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DEGRADATION MECHANISMS AND FLAW EVALUATION ASSOCIATED WITH A LEAK IDENTIFIED IN MAIN STEAM SYSTEM BYPASS VALVE Q2N11V0003B AT FARLEY UNIT 2

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1.0	1-1 to 1-4	0	8/6/07	Initial Issue
2.0	2-1 to 2-13			
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1.0 INTRODUCTION

A small pinhole leak was discovered in the bonnet of a small bore main steam system isolation valve (Q2N11V0003B) at Farley Nuclear Plant (FNP), Unit 2. This valve is the upstream Main Steam Isolation Valve (MSIV) bypass line isolation valve for the "B" main steam line. Valve Q2N11V0003B is a 3-inch, Class 600 lb, pressure seal, flexible wedge, gate valve with pneumatic actuator. This safety-related, ASME Section III, Class 2 valve, was manufactured by Velan Valve Company for FNP. The valve body and bonnet material are SA-105 Gr. II carbon steel [1.1].

The leak is located above the threaded section of the bonnet as shown in Figure 1-1 [1.2]. The valve is located on a horizontal line with the valve bonnet pointing upwards. Pictures of the affected valve are shown in Figures 1-2 and 1-3 [1.3].

Valve Q2N11V0003B is subjected to an operating pressure of 750 psig and an estimated operating temperature of 350°F when the valve is closed [1.4]. The design pressure and temperature of the valve are 1163 psig and 565°F, respectively [1.1].

Although a formal root cause evaluation has not been completed due to the valve remaining in service, it is believed that this defect is a fabrication defect associated with the carbon steel forging. The objective of this report is to evaluate possible degradation mechanisms associated with the leak and to determine the allowable flaw size to demonstrate structural stability. A flaw growth analysis considering fatigue is also performed to predict the flaw size at the end of the current cycle. Conservative loading conditions are used for the evaluation.

The report is organized in the following manner. A degradation mechanism evaluation is performed in Section 2 to identify potential mechanisms that may have caused the leak. In Section 3, a flaw evaluation is performed to determine the allowable flaw sizes in both the axial and circumferential directions. A fatigue crack growth analysis based on full pressure cycling is included in Section 4. The summary and conclusions for the report are provided in Section 5. Recommendations are provided in Section 6 followed by a list of references in Section 7.

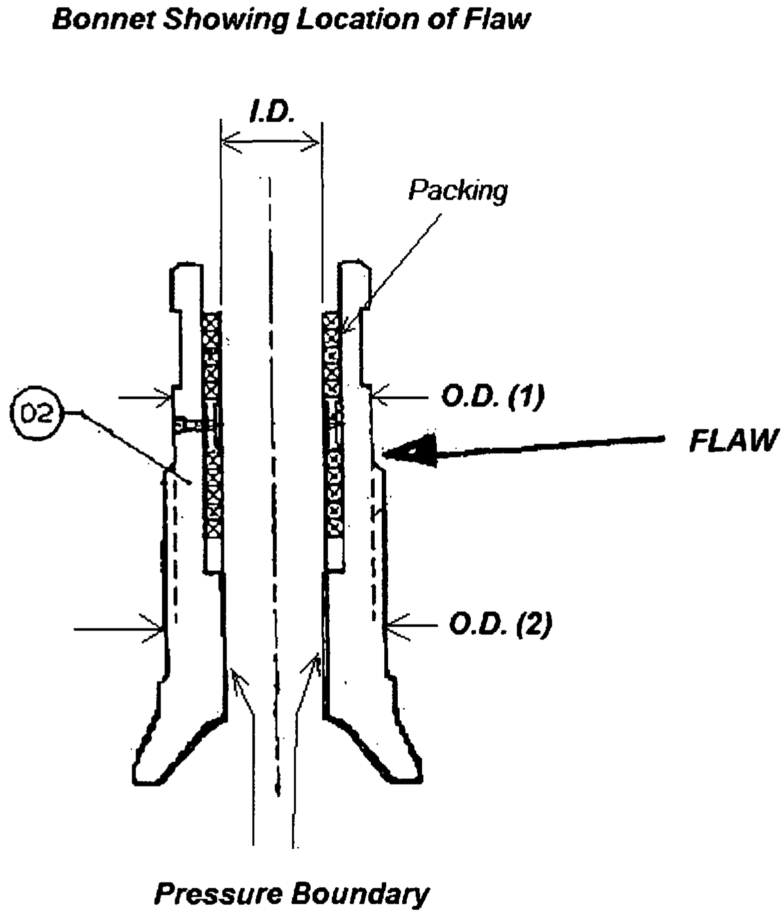

Figure 1-1. Approximate Location of Flaw in Valve Q2N11V0003B [1.2]

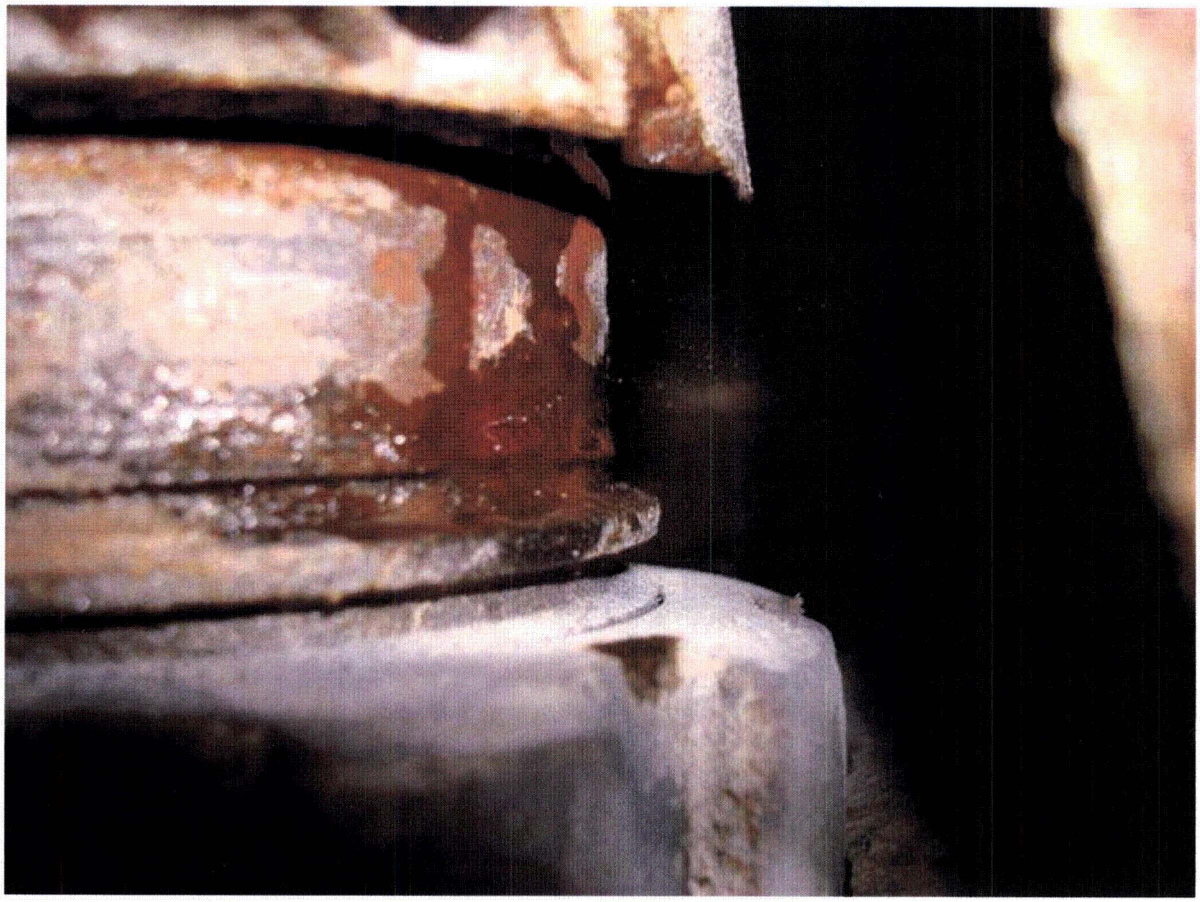

Figure 1-2. Picture of Leak in Valve Bonnet [1.3]

Figure 1-3. Picture of Entire Valve Body and Actuator [1.3]

2.0 EVALUATION OF POTENTIAL DEGRADATION MECHANISMS

A formal root cause analysis of the leak has not been completed, due to a lack of forensic evidence pending valve repair or replacement. However, based on the materials used in the valve manufacture, in addition to the design conditions and known degradation mechanisms that are encountered in nuclear plant piping components, an evaluation is performed to identify all potential degradation mechanisms that may have contributed to the observed leak. The evaluation is performed using the basic outline and format provided for assessment of potentially operative degradation mechanisms as defined in the EPRI Risk –Informed Inservice Inspection (RI-ISI) methodology [2.1] and has been used effectively for identification of system degradation mechanisms for several plants. This is supplemented by the degradation mechanisms identified for nuclear power plant components in Reference [2.2].

2.1 Possible Degradation Mechanisms

As noted in the EPRI RI-ISI report [2.1] and in the EPRI report on Degradation Mechanisms [2.2], possible degradation mechanisms for SA 105 Gr. II carbon steel to be considered for the MSIV bypass valve application include the following:

- General Corrosion and Wastage
  - General thinning
- Hydrogen Cracking
  - Hydrogen embrittlement
- Stress Corrosion Cracking
  - Transgranular stress corrosion cracking
- Localized Corrosion
  - Pitting
  - Crevice corrosion
  - Under deposit corrosion
  - Microbiologically influenced corrosion
- Flow Sensitive Mechanisms
  - Erosion-cavitation
  - Flow accelerated corrosion
- Fatigue
  - Mechanical fatigue
  - Thermal stratification, cycling, and striping
  - Thermal transients

Overload, vibration, material embrittlement (radiation effects and thermal aging), maintenance practices, and fabrication defects are also considered here.

2.2 Degradation Mechanism Evaluation

The system was evaluated for normal operating conditions as well as conditions of plant heatup and cooldown. All other system transients, including any water chemistry transients, were considered either mild or slow acting with respect to temperature (not a thermal transient instigator and no other mechanisms apply) or are emergency/faulted events that have not occurred to date.

2.2.1 General Corrosion and Wastage

Since valve Q2N11V0003B is fabricated from carbon steel, it is potentially susceptible to general corrosion or wastage. Since the secondary side steam environment is a highly controlled environment with strict control of oxygen, and control of water chemistry, including contaminants and organic species, general corrosion rates should be quite low. Plant operating specifications typically provide for anticipated or bounding corrosion rates to be expected in this valve in the secondary side environment.

General corrosion and wastage is also not considered a likely damage mechanism for the identified leakage due to the location of the leakage in the valve bonnet. However, an examination of a spare valve body from storage revealed some evidence of general corrosion at a mating surface, which may produce a source of leakage from mating surfaces if the surfaces are not cleaned and assembled properly. This potential issue is not likely related to the leakage identified in the valve body (which appears to be a through-thickness flaw versus a leak at an interface) and would not be a source of failure of the valve.

2.2.2 Hydrogen Cracking

Hydrogen embrittlement in carbon steels is generally associated with components heat treated to high strength levels and operating at low temperatures, usually near room temperature. It is usually manifest as delayed cracking and is seen as intergranular cracking along prior austenite grain boundaries. Notches concentrate stresses which tend to shorten delayed time for cracking.

Carbon steels typically require hardness levels greater than Rockwell C35 for such cracking to occur. Hardness levels for SA 105 carbon steel can be found in the supplemental requirements of the ASME SA 105 specification as being in the range of 137 to 187 Brinell, corresponding to Rockwell hardness levels less than Rockwell C21. Consequently, it is very unlikely that the SA 105 carbon steel was fabricated with hardness levels above Rockwell C21. In addition, the normal operating conditions of the valve are at too high a temperature to promote hydrogen embrittlement in the MSIV bypass valve.

2.2.3 Stress Corrosion Cracking

Transgranular stress corrosion cracking (TGSCC) is a phenomenon that occurs through the grains of a material and usually occurs in the presence of halogens and sulfides. It is not usually associated with a specific metallurgical condition but is affected by high local residual stresses, such as caused by welding or local cold work.

In carbon steels, TGSCC is possible in sulfur, nitrite or nitrate bearing environments, but these environments are not applicable to the highly controlled MSIV bypass valve secondary side steam environment.

2.2.4 Localized Corrosion (LC)

Valve Q2N11V0003B is normally closed and as such no steam flows through the valve during normal operation of the plant. Even if the valve were to become wet when the valve is in operation, the strict control of oxygen, other oxidizing species and the control of contaminants and organic species in the PWR secondary side environment suggests that these mechanisms are not operative.

2.2.4.1 Pitting

Pitting corrosion is a form of localized attack on exposed surfaces with far greater corrosion rates at some locations than at others. High local concentrations of impurity ions, such as chlorides and sulfates, tend to concentrate in oxygen depleted pits, giving rise to a potentially concentrated zone in this region.

Since the oxygen, oxidizing species and other contaminants are controlled to very low levels in the PWR secondary side steam environment, pitting is not an active degradation mechanism for this valve during normal operation.

2.2.4.2 Crevice Corrosion

Crevice corrosion is an electrochemical reaction caused by the electrochemical potential differences between an oxygenated bulk medium and zones depleted in oxygen by geometry. It is associated with narrow gaps that can result in oxygen depletion and a relatively high concentration of impurity ions within the crevice.

Since the oxygen, oxidizing species and other contaminants are controlled to very low levels in the PWR secondary side steam environment, crevice corrosion is not an active degradation mechanism for this valve during normal operation. The oxygen level is typically below 10 ppb in the PWR secondary side steam environment [2.3].

2.2.4.3 Under Deposit Corrosion

Under deposit corrosion is a form of crevice corrosion where suspended solids or corrosion products generated in upstream locations actually produce a creviced environment. Like crevice corrosion, an oxygenated environment produces the driving force for dissolution at anodic areas that are depleted in oxygen and where a high concentration of impurity ions can result in accelerated localized corrosion.

Since the oxygen, oxidizing species and other contaminants are controlled to very low levels in the PWR secondary side steam environment, under deposit corrosion is not an active degradation mechanism for this valve.

2.2.4.4 Microbiologically Influenced Corrosion

Microbiologically influenced corrosion (MIC) is caused by microbes, primarily bacteria, creating localized environments that cause damage to carbon steel, copper alloys, and stainless steels, especially to welds and heat affected zones in austenitic stainless steels. Areas considered susceptible to degradation from MIC are piping components with fluids containing organic material or with organic material deposits. Systems with low to intermittent flow, temperatures less than 150°F, and pH below 10 are candidates for MIC.

For the MSIV bypass valve, the main steam line environment is well controlled, at high temperature other than during periods when the plant is shut down and there is no evidence of organic material that would provide a source of the microbes or nutrients for MIC. Consequently, MIC is not considered to be an active degradation mechanism for this component.

2.2.4.5 Summary of Localized Corrosion Mechanisms

Based on the information provided above, the leaking flaw in Valve Q2N11V0003B is not attributed to localized corrosion. All of these conclusions are based upon the nominal MSIV environment: high purity water or steam with controlled chemical conditions and the exclusion of oxygen; no intrusion of damaging species (e.g., raw water which could introduce chlorides, sulfates, or microbes) is considered since no such chemical transients were provided or suggested as conditions affecting performance of the MSIV bypass valve.

2.2.5 Flow Sensitive (FS) Mechanisms

2.2.5.1 Erosion-Cavitation (E-C)

This heading is only used to be consistent with the EPRI RI-ISI program and to assist the reader in understanding that degradation that involves the interaction of erosion and corrosion events, ranging from 100% erosion to 100% corrosion, can occur even when those events do not fit the EPRI definition of flow-accelerated corrosion (FAC).

2.2.5.2 Flow Accelerated Corrosion (FAC)

Valve Q2N11V0003B is not susceptible to FAC, as defined by EPRI, since there is no flow in the bonnet region where the leak is located.

2.2.6 Fatigue

2.2.6.1 Mechanical Fatigue

High cycle mechanical fatigue, due to vibration, is a potential degradation mechanism for MSIV bypass valve Q2N11V0003B. There has been a prior history of high cycle vibration related fatigue in the main steam system piping, and significant efforts have been made to reduce or eliminate the vibration in the main steam system [2.18]. Although the effects of fatigue damage are cumulative, it is doubtful that high cycle fatigue could have been a contributor to the pinhole leak without causing significant additional damage to the valve. This is discussed further in Section 4.0.

The MSIV bypass line contains two 3" normally closed bypass valves. Q2N11V0003B corresponds to the first bypass valve along the bypass line (herein referred to as the upstream bypass valve). The second bypass valve is located downstream of the first bypass valve (herein referred to as the downstream bypass valve). Vibration data was collected for both the upstream [2.5 and 2.6] and downstream [2.4] MSIV bypass valves for main steam lines A, B, and C on the valve bodies.

The vibration data [2.5 and 2.6] for the upstream bypass valves shows that the main dynamic response occurs at frequencies less than 40 Hz. Similarly, a review of the vibration data [2.4] for the downstream bypass valves show that the main dynamic response occurs at frequencies less than 50 Hz. Since the vibration data was provided as frequency spectra, the phasing information was not available. Thus, the response of the actuator is assumed to be rigid body since the frequency range of the response (50 Hz) is less than the calculated fundamental natural frequency of the valve assembly (including the actuator) as 63.9 Hz [2.7].

The bypass line is anchored at either end to the 32" main steam header and will be excited by the flow in the main steam header. Thus, the steady state vibration of the bypass valve assembly is due to the turbulent flow in the main steam header. The turbulent flow in the main steam header is sufficient to subject the bypass valve to peak vibration levels that are not insignificant (1 inch per second (ips), 0-peak), but since the vibration is considered rigid body, there is minimal relative motion between the valve yoke (leak location) and the actuator. The root-mean-square (RMS) values are less than 0.44 ips at approximately 23 Hz which is well below the fundamental frequency of 63.9 Hz.

In general, the vibration levels for the upstream bypass valves on main steam line A and B are higher than the upstream bypass valve on main steam line C. This is attributed to the differences in configuration between these lines. The bypass line routing for main steam line C is shorter than the bypass line routing for main steam lines A and B, and as would be expected, the steady state vibration levels are lower for the bypass valves on main steam line C than the bypass valves on main steam lines A and B.

Since there is minimal relative movement between valve yoke (near the leak location) and the actuator, vibration levels are not large enough to cause flaw initiation. However, if the bonnet was loose, the vibration amplitude levels would probably have increased and could have contributed to crack growth; however, there is no evidence that this occurred.

To confirm that the vibration is essentially rigid body motion, it is recommended to evaluate simultaneously collected steady state vibration data from at least two points (e.g., valve yoke and bottom of the actuator plate), in the axial direction, on MSIV bypass valve Q2N11V0003B and confirm that the motion is in phase.

Based upon the measurements of vibration data present in the MSIV bypass line, the contribution of vibration to initiation or possible propagation of a flaw in the bonnet is considered to be small.

MSIV bypass valve Q2N11V0003B is not expected to be subjected to any significant low cycle fatigue due to pressure cycles. A discussion of fatigue associated with these full pressure cycles is addressed in Section 4 of this report.

2.2.6.2 Thermal Stratification, Cycling, and Striping (TASCS)

The system normally runs hot and there is no potential for the mixing of hot and cold fluids. As such, TASCS is not a credible mechanism.

2.2.6.3 Thermal Transients (TT)

Since the system normally runs hot and the valve is only open during startup and shutdown evolutions when rate of temperature change is closely monitored, this valve is not expected to have been exposed to any significant thermal transients. Furthermore, the bonnet location where the leak is present is not directly exposed to the process fluid, so any thermal changes would be less significant at this location.

2.3 Overload

Valve Q2N11V0003B is not considered susceptible to overload due to design and operating conditions.

2.4 Embrittlement

The location of Valve Q2N11V0003B in the Auxiliary Building is such that no radiation embrittlement effects could occur. Further, the operating temperature of the gate valve is far too low to have produced any thermal aging that would produce an embrittled structure.

2.5 Fabrication Defects

The nature of the leaking flaw in Valve Q2N11V0003B is most consistent with a minor fabrication defect or imperfection associated with fabrication or installation of the valve. Although fabrication defects are not common in forged components, the geometry associated with the valve, including stress concentrations, may have given rise to a fabrication related defect. Installation loadings, in combination with a pre-existing fabrication defect and local stress concentration, could have been a contributor to producing a surface crack or extending a crack associated with the defect.

Appendix A provides a timeline that shows a history of leakage in the bonnet area of the valve that provides some insight into the possible failure progression.

Q2N11V0003B has a history of steam leaks going back at least 3 operating cycles [2.8 through 2.10, 2.12, and 2.13]. Prior to 2R17, the packing arrangement (shown in Figure 2-1) isolated the flaw location from the system pressure [2.8]. Leakage identified in October 2002 was due to loose bonnet bolts. Immediately following startup from 2R16 in April 2004, the valve was observed to be leaking in the body to bonnet area and no leakage was observed in the area of the packing [2.9]. The bonnet clamp was confirmed to be tight. The leakage gradually worsened during the operating cycle. In addition, damage was observed in the area where the actuator and valve stem are connected and the condition report notes that this is a recurring issue [2.9]. The combination of loose bolting prior to 2R16 and the actuator to valve stem damage [2.11] suggests vibration as a possible contributor to the observed problems to this point. However, there is no evidence to suggest that vibration could have been the cause of crack initiation or crack growth at the location of the observed flaw.

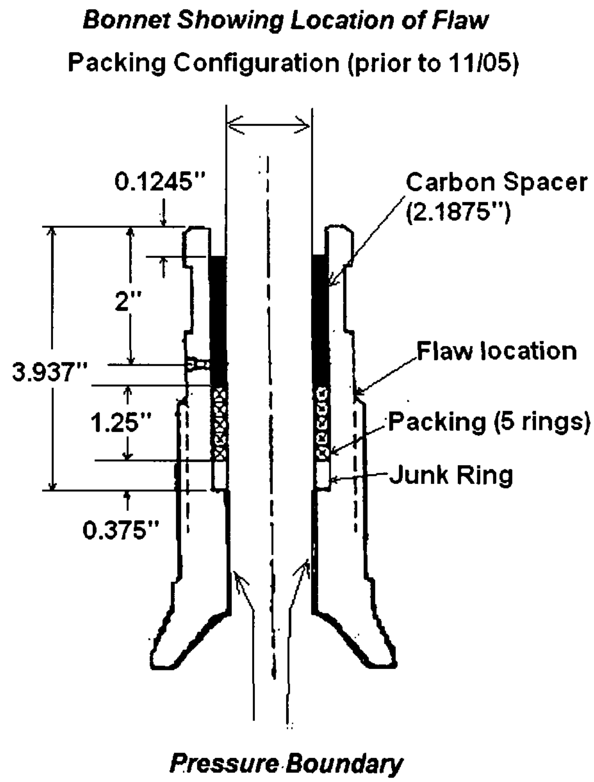

Figure 2-1: Packing Configuration Prior to 2R17

During 2R17, the maintenance work order [2.9] notes that there is evidence of leakage outside of the seal, but is not specific as to what the evidence was or how detailed an inspection was performed of other areas of the valve. During this maintenance, the packing configuration was changed to that shown in Figure 2-2. In addition, the packing torque was raised significantly, resulting in an increase in packing friction and a corresponding increase in the radial load on the bonnet in the stuffing box area. The lower packing rings are in the vicinity of the location where the flaw was later discovered.

Within days following 2R17, the valve was again noted to have a leak underneath the insulation [2.12]. When the insulation was removed, the bonnet leak was noted and suspected to be in the pressure seal area. Again, there is no description of specific areas examined. In addition, damage is observed in the area where the actuator and valve stem are connected for the other valve on the 3" bypass line (Q2N11V003E) [2.13]. This lends further support to there being vibration in the line that could be contributing to valve leakage.

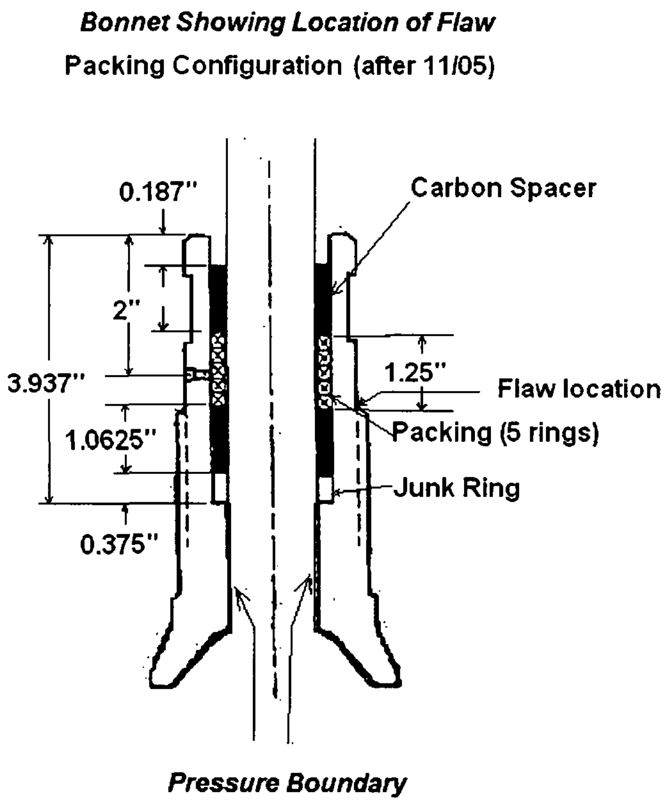

Figure 2-2: Packing Configuration Following 2R17

Prior to 2R18, the maintenance work order that removed the insulation from the valve stated "found bonnet leak, suspect pressure seal gasket area" [2.12]; again without any discussion of what specifically was inspected. During this maintenance, the packing configuration remained the same as shown in Figure 2-2. In addition, the packing torque was reduced back to 13 ft-lbs resulting in a reduction in packing friction and a corresponding decrease in the radial load on the bonnet in the stuffing box area. The bonnet clamp was tightened using a hammer and bar. This is a maintenance practice allowed by the valve manufacturer and is not unique to this valve [2.16].

Approximately 6 weeks following startup from 2R18, an engineering support walkdown of the area resulted in the identification of both a packing leak and a through-wall leak on the bonnet [2.14]. When the packing was checked, the torque was 9 ft-lbs. This is significantly less than the 13 ft-lbs that the work order shows was applied to the packing during the valve repair. When the packing was torqued to 12.5 ft-lbs the packing leak stopped and the through-wall leak was slowed considerably.

The hypothesis is that there was a subsurface flaw in the forging that escaped detection during original valve manufacture. Due to the packing configuration shown in Figure 2-1, this flaw was not exposed to significant thermal or pressure loads for the majority of its operating history. Following 2R17, the change in packing configuration to that shown in Figure 2-2 and increase in packing stud torque resulted in a higher radial load in the area of the flaw, where there is a stress concentration. This, in combination with a pre-existing fabrication defect, may have resulted in a small crack on the inside surface. The load on the bonnet that would result from a flaw connected to the inside surface would produce additional stress at the location of the flaw and eventually drive the flaw to the outer surface.

The loads produced by packing or internal pressure are accounted for in the design of the component and could not have initiated a crack alone. Since increasing the torque from 9 ft-lbs to 12.5 ft-lbs significantly reduced the leakage at the flaw location on 7/5/2007, it is likely that the packing extends below the location of the flaw. Following 2R18, the leak was not immediately observed, as occurred following 2R16 and 2R17. This suggests the packing was originally performing its intended function until it loosened up, most likely due to system vibration given the previous history, and allowed the system pressure to place additional stress at the flaw location.

Using the bar and hammer to tighten the bonnet clamp is unlikely to have created the flaw or significantly contributed to flaw propagation. This is because the location of the flaw is above the area of the threads that would be under load as the clamp is tightened. Damage could have been caused by striking the bonnet during the evolution, but no marks were observed on the bonnet and the bonnet was noted to be smooth on the NDE report [2.15].

Further support for a pre-existing flaw is supported by the NDE report that notes a loss of signal 1/3 of the way through the bonnet wall and that light sanding opened up two additional leaks (reported as "pinhole leaks" by station personnel [2.17]) in the vicinity of the original location.

2.6 Summary of Degradation Mechanism Evaluation

From the above evaluation, corrosion, hydrogen embrittlement, TGSCC, localized corrosion, flow sensitive mechanisms, and thermal embrittlement are not the likely sources of the leaking flaw. The leaking flaw most likely initiated at a defect associated with the fabrication of the valve, and is likely associated with a stress concentration, due to a mechanical notch or an imperfection associated with the forged component.

Based on the discussion provided above, the most likely cause is a latent manufacturing defect that, over time, resulted in leakage due to a combination of mechanical and pressure stresses from radial packing load and system pressure. This is supported by the lack of observed leakage on other valves of the same design, application, environment and manufacture as Q2N11V0003B. The timing of the observed leakage can be explained by the changes to the valve packing configuration and applied loads at the flaw location as described in Section 2.5.

3.0 FLAW EVALUATION

The ASME Code recognizes that small leaks may occur in piping, and methods have been developed to evaluate conditions of leakage until repairs can be made. For example, Code Case N-513-1 [3.1] allows a plant owner to perform an evaluation for temporary acceptance of leaking flaws in moderate energy Class 2 or Class 3 piping. While the Farley MSIV bypass valve is a Class 2 component, it is not within the scope of the Code Case since it is not a pipe and its operating pressure and temperature exceed the Code Case moderate energy limits. As such, the Code does not permit leakage from this component without a relief request. The approach used herein to evaluate this flaw follows the methodology described in Code Case N-513-1 assuming the bonnet may be modeled as a pipe. While this is not a Code approved method, this approach has been used to evaluate similar through-wall flaws in support of requesting NRC relief.

The Code of record for Farley Unit 2 is the 1989 version of the ASME Code [3.2]. Code Case N-513-1 uses the evaluation rules for flaws in ferritic piping contained in non-mandatory Appendix H of Section XI (pre-2001). The steps in the evaluation are described below. Allowable flaw sizes have been determined using the methodology presented in Section 3.2 and as specified in Reference [3.1] for both the axial and circumferential directions, respectively. Flaw growth evaluation considering fatigue as a possible mechanism described in Section 4.0 is performed using the methodology in ASME Code Section XI, Appendix C [3.2] for carbon steel components. No other flaw growth mechanisms are deemed likely at this location, as documented in Section 2.0.

3.1 Assumptions and Design Input

The following assumptions were used in the analysis of the flaw in MSIV bypass valve Q2N11V0003B:

1. ASME service level A/B safety factors [3.3] are conservatively applied for the allowable flaw lengths.
2. Dead weight and thermal loading are assumed negligible.

The following design inputs are used for the analysis (material properties are taken at the given operating temperature):

1. The valve bonnet is SA-105 Gr. II carbon steel forging material [1.1]
2. Operating pressure, p = 750 psig [1.4]
3. Operating temperature = 350°F [1.4]
4. Bonnet neck I.D. dimension, D_i = 1.625 inches [3.4]
5. Bonnet neck O.D. dimension, D_o = 2.5 inches [3.4]
6. The mean radius, $R = (D_o + D_i)/4 =$ 1.03125 inches
7. The bonnet thickness at the stuffing box area, t = 0.4375 inch [3.4].
8. The Code yield stress, S_y = 31.35 ksi [3.5]
9. The Code ultimate tensile stress, S_u = 70 ksi [3.5]
10. The design stress intensity = 19.6 ksi [3.5]
11. Pressure for accident condition, p = 1194 psig [3.7]
12. The maximum height of the observed pinhole leak area is 0.625 inches [2.15].
13. The maximum width of the observed pinhole leak area is 0.25 inches [2.15].

3.2 Allowable Flaw Size Determination

The allowable flaw sizes are determined in this section considering the flaw to be a through-wall planar flaw. The allowable flaw size is the maximum flaw size permitted by ASME Code Section XI and employs a safety factor such that failure (limit load or brittle fracture) is prevented.

3.2.1 Axial Flaw

For an axial through-wall flaw in a pipe, the assumed flaw geometry is shown in Figure 3-1.

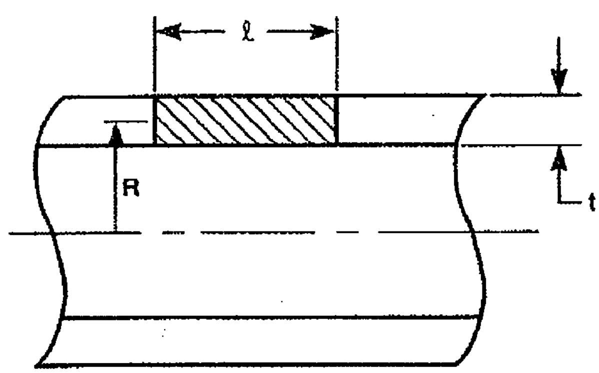

Figure 3-1. Assumed Axial Flaw Geometry in a Pipe

For an axial flaw, the stress of interest is the hoop stress resulting from operating pressure loading. This is given by the expression:

$$\sigma_h = \frac{pD_0}{2t} = 2.142 \text{ ksi}$$

The allowable axial through-wall flaw lengths, l_{all}, can be determined using the relationship from Reference [3.2] which is given as:

$$l_{all} = 1.58\sqrt{Rt}\left[\left(\frac{\sigma_f}{SF\,\sigma_h}\right)^2 - 1\right]^{\frac{1}{2}} \tag{1}$$

where:

$R =$ mean bonnet radius

t = bonnet thickness

σ_f = material flow stress = (Sy +Su)/2

SF = safety factor = 3.0 for allowable flaw size from C-3420 [3.2]

The above expression is also used in Code Case N-513-1 [3.1] for the evaluation of axial through-wall flaws. The screening criterion in the Code Case suggests the use of these limit load equations to determine the allowable flaw length. Using Eq. (1), the maximum allowable axial flaw length is l_{all} = 8.30 inches using the limit load solution.

For comparison, a conservative linear elastic fracture mechanics (LEFM) analysis for the axial flaw was also performed using the **pc-CRACK** program [4.1]. The results showed an allowable flaw size of 5.6 inches would be required to exceed the criterion for initiation ($K_I > K_{IC}$), including the code defined safety factor of $\sqrt{10}$ [3.6]. The results using LEFM are more conservative even though the Code Case N-513-1 method allows the use of limit load. Both the limit load and LEFM produce an allowable flaw size that is larger than the maximum height of the observed indications from the NDE report of 0.625 inches [2.15].

3.2.2 Circumferential Flaw

For a circumferential flaw, the stresses of interest are the axial stresses resulting from internal pressure and the bending stress resulting from seismic loads and other (pressure + stem thrust) loads. The circumferential flaw was analyzed as follows for an a/t ratio of 1.0.

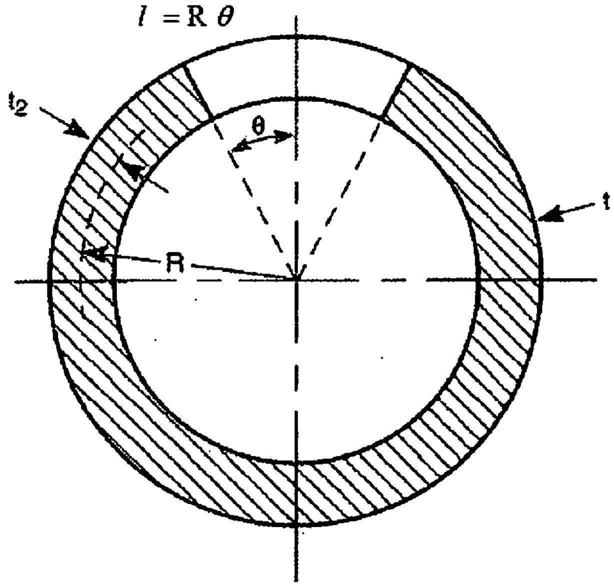

Figure 3-2. Assumed Circumferential Flaw Geometry in a Pipe

The axial stress resulting from the operating pressure of 750 psig is given by:

$$\sigma_{axial} = \frac{pD_0}{4t} = 1.071 \text{ ksi}$$

A maximum bending moment of 346 in-lb and a stem thrust force of 5008 lbs [2.7] was added to the pressure load to obtain the maximum stresses on the bonnet cross section.

The screening criteria in Code Case N-513-1 [3.1] suggest the use of LEFM for the circumferential flaw analysis.

The **pc-CRACK** program [4.1] was used to solve for the maximum allowable circumferential flaw length based on linear elastic fracture mechanics (LEFM). The results show that a maximum flaw length of 3.8 inches would be required to exceed the criterion for initiation ($K_I > K_{IC}$), including the Code defined safety factor of $\sqrt{10}$ [3.6]. This is compared to the maximum width of indications from the NDE report of 0.25 inches [2.15].

Accident conditions with pressure reaching a maximum of 1194 psi were also evaluated using **pc-CRACK** with the appropriate Code safety factors for service level C&D Conditions. The results show that, for service levels C&D, the maximum allowable flaw size for an axial flaw is 7.09 inches [3.6]. Also, the maximum allowable flaw size for a circumferential flaw under service levels C&D conditions is 4.46 inches [3.6]. The circumferential flaw is bounded by the maximum circumferential flaw length of 3.8 inches for service level A&B conditions.

Table 3-1 shows the results for the maximum allowable lengths of axial and circumferential flaws in the bonnet from the flaw evaluation [3.6].

Table 3-1: ASME Section XI Maximum Allowable Through-Wall Flaw Lengths [3.6]

Through-wall Flaw	Service Level	Limit Load	LEFM
Axial Length (in.)	A & B	8.30	**5.66**
	C & D	N/A	7.09
Circumferential Length (in.)	A & B	N/A	**3.8**
	C & D	N/A	4.46

To be conservative, the results of the LEFM analyses for service level A & B conditions are used for both the limiting axial and circumferential flaws even though the Code Case N-513-1 method would allow the use of limit load for the axial flaw geometry. These results show that the maximum allowable axial flaw length of 5.66 inches in the bonnet, or a maximum allowable circumferential flaw length of 3.8 inches, will assure the structural integrity of the bonnet for all conditions (service level A&B and service level C&D).

4.0 FLAW GROWTH ANALYSIS

In this section, a conservative fatigue analysis is performed to determine the beginning of cycle through-wall flaw length that will not reach the allowable through-wall flaw length in one operating cycle. The material of the bonnet is carbon steel. As such, the fatigue crack growth evaluation is performed by the fatigue crack growth methodology in ASME Code Section XI, Appendix A [4.2] for carbon and low alloy steel components using the QA software package **pc-CRACK** [4.1].

Since the defect is through-wall, the end of life flaw size due to fatigue crack growth is calculated using material properties for carbon steel and the appropriate operating stresses due to the valve opening and closing 100 times. Per Reference [4.2], the fatigue crack growth rate for ferritic steels for a LWR environment can be used.

The fatigue crack growth rate is given by:

$$\frac{da}{dN} = C_o(\Delta K_I)^n \quad \text{units of inches/cycle} \qquad (15)$$

where:

ΔK_I = stress intensity factor range (K_{max} - K_{min})

n = 5.95 (from A-4300) for ferritic materials in LWR environments with low ΔK_I values [4.2]

C_o = C x S

where C is a scaling parameter as given by:

$$C = 1.02 \times 10^{-12}$$

and S is a scaling parameter to account for R ratio as given by:

$$S = 1.0 \quad (0 \le R \le 0.25)$$
$$= 26.9\,R - 5.725 \; (0.25 \le R \le 0.65)$$
$$= 11.76 \; (0.65 < R < 1.0)$$

with,

$$R = K_{min} / K_{max}.$$

At the location of the flaw, there are no thermal transients other than pressure cycles. Hence, the evaluation is performed by assuming 100 full pressure cycles for valve opening (0 to 750 psig) which is conservative relative to the time that this flaw is expected to be in service. Fatigue due to vibration is not considered significant at the leak location and is not expected to contribute to fatigue crack growth. As discussed in Section 2.2.6.1, the dynamic response of the valve occurs at frequencies less than 40 Hz, which corresponds to 3.5×10^6 cycles per day. If the stresses due to vibration were greater than the endurance limit, a crack would have initiated and grown within one day of operation. Since the leak was not detected during initial operation of the bypass valve, the steady state stresses due to vibration are less than the endurance limit and would not have contributed to the cumulative fatigue usage at this location. The results of the fatigue crack growth analyses show that fatigue is insignificant ($da < 10^{-9}$ inches) for these conditions.

As a result of these analyses, it is seen that calculated maximum axial and circumferential through-wall flaw lengths are significantly greater than the indications of backwall thinning from the NDE report by a factor of 9 for an assumed axial flaw and a factor of 15.2 for an assumed circumferential flaw. This demonstrates that there is no concern for the structural integrity of the bonnet for one more operating cycle, even under the most severe loading conditions.

5.0 SUMMARY AND CONCLUSIONS

Based on the evaluations performed in this report, the following conclusions can be made:

- General corrosion, hydrogen embrittlement, TGSCC, localized corrosion, flow sensitive mechanisms, and thermal embrittlement are not the likely sources of the leaking flaw. The leaking flaw most likely initiated at a defect associated with the fabrication of the valve, and is likely associated with a stress concentration due to a mechanical notch or an imperfection associated with the forged component.

- The most likely cause of the observed leak is a latent manufacturing defect that, over time, resulted in leakage due to a combination of mechanical and pressure stresses from radial packing load and system pressure.

- Based on the measurements of vibrations in the MSIV bypass valve, the contributions of fatigue cycling to the initiation or possible propagation of a flaw in the bonnet is insignificantly small.

- The calculated maximum axial and circumferential through-wall flaw lengths are significantly greater than the indications of backwall thinning from the NDE report by a factor of 9 for an assumed axial flaw and a factor of 15.2 for an assumed circumferential flaw. This demonstrates that there is no concern for the structural integrity of the bonnet for one more operating cycle, even under the most severe loadings including normal operation (level A&B) and accident (level C&D) conditions.

6.0 RECOMMENDATIONS

It is recommended that the following actions be taken to monitor the leakage from the pinhole in Valve Q2N11V0003B:

- Walk down the line on a regular basis (possibly daily) to monitor leakage
- Perform periodic UT examination of the flaw region to verify no significant changes in the flaw characterization at intervals of no more than 90 days.
- Confirm there is rigid body motion between the valve and actuator as discussed in Section 2.2.6.1.

7.0 REFERENCES

[1.1] Velan Engineering Companies, Certificate of Compliance, 3" 600 lb. Pressure Seal Gate Valve, Air Cylinder Operated, Farley Unit 2, Contract No. FNP-2-21, August 1, 1973, SI File No. FNP-08Q-201.

[1.2] Drawing No. P2-0607-N07, Velan 3" Pressure Vessel Seal Gate Valve, Joseph M. Farley Nuclear Plant, Rev. G, March 20, 1995, SI File No. FNP-08Q-202.

[1.3] Pictures of Leak in Valve and Valve Configuration, E-mails from Andrew Patko to Tim Griesbach, July 18, 2007, SI File No. FNP-08Q-203.

[1.4] Operating Temperature and Pressure Information, Telecon Record (temperature) dated 7/18/07, and E-mail from Andy Patko to Tim Griesbach (pressure), dated 7/24/07, SI File No. FNP-08Q-204.

[2.1] "Revised Risk-Informed Inservice Inspection Evaluation Procedure," EPRI TR-112657, Revision B-A, December 1999.

[2.2] J. F. Copeland et al., "Component Life Estimation – LWR Structural Materials Degradation Mechanisms," EPRI Report NP-5461, September 1987.

[2.3] "PWR Secondary Water Chemistry Guidelines-Revision 4, EPRI TR-102134-R4, November 1996.

[2.4] E-mail from Andrew Patko to Tim Griesbach, Subject: "FW: MSIV Data taken July 5, 2007," July 18, 2007, SI File No. FNP-08Q-205.

[2.5] E-Mail from Jeremy Dykes to Tim Griesbach, Subject: "MSIV Bypass Valve Vibration," July 20, 2007, SI File No. FNP-08Q-206.

[2.6] E-mail from Jeremy Dykes to Tim Griesbach, Subject: "FW: Scan from Xerox WorkCentre," July 26, 2007, SI File No. FNP-08Q-207.

[2.7] "Seismic Analysis of Velan 3" – 600 LB Pressure Seal Stop Check Valve With Cowan Dynamics Air Cylinder Actuator," Ref. No. SR-6227, Velan Engineering Companies, November 10, 1975, SI File No. FNP-08Q-208.

[2.8] Farley Nuclear Plant Work Order M02006820, Q2N11V0003B has small body to bonnet steam leak, dated 11/8/02, SI File No. FNP-08Q-209.

[2.9] Farley Nuclear Plant Work Order M04003150, Q2N11V0003B has water dripping out of valve insulation, dated 4/15/04, SI File No. FNP-08Q-210.

[2.10] Farley Nuclear Plant Condition Report 2004105834, Q2N11V0003B has small steam leak, dated 11/17/04, SI File No. FNP-08Q-211.

[2.11] Farley Nuclear Plant Condition Report 2005102654, Q2N11V0003B has broken latch restricting valve open motion, dated 3/5/05, SI File No. FNP-08Q-212.

[2.12] Farley Nuclear Plant Work Order 2053235701, Q2N11V0003B has leak under insulation, dated 12/14/05, SI File No. FNP-08Q-213.

[2.13] Farley Nuclear Plant Condition Report 2005112450, Damaged Hand Wheel on Q2N11V0003E, dated 6/25/05, SI File No. FNP-08Q-214.

[2.14] Farley Nuclear Plant Condition Report 2007106566, Q2N11V0003B has packing leak and through-wall leak on bonnet, dated 7/5/07, SI File No. FNP-08Q-215.

[2.15] Applied Technical Services Ultrasonic Inspection Report, Job # A115613, dated 7/8/07, SI File No. FNP-08Q-216.

[2.16] E-mail from A. Patko to T. Herrmann, dated 7/26/07, SI File No. FNP-08Q-217.

[2.17] E-mail from A. Patko to T. Herrmann, dated 7/25/07, SI File No. FNP-08Q-218.

[2.18] Altran Technical Report No. 01036-TR-04, Revision 0, Nov. 2001, "Farley Unit 2 Main Steam Line Vibration," SI File No. SNOC-31-201.

[3.1] ASME Code Case N-513-1, "Evaluation Criteria for Temporary Acceptance of Flaws in Moderate Energy Class 2 or Class 3 Piping Section XI, Division 1," Cases of ASME Boiler and Pressure Vessel Code, March 28, 2001.

[3.2] ASME Boiler and Pressure Vessel Code, Section XI, and Section XI Appendices, 1989 Edition, 2000 Addenda.

[3.3] ASME Boiler and Pressure Vessel Code, Section III, 2004 Edition.

[3.4] E-mail from Andrew Patko to Terry Hermann and Tim Griesbach, Subject: "RE: Dimensions of the Bonnet", July 20, 2007, SI File No. FNP-08Q-219.

[3.5] ASME Boiler and Pressure Vessel Code, Section III Appendices, 1989 Edition, 2000 Addenda.

[3.6] Structural Integrity Associates Calculation No. FNP-08Q-301, Rev. 0, "Flaw Evaluation in MSIV Bypass Valve in Farley Unit 2," August 6, 2007.

[3.7] E-mail from Andrew Patko to Tim Griesbach, Subject: "RE: MSIBV Draft Report", August 01, 2007, SI File No. FNP-08Q-220.

[4.1] Structural Integrity Associates, Inc., "**pc-CRACK™** Fracture Mechanics Software," Version 3.1 – 98348, 1998.

[4.2] ASME Boiler and Pressure Vessel Code, Section XI, and Section XI Appendices, 2004 Edition.

APPENDIX A

TIMELINE / SEQUENCE OF EVENTS

Date	Event/Comments	Source Document
10/28/2002	A "small body to bonnet steam leak" on valve Q2N11V0003B is identified.	Farley Nuclear Plant Work Order M02006820
11/7/2002	Some insulation was removed to see where the steam is coming from. The "steam seems to be coming from pressure seal area".	Farley Nuclear Plant Work Order M02006820
3/13/2004	2R16 begins	E-mail from A. Patko to T. Herrmann dated 7/26/2007
4/5/2004	Valve is disassembled. The work order notes "found bonnet loose before disassembly". Inspection of accessible areas of the stuffing box and valve stem is performed. No notes of nicks, scratches or worn surfaces.	Farley Nuclear Plant Work Order M02006820
4/7/2004	Valve seal ring and packing are replaced. Packing is located at the bottom of the stuffing box with the carbon spacer at the top of the stuffing box. The packing is torqued to 13 ft-lbs. No post maintenance leak testing was noted.	Farley Nuclear Plant Work Order M02006820
4/15/2004	2R16 ends	E-mail from A. Patko to T. Herrmann dated 7/26/2007
4/15/2004	During examination of nearby components during startup, valve Q2N11V0003B was noted to have a leak described as follows: "Water is dripping out of valve insulation at a rate of 1 drop every 3 seconds. Valve packing is dry. Valve appears to have a body to bonnet leak. Checked bonnet clamp for tightness as requested. Found SAT."	Farley Nuclear Plant Work Order M04003150
11/17/2004	Condition report written noting valve Q2N11V0003B has a "small steam leak" approximately 14 drops per minute. It notes work order M04003151 was used to check the bonnet clamp and proper valve assembly.	CR 2004105834

Date	Event/Comments	Source Document
11/19/2004	The leak is now noted to be getting worse at approximately 30 drops per minute and that the "lagging is starting to shred around the pipe, next to the valve". It notes work order M04003151 will make the valve repair.	CR 2004105834
3/5/2005	The pin used to connect the valve operator stem to the valve stem during manual valve operation was observed to have a broken latch that could have restricted valve open motion. The CR notes that "this is a recurring issue for these valves".	CR 2005102654
10/15/2005	2R17 begins	E-mail from A. Patko to T. Herrmann dated 7/26/2007
10/22/2005	Valve Q2N11V0003B is brought to the shop and disassembled. "Found evidence of leakage outside of seal".	Farley Nuclear Plant Work Order M0400315002
11/7/2005	Valve reassembled with new seal ring and packing. Valve packing configuration is changed to split the carbon spacer and place the lower spacer on the junk ring, then place the 5 rings of packing above the lower spacer and then use the upper spacer above the packing. This raises the bottom of the packing slightly more than 1" and places the bottom of the packing near the top of the bonnet threads. The packing torque is increased to 22 ft-lbs (no explanation provided). In addition, the stud diameter is listed as 5/8" on the valve packing data sheet instead of ½" shown on the previous valve packing data sheet (the stud diameter was subsequently confirmed to be 5/8"). The calculated packing friction increased from 323 lbs to 563 lbs. Inspection of <u>accessible</u> areas of the stuffing box and valve stem is performed. No notes of nicks, scratches or worn surfaces. No post maintenance leak testing was noted.	Farley Nuclear Plant Work Order M0400315002
12/9/2005	2R17 ends	E-mail from A. Patko to T. Herrmann dated 7/26/2007

Date	Event/Comments	Source Document
12/14/2005	Valve Q2N11V0003B was noted to have a leak described as follows: "Valve appears to have a body to bonnet leak underneath insulation".	Farley Nuclear Plant Work Order 2053235701
12/30/2005	Insulation was removed and "found bonnet leak, suspect pressure seal gasket area".	Farley Nuclear Plant Work Order 2053235701
6/25/2006	The hand wheel for the manual jacking device for Q2N11V0003E (on same steam line) "looks to be broken. The hand wheel is rubbing against a support". The CR notes this impacts the ability to manually operate the valve and that this valve also has a broken pin similar to the condition on valve Q2N11V0003B on 3/5/2005.	CR 2005112450
4/9/2007	2R18 begins	E-mail from A. Patko to T. Herrmann dated 7/26/2007
5/2/2007	The valve is reassembled with a new seal ring and packing. The packing configuration is the same as prior to maintenance, except the packing torque is returned to 13 ft-lbs (no explanation provided) and the calculated stem friction is 331 lbs. Inspection of <u>accessible</u> areas of the stuffing box and valve stem is performed. No notes of nicks, scratches or worn surfaces. No post maintenance leak testing was noted. "...with the small ID of the bonnet, it is difficult to get a thorough visual inspection..." The bonnet clamp is tightened using a hammer and bar. The Velan manual gives three options for tightening this clamp including: 1) Use a C-wrench with a torque wrench to tighten to 650 ft-lb 2) Use a standard wrench with a 36" extension and tap with a hammer until the bonnet clamp stops moving	Farley Nuclear Plant Work Order 2053235701 E-mail from J. Dykes to T. Griesbach dated 7/19/2007 E-mail from A. Patko to T. Herrmann dated 7/26/2007

Date	Event/Comments	Source Document
	3) Use a bar and a hammer, tapping and finish by strong hitting until the bonnet clamp no longer moves.	
5/29/2007	2R18 ends	E-mail from A. Patko to T. Herrmann dated 7/26/2007
7/5/2007	During an engineering support walk down of the main steam valve room area, "valve Q2N11V0003B has a packing leak and a through-wall leak on the bonnet." The flaw is noted as being "in the packing gland area of the valve". "Found packing nuts moved at 9 ft-lbs. Torqued packing to 12.5 ft-lbs (150 in lbs). Stopped packing leak and steam leak from pin hole in bonnet slowed considerably." The flaw is noted as being "on a short flat portion of the bonnet where the bonnet transitions from an OD threaded connection to a necked down, center bored area which forms the stuffing box."	Farley Nuclear Plant Work Order 2071565701 CR 2007106566 E-mail from A. Patko to T. Griesbach dated 7/18/2007
7/8/2007	Ultrasonic testing of the flaw location identified a loss of signal approximately 0.100" deep into the 0.300" thick bonnet. The surface is noted to be smooth. In addition, light sanding opened the leak up to a linear indication and revealed two additional leaks in the same area. The overall area where the identified flaws are located is approximately ¼" wide by 5/8" tall.	Applied Technical Services Ultrasonic Inspection Report – Job # A115613
7/26/2007	Measurements taken at Q2N11V0003B provide a location of the flaw at between 1.75" and 2.25" below the top of the bonnet.	E-mail from A. Patko to T. Herrmann dated 7/27/2007