VIRGINIA ELECTRIC AND POWER COMPANY
RICHMOND, VIRGINIA 23261

March 23, 1998

United States Nuclear Regulatory Commission
Attention: Document Control Desk
Washington, D. C. 20555

Serial No. 98-177
NL&OS/GDM R1
Docket No. 50-280
License No. DPR-32

Gentlemen:

VIRGINIA ELECTRIC AND POWER COMPANY
SURRY POWER STATION UNIT 1
ASME SECTION XI RELIEF REQUEST

On March 22, 1998, evidence of minor leakage was detected on the Unit 1 Residual Heat Removal (RHR) Class 2 piping. The leak was identified at a location downstream of the RHR heat exchangers' discharge and bypass piping in the common return header that feeds both Loops B and C Reactor Coolant System cold legs. Although the RHR piping is capable of performing its intended function, the piping does not meet the ASME code acceptance criteria due to the through-wall leakage. An evaluation, which included a quantitative structural analysis, determined the RHR piping to be fully capable of performing its intended function.

Therefore, pursuant to 10 CFR 50.55a(a)(3)(ii), a one-time relief is requested from ASME Section XI pressure boundary leakage corrective action and flaw evaluation requirements to permit a determination of operability of the RHR system. The relief request and the basis for the request are provided in Attachment 1. Attachment 2 provides the results of the quantitative structural analysis evaluation.

This request has been approved by the Surry Station Nuclear Safety and Operating Committee. If you have any questions or require additional information, please contact us.

Very truly yours,

R F Saunders

R. F. Saunders
Vice President - Nuclear Engineering and Services

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A047

Attachments

9803270073 980323
PDR ADOCK 05000280
P PDR

cc: United States Nuclear Regulatory Commission
Region II
Atlanta Federal Center
61 Forsyth Street, SW, Suite 23T85
Atlanta, Georgia 30303

Mr. R. A. Musser
NRC Senior Resident Inspector
Surry Power Station

Commitment Summary

1. The RHR piping will be repaired or replaced prior to the unit exceeding 350 degrees and 450 psig during the startup. Should a temporary non-Code repair prove to be the most viable option until a Code repair can be implemented during a refueling outage, additional code relief would be requested prior to the unit exceeding 350 degrees and 450 psig during the maintenance outage.

2. During the shutdown condition a visual examination of the location will be conducted once per day prior to the repair or replacement to monitor for any changes in leakage that would require immediate attention.

Attachment 1

ASME Section XI Relief Request
Residual Heat Removal System Piping

Surry Power Station Unit 1

Attachment 1

Relief Request
Surry Power Station Unit 1

I. Identification of Components

System: Residual Heat Removal
Class: ASME Class 2
Drawing: 11448-WMKS-0122A1
Component: Piping identified as 12"-RH-19-602 near Weld 2-02

II. Impractical Code Requirements

ASME Section XI, 1989 Edition, IWA-5250, Corrective Measures, and IWC-3600, Analytical Evaluation of Flaws, as applied to through-wall leakage in the piping pressure boundary.

III. Basis For Relief

Surry Unit 1 was ramping down to cold shutdown to effect repairs on unrelated equipment when a through-wall leak was identified on piping approximately 1/8" upstream of the toe of weld 2-02 on 12"-RH-19-602. The piping is seamed (welded) austenitic stainless type 304.

The leakage was identified when collected boric acid was observed at the location identified above. Boric acid accumulation was estimated as 8" long, 1" wide by 1/4" thick. No boric acid accumulation was found on the floor. The boric acid was removed to identify the leakage source. A rounded indication measuring 1/32" in diameter was found approximately 1/8" upstream of the toe of weld 2-02. Seepage, which quickly solidified, was identified at the location approximately 20 seconds after cleaning.

Flaw characterization was attempted using ultrasonic techniques (UT). An ultrasonic thickness examination at the location measured the piping thickness as 0.374 inches. The 12 inch schedule 40S piping nominal thickness is 0.375 inches. A shear wave ultrasonic examination was performed at the weld including approximately 4 inches of base metal for 360 degrees. The exam consisted of 45 and 60 degree shear wave scans in three directions (clockwise, counterclockwise and perpendicular to the weld). A zero degree scan was also performed on the area. Typical reflectors associated with intergranular stress corrosion cracking (IGSCC), transgranular cracking or subsurface cavities were not identified. No indications were identified by the UT examinations. As such, specific sizing could not be determined.

The ASME Section XI Code in IWA-5250 and IWC-3600 requires the repair or replacement of through-wall leakage found during operation. As such, the piping was declared inoperable pending repair or replacement. Since the RHR piping was declared inoperable, the two cooling loops required for decay heat removal by Technical Specifications (TS 3.1.A.1.d) were satisfied by Reactor Coolant System loops.

A structural analysis using fracture mechanics was performed on the affected piping. The problem assumed a through-wall flaw 0.34 inches in length or approximately ten times greater than the surface conditions identified. The analysis confirmed that piping structural integrity would remain stable with assuming a flaw of this size. Based on the structural analysis of the affected line, the RHR system remains available to perform its intended safety function.

The planned Surry maintenance outage was scheduled to repair the pressurizer manway and power operated relief valves (PORVs) to eliminate leakage and to replace a reactor coolant pump motor, all unrelated conditions. If the Reactor Coolant System (RCS) were to remain pressurized and a pressurizer bubble were to be reestablished in order to perform RHR repairs now, leakage through the pressurizer manway and PORVs would be likely.

Although RHR is in service, Tech Spec 3.5.A.3 requires all system piping and valves required to establish a flow path (RHR) be operable. The flaw is in a common return line for both trains of RHR and the Technical Specifications do not provide an action statement for the inoperable piping. It would be inappropriate to leave cold shutdown unless the piping could be considered operable. However, the RHR system needs to be isolated and drained to facilitate Code repairs which requires another mode of cooling. Remaining at Cold Shutdown with RHR isolated and drained creates the specific hardship.

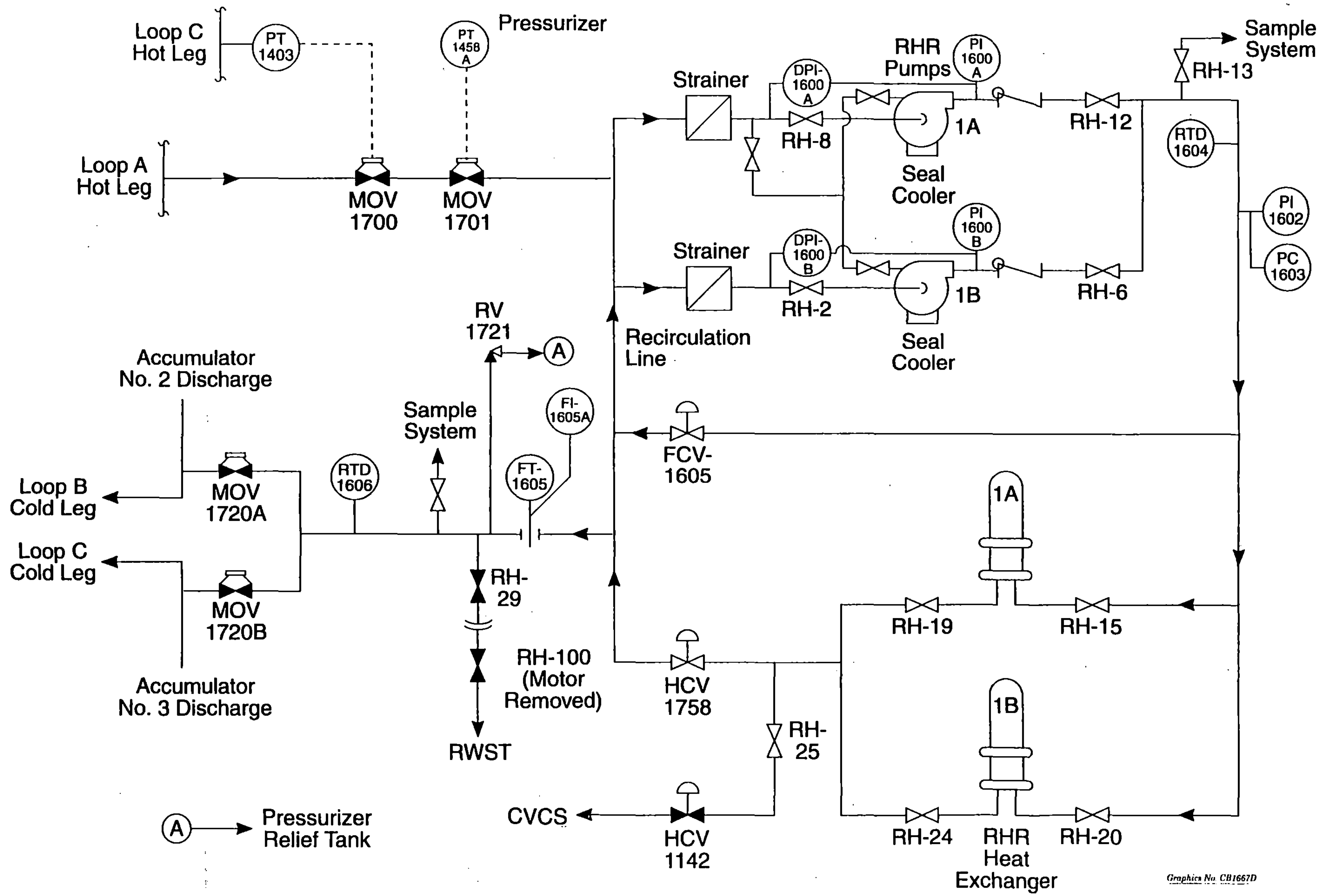
With the plant at Cold Shutdown, in conjunction with the need to isolate and drain the RHR system for repairs, the only available method for maintaining the plant at less than 200 degrees would be to use the currently operable/operating RCS loops. This method is not preferred for cooling the RCS at less than 200 degrees. Specifically, the RCS cooling method requires the RCS to remain at approximately 300 psig. This method utilizes an RCP pumping the reactor coolant through the steam generator primary side and feeding/steaming on the secondary side. Therefore, the temperature at which the primary side can be maintained is dependent on steam generator pressure (due to the delta T across the steam generator and the relationship between Tsat and Psat). The specific hardships to this approach are that 1) the RCS would have to remain pressurized preventing the necessary outage maintenance and 2) the only way to use this method and keep temperature less 200 degrees F would require having the steam generators steaming to a vacuum. The source of the vacuum would have to be the main condenser. The secondary systems/components that would be necessary to implement this approach are non-safety related with their power sources coming from non-emergency buses. As a result, this approach relies on a backup method of cooling the reactor that is not normally used. Additionally, the operations staff has had no formal training on using this method of plant cooling nor are procedures currently available for providing the required guidance. In order to ensure positive control of the evolution, procedures would have to be developed and training would have to be conducted prior to implementing the repair. Therefore, the option of repairing the flaw in the current operating condition (i.e., relying on heat removal from the steam generators at below 200 degrees) is undesirable.

Defueling is not a practical approach for repairs due to the significant and unplanned impacts it would cause to the presently planned maintenance outage scope. Furthermore, even if it were desired to place the plant in a defueled condition, it would require operating for some period of time without RCS loops and only the RHR system while the fuel was being removed which would also require relief.

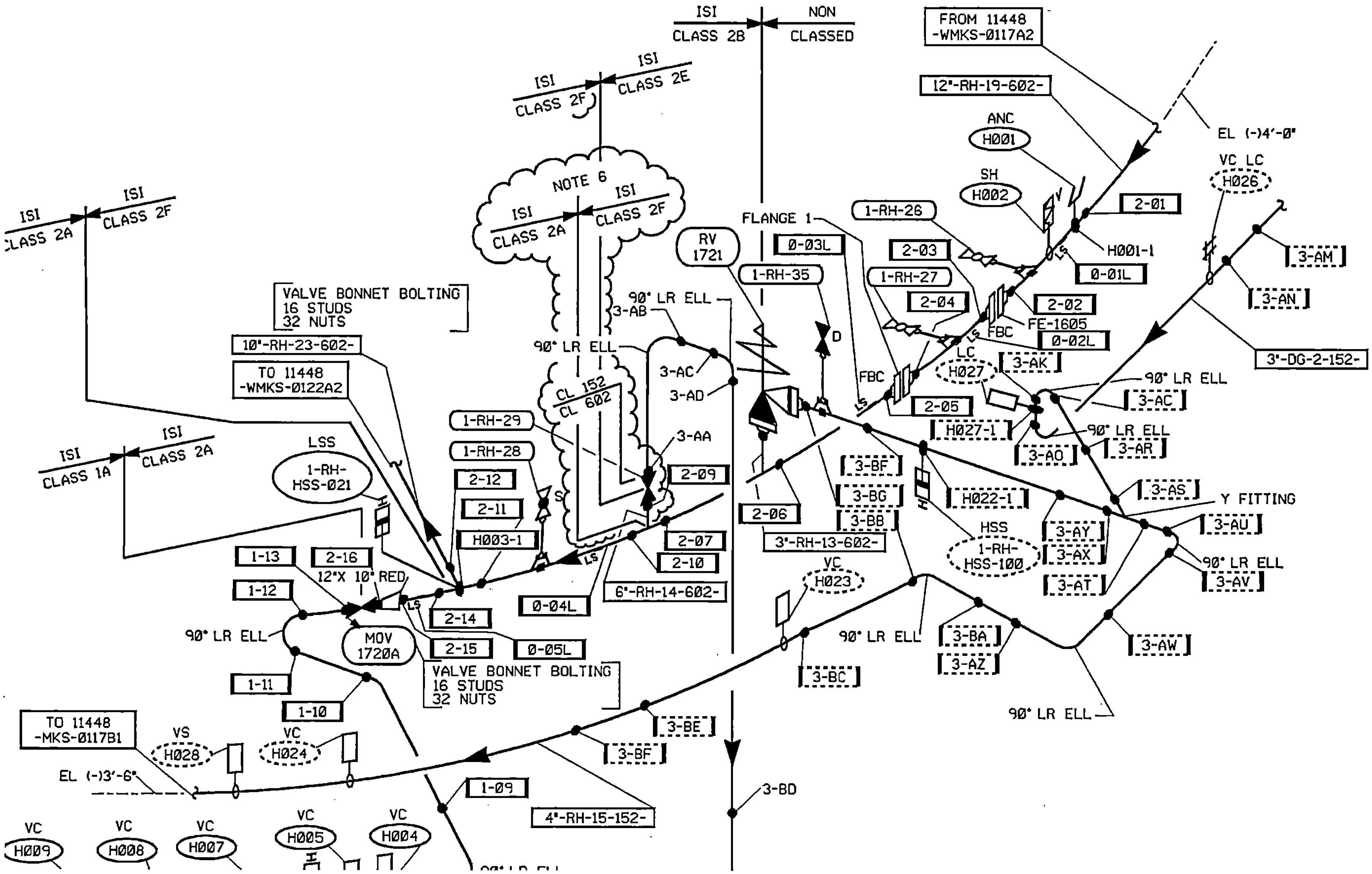
Although we cannot specifically characterize the failure mechanism at this time, based on previous ISI examinations, pressure testing and visual walkdowns in accordance with ASME Section XI, no additional evidence exists which would indicate that this type of flaw is present elsewhere within the RHR System. Therefore, given the minor leakage observed and the analyzed structural integrity of the affected RHR piping, performing the repair or replacement in an abnormal cooling configuration as well as delaying the repair of the equipment mentioned above would result in a hardship.

IV. Alternate Requirements

Alternatively, the RHR piping will be placed in service and repaired or replaced prior the unit exceeding 350 degrees and 450 psig during the startup. These alternative arrangements will allow careful planning and staging of resources to complete the appropriate Code requirements and allow immediate repair or replacement of the unrelated equipment. Should a temporary non-Code repair prove to be the most viable option until a Code repair can be implemented during a refueling outage, additional code relief would be requested prior to exceeding 350 degrees and 450 pisg in the RCS following the maintenance outage. During the shutdown condition, a visual examination of the location will be conducted once per day prior to the repair or replacement to monitor for any changes in leakage that would require immediate attention.



RESIDUAL HEAT REMOVAL
SYSTEM DIAGRAM
11-18-97



ISI
CLASS 2B
NON
CLASSED
FROM 11448
-WMKS-0117A2
12"-RH-19-602-
EL (-)4'-0"
ANC
H001
SH
H002
2-01
H001-1
0-01L
VC LC
H026
3-AM
3-AN
3'-DG-2-152-
1-RH-26
2-03
1-RH-27
2-04
2-02
FE-1605
0-02L
FBC
LC
H027
3-AK
2-05
H027-1
90° LR ELL
3-AC
3-AO
3-AR
3-AS
Y FITTING
3-AU
3-AY
3-AX
3-AT
3-AV
3-AW
H022-1
HSS
1-RH-
HSS-100
FLANGE 1
0-03L
RV
1721
1-RH-35
D
3-BF
3-BG
3-BB
2-06
3'-RH-13-602-
VC
H023
3-BA
3-AZ
3-BC
3-BE
3-BD
ISI
CLASS 2F
ISI
CLASS 2E
NOTE 6
ISI
CLASS 2A
ISI
CLASS 2F
CL 152
CL 602
3-AB
3-AC
3-AD
3-AA
2-09
2-07
2-10
6'-RH-14-602-
0-04L
1-RH-29
1-RH-28
2-12
2-11
H003-1
VALVE BONNET BOLTING
16 STUDS
32 NUTS
10"-RH-23-602-
TO 11448
-WMKS-0122A2
ISI
CLASS 2A
ISI
CLASS 2F
ISI
CLASS 1A
ISI
CLASS 2A
LSS
1-RH-
HSS-021
1-13
2-16
12"X 10" RED
1-12
2-14
2-15
0-05L
MOV
1720A
VALVE BONNET BOLTING
16 STUDS
32 NUTS
1-11
1-10
1-09
4'-RH-15-152-
TO 11448
-MKS-0117B1
VS
H028
VC
H024
EL (-)3'-6"
VC
H009
VC
H008
VC
H007
VC
H005
VC
H004

Attachment 2

Structural Analysis Assessment of RHR Piping

Surry Power Station Unit 1

Attachment 2

Structural Integrity Evaluation
12-RH-19-602 Line With Through-Wall Leak
Surry Power Station Unit 1

Evaluation

An analysis of 12-RH-19-602 line with a minor through-wall leak upstream of flow element 1-RH-FE-1605 was performed to evaluate the structural integrity of the piping. Three different analyses were performed to establish structural integrity:

(1) Area reinforcement analysis to establish that no ductile tearing of the line will occur when a postulated hole type of flaw is subjected to applicable design pressure.

(2) A limit load analysis to establish that no ductile rupture will occur when the line with a postulated crack-like flaw is subjected to dead weight, thermal expansion, design basis earthquake loading in addition to design pressure.

(3) A fracture mechanics analysis to establish that no brittle fracture will occur when the line with a postulated crack-like flaw is subjected to dead weight, thermal expansion, design basis earthquake loading in addition to design pressure.

No flaw was determined from ultrasonic testing measurement at the location. Flaw size was conservatively determined by visual observation to be 1/32". There is no clear indication of any crack-like flaw at the location. For the purpose of conservative analysis, a through-wall hole and through-wall crack were postulated.

Loading Conditions:

- Design Pressure: - 600 psig, Design Temperature: - 400°F
- Dead weight forces and moments at the location from Reference 1.
- Thermal expansion forces and moments at the location from Reference 1.
- Design basis earthquake forces and moments at the location from Reference 1.

(1) Area Reinforcement Analysis

An analysis was performed to determine the largest postulated hole the line can sustain without ductile tearing when subjected to design pressure. The analysis showed that the pipe parent material will provide adequate reinforcement to a hole 0.34" in diameter such that no ductile tearing will occur. The estimated actual size of the flaw in the pipe is determined to be approximately 1/32" (0.03") which is significantly smaller than the 0.34" limiting flaw size determined from the area reinforcement analysis. Therefore, ductile tearing of the piping is unlikely.

(2) Limit Load Analysis

The limit load analysis yielded a minimum factor of safety of 17 based upon the analyzed flaw length. The analysis considered a material flow stress of 36.4 ksi representing the mid-point of the ultimate strength and yield point stress for A312-TP304 stainless steel material at the design temperature of 400°F. The calculated pipe loads from the stress calculation of Reference 1 were applied at the flaw location. The results of the analysis indicate that there is enough margin against net section plasticity such that a ductile rupture will not occur at the leak location.

(3) Fracture Mechanics Evaluation

The flaw location was analyzed using the maximum permissible flaw length of 0.34". The flawed pipe section was analyzed for a design pressure of 600 psig in addition to the loads from normal operating thermal, dead weight and seismic DBE loadings. The calculated stress intensity factors for bending (K_{IB}), pressure (K_{IP}) and axial tension (K_{IT}) were multiplied with a safety factor of 1.4 before adding the residual stress (K_{IR}) intensity factor. The residual stress intensity factor was calculated per Reference 3. For the purpose of this evaluation, a generic allowable (K_{IC}) of 135 ksi $\sqrt{in}$ was used for the material using the guidance from NRC Generic Letter 90-05 (Reference 4). The review of the results indicates that the ratio of the calculated stress intensity factor to the allowable stress intensity factor is 0.175 indicating that the piping can sustain a significantly larger flaw than the analyzed flaw. Therefore, a failure of brittle fracture is highly unlikely to occur at the flaw location.

Conclusion

Based on the area reinforcement analysis, the limit load analysis, and the fracture mechanics evaluation performed for the flaw location identified and attached herewith, it is concluded that the flaw location with maximum flaw size of up to 0.34" will perform its intended function by maintaining structural integrity. The following conclusions can therefore be drawn:

1. Ductile tearing is unlikely to occur at the flaw location when the piping is subjected to the design pressure of 600 psig.

2. The limit load analysis shows that there is adequate margin against a ductile rupture.

3. The fracture mechanics analysis shows that the calculated stress intensity factor is well below the allowable stress intensity factor. A brittle fracture failure is therefore unlikely.

References

1. Pipe Stress Calculation 12846.22-NP(N)-537-X12, Rev. 2, Addendum 02A

2. Ductile Fracture Handbook by EPRI (NP-6301-D)

3. Evaluation of Flaws in Ferritic Piping by EPRI (NP-6045)

4. NRC Generic Letter 90-05, Guidance for Performing Temporary Non-Code Repair of ASME Code Class 1, 2, and 3 Piping

STRUCTURAL INTEGRITY EVALUATION OF RHR PIPE

LINE NO.: 12-RH-19-602 DATA POINT: 190-200

CALCULATION NO.: 12846.22-NP(N)-537-X12, Rev. 2, Add 02A WELD NO.:

LEAKER/ AUGMENT DWG. NO.:

CASE	DEAD WEIGHT	THERM-1	THERM-2	MAX. THERM	OBE SAM	OBEI	DBET	TOTAL
AXIAL FORCE F_X (lbs)	61	6702	N/A	6702	N/A	N/A	2077	8840
TORSION -M_X (ft-lbs)	383	2031	↓	2031	↓	↓	387	2801
BENDING MOMENT M_Y (ft-lbs)	64	2081	↓	64	↓	↓	3968	6113
BENDING MOMENT M_Z (ft-lbs)	2800	1899	↓	1899	↓	↓	2183	6882

TOTAL = DEAD WEIGHT + MAXIMUM THERMAL + [DBEI + 2(OBEA)]

(1) NUPIPE RUN DATED:

(2) OUTSIDE DIAMETER = 12.75" WALL THICKNESS = 0.375"

(3) DBEA = 2(OBEA)

(4) ANALYZED FLAW LENGTH = 0.34"

(5) MEASURED FLAW LENGTH =

(6) STRESS INTENSITY RATIO = 0.175 FILE NAME: Frac200.mcd

(7) LIMIT LOAD F_S = 17.33 FILE NAME: Frac201.mcd

STRUCTURAL INTEGRITY EVALUATION OF RHR PIPE

```
     Run (R)           Branch (B)          BRANCH REINFORCEMENT AREA CHECK
Do = 12.750 in       do =  0.340 in
Tn =  0.375 in       Tn =  0.000 in        Component ID:THRU-WALL
Tm =  0.258 in       Tm =  0.000 in
Ta =  0.375 in       Ta =  0.000 in        Line Number: 12-RH-19-602
WRate0.0000 in/yr WRate 0.0000 in/yr
Te =  0.000 in      alpha=     90 deg      Reqd Reinforcement =    0.09 in2
Width Reinforcing Ring = 0.000 in
```

time (yrs)	Ta(R) (in)	Ta(B) (in)	d1 (in)	d2 (in)	L (in)	A1 (in2)	A2 (in2)	A4 (in2)	A1+A2+A4 Total	Req'd (in2)
0.0	0.375	0.000	0.34	0.55	0.000	0.09	0.00	0.00	0.09	0.09
0.2	0.375	0.000	0.34	0.55	0.000	0.09	0.00	0.00	0.09	0.09
0.4	0.375	0.000	0.34	0.55	0.000	0.09	0.00	0.00	0.09	0.09
0.6	0.375	0.000	0.34	0.55	0.000	0.09	0.00	0.00	0.09	0.09
0.8	0.375	0.000	0.34	0.55	0.000	0.09	0.00	0.00	0.09	0.09
1.0	0.375	0.000	0.34	0.55	0.000	0.09	0.00	0.00	0.09	0.09
1.2	0.375	0.000	0.34	0.55	0.000	0.09	0.00	0.00	0.09	0.09
1.4	0.375	0.000	0.34	0.55	0.000	0.09	0.00	0.00	0.09	0.09
1.6	0.375	0.000	0.34	0.55	0.000	0.09	0.00	0.00	0.09	0.09
1.8	0.375	0.000	0.34	0.55	0.000	0.09	0.00	0.00	0.09	0.09
2.0	0.375	0.000	0.34	0.55	0.000	0.09	0.00	0.00	0.09	0.09
2.2	0.375	0.000	0.34	0.55	0.000	0.09	0.00	0.00	0.09	0.09
2.4	0.375	0.000	0.34	0.55	0.000	0.09	0.00	0.00	0.09	0.09
2.6	0.375	0.000	0.34	0.55	0.000	0.09	0.00	0.00	0.09	0.09
2.8	0.375	0.000	0.34	0.55	0.000	0.09	0.00	0.00	0.09	0.09
3.0	0.375	0.000	0.34	0.55	0.000	0.09	0.00	0.00	0.09	0.09
3.2	0.375	0.000	0.34	0.55	0.000	0.09	0.00	0.00	0.09	0.09
3.4	0.375	0.000	0.34	0.55	0.000	0.09	0.00	0.00	0.09	0.09
3.6	0.375	0.000	0.34	0.55	0.000	0.09	0.00	0.00	0.09	0.09
3.8	0.375	0.000	0.34	0.55	0.000	0.09	0.00	0.00	0.09	0.09
4.0	0.375	0.000	0.34	0.55	0.000	0.09	0.00	0.00	0.09	0.09
4.2	0.375	0.000	0.34	0.55	0.000	0.09	0.00	0.00	0.09	0.09
4.4	0.375	0.000	0.34	0.55	0.000	0.09	0.00	0.00	0.09	0.09
4.6	0.375	0.000	0.34	0.55	0.000	0.09	0.00	0.00	0.09	0.09
4.8	0.375	0.000	0.34	0.55	0.000	0.09	0.00	0.00	0.09	0.09
5.0	0.375	0.000	0.34	0.55	0.000	0.09	0.00	0.00	0.09	0.09
5.2	0.375	0.000	0.34	0.55	0.000	0.09	0.00	0.00	0.09	0.09
5.4	0.375	0.000	0.34	0.55	0.000	0.09	0.00	0.00	0.09	0.09
5.6	0.375	0.000	0.34	0.55	0.000	0.09	0.00	0.00	0.09	0.09
5.8	0.375	0.000	0.34	0.55	0.000	0.09	0.00	0.00	0.09	0.09
6.0	0.375	0.000	0.34	0.55	0.000	0.09	0.00	0.00	0.09	0.09
6.2	0.375	0.000	0.34	0.55	0.000	0.09	0.00	0.00	0.09	0.09
6.4	0.375	0.000	0.34	0.55	0.000	0.09	0.00	0.00	0.09	0.09
6.6	0.375	0.000	0.34	0.55	0.000	0.09	0.00	0.00	0.09	0.09
6.8	0.375	0.000	0.34	0.55	0.000	0.09	0.00	0.00	0.09	0.09
7.0	0.375	0.000	0.34	0.55	0.000	0.09	0.00	0.00	0.09	0.09
7.2	0.375	0.000	0.34	0.55	0.000	0.09	0.00	0.00	0.09	0.09
7.4	0.375	0.000	0.34	0.55	0.000	0.09	0.00	0.00	0.09	0.09
7.6	0.375	0.000	0.34	0.55	0.000	0.09	0.00	0.00	0.09	0.09
7.8	0.375	0.000	0.34	0.55	0.000	0.09	0.00	0.00	0.09	0.09
8.0	0.375	0.000	0.34	0.55	0.000	0.09	0.00	0.00	0.09	0.09
8.2	0.375	0.000	0.34	0.55	0.000	0.09	0.00	0.00	0.09	0.09
8.4	0.375	0.000	0.34	0.55	0.000	0.09	0.00	0.00	0.09	0.09
8.6	0.375	0.000	0.34	0.55	0.000	0.09	0.00	0.00	0.09	0.09
8.8	0.375	0.000	0.34	0.55	0.000	0.09	0.00	0.00	0.09	0.09
9.0	0.375	0.000	0.34	0.55	0.000	0.09	0.00	0.00	0.09	0.09

Reference: USAS B31.1.0 - 1967 "Power Piping" Section 104.3

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STRUCTURAL INTEGRITY EVALUATION OF RHR PIPE

LIMIT LOAD EVALUATION FOR THRU-WALL LEAK
12-RH-19-602/ SURRY UNIT 1

-Axial Load, F	$F := 8840$	lbs
- Torsion, T	$T := 2801$	ft-lbs
-Bending Moment	$MY := 6113$	ft-lbs
-Bending Moment	$MZ := 6882$	ft-lbs

-Resultant Moment $MR := \sqrt{MY^2 + MZ^2 + T^2}$ $MR = 9.622 \cdot 10^3$

$P := 600$

$T := 400$

$Sh := 13770$

$Sy := 20800$

$Su := 52000$

$\sigma_f := 0.5 \cdot (Sy + Su)$

$\sigma_f = 3.64 \cdot 10^4$

$t := 0.375$

$R_i := \frac{12.75 - 2 \cdot t}{2}$

$R_i = 6$

$R_m := \frac{12.75 - t}{2}$

$R_m = 6.188$

$\theta := \frac{0.17}{R_m}$ $\theta = 0.027$

$degrees := \frac{\theta \cdot 180}{\pi}$ $degrees = 1.574$

$\beta := \frac{\theta}{2} + \left(\frac{\pi \cdot R_i^2 \cdot P + F}{4 \cdot \sigma_f R_m \cdot t} \right)$

$\beta = 0.241$

$$M := 2\cdot\sigma_f R_m{}^2\cdot t\cdot(2\cdot\cos(\beta) - \sin(\theta))$$

$M = 2.001\cdot10^6$ in-lbs

$$M_a := \frac{M}{12}$$

$M_a = 1.668\cdot10^5$ ft-lbf

The calculated factor of safety is,

$$F_s := \frac{M_a}{MR}$$

$F_s = 17.334$

STRUCTURAL INTEGRITY EVALUATION OF RHR PIPE

K-FACTOR EVALUATION FOR THRU-WALL LEAK
LINE 12-RH-19-602 / SURRY UNIT 1

Fracture Mechanics evaluation

The Stress Intensification Factor(s), K, due to bending, internal pressure and axial tension are to be determined. Postulated Crack Length 0.34" (Circumferential)

K due to Bending Moment

CONSTANTS

Applied Moment	$M := 110459$		in-lbs
Outside diameter	$OD := 12.75$ in		
thickness(pipe)	$t := 0.375$ in		
meam radius	$R_m := \frac{OD - t}{2}$	$R_m = 6.188$	
theta, radians	$\theta := \frac{0.17}{R_m}$	$\theta = 0.027$	

RANGE CONSTRAINTS

R.m/t must be in the range of 10< R(m)/t <=20

$\frac{R_m}{t} = 16.5$ since >=10

θ/π must be in the range of $0 \le \theta/\pi \le 0.55$

$$\frac{\theta}{\pi} = 8.745 \cdot 10^{-3}$$

$$A := \left(0.4 \cdot \frac{R_m}{t} - 3.0\right)^{0.25} \qquad A = 1.377$$

hence,

$$F_b := 1 + A \cdot \left[4.5967 \cdot \left(\frac{\theta}{\pi}\right)^{1.5} + 2.6422 \cdot \left(\frac{\theta}{\pi}\right)^{4.24}\right]$$

$$F_b = 1.005$$

and,

$$\sigma_b := \frac{M}{\pi \cdot R_m^2 \cdot t} \qquad \sigma_b = 2.449 \cdot 10^3$$

K(I) due to bending is found by:

$$K_{IB} := \left[\sigma_b \cdot (\pi \cdot R_m \cdot \theta)^{0.5}\right] \cdot F_b$$

$K_{IB} = 1.799 \cdot 10^3$ psi $\sqrt{in}$

K due to Internal Pressure

CONSTANTS

Pressure $P := 600$

RANGE CONSTRAINTS

λ must be in the range of $\lambda <= 5$

$$\lambda := \theta \cdot \left(\frac{R_m}{t}\right)^{0.5} \qquad \lambda = 0.112$$

hence,

$F_{m1} := 1 + 0.1501 \cdot \lambda^{1.5}$ (for $\lambda <= 2$) $F_{m2} := 0.8875 + 0.2625 \cdot \lambda$ (for $2 < \lambda <= 5$)

Internal Pressure

$$\sigma_m := \frac{P \cdot OD}{4 \cdot t} \qquad \sigma_m = 5.1 \cdot 10^3$$

$$K_{IP} := \sigma_m \cdot (\pi \cdot R_m \cdot \theta)^{0.5} \cdot \mathrm{if}(\lambda \le 2, F_{m1}, F_{m2})$$

$K_{IP} = 3.748 \cdot 10^3$ psi $\sqrt{in}$

K due to Axial Tension

CONSTANTS

$P_a := 8844$ axial load

$\sigma_t := \frac{P_a}{2 \cdot \pi \cdot R_m \cdot t}$ $\sigma_t = 606.628$

for R/t <=10

$A_t := \left(0.4 \cdot \frac{R_m}{t} - 3.0\right)^{.25}$ $A_t = 1.377$

$F_t := 1 + A_t \cdot \left[5.3303 \cdot \left(\frac{\theta}{\pi}\right)^{1.5} + 18.77 \cdot \left(\frac{\theta}{\pi}\right)^{4.24}\right]$

$F_t = 1.006$

thus,

$K_{It} := \sigma_t \cdot (\pi \cdot R_m \cdot \theta)^{0.5} \cdot F_t$

$K_{It} = 445.987$ psi $\sqrt{in}$

CALCULATION OF RESIDUAL STRESS

$S := 20800.0$ psi Yield Stress for Stainless Steel 304

$F_t := 1 + A \cdot \left[5.3303 \cdot \left(\frac{\theta}{\pi}\right)^{1.5} + 18.773 \cdot \left(\frac{\theta}{\pi}\right)^{4.24}\right]$

$F_t = 1.006$

$K_{IR} := S \cdot (\pi \cdot R_m \cdot \theta)^{0.5} \cdot F_t$

$K_{IR} = 1.529 \cdot 10^4$ psi $\sqrt{in}$

Total K(I)

$$K_T := 1.4 \cdot \left(K_{IB} + K_{IP} + K_{It}\right) + K_{IR}$$

$$K_{ALL} := 135000\ \text{psi}\ \sqrt{\text{in}}$$

STRESS RATIO (SR)

$$SR := \frac{K_T}{K_{ALL}}$$

$$SR = 0.175$$