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ENGINEERING EVALUATION

MOTOR-OPERATED VALVE KEY FAILURES

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ABBREVIATIONS

AISI	American Iron and Steel Institute
ANO	Arkansas Nuclear One
CCW	component cooling water
ESW	essential service water
HPCS	high-pressure core spray
HPSI	high-pressure safety injection
IN	Information Notice
LER	Licensee Event Report
LPCI	low-pressure coolant injection
LPSI	low-pressure safety injection
MOV	motor-operated valve
NPRDS	Nuclear Plant Reliability Data System
RBCCW	reactor building closed cooling water
RCIC	reactor core isolation cooling
RHR	residual heat removal
SCSS	Sequence Coding and Search System
SDC	shutdown cooling

1 SUMMARY

Licensee Event Report (LER) 95-006 issued on April 18, 1995, for Palo Verde Unit 1 describes an event involving several occurrences of motor pinion key failures that were not detected during surveillance testing but were discovered in several separate maintenance activities. Some of the key failures had existed for some time. The affected valves were installed in the containment spray system and the low-pressure safety injection (LPSI) system. The key failures represent a potential common-mode failure mechanism for the safety-related systems.

The event prompted a search for similar motor-operated valve (MOV) key failures at other plants over the time period from January 1990 to September 1995. A total of 73 reports were identified which involved 46 plants. Among these, 11 reports involved anti-rotation keys, 22 reports involved valve operator-to-valve stem keys, and 40 reports involved Limitorque valve operator motor pinion gear keys. The information relating to these reports was obtained from the LERs in the Sequence Coding and Search System (SCSS) database file, component failure reports in the Nuclear Plant Reliability Data System (NPRDS), 10 CFR 50.55(e) reports, and 10 CFR 21 reports.

Many of these key failures were not detected during surveillance tests but were detected during valve demands, during valve operations, or during maintenance activities, and had existed for some time before they were discovered. There were a number of key failures which were discovered during maintenance activities even though the valves had been operated satisfactorily and passed all previous surveillance tests. Some of the key failures could have caused a common-cause failure that could render redundant trains of certain safety-related systems inoperable had they remained undetected.

Installation and design deficiencies were the two causes of anti-rotation key failures. Installation deficiencies were generally associated with inadequate staking and securing of setscrews during installation of the keys. It appeared that the installation instructions provided by the vendors were not always included in licensee maintenance procedures. This problem occurred at six plants with valves supplied by five different manufacturers.

The anti-rotation key failures due to design deficiencies involved keys installed in 2-inch and 6-inch Velan globe valves. The keys in the 2-inch valves were designed with sharp inside corners which produced high stress in the area, resulting in sudden brittle failure. The generic implications of the problem and the corrective actions were addressed by a Velan service bulletin and an NRC Information Notice (IN) in 1993. The keys in the 6-inch valves became undersized as a result of an increase in the depth of the keyway after a design change. The vendor notified the users of the problem and recommended corrective measures in 1994.

The dominant attributed causes of valve operator-to-valve stem key failures were key loosening associated with setscrew loosening or improper staking, and wear without early detection. Most failures were not discovered from normal valve surveillance.

There were three main causes of motor pinion key failure: (1) high impact loads, (2) improper material, and (3) inadequate installations.

The pinion key failures which were caused by high impact loads or improper material appear to involve American Iron and Steel Institute (AISI) type 1018 keys in high speed and high inertia configurations. Some of the concerns of AISI 1018 keys not being appropriate for certain actuator configurations have been previously identified in several INs. The INs indicated that replacement with harder AISI 4140 keys may be appropriate. In addition, failures of the AISI 1018 pinion keys also occurred with actuator configurations not identified in those INs.

The installation deficiencies were associated with inadequate staking, insufficient setscrew securing, or failure to stake the key following replacement of motor or pinion gears. Although licensees revised their MOV maintenance procedures to include restaking the pinion key or motor shaft as recommended by Limitorque Maintenance Update 89-1, many licensees did not investigate the potential problems of maintenance activities that were conducted before their procedure changes. Also, plant MOV maintenance procedures or program activities may not include the requirement to verify that the key is staked as required.

2 INTRODUCTION

LER 95-006 issued on April 18, 1995, from Palo Verde Unit 1 describes an event involving several occurrences of motor pinion key failures that were not detected in surveillance testing but discovered during plant maintenance services. The review of this event led to the initiation of a search for and evaluation of similar problems at other operating plants. The intent of this evaluation was to determine the prevalence of such problems and to identify the generic implications from these plant events.

The event at Palo Verde Unit 1 involved a number of key failures that were identified in several separate maintenance activities. Some of the key failures had existed for some time. The affected valves were installed in the containment spray system and the LPSI system. The key failures represent a potential common-mode failure mechanism for the safety-related systems.

On April 18, 1993, Unit 2 was defueled when it was identified by the licensee maintenance personnel, following completion of as-found static diagnostic testing, that the motor pinion gear key for the train A containment spray header isolation valve was sheared and the motor was free-wheeling without moving the valve stem. Investigation into the cause of the key failure revealed that the actuator with the failed key was replaced in December 1991 and that the failed pinion key was in service for only one operating cycle. Based on a reasonable estimate for the number of valve strokes required to perform as-left diagnostic testing, as-left and as-found local leak rate testing and periodic American Society of Mechanical Engineers Section XI testing, the actuator was assumed to have been cycled less than 50 times prior to failure. Comparison of the applied 8 ksi shear stress with the material strength of 21 ksi suggested that the failure was not simply a shear failure and may have been the result of an additional shock load acting on the motor pinion key. AISI 1018 material properties do not provide the key with sufficient margin to withstand the shock load associated with the high stem speed of the actuator. The key was replaced with a key made from AISI 4140 material.

Concurrently with the root cause investigation, the licensee was investigating Limitorque Maintenance Update 92-02 for potential impact on Units 1, 2, and 3. One of the Maintenance Update 92-02 recommendations was the replacement of AISI 1018 pinion key material with AISI 4140 material. This part of the investigation was completed on September 10, 1993. The investigation identified a total of 227 valves that were susceptible to this type of failure and the replacements were scheduled based on their susceptibility to failure. While performing the key replacements for 225 of the 227 valves, four additional pinion keys were found sheared during four different scheduled replacements. The pinion keys of Unit 1 train B containment spray header isolation valve, Unit 3 train B containment spray header isolation valve, Unit 3 train B LPSI header isolation valve, and Unit 3 train A containment isolation valve were found sheared on October 18, 1993, March 23, 1994, April 2, 1994, and April 13, 1994, respectively. The licensee's further evaluation determined that a common-mode failure mechanism had existed that could have caused two independent trains to become inoperable.

The AEOD search for MOV key failures included the LERs in the SCSS LER database file, component failure reports in the NPRDS, 10 CFR 50.55(e) reports, and 10 CFR 21 reports during the period from January 1990 to September 1995. This review identified a large number of reports involving key failure problems that also posed a potential safety problem to plant operations. A total of 73 reports were identified which involved 46 plants. Among these, 11 reports involved vaive anti-rotation keys, 22 reports involved valve operator-to-valve stem keys, and 40 reports involved Limitorque valve operator motor pinion gear keys, Based on the categories, a brief description of these reports involving key failures are listed in the Appendix, Table A, "Anti-Rotation Key Failures," Table B, "Valve Operator to Valve Stem Key Failures," and Table C, "Operator Motor Pinion Gear Key Failures." Each of these categories along with their causes, safety implications, corrective actions taken, and the need for follow-up actions are discussed in the following sections.

3 DISCUSSION

A total of 73 reports involving MOV key failures are covered in this study. Among these, 11 reports involved valve anti-rotation keys, 22 reports involved valve operator-to-valve stem keys, and 40 reports involved Limitorque valve operator motor pinion gear keys. Table 1, "Number of Motor-Operated Valve Key Failures — 1990 Through September 1995," lists the number of MOV key failures for these three types of keys. A review of these events shows that the MOV key failures can be attributed to installation and design deficiencies for anti-rotation keys, loosening or slipping off, wear or normal aging, excessive force or overtorque, and discrepancies in material or size for valve operator-to-stem keys, and high impact loads, improper materials, installation deficiency, wear or normal aging, and vibration for motor pinion gear keys. Table 2, "Motor-Operated Valve Key Failure Events," is a list of the causes along with the key types and the conditions under which the key failures occurred. The three conditions identified are: on demand operation, surveillance testing, and valve maintenance activity. Table 3, "Number of Motor-Operated Valve Key Failures in Terms of Major-Attributed Causes and Calendar Years," lists the number of failures for each cause category.

3.1 Anti-Rotation Key Failures

The anti-rotation device is a key that fits into the valve yoke bushing and the valve stem keyway. The key prevents the valve stem from rotating while at the same time allowing the stem to traverse up and down. When the key becomes broken or its securing device such as the setscrew becomes loose, the anti-rotation device could slide down the valve stem so that it no longer engages the valve stem key. This allows the motor-operator to rotate the stem freely with no linear movement of stem and disc, thus rendering the valve inoperable.

A total of 11 reports involving anti-rotation key failure are listed in Table A in the Appendix. The 11 reports came from 11 plants: Waterford Unit 3, Calvert Cliffs, Kewaunee, Crystal River Unit 3, Plant A* Unit 1, Plant B Unit 2, Plant C Unit 2, Plant D, Plant E Unit 2, Plant F Unit 3, and Plant G, Unit 1. The key failures in seven of these reports were discovered during surveillance stroke tests and most of them had existed for some time. Three occurred on demand or during system operations, and the remaining one failure was found during maintenance. Those key failures identified during surveillance and system operations were subsequently determined to have caused degraded conditions sufficient to prevent the affected systems from performing their proper safety functions in certain postulated or operating conditions.

Six reported events involved loose or missing keys that resulted from inadequate installations, while the other five events involved broken or degraded keys that were attributed to design and/or material problems.

The six reports that were related to inadequate installations were submitted from Crystal River Unit 3, Plant A Unit 1, Plant E Unit 2, Plant G Unit 1, Waterford Unit 3, and Plant F Unit 3. The valves involved were supplied by Walworth, Henry Pratt, ARM, NEMA, and Anchor/Darling. The inadequate installations were associated with inadequate staking and securing of setscrews during installation of anti-rotation keys.

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* Information obtained from the proprietary Nuclear Plant Reliability Data System (NPRDS) is not identified with an actual plant in order to issue this report as a nonproprietary documents.

Table 1 Number of Motor-Operated Valve Key Failures — 1990 Through September 1995

Types of Key	Calendar Year						
	1990	1991	1992	1993	1994	1995	Total
Antirotation Key	3	2		8	10		23
Valve Operator-Stem Key	2	6	6	2	6		22
Operator Motor Pinion Gear Key	11	22	6	14	1	6	60
Total	16	30	12	24	17	6	105

Table 2 Motor-Operated Valve Key Failure Events

Attributed Cause	Condition of Event		
Category	On Demand Operation	Surveillance Testing	Maintenance Activity
1. Antirotation Key			
a. Installation Deficiency	3	3	
b. Design Deficiency		4	1
2. Valve Operator-to-Stem Keys			
a. Loosening or Slipping Off	4	4	1
b. Wear or Normal Aging	5		
c. Excessive Force or Over-Torque	5		
d. Discrepancies in Material or Size	2	1	
3. Operator Motor Pinion Gear Key			
a. High Impact Loads	4	7	4
b. Improper Materials	2	1	5
c. Installation Deficiency	4	7	2
d. Wear or Normal Aging	1	1	
e. Vibration		2	
	30	30	13
Total Events	73		

Table 3 Number of Motor-Operated Valve Key Failures in Terms of Major Attributed Causes and Calendar Years

Cause Category	Calendar Year						
	1990	1991	1992	1993	1994	1995	TOTAL
1. Antirotation Key							
a. Installation Deficiency	3	1			2		6
b. Design Deficiency		1		8	8		17
2. Valve Operator-to-Stem Keys							
a. Loosening or Slipping Off	1	4	3		1		9
b. Wear or Normal Aging			2	1	2		5
c. Excessive Force or Over-Torque		1	1	1	2		5
d. Discrepancies in Material or Size	1	1			1		3
3. Operator Motor Pinion Gear Key							
a. High Impact Loads	7	9	2	5		5	28
b. Improper Materials	2	7	1	3			13
c. Installation Deficiency	1	4	3	6		1	15
d. Wear or Normal Aging	1	1					2
e. Vibration		1			1		2
Total	16	30	12	24	17	6	105

From the Plant E Unit 2 report, the key for the "B" emergency service water pump gate valve was found missing during a quarterly surveillance. The affected valve was supplied by ARM Company. Subsequent licensee investigation revealed that during the previous installation the key was not staked as required by the manufacturer's procedures. Improper securing of setscrews was reported from Crystal River Unit 3, Waterford Unit 3, and Plant F Unit 3. At Crystal River Unit 3, at 14 percent power, while the unit was ascending in power, the pressurizer spray valve (RCV-14) failed to close when operators attempted to close the valve with its control switch, resulting in decreasing reactor coolant system pressure. The valve failure was caused by a missing anti-rotation key. The valve was a Walworth globe valve. As a result of the failure analysis, the licensee revised the maintenance procedures to ensure proper installation of the anti-rotation key and its setscrew. Other applicable maintenance procedures also were revised as necessary to address the installation of anti-rotation devices as required by the specific valve design. At both Waterford Unit 3 and Plant F Unit 3, the anti-rotation keys had slipped off the valve stems. The affected valves were Anchor/Darling globe valves. The vendor manual recommendation for using Locktite when installing the setscrew on the anti-rotation device was omitted from the work instructions.

To preclude the possibility of future failures, Anchor Darling has provided recommendations on how to secure the setscrew on anti-rotation devices. The recommended corrective action to assure valve operability is to lock the setscrews in place. To accomplish this, the methods recommended are: a) stake the setscrew in place, or b) apply a nuclear grade thread locking compound to setscrew threads. The recommended compound is "Locktite" pipe sealant No. 580. To detect a loose setscrew on the anti-rotation device, the industry has provided two methods. One of the methods is to check the correlation between valve position change and valve downstream fluid parameters when positioning a valve from the control panel. The other method is to compare valve stroke times to those from previous tests. It was also recommended that once the problem has been identified, valve operation using the motor operator should be avoided until the anti-rotation device is properly reinstalled and the limit switch settings verified.

The five reports involving anti-rotation key failures which were attributed to design and/or material problems were submitted by Kewaunee, Calvert Cliffs Units 1 and 2, Plant D, Plant C, and Plant B Unit 2. The valves affected were supplied by Velan, Fisher, and Walworth.

One of the two redundant safety injection recirculation valves failed to close completely during an MOV dynamic test at Kewaunee. Investigation revealed that the anti-rotation device, an L-shaped key between the valve stem and the yoke bushing, had broken. The valve that failed was a 2-inch Velan globe valve. Subsequent licensee inspections of the eight similar valves found that five had broken anti-rotation keys. The investigation into the event could not determine when the keys failed. However, it was assumed that they failed soon after the valves were installed during original construction. The failure went undetected because the washer which is installed in the bushing between the key and the operator obscures the top view of the key even with the operator removed. The key in question failed in a brittle manner with fractures beginning on either side of the key at the sharp radius of the inside corner of the L-shaped key and propagating into the body of the key. Machining of the sharp inside corner of the L-shaped key may have contributed to the failure of the key by producing high stresses in the corner of the key. It is likely that the rotational action of the valve stem impacted on both sides of the key, exceeding the impact strength of the material at the sharp radius of the key. Velan, on April 5, 1993, issued Service Bulletin #SB-106 (Ref. 1). This bulletin recommends that the keys be inspected for possible wear which could result in failure and that consideration should also be given to replacing keys at the earliest convenient time. The replacement keys, which have been supplied by Velan for the past 2-1/2 years, are made of AISI 4140 alloy steel, as opposed to 440C stainless steel. IN 93-42, "Failure of Anti-Rotation Keys in Motor-Operated Valves Manufactured by Velan," June 9, 1993 (Ref. 2), was issued to address the generic implications of this event.

In the report from Calvert Cliffs, the anti-rotation key of a 6-inch Velan globe valve was observed to slip through its yoke (valve bushing) during a stroke test following replacement of the key. The key was examined and found to be undersized for its keyway. The same problem was noted for all eight 6-inch valves in Units 1 and 2. These 6-inch valves are safety-related LPSI loop isolation valves. The licensee investigation concluded that the keyway depth in all 6-inch valve stems is deeper than shown in the vendor's drawings. The vendor increased the depth of the keyway in a design change to the 6-inch valves in the early 1970s. However, the corresponding dimensional changes to the key were not incorporated in the key drawing. The licensee determined that this defect could have created a substantial safety hazard at the plant had the undersized keys gone unnoticed after installation and the valves placed back in service. On April 1, 1994, The licensee reported this defect to NRC as a 10 CFR Part 21 report. The vendor has stated that they are reviewing other globe valve stem and key drawings to ensure that this error does not apply to other valve sizes as well.

3.2 Valve Operator-to-Valve Stem Key Failures

Table B lists 22 reports describing valve operator-to-valve stem key failures at 19 plants. The key failures in 16 of the 22 reports were detected either on demand or during system operations and those in the other six reports were discovered during surveillance tests. Most of the affected valves were installed in safety-related systems such as residual heat removal (RHR), essential service water (ESW), component cooling water (CCW), low-pressure coolant injection (LPCI), reactor core isolation cooling (RCIC), and the containment isolation. The valves affected were manufactured by various suppliers: Fisher, Bettis, Rotork, Henry Pratt, Allis Chalmers, NEMA, Continental, Posi-Seal International, and Crane. The majority of the key failure events were reported in NPRDS as individual component failures. However, many of these key failures which were not detected during surveillance and had existed for some time could have caused a potential loss of train or system of the affected systems.

Reviews of these reports indicate that the causes of key failures are: (1) loosening or slipping off (9 events), (2) wear or normal aging (5 events), (3) excessive force or over torque (5 events), and (4) discrepancies in material or size (3 events).

Nine reports involving keys that were loose or had slipped off were identified by Plant V Unit 2, Plant U Unit 1, Plant R Unit 2, Plant Q Unit 2, Plant P Unit 3, Plant K Unit 1, and Plant O Unit 1. The causes of loose keys were setscrew loosening and/or improper staking. Plant K Unit 1 experienced key loosening events in 1991 and 1994. In the 1991 event, the "A" feedwater control valve could not be operated manually due to the handwheel rotating freely. There were no adverse effects on the plant or system since the system was not in operation. In the 1994 event, the reactor building closed cooling water outlet valve, V-5-0106, failed to open on demand. The shutdown cooling (SDC) system was degraded, reducing the system heat removal capability. The setscrew for the valve stem key had loosened, allowing the key to fall out of its keyway. This disengaged the operator from the valve stem and prevented the valve from operating. The licensee corrective action was to revise the maintenance procedure to provide additional instructions to locktite setscrews and to stake keyways. Plant O Unit 1 also experienced two key failures in 1992 and 1991. Both events involved the condenser to feedwater pump suction valve. In the 1992 event, a shift operator found that the valve did not close either manually or by motor operator. The key which coupled the valve to the valve operator had fallen out. The key did not appear to have been mechanically staked into the keyway. Field orientation of the key was vertical, which would have contributed to its falling out during operation. In the 1991 event, while operations was attempting to operate the valve, the indicating light showed valve repositioning when the valve position was not changing. The stem nut key was found missing, resulting in the operator not driving the valve stem.

This problem was addressed by the industry in the 1980s. Particularly, in 1988, the industry issued a generic communication (Ref. 3) concerning safety-related valve failures due to loosening or missing keys at several operating plants. Some keys in those plants had disengaged and thus disabled the affected MOVS. Those failures were attributed to loose setscrews, worn keys, design tolerance variation, or improper assembly. The industry provided several preventative and corrective measures:

- Stem keys that are not fully captured by a positive locking mechanism should be secured or inspected upon installation and periodically afterward for loosening/disengagement. Setscrews have not always proven a reliable means of securing these keys. Appendix E of EPRI Report NP-5479, "Application Guidelines for Check Valves in Nuclear Power Plants," January 1988, provides additional guidance on locking devices.

- Most keys are fabricated to be 0.001 to 0.003 inches smaller than the keyways for a snug fit that minimizes impact load during operation. Loose shaft keys are subject to high wear rates that can lead to vibration, misalignment, or disengagement. Radially loose or worn keys should be replaced with properly fitting keys.

- A post-installation inspection should be conducted to assure that valve keys have been properly installed. The inspection should be conducted by qualified personnel.

- When installing or replacing material for stem keys, the proper key material should be verified by piece description, part number, or material testing.

Five key failure reports identified were attributed to either wear or normal aging. These reports were from Plant H Unit 1, Plant M Unit 1, Plant N Units 1 and 2, and Plant I Unit 1. In four of the five reports, the keys were found to be sheared after the associated valves failed to operate on demand. In the other report (Plant M Unit 1), the key of an RHR flow control valve was found to be worn following a detection of leakage from the valve. For the report from Plant H, with the plant at 98 percent power, the CCW to RHR heat exchanger bypass valve remained closed when the operator tried to open it. The valve had to be operated via its local handwheel instead of via its control circuitry. The Woodruff key had stripped, allowing the actuator shaft to slip on the valve stem. Suspected root cause was wear, as the key was installed in 1983. The report from Plant I Unit 1 describes an event while the unit was operating at full power. The containment pressure-vacuum relief control valve failed to open when a control room operator attempted to open it. The valve stem key was found sheared. Both events which occurred at Plant N Units 1 and 2 involved the RHR heat exchanger outlet control valves. The valves failed to respond on demand during refueling outages with the reactor being cooled by the RHR systems.

The five reports of key failures that were attributable to excessive force or overtorque were submitted by Crystal River Unit 3 (LER 93-001), Plant J Unit 2 (10/03/94, 10/23/94), Plant J Unit 1 (9/02/92), and Plant S Unit 2 (10/17/91). In three of the five reports, the keys were found to be sheared after the associated valves failed to open on demand. In the other two reports (Crystal River Unit 3, Plant J Unit 1 (9/02/92)), the keys in the valve stems broke when the operators were attempting to close the valves during operations. For the report from Crystal River Unit 3, while the unit was in Mode 4 and cooling down for a planned maintenance outage, following switching from steam generator cooling to decay heat removal system cooling, the decay heat removal heat exchanger outlet valve inadvertently opened, causing additional reactor coolant system cooldown. An attempt was made to close the valve manually. However, after several minutes, the valve started to drift open due to damage to the stem key connecting the valve to its actuator. The licensee investigation attributed the key damage to overstress resulting from improper manual operation. Plant J Unit 2 experienced two repeated key failures in 1994. Both events involved the same condensate isolation valve and the key failures occurred under the same condition. With the unit at full power, the valve failed to open when operations attempted to open it. Subsequent investigation revealed that the key had sheared. The key failures were attributed to overtorque. The event of key failure at Plant J Unit 1 occurred on September 2, 1992. The main intake valve from the steam packing exhausting outlet line to the demineralizer failed to close on demand. The key in the valve stem broke during an attempt to close the valve. In the report of Plant S Unit 2, the condensate demineralizer inlet flow control valve would not open on demand. The key between the gear drive and the valve shaft was found sheared. The cause was presumed to be excessive force.

The three events of key failures that were due to improper material or size occurred at three plants: Plant L Unit 3 (5/17/94), Plant T Unit 2 (10/09/91), and Diablo Canyon Unit 2 (LER 90-008). The three affected valves were Fisher valves with Woodruff keys. The valves were for containment isolation, RHR bypass, and RHR heat exchanger outlet control. Two of the key failures occurred during operations while the other one occurred during a local leak rate test.

3.3 Limitorque Motor Pinion Gear Key Failures

The motor pinion gear is located on the shaft of the electric motor and transmits motor torque to the worm shaft gear. The motor pinion gear is connected to the motor shaft by means of a key which transfers rotary force from the motor shaft to the gear. A set screw is used to prevent axial movement of the motor pinion gear on the motor shaft. Twenty-seven plants have experienced failure of pinion keys that resulted in the disabling of associated safety-related valves. Table 3 describes 40 events of pinion key failures that occurred in these 27 plants. Among these, 9 events were reported in the LER system, 25 events in the NPRDS, and 6 events reported as 10 CFR 21 and 50.55(e) reports. Most of these key failures were discovered during valve surveillances. Some of them were detected on demand, during operations, or during maintenance activities. However, a significant number of the key failures had existed for some time before they were discovered.

Reviews of these reports indicate that there were three main causes of key failures: (1) high impact load (15 events), (2) improper material (8 events), and (3) inadequate installation (13 events).

The key failures which were caused by high impact loads or improper material appear to involve AISI type 1018 keys in high speed and high inertia configurations. Limitorque engineering staff evaluated the use of AISI 1018 material in larger actuators (SMB-3, 4, and 5) and determined that the material was suitable for normal service. However, AISI 4140 steel motor pinion keys increased the impact resistance and provided additional margin in those instances where impact and shock loadings are possible in frequent reversal or motor stall situations. In this respect, several INs have been issued addressing failures of keys in certain actuators with larger motors. IN 81-08, "Repetitive Failures of Limitorque Operator SMB-4 Motor-to-Shaft Key," March 20, 1981 (Ref. 4), identified key failures on SMB-3, 4 and 5 actuators with 150 ft-lb or greater motors resulting from use of improper material and indicated that replacement with harder AISI 4140 keys may be appropriate. IN 88-84, "Defective Motor Shaft Keys in Limitorque Motor Actuators," October 20, 1988 (Ref. 5), identified a concern with SMB-000 through 2 actuators with 25 ft-lb motors or greater having a nonconformance key material installed. IN 90-37, "Sheared Pinion Gear-to-Shaft Keys in Limitorque Motor Actuators," May 24, 1990 (Ref. 6), identified failures of AISI 1018 keys in SMB-0 actuators with 25 ft-lb motors on high speed (closing within 10 seconds) butterfly valves. IN 94-10, "Failure of Motor-Operated Valve Electric Power Train Due to Sheared or Dislodged Motor Pinion Gear Key," February 4, 1994 (Ref. 7), discussed previous concerns of sheared pinion keys and keys not being staked upon reinstallation.

The 15 reports that were related to high impact loads were identified by Palo Verde (LER 95-006, 04/18/95), Clinton (10/8/93), Plant I Unit 1 (07/26/92), Plant I Unit 1 (4/19/90), Plant I Unit 2 (11/23/92), Plant AC Unit 2 (11/21/91), Diablo Canyon Units 1 and 2 (LER 91-021, 09/16/91), Plant O Unit 1 (11/01/91), Plant J Unit 1 (10/13/91), Plant AF (08/14/90), Watts Bar Units 1 and 2, while the reports involving pinion key failure that resulted from improper material were submitted from FitzPatrick (LER 92-028, 05/21/92), Plant AA (03/16/92) and (12/18/91), Plant P Unit 1 (09/4/91), Plant X Unit 3 (02/08/91), Cooper (LER 90-006, 02/26/90), Dresden Unit 2 (LER 90-002, 01/16/90) and Salem Unit 1 (LER 90-016, 04/19/90). Reviews of these reports indicate that: (1) the key failures were not limited to the keys installed in the actuators identified in INs, (2) pinion key failure continued to occur on the identified actuators despite the INs, (3) the plant MOV surveillance or maintenance programs did not lead to the early detection of key degradation, and thus, a significant number of key failures had existed for some time prior to their discoveries, and (4) there was lack of systematic replacement of all AISI 1018 pinion keys.

The report from Palo Verde (LER 95-006) described failures of five pinion keys. Four of them were installed in the containment spray header isolation valves with SB-0 actuators, and the other one in a LPSI header isolation valve with an SB-3 actuator. On April 18, 1993, the pinion key of the train A containment spray header isolation valve of Unit 2 was found sheared following completion of as-found static diagnostic testing. The failed key was in service for only one operating cycle, and the actuator was assumed to have been cycled less than 50 times prior to failure. The other four keys were found sheared in four separate scheduled replacements in 1993 and 1994. The keys had been sheared for some time. The scheduled replacements of AISI 1018 keys with AISI 4140 keys were based on the licensee investigation in response to Limitorque Maintenance Update 92-02 which provided a summary of pinion key concerns and described a decision to only supply pinion keys made of AISI 4140 material. The actuators of model SB-0 were determined not to be a high priority for key replacement based on Update 92-02.

During the 1990 refueling outage at Cooper, while performing maintenance on an RHR train B throttle valve (M034B), a sheared pinion key was discovered in the actuator of an SMB-4. The valve had been operating satisfactorily and passed all tests. Spare keys from the same purchase order were immediately tested and determined to be of an incorrect material. Upon inspection of the corresponding train A valve (M034A), its pinion key was found to be deformed. Subsequent investigation determined an additional eight valves had suspect keys. In conjunction with IN 81-08, in June 1981, Limitorque issued a letter recommending the installation of AISI 4140 pinion keys in SMB-3, 4, and 5 actuators. The letter noted that actuators had been shipped with keys made from AISI 1018 and 4140 until May 1981. However, it was not possible for Cooper to determine from their records which key was in any given actuator.

The event reported in LER 92-028 at FitzPatrick occurred on May 21, 1992. In response to IN 81-08, in September 1981, the licensee identified six valves in the affected categories (SMB-3, 4, and 5) where the pinion key for the actuators should be made from AISI 4140 material, but the licensee did not replace the keys. During the 1992 refueling outage, three of the six keys were found to be sheared or nearly sheared during a replacement activity. The affected valves were RHR/LPCI A and B system isolation valves and the RHR heat exchanger B outlet isolation valve. The licensee attributed the three pinion key failures to: (1) the difference between the AISI 4140 keys and the AISI 1018 keys cannot be discerned by visual inspection because there are no stamps or physical markings to differentiate the new from the old material, (2) MOV overhaul and inspection program activities did not include the requirement to remove and inspect the pinion key for wear or cracking, and (3) the potential effect of common-cause or common-mode failures to make redundant trains inoperable was not addressed by the initial reviewers of IN 81-08. Subsequent licensee review of industry data on key failures indicated that between 1984 and 1991, 150 key failures were reported. Forty of the failures could be identified with pinion keys.

Two other events of key failure at FitzPatrick occurred on March 16, 1992, and December 18, 1991. In both events, the keys were found broken while performing preventive maintenance during plant shutdown. One affected valve in the first event was the RHR B loop heat exchanger outlet control valve with actuator SMB-0-25. The events involved both RHR A and B loop outboard injection isolation valves with actuators of SMB-4T-250. The key failures were attributed to the weakness of AISI 1018 key material. The problem with the SMB-4T-250 actuator had been identified in IN 81-08.

The October 8, 1993 event of key failure at Clinton was reported as a 10 CFR 21 report. The licensee discovered a broken pinion key in the actuator of high-pressure core spray (HPCS) system injection and outboard containment isolation valve 1E22-F004 while installing a modification to change the actuator gear ratio and replace the valve stem and disc. The failure existed undetected until the valve was disassembled to install the modification. The cause was excessive torque during valve backseating and MOVATS testing. The key failure did not render the valve incapable of performing its safety function because the key had sheared in a manner which mechanically bound the pinion gear to the motor shaft. The broken AISI 1018 key was replaced with a key made from AISI 4140 material. The actuator was Limitorque model SB-3 with a motor of 40 ft-lb torque rating and 3600 rpm speed. This motor was rated lower than the threshold for replacement discussed in IN 81-08 and recommended by Limitorque Maintenance Update 92-2 and is a different actuator type.

In the report of Salem Unit 1 (LER 90-016), the AISI 1018 pinion keys in the actuators of six service water valves (three per unit) were found sheared or severely deformed. These keys had failed under conditions of normal operation, and one of them showed significant deformation after only 15 valve cycles. The valves were 30-inch butterfly valves using SMB-0 actuators with 25 ft-lb high speed motors (3600 rpm), and the valves are required to close within 10 seconds. The cause was high impact loading during fast closures. The licensee hardness tests confirmed that the material was within the ASTM-1018 range that was specified by Limitorque. The keys were replaced with the harder AISI 4140 keys.

The event at Diablo Canyon Units 1 and 2 occurred on September 16, 1991 and was reported in LER 91-021. The actuators (SB-3-80) of two cold leg accumulator injection valves and two RHR heat exchanger outlet valves would not engage electrically during postmaintenance testing. The keys were sheared due to improper key material. Short stroking due to electrical engagement of the actuators also contributed to the failures. The keys were supplied with the actuators by the vendor. The key material was considered outdated but still acceptable according to the vendor's design. The keys were replaced with stronger AISI 4140 keys.

The models of actuators in the remaining reports of pinion key failures which resulted from impact loading or improper material were Limitorque SB-2, 0, SMB-00,and SMB-000. Four events involved model SB-0 and one event involved each of the other models. The pinion keys in the actuators of these models were not identified as susceptible to failure by the INs.

At Watts Bar Units 1 and 2, the pinion key of the RHR pump suction to containment sump isolation valve 1-FCV-63-72-A was found deformed and located approximately one-third out of its slot (Ref. 8). The motor shaft was also found cracked in two places. The redundant train valve actuator (1-FCV-63-73-B) was then examined, which revealed a similarly deformed key, still in complete engagement with no motor shaft cracking. The failed actuators were model SB-3, equipped with 100 ft-lb motors. Subsequently, TVA discovered additional examples of deformed key/keyway slots on a size 2, type SBD actuator and a size 0, type SB actuator. The damaged valves identified had Limitorque actuators with smaller motors and thus fell outside the torque criteria identified in the 1981 Limitorque notifications and were not subject to that required corrective action. The described conditions are indicative of rapid impact overloading (i.e., the motor stops/starts too quickly). The root cause analysis indicates that insufficient consideration was given to the overall working mechanisms of the actuator/valve combination. While manufacturing guidelines are given to preclude using nonconservative gear ratios, motors, or valve stem leads, no guidelines are established to ensure that nonconservative combinations of all three are not used.

Following the failures of pinion keys in the RHR pump suction to containment sump isolation valves, the licensee of Watts Bar conducted an extensive deficiency investigation (Refs. 9 and 10) that indicates that increasing the strength of the key/shaft has not reduced the deformation to an acceptable limit.

- A motor shaft and key, both of type 4140 material, were installed in the RHR pump suction valve actuator (100 ft-lbs, SB-3) to replace the defective key and shaft which were made from type 1018 and type 1144 steel, respectively. The valve was cycled approximately 15 times during MOVATS testing. The shaft keyway was significantly deformed (0.020 in of taper), and the key had slight indentions along both sides. The measured maximum thrust during the test was 50,000 lbs. This is much less than the maximum design thrust of 140,000 lbs for the actuator.

- Inspection of 14 actuators revealed two cracked shafts, minor keyway deformation, and minor to severe key deformation for type 1018 keys installed in type 1144 shafts. For type 4140 keys installed in type 1144 shafts, the relatively harder keys suffered less damage than the type 1018 keys. However, the shaft keyways were more severely deformed in the actuators with type 4140 keys than in the actuators with type 1018 keys.

Failures of AISI type 1018 keys have been attributed to insufficient material strength for certain Limitorque actuators. Limitorque had previously notified the industry in 1981 that AISI 4140 keys are required in SMB-3, 4, and 5 actuators with 150 ft-lb or larger motors. Operating experience indicates that key failure has occurred at torque levels below the published Limitorque actuator torque ratings.

A Cooper report describes an event in which a sheared pinion key was found during normal maintenance but the valve had been operating satisfactorily and passed all previous surveillance tests. The key had sheared in a manner which bound the pinion gear to the motor shaft. Hence, the valve remained functional.

The 13 reports of key failures that were caused by inadequate installation were from 11 plants: Waterford Unit 3 (LER 93-005, 10/07/93)), Cooper (LER 93-031, 08/30/93), Plant W Unit 2 (06/09/93), Plant C Unit 1 (08/24/93) and (06/15/93), Plant M Unit 1 (09/16/92), Plant Y Unit 1 (03/28/92), Plant Z Unit 1 (09/09/92), Plant AD Unit 2 (08/05/91), Plant F Unit 2 (11/07/91) and (06/13/91), Plant AB Unit 1 (11/22/91), and Arkansas Unit 2 (LER 90-020, 09/28/90). The key failures in five of these reports were identified during valve demand operations and those in the other eight reports were discovered during valve surveillance and maintenance activities. The inadequate installations were associated with inadequate key staking, insufficient setscrew securing, or failure to stake the key following replacement of motor or pinion gear. Most of these were attributed to inadequate maintenance procedures or guidance.

The event at Cooper occurred on August 30, 1993, and was reported in LER 93-031. The high-pressure safety injection (HPSI) pump discharge valve failed to open during the performance of a surveillance, causing the valve to be declared inoperable. Subsequent investigation revealed that the SB-3 Limitorque operator motor pinion gear key had dislodged from its keyway, allowing the motor shaft to spin without transferring torque to the motor pinion gear. The cause was attributed to the failure to stake the motor shaft keyway following a motor replacement in 1990. The Limitorque Update 89-1 indicates that restaking of the motor shaft is required when the motor or pinion key is replaced. Cooper revised its maintenance procedure to include the requirement in 1991. However, the licensee did not review the potential consequences of maintenance activities that had been performed before the procedure was revised. Staking of the motor shaft had not been a requirement during that time. The licensee corrective action was to conduct a review of operational requirements and MOV maintenance history to determine the MOVs that need additional investigations for susceptibility to the problem.

A similar condition of key dislodging also occurred at Waterford in October 1993. With the unit at full power, it was discovered that the pinion keys in both MOVs for isolating the SDC system suction line had slipped out of their keyways. The pinion keys were not staked following the motor replacements in 1992. This condition was the result of an inadequate procedure in that the maintenance procedure did not contain the information provided by the Limitorque Maintenance Update 89-1. Since the condition affected isolation valves in both trains of the SDC system, the potential existed for a common-mode/common-cause failure of the safety system for decay heat removal. The licensee revised the plant maintenance procedures to require that the motor pinion gear key be staked to the shaft and to ensure that MOV inspections verify that the key is staked as required.

On September 9, 1992, RHR isolation valve 34A would not close on electrical signal demand at Plant Z Unit 1. Subsequent licensee investigation found that the pinion key had slipped down the motor shaft. The key was not adequately secured during previous maintenance. Consequently, the licensee staked the key to the motor shaft to prevent movement.

Two reports from Plant F Unit 2 involved the 2D high-pressure service water heat exchanger outlet valve in two separate events in 1991. In the first event, the valve would not close when a signal was applied while the plant was at full power. The pinion key was found missing. Subsequently, a new key was installed to restore the valve operability. In the second event, with the plant at power, the valve operator continued to run for four hours after the valve was stroked closed. Similar to the first event, the pinion key was also missing allowing the pinion gear to rotate on the motor shaft. The licensee could not determine the cause of the missing key. In the other remaining reports, the loose or missing keys were attributed to improperly installed or missing setscrews.

4 FINDINGS AND CONCLUSIONS

Based on the preceding discussion and related follow-up activities conducted for this study, the following findings and conclusions are provided.

A total of 73 reports involving MOV key failures associated with safety-related systems have been identified from 46 operating plants. Among the 73 reports, 11 involved valve anti-rotation keys, 22 involved valve operator-to-valve stem keys, and 40 involved motor pinion keys of Limitorque valve actuators. Many of these key failures were not detected during surveillance tests but were detected on demand, during valve operations, or during maintenance activities and had existed for some time before they were discovered. There were a number of key failures which were discovered during maintenance of valves that had been operated satisfactorily and passed all previous surveillance tests. These were significant deficiencies which could have caused a common-cause failure that could render redundant trains of certain safety-related systems inoperable had these remained undetected.

4.1 Anti-Rotation Key Failures

a. A total of 11 events involved anti-rotation key failures. The key failures in seven of these events were discovered during surveillance testing and most of them had existed for some time. Three failures occurred on demand or during system operations, and the remaining one during a maintenance activity.

b. Installation and design deficiencies were the two causes of anti-rotation key failures. Six events involving loose or missing keys resulted from inadequate installation, and the other five events involving broken or degraded keys were attributed to design deficiencies and/or material problems.

c. Installation deficiencies were generally associated with inadequate staking and securing of setscrews during installation of anti-rotation keys. It appeared that the installation instructions provided by the vendors were not always included in licensee maintenance procedures. Thus, the maintenance personnel were not aware that the keys or their setscrews were not staked or secured as required by the vendor procedures when they performed installations. The problem occurred at six plants and involved valves from five different manufacturers.

d. Two events involved a design problem with keys installed in 2-inch Velan globe valves. The L shaped key failed in a brittle manner with fractures beginning on either side of the key at the sharp radius of the inside corners and propagating into the body of the key. Velan, on April 5, 1993, issued Service Bulletin #SB-106 recommending inspection of the keys for wear and replacement. IN 93-42 (Ref. 2) was issued to address the generic implications of the problem.

e. Undersized keys were found in all eight Velan 6-inch globe valves at Calvert Cliffs. The keyway depth in these valve stems was deeper than shown in the vendor's drawings. The vendor increased the depth of the key slot in a design change to the 6-inch globe valve in the late 1970s. However, the corresponding dimensional changes to the key were not incorporated into the key drawing. The licensee issued a 10 CFR 21 notification to NRC on April 1, 1994. Discussions with the licensee indicated that the valve vendor notified the users of Velan 6-inch globe valves of the undersized key problem in April 1994 and requested the users to verify a proper fit for key and key slot when installing a new key for 6-inch globe valves.

4.2 Valve Operator-to-Valve Stem Key Failures

a. Twenty-two events of valve operator-to-valve stem key failures have been reported from 19 plants. The key failures in 16 of these events were detected either on demand or during system operations and those in the other six events were discovered during surveillance. Many of these key failures had existed for some time before they were detected. The valves affected were manufactured by ten different suppliers. This indicates that the failures of valve operator-to-valve stem keys were not unique to the valves of one particular supplier but occur among valves from several manufacturers.

b. The causes of key failures are: (1) loosening or slipping off (9 events), (2) wear or normal aging (5 events), (3) excessive force or overtorque (5 events), and discrepancies in material or size (3 events).

c. The causes of loose or slipping off keys were setscrew loosening and/or improper staking. This problem was addressed by the industry in the 1980s. Particularly, in 1988, the industry issued a generic communication (Ref. 3) concerning safety-related valve failures due to loosening or missing keys at several operating plants. The communication also provided several preventative and corrective measures.

d. Most of the key failures identified were not discovered during normal valve surveillance testing, and many of those key failures which were detected during surveillance testing had existed for some time before they were discovered.

4.3 Limitorque Motor Pinion Gear Key Failures

a. A total of 40 reports involving motor pinion key failures have been identified from 27 operating plants. Some of the key failures could have adversely affected MOV operability. There were three main causes of the key failures: (1) high impact loads (15 reports), (2) improper material (8 reports), and (3) inadequate installations (13 reports).

b. The following NRC and industry notices have been issued over the past several years regarding motor pinion gear key failures:

- IN 81-08 (Ref. 4): Repetitive failures of AISI 1018 keys in SMB-4 actuators with 150 ft-lb or greater motors. Limitorque recommended replacement with 4140 keys.

- Limitorque Letter (June 1981): AISI 4140 keys are required for SMB-3, 4, and 5 actuators with 150 ft-lb or greater motors.

- IN 88-84 (Ref 5): Commercial grade keys used in some models of actuators prior to September 1983. Limitorque indicated a lack of material control for keys prior to this date.

- Limitorque Maintenance Update 89-1 provided recommendations for securing the pinion key when replacing the motor or pinion gear.

- IN 90-37 (Ref. 6): Failures of AISI 1018 keys in SMB-O actuators with 25 ft-lb motors on high speed (closing within 10 seconds) butterfly valves. The failed keys were replaced with keys made from a harder material, such as AISI 4140 steel.

- Limitorque Maintenance Update 92-2 indicated that the material for motor pinion keys for the SMB-000 through 2 actuators had been changed from AISI 1018 to AISI 4140 steel. The purpose of the material change was primarily due to customer request for higher strength material.

- IN 94-10 (Ref. 7): Restating the recommendations provided in both Limitorque Maintenance Updates 89-1 and 92-2 following three loose key events at three operating plants in 1993.

c. The key failures which were caused by high impact loads or improper material appear to involve AISI type 1018 keys in high speed and high inertia configurations. Apparently, the AISI 1018 motor pinion keys are not appropriate for certain actuator configurations based on the NRC and industry notices summarized in Item b.

d. Some of the concerns with AISI type 1018 motor pinion keys not being appropriate for certain actuator configurations have been previously identified in several INs (Refs. 4, 5, 6, and 7). However, these problems continue to exist. For example, IN 81-08 identified AISI 1018 key failures on SMB-3, 4 and 5 actuators with 150 ft-lb or greater motors resulting from use of improper material and indicated that replacement with harder AISI 4140 keys may be appropriate. However, 1990, 1991, and 1992 LERs from Fitzpatrick, Diablo Canyon Units 1 and 2, and Cooper reported AISI 1018 key failures on the actuators identified in the 1981 IN. Although, in this respect, Limitorque issued a letter in June 1981 recommending the installation of AISI 4140 pinion keys in SMB-3, 4, and 5 actuators and informing licensees that actuators had been shipped with keys made from AISI 1018 and 4140 until May 1981, the licensees of these plants could not differentiate the materials for keys installed in any given actuator from their records. Therefore, the susceptible keys had not been replaced until they were found sheared. Moreover, following the occurrence of three pinion key failures in 1992, the licensee for FitzPatrick reviewed industry data on key failures and found that between 1984 and 1991, 150 MOV key failures were reported. Forty of these failures were identified with motor pinion keys.

e. In 1992, Limitorque issued Maintenance Update 92-2 which stated that the material for motor pinion keys supplied with SMB-000 through -2 actuators had recently been changed from AISI 1018 to AISI 4140 because of customer requests for higher strength material. However, Limitorque engineering could not justify a reason for changing the key material.

f. Failures of the AISI 1018 motor pinion keys due to impact loading or improper material also occurred in smaller actuators (SMB-000 through 2) and actuators with smaller motors falling outside the torque criteria identified in both the 1981 Limitorque notifications and Limitorque Maintenance Update 92-2.

g. The identification of AISI 1018 key failures in some plants did not lead to checks for similar configurations in other valves to prevent other failures. This could be attributed to inadequate information available for the industry to develop criteria to allow identification of the actuator configurations susceptible to the AISI 1018 key failures.

h. Although some licensees have identified valves that were in affected categories susceptible to the AISI 1018 key failures, replacement schedules either were not established or were inappropriate. Thus, some of the keys were not replaced until sheared. Limitorque had previously indicated that only the actuators of size SMB-3 or 4 were susceptible to AISI 1018 key failures. However, specific information with respect to the torque and number of cycles that caused failure were not provided. Without such information, the key replacements for valves identified to be susceptible to the AISI 1018 key failures could not be properly prioritized and appropriate schedules established.

i. The replacement of a relatively soft key material with a harder material inherently increases the potential for damage or failure in the mated keyway. Subsequent to the failures of pinion keys in the RHR pump suction isolation valves, the licensee of Watts Bar conducted an extensive deficiency investigation (Refs. 9 and 10) that indicates that the replacement of Type 1018 keys with harder Type 4140 key material may lead to increased keyway damage. Consequently, the possibility of a failure in the motor pinion-to-shaft connection may not be eliminated by the key replacement.

j. Deformation of the keyway allows increased clearance between the key and the keyway. The possible loose fit of a key or a slight key rotation presents a complex stress problem that is not completely understood or analyzed and may produce a severe and complex stress concentration on the sides and edges of the key as well as the edges of the keyway. This could cause the shaft to fracture at the sharp keyway corner.

k. Installation deficiencies were associated with inadequate key staking, insufficient setscrew securing, or failure to stake the key following replacement of motors or pinion gears. Most of these were attributed to inadequate maintenance procedures or guidance.

l. In 1989, Limitorque issued Maintenance Update 89-1 which made recommendations for securing the motor pinion key when replacing the motor or the pinion gear. The Update gave a procedure for staking the shaft at the open end of the keyway to mechanically lock the key in place. Although licensees revised their MOV maintenance procedures to include restaking the pinion key or motor shaft as recommended by the Update, many of the licensees did not investigate the potential consequences of maintenance activities that had been conducted before their procedure changes. Also, plant MOV maintenance procedures or program activities may not include the requirement to verify whether the key is staked as required.

5 REFERENCES

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2. U.S. Nuclear Regulatory Commission, Information Notice 93-42, "Failure of Anti-Rotation Keys in Motor-Operated Valves Manufactured by Velan," June 9, 1993.

3. Industry Communication on Loose Shaft Keys Disabling Motor-Operated Valves and Other Components, April 6, 1988.

4. U.S. Nuclear Regulatory Commission, Information Notice 81-08, "Repetitive Failures of Limitorque Operator SMB-4 Motor-to-Shaft Key," March 20, 1981.

5. U.S. Nuclear Regulatory Commission, Information Notice 88-84, "Defective Motor Shaft Keys in Limitorque Motor Actuators," October 20, 1988.

6. U.S. Nuclear Regulatory Commission, Information Notice 90-37, "Sheared Pinion Gear-to-Shaft Keys in Limitorque Motor Actuators," May 24, 1990.

7. U.S. Nuclear Regulatory Commission, Information Notice 94-10, "Failure of Motor-Operated Valve Electric Power Train Due to Sheared or Dislodged Motor Pinion Gear Key," February 4, 1994.

8. Watts Bar Nuclear Plant Units 1 and 2, WBRD-50-390/86-64 and WBRD-50-391/87-23 (Final Report), "Failed Motor Pinion Keys and Motor Shaft in Limitorque Operators," April 8, 1993.

9. Watts Bar Nuclear Plant Units 1 and 2, WBRD-50-390/86-64 and WBRD-50-391/87-23 (Third Interim Report), "Failed Motor Pinion Keys and Motor Shaft in Limitorque Operators," November 2, 1987.

10. Watts Bar Nuclear Plant Units 1 and 2, WBRD-50-390/86-64 and WBRD-50-391/87-23 (Fifth Interim Report), "Failed Motor Pinion Keys and Motor Shaft in Limitorque Operations," January 31, 1991.

APPENDIX

Table A Anti-Rotation Key Failures

Plant LER No. Event Date	Description of Event	Causes	Corrective Actions
Waterford 3 94-014 06/10/94	With the plant in operation, it was discovered during preparation for VOTES testing on the HPSI flow control valve, that the anti-rotation device had slipped off the valve stem. The valve was placed out of service and a limiting condition for operation was entered. The last stroke performance testing done on the valve had been performance with satisfactory results, but the potential for valve failure in this condition had high probability. The valve is a 3-inch Anchor/ Darling globe valve.	Inadequate work instruction that was followed as written. The vendor manual recommendation for using Locktite when installing the setscrew on the anti-rotation device was omitted from the work instruction. The setscrew had backed out, allowing the anti-rotation device to slip off.	Reinstalled the setscrew with locktite.
Plant A* 1 04/21/94	During startup surveillance activities, an operator received an alarm that the accumulator tank 1A discharge valve was not indicating full open when opened. The valve provides safety injection flow from the accumulator. This failure rendered the train inoperable.	The shaft anti-rotation device was loose and the shaft key missing. The root cause was a design application inadequacy where the bolting strength was not appropriate for this design.	The shaft key, bolts and anti-rotation device were replaced.
Calvert Cliffs 1 & 2 10 CFR 21 04/01/94	With Unit 1 in refueling outage, after replacement of an anti-rotation key in one of four 6-inch Velan motor-operated globe valves, the valve was stroked to verify proper operation. During the stroke, the key slipped out through its yoke and the valve stem then rotated freely inside the yoke, preventing the valve from moving. The key was examined and found to be undersized for its keyway. The same problem also existed for Velan 6-inch globe valves in Units 1 and 2.	The keyway depth in all of the 6-inch valve stems is deeper than shown in the vendor's drawings. The vendor increased the depth of the key slot in a design change to the 6-inch valve in the end of 1970s. However, for some reason, the corresponding dimensional changes to the key were not incorporated in the key drawing.	1. New keys with proper dimensions were installed and performed satisfactorily. 2. The vendor has stated that they are reviewing other globe valve stem and key drawings to ensure that this error does not apply to other valve sizes as well.

* Information obtained from the proprietary Nuclear Plant Reliability Data System (NPRDS) is not identified with an actual plant in order to issue this report as a nonproprietary documents.

Table A   Anti-Rotation Key Failures (Cont.)

Plant LER No. Event Date	Description of Event	Causes	Corrective Actions
Plant B 2 09/25/93	With the plant in refueling outage, the Loop 3 hot leg injection valve would not close against safety injection pump pressure during performance of a special procedure (MOV full differential pressure stroke test). The anti-rotation key was found to be binding upon disassembly of the valve. The valve was a 2-inch Velan globe valve.	The root cause was unknown and no suspected cause could be determined.	Replaced the anti-rotation key with a new one.
Kewaunee 1 93-008 03/27/93	During MOV dynamic testing, one of two redundant safety injection recirculation valves to the refueling water storage tank failed to close completely. The valve failure was due to a broken anti-rotation device, an 'L' shaped key. The valve was a 2-inch Velan globe valve. Subsequent inspection of the other seven Velan globe valves installed in the safety-related systems found five of the valves also had broken keys. The failures went undetected because there is a washer in the bushing between the key and the motor operator, which obscures the top view of the key, even when the motor operator is not installed. This washer is not normally removed when maintenance is performed on the motor operator. Therefore, the failure went undetected.	Low cycle fatigue or sudden brittle failure. It was assumed the keys failed soon after the valves were installed in original service. Machining of the sharp inside corner of the L-shaped key may have contributed to the failure of the anti-rotation keys by producing high stresses in the corners of the keys. Also, depending on the length of the key and the length of the keyway, some keys may be bottoming out in the stem keyway when the valve is opened.	Designed a new key to eliminate the identified design weakness.

Table A Anti-Rotation Key Failures (Cont.)

Plant LER No. Event Date	Description of Event	Causes	Corrective Actions
Crystal River 3 91-018 12/08/91	While the unit was ascending in power at 14 percent power, the pressurizer spray valve, RCV-14, failed to close (the indicating light falsely indicated that the valve was closed). The valve remained open in spite of the operator's attempt to close it with its control switch. the valve was a Walworth 2 1/2-inch globe valve.	The failure of the valve to close was attributed to a missing valve stem anti-rotation key and its retaining bolt.	The anti-rotation key and setscrew were replaced. Revised procedure to ensure proper installation of the anti-rotation key. Reviewed all MOVs for anti-rotation device applicability.
Plant C 11/14/91	While performing surveillance on the 'A' loop of RHR service water and with the plant at full power, the 'A' RHR service water discharge valve failed to open. The failure was detected when the control room did not receive an open indication. The 'A' RHR loop was declared inoperable. The anti-rotation key mounted in the valve yoke had failed and allowed the stem to turn rather than to drive upward. The failed valve was a Walworth 12-inch globe valve.	Fatigue crack at a machining defect due to stress from shock impact during operation. The failed key had been machined with too small of a radius at the transition area between the tang and the base of the key.	A new key with a larger radius at the transition area was installed.
Plant D 02/21/91	With the plant at full power, during routine surveillance testing of the FW-F-7 standby feedwater recirculating valve of the MFW system, it was discovered that it could not be stroked manually. the anti-rotation key was found broken. The valve was a Fisher valve.	The key was poorly designed.	Manufactured a newly designed key.

Table A Anti-Rotation Key Failures (Cont.)

Plant LER No. Event Date	Description of Event	Causes	Corrective Actions
Plant E 2 12/06/90	While the unit was at power, during a quarterly surveillance, the emergency pond to 'B' service water pump sluice gate failed to open when the handswitch was placed to open. Investigation revealed that the valve operator shaft to the sluice gate coupling key was missing. The valve was made by Armco Inc.	Installation error was the most likely cause of the loss of coupling key.	The stem was cleaned and a key was installed and peened in place.
Plant F 3 11/28/90	While the unit was at power, operations personnel in the control room received a split indication (valve in mid position) for the reactor water cleanup outlet isolation valve (4-inch Anchor/ Darling globe valve) when stroked open. Further investigation revealed an improper and broken setscrew, allowing the anti-rotation device to slip up and down. This degraded system operation.	An improper setscrew was installed during previous maintenance.	1. The anti-rotation device was drilled and tapped. 2. The new setscrew was spotted the to stem and installed with locktite.
Plant G 1 10/05/90	During surveillance testing, the anti-rotation pin clamp for the HPCS valve F011 (NEMA valve) to the condensate storage tank was observed to be bent and the key had fallen out.	Not determined.	Replaced with a new key.

Table B Valve Operator-to-Valve Stem Key Failures

Plant LER No. Event Date	Description of Event	Causes	Corrective Actions
Plant H 1 11/17/94	With the plant at 98-percent power, the CCW to RHR heat exchanger bypass valve remained closed when the operator tried to open it. The valve had to be operated via its local handwheel instead of via its control circuitry. A Fisher 12-inch butterfly valve.	The actuator shaft slipped on the valve stem due to a stripped Woodruff key. The suspected root cause was wear, as the key has been in place since 1983.	Removed the setscrew and remainder of the Woodruff key. Installed a new key specified by Engineers.
Plant I 1 11/02/94	With the plant at full power, the containment pressure-vacuum relief control valve (1VC5) failed to open when a control room operator tried to open it. The valve shaft key was found sheared. A 10-inch butterfly valve.	Due to normal aging/cyclic fatigue.	Replaced with a new key.
Plant J 2 10/23/94	The unit was at full power when operations attempted to open the condensate isolation valve. The valve failed to open. Subsequent investigation revealed that the key had sheared. Since the primary function of the valve is isolation, the valve failed in its safe position. Posi-Seal International 16-inch butterfly valve.	The cause could not be determined The suspected cause was due to material defects or overtorqueing. According to the vendor, the failure was suspected to be a design problem.	The key was replaced.
Plant J 2 10/03/94	Similar to the 10/23/94 event described in the preceding page.		The key was replaced.

Table B Valve Operator-to-Valve Stem Key Failures (Cont.)

Plant LER No. Event Date	Description of Event	Causes	Corrective Actions
Plant K 1 05/23/94	With the plant in shutdown, while placing the shutdown cooling (SDC) system into service, the reactor building closed cooling water (RBCCW) outlet valve (V-5-0106) failed to open on demand. The SDC system was degraded, reducing the system heat removal capability. The setscrew for the valve stem locking key had loosened, allowing the locking key to fall out of its keyway. This disengaged the actuator from the valve stem and prevented the valve from operating. NEMA valve.	The upside down orientation of the actuator allowed the key to slide out of its keyway.	Revised maintenance procedure to provide additional instructions to locktite setscrew and to stake keyway when installing spline adaptor.
Plant L 3 05/17/94	With the unit at full power, a local leak rate test of penetration #18 containment isolation valve revealed an excessive leakage. An incorrect size of Woodruff key (too small) was noted. Fisher control valve.	An incorrect size of Woodruff key was installed due to personnel error. This allowed movement of the actuator arm relative to the stem, causing excessive wear on actuator parts and incomplete/inconsistent closure of the valve.	Replaced with a new key of correct size.
Plant M 1 03/12/93	With the plant in refueling outage, the RHR heat exchanger flow control valve and the bypass valve were closed. Flow was still approximately 100 gpm. Subsequent trouble shooting found the leakage was from the bypass valve. Fisher 8-inch butterfly valve.	A worn Woodruff key between the valve shaft and actuator arm.	Replaced the Woodruff key.

Table B Valve Operator-to-Valve Stem Key Failures (Cont.)

Plant LER No. Event Date	Description of Event	Causes	Corrective Actions
Crystal River 3 93-001 03/05/93	While the unit was in Mode 4 and cooling down for a planned maintenance outage, following switching from steam generator cooling to decay heat system cooling, the cooldown exceeded the technical specification limits. The decay heat removal exchanger outlet valve unexpectedly opened, causing additional RCS cooldown. An attempt was made to close the valve manually. However, after several minutes, the valve started to open again due to damage to the stem key connecting the valve to its actuator.	Improper manual operation and overstress caused the damage.	Stem key replaced. Revised procedure to include instruction for taking manual control of the valve.
Plant N 1 12/11/92	During a scheduled refueling outage, a control room operator started No. 12 RHR pump and opened the RHR heat exchanger outlet control valve CV 31236, and noted no flow with the controller at 50 percent. The pump was secured and the train was then taken out of service. Inspection found the key connecting the valve stem to the actuator was sheared.	The distraction from disc to body interference created undue stress on the key. Failure analysis concluded that the key failure was a normal aging-related degradation.	
Plant N 2 10/31/92	During a scheduled maintenance shutdown with the reactor being cooled by the RHR system, the control board operator noted that the 22 RHR heat exchanger outlet control valve would not respond. The Woodruff key which connects the actuator to the butterfly valve stem had sheared. A Continental 8-inch butterfly valve.	Normal aging and a possible pre-existing stress due to a slightly bent shaft and machining of the key were the likely contributing factors.	The key was replaced and the bent stem was to be replaced during the next outage.

Table B Valve Operator-to-Valve Stem Key Failures (Cont.)

Plant LER No. Event Date	Description of Event	Causes	Corrective Actions
Plant O 1 10/15/92	While the plant was tripped, a shift operator found that the condenser to feedwater pump 1-A suction valve did not close either manually or by motor operator. The valve remains open in normal plant condition.	The key which coupled the valve to the valve actuator had fallen out. The originally installed key did not appear to have been mechanically staked into the keyway. Field orientation of the key was vertical, which would have contributed to it falling out during operation.	Reinstalled the key.
Plant P 3 09/12/92	During a functional test of the valve actuator for the 3B LPCI outlet valve 3LPSW-78, the valve moved slightly in the close direction and stopped. The valve could not be reopened. The key was missing. Allis Chalmers 16-inch butterfly valve.	The root cause was not determined.The probable cause of the missing key was improper action during previous maintenance.	Installed a new key and a setscrew was staked to prevent key from loosening.
Plant J 1 09/02/92	With the unit at full power, during a routine core sampling of the resin of demineralizer "G", the main intake valve HV1160G from the steam packing exhausting outlet line to the demineralizer failed to close on demand. The key in the valve stem broke when attempting to close the valve, preventing any valve stroke. 16-inch Posi-Seal International butterfly valve.	The root cause was unknown. The suspected cause was an evident loose retaining bolt.	Replaced the key.

Table B Valve Operator-to-Valve Stem Key Failures (Cont.)

Plant LER No. Event Date	Description of Event	Causes	Corrective Actions
Plant Q 2 01/15/92	With the unit in a scheduled outage, the RHR heat exchanger 2A cooling water automatic supply valve failed to operate. The actuator was operated from the control room, and the indications for valve position would vary from full closed to full open position. However, the flow indications remained unchanged. The RHR train was declared inoperable. Henry Pratt 16-inch butterfly valve.	The valve shaft drive key was loose and became mispositoned.	Replaced the key.
Plant R 2 12/31/91	During normal system operation, the steam generator "A" blowdown isolation bypass would not open from the control room. The valve function was lost. Train "B" was in service and degraded due to the loss of one functional flow path. A Rotork control valve.	The stem key was not installed in the previous maintenance.	Installed a new key.
Plant S 2 10/17/91	During a refueling outage, plant operators noticed that the condensate demineralizer inlet flow control valve would not open on demand. Subsequent investigation revealed that the key between the gear drive and the valve shaft had sheared. The system would have been degraded due to loss of all condensate demineralizer flow had it been in service. The valve was a Rotork control valve.	The cause was not determined but presumed to be excessive force.	Replaced the key.

Table B Valve Operator-to-Valve Stem Key Failures (Cont.)

Plant LER No. Event Date	Description of Event	Causes	Corrective Actions
Plant T 2 10/09/91	While attempting to establish RHR cooling for a refueling shutdown, it was discovered that the 11A RHR heat exchanger outlet control valve actuator had become separated from the valve stem. This resulted in loss of one train of the RHR system. The failure was due to a sheared Woodruff key in the actuator shaft. A Fisher valve.	Improper key type and very tight valve packing.	Replaced with a proper key. The valve was repacked and all eight studs were replaced to ensure proper full nut engagement.
Plant O 1 10/08/91	During a refueling outage, operations personnel were attempting to operate the actuator for the condensate to the feedwater pump suction valve. The valve did not change position. The stem nut key was missing.	Unknown	Replace the whole gear box.
Plant K 1 05/12/91	With the plant shutdown for a refueling outage and the feedwater system out of service for maintenance, the "A" feedwater control valve was not able to be operated manually due to the handwheel rotating freely. There were no adverse effects on the plant or system since the system was not in operation. Had it been, this would have resulted in a degraded train.	The key between the gear drive and the valve stem had come out of the cylinder adapter allowing the worm gear to rotate freely. The cause of the key to come out was unknown.	Reinstalled the key.
Plant U 1 04/11/91	The RCIC turbine steam supply stop valve actuator would not declutch for manual operation during an environment qualification inspection. Upon disassembly of the valve, the key on the valve was found to be missing.	Unknown	Installed a new key.

Table B Valve Operator-to-Valve Stem Key Failures (Cont.)

Plant LER No. Event Date	Description of Event	Causes	Corrective Actions
Plant V 2 10/14/90	During a startup, No. 22 service water heat exchanger saltwater outlet valve failed to open when the actuator was switched to the open position. The key in the actuator that connects the actuator to the valve stem had slipped out of its keyway.	The key and keyway were slightly worn, allowing the key to slip out.	Reinstalled and staked the key.
Diablo Canyon 2 90-008 04/03/90	RHR heat exchanger bypass valve RHR-2-HCV-670 was not capable of being positioned to control flow due to failure of the Woodruff key which connects the valve stem to the actuator lever arm. Fisher type-7600 butterfly valve.	Improper material: The key should be made of alloy steel, instead of carbon steel. This was due to inadequate verification of subsupplier material by the vendor (Fisher). Multiple valve drawings in the licensee's file also contributed to the cause.	1. Identification and inspection of other potentially affected valves. 2. Removing redundant drawings that do not explicitly specify use of alloy steel keys. 3. Requesting the vendor to consider issuing a 10 CFR 21 report.

Table C Operator Motor Pinion Gear Key Failures

Plant LER No. Event Date	Description of Event	Causes	Corrective Actions
Plant AD 3 09/29/95	With the unit in shutdown after a turbine trip, during an attempt to close the 3A feedwater pump discharge valve, the valve motor would rotate but the valve stem would not move. Subsequent investigations found the motor pinion key missing from the motor shaft allowing the pinion gear to slip on the shaft. The key was found in the actuator grease.	The cause could not be determined. The suspected cause was inadequate installation.	The motor pinion key was replaced with a new key.
Palo Verde 1, 2 & 3 95-006 04/18/95	Unit 2 was in a refueling outage when the pinion key of train "A" containment spray header isolation valve was sheared and the motor was free-wheeling without moving the valve stem following completion of as-found static diagnostic testing. The failed key was in service for only one operating cycle, and the actuator was assumed to have been cycled less than 50 times prior to failure. Four additional pinion gear keys were found sheared in four separate scheduled replacements in Unit 1 and 3. Those keys were installed in the containment spray header isolation valves and LPSI header isolation valves. (SB-0 and 3 actuators)	The apparent root cause was that the AISI 1018 key material properties did not provide sufficient margin to withstand shock loads associated with normal operation and diagnostic testing of some MOVs.	Replaced with AISI 4140 keys.

Table C Operator Motor Pinion Gear Key Failures (Cont.)

Plant LER No. Event Date	Description of Event	Causes	Corrective Actions
Plant F 2 10/10/94	With the unit in shutdown for refueling, the "A" loop core spray full test valve would not open on an open demand signal. The valve motor was observed running but with no stem travel. Since the unit was shutdown and redundant trains were operable, there was no significant effect on plant operation. Investigation found that the pinion key had dislodged from the keyway. (SMB-2-60 actuator)	Flow-induced vibration.	Both pinion gear and key were replaced and the key was staked at the end to prevent it from becoming loose.
Clinton 10 CFR 21 10/08/93	The licensee discovered a broken pinion key in the actuator of HPCS outboard containment isolation valve 1E22-F004 while installing a modification to change the actuator gear ratio and replace the valve stem and disc. The failure had existed undetected until the valve was disassembled to install the modification. The actuator was Limitorque SB-3 with a 40 ft-lb, 3600 rpm motor. Subsequent investigations identified additional 13 MOVs which may be susceptible to pinion key failure as a result of backseating or MOVATS calibration. The actuator models were SMB-0 and SB-0. The keys installed in some of the actuators were made from AISI 4140 material. (SMB-3-40, SMB-0, and SB-0 actuators)	Excessive torque during valve backseating and MOVATS testing.	Replace the AISI 1018 key with a 4140 key. Revised maintenance procedures for certain actuator sizes and combinations to prevent excessive backseating and to add limitations to prevent the use of MOVATS calibration.

Table C Operator Motor Pinion Gear Key Failures (Cont.)

Plant LER No. Event Date	Description of Event	Causes	Corrective Actions
Waterford 3 93-005 10/07/93	With the unit at full power, it was discovered that the pinion keys in both MOVs for isolating the shutdown cooling system suction line had slipped out of the keyways, allowing the motors to run free while not transmitting any torque to the valves. (SMB-0 actuator)	Failure to stake the pinion keys following motor replacement. Inadequate procedure in that the maintenance procedures did not contain information provided in Limitorque Maintenance Update 89-1.	Staked the key and revised maintenance procedures.
Cooper 93-031 08/30/93	The HPCI pump discharge valve failed to open during performance of a surveillance. The pinion key in the Model SB-3 actuator was dislodged from its keyway, allowing the motor shaft to spin without transferring torque to the valve stem. (SB-3 actuator)	Failure to stake the motor shaft keyway following a motor replacement in 1990. Limitorque Maintenance Update 89-1 recommends that restaking of the motor shaft is required when the motor is replaced. Although the plant MOV maintenance procedure was revised to include the recommendation in 1991, no inspection of previously rebuilt motor activities was conducted.	1. The key was replaced and the shaft was properly restaked. 2. Conducted a review of operational requirements and MOV maintenance history, and determined which MOVs needed additional investigations for susceptibility to the problem. (Only valves with actuator size 0 or larger were susceptible.)
Plant C 1 08/24/93	With the plant at power, the "A" RHR heat exchanger service water flow control valve (V10-89A) failed to close following a surveillance test. The "A" RHR train was degraded due to the loss of service water flow control. A sheared setscrew allowed the pinion key to fall out of its keyway. (SMB-2 actuator)	The flow control loop was poorly designed such that frequent directional changes were required in order to control flow.	1. Replaced with a new motor, pinion gear, key and setscrew. 2. The deadband of the valve position modulator was widened to provide a smoother throttling

Table C Operator Motor Pinion Gear Key Failures (Cont.)

Plant LER No. Event Date	Description of Event	Causes	Corrective Actions
Plant C 1 06/15/93	The "B" RHR heat exchanger SW flow control valve failed to stroke in the closing direction during a surveillance test. The pinion key had fallen out of its keyway. (SMB-2 actuator)	A combination of excessive vibration and cyclic fatigue that occurs when the valve is performing its throttling function.	A new key was installed and secured with setscrews and lockwire.
Plant W 2 06/09/93	With the unit at full power, while running torus cooling, the RHR Division 1 containment cooling isolation test valve failed to close. With the valve open, the unit could not restart torus cooling. The unit entered the 72 hour limiting condition of operation. Upon removal of the motor, the pinion gear was found free to spin on the shaft. (SMB-4 actuator)	The apparent cause was the setscrew not being properly installed and seated during original installation. No spot was drilled on the shaft for setscrew seating.	Drilled a spot on the shaft for setscrew seating. Staked a new pinion key and installed a setscrew.
Bellefonte 1 & 2 10 CFR 50.55(e) 06/01/93	Potential Limitorque actuator failure caused by excessive keyway depth. The equipment records revealed that the plant did possess a significant quantity (approximately 250) of the suspected actuators. Many of the actuators were installed or designed for installation in safety-related systems throughout both Units 1 and 2.	This manufacturing deficiency relative to the machining of the keyway was reported in a 10 CFR 21 notification issued by Limitorque. The notification identified the suspected pinion gears to be those 41 tooth pinion gears utilized in actuator types SMB, SB, and SBD, SIZES 00 and 0 within a specified serial number range and any replacement gears furnished between August 1974 and August 1978.	Performed an inspection of the keyway depth on the cited 41 tooth pinion gears and replaced those found defective within 1 year.

Table C Operator Motor Pinion Gear Key Failures (Cont.)

Plant LER No. Event Date	Description of Event	Causes	Corrective Actions
Plant X 2 04/18/93	During MOVATS testing , the containment spray train "A" isolation valve motor was free wheeling and the valve would not move. The failure was identified during inspections following static diagnostic function tests. The pinion key had sheared. (SB-0 actuator)	Related to inertia shock load during static diagnostic testing. This was an additional shock load not normally experienced by the actuator because the design stresses on the key were well within the material strength.	Replaced with a key made from AISI 4140 material to compensate for the shock load.
Plant I 2 11/23/92	With the unit at full power, the CCW heat exchanger outlet control valve (21SW127) remained in the full open position despite the closing signal from the control room operator. The failure was due to a broken pinion key.	Aging/cyclic fatigue.	Replaced the key.
Plant M 1 09/16/92	While performing change out for the pinion gear of RHR pump "B" suction valve BNHV8812B, maintenance personnel found the key had sheared. (SB-2 actuator)	Improper staking of the setscrew, allowing the setscrew to back out during operation.	Staked the setscrew.
Plant Z 1 09/09/92	During RHR loop "A" outage testing with loop "B" supplying shutdown cooling, a technician found RHR isolation valve 34A would not close on electrical signal demand. Investigation found that the pinion key had slipped down the motor shaft. (SMB-1-40 actuator)	Inadequate locking of the pinion key during previous maintenance.	

Table C Operator Motor Pinion Gear Key Failures (Cont.)

Plant LER No. Event Date	Description of Event	Causes	Corrective Actions
Plant I 1 07/26/92	The polisher system inlet valve failed to open when an operator tried to open it. The valve motor breaker also tripped open. This degraded the system. The failure was due to a sheared pinion key. (SMB-0-15 actuator)	The licensee suspected the cause to be from a high differential pressure across the valve disc.	The pinion gear and key were replaced.
FitzPatrick 92-028 05/21/92	In response to IN 81-08, in September 1981, the licensee identified six valve actuators in the category that the pinion keys for these actuators should be made from AISI 4140 material. The licensee did not replace them at that time. In the 1992 refueling outage, during inspection and replacement of the keys to be replaced, three of the six keys were found nearly sheared or completely sheared. The affected valves were LPCI isolation valves (Trains A and B) and RHR heat exchanger B outlet isolation valve. (SMB-3, 4 and 5 actuators)	Periodic preventative maintenance generally did not remove the motor pinion or check the key. MOV overhaul and inspection program only verified that a key was installed, but typically did not remove the key for inspection.	Replaced with AISI 4140 keys. Developed a program plan to consolidate identified industry operating experience and vendor information program problems.
Plant Y 1 03/28/92	The plant was in refueling outage. During a maintenance activity, the manual clutch on the actuator of a steam generator main steam isolation valve would not stay engaged when pressure was removed from the clutch handle. Removal of the motor revealed that the setscrew for the pinion key was missing.	Normal wear and degradation.	Cleaned the gear box and installed a new setscrew. Verified valve operability.
Plant AA 03/16/92	During plant shutdown, while performing preventive maintenance, the RHR "B" loop heat exchanger outlet valve pinion key was found broken. (SMB-0-25 actuator)	The key was made of weaker material.	Replaced with a new key of the proper material.

Table C Operator Motor Pinion Gear Key Failures (Cont.)

Plant LER No. Event Date	Description of Event	Causes	Corrective Actions
Plant AA 12/18/91	During plant shutdown while performing preventive maintenance, both RHR A and B loop outboard injection valve pinion keys were found broken. The valve operations were degraded. Plant operation was not affected due to cold shutdown. (SMB-4T-250 actuator)	Design defect; the AISI 1018 key was too weak for the application. The problem was identified earlier by GE. SIL 378 and IN 81-08.	Replaced with AISI 4140 keys.
Plant AB 1 11/22/91	During a plant startup, the "B" feedwater injection isolation valve would not open electrically or manually when operations attempted to establish feedwater flow to the reactor. The "B" train was rendered inoperable. Disassembly of the valve actuator found the pinion gear had slipped on the motor shaft due to a loose setscrew. The handwheel gear and clutch mating gear were also found damaged. NEMA valve, (SMB-2-60 actuator)	Unknown.	Reinstalled the pinion gear and replaced the damaged gears.
Plant AC 2 11/21/91	During plant operation, the essential cooling water pump 2B discharge valve would not close from the control panel or the motor control center but closed automatically when the pump was secured. The valve could not be controlled manually either. The pinion key was broken. (SMB-0-25 actuator)	Unknown.	The key was replaced.

Table C Operator Motor Pinion Gear Key Failures (Cont.)

Plant LER No. Event Date	Description of Event	Causes	Corrective Actions
Plant F 2 11/07/91	With the unit at power, the 2D high pressure service water heat exchanger outlet valve actuator continued to run for four hours after the valve was stroked closed. The pinion key was missing allowing the pinion gear to rotate on the motor shaft. (SMB-2-60 actuator)	Unknown.	The motor pinion and key were replaced.
Plant O 1 11/01/91	While in the first refueling outage, a scheduled maintenance refurbishment of the RHR pump 2 hot leg loop 4 recirculation isolation valve actuator found the pinion key broken. (SB-2 actuator)	An overtorque condition due to a setpoint which allowed the actuator to incur a torque greater than the torque rating.	Replaced the broken key and reset the torque switch to a new setpoint.
Plant J 1 10/13/91	While the unit was at full power, operations personnel noticed that the pinion key for the "A" condensate demineralizer inlet valve was broken. This would have prevented the valve from opening. (SMB-00-15 actuator)	Unknown.	The key was replaced.
Diablo Canyon 1 & 2 91-021 09/16/91	During refueling while performing post maintenance testing, the following valve actuators would not engage electrically: two safety accumulator injection to the cold leg valve actuators and two RHR heat exchanger outlet to Loop 3 and 4 valve actuators. The pinion keys were sheared, allowing the motor shaft to rotate within the pinion gear. (SB-3-80 actuators)	Abnormal high forces on the keys resulted from electrical 'short stroking' of the valves. The key material was inadequate.	1. Replaced the keys with stronger material (AISI 4140) 2. Revised the operating and maintenance procedures to prevent valve 'short stroking.'

Table C Operator Motor Pinion Gear Key Failures (Cont.)

Plant LER No. Event Date	Description of Event	Causes	Corrective Actions
Plant P 1 09/04/91	The actuator of the 1B LPSI valve (1LP-18) at Unit 1 provided faulty position indication to the control room while the valve was closing. The pinion key was sheared. (SMB-4-150 actuator)	Material defect.	Replaced with a new key.
Plant AD 2 08/05/91	With the unit at 90 percent power, while performing the monthly HPCI operability test, MOV 2-2301-10 would not open. The valve failing to open was due to the pinion key coming loose on the shaft. (SMB-3-150 actuator)	Improper installation from a previous repair.	The key was re-tightened.
Plant F 2 06/13/91	With the unit at power, the 2D high pressure service water heat exchanger outlet valve would not close when a signal was applied. Further investigation revealed that the pinion key was missing. (SMB-2-60 actuator)	Unknown.	Installed a new key.
Plant AE 2 04/08/91	The "A" RHR shutdown cooling injection containment isolation valve would not fully close during a post maintenance test with flow through the valve. The train was degraded. Plant operation was unaffected due to the unit being in refueling outage. Upon disassembly, the pinion key was slipping out of the shaft. (SMB-2-60 actuator)	Flow-induced vibration because the valve was required to operate at a lower than design flow.	Replaced the damaged parts.

Table C Operator Motor Pinion Gear Key Failures (Cont.)

Plant LER No. Event Date	Description of Event	Causes	Corrective Actions
Plant V 2 03/05/91	With the unit in shutdown and the main feedwater system in service, No. 22 steam generator feedwater isolation valve would not open from a signal from the control room. One of the two feedwater trains was lost. The pinion key of the motor had sheared and the pinion gear would not turn. (SMB-2-60 actuator)	The probable cause was wear on the key.	Replaced the gear and key.
Plant X 3 02/08/91	With the unit in refueling outage, the containment spray control train "A" isolation valve successfully stroked during an MOV valve acceptance test but then failed to close . The valve had been opened under static conditions. The pinion key was found broken. (SB-0 actuator)	Improper material. The failed key was found to be similar to AISI 1050. The specified key material was AISI 1018.	Replaced with a new key made from AISI 4140.
Plant AD 2 10/07/90	The LPCI discharge to reactor recirculation valve (2-1501-22A) failed to open upon demand during operability surveillance. The pinion key was found worn. (SMB-4-80 actuator)	Aging and wear.	Replaced with a new key.
Arkansas 2 90-020 09/28/90	During a planned power reduction from full power, the discharge valve of main condenser circulating water pump 2P-3B failed to automatically close when the pump was secured. The valve failure resulted from the disengagement of the pinion key from the motor shaft, allowing the pinion gear to turn freely on the shaft.	Vibration caused a setscrew used to secure the key to loosen. An inadequate work instruction caused the installation of a setscrew which was too small to allow proper locking.	Revised maintenance procedure to include detail instructions on motor pinion gear installation.

Table C Operator Motor Pinion Gear Key Failures (Cont.)

Plant LER No. Event Date	Description of Event	Causes	Corrective Actions
Plant AF 2 08/14/90	With the unit in operation, while attempting to operate the auxiliary feedwater pump for the performance of surveillance instruction 133, the pump turbine stop valve could not be opened to control the pump. The pinion key had broken inside the drive sleeve assembly. The plant was not affected but the train was lost. (SMB-000 actuator)	Unknown. Assumed to be the stress from operating the valve with handwheel.	Replaced the key.
Salem 1 90-016 04/19/90	The AISI 1018 pinion keys in the actuators of six service water valves (three per unit) were found sheared or severely deformed. These keys had failed under conditions of normal operation, and one of them showed significant deformation after only 15 valve cycles. The valves were 30-inch butterfly valves using SMB-0 actuators with 25 ft-lb high speed motors (3600 rpm), and the valves are required to close within 10 seconds. (SMB-0-25 actuator)	High impact load during fast closure - inadequate design. The key material, although within the manufacturer's specifications, was too soft for its intended application.	The failed keys were replaced with keys made from a harder material, such as AISI 4140 stainless steel.
Cooper 90-006 03/26/90	During the 1990 refueling outage, a sheared pinion key was discovered in throttle valve RHR-MO-M034B of the suppression chamber cooling loop B. The valve had been operating satisfactorily and passed all testing. Spare keys from the same purchase order were immediately tested and determined to be of an incorrect material. Inspection of the corresponding valve in loop A also found the pinion key to be deformed. Subsequent investigation determined an additional eight valves had the suspected keys. IN 81-08 identifies similar failures. (SMB-4 actuator)	Standard type AISI 1018 keys had been installed instead of the required special type of AISI 4140. Inadequate performance by the vendor, personnel error by non-licensed personnel, and programmatic deficiencies.	Performed extensive research to identify previous similar failures in size 3 and 4 Limitorque actuators and to establish the currently installed key material.

Table C Operator Motor Pinion Gear Key Failures (Cont.)

Plant LER No. Event Date	Description of Event	Causes	Corrective Actions
Dresden 2 90-002 01/16/90	While preparing to align the "B" shutdown cooling loop, discharge valve MO2-1001-4B of the 2B shutdown cooling pump failed to open via its control switch. The pinion key had sheared. (SMB-4-200 actuator)	The AISI 1018 key was insufficient for the application.	1. Replaced with a higher strength key made from AISI 4140 material. 2. Revised MOV maintenance procedure to enhance MOV overhaul frequency.