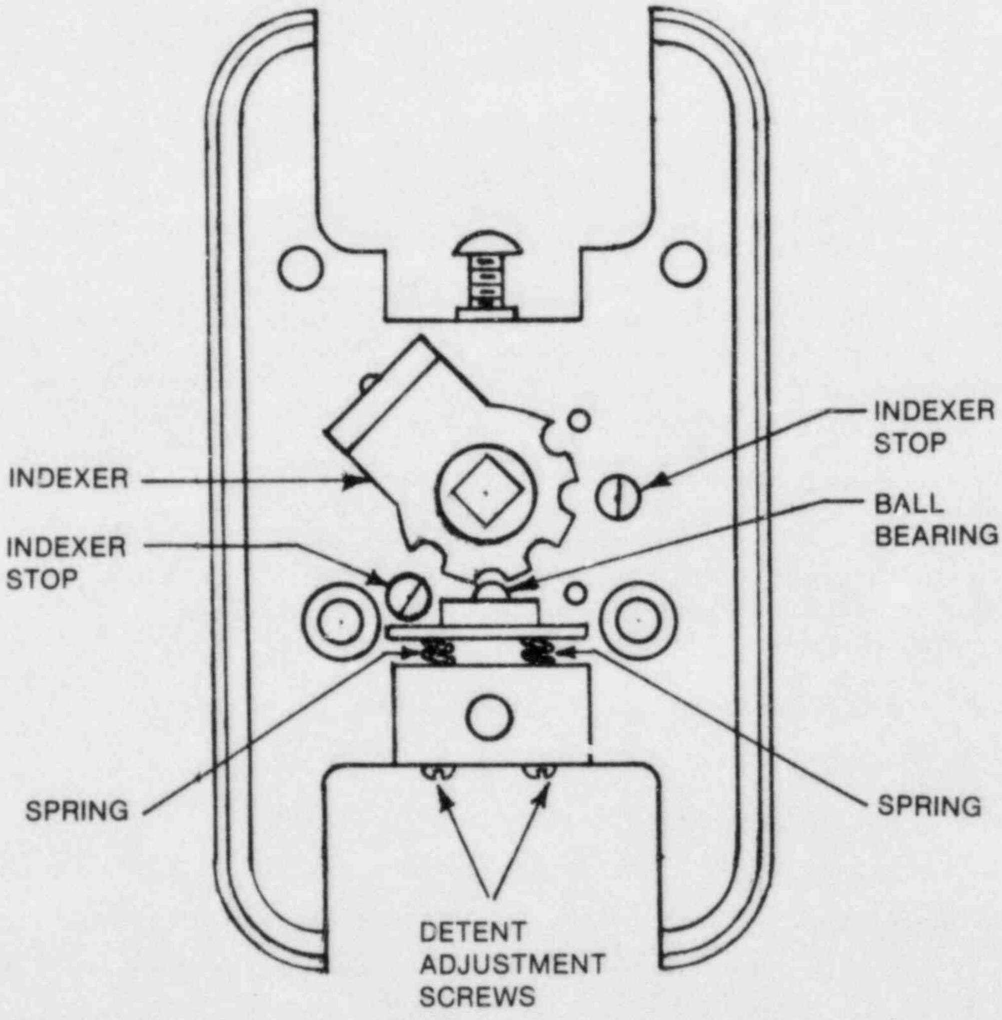

Figure 4. SB-1 Switch Indexer Mechanism

the start-up/hot-standby position. This indicates that a greater torque is required to place the switch correctly in the next position than to remove the switch from its starting position.

4.3 DISASSEMBLY AND INSPECTION

Upon completion of the testing discussed in Section 4.2, Switches 5896-1 and 5896-2 were disassembled; each part was marked to ensure correct reassembly. Comparison of the parts from Switch 5896-1 with those of Switch 5896-2 revealed the following:

- All moving parts for Switch 5896-1 showed some signs of wear from years of operation; however, the wear was not significant enough to impede operation.
- The shunt connections for Contacts 2 and 12 of Switch 5896-1 appeared to have been pried toward the front of the switch, but there were no interferences in their travel, and damage to the shunt connections would not cause misoperation of the switch.
- The contact opening cam for Contacts 9 and 10 of Switch 5898-1 had some surface irregularities. The surface irregularities were in a position where the cam would normally push the contacts open, and the raised surface would tend to open the contact further. The further opening occurs only when the contacts are required to be open and does not affect operation.
- All contact surfaces showed some discoloration from oxidation.

The false detent in the switch operation was initially attributed to the switch position indexers. As a result, the indexers from Switches 5896-1 and 5896-2 were examined under a microscope to identify any significant wear or machining imperfections that could contribute to the false detent. The indexers from Switch 5896-1 showed a wear line at the point at which the indexer surface contacts the ball bearing used to maintain the detent. The edges of the detent slot were slightly rounded at the point of wear. The effect of the wear on the indexer is to allow the ball bearing to ride in the groove created by the wear and to relieve some of the compression on the indexer springs (Figure 4).

5. DISCUSSION OF FINDINGS

5.1 PROBABLE CAUSE OF MALFUNCTIONS

The most probable cause of the switch malfunctions appears to be a combination of effects relating to the design of the indexer mechanism for the SB-1 switch and the contact development for this specific application. Figure 4 provides a drawing of the switch indexer mechanism, and Table 4 lists the number of contacts traveling from open to closed when changing the switch from position to position. Investigation of the false detent noted during the functional testing revealed that the false detent is dependent upon the adjustment screw positions of the detent springs of the indexer mechanism and the number of contacts closing in a particular switch position.

In examining the indexer mechanism, it was found that the adjustment screw position causes the torque required to move the switch handle from position to position to vary and can also change the operator's perception of when the detent position is reached. The greater the number of threads visible on the detent adjustment screws, the smaller the torque required to turn the switch handle and the greater the tendency to place the switch in a false detent position. Tightening of the detent spring adjustment screws makes it more difficult to change switch positions but tends to remove the possibility of inadvertently leaving the switch in an intermediate position (false detent); the larger turning torque required at the handle to start the position change tends to drive the switch past the false detent and into the next position, although the false detent still occurs occasionally.

The switch operating torque measurements, with the detent adjustment screws loosened, indicated that a greater torque was required to place the switch in the next position from the false detent position than to remove it from its starting position, i.e., a greater torque is required to place the switch in the start-up/hot-standby position from the intermediate position than to move the switch from the run position to the intermediate position before start-up/hot-standby. This condition is a result of the torque required to move the contacts to the closed position as discussed below.

The moving contact arm design also influences the amount of torque required to change switch positions. The moving contacts are designed to

Table 4. Number of Contacts Traveling from Full-Open to Full-Close Position

Switch Position		Switch Number		
From	To	5896-1	5896-2	5896-3[a]
Shutdown	Refuel	7	8	13
Refuel	Start-up/ Hot Standby	2	2	2
Start-up/ Hot Standby	Run	15	14	25
Run	Start-up/ Hot Standby	15	14	19
Start-up/ Hot Standby	Refuel	4	4	8
Refuel	Shutdown	3	4	5

a. Switch 5896-3 has 64 contacts, whereas Switches 5896-1 and 5896-2 have only 40 each.

provide a wiping action with the stationary contact so that oxidation buildup is removed by switch operation. The moving contact is constructed of several pieces: the contact arm, contact carrier, shunt connection, pin, and spring. Figure 5 shows these parts. The switch is designed so that when a closing cam pushes a contact to the closed position, the moving contact first touches the stationary contact at a point below the center of the stationary contact. Continued movement of the cam presses the moving contact against the stationary contact, causing a wiping action of the moving contact and compression of the spring. The contact carrier forces the moving contact in an upward direction, wiping the two contacts against each other and releasing some of the compression of the spring. The effect of the contact arm spring torques can be felt at the switch handle; the more contacts being closed in any one switch position, the greater the torque required to move the switch handle when the switch is arriving at a new detent position. When multiple contacts are being closed at a single switch position, the contact closures are not simultaneous, which is a result of slight differences in the contact cams and contact arms. However, a sufficient number of contacts close and partially compress the contact arm springs to increase the torque required to complete the switch travel. The additional torque required to complete the switch travel misleads the operator to believe that complete travel has taken place; the false detent is mistaken for the correct switch position, when, in fact, several contacts are left open.

The indexer adjustment and number of contacts closing provides the most probable explanation for the switch malfunctions. As previously noted, when received, Switch 5896-1 had three complete threads showing (loose detent). The false detent was first noticed during functional testing of the switch when moving the switch from the run to the start-up/hot-standby position. As can be seen from Table 4, 15 contacts close during this operation. With the smaller torque required to move the indexer out of the run position and the larger torque required to compress most of the 15 springs on the contacts as they are closed, the resistance of the switch handle to movement just prior to the start-up/hot-standby position when transferring from the run position led the operator to believe that the full travel position had been reached. It was noted that not all contacts had closed when this false detent position had been reached. Tightening of the detent spring adjustment screws did make it

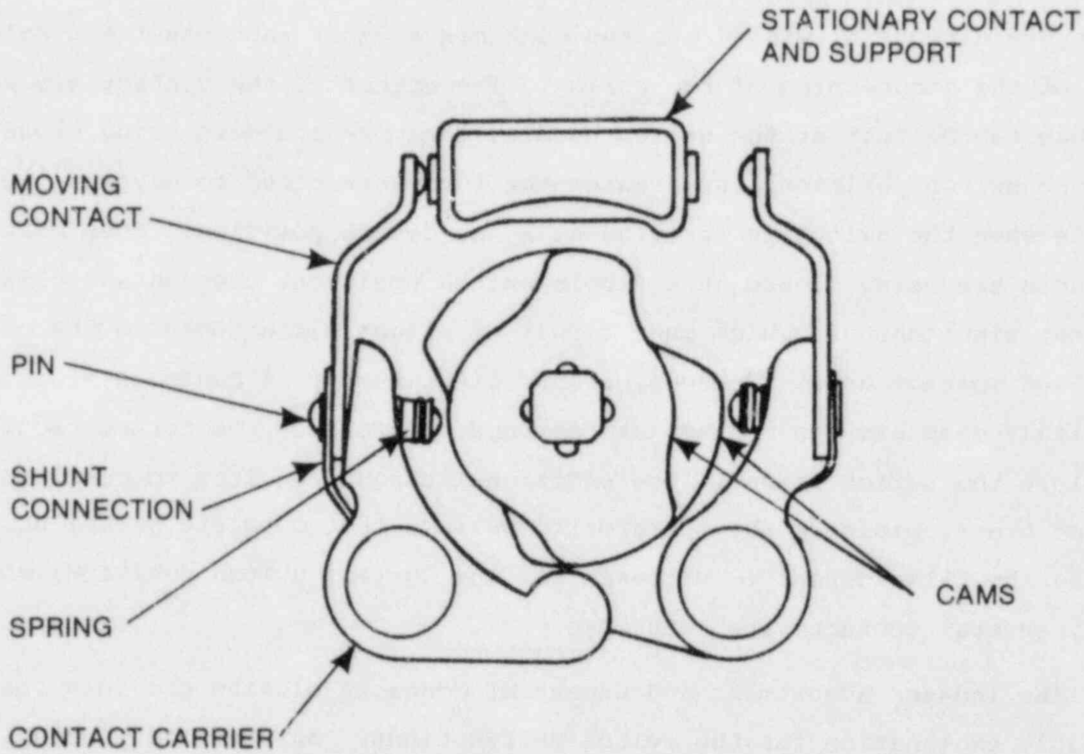

Figure 5. Cam-Operated Contacts

more difficult to leave the switch in the false detent position when changing switch positions; however, some false detents still occurred during transfer attempts after the screws were tightened. Switch 5896-2 was also tested with the detent spring adjustment screws in both the tightened and loose positions, and the results were similar to those noted for Switch 5896-1, indicating that the false detent is related to the indexer design and not to age-related conditions or defects of a particular switch.

5.2 SUSCEPTIBILITY OF THE SB-9 SWITCH TO SIMILAR MALFUNCTIONS

The design of the detent mechanism for the SB-9 switch is entirely different from the mechanism used in the SB-1. The SB-9 switch (5896-3) uses a star wheel with a spring-loaded roller to provide a positive position detent (Figure 6). An intermediate position or a false detent position does not occur on the SB-9 switch as a result of the detent design. The detent mechanism is arranged so that the greatest amount of torque must be applied to the switch handle to pass the high point on the star wheel. Once this point has been reached, the spring torque will continue the star wheel travel until the detent position is reached, forcing the contacts to the desired position; conversely, if the star wheel point is not passed and the switch handle is released, the switch will return to its starting position. The SB-1 switch, on the other hand, requires a large force to be applied to the handle in order to move the indexer out of the detent position. Once removed from the detent position, if the SB-1 switch handle is released, the switch will remain in the intermediate position. In addition, the contacts closing on the SB-1 switch require additional torque to be applied to the switch handle, whereas the spring and roller arrangement of the SB-9 detent mechanism overcomes the spring forces of the contact arms and actually reduces the torque that must be applied to the switch handle to achieve the final desired position. The result is that the SB-9 switch is not susceptible to a false detent malfunction as is the SB-1 switch.

5.3 ADDITIONAL FAILURE MODES OF THE SB-9 REACTOR MODE SWITCH

During the course of the evaluation, the failure modes identified for the SB-1 switch were evaluated for applicability to the SB-9 switch, and an analysis was performed to identify any failure modes for the SB-9 switch that had not been previously identified for the SB-1.

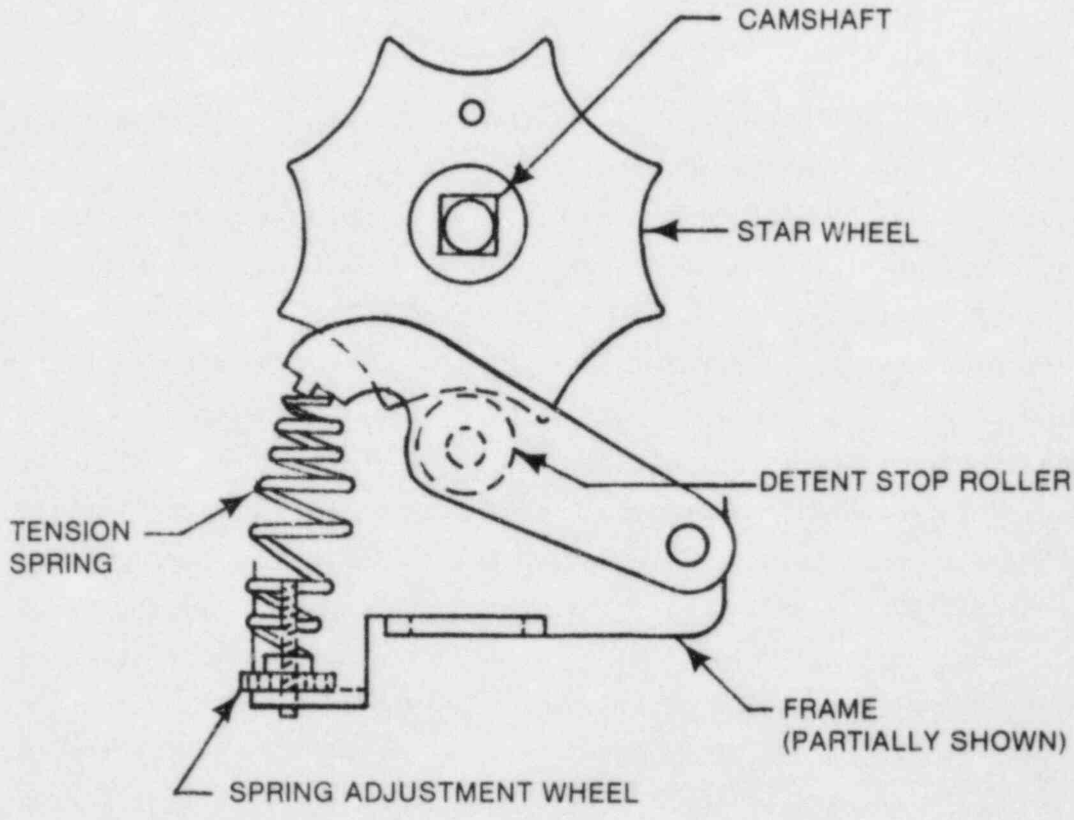

Figure 6. SB-9 Detent Mechanism

The SB-9 switch is similar in design and construction to the SB-1. With the exception of the indexer mechanisms, the parts from the two switches appear to be interchangeable. No new failure modes were identified for the SB-9 switch. The failure modes identified in Appendix A, "Failure Modes and Effects Analysis of GE SB-1 Reactor Mode Switch," are also applicable to the SB-9 switch; however, evaluation of these failure modes leads to the conclusion that they are low probability events for both switch designs and are easily identifiable upon inspection.

6. OTHER POTENTIAL FAILURE MECHANISMS

In order to complete the evaluation of the mode switch malfunctions, it was necessary to postulate all possible failure mechanisms for the reactor mode switch. A failure modes and effects analysis (FMEA) was prepared for the SB-1 switch. This FMEA is included as Appendix A. All failure modes included in the FMEA are low probability events; had any of these occurred in Switch 5855-1, the failure mode would have been identified during receipt inspection, functional testing, or disassembly. In addition to the FMEA, several external influences that may have contributed to the events noted in IE Information Notice 83-41 [1] were identified and are discussed below.

6.1 INTERFERENCE FROM TERMINAL LUGS

During preparation of the wiring for functional testing of the switches, it was noticed that crimping of the terminal lugs using a standard crimping tool would occasionally bend the barrel portion of the lug at an angle with respect to the spade portion. After the wiring was connected to the top switch terminal and the switch handle moved, several of the lugs interfered with the travel of the moving contact. Measurements showed that a bend angle of 15 degrees would prevent the contact from closing. Although preventing contact closure, bending of a terminal lug to create sufficient interference to prevent contact closure would occur only during installation, repair, or external physical disturbance and would be readily observable during preoperational checks.

6.2 DEBRIS

Discussions with Quad Cities Station personnel revealed that, as a result of the large number of wires terminating on the reactor mode switch, the NEMA 1 protective covers would not fit over the wiring, thus leaving the individual contacts open to the internal environment of the control board. In addition, the HVAC air flow path in the control board at Quad Cities is directly across the reactor mode switch. This arrangement raises the possibility of a piece of debris or a buildup of dust or dirt interfering with contact operation. Quad Cities Station personnel stated that on more than one occasion a switch (not the reactor mode switch) whose position had not been changed for several days failed to make contact when initially repositioned.

During review of the event, Quad Cities Station personnel indicated to FRC that the failure of a contact to close was repeatable by moving the reactor mode switch back and forth between positions. Quad Cities personnel attributed the switch malfunction to dirt or debris interfering with contact closure although no debris was found between switch contacts or near the switch. The lack of debris indicates that although contact interference is possible, the malfunctions at Quad Cities Station may have had another cause. The potential for switch malfunction due to contact interference from debris exists when the NEMA 1 terminal covers are not used. Although it appears that the use of any two-bank switch will not allow use of the terminal covers due to the bulkiness of wiring, reducing the number of contacts per bank and increasing the number of switch banks may allow use of the terminal covers.

6.3 EXTERNAL RELAY FAILURE

References 4 and 5, Quad Cities Primary Containment Isolation Schematic Drawings, show that the failure of one relay in the trip logic will produce the same effect as failure of one of the four main steam line low pressure bypass contacts on the reactor mode switch. However, failure of a relay in the trip logic would be detectable and replacement of the reactor mode switch would not correct the trip problem. No relay failures were identified at either the Quad Cities or the Dresden plant.

7. CONCLUSIONS

The following conclusions have been reached as a result of the testing performed during the evaluation:

- The SB-1 reactor mode switch malfunctions reported at Quad Cities Unit 1 and Dresden Unit 2 were most probably the result of the switch being positioned in a false detent position, allowing one or more of the contacts required to be closed in the respective position to remain open and allow initiation of the Group 1 isolation.
- The false detent noted in the SB-1 switch operation is a combination of effects related to the switch indexer design and the contact arrangement for this switch application.
- The false detent in the SB-1 switch is related to the indexer design and not age-related conditions or defects of a particular switch.
- Use of the reactor mode switch without the NEMA 1 covers in place creates the potential for dirt or debris to lodge between the moving and stationary contacts and to impede contact closure.
- The SB-9 switch, with its more positive detent mechanism, is not susceptible to the false detent condition noted on the SB-1 switch.
- The review of the SB-9 switch design did not reveal any new failure mechanisms.
- The failure modes and effects analysis did not indicate any additional failure modes that may have contributed to the switch malfunctions at Quad Cities Unit 1 and Dresden Unit 2.

8. RECOMMENDATIONS

As a result of the technical evaluation, the following recommendations can be offered:

1. Control room operators should be informed of the possibility of the false detent on the SB-1 switch, including methods to detect and to avoid the occurrence of this condition.

   Three methods exist for an operator to determine that the reactor mode switch is in a false detent position. They are:

   a. Pointer position - The pointer on the switch handle will not be in the proper position.

   b. Keylock - During testing, it was found that the key for the switch lock could not be removed with the switch in a false detent. Key removal could be used to verify that the switch is in the proper position.

   c. Extraneous alarms - When the switch is in a false detent position, not all interlocks will be engaged, causing annuniciation for the open interlocks.

2. The NEMA 1 terminal covers should be modified as necessary to ensure that the covers are large enough to fit over the quantity of wires normally associated with a switch of this size. Use of the terminal covers should preclude the possibility of foreign matter interfering with switch operation.

3. Existing procedures for installation of terminations on the switches should be reviewed to ensure that instructions for crimping the terminal lugs are adequate to eliminate the potential for bending of terminal lugs in a manner that might interfere with switch operation. Following installation, replacement, or repair, terminal lugs should be inspected to ensure that they do not to interfere with moving contact operation.

4. When replacement of existing SB-1 reactor mode switches is contemplated, the SB-9 switch should be considered for its more positive detent mechanism.

9. REFERENCES

1. IE Information Notice 83-42, "Reactor Mode Switch Malfunctions" USNRC, June 23, 1983

2. Quad Cities Station Unit 1 Schematic Diagram, Reactor Protection System Channel "A" Scram and Auxiliary Trip Relays, Drawing No. 4E1465, Revision N

3. Quad Cities Station Unit 1 Schematic Diagram, Reactor Protection System Channel "B" Scram and Auxiliary Trip Relays, Drawing No. 4E1466, Revision 9

4. Quad Cities Station Unit 1 Schematic Diagram, Primary Containment Isolation System, Panel 901-15 Trip Logic and Condenser, Drawing No. 4E1503A, Revision N

5. Quad Cities Station Unit 1 Schematic Diagram, Primary Containment Isolation System, Panel 901-17 Trip Logic and Condenser, Drawing No. 4E1503B, Revision Q

APPENDIX A

FAILURE MODES AND EFFECTS ANALYSIS OF GE SB-1 REACTOR MODE SWITCH

The failure modes and effects analysis was performed to ensure that all failure modes for the SB-1 switch were identified and evaluated. The results of the evaluation are reported in Table A-1. The majority of the postulated failures involve failure of a metallic component of the switch mechanism. Due to the low stresses placed on these metallic components during switch operation, the probability of their failure is considered to be very low.

Table A-1. Failure Modes and Effects Analysis of GE SB-1 Reactor Mode Switch

Failure	Effect on Device	Effect on Operation
1. Slipped Handle	Contacts will not complete travel when switch is rotated	Required contacts for switch position may remain open
2. Shaft Bearing Freeze-up	Switch will not change positions	Contacts will remain in existing position
3 Shaft Fracture (Break) Front	Switch will not change positions	Contacts will remain in existing position
4. Shaft Fracture (Break) Between Stages	Contacts on opposite side of break will remain in existing position	No movement of contacts on opposite side of break
5. Gear Tooth Break		
a. Driving Gear	a. Driven gear will not move until switch handle is rotated beyond driving gear break	a. Contacts on driven gear bank will not move until driven gear and driving gear engage, resulting in incorrect positioning of contacts on driven gear bank
b. Driven Gear	b. Driven gear will not move when switch handle is rotated	b. Contacts on driven gear bank will remain in existing position, resulting in incorrect positioning of contacts
6. Indexer Failure (Single)	Position will be determined by indexer on other bank and maintained by gears for both banks	Higher probability of mispositioning of switch by operator
7. Indexer Failure (Both)	Switch handle will move freely from position to position with no noticeable detent	Higher probability of overtravel or undertravel by operator, resulting in incorrect contact positions
8. Cam Failure		
a. Cam Slippage	a. Single contact out of sequence	a. Contact will not change state properly
b. Cam Break		
b.1. Closing Cam	b.1. Moving contact will remain in open position	b.1. Contact will not be forced to close. Contact may drift closed but will neither be firmly held closed nor firmly held open
b.2. Common Opening Cam	b.2. Will not open contacts	b.2. Contact will tend to remain in closed position; however, it will not be firmly held closed when it is supposed to be open

Table A-1 (Cont.)

Failure	Effect on Device	Effect on Operation
9. Moving Contact Pin Failure	Common opening cam will not move contact	Contact will tend to remain in closed position when it is supposed to be open
10. Moving Contact Spring Failure	Moving contact will float	Contact may open or close
11. Closing Cam, Cam Follower Failure	Moving contact spring will force moving contact away from stationary contact	Contact may open. Contacts could be touching, but contact closing torque would not be present
12. Dirt Buildup on Contact	Sufficient buildup may keep contact from closing	Contact will remain open
13. Contact Shorting		
a. Single Contact to Ground b. Contact to Contact	a. Drop-out single circuit b. May create path through open circuit	a. Contact will be open b. Open contact will be closed electrically
14. Contact Bank Bolt Loosening	May provide sufficient play for cam follower to slip off cam	Contact may float open

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16. ABSTRACT (200 words or less)
As a result of reactor mode switch malfunctions at operating nuclear power plants (IE Information Notice 83-42), the NRC requested that the Franklin Research Center perform a failure evaluation of the GE SB-1 reactor mode switch.
The objectives of the program were to identify the failure mechanisms for the SB-1 switch and dermine if the failure mechanisms were the result of age-related conditions, defects of a particular switch, or design. In addition, the vendor proposed SB-9 replacement switch was evaluated for susceptibility to similar failure mechanisms.
The SB-1 reactor mode switch that malfunctioned at Quad Cities Unit 1 was evaluated along with new SB-1 and SB-9 switches.
The SB-1 reactor mode switch malfunctions were most probably the result of the switch being placed in a false detent position (an intermediate switch position just prior to the actual detent position) which allowed several of the contacts required to be closed to remain open. The false detent noted in the SB-1 switch operation is a result of the indexer mechanism design and not age-related conditions or a defect of a particular switch. The indexer mechanism for the SB-9 switch is of a different design and is not susceptible to a similar failure mechanism.

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