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TECHNICAL SUPPORT FOR ALTERNATE PLUGGING CRITERIA WITH TUBE EXPANSION AT TUBE SUPPORT PLATE INTERSECTIONS FOR BRAIDWOOD-1 AND BYRON-1 MODEL D4 STEAM GENERATORS

ADDENDUM 1
TUBE SUPPORT PLATE ANALYSIS USING "RELAP5" LOADS

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Technical Support for Alternate Plugging Criteria with Tube Expansion at Tube Support Plate Intersections for Braidwood-1 and Byron-1 Model D4 Steam Generators

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1.0 INTRODUCTION

This addendum to WCAP-14273 summarizes results of calculations to determine relative tube support plate / tubesheet displacements subject to steam line break pressure loads. The loads considered in the addendum evaluation have been calculated using the RELAP5M3 Version 1.1 computer code (hereafter referred to as RELAP).

Section 2 of the addendum summarizes changes that have been made to the structural model subsequent to the completion of WCAP-14273. These changes provide a more accurate representation of the tube bundle geometry, and the expanded tube / plate interface. Section 3 provides a summary of the displacement results for the RELAP pressure drops, and a comparison of these results to those obtained using pressure drops generated with the TRANFLO computer code. Finally, in Section 4, a summary of the resulting tube expansion locations is provided.

2.0 REVISED FINITE ELEMENT MODEL

Subsequent to the completion of WCAP-14273, several modifications have been made to the finite element model. These changes include the addition of the wrapper and partition plate, extension of the shell up to the top support plate, inclusion of the expanded tubes, and a revision as to how the tube / plate expansion zone interface is modeled. A geometry plot showing the updated model is provided in Figure 1. A similar plot without the partition plate is shown in Figure 2.

Relative to the modeling of the expansion zone stiffness, the tube / plate interface in WCAP-14273 was modeled as shown in Figure 3. In this figure, K_{tube} represents the stiffness of the tube segment between passes. The stiffness K_{exp} represents the stiffness of the expansion zone of the tube subject to an extrusion type loading from the plate. In other words, this stiffness is based on the load / deflection characteristics for loads that tend to pull the tube through the plate, or vice versa. As shown in Figure 3, K_{exp} was modeled in series not only with the plate, as it should be, but also with the tube segment in the next pass. This is a conservative representation of the expanded tube, particularly for the upper plates, as the cumulative effect of having a number of expansion zone stiffnesses in series with the tube stiffnesses is to significantly reduce the overall stiffness of the tube. Modeling the tube / plate expansion zone interface as shown in Figure 4 is a more accurate representation of the interface. Using this method, the tube and expansion zone stiffnesses are still in series with the plate stiffness, as required, however, the tube stiffness for the upper plates is not affected by the lower expansions. Thus, the representation in Figure 4 more accurately models a tube when more than one expansion zone exists along its length.

One final change, which is not related to tube bundle geometry, is the stiffness of the tube in the expansion zone region. In WCAP-14273, an expansion zone stiffness of [ ]^{a,b,c,e} lb/in was used. For these calculations, the expansion zone stiffness has been reduced to [ ]^{a,b,c,e} lb/in.

The combined effect of the above changes is shown in Table 1, where a comparison of the maximum plate displacements is provided for the TRANFLO loads using the WCAP-14273 model, and the revised model. These results show that the effects vary from plate to plate, with the upper plates seeing the largest effect, a 0.0136 inch reduction in maximum plate displacement. Overall, the combined effect of the above changes is to not significantly affect the plate response.

3.0 ANALYSIS RESULTS FOR RELAP LOADS

A plot showing the RELAP pressure drops for each of the plates is provided in Figure 5 for the full four seconds of the transient, as obtained from Reference (1). A plot showing the RELAP pressure drops for just the first one-half second is provided in Figure 6. As with the TRANFLO analysis, the RELAP pressure drops are converted to loads on the plates by multiplying the pressure drops by a ratio of the thermal hydraulic control volume area to the plate area in the finite element model. A factor of 1.5 was then applied to the plate loads to account for analysis uncertainties.

A preliminary time-history evaluation of the RELAP pressure loads was performed using a linear approximation of the plate / spacer interaction, except between the tubesheet and Plate A(1H). The maximum displacements that are obtained using the RELAP pressure loads for the reference set of expansions (those documented in WCAP-14273) are summarized in Table 2. Maximum time-history displacements for a non-linear plate / spacer interaction for all plates are also summarized in Table 2. These results show all plates to satisfy the 0.100 inch displacement limit, except for Plate L(8H). (Note that Plate A(1H) is excluded from this limit, as expansion is not used for this plate.)

With the inclusion of two additional expansions (one for each half of the plate) for Plate L(8H), the maximum time-history displacement is shown to be less than the 0.100 inch limit. A summary of the maximum plate displacements with the additional expansions are also provided in Table 2. Results are again shown both for a linear and a non-linear solution. Displacement time history plots for the limiting location for each plate are provided in Figures 7 and 8. Figure 7 shows the displacement time history for the bottom four plates, and Figure 8 the time history response for the upper four plates.

The time step used in evaluating the RELAP pressure loads is [ ][a,c] second, which is smaller than the [ ][a,c] second time step used for the TRANFLO pressure loads, due to the high frequency load oscillations that occur during the initial stages of the transient. As a convergence check for the RELAP solution, a non-linear solution was also performed for a time step of [ ][a,c] second. The results for the two solutions are summarized in Table 3, and show excellent agreement. Thus, the results summarized in Table 2 represent a converged solution for the RELAP pressure loads.

For means of comparison, the maximum displacements for the TRANFLO and RELAP pressure drops are shown in Table 4. The TRANFLO results have been obtained using the revised model discussed above, and are therefore on a consistent basis with the RELAP results. Table 4 shows the maximum pressure drop for each plate and the

corresponding maximum displacement. These results show that the RELAP pressure loads for Plates N(10) and P(11) are very close to the TRANFLO values. For the lower plates, Plates A(1H), C(3H), and F(5H), the RELAP loads are actually smaller than the TRANFLO loads, and are also predominantly in the up direction. That is, RELAP does not predict any significant flow split as does the TRANFLO code. Due to the flow split predicted by TRANFLO, the RELAP loads on the middle plates, Plates L(8H) and M(9), are higher than the TRANFLO loads for these plates. It is the higher loads on Plate L(8H) that result in the need for additional expansions for this plate.

With the inclusion of the additional expansion(s) for Plate L(8H), it is necessary to confirm that the selected degrees of freedom (DOF) still provide a close approximation of the plate response. Using the methodology and criteria discussed in Section 7.6 of WCAP-14273, calculations were performed for Plate L(8H) with the additional tube expansion(s). A summary of the natural frequencies for the full set of DOF and the reduced set of DOF is provided in Table 5, and shows that the reduced set of DOF provides a good approximation of the plate response.

4.0 REVISED SET OF PLATE EXPANSIONS

A summary of the final set of expansions, including the additional expansions for Plate L(8H), is provided in Table 6. There is no change to the set of acceptable tube locations for expansion defined in WCAP-14273. A plot showing the acceptable tube locations is provided in Figure 9. An example generic tube expansion matrix is given in Table 7. Tables 6 and 7 provide the number and generic tube locations and TSP elevations for expansion. The locations shown as darkened circles in Figure 9 are acceptable alternate locations to the generic tubes within each group of alternate locations.

5.0 REFERENCE

1.0 Com Ed Document Number PSA-B-95-17, "Calculation of Byron 1/ Braidwood 1 D4 Steam Generator Tube Support Plate Loads with RELAP5M3", K. B. Ramsden, 10/95.

Table 1

Comparison of Displacement Results
WCAP-14273 Versus Revised Model

Plate	WCAP-14273 Model Displacement	Revised Model Displacement
A	-0.5603	-0.5884
C	-0.0581	-0.0598
F	-0.0788	-0.0778
J	0.0404	0.0373
L	0.0683	0.0675
M	0.0692	0.0633
N	0.0877	0.0753
P	0.0958	0.0822

Table 2

Summary of Maximum Relative Plate / Tubesheet Displacements
Model D4 Steam Generator

RELAP Loads
Load Factor = 1.5

Plate	Reference Expansions		Added Expansions *	
	Linear	Non-Linear	Linear	Non-Linear
A	0.1261	0.1258	0.1116	0.1208
C	0.0574	0.0590	0.0566	0.0566
F	0.0585	0.0607	0.0583	0.0580
J	0.0761	0.0752	0.0767	0.0745
L	0.1087	0.1122	0.0745	0.0773
M	0.0824	0.0843	0.0863	0.0848
N	0.0801	0.0855	0.0784	0.0848
P	0.0858	0.0899	0.0858	0.0884

* Added 2 Expansions to Plate L (No new tubes)

Table 3

Comparison of Transient Iteration Times
SLB From Hot Standby
Model D4 Steam Generator

Time Steps of [0.0001 and 0.00005][a,c] Second

RELAP Loads

Maximum Plate / Tubesheet Displacements

Plate	DT = 0.00005	DT = 0.0001
A	0.1208	0.1208
C	0.0566	0.0566
F	0.0580	0.0580
J	0.0745	0.0744
L	0.0773	0.0773
M	0.0848	0.0847
N	0.0848	0.0848
P	0.0884	0.0884

Table 4

Comparison of Displacement Results
TRANFLO Versus RELAP

	TRANFLO *		RELAP **	
Plate	DP (L..F.=2.0)	Displacement	DP (L..F.=1.5)	Displacement
A	-2.846	-0.5884	0.303	0.1208
C	-2.415	-0.0598	0.357	0.0566
F	-1.425	-0.0778	0.503	0.0580
J	-0.777	0.0373	0.987	0.0745
L	1.281	0.0675	2.031	0.0773
M	1.156	0.0633	1.428	0.0848
N	2.033	0.0753	2.008	0.0848
P	2.909	0.0822	2.874	0.0884

*TRANFLO Results for Revised Stiffness Representation and Kexp= [ ]^{a,c} lb/in
**Two Additional Expansions for Plate L

Table 5

Comparison of Natural Frequencies
Full Versus Reduced DOF

Plate	Mode	Full DOF	Reduced DOF	Ratio
L	1	44.36	47.35	0.933
	2	46.88	51.38	0.904
	3	52.63	55.25	0.950
	4	57.98	61.17	0.945
	5	64.98	67.56	0.960
	6	65.66	69.34	0.944

Table 6

Expanded Tube Locations

a,c

Table 7

Example of Generic Tube Expansion Matrix

a,c

a,c

Figure 1. Revised Finite Element Model

a,c

[ ]

**Figure 2. Revised Finite Element Model
Partition Plate Removed**

a,c

[ ]

Figure 3. Expanded Tube / Plate Interface
WCAP-14273 Representation

a,c

Figure 4. Expanded Tube / Plate Interface
Revised Representation

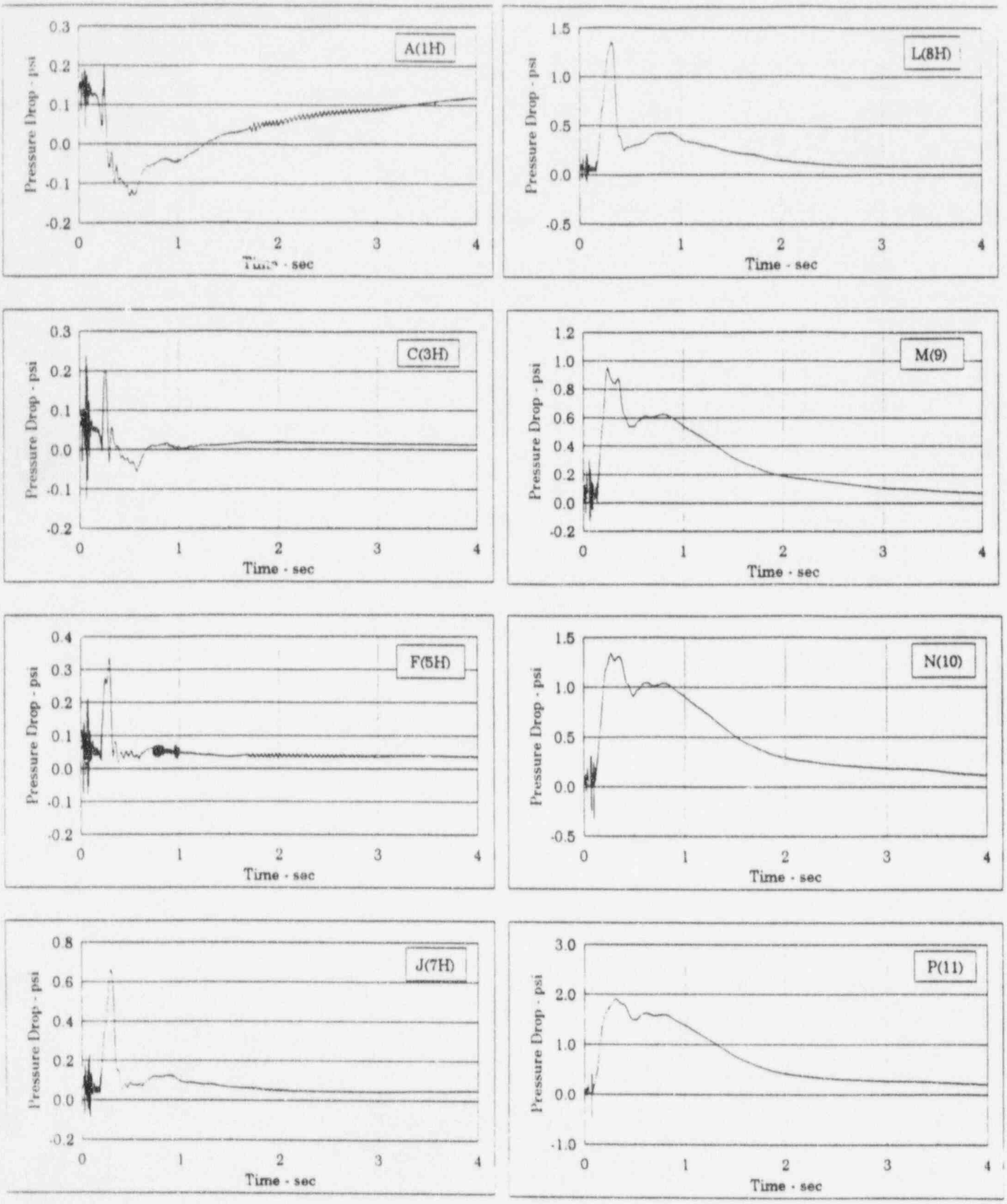

Figure 5. RELAP Pressure Drops

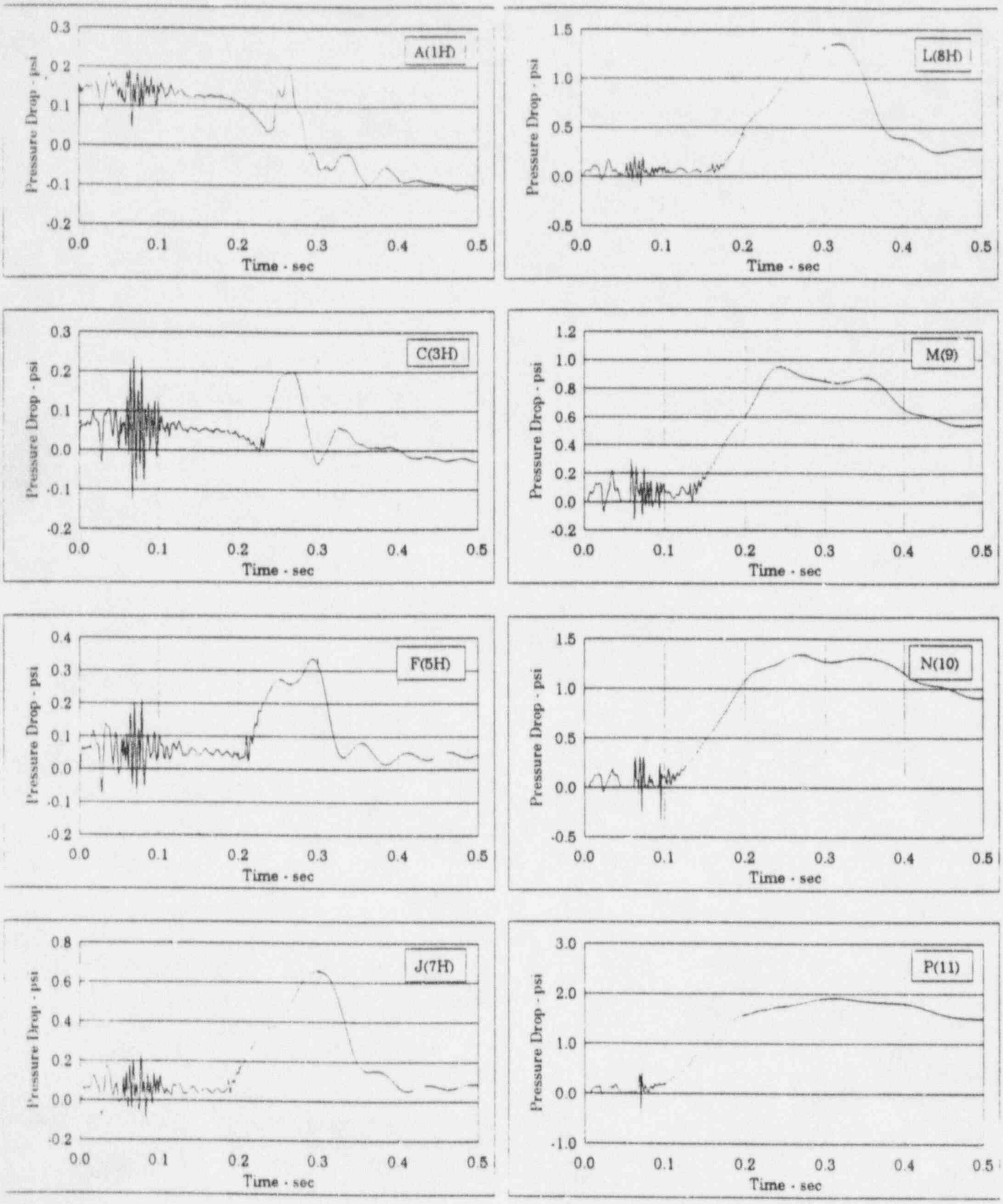

Figure 6. RELAP Pressure Drops: Time = 0. - 0.5 Second

a,c

Figure 7. Relative Plate / Tubesheet Displacement Time History Response
SLB from Hot Standby
RELAP Pressure Loads
Plate A(1H), C(3H), F(5H), J(7H)

a,c

Figure 8. Relative Plate / Tubesheet Displacement Time History Response
SLB from Hot Standby
RELAP Pressure Loads
Plate L(8H), M(9), N(10), P(11)

a,c

Figure 9. Map of Tube Expansion Locations