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Report No. 6 Impact Properties of Steels Taken From Four Failed Tank Cars

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Metallurgy Division
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National Bureau of Standards
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Summary Report

Prepared for

Federal Railroad Administration
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U. S. DEPARTMENT OF COMMERCE, Frederick B. Dent, Secretary
NATIONAL BUREAU OF STANDARDS, Richard W. Roberts, Director

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1. PREFACE

An overview of the results and metallurgical analyses of the findings of impact tests conducted at the National Bureau of Standards on samples of tank-car materials submitted by the Federal Railroad Administration is presented. The submitted samples were taken from tank cars which had been involved in service accidents during the period January 1970 to January 1971. One of these tank cars had been fabricated from ASTM A212 steel and the remaining four tank cars from AAR TC128 steels. The impact test data were reported earlier in four tank-car accident reports.

It is recognized that the analyses given here are based on only a limited number of plates, which cannot be considered a sufficiently large number of samples to justify a definitive comparison of the impact properties of the various grades of steel from which the cars were constructed. However, as a data compilation detailing the characteristics of tank car steels, this report can serve as a basis for further analysis and as an example of how impact data can be handled to derive a general understanding of the fracture characteristics of these materials. The data do allow a comparison of longitudinal, transverse, and short transverse properties in these plates, and they illustrate impact toughness trends as they relate to chemical composition, grain size and cleanliness of the specific plates studied. Further, they illustrate the comparative results that are expected from Charpy-V-notch tests vis-a-vis those from Dynamic Tear tests for the steels tested. When these various findings on the impact properties and on the metallurgical factors affecting them are considered along with the observed behaviors of those materials in service and with the service requirements which can be developed from larger numbers of service failures, recommendations as to approaches to improved materials and improved specifications for such materials can be formulated. Although some general conclusions (based upon results of the program and of the analyses of the available data) are given here, what is needed are specific recommendations on materials requirements for tank-car applications and on the various approaches that can be taken to meet these requirements economically.

Impact Properties of Steels Taken
From Four Failed Tank-Cars

2. INTRODUCTION

The Federal Railroad Administration (FRA) has sponsored research studies aimed at the development of knowledge that could be used to prevent or minimize the sometimes catastrophic effects of tank-car failures. As part of these studies, the FRA has requested that the National Bureau of Standards (NBS) conduct metallurgical analyses on steel samples taken from failed tank cars involved in four accidents. The results of the NBS analyses are given in four reports[1-4], and in a summary report[5] titled "Analysis of Findings of Four Tank-Car Accident Reports". With minor exceptions, the summary report analyzes all findings of the other four reports except for the results of impact tests. The impact test results are analyzed in the present report on the "Impact Properties of Steels Taken from Four Tank-Car Accidents", and so this report is complementary to the summary report.

This report deals with impact-test results of samples of six steel plates and three weldments taken from four failed tank cars, each from a different tank-car accident site. The six plate steels include four produced to specifications of AAR-TC128 and two produced to specifications of ASTM A212-B; three of these plates represent head plates and three represent shell plates. The weldments represent shell-to-shell and head-to-shell weldments of TC128-B steel plates.

Although the samples were taken from tank cars that had failed in service, it is believed that the samples were judicously selected so that the impact properties reported in the four reports that are here summarized and reanalyzed are germane to the plates in the tank cars in service, except where noted otherwise.

3. IMPACT TESTS AND PROCEDURES

Two types of impact tests were used in this investigation: standard Charpy V-notch (CVN) tests and dynamic-tear tests, (DT). A summary of these tests and the samples from which specimens were taken is given in Table 1. Test methods used for the DT tests were those developed [6,7] by the Naval Research Laboratory and the test methods for the CVN tests were in accordance with ASTM Designation E 23-66.

The CVN tests were conducted on specimens from three head-plate samples and three shell-plate samples taken from four accident sites. These six plates represent three grades of steels: One head plate and one shell plate of ASTM A212-B steel, two shell plates and one head plate of AAR TC128-B steel, and one head plate of TC128-A steel. Additional specimens represent a weldment of TC128-B steel plates taken from the Callao accident: These include weld-metal specimens and weld heat-affected-zone (HAZ) specimens of one head plate and one shell plate of AAR TC128-B steel.

The DT tests were conducted on specimens from one head and one shell plate of TC128-B steel taken from the Callao accident.

For all sets of impact specimens, tests were conducted over a temperature range selected to show the transition from ductile to brittle fracture. In addition, the DT test specimens* were tested at elevated temperatures up to 1300 F. This was done to simulate the response of the steel to fracture under the broad range of temperatures likely to be encountered when a tank car is engulfed in a fire.

The Charpy specimens were standard size of .394 x .394 x 2.165 inches and they were machined from the quarterthickness location of the plate steel or weld-metal, except for those from the HAZ of the Callao head- and shell-plate samples, from which the specimens were taken from the midthickness location.

Specimens for the DT tests were full-plate-thickness specimens (nominally 11/16-inches thick for the head-plate specimens, and 5/8-inches thick for the shell-plate specimens), with length and width dimensions of 7 1/8 and 1 5/8 inches, respectively, and with a saw-cut and cold-pressed notch with a depth of 3/8 inch.

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*These specimens were at temperature for about 25 minutes prior to testing.

3.1 Orientations of Specimens

The orientations of specimens and the notch configurations used in impact tests and the orientation codes for these various types of impact-test specimens are given in Figure 1. Each type of specimen had a 2-letter code. The first letter of the orientation code represents the long axis of the test specimen and the second letter represents the direction of crack propagation; the letters L, T, and S were used in these codes to represent three orthogonal plate directions: longitudinal, transverse, and short-transverse (or thickness) direction. The longitudinal direction is the principal (or final) rolling direction and the standard longitudinal and transverse configurations were therefore respectively designated LT and TL. Thus, the LT specimen has its long axis in the final rolling direction of the plate and the notch is oriented so as to produce crack propagation in the transverse direction (perpendicular to the rolling direction) of the plate.

The LT and TL specimens are the standard longitudinal and transverse orientations, and they were used for CVN tests of all head-plate, shell-plate, and weld-metal steels* tested, as well as for the DT tests of head-plate and shell-plate steels. Specimens of these orientations relate to the cases involving through-thickness cracks that grow in directions parallel to the plate surfaces, and the results of these tests are generally considered to be most important.

The LS and TS specimens are, respectively, longitudinal and transverse specimens that are notched to give crack propagation in the short-transverse (or thickness) direction of the plate. CVN specimens tested with these orientations include the Belle B-head plate of TC128-A steel and two TC128-B steels, Callao A-head and shell No. 1. Specimens with these orientations relate to cases involving cracks that propagate in a direction perpendicular to the plate surfaces, such as in the initial rupture of a plate in a tank car that is impacted by some external force.

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*In addition, TL specimens of the weld heat-affected-zone (HAZ) regions of the head-plate and shell-plate TC128-B steels from Callao were tested. It is noted in report No. 4 (ref. 4) that the HAZ head-plate specimens are not of the true TL orientation as defined here; they are roughly intermediate between TL and LT as is obvious in Figure 5 of that report (see "Impacts HF" vis-a-vis "Rolling Direction").

The SL and ST specimens are short-transverse specimens with notches that give crack propagation in the longitudinal and transverse plate directions, respectively. CVN specimens with these orientations were tested only for the "A" head-plate of TC128-B steel from the Callao accident. These orientations may relate in a general sense to cases involving fracture along planes parallel with the plate surfaces, such as occurred along the fracture edge of Callao plate K-7--in reference 4, this is the edge of the area marked #7 in Figure 9 and area N in Figure 26. This type of fracture is commonly called lammellar-tearing.

3.2 Data Analyses

The experimental data for impact tests were analyzed by a computer method that calculates the curves of best fit for the available data using least-squares analyses and then plots the calculated curves and the experimental data using an incremental digital plotter.

These computations were made for a total of 20 different CVN data sets, each of which represents only one specimen orientation for one of the six steels tested. For these CVN tests, a complete data set includes results for three fracture criteria: percent-shear-fracture appearance, energy absorption, and lateral expansion. Computations were also made for four DT data sets representing two of the six steels. For the DT tests, a complete data set includes results for only the first two of the three criteria, as lateral expansion is not measured in the DT tests.

The results of the computer analyses of all except four of the CVN data sets were presented earlier[2-4]. The four exceptions are analyses of the Belle data. Thus, the results of the computer analyses of these four sets, each having data for three fracture criteria, are presented here in Appendix A Tables 1 through 4 and Appendix A Figures A, B, and C: Included are a complete data set for each of four specimen orientations tested: LT, TL, LS, and TS. Each of the Figures shows all data and results for one of the fracture criteria. The scales used on the axes for these plots are those established in earlier reports[2,3,4] in which computer analyzed data were presented. Therefore, comparisons of the various data collected to date can be readily made by overlaying two or more plots. The raw data* for these tests of the Belle sample had to be reanalyzed for this report because the computer method was developed after the previous report[1] had been issued.

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*The raw data from lateral expansion measurement was not taken until this computer analysis was made. Thus, it was not reported earlier[1].

The 20 individual CVN data sets were combined in various ways to make comparisons and analyses given in this report. Calculational methods used for individual data sets are different from those reported here for combined data sets. The calculational results of the combined data sets give the best-fit curve based upon the weighted mean value for all data at each test temperature, whereas computed curves for individual data sets are based upon the individual data points at each test temperature. This new method of calculation using the weighted mean values is considered desirable for reasons not germane to this discussion, but it is noted that this method was used only when more than one data set was combined to make a new, larger set to be analyzed by computer methods.

4. RESULTS AND DISCUSSIONS OF CVN AND DT IMPACT TESTS

The results of CVN tests of the 20 individual data sets and of 18 data sets that include combined data from various of these individual data sets are given in Figures 2 through 14 and in Appendices A through F.* The results of DT tests were given earlier[4]. For individual data sets, the figures show only the calculated curves that represent these data sets. For combined data sets, the figures show both the raw data and the calculated curves; in addition, the appendix tables give this same information for the combined data sets. Appendices of previous reports[2-4] gave this information for the individual data sets*.

A summary of the findings of CVN test results for the six plate steels, one weldment, and two heat-affected zones is given as Table 2. In general, trends observed in the energy absorption (E. A.) data are similar to trends observed in the lateral expansion (L. E.) data, and the observations of CVN test results are generally similar to those of the DT test results. Thus, for brevity, the discussion to follow frequently will refer only to E. A. data of CVN tests, with the understanding that similar behavior obtains for either L. E. data of CVN tests, or E. A. data of DT tests (which are discussed near the end of this report).

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*One exception to this is the presentation of the individual sets of the Belle data. The plots of these data and calculations are given in Appendix A.

Various comparisons of CVN test results are made in this report. These include CVN studies of: (1) effects of orientation of specimen and notch--six orientations were tested for one steel and four orientations were tested for each of two additional steels; (2) the relationship between the longitudinal (LT orientation) and transverse (TL orientation) test results for the combined data for all six steels tested, for the combined data of only the three head-plate steels tested, and for the combined data for only the three shell-plate steels tested; (3) a comparison, on a plate-by-plate basis, of the six steel plates; (4) a comparison of the combined data from the three head-plate steels with that from the three shell-plate steels, (5) a comparison of all data from the four AAR TC128 steels with that from the two ASTM A212-B steels; and (6) a comparison based on the three grades (according to the ASTM or AAR specifications) to which the steels were produced. Almost all of these are new calculational results that are tabulated in the appendices. These include calculations for all results shown in Figures 4 through 6 and in 9 through 12 and for four of the eight sets of calculations made for Figures 13 and 14. Summaries of these various calculational results are given in various summary tables numbered 2 to 14 for individual and/or combined data sets.

Each of the Figures represents a given type of comparison used in the analyses and discussions of this report. Within each figure number, there are three lettered frames, one for each of the three fracture criteria: Percent-shear-fracture appearance is the A frame, energy absorption is the B frame, and lateral expansion is the C frame. The same scale is used for all B and C frames (of the B and C figures) in the body of the report. The scale for all A frames is also held constant throughout the body of the report. However, these scales differ from the scales given in the three figures of Appendix A in which the Belle data were plotted on the same scales used in previous reports [2-4]. In addition, it is noted that the scales used [4] for plots of E. A. data of DT tests were based on the understanding that these E. A. values of DT tests are about 10 times the values obtained in CVN tests (due principally to the larger areas of the fractures in the DT test specimens). Therefore these energy values were divided by 10 so that they could be plotted [4] on the same frame with the CVN data with which they were to be compared.

Each Appendix gives the observed and calculated results for the figure of the report that it represents. These results are given as a series of tables. The sequence of presentation of the tables within an Appendix corresponds to the sequence given in the corresponding figure. This sequence is given in the figures under the words SPECIMEN IDENTIFICATION, shown in the upper left-hand corner of each frame of the figure. The tables within an Appendix are thus designated 1A, 1B, 1C; 2A, 2C; etc., with the A, B, and C letter designations representing the three fracture criteria (as discussed above), and with the numbers 1, 2, etc. representing the various classes of data that are listed (under the words SPECIMEN INDENTIFICATION) in the corresponding figure. Some appendices contains LT data from one figure and TL data from the very next figure; for these appendices, the number sequence in the appendix includes the list for the LT data sets and then the list for the TL data sets of the second figure.

4.01 Transition Zone

The transition zone begins at the highest temperature on the lower shelf and it extends to the lowest temperature of the upper shelf. The impact test results for individual data sets and those for the combined data sets indicate that within a given data set, the transition zone begins and ends at roughly the same temperatures irrespective of the fracture criteria. This is observed (in the figures) by comparing the plotted curves of the A, B, and C frames for a given set of data. Further, it is noted that with increasing temperatures in the transition zone, the magnitude of the values of E. A. in DT and CVN tests (and of L. A. in CVN tests) is roughly linearly related to (nearly proportional to) the magnitude of the percent shear-fracture-appearance (SFA) values.

4.02 Lower-Shelf Behavior

The lower shelf extends from very low temperatures up to the temperature of the lower limit of the transition zone. For all orientations of specimens tested, the percent SFA on the lower shelf is zero or nearly zero, and the values of energy absorption vary only over a very narrow range of low values (i.e. low in relation to upper-shelf energy values) for either CVN or DT tests. Similarly, in CVN tests lateral expansion values in the lower-shelf region are low in magnitude and narrow in range.

4.03 Upper-Shelf Behavior

The upper shelf begins at the upper (temperature)limit of the transition zone, and it extends to all higher temperatures used in the tests. Along the upper shelf the SFA is 100 percent, for both DT and CVN tests and for all orientations of specimens and notches. The magnitudes of the upper-shelf values of E. A. and L. E. are governed, in part, by the directionality of the microstructure of the material, and therefore, the effect of this directionality on impact properties can be assessed by tests with specimens having various orientations of axes and notches.

4.04 Transition Temperatures

The temperature at which a given value of one of the fracture criteria is met is called a transition temperature (TT). Three arbitrary transition temperatures have been chosen for the purposes of the discussions given in this report. These are the 15 ft-lb TT, the 15 mil TT, and the 50-percent SFA TT. In metallurgical analyses, transition temperatures can be valuable for characterizing significant differences in the fracture properties of steels, and they have been used (on an emperical basis) for determining the suitability of steels for various applications, in which fracture by impact loading and in which rapid crack propagation are important. The arbitrarily chosen transition temperatures mentioned above are not to be taken as recommendations of suitable criteria for tank-car steel specifications; They were chosen arbitrarily for the purposes of the discussions of the results of calculations based on the impact-test results of six plates taken from failed tank cars.

4.1 Effects of Orientation of Specimen and Notch

Three of the six steels were tested in only the LT and TL orientations, two steels were tested in four orientations (LS, LT, TS, and TL), and one steel was tested with six orientations (LS, LT, TS, TL, ST, and SL). Figure 1 gives the orientation code. The results for four orientations of the Belle sample are presented in Appendix A, as Figures A, B, and C and as Tables 1, 2, 3, and 4. The results for four orientations of the Callao shell-plate K-5 are presented as Figure 2, and those for six orientations of Callao head-plate K-1 are presented as Figure 3. The results for the other three steels tested with only two orientations were presented in earlier reports[2-4].

The effects of orientation of specimen and notch are similar for each of the steels tested. In general, the orientation of the specimen and the notch (1) greatly affects upper-shelf values of lateral expansion (L. E.) and of energy absorption (E. A.), (2) affects the transition temperatures at which a given level of E. A. or L. E. is obtained; and (3) has little affect on the lower-shelf values of L. E. and E. A., or on the temperature limits of the transition zone, or on the 50-percent- shear-fracture-appearance values. Pertinent CVN test data (from the Belle sample and from the Callao head and shell plates) in support of these findings are given in Table 3. In addition, the plots of Figures 1 and 2 and of Figures A, B, and C of Appendix A are good visual aids for understanding these behaviors, which are described below.

4.11 Upper-Shelf Behavior For Various CVN Orientations

The upper-shelf values for a given steel vary greatly with orientation of the specimen and with orientation of the notch. As shown in Table 3, for a given steel, the values for CVN tests decrease in the order LS, LT, TS, TL, ST, SL, with the values for the ST and SL orientations being nearly equal. For example, for the Callao head plate steel, these values are, respectively, 85.9, 54.0, 45.2, 37.5, 15.8, and 13.9.

As a function of CVN specimen orientation, the shelf-energy values thus decrease in the order: longitudinal specimens, transverse specimens, short-transverse specimens. Similar results are shown for the DT tests; their energy values decrease in the same order: LT, TL. This general behavior is believed to be due principally to the morphology of inclusions in the steel. An inclusion can be thought of as an orthogonal parallelepiped, with 3 orthogonal directions L, T and S as defined earlier. With this model, the dimensions of the inclusion in these directions are greatest in the L direction and smallest in the S direction. If the "plane" of the inclusion is defined as that plane which contains the L and T directions (the two longer dimensions), then the effect of inclusions on the observed results of these impact tests is consistent with the following explanation for the energy-absorption and lateral-expansion data.

Fracture of short-transverse specimens (ST and SL orientations) occurs with the least amount of energy absorption because the fracture plane in these specimens is parallel with the "plane" of the inclusions (i.e. it contains the L and T axes of the inclusions). In addition, when the steel is bonded the fracture plane is parallel to the alternate layers of the banded microstructure. These geometric realities detract from the energy absorption in short-transverse specimens. In the other orientations, the fracture plane is perpendicular to the alternate layers of the microstructure.

In transverse specimens (TS and TL orientations), the fracture plane is perpendicular to the "plane" of the inclusions and it contains only the longest and shortest (L and S) axes of the inclusions; thus, in these specimens the progress of the crack front is damped more frequently with the tough metal matrix which contains the inclusions, and energy absorption is accordingly increased.

In the longitudinal specimens (LS and LT orientations), the fracture plane is perpendicular to the "plane" of the inclusions and the fracture plane must cut across (or bisect) the inclusions. Thus, the fracture plane contains only the two shorter axes (T and S) of the inclusions, with the results of a further comparative enhancement of the damping action from the tough metal matrix and a concomitant increase in the energy-absorption value required for fracture.

For a given specimen orientation, either longitudinal or transverse, crack propagation in the short-transverse (S) direction requires more energy than in the corresponding transverse (T) or longitudinal (L) direction, i.e. LS compared with LT, and TS compared with TL. This occurs despite the fact that the pair of inclusion axes contained in the fracture plane is the same for both orientations (for LS and LT or for TS and TL). Therefore, this effect is believed to be principally due to microstructural banding in the steel. In a banded carbon-manganese steel, there exist alternate layers of tough ferrite and a comparatively brittle ferrite-pearlite mixture. Crack propagation in the S direction, in the LS and TS specimens, occurs by fracture which progresses through alternate layers of brittle and tough materials, with the net result of an enhanced damping action from the tough material in the alternate layers; this phenomenon would be expected to give rise to greater energy-absorption values when compared with the values for the corresponding fracture along the T or L directions. Crack propagation in the T and L directions occurs through all layers of the material simultaneously, and this propagation of a crack would be expected to require comparatively less energy.

4.12 Transition-Zone Limits of Temperature for Various CVN Orientations

The results given in Figures 2 and 3 and in Appendix A indicate that, for a given steel, the CVN transition zone begins and ends over roughly the same range of temperatures irrespective of either the fracture criteria or the orientations of either the specimen or the notch. This is particularly evident in the percent-shear-fracture-appearance (SFA) plots, which graphically show this behavior. For example, in Figure 3A, the Callao head-plate steel shows this behavior, and in Appendix A the Belle sample shows it. For the Callao shell plate, shown in Figure 2A, an exception to the above behavior is observed for specimens designated STB, which have the LS orientation (longitudinal specimens with crack propagation in the short-transverse direction). The results for these specimens were so highly variable that the transition curves could not be defined from the available data sufficiently to render them meaningful.

4.13 Effect on Notch Orientation on the CVN Transition Temperatures

As was discussed above, for a given steel the limits of the transition occur at the approximately same temperatures irrespective of the fracture criteria and irrespective of the orientations of the specimens or of the notches. In addition, the values of the fracture criteria in the lower shelf are relatively independent of the orientations. With this in mind, it becomes apparent that for the steels tested, either the 15-ft-lb or the 15-mil transition temperatures will tend to be in the inverse order of the upper-shelf values of either energy absorption or lateral expansion. For example, in Table 3, the shelf-energy absorption values for the head plate K-1 decrease in the order LS, LT, TS, TL, ST, SL and the corresponding 15-mil transition temperatures for these specimens are respectively 10, 41, 64, 170, and 175 F. The transition temperatures for each of the other steels in the table tend to follow this same trend for their various orientations of specimens and notches, but the correlation is not as good due to the variability of test data and to the resulting variability in the curves calculated to fit the data.

This variable behavior in the 15-ft-lb and 15-mil TT values is not observed to occur in the case of 50-percent SFA TT values. In fact, the 50-percent SFA TT values are relatively invariant, even when the upper-shelf E. A. and L. E. values vary widely. Table 3 shows that for a given steel, each of the 50-percent SFA values for the various orientations tested are, in general, within 10 F of the mean value. This invariant character of this fracture criteria points up its fundamental character and hence its usefulness an a guideline for determinations of real differences in behaviors of materials.

4.2 Orientation Effects in Combined CVN Data

The combined data sets of the various longitudinal (LT) specimens and transverse (TL) specimens are presented and compared in Figures 4, 5, and 6, and in Appendices B. C and D. In Figure 4, all data for the six plate steels tested are given, and in figures 5 and 6 are given the results for the three head-plate steels and for the three shell-plate steels, respectively. The same general effects of orientation discussed above for individual data sets are observed to obtain for these combined data sets, and this supports the validity of the practice of combining data sets for the purpose of making comparisons of data taken from more than one individual data set.

Thus, results taken from the tables of Appendices B, C and D are given in Table 4. This table shows that shelf-energy absorption values for the steel plates taken from tank cars of the four accidents[1-4] are about 67 and 41 ft-lb, respectively, for longitudinal and transverse specimens. For transverse specimens, the 15 ft-lb and the 15- mil transition temperatures average 9 to 24 F, but as is indicated by the data points on the figures 4B and 4C, the scatter in the behavior is very wide, and these fracture criteria are not met even at 80 F in selected specimens taken from tank cars. The 50-percent SFA value for either longitudinal or transverse specimens is 68 F, and here, too, the scatter in data taken on the six steels plotted on Figure 4A is very wide and is such that this criterion is not met even at 120 F for selected data.

The data for head-plate specimens, given in Figure 5, vary more widely than the data for shell-plate specimens, given in Figure 6. This wide variance in test results of head-plate specimens gives rise to an unusually shaped pair of curves in Figure 5A, where the SFA data is presented. The analysis of longitudinal test results gives a curve of very steep slope while that of transverse specimens gives a much more gentle slope; nevertheless, the 50-percent SFA data for LT and TL head-plate specimens are similar, being respectively 66 and 80. For the shell plate specimens these values are respectively 59 and 48 for LT and TL specimens.

For either the head-plate data or for the shell-plate data or for combined head and shell data, the 15 ft-lb and 15 mil TT values are similar for LT and TL specimens, with the values for LT specimens being only slightly lower in general than those for TL. As would be expected from the shapes of the curves and from the earlier discussions, for higher values of either of these fracture criteria the differences between the transition temperatures for the two orientations would increase.

4.3 Anisotropy Indices for Plate Steels

Anisotropy of plate materials is assessed by an anisotropy index defined here as the ratio of the maximum shelf-energy absorption in transverse specimens of TL orientation to the maximum shelf-energy absorption of longitudinal specimens of LT orientation. Then a value of 1 represents a completely isotropic plate and lower values represent the anisotropy which may be present in partially cross-rolled or straight-away-rolled plate. This index is given in Table 5 for each of three head-plate and three shell-plate steels.

The data of this table show that the anisotropy index from CVN tests of the head-plate steels averages 0.68, and that the index for the shell-plate steels is 0.50. These indices indicate that each head plate was cross rolled more than any of the shell plates. The DT test results for one head and one shell plate (both Callao) tend to confirm this finding, with indices of 0.65 and 0.51 for head and shell plates, respectively. Nevertheless, we note that the axes for the head plates from Belle and Crescent City may deviate substantially from true longitudinal and true transverse directions, and if this is true for either of these steels, the index for that steel would be increased with increasing amounts of misalignment from the true longitudinal and transverse directions. Thus, it is concluded that the head plate of Callao appears to have been cross rolled to a greater extent than were any of the other plates (head or shell) and that the other two head plates (Belle and C. City) may also have been cross rolled to a degree similar to that of the Callao head plate.

The shelf-energy values for the six steels are plotted, for both LT and TL specimens, as functions of their respective strength levels in Figure 15. This plot shows that in general the shelf energy, whether longitudinal or transverse, decreases with increasing strength level for the six steels, reflecting the strength level dependency of ductility reported for these steels[5]. Further, the two plots show that the relationship between longitudinal and transverse shelf energy is relatively independent of strength level; i.e., by comparing the two plots at various levels of strength, it is observed that the energy of TL specimens is nearly half that of LT specimens, with only a slight tendency for an increase in the ratio TL energy/LT energy as strength level is increased. Thus, it is concluded that the anisotropy index is not strength-level dependent, but that head-plate steels may have been cross rolled to a greater extent than were the shell-plate steels.

4.4 Results for Individual Data Sets Representing Six Steel Plates

The 12 calculated curves representing six sets each of LT and TL test results are given as Figures 7 and 8, respectively, for longitudinal and transverse specimens taken from the six steel plates. A brief summary of transition temperatures and upper-shelf energy values taken from the appendices of other reports[2-4] and from Appendix A of this report is given as Table 6.

Marked differences are observed for these various carbon-manganese steels. Because these differences are generally similar for the longitudinal and for the transverse specimens, only the longitudinal results will be discussed in detail. Shelf-energy values vary from 46 to 81 for LT specimens and from 25 to 55 for TL specimens. The 15-ft-lb TT values vary (for LT specimens) from -47 to +92 F and the 15-mil TT values vary from -43 to +72 F. The 50-percent SFA values are much higher and they vary from -11 to 138 F.

The variation of shelf-energy values are shown in Figure 15 to roughly follow the variation in strength levels of the steels, with the steels of lower strength level having the highest shelf-energy levels. The effects of the inclusion content and of the presence of vanadium on this behavior are discussed later in section 4.8.

It is noted in Figures 7 and 8 that the axes of the head-plate specimens for Belle and Crescent City may deviate from true longitudinal and transverse directions of the plate from which they are taken. If, in fact, the axis for either steel does deviate substantially, then it would be expected that the longitudinal values would fall below the trend line of Figure 15 and the transverse value would fall above the trend line. These two conditions are not met for either steel, indicating that the nominal directions are not substantially different from the true plate directions.

Except for the Callao head-plate (K-1), each of the TC128 steels tested have lower TT values than do either of the two A212-B grades. The variable microstructures of the Callao head plate, which had been hot formed and stress relieved, are reflected in the relatively high transition temperatures of this plate, as described and discussed in the findings report[5], and they are illustrative of factors which can lead to departures from the expected hot-rolled properties of plate steels. The attainment of the desired fine-grained ferritic microstructure in the hot-formed plate is dependent upon the use of an austenitizing temperature in heating the plate for hot forming that is high enough to obtain substantially homogeneous austenite, but not so high that significant grain growth occurs, and upon a cooling rate during the hot-forming operations that is at least as rapid as the air cooling of the plate after rolling. In this instance, the relatively coarse-grained microstructure indicates that the plate had been heated to an austenitizing temperature somewhat above the grain coarsening temperature for this steel. Furthermore, in steels containing vanadium, as this was, the vanadium carbides, which are difficult to dissolve in austenite, will normally be only partially taken into solution at temperatures below the grain coarsening temperature, and the resulting strength would normally be lower, and the impact properties correspondingly better than those of the hot-rolled product. In this instance, however, the high strength of this plate, indicates that, at the presumably relatively high temperature to which it had been heated for hot forming, significant amounts of vanadium carbides had been dissolved in the austenite and had precipitated during cooling. The impact transition temperatures of this plate are, thus, probably inferior to those that would be expected in a hot-rolled plate, finished at a suitably low temperature and hot rolled from the same heat of steel.

The steel with the lowest transition temperatures is the Belle sample, a TC128-A steel. This steel also has the finest ferrite G.S. Number (8.5) and a fine pearlite colony size, both of which may be attributed to the presence of vanadium and the rolling practice. While the A212-B steels have low strength, they also have coarser ferrite grain sizes (6.0 for the head plate and 7.0 for the shell plate), and the pearlite colony size is coarse for both plates; the head plate was not produced to fine-grain practice and it indeed has transition temperatures that are higher than those of the shell plate, a result that is expected. The other steel not made to fine-grain practice is Callao shell plate K-5; this steel has transition temperatures that are generally intermediate among the four TC128 steels tested. This result is somewhat anomalous, as this steel would be expected to have comparatively high transition temperatures; apparently, other processing factors for this steel are overriding the effect of deoxidation practice on the impact transition temperatures....the steel does, for example, have intermediate pearlite colony size indicating that the finish rolling temperatures were relatively low for this plate.

4.5 Comparison of Results of Combined Head and Combined Shell Data

The longitudinal (LT) and transverse (TL) test results for combined data from the three head plates and from the three shell plates are presented in Appendices C and D and as Figures 9 and 10, respectively, for LT and TL specimens. A summary of these results is given as Table 7. The results indicate that the CVN impact properties of the three head-plate steels are very similar to those of the shell-plate steels, but that the head-plate test results are much more highly variable than those of the shell-plate steels. This latter effect is apparent on the plots of the raw data, shown in the figures. In assessing the high variability of results of the head-plate tests, we note that the head-plate steels include a TC128-A steel which had the lowest transition temperatures, and it includes the A212-B steel not produced to fine-grain practice and this steel has the highest transition temperatures. Because this latter steel was not produced to fine-grain practice, it would be expected to have relatively high transition temperatures compared to A212-B steels that were produced to fine-grain practice.

The third head-plate steel is a TC128-B steel that contained more than the 0.02 percent vanadium needed to qualify it as a grade A steel, and this steel also has an unusually coarse microstructure in the part of the plate from which the CVN specimens were taken. The three shell-plate steels are less variable and they include an A212-B steel made to fine-grain practice, and two TC128-B steels, one of which contains sufficient vanadium to qualify for grade A and one of which was not made to fine-grain practice.

4.6 Comparison of Four TC128 Steels and Two A212-B Steels

The longitudinal (LT) and transverse (TL) test results for combine data from the four TC128 steels and from two A212 steels are presented as Figure 11 for longitudinal (LT) specimens, as Figure 12 for transverse (TL) specimens, and as Appendix F. A summary of these results is presented as Table 8.

The results indicate that the TC128 steels have lower but highly variable transition temperatures and that the upper-shelf energy absorption values of the A212-B steels are significantly higher than those of the TC128 steels.

For longitudinal specimens of the TC128 steels, the 15-ft-lb and 15-mil TT values are respectively -5.7 and 3.9 F. Taking the TT values for both LT and TL specimens into account, we note that the TT values of the two A212-B steels are 42 F higher than those of the combined TC128 steels. The 50-percent SFA TT values are much higher, but the difference between the two sets of combined data averages 45 F. Thus, the differences between the two types of steel are similarly large by various criteria and they are believed to be significant.

The generally lower transition temperatures of the TC28 steels, as compared with the A212-B steels investigated, reflects primarliy the higher managanese and lower carbon contents, and correspondingly higher manganese-carbon ratios, of the TC128 steels which had a mean composition of 0.26 C and 1.27 Mn with a Mn/C ratio of 4.88, in contrast with the A212 steels which had a mean composition of 0.30 C and 0.79 Mn and a Mn/C ratio of 2.63. The relatively high transition temperatures reflect both their coarse ferrite grains and their relatively large percentages of pearlite, which itself is due to their higher levels of carbon. With its low manganese content, the ferrite grain size of the hot-formed A212 steels is relatively large, particularly in the heat which was not produced to a "fine grain" practice, and it is therefore necessary to use a relatively high carbon content to meet the strength requirements.

The plots of the data on figures 11 and 12 indicate that the variability in test results for the four TC128 steels is very large and much larger than that for the two A212-B steels tested, reflecting that there are significant differences in the transition temperatures among the TC128 steels tested. These differences appear to reflect primarily differences in strength, with the B-head steel from the Belle accident having the lowest 15-foot-pound transition temperature of -46.5 at a tensile strength of 84 Ksi, which is just above the minimum requirement, and the South Byron shell plate having a transition temperature of 18 F at a tensile strength of 103 Ksi, which is just above the maximum level of the specification. The Callao shell plate, although it was made from a heat which was not produced to a "fine grain" practice and had a somewhat larger ferrite grain size than the other TC128 steels, still has a reasonable low transition temperature of -5 F at its realatively low tensile strength of 87 Ksi.

Another factor which must be taken into consideration in evaluating these findings, although specific data is apparently not available, is the fact that these tests were made on material which had been stress relieved following a forming operation, so that the properties may differ from those of the original hot-rolled plates. Variations in the stress-relieving treatment could significantly affect the properties, primarily because of the possible effect of the tempering on the strength. Thus, among these TC128 steels, the steels, with vanadium would, if the carbon content is not correspondingly decreased, be expected to be higher in strength in the hot-rolled condition than those without vanadium, because of the strength increment from the vanadium carbide precipitation. The South Byron shell steel which contained vanadium and had the highest strength of the TC128 plates tested, is illustrative of this expected effect of vanadium. The Belle B-head steel which also contained vanadium, however, had the lowest strength among the TC128 plates, and the low strength of this plate, therefore, presumably results from tempering at a relatively high temperature in the stress relieving operation.

The higher values of shelf energy of the two A212-B steels may relate to their relative cleanliness; these two steels are the only steels of those tested that have only moderate levels of inclusion content.

4.7 Results of Data Combined on the Basis of the Grade of Steel

The six steels were produced according to three grades of steel: TC128-A, TC128-B and A212-B. However, we note that the principal difference between the two TC128 grades is the Grade A requirement of a minimum vanadium content of 0.02 percent by weight. Thus, for the purpose of comparison of the six steels according to the grade to which the steels were produced, the steels have been grouped into four classes with the three TC128-B steels being divided into two groups, one group with two steels containing more than the 0.02-percent vanadium and one group of one steel without the vanadium. The plots of the data and calculational results for these four classes of steels are given as Figures 13 and 14 and as Appendix G. A summary of these results is presented as Table 9.

The upper-shelf energy-absorption values indicate that the steels rank as follows, beginning with the highest values: two A212-B steels, one TC128-B steel without vanadium, one TC128-A steel, and two TC128-B steels that contain more than 0.02-percent vanadium: The inclusion content ranks(5) for these four classes of steels are, respectively, as follows: Rank 1.0 (ave.), Rank 2.0, Rank 3.0, and Rank 2.5 (ave.). The results indicate that lowering inclusion content can be helpful to improved upper-shelf energy absorption, but that other factors may also affect upper-shelf energy levels.

On the basis of transition temperatures, the steel classes rank as follows, beginning with the lowest TT values: TC128-A, TC128-B without vanadium, TC128-B with vanadium, and A212-B. These differences are related to differences in the ferrite grain size and to differences in the contents of principally carbon, manganese and phosphorous of these steels.

On comparing steels on the basis of their vanadium content, it is noted that the one TC128-B steel without vanadium has 15-mil and 15-ft-lb transition temperatures that are about 22 F below those of the two TC128-B steels with vanadium, but the 50-percent SFA TT values for the steel without vanadium are about the same as the values for the two steels with vanadium, indicating that the apparent differences attributable to vanadium may be marginal, and that the effect of vanadium on transition temperatures in TC128-B steels is not firmly established by the limited available data. However, the TC128 steels have transition temperatures that are superior to those of the A212-B steels, a fact which will be discussed later.

4.8 Upper-Shelf Energy Absorption

The upper-shelf energy-absorption values for the six carbon-manganese steels tested for these investigations are plotted as functions of the ultimate tensile strength (UTS) in Figure 15 and as functions of the yield strength (YS) in Figure 16. The correlation with UTS is reasonably good. The correlation with YS is based not upon values for only carbon-managanese steels, but upon values obtained for a wide variety of steels reported[9] from a major steel producer's general findings. This YS correlation is poor for the steels investigated, and it indicates that the presence of vanadium and increased inclusion content levels may tend to decrease the shelf-energy of these steels. Shelf energy of the six plate steels and the one weldment investigated are much more strongly affected by increases in YS than are the various steels included[9] in the solid trend line of Figure 16. The dotted line of Figure 16 representing six steels tested, shows that for these steels, with increasing YS values from 47 to 70 the upper-shelf energy-absorption values decrease sharply from 81 to 46 ft-lb. It is noted that the three steels with the lowest shelf-energy values each contain vanadium. One is a TC128-A steel (Belle, B head) with a high inclusion content and the other two are TC128-B steels (Callao K-1 A-head and the S. Byron shell plate). These later two have the lowest shelf-energy values of the six steels tested and their inclusion contents are intermediate (for K-1) and high (for S. Byron). The other three steels do not contain vanadium and inclusion contents are intermediate (for the TC128-B steel) or moderate (for the A212-B steels) and they do not depart greatly from the published trend line. These results indicate that increased inclusion content levels and the presence of vanadium tend to decrease upper-shelf energy-absorption values.

Crack initiation and propagation at temperatures on the upper shelf occur by a fracture mode known as dimpled rupture or normal rupture, which proceeds as a result of the progressive formation and coalescence of voids at or ahead of the crack tip. As inclusions are the main source of void initiation in these steels, it is apparent that the inclusion content will be a predominant factor effecting this behavior. Further, as the predominant inclusion in each of these steels is manganese sulfide and as the rolling practice for each of the plates is similar, although the head-plate steels seem to have received more cross rolling than the shell-plate steels, it is expected that the shelf-energy absorption of the steels will decrease with increases in the inclusion content, due to the increased number of initiation sites present in the steels with higher inclusion contents.

Furthermore, on a microscopic scale, the void coalescence process proceeds by the necking and rupture in tension of small elemental volumes lying along, or ahead of the crack front, which is analogous to the process, on a macro-scale which leads to the failure in the tensile test. The susceptibility to failure of this type is therefore increased by (1) a high yield stress which leads to a high flow stress for the initiation of these plastic processes, and (2) a low strain hardening capacity or a low uniform elongation prior to the necking which leads to the rupture.

4.9 Energy Absorption at Various Service Temperatures

In table 10, CVN energy-absorption values are given for various service temperatures from -40 to +80 F, in increments of 20 F. Values are given both for the individual data sets of each of the six plates tested and for combined data for each of the three categories: three head-plates, three shell plates, and all six plates. These calculational results indicate that, in general, the transverse (TL) values of energy absorption for a given temperature are slightly lower than the longitudinal (LT) values; at high values of energy absorption the TL values are much less than the LT values. These findings hold true for the individual data sets as well as for the combined data sets.

A table of this type, which is readily prepared from the appendices of this report and previous reports[1-4], is useful in making assessments the probability of obtaining a given level of energy absorption for various temperatures of service. For example, for transverse specimens, a 15-ft-lb criteria is met at 80 F by five of the six steels tested, at 60 F and at 40 F by three steels, at 20 F and 0 F by two steels and at -20 and -40 F by only one steel.

The results of the combined data sets are given in comparison with averaged results of the individual data sets of each of the three categories. For any service temperature, the results of combined data analyses do not differ by more than about 5 ft-lb from those of the averaged data for individual sets, and generally, the agreement is within about 2 ft-lb at any given temperature. If the energy-absorption values were to include statistical limits, the combined data sets would prove to be most useful for making probability statements, but statistical limits of the type needed have not yet been incorporated into the computer method used for these calculations.

4.10 Behavior of Weldments of TC128-B Steel

CVN specimens of weld-metal and weld heat-affected-zone (HAZ) regions were taken from samples of steel taken from a tank car designated GATX 94451 that failed in Callao, Mo. The weld-metal specimens represent shell-shell weldments of TC128-B steel of this tank car. The specimens are of two orientations, longitudinal (LT) and transverse (TL), as defined in Figure 1, and they were taken respectively from Callao plate samples K-11 and K-8. The weld-HAZ specimens are of the TL orientation, and they represent weld HAZ regions of the "A" head plate and of shell course number 1; they were taken, respectively, from Callao plate samples K-2 and K-8.

Test results for the weld-metal and the weld-HAZ regions are respectively presented in the Callao report(4) (as Figures 37 and 38 and as Appendices F and G). A brief summary of these findings is presented here as table 11, where along with these results, results are presented for the unaffected base metal of the steels for which weldment data are given.

The results indicate that the impact characteristics of the weldments tested are much more favorable than those of the base metals. In addition, the results of the weld-metal tests indicate that the longitudinal and the transverse weld-metal results are similarly favorable and the results of the weld-HAZ tests are even better. The head-plate and the shell-plate steels have 15-ft-lb TT values of 64 and 3 F, whereas the weld-metal values average -37 F and those of the HAZ regions average -48 F. The upper-shelf values for the head plate are +46 ft-lb for the unaffected base metal and +49 ft-lb for the weld-HAZ region of this plate, and those of the shell plate are 38 and 45 ft-lb, respectively, for the base metal and the weld-HAZ region. Upper-shelf energy of the weld metal is most favorable, being about 67 ft-lb. Thus, the transition temperature values and the shelf-energy absorption values of the weld-metal (LT and TL) specimens, and of the HAZ specimens of both the head-plate and the shell-plate tests, are believed to reflect good welding practice*.

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*We suspect that the CVN values obtained for the HAZ region might not be representative of the behavior of the plate in service. This suspicion is based on our finding that the shape of the HAZ region precludes the placement of the notch uniformly along the coarse-grained region of the HAZ. (This region is considered to be the most brittle region in many weldments). For this reason it is believed that the DT test might be a more suitable test method for determining the impact characteristics of the HAZ of weldments of plate material of thickness levels similar to those of the plate materials tested in this work. This belief is based on the presumption that while the problem of the initial placement of the notch would not be alleviated for the DT test, the crack path in the DT test is much longer than in the CV test. Then, perhaps as crack propagation progresses, the crack front would seek and follow the most brittle region along a weldment in a manner similar to that which would obtain in the fracture along a weldment in a large plate in service.

4.11 Dynamic-Tear Tests

As was shown in table 1, dynamic-tear (DT) tests were conducted on one head and one shell plate of AAR TC128-B steels taken from the Callao accident. Both longitudinal (LT) and transverse (TL) specimens were tested over the range of temperatures from -50 to +1300 F. Thus, some of these tests were conducted at temperatures similar to those used in the CVN tests of these steels, and the results of these tests can be used to compare the behavior of impact loading under the two types of test conditions. In addition, the results of the elevated-temperature tests of DT specimens provide preliminary estimates of the behavior of the two steels tested under short-time exposure (about 25 minutes) to air at temperatures likely to be encountered in a fire. Although the significance of the results of elevated-temperature impact tests has not been clearly established, they indicate that the critical flaw size for rapid propagation of a crack in a vessel at temperatures near 1050 F is smaller than that at lower temperatures. The results of these various DT tests were presented in the Callao report(4), (as Figures 34 to 37, 39, and 40, and Appendices B through E). Only Summary tables are presented here.

4.11.1 Ambient-Temperature Results

A comparison of the results of DT and CVN tests, given in Tables 12 and 13, indicates that the DT test gives higher transition temperatures but lower values of upper-shelf energy-per-unit area. In addition, it is noted that the nil-ductility- transition (NDT) temperature can be established from DT test results, and the NDT temperature is about 40 F for the head-plate steel tested and about 34 F for the shell-plate steel tested.*

As shown in Table 12, DT test results show similar TT values for 50-percent SFA and 50-percent of maximum energy absorption: for the head-plate steel these transition temperatures are respectively 90 and 82 F, and for the shell-plate steel they average 92 and 87 F.

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*The tank car from which these samples were taken apparently failed upon impact with a part of a bridge and it is estimated that the temperature of the steel of the tank car was about 15°F when this occurred. Steels with NDT temperatures at and above this temperature would be expected to fail in a fast, brittle-fracture mode under severe impact conditions. Thus, brittle failure was virtually assured for these steels under severe impact conditions at 15°F. However, the method by which these NDT temperatures were determined are non-standard methods and the NDT values of these particular steels are therefore somewhat open to question.

A comparison of DT and CVN test results must take into account the previously discussed microstructural heterogeneity of the head-plate steel. This is particularly important because the CVN specimens were taken from one side of the plate thickness whereas the DT specimens were full plate thickness.

For the shell plate, the expected difference between TT values for results of LT and TL specimens is shown in the TT values given in Table 12 for each of two fracture criteria, one based on energy absorption and one based on SFA. For the head-plate tests, these differences are much larger than expected; this point is elaborated upon below.

To facilitate comparisons of DT and CVN tests results (i.e. transition temperatures) an arbitrary energy level was selected for the DT results that are to be compared with 15-ft-lb CVN results. This energy level is called the DTEE, dynamic-tear equivalent energy. DTEE is a calculated energy level that is the same fraction of the DT upper-shelf energy as the fractional energy level that 15-ft-lb represents for the CVN upper-shelf energy level.

For the head plate, the difference between the transition temperatures of LT and TL orientations for CVN specimens is as expected, but it is very large for the DT test specimens. It is noted[4] that the transition temperatures of longitudinal DT (HDTL) specimens occur at unexpectedly low values in DT tests of this head-plate steel. These low values of transition temperatures are attributed[4,5] to microstructural inhomogeneity in the DT test specimens of this head-plate steel.

Excluding the anomalous results of the longitudinal head-plate specimens, it is observed that, for both fracture criteria given, transition temperatures of DT tests average about 45 F higher than those of CVN tests, indicating that, for these steels, the DT test provides more conservative estimates of the impact behavior.

When compared on the basis of energy-per-unit area, Table 13 indicates that greater energy is required for shear fracture of DT specimens than for CVN specimens. For all results, except those for the anomalous longitudinal head-plate specimens, the DT values are less than twice those of the CVN values; for the longitudinal head-plate specimens, the DT value is slightly more than twice those of the CVN value. These results indicate that the CVN test gives more conservative estimates of upper-shelf energy required for fracture.

4.11.2 Anisotropy Indices for Plate Steels

As discussed earlier, anisotropy of plate materials may be assessed by an anisotropy index defined here as the ratio of the maximum shelf-energy absorption in transverse specimens of TL orientation to the maximum shelf-energy absorption of longitudinal specimens of LT orientation. This index is tabulated below for the head-plate and shell-plate steels.

Anisotropy Index	
Head Plate K-1	Shell Plate K-5
38/54 = .70	38/75 = .51
420/650 = .65	377/746 = .51

It is apparent from the table that the head plate is less anisotropic than the shell plate. However, the head plate was not fully cross rolled, as its indices are less than one. The indices from DT tests compare favorably with those from CVN tests. The DT results for the head plate indicate a slightly lower index than expected, but this too might be related to the anomalous effects attributed above to microstructural differences between the longitudinal and transverse DT specimens.

4.11.3 Elevated-Temperature Test Results

The results of elevated-temperature DT tests show that at temperatures of from the beginning of the upper shelf to 1300 F the fracture appearance is 100-percent shear, but the energy-absorption values are variable and the energy-absorption plots have minimum values at temperatures near 1050 F. These findings were presented as Figures 39 and 40 of reference 4 and they are summarized here in Table 12.

For each of the four sets of tests conducted, a minimum value of energy absorption occurs in the range of temperatures from 850 to 1100 F, depending on the steel and the specimen orientations. For three of these sets, the minima fall within a narrow range of 1000-1100°F. The fourth set, HDTL, has a minimum at 850°F, which may be misleading because a measurement was not taken at 1100°F.

The results of tests of transverse head-plate specimens indicate that the magnitude of the decrease in upper-shelf energy-absorption values at elevated temperatures can be greater than 50-percent of the maximum energy absorption that is obtained over the usual range of impact test temperatures. Although the significance of these results has not been clearly established, they indicate that TC128-B steels can be embrittled at elevated temperatures in a manner that permits propagation of a crack at temperatures near 1050 F to occur with relatively small levels of energy absorption. The cause of this embrittlement has not been established and it is uncertain as to whether these results may be relevant to the slow-deformation strength or to the creep-rupture properties at these elevated temperatures.

5. SUMMARY

Results obtained from impact tests of two plates of ASTM A212 steel, four plates of AAR TC128 steel, and two weldments of TC128 steel can be summarized as follows:

5.1 Anisotropy of the impact properties of the steels tested was three dimensional. The upper-shelf values and the transition temperature (TT) values were affected by orientation of specimen and notch, but the 50-percent SFA value was not affected.

5.1.1 For the six orientations tested, upper-shelf values of energy absorption and lateral expansion varied widely with orientation and tended to decrease in the order LS, LT, TS, TL, ST, SL; the corresponding values for 15-mil and 15-ft-lb transition temperatures also varied widely and they tended to be in inverse order to the level of their upper-shelf values.

5.1.2 For the six steels tested, SFA values are not greatly affected by orientation of specimen and notch; the 50-percent SFA criteria is shown to have an invariant character for all orientations tested for a given steel with the mean value for various orientations being generally within 10 F of the value for any individual orientation.

5.1.3 The 50-percent SFA TT value for combined data of the six steels was 68 F for either longitudinal or transverse specimens, but this fracture criterion varied widely for the six individual steels tested, as for example, for longitudinal (LT) specimens the values range from -11 to +138 F.

5.1.4 The temperature at which 50-percent SFA obtains was approximately the same as the temperature at which 50-percent of maximum energy absorption obtains. This was true for any individual data set as well as for any combined data set. Consequently, the 50-percent SFA criteria was shown to be generally satisfied at a considerably higher temperature than the temperatures at which the 15-mil or 15-ft-lb criteria were satisfied.

5.2 For a given orientation of specimen and notch, upper-shelf energy-absorption values for the six steel plates varied widely. The results indicated that shelf-energy absorption tended to decrease with increases in the inclusion content and the strength level of the steels, with this strength level dependency reflecting the strength level dependency of ductility. In addition, the shelf-energy absorption values for LT and TL specimens indicated that the head plates were cross rolled to a greater extent than were the shell plates.

5.2.1 Shelf-energy absorption values for the combined data from the six steel plates were about 67 and 41 ft-lb, respectively, for longitudinal (LT) and transverse (TL) specimens.

5.2.2 Shelf-energy absorption values for the six steels varied widely: For longitudinal (LT) specimens they ranged from 46 to 81 ft-lb, and for transverse specimens they ranged from 25 to 55 ft-lb.

5.2.3 When compared with a published trend line, three of the six steels tested had relatively low values of shelf-energy absorption for their respective yield-strength levels. These three steels were TC128-A and -B steels that contain vanadium and have either high or intermediate inclusion contents. These results indicate that increased inclusion content levels and the strengthening effect due to vanadium tended to sharply decrease shelf-energy absorption values.

5.2.4 The anisotropy index values derived from shelf-energy levels of CVN and DT impact tests indicated that each of the three head-plate steels were cross rolled to a greater extent than were any of the shell-plate steels. The indices derived from DT tests compared favorably with those derived from CVN tests.

5.3 Transition temperatures of the six steels tested varied widely, due to wide differences in the ferrite grain size and the contents of carbon, manganese, and phosphorous. Only one of these steels was produced to TC128-A specifications and it had fine ferrite grains and a fine pearlite colony size, both of which may be attributed to the presence of vanadium and the rolling practice. This steel had the lowest transition temperatures of the six steels tested. Transition temperatures of the three steels producted to TC128-B specifications were lower than those of the A212-B steels, and the A212-B steel produced to fine-grain practice had lower TT values than the one that was not produced to fine-grain practice.

5.3.1 Transition temperatures of the combined data for the six steels tested in both LT and TL orientations averaged 14 and 20 F, respectively for the 15-ft-lb and 15-mil criteria.

5.3.2 Transition temperatures for the six individual data sets of the six plates tested varied widely, especially those for the head-plate steels. The 15-ft-lb (LT) values ranged from -47 to +92 F for the head plates and from -5 to +32 F for the shell plates, while the values for the combined data were similar, being +13 and +7 F respectively for the head plates and the shell plates.

5.3.3 The six steels tested were catagorized into four classes of steels. These classes can be ranked on the basis of transition temperature, beginning with the class of lowest TT values: TC128-A, TC128-B without vanadium, TC128-B with vanadium, and A212-B.

5.4 Results from combined data sets indicate that the two A212-B steels tested had higher values of upper-shelf energy absorption but inferior (higher) TT values when compared with the values for the four TC128 steels tested. In addition, the variability in the test results for the four TC128 steels was large and much larger than that for the two A212-B steels. The higher values of shelf energy of the two A212-B steels may be attributable to their cleanliness. Their relatively high TT values may be attributed to comparatively less favorably levels of carbon to manganese when compared with that of the TC128 steels.

5.5 The results of CVN impact tests of specimens taken from weldments of TC128-B steels indicated that the impact characteristic of the weldments tested are much more favorable than those of the base metals of these welded steel plates. For example, the 15 ft-lb TT values of the steels averaged 38 F (for TL specimens) whereas those of the weld metal were -37 F and those of the weld-HAZ region tests (TL) averaged -48 F. The transition temperatures and the shelf-energy absorption values of the weldments tested were believed to reflect good welding practice.

5.6 A comparison of results of DT and CVN tests results for a head-plate steel and a shell-plate steel indicated that the DT test gives more conservative estimates (by about 45 F) of transition temperatures and the CVN test gives more conservative estimates (by a factor of 1/2) of the upper-shelf energy-absorption per unit area. However, for the Callao head plate (k-1) this relationship between the transition temperatures as determined by the two test methods was not observed to hold, and this finding was attributed to the microstructural variability of this head plate, which had fine ferrite on one side and coarse ferrite on the other side of the plate thickness, and to the fact that the CVN specimens were taken only from the coarse-grained half of the thickness of this plate, whereas the DT specimens represented the full thickness.

5.7 The results of DT tests conducted at elevated temperatures indicated that upper-shelf energy-absorption values for two TC128-B steels varied with temperature (for 25 minute exposure time), and at temperatures near 1050 F the energy-absorption value can be less than 50-percent of the value measured at temperatures near the ambient temperature. The results indicated that the impact toughness of the steel at temperatures above that of the ambient air, can be significantly decreased by elevated-temperature embrittlement which occurs by a mechanism that has not been clarified.

6. CONCLUSIONS

6.1 The variability of impact properties of steels used as plate material in tank cars and the factors that contribute to this variability should be given consideration in specifications for steels used for plate material of tank cars. Impact properties of these steels are principally governed by ferrite grain size and the levels of carbon, manganese, and phosphorous, and the content of inclusions in these steels.

Transition temperatures obtained from CVN tests of six plate steels taken from four failed tank cars indicate that the variance of TT values of these steels is large, with 15-ft-lb CVN longitudinal-specimen transition temperatures that range from -47 to +92 F. This wide variability of transition temperatures is variously attributable to variations in such factors as the levels of carbon, manganese, and phosphorous, and the ferrite grain size which itself is affected by the presence of vanadium, the deoxidation practice, as well as other factors that can be governed by the specification to which the steel is produced.

Upper-shelf energy-absorption values obtained from these CVN tests indicate that the six steels tested vary widely in ability to resist failure at temperatures at which the shear mode predominates. Various factors affect this behavior and in the steels tested the upper-shelf energy-absorption value appears to decrease with high inclusion content, which is related to the sulfur content of the steel, and with increased strength level of the steel, which is affected by various compositional and processing factors.

6.2 The results of CVN impact tests of six steel plates and those of DT tests of two steel plates indicate that these steels taken from failed tank cars have relatively high transition temperatures and poor resistance to failure under impact loading conditions. The relatively high transition temperatures of these steels is demonstrated by the finding that a modest fracture criterion of 15-ft-lb energy absorption in transverse specimens was satisfied by only one (of six tested) steel at temperatures of -20 to -40 F and by only three steels at temperatures of +40 and +60 F. The relatively poor resistance to failure under impact loading and the tendency for rapid, brittle crack propagation at common service temperatures is supported by the findings of the CVN and DT test results. The combined data for six plate steels indicate that a 15-ft-lb CVN criterion was satisfied at 9 and 19 F, respectively, for longitudinal and transverse specimens, but that the variance was large: For longitudinal specimens of the six individual steels, these temperatures ranged from -47 to +92 F. Further, for one of these steels (the Callao shell-plate K-5), the 15 ft-lb transition temperatures were -5 and +3 F, respectively, for longitudinal and transverse specimens. The nil ductility temperature for this steel, as estimated from the results of DT tests, is 30 and 38 F, respectively, for longitudinal and transverse specimens, indicating that at many service temperatures this steel would have very little resistance to impact loads and that failure would tend to be brittle with rapid crack propagation.

With these considerations in mind, it would be desirable to use steels with (1) greater resistance to brittle failure under impact loading conditions and (2) greater resistance to rapid crack propagation under normal and abusive service conditions. The need for steels with such improved properties should be assessed.

6.3 The need for improved impact properties for head-plate steels and shell-plate steels should be determined independently, since some of the design alternatives might involve improved properties for the head plates, the shell plates, or both.

The results of impact tests of three head-plate steels and those of three shell-plate steels indicate that impact characteristics of the head-plate steels tested were similar to those of the shell-plate steels tested but that the impact properties of the head-plates tested were much more highly variable than those of the shell-plates tested. Average transition temperatures of three head plates are 13 and 33 F, respectively, for longitudinal and transverse CVN specimens: Those for three shell plates are 7 and 23 F, respectively. The 15 ft-lb TT values for longitudinal specimens cover a wide range from -47 to +92 F for the head plates and a narrower range from -5 to +32 F for the shell plates.

6.4 The anisotropy of impact properties of steels used as the plate material of tank cars should be assessed in relation to the design of tank cars, and this should be done with the understanding that circumferencial failure of tank cars is promoted by the current design. The anisotropy of these steels tends to be such that upper-shelf energy absorption and transition temperatures are affected by specimen orientation. Energy absorption values tend to decrease in the following order of specimen orientations: LS, LT, TS, TL, ST, SL, and the corresponding transition temperature values tend to be in the inverse order to that of the shelf-energy absorption values for various orientations. Thus, longitudinal specimens tend to have the highest upper-shelf energy absorption and the lowest transition temperatures, and transverse specimens have significantly poorer impact properties. Hence, failure is promoted in the direction of final rolling of the plate--this was shown to be especially true for the shell-plate steels but it is also true for the head-plate steels tested. The result is that fracture in the circumferential direction of the tank car is promoted in shell plates and this can and does sometimes[2] lead to rocketing of large tank car sections.

6.5 The elevated-temperature embrittlement demonstrated by TC128-B steel should be studied further and the results should be interfaced with the elevated-temperature requirements of steels used for plate materials of tank cars. The results of elevated-temperature DT impact tests indicate that upper-shelf energy-absorption values are a function of temperature and that, at temperatures near 1050 F, the energy absorption in DT tests can be less than 50-percent of the value measured at temperatures slightly above the temperature of ambient air. These results indicate that at these temperatures an elevated-temperature embrittlement of the steel occurs by a mechanism that has not yet been established. The decrement in the energy-absorption capacity at elevated temperatures has been observed for two TC128-B steel plates tested after exposure at various temperatures for about 25 minutes in air. The effect of time at temperature on this decrement is not now known, and the susceptibility of AAR TC128-A steels or that of ASTM A212-B steels or other steels used as plate materials of tank cars is not known nor is the most important effect of strain rate known. Thus the significance of this embrittlement is now open to question.

7. ACKNOWLEDGEMENT

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Table 1. Summary of Impact Tests

Accident	Steel Specification	Nominal Plate Thickness	Location of CVN Specimens	Identification of Plate Sample	Limits of Test Temperatures, F CVN	Limits of Test Temperatures, F DT
Belle, W. Va.	AAR TC128-A-69	11/16"	Inside Quarterthickness	Belle B-Head	-320/+212	(a)
South Byron, N.Y.	AAR TC128-B-65	5/8"	Outside Quarterthickness	South Byron Shell	-120/+212	(a)
Callao, Mo.	AAR TC128-B-65	11/16"	Inside Quarterthickness	A-Head, K-1	-100/+212	-50/+1300
Callao, Mo.	AAR TC128-B-65	5/8"	Inside Quarterthickness	Shell K-5	-100/+160	-50/+1300
Callao, Mo.	Weld Metal	N.A.	Inside Quarterthickness	K-11 (b)	-100/+212	(a)
Callao, Mo.	Weld Metal	N.A.	Inside Quarterthickness	K-8 (c)	-100/+212	(a)
Callao, Mo.	AAR TC128-B-65	11/16"	Weld HAZ (d)	A-Head, K-2	-100/+160	(a)
Callao, Mo.	AAR TC128-B-65	5/8"	Weld HAZ (d)	Shell, K-8		
Crescent City, Ill.	A212-B-65	11/16"	Inside Quarterthickness	A-Head, FRA-2	- 50/+275	(a)
Crescent City, Ill.	A212-B-65	5/8"	Inside Quarterthickness	Shell, FRA-2	-120/+275	(a)

(a) Not tested.

(b) Weld metal between shell courses 4 and 5.

(c) Weld metal between shell courses 1 and 2.

(d) Midthickness.

Table 2. Summary of Results of Calculations for Individual Data Sets of CVN Impact Tests

Steel Specification	Plate Identification	Head or Shell	Orientation[(a)]	Specimen Identification Code[(b)]	Transition Temperature, F: 15 ft-lb Energy Absorption	15 Mil Lateral Expansion	50 Percent Shear Fracture Appearance	Upper-Shelf Energy, ft-lb
AAR TC128-A-69	Belle	B-Head	LT	D1-D16	-46.5	-42.8	-10.5	68.0
			TL	B1-B16	-48.8	-50.4	-20.7	40.2
			LS	C1-C16	-62.2	-45.3	-34.9	>120.0
			TS	A1-A16	-74.3	-62.1	-31.1	41.1
AAR TC128-B-65	South Byron	Shell, 2	LT	B1-B19	17.8	13.8	36.3	45.5
			TL	B22-B40	26.3	20.6	28.0	25.0
AAR TC128-B-65	K-1, Callao	Head	LT	HLH1-HLH19	55.6	40.7	85.9	54.0
			TL	HTF61-HTF76	72.0	63.9	98.1	37.5
			LS	HLI21-HLI40	4.0	10.1	83.0	85.9
			TS	HTG41-HTG58	75.4	63.9	98.3	45.2
			SL	SE1/SE35 (odd)	(210.0)[(k)]	175.0	80.0	13.9
			ST	SE21 SE40 (even)(j)	188.1	170.3	86.7	15.8
AAR TC128-B-65	K-5 Callao	Shell	LT	STA21-STA39	- 4.8	- 4.4	60.0	74.5
			TL	SLC41-SLC58	3.3	14.8	52.3	37.8
			LS	STB1-STB20	(c)	(c)	(c)	>120.0
			TS	SLD61-SLD77	- 1.8	3.0	46.8	54.8
A212-B-65	FRA-2, Crescent City	A-Head	LT[(d)]	C56-C73	92.3	72.0	137.7	81.4
			TL[(d)]	C41-C55	84.4	69.4	143.1	55.2
	FRA-2, Crescent City	Shell	LT	C1-C20	32.5	27.5	83.5	76.2
			TL	C21-C40	62.1	42.5	87.6	34.5
Weld Metal	K-11, Callao	(e)	LT	WL1-WL19	-34.3	-30.0	60.3	74.7
	K-8, Callao	(f)	TL	WM21-WM40	-39.1	-35.5	59.2	60.1
HAZ	A-Head, Callao	(g)	TL[(h)]	HJ1-HJ1?	-49.4	-52.0	-16.5	49.1
HAZ	K-8, Callao	(i)	TL	HK1-HK17	-45.6	-45.3	- 3.8	44.8

(a) Orientation Code is described in Figure 1.

(b) The letter-number code refers to the specimen numbers reported earlier[1-4].

(c) This set of specimens has highly variable impact characteristics, and no valid estimate could be derived from the available data.

(d) These head plate specimens are not oriented with respect to plate rolling direction. Longitudinal(L) and transverse (T) mean, respectively, parallel and perpendicular to the axis of the weld only.

(e) Weld metal between shell courses 4 and 5.

(f) Weld metal between shell courses 1 and 2.

(g) HAZ between the A-head and shell course 1.

(h) The orientation code for these HAZ specimen of the head-plate steel applies to the direction of welding.

(i) HAZ between shell courses 1 and 2.

(j) Specimens 8, 10, and 26 not tested.

(k) Maximum value of 13.9 ft-lb occurs at 210 F.

Table 3. Effect of Orientation of Specimen and Notch on CVN Impact Test Results.

Specimen Orientation (a)	Specimen Identification	Transition Temperatures, F: 15 ft-lb Energy Absorption	15 Mil Lateral Expansion	50 Percent Shear Fracture	Energy Absorption (ft-lbs): Upper Shelf Maximum Value	Approximate Lower Shelf Value at -100 F
Callao Head Plate K-1						
Longitudinal Specimens						
1 LS	HLI	4.0	10.1	83.0	85.9	6.2
2 LT	HLH	55.6	40.7	85.8	54.0	2.5
Transverse Specimens						
3 TS	HTG	75.4	63.9	98.3	45.2	3.0
4 TL	HTF	72.0	63.9	98.1	37.5	2.0
Short-Transverse Specimens						
5 ST	SE	188.1	170.3	86.7	15.8	2.1
6 SL	SE	(b)	175.0	80.0	13.9	2.5
			Overall Ave.	88.6		
Callao Shell Plate K-5						
Longitudinal Specimens						
1 LS	STB	(c)	(c)	(c)	>120.0	7.6
2 LT	STA	- 4.8	- 4.4	60.0	74.5	6.4
Transverse Specimens						
3 TS	SLD	- 1.8	3.0	46.8	54.8	6.3
4 TL	SLC	3.3	14.8	52.3	37.8	0
			Overall Ave.	53.0		
Belle Head Plate Steel						
Longitudinal Specimens						
1 LS	C	- 62.2	- 45.3	-34.9	>120.0	1.0
2 LT	D	- 46.5	- 42.8	-10.5	68.0	3.5
Transverse Specimens						
1 TS	A	- 74.3	- 62.1	-31.1	41.1	6.9
2 TL	B	- 48.9	- 50.4	-20.7	40.2	4.4
			Overall Ave.	-24.3		

(a) Orientation Code is given in Figure 1.
(b) Upper shelf values for these specimens are 13.9 ft-lb at 210 F and 13.5 ft-lb at 160 F.
(c) This set of specimens has highly variable impact characteristics, and no valid estimate could be derived from the available data.

Table 4. Results of Calculations of Combined Data for Longitudinal and for Transverse Specimens.

Number of Specimens and Orientation (a)	Specimen Identification and Location	Transition Temperatures, F			Maximum Shelf Energy Absorption, ft-lb
		15 ft-lb Energy Absorption	15 Mil Lateral Expansion	50 Percent Shear Fracture	
Six Plate Steels (See Figure 4)					
106 LT	3 Head & 3 Shell	9.2	15.7	68.4	66.8
103 TL	3 Head & 3 Shell	19.3	23.7	67.7	41.0
Three Head-Plate Steels (See Figure 5)					
50 LT	Head	12.8	20.5	66.2	69.0
48 TL	Head	33.1	8.6	79.9	47.4
Three Shell-Plate Steels (See Figure 6)					
56 LT	Shell	7.2	13.7	58.7	72.2
55 TL	Shell	23.3	24.4	47.6	34.9

(a) See Figure 1 for orientation code.

Table 5. Anisotropy Indices for Six Steel Plates

Steel	Upper-Shelf Energy TL/LT (ft-lb)			Cross-Rolling Index	
	CVN Tests	DT Tests		CVN Tests	DT Tests
Head Plates					
Callao K-1	38/54	420/650		.70	.65
Belle*	40/61	**		.66	
Crescent City*	55/81	**		.68	
			Average	.68	
Shell Plates					
Callao, K-5	38/75	377/746		.51	.51
South Byron	25/46	**		.54	
Crescent City	35/76	**		.46	
			Average	.50	

* Axes for head plates for Belle and Crescent City may deviate substantially from true longitudinal and transverse directions.

** Not tested.

Table 6. Results of Calculations for Individual Data Sets of Longitudinal and Transverse Specimens Taken from Six Plate Steels.

Plate Identification	Head or Shell	Steel	Specimen Code	Transition Temperature, F: 15 ft-lb	15 mil	50% SFA	Upper Shelf Energy, ft-lb	Arbitrary Inclusion Rank[a] (ref. 5)	ASTM Ferrite Grain Size No.	Comments on Microstructures
Longitudinal Specimens (See Figure 7)										
Belle[b,c]	B-Head	AAR TC128-A	D1-D16	-46.5	-42.8	- 10.6	68.0	3	8.5	Fine pearlite colonies
South Byron[c]	Shell 2	AAR TC128-B	B1-B19	17.8	13.8	36.3	45.5	3	8.0	Intermediate pearlite colonies.
Callao[c,d]	Head, K-1	AAR TC128-B	HLH1-HLH19	55.6	40.7	85.8	54.0	2	7.0	Coarse pearlite colonies.
Callao[e]	Shell, K-5	AAR TC128-B	STA21-STA39	- 4.8	- 4.4	60.0	74.5	2	7.0	Intermediate pearlite colonies.
Crescent City[b,e]	A-Head	A212-B-65	C56-C73	92.3	72.0	137.7	81.4	1	6.0	Pearlite is coarse and ferrite is coarse and acicular.
Crescent City	Shell	A212-B-65	C1-C20	32.5	27.5	83.5	76.2	1	7.0	Coarse pearlite colonies.
Transverse Specimens (See Figure 8)										
Belle	B-Head	AAR TC128-A	B1-B16	-48.8	-50.4	- 20.1	40.2	3	8.5	Fine Pearlite colonies
South Byron	Shell	AAR TC128-B	B22-B40	26.3	20.6	28.0	25.0	3	8.0	Intermediate pearlite colonies.
Callao	Head, K-1	AAR TC128-B	HTF61-HTF76	72.0	63.9	98.1	37.5	2	7.0	Coarse pearlite colonies.
Callao	Shell, K-5	AAR TC128-B	SLC41-SLC58	4.4	14.8	52.3	37.6	2	7.0	Intermediate pearlite colonies.
Crescent City	A-Head	A212-B	C41-C55	84.4	69.4	143.1	55.2	1	6.0	Pearlite is coarse and ferrite is coarse and acicular.
Crescent City	Shell	A212-B	C21-C40	62.1	42.5	87.6	34.5	1	7.0	Coarse pearlite colonies.

(a) Rank 1 is moderate inclusion content.
Rank 2 is intermediate inclusion content.
Rank 3 is higher inclusion content.

(b) The axes for these specimens may deviate from the true longitudinal and transverse directions of the plate from which they were taken.

(c) These steels contain more than 0.02 percent vanadium.

(d) Hot-formed head plate.

(e) These steels were not produced to fine-grain practice.

Table 7. Comparison of Calculations of Combined Data Sets for Three Head-Plate Steels and for Three Shell-Plate Steels.

Number of Specimens and Orientation (a)	Specimen Identification and Location	Transition Temperatures, F			Maximum Shelf Energy Absorption, ft-lb
		15 ft-lb Energy Absorption	15 Mil Lateral Expansion	50 Percent Shear Fracture	
Longitudinal Specimens (See Figure 9)					
50 LT	3 Head Plates	12.8	20.5	66.2	69.0
56 LT	3 Shell Plates	7.2	12.7	13.7	72.2
Transverse Specimens (See Figure 10)					
48 TL	3 Head Plates	33.1	8.6	79.9	47.4
55 TL	3 Shell Plates	23.3	24.4	47.6	34.9

(a) See Figure 1 for orientation code.

Table 8. Results of Calculations of Combined Data for Four AAR TC128 Steels and for Two ASTM A212-B Steels.

Number of Specimens and Orientation (a)	Steel Specification	Transition Temperatures, F: 15 ft-lb Energy Absorption	Transition Temperatures, F: 15 Mil Lateral Expansion	Transition Temperatures, F: 50 Percent Shear Fracture	Maximum Shelf Energy Absorption, ft-lb
Longitudinal Specimens (See Figure 11)					
70 LT	TC128	- 5.7	3.9	54.4	62.0
36 LT	A212-B	35.1	39.3	94.9	78.9
Transverse Specimens (See Figure 12)					
68 TL	TC128	6.8	8.7	49.7	35.8
35 TL	A212-B	67.5	45.1	99.1	49.9

(a) See Figure 1 for orientation code.

Table 9. Results of Calculations of Data Combined on the Basis of the Grade to which the Steels were Produced.

Number of Specimens and Orientation(a)	Steel Specification	Transition Temperatures, F: 15 ft-lb Energy Absorption	15 Mil Lateral Expansion	50 Percent Shear Fracture	Maximum Shelf Energy Absorption, ft-lb	Inclusion Content(b) Rank (ref. 5)
Longitudinal Specimens (See Figure 13)						
16 LT	TC128-A	-46.5	-42.8	-10.5	68.0	3.0
17 LT	TC128-B w/o V	- 4.8	- 4.4	60.0	74.5	2.0
36 LT	A212-B	35.1	39.3	94.9	78.9	1.0
37 LT	TC128-B with V	17.5	18.9	61.3	52.3	2.5
Transverse Specimens (See Figure 14)						
16 TL	TC128-A	-48.8	-50.4	-20.7	40.2	3.0
17 TL	TC128-B w/o V	3.3	14.8	52.3	37.8	2.0
35 TL	A212-B	67.5	45.1	99.1	49.9	1.0
35 TL	TC128-B with V	44.0	33.2	47.2	32.8	2.5

(a) See Figure 1 for orientation code.

(b) 1 is high content and 3 is moderate content.

Table 10. CVN Energy-Absorption Values for Six Steels at Various Service Temperatures

Grade of Steel	Plate Identification	-40 F	-20 F	0 F	20 F	40 F	60 F	80 F
Longitudinal (LT) Specimens								
AAR TC128-A	Belle, "B" Head	18.0	29.7	44.0	50.1	56.9	67.3	67.5
AAR TC128-B	Callao, A-Head K-1	2.5	2.5	2.5	3.1	5.6	18.9	38.5
ASTM A212-B	Crescent City, A-Head FRA 2	3.0	3.5	4.0	4.5	6.4	8.7	11.7
	Average of Above Data	7.8	11.9	16.8	19.2	23.0	31.6	39.2
	Value From Combined Head Plate Calculations of Appendix C	6.6	9.2	12.5	16.6	21.4	27.0	33.0
AAR TC128-B	Callao, Shell K-5	9.7	11.8	16.3	23.6	34.4	48.1	61.6
AAR TC128-B	South Byron Shell Plate	3.0	4.6	8.6	16.2	28.8	40.6	45.1
ASTM A212-B	Crescent City, Shell FRA-2	3.4	5.0	6.7	10.9	18.1	29.1	43.9
	Average of Above Data	5.4	7.1	10.5	16.9	27.1	39.3	50.2
	Value From Combined Shell-Plate Calculations of Appendix D	4.4	7.0	12.5	20.2	29.7	40.1	50.1
	Average of All Six Individual Data Sets	6.6	9.5	13.7	18.1	25.0	35.5	44.7
	Value of Combined Data for Six Steels, Appendix B	5.2	8.3	12.6	18.2	25.0	32.8	40.9
Transverse (TL) Specimens								
AAR TC128-A	Belle "B" Head	17.9	25.1	31.6	33.8	36.2	38.6	40.2
AAR TC128-B	Callao, A-Head K-1	4.3	4.6	4.9	5.5	7.2	10.5	16.7
ASTM A212-B	Crescent City, A-Head FRA-2	3.0	3.5	4.0	4.5	6.4	8.7	11.7
	Average of Above Data	8.4	11.1	13.5	14.6	16.6	19.3	22.9
	Value From Combined Head-Plate Calculations of Appendix C	6.3	8.2	10.4	13.1	16.1	19.5	23.1
AAR TC128-B	Callao, Shell K-5	9.0	10.9	15.5	23.2	34.1	45.7	52.9
AAR TC128-B	South Byron Shell Plate	3.0	4.8	7.9	13.1	19.1	23.4	24.8
ASTM A212-B	Crescent City, Shell FRA-2	3.0	4.0	5.3	7.5	10.4	14.5	19.6
	Average of Above Data	5.0	6.6	9.6	14.6	21.2	27.9	32.4
	Value From Combined Shell-Plate Calculations of Appendix D	4.6	6.9	10.3	14.3	18.7	23.0	26.9
	Average of All Six Individual Data Sets	6.7	8.8	11.5	14.6	18.9	23.6	27.6
	Value of Combined Data for Six Steels, Appendix B	7.3	9.6	12.2	15.1	18.2	21.4	24.6

Table 11. Results of CVN Impact Tests of Weldments

Specimen Orientation	Specimen Identification and Location	Transition Temperatures, F: 15 ft-lb Energy Absorption	15 Mil Lateral Expansion	50 Percent Shear Fracture	Upper-Shelf Energy Absorption, ft-lb
Steel From the "A" Head Plate of the Callao (Sample K-1)					
LT	HLH	55.6	40.7	85.8	54.0
TL	HTF	72.0	63.9	98.1	37.5
Average		63.8	52.3	61.3	45.8
Steel From Shell Course Number 1 of Callao (Sample K-5)					
Transverse Specimens					
TL	SLC	3.3	14.8	52.3	37.8
Weld Metal of Shell/Shell Weldments					
Longitudinal Specimens From Callao Plate K-11					
LT	WL	- 34.3	- 30.0	60.3	74.7
Transverse Specimens From Callao Plate K-8					
TL	WM	- 39.1	- 35.5	59.2	60.1
Heat-Affected Zone of AAR TC128-B Steels Shown Above					
"A"Head Plate of Callao Sample K-2					
TL[(a)]	HJ	- 49.4	- 52.0	- 16.5	49.1
Shell Course Number 1 of Callao (Sample K-8)					
TL	HK	- 45.6	- 45.3	- 3.8	44.8

(a) The orientation code for these head-plate HAZ specimens applies to the direction of welding. The angle between the specimen axis and the principal rolling direction of the plate is about 45°, and thus these results would be expected to be intermediate between those that would obtain for true longitudinal and true transverse specimens.

Table 12. Results of Dynamic-Tear Tests for Specimens from Two AAR TC128-B Steel Plates.

	Specimen Thickness (inch)	Specimen Orientation (a)	Specimen Designation (in ref. 4)	Estimated NDT(b) Temperature (F) (@ 100 ft-lb)	Estimated NDT(b) Temperature (F) (@ 75 ft-lb)	50 Percent-Shear-Fracture Appearance Temp. (F)	50 Percent of Maximum En. Abs. (ft-lb)	50 Percent of Maximum En. Abs. Temp. (F)	Maximum Upper-Shelf En. Absorption(c) (ft-lb)	Approximate Minimum Along Upper Shelf(d) (ft-lb)	Approximate Minimum Along Upper Shelf(d) Temp. (F)
"A" Head Plate											
Longitudinal (Fig. 34 of ref. 4)	11/16	LT	HDTL	12	3	47	325	43	650	445	850
Transverse (Fig. 35 of ref. 4)	11/16	TL	HDTT	83	61	133	210	121	420	195	1050
Average				48	32	90	268	82	535	320	950
Shell Plate K-5											
Longitudinal (Fig. 36 of ref. 4)	5/8	LT	SDTL	42	17	96	373	95	746	425	1000
Transverse (Fig. 37 of ref. 4)	5/8	TL	SDTT	47	29	87	189	79	377	257	1100
Average				45	23	92	281	87	562	341	1050

(a) Orientation codes are given in Figure 1.

(b) Based on recommendations given in Reference 8.

(c) For temperatures below 300 F only.

(d) For temperatures above 300 F only.

Table 13. Comparison of Results of CVN and DT Tests of One-Head and One-Shell Plate of AAR TC128-B Steels.

Head or Shell	Figure Number(a) (ref. 4)	Specimen Orientation	Upper-Shelf Energy(b) CVN (X) ft-lb	Upper-Shelf Energy(b) DT (X') ft-lb	Upper-Shelf Energy/Area(c) CVN(b) (in.-lb)/in.² X 10³	Upper-Shelf Energy/Area(c) DT(d) (in.-lb)/in.² X 10³	DTEE(e) 15(X'/X) ft-lb	Transition Temperatures, Energy Absorption, CVN 15 ft-lb F	Transition Temperatures, Energy Absorption, DTEE 15 ft-lb F	Transition Temperatures, 50% Shear Fracture Appearance, CVN F	Transition Temperatures, 50% Shear Fracture Appearance, DT F
Head	Fig. 34	LT	54.0	650	5.2	11.1	181	56	26	86	47
Head	Fig. 35	TL	37.5	420	3.6	7.2	168	72	110	98	133
Shell	Fig. 36	LT	74.5	746	7.2	12.7	150	- 5	61	60	96
Shell	Fig. 37	TL	37.8	377	3.6	6.4	150	3	67	52	87

(a) Plots of CVN and DT results are given in reference number 4, Figures numbered 34-37.

(b) Let X represent the CVN upper shelf energy and X' represent the DT upper shelf energy.

(c) These calculational results are approximations. More precise values will be given in a future report which will include precracked Charpy test data.

(d) The dynamic tear energy equivalent (DTEE) of the 15 ft-lb Charpy energy is defined as 15 X'/X.

(e) The DTEE transition temperature occurs at a DT energy level that is the same fraction of the DT upper shelf as the fraction 15 ft-lb/CVN upper shelf, i.e, DTEE/DT upper shelf = 15 ft-lb/CVN upper shelf.

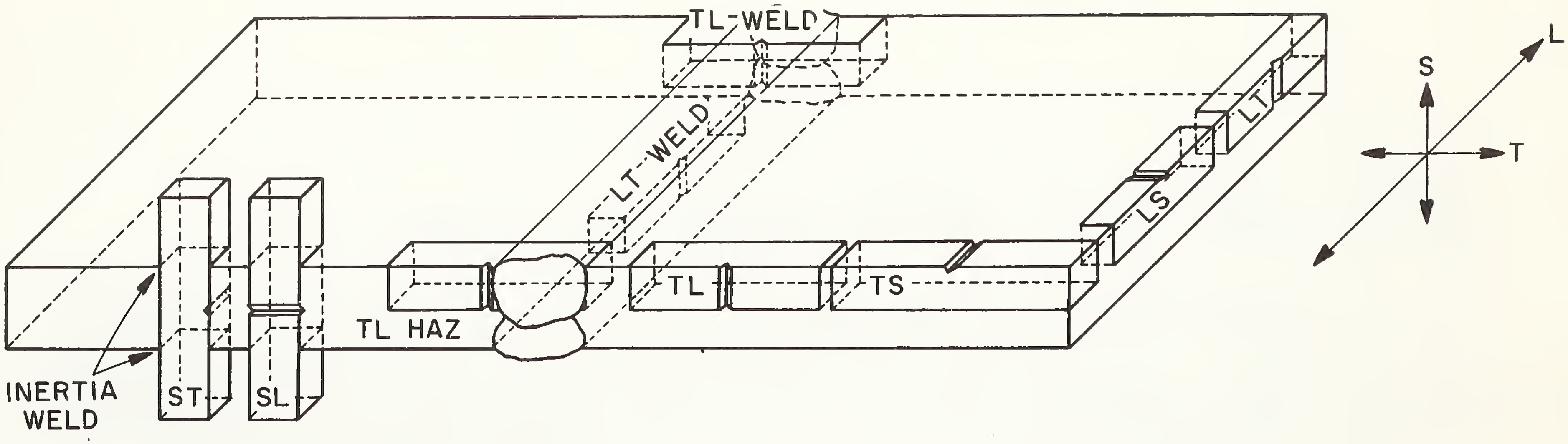


Figure 1. Orientation Codes of Various Impact Test Specimens.

Specimen Orientation Code: The two letter code gives direction of the long axis of the specimen (L, T, or S) followed by the direction of crack propagation (L, T, or S). The letters L, T, and S refer to the three orthogonal plate directions, as defined below:

- L Longitudinal or rolling direction of plate. For weld-metal specimens, this refers to the direction of welding.
- T Transverse direction: perpendicular to rolling direction but in the plane of the plate. For weld-metal and heat-affected-zone specimens, this refers to the perpendicular to the welding direction.
- S Short-transverse direction: perpendicular to L and T.

FIGURE 2A

CVN IMPACT TEST RESULTS FOR FOUR ORIENTATIONS OF AAR TC128-B STEEL SPECIMENS--CALLAO SHELL PLATE.

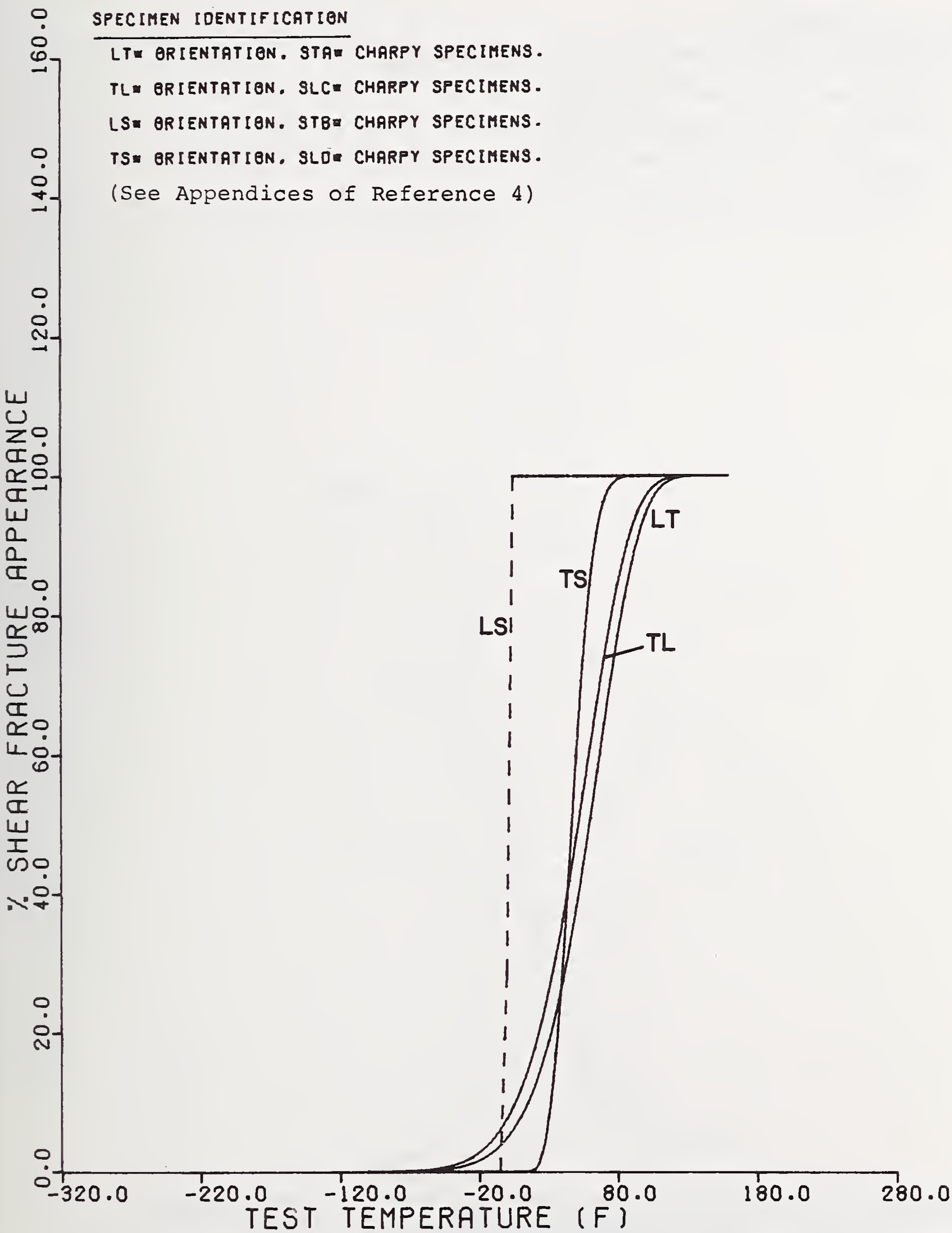


FIGURE 2B

CVN IMPACT TEST RESULTS FOR FOUR ORIENTATIONS OF AAR TC128-B STEEL SPECIMENS
CALLAO SHELL PLATE.

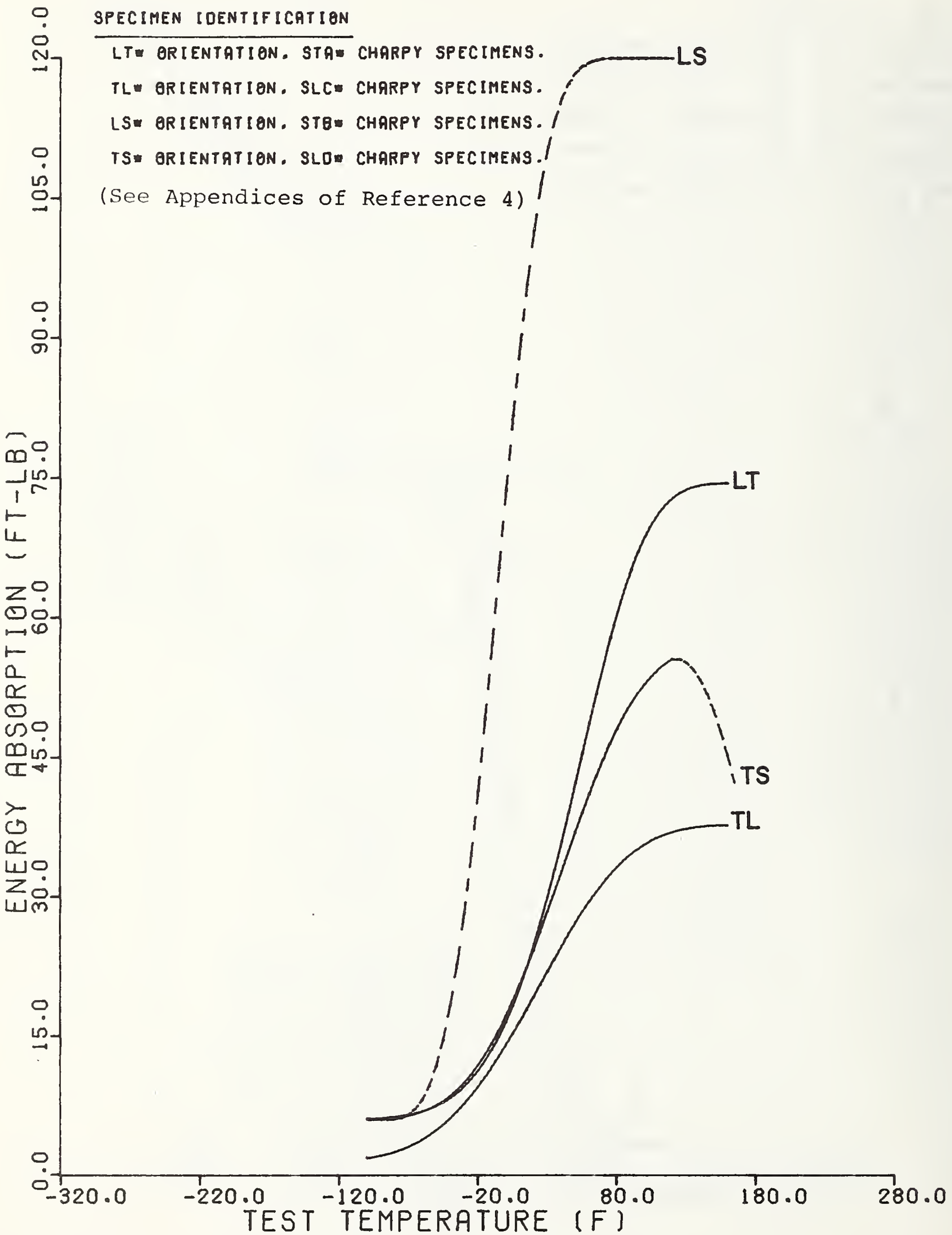


FIGURE 2C

CVN IMPACT TEST RESULTS FOR FOUR ORIENTATIONS OF AAR TC128-B STEEL SPECIMENS--CALLAO SHELL PLATE.

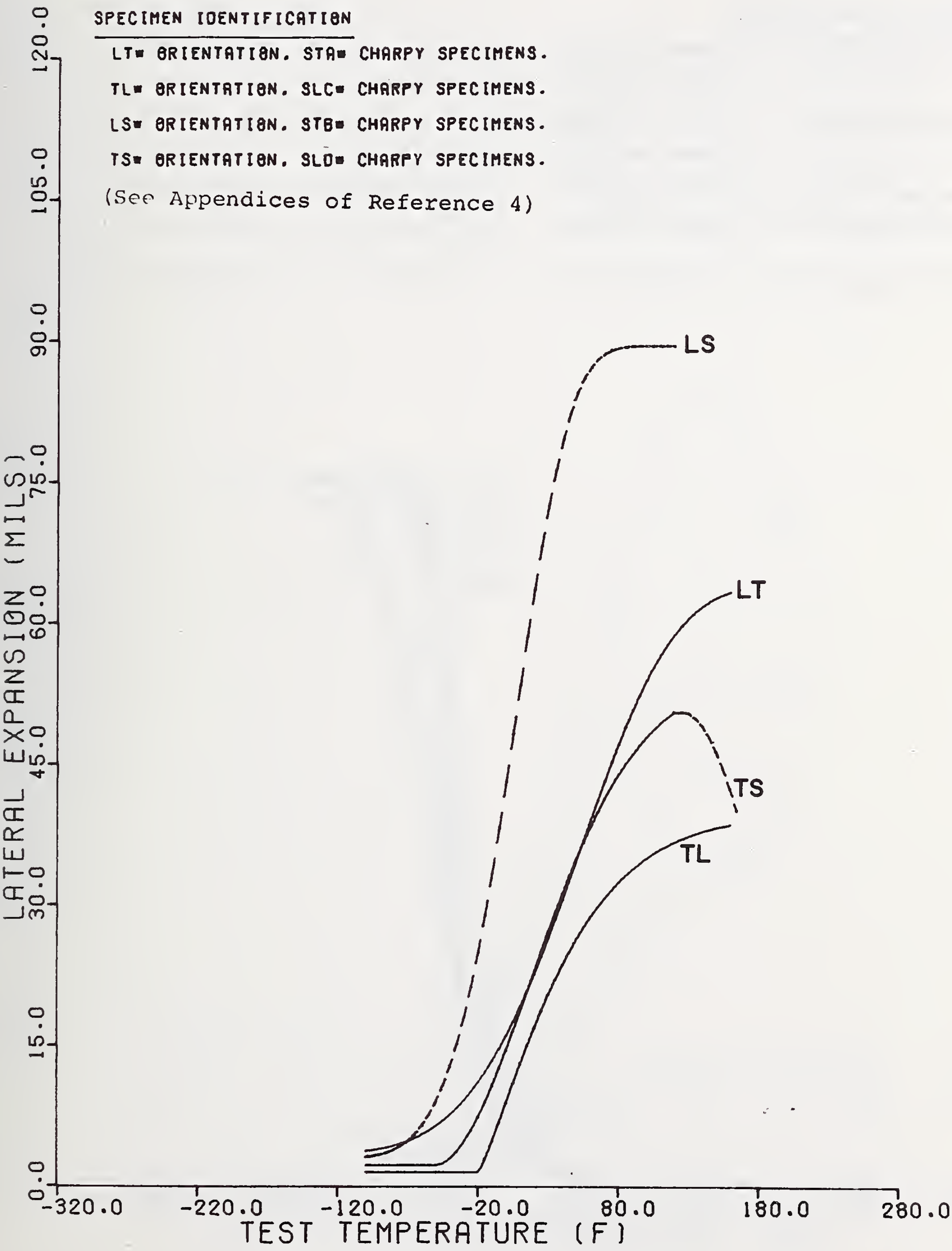


FIGURE 3A

CVN IMPACT TEST RESULTS FOR SIX ORIENTATIONS OF AAR TC128-B STEEL SPECIMENS--CALLAO HEAD PLATE.

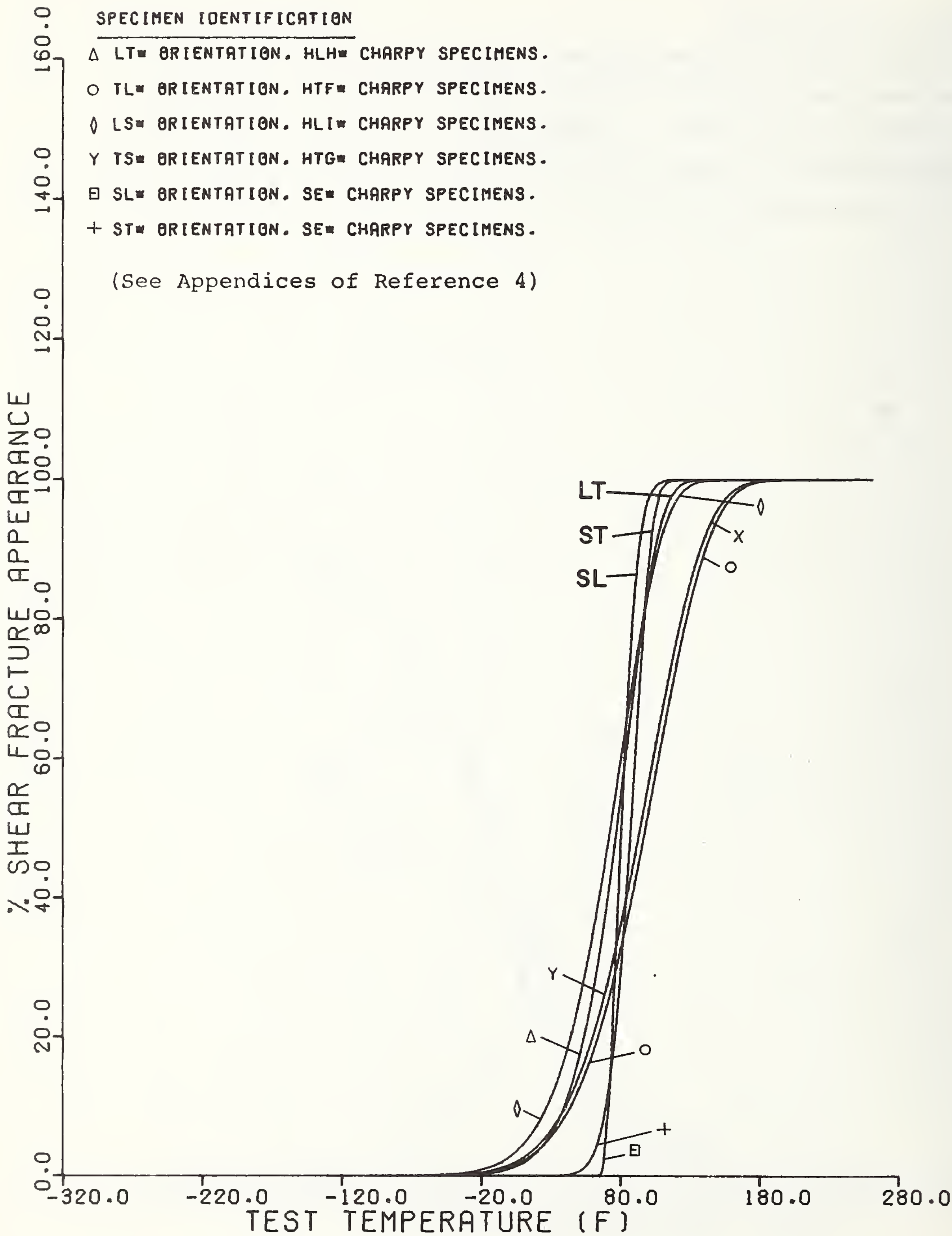


FIGURE 3B

CVN IMPACT TEST RESULTS FOR SIX ORIENTATIONS OF AAR TC128-B STEEL SPECIMENS--CALLAO HEAD PLATE.

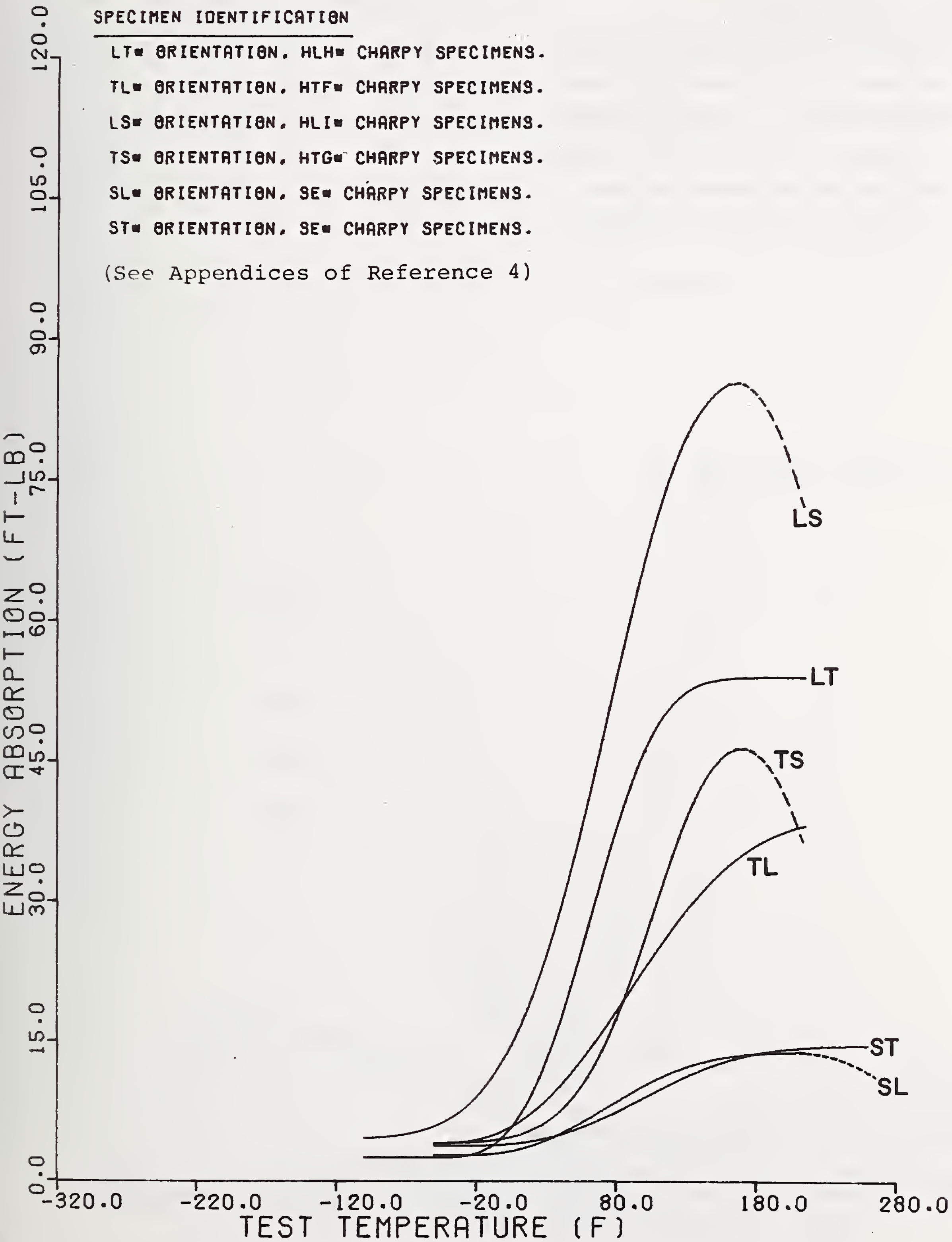


FIGURE 3C

CVN IMPACT TEST RESULTS FOR SIX ORIENTATIONS OF AAR TC128-B STEEL SPECIMENS--
CALLAO HEAD PLATE.

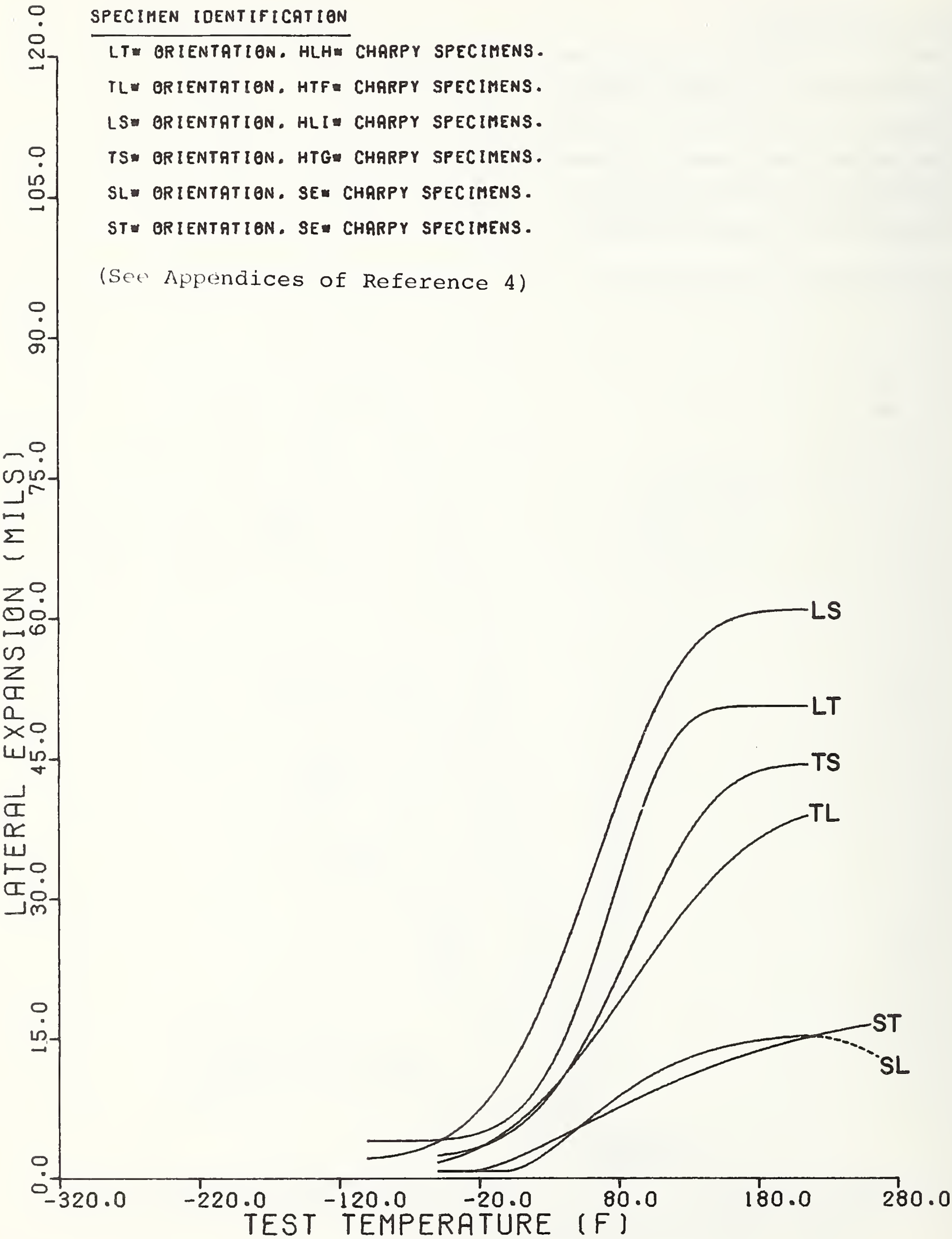


FIGURE 4A

COMPARISON OF LONGITUDINAL AND TRANSVERSE CVN IMPACT-TEST RESULTS FOR SIX STEEL PLATES TAKEN FROM FOUR ACCIDENTS.

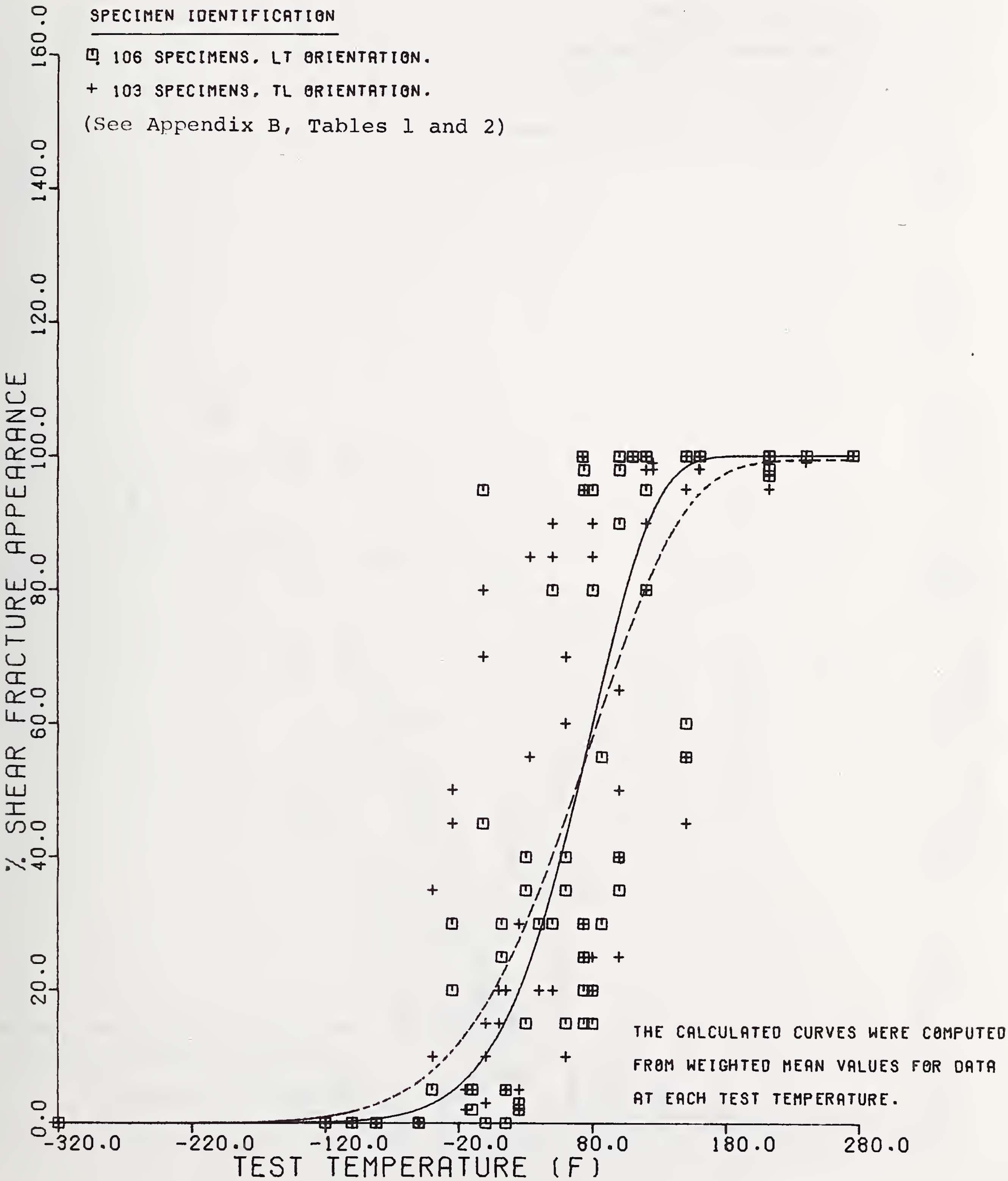


FIGURE 4B

COMPARISON OF LONGITUDINAL AND TRANSVERSE CVN IMPACT-TEST RESULTS FOR SIX STEEL PLATES TAKEN FROM FOUR ACCIDENTS.

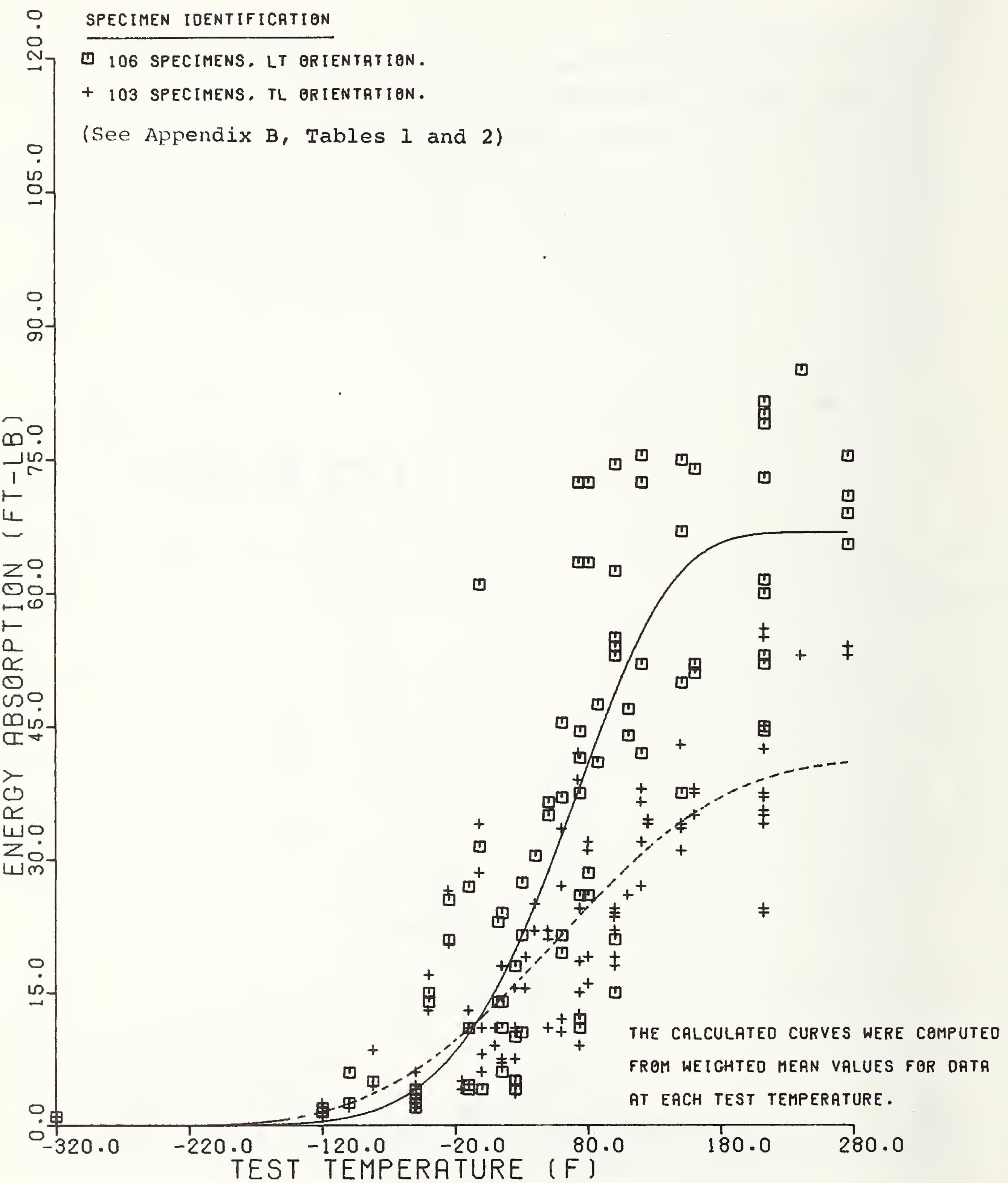


FIGURE 4C

COMPARISON OF LONGITUDINAL AND TRANSVERSE CVN IMPACT-TEST RESULTS FOR SIX STEEL PLATES TAKEN FROM FOUR ACCIDENTS.

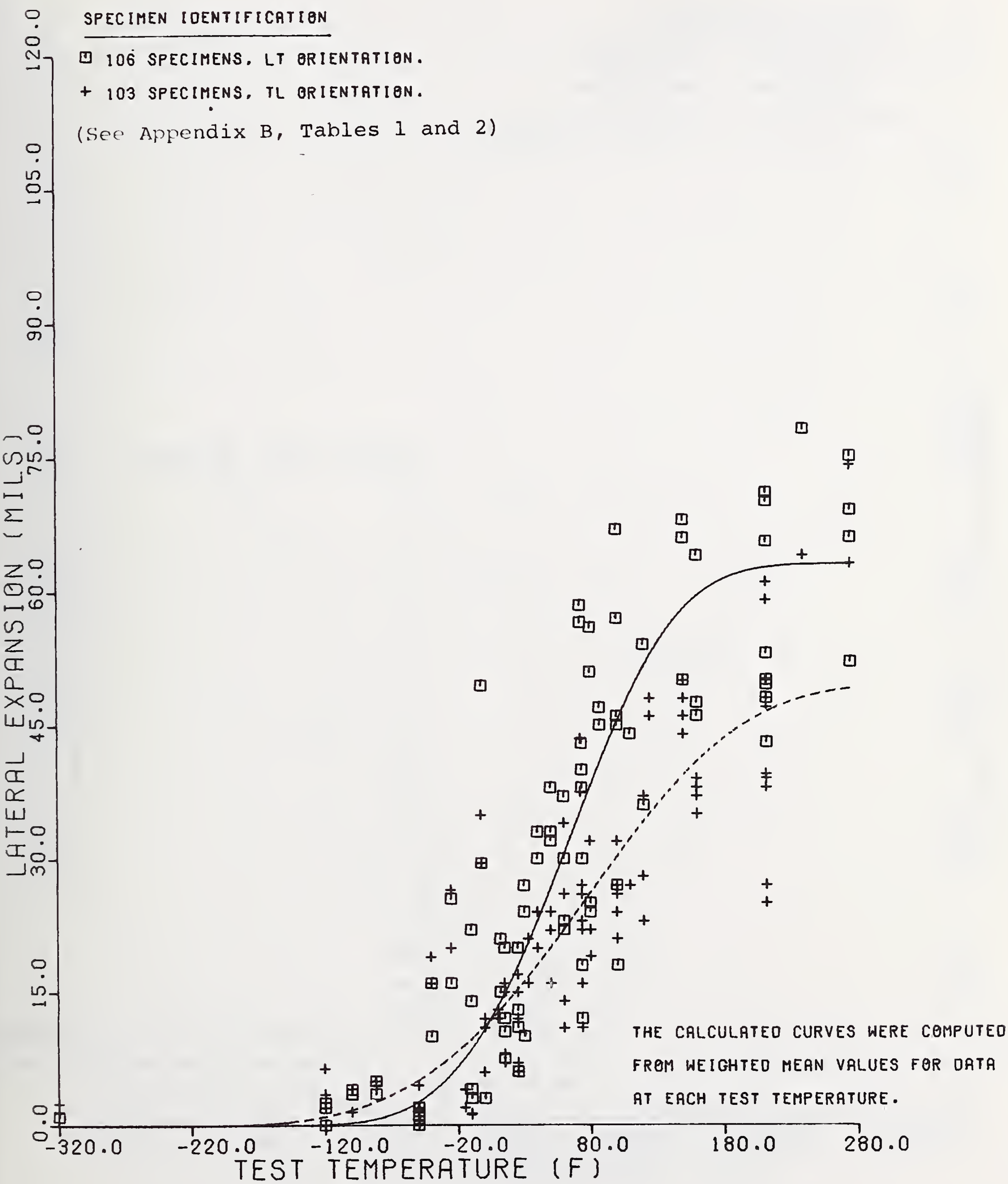


FIGURE 5A

COMPARISON OF LONGITUDINAL AND TRANSVERSE CVN IMPACT-TEST RESULTS FOR HEAD-PLATE SPECIMENS TAKEN FROM THREE ACCIDENTS.

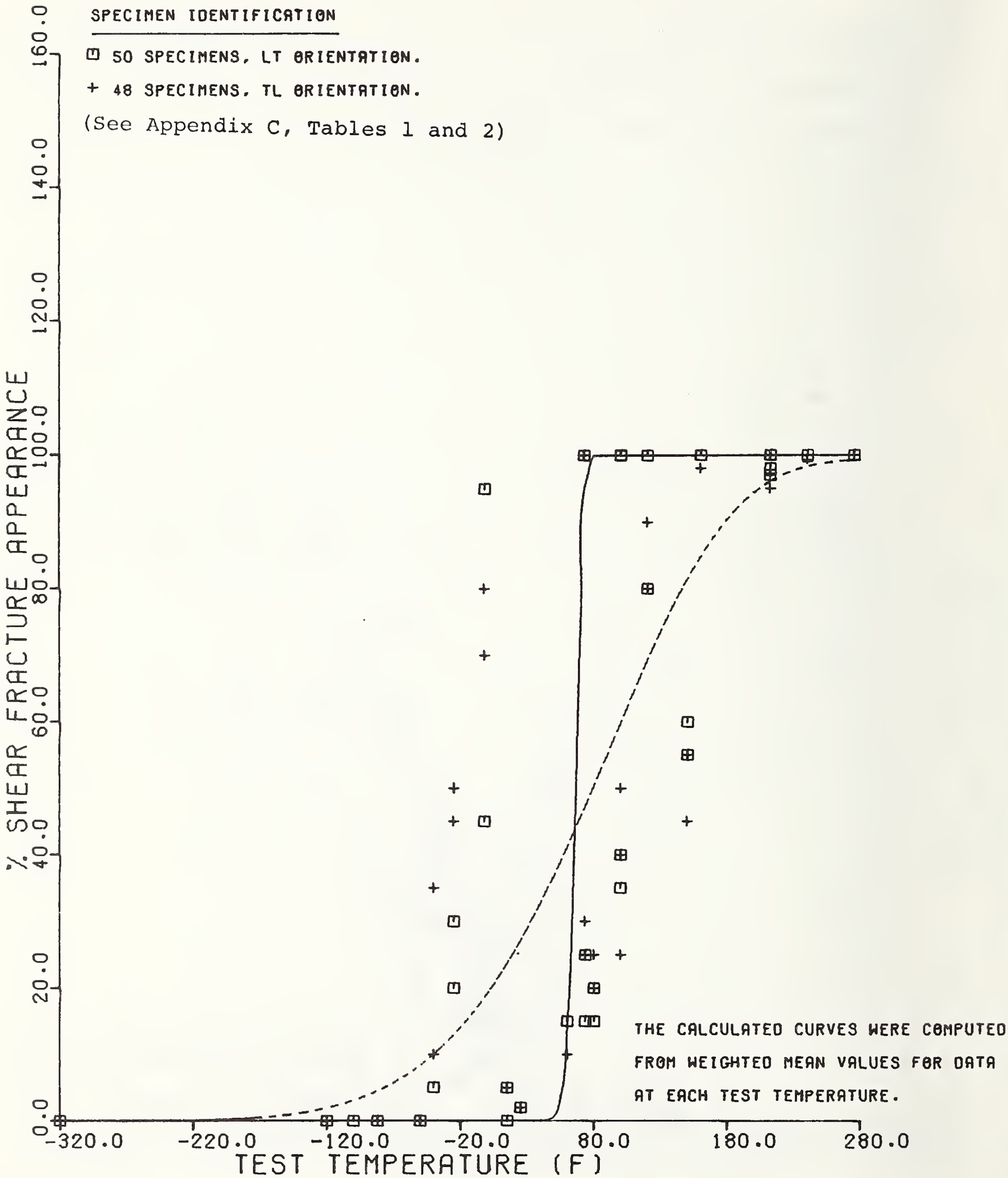


FIGURE 5D

COMPARISON OF LONGITUDINAL AND TRANSVERSE CVN IMPACT-TEST RESULTS FOR HEAD-PLATE SPECIMENS TAKEN FROM THREE ACCIDENTS.

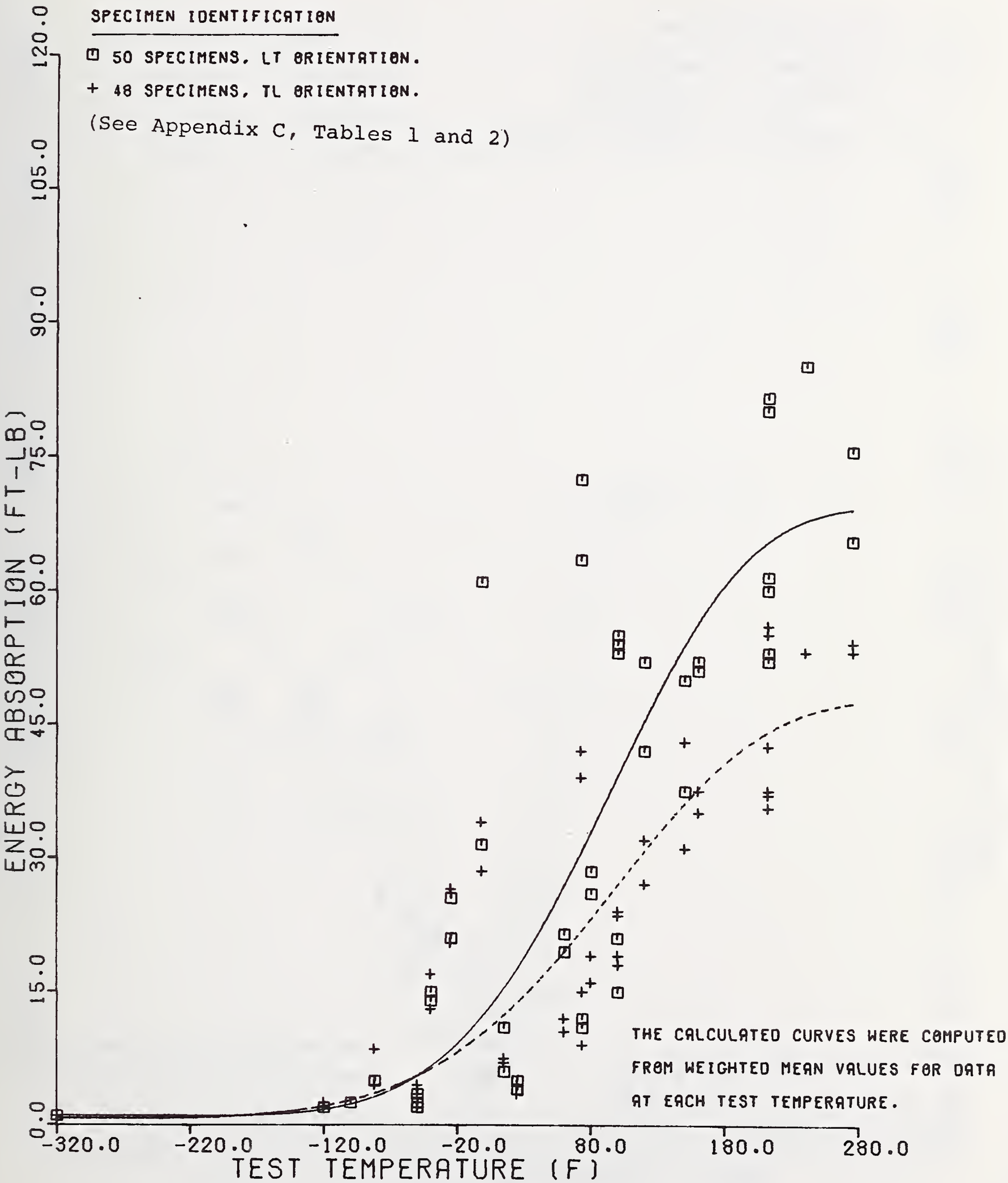


FIGURE 5C

COMPARISON OF LONGITUDINAL AND TRANSVERSE CVN IMPACT-TEST RESULTS FOR HEAD-PLATE SPECIMENS TAKEN FROM THREE ACCIDENTS.

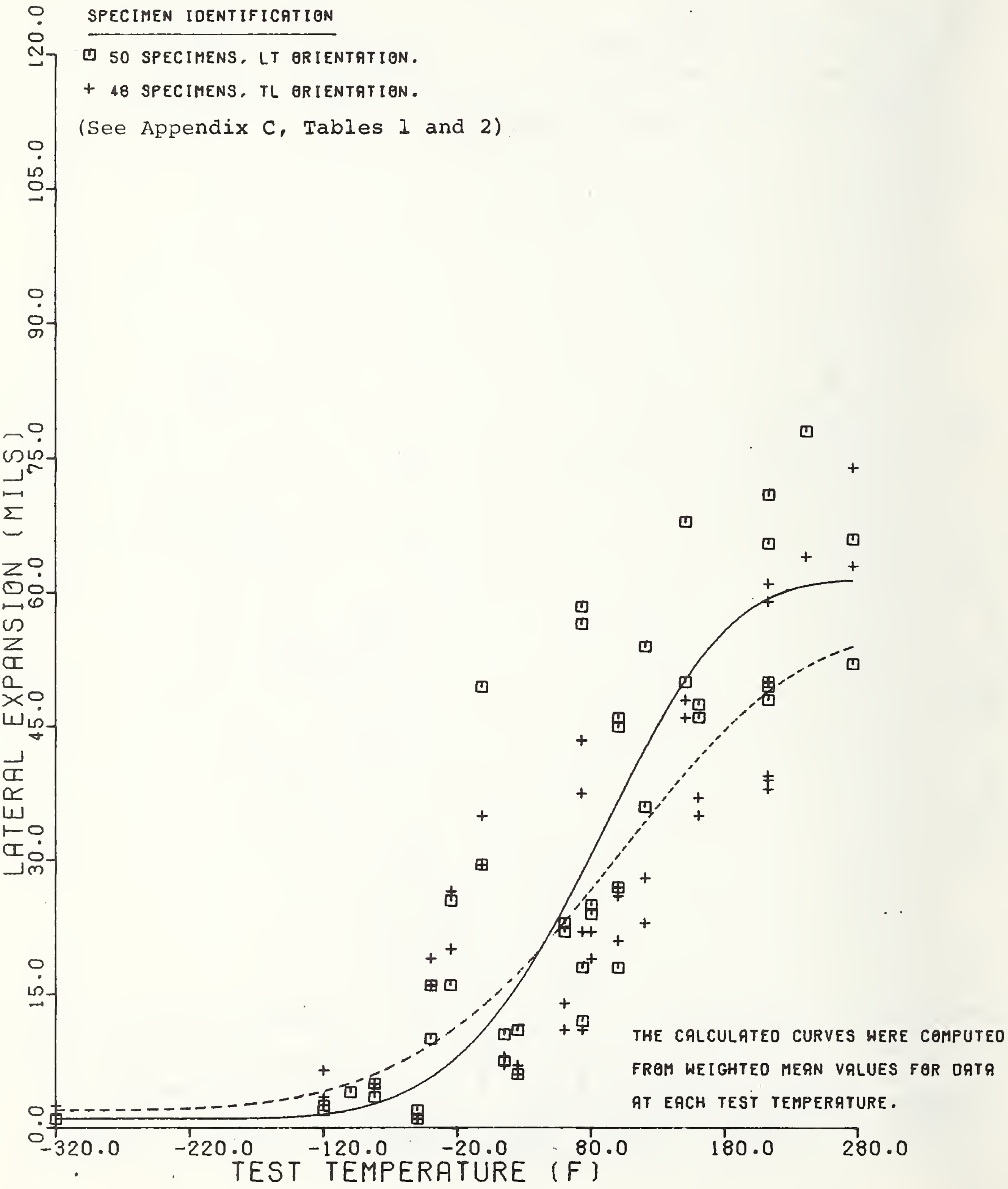


FIGURE 6A

COMPARISON OF LONGITUDINAL AND TRANSVERSE CVN IMPACT-TEST RESULTS FOR SHELL-PLATE SPECIMENS TAKEN FROM THEEE ACCIDENTS.

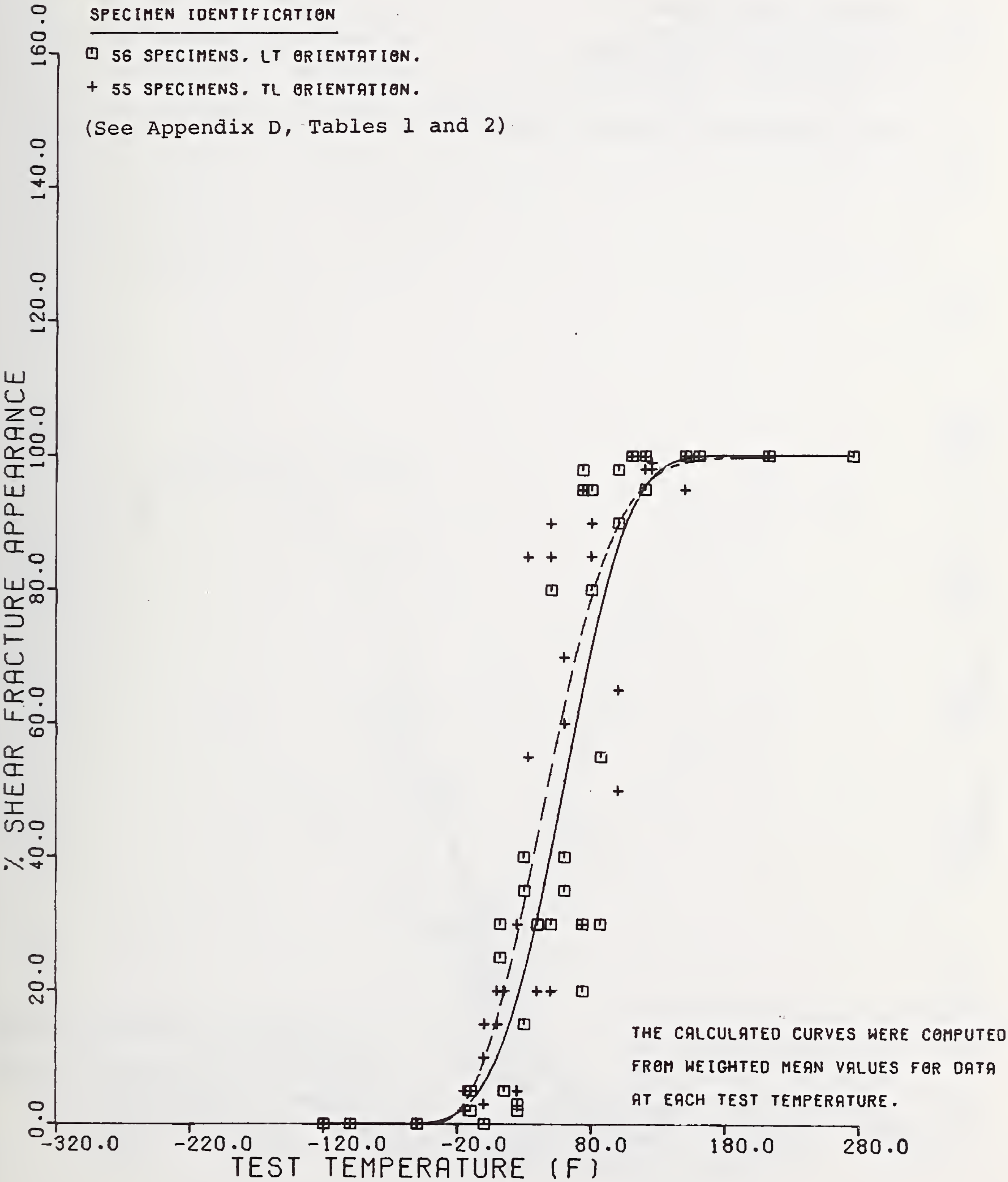


FIGURE 6D

COMPARISON OF LONGITUDINAL AND TRANSVERSE CVN IMPACT-TEST RESULTS FOR SHELL-PLATE SPECIMENS TAKEN FROM THEEE ACCIDENTS.

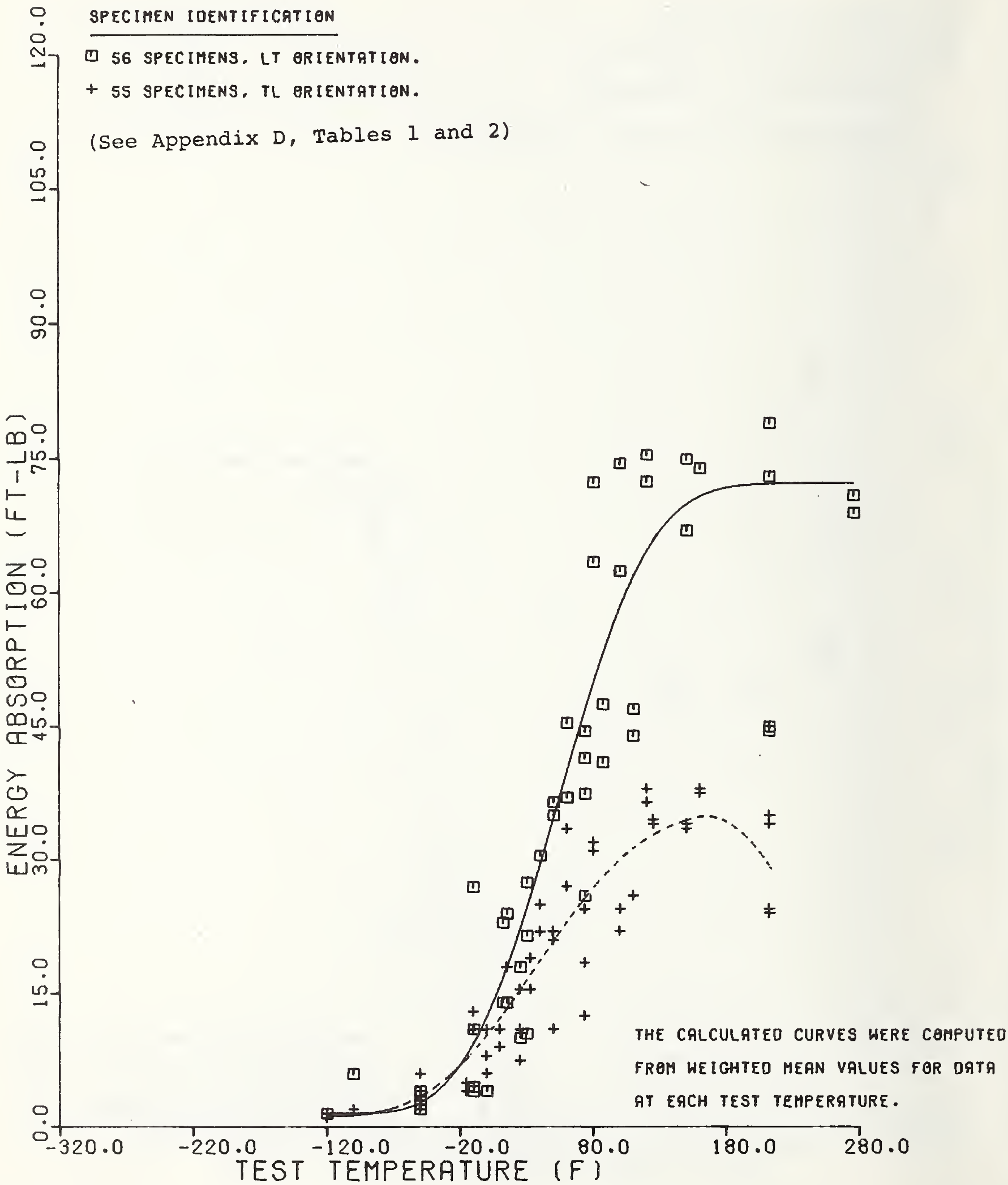


FIGURE 6C

COMPARISON OF LONGITUDINAL AND TRANSVERSE CVN IMPACT-TEST RESULTS FOR SHELL-PLATE SPECIMENS TAKEN FROM THEEE ACCIDENTS.

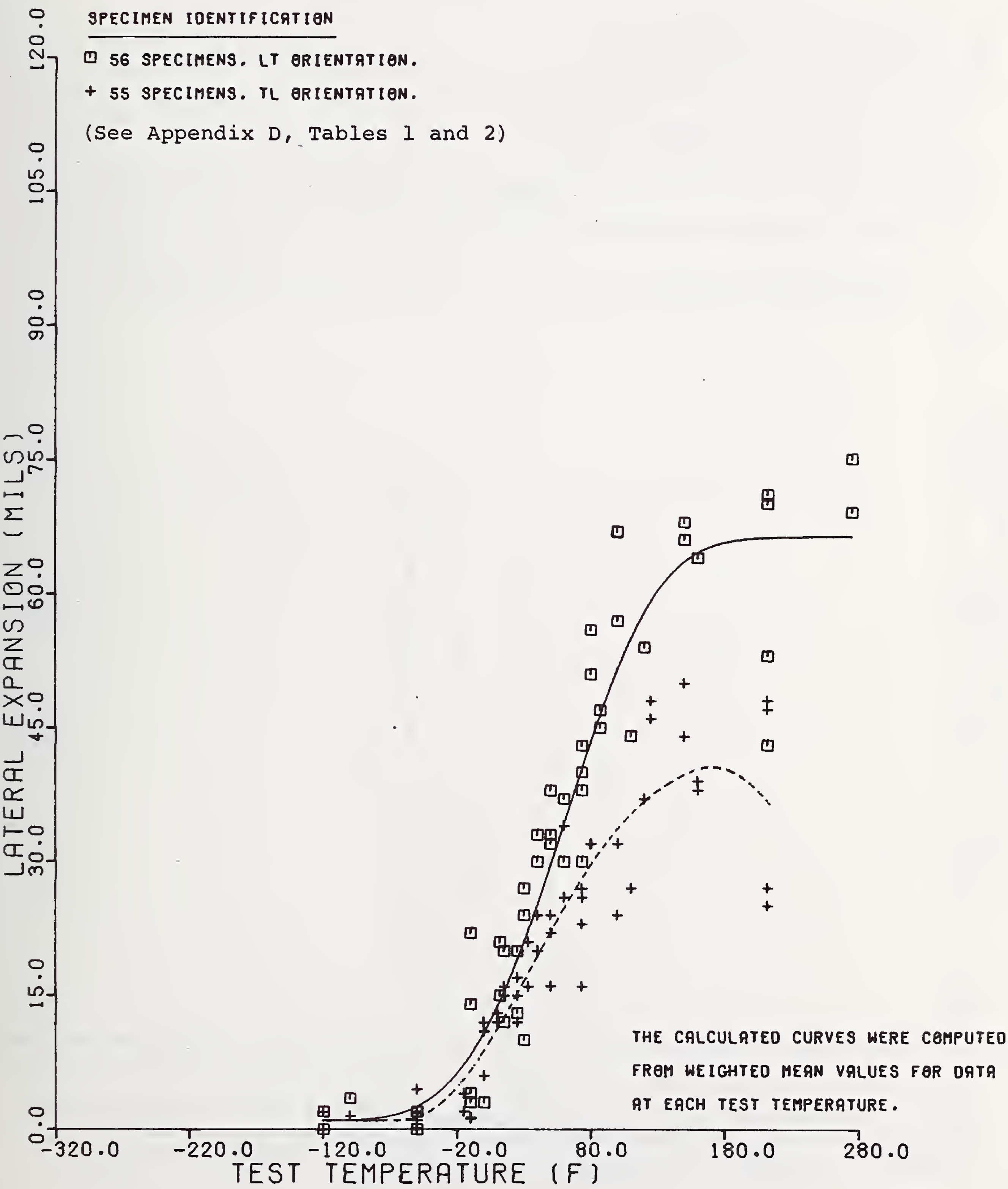


FIGURE 7A

CVN IMPACT TEST RESULTS FOR LONGITUDINAL SPECIMENS--
SIX STEEL PLATES FROM FOUR TANK CARS.

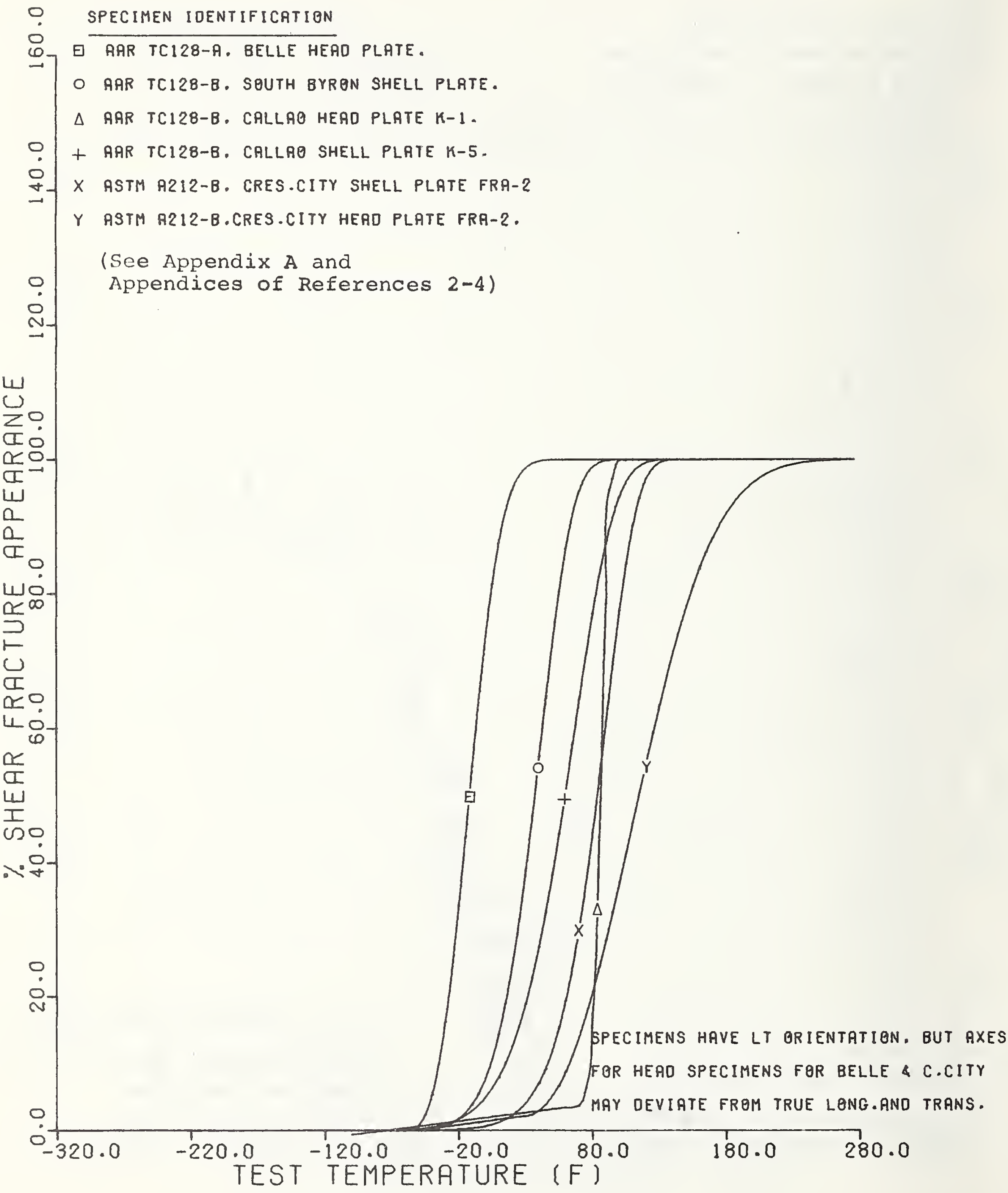


FIGURE 7B

CVN IMPACT TEST RESULTS FOR LONGITUDINAL SPECIMENS--
SIX STEEL PLATES FROM FOUR TANK CARS.

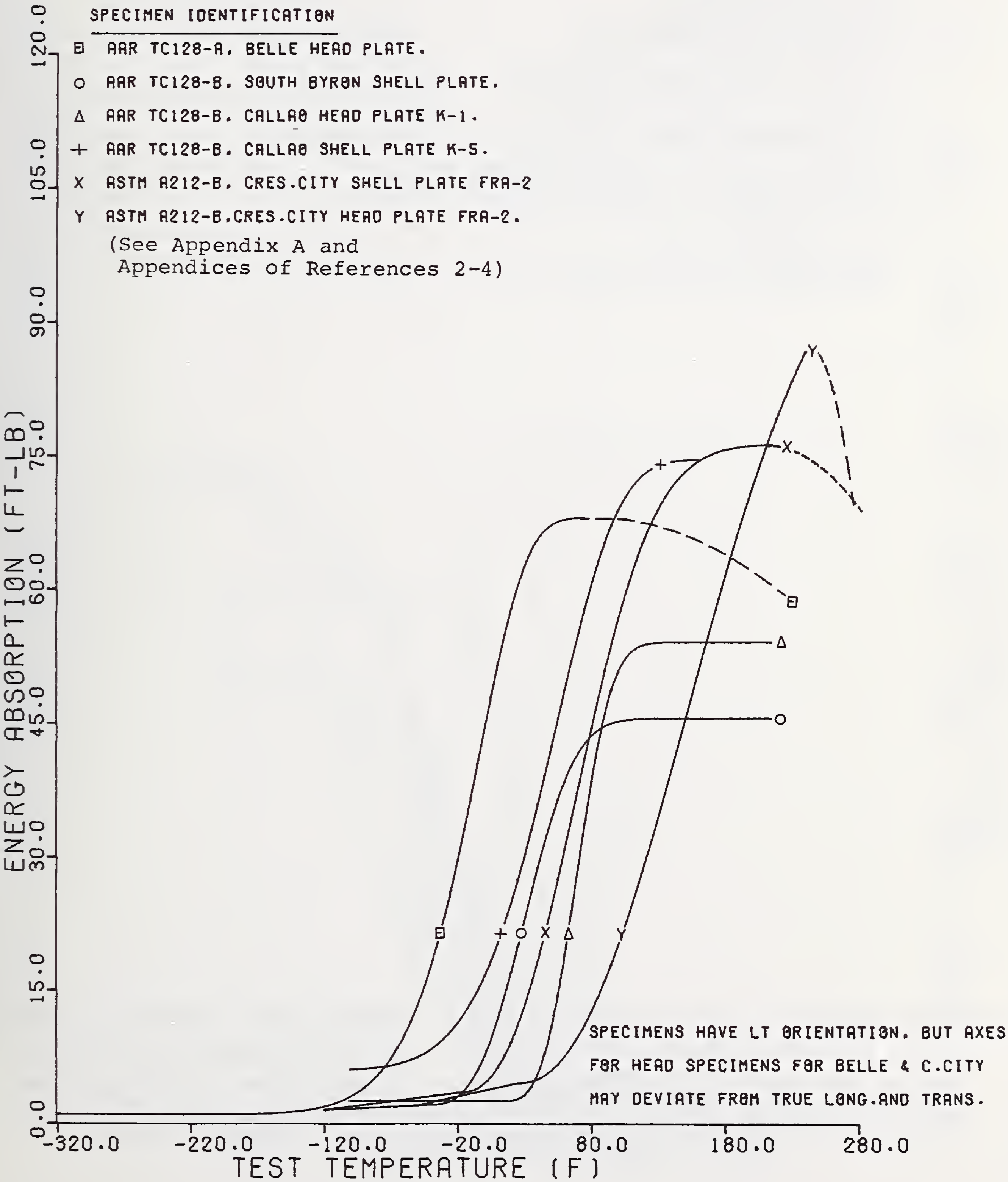


FIGURE 7C

CVN IMPACT TEST RESULTS FOR LONGITUDINAL SPECIMENS--
SIX STEEL PLATES FROM FOUR TANK CARS.

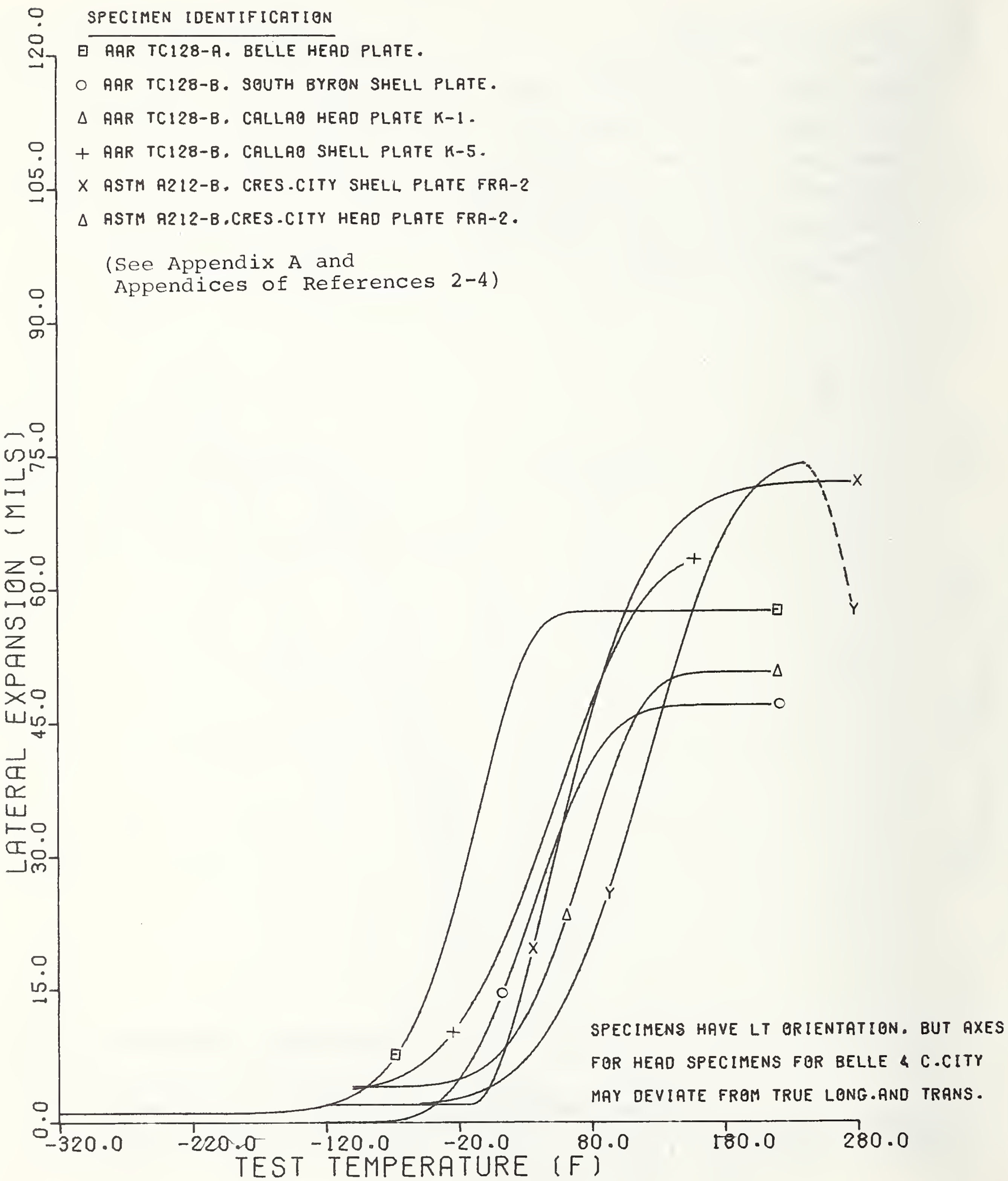


FIGURE 8A

CVN IMPACT TEST RESULTS FOR TRANSVERSE SPECIMENS--
SIX STEEL PLATES FROM FOUR TANK CARS.

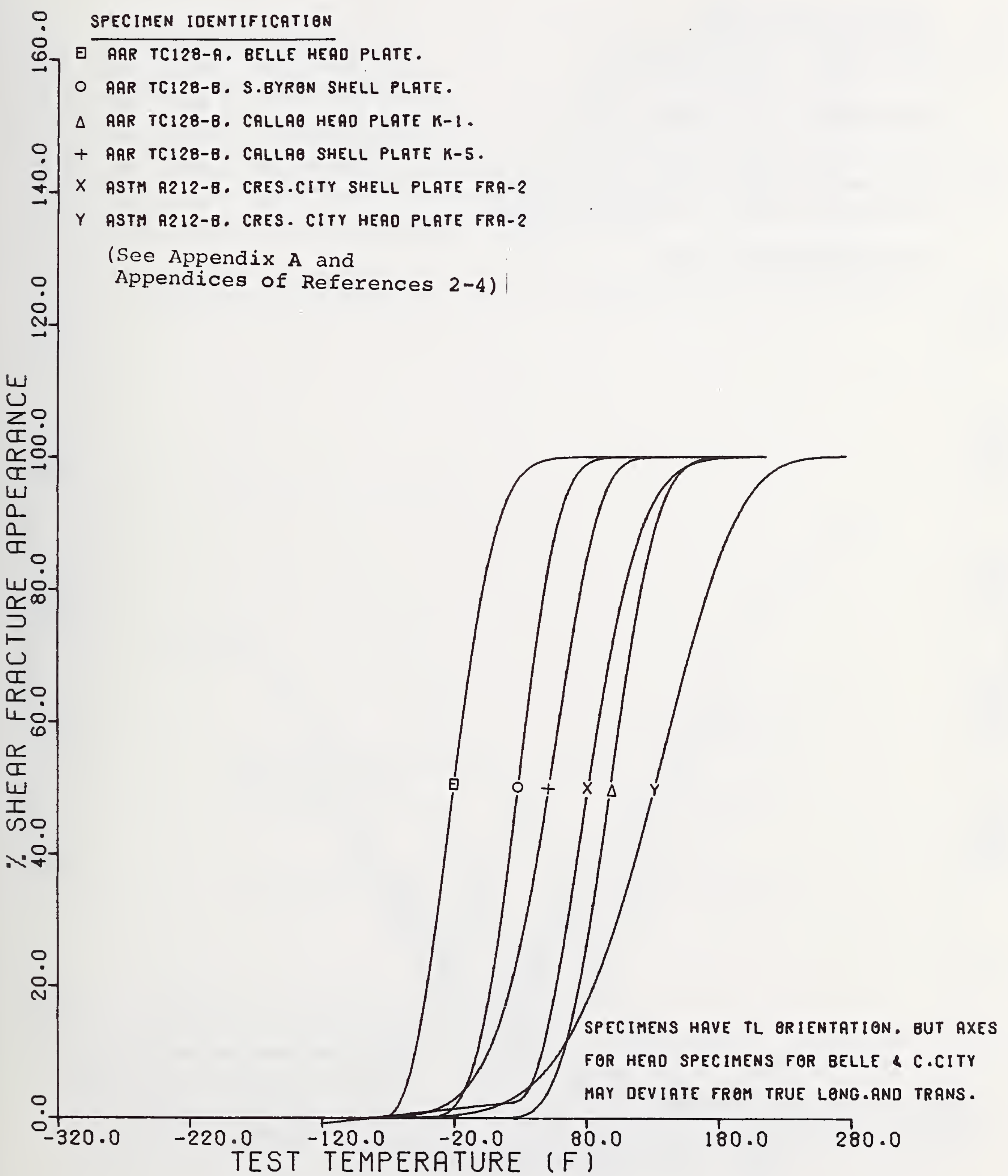


FIGURE 8D

CVN IMPACT TEST RESULTS FOR TRANSVERSE SPECIMENS--
SIX STEEL PLATES FROM FOUR TANK CARS.

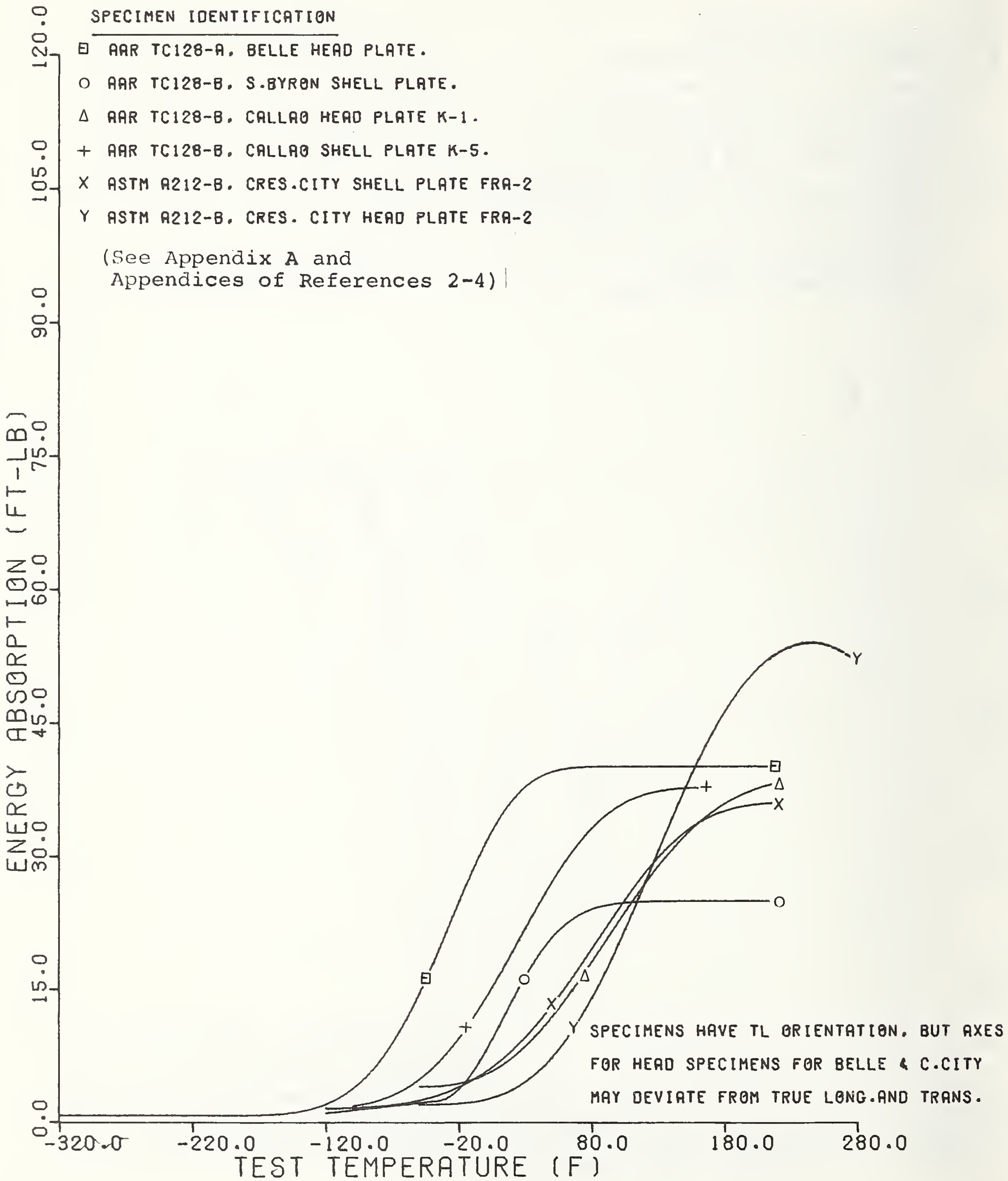


FIGURE 8C

CVN IMPACT TEST RESULTS FOR TRANSVERSE SPECIMENS--
SIX STEEL PLATES FROM FOUR TANK CARS.

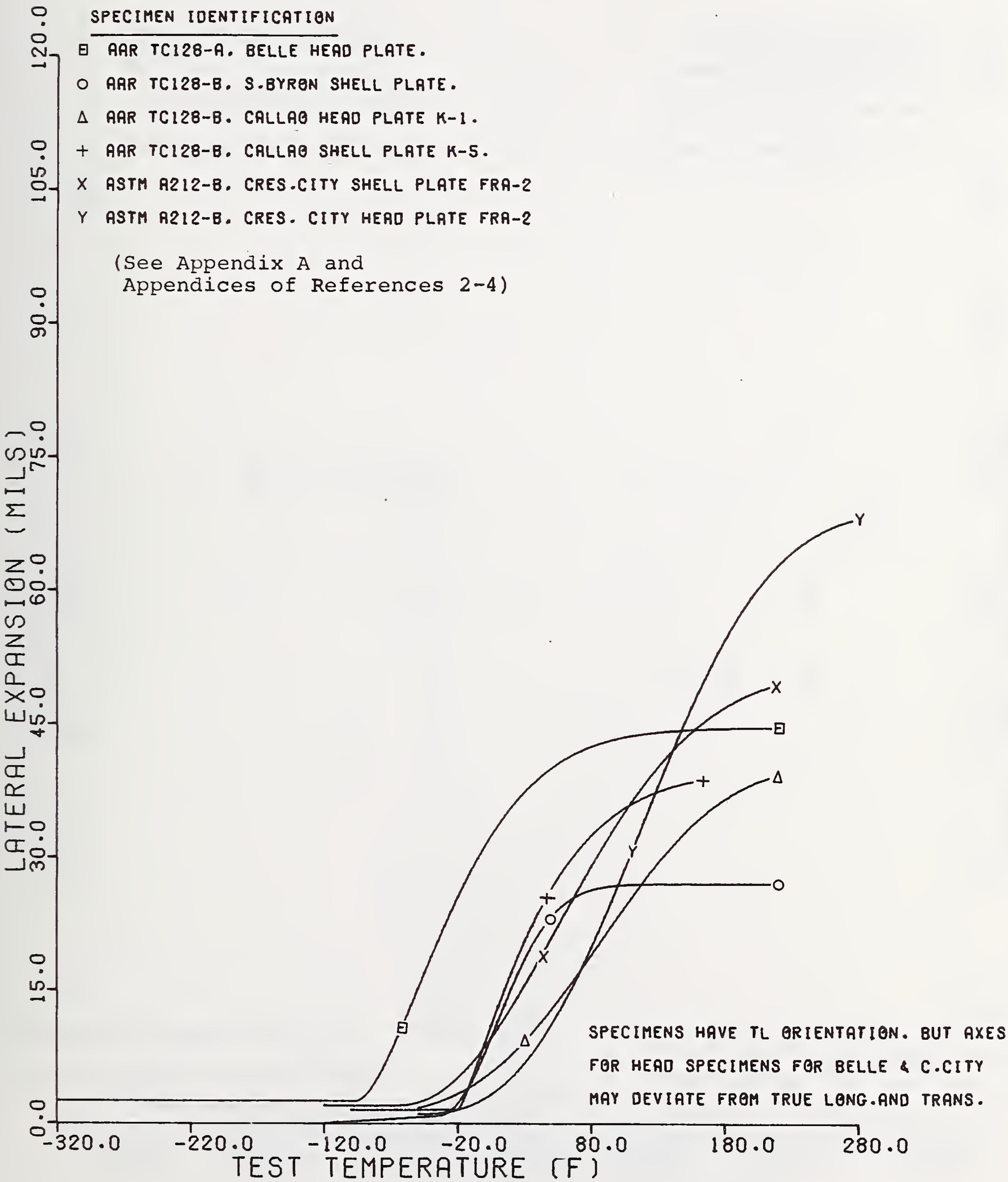


FIGURE 9A

COMPARISON OF HEAD-PLATE AND SHELL-PLATE CVN IMPACT-TEST RESULTS FOR LONGITUDINAL SPECIMENS OF LT ORIENTATION.

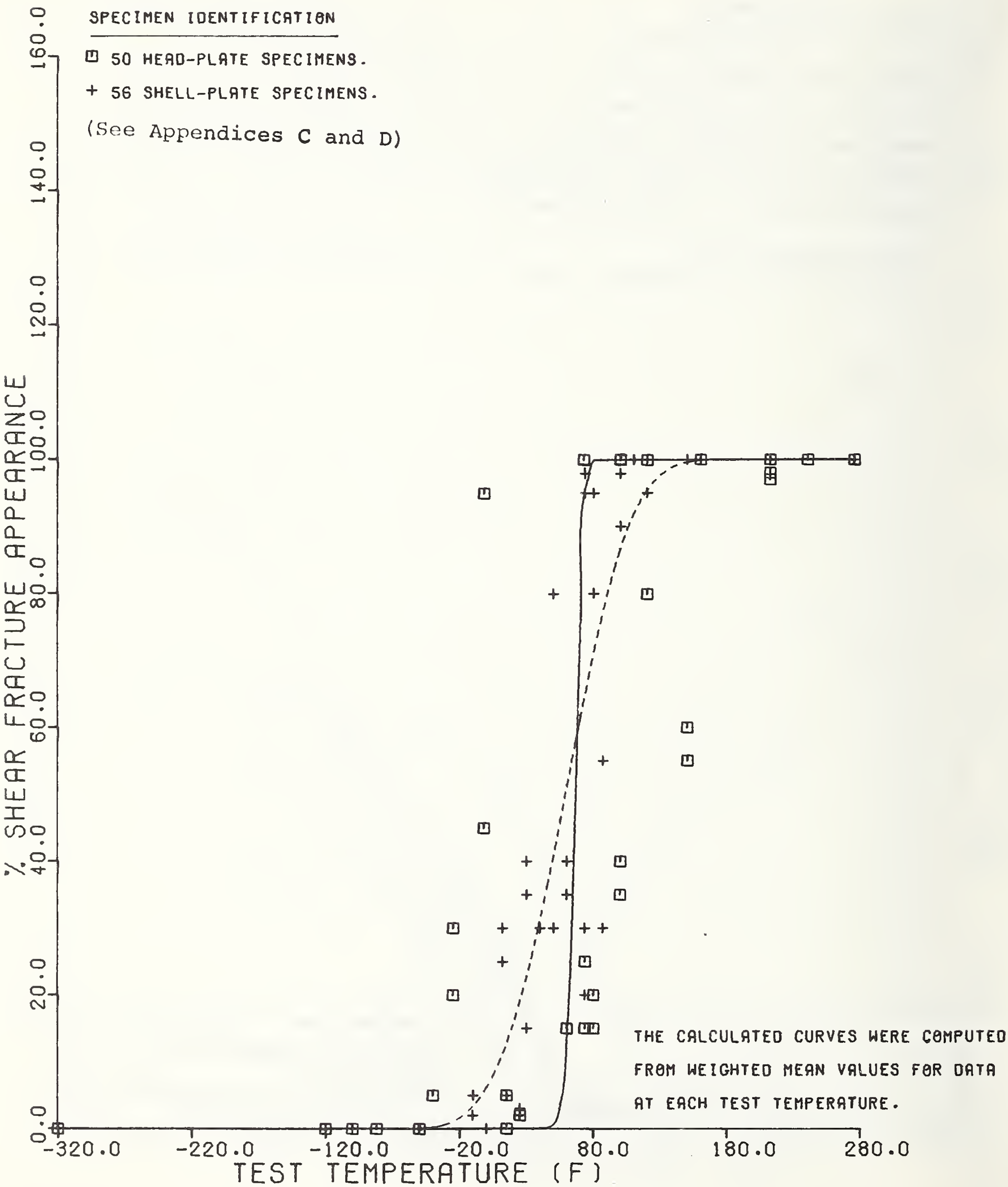


FIGURE 9B

COMPARISON OF HEAD-PLATE AND SHELL-PLATE CVN IMPACT-TEST RESULTS FOR LONGITUDINAL SPECIMENS OF LT ORIENTATION.

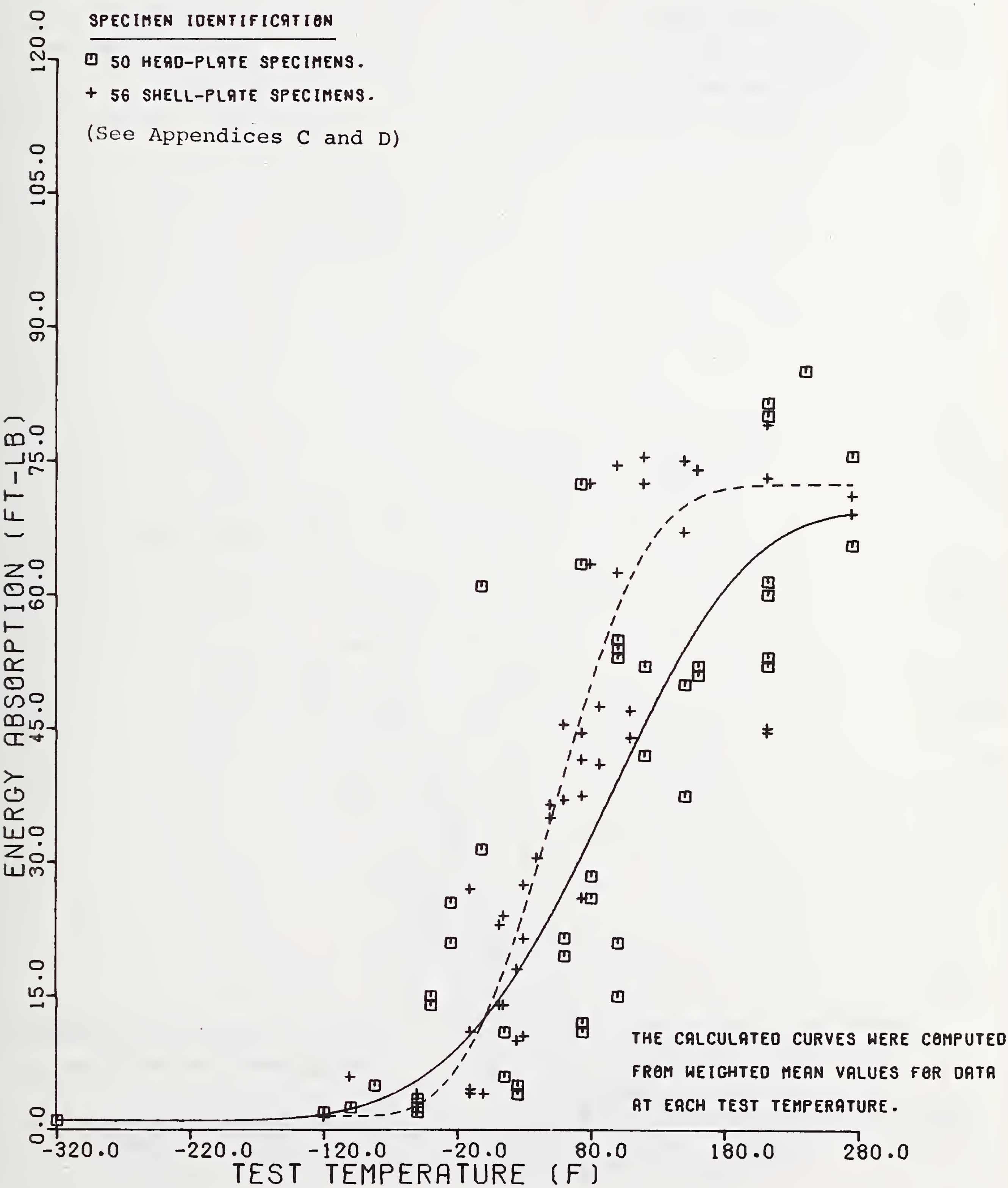


FIGURE 9C

COMPARISON OF HEAD-PLATE AND SHELL-PLATE CVN IMPACT-TEST RESULTS FOR LONGITUDINAL SPECIMENS OF LT ORIENTATION.

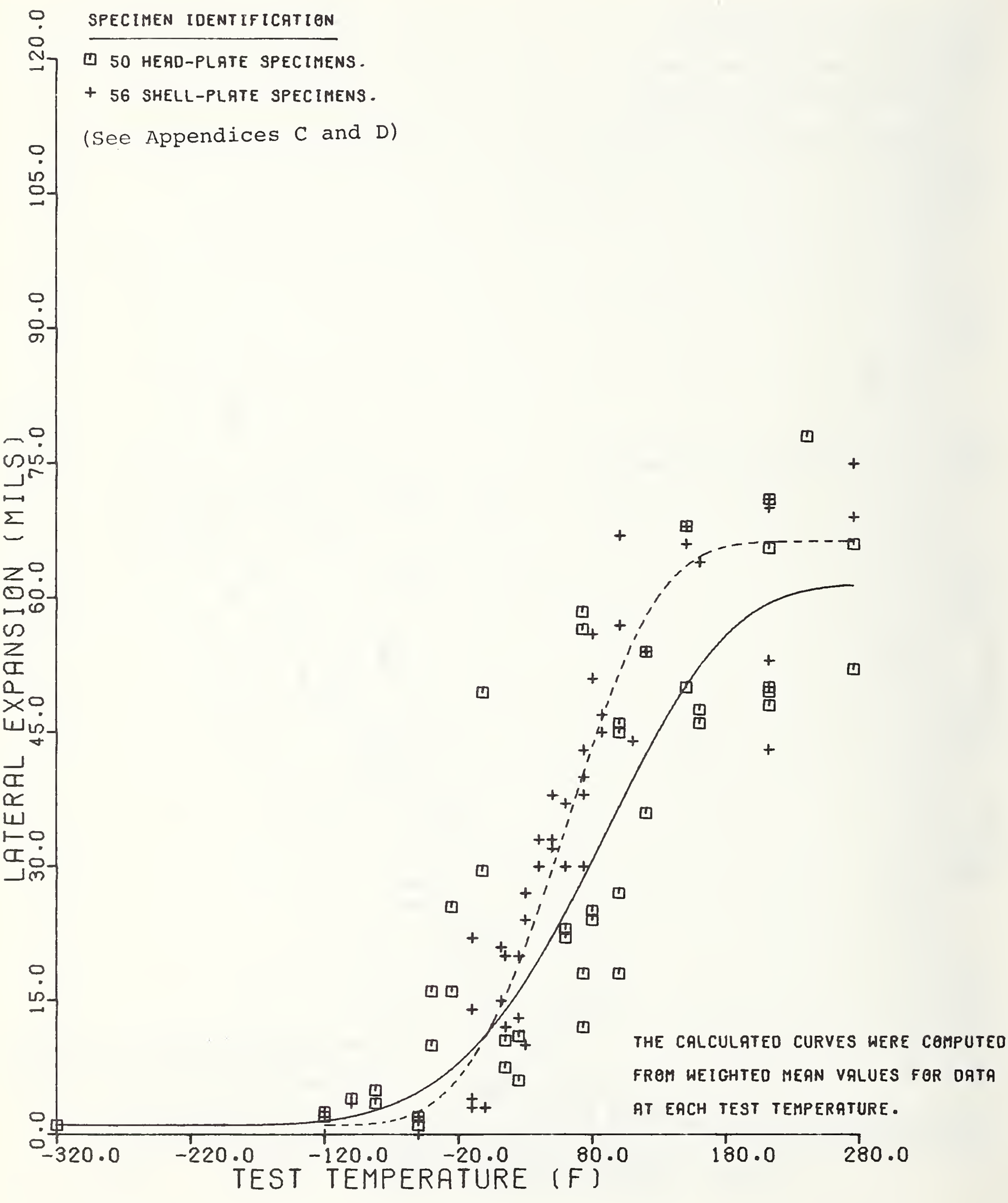


FIGURE 10A

COMPARISON OF HEAD-PLATE AND SHELL-PLATE CVN IMPACT-TEST RESULTS OF TRANSVERSE SPECIMENS OF TL ORIENTATION.

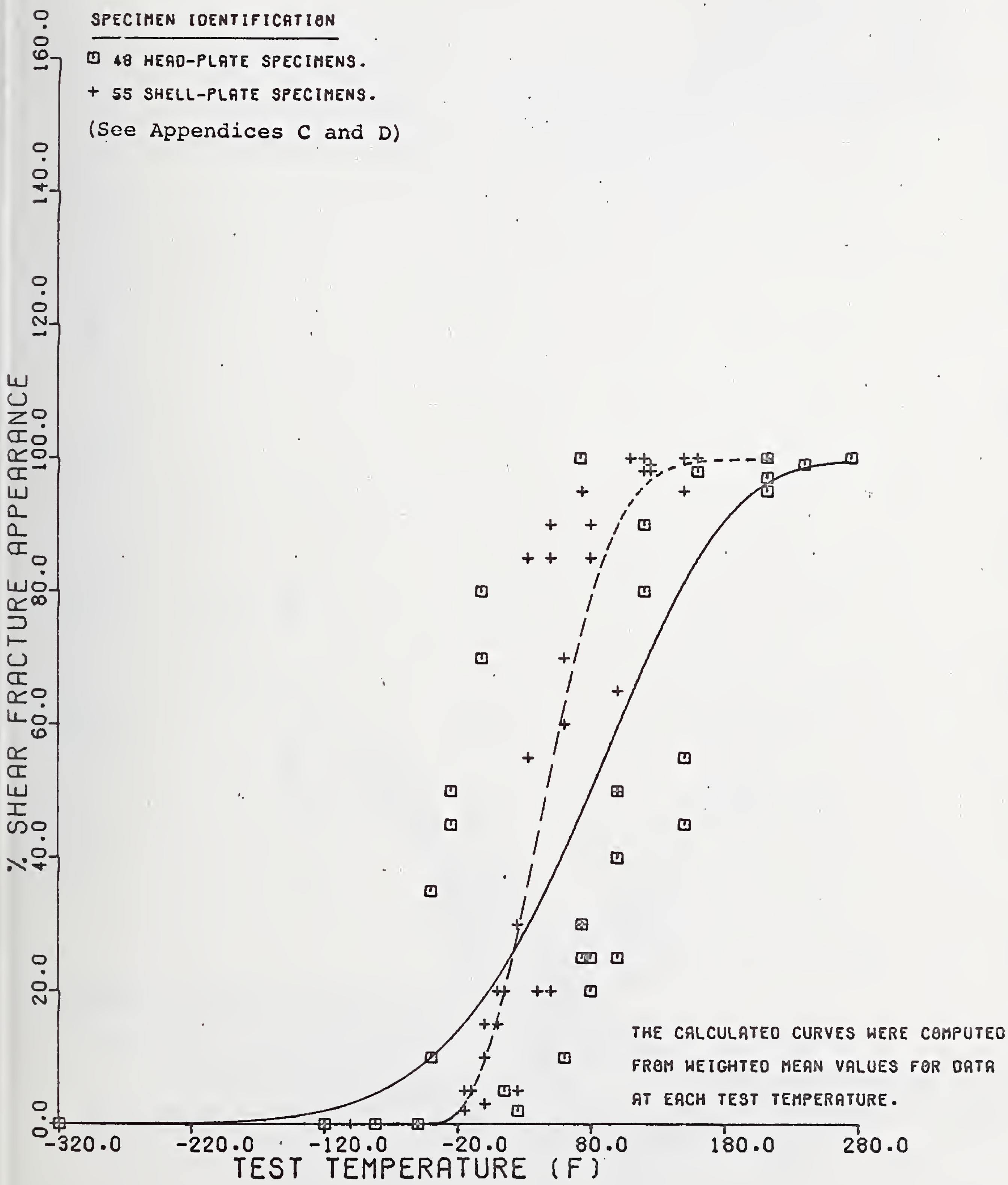


FIGURE 10B

COMPARISON OF HEAD-PLATE AND SHELL-PLATE CVN IMPACT-TEST RESULTS OF TRANSVERSE SPECIMENS OF TL ORIENTATION.

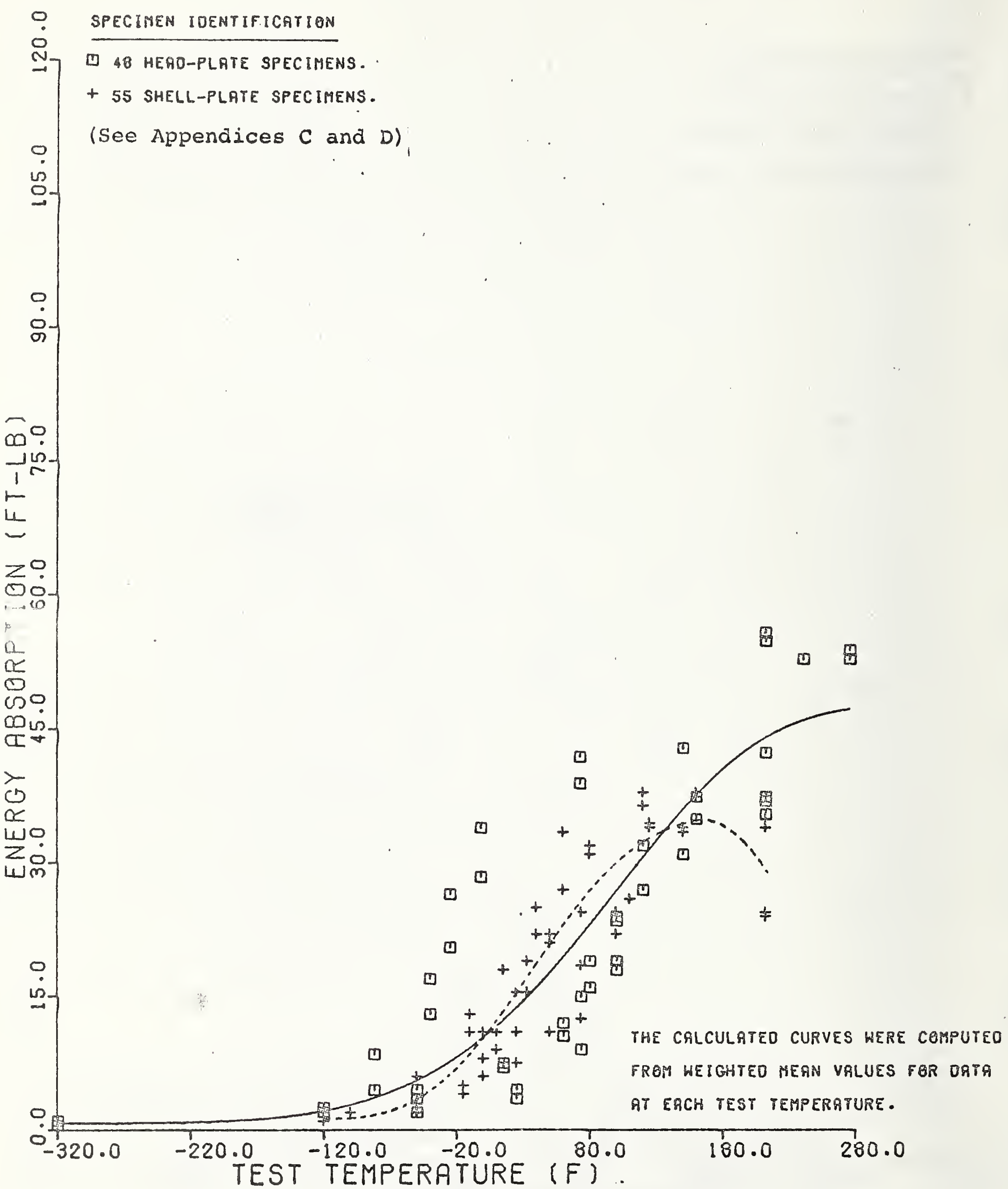


FIGURE 10C

COMPARISON OF HEAD-PLATE AND SHELL-PLATE CVN IMPACT-TEST RESULTS OF TRANSVERSE SPECIMENS OF TL ORIENTATION.

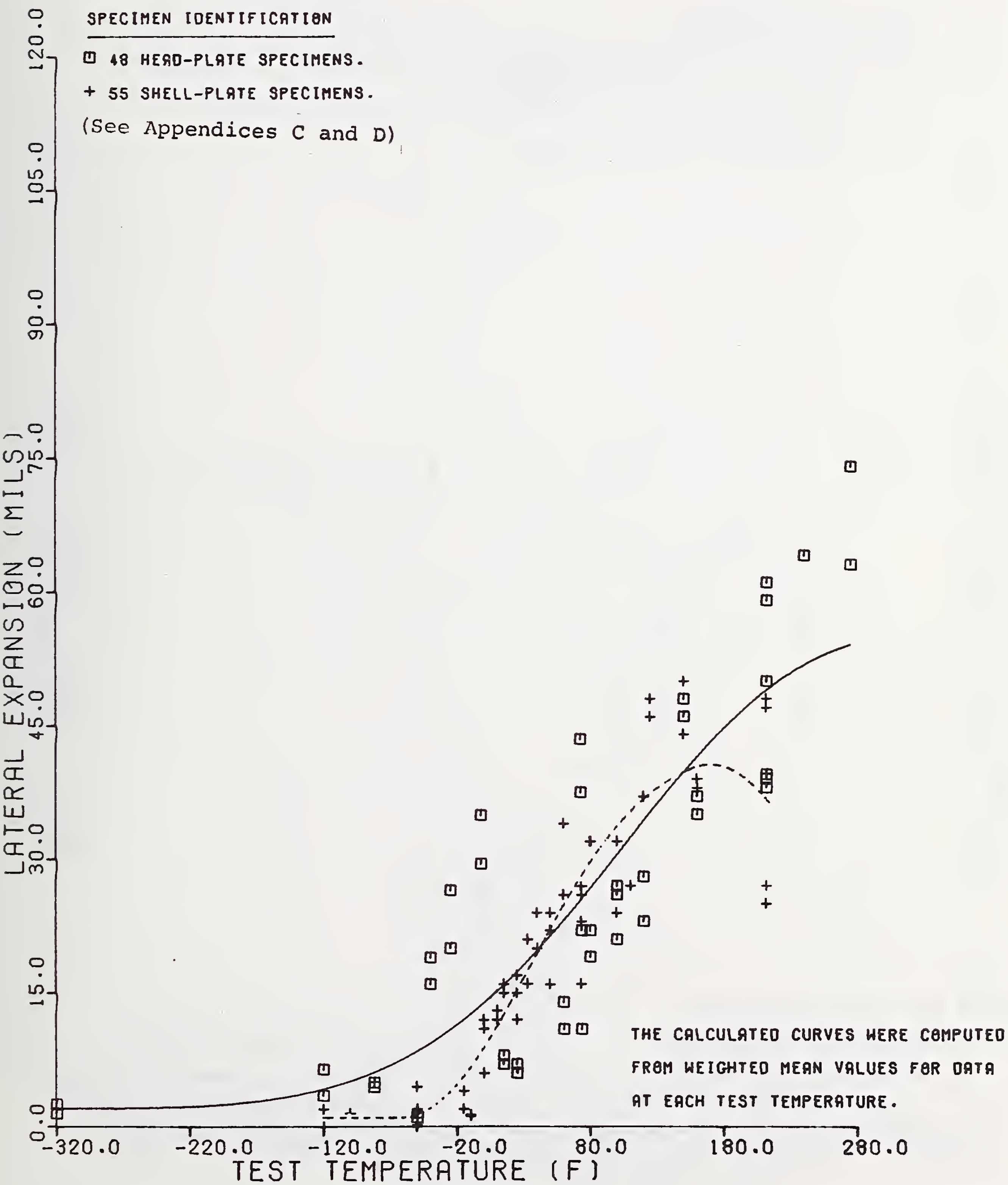


FIGURE 11A

RESULTS OF LONGITUDINAL CVN IMPACT TESTS FOR AAR TC128 STEELS AND ASTM A212-B STEELS.

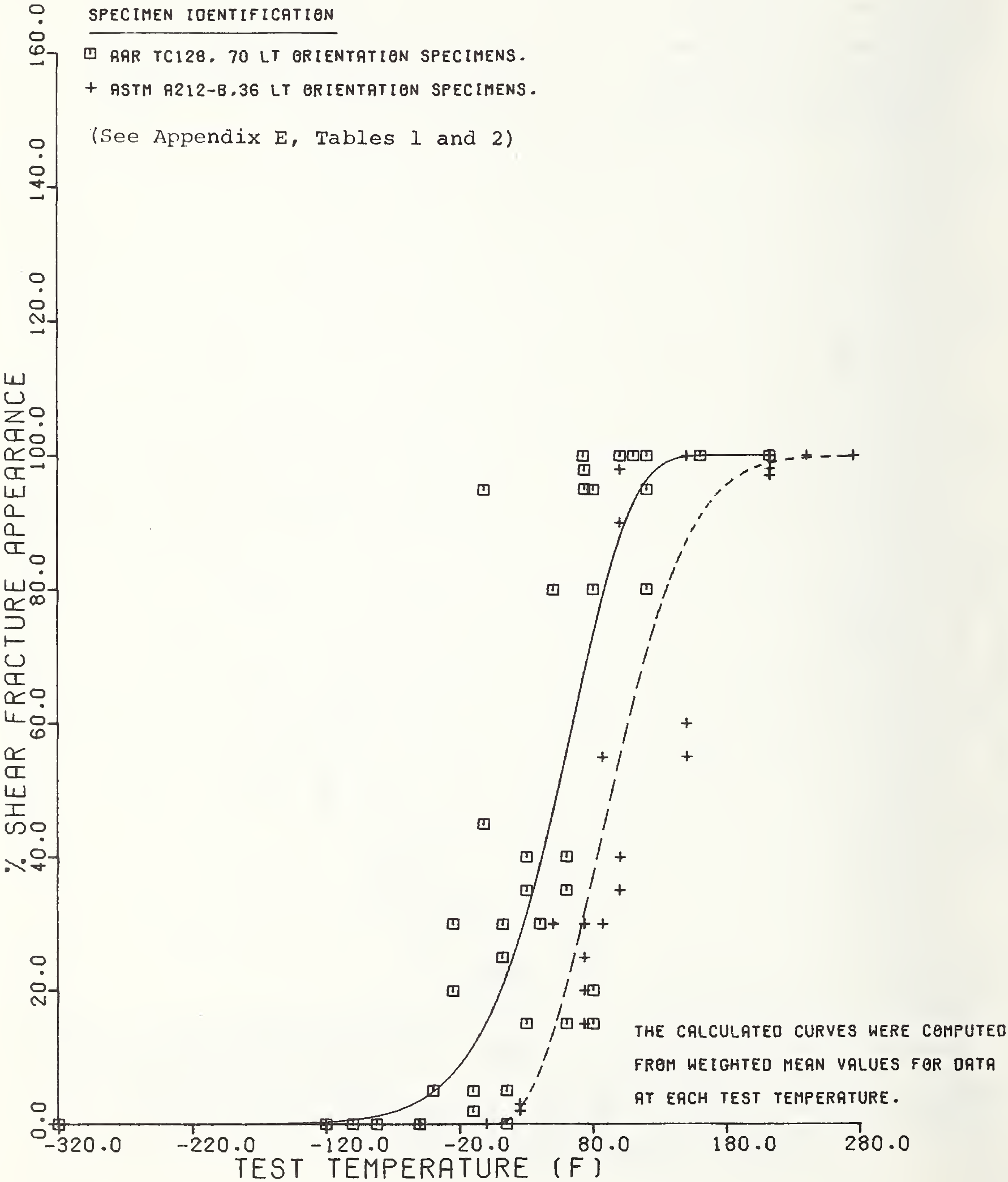


FIGURE 11B

RESULTS OF LONGITUDINAL CVN IMPACT TESTS FOR AAR TC128 STEELS AND ASTM A212-B STEELS.

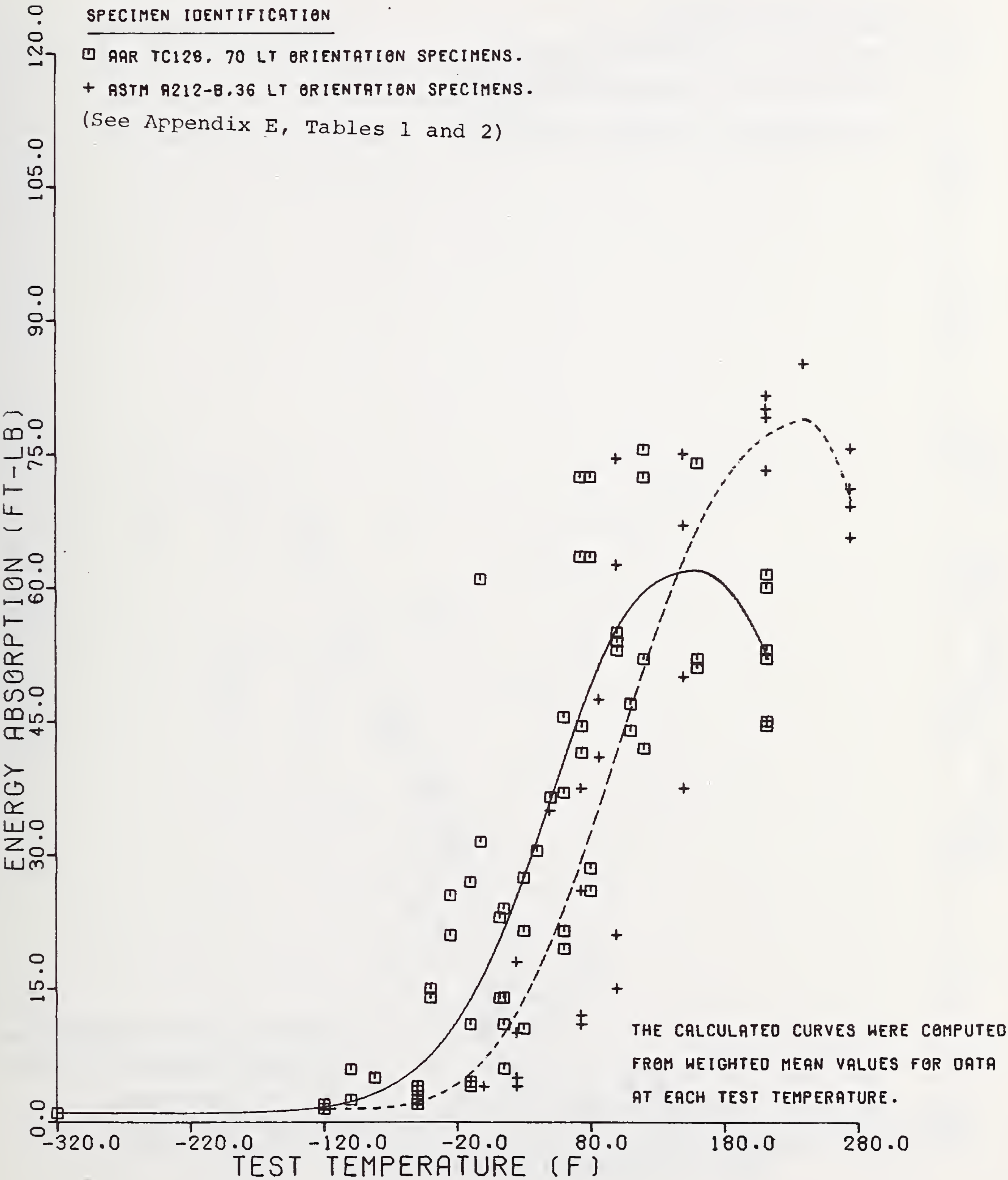


FIGURE 11C

RESULTS OF LONGITUDINAL CVN IMPACT TESTS FOR AAR TC128 STEELS AND ASTM A212-B STEELS.

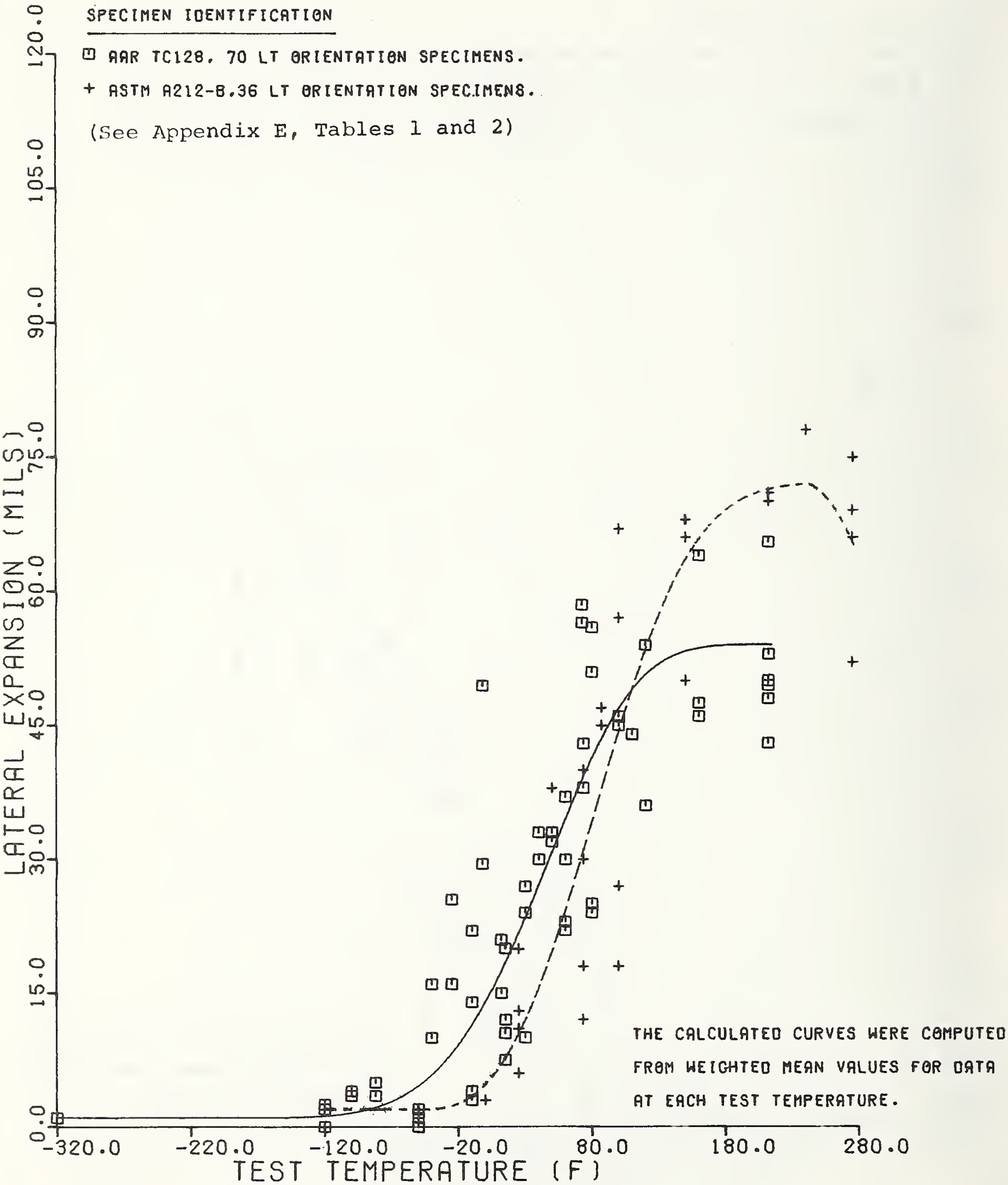


FIGURE 12A

RESULTS OF TRANSVERSE CVN IMPACT TESTS FOR AAR TC128 STEELS AND ASTM A212-B STEELS.

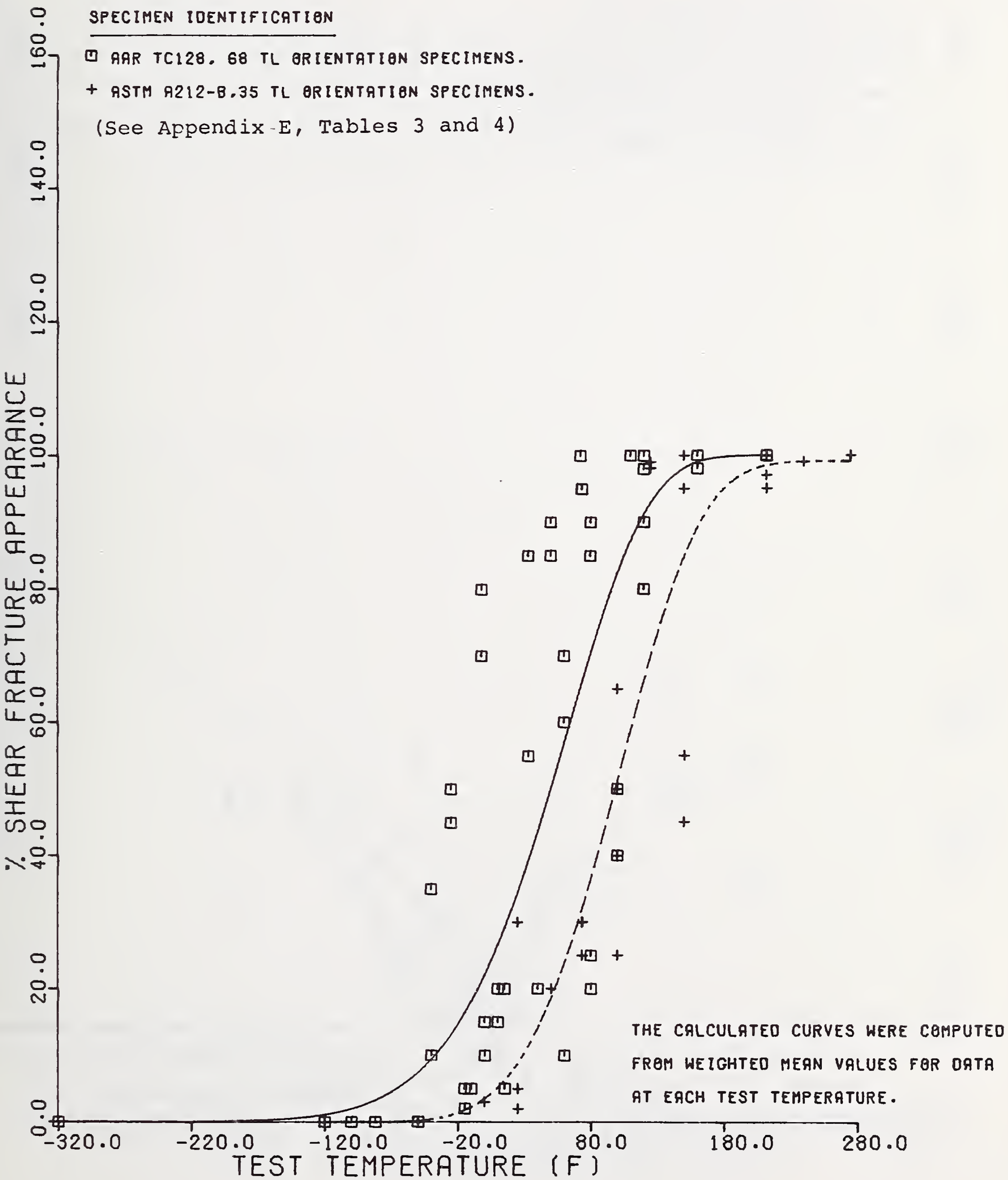


FIGURE 12B

RESULTS OF TRANSVERSE CVN IMPACT TESTS FOR AAR TC128 STEELS AND ASTM A212-B STEELS.

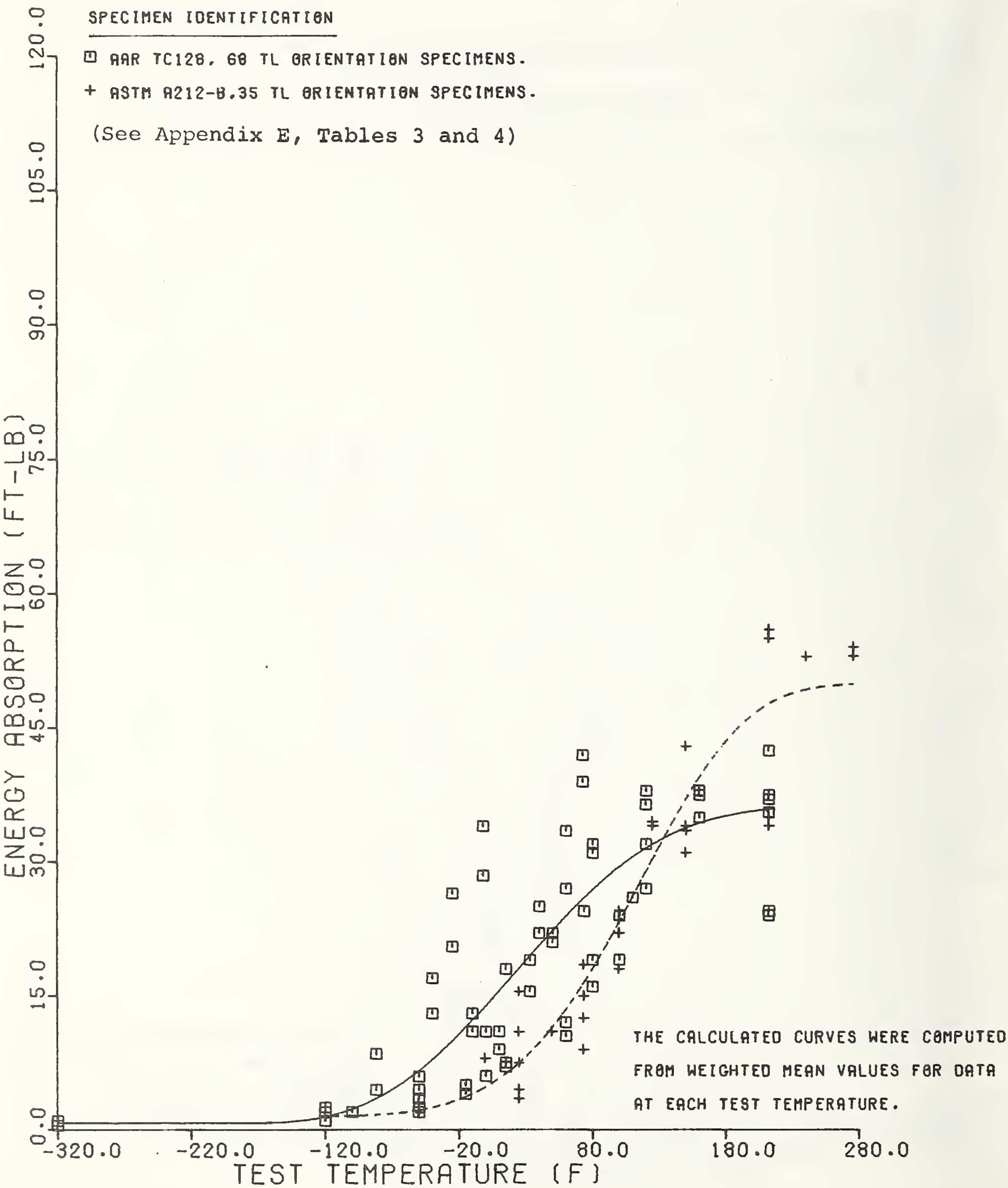


FIGURE 12C

RESULTS OF TRANSVERSE CVN IMPACT TESTS FOR AAR TC128 STEELS AND ASTM A212-B STEELS.

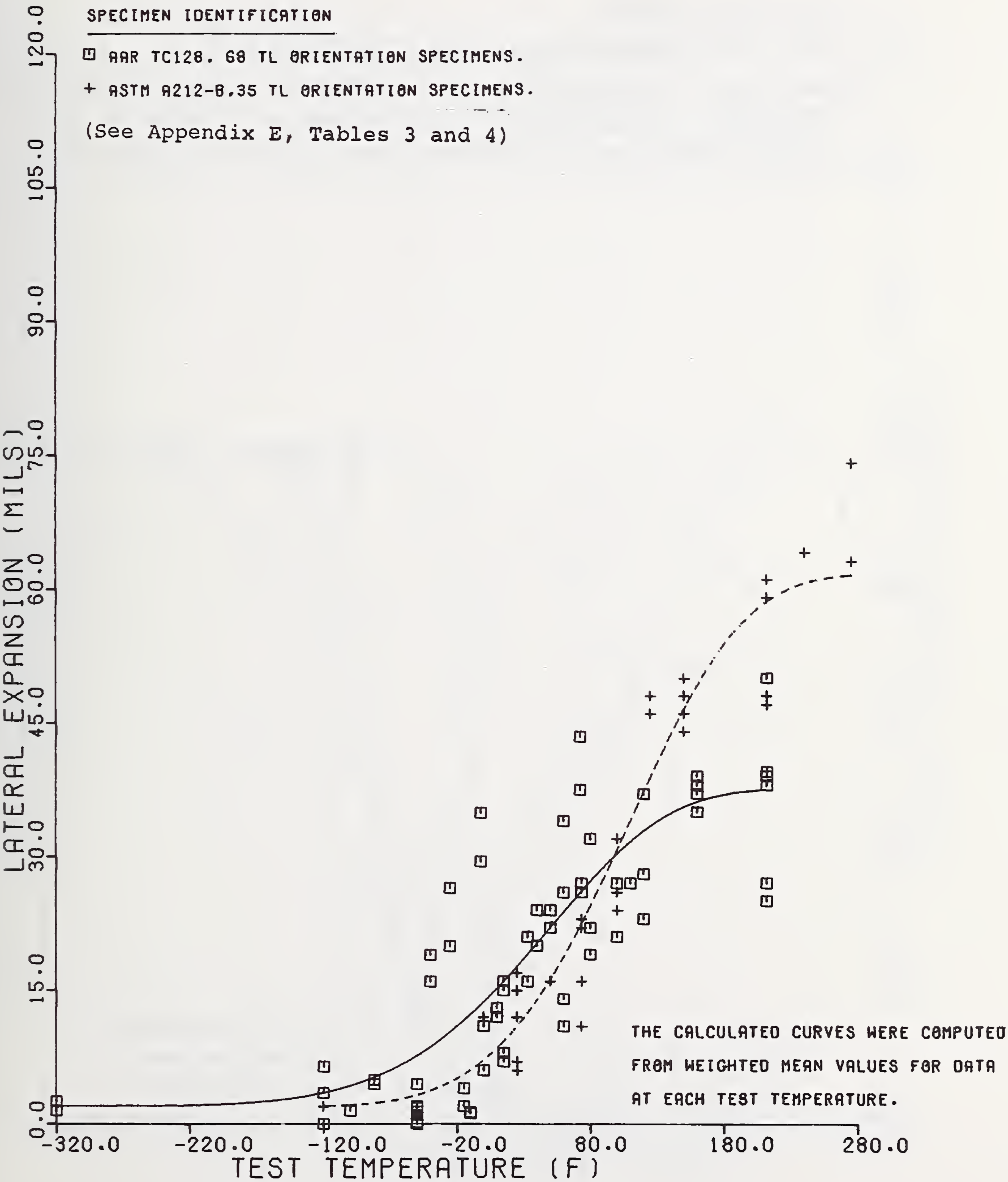


FIGURE 13A

RESULTS OF IMPACT TESTS FOR THREE GRADES OF STEEL ...CVN SPECIMENS OF LT ORIENTATION FROM FOUR ACCIDENTS.

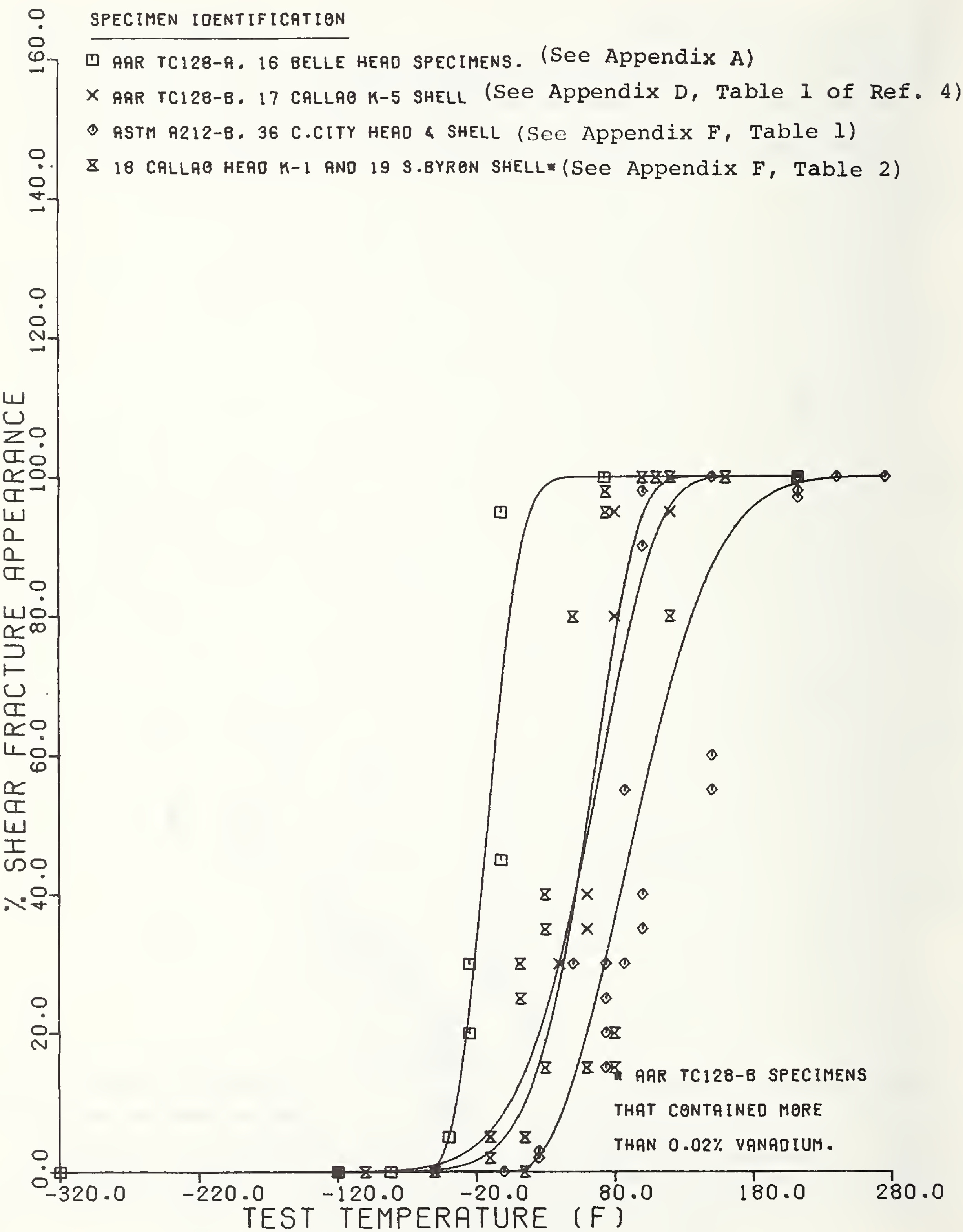


FIGURE 13B

RESULTS OF IMPACT TESTS FOR THREE GRADES OF STEEL
...CVN SPECIMENS OF LT ORIENTATION FROM FOUR ACCIDENTS.

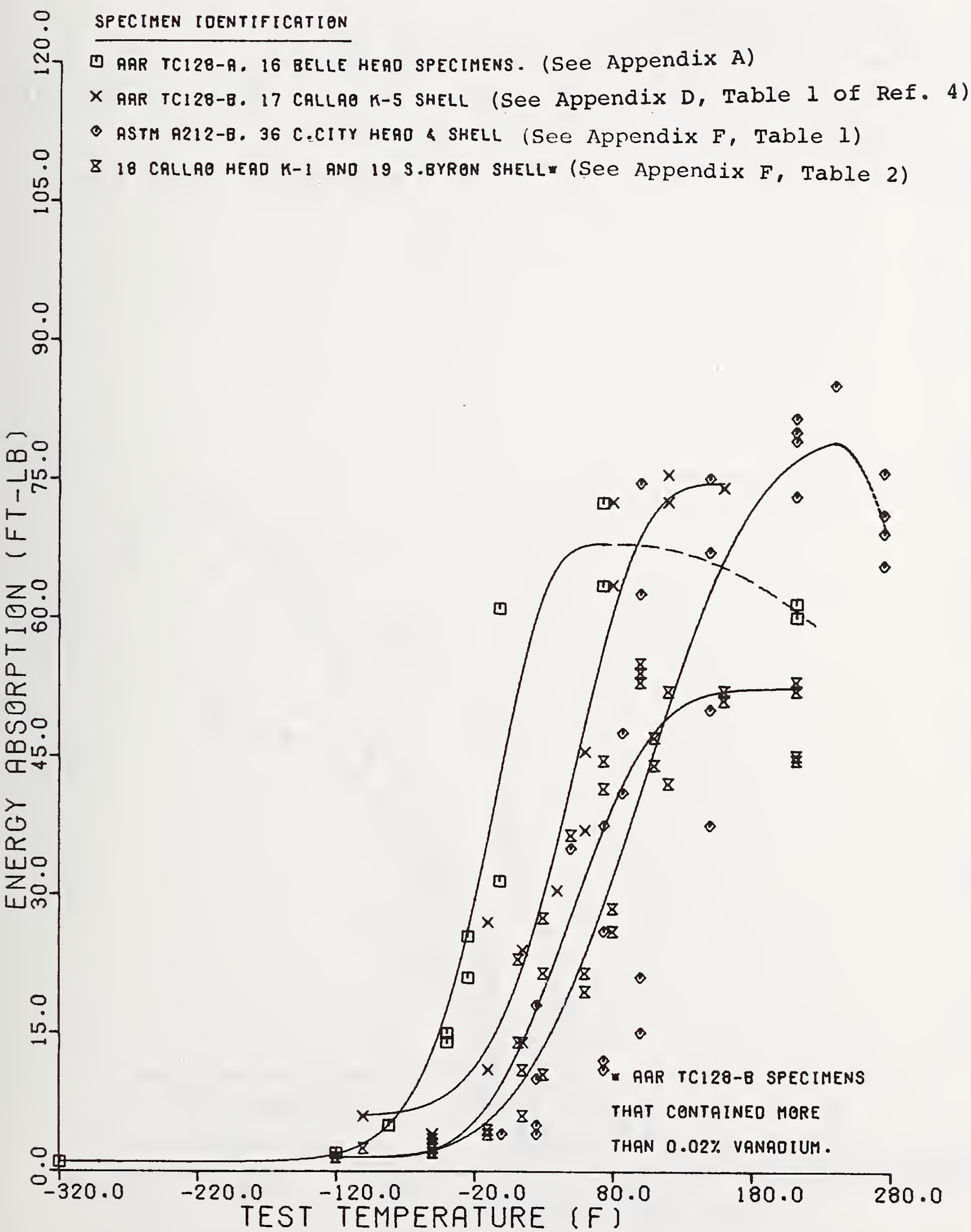


FIGURE 13C

RESULTS OF IMPACT TESTS FOR THREE GRADES OF STEEL
...CVN SPECIMENS OF LT ORIENTATION FROM FOUR ACCIDENTS.

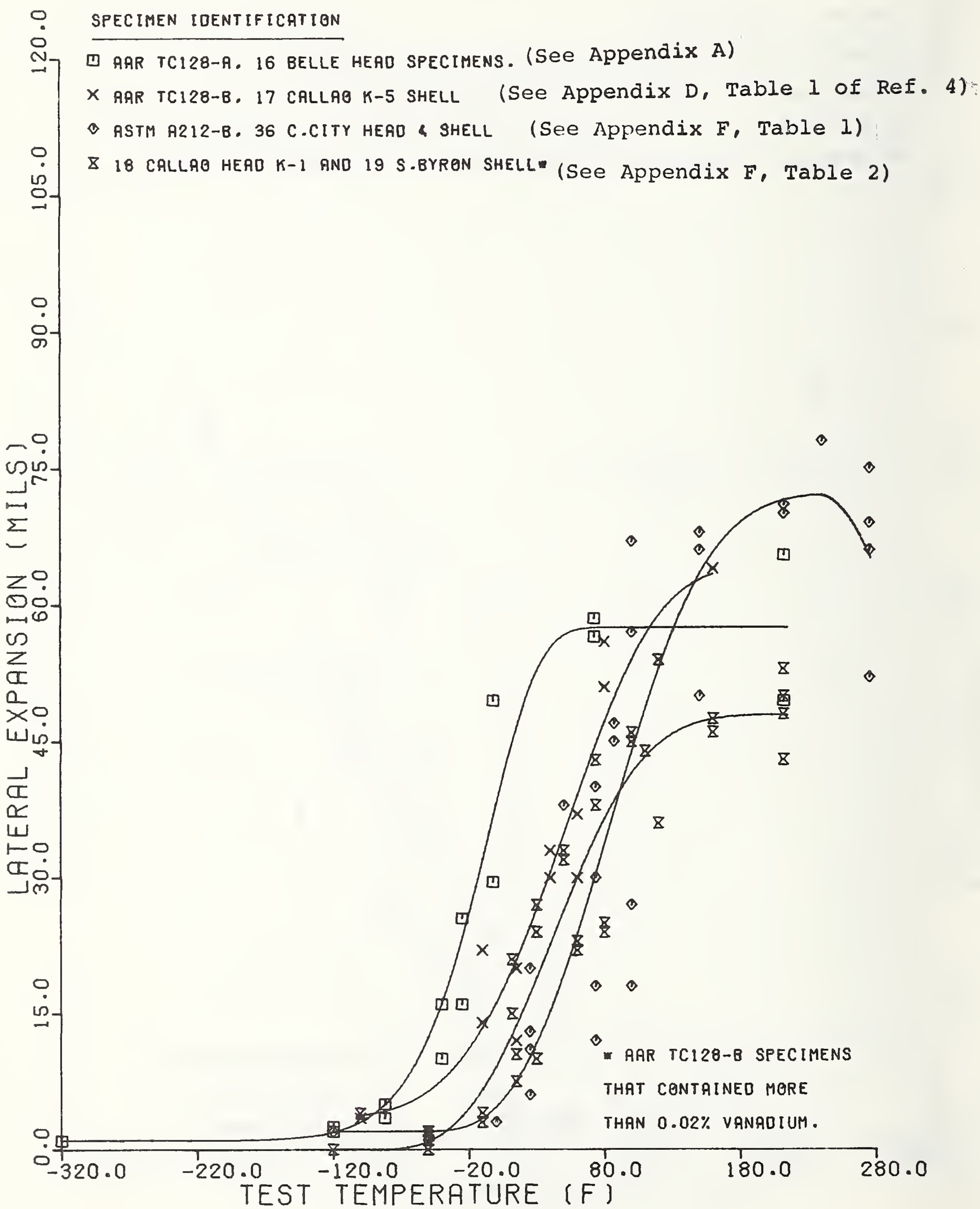


FIGURE 14A

RESULTS OF IMPACT TESTS FOR THREE GRADES OF STEEL
...CVN SPECIMENS OF TL ORIENTATION FROM FOUR ACCIDENTS.

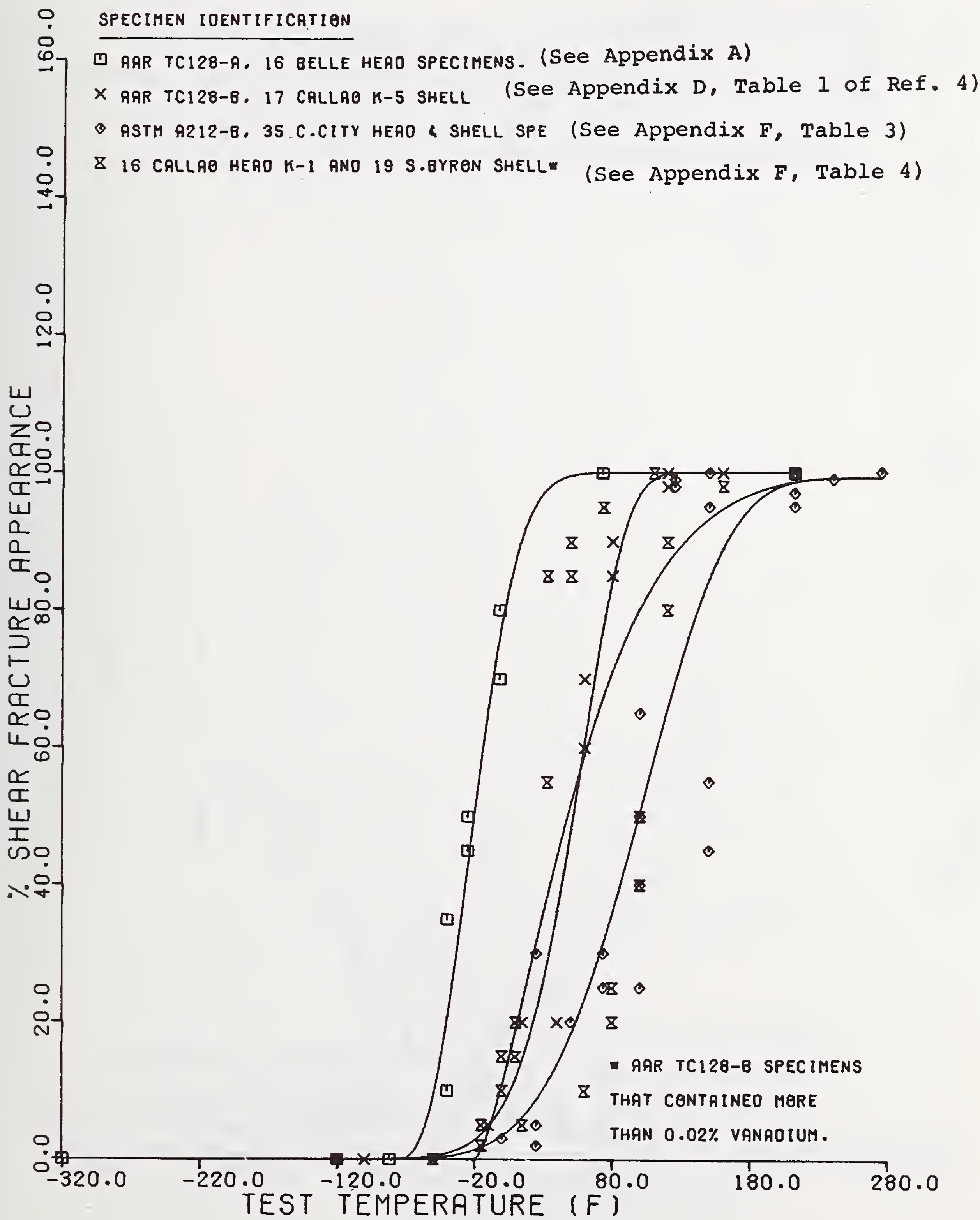


FIGURE 14D

RESULTS OF IMPACT TESTS FOR THREE GRADES OF STEEL
...CVN SPECIMENS OF TL ORIENTATION FROM FOUR ACCIDENTS.

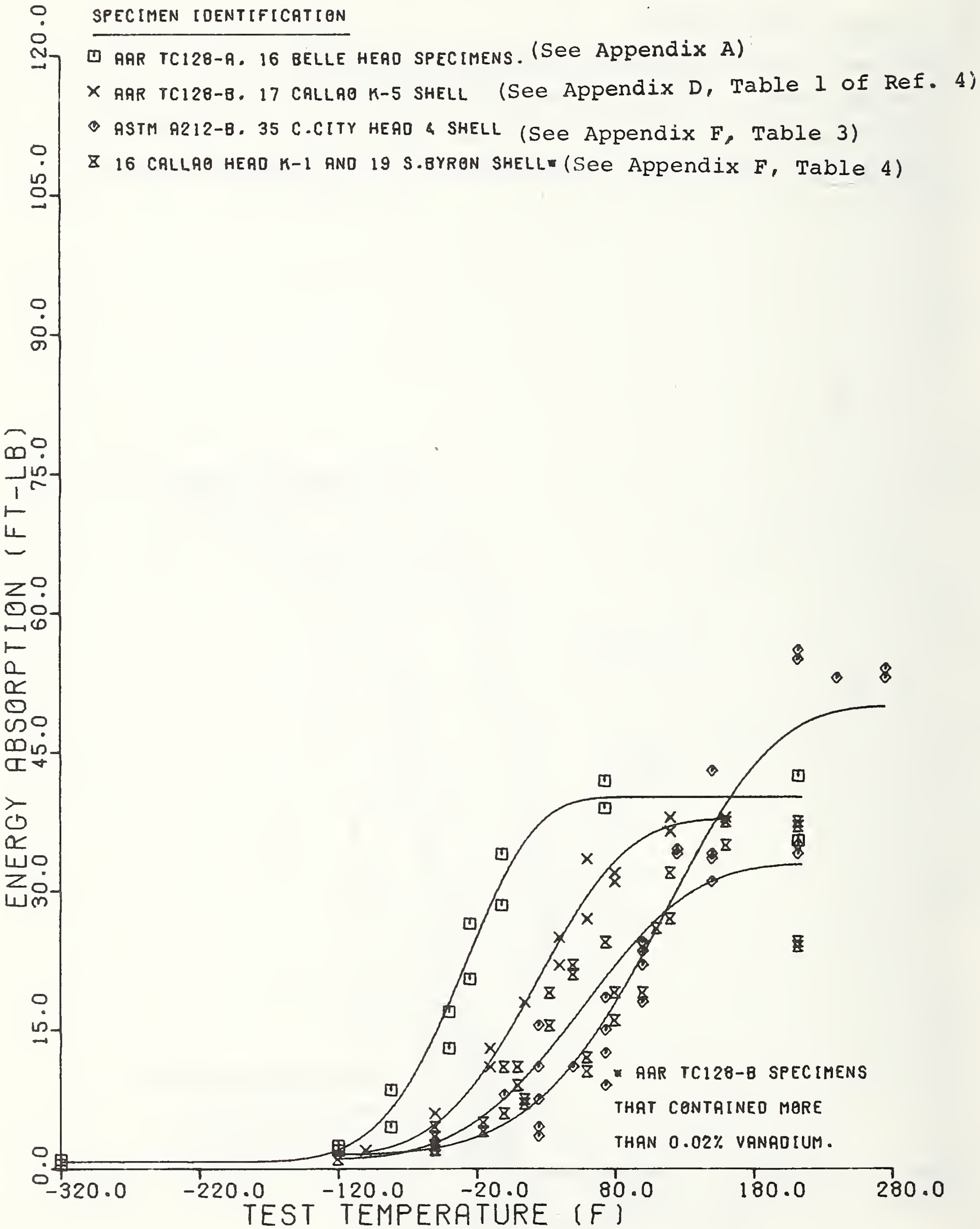


FIGURE 14C

RESULTS OF IMPACT TESTS FOR THREE GRADES OF STEEL
...CVN SPECIMENS OF TL ORIENTATION FROM FOUR ACCIDENTS.

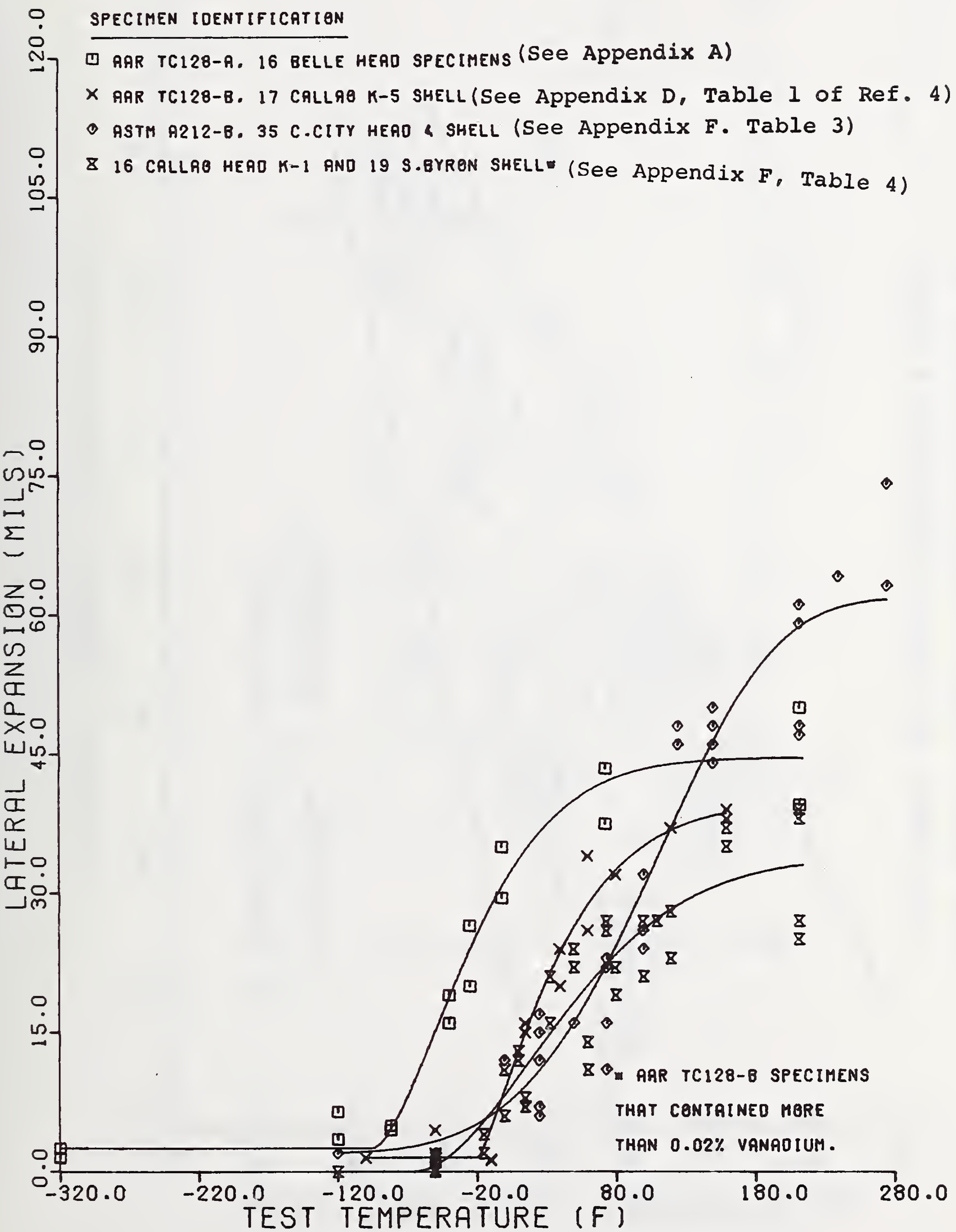
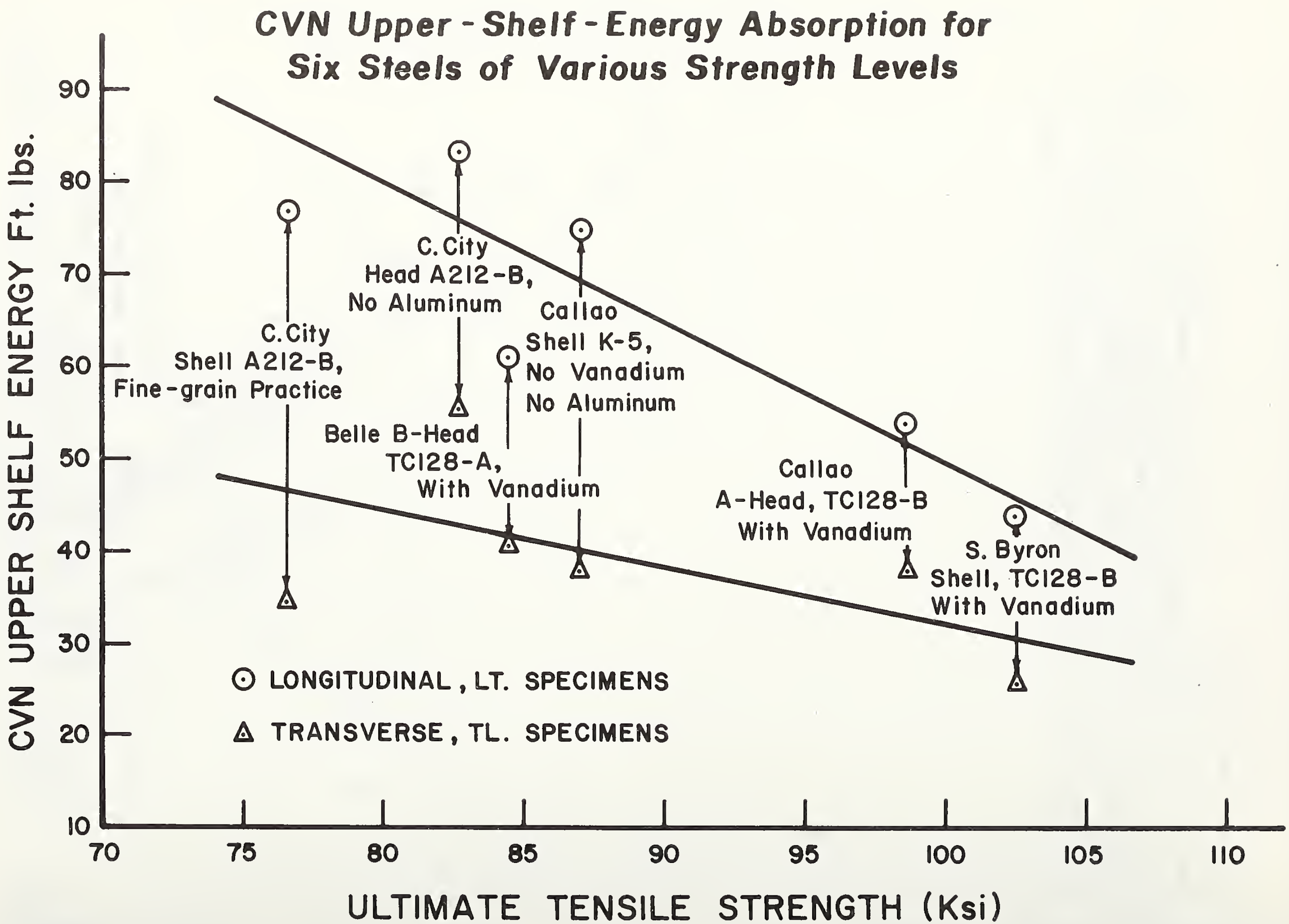


Figure 15.



CVN Upper-Shelf-Energy Absorption for Six Steels of Various Strength Levels
CVN UPPER SHELF ENERGY Ft. lbs.
90
80
70
60
50
40
30
20
10
70
75
80
85
90
95
100
105
110
ULTIMATE TENSILE STRENGTH (Ksi)
C.City Shell A212-B, Fine-grain Practice
C.City Head A212-B, No Aluminum
Belle B-Head TC128-A, With Vanadium
Callao Shell K-5, No Vanadium No Aluminum
Callao A-Head, TC128-B With Vanadium
S. Byron Shell, TC128-B With Vanadium
LONGITUDINAL, LT. SPECIMENS
TRANSVERSE, TL. SPECIMENS

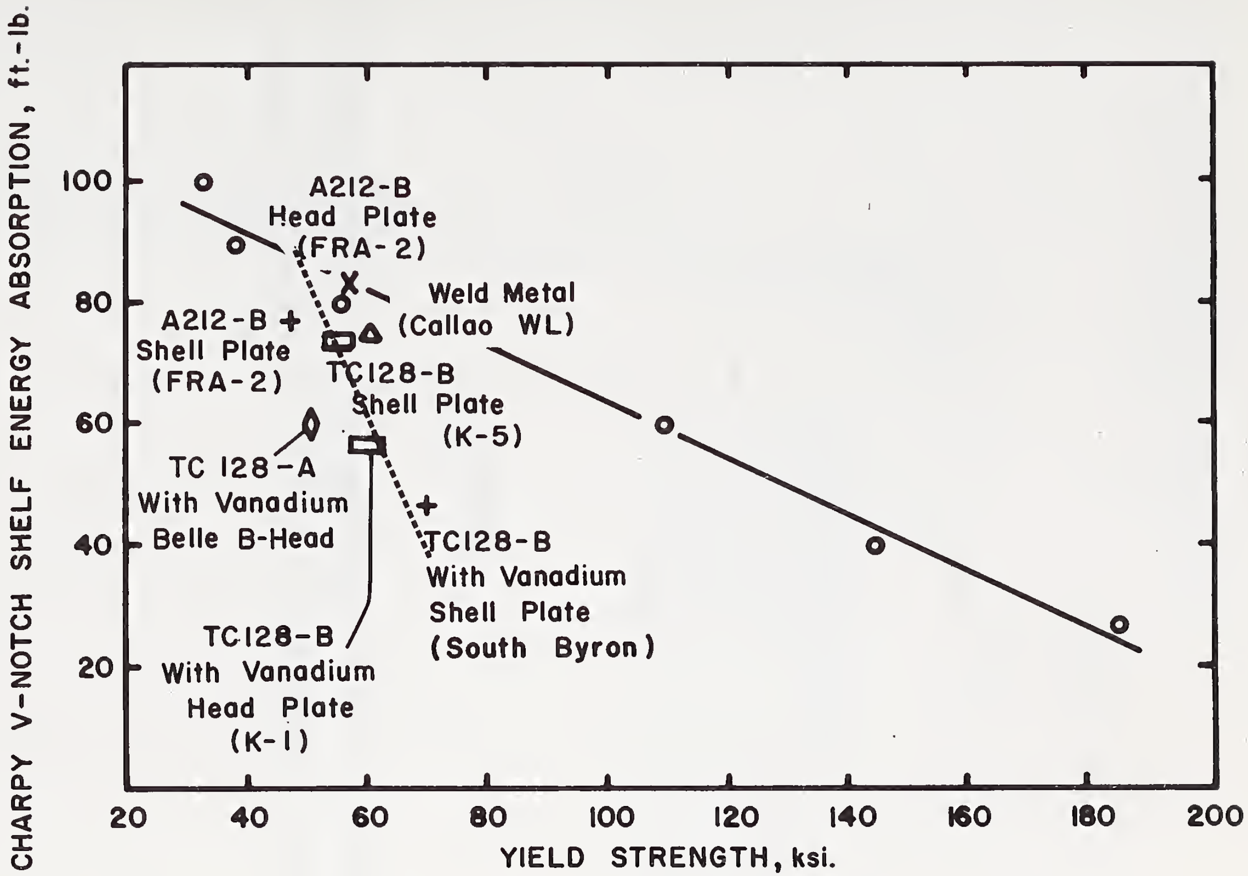


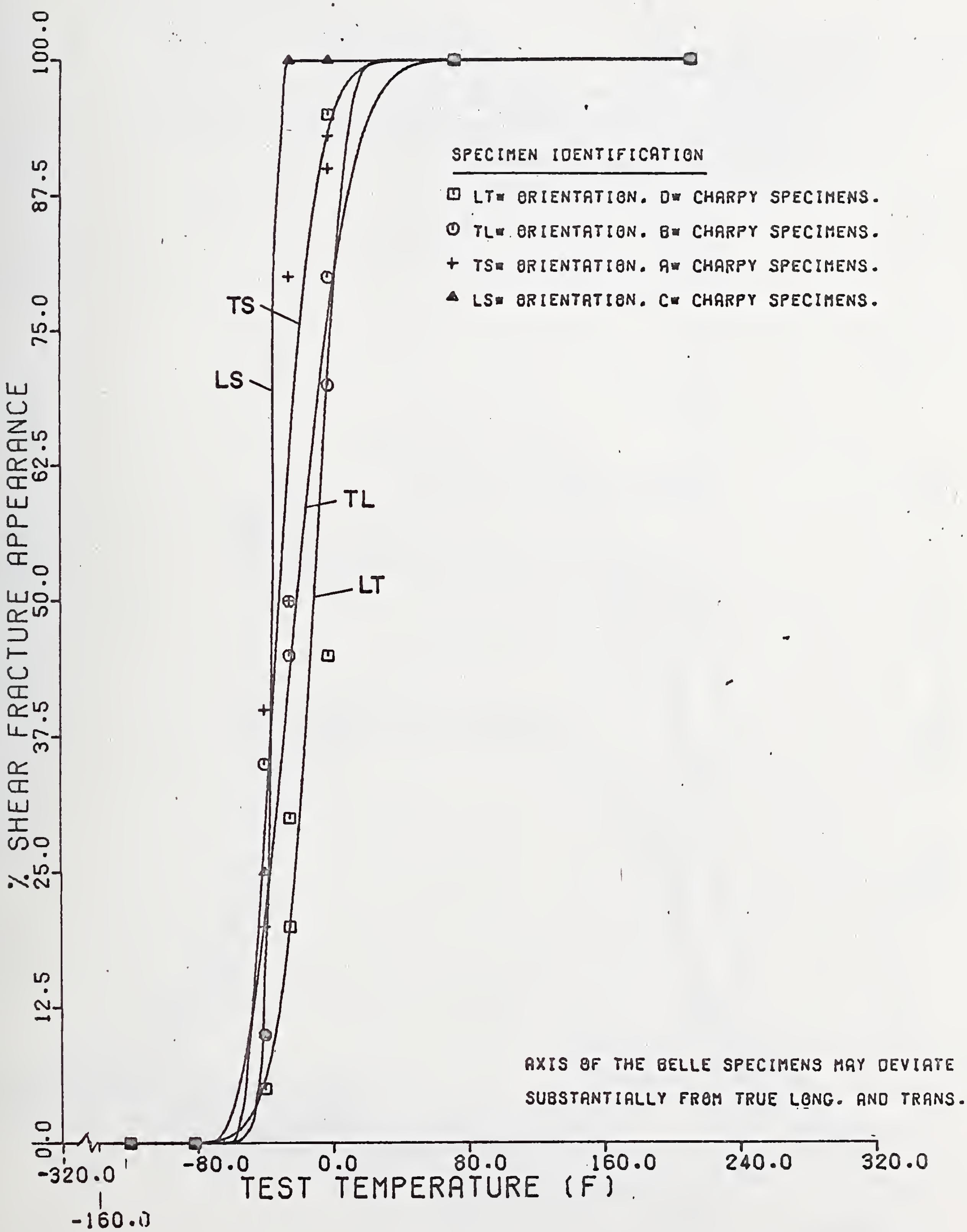
Figure 16. CVN Upper-Shelf Energy as a Function of YIELD STRENGTH for Longitudinal (LT) Specimens for Various Steels. The solid line is fitted to the circles given in a published[9] trend line. The dotted line is fitted to the data from six tank-car steels tested.

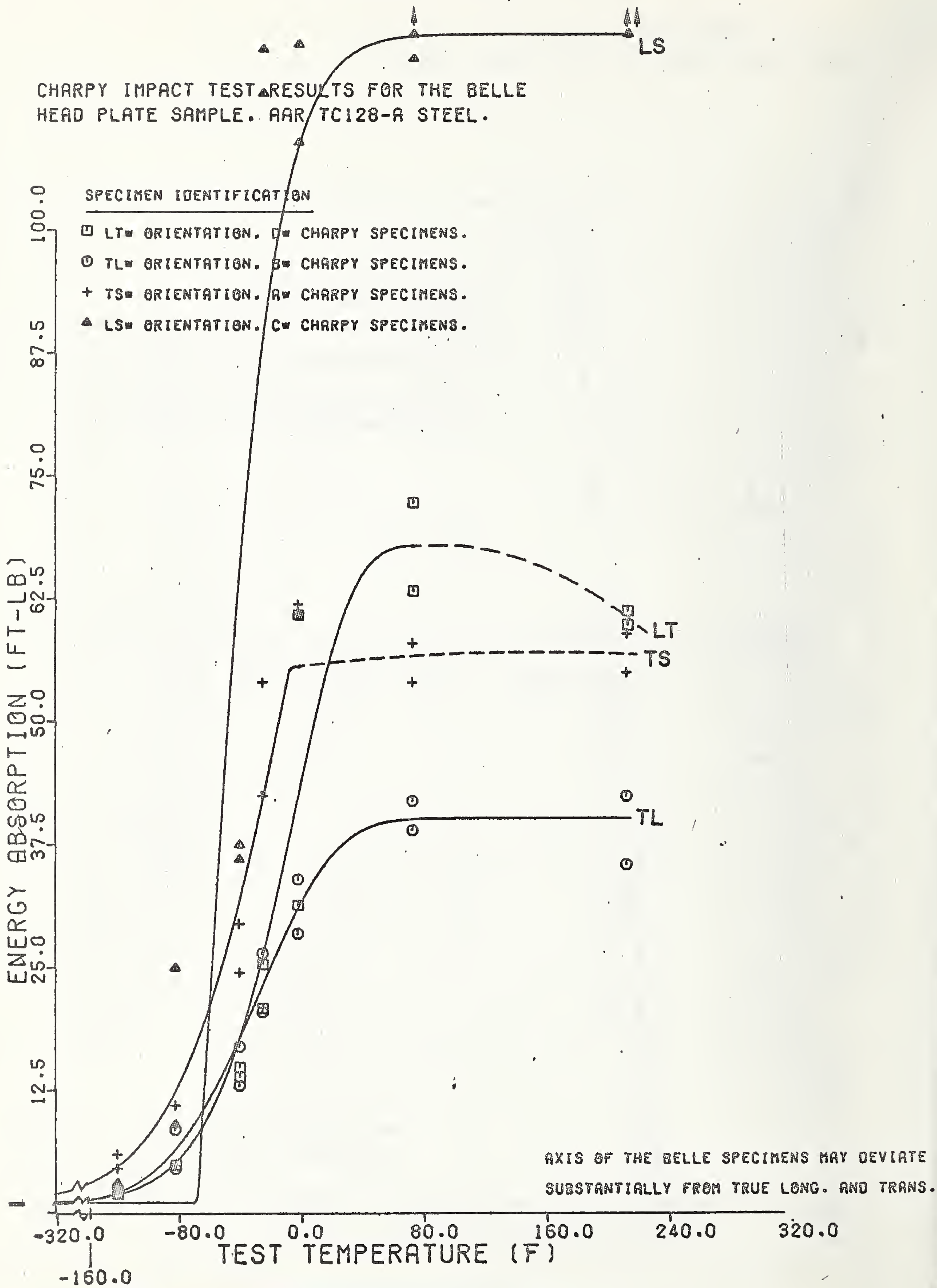
APPENDIX A

CVN Results for Four Orientations of Specimens Taken from the Belle Head-Plate Sample of AAR TC128-A Steel

APPENDIX A, FIGURE A

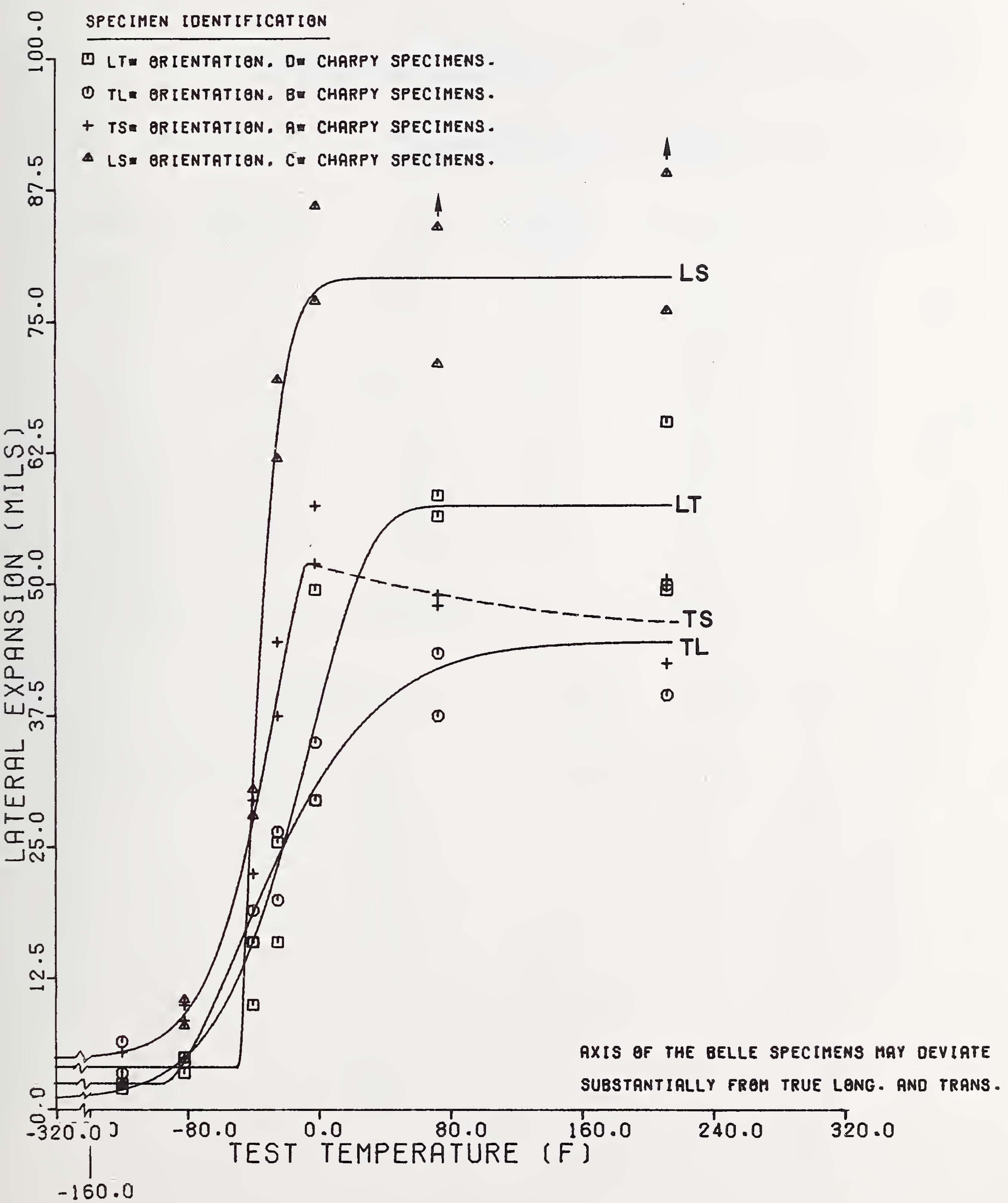
CHARPY IMPACT TEST RESULTS FOR THE BELLE HEAD PLATE SAMPLE. AAR TC128-A STEEL.




CHARPY IMPACT TEST RESULTS FOR THE BELLE
HEAD PLATE SAMPLE. AAR TC128-A STEEL.
SPECIMEN IDENTIFICATION
LT= ORIENTATION. D= CHARPY SPECIMENS.
TL= ORIENTATION. B= CHARPY SPECIMENS.
TS= ORIENTATION. A= CHARPY SPECIMENS.
LS= ORIENTATION. C= CHARPY SPECIMENS.
LS
LT
TS
TL
ENERGY ABSORPTION (FT-LB)
100.0
87.5
75.0
62.5
50.0
37.5
25.0
12.5
-320.0
-80.0
0.0
80.0
160.0
240.0
320.0
-160.0
TEST TEMPERATURE (F)
AXIS OF THE BELLE SPECIMENS MAY DEVIATE
SUBSTANTIALLY FROM TRUE LONG. AND TRANS.

APPENDIX A, FIGURE C

CHARPY IMPACT TEST RESULTS FOR THE BELLE HEAD PLATE SAMPLE. AAR TC128-A STEEL.



APPENDIX A, TABLE 1A

CHARPY IMPACT TEST RESULTS FOR THE BELLE
HEAD PLATE SAMPLE, AAR TC128-A STEEL.
CALCULATIONS FOR SHEAR FRACTURE APPEARANCE DATA OF
LT* ORIENTATION, D* CHARPY SPECIMENS.

AXIS OF THE BELLE SPECIMENS MAY DEVIATE
SUBSTANTIALLY FROM TRUE LONG. AND TRANS.

SPECIMEN	TEMPERATURE(F)	OBSERVED SHEAR FRACTURE (%)	CALCULATED SHEAR FRACTURE (%)
D6	-320.0	.00	.0
D16	-320.0	.00	.0
D10	-120.0	.00	.0
D2	-120.0	.00	.0
D13	-82.0	.00	.0
D8	-82.0	.00	.0
D4	-40.0	5.00	6.0
D12	-40.0	5.00	6.0
D11	-25.0	20.00	20.5
D3	-25.0	30.00	20.5
D9	-2.0	45.00	71.4
D1	-2.0	95.00	71.4
D15	72.5	100.00	100.0
D7	72.5	100.00	100.0
D5	212.0	100.00	100.0
D14	212.0	100.00	100.0

TRANSITION REGION, CALCULATED VALUES

% SHEAR FRACTURE	CALCULATED TEMPERATURE(F)	/	TEMPERATURE (F)	CALCULATED SHEAR FRACTURE(%)
2.0	-51.0	/	-50.0	2.2
5.0	-41.0	/	-45.0	3.7
10.0	-34.1	/	-40.0	6.0
15.0	-29.2	/	-35.0	9.3
50.0	-10.5	/	-30.0	14.0
85.0	4.4	/	-25.0	20.5
90.0	7.5	/	-20.0	29.0
95.0	11.7	/	-15.0	39.4
98.0	16.2	/	-10.0	51.3
		/	-5.0	64.0
		/	.0	76.0
		/	5.0	86.1
		/	10.0	93.2

APPENDIX A, TABLE 1B

CHARPY IMPACT TEST RESULTS FOR THE BELLE
HEAD PLATE SAMPLE, AAR TC128-A STEEL.
CALCULATIONS FOR ENERGY ABSORPTION DATA OF
LT* ORIENTATION, D* CHARPY SPECIMENS.

AXIS OF THE BELLE SPECIMENS MAY DEVIATE
SUBSTANTIALLY FROM TRUE LONG. AND TRANS.

SPECIMEN	TEMPERATURE(F)	OBSERVED ENERGY ABSORPTION(FT-LB)	CALCULATED ENERGY ABSORPTION(FT-LB)
D6	-320.0	1.00	1.0
D16	-320.0	1.00	1.0
D10	-120.0	2.00	1.8
D2	-120.0	2.00	1.8
D13	-82.0	5.00	5.1
D8	-82.0	5.00	5.1
D4	-40.0	14.00	18.0
D12	-40.0	15.00	18.0
D11	-25.0	21.00	26.4
D3	-25.0	25.50	26.4
D9	-2.0	31.50	42.6
D1	-2.0	61.00	42.6
D15	72.5	72.50	67.9
D7	72.5	63.50	67.9
D5	212.0	60.00	60.8
D14	212.0	61.50	60.8

TRANSITION REGION, CALCULATED VALUES

ENERGY ABSORPTION	CALCULATED TEMPERATURE(F)	/	TEMPERATURE (F)	CALCULATED ENERGY ABSORPTION(FT-LB)
5.0	-82.9	/	-80.0	5.5
10.0	-60.3	/	-75.0	6.4
15.0	-46.5	/	-70.0	7.4
20.0	-36.0	/	-65.0	8.7
25.0	-27.3	/	-60.0	10.1
30.0	-19.5	/	-55.0	11.7
35.0	-12.4	/	-50.0	13.6
40.0	-5.5	/	-45.0	15.6
45.0	1.3	/	-40.0	18.0
50.0	8.4	/	-35.0	20.5
55.0	16.2	/	-30.0	23.4
60.0	25.5	/	-25.0	26.4
65.0	39.6	/	-20.0	29.7
		/	-15.0	33.1
		/	-10.0	36.7
		/	-5.0	40.4
		/	.0	44.0
		/	5.0	47.6
		/	10.0	51.1
		/	15.0	54.3

APPENDIX A, TABLE 1C

CHARPY IMPACT TEST RESULTS FOR THE BELLE HEAD PLATE SAMPLE, AAR TC128-A STEEL. CALCULATIONS FOR LATERAL EXPANSION DATA OF LT* ORIENTATION, D* CHARPY SPECIMENS.

AXIS OF THE BELLE SPECIMENS MAY DEVIATE SUBSTANTIALLY FROM TRUE LONG. AND TRANS.

SPECIMEN	TEMPERATURE(F)	OBSERVED LATERAL EXPANSION (MILS)	CALCULATED LATERAL EXPANSION (MILS)
D6	-320.0	1.00	1.0
D16	-320.0	1.00	1.0
D10	-120.0	2.00	1.9
D2	-120.0	2.50	1.9
D13	-82.0	3.50	5.0
D8	-82.0	5.00	5.0
D4	-40.0	10.00	16.2
D12	-40.0	15.00	16.2
D11	-25.0	10.00	23.4
D3	-25.0	25.50	23.4
D9	-2.0	29.50	36.9
D1	-2.0	49.50	36.9
D15	72.5	50.50	57.5
D7	72.5	58.50	57.5
D5	212.0	65.50	57.5
D14	212.0	49.50	57.5

TRANSITION REGION, CALCULATED VALUES

LATERAL EXPANSION(MILS)	CALCULATED TEMPERATURE(F)	/	TEMPERATURE (F)	CALCULATED LATERAL EXPANSION(MILS)
5.0	-81.5	/	-80.0	5.3
10.0	-57.5	/	-75.0	6.1
15.0	-42.3	/	-70.0	7.0
20.0	-31.5	/	-65.0	8.1
25.0	-22.3	/	-60.0	9.3
30.0	-13.3	/	-55.0	10.8
35.0	-5.1	/	-50.0	12.4
40.0	3.1	/	-45.0	14.2
45.0	12.0	/	-40.0	16.2
50.0	22.4	/	-35.0	18.4
55.0	38.5	/	-30.0	20.5
		/	-25.0	23.4
		/	-20.0	26.1
		/	-15.0	29.0
		/	-10.0	32.0
		/	-5.0	35.1
		/	.0	38.1
		/	5.0	41.1
		/	10.0	43.9
		/	15.0	46.6

APPENDIX A, TABLE 2A

CHARPY IMPACT TEST RESULTS FOR THE BELLE
HEAD PLATE SAMPLE, AAR TC128-A STEEL.
CALCULATIONS FOR SHEAR FRACTURE APPEARANCE DATA OF
TL* ORIENTATION, B* CHARPY SPECIMENS.

SPECIMEN	TEMPERATURE(F)	OBSERVED SHEAR FRACTURE (%)	CALCULATED SHEAR FRACTURE (%)
B6	-320.0	.00	.0
B16	-320.0	.00	.0
B10	-120.0	.00	.0
B2	-120.0	.00	.0
B13	-82.0	.00	.0
B8	-82.0	.00	.0
B4	-40.0	10.00	20.8
B12	-40.0	35.00	20.8
B11	-25.0	50.00	43.1
B3	-25.0	45.00	43.1
B9	-2.0	70.00	76.3
B1	-2.0	80.00	76.3
B15	72.5	100.00	100.0
B7	72.5	100.00	100.0
B5	212.0	100.00	100.0
B14	212.0	100.00	100.0

TRANSITION REGION, CALCULATED VALUES

% SHEAR FRACTURE	CALCULATED TEMPERATURE(F)	/	TEMPRATURE (F)	CALCULATED SHEAR FRACTURE(%)
2.0	-62.0	/	-60.0	2.8
5.0	-55.0	/	-55.0	5.7
10.0	-49.6	/	-50.0	9.7
15.0	-44.6	/	-45.0	14.7
50.0	-20.7	/	-40.0	20.8
85.0	6.6	/	-35.0	27.7
90.0	13.3	/	-30.0	35.3
95.0	23.2	/	-25.0	43.1
98.0	34.4	/	-20.0	51.0
		/	-15.0	58.8
		/	-10.0	66.0
		/	-5.0	72.7
		/	.0	78.5
		/	5.0	83.6
		/	10.0	87.7
		/	15.0	91.1
		/	20.0	93.7
		/	25.0	95.6
		/	30.0	97.1

CHARPY IMPACT TEST RESULTS FOR THE BELLE HEAD PLATE SAMPLE, AAR TC128-A STEEL.
CALCULATIONS FOR ENERGY ABSORPTION DATA OF TL* ORIENTATION, B* CHARPY SPECIMENS.

SPECIMEN	TEMPERATURE(F)	OBSERVED ENERGY ABSORPTION(FT-LB)	CALCULATED ENERGY ABSORPTION(FT-LB)
B6	-320.0	1.00	.8
B16	-320.0	.50	.8
B10	-120.0	2.50	2.0
B2	-120.0	2.00	2.0
B13	-82.0	8.50	6.5
B8	-82.0	4.50	6.5
B4	-40.0	18.00	17.9
B12	-40.0	17.00	17.9
B11	-25.0	26.50	23.3
B3	-25.0	20.50	23.3
B9	-2.0	28.50	31.1
B1	-2.0	34.00	31.1
B15	72.5	42.00	40.1
B7	72.5	39.00	40.1
B5	212.0	42.50	40.2
B14	212.0	35.50	40.2

TRANSITION REGION, CALCULATED VALUES

ENERGY ABSORPTION	CALCULATED TEMPERATURE(F)	/	TEMPERATURE (F)	CALCULATED ENERGY ABSORPTION(FT-LB)
5.0	-90.8	/	-90.0	5.1
10.0	-66.0	/	-85.0	5.9
15.0	-48.8	/	-80.0	6.9
20.0	-34.1	/	-75.0	7.9
25.0	-20.2	/	-70.0	9.0
30.0	-5.4	/	-65.0	10.3
35.0	13.0	/	-60.0	11.6
40.0	64.3	/	-55.0	13.1
		/	-50.0	14.6
		/	-45.0	16.2
		/	-40.0	17.9
		/	-35.0	19.7
		/	-30.0	21.5
		/	-25.0	23.3
		/	-20.0	25.1
		/	-15.0	26.8
		/	-10.0	28.5
		/	-5.0	30.1
		/	.0	31.6
		/	5.0	33.0

APPENDIX A, TABLE 2C

CHARPY IMPACT TEST RESULTS FOR THE BELLE HEAD PLATE SAMPLE, AAR 1C128-A STEEL. CALCULATIONS FOR LATERAL EXPANSION DATA OF TL* ORIENTATION, B* CHARPY SPECIMENS.

SPECIMEN	TEMPERATURE(F)	OBSERVED LATERAL EXPANSION (MILS)	CALCULATED LATERAL EXPANSION (MILS)
B6	-320.0	1.50	2.5
B16	-320.0	2.50	2.5
B10	-120.0	3.50	2.5
B2	-120.0	6.50	2.5
B13	-82.0	5.00	4.6
B8	-82.0	4.50	4.6
B4	-40.0	16.00	18.8
B12	-40.0	19.00	18.8
B11	-25.0	26.50	24.0
B3	-25.0	20.00	24.0
B9	-2.0	29.50	30.7
B1	-2.0	35.00	30.7
B15	72.5	43.50	42.0
B7	72.5	37.50	42.0
B5	212.0	50.00	44.5
B14	212.0	39.50	44.5

TRANSITION REGION, CALCULATED VALUES

LATERAL EXPANSION(MILS)	CALCULATED TEMPERATURE(F)	/	TEMPERATURE (F)	CALCULATED LATERAL EXPANSION(MILS)
5.0	-80.4	/	-80.0	5.1
10.0	-64.3	/	-75.0	6.5
15.0	-50.4	/	-70.0	8.1
20.0	-36.6	/	-65.0	9.8
25.0	-21.8	/	-60.0	11.5
30.0	-4.3	/	-55.0	13.3
35.0	16.7	/	-50.0	15.2
40.0	49.7	/	-45.0	17.0
		/	-40.0	18.8
		/	-35.0	20.6
		/	-30.0	22.3
		/	-25.0	24.0
		/	-20.0	25.6
		/	-15.0	27.1
		/	-10.0	28.6
		/	-5.0	30.0
		/	.0	31.3
		/	5.0	32.5
		/	10.0	33.6
		/	15.0	34.7

APPENDIX A, TABLE 3A

CHARPY IMPACT TEST RESULTS FOR THE BELLE HEAD PLATE SAMPLE, AAR TC128-A STEEL.
CALCULATIONS FOR SHEAR FRACTURE APPEARANCE DATA OF TS* ORIENTATION, A* CHARPY SPECIMENS.

SPECIMEN	TEMPERATURE(F)	OBSERVED SHEAR FRACTURE (%)	CALCULATED SHEAR FRACTURE (%)
A6	-320.0	.00	.0
A16	-320.0	.00	.0
A10	-120.0	.00	.0
A2	-120.0	.00	.0
A13	-82.0	.00	.0
A8	-82.0	.00	.0
A4	-40.0	40.00	28.6
A12	-40.0	20.00	28.6
A11	-25.0	50.00	63.5
A3	-25.0	80.00	63.5
A9	-2.0	90.00	93.3
A1	-2.0	93.00	93.3
A15	72.5	100.00	100.0
A7	72.5	100.00	100.0
A5	212.0	100.00	100.0
A14	212.0	100.00	100.0

TRANSITION REGION, CALCULATED VALUES

% SHEAR FRACTURE	CALCULATED TEMPERATURE(F)	/	TEMPERATURE (F)	CALCULATED SHEAR FRACTURE(%)
2.0	-55.3	/	-50.0	8.3
5.0	-52.4	/	-45.0	17.5
10.0	-49.0	/	-40.0	28.6
15.0	-46.2	/	-35.0	40.7
50.0	-31.1	/	-30.0	52.5
85.0	-11.6	/	-25.0	63.5
90.0	-6.6	/	-20.0	73.0
95.0	1.1	/	-15.0	80.7
98.0	10.1	/	-10.0	86.8
		/	-5.0	91.3
		/	.0	94.4
		/	5.0	96.6
		/	10.0	98.0

APPENDIX A, TABLE 3B

CHARPY IMPACT TEST RESULTS FOR THE BELLE
HEAD PLATE SAMPLE, AAR TC128-A STEEL.
CALCULATIONS FOR ENERGY ABSORPTION DATA OF
TS* ORIENTATION, A* CHARPY SPECIMENS.

SPECIMEN	TEMPERATURE(F)	OBSERVED ENERGY ABSORPTION(FT-LB)	CALCULATED ENERGY ABSORPTION(FT-LB)
A6	-320.0	1.00	1.0
A16	-320.0	1.00	1.0
A10	-120.0	6.00	4.7
A2	-120.0	4.50	4.7
A13	-82.0	11.00	12.4
A8	-82.0	11.00	12.4
A4	-40.0	29.50	32.0
A12	-40.0	24.50	32.0
A11	-25.0	42.50	42.3
A3	-25.0	54.00	42.3
A9	-2.0	61.00	55.7
A1	-2.0	62.00	55.7
A15	72.5	54.00	56.7
A7	72.5	58.00	56.7
A5	212.0	55.00	56.9
A14	212.0	59.00	56.9

TRANSITION REGION, CALCULATED VALUES

ENERGY ABSORPTION	CALCULATED TEMPERATURE(F)	/	TEMPERATURE (F)	CALCULATED ENERGY ABSORPTION(FT-LB)
5.0	-117.7	/	-110.0	6.1
10.0	-90.7	/	-105.0	6.9
15.0	-74.3	/	-100.0	7.9
20.0	-62.1	/	-95.0	9.0
25.0	-52.0	/	-90.0	10.2
30.0	-43.3	/	-85.0	11.5
35.0	-35.4	/	-80.0	13.1
40.0	-28.2	/	-75.0	14.8
45.0	-21.3	/	-70.0	16.6
50.0	-14.7	/	-65.0	18.7
55.0	-8.2	/	-60.0	21.0
		/	-55.0	23.4
		/	-50.0	26.1
		/	-45.0	29.0
		/	-40.0	32.0
		/	-35.0	35.3
		/	-30.0	38.7
		/	-25.0	42.3
		/	-20.0	46.0
		/	-15.0	49.8

APPENDIX A, TABLE 3C

CHARPY IMPACT TEST RESULTS FOR THE BELLE
HEAD PLATE SAMPLE, AAR TC128-A STEEL.
CALCULATIONS FOR LATERAL EXPANSION DATA OF
TS* ORIENTATION, A* CHARPY SPECIMENS.

SPECIMEN	TEMPERATURE(F)	OBSERVED LATERAL EXPANSION (MILS)	CALCULATED LATERAL EXPANSION (MILS)
A6	-320.0	4.50	4.9
A16	-320.0	2.00	4.9
A10	-120.0	5.50	5.5
A2	-120.0	3.00	5.5
A13	-82.0	10.00	9.1
A8	-82.0	6.50	9.1
A4	-40.0	29.50	27.7
A12	-40.0	22.50	27.7
A11	-25.0	37.50	39.6
A3	-25.0	44.50	39.6
A9	-2.0	57.50	51.8
A1	-2.0	52.00	51.8
A15	72.5	48.00	49.1
A7	72.5	49.00	49.1
A5	212.0	50.50	46.4
A14	212.0	42.50	46.4

TRANSITION REGION, CALCULATED VALUES

LATERAL EXPANSION(MILS)	CALCULATED TEMPERATURE(F)	/	TEMPERATURE (F)	CALCULATED LATERAL EXPANSION(MILS)
5.0	-147.5	/	-140.0	5.1
10.0	-77.8	/	-135.0	5.1
15.0	-62.1	/	-130.0	5.2
20.0	-51.8	/	-125.0	5.3
25.0	-43.8	/	-120.0	5.5
30.0	-36.9	/	-115.0	5.7
35.0	-30.5	/	-110.0	5.9
40.0	-24.5	/	-105.0	6.2
45.0	-18.2	/	-100.0	6.6
50.0	-11.3	/	-95.0	7.1
55.0	-2.3	/	-90.0	7.8
		/	-85.0	8.6
		/	-80.0	9.5
		/	-75.0	10.7
		/	-70.0	12.1
		/	-65.0	13.8
		/	-60.0	15.9
		/	-55.0	18.3
		/	-50.0	21.0
		/	-45.0	24.2

APPENDIX A, TABLE 4A

CHARPY IMPACT TEST RESULTS FOR THE BELLE
HEAD PLATE SAMPLE, AAR TC128-A STEEL.
CALCULATIONS FOR SHEAR FRACTURE APPEARANCE DATA OF
LS* ORIENTATION, C* CHARPY SPECIMENS.

SPECIMEN	TEMPERATURE(F)	OBSERVED SHEAR FRACTURE (%)	CALCULATED SHEAR FRACTURE (%)
C6	-320.0	.00	.0
C16	-320.0	.00	.0
C10	-120.0	.00	.0
C2	-120.0	.00	.0
C13	-82.0	.00	.0
C8	-82.0	.00	.0
C4	-40.0	10.00	16.3
C12	-40.0	25.00	16.3
C11	-25.0	100.00	100.0
C3	-25.0	100.00	100.0
C9	-2.0	100.00	100.0
C1	-2.0	100.00	100.0
C15	72.5	100.00	100.0
C7	72.5	100.00	100.0
C5	212.0	100.00	100.0
C14	212.0	100.00	100.0

TRANSITION REGION, CALCULATED VALUES

% SHEAR FRACTURE	CALCULATED TEMPERATURE(F)	/	TEMPERATURE (F)	CALCULATED SHEAR FRACTURE(%)
2.0	-4[illegible].0	/	-40.0	16.3
5.0	-44.6	/	-35.0	49.1
10.0	-42.0	/	-30.0	91.9
15.0	-40.3	/		
50.0	-34.9	/		
85.0	-31.1	/		
90.0	-30.3	/		
95.0	-29.3	/		
98.0	-28.3	/		

APPENDIX A, TABLE 4B

CHARPY IMPACT TEST RESULTS FOR THE BELLE
HEAD PLATE SAMPLE, AAR TC128-A STEEL.
CALCULATIONS FOR ENERGY ABSORPTION DATA OF
LS* ORIENTATION, C* CHARPY SPECIMENS.

SPECIMEN	TEMPERATURE(F)	OBSERVED ENERGY ABSORPTION(FT-LB)	CALCULATED ENERGY ABSORPTION(FT-LB)
C6	-320.0	1.00	1.0
C16	-320.0	1.00	1.0
C10	-120.0	3.00	1.0
C2	-120.0	2.50	1.0
C13	-82.0	9.00	1.0
C8	-82.0	25.00	1.0
C4	-40.0	36.00	66.4
C12	-40.0	37.50	66.4
C11	-25.0	114.00	89.7
C3	-25.0	118.50	89.7
C9	-2.0	119.00	108.3
C1	-2.0	109.00	108.8
C15	72.5	120.00	119.8
C7	72.5	117.50	119.3
C5	212.0	120.00	120.0
C14	212.0	120.00	120.0

TRANSITION REGION, CALCULATED VALUES

ENERGY ABSORPTION	CALCULATED TEMPERATURE(F)	/	TEMPERATURE (F)	CALCULATED ENERGY ABSORPTION(FT-LB)
5.0	-67.2	/	-60.0	21.2
10.0	-64.8	/	-55.0	33.4
15.0	-62.6	/	-50.0	45.3
20.0	-60.5	/	-45.0	56.4
25.0	-58.4	/	-40.0	66.4
30.0	-56.4	/	-35.0	75.3
35.0	-54.4	/	-30.0	83.0
40.0	-52.3	/	-25.0	89.7
45.0	-50.2	/	-20.0	95.3
50.0	-48.0	/	-15.0	100.0
55.0	-45.7	/	-10.0	103.9
60.0	-43.3	/	-5.0	107.2
65.0	-40.8	/	.0	109.8
70.0	-38.1	/	5.0	111.9
75.0	-35.2	/	10.0	113.7
80.0	-32.1	/	15.0	115.0
85.0	-28.6	/	20.0	116.1
90.0	-24.7	/	25.0	117.0
95.0	-20.3	/	30.0	117.7
100.0	-15.0	/	35.0	118.2
105.0	-8.5	/		
110.0	.4	/		
115.0	14.3	/		

APPENDIX A, TABLE 4C

CHARPY IMPACT TEST RESULTS FOR THE BELLE HEAD PLATE SAMPLE, AAR TC128-A STEEL. CALCULATIONS FOR LATERAL EXPANSION DATA OF LS* ORIENTATION, C* CHARPY SPECIMENS.

SPECIMEN	TEMPERATURE(F)	OBSERVED LATERAL EXPANSION (MILS)	CALCULATED LATERAL EXPANSION (MILS)
C6	-320.0	3.60	4.0
C16	-320.0	4.50	4.0
C10	-120.0	2.50	4.0
C2	-120.0	2.50	4.0
C13	-82.0	8.00	4.0
C8	-82.0	10.50	4.0
C4	-40.0	28.00	31.3
C12	-40.0	30.50	31.3
C11	-25.0	69.50	64.4
C3	-25.0	62.00	64.4
C9	-2.0	86.00	77.8
C1	-2.0	77.00	77.8
C15	72.5	84.00	79.2
C7	72.5	71.00	79.2
C5	212.0	89.00	79.2
C14	212.0	76.00	79.2

TRANSITION REGION, CALCULATED VALUES

LATERAL EXPANSION(MILS)	CALCULATED TEMPERATURE(F)	/	TEMPERATURE (F)	CALCULATED LATERAL EXPANSION(MILS)
5.0	-49.2	/	-40.0	31.3
10.0	-47.0	/	-35.0	45.3
15.0	-45.3	/	-30.0	56.3
20.0	-43.7	/	-25.0	64.4
25.0	-42.1	/	-20.0	69.9
30.0	-40.4	/	-15.0	73.6
35.0	-38.8	/	-10.0	75.9
40.0	-37.0	/	-5.0	77.3
45.0	-35.1	/	.0	78.1
50.0	-33.0	/		
55.0	-30.7	/		
60.0	-27.9	/		
65.0	-24.5	/		
70.0	-19.9	/		
75.0	-12.2	/		

APPENDIX B

CVN Results of LT and TL Specimens of Combined Data from Six Plate Steels

COMPARISON OF LONGITUDINAL AND TRANSVERSE CVN IMPACT-TEST
RESULTS FOR SIX STEEL PLATES TAKEN FROM FOUR ACCIDENTS.
CALCULATIONS FOR SHEAR FRACTURE APPEARANCE DATA OF
106 SPECIMENS, LT ORIENTATION.
THE CALCULATED CURVES WERE COMPUTED
FROM WEIGHTED MEAN VALUES FOR DATA
AT EACH TEST TEMPERATURE.

SPECIMEN	TEMPERATURE(F)	OBSERVED SHEAR FRACTURE (%)	CALCULATED SHEAR FRACTURE (%)
D6	-320.0	.00	.0
D16	-320.0	.00	.0
D10	-120.0	.00	.1
D2	-120.0	.00	.1
B14	-120.0	.00	.1
C15	-120.0	.00	.1
HLH-15	-100.0	.00	.3
STA-34	-100.0	.00	.3
D13	-82.0	.00	.6
D8	-82.0	.00	.6
C1	-50.0	.00	2.0
C3	-50.0	.00	2.0
C2	-50.0	.00	2.0
B2	-50.0	.00	2.0
C41	-50.0	.00	2.0
C42	-50.0	.00	2.0
C43	-50.0	.00	2.0
HLH-1	-50.0	.00	2.0
HLH-2	-50.0	.00	2.0
B3	-50.0	.00	2.0
STA-21	-50.0	.00	2.0
STA-22	-50.0	.00	2.0
B1	-50.0	.00	2.0
D12	-40.0	5.00	2.9
D4	-40.0	5.00	2.9
D3	-25.0	30.00	4.8
D11	-25.0	20.00	4.8
B10	-10.0	2.00	7.6
B11	-10.0	5.00	7.6
STA-35	-10.0	5.00	7.6
STA-36	-10.0	5.00	7.6
D1	-2.0	95.00	9.7
D9	-2.0	45.00	9.7
C14	.0	.00	10.2
B7	12.0	25.00	14.3
B6	12.0	30.00	14.3
HLH-8	15.0	5.00	15.5
HLH-7	15.0	.00	15.5
STA-28	15.0	5.00	15.5
STA-37	15.0	5.00	15.5
C11	25.0	2.00	20.0
C10	25.0	3.00	20.0
C50	25.0	2.00	20.0
C51	25.0	2.00	20.0
B13	30.0	35.00	22.6
B12	30.0	15.00	22.6
B19	30.0	40.00	22.6
STA-38	40.0	30.00	28.6
STA-39	40.0	30.00	28.6
B16	50.0	80.00	35.4
C20	50.0	30.00	35.4
B15	50.0	90.00	35.4
STA-29	60.0	35.00	43.1
STA-30	60.0	40.00	43.1
HLH-9	60.0	15.00	43.1
HLH-10	60.0	15.00	43.1
D15	72.5	100.00	53.5
D7	72.5	100.00	53.5
C4	73.5	30.00	54.4
C5	73.5	20.00	54.4
C44	73.5	25.00	54.4
C45	73.5	15.00	54.4
B5	73.5	98.00	54.4
B4	73.5	95.00	54.4
HLH-3	80.0	15.00	60.0
STA-23	80.0	95.00	60.0
STA-24	80.0	80.00	60.0
HLH-4	80.0	20.00	60.0
C16	87.0	30.00	66.0
C17	87.0	55.00	66.0
HLH-18	100.0	100.00	76.5
C49	100.0	40.00	76.5
C8	100.0	98.00	76.5
C9	100.0	90.00	76.5
C48	100.0	35.00	76.5
HLH-16	100.0	100.00	76.5
HLH-17	100.0	100.00	76.5
B18	110.0	100.00	83.5
B17	110.0	100.00	83.5
HLH-19	120.0	100.00	89.4
STA-25	120.0	100.00	89.4
STA-26	120.0	95.00	89.4
HLH-6	120.0	80.00	89.4
C13	150.0	100.00	98.3
C52	150.0	60.00	98.3
C53	150.0	55.00	98.3
C12	150.0	100.00	98.3
STA-32	160.0	100.00	99.3
STA-33	160.0	100.00	99.3
HLH-11	160.0	100.00	99.3
HLH-12	160.0	100.00	99.3
D14	212.0	100.00	99.9
D5	212.0	100.00	99.9
B8	212.0	100.00	99.9
C46	212.0	97.00	99.9
C47	212.0	98.00	99.9
C6	212.0	100.00	99.9
HLH-13	212.0	100.00	99.9
HLH-14	212.0	100.00	99.9
C7	212.0	100.00	99.9
B9	212.0	100.00	99.9
C67	240.0	100.00	99.9
C18	275.0	100.00	99.9
C19	275.0	100.00	99.9
C54	275.0	100.00	99.9
C55	275.0	100.00	99.9

TRANSITION REGION, CALCULATED VALUES

% SHEAR FRACTURE	CALCULATED TEMPERATURE(F)	/	TEMPERATURE (F)	CALCULATED SHEAR FRACTURE(%)
2.0	-50.1	/	-50.0	2.0
5.0	-23.5	/	-45.0	2.4
10.0	-.8	/	-40.0	2.9
15.0	13.8	/	-35.0	3.4
50.0	68.4	/	-30.0	4.0
85.0	112.2	/	-25.0	4.8
90.0	121.3	/	-20.0	5.6
95.0	134.0	/	-15.0	6.5
98.0	147.5	/	-10.0	7.6
		/	-5.0	8.8
		/	.0	10.2
		/	5.0	11.8
		/	10.0	13.5
		/	15.0	15.5
		/	20.0	17.6
		/	25.0	20.0
		/	30.0	22.6
		/	35.0	25.5
		/	40.0	28.6
		/	45.0	31.9

APPENDIX B, TABLE 1B

COMPARISON OF LONGITUDINAL AND TRANSVERSE CVN IMPACT-TEST RESULTS FOR SIX STEEL PLATES TAKEN FROM FOUR ACCIDENTS.
CALCULATIONS FOR ENERGY ABSORPTION DATA OF 106 SPECIMENS, LT ORIENTATION.
THE CALCULATED CURVES WERE COMPUTED FROM WEIGHTED MEAN VALUES FOR DATA AT EACH TEST TEMPERATURE.

SPECIMEN	TEMPERATURE(F)	OBSERVED ENERGY ABSORPTION(FT-LB)	CALCULATED ENERGY ABSORPTION(FT-LB)
D6	-320.0	1.00	.0
D16	-320.0	1.00	.0
D10	-120.0	2.00	.4
D2	-120.0	2.00	.4
B14	-120.0	1.50	.4
C15	-120.0	1.50	.4
HLH-15	-100.0	2.50	.9
STA-34	-100.0	6.00	.9
D13	-82.0	5.00	1.6
D6	-82.0	5.00	1.6
C1	-50.0	2.00	4.0
C3	-50.0	3.00	4.0
C2	-50.0	3.50	4.0
B2	-50.0	2.00	4.0
C41	-50.0	2.00	4.0
C42	-50.0	2.00	4.0
C43	-50.0	2.00	4.0
HLH-1	-50.0	3.50	4.0
HLH-2	-50.0	2.50	4.0
B3	-50.0	2.00	4.0
STA-21	-50.0	4.00	4.0
STA-22	-50.0	4.00	4.0
B1	-50.0	2.00	4.0
D12	-40.0	15.00	5.2
D4	-40.0	14.00	5.2
D3	-25.0	25.50	7.4
D11	-25.0	21.00	7.4
B10	-10.0	4.00	10.3
B11	-10.0	4.50	10.3
STA-35	-10.0	27.00	10.3
STA-36	-10.0	11.00	10.3
D1	-2.0	61.00	12.1
D9	-2.0	31.50	12.1
C14	.0	4.00	12.6
B7	12.0	23.00	15.8
B6	12.0	14.00	15.8
HLH-8	15.0	6.00	16.7
HLH-7	15.0	11.00	16.7
STA-28	15.0	14.00	16.7
STA-37	15.0	24.00	16.7
C11	25.0	18.00	19.8
C10	25.0	10.00	19.8
C50	25.0	4.00	19.8
C51	25.0	5.00	19.8
B13	30.0	27.50	21.4
B12	30.0	10.50	21.4
B19	30.0	21.50	21.4
STA-38	40.0	30.50	25.0
STA-39	40.0	30.50	25.0
B16	50.0	36.50	28.8
C20	50.0	35.00	28.8
B15	50.0	36.50	28.8
STA-29	60.0	37.00	32.8
STA-30	60.0	45.50	32.8
HLH-9	60.0	21.50	32.8
HLH-10	60.0	19.50	32.8
D15	72.5	72.50	37.8
D7	72.5	63.50	37.8
C4	73.5	37.50	38.3
C5	73.5	26.00	38.3
C44	73.5	11.00	38.3
C45	73.5	12.00	38.3
B5	73.5	44.50	38.3
B4	73.5	41.50	38.3
HLH-3	80.0	28.50	40.9
STA-23	80.0	72.50	40.9
STA-24	80.0	63.50	40.9
HLH-4	80.0	26.00	40.9
C16	87.0	41.00	43.7
C17	87.0	47.50	43.7
HLH-18	100.0	54.00	48.7
C49	100.0	15.00	48.7
C8	100.0	74.50	48.7
C9	100.0	62.50	48.7
C48	100.0	21.00	48.7
HLH-16	100.0	55.00	48.7
HLH-17	100.0	53.00	48.7
B18	110.0	47.00	52.3
B17	110.0	44.00	52.3
HLH-19	120.0	52.00	55.4
STA-25	120.0	75.50	55.4
STA-26	120.0	72.50	55.4
HLH-6	120.0	42.00	55.4
C13	150.0	67.00	62.4
C52	150.0	50.00	62.4
C53	150.0	37.50	62.4
C12	150.0	75.00	62.4
STA-32	160.0	74.00	63.8
STA-33	160.0	74.00	63.8
HLH-11	160.0	52.00	63.8
HLH-12	160.0	51.00	63.8
D14	212.0	61.50	66.6
D5	212.0	60.00	66.6
B8	212.0	45.00	66.6
C46	212.0	80.00	66.6
C47	212.0	81.50	66.6
C6	212.0	73.00	66.6
HLH-13	212.0	53.00	66.6
HLH-14	212.0	52.00	66.6
C7	212.0	79.00	66.6
B9	212.0	44.50	66.6
C67	240.0	85.00	66.8
C18	275.0	69.00	66.8
C19	275.0	71.00	66.8
C54	275.0	65.50	66.8
C55	275.0	75.50	66.8

TRANSITION REGION, CALCULATED VALUES

ENERGY ABSORPTION	CALCULATED TEMPERATURE(F)	/	TEMPERATURE (F)	CALCULATED ENERGY ABSORPTION(FT-LB)
5.0	-41.6	/	-40.0	5.2
10.0	-11.4	/	-30.0	6.6
15.0	9.2	/	-20.0	8.3
20.0	25.7	/	-10.0	10.3
25.0	40.0	/	.0	12.6
30.0	53.1	/	10.0	15.2
35.0	65.5	/	20.0	18.2
40.0	77.8	/	30.0	21.4
45.0	90.2	/	40.0	25.0
50.0	103.5	/	50.0	28.8
55.0	118.6	/	60.0	32.8
60.0	137.7	/	70.0	36.8
65.0	171.6	/	80.0	40.9
		/	90.0	44.9
		/	100.0	48.7
		/	110.0	52.3
		/	120.0	55.4
		/	130.0	58.2
		/	140.0	60.5
		/	150.0	62.4

COMPARISON OF LONGITUDINAL AND TRANSVERSE CVN IMPACT-TEST RESULTS FOR SIX STEEL PLATES TAKEN FROM FOUR ACCIDENTS.
CALCULATIONS FOR LATERAL EXPANSION DATA OF 106 SPECIMENS, LT ORIENTATION.
THE CALCULATED CURVES WERE COMPUTED FROM WEIGHTED MEAN VALUES FOR DATA AT EACH TEST TEMPERATURE.

SPECIMEN	TEMPERATURE(F)	OBSERVED LATERAL EXPANSION (MILS)	CALCULATED LATERAL EXPANSION (MILS)
D6	-320.0	1.00	.0
D16	-320.0	1.00	.0
D10	-120.0	2.00	.0
D2	-120.0	2.50	.0
B14	-120.0	.00	.0
C15	-120.0	2.00	.0
HLH-15	-100.0	4.00	.2
STA-34	-100.0	3.50	.2
D13	-82.0	3.50	.6
D8	-82.0	5.00	.6
C1	-50.0	2.00	2.6
C3	-50.0	2.00	2.6
C2	-50.0	2.00	2.6
B2	-50.0	2.00	2.6
C41	-50.0	1.00	2.6
C42	-50.0	1.00	2.6
C43	-50.0	2.00	2.6
HLH-1	-50.0	2.00	2.6
HLH-2	-50.0	1.00	2.6
B3	-50.0	.00	2.6
STA-21	-50.0	2.00	2.6
STA-22	-50.0	2.00	2.6
B1	-50.0	.00	2.6
D12	-40.0	16.00	3.6
D4	-40.0	10.00	3.6
D3	-25.0	25.50	5.7
D11	-25.0	16.00	5.7
B10	-10.0	3.00	8.5
B11	-10.0	4.00	8.5
STA-35	-10.0	14.00	8.5
STA-36	-10.0	22.00	8.5
D1	-2.0	49.50	10.3
D9	-2.0	29.50	10.3
C14	.0	3.00	10.8
B7	12.0	21.00	13.9
B6	12.0	15.00	13.9
HLH-8	15.0	7.50	14.8
HLH-7	15.0	10.50	14.8
STA-28	15.0	12.00	14.8
STA-37	15.0	20.00	14.8
C11	25.0	20.00	17.9
C10	25.0	13.00	17.9
C50	25.0	6.00	17.9
C51	25.0	11.00	17.9
B13	30.0	27.00	19.5
B12	30.0	10.00	19.5
B19	30.0	24.00	19.5
STA-38	40.0	30.00	23.0
STA-39	40.0	33.00	23.0
B16	50.0	32.00	26.7
C20	50.0	38.00	26.7
B15	50.0	33.00	26.7
STA-29	60.0	30.00	30.5

SPECIMEN	TEMPERATURE(F)	OBSERVED LATERAL EXPANSION (MILS)	CALCULATED LATERAL EXPANSION (MILS)
STA-30	60.0	37.00	30.5
HLH-9	60.0	22.00	30.5
HLH-10	60.0	23.00	30.5
D15	72.5	56.50	35.3
D7	72.5	58.50	35.3
C4	73.5	40.00	35.7
C5	73.5	30.00	35.7
C44	73.5	12.00	35.7
C45	73.5	18.00	35.7
B5	73.5	43.00	35.7
B4	73.5	38.00	35.7
HLH-3	80.0	24.00	38.2
STA-23	80.0	56.00	38.2
STA-24	80.0	51.00	38.2
HLH-4	80.0	25.00	38.2
C16	87.0	45.00	42.9
C17	87.0	47.00	42.9
HLH-18	100.0	46.00	45.4
C49	100.0	18.00	45.4
C8	100.0	67.00	45.4
C9	100.0	57.00	45.4
C46	100.0	27.00	45.4
HLH-16	100.0	46.00	45.4
HLH-17	100.0	45.00	45.4
B18	110.0	44.00	49.6
B17	110.0	44.00	49.6
HLH-19	120.0	54.00	51.5
STA-25	120.0	54.00	51.5
STA-26	120.0	54.00	51.5
HLH-6	120.0	36.00	51.5
C13	150.0	68.00	58.2
C52	150.0	50.00	58.2
C53	150.0	68.00	58.2
C12	150.0	66.00	58.2
STA-32	160.0	64.00	59.4
STA-33	160.0	64.00	59.4
HLH-11	160.0	46.00	59.4
HLH-12	160.0	47.50	59.4
D14	212.0	49.50	62.5
D5	212.0	65.50	62.5
B8	212.0	53.00	62.5
C46	212.0	71.00	62.5
C47	212.0	71.00	62.5
C6	212.0	70.00	62.5
HLH-13	212.0	48.00	62.5
HLH-14	212.0	50.00	62.5
C7	212.0	71.00	62.5
B9	212.0	43.00	62.5
C67	240.0	78.00	62.8
C18	275.0	75.00	62.9
C19	275.0	69.00	62.9
C54	275.0	66.00	62.9
C55	275.0	52.00	62.9

TRANSITION REGION, CALCULATED VALUES

LATERAL EXPANSION(MILS)	CALCULATED TEMPERATURE(F)	/	TEMPERATURE (F)	CALCULATED LATERAL EXPANSION(MILS)
5.0	-29.7	/	-20.0	6.6
10.0	-3.3	/	-15.0	7.5
15.0	15.7	/	-10.0	8.5
20.0	31.4	/	-5.0	9.6
25.0	45.5	/	.0	10.8
30.0	58.8	/	5.0	12.0
35.0	71.7	/	10.0	13.4
40.0	84.9	/	15.0	14.8
45.0	99.9	/	20.0	16.3
50.0	114.7	/	25.0	17.9
55.0	134.2	/	30.0	19.5
60.0	165.4	/	35.0	21.2
		/	40.0	23.0
		/	45.0	24.9
		/	50.0	26.7
		/	55.0	28.6
		/	60.0	30.5
		/	65.0	32.4
		/	70.0	34.3
		/	75.0	36.3

APPENDIX B, TABLE 2A

COMPARISON OF LONGITUDINAL AND TRANSVERSE CVN IMPACT-TEST RESULTS FOR SIX STEEL PLATES TAKEN FROM FOUR ACCIDENTS.
CALCULATIONS FOR SHEAR FRACTURE APPEARANCE DATA OF 103 SPECIMENS, TL ORIENTATION.

SPECIMEN	TEMPERATURE(F)	OBSERVED SHEAR FRACTURE (%)	CALCULATED SHEAR FRACTURE (%)
B6	-320.0	.00	.0
B16	-320.0	.00	.0
B10	-120.0	.00	1.0
B2	-120.0	.00	1.0
B37	-120.0	.00	1.0
C35	-120.0	.00	1.0
SLC-54	-100.0	.00	1.7
B6	-82.0	.00	2.9
B13	-82.0	.00	2.9
B22	-50.0	.00	6.2
C21	-50.0	.00	6.2
C22	-50.0	.00	6.2
C23	-50.0	.00	6.2
B23	-50.0	.00	6.2
C56	-50.0	.00	6.2
C57	-50.0	.00	6.2
C58	-50.0	.00	6.2
HTF-61	-50.0	.00	6.2
HTF-62	-50.0	.00	6.2
SLC-44	-50.0	.00	6.2
SLC-45	-50.0	.00	6.2
B24	-50.0	.00	6.2
B4	-40.0	10.00	7.8
B12	-40.0	35.00	7.8
B11	-25.0	50.00	10.8
B3	-25.0	45.00	10.8
B36	-15.0	2.00	13.2
B35	-15.0	5.00	13.2
SLC-55	-10.0	5.00	14.6
SLC-56	-10.0	5.00	14.6
B9	-2.0	70.00	17.0
B1	-2.0	80.00	17.0
B33	.0	15.00	17.7
C36	.0	3.00	17.7
B34	.0	10.00	17.7
B31	10.0	15.00	21.2
B32	10.0	20.00	21.2
SLC-51	15.0	20.00	23.1
HTF-67	15.0	5.00	23.1
HTF-68	15.0	5.00	23.1
SLC-50	15.0	20.00	23.1
C31	25.0	30.00	27.3
C37	25.0	5.00	27.3
C65	25.0	2.00	27.3
C66	25.0	2.00	27.3
C30	25.0	5.00	27.3
B28	33.0	55.00	31.0
B27	33.0	85.00	31.0
SLC-57	40.0	20.00	34.5
SLC-58	40.0	20.00	34.5
B38	50.0	90.00	39.8
B39	50.0	85.00	39.8
C40	50.0	20.00	39.8
HTF-70	60.0	10.00	45.5
SLC-41	60.0	60.00	45.5
SLC-42	60.0	70.00	45.5
HTF-69	60.0	10.00	45.5
B7	72.5	100.00	52.0
B15	72.5	100.00	52.0
C24	73.5	30.00	53.5
C25	73.5	30.00	53.5
B25	73.5	95.00	53.5
C59	73.5	30.00	53.5
C60	73.5	25.00	53.5
B26	73.5	95.00	53.5
SLC-47	80.0	95.00	57.4
HTF-63	80.0	25.00	57.4
HTF-64	80.0	20.00	57.4
SLC-46	80.0	90.00	57.4
C64	100.0	25.00	69.4
C29	100.0	50.00	69.4
C28	100.0	65.00	69.4
HTF-75	100.0	50.00	69.4
HTF-76	100.0	40.00	69.4
C63	100.0	40.00	69.4
B40	110.0	100.00	75.0
SLC-49	120.0	98.00	80.1
HTF-65	120.0	90.00	80.1
HTF-66	120.0	80.00	80.1
SLC-48	120.0	100.00	80.1
C39	125.0	99.00	82.5
C38	125.0	98.00	82.5
C70	150.0	55.00	91.8
C34	150.0	95.00	91.8
C33	150.0	100.00	91.8
C69	150.0	45.00	91.8
HTF-72	160.0	98.00	94.3
SLC-52	160.0	100.00	94.3
SLC-53	160.0	100.00	94.3
HTF-71	160.0	98.00	94.3
HTF-74	212.0	100.00	99.2
B14	212.0	100.00	99.2
B5	212.0	100.00	99.2
B29	212.0	100.00	99.2
C26	212.0	100.00	99.2
C61	212.0	95.00	99.2
C62	212.0	97.00	99.2
C27	212.0	100.00	99.2
B30	212.0	100.00	99.2
HTF-73	212.0	100.00	99.2
C73	240.0	99.00	99.4
C71	275.0	100.00	99.5
C72	275.0	100.00	99.5

TRANSITION REGION, CALCULATED VALUES

TEMPERATURE (F)	CALCULATED SHEAR FRACTURE(%)
-90.0	2.3
-80.0	3.0
-70.0	3.9
-60.0	4.9
-50.0	6.2
-40.0	7.8
-30.0	9.7
-20.0	12.0
-10.0	14.6
.0	17.7
10.0	21.2
20.0	25.2
30.0	29.6
40.0	34.5
50.0	39.8
60.0	45.5
70.0	51.4
80.0	57.4
90.0	63.5
100.0	69.4

% SHEAR FRACTURE	CALCULATED TEMPERATURE(F)
2.0	-95.1
5.0	-59.5
10.0	-28.7
15.0	-8.7
50.0	67.7
85.0	130.8
90.0	144.2
95.0	163.5
98.0	185.7

COMPARISON OF LONGITUDINAL AND TRANSVERSE CVN IMPACT-TEST
RESULTS FOR SIX STEEL PLATES TAKEN FROM FOUR ACCIDENTS.
CALCULATIONS FOR ENERGY ABSORPTION DATA OF
103 SPECIMENS, TL ORIENTATION.

SPECIMEN	TEMPERATURE(F)	OBSERVED ENERGY ABSORPTION(FT-LB)	CALCULATED ENERGY ABSORPTION(FT-LB)
B6	-320.0	1.00	.0
B16	-320.0	.50	.0
B10	-120.0	2.50	1.5
B2	-120.0	2.00	1.5
B37	-120.0	1.00	1.5
C35	-120.0	1.50	1.5
SLC-54	-100.0	2.00	2.5
B5	-82.0	4.50	3.6
B13	-82.0	8.50	3.6
B22	-50.0	2.00	6.2
C21	-50.0	2.00	6.2
C22	-50.0	2.00	6.2
C23	-50.0	3.00	6.2
B23	-50.0	2.50	6.2
C56	-50.0	2.00	6.2
C57	-50.0	2.00	6.2
C58	-50.0	2.00	6.2
HTF-61	-50.0	3.50	6.2
HTF-62	-50.0	4.50	6.2
SLC-44	-50.0	6.00	6.2
SLC-45	-50.0	2.50	6.2
B24	-50.0	2.00	6.2
B4	-40.0	13.00	7.3
B12	-40.0	17.00	7.3
B11	-25.0	26.50	9.0
B3	-25.0	20.50	9.0
B36	-15.0	4.00	10.2
B35	-15.0	5.00	10.2
SLC-55	-10.0	11.00	10.8
SLC-56	-10.0	13.00	10.8
B9	-2.0	28.50	11.9
B1	-2.0	34.00	11.9
B33	.0	11.00	12.2
C36	.0	8.00	12.2
B34	.0	6.00	12.2
B31	10.0	9.00	13.6
B32	10.0	11.00	13.6
SLC-51	15.0	18.00	14.4
HTF-67	15.0	7.00	14.4
HTF-68	15.0	7.50	14.4
SLC-50	15.0	18.00	14.4
C31	25.0	15.50	15.9
C37	25.0	11.00	15.9
C65	25.0	3.50	15.9
C66	25.0	4.50	15.9
C30	25.0	7.50	15.9
B28	33.0	15.50	17.1
B27	33.0	19.00	17.1
SLC-57	40.0	22.00	18.2
SLC-58	40.0	25.00	18.2
B38	50.0	22.00	19.8
B39	50.0	21.00	19.8
C40	50.0	11.00	19.8
HTF-70	60.0	10.50	21.4
SLC-41	60.0	27.00	21.4
SLC-42	60.0	33.50	21.4
HTF-69	60.0	12.00	21.4
B7	72.5	39.00	23.4
B15	72.5	42.00	23.4
C24	73.5	12.50	23.6
C25	73.5	18.50	23.6
B25	73.5	24.50	23.6
C59	73.5	15.00	23.6
C60	73.5	9.00	23.6
B26	73.5	24.50	23.6
SLC-47	80.0	31.00	24.6
HTF-63	80.0	19.00	24.6
HTF-64	80.0	16.00	24.6
SLC-46	80.0	32.00	24.6
C64	100.0	23.50	27.7
C29	100.0	22.00	27.7
C28	100.0	24.50	27.7
HTF-75	100.0	24.00	27.7
HTF-76	100.0	19.00	27.7
C63	100.0	18.00	27.7
B40	110.0	26.00	29.2
SLC-49	120.0	36.50	30.6
HTF-65	120.0	32.00	30.6
HTF-66	120.0	27.00	30.6
SLC-48	120.0	38.00	30.6
C39	125.0	34.00	31.2
C38	125.0	34.50	31.2
C70	150.0	43.00	34.2
C34	150.0	33.50	34.2
C33	150.0	34.00	34.2
C69	150.0	31.00	34.2
HTF-72	160.0	37.50	35.3
SLC-52	160.0	38.00	35.3
SLC-53	160.0	37.50	35.3
HTF-71	160.0	35.00	35.3
HTF-74	212.0	37.50	39.1
B14	212.0	35.50	39.1
B5	212.0	42.50	39.1
B29	212.0	24.50	39.1
C26	212.0	35.00	39.1
C61	212.0	55.00	39.1
C62	212.0	56.00	39.1
C27	212.0	34.00	39.1
B30	212.0	24.00	39.1
HTF-73	212.0	37.00	39.1
C73	240.0	53.00	40.2
C71	275.0	54.00	41.0
C72	275.0	53.00	41.0

TRANSITION REGION, CALCULATED VALUES

ENERGY ABSORPTION	CALCULATED TEMPERATURE(F)	/	TEMPERATURE (F)	CALCULATED ENERGY ABSORPTION(FT-LB)
5.0	-63.5	/	-60.0	5.3
10.0	-16.5	/	-50.0	6.2
15.0	19.3	/	-40.0	7.3
20.0	51.1	/	-30.0	8.4
25.0	82.4	/	-20.0	9.6
30.0	115.9	/	-10.0	10.9
35.0	157.3	/	.0	12.2
40.0	233.0	/	10.0	13.6
		/	20.0	15.1
		/	30.0	16.6
		/	40.0	18.2
		/	50.0	19.8
		/	60.0	21.4
		/	70.0	23.0
		/	80.0	24.6
		/	90.0	26.2
		/	100.0	27.7
		/	110.0	29.2
		/	120.0	30.6
		/	130.0	31.9

COMPARISON OF LONGITUDINAL AND TRANSVERSE CVN IMPACT-TEST RESULTS FOR SIX STEEL PLATES TAKEN FROM FOUR ACCIDENTS.
CALCULATIONS FOR LATERAL EXPANSION DATA OF
103 SPECIMENS, TL ORIENTATION.

SPECIMEN	TEMPERATURE(F)	OBSERVED LATERAL EXPANSION (MILS)	CALCULATED LATERAL EXPANSION (MILS)
B6	-320.0	1.50	.0
B16	-320.0	2.50	.0
B10	-120.0	3.50	1.0
B2	-120.0	6.50	1.0
B37	-120.0	.00	1.0
C35	-120.0	2.00	1.0
SLC-54	-100.0	1.50	1.7
B8	-80.0	4.50	2.6
B13	-80.0	5.00	2.6
B22	-50.0	.20	5.0
C21	-50.0	1.00	5.0
C22	-50.0	1.00	5.0
C23	-50.0	2.00	5.0
B23	-50.0	1.80	5.0
C56	-50.0	1.00	5.0
C57	-50.0	1.00	5.0
C58	-50.0	1.00	5.0
HTF-61	-50.0	1.00	5.0
HTF-62	-50.0	1.00	5.0
SLC-44	-50.0	4.50	5.0
SLC-45	-50.0	2.00	5.0
B24	-50.0	.00	5.0
B4	-40.0	16.00	6.0
B12	-40.0	19.00	6.0
B11	-25.0	26.50	7.7
B3	-25.0	20.00	7.7
B36	-15.0	2.00	9.0
B35	-15.0	4.00	9.0
SLC-55	-10.0	1.30	9.7
SLC-56	-10.0	1.20	9.7
B9	-2.0	29.50	10.8
B1	-2.0	35.00	10.8
B33	.0	11.00	11.1
C36	.0	12.00	11.1
B34	.0	6.00	11.1
B31	10.0	13.00	12.7
B32	10.0	12.00	12.7
SLC-51	15.0	16.00	13.5
HTF-67	15.0	7.00	13.5
HTF-68	15.0	8.00	13.5
SLC-50	15.0	15.00	13.5
C31	25.0	17.00	15.2
C37	25.0	15.00	15.2
C65	25.0	7.00	15.2
C66	25.0	6.00	15.2
C30	25.0	12.00	15.2
B28	33.0	16.00	16.7
B27	33.0	21.00	16.7
SLC-57	40.0	24.00	18.0
SLC-58	40.0	20.00	18.0
B38	50.0	24.00	19.9
B39	50.0	22.00	19.9
C40	50.0	16.00	19.9
HTF-70	60.0	11.00	21.9
SLC-41	60.0	26.00	21.9
SLC-42	60.0	34.00	21.9
HTF-69	60.0	14.00	21.9
B7	72.5	37.50	24.5
B15	72.5	43.50	24.5
C24	73.5	16.00	24.7
C25	73.5	23.00	24.7
B25	73.5	26.00	24.7
C59	73.5	22.00	24.7
C60	73.5	11.00	24.7
B26	73.5	27.00	24.7
SLC-47	80.0	32.00	26.1
HTF-63	80.0	22.00	26.1
HTF-64	80.0	19.00	26.1
SLC-46	80.0	32.00	26.1
C64	100.0	26.00	30.2
C29	100.0	24.00	30.2
C28	100.0	32.00	30.2
HTF-75	100.0	27.00	30.2
HTF-76	100.0	21.00	30.2
C63	100.0	26.00	30.2
B40	110.0	27.00	32.2
SLC-49	120.0	37.00	34.1
HTF-65	120.0	23.00	34.1
HTF-66	120.0	28.00	34.1
SLC-48	120.0	37.00	34.1
C39	125.0	46.00	35.0
C38	125.0	48.00	35.0
C70	150.0	46.00	39.3
C34	150.0	44.00	39.3
C33	150.0	50.00	39.3
C69	150.0	48.00	39.3
HTF-72	160.0	37.00	40.8
SLC-52	160.0	38.00	40.8
SLC-53	160.0	39.00	40.8
HTF-71	160.0	35.00	40.8
HTF-74	212.0	38.00	46.4
B14	212.0	39.50	46.4
B5	212.0	50.00	46.4
B29	212.0	25.00	46.4
C26	212.0	47.00	46.4
C61	212.0	59.00	46.4
C62	212.0	61.00	46.4
C27	212.0	48.00	46.4
B30	212.0	27.00	46.4
HTF-73	212.0	39.00	46.4
C73	240.0	64.00	48.0
C71	275.0	63.00	49.0
C72	275.0	74.00	49.0

TRANSITION REGION, CALCULATED VALUES

LATERAL EXPANSION(MILS)	CALCULATED TEMPERATURE(F)	/	TEMPERATURE (F)	CALCULATED LATERAL EXPANSION(MILS)
5.0	-50.4	/	-50.0	5.0
10.0	-7.5	/	-40.0	6.0
15.0	23.7	/	-30.0	7.1
20.0	50.3	/	-20.0	8.3
25.0	74.9	/	-10.0	9.7
30.0	99.2	/	.0	11.1
35.0	124.8	/	10.0	12.7
40.0	154.3	/	20.0	14.4
45.0	194.7	/	30.0	16.1
		/	40.0	18.0
		/	50.0	19.9
		/	60.0	21.9
		/	70.0	24.0
		/	80.0	26.1
		/	90.0	28.1
		/	100.0	30.2
		/	110.0	32.2
		/	120.0	34.1
		/	130.0	35.9
		/	140.0	37.7

APPENDIX C

CVN Results of LT and TL Specimens of Combined Data from Three Head-Plate Steels

COMPARISON OF HEAD-PLATE AND SHELL-PLATE CVN IMPACT-TEST RESULTS FOR LONGITUDINAL SPECIMENS OF LT ORIENTATION. CALCULATIONS FOR SHEAR FRACTURE APPEARANCE DATA OF 50 HEAD-PLATE SPECIMENS.

THE CALCULATED CURVES WERE COMPUTED FROM WEIGHTED MEAN VALUES FOR DATA AT EACH TEST TEMPERATURE.

SPECIMEN	TEMPERATURE(F)	OBSERVED SHEAR FRACTURE (%)	CALCULATED SHEAR FRACTURE (%)
D6	-320.0	.00	.0
D16	-320.0	.00	.0
D10	-120.0	.00	.0
D2	-120.0	.00	.0
HLH-15	-100.0	.00	.0
D8	-82.0	.00	.0
D13	-82.0	.00	.0
C42	-50.0	.00	.0
C43	-50.0	.00	.0
HLH-1	-50.0	.00	.0
HLH-2	-50.0	.00	.0
C41	-50.0	.00	.0
D4	-40.0	5.00	.0
D12	-40.0	5.00	.0
D11	-25.0	20.00	.0
D3	-25.0	30.00	.0
D9	-2.0	45.00	.0
D1	-2.0	95.00	.0
HLH-8	15.0	5.00	.0
HLH-7	15.0	.00	.0
C51	25.0	2.00	.0
C50	25.0	2.00	.0
HLH-10	60.0	15.00	15.0
HLH-9	60.0	15.00	15.0
D15	72.5	100.00	90.0
D7	72.5	100.00	90.0
C45	73.5	15.00	93.5
C44	73.5	25.00	93.5
HLH-4	80.0	20.00	99.8
HLH-3	80.0	15.00	99.8
C49	100.0	40.00	99.9
C48	100.0	35.00	99.9
HLH-16	100.0	100.00	99.9
HLH-17	100.0	100.00	99.9
HLH-18	100.0	100.00	99.9
HLH-6	120.0	80.00	99.9
HLH-19	120.0	100.00	99.9
C52	150.0	60.00	99.9
C53	150.0	55.00	99.9
HLH-12	160.0	100.00	99.9
HLH-11	160.0	100.00	99.9
HLH-14	212.0	100.00	99.9
D5	212.0	100.00	99.9
C46	212.0	97.00	99.9
C47	212.0	98.00	99.9
D14	212.0	100.00	99.9
HLH-13	212.0	100.00	99.9
C67	240.0	100.00	99.9
C55	275.0	100.00	99.9
C54	275.0	100.00	99.9

TRANSITION REGION, CALCULATED VALUES

% SHEAR FRACTURE	CALCULATED TEMPERATURE(F)	/	TEMPERATURE (F)	CALCULATED SHEAR FRACTURE(%)
2.0	53.2	/	60.0	15.0
5.0	56.0	/	65.0	41.5
10.0	58.4	/	70.0	77.0
15.0	60.0	/		
50.0	66.2	/		
85.0	71.4	/		
90.0	72.5	/		
95.0	74.0	/		
98.0	75.7	/		

APPENDIX C, TABLE 1B

COMPARISON OF HEAD-PLATE AND SHELL-PLATE CVN IMPACT-TEST RESULTS FOR LONGITUDINAL SPECIMENS OF LT ORIENTATION.
CALCULATIONS FOR ENERGY ABSORPTION DATA OF 50 HEAD-PLATE SPECIMENS.

THE CALCULATED CURVES WERE COMPUTED FROM WEIGHTED MEAN VALUES FOR DATA AT EACH TEST TEMPERATURE.

SPECIMEN	TEMPERATURE(F)	OBSERVED ENERGY ABSORPTION(FT-LB)	CALCULATED ENERGY ABSORPTION(FT-LB)
D6	-320.0	1.00	1.0
D16	-320.0	1.00	1.0
D10	-120.0	2.00	1.7
D2	-120.0	2.00	1.7
HLH-15	-100.0	2.50	2.3
D8	-82.0	5.00	3.1
D13	-82.0	5.00	3.1
C42	-50.0	2.00	5.5
C43	-50.0	2.00	5.5
HLH-1	-50.0	3.50	5.5
HLH-2	-50.0	2.50	5.5
C41	-50.0	2.00	5.5
D4	-40.0	14.00	6.6
D12	-40.0	15.00	6.6
D11	-25.0	21.00	8.4
D3	-25.0	25.50	8.4
D9	-2.0	31.50	12.1
D1	-2.0	61.00	12.1
HLH-8	15.0	6.00	15.5
HLH-7	15.0	11.00	15.5
C51	25.0	5.00	17.7
C50	25.0	4.00	17.7
HLH-10	60.0	19.50	27.0
HLH-9	60.0	21.50	27.0
D15	72.5	72.50	30.7
D7	72.5	63.50	30.7
C45	73.5	12.00	31.0
C44	73.5	11.00	31.0
HLH-4	80.0	26.00	33.0
HLH-3	80.0	28.50	33.0
C49	100.0	15.00	39.2
C48	100.0	21.00	39.2
HLH-16	100.0	55.00	39.2
HLH-17	100.0	53.00	39.2
HLH-18	100.0	54.00	39.2
HLH-6	120.0	42.00	45.5
HLH-19	120.0	52.00	45.5
C52	150.0	50.00	53.9
C53	150.0	37.50	53.9
HLH-12	160.0	51.00	56.4
HLH-11	160.0	52.00	56.4
HLH-14	212.0	52.00	65.4
D5	212.0	60.00	65.4
C46	212.0	80.00	65.4
C47	212.0	81.50	65.4
D14	212.0	61.50	65.4
HLH-13	212.0	53.00	65.4
C67	240.0	85.00	67.8
C55	275.0	75.50	69.0
C54	275.0	65.50	69.0

TRANSITION REGION. CALCULATED VALUES

ENERGY ABSORPTION	CALCULATED TEMPERATURE(F)	/	TEMPERATURE (F)	CALCULATED ENERGY ABSORPTION(FT-LB)
5.0	-55.7	/	-50.0	5.5
10.0	-14.5	/	-40.0	6.6
15.0	12.8	/	-30.0	7.8
20.0	34.4	/	-20.0	9.2
25.0	53.2	/	-10.0	10.7
30.0	70.3	/	.0	12.5
35.0	86.5	/	10.0	14.4
40.0	102.4	/	20.0	16.6
45.0	118.5	/	30.0	18.9
50.0	135.5	/	40.0	21.4
55.0	154.2	/	50.0	24.1
60.0	176.6	/	60.0	27.0
65.0	208.4	/	70.0	29.9
		/	80.0	33.0
		/	90.0	36.1
		/	100.0	39.2
		/	110.0	42.4
		/	120.0	45.5
		/	130.0	48.4
		/	140.0	51.3

APPENDIX C, TABLE 1C

COMPARISON OF HEAD-PLATE AND SHELL-PLATE CVN IMPACT-TEST RESULTS FOR LONGITUDINAL SPECIMENS OF LT ORIENTATION.
CALCULATIONS FOR LATERAL EXPANSION DATA OF 50 HEAD-PLATE SPECIMENS.
THE CALCULATED CURVES WERE COMPUTED FROM WEIGHTED MEAN VALUES FOR DATA AT EACH TEST TEMPERATURE.

SPECIMEN	TEMPERATURE(F)	OBSERVED LATERAL EXPANSION (MILS)	CALCULATED LATERAL EXPANSION (MILS)
D6	-320.0	1.00	1.0
D16	-320.0	1.00	1.0
D10	-120.0	2.00	1.5
D2	-120.0	2.50	1.5
HLH-15	-100.0	4.00	2.0
D8	-82.0	5.00	2.7
D13	-82.0	3.50	2.7
C42	-50.0	1.00	4.7
C43	-50.0	2.00	4.7
HLH-1	-50.0	2.00	4.7
HLH-2	-50.0	1.00	4.7
C41	-50.0	1.00	4.7
D4	-40.0	10.00	5.6
D12	-40.0	16.00	5.6
D11	-25.0	16.00	7.3
D3	-25.0	25.50	7.3
D9	-2.0	29.50	10.7
D1	-2.0	49.50	10.7
HLH-8	15.0	7.50	13.8
HLH-7	15.0	10.50	13.8
C51	25.0	11.00	16.0
C50	25.0	6.00	16.0
HLH-10	60.0	23.00	24.8
HLH-9	60.0	22.00	24.8
D15	72.5	56.50	28.4
D7	72.5	58.50	28.4
C45	73.5	18.00	28.7
C44	73.5	12.00	28.7
HLH-4	80.0	25.00	30.7
HLH-3	80.0	24.00	30.7
C49	100.0	18.00	36.7
C48	100.0	27.00	36.7
HLH-16	100.0	46.00	36.7
HLH-17	100.0	45.00	36.7
HLH-18	100.0	46.00	36.7
HLH-6	120.0	36.00	42.5
HLH-19	120.0	54.00	42.5
C52	150.0	50.00	50.2
C53	150.0	68.00	50.2
HLH-12	160.0	47.50	52.3
HLH-11	160.0	46.00	52.3
HLH-14	212.0	50.00	59.3
D5	212.0	65.50	59.3
C46	212.0	71.00	59.3
C47	212.0	71.00	59.3
D14	212.0	49.50	59.3
HLH-13	212.0	48.00	59.3
C67	240.0	78.00	60.8
C55	275.0	52.00	61.4
C54	275.0	66.00	61.4

TRANSITION REGION, CALCULATED VALUES

LATERAL EXPANSION(MILS)	CALCULATED TEMPERATURE(F)
5.0	-46.8
10.0	-6.2
15.0	20.5
20.0	41.9
25.0	60.6
30.0	77.8
35.0	94.5
40.0	111.3
45.0	129.0
50.0	149.1
55.0	174.7
60.0	222.3

TEMPERATURE (F)	CALCULATED LATERAL EXPANSION(MILS)
-40.0	5.6
-30.0	6.7
-20.0	8.0
-10.0	9.4
.0	11.0
10.0	12.9
20.0	14.9
30.0	17.1
40.0	19.5
50.0	22.1
60.0	24.8
70.0	27.7
80.0	30.7
90.0	33.7
100.0	36.7
110.0	39.6
120.0	42.5
130.0	45.3
140.0	47.8
150.0	50.2

COMPARISON OF HEAD-PLATE AND SHELL-PLATE CVN IMPACT-TEST RESULTS OF TRANSVERSE SPECIMENS OF TL ORIENTATION.
CALCULATIONS FOR SHEAR FRACTURE APPEARANCE DATA OF 48 HEAD-PLATE SPECIMENS.
THE CALCULATED CURVES WERE COMPUTED FROM WEIGHTED MEAN VALUES FOR DATA AT EACH TEST TEMPERATURE.

SPECIMEN	TEMPERATURE(F)	OBSERVED SHEAR FRACTURE (%)	CALCULATED SHEAR FRACTURE (%)
B6	-320.0	.00	.0
B16	-320.0	.00	.0
B10	-120.0	.00	2.0
B2	-120.0	.00	2.0
B13	-82.0	.00	4.5
B8	-82.0	.00	4.5
C56	-50.0	.00	8.4
C57	-50.0	.00	8.4
C58	-50.0	.00	8.4
HTF-61	-50.0	.00	8.4
HTF-62	-50.0	.00	8.4
B12	-40.0	35.00	10.0
B4	-40.0	10.00	10.0
B3	-25.0	45.00	12.9
B11	-25.0	50.00	12.9
B1	-2.0	80.00	17.4
B9	-2.0	70.00	18.4
HTF-67	15.0	5.00	23.5
HTF-68	15.0	5.00	23.5
C65	25.0	2.00	26.0
C66	25.0	2.00	26.0
HTF-69	60.0	10.00	40.9
HTF-70	60.0	10.00	40.9
B7	72.5	100.00	46.5
B15	72.5	100.00	46.5
C59	77.5	30.00	47.0
C60	77.5	25.00	47.0
HTF-63	80.0	25.00	50.0
HTF-64	80.0	20.00	50.0
C63	100.0	40.00	59.5
C64	100.0	25.00	59.5
HTF-75	100.0	50.00	59.5
HTF-76	100.0	40.00	59.5
HTF-65	120.0	90.00	68.9
HTF-66	120.0	80.00	68.9
C69	150.0	45.00	81.3
C70	150.0	55.00	81.3
HTF-71	160.0	98.00	84.7
HTF-72	160.0	98.00	84.7
B14	212.0	100.00	96.1
B5	212.0	100.00	96.1
HTF-73	212.0	100.00	96.1
HTF-74	212.0	100.00	96.1
C61	212.0	95.00	96.1
C62	212.0	97.00	96.1
C73	240.0	99.00	98.4
C72	275.0	100.00	99.7
C71	275.0	100.00	99.3

TRANSITION REGION, CALCULATED VALUES

% SHEAR FRACTURE	CALCULATED TEMPERATURE(F)	/	TEMPERATURE (F)	CALCULATED SHEAR FRACTURE(%)
2.0	-119.2	/	-110.0	2.5
5.0	-77.0	/	-95.0	3.4
10.0	-39.9	/	-80.0	4.7
15.0	-15.4	/	-65.0	6.3
50.0	79.9	/	-50.0	8.4
85.0	160.9	/	-35.0	10.7
90.0	178.3	/	-20.0	13.0
95.0	203.5	/	-5.0	17.6
98.0	232.6	/	10.0	21.0
		/	25.0	26.0
		/	40.0	32.5
		/	55.0	38.7
		/	70.0	45.4
		/	85.0	52.4
		/	100.0	59.5
		/	115.0	66.6
		/	130.0	73.3
		/	145.0	79.4
		/	160.0	84.7
		/	175.0	89.2

COMPARISON OF HEAD-PLATE AND SHELL-PLATE CVN IMPACT-TEST
RESULTS OF TRANSVERSE SPECIMENS OF TL ORIENTATION.
CALCULATIONS FOR ENERGY ABSORPTION DATA OF
48 HEAD-PLATE SPECIMENS.
THE CALCULATED CURVES WERE COMPUTED
FROM WEIGHTED MEAN VALUES FOR DATA
AT EACH TEST TEMPERATURE.

SPECIMEN	TEMPERATURE(F)	OBSERVED ENERGY ABSORPTION(FT-LB)	CALCULATED ENERGY ABSORPTION(FT-LB)
B6	-320.	1.00	.8
B16	-320.0	.50	.8
B10	-120.0	2.50	2.1
B2	-120.0	2.00	2.1
B13	-82.0	8.50	3.6
B8	-82.0	4.50	3.6
C56	-50.0	2.00	5.5
C57	-50.0	2.00	5.5
C58	-50.0	2.00	5.5
HTF-61	-50.0	3.50	5.5
HTF-62	-50.0	4.50	5.5
B12	-40.0	17.00	6.3
B4	-40.0	13.00	6.3
B3	-25.0	20.50	7.7
B11	-25.0	26.50	7.7
B1	-2.0	34.00	10.2
B9	-2.0	28.50	10.2
HTF-67	15.0	7.00	12.4
HTF-68	15.0	7.50	12.4
C65	25.0	3.50	13.8
C66	25.0	4.50	13.8
HTF-69	60.0	12.00	19.5
HTF-70	60.0	10.50	19.5
B7	72.5	39.00	21.7
B15	72.5	42.00	21.7
C59	73.5	15.00	21.9
C60	73.5	9.00	21.9
HTF-63	80.0	19.00	23.1
HTF-64	80.0	16.00	23.1
C63	100.0	18.00	26.9
C64	100.0	23.50	26.9
HTF-75	100.0	24.00	26.9
HTF-76	100.0	19.00	26.9
HTF-65	120.0	32.00	30.8
HTF-66	120.0	27.00	30.8
C69	150.0	31.00	36.1
C70	150.0	43.00	36.1
HTF-71	160.0	35.00	37.8
HTF-72	160.0	37.50	37.8
B14	212.0	35.50	44.2
B5	212.	42.50	44.2
HTF-73	212.	37.00	44.2
HTF-74	212.	37.50	44.2
C61	212.	55.00	44.2
C62	212.0	56.00	44.2
C73	240.0	53.00	45.1
C72	275.0	53.00	47.4
C71	275.	54.00	47.4

TRANSITION REGION, CALCULATED VALUES

ENERGY ABSORPTION	CALCULATED TEMPERATURE(F)	/	TEMPERATURE (F)	CALCULATED ENERGY ABSORPTION(FT-LB)
5.0	-57.6	/	-50.0	5.5
10.0	-3.4	/	-40.0	6.3
15.0	33.1	/	-30.0	7.2
20.0	62.9	/	-20.0	8.2
25.0	89.9	/	-10.0	9.2
30.0	116.0	/	.0	10.4
35.0	143.4	/	10.0	11.7
40.0	175.2	/	20.0	13.1
45.0	222.4	/	30.0	14.5
		/	40.0	16.1
		/	50.0	17.7
		/	60.0	19.5
		/	70.0	21.3
		/	80.0	23.1
		/	90.0	25.0
		/	100.0	26.9
		/	110.0	28.9
		/	120.0	30.8
		/	130.0	32.6
		/	140.0	34.4

APPENDIX C, TABLE 2C

COMPARISON OF HEAD-PLATE AND SHELL-PLATE CVN IMPACT-TEST
RESULTS OF TRANSVERSE SPECIMENS OF TL ORIENTATION.
CALCULATIONS FOR LATERAL EXPANSION DATA OF
48 HEAD-PLATE SPECIMENS.

THE CALCULATED CURVES WERE COMPUTED
FROM WEIGHTED MEAN VALUES FOR DATA
AT EACH TEST TEMPERATURE.

SPECIMEN	TEMPERATURE(F)	OBSERVED LATERAL EXPANSION (MILS)	CALCULATED LATERAL EXPANSION (MILS)
B6	-120.0	1.50	2.0
B16	-120.0	2.50	2.0
B10	-120.0	3.50	4.2
B2	-120.0	6.50	4.2
B13	-80.0	5.00	6.1
B8	-80.0	4.50	6.1
C56	-50.0	1.00	8.4
C57	-50.0	1.00	8.4
C58	-50.0	1.00	8.4
HTF-61	-50.0	1.00	8.4
HTF-62	-50.0	1.00	8.4
B12	-40.0	19.00	9.3
B4	-40.0	16.00	9.3
B3	-25.0	20.00	10.9
B11	-25.0	26.50	10.9
B1	-2.0	35.00	13.6
B9	-2.0	29.50	13.6
HTF-67	15.0	7.00	15.9
HTF-68	15.0	8.00	15.9
C65	25.0	7.00	17.4
C66	25.0	6.00	17.4
HTF-69	60.0	14.00	23.1
HTF-70	60.0	11.00	23.1
B7	72.5	37.50	25.4
B15	72.5	43.50	25.4
C59	73.5	22.00	25.5
C60	73.5	11.00	25.5
HTF-63	80.0	22.00	26.7
HTF-64	80.0	19.00	26.7
C63	100.0	26.00	30.5
C64	100.0	26.00	30.5
HTF-75	100.0	27.00	30.5
HTF-76	100.0	21.00	30.5
HTF-65	120.0	23.00	34.3
HTF-66	120.0	28.00	34.3
C69	150.0	48.00	39.8
C70	150.0	46.00	39.8
HTF-71	160.0	35.00	41.5
HTF-72	160.0	37.00	41.5
B14	212.0	39.50	48.9
B5	212.0	50.00	48.9
HTF-73	212.0	39.00	48.9
HTF-74	212.0	38.00	48.9
C61	212.0	53.00	48.9
C62	212.0	61.00	48.9
C73	240.0	64.00	51.7
C72	275.0	74.00	54.6
C71	275.0	63.00	54.6

TRANSITION REGION CALCULATED VALUES

LATERAL EXPANSION(MILS)	CALCULATED TEMPERATURE(F)	/	TEMPERATURE (F)	CALCULATED LATERAL EXPANSION(MILS)
5.0	-101.3	/	-100.0	5.1
10.0	-33.3	/	-85.0	5.9
15.0	8.6	/	-70.0	6.9
20.0	41.7	/	-55.0	8.0
25.0	70.5	/	-40.0	9.3
30.0	97.4	/	-25.0	10.9
35.0	123.8	/	-10.0	12.6
40.0	151.4	/	5.0	14.5
45.0	182.2	/	20.0	16.6
50.0	221.7	/	35.0	18.9
		/	50.0	21.4
		/	65.0	24.0
		/	80.0	26.7
		/	95.0	29.6
		/	110.0	32.4
		/	125.0	35.2
		/	140.0	38.0
		/	155.0	40.6
		/	170.0	43.1
		/	185.0	45.4

APPENDIX D

CVN Results of LT and TL Specimens of Combined Data from Three Shell-Plate Steels

APPENDIX D, TABLE 1A

COMPARISON OF HEAD-PLATE AND SHELL-PLATE CVN IMPACT-TEST RESULTS FOR LONGITUDINAL SPECIMENS OF LT ORIENTATION. CALCULATIONS FOR SHEAR FRACTURE APPEARANCE DATA OF 56 SHELL-PLATE SPECIMENS.

SPECIMEN	TEMPERATURE(F)	OBSERVED SHEAR FRACTURE (%)	CALCULATED SHEAR FRACTURE (%)
B14	-120.0	.00	.0
C15	-120.0	.00	.0
STA-34	-100.0	.00	.0
B1	-50.0	.00	.0
C1	-50.0	.00	.0
C2	-50.0	.00	.0
C3	-50.0	.00	.0
B2	-50.0	.00	.0
STA-21	-50.0	.00	.0
STA-22	-50.0	.00	.0
B3	-50.0	.00	.0
B10	-10.0	2.00	3.4
B11	-10.0	5.00	3.4
STA-35	-10.0	5.00	3.4
STA-36	-10.0	5.00	3.4
C14	.0	.00	6.2
B7	12.0	25.00	11.2
B6	12.0	30.00	11.2
STA-28	15.0	5.00	12.8
STA-37	15.0	5.00	12.8
C11	25.0	2.00	19.2
C10	25.0	3.00	19.2
B19	30.0	40.00	22.9
B13	30.0	35.00	22.9
B12	30.0	15.00	22.9
STA-38	40.0	30.00	31.4
STA-39	40.0	30.00	31.4
B15	50.0	80.00	41.1
B16	50.0	80.00	41.1
C20	50.0	30.00	41.1
STA-29	60.0	35.00	51.4
STA-30	60.0	40.00	51.4
B5	73.5	98.00	65.2
B4	73.5	95.00	65.2
C4	73.5	30.00	65.2
C5	73.5	20.00	65.2
STA-24	80.0	80.00	71.4
STA-23	80.0	95.00	71.4
C16	87.0	30.00	77.5
C17	87.0	55.00	77.5
C8	100.0	98.00	86.8
C9	100.0	90.00	86.8
B17	110.0	100.00	92.0
B18	110.0	100.00	92.0
STA-26	120.0	95.00	95.5
STA-25	120.0	100.00	95.5
C12	150.0	100.00	99.6
C13	150.0	100.00	99.6
STA-32	160.0	100.00	99.8
STA-33	160.0	100.00	99.8
B9	212.0	100.00	100.0
B8	212.0	100.00	100.0
C6	212.0	100.00	100.0
C7	212.0	100.00	100.0
C18	275.0	100.00	100.0
C19	275.0	100.00	100.0

TRANSITION REGION, CALCULATED VALUES

% SHEAR FRACTURE	CALCULATED TEMPERATURE(F)	/	TEMPERATURE (F)	CALCULATED SHEAR FRACTURE(%)
2.0	-17.2	/	-10.0	3.4
5.0	-3.6	/	-5.0	4.6
10.0	9.5	/	.0	6.2
15.0	18.7	/	5.0	8.0
50.0	58.7	/	10.0	10.2
85.0	97.1	/	15.0	12.8
90.0	105.8	/	20.0	15.8
95.0	118.3	/	25.0	19.2
98.0	132.0	/	30.0	22.9
		/	35.0	27.0
		/	40.0	31.4
		/	45.0	36.2
		/	50.0	41.1
		/	55.0	46.2
		/	60.0	51.4
		/	65.0	56.6
		/	70.0	61.7
		/	75.0	66.7
		/	80.0	71.4
		/	85.0	75.8

COMPARISON OF HEAD-PLATE AND SHELL-PLATE CVN IMPACT-TEST RESULTS FOR LONGITUDINAL SPECIMENS OF LT ORIENTATION.
CALCULATIONS FOR ENERGY ABSORPTION DATA OF 56 SHELL-PLATE SPECIMENS.

SPECIMEN	TEMPERATURE(F)	OBSERVED ENERGY ABSORPTION(FT-LB)	CALCULATED ENERGY ABSORPTION(FT-LB)
B14	-120.0	1.50	1.5
C15	-120.0	1.50	1.5
STA-34	-100.0	6.00	1.5
B1	-50.0	2.00	2.7
C1	-50.0	2.00	2.7
C2	-50.0	3.50	2.7
C3	-50.0	3.00	2.7
B2	-50.0	2.00	2.7
STA-21	-50.0	4.00	2.7
STA-22	-50.0	4.00	2.7
B3	-50.0	2.00	2.7
B10	-10.0	4.00	9.4
B11	-10.0	4.50	9.4
STA-35	-10.0	27.00	9.4
STA-36	-10.0	11.00	9.4
C14	.0	4.00	12.5
B7	12.0	23.00	16.8
B6	12.0	14.00	16.8
STA-28	15.0	14.00	19.1
STA-37	15.0	24.00	19.1
C11	25.0	18.00	22.4
C10	25.0	10.00	22.4
B19	30.0	21.50	24.8
B13	30.0	27.50	24.8
B12	30.0	10.50	24.8
STA-38	40.0	30.50	29.7
STA-39	40.0	30.50	29.7
B15	50.0	36.50	34.9
B16	50.0	36.50	34.9
C20	50.0	35.00	34.9
STA-29	60.0	37.00	40.1
STA-30	60.0	45.50	40.1
B5	73.5	44.50	47.0
B4	73.5	41.50	47.0
C4	73.5	37.50	47.0
C5	73.5	26.00	47.0
STA-24	80.0	63.50	50.1
STA-23	80.0	72.50	50.1
C16	87.0	41.00	53.3
C17	87.0	47.50	53.3
C8	100.0	74.50	58.6
C9	100.0	62.50	58.6
B17	110.0	44.00	62.0
B18	110.0	47.00	62.0
STA-26	120.0	72.50	64.8
STA-25	120.0	75.50	64.8
C12	150.0	75.00	69.9
C13	150.0	67.00	69.9
STA-32	160.0	74.00	70.8
STA-33	160.0	74.00	70.8
B9	212.0	44.50	72.2
B8	212.0	45.00	72.2
C6	212.0	73.00	72.2
C7	212.0	79.00	72.2
C18	275.0	69.00	72.2
C19	275.0	71.00	72.2

TRANSITION REGION, CALCULATED VALUES

ENERGY ABSORPTION	CALCULATED TEMPERATURE(F)	/	TEMPERATURE (F)	CALCULATED ENERGY ABSORPTION(FT-LB)
5.0	-30.6	/	-30.0	5.1
10.0	-8.0	/	-25.0	6.0
15.0	7.2	/	-20.0	7.0
20.0	19.6	/	-15.0	8.1
25.0	30.5	/	-10.0	9.4
30.0	40.6	/	-5.0	10.9
35.0	50.2	/	.0	12.5
40.0	59.8	/	5.0	14.2
45.0	69.5	/	10.0	16.1
50.0	79.7	/	15.0	18.1
55.0	90.9	/	20.0	20.2
60.0	104.0	/	25.0	22.4
65.0	120.9	/	30.0	24.8
70.0	150.5	/	35.0	27.2
		/	40.0	29.7
		/	45.0	32.3
		/	50.0	34.9
		/	55.0	37.5
		/	60.0	40.1
		/	65.0	42.7

COMPARISON OF HEAD-PLATE AND SHELL-PLATE CVN IMPACT-TEST RESULTS FOR LONGITUDINAL SPECIMENS OF LT ORIENTATION. CALCULATIONS FOR LATERAL EXPANSION DATA OF 56 SHELL-PLATE SPECIMENS.

SPECIMEN	TEMPERATURE(F)	OBSERVED LATERAL EXPANSION (MILS)	CALCULATED LATERAL EXPANSION (MILS)
B14	-120.0	.00	1.0
C15	-120.0	2.00	1.0
STA-34	-100.0	3.50	1.0
B1	-50.0	.00	2.5
C1	-50.0	2.00	2.5
C2	-50.0	2.00	2.5
C3	-50.0	2.00	2.5
B2	-50.0	2.00	2.5
STA-21	-50.0	2.00	2.5
STA-22	-50.0	2.00	2.5
B3	-50.0	.00	2.5
B10	-10.0	3.00	8.3
B11	-10.0	4.00	8.3
STA-35	-10.0	14.00	8.3
STA-36	-10.0	22.00	8.3
C14	.0	3.00	10.8
B7	12.0	21.00	14.4
B6	12.0	15.00	14.4
STA-28	15.0	12.00	15.5
STA-37	15.0	20.00	15.5
C11	25.0	20.00	19.1
C10	25.0	13.00	19.1
B19	30.0	24.00	21.1
B13	30.0	27.00	21.1
B12	30.0	10.00	21.1
STA-38	40.0	30.00	25.3
STA-39	40.0	33.00	25.3
B15	50.0	33.00	29.7
B16	50.0	32.00	29.7
C20	50.0	38.00	29.7
STA-29	60.0	30.00	34.4
STA-30	60.0	37.00	34.4
B5	73.5	43.00	40.6
B4	73.5	38.00	40.6
C4	73.5	40.00	40.6
C5	73.5	30.00	40.6
STA-24	80.0	51.00	43.5
STA-23	80.0	56.00	43.5
C16	87.0	45.00	46.5
C17	87.0	47.00	46.5
C8	100.0	67.00	51.6
C9	100.0	57.00	51.6
B17	110.0	44.00	55.1
B18	110.0	44.00	55.1
STA-26	120.0	54.00	58.0
STA-25	120.0	54.00	58.0
C12	150.0	66.00	63.6
C13	150.0	68.00	63.6
STA-32	160.0	64.00	64.6
STA-33	160.0	64.00	64.6
B9	212.0	43.00	66.2
B8	212.0	53.00	66.2
C6	212.0	70.00	66.2
C7	212.0	71.00	66.2
C18	275.0	75.00	66.2
C19	275.0	69.00	66.2

TRANSITION REGION, CALCULATED VALUES

LATERAL EXPANSION(MILS)	CALCULATED TEMPERATURE(F)	/	TEMPERATURE (F)	CALCULATED LATERAL EXPANSION(MILS)
5.0	-27.8	/	-20.0	6.3
10.0	-3.1	/	-15.0	7.3
15.0	13.7	/	-10.0	8.3
20.0	27.3	/	-5.0	9.5
25.0	39.4	/	.0	10.8
30.0	50.6	/	5.0	12.3
35.0	61.4	/	10.0	13.8
40.0	72.2	/	15.0	15.5
45.0	83.4	/	20.0	17.2
50.0	95.6	/	25.0	19.1
55.0	109.8	/	30.0	21.1
60.0	128.5	/	35.0	23.1
65.0	166.2	/	40.0	25.3
		/	45.0	27.5
		/	50.0	29.7
		/	55.0	32.0
		/	60.0	34.4
		/	65.0	36.7
		/	70.0	39.0
		/	75.0	41.3

APPENDIX D, TABLE 2A

COMPARISON OF HEAD-PLATE AND SHELL-PLATE CVN IMPACT-TEST RESULTS OF TRANSVERSE SPECIMENS OF TL ORIENTATION.
CALCULATIONS FOR SHEAR FRACTURE APPEARANCE DATA OF 55 SHELL-PLATE SPECIMENS.

SPECIMEN	TEMPERATURE(F)	OBSERVED SHEAR FRACTURE (%)	CALCULATED SHEAR FRACTURE (%)
B37	-120.0	.00	.0
C35	-120.0	.00	.0
SLC-54	-100.0	.00	.0
B22	-50.0	.00	.0
C21	-50.0	.00	.0
C22	-50.0	.00	.0
C23	-50.0	.00	.0
B23	-50.0	.00	.0
SLC-44	-50.0	.00	.0
SLC-45	-50.0	.00	.0
B24	-50.0	.00	.0
B35	-15.0	5.00	2.9
B36	-15.0	2.00	2.9
SLC-55	-10.0	5.00	4.5
SLC-56	-10.0	5.00	4.5
C36	.0	3.00	9.1
B34	.0	10.00	9.1
B33	.0	15.00	9.1
B32	10.0	20.00	15.5
B31	10.0	15.00	15.5
SLC-51	15.0	20.00	19.2
SLC-50	15.0	20.00	19.2
C31	25.0	30.00	27.8
C37	25.0	5.00	27.8
C30	25.0	5.00	27.8
B27	33.0	85.00	35.4
B28	33.0	55.00	35.4
SLC-57	40.0	20.00	42.4
SLC-58	40.0	20.00	42.4
B38	50.0	90.00	52.4
B39	50.0	85.00	52.4
C40	50.0	20.00	52.4
SLC-42	60.0	70.00	62.0
SLC-41	60.0	60.00	62.0
B26	73.5	95.00	73.6
C24	73.5	30.00	73.6
C25	73.5	30.00	73.6
B25	73.5	95.00	73.6
SLC-47	80.0	85.00	78.4
SLC-46	80.0	90.00	78.4
C29	100.0	50.00	89.6
C28	100.0	65.00	89.6
B40	110.0	100.00	93.2
SLC-49	120.0	98.00	95.7
SLC-48	120.0	100.00	95.7
C38	125.0	98.00	96.7
C39	125.0	99.00	96.7
C34	150.0	95.00	99.1
C33	150.0	100.00	99.1
SLC-53	160.0	100.00	99.5
SLC-52	160.0	100.00	99.5
B29	212.0	100.00	99.9
C26	212.0	100.00	99.9
C27	212.0	100.00	99.9
B30	212.0	100.00	99.9

TRANSITION REGION, CALCULATED VALUES

% SHEAR FRACTURE	CALCULATED TEMPERATURE(F)	/	TEMPERATURE (F)	CALCULATED SHEAR FRACTURE(%)
2.0	-18.4	/	-10.0	4.5
5.0	-8.7	/	-5.0	6.6
10.0	1.6	/	.0	9.1
15.0	9.4	/	5.0	12.1
50.0	47.6	/	10.0	15.5
85.0	90.6	/	15.0	19.2
90.0	101.0	/	20.0	23.4
95.0	116.7	/	25.0	27.8
98.0	134.7	/	30.0	32.5
		/	35.0	37.4
		/	40.0	42.4
		/	45.0	47.4
		/	50.0	52.4
		/	55.0	57.3
		/	60.0	62.0
		/	65.0	66.5
		/	70.0	70.8
		/	75.0	74.8
		/	80.0	78.4
		/	85.0	81.7

APPENDIX D, TABLE 2C

COMPARISON OF HEAD-PLATE AND SHELL-PLATE CVN IMPACT-TEST RESULTS OF TRANSVERSE SPECIMENS OF TL ORIENTATION.
CALCULATIONS FOR ENERGY ABSORPTION DATA OF 55 SHELL-PLATE SPECIMENS.

SPECIMEN	TEMPERATURE(F)	OBSERVED ENERGY ABSORPTION(FT-LB)	CALCULATED ENERGY ABSORPTION(FT-LB)
B37	-120.0	1.00	1.3
C35	-120.0	1.50	1.3
SLC-54	-100.0	2.00	1.3
B22	-50.0	2.00	3.4
C21	-50.0	2.00	3.4
C22	-50.0	2.00	3.4
C23	-50.0	3.00	3.4
B23	-50.0	2.50	3.4
SLC-44	-50.0	6.00	3.4
SLC-45	-50.0	2.50	3.4
B24	-50.0	2.00	3.4
B35	-15.0	5.00	7.7
B36	-15.0	4.00	7.7
SLC-55	-10.0	11.00	8.5
SLC-56	-10.0	13.00	8.5
C36	.0	8.00	10.3
B34	.0	6.00	10.3
B33	.0	11.00	10.3
B32	10.0	11.00	12.2
B31	10.0	9.00	12.2
SLC-51	15.0	18.00	13.2
SLC-50	15.0	18.00	13.2
C31	25.0	15.50	15.4
C37	25.0	11.00	15.4
C30	25.0	7.50	15.4
B27	33.0	19.00	17.1
B28	33.0	15.50	17.1
SLC-57	40.0	22.00	18.7
SLC-58	40.0	25.00	18.7
B38	50.0	22.00	20.9
B39	50.0	21.00	20.9
C40	50.0	11.00	20.9
SLC-42	60.0	33.50	23.0
SLC-41	60.0	27.00	23.0
B26	73.5	24.50	25.7
C24	73.5	12.50	25.7
C25	73.5	18.50	25.7
B25	73.5	24.50	25.7
SLC-47	80.0	31.00	26.9
SLC-46	80.0	32.00	26.9
C29	100.0	22.00	30.0
C28	100.0	24.50	30.0
B40	110.0	26.00	31.3
SLC-49	120.0	36.50	32.4
SLC-48	120.0	38.00	32.4
C38	125.0	34.50	32.8
C39	125.0	34.00	32.8
C34	150.0	33.50	34.5
C33	150.0	34.00	34.5
SLC-53	160.0	37.50	34.9
SLC-52	160.0	38.00	34.9
B29	212.0	24.50	29.4
C26	212.0	35.00	29.4
C27	212.0	34.00	29.4
B30	212.0	24.00	29.4

TRANSITION REGION, CALCULATED VALUES

ENERGY ABSORPTION	CALCULATED TEMPERATURE(F)	/	TEMPERATURE (F)	CALCULATED ENERGY ABSORPTION(FT-LB)
5.0	-34.2	/	-30.0	5.5
10.0	-1.5	/	-25.0	6.2
15.0	23.3	/	-20.0	6.9
20.0	46.0	/	-15.0	7.7
25.0	70.0	/	-10.0	8.5
30.0	99.7	/	-5.0	9.4
		/	.0	10.3
		/	5.0	11.2
		/	10.0	12.2
		/	15.0	13.2
		/	20.0	14.3
		/	25.0	15.4
		/	30.0	16.5
		/	35.0	17.6
		/	40.0	18.7
		/	45.0	19.8
		/	50.0	20.9
		/	55.0	21.9
		/	60.0	23.0
		/	65.0	24.0

APPENDIX D, TABLE 2C

COMPARISON OF HEAD-PLATE AND SHELL-PLATE CVN IMPACT-TEST RESULTS OF TRANSVERSE SPECIMENS OF TL ORIENTATION.
CALCULATIONS FOR LATERAL EXPANSION DATA OF
55 SHELL-PLATE SPECIMENS.

SPECIMEN	TEMPERATURE(F)	OBSERVED LATERAL EXPANSION (MILS)	CALCULATED LATERAL EXPANSION (MILS)
B37	-120.0	.00	1.0
C35	-120.0	2.00	1.0
SLC-54	-100.0	1.50	1.0
B22	-50.0	.20	1.4
C21	-50.0	1.00	1.4
C22	-50.0	1.00	1.4
C23	-50.0	2.00	1.4
B23	-50.0	1.80	1.4
SLC-44	-50.0	4.50	1.4
SLC-45	-50.0	2.00	1.4
B24	-50.0	.00	1.4
B35	-15.0	4.00	5.6
B36	-15.0	2.00	5.6
SLC-55	-10.0	1.30	6.6
SLC-56	-10.0	1.20	6.6
C36	.0	12.00	8.7
B34	.0	6.00	8.7
B33	.0	11.00	8.7
B32	10.0	12.00	11.2
B31	10.0	13.00	11.2
SLC-51	15.0	16.00	12.5
SLC-50	15.0	15.00	12.5
C31	25.0	17.00	15.2
C37	25.0	15.00	15.2
C30	25.0	12.00	15.2
B27	33.0	21.00	17.4
B28	33.0	16.00	17.4
SLC-57	40.0	24.00	19.3
SLC-58	40.0	20.00	19.3
B38	50.0	24.00	22.1
B39	50.0	22.00	22.1
C40	50.0	16.00	22.1
SLC-42	60.0	34.00	24.7
SLC-41	60.0	26.00	24.7
B26	73.5	27.00	28.1
C24	73.5	16.00	28.1
C25	73.5	23.00	28.1
B25	73.5	26.00	28.1
SLC-47	80.0	32.00	29.6
SLC-46	80.0	32.00	29.6
C29	100.0	24.00	33.6
C28	100.0	32.00	33.6
B40	110.0	27.00	35.3
SLC-49	120.0	37.00	36.7
SLC-48	120.0	37.00	36.7
C38	125.0	48.00	37.4
C39	125.0	46.00	37.4
C34	150.0	44.00	39.8
C33	150.0	50.00	39.8
SLC-53	160.0	39.00	40.4
SLC-52	160.0	38.00	40.4
B29	212.0	25.00	36.8
C26	212.0	47.00	36.8
C27	212.0	48.00	36.8
B30	212.0	27.00	36.8

TRANSITION REGION, CALCULATED VALUES

LATERAL EXPANSION(MILS)	CALCULATED TEMPERATURE(F)
5.0	-18.2
10.0	5.3
15.0	24.4
20.0	42.5
25.0	61.0
30.0	81.8
35.0	108.1
40.0	153.5

TEMPERATURE (F)	CALCULATED LATERAL EXPANSION(MILS)
-10.0	6.6
-5.0	7.6
.0	8.7
5.0	9.9
10.0	11.2
15.0	12.5
20.0	13.8
25.0	15.2
30.0	16.5
35.0	17.9
40.0	19.3
45.0	20.7
50.0	22.1
55.0	23.4
60.0	24.7
65.0	26.0
70.0	27.3
75.0	28.5
80.0	29.6
85.0	30.7

APPENDIX E

CVN Results of LT and TL Specimens of Combined Data on Four TC128 Steels and Combined Data of Two A212-B Steels

RESULTS OF LONGITUDINAL CVN IMPACT TESTS FOR
AAR TC128 STEELS AND ASTM A212-B STEELS.
CALCULATIONS FOR SHEAR FRACTURE APPEARANCE DATA OF
AAR TC128, 70 LT ORIENTATION SPECIMENS.
THE CALCULATED CURVES WERE COMPUTED
FROM WEIGHTED MEAN VALUES FOR DATA
AT EACH TEST TEMPERATURE.

SPECIMEN	TEMPERATURE(F)	OBSERVED SHEAR FRACTURE (%)	CALCULATED SHEAR FRACTURE (%)
D6	-320.0	.00	.0
D16	-320.0	.00	.0
D10	-120.0	.00	.3
D2	-120.0	.00	.3
B14	-120.0	.00	.3
HLH-15	-100.0	.00	.6
STA-34	-100.0	.00	.6
D8	-82.0	.00	1.2
D13	-82.0	.00	1.2
B1	-50.0	.00	3.5
HLH-1	-50.0	.00	3.5
HLH-2	-50.0	.00	3.5
B2	-50.0	.00	3.5
STA-21	-50.0	.00	3.5
STA-22	-50.0	.00	3.5
B3	-50.0	.00	3.5
D4	-40.0	5.00	4.8
D12	-40.0	5.00	4.8
D11	-25.0	20.00	7.6
D3	-25.0	30.00	7.6
B11	-10.0	5.00	11.7
B10	-10.0	2.00	11.7
STA-35	-10.0	5.00	11.7
STA-36	-10.0	5.00	11.7
D9	-2.0	45.00	14.5
D1	-2.0	95.00	14.5
B7	12.0	25.00	20.7
B6	12.0	30.00	20.7
HLH-8	15.0	5.00	22.3
HLH-7	15.0	.00	22.3
STA-28	15.0	5.00	22.3
STA-37	15.0	5.00	22.3
B13	30.0	35.00	31.5
B12	30.0	15.00	31.5
B19	30.0	40.00	31.5
STA-38	40.0	30.00	39.0
STA-39	40.0	30.00	39.0
B16	50.0	90.00	47.0
B15	50.0	80.00	47.0
STA-29	60.0	35.00	55.8
STA-30	60.0	40.00	55.8
HLH-9	60.0	15.00	55.8
HLH-10	60.0	15.00	55.8
D7	72.5	100.00	67.0
D15	72.5	100.00	67.0
B4	73.5	95.00	67.0
B5	73.5	93.00	67.0
HLH-3	80.0	15.00	73.4
STA-23	80.0	75.00	73.4
STA-24	80.0	90.00	73.4
HLH-4	80.0	20.00	73.4
HLH-17	100.0	100.00	87.9
HLH-18	100.0	100.00	87.9
HLH-16	100.0	100.00	87.9
B17	110.0	100.00	92.0
B13	110.0	100.00	92.0
HLH-19	120.0	100.00	96.3
STA-25	120.0	100.00	96.3
STA-26	120.0	95.00	96.3
HLH-6	120.0	80.00	96.3
STA-32	160.0	100.00	100.0
STA-33	160.0	100.00	100.0
HLH-11	160.0	100.00	100.0
HLH-12	160.0	100.00	100.0
HLH-13	212.0	100.00	100.0
HLH-14	212.0	100.00	100.0
D5	212.0	100.00	100.0
B8	212.0	100.00	100.0
B9	212.0	100.00	100.0
D14	212.0	100.00	100.0

TRANSITION REGION, CALCULATED VALUES

% SHEAR FRACTURE	CALCULATED TEMPERATURE(F)
2.0	-66.9
5.0	-38.9
10.0	-15.5
15.0	-.7
50.0	53.4
85.0	95.4
90.0	103.9
95.0	115.7
98.0	128.0

TEMPERATURE (F)	CALCULATED SHEAR FRACTURE(%)
-60.0	2.5
-55.0	3.0
-50.0	3.5
-45.0	4.1
-40.0	4.8
-35.0	5.6
-30.0	6.6
-25.0	7.6
-20.0	8.8
-15.0	10.1
-10.0	11.7
-5.0	13.4
.0	15.3
5.0	17.4
10.0	19.7
15.0	22.3
20.0	25.1
25.0	28.2
30.0	31.5
35.0	35.1

APPENDIX E, TABLE 1B

RESULTS OF LONGITUDINAL CVN IMPACT TESTS FOR AAR TC128 STEELS AND ASTM A212-B STEELS.
CALCULATIONS FOR ENERGY ABSORPTION DATA OF AAR TC128, 70 LT ORIENTATION SPECIMENS.
THE CALCULATED CURVES WERE COMPUTED FROM WEIGHTED MEAN VALUES FOR DATA AT EACH TEST TEMPERATURE.

SPECIMEN	TEMPERATURE(F)	OBSERVED ENERGY ABSORPTION(FT-LB)	CALCULATED ENERGY ABSORPTION(FT-LB)
D6	-320.0	1.00	1.0
D16	-320.0	1.00	1.0
D10	-120.0	2.00	1.7
D2	-120.0	2.00	1.7
B14	-120.0	1.50	1.7
HLH-15	-100.0	2.50	2.3
STA-34	-100.0	6.00	2.3
D8	-82.0	5.00	3.2
D13	-82.0	5.00	3.2
B1	-50.0	2.00	6.2
HLH-1	-50.0	3.50	6.2
HLH-2	-50.0	2.50	6.2
B2	-50.0	2.00	6.2
STA-21	-50.0	4.00	6.2
STA-22	-50.0	4.00	6.2
B3	-50.0	2.00	6.2
D4	-40.0	14.00	7.6
D12	-40.0	15.00	7.6
D11	-25.0	21.00	10.3
D3	-25.0	25.50	10.3
B11	-10.0	4.50	13.9
B10	-10.0	4.00	13.0
STA-35	-10.0	27.00	13.8
STA-36	-10.0	11.00	13.0
D9	-2.0	31.50	16.1
D1	-2.0	61.00	16.1
B7	12.0	23.00	20.6
B6	12.0	14.00	20.6
HLH-8	15.0	6.00	21.7
HLH-7	15.0	11.00	21.7
STA-28	15.0	14.00	21.7
STA-37	15.0	24.00	21.7
B13	30.0	27.50	27.5
B12	30.0	10.50	27.5
B19	30.0	21.50	27.5
STA-38	40.0	30.50	31.0
STA-39	40.0	30.50	31.9
B16	50.0	36.50	36.2
B15	50.0	36.50	36.2
STA-29	60.0	37.00	40.6
STA-30	60.0	45.50	40.6
HLH-9	60.0	21.50	40.6
HLH-10	60.0	19.50	40.6
D7	72.5	63.50	45.0
D15	72.5	72.50	45.0
B4	73.5	41.50	46.3
B5	73.5	44.50	46.3
HLH-3	80.0	28.50	49.0
STA-23	80.0	72.50	49.0
STA-24	80.0	63.50	49.0
HLH-4	80.0	26.00	49.0
HLH-17	100.0	53.00	55.4
HLH-18	100.0	54.00	55.4
HLH-16	100.0	55.00	55.4
B17	110.0	44.00	57.7
B18	110.0	47.00	57.7
HLH-19	120.0	52.00	59.5
STA-25	120.0	75.50	59.5
STA-26	120.0	72.50	59.5
HLH-6	120.0	42.00	59.5
STA-32	160.0	74.00	62.0
STA-33	160.0	74.00	62.0
HLH-11	160.0	52.00	62.0
HLH-12	160.0	51.00	62.0
HLH-13	212.0	53.00	52.7
HLH-14	212.0	52.00	52.7
D5	212.0	60.00	52.7
B8	212.0	45.00	52.7
B9	212.0	44.50	52.7
D14	212.0	61.50	52.7

TRANSITION REGION, CALCULATED VALUES

ENERGY ABSORPTION	CALCULATED TEMPERATURE(F)
5.0	-60.0
10.0	-26.4
15.0	-5.7
20.0	10.3
25.0	23.8
30.0	35.9
35.0	47.4
40.0	58.6
45.0	70.3
50.0	83.0
55.0	98.6
60.0	124.2

TEMPERATURE (F)	CALCULATED ENERGY ABSORPTION(FT-LB)
-60.0	5.0
-55.0	5.5
-50.0	6.2
-45.0	6.8
-40.0	7.6
-35.0	8.4
-30.0	9.3
-25.0	10.3
-20.0	11.4
-15.0	12.5
-10.0	13.8
-5.0	15.2
.0	16.7
5.0	18.2
10.0	19.9
15.0	21.7
20.0	23.5
25.0	25.5
30.0	27.5
35.0	29.6

APPENDIX E, TABLE 1C

RESULTS OF LONGITUDINAL CVN IMPACT TESTS FOR AAR TC128 STEELS AND ASTM A212-B STEELS.
CALCULATIONS FOR LATERAL EXPANSION DATA OF AAR TC128, 70 LT ORIENTATION SPECIMENS.
THE CALCULATED CURVES WERE COMPUTED FROM WEIGHTED MEAN VALUES FOR DATA AT EACH TEST TEMPERATURE.

SPECIMEN	TEMPERATURE(F)	OBSERVED LATERAL EXPANSION (MILS)	CALCULATED LATERAL EXPANSION (MILS)
D6	-320.0	1.00	1.0
D16	-320.0	1.00	1.0
D10	-120.0	2.00	1.2
D2	-120.0	2.50	1.2
B14	-120.0	.00	1.2
HLH-15	-100.0	4.00	1.5
STA-34	-100.0	3.50	1.5
D8	-82.0	5.00	2.2
D13	-82.0	3.50	2.2
B1	-50.0	.00	4.6
HLH-1	-50.0	2.00	4.6
HLH-2	-50.0	1.00	4.6
B2	-50.0	2.00	4.6
STA-21	-50.0	2.00	4.6
STA-22	-50.0	2.00	4.6
B3	-50.0	.00	4.6
D4	-40.0	10.00	5.8
D12	-40.0	16.00	5.8
D11	-25.0	16.00	8.2
D3	-25.0	25.50	8.2
B11	-10.0	4.00	11.4
B10	-10.0	3.00	11.4
STA-35	-10.0	14.00	11.4
STA-36	-10.0	22.00	11.4
D9	-2.0	29.50	13.4
D1	-2.0	49.50	13.4
B7	12.0	21.00	17.4
B6	12.0	15.00	17.4
HLH-8	15.0	7.50	18.3
HLH-7	15.0	10.50	18.3
STA-28	15.0	12.00	18.3
STA-37	15.0	20.00	18.3
B13	30.0	27.00	23.4
B12	30.0	10.00	23.4
B19	30.0	24.00	23.4
STA-38	40.0	30.00	27.0
STA-39	40.0	33.00	27.0
B16	50.0	32.00	30.2
B15	50.0	33.00	30.2
STA-29	60.0	30.00	34.5
STA-30	60.0	37.00	34.5
HLH-9	60.0	22.00	34.5
HLH-10	60.0	23.00	34.5
D7	72.5	58.50	39.0
D15	72.5	56.50	39.0
B4	73.5	38.00	39.2
B5	73.5	43.00	39.2
HLH-3	80.0	24.00	41.3
STA-23	80.0	56.00	41.3
STA-24	80.0	51.00	41.3
HLH-4	80.0	25.00	41.3
HLH-17	100.0	45.00	46.9
HLH-18	100.0	46.00	46.9
HLH-16	100.0	46.00	46.9
B17	110.0	44.00	49.0
B18	110.0	44.00	49.0
HLH-19	120.0	54.00	50.6
STA-25	120.0	54.00	50.6
STA-26	120.0	54.00	50.6
HLH-6	120.0	36.00	50.6
STA-32	160.0	64.00	53.6
STA-33	160.0	64.00	53.6
HLH-11	160.0	46.00	53.6
HLH-12	160.0	47.50	53.6
HLH-13	212.0	48.00	54.0
HLH-14	212.0	50.00	54.0
D5	212.0	65.50	54.0
B8	212.0	53.00	54.0
B9	212.0	43.00	54.0
D14	212.0	49.50	54.0

TRANSITION REGION, CALCULATED VALUES

LATERAL EXPANSION(MILS)	CALCULATED TEMPERATURE(F)
5.0	-46.2
10.0	-16.1
15.0	3.9
20.0	20.1
25.0	34.4
30.0	47.9
35.0	61.5
40.0	75.8
45.0	92.5
50.0	116.0

TEMPERATURE (F)	CALCULATED LATERAL EXPANSION(MILS)
-40.0	5.8
-35.0	6.5
-30.0	7.3
-25.0	8.2
-20.0	9.2
-15.0	10.2
-10.0	11.4
-5.0	12.6
.0	13.9
5.0	15.3
10.0	16.8
15.0	18.3
20.0	20.0
25.0	21.7
30.0	23.4
35.0	25.2
40.0	27.0
45.0	28.9
50.0	30.2
55.0	32.6

RESULTS OF LONGITUDINAL CVN IMPACT TESTS FOR
AAR TC128 STEELS AND ASTM A212-B STEELS.
CALCULATIONS FOR SHEAR FRACTURE APPEARANCE DATA OF
ASTM A212-B,36 LT ORIENTATION SPECIMENS.

SPECIMEN	TEMPERATURE(F)	OBSERVED SHEAR FRACTURE (%)	CALCULATED SHEAR FRACTURE (%)
C15	-120.0	.00	.0
C3	-50.0	.00	.0
C2	-50.0	.00	.0
C1	-50.0	.00	.0
C41	-50.0	.00	.0
C42	-50.0	.00	.0
C43	-50.0	.00	.0
C14	.0	.00	.0
C11	25.0	2.00	2.3
C10	25.0	3.00	2.3
C50	25.0	2.00	2.3
C51	25.0	2.00	2.3
C20	50.0	30.00	13.4
C44	73.5	25.00	31.2
C45	73.5	15.00	31.2
C4	73.5	30.00	31.2
C5	73.5	20.00	31.2
C16	87.0	30.00	43.0
C17	87.0	55.00	43.0
C48	100.0	35.00	54.4
C49	100.0	40.00	54.4
C8	100.0	98.00	54.4
C9	100.0	90.00	54.4
C12	150.0	100.00	87.1
C13	150.0	100.00	87.1
C52	150.0	60.00	87.1
C53	150.0	55.00	87.1
C46	212.0	97.00	99.0
C47	212.0	98.00	99.0
C6	212.0	100.00	99.0
C7	212.0	100.00	99.0
C67	240.0	100.00	99.8
C19	275.0	100.00	100.0
C54	275.0	100.00	100.0
C55	275.0	100.00	100.0
C18	275.0	100.00	100.0

TRANSITION REGION, CALCULATED VALUES

% SHEAR FRACTURE	CALCULATED TEMPERATURE(F)	TEMPERATURE (F)	CALCULATED SHEAR FRACTURE(%)
2.0	23.9	30.0	3.7
5.0	33.5	35.0	5.6
10.0	44.2	40.0	7.8
15.0	52.4	45.0	10.5
50.0	94.9	50.0	13.4
85.0	145.1	55.0	16.7
90.0	157.6	60.0	20.3
95.0	176.3	65.0	24.2
98.0	197.7	70.0	28.3
		75.0	32.5
		80.0	36.9
		85.0	41.3
		90.0	45.7
		95.0	50.1
		100.0	54.4
		105.0	58.6
		110.0	62.7
		115.0	66.6
		120.0	70.3
		125.0	73.7

RESULTS OF LONGITUDINAL CVN IMPACT TESTS FOR AAR TC128 STEELS AND ASTM A212-B STEELS. CALCULATIONS FOR ENERGY ABSORPTION DATA OF ASTM A212-B,36 LT ORIENTATION SPECIMENS.

SPECIMEN	TEMPERATURE(F)	OBSERVED ENERGY ABSORPTION(FT-LB)	CALCULATED ENERGY ABSORPTION(FT-LB)
C15	-120.0	1.50	1.5
C3	-50.0	3.00	2.2
C2	-50.0	3.50	2.2
C1	-50.0	2.00	2.2
C41	-50.0	2.00	2.2
C42	-50.0	2.00	2.2
C43	-50.0	2.00	2.2
C14	.0	4.00	6.9
C11	25.0	18.00	12.2
C10	25.0	10.00	12.2
C50	25.0	4.00	12.2
C51	25.0	5.00	12.2
C20	50.0	35.00	19.9
C44	73.5	11.00	29.2
C45	73.5	12.00	29.2
C4	73.5	37.50	29.2
C5	73.5	26.00	29.2
C16	87.0	41.00	35.2
C17	87.0	47.50	35.2
C48	100.0	21.00	41.2
C49	100.0	15.00	41.2
C8	100.0	74.50	41.2
C9	100.0	62.50	41.2
C12	150.0	75.00	62.8
C13	150.0	67.00	62.8
C52	150.0	50.00	62.8
C53	150.0	37.50	62.8
C46	212.0	80.00	76.9
C47	212.0	81.50	76.9
C6	212.0	73.00	76.9
C7	212.0	79.00	76.9
C67	240.0	85.00	78.9
C19	275.0	71.00	70.3
C54	275.0	65.50	70.3
C55	275.0	75.50	70.3
C18	275.0	69.00	70.3

TRANSITION REGION, CALCULATED VALUES

ENERGY ABSORPTION	CALCULATED TEMPERATURE(F)
5.0	-13.6
10.0	15.8
15.0	35.1
20.0	50.3
25.0	63.5
30.0	75.4
35.0	86.6
40.0	97.4
45.0	108.1
50.0	119.0
55.0	130.3
60.0	142.5
65.0	156.2
70.0	173.0
75.0	197.1

TEMPERATURE (F)	CALCULATED ENERGY ABSORPTION(FT-LB)
-10.0	5.5
.0	6.9
10.0	8.8
20.0	11.0
30.0	13.5
40.0	16.5
50.0	19.9
60.0	23.6
70.0	27.7
80.0	32.0
90.0	36.6
100.0	41.2
110.0	45.9
120.0	50.5
130.0	54.9
140.0	59.0
150.0	62.8
160.0	66.2
170.0	69.2
180.0	71.7

APPENDIX E, TABLE 2C

RESULTS OF LONGITUDINAL CVN IMPACT TESTS FOR
AAR TC128 STEELS AND ASTM A212-B STEELS.
CALCULATIONS FOR LATERAL EXPANSION DATA OF
ASTM A212-B,36 LT ORIENTATION SPECIMENS.

SPECIMEN	TEMPERATURE(F)	OBSERVED LATERAL EXPANSION (MILS)	CALCULATED LATERAL EXPANSION (MILS)
C15	-120.0	2.00	2.0
C3	-50.0	2.00	2.0
C2	-50.0	2.00	2.0
C1	-50.0	2.00	2.0
C41	-50.0	1.00	2.0
C42	-50.0	1.00	2.0
C43	-50.0	2.00	2.0
C14	0.0	3.00	4.7
C11	25.0	20.00	10.2
C10	25.0	13.00	10.2
C50	25.0	6.00	10.2
C51	25.0	11.00	10.2
C20	50.0	38.00	19.3
C44	73.5	12.00	30.5
C45	73.5	18.00	30.5
C4	73.5	40.00	30.5
C5	73.5	30.00	30.5
C16	87.0	45.00	37.4
C17	87.0	47.00	37.4
C48	100.0	27.00	44.0
C49	100.0	18.00	44.0
C8	100.0	67.00	44.0
C9	100.0	57.00	44.0
C12	150.0	66.00	63.4
C13	150.0	68.00	63.4
C52	150.0	50.00	63.4
C53	150.0	68.00	63.4
C46	212.0	71.00	71.4
C47	212.0	71.00	71.4
C6	212.0	70.00	71.4
C7	212.0	71.00	71.4
C67	240.0	78.00	72.0
C19	275.0	69.00	65.5
C54	275.0	66.00	65.5
C55	275.0	52.00	65.5
C18	275.0	75.00	65.5

TRANSITION REGION, CALCULATED VALUES

LATERAL EXPANSION(MILS)	CALCULATED TEMPERATURE(F)	/	TEMPERATURE (F)	CALCULATED LATERAL EXPANSION(MILS)
5.0	2.2	/	10.0	6.4
10.0	26.3	/	15.0	7.5
15.0	39.3	/	20.0	8.9
20.0	51.5	/	25.0	10.2
25.0	62.4	/	30.0	11.7
30.0	72.5	/	35.0	13.4
35.0	82.3	/	40.0	15.3
40.0	92.1	/	45.0	17.2
45.0	102.1	/	50.0	19.3
50.0	112.8	/	55.0	21.6
55.0	124.5	/	60.0	23.9
60.0	138.3	/	65.0	26.3
65.0	156.3	/	70.0	28.7
70.0	188.7	/	75.0	31.3
		/	80.0	33.8
		/	85.0	36.4
		/	90.0	38.9
		/	95.0	41.5
		/	100.0	44.0
		/	105.0	46.4

APPENDIX E, TABLE 3A

RESULTS OF TRANSVERSE CVN IMPACT TESTS FOR
AAR TC128 STEELS AND ASTM A212-B STEELS.
CALCULATIONS FOR SHEAR FRACTURE APPEARANCE DATA OF
AAR TC128, 68 TL ORIENTATION SPECIMENS.
THE CALCULATED CURVES WERE COMPUTED
FROM WEIGHTED MEAN VALUES FOR DATA
AT EACH TEST TEMPERATURE.

SPECIMEN	TEMPERATURE(F)	OBSERVED SHEAR FRACTURE (%)	CALCULATED SHEAR FRACTURE (%)
B6	-320.0	.00	.0
B16	-320.0	.00	.0
B10	-120.0	.00	1.1
B2	-120.0	.00	1.1
B37	-120.0	.00	1.1
SLC-54	-100.0	.00	1.9
B13	-82.0	.00	3.2
B6	-82.0	.00	3.2
B24	-50.0	.00	7.4
B22	-50.0	.00	7.4
HTF-61	-50.0	.00	7.4
HTF-62	-50.0	.00	7.4
SLC-44	-50.0	.00	7.4
SLC-45	-50.0	.00	7.4
B23	-50.0	.00	7.4
B12	-40.0	35.00	9.4
B4	-40.0	10.00	9.4
B3	-25.0	45.00	13.2
B11	-25.0	50.00	13.2
B35	-15.0	5.00	16.3
B36	-15.0	2.00	16.3
SLC-55	-10.0	5.00	19.1
SLC-56	-10.0	5.00	19.1
B1	-2.0	80.00	21.2
B9	-2.0	70.00	21.2
B33	.0	15.00	22.1
B34	.0	10.00	22.1
B31	10.0	15.00	26.6
B32	10.0	20.00	26.6
SLC-51	15.0	20.00	29.1
HTF-67	15.0	5.00	29.1
HTF-68	15.0	5.00	29.1
SLC-50	15.0	20.00	29.1
B27	33.0	85.00	39.2
B28	33.0	55.00	39.2
SLC-57	40.0	20.00	43.6
SLC-58	40.0	20.00	43.6
B39	50.0	85.00	50.2
B38	50.0	90.00	50.2
HTF-70	60.0	10.00	57.0
SLC-41	60.0	60.00	57.0
SLC-42	60.0	70.00	57.0
HTF-69	60.0	10.00	57.0
B7	72.5	100.00	65.5
B15	72.5	100.00	65.5
B25	73.5	95.00	66.2
B26	73.5	95.00	66.2
SLC-47	80.0	85.00	70.5
HTF-63	80.0	25.00	70.5
HTF-64	80.0	20.00	70.5
SLC-46	80.0	90.00	70.5
HTF-76	100.0	40.00	82.4
HTF-75	100.0	50.00	82.4
B40	110.0	100.00	87.3
SLC-49	120.0	98.00	91.2
HTF-65	120.0	90.00	91.2
HTF-66	120.0	80.00	91.2
SLC-48	120.0	100.00	91.2
HTF-72	160.0	98.00	98.9
SLC-52	160.0	100.00	98.9
SLC-53	160.0	100.00	98.9
HTF-71	160.0	98.00	98.9
B30	212.0	100.00	99.9
B14	212.0	100.00	99.9
B5	212.0	100.00	99.9
HTF-73	212.0	100.00	99.9
HTF-74	212.0	100.00	99.9
B29	212.0	100.00	99.9

TRANSITION REGION, CALCULATED VALUES

% SHEAR FRACTURE	CALCULATED TEMPERATURE(F)
2.0	-99.1
5.0	-65.8
10.0	-37.4
15.0	-19.1
50.0	49.7
85.0	105.1
90.0	116.6
95.0	132.7
98.0	149.9

TEMPERATURE (F)	CALCULATED SHEAR FRACTURE(%)
-90.0	2.6
-80.0	3.4
-70.0	4.5
-60.0	5.8
-50.0	7.4
-40.0	9.4
-30.0	11.8
-20.0	14.7
-10.0	18.1
.0	22.1
10.0	26.6
20.0	31.7
30.0	37.4
40.0	43.6
50.0	50.2
60.0	57.0
70.0	63.9
80.0	70.5
90.0	76.7
100.0	82.4

APPENDIX C, TABLE 3B

RESULTS OF TRANSVERSE CVN IMPACT TESTS FOR AAR TC128 STEELS AND ASTM A212-B STEELS. CALCULATIONS FOR ENERGY ABSORPTION DATA OF AAR TC128, 6B TL ORIENTATION SPECIMENS.
THE CALCULATED CURVES WERE COMPUTED FROM WEIGHTED MEAN VALUES FOR DATA AT EACH TEST TEMPERATURE.

SPECIMEN	TEMPERATURE(F)	OBSERVED ENERGY ABSORPTION(FT-LB)	CALCULATED ENERGY ABSORPTION(FT-LB)
B6	-320.0	1.00	.8
B16	-320.0	.50	.8
B10	-120.0	2.50	1.4
B2	-120.0	2.00	1.4
B37	-120.0	1.00	1.4
SLC-54	-100.0	2.00	2.3
B13	-82.0	8.50	3.5
B8	-82.0	4.50	3.5
B24	-50.0	2.00	6.6
B22	-50.0	2.00	6.6
HTF-61	-50.0	3.50	6.6
HTF-62	-50.0	4.50	6.6
SLC-44	-50.0	6.00	6.6
SLC-45	-50.0	2.50	6.6
B23	-50.0	2.50	6.6
B12	-40.0	17.00	7.9
B4	-40.0	13.00	7.9
B3	-25.0	20.50	9.9
B11	-25.0	26.50	9.9
B35	-15.0	5.00	11.5
B36	-15.0	4.00	11.5
SLC-55	-10.0	11.00	12.2
SLC-56	-10.0	13.00	12.2
B1	-2.0	34.00	13.5
B9	-2.0	28.50	13.5
B33	.0	11.00	13.9
B34	.0	6.00	13.9
B31	10.0	9.00	15.5
B32	10.0	11.00	15.5
SLC-51	15.0	18.00	16.4
HTF-67	15.0	7.00	16.4
HTF-68	15.0	7.50	16.4
SLC-50	15.0	18.00	16.4
B27	33.0	19.00	19.5
B28	33.0	15.50	19.5
SLC-57	40.0	22.00	20.7
SLC-58	40.0	25.00	20.7
B39	50.0	21.00	22.3
B38	50.0	22.00	22.3
HTF-70	60.0	10.50	23.9
SLC-41	60.0	27.00	23.9
SLC-42	60.0	33.50	23.9
HTF-69	60.0	12.00	23.9
B7	72.5	39.00	25.8
B15	72.5	42.00	25.8
B25	73.5	24.50	26.0
B26	73.5	24.50	26.0
SLC-47	80.0	31.00	26.9
HTF-63	80.0	19.00	26.9
HTF-64	80.0	16.00	26.9
SLC-46	80.0	32.00	26.9
HTF-76	100.0	19.00	29.5
HTF-75	100.0	24.00	29.5
B40	110.0	26.00	30.6
SLC-49	120.0	36.50	31.5
HTF-65	120.0	32.00	31.5
HTF-66	120.0	27.00	31.5
SLC-48	120.0	38.00	31.5
HTF-72	160.0	37.50	34.3
SLC-52	160.0	38.00	34.3
SLC-53	160.0	37.50	34.3
HTF-71	160.0	35.00	34.3
B30	212.0	24.00	35.8
B14	212.0	35.50	35.8
B5	212.0	42.50	35.8
HTF-73	212.0	37.00	35.8
HTF-74	212.0	37.50	35.8
B29	212.0	24.50	35.8

TRANSITION REGION, CALCULATED VALUES

ENERGY ABSORPTION	CALCULATED TEMPERATURE(F)
5.0	-64.7
10.0	-24.6
15.0	6.8
20.0	36.0
25.0	66.9
30.0	104.8
35.0	176.6

TEMPERATURE (F)	CALCULATED ENERGY ABSORPTION(FT-LB)
-60.0	5.5
-50.0	6.6
-40.0	7.9
-30.0	9.2
-20.0	10.7
-10.0	12.2
.0	13.9
10.0	15.5
20.0	17.3
30.0	19.0
40.0	20.7
50.0	22.3
60.0	23.9
70.0	25.5
80.0	26.9
90.0	28.2
100.0	29.5
110.0	30.6
120.0	31.5
130.0	32.4

RESULTS OF TRANSVERSE CVN IMPACT TESTS FOR
AAR TC128 STEELS AND ASTM A212-B STEELS.
CALCULATIONS FOR LATERAL EXPANSION DATA OF
AAR TC128, 68 TL ORIENTATION SPECIMENS.
THE CALCULATED CURVES WERE COMPUTED
FROM WEIGHTED MEAN VALUES FOR DATA
AT EACH TEST TEMPERATURE.

SPECIMEN	TEMPERATURE(F)	OBSERVED LATERAL EXPANSION (MILS)	CALCULATED LATERAL EXPANSION (MILS)
B6	-320.0	1.50	2.0
B16	-320.0	2.50	2.0
B10	-120.0	3.50	3.5
B2	-120.0	6.50	3.5
B37	-120.0	.00	3.5
SLC-54	-100.0	1.50	4.3
B13	-82.0	5.00	5.2
B8	-82.0	4.50	5.2
B24	-50.0	.00	7.7
B22	-50.0	.20	7.7
HTF-61	-50.0	1.00	7.7
HTF-62	-50.0	1.00	7.7
SLC-44	-50.0	4.50	7.7
SLC-45	-50.0	2.00	7.7
B23	-50.0	1.80	7.7
B12	-40.0	19.00	8.6
B4	-40.0	16.00	8.6
B3	-25.0	20.00	10.3
B11	-25.0	26.50	10.3
B35	-15.0	4.00	11.6
B36	-15.0	2.00	11.6
SLC-55	-10.0	1.30	12.2
SLC-56	-10.0	1.20	12.2
B1	-2.0	35.00	13.4
B9	-2.0	29.50	13.4
B33	.0	11.00	13.7
B34	.0	6.00	13.7
B31	10.0	13.00	15.2
B32	10.0	12.00	15.2
SLC-51	15.0	16.00	16.0
HTF-67	15.0	7.00	16.0
HTF-68	15.0	8.00	16.0
SLC-50	15.0	15.00	16.0
B27	33.0	21.00	19.0
B28	33.0	16.00	19.0
SLC-57	40.0	24.00	20.2
SLC-58	40.0	20.00	20.2
B39	50.0	22.00	22.0
B38	50.0	24.00	22.0
HTF-70	60.0	11.00	23.8
SLC-41	60.0	26.00	23.8
SLC-42	60.0	34.00	23.8
HTF-69	60.0	14.00	23.8
B7	72.5	37.50	25.9
B15	72.5	43.50	25.9
B25	73.5	26.00	26.1
B26	73.5	27.00	26.1
SLC-47	80.0	32.00	27.2
HTF-63	80.0	22.00	27.2
HTF-64	80.0	19.00	27.2
SLC-46	80.0	32.00	27.2
HTF-76	100.0	21.00	30.3
HTF-75	100.0	27.00	30.3
B40	110.0	27.00	31.6
SLC-49	120.0	37.00	32.8
HTF-65	120.0	23.00	32.8
HTF-66	120.0	28.00	32.8
SLC-48	120.0	37.00	32.8
HTF-72	160.0	37.00	36.1
SLC-52	160.0	38.00	36.1
SLC-53	160.0	39.00	36.1
HTF-71	160.0	35.00	36.1
B30	212.0	27.00	37.4
B14	212.0	39.50	37.4
B5	212.0	50.00	37.4
HTF-73	212.0	39.00	37.4
HTF-74	212.0	38.00	37.4
B29	212.0	25.00	37.4

TRANSITION REGION, CALCULATED VALUES

LATERAL EXPANSION(MILS)	CALCULATED TEMPERATURE(F)
5.0	-85.8
10.0	-27.6
15.0	8.7
20.0	38.7
25.0	67.1
30.0	98.1
35.0	142.9

TEMPERATURE (F)	CALCULATED LATERAL EXPANSION(MILS)
-80.0	5.3
-70.0	6.0
-60.0	6.8
-50.0	7.7
-40.0	8.6
-30.0	9.7
-20.0	10.9
-10.0	12.2
.0	13.7
10.0	15.2
20.0	16.8
30.0	18.5
40.0	20.2
50.0	22.0
60.0	23.8
70.0	25.5
80.0	27.2
90.0	28.8
100.0	30.3
110.0	31.6

APPENDIX E, TABLE 4A

RESULTS OF TRANSVERSE CVN IMPACT TESTS FOR
AAR TC128 STEELS AND ASTM A212-B STEELS.
CALCULATIONS FOR SHEAR FRACTURE APPEARANCE DATA OF
ASTM A212-B,35 TL ORIENTATION SPECIMENS.

SPECIMEN	TEMPERATURE(F)	OBSERVED SHEAR FRACTURE (%)	CALCULATED SHEAR FRACTURE (%)
C35	-120.0	.00	.0
C22	-50.0	.00	.2
C23	-50.0	.00	.2
C21	-50.0	.00	.2
C56	-50.0	.00	.2
C57	-50.0	.00	.2
C58	-50.0	.00	.2
C36	.0	3.00	3.4
C30	25.0	5.00	8.7
C31	25.0	30.00	8.7
C37	25.0	5.00	8.7
C65	25.0	2.00	8.7
C66	25.0	2.00	8.7
C40	50.0	20.00	18.2
C59	73.5	30.00	31.6
C60	73.5	25.00	31.6
C25	73.5	30.00	31.6
C24	73.5	30.00	31.6
C63	100.0	40.00	50.7
C64	100.0	25.00	50.7
C29	100.0	50.00	50.7
C28	100.0	65.00	50.7
C38	125.0	98.00	69.4
C39	125.0	99.00	69.4
C34	150.0	95.00	84.6
C33	150.0	100.00	84.6
C69	150.0	45.00	84.6
C70	150.0	55.00	84.6
C61	212.0	95.00	98.6
C62	212.0	97.00	98.6
C27	212.0	100.00	98.6
C26	212.0	100.00	98.6
C73	240.0	99.00	99.1
C72	275.0	100.00	99.2
C71	275.0	100.00	99.2

TRANSITION REGION, CALCULATED VALUES

% SHEAR FRACTURE	CALCULATED TEMPERATURE(F)	/	TEMPERATURE (F)	CALCULATED SHEAR FRACTURE(%)
2.0	-12.0	/	-10.0	2.2
5.0	9.4	/	.0	3.4
10.0	29.2	/	10.0	5.1
15.0	42.8	/	20.0	7.4
50.0	99.1	/	30.0	10.2
85.0	150.9	/	40.0	13.9
90.0	162.6	/	50.0	18.2
95.0	180.1	/	60.0	23.4
98.0	202.0	/	70.0	29.4
		/	80.0	36.0
		/	90.0	43.2
		/	100.0	50.7
		/	110.0	58.4
		/	120.0	65.8
		/	130.0	72.8
		/	140.0	79.1
		/	150.0	84.6
		/	160.0	89.0
		/	170.0	92.5
		/	180.0	95.0

RESULTS OF TRANSVERSE CVN IMPACT TESTS FOR
AAR TC128 STEELS AND ASTM A212-B STEELS.
CALCULATIONS FOR ENERGY ABSORPTION DATA OF
ASTM A212-B,35 TL ORIENTATION SPECIMENS.

SPECIMEN	TEMPERATURE(F)	OBSERVED ENERGY ABSORPTION(FT-LB)	CALCULATED ENERGY ABSORPTION(FT-LB)
C35	-120.0	1.50	1.5
C22	-50.0	2.00	2.2
C23	-50.0	3.00	2.2
C21	-50.0	2.00	2.2
C56	-50.0	2.00	2.2
C57	-50.0	2.00	2.2
C58	-50.0	2.00	2.2
C36	.0	8.00	4.9
C30	25.0	7.50	7.5
C31	25.0	15.50	7.5
C37	25.0	11.00	7.5
C65	25.0	3.50	7.5
C66	25.0	4.50	7.5
C40	50.0	11.00	11.4
C59	73.5	15.00	16.4
C60	73.5	9.00	16.4
C25	73.5	18.50	16.4
C24	73.5	12.50	16.4
C63	100.0	18.00	23.2
C64	100.0	23.50	23.2
C29	100.0	22.00	23.2
C28	100.0	24.50	23.2
C38	125.0	34.50	30.2
C39	125.0	34.00	30.2
C34	150.0	33.50	37.0
C33	150.0	34.00	37.0
C69	150.0	31.00	37.0
C70	150.0	43.00	37.0
C61	212.0	55.00	47.7
C62	212.0	56.00	47.7
C27	212.0	34.00	47.7
C26	212.0	35.00	47.7
C73	240.0	53.00	49.3
C72	275.0	53.00	49.9
C71	275.0	54.00	49.9

TRANSITION REGION, CALCULATED VALUES

ENERGY ABSORPTION	CALCULATED TEMPERATURE(F)	/	TEMPERATURE (F)	CALCULATED ENERGY ABSORPTION(FT-LB)
5.0	2.4	/	10.0	5.7
10.0	42.0	/	15.0	6.3
15.0	67.5	/	20.0	6.9
20.0	88.1	/	25.0	7.5
25.0	106.5	/	30.0	8.1
30.0	124.1	/	35.0	8.9
35.0	142.2	/	40.0	9.7
40.0	162.5	/	45.0	10.5
45.0	189.1	/	50.0	11.4
		/	55.0	12.4
		/	60.0	13.4
		/	65.0	14.4
		/	70.0	15.6
		/	75.0	16.7
		/	80.0	17.9
		/	85.0	19.2
		/	90.0	20.5
		/	95.0	21.8
		/	100.0	23.2
		/	105.0	24.6

APPENDIX E, TABLE 4C

RESULTS OF TRANSVERSE CVN IMPACT TESTS FOR
AAR TC128 STEELS AND ASTM A212-B STEELS.
CALCULATIONS FOR LATERAL EXPANSION DATA OF
ASTM A212-B,35 TL ORIENTATION SPECIMENS.

SPECIMEN	TEMPERATURE(F)	OBSERVED LATERAL EXPANSION (MILS)	CALCULATED LATERAL EXPANSION (MILS)
C35	-120.0	2.00	2.0
C22	-50.0	1.00	3.3
C23	-50.0	2.00	3.3
C21	-50.0	1.00	3.3
C56	-50.0	1.00	3.3
C57	-50.0	1.00	3.3
C58	-50.0	1.00	3.3
C36	.0	12.00	7.2
C30	25.0	12.00	10.9
C31	25.0	17.00	10.9
C37	25.0	15.00	10.9
C65	25.0	7.00	10.9
C66	25.0	6.00	10.9
C40	50.0	16.00	16.1
C59	73.5	22.00	22.4
C60	73.5	11.00	22.4
C25	73.5	23.00	22.4
C24	73.5	16.00	22.4
C63	100.0	26.00	30.6
C64	100.0	26.00	30.6
C29	100.0	24.00	30.6
C28	100.0	32.00	30.6
C38	125.0	48.00	38.8
C39	125.0	46.00	38.8
C34	150.0	44.00	46.4
C33	150.0	50.00	46.4
C69	150.0	48.00	46.4
C70	150.0	46.00	46.4
C61	212.0	59.00	58.6
C62	212.0	61.00	58.6
C27	212.0	48.00	58.6
C26	212.0	47.00	58.6
C73	240.0	64.00	60.6
C72	275.0	74.00	61.5
C71	275.0	63.00	61.5

TRANSITION REGION, CALCULATED VALUES

LATERAL EXPANSION(MILS)	CALCULATED TEMPERATURE(F)	/	TEMPERATURE (F)	CALCULATED LATERAL EXPANSION(MILS)
5.0	-21.6	/	-20.0	5.1
10.0	19.6	/	-10.0	6.1
15.0	45.1	/	.0	7.2
20.0	65.0	/	10.0	8.5
25.0	82.3	/	20.0	10.1
30.0	98.2	/	30.0	11.8
35.0	113.5	/	40.0	13.9
40.0	128.9	/	50.0	16.1
45.0	145.1	/	60.0	18.7
50.0	163.4	/	70.0	21.4
55.0	186.6	/	80.0	24.3
60.0	228.5	/	90.0	27.4
		/	100.0	30.6
		/	110.0	33.9
		/	120.0	37.1
		/	130.0	40.4
		/	140.0	43.5
		/	150.0	46.4
		/	160.0	49.1
		/	170.0	51.6

APPENDIX F

CVN Results of LT and TL Specimens of Combined Data of Two A212-B Steels, and of Combined Data of Two TC128-B Steels that Contain Vanadium

APPENDIX F, TABLE 1A

RESULTS OF IMPACT TESTS FOR THREE GRADES OF STEEL
...CVN SPECIMENS OF LT ORIENTATION FROM FOUR ACCIDENTS.
CALCULATIONS FOR SHEAR FRACTURE APPEARANCE DATA OF SPECIMENS.
ASTM A212-B, 36 C.CITY HEAD & SHELL

SPECIMEN	TEMPERATURE(F)	OBSERVED SHEAR FRACTURE (%)	CALCULATED SHEAR FRACTURE (%)
C15	-120.0	.00	.0
C2	-50.0	.00	.0
C3	-50.0	.00	.0
C1	-50.0	.00	.0
C41	-50.0	.00	.0
C42	-50.0	.00	.0
C43	-50.0	.00	.0
C14	.0	.00	.0
C11	25.0	2.00	2.3
C10	25.0	3.00	2.3
C50	25.0	2.00	2.3
C51	25.0	2.00	2.3
C20	50.0	30.00	13.4
C44	73.5	25.00	31.2
C45	73.5	15.00	31.2
C4	73.5	30.00	31.2
C5	73.5	20.00	31.2
C16	87.0	30.00	43.0
C17	87.0	55.00	43.0
C48	100.0	35.00	54.4
C49	100.0	40.00	54.4
C8	100.0	98.00	54.4
C9	100.0	90.00	54.4
C12	150.0	100.00	87.1
C13	150.0	100.00	87.1
C52	150.0	60.00	87.1
C53	150.0	55.00	87.1
C46	212.0	97.00	99.0
C47	212.0	98.00	99.0
C6	212.0	100.00	99.0
C7	212.0	100.00	99.0
C67	240.0	100.00	99.8
C19	275.0	100.00	100.0
C54	275.0	100.00	100.0
C55	275.0	100.00	100.0
C18	275.0	100.00	100.0

TRANSITION REGION, CALCULATED VALUES

% SHEAR FRACTURE	CALCULATED TEMPERATURE(F)	/	TEMPERATURE (F)	CALCULATED SHEAR FRACTURE(%)
2.0	23.9	/	30.0	3.7
5.0	33.5	/	35.0	5.6
10.0	44.2	/	40.0	7.8
15.0	52.4	/	45.0	10.5
50.0	94.9	/	50.0	13.4
85.0	145.1	/	55.0	16.7
90.0	157.6	/	60.0	20.3
95.0	176.3	/	65.0	24.2
98.0	197.7	/	70.0	28.3
		/	75.0	32.5
		/	80.0	36.9
		/	85.0	41.3
		/	90.0	45.7
		/	95.0	50.1
		/	100.0	54.4
		/	105.0	58.6
		/	110.0	62.7
		/	115.0	66.6
		/	120.0	70.3
		/	125.0	73.7

APPENDIX F, TABLE 1B

RESULTS OF IMPACT TESTS FOR THREE GRADES OF STEEL
...CVN SPECIMENS OF LT ORIENTATION FROM FOUR ACCIDENTS.
CALCULATIONS FOR ENERGY ABSORPTION DATA OF
ASTM A212-B, 36 C.CITY HEAD & SHELL SPECIMENS.

SPECIMEN	TEMPERATURE(F)	OBSERVED ENERGY ABSORPTION(FT-LB)	CALCULATED ENERGY ABSORPTION(FT-LB)
C15	-120.0	1.50	1.5
C2	-50.0	3.50	2.2
C3	-50.0	3.00	2.2
C1	-50.0	2.00	2.2
C41	-50.0	2.00	2.2
C42	-50.0	2.00	2.2
C43	-50.0	2.00	2.2
C14	.0	4.00	6.9
C11	25.0	18.00	12.2
C10	25.0	10.00	12.2
C50	25.0	4.00	12.2
C51	25.0	5.00	12.2
C20	50.0	35.00	19.9
C44	73.5	11.00	29.2
C45	73.5	12.00	29.2
C4	73.5	37.50	29.2
C5	73.5	26.00	29.2
C16	87.0	41.00	35.2
C17	87.0	47.50	35.2
C48	100.0	21.00	41.2
C49	100.0	15.00	41.2
C6	100.0	74.50	41.2
C9	100.0	62.50	41.2
C12	150.0	75.00	62.8
C13	150.0	67.00	62.8
C52	150.0	50.00	62.8
C53	150.0	37.50	62.8
C46	212.0	80.00	76.9
C47	212.0	81.50	76.9
C6	212.0	73.00	76.9
C7	212.0	79.00	76.9
C67	240.0	85.00	79.9
C19	275.0	71.00	70.3
C54	275.0	65.50	70.3
C55	275.0	75.50	70.3
C18	275.0	69.00	70.3

TRANSITION REGION, CALCULATED VALUES

ENERGY ABSORPTION	CALCULATED TEMPERATURE(F)	/	TEMPERATURE (F)	CALCULATED EFERGY ABSORPTION(FT-LB)
5.0	-13.6	/	-10.0	5.5
10.0	15.8	/	.0	6.9
15.0	35.1	/	10.0	8.8
20.0	50.3	/	20.0	11.0
25.0	63.5	/	30.0	13.5
30.0	75.4	/	40.0	16.5
35.0	86.6	/	50.0	19.9
40.0	97.4	/	60.0	23.6
45.0	108.1	/	70.0	27.7
50.0	119.0	/	80.0	32.0
55.0	130.3	/	90.0	36.6
60.0	142.5	/	100.0	41.2
65.0	156.2	/	110.0	45.9
70.0	173.0	/	120.0	50.5
75.0	197.1	/	130.0	54.9
		/	140.0	59.0
		/	150.0	62.8
		/	160.0	66.2
		/	170.0	69.2
		/	180.0	71.7

APPENDIX F, TABLE 1C

RESULTS OF IMPACT TESTS FOR THREE GRADES OF STEEL
...CVN SPECIMENS OF LT ORIENTATION FROM FOUR ACCIDENTS.
CALCULATIONS FOR LATERAL EXPANSION DATA OF
ASTM A212-B, 36 C.CITY HEAD & SHELL SPECIMENS.

SPECIMEN	TEMPERATURE(F)	OBSERVED LATERAL EXPANSION (MILS)	CALCULATED LATERAL EXPANSION (MILS)
C15	-120.0	2.00	2.0
C2	-50.0	2.00	2.0
C3	-50.0	2.00	2.0
C1	-50.0	2.00	2.0
C41	-50.0	1.00	2.0
C42	-50.0	1.00	2.0
C43	-50.0	2.00	2.0
C14	.0	3.00	4.7
C11	25.0	20.00	10.2
C10	25.0	13.00	10.2
C50	25.0	6.00	10.2
C51	25.0	11.00	10.2
C20	50.0	38.00	19.3
C44	73.5	12.00	30.5
C45	73.5	18.00	30.5
C4	73.5	40.00	30.5
C5	73.5	30.00	30.5
C16	87.0	45.00	37.4
C17	87.0	47.00	37.4
C48	100.0	27.00	44.0
C49	100.0	18.00	44.0
C8	100.0	67.00	44.0
C9	100.0	57.00	44.0
C12	150.0	66.00	63.4
C13	150.0	68.00	63.4
C52	150.0	50.00	63.4
C53	150.0	68.00	63.4
C46	212.0	71.00	71.4
C47	212.0	71.00	71.4
C6	212.0	70.00	71.4
C7	212.0	71.00	71.4
C67	240.0	78.00	72.0
C19	275.0	69.00	65.5
C54	275.0	66.00	65.5
C55	275.0	52.00	65.5
C18	275.0	75.00	65.5

TRANSITION REGION, CALCULATED VALUES

LATERAL EXPANSION(MILS)	CALCULATED TEMPERATURE(F)	/	TEMPERATURE (F)	CALCULATED LATERAL EXPANSION(MILS)
5.0	2.2	/	10.0	6.4
10.0	24.3	/	15.0	7.5
15.0	39.3	/	20.0	8.8
20.0	51.5	/	25.0	10.2
25.0	62.4	/	30.0	11.7
30.0	72.5	/	35.0	13.4
35.0	82.3	/	40.0	15.3
40.0	92.1	/	45.0	17.2
45.0	102.1	/	50.0	19.3
50.0	112.8	/	55.0	21.6
55.0	124.5	/	60.0	23.9
60.0	138.3	/	65.0	26.3
65.0	156.3	/	70.0	28.7
70.0	188.7	/	75.0	31.3
		/	80.0	33.8
		/	85.0	36.4
		/	90.0	38.9
		/	95.0	41.5
		/	100.0	44.0
		/	105.0	46.4

APPENDIX F, TABLE 2A

RESULTS OF IMPACT TESTS FOR THREE GRADES OF STEEL
...CVN SPECIMENS OF LT ORIENTATION FROM FOUR ACCIDENTS.
CALCULATIONS FOR SHEAR FRACTURE APPEARANCE DATA OF
18 CALLAO HEAD K-1 AND 19 S. BYRON SHELL SPECIMENS
OF AAR TC128-B STEELS THAT CONTAIN VANADIUM.

SPECIMEN	TEMPERATURE(F)	OBSERVED SHEAR FRACTURE (%)	CALCULATED SHEAR FRACTURE (%)
B14	-120.0	.00	.0
HLH-15	-100.0	.00	.0
B3	-50.0	.00	1.0
B1	-50.0	.00	1.0
HLH-1	-50.0	.00	1.0
HLH-2	-50.0	.00	1.0
B2	-50.0	.00	1.0
B10	-10.0	2.00	5.0
B11	-10.0	5.00	5.0
B6	12.0	30.00	13.2
B7	12.0	25.00	13.2
HLH-8	15.0	5.00	14.6
HLH-7	15.0	.00	14.6
B19	30.0	40.00	23.2
B13	30.0	35.00	23.2
B12	30.0	15.00	23.2
B15	50.0	90.00	39.1
B16	50.0	80.00	39.1
HLH-10	60.0	15.00	48.7
HLH-9	60.0	15.00	48.7
B5	73.5	98.00	62.3
B4	73.5	95.00	62.3
HLH-4	80.0	20.00	68.8
HLH-3	80.0	15.00	68.8
HLH-16	100.0	100.00	85.8
HLH-17	100.0	100.00	85.8
HLH-18	100.0	100.00	85.8
B18	110.0	100.00	91.8
B17	110.0	100.00	91.8
HLH-6	120.0	80.00	95.8
HLH-19	120.0	100.00	95.8
HLH-12	160.0	100.00	100.0
HLH-11	160.0	100.00	100.0
B8	212.0	100.00	100.0
HLH-13	212.0	100.00	100.0
HLH-14	212.0	100.00	100.0
B9	212.0	100.00	100.0

TRANSITION REGION, CALCULATED VALUES

% SHEAR FRACTURE	CALCULATED TEMPERATURE(F)	/	TEMPERATURE (F)	CALCULATED SHEAR FRACTURE(%)
2.0	-35.2	/	-30.0	2.5
5.0	-14.2	/	-25.0	3.2
10.0	4.0	/	-20.0	3.9
15.0	15.9	/	-15.0	4.9
50.0	61.3	/	-10.0	5.9
85.0	98.8	/	-5.0	7.2
90.0	106.6	/	.0	8.7
95.0	117.6	/	5.0	10.4
98.0	129.2	/	10.0	12.3
		/	15.0	14.6
		/	20.0	17.1
		/	25.0	20.0
		/	30.0	23.2
		/	35.0	26.7
		/	40.0	30.5
		/	45.0	34.7
		/	50.0	39.1
		/	55.0	43.8
		/	60.0	48.7
		/	65.0	53.7

APPENDIX F, TABLE 2D

RESULTS OF IMPACT TESTS FOR THREE GRADES OF STEEL
...CVN SPECIMENS OF LT ORIENTATION FROM FOUR ACCIDENTS.
CALCULATIONS FOR SHEAR FRACTURE APPEARANCE DATA OF
18 CALLAO HEAD K-1 AND 19 S. BYRON SHELL SPECIMENS
OF AAR TC128-B STEELS THAT CONTAIN VANADIUM.

SPECIMEN	TEMPERATURE(F)	OBSERVED ENERGY ABSORPTION(FT-LB)	CALCULATED ENERGY ABSORPTION(FT-LB)
B14	-120.0	1.50	1.5
HLH-15	-100.0	2.50	1.5
B3	-50.0	2.00	2.3
B1	-50.0	2.00	2.3
HLH-1	-50.0	3.50	2.3
HLH-2	-50.0	2.50	2.3
B2	-50.0	2.00	2.3
B10	-10.0	4.00	7.3
B11	-10.0	4.50	7.3
B6	12.0	14.00	13.1
B7	12.0	23.00	13.1
HLH-8	15.0	6.00	14.1
HLH-7	15.0	11.00	14.1
B19	30.0	21.50	19.6
B13	30.0	27.50	19.6
B12	30.0	10.50	19.6
B15	50.0	36.50	27.9
B16	50.0	36.50	27.9
HLH-10	60.0	19.50	32.0
HLH-9	60.0	21.50	32.0
B5	73.5	44.50	37.3
B4	73.5	41.50	37.3
HLH-4	80.0	26.00	39.7
HLH-3	80.0	28.50	39.7
HLH-16	100.0	55.00	45.6
HLH-17	100.0	53.00	45.6
HLH-18	100.0	54.00	45.6
B18	110.0	47.00	47.7
B17	110.0	44.00	47.7
HLH-6	120.0	42.00	49.3
HLH-19	120.0	52.00	49.3
HLH-12	160.0	51.00	52.0
HLH-11	160.0	52.00	52.0
B8	212.0	45.00	52.3
HLH-13	212.0	53.00	52.3
HLH-14	212.0	52.00	52.3
B9	212.0	44.50	52.3

TRANSITION REGION, CALCULATED VALUES.

ENERGY ABSORPTION	CALCULATED TEMPERATURE(F)	/	TEMPERATURE (F)	CALCULATED ENERGY ABSORPTION(FT-LB)
5.0	-22.3	/	-20.0	5.4
10.0	1.4	/	-15.0	6.3
15.0	17.5	/	-10.0	7.3
20.0	31.0	/	-5.0	8.4
25.0	43.2	/	.0	9.6
30.0	55.1	/	5.0	11.0
35.0	67.4	/	10.0	12.5
40.0	80.9	/	15.0	14.1
45.0	97.7	/	20.0	15.9
50.0	125.8	/	25.0	17.7
		/	30.0	19.6
		/	35.0	21.6
		/	40.0	23.7
		/	45.0	25.7
		/	50.0	27.8
		/	55.0	29.9
		/	60.0	32.0
		/	65.0	34.1
		/	70.0	36.0
		/	75.0	37.9

APPENDIX F, TABLE 2C

RESULTS OF IMPACT TESTS FOR THREE GRADES OF STEEL
...CVN SPECIMENS OF LT ORIENTATION FROM FOUR ACCIDENTS.
CALCULATIONS FOR SHEAR FRACTURE APPEARANCE DATA OF
18 CALLAO HEAD K-1 AND 19 S. BYRON SHELL SPECIMENS
OF AAR TC128-B STEELS THAT CONTAIN VANADIUM.

SPECIMEN	TEMPERATURE(F)	OBSERVED LATERAL EXPANSION (MILS)	CALCULATED LATERAL EXPANSION (MILS)
B14	-120.0	.00	.0
HLH-15	-100.0	4.00	.0
B3	-50.0	.00	.9
B1	-50.0	.00	.9
HLH-1	-50.0	2.00	.9
HLH-2	-50.0	1.00	.9
B2	-50.0	2.00	.9
B10	-10.0	3.00	6.6
B11	-10.0	4.00	6.6
B6	12.0	15.00	12.7
B7	12.0	21.00	12.7
HLH-8	15.0	7.50	13.7
HLH-7	15.0	10.50	13.7
B19	30.0	24.00	18.9
B13	30.0	27.00	18.9
B12	30.0	10.00	18.9
B15	50.0	33.00	26.4
B16	50.0	32.00	26.4
HLH-10	60.0	23.00	30.0
HLH-9	60.0	22.00	30.0
B5	73.5	43.00	34.6
B4	73.5	38.00	34.6
HLH-4	80.0	25.00	36.5
HLH-3	80.0	24.00	36.5
HLH-16	100.0	46.00	41.5
HLH-17	100.0	45.00	41.5
HLH-18	100.0	46.00	41.5
B18	110.0	44.00	43.3
B17	110.0	44.00	43.3
HLH-6	120.0	36.00	44.8
HLH-19	120.0	54.00	44.8
HLH-12	160.0	47.50	47.4
HLH-11	160.0	46.00	47.4
B6	212.0	53.00	47.9
HLH-13	212.0	48.00	47.9
HLH-14	212.0	50.00	47.9
B9	212.0	43.00	47.9

TRANSITION REGION, CALCULATED VALUES

LATERAL EXPANSION(MILS)	CALCULATED TEMPERATURE(F)	/	TEMPERATURE (F)	CALCULATED LATERAL EXPANSION(MILS)
5.0	-17.4	/	-10.0	6.6
10.0	3.1	/	-5.0	7.8
15.0	18.9	/	.0	9.1
20.0	32.9	/	5.0	10.5
25.0	46.3	/	10.0	12.1
30.0	59.9	/	15.0	13.7
35.0	74.9	/	20.0	15.4
40.0	93.2	/	25.0	17.1
45.0	122.1	/	30.0	18.9
		/	35.0	20.8
		/	40.0	22.6
		/	45.0	24.5
		/	50.0	26.4
		/	55.0	28.2
		/	60.0	30.0
		/	65.0	31.8
		/	70.0	33.4
		/	75.0	35.0
		/	80.0	36.5
		/	85.0	37.9

APPENDIX F, TABLE 3A

RESULTS OF IMPACT TESTS FOR THREE GRADES OF STEEL
...CVN SPECIMENS OF TL ORIENTATION FROM FOUR ACCIDENTS.
CALCULATIONS FOR SHEAR FRACTURE APPEARANCE DATA OF
ASTM A212-B, 35 C.CITY HEAD & SHELL SPECIMENS.

SPECIMEN	TEMPERATURE(F)	OBSERVED SHEAR FRACTURE (%)	CALCULATED SHEAR FRACTURE (%)
C35	-120.0	.00	.0
C22	-50.0	.00	.2
C23	-50.0	.00	.2
C21	-50.0	.00	.2
C56	-50.0	.00	.2
C57	-50.0	.00	.2
C58	-50.0	.00	.2
C36	.0	3.00	3.4
C30	25.0	5.00	8.7
C31	25.0	30.00	8.7
C37	25.0	5.00	8.7
C65	25.0	2.00	8.7
C66	25.0	2.00	8.7
C40	50.0	20.00	18.2
C59	73.5	30.00	31.6
C60	73.5	25.00	31.6
C25	73.5	30.00	31.6
C24	73.5	30.00	31.6
C63	100.0	40.00	50.7
C64	100.0	25.00	50.7
C29	100.0	50.00	50.7
C28	100.0	65.00	50.7
C38	125.0	98.00	69.4
C39	125.0	99.00	69.4
C34	150.0	95.00	84.6
C33	150.0	100.00	84.6
C69	150.0	45.00	84.6
C70	150.0	55.00	84.6
C61	212.0	95.00	98.6
C62	212.0	97.00	98.6
C27	212.0	100.00	98.6
C26	212.0	100.00	98.6
C73	240.0	99.00	99.1
C72	275.0	100.00	99.2
C71	275.0	100.00	99.2

TRANSITION REGION, CALCULATED VALUES

% SHEAR FRACTURE	CALCULATED TEMPERATURE(F)	/	TEMPERATURE (F)	CALCULATED SHEAR FRACTURE(%)
2.0	-12.0	/	-10.0	2.2
5.0	9.4	/	.0	3.4
10.0	29.2	/	10.0	5.1
15.0	42.8	/	20.0	7.4
50.0	99.1	/	30.0	10.2
85.0	150.9	/	40.0	13.9
90.0	162.6	/	50.0	18.2
95.0	180.1	/	60.0	23.4
98.0	202.0	/	70.0	29.4
		/	80.0	36.0
		/	90.0	43.2
		/	100.0	50.7
		/	110.0	58.4
		/	120.0	65.8
		/	130.0	72.8
		/	140.0	79.1
		/	150.0	84.6
		/	160.0	89.0
		/	170.0	92.5
		/	180.0	95.0

APPENDIX F, TABLE 3B

RESULTS OF IMPACT TESTS FOR THREE GRADES OF STEEL
...CVN SPECIMENS OF TL ORIENTATION FROM FOUR ACCIDENTS.
CALCULATIONS FOR ENERGY ABSORPTION DATA OF
ASTM A212-B, 35 C.CITY HEAD & SHELL SPECIMENS.

SPECIMEN	TEMPERATURE(F)	OBSERVED ENERGY ABSORPTION(FT-LB)	CALCULATED ENERGY ABSORPTION(FT-LB)
C35	-120.0	1.50	1.5
C22	-50.0	2.00	2.2
C23	-50.0	3.00	2.2
C21	-50.0	2.00	2.2
C56	-50.0	2.00	2.2
C57	-50.0	2.00	2.2
C58	-50.0	2.00	2.2
C36	.0	8.00	4.8
C30	25.0	7.50	7.5
C31	25.0	15.50	7.5
C37	25.0	11.00	7.5
C65	25.0	3.50	7.5
C66	25.0	4.50	7.5
C40	50.0	11.00	11.4
C59	73.5	15.00	16.4
C60	73.5	9.00	16.4
C25	73.5	18.50	16.4
C24	73.5	12.50	16.4
C63	100.0	18.00	23.2
C64	100.0	23.50	23.2
C29	100.0	22.00	23.2
C28	100.0	24.50	23.2
C38	125.0	34.50	30.2
C39	125.0	34.00	30.2
C34	150.0	33.50	37.0
C33	150.0	34.00	37.0
C69	150.0	31.00	37.0
C70	150.0	43.00	37.0
C61	212.0	55.00	47.7
C62	212.0	56.00	47.7
C27	212.0	34.00	47.7
C26	212.0	35.00	47.7
C73	240.0	53.00	49.3
C72	275.0	53.00	49.9
C71	275.0	54.00	49.9

TRANSITION REGION, CALCULATED VALUES

ENERGY ABSORPTION	CALCULATED TEMPERATURE(F)	/	TEMPERATURE (F)	CALCULATED ENERGY ABSORPTION(FT-LB)
5.0	2.4	/	10.0	5.7
10.0	42.0	/	15.0	6.3
15.0	67.5	/	20.0	6.9
20.0	88.1	/	25.0	7.5
25.0	106.5	/	30.0	8.1
30.0	124.1	/	35.0	8.9
35.0	142.2	/	40.0	9.7
40.0	162.5	/	45.0	10.5
45.0	189.1	/	50.0	11.4
		/	55.0	12.4
		/	60.0	13.4
		/	65.0	14.4
		/	70.0	15.6
		/	75.0	16.7
		/	80.0	17.9
		/	85.0	19.2
		/	90.0	20.5
		/	95.0	21.8
		/	100.0	23.2
		/	105.0	24.6

RESULTS OF IMPACT TESTS FOR THREE GRADES OF STEEL
...CVN SPECIMENS OF TL ORIENTATION FROM FOUR ACCIDENTS.
CALCULATIONS FOR LATERAL EXPANSION DATA OF
ASTM A212-B, 35 C.CITY HEAD & SHELL SPECIMENS.

SPECIMEN	TEMPERATURE(F)	OBSERVED LATERAL EXPANSION (MILS)	CALCULATED LATERAL EXPANSION (MILS)
C35	-120.0	2.00	2.0
C22	-50.0	1.00	3.3
C23	-50.0	2.00	3.3
C21	-50.0	1.00	3.3
C56	-50.0	1.00	3.3
C57	-50.0	1.00	3.3
C58	-50.0	1.00	3.3
C36	.0	12.00	7.2
C30	25.0	12.00	10.9
C31	25.0	17.00	10.9
C37	25.0	15.00	10.9
C65	25.0	7.00	10.9
C66	25.0	6.00	10.9
C40	50.0	16.00	16.1
C59	73.5	22.00	22.4
C60	73.5	11.00	22.4
C25	73.5	23.00	22.4
C24	73.5	16.00	22.4
C63	100.0	26.00	30.6
C64	100.0	26.00	30.6
C29	100.0	24.00	30.6
C28	100.0	32.00	30.6
C38	125.0	48.00	39.8
C39	125.0	46.00	39.8
C34	150.0	44.00	46.4
C33	150.0	50.00	46.4
C69	150.0	48.00	46.4
C70	150.0	46.00	46.4
C61	212.0	59.00	58.6
C62	212.0	61.00	58.6
C27	212.0	48.00	58.6
C26	212.0	47.00	58.6
C73	240.0	64.00	60.6
C72	275.0	74.00	61.5
C71	275.0	63.00	61.5

TRANSITION REGION, CALCULATED VALUES

LATERAL EXPANSION(MILS)	CALCULATED TEMPERATURE(F)	/	TEMPERATURE (F)	CALCULATED LATERAL EXPANSION(MILS)
5.0	-21.6	/	-20.0	5.1
10.0	19.6	/	-10.0	6.1
15.0	45.1	/	.0	7.2
20.0	65.0	/	10.0	8.5
25.0	82.3	/	20.0	10.1
30.0	98.2	/	30.0	11.8
35.0	113.5	/	40.0	13.9
40.0	128.9	/	50.0	16.1
45.0	145.1	/	60.0	18.7
50.0	163.4	/	70.0	21.4
55.0	186.6	/	80.0	24.3
60.0	228.5	/	90.0	27.4
		/	100.0	30.6
		/	110.0	33.9
		/	120.0	37.1
		/	130.0	40.4
		/	140.0	43.5
		/	150.0	46.4
		/	160.0	49.1
		/	170.0	51.6

RESULTS OF IMPACT TESTS FOR THREE GRADES OF STEEL
...CVN SPECIMENS OF TL ORIENTATION FROM FOUR ACCIDENTS.
CALCULATIONS FOR SHEAR FRACTURE APPEARANCE DATA OF
16 CALLAO HEAD K-1 AND 19 S.BYRON SHELL SPECIMENS.

SPECIMEN	TEMPERATURE(F)	OBSERVED SHEAR FRACTURE (%)	CALCULATED SHEAR FRACTURE (%)
B37	-120.0	.00	.0
B23	-50.0	.00	.0
B24	-50.0	.00	.0
B22	-50.0	.00	.0
HTF-61	-50.0	.00	.0
HTF-62	-50.0	.00	.0
B36	-15.0	2.00	1.5
B35	-15.0	5.00	1.5
B34	.0	10.00	11.0
B33	.0	15.00	11.0
B32	10.0	20.00	19.1
B31	10.0	15.00	19.1
HTF-67	15.0	5.00	23.3
HTF-68	15.0	5.00	23.3
B28	33.0	55.00	38.6
B27	33.0	85.00	38.6
B38	50.0	90.00	52.1
B39	50.0	85.00	52.1
HTF-69	60.0	10.00	59.1
HTF-70	60.0	10.00	59.1
B26	73.5	95.00	67.5
B25	73.5	95.00	67.5
HTF-63	80.0	25.00	71.1
HTF-64	80.0	20.00	71.1
HTF-75	100.0	50.00	80.3
HTF-76	100.0	40.00	80.3
B40	110.0	100.00	83.0
HTF-65	120.0	90.00	87.0
HTF-66	120.0	80.00	87.0
HTF-71	160.0	98.00	94.8
HTF-72	160.0	98.00	94.8
HTF-73	212.0	100.00	98.6
HTF-74	212.0	100.00	98.6
B29	212.0	100.00	98.6
B30	212.0	100.00	98.6

TRANSITION REGION, CALCULATED VALUES

% SHEAR FRACTURE	CALCULATED TEMPERATURE(F)	/	TEMPERATURE (F)	CALCULATED SHEAR FRACTURE(%)
2.0	-13.9	/	-10.0	4.1
5.0	-8.6	/	.0	11.0
10.0	-1.3	/	10.0	19.1
15.0	5.1	/	20.0	27.6
50.0	47.2	/	30.0	36.1
85.0	113.4	/	40.0	44.4
90.0	132.2	/	50.0	52.1
95.0	162.0	/	60.0	59.1
98.0	198.2	/	70.0	65.5
		/	80.0	71.1
		/	90.0	76.0
		/	100.0	80.3
		/	110.0	83.0
		/	120.0	87.0
		/	130.0	89.5
		/	140.0	91.6
		/	150.0	93.3
		/	160.0	94.8
		/	170.0	95.9
		/	180.0	96.8

APPENDIX F, TABLE 4D

RESULTS OF IMPACT TESTS FOR THREE GRADES OF STEEL
...CVN SPECIMENS OF LT ORIENTATION FROM FOUR ACCIDENTS.
CALCULATIONS FOR SHEAR FRACTURE APPEARANCE DATA OF
16 CALLAO HEAD K-1 AND 19 S. BYRON SHELL SPECIMENS
OF AAR TC128-B STEELS THAT CONTAIN VANADIUM.

SPECIMEN	TEMPERATURE(F)	OBSERVED ENERGY ABSORPTION(FT-LB)	CALCULATED ENERGY ABSORPTION(FT-LB)
B37	-120.0	1.00	1.0
B23	-50.0	2.50	2.8
B24	-50.0	2.00	2.8
B22	-50.0	2.00	2.8
HTF-61	-50.0	3.50	2.8
HTF-62	-50.0	4.50	2.8
B36	-15.0	4.00	5.7
B35	-15.0	5.00	5.7
B34	.0	6.00	7.6
B33	.0	11.00	7.6
B32	10.0	11.00	9.0
B31	10.0	9.00	9.0
HTF-67	15.0	7.00	9.8
HTF-68	15.0	7.50	9.8
B28	33.0	15.50	12.9
B27	33.0	19.00	12.9
B38	50.0	22.00	16.2
B39	50.0	21.00	16.2
HTF-69	60.0	12.00	18.1
HTF-70	60.0	10.50	18.1
B26	73.5	24.50	20.7
B25	73.5	24.50	20.7
HTF-63	80.0	19.00	22.0
HTF-64	80.0	16.00	22.0
HTF-75	100.0	24.00	25.4
HTF-76	100.0	19.00	25.4
B40	110.0	26.00	26.9
HTF-65	120.0	32.00	28.3
HTF-66	120.0	27.00	28.3
HTF-71	160.0	35.00	31.6
HTF-72	160.0	37.50	31.6
HTF-73	212.0	37.00	32.8
HTF-74	212.0	37.50	32.8
B29	212.0	24.50	32.8
B30	212.0	24.00	32.8

TRANSITION REGION, CALCULATED VALUES

ENERGY ABSORPTION	CALCULATED TEMPERATURE(F)	/	TEMPERATURE (F)	CALCULATED ENERGY ABSORPTION(FT-LB)
5.0	-21.6	/	-20.0	5.2
10.0	16.1	/	-15.0	5.7
15.0	44.0	/	-10.0	6.3
20.0	69.7	/	-5.0	6.9
25.0	97.3	/	.0	7.6
30.0	136.4	/	5.0	8.3
		/	10.0	9.0
		/	15.0	9.8
		/	20.0	10.6
		/	25.0	11.5
		/	30.0	12.4
		/	35.0	13.3
		/	40.0	14.2
		/	45.0	15.2
		/	50.0	16.2
		/	55.0	17.1
		/	60.0	18.1
		/	65.0	19.1
		/	70.0	20.1
		/	75.0	21.0

APPENDIX F, TABLE 4C

RESULTS OF IMPACT TESTS FOR THREE GRADES OF STEEL ...CVN SPECIMENS OF LT ORIENTATION FROM FOUR ACCIDENTS. CALCULATIONS FOR SHEAR FRACTURE APPEARANCE DATA OF 16 CALLAO HEAD K-1 AND 19 S. BYRON SHELL SPECIMENS OF AAR TC128-B STEELS THAT CONTAIN VANADIUM.

SPECIMEN	TEMPERATURE(F)	OBSERVED LATERAL EXPANSION (MILS)	CALCULATED LATERAL EXPANSION (MILS)
B37	-120.0	.00	.0
B23	-50.0	1.80	.7
B24	-50.0	.00	.7
B22	-50.0	.20	.7
HTF-61	-50.0	1.00	.7
HTF-62	-50.0	1.00	.7
B36	-15.0	2.00	5.5
B35	-15.0	4.00	5.5
B34	.0	6.00	8.3
B33	.0	11.00	8.3
B32	10.0	12.00	10.3
B31	10.0	13.00	10.3
HTF-67	15.0	7.00	11.3
HTF-68	15.0	8.00	11.3
B28	33.0	16.00	15.0
B27	33.0	21.00	15.0
B38	50.0	24.00	18.3
B39	50.0	22.00	18.3
HTF-69	60.0	14.00	20.1
HTF-70	60.0	11.00	20.1
B26	73.5	27.00	22.3
B25	73.5	26.00	22.3
HTF-63	80.0	22.00	23.4
HTF-64	80.0	19.00	23.4
HTF-75	100.0	27.00	26.1
HTF-76	100.0	21.00	26.1
B40	110.0	27.00	27.2
HTF-65	120.0	23.00	28.3
HTF-66	120.0	28.00	28.3
HTF-71	160.0	35.00	31.2
HTF-72	160.0	37.00	31.2
HTF-73	212.0	39.00	32.9
HTF-74	212.0	38.00	32.9
B29	212.0	25.00	32.9
B30	212.0	27.00	32.9

TRANSITION REGION, CALCULATED VALUES

LATERAL EXPANSION(MILS)	CALCULATED TEMPERATURE(F)	/	TEMPERATURE (F)	CALCULATED LATERAL EXPANSION(MILS)
5.0	-17.6	/	-10.0	6.4
10.0	8.6	/	-5.0	7.3
15.0	33.2	/	.0	8.3
20.0	59.6	/	5.0	9.3
25.0	91.6	/	10.0	10.3
30.0	140.8	/	15.0	11.3
		/	20.0	12.3
		/	25.0	13.3
		/	30.0	14.4
		/	35.0	15.4
		/	40.0	16.3
		/	45.0	17.3
		/	50.0	18.3
		/	55.0	19.2
		/	60.0	20.1
		/	65.0	20.9
		/	70.0	21.8
		/	75.0	22.6
		/	80.0	23.4
		/	85.0	24.1

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15. SUPPLEMENTARY NOTES

16. ABSTRACT *(A 200-word or less factual summary of most significant information. If document includes a significant bibliography or literature survey, mention it here.)*

An overview of the results and metallurgical analyses of the findings of impact tests conducted at the National Bureau of Standards on samples of tank-car materials submitted by the Federal Railroad Administration is presented. The submitted samples were taken from tank cars which had been involved in service accidents during the period January 1970 to January 1971. One of these tank cars had been fabricated from ASTM A212 steel and the remaining four tank cars from AAR TC128 steels.

As a data compilation detailing the characteristics of tank car steel this report can serve as a basis for further analysis and as an example of how impact data can be handled to derive a general understanding of the fracture characteristics of these materials. The data do allow a comparison of longitudinal, transverse, and short transverse properties in these plate and they illustrate impact toughness trends as they relate to chemical composition, grain size and cleanliness of the specific plates studied. Further, they illustrate the comparative results that are expected from Charpy-V-notch tests vis-a-vis those from Dynamic Tear tests for the steels tested. When these various findings on the impact properties and on the metallurgical factors affecting them are considered along with the observed behaviors of these materials in service, recommendations as to approaches to improved materials and improved specifications for such materials can be formulated.

17. KEY WORDS *(six to twelve entries; alphabetical order; capitalize only the first letter of the first key word unless a proper name; separated by semicolons)*

Anisotropy; carbon-manganese steels; Charpy-V-notch; dynamic tear; impact tests; pressure-vessel steels; shelf energy; tank-car steels; toughness; transition temperatures

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