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ROBERT E. GINNA NUCLEAR POWER PLANT

CONTAINMENT VESSEL

EVALUATION OF DOME LINER AND STUDS

Prepared For

ROCHESTER GAS AND ELECTRIC CORPORATION

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b. Procedures (continued)

Strontium-89 and Strontium-90 activities are determined in quarterly composited air particulate filters. Stable strontium carrier is added to the sample and it is leached in nitric acid to bring deposits into solution. The mixture is then filtered. Half of the filtrate is taken for strontium analysis and is reduced in volume by evaporation. Strontium is precipitated as $Sr(NO_3)_2$ using fuming (90%) nitric acid. An iron (ferric hydroxide) scavenge is performed, followed by addition of stable yttrium carrier and a 5 to 7 day period for yttrium ingrowth. Yttrium is then precipitated as hydroxide, is dissolved and re-precipitated as oxalate. The yttrium oxalate is mounted on a nylon planchet and is counted in a low level beta counter to infer strontium-90 activity. Strontium-89 activity is determined by precipitating $SrCo_3$ from the sample after yttrium separation. This precipitate is mounted on a nylon planchet and is covered with 80 mg/cm^2 aluminum absorber for level beta counting.

3. Results and Conclusions

A summary of data is presented in Table V.A.2.

a. Airborne Radioactive Particulates

A total of five hundred nineteen (519) weekly samples from ten (10) locations was analyzed for gross beta. One sample was not obtained due to theft of air monitoring equipment. Results were comparable to previous years. Figure 5.B.2 illustrates the average concentration of gross beta in air particulates.

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I. INTRODUCTION

This report presents the results of an evaluation of the integrity of the Ginna containment dome liner and studs under pressure and temperature loads that are caused by the Loss of Coolant Accident (LOCA) and Steamline Break (SB) loading conditions. This report supersedes the February 1, 1982 report (1) prepared by Gilbert/Commonwealth (G/C) on the same subject, because of additional information which became available concerning the type and spacing of studs actually used on the dome liner, and because of questions and comments received from the USNRC during their review of the February 1, 1982 report. The NRC comments were provided as part of the Safety Evaluation Report (SER) on SEP Topic III-7.B, dated April 21, 1982. This SER was transmitted to G/C in Reference 2. This reference also contained revised pressure and temperature transient curves for the LOCA condition. In addition, pressure and temperature curves for the Steamline Break condition were provided for the first time. G/C was requested to review and compare these curves with those used for the previous evaluation (1) and to consider these latest curves in the evaluation of the dome liner and studs.

This report provides in Section II the basis for the stud configurations (type, size, and spacing) used in the current evaluation. In Section III, the LOCA and Steamline Break transients are compared with those used to obtain the liner stresses reported in Reference 1. Section IV describes the interaction between the liner and the studs and the basis for establishing the limiting liner stresses used in the analysis of the studs. In Section V, the liner stresses produced by the LOCA and Steamline Break conditions are identified and compared with the limiting values. The determination of the stud force-displacement curves used in the liner-stud interaction analysis is also presented in Section V. Section V concludes with a discussion of an analysis to determine the effect of internal

pressure on the buckling capacity of the liner, which also influences the limiting liner stresses and the forces and displacements for the studs. In Section VI the results and conclusions of the liner-stud interaction analyses are presented. Then the expected performance of the liner and studs under the LOCA pressure and temperature transients, considering the effect of the pressure on liner buckling, is discussed. The overall conclusions on the structural integrity of the dome liner and studs appear in Section VII.

II. DOME LINER STUDS

The studs originally specified for the dome liner appeared on G/C Drawing D-521-051, Rev. 3. This drawing shows 3/4 inch diameter by 3 inch long headed Nelson studs spaced at 4'-3" along each circumferential coordinate line, and the circumferential lines are also spaced at 4'-3". This information subsequently appeared on the original issue of the liner fabrication drawing prepared by Chicago Bridge and Iron. However, the CB&I drawing was voided by Revision 1 with an accompanying note which indicated that the size and spacing of the studs were changed. The note also indicated that the constructor (Bechtel Corporation) was responsible for furnishing and installing the studs. No other drawings which would give an indication of the revised stud size and spacing were found. However, two photographs showing construction in progress on the dome were provided by RG&E. These photographs show studs installed about half way up the dome. The size of the studs can not be determined from the photographs. However, use of the photographs in conjunction with CB&I liner plate drawings enabled their spacing to be determined. The spacing of the studs was determined to be 2'-0" along each circumferential coordinate line, with a 2'-0" spacing between these coordinate lines.

In an effort to establish the size of the studs an extensive review of files, and discussions with personnel associated with

the project during construction, was undertaken. Based on this review, the available information indicates that two different stud schemes were used. These are shown in Figure 1. One scheme starts at the springline between the dome and cylinder, and extends over a 55° meridional arc distance above the springline. In this region the studs are 5/8 inch diameter Nelson S6L studs, and they are spaced at 2'-0" as shown in Figure 1. The S6L studs have internal threads to accept 1/2 inch diameter threaded fasteners. Construction reports indicate that 1/2 inch diameter rods were threaded into the studs, and the other end of the rod was bent around the three layers of #18 reinforcement in the dome. This was done to support the liner during concrete placement. The S6L studs are shown in Figure 2 as they appeared in the May 1968 edition of the Nelson catalog (3) that was in effect during the time that the Ginna containment vessel was constructed.

Above the 55° meridional coordinate line and extending to the apex, the studs conform to the configuration originally specified: 3/4 inch diameter by 3 inch long headed Nelson studs spaced at 4'-3", as shown in Figure 1.

The analyses and results described in this report are based on the stud configurations shown in Figure 1.

III. LOADS

This section compares and evaluates the revised LOCA and new Steamline Break pressure and temperature curves. These curves appear in Appendix A, and they have been approved as part of SEP Topics VI-2.D and VI-3.

A. Revised LOCA

Figure 3 compares the revised LOCA temperature transient from Figure A-1 with that used in the previous evaluation of the

liner (1). In the previous evaluation, a heat transfer analysis of the containment structure was performed based on the G/C curve in Figure 3. From this analysis a maximum liner temperature of 250° F occurring at 300 seconds into the transient was obtained.

As seen from Figure 3, the two transient curves are similar out to 1000 seconds. The latest curve has a peak temperature of 290° F which occurs at 30 seconds. This compares with a maximum temperature from the previous curve of 280° F which occurs at approximately 10 seconds into the transient. Because of the similarity between the two curves, it was initially concluded that a new heat transfer analysis for the revised LOCA would not be required and that the liner temperature of 250° F at 300 seconds was a reasonable value to consider as the maximum liner temperature for the revised LOCA temperature transient.

Much later in the overall evaluation, after the liner-stud interaction analyses had been completed based on the 250° F liner temperature, a heat transfer analysis was performed for the revised LOCA temperature transient as part of the study of the effect of internal pressure on liner buckling. The results indicated the maximum liner temperature to be 260° F, which exceeds the 250° F value by 4%. However, this difference did not effect the liner-stud interaction results because, as will be evident later, the limiting stresses used for the liner in these analyses would be reached at liner temperatures that are considerably lower than even 250° F.

Figure 4 compares the revised LOCA pressure transient from Figure A-2 with that used in the previous liner evaluation (1). These pressure curves have similar time histories, with the main difference being the somewhat higher peak pressure value from the new curve, 74 psia or 59.3 psig at 30 seconds,

versus 67.2 psia or 52.5 psig, which occurs between 10 and 30 seconds. For purposes of the liner evaluation, the pressures from these two curves at the time of maximum liner temperature, 300 seconds, is important. At this time, the pressure from the revised curve is 58 psia (43.3 psig) versus 56.5 psia (41.8 psig) from the previous curve. Therefore, there is not a significant difference in the latest LOCA pressure from that used in the previous liner evaluation.

In summary, the dome liner and studs were evaluated for the latest LOCA pressure and temperature transients in Appendix A based on a liner temperature of 250° F coincident with an internal pressure of 42 psig.

B. Steamline Break

The Steamline Break temperature curves identified as "RG&E Model" in Figures A-3 and A-5 are compared in Figure 5 with the LOCA condition. The peak air temperatures for the Steamline Breaks are 358° F and 375° F, which exceed the LOCA peak temperature of 290° F. However, for the liner evaluation it is the peak liner temperature rather than the peak air temperature which is important. Based on the following discussion the peak liner temperature is not expected to be significantly different for the LOCA or Steamline Break conditions.

In the final report by Structural Mechanics Associates, Inc. (SMA) on their evaluation of the Ginna containment vessel (4), a LOCA temperature transient curve is shown in Figure 3-1 which has a similar shape to that of the Steamline Break curves in Figure 5 herein. From the SMA curve, a peak air temperature of 421° F occurring in 34 seconds is indicated. The results of a heat transfer analysis reported by SMA indicated that the peak liner temperature under this

condition is 267° F, occurring at 380 seconds. This value is only 7 percent higher than the 250° F peak liner temperature obtained from a LOCA condition with the peak air temperature of 280° F. The peak liner temperatures are not very different because even though the peak LOCA air temperatures are less than the Steamline Break, the LOCA temperature remains near its maximum considerably longer than the temperature for Steamline Break, thus allowing more time for the liner temperature to increase. Considering that the peak air temperature for the current Steamline Break is 375° F, rather than 421° F, the peak liner temperature associated with the 375° F curve would be expected to be less than the 267° F value obtained from the heat transfer analysis of the 421° F curve in the SMA report. Based on this, the temperature of the liner is not expected to be significantly different from the LOCA value of 250° F.

Figure 6 compares the pressure transients for the "RG&E Model" Steamline Break from Figures A-4 and A-6 with that from the LOCA. Here it is seen that the peak Steamline Break pressure of 72.5 psia in the containment is approximately the same as the peak LOCA pressure of 74 psia. The peak steamline value of 72.5 psia occurs at approximately 150 seconds. The Steamline Break pressure curves are not defined in the 300-400 second range where the liner temperature is a maximum. Because of this, it is necessary to use as the corresponding pressure the peak pressure value of 72.5 psia (57.8 psig), which makes the evaluation of the liner and studs slightly conservative.

Based on the above discussion, a liner temperature of 250° F coincident with a pressure of 57.8 psig were used for the Steamline Break condition in the evaluation of the dome liner and studs.

IV. PROBLEM DEFINITION

The purpose of this section is to compare the two types of analysis problems associated with the studs in the Insulation Termination Region (ITR) and the studs located in the General Region of the Dome sufficiently far away from the ITR. Refer to Figure 7 for the following discussion.

A. General Dome

In the General Dome (Figure 7.A), the liner panels between studs are stressed equally under the pressure and temperature loads corresponding to the LOCA or Steamline Break conditions. For a liner without imperfections, all of the liner panels between the studs would reach their limiting stress capacities simultaneously. Under this condition, there would be no resultant shear force on the studs. However, if one panel is assumed to buckle prior to others, shear forces would be experienced by the adjacent studs. With the one panel buckled, the adjacent panels and studs displace towards the buckled panel. As a result of this displacement, the buckled panel displaces laterally further away from the concrete and exhibits a fall-off in its membrane stress as described in Reference 5. The extent of stress fall-off depends on the final displacement, Δ, of the studs on either side of the buckled panel. The difference between the fall-off stress in the buckled panel and the final stress in the adjacent panel produces a shear on the stud. The largest shear force and displacement occur for stud #1.

The liner plate material for the Ginna liner is ASTM A 442 Grade 60 carbon steel, which has a minimum specified yield strength of 32 ksi. It is expected that the liner would have an actual mean yield strength of 48 ksi based the information in Reference 6. In the General Dome for the liner panels

between the 3/4 inch diameter headed studs spaced at 4'-3", the calculated buckling stress is 5.8 ksi. For the liner panels between the 5/8 inch diameter S6L studs spaced at 2'-0", the calculated buckling stress is 26 ksi. Since in both of these cases the calculated buckling stress is much less than the 32 ksi or 48 ksi yield strength, the calculated buckling stress is used as the value of limiting stress for all panels in the model adjacent to panel 1-1. The limiting compressive stresses in these panels of 26 ksi (or 5.8 ksi) combine and displace the critical stud (#1) in the direction of the buckled panel in the model for the General Dome.

B. Insulation Termination Region (ITR)

In the Insulation Termination Region, the stresses in the liner behind the insulation are small relative to the large compressive stresses produced in the uninsulated portion of the liner. In the liner panel immediately outside of the insulation, the largest compressive stress that is capable of being developed will produce the largest displacement of the studs. This is the limiting stress corresponding to the calculated buckling stress of 26 ksi. With the panel stressed to this value, all of the studs behind the insulation will displace as indicated in Figure 7.B. The stud which experiences the greatest displacement is stud #1.

V. ANALYSIS

A. Controlling Loads

It was concluded in Section III that the controlling LOCA loads on the dome liner are a liner temperature of 250° F coincident with an internal pressure of 42 psig. For the controlling Steamline Break condition the liner temperature is 250° F with an internal pressure of 57.8 psig. The 250° F

temperature applies in the uninsulated portion of the dome liner. Behind the insulation the liner temperature decreases as indicated in Figure 4 of Reference 1. Similar to the analyses described in Reference 1, the liner stresses were obtained using the elastic, shell analysis computer program KSHEL1 for the controlling LOCA and Steamline Break loads. The results of these analyses indicated that the stresses in the uninsulated portion of the liner were generally in the neighborhood of 45 ksi compression. This value exceeds the limiting stresses of 26 ksi and 5.8 ksi discussed previously. Therefore, these limiting stresses control, and they were used in the liner-stud interaction analyses.

As additional cases, the liner-stud interaction analyses also reviewed somewhat higher values of limiting stresses in order to determine the sensitivity of the stud displacements to variations in the stress limits. This accounts for the real possibility that some liner panels may buckle at a stress greater than their theoretical value. For this purpose, the limiting stress of 26 ksi for the 2'-0" panels was increased only 10%, resulting in 29 ksi as an additional case for the analysis of the 5/8 inch diameter S6L studs in the General Dome and in the Insulation Termination Region. Considering the usual scatter in buckling test results, it is not unreasonable to expect that there would be liner panels which could develop membrane compressive stresses 10% above the theoretical buckling value of 26 ksi. For the liner panels in the General Dome where the 3/4 inch headed studs at 4'-3" spacing exist, since the 5.8 ksi stress limit was relatively low, it was practically doubled to 12 ksi. This value was used as a conservatively high stress limit.

B. Liner-Stud Interaction

For the General Dome, the analysis was based on the method developed in Reference 5 using the model in Figure 7.A. The appropriate equations in this reference were modified to include the effect of the internal pressure on the stress fall-off curve for the buckled panel 1-1. For the Insulation Termination Region, a somewhat different liner-stud interaction analysis was performed using the model in Figure 7.B. The main difference is that the stress in the buckled panel (26 ksi or 29 ksi) is given, and the stress fall-off concept does not apply. In these analyses, the force-displacement curves of the embedded studs are required for the 3/4 inch diameter headed studs and for the 5/8 inch diameter S6L studs of Figure 2. The determination of these curves is discussed below.

3/4 Inch Diameter Studs

The curve used for the 3/4 inch headed studs is the same as that discussed in Reference 1 and is shown in Figure 8. This curve is based both on the test results and recommendations from Reference 7 and from test data reported in Reference 8. From Reference 7 the shape of the force-displacement relationship is provided by equation (4) in the reference as $Q = Qu\ (1-e^{-18\Delta})^{2/5}$. In the equation, Δ is the stud displacement; Q is the corresponding stud force; and Qu is the ultimate stud capacity. The ultimate stud capacity was obtained from equation (3) of Reference 7 as 31.1 kips. Test data from Reference 8 for 3/4 inch diameter studs in shear (Table IX) support this value for Qu. The ultimate shear force values reported here from four stud tests all exceed 31.1 kips. Also from Reference 8, a displacement of 0.341 inches at failure (Table X) is reported for the 3/4 inch studs, and this value is used as the ultimate displacement in Figure 8.

An NRC staff comment contained in the SER included in Reference 2 refers to a Nelson publication (9) in which the ultimate stud capacity is conservatively taken to be the lesser of the values calculated below:

1. $Suc = \phi\ 6.66 \times 10^{-3}\ As\ (fc')^{0.3}\ (Ec)^{0.44}$
$= (0.85)\ 6.66 \times 10^{-3}\ (0.442)\ (5000)^{0.3}\ (4 \times 10^6)^{0.44}$
$= 25.9$ kips

2. $Sue = 0.9\ As\ fs = 0.9\ (0.442)\ (60\ ksi)$
$= 23.9$ kips

Thus, 23.9 kips would control. However, use of this value for Qu in the liner-stud interaction analysis would be too conservative in light of the test results from Reference 7 and Reference 8 discussed above. Therefore, the value of 31.1 kips for Qu was retained in the present work in order to construct a realistic evaluation of the studs.

5/8 Inch Diameter S6L Studs

Unlike the 3/4 inch headed studs, force-displacement property data for the 5/8 inch S6L studs was not found in the Nelson literature. Therefore, the curve for these studs was constructed indirectly from tests on other types of anchors. In Reference 10, direct shear tests on 3/8 inch diameter and 1/2 inch diameter Nelson D2L deformed reinforcing bar anchors are reported. The embedment lengths of these bars varied over 3", 6", 12" and 18 inches. The test results for the 18 inch long bars indicate that these bars failed in shear at or slightly above the minimum specified tensile strength of the bar material, which was 80 ksi. The results from the tests on the 18 inch long bars are believed to be applicable to the 5/8 inch S6L studs installed on the dome liner since these studs were actually extended in length by the 1/2 inch

diameter threaded rods that bent around the 3 layers of #18 dome reinforcement. The studs with the rods had straight embedment distances of 9-1/2", 14", and 18-1/2". This configuration will adequately develop these studs to allow them to achieve their minimum specified tensile capacity in shear based on the test results for the 18 inch long straight deformed bars. The capacity for the 5/8 inch diameter S6L stud then becomes

$$Fu = As\ fs = (\pi/4)(0.437)^2(60\ \text{ksi}) = 9.0\ \text{kips},$$

where from Figure 2 the minimum diameter of the stud (0.437 inch at the base) was used. For use in the evaluation as a lower bound study capacity, 8.3 kips was used. This represents approximately a 10% reduction of the 9.0 kips value.

Actually the 9.0 kips value itself would appear to be a conservatively low value for the S6L studs due to their lower specified tensile strength of 60 ksi compared with the corresponding value of 80 ksi for the deformed bars tested in Reference 10. This would be the case because the actual tensile strengths of the S6L stud material are expected to consistently exceed their 60 ksi minimum specified value by greater margins than would occur for the 80 ksi strength material for the deformed bars. An example of the increase for 60 ksi grade studs is seen in the tests on the 3/4 inch diameter headed studs discussed previously. The steel for these studs (A108) has a minimum specified tensile strength of 60 ksi, which when multiplied by the stud area (0.442 in^2) gives a capacity of 26.5 kips. However, as discussed earlier, these studs consistently failed above 30 kips in the tests reported in References 7 and 8. Therefore, use of the value Qu = 8.3 kips in the liner-stud interaction analyses is regarded as a conservative lower bound on the expected actual

capacity of the 5/8 inch diameter S6L studs. The determination of a more realistic value is discussed below.

The results and recommendations of Reference 7 were used to establish what is regarded as an expected value for Qu for the 5/8 inch diameter S6L studs. Reference 7 is applicable because the headed studs tested in this reference have a minimum specified tensile strength of 60 ksi which is the same as the specified tensile strength of 5/8 inch S6L stud material. Also, the embedment afforded the S6L studs on the dome by the bent 1/2 inch threaded rods is believed to be at least as effective as the head on the studs tested in Reference 7. Using equation (3) from Reference 7 gives

$$
\begin{aligned}
Qu &= (1/2)\ As \sqrt{fc'\ Ec} \\
&= (0.5)\ (\pi/4)\ (0.437)^2 \sqrt{(5)(4000)} \\
&= 10.6 \text{ kips}
\end{aligned}
$$

Curves corresponding to Qu = 8.3 kips (lower bound) and Qu = 10.6 kips (best estimate) are shown in Figure 9. The ultimate displacement of 0.167 inch is the limit chosen for the 5/8 inch diameter S6L studs. In the absence of any specific data on these studs, the 0.167 inch value was obtained from the tests on 1/2 inch diameter headed studs reported in Reference 8 (Table X). The value is in reasonable agreement with the deformed bar tests from Reference 10. In these tests on the 1/2 inch diameter by 18 inch long deformed bars, an ultimate displacement of approximately 0.160 inches was reported.

In summary, the liner-stud interaction analyses were based on the force-displacement curve for the 3/4 inch diameter headed studs shown in Figure 8. This curve is based on actual test results as reported in References 7 and 8. The curves for the 5/8 inch diameter S6L studs are shown in Figure 9. In

the absence of specific test data on the S6L studs, lower bound and best estimate curves were constructed based on tests reported in References 7 and 10.

C. Effect of Internal Pressure on Liner Buckling

In the SER included in Reference 2, one NRC staff comment is that the effect of the internal pressure to increase the calculated buckling stress of the dome liner should be considered in analysis of the studs in the Insulation Termination Region. Actually, the internal pressure potentially affects the liner buckling stress and stud evaluation in all three regions of the dome liner identified in Section II. Therefore, an evaluation of all the studs was performed considering the internal pressure effect as a separate case in addition to the liner-stud interaction analyses described previously.

In order to specifically address the NRC comment, it was necessary to solve the fundamental buckling problem of a straight strut, clamped at its ends, under the combined loads of a uniform temperature increase over the length of the strut plus a uniform lateral pressure. In addition the strut is continuously supported on the side opposite the pressure, which permits buckling to occur only in the direction opposed by the pressure. The resulting model is shown in Figure 10. The length of the strut, L, corresponds to the stud spacing of either 2'-0" (24 inches) or 4'-3" (51 inches). The temperature increase of the strut, ΔT, corresponds to the temperature increase (above a stress free state at 70° F) which the liner experiences under a LOCA or Steamline Break condition. Likewise, the pressure on the strut, P, corresponds to the internal pressure in the containment (above atmospheric) occurring simultaneously with the liner temperature.

The buckling problem was solved using an energy method. In this approach, expressions were derived for the strain energy in the strut both before (straight) and after (deflected) buckling. In the unbuckled position the strain energy is that due only to the membrane compressive stress in the strut produced by the full restraint to ΔT. In the deflected position both bending and membrane strain energy are present. Also in the deflected position, only lateral displacements which satisfy the equilibrium conditions on the strut are admissible. The buckling problem is solved by determining the value of temperature increase, ΔT, in the presence of the pressure, P, required to make the strain energy of the straight strut equal to the sum of (1) the strain energy of the deflected strut and (2) the work done as P displaces from the straight to the deflected position of the strut. This value of temperature is the temperature increase required to buckle the strut (the liner panel) as it is concurrently acted upon by the specific pressure.

The resulting buckling curves for the liner panels corresponding to stud spacings of 24 inches and 51 inches are shown in Figure 11. The values at $P = 0$ are $\Delta T = 27.4^{\circ}$ F for $L = 51$ inches and $\Delta T = 123.6^{\circ}$ F for $L = 24$ inches, both of which produce corresponding liner stresses equal to the Euler buckling values. From the curves in Figure 11, the increase in liner temperature required to cause buckling as the pressure increases is evident. For example, an internal pressure of 10 psig (24.7 psia) increases the buckling temperature (and stress) by factors of 6.0 ($L = 51$ inches) and 1.7 ($L = 24$ inches).

Superimposed on the buckling curves, are values of liner temperature and internal pressure which are based on the LOCA curves of Figures 3 and 4. These are discussed in Section VI.

VI. RESULTS AND CONCLUSIONS

The results of the liner-stud interaction analyses are presented first for limiting stresses of 26 ksi and 29 ksi for the 5/8 inch diameter S6L studs spaced at 24 inches and for limiting stresses of 5.8 ksi and 12 ksi for the 3/4 inch diameter headed studs spaced at 51 inches. Following this, the effect that the internal pressure has on the results are discussed.

A. Insulation Termination Region

The results from four separate liner-stud interaction analyses are presented in Table 1 for the studs in Insulation Termination Region of the dome liner. These studs are the 5/8 inch diameter S6L studs shown in Figure 2. Column (1) identifies the stud capacity, Qu, which is based on the force-displacement curve from Figure 9 used in the particular analysis. Column (2) identifies the stress in the liner just outside the insulation. The acceptance criteria for the studs is based on stud displacement, and the maximum displacement occurs for the #1 stud in Figure 7.B. These values are shown in column (3), and they are to be compared with the ultimate stud displacement of 0.167 inches in column (4). The percentage of the maximum displacement relative to the ultimate value is indicated in column (5). These values range from 84% to 99%. The results associated with the 10.6 kips stud capacity are more applicable than the values associated with the 8.3 kip lower bound stud capacity, for the reasons discussed in Section V. Therefore, the maximum stud displacement is estimated to be either 84% or 95% of its ultimate value, depending on the maximum stress which will be developed in the liner. These results are less than the 100% value indicating stud failure. However, considering the magnitude of the displacements and their sensitivity to the 10% increase in the theoretical limiting liner stress of 26 ksi, some of the studs located just outside the insulation could possibly fail.

Any stud failures which might occur would not be expected to tear the liner, based on test results reported in Reference 11. This reference describes tests conducted on 1/2", 5/8", and 3/4" diameter headed studs attached to steel flanges of various thicknesses, ranging from 0.128" thick to 0.389" thick. A total of 41 specimens were tested in all. The primary objective of the tests was to determine the mode of failure of the studs, and under what conditions failure would occur by tearing of the flanges rather than in the stud itself. The main conclusion reached from the tests is that if the ratio of stud diameter to flange thickness is less than 2.7 then the studs will fail in their shank and flange tearing or pull-out will not occur. For the 5/8 inch diameter S6L studs, the diameter-to-thickness ratio is 0.437/0.375 or 1.17. This value is much less than the 2.7 limiting value; therefore, any failure of the S6L dome liner studs would not result in a tearing of the liner.

B. General Dome

The results of the liner-stud interaction analysis for both regions of the general dome are presented in Table 2. The results in columns (1) thru (5) were identified earlier. For the buckled panel in the general dome model (Figure 7.A), the displacements and strains are also of interest; and these values are indicated in columns (6) thru (9). The results for the 5/8 inch diameter S6L studs and 3/4 inch diameter headed studs are discussed separately below.

5/8 Inch Diameter S6L Studs

As indicated in the previous discussion of the Insulation Termination Region, the results which are based on the stud capacity of 10.6 kips, rather than 8.3 kips, are considered to represent the best estimate for the S6L studs. The

results in column (5) indicate a maximum stud displacement of either 68% or 102% of the ultimate value, depending on whether the limiting stress in all the unbuckled panels is 26 ksi or 29 ksi. Thus, the stud displacements are very sensitive to the stress limit developed in the adjacent panels. These results can be interpreted as follows referring to the model in Figure 7.B. For the studs adjacent to the buckled panel (1-1) to actually displace 102% of their ultimate value, the stress in all 19 adjacent panels would have to reach 29 ksi. This condition would occur only if there were no initial imperfections in these panels to cause them to buckle at a stress less than 29 ksi. If only one panel within the 19 panel group were to buckle at less than 29 ksi the displacement of the #1 stud in the model would probably be reduced to below 100%. Considering the results, it is possible that some of the S6L studs in the General Dome Region could fail. However, based on the test results in Reference 11 discussed previously, any stud failures would not tear the liner in the process.

The relatively large lateral displacements in column (6) for the 24 inch buckled panel (1-1) deserve some attention because of the large associated strains. Due to these lateral displacements of the buckled panels, plastic hinging is calculated to occur. The strains which are produced across the liner section in the hinge region are given in columns (7), (8), and (9).

The largest membrane strain from column (7) for a Qu of 10.6 kips is 0.0096 inches/inch compression. This value is 6 times the yield strain based on a 48 ksi liner yield stress. However this strain, being compression, is not significant as far as liner integrity is concerned.

The extreme fiber strains (bending plus membrane) indicated in columns (8) and (9) are large by conventional measures as the results in column (10) indicate. Here, for the worst case, the extreme fiber strain is 39 times the yield strain of the liner material. To put this magnitude of strain in perspective, an extreme fiber strain equal to 39 times yield would be produced in a bend test if the liner were bent around a circular pin having a diameter of 5.6 inches. The liner, being a low carbon steel, is ductile enough to be bent to this diameter without tearing. The version of the ASTM specification, A442, used for the Ginna containment liner material required that liner specimens be cold bent through 180° around a pin diameter equal to the liner thickness of 0.375 inches without cracking the specimen. It is indicated on page 5.1.2-74 of the Ginna FSAR that these tests were performed for each as-rolled liner plate supplied. This test produces an extreme fiber strain in the liner which is calculated to be 313 times the yield strain. These tests demonstrated that the liner is capable of undergoing bending strains which are much larger than those calculated for the buckled panels. Therefore, the structural integrity of the liner will not be impaired under the strain conditions calculated to exist.

3/4 Inch Diameter Headed Studs

The maximum stud displacements corresponding to limiting stresses in the unbuckled panels of 5.8 ksi and 12 ksi are shown in column (3) of Table 2. In both cases the maximum stud displacements are small, being only 11% of the ultimate value at worst. The corresponding strains in the buckled panel (1-1) due to the lateral displacement of the panel are also small; the largest value is only 1.5 times the yield strain. Thus, even though the liner is supported by a relatively large stud spacing of 51 inches, which results in

a low buckling capacity, the displacement of the liner does not produce strains which would impair its structural integrity.

Based on these results, it can be concluded that failure of the 3/4 inch diameter headed studs is extremely unlikely. Any stud failures that might unexpectedly occur would not tear the liner, even for studs as large as these. Recalling the conclusions discussed previously from Reference 11, the stud diameter-to-liner thickness ratio is 0.75/0.375 or 2; and this is well within the 2.7 limit below which stud failure does not tear the liner in the process.

C. Effect of Internal Pressure on Liner Buckling and Stud Integrity

The buckling capacity of the liner under the combined effects of a temperature increase and coincident pressure is presented in Figure 11. The curves in the figure define the buckling capacity in the two regions of the liner where the stud spacings of 24 inches and 51 inches exist. For comparison, values of the liner temperature and internal pressure are indicated. These result from the LOCA conditions in Figures 3 and 4. The liner temperatures were obtained from a heat transfer analysis of the LOCA temperature transient in Figure 3. The time into the LOCA transient is indicated for several of the pressure and temperature values. For example, at 100 seconds into the transient the liner temperature has increased 173° F (above 70° F) and the simultaneous pressure on the liner is 53 psig (67.7 psia).

The comparison in Figure 11 indicates that for the first 2.15 hours (7740 seconds) into the transient, the internal pressure prevents the liner from buckling in all regions of

the dome. During this time the liner reaches a maximum temperature of approximately 260° F (190° F increase above 70° F), which is considerably above the temperature required to buckle it even in the region where the studs are spaced at 24 inches. However, buckling does not occur because at this temperature the coincident containment pressure is 42.7 psia (28 psig). After 2.15 hours into the transient, when the internal pressure has decreased to 24.7 psia (10 psig), the results indicate that the region of the liner where the studs are spaced at 51 inches (3/4 inch headed studs) is susceptible to buckling. By that time, the liner temperature has reduced to approximately 250° F. The region of the liner where the studs are spaced at 24 inches (5/8 inch S6L studs) remains unbuckled. The effect of these results on the liner and stud evaluation is discussed below.

In Section V1.A and Section V1.B the conclusions regarding the potential for stud failure were that failure of some of the 5/8 inch diameter S6L studs located in the Insulation Termination Region and in the General Dome Region might occur, depending on whether or not the limiting stress of 26 ksi is actually exceeded. For the 5/8 inch diameter S6L studs in the General Dome, this conclusion was based on an initial assumption that one panel has buckled. However, the comparison in Figure 11 indicates that the liner panels associated with these studs are not likely to buckle because of the effect of the internal pressure. The assumption that a buckled panel exists with the result that shear forces are produced in the studs is not considered to be realistic in light of these results. Therefore, stud failure is not expected to actually occur. For the remaining 5/8 inch diameter S6L studs in the region of the liner where the insulation terminates, the fact that the liner panel remains unbuckled increases the stress that is capable of developing well above the 26 ksi and 29 ksi limits used in the previous

interaction analyses. The stress increases to a maximum value of approximately 47 ksi, which corresponds to the maximum liner temperature of 260° F. The 47 ksi compressive stress exceeds the specified minimum yield strength of 32 ksi, but it is considered to be achievable since the actual average yield strength of the liner plates is expected to be in the neighborhood of 48 ksi, as previously mentioned. The effect of a 47 ksi stress occurring in the liner region outside the insulation would be to cause failure of the studs in the Insulation Termination Region of the dome. However, based on the test results in Reference 11 discussed previously, failure of these studs would not affect the integrity of the liner.

The remaining studs are the 3/4 inch diameter headed anchors in the region of the General Dome which extends from the 55° meridian to the apex. The conclusions in Section VI.B were that because of the relatively low buckling capacity of the liner in this region, the limiting stresses were small. The corresponding calculated stud displacements were considerably less than their ultimate values and stud failure was considered to be very unlikely. When the pressure effect is taken into account, it is also concluded that these studs will not fail during at least the first 2.15 hours of the LOCA transient because the liner panels would not buckle and, consequently, no unbalanced panel forces exist to produce shear on the studs. Beyond this time, from Figure 11, the LOCA pressures and temperatures fall somewhat below the buckling curve for the 51 inch stud spacing and buckling of some liner panels could occur. If one panel buckles but adjacent panels do not, the 250° F liner temperature would produce a 45 ksi compressive stress in the unbuckled panels. This would result in an unbalanced shear force in the studs that is large enough to cause their failure. However, this condition would not affect liner integrity because, as

previously discussed, the ratio of stud diameter-to-liner thickness being 2.0 is significantly less than the limiting value of 2.7 required to tear the liner. Aside from this, after 2.15 hours into the LOCA transient the internal pressure is down to approximately 10 psig which is far below the maximum value of 60 psig that the containment structure has been designed to resist; and the stresses in the reinforced concrete structure are relatively low.

VII. OVERALL CONCLUSIONS

Of the results and conclusions presented above, those based on a consideration of the internal pressure are considered to be more realistic since pressure would actually be present in a LOCA transient loading condition on the liner.

In the region of the dome where the insulation terminates, the liner is expected to remain in an unbuckled condition. As a result, unbalanced compression stresses in the liner are produced which are large enough to result in failure of the 5/8 inch diameter S6L studs located in this region based on the results of the liner-stud interaction analyses described herein. However, failure of these studs would be limited to the shank of the studs and not in the liner. Therefore, the leak tight integrity of the liner will be maintained.

Above the insulation and extending to the 55° meridional coordinate axis on the dome, a distance of approximately 35 feet, the liner is expected to remain in an unbuckled condition, and no unbalanced compressive stresses exist in the liner. Because of this, no shear forces are produced in the 5/8 inch diameter S6L studs in this region and, consequently, stud failure would not be expected to occur.

Above the 55^{o} meridional coordinate axis and extending to the apex of the dome, the liner panels are susceptible to buckling late in the LOCA transient after the containment pressure has reduced to approximately 17% of the design pressure of the containment structure. In the event that a panel buckles but adjacent panels remain unbuckled, unbalance compressive stresses are produced which are large enough to fail some of the 3/4 inch diameter studs in this region. However, failure of these studs is predicted to occur in the shank of the studs and not in the liner. In addition, the liner plate material has demonstrated capacity to accommodate strains which are much greater than the strains which the buckled liner panels are expected to undergo. Therefore, the leak tightness of the liner will be maintained.

REFERENCES

1. Robert E. Ginna Nuclear Power Plant - Containment Vessel Evaluation, February 1, 1982.

2. Letter from T. R. Weis (RG&E) to D. R. Campbell (G/C), Re: Ginna Station - SEP TOPIC III - 7.B, letter no. 13NI-RG-L0532, May 24, 1982.

3. Nelson Standard In-Stock Stud Catalog, May 1968.

4. Structural Review of the Robert E. Ginna Nuclear Power Plant Under Combined Loads for the Systematic Evaluation Program, NUREG/CR-2580, March 1982.

5. "Liner Anchorage Analysis for Nuclear Containments", Windstead, T. L.; Burdette, E. G.; and Armentrout, D. R.; Journal of Structural Division ASCE, VOL. 101, NO. ST10, Proc. Paper 11635, October 1975, p. 2103.

6. Response of the Zion and Indian Point Containment Buildings to Severe Accident Pressures, NUREG/CR-2569, May 1982.

7. "Shear Strength of Stud Connections in Lightweight and Normal Weight Concrete"; Ollgaard, J. G.; Slutter, R. G.; and Fisher, J. W.; AISC Engineering Journal, pp. 55-64, April 1971.

8. Design Data - Nelson Concrete Anchor, TRW Report.

9. Embedment Properties of Headed Studs, TRW-Nelson Division, 1977.

10. Shear Strength of Deformed Bar Anchors, Report for Nelson Stud Welding by D. R. Barna, April 1972.

11. "Shear Strength of Thin Flange Composite Specimens", Goble, G. G., AISC Engineering Journal, pp. 62-65, April 1968.

TABLES

STUD CAPACITY, Qu (kips)	BUCKLED PANEL STRESS (ksi)	MAXIMUM STUD DISPL., Δ (inches)	ULTIMATE STUD DISPL., (inches)	MAX/ULT. DISPL. (%)
(1)	(2)	(3)	(4)	(5)
10.6	26	0.141	0.167	84
8.3	26	0.148	0.167	89
10.6	29	0.159	0.167	95
8.3	29	0.166	0.167	99

TABLE 1 - MAXIMUM DISPLACEMENTS OF 5/8 INCH S6L STUDS IN INSULATION TERMINATION REGION

STUD CAPACITY, Qu (kips) (1)	STRESS LIMIT IN UNBUCKLED PANELS (ksi) (2)	MAXIMUM STUD DISPL., Δ (inches) (3)	ULTIMATE STUD DISPL. (inches) (4)	MAX/ULT. DISPL. (%) (5)	LINER LATERAL DISPL. (INCHES) (6)	MAXIMUM LINER STRAINS (inches per inch) MEMB.-COMP. (7)	MEMB. & BEND.-COMP. (8)	MEMB. & BEND.-TEN. (9)	COL. (8)/εy (10)
	5/8 Inch Diameter S6L Studs at 24 Inches								
10.6	26	0.113	0.167	68	1.67	0.0096	0.0558	0.0366	35
8.3	26	0.150	0.167	90	1.92	0.0097	0.0626	0.0433	39
10.6	29	0.170	0.167	102	2.03	0.0088	0.0597	0.0422	37
8.3	29	> 0.300	0.167	>>100	n/a	n/a	n/a	n/a	n/a
	3/4 Inch Diameter Headed Studs at 51 Inches								
31.1	5.8	0.00343	0.341	1	0.42	0.000177	0.000767	0.000413	0.5
31.1	12	0.0388	0.341	11	1.41	0.00020	0.0024	0.0019	1.5

$\varepsilon y = 48/30000 = 0.0016$ inches/inch

TABLE 2. MAXIMUM DISPLACEMENTS OF STUDS IN GENERAL DOME

FIGURES

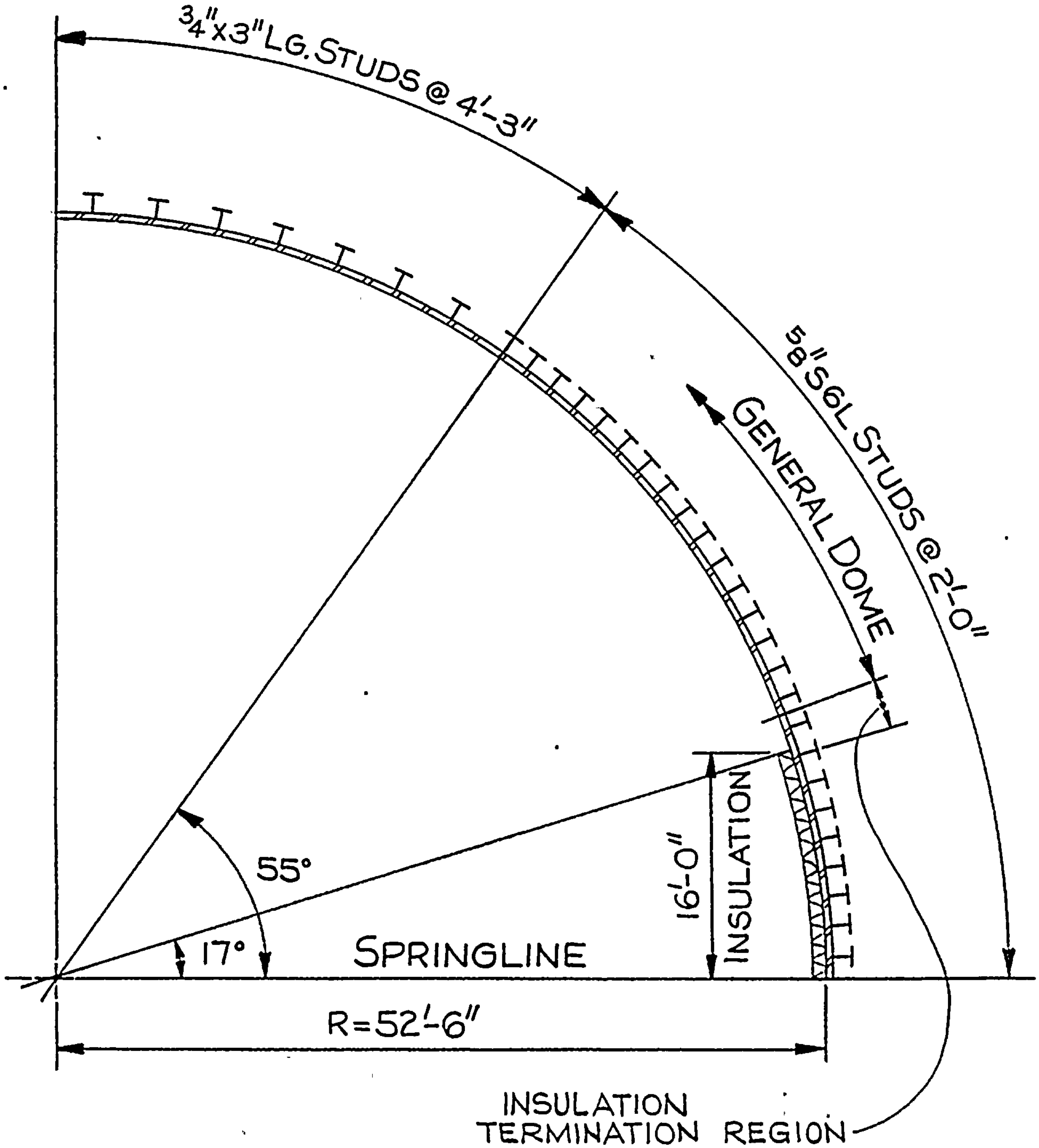
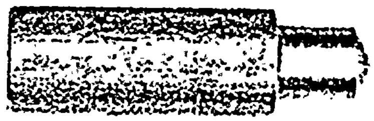


FIGURE 1- DOME LINER AND STUDS

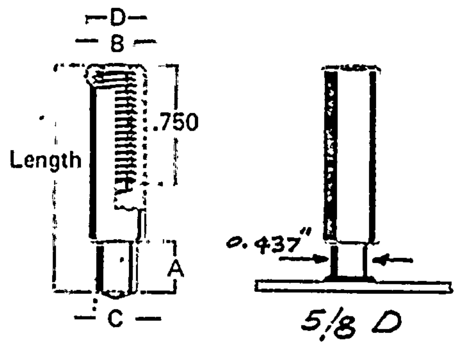
→ S6L



Major Diameter D	A	Tap Diameter B	Weld Base Diameter C	Ferrule Number
½	.437	⅜-16	.375	100-101-031
⅝	.500	½-13	.437	100-101-032

[illegible]

DESCRIPTION	PART NO.
½ x 2 S6L	101-101-006
⅝ x 2 S6L	101-101-007



MATERIAL: Low Carbon Steel:

C-.23% max.	P-.040% max.
Mn-.60% max.	S-.050% max.

Stainless Steels: Nelson studs are also available in stainless steel. Type 304 is the most commonly used. Other grades of 300 series stainless steel (except Type 303) available when required.

THREAD: Standard thread is UNC2A.

ANNEALING: To increase stud ductility, studs can be annealed to 75 Rockwell B Max. for low carbon steel studs; 85 Rockwell B Max. for stainless steel studs.

FIGURE 2

5/8 INCH DIAMETER S6L NELSON STUDS

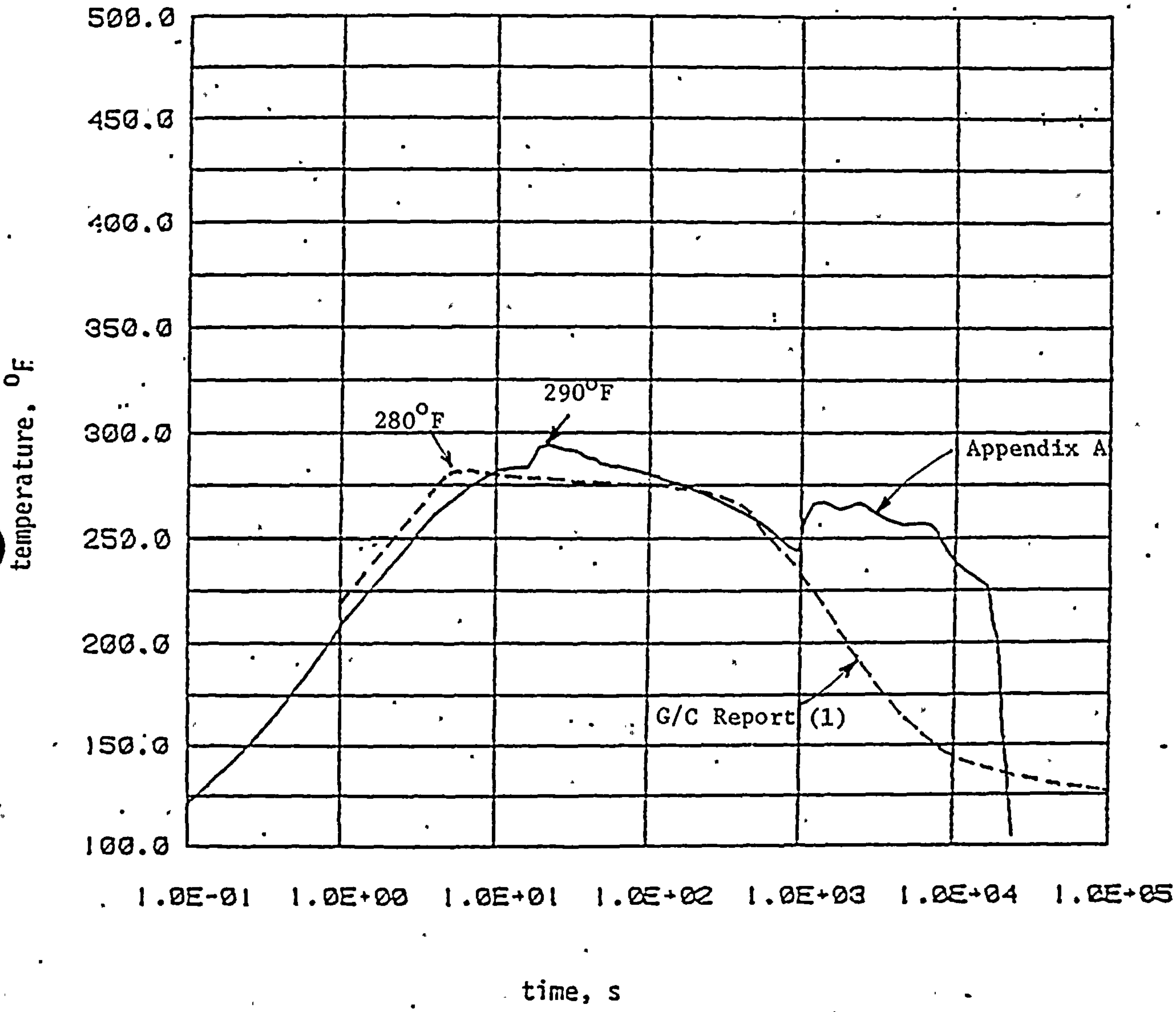


FIGURE 3. LOCA TEMPERATURE TRANSIENT

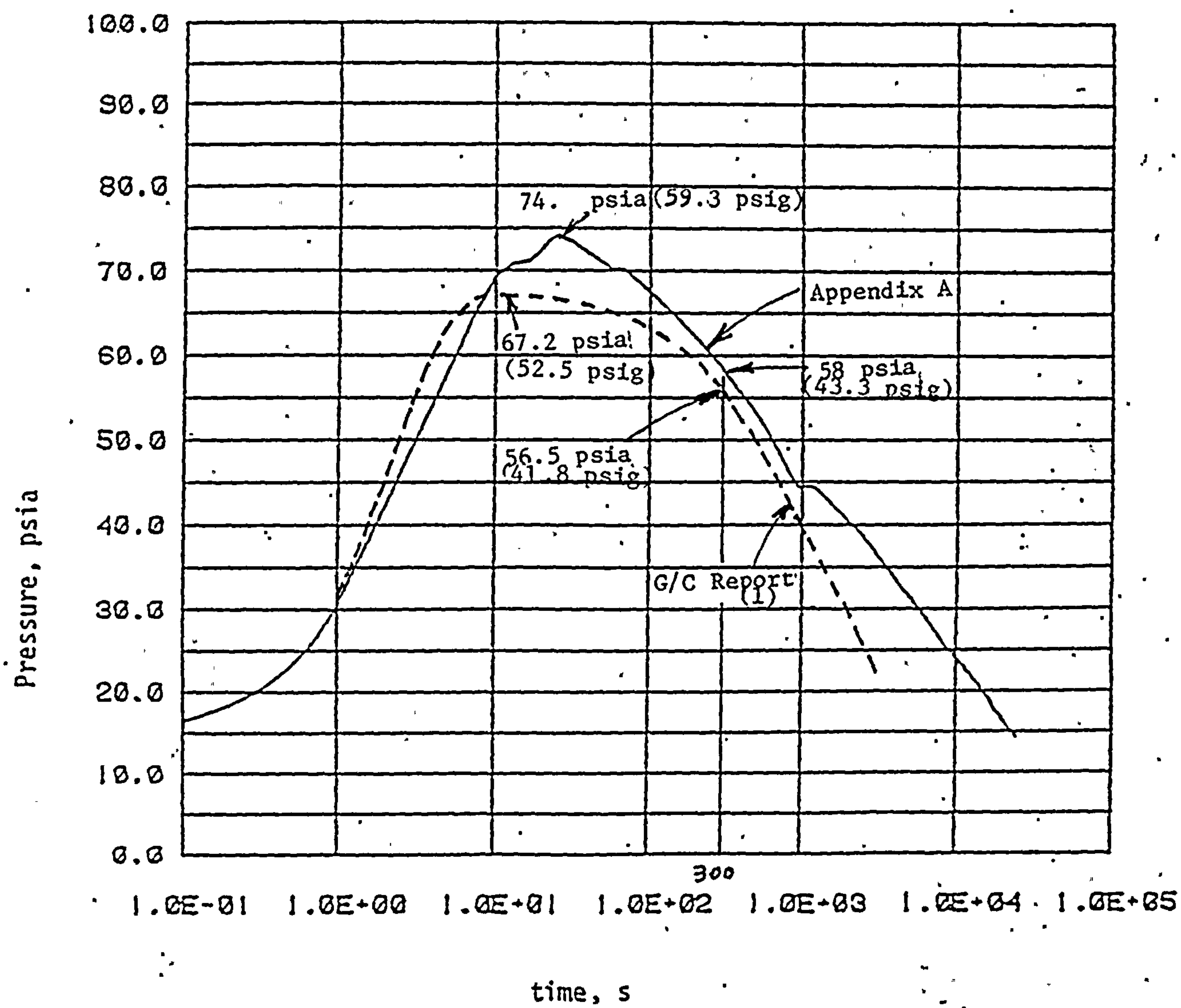


FIGURE 4. LOCA PRESSURE TRANSIENT

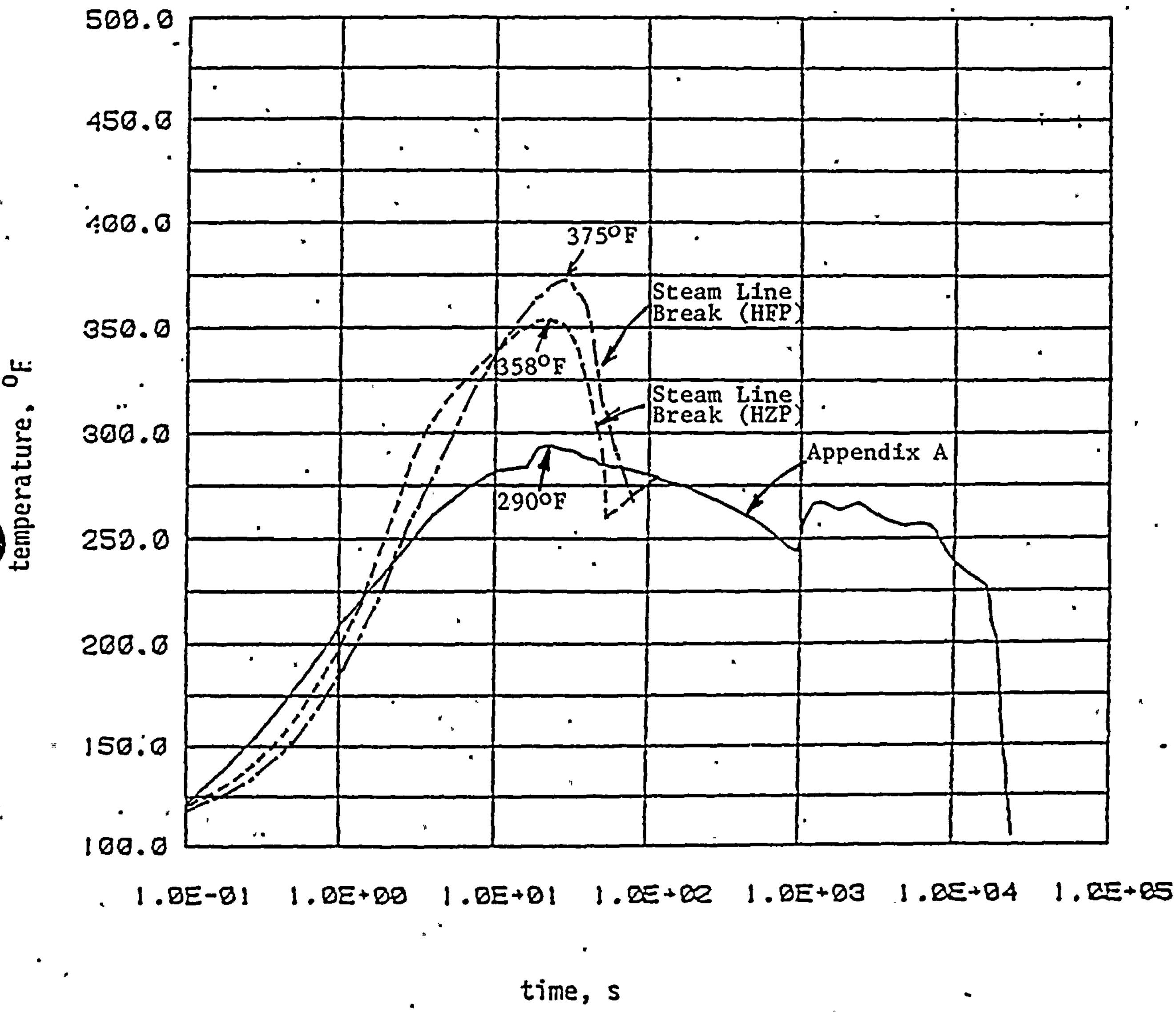


FIGURE 5. COMPARISON OF STEAMLINE BREAK AND LOCA TEMPERATURE TRANSIENTS

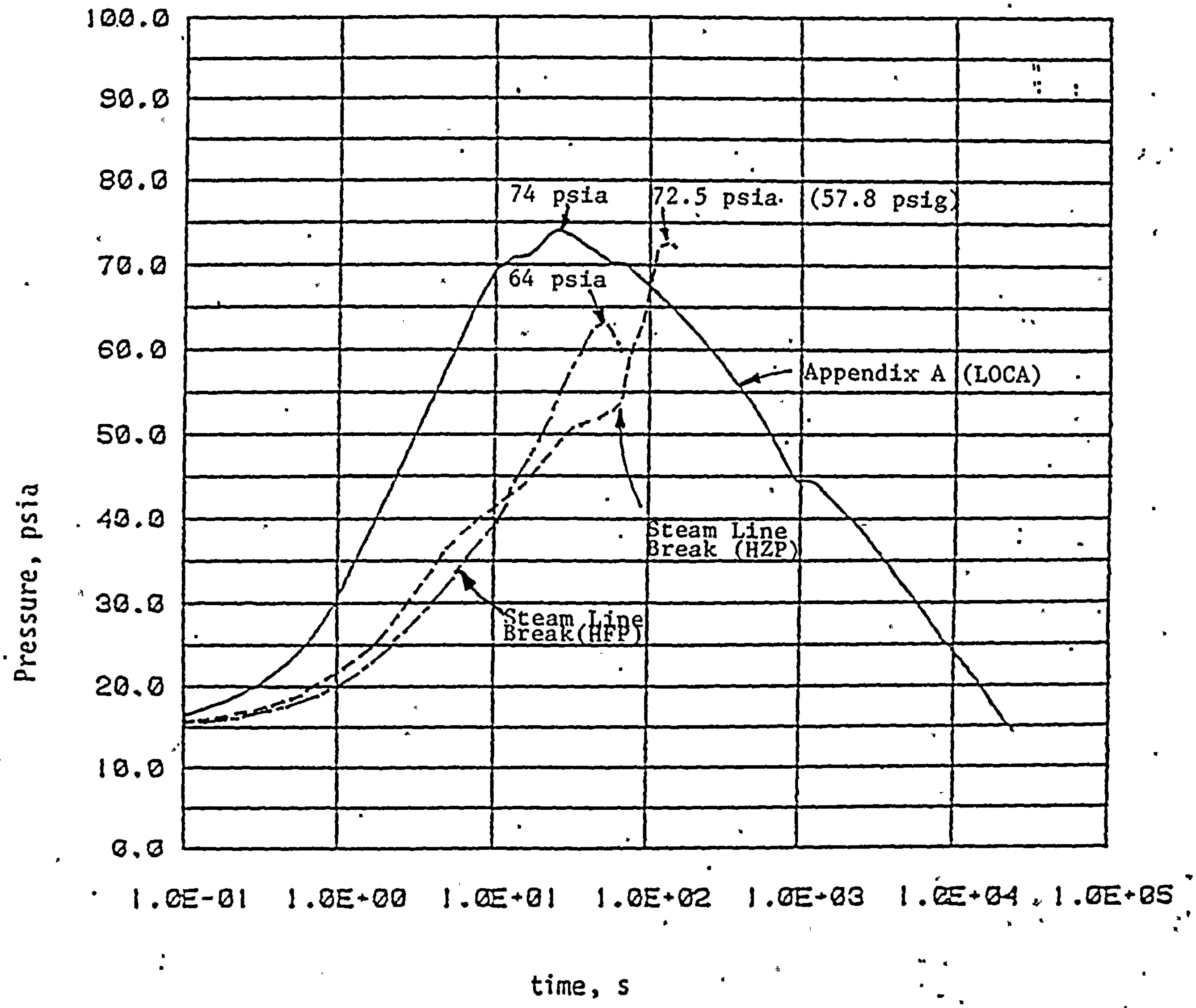
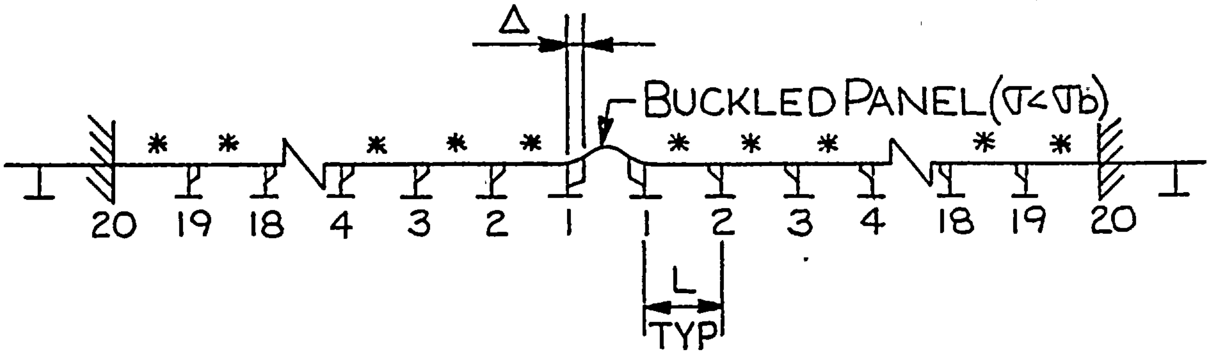


FIGURE 6. COMPARISON OF STEAMLINE BREAK AND LOCA PRESSURE TRANSIENTS



3/4" HEADED STUDS : L = 4'-3"
* UNBUCKLED PANELS : σ(LIMIT)=5.8 KSI
5/8" S6L STUDS : L = 2'-0"
* UNBUCKLED PANELS : σ(LIMIT)= 26 KSI

FIGURE 7.A-GENERAL DOME MODEL

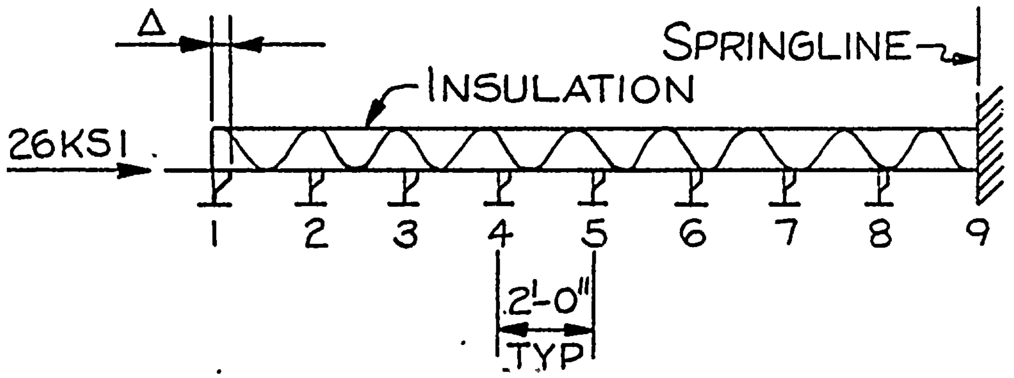


FIGURE 7.B-INSULATION TERMINATION REGION MODEL

FIGURE 7-LINER-STUD INTERACTION MODELS

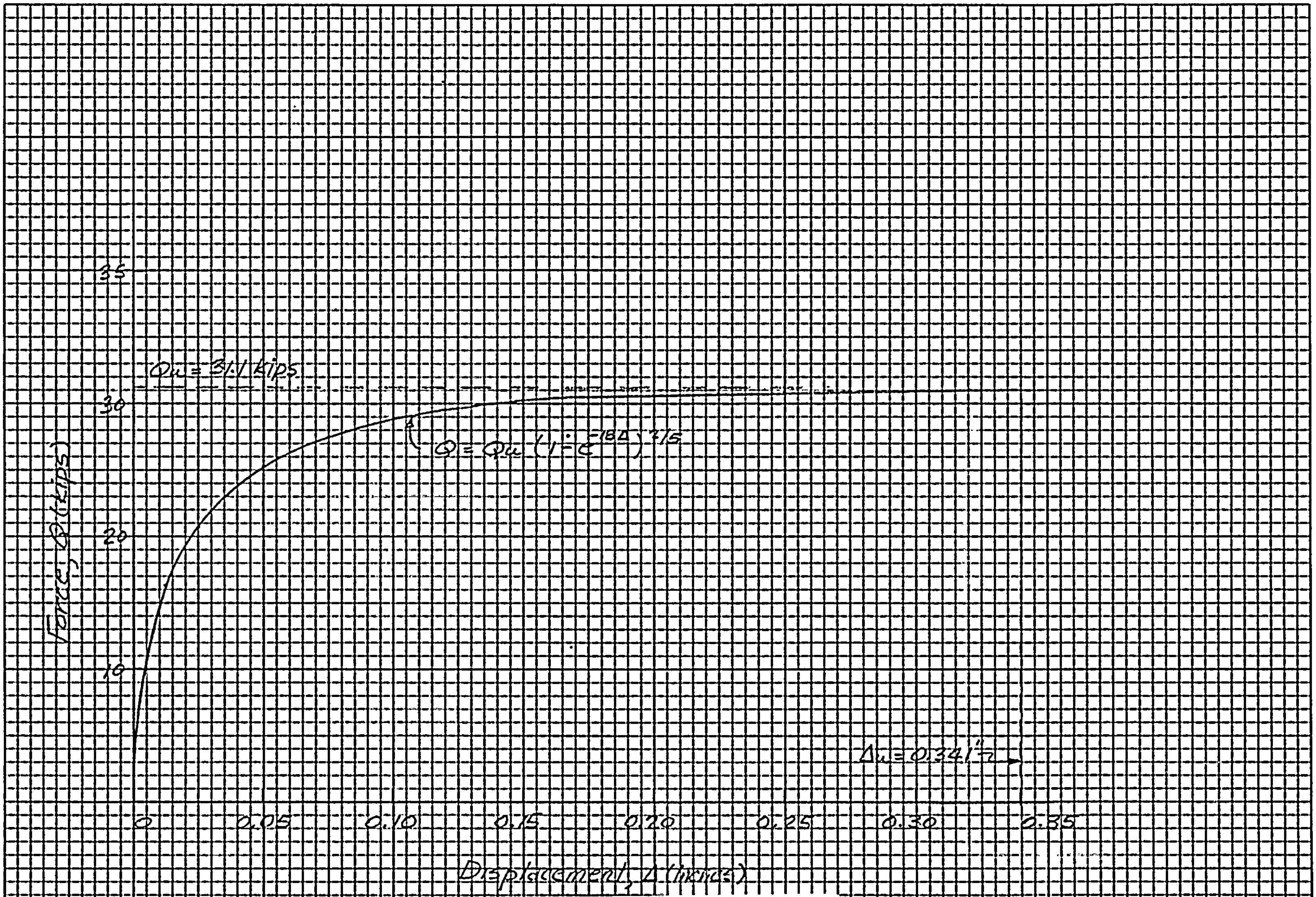


FIGURE 8. FORCE-DISPLACEMENT CURVE FOR 3/4 INCH HEADED STUDS

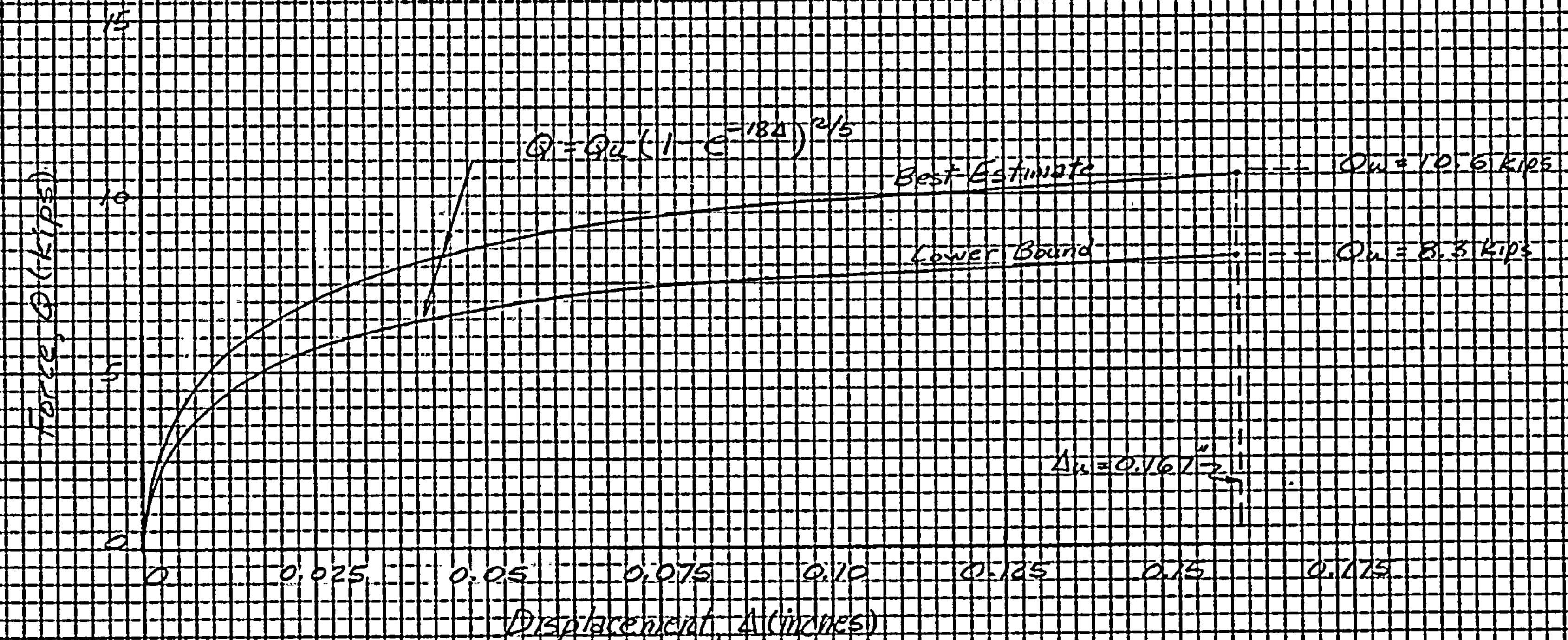


FIGURE 9. FORCE-DISPLACEMENT CURVE FOR 5/8 INCH S6L STUDS

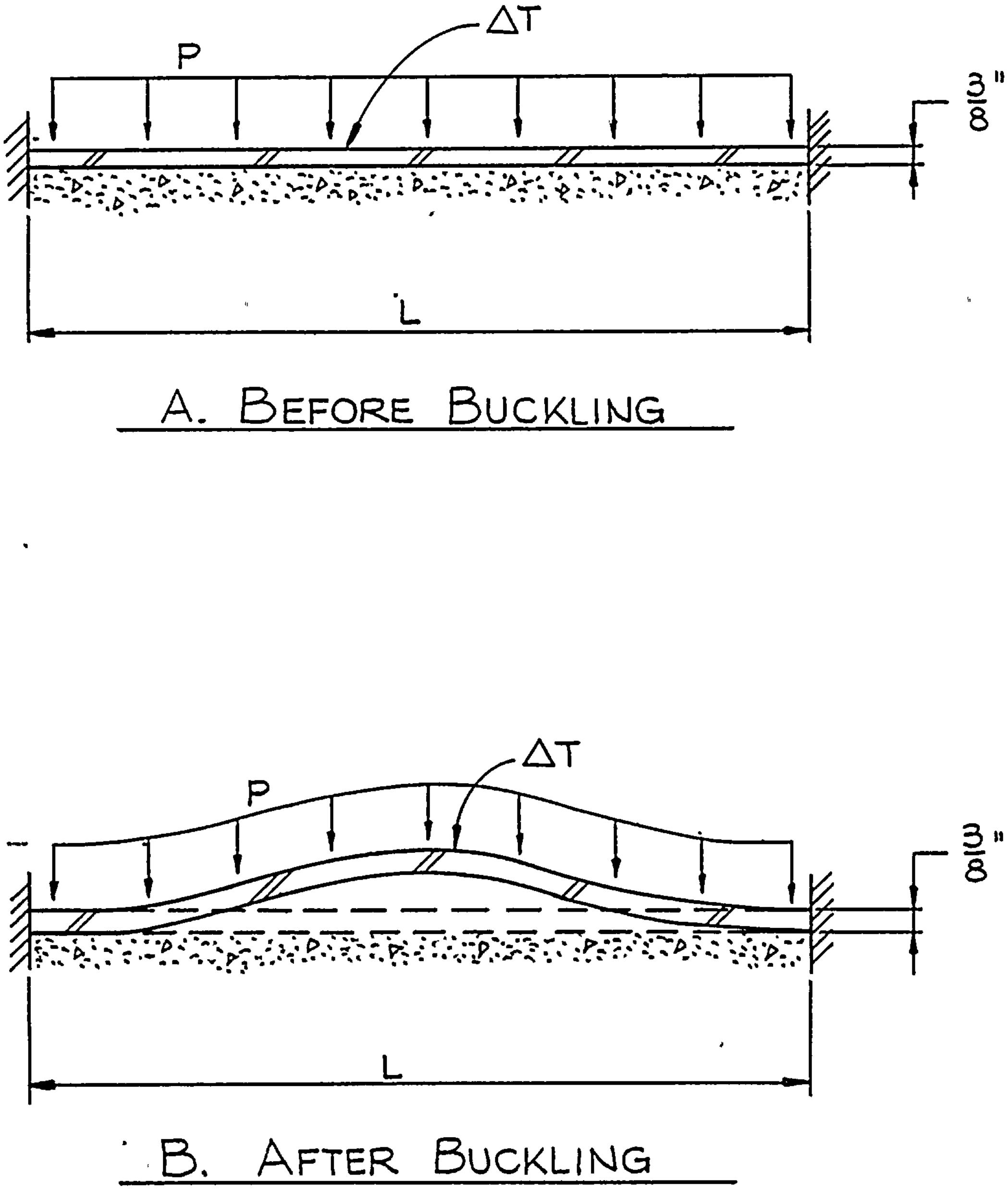


FIGURE 10. STRUT BUCKLING UNDER P AND ΔT

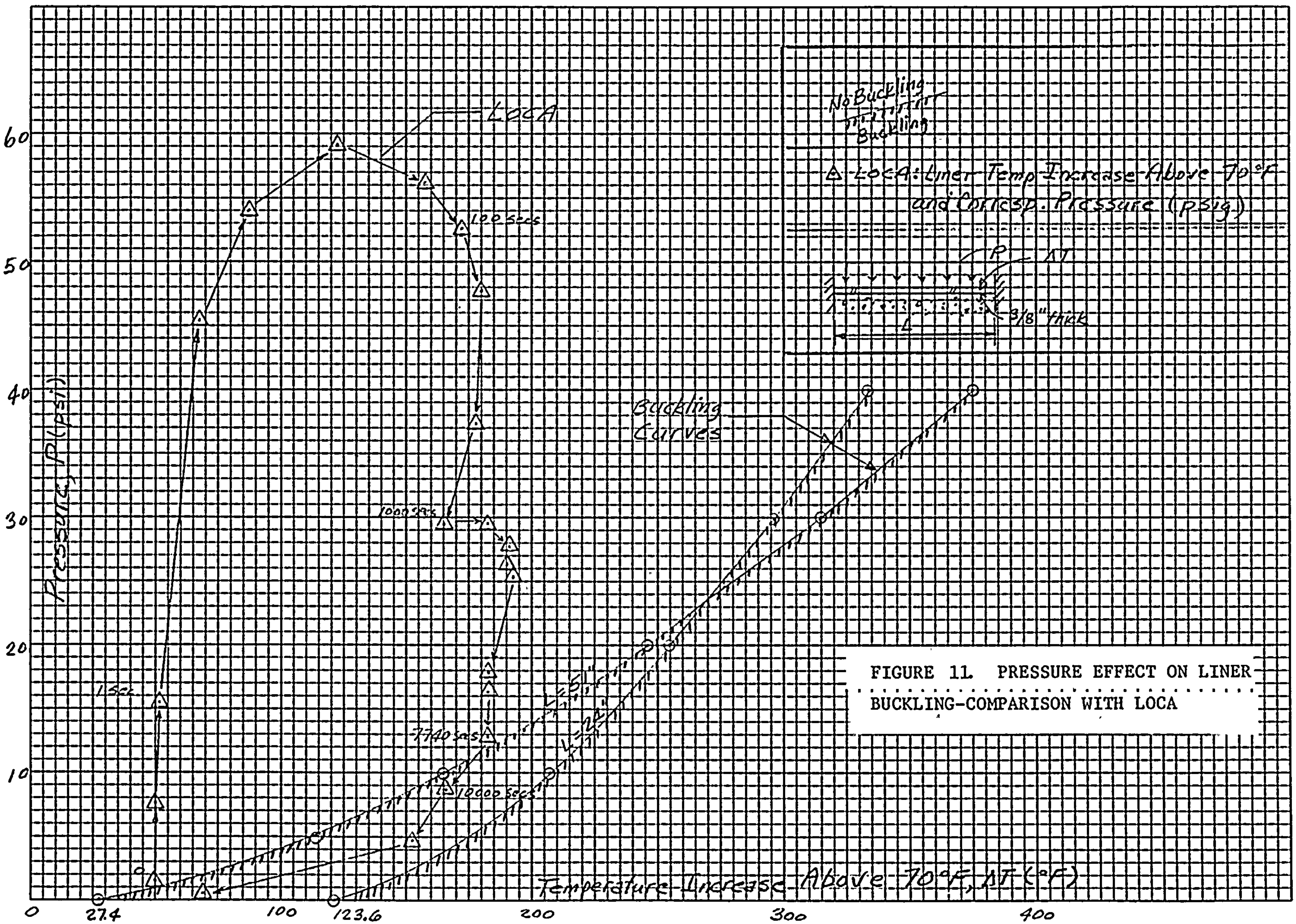


FIGURE 11. PRESSURE EFFECT ON LINER BUCKLING-COMPARISON WITH LOCA

APPENDIX A

LOCA AND STEAMLINE BREAK

PRESSURE/TEMPERATURE TIME HISTORIES

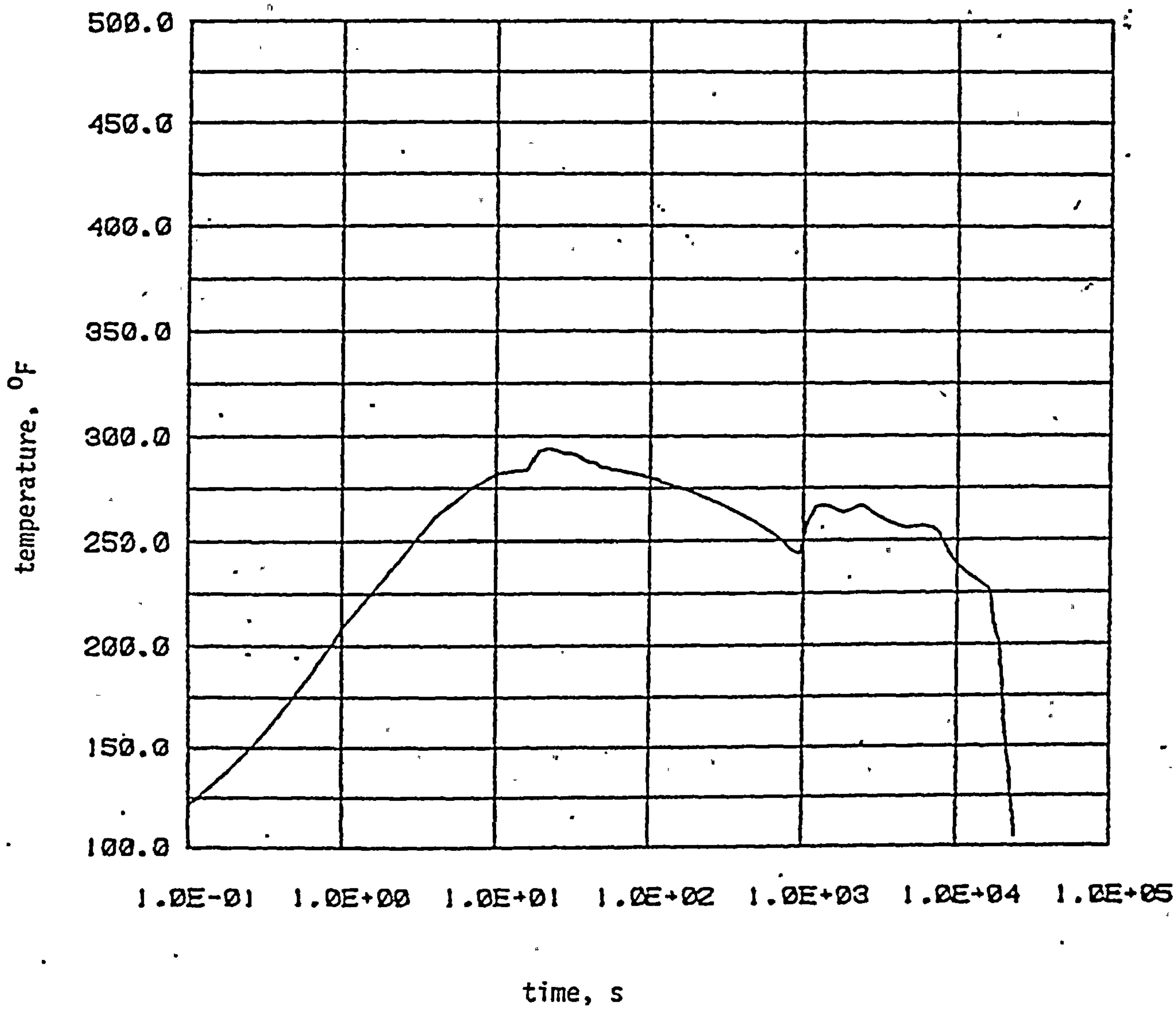


Figure A-1 Containment Atmosphere Temperature, Ginna Double-Ended Suction Leg Break

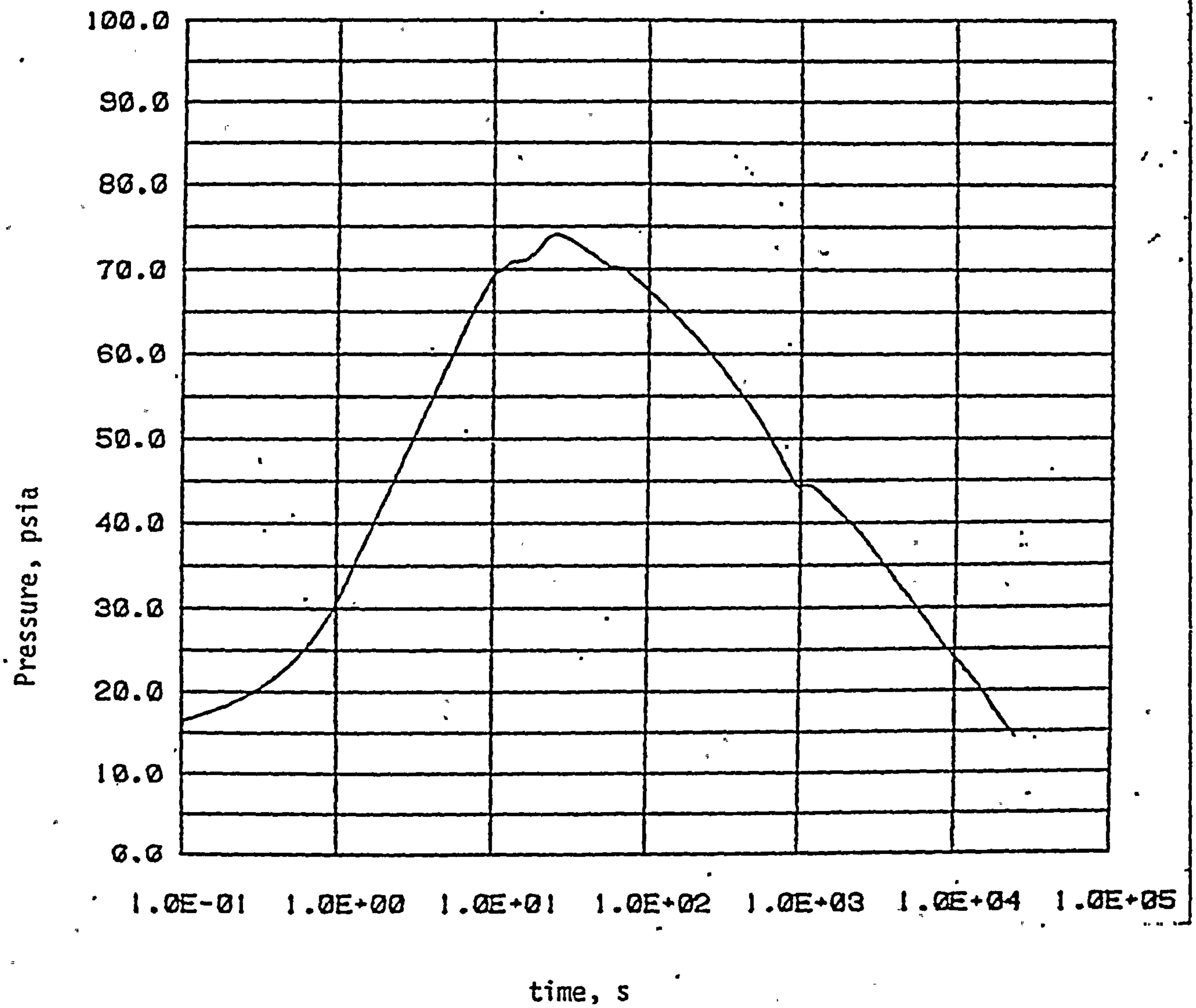


Figure A-2 Containment Atmosphere Pressure, Ginna Double-Ended Suction Leg Break

46 1242

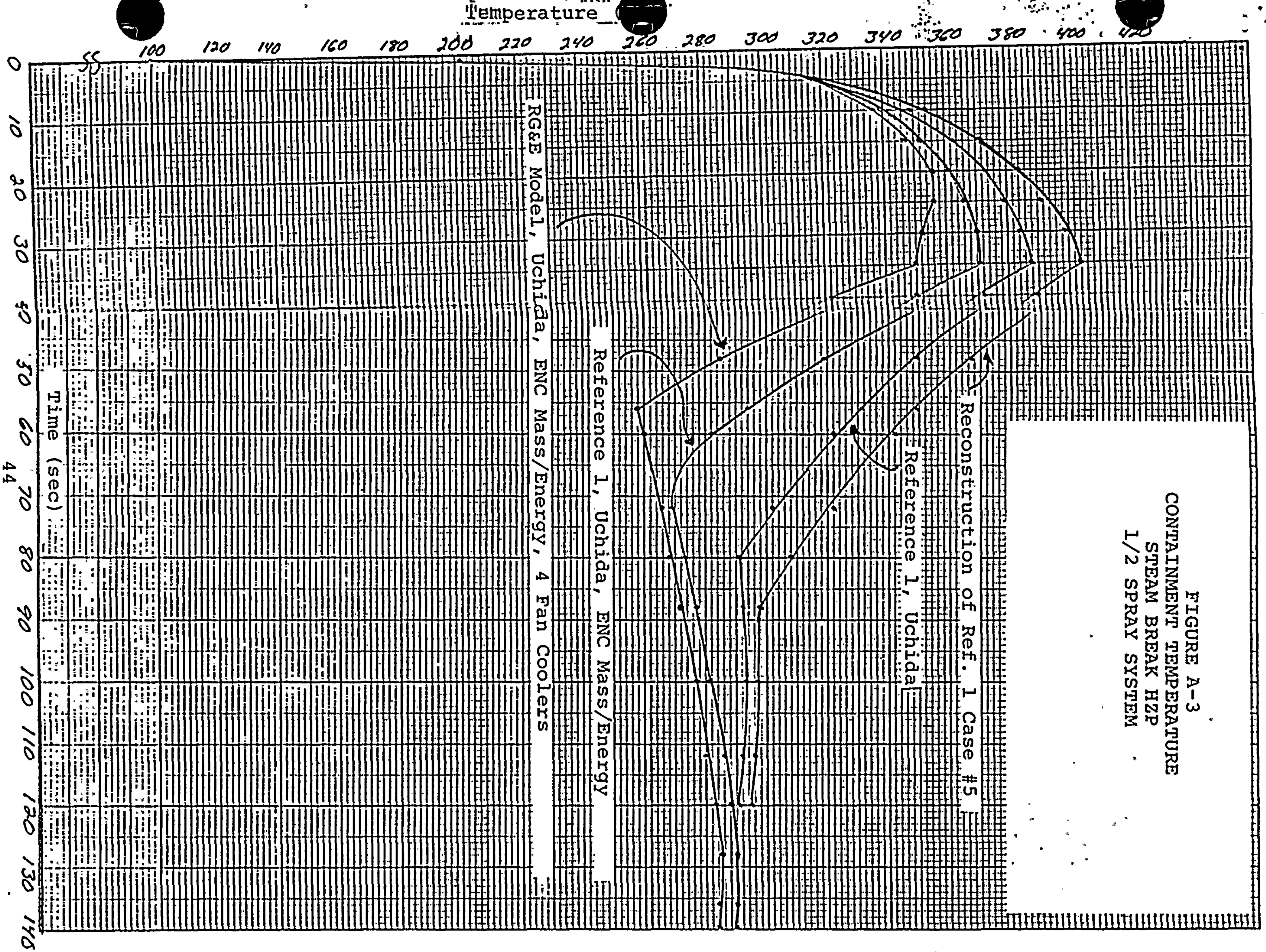


FIGURE A-3
CONTAINMENT TEMPERATURE
STEAM BREAK HZP
1/2 SPRAY SYSTEM

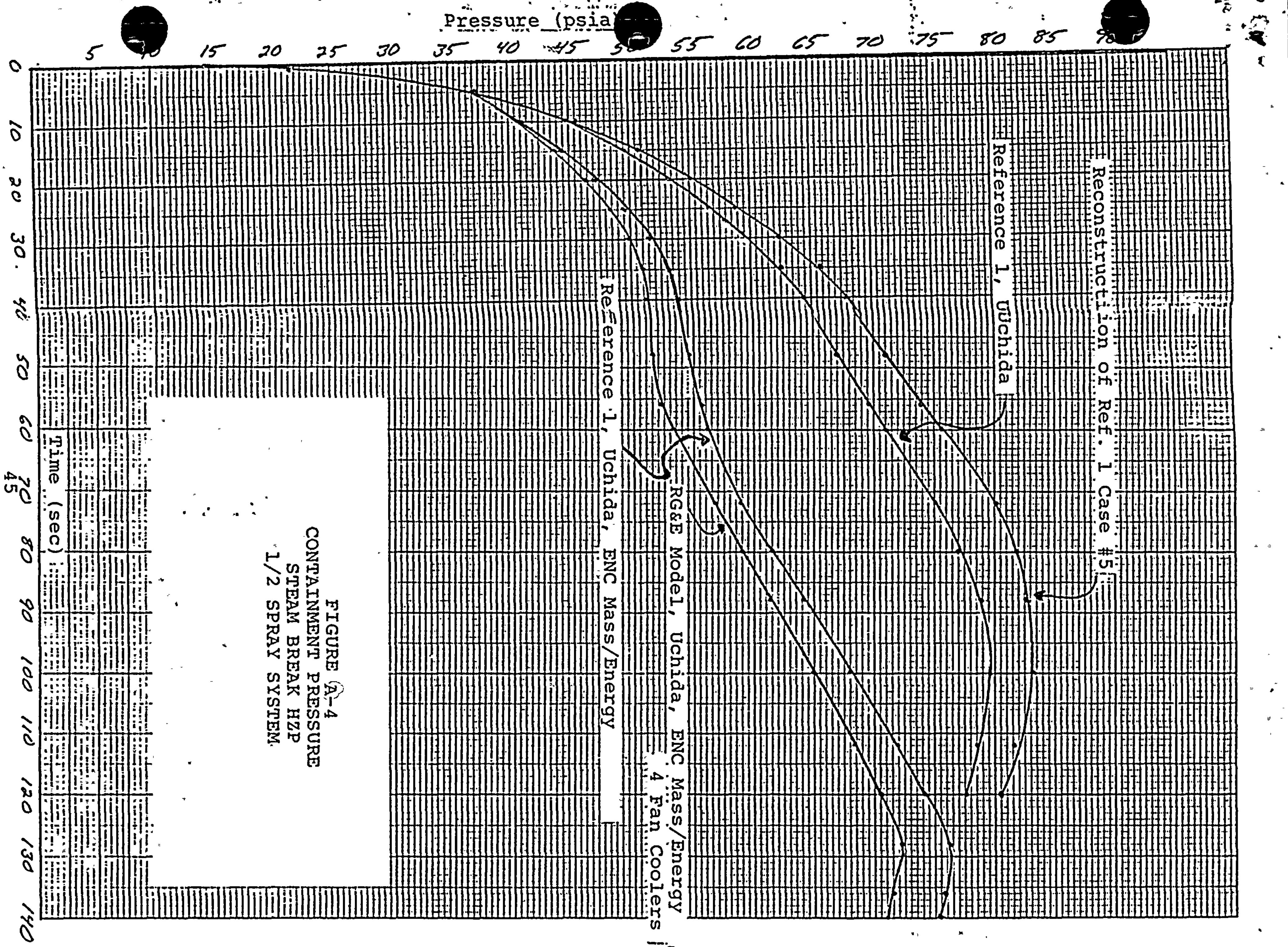


FIGURE A-4
CONTAINMENT PRESSURE
STEAM BREAK HZP
1/2 SPRAY SYSTEM

K&E 20 X 20 TO THE INCH • 7 X 10 INCHES KEUFFEL & ESSER CO. MADE IN U.S.A. 46 1242

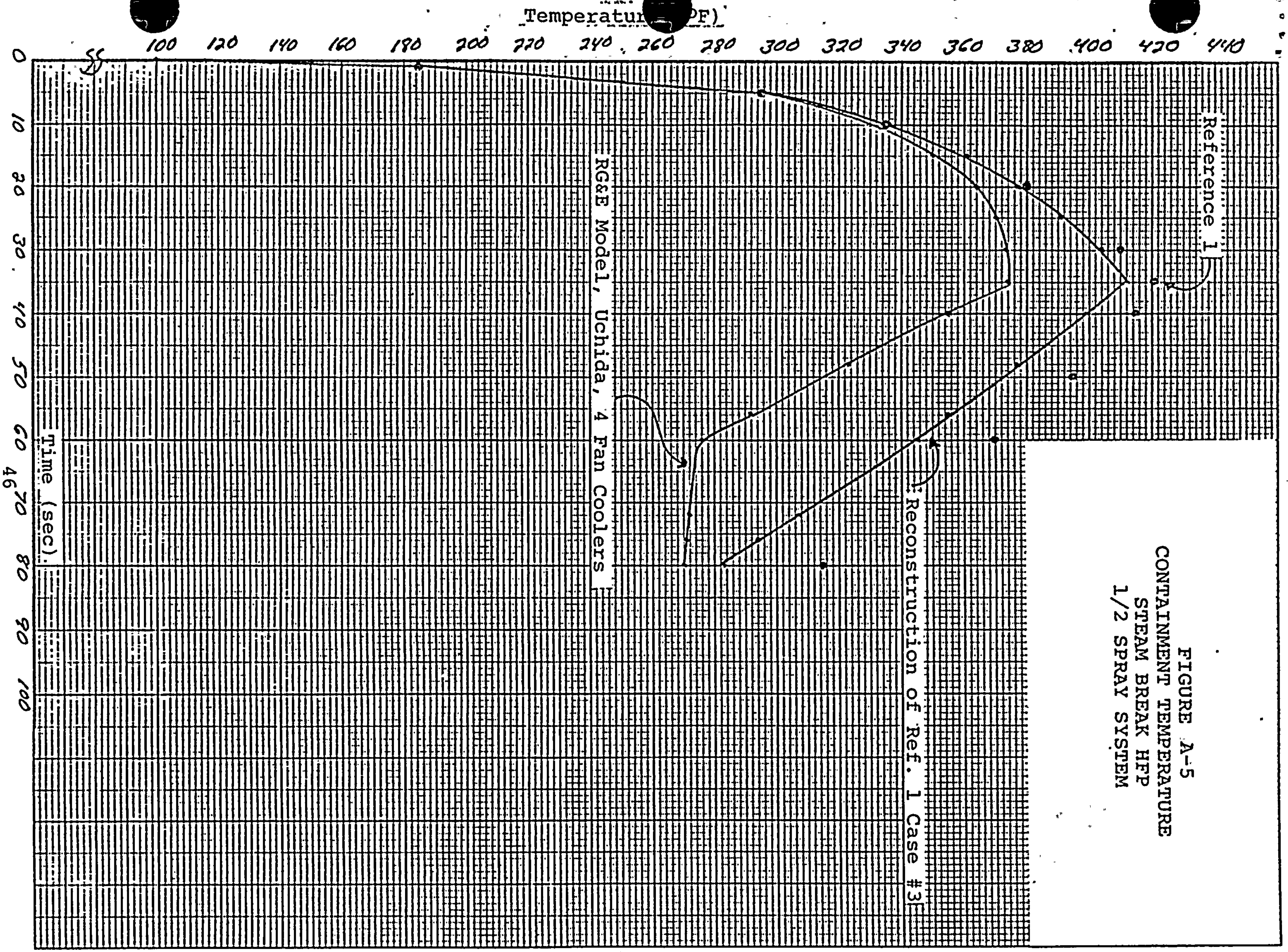


FIGURE A-5
CONTAINMENT TEMPERATURE
STEAM BREAK HFP
1/2 SPRAY SYSTEM

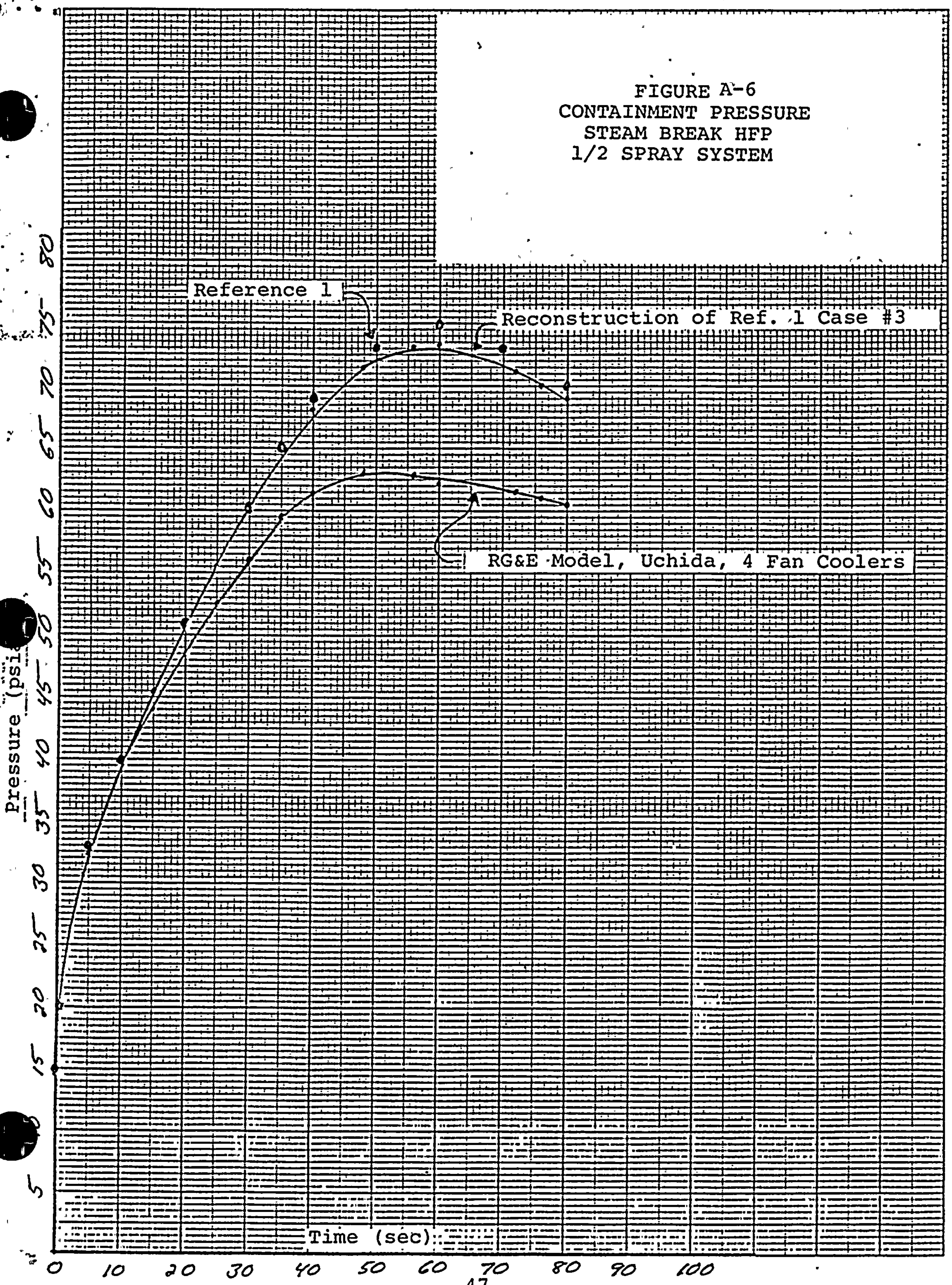


FIGURE A-6
CONTAINMENT PRESSURE
STEAM BREAK HFP
1/2 SPRAY SYSTEM