GE Nuclear Energy

General Electric Company
175 Curtner Avenue, San Jose, CA 95125

April 19, 1993

Docket No. STN 52-001

Chet Poslusny, Senior Project Manager
Standardization Project Directorate
Associate Directorate for Advanced Reactors
and License Renewal
Office of the Nuclear Reactor Regulation

Subject: Submittal Supporting Accelerated ABWR Review Schedule - **Chapter 3, DFSER Open Items 3.9.3.1-2 and 14.1.3.3.5.10-1, Thermal Striping**

Dear Chet:

Attachment A addresses the subject two DFSER items for close-out.

Please provide copies of this transmittal to Shou Hou, Dave Terao and Jim Brammer.

Sincerely,

Jack Fox

Jack Fox
Advanced Reactor Programs

cc: Giuliano DeGrassi (BNL)
Norman Fletcher (DOE)
Maryann Herzog (GE)
Henry Hwang (GE)
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ATTACHMENT A April 19, 1993

DFSER OPEN ITEMS 3.9.3.1-2 & 14.1.3.3.5.10-1
FATIGUE DUE TO THERMAL STRIPING EFFECTS

Subject: **ABWR Piping DFSER Open Items 14.1.3.3.5.10-1, ITAAC-Methodology to Address Thermal Striping, and 3.9.3.1-2, Thermal Stratification Load Definition**

Purpose: This attachment summarizes the evaluation of the thermal striping effects performed for the ABWR feedwater piping. It is shown that the thermal-striping fatigue effects are negligible in the ABWR feedwater piping.

References:

(1) GE Drawing 103E1414, "Feedwater Press/Temp Cycle Chart and Load Set"

(2) "Fatigue of LMFBR Piping Due to Flow Stratification," by W.S. Woodward, Westinghouse Electric Corp.

(3) "Development of a Thermal Striping Spectrum for use in Evaluating Pressurizer Surge Line Fatigue", by A.F. Deardorff, Structural Integrity Associates, Inc.; W. Hafner and L. Wolf, Battelle; J.H. Kim, EPRI.

(4) NEDO-21821-A, 1980. "Boiling Water Reactor Feedwater Nozzle/Sparger Final Report," by H.Watenabe.

1.0 BACKGROUND

Thermal stratification can occur in the ABWR feedwater piping as described in ABWR SSAR Subsection 3.9.3.1. Thermal stratification is specified as a feedwater piping system design load. The thermal stratification temperatures and number of occurrences are specified in Reference 1.

Under stratified flow conditions, it has been reported in References 2 and 3 that a relatively thin dynamic interface region exists, which oscillates in a wave pattern. This results in undulation in the hot-to-cold interface region which produces thermal striping on the inside of the pipe wall. This thermal striping phenomenon has been observed in LMFBR water model flow tests performed by Westinghouse (Reference 2) as well as in experimental studies performed at the German HDR test facility (Reference 3).

These flow tests have indicated that the frequency of oscillation can range between 0.1 and 3 hz. Reference 2 states that "Fifteen percent of this total measured less than 10 percent of the fluid stratification ΔT. Seventy percent of the cycles were less than thirty-five percent of the fluid ΔT, while only two percent measured less than sixty percent of the fluid ΔT. Thus only a small percent of the total cycles approached the maximum amplitude."

Thermal striping stresses are the result of differences between the pipe inside surface temperatures which vary with time due to the interface oscillation and the average through-wall temperatures. Provided in this attachment is a summary of the results of the feedwater piping thermal striping stress analysis. These results confirm that the feedwater thermal striping fatigue usage is minimal and therefore, thermal striping fatigue effects are negligible per the ASME Section III Code fatigue evaluation requirements.

2.0 THERMAL STRIPING EVALUATION FOR FEEDWATER HEADER PIPE

2.1 Description

The operating conditions that result in stratification in the ABWR feedwater header are different from the conditions reported in References 2 and 3. Stratification in the header is worst when the feedwater line is filled with hot water and colder water is introduced at a low (2.1%) flow rate. Striping during this period, if it exists at all, will not be sustained for the following reason: As the hot water is flushed from the piping, the hot-to-cold interface will move upward, so the points at the pipe surfaces that could be subjected to temperature fluctuations caused by striping are constantly changing. This prevents a large number of temperature cycles occurring at any one point on the pipe surface. Further, the interface between the hot and cold water will not remain sharp along the header; the diffusion zone at the interface will continually widen because of heat transfer and turbulence between the hot and cold fluids.

However, calculations summarized in Section 2.2 through 2.3 show that stresses at the pipe wall due to striping are well below the metal endurance limit, and are therefore negligible, even when these very conservative assumptions are made:

a) The elevation of the stratification interface remains at the same elevation in the feedwater header for long periods of time.

b) The step change in temperature at the interface is assumed to be equal to the maximum difference in temperature between the hot and cold fluids.

c) The interface between the hot and cold fluids is assumed to be sharp.

d) The frequency of striping at the interface is assumed to be the frequency that results in the maximum thermal stress at the pipe wall.

2.2 Feedwater Line Header Striping Stress Evaluations

The maximum thermal stratification ΔT in the horizontal feedwater header pipe inside the containment is 120° F, per Reference 1. This is the maximum temperature difference between the top and the bottom of the pipe. Reference 3 indicates that the striping temperature range is less than 60% of the top and bottom pipe stratification ΔT. In this analysis, it is conservatively assumed to be 120° F.

The striping frequency can be between 0.1 to 3 Hz. Based on Reference 3 test data, striping occurs at a combination of all frequencies between 0.1 to 3 Hz (period 10 sec to 0.33 sec). Because the pipe inside surface is assumed to be subject to a step change in temperature, the longer the period is assumed, the higher the stress will be. The reason is that during very short period of a cycle the metal temperature does not have enough time to react before the temperature is reversed. Therefore, the worst period of 10 second (0.1 Hz) is assumed in the calculation. Another case with 0.5 Hz (2 sec period) is also considered to show the difference in the results.

The surface heat transfer coefficient (h_c) during striping is calculated as follows:

Flow rate	= 2.1% rated flow
	= 420 gpm (use 600 gpm for conservatism)
Pipe inside diameter	= 19.25"
Water temperature	= 420° F, assumed maximum for h_c calculation
Viscosity	= 0.164E-5 ft-sq/sec
k	= 0.375 btu/hr ft F
V	= 0.66 ft/sec
Re	= 0.647E6
Pr	= 0.907
h_c	= 0.023 (k/D)(Re)**0.8 (Pr)**0.333 (Eq. 1)
	= 232 btu/hr ft-sq F

The maximum top layer temperature is 270° F. Assuming this temperature, the heat transfer coefficient is calculated to be as follows:

Viscosity	= 0.249E-5 ft-sq/sec
k	= 0.396 btu/hr ft F
Re	= 0.425E6
Pr	= 1.342
V	= 0.66 ft/sec
h_c	= 0.023 (k/D)(Re)**0.8 (Pr)**0.333
	= 199 btu/hr ft-sq F

It will be conservative to use h_c=232 btu/hr ft-sq F for temperature gradient analysis.

2.3 Results of Calculations for Header Pipe

The heat transfer coefficient was input to a heat transfer program to compute the temperature gradient time histories. The heat transfer program is a finite difference program. The pipe wall thickness was divided into 10 elements to obtain accurate temperature gradients. The time step is 0.00549 minutes. The print out times are set by the program.

The temperature gradient time histories at the pipe inside surface, as it responds to striping, for each case of striping period, are tabulated in Tables 1 and 2. The combined stress due to DT1 and DT2 (linear and nonlinear components of temperature gradient, respectively) is as follows:

$$
\begin{aligned}
\text{Stress} &= K_3\, E(\text{alpha})DT1/(2(1-0.3)) + E(\text{alpha})DT2/(1-0.3) \\
&= 1.0 \times 27.9 \times (6.41) \times DT1/1.4 + 27.9 \times (6.41) \times DT2/0.7 \\
&= 127.7\ DT1 + 255.5\ DT2 \qquad \text{(Eq. 2)}
\end{aligned}
$$

For 10 sec (0.1 Hz) case, the stress reaches its maximum at 2205 psi as indicated by Table 1. This maximum alternating stress is below the endurance limit of 10000 psi for carbon steel. Table 2 shows that, if the period is 2 sec (0.5 Hz), the maximum alternating stress is only 1106 psi.

This confirms that even if striping exists under the assumed conservative conditions, it will not cause any significant high-cycle fatigue effect in the header pipe.

3.0 THERMAL STRIPING EVALUATION AT FEEDWATER NOZZLE

3.1 Description

Thermal stratification in the ABWR feedwater pipe at the RPV nozzle is defined in Reference 1. The worst stratification occurs when thermal sleeve and sparger are filled with 270°F water and cooler make up water is introduced to the RPV at a low (2.1%) feedwater flow rate. Stratification is caused by transfer of heat from the RPV into the cooler water in the thermal sleeve and sparger. This heat transfer causes a "thermally driven convective pattern in the horizontal pipe section" which does not create striping as easily as the hot and cold stream flow.

The condition identified in Reference 4 is different from the conditions reported in References 2 and 3. There is no back flow of hot RPV water into the system. Instead there is only gradual heating of the fluid in the feedwater pipe by the thermally driven convection patterns.

Striping during this period, if it exists at all, is not significant for the following reasons:

A). The hot to cold interface does not remain at the same elevation in the pipe at the nozzle. As the heated water in the thermal sleeve and sparger flows by convection into the top of the feedwater pipe, the hot to cold interface will continuously move downward until a surge of cooler feedwater flow purges the hot water from the piping. The process will then start again. As a result, the points at the pipe surfaces that could

be subjected to temperature fluctuations caused by striping, are constantly changing. This prevents the accumulation of a large number of temperature cycles at any one point on the pipe surface.

B) As the convection driven hot water flows into the feedwater pipe the initial temperature difference between the hot and cold water will be small and will gradually increase. Only at the end of the process will temperatures differences reach maximum values.

C) The interface between the hot and cold water is not a step change. The convection driven flow of hot water into the feedwater pipe will result in a relatively wide diffusion zone at the interface. This diffusion zone will continually widen because of heat transfer and turbulence between the hot and cooler fluids.

D) Calculations summarized in section 3.2 show stresses at the pipe wall due to striping are well below the metal endurance limit, and are therefore negligible, even when the very conservative assumptions listed in Section 2.1 are made.

3.2 Striping Stress Evaluations

Although the possibility of striping at the nozzle is small as indicated in paragraph 3.1, a study similiar to the one performed on the header pipe has been made for the piping at the feedwater nozzle. The worst possible striping temperature of 282° F was assumed per Reference 1.

The analysis procedures used in the header striping calculations are also used for the pipe at the nozzle. The heat transfer coefficient used is 270 btu/hr-ft sq-F instead of 232 for the header.

The results of the calculations are tabulated in Tables 3 and 4. Table 3 provides the results of the evaluation for a thermal striping frequency of 0.1 Hz. For 0.1 Hz case, the stress reaches maximum at 5391 psi. This maximum alternating stress is below the endurance limit of 10000 psi for carbon steel. Table 4 shows that if the period is 2 sec (0.5 Hz), the maximum alternating stress is only 2831 psi.

Another case with a higher heat transfer coefficient has also been studied. The heat transfer coefficient is assumed to be 540 btu/hr-ft sq-F, which is two times the value used in the calculations for Tables 3 and 4. The striping temperature range is assumed to be 60% of the stratification ΔT. This assumption is based on Reference 2 and is discussed further in Paragraph 1.0. The period is conservatively assumed to be 10 seconds (0.1 Hz).The results of the analysis showed that the maximum alternating stress is 5517 psi. The stress is still below the endurance limit of the material.

4.0 CONCLUSIONS

Evaluations for the worst postulated thermal striping conditions have been performed. Conservative values of striping temperatures and frequencies of oscillation were used in the calculations. These evaluation results confirm that thermal striping fatigue is insignificant. Therefore, it is concluded that thermal striping need not be considered as a design load for ABWR feedwater piping.

TABLE 1 STRIPING STRESSES IN FEEDWATER HEADER
(Period 10 sec , 120° F striping, h_c=232 btu/hr ft-sq F)

Time (min)	DT1 °F	DT2 °F	STRESS (Eq. 2)	
0.0	0.0	0.0	0	
0.011	-0.634	-2.638	-751	
0.022	-1.788	-3.382	-1086	
0.027	-2.337	-3.632	-1219	
0.038	-3.399	-4.022	-1453	
0.049	-4.425	-4.324	-1660	
0.06	-5.427	-4.576	-1852	
0.071	-6.408	-4.796	-2032	
0.082	-7.372	-4.994	-2205	(max)
0.087	-7.848	-2.026	-1511	
0.098	-5.249	3.433	205	
0.115	-2.123	4.889	972	
0.131	0.486	5.428	1440	
0.148	2.728	5.612	1772	
0.169	5.273	1.81	1129	
0.18	2.891	-2.939	-379	
0.191	0.942	-4.109	-924	
0.202	-0.756	-4.711	-1293	
0.219	-2.969	-5.14	-1683	
0.24	-5.452	-5.303	-2039	
0.262	-4.024	3.234	310	
0.279	-1.029	4.726	1070	
0.301	2.205	5.383	1647	
0.322	4.856	5.521	2019	
0.339	4.709	-2.012	87	
0.361	0.672	-4.543	-1069	
0.383	-2.454	-5.215	-1636	
0.399	-4.417	-5.355	-1921	
0.421	-6.646	-1.95	-1339	
0.443	-2.05	4.373	850	
0.459	0.597	5.152	1384	
0.481	3.532	5.494	1844	
0.497	5.396	5.525	2089	
0.552	-2.478	-5.204	-1637	
0.601	-2.603	3.874	653	
0.65	4.49	5.483	1963	
0.699	1.285	-4.604	-1006	
0.749	-5.161	-5.424	-2033	
0.798	2.039	5.198	1579	
0.831	5.897	5.443	2131	

TABLE 2 STRIPING STRESSES IN FEEDWATER HEADER
(Period 2 sec, 120°F striping, h_c=232 btu/hr ft-sq F)

Time (min)	DT1 °F	DT2 °F	STRESS (Eq. 2)	
0.0	0.0	0.0	0	
0.011	-0.714	-3.199	-903	
0.022	-2.24	0.929	-49	
0.027	-1.135	2.792	565	
0.038	0.706	-1.226	-222	
0.049	-1.208	-3.75	-1106	(max)
0.06	-0.933	2.952	631	
0.071	0.88	-1.128	-175	
0.082	-1.054	-3.688	-1071	
0.087	-1.875	1.185	63	
0.098	0.144	3.763	974	
0.115	-0.939	-3.674	-1052	
0.131	0.245	3.768	988	
0.148	-0.851	-3.675	-1042	
0.164	0.323	3.765	997	

TABLE 3 STRIPING STRESSES AT FEEDWATER NOZZLE
(Period 10 sec , 282°F striping, hc=270 btu/hr ft-sq F)

Time (min)	DT1 °F	DT2 °F	STRESS (Eq. 2)	
0.0	0.0	0.0	0	
0.01	-5.549	-8.352	-2826	
0.021	-10.902	-9.182	-3717	
0.029	-14.393	-9.238	-4174	
0.04	-18.003	-9.055	-4586	
0.05	-20.932	-8.775	-4887	
0.061	-23.305	-8.479	-5113	
0.069	-24.869	-8.251	-5254	
0.08	-26.476	-7.988	-5391	(max)
0.09	-19.148	8.129	-367	
0.101	-8.913	10.676	1580	
0.115	2.029	11.073	3070	
0.13	10.24	10.583	3989	
0.151	18.588	9.665	4816	
0.17	20.536	4.274	3694	
0.18	10.064	-9.1	-1033	
0.191	1.993	-10.168	-2330	
0.201	-4.518	-10.225	-3171	
0.22	-13.362	-9.62	-4140	
0.241	-20.047	-8.816	-4785	
0.26	-12.993	8.495	508	
0.281	3.284	10.748	3147	
0.299	13.073	10.232	4259	
0.32	20.472	9.391	4985	
0.339	18.991	-5.95	901	
0.36	1.114	-10.332	-2483	
0.379	-9.48	-10.017	-3748	
0.4	-17.498	-9.19	-4557	
0.421	-16.847	6.238	-555	
0.44	-0.554	10.57	2614	
0.461	11.357	10.317	4063	
0.48	18.628	9.574	4798	
0.501	24.095	5.291	4404	
0.551	-12.334	-9.817	-4060	
0.601	-5.668	10.163	1862	
0.649	19.037	9.491	4828	
0.699	-3.084	-10.404	-3034	
0.75	-22.156	-8.633	-5007	
0.8	12.816	10.15	4206	
0.833	23.352	8.864	5217	

TABLE 4 STRIPING STRESSES AT FEEDWATER NOZZLE
(Period 2 sec, 282°F striping, hc=270 btu/hr ft-sq F)

Time (min)	DT1 °F	DT2 °F	STRESS (Eq. 2)	
0.0	0.0	0.0	0	
0.01	-5.549	-8.352	-2826	
0.021	-4.937	5.504	771	
0.029	1.3	8.475	2318	
0.04	-1.168	-6.449	-1786	
0.05	-7.494	-2.068	-1477	
0.061	1.031	8.122	2194	
0.069	3.008	-3.678	-552	
0.08	-4.362	-8.212	-2640	
0.09	-1.303	6.752	1550	
0.101	5.507	1.862	1172	
0.115	-5.158	-8.567	-2831	(max)
0.13	3.328	8.438	2566	
0.151	-6.113	-1.892	-1257	
0.165	4.769	8.72	2821	(max)