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PG&E Letter DCL-02-002

U.S. Nuclear Regulatory Commission
ATTN: Document Control Desk
Washington, DC 20555-0001

Docket No. 50-323, OL-DPR-82
Docket No. 50-275, OL-DPR-80
Diablo Canyon Units 2 and 1
Licensee Event Report 2-2002-001-00
Fasteners Failed due to Stress Corrosion Cracking

Dear Commissioners and Staff:

In accordance with NUREG-1022, Revision 2, Section 2.7, PG&E is submitting the enclosed voluntary licensee event report regarding certain degraded pressure boundary stainless steel fasteners installed in primary and secondary systems in Units 1 and 2. The in-service failure of these fasteners by stress corrosion cracking could have prevented fulfillment of a safety function.

This event did not adversely affect the health and safety of the public.

Sincerely,

David H. Oatley

cc: Ellis W. Merschoff
David L. Proulx
Girija S. Shukla
Diablo Distribution
INPO

Enclosure

LMP/2246/N0002134

IE22

LICENSEE EVENT REPORT (LER)

FACILITY NAME (1)	DOCKET NUMBER (2)	PAGE (3)
Diablo Canyon Unit 2	0 5 0 0 0 3 2 3	1 OF 10

TITLE (4)

Fasteners Failed due to Stress Corrosion Cracking

EVENT DATE (5)			LER NUMBER (6)			REPORT DATE (7)			OTHER FACILITIES INVOLVED (8)	
MO	DAY	YEAR	YEAR	SEQUENTIAL NUMBER	REVISION NUMBER	MO	DAY	YEAR	FACILITY NAME	DOCKET NUMBER
08	31	2001	2002	- 0 0 1 -	0 0	01	15	2002	Diablo Canyon Unit 1	0 5 0 0 0 2 7 5

OPERATING MODE (9)	THIS REPORT IS SUBMITTED PURSUANT TO THE REQUIREMENTS OF 10 CFR: (11)	
1		10 CFR
POWER LEVEL (10)	X	OTHER Voluntary
1 0 0		(SPECIFY IN ABSTRACT BELOW AND IN TEXT, NRC FORM 366A)

LICENSEE CONTACT FOR THIS LER (12)

	TELEPHONE NUMBER	
	AREA CODE	
Roger Russell - Senior Regulatory Services Engineer	805	545-4327

COMPLETE ONE LINE FOR EACH COMPONENT FAILURE DESCRIBED IN THIS REPORT (13)

CAUSE	SYSTEM	COMPONENT	MANUFACTURER	REPORTABLE TO EPIX	CAUSE	SYSTEM	COMPONENT	MANUFACTURER	REPORTABLE TO EPIX
B	S B	P C V	C 6 3 5	Yes					

SUPPLEMENTAL REPORT EXPECTED (14)		EXPECTED SUBMISSION DATE (15)	MON	DAY	YR
[ ] YES (If yes, complete EXPECTED SUBMISSION DATE)	[X] NO				

ABSTRACT (Limit to 1400 spaces, i.e., approximately 15 single-spaced typewritten lines.) (16)

On August 31, 2001, with Unit 2 in Mode 1 (Power Operation) at 100 percent power, a PG&E employee investigating a steam leak discovered a broken stud on a valve bonnet for a steam generator 10 percent atmospheric steam dump valve. Investigations found the remaining seven bonnet fasteners had cracks in either the studs or nuts. On October 3, 2001, based on results from multiple Charpy impact tests of fasteners in similar service, PG&E concluded the material had become embrittled.

The fasteners failed due to Stress Corrosion Cracking (SCC). PG&E has determined that the SCC was caused by a combination of unanticipated high temperature embrittlement and elevated stress in the presence of corrodants. Ten years of operation at temperatures of as low as 470 degrees F embrittled the ASME SA 564, Type 630, Condition H1100 (17-4 PH) stainless steel material, causing increased susceptibility to SCC. Higher than expected stress was presumably caused by inadequate administrative controls over the maintenance torquing practices.

Corrective actions include replacing embrittled material in plant locations where it is highly susceptible to SCC, and/or exposed to significant impact loads at low temperature. Also, maintenance practices are being revised to enhance torquing practices.

TEXT

I. Plant Conditions

Units 2 and 1 were in Mode 1 (Power Operation) at 100 percent power.

II. Description of Problem

A. Background

Diablo Canyon Power Plant uses ASME SA 564, Type 630, Condition H1100 (hereafter, 17-4 PH) stainless steel in primary and secondary systems on both units in valve stems, bolts, studs, nuts, screws, washers and pins. High temperature applications include external pressure boundary (e.g., bonnet and flange fasteners) and internal (e.g., retainer nuts and valve stems) locations.

The 17-4 PH material is a precipitation hardening stainless steel. The 17-4 PH steel is also designated as Unified Numbering System alloy S17400. PG&E chose this material as an upgrade to the original fasteners in these applications because of its corrosion resistance, high strength, fatigue resistance and because its coefficient of thermal expansion is close to that of the original fasteners. The 2001 ASME Code Section II, SA-564, states, "These steels are generally used for parts requiring corrosion resistance and high strength at room temperature, or at temperatures up to 600 degrees F."

In response to NRC Information Notice 92-60, "Valve Stem Failure Caused By Embrittlement," PG&E replaced several 17-4 PH valve stems. Based on industry data available at the time, PG&E chose 550 degrees F as a conservative lower threshold for evaluating embrittlement of 17-4 PH. PG&E evaluated external bolting applications and concluded bonnet bolting would not be susceptible to embrittlement because of exposure to lower operating temperatures than internal components. Further, should the bolting become embrittled, there would be no stress corrosion cracking (SCC) because of a lack of corrodants, and static loading conditions, rather than the repeated high stress that valve stems experience.

Each main steam line is equipped with a 10 percent atmospheric steam dump valve [SB] [PCV] located outside containment, adjacent to the main steam safety valves (MSSVs) [RV] and upstream of the main steam isolation valve [ISV]. The atmospheric steam dump valves (ADVs) minimize challenges to the MSSVs, and allow for adjustable steam generator pressure control. The ADVs are air operated with a programmed and manually adjustable lift set point. They are also referred to as steam generator power operated relief valves (PORVs). Each ADV can be isolated using a manual block valve.

The safety related functions of the ADVs are: (1) cool down the reactor coolant system (RCS) [AB] after a seismic event; (2) cool down the RCS after a steam generator tube rupture, and (3) provide containment isolation.

The ADVs are 8-inch diameter Copes-Vulcan globe valves with eight fasteners attaching the bonnet to the valve body. The bonnet fasteners are 1-3/8 inch diameter, 6-inch long threaded studs with nuts, both made of type 17-4 PH stainless steel. PG&E replaced the original fasteners (B7 material) with this 17-4 PH material in 1991. The fasteners are fully covered by thermal insulation. When covered, the external temperature of the fasteners was approximately 470 degrees F, and the external valve body was up to 500 degrees F.

Technical Specification (TS) 3.6.3, "Containment Isolation Valves," allows an ADV to be inoperable for up to 72 hours, or be isolated.

TS 3.7.4, "10 Percent Atmospheric Dump Valves," allows an ADV to be inoperable for up to 7 days.

B. Event Description

On August 30, 2001, with Unit 2 at 100 percent power, a PG&E non-licensed operator identified water dripping from insulation, indicative of a steam leak, in the vicinity of a Unit 2 ADV (MS-2-PCV-21). Insulation covered the area of the leak, and the operator believed that the leak was coming from a test connection near PCV-21.

On August 31, 2001, a PG&E insulation and coatings worker removed insulation from the area of the leak, and identified that the leak was from the bonnet of PCV-21, in the vicinity of a broken stud. He removed the broken stud and took it to the plant metallurgist for examination.

On September 6, 2001, PG&E engineers inspected PCV-21, and noticed that in addition to the broken stud, two of the bonnet nuts were also cracked. At 09:36 PDT after the engineers informed the shift foreman of the condition of fasteners on PCV-21, Operations declared the valve inoperable and isolated PCV-21.

Investigators used ultrasonic testing (UT) to detect cracks in the remaining studs of PCV-21 by placing a transducer on the top of each stud, above the nut. A total of six of the eight valve bonnet studs were broken or had significant cracks. The last two studs remained intact without cracks, but

the associated nuts, while intact, had visible cracks. These intact studs were located 180 degrees apart. The valve bonnet has eight fasteners located at the 1, 2, 4, 5, 7, 8, 10 and 11 o'clock positions. The following describes the as-found condition of each of these fasteners:

1 o'clock: UT of the stud identified a crack 4 inches from the top. The intact nut was removed at a very low torque. The stud broke in the valve body at a very low torque.

2 o'clock: UT of the stud identified no cracks. The nut had a visible crack running parallel to the stud axis, through the full nut thickness on one face. The nut required a relatively high torque to begin loosening, and then was removed easily.

4 o'clock: The stud was found broken at 2 inches from the top. The intact nut was removed at a very low torque.

5 o'clock: UT of the stud identified a crack 4-1/4 inches from the top. The intact nut was removed at a very low torque. The stud was removed intact.

7 o'clock: UT of the stud identified a crack 4-1/4 inches from the top. The intact nut was removed at a very low torque. The stud was removed intact.

8 o'clock: UT of the stud identified no cracks. The nut had a visible crack running parallel to the stud axis, through the full nut thickness on one face. The nut required a relatively high torque to begin loosening, and then was removed easily.

10 o'clock: UT of the stud identified a crack 4 inches from the top. The intact nut was removed at a very low torque. The stud broke in the valve body at a very low torque.

11 o'clock: This was the first stud found broken, 3-1/4 inches from the top. The intact nut was removed at a very low torque.

There was no evidence of steam cutting of the studs in the area of the leak.

On September 8, 2001, at 12:40 PDT, after replacing the fasteners, PCV-21 was unisolated and declared operable. The valve had been declared inoperable for approximately 51 hours.

A series of investigative actions were initiated to support the failure analysis and cause analysis. The maintenance history of PCV-21 was reviewed and the maintenance personnel who performed the previous assembly were interviewed. A literature search revealed early 1990s industry studies that indicate the embrittlement of 17-4 PH material "cannot be ruled out" after

long-term exposure to temperatures as low as 482 degrees F.

It was determined that the 17-4 PH fasteners installed in both DCPP units' ADVs were from the identical heat of material.

On October 3, 2001, PG&E metallurgists presented results from a series of tests on this heat, including a stud removed from PCV-21, a stud removed from an adjacent ADV, and an unused stud from the warehouse. They concluded the bonnet studs in all ADVs had become embrittled, apparently due to exposure to high temperature for an extended time period. Charpy V-notch testing indicated that the toughness of the material had decreased by approximately 85 percent, from an average of 61 foot-pounds to approximately 10 foot-pounds at room temperature. Additional testing confirmed yield and ultimate strength were slightly increased as compared with as-installed, while all other properties were consistent with the purchase specifications and data from the certified material test reports.

The metallurgists examined the fractured faces of failed studs via scanning electron microscopy, and found evidence of SCC at the initiation of the cracks.

Investigations confirmed 17-4 PH material is used elsewhere in high temperature pressure boundary applications in DCPP primary and secondary systems.

Readily accessible 17-4 PH fasteners installed in high temperature applications, including all ADVs and MSSVs in both DCPP units, were inspected via UT. No other cracked fasteners were identified. However, as a precaution, the entire population of ADV bonnet fasteners (64) were replaced.

C. Inoperable Structures, Components, or Systems that Contributed to the Event

None

D. Other Systems or Secondary Functions Affected

As discussed in the analysis section below, the degraded fastener material serves a pressure boundary function in various primary and secondary systems.

E. Method of Discovery

A PG&E non-licensed operator discovered the steam leak. A PG&E maintenance worker removing insulation from PCV-21 discovered the specific leak location, and a broken stud. PG&E metallurgists identified the generic implications of the degraded fastener material.

F. Operator Actions

When operators were informed of the degraded condition of PCV-21, they isolated the valve and declared it inoperable.

G. Safety System Responses

None

III. Cause of the Problem

A. Immediate Cause

The immediate cause of the failure of the fasteners on PCV-21 was SCC. Once the critical crack size was achieved, the cracks propagated rapidly through the 1-3/8 diameter 17-4 PH stainless steel studs. The studs were left in a tensioned condition during the previous refueling outage in May 2001. Within three months, cracks had propagated completely through one stud, to a significant extent through five additional studs, and through a single face of two nuts.

B. Contributory Causes

SCC requires the simultaneous presence of three contributing factors: (1) susceptible material, (2) elevated stress, and (3) exposure to a corrodant. PG&E engineers visually and/or UT inspected over 600 fasteners. These fasteners were all made of the same material, installed in systems of same temperature with similar service life, and exposed to a similar marine atmosphere. These inspections identified no other crack indications outside of PCV-21, which support the conclusion that the combination of contributory factors was unique to PCV-21.

The following describes how these three contributing factors most likely caused SCC in the PCV-21 fasteners.

1. High temperature embrittlement of the 17-4 PH stainless steel made it more susceptible to SCC. PCV-21 fasteners were installed in 1991 and

maintained at a temperature of at least 470 degrees F. Based on the ASME Code, 17-4 PH is not considered susceptible to embrittlement at operating temperatures below 600° F. However, test results show that the DCPP fasteners became embrittled after 10 years at temperatures as low as 470 degrees F. The industry literature states the rate of embrittlement varies significantly based on variations in the chemical analysis of individual heats of this material. The chemical composition of the heat used in PCV-21 fasteners makes them more susceptible to embrittlement. Electric Power Research Institute (EPRI) "Materials Handbook for Nuclear Power Plant Pressure Boundary Applications" (TR-109668 Revision 2, Final Report, October 2000) supports this conclusion.

2. The fasteners were more highly stressed than the balance of the fastener population, perhaps to a degree in excess of procedural limits due to inadequate maintenance practices. Circumstantial evidence supports the conclusion that the fasteners were stressed beyond that expected at 1210 foot-pounds applied torque, but remained below the yield stress of the material. PG&E concluded that this higher stress was the most likely explanation for the failure of all 8 fasteners on PCV-21, and not elsewhere. Elevated stress is a significant contributor to SCC growth rate. This elevated stress may have been caused by a number of factors, including:

    a. The component history for PCV-21 indicates that these fasteners have been removed and re-installed five times, which is more than any other of the installed high temperature 17-4 PH fasteners. The threads of the nuts and studs become smoother with each tensioning, and therefore more efficient at converting torque to a tensile stress on the stud. Therefore, given equal torque, the tensile stress on PCV-21 studs was higher than in studs in other components.

    b. During the previous refueling, the as-left torque on all eight PCV-21 fasteners was documented to be 1210 foot-pounds, which is approximately 10 percent higher than the documented torque in any other ADV. Documentation in the work orders contained discrepancies regarding the torquing devices used for this job. Deformity of the nuts suggests an impact device was used to remove and install the nuts during previous maintenance, contrary to work documentation. However, subsequent interviews with the maintenance personnel involved could not explain these discrepancies. Based on the circumstantial evidence, discrepancies in the work order, and lack of recall concerning

these discrepancies, PG&E believes that the actual as-left torque may have been higher than 1210 foot-pounds.

3. The fasteners were exposed to a corrosive environment (marine atmosphere). While these fasteners are normally hot and covered in insulation, the valve remained disassembled for nine days during the previous refueling outage in May 2001. The fasteners were exposed to the marine atmosphere during this period, possibly leaving a corrosive chloride coating on the studs and nuts.

IV. Assessment of Safety Consequences

The safety related functions of the ADVs are: 1) cool down the RCS after a Hosgri seismic event; 2) cool down the RCS after a steam generator tube rupture; and 3) provide containment isolation. The actual safety consequences of the degraded fasteners on PCV-21 had very low risk significance because the leak was identified and the valve was isolated prior to actual failure. An unbroken stud with its cracked nut from PCV-21 was tensile tested, and this single stud withstood 132,000 pounds of force, indicating significant clamping force capability remained in the pressure boundary joint. Engineering concluded that even in its degraded condition, PCV-21 would not have failed during any significant transient condition and was capable of performing its safety function.

However, the potential safety consequences of the failure of PCV-21 were also evaluated. Had the degraded condition of PCV-21 gone undetected and the two remaining nuts progressed further toward failure, and had a steam generator tube rupture event occurred in steam generator 2-3, PCV-21 bonnet fastener failures could have resulted in an unisolatable release because the adjacent manual block valve may not have been accessible under the accident conditions. Therefore, the embrittled condition of these fasteners could have prevented fulfillment of a safety function needed to control the release of radioactive material. However, because the failure requires multiple causes, (i.e., embrittlement and high stress), the condition was not reported under 10 CFR 50.73(a)(2)(ix)(A).

The physical evidence at DCPP suggests that the temperature needed to cause embrittlement may be as low as 470 degrees F. The following systems contain components with 17-4 PH material exposed to elevated temperature, and thus susceptible to high temperature embrittlement:

RCS, including: the pressurizer [PZR] PORV block valve bonnet bolting, and pressurizer spray isolation valve bonnet bolting.

TEXT

Chemical and Volume Control System and Safety Injection [BQ] system, including bonnet fasteners in the first off check valves [CKV].

Auxiliary feedwater [BA], including: bonnet fasteners in first off check valves [CKV] adjacent to main feedwater piping; components in the steam supply to the Terry turbine [TRB], and other check valves.

Where the material is used as bolting material for components that make up portions of the primary and secondary system pressure boundaries, the safety function of the bolting material is to maintain pressure boundary integrity so that the affected structures, systems, and components (SSC) will carry out their intended design functions. This safety function must be met for all modes of plant operation, and for all accidents and malfunctions described in the Final Safety Analysis Report Update (FSARU).

The embrittled material possesses greatly reduced impact toughness at low (room) temperature but maintains significant impact toughness at elevated temperature. Therefore, the embrittled material is only susceptible to failure under impact loads at low temperatures.

External 17-4 PH fasteners installed in the primary system are less susceptible to SCC because they are less likely to be exposed to chlorides, and boric acid is believed to be less corrosive than chlorides.

For internal applications, material integrity must be maintained in each case to assure the affected SSC will perform its intended safety function. PG&E did not consider internal applications to be susceptible to failure based on the response to NRC Information Notice 92-60, "Valve Stem Failure Caused By Embrittlement."

Therefore, the failure of PCV-21 fasteners had no actual safety consequences because the combination of factors were unique to the valve, the degraded fasteners were discovered and replaced prior to complete failure, and the valve was capable of performing its required functions in the as-found condition. Therefore, the event did not adversely affect the health and safety of the public.

V. Corrective Actions

A. Immediate Corrective Actions

1. PCV-21 was isolated and the fasteners replaced.
2. Fasteners installed in other ADVs and MSSVs were visually and/or UT inspected. No other cracked fasteners were found.
3. ADV fasteners were replaced.

4. An operability evaluation was created to address the embrittled material installed in the plant.

B. Corrective Actions to Prevent Recurrence

1. Engineering is evaluating the as-left torque, actual service temperature, time at elevated temperature, chemical analysis of individual material heats, corrosive environment, and potential for impact loads at low temperature. Engineering will use this information to prioritize inspections and replacement of the remaining installed 17-4 PH fasteners.

2. Maintenance practices are being revised to more explicitly control torquing, especially on this material.

VI. Additional Information

A. Failed Components

Stainless steel ASME SA 564, Type 630, Condition H1100 (17-4 PH), 1-3/8 diameter studs and nuts failed while installed in an eight inch Copes-Vulcan model D-100-160-3 steam dump valve.

B. Previous Similar Events

None.