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BASIS FOR GE RT_{NDT} ESTIMATION METHOD

Prepared for the BWR Owners' Group

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BACKGROUND

Prior to the summer of 1972, the requirements of the ASME Code related to vessel low alloy steel fracture toughness centered around demonstration, using longitudinally oriented Charpy specimens, that 30 ft-lb impact energy could be achieved at a specified temperature. In the Summer 1972 addendum to the Code, the fracture toughness requirements were changed to determination of a RT_{NDT} based in part on demonstrating 50 ft-lb impact energy, using transversely oriented specimens. For plants whose materials had been tested prior to the change, it was necessary to estimate an equivalent RT_{NDT} using the available 30 ft-lb data.

GE developed an estimation method in the late 1970s which was used to address NRC concerns on vessel beltline fracture toughness for many BWR/4 and BWR/5 plants during the FSAR approval process. The method has since been applied to other BWR/4 and BWR/3 plants as GE has performed surveillance capsule testing and has updated pressure-temperature (P-T) curves. The method has also been applied to beltline weld data at one BWR/2. Due to the differences between BWR/2 plates and BWR/3-6 plates, the estimation method has not been used on BWR/2 plates. The timing of the 1972 Code change was such that it was possible to determine BWR/6 RT_{NDT} values per the Code. In all, about two dozen BWRs have submitted RT_{NDT} values based on the GE estimation method, and have received NRC approval for their use.

A key part of the estimation method is an adjustment to the test temperature of 2°F/ft-lb for every ft-lb between the lowest Charpy energy and 50 ft-lb. The adjustment of 2°F/ft-lb was selected as a conservative representation of the Charpy curve transition region for longitudinally oriented plate and for welds typical of those used in BWR beltlines. As a further conservatism, the estimation is made starting with the lowest Charpy energy of the several specimens tested at the designated test temperature. Figures 1, 2 and 3 show how the method conservatively estimates the temperature associated with the 50 ft-lb impact energy for typical plate and weld Charpy curves.

The purpose of this paper is to document the basis for selection of the 2°F/ft-lb adjustment used to estimate BWR beltline RT_{NDT} values.

SA533 PLATE MATERIAL

In Welding Research Council Bulletin 217, Hodge presented generalized results of the HVYSTL data bank maintained by the PVRC [1]. For SA533 material, results of tests performed on 24* plates were summarized. These plates ranged in thickness from 6 inches to 12 inches. Heat treatments were very similar to those used in fabricating beltline plates, including time at elevated temperature to simulate post-weld heat treatment. In fact, 9 of the identified test plates were provided by GE, in all likelihood archive plates from operating BWRs.

Figure 1 in [1] shows an average curve of longitudinal Charpy impact energy for all SA533 plates tested. This is reproduced here as Figure 4. The inverse slope of the 1/4 T specimen curve, in the temperature range of -50°F to 0°F, is 0.5 ft-lb/°F, or 2°F/ft-lb. Some of the data making up this averaged curve are shown in Table 5(a) in [1]. There the averaged Charpy data for groups of plates, by thickness, are given at -50°F and at 50°F. These data are shown in Table 1, along with the calculated slopes and inverse slopes. The overall inverse slope for the data is 1.87°F/ft-lb, and the inverse slope of the typical BWR beltline plates (6-6.5 inches thick) is 1.28 °F/ft-lb.

During the review of a BWR/5 FSAR in 1979, the NRC requested further verification of the 2°F/ft-lb adjustment. GE provided data, shown in Table 2, from another BWR/5 vessel's plates where full Charpy curve data were available. In nearly every case, the inverse slope is considerably lower than 2°F/ft-lb. The average Charpy curve inverse slope in Table 2 is 1.24°F/ft-lb, and the highest value is 2.20°F/ft-lb. It should be noted that the GE approach of adjusting the lowest Charpy energy data at a given temperature adds further conservatism, as shown in Figure 1. Therefore, even for a plate with an inverse slope slightly higher than 2°F/ft-lb, the RT_{NDT} estimation is expected to be conservative compared to that which would be obtained from the best fit of the Charpy data. This is seen in Figure 5, where the full Charpy curve for Heat C6003-2 has been plotted. The inverse slope in Table 2 for this heat is 2.2°F/ft-lb. Even so, when applying the 2°F/ft-lb adjustment to the lowest Charpy data at 10°F, the resulting 50 ft-lb temperature is conservative.

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* The text in [1] refers to 24 plates, but the tables in [1] identify a total of 29 plates.

WELD MATERIALS

The 2°F/ft-lb adjustment factor has been applied to submerged arc weld (SAW) and shielded metal arc weld (SMAW) materials for BWR/2-5 vessel beltline welds. Table 3 shows the weld data used to support the use of the adjustment factor for SAW and SMAW materials. These data were submitted to the NRC in 1979, again as part of the FSAR review process for a BWR/5. Not surprisingly, the 2°F/ft-lb factor is quite conservative for SMAW materials, which generally have very high upper shelf energies. The average Charpy curve inverse slope for SMAW in Table 3 is 0.78°F/ft-lb, and the highest value is 1.62°F/ft-lb.

For the SAW materials, the average inverse slope from Table 3 is 1.5°F/ft-lb, and the highest value is 2.25°F/ft-lb for Linde 124 weld heat 4P7465. The Charpy data for 4P7465 is plotted in Figure 6 for comparison with the RT_{NDT} estimation method. As seen in the figure, while the 2°F/ft-lb adjustment may be slightly non-conservative, the resulting 50 ft-lb temperature is still conservative because the lowest Charpy energy value at a given temperature is used in the estimation approach.

Table 1

WRC BULLETIN 217 SA533 TRANSITION REGION DATA

Source	Thickness (inches)	Orientation	Number of Plates	-50°F Data (ft-lb)	50°F Data (ft-lb)	(ft-lb/°F) Slope	(°F/ft-lb) Inverse Slope
GE	6-6.5	Long.	5	24	102	0.78	1.28
CE	7-7.5	Long.	6	24	74	0.50	2.00
GE	8-8.5	Long.	4	16	66	0.50	2.00
CE	8.5-9	Long.	1	20	72	0.52	1.92
W	9.5-10	Long.	6	7	52	0.45	2.22
CE	11.5-12	Long.	3	7	56	0.49	2.04
W	11.5-12	Long.	4	10	71	0.61	1.64
			29				Avg. = 1.87

Table 2

REACTOR VESSEL DATA FOR CHARPY CURVE SLOPE,
SA-533 GR. B, CL. 1 PLATES, LONGITUDINAL TESTS AT 1/4T

HEAT NO.	VALUES FOR 50 ft-lb INTERPOLATION Min. ft-lb TEST TEMP., °F	INVERSE CHARPY CURVE SLOPE (°F/ft-lb)
C5978-1	109 (110°F), 48 (40°F)	1.15
B0078-1	94 (40°F), 49 (10°F)	0.70
C6003-2	82 (110°F), 49 (40°F)	2.20
C5979-2	72 (40°F), 49 (10°F)	1.30
C6003-3	64 (110°F), 22 (40°F)	1.70
C5978-2	90 (110°F), 41 (40°F)	1.43
C5979-1	65 (40°F), 43 (10°F)	1.36
C6345-1	77 (10°F), 15 (-40°F)	0.81
C6318-1	66 (10°F), 14 (-40°F)	0.96
C6345-2	67 (10°F), 16 (-40°F)	0.98
A5333-1	53 (10°F), 11 (-40°F)	1.19
C6123-2	60 (10°F), 10 (-40°F)	1.00
C5987-1	80 (40°F), 35 (10°F)	0.67
C5987-2	51 (10°F), 10 (-40°F)	1.22
C5996-2	66 (10°F), 18 (-40°F)	1.04
C5996-1	60 (10°F), 12 (-40°F)	1.04
C5540-1	63 (10°F), 23 (-40°F)	1.25
C5328-1	83 (40°F), 47 (10°F)	0.83
C5505-2	63 (10°F), 31 (-40°F)	1.56
C5445-3	67 (10°F), 34 (-40°F)	1.16
C7434-1	65 (10°F), 37 (-40°F)	1.78
C7376-2	65 (10°F), 40 (-40°F)	2.00

Table 3

REACTOR VESSEL DATA FOR CHARPY CURVE SLOPE, SMAW (E8018G) AND SAW (INMM/LINDE 124 FLUX)

HEAT/LOT	TYPE	VALUES FOR 50 ft-lb INTERPOLATION Min. ft-lb TEST TEMP., °F	INVERSE CHARPY CURVE SLOPE (°F/ft-lb)
402P3162/HA26B27AE	E8018G	53 (-10°F), 37 (-20°F)	0.63
401P2871/HA30B27AF	E8018G	75 (10°F), 27 (0°F)	0.21
5P5657/--	INMM	51 (0°F), 19 (-60°F)	1.87
03L048/B525B7AF	E8018G	61 (0°F), 36 (-10°F)	0.40
02R486/J404B27AG	E8018G	52 (-10°F), 41 (-20°F)	0.91
L83978/J414B27AD	E8018G	51 (-20°F), 14 (-80°F)	1.62
5P7397/0156	INMM	55 (10°F), 19 (-50°F)	1.67
40150371/B504B27AE	E8018G	61 (-20°F), 23 (-60°F)	1.05
3P4966/0342	INMM	54 (-20°F), 9 (-80°F)	1.33
402P3162/H426B27AE	E8018G	54 (-10°F), 37 (-20°F)	0.59
1P6484/0156	INMM	60 (40°F), 34 (30°F)	0.38
4P7465/0751	INMM	57 (0°F), 26 (-70°F)	2.25
492L4871/A421B27AE	E8018G	50 (0°F), 38 (-10°F)	0.83
422K8511/G313A27AD	E8018G	65 (-20°F), 26 (-40°F)	0.51
640892/J424B27AE	E8018G	55 (0°F), 38 (-10°F)	0.59
07R458/5403B27AG	E8018G	59 (0°F), 10 (-60°F)	1.22

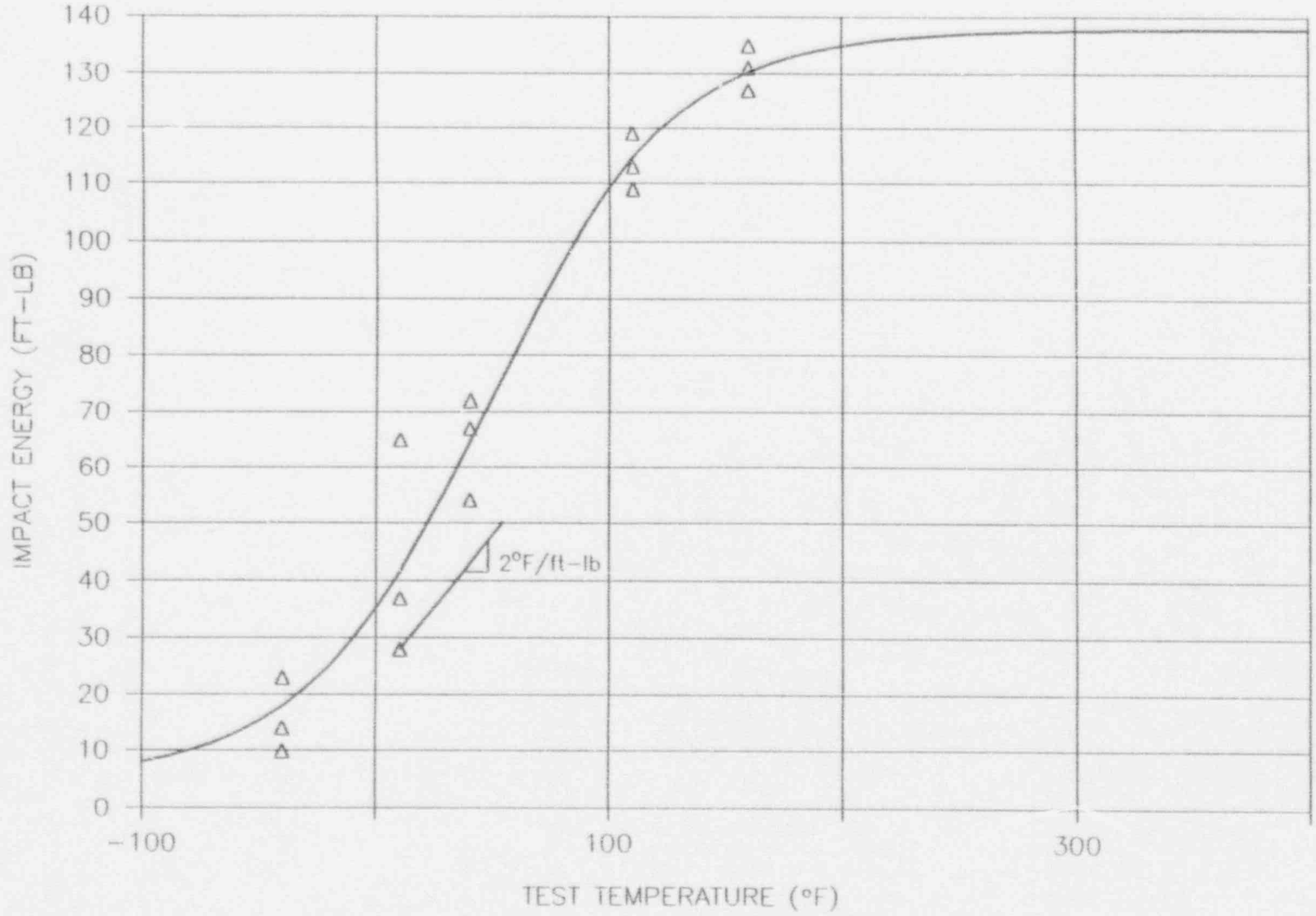

Figure 1. RT_{NDT} Method Applied to Typical SA533 Plate

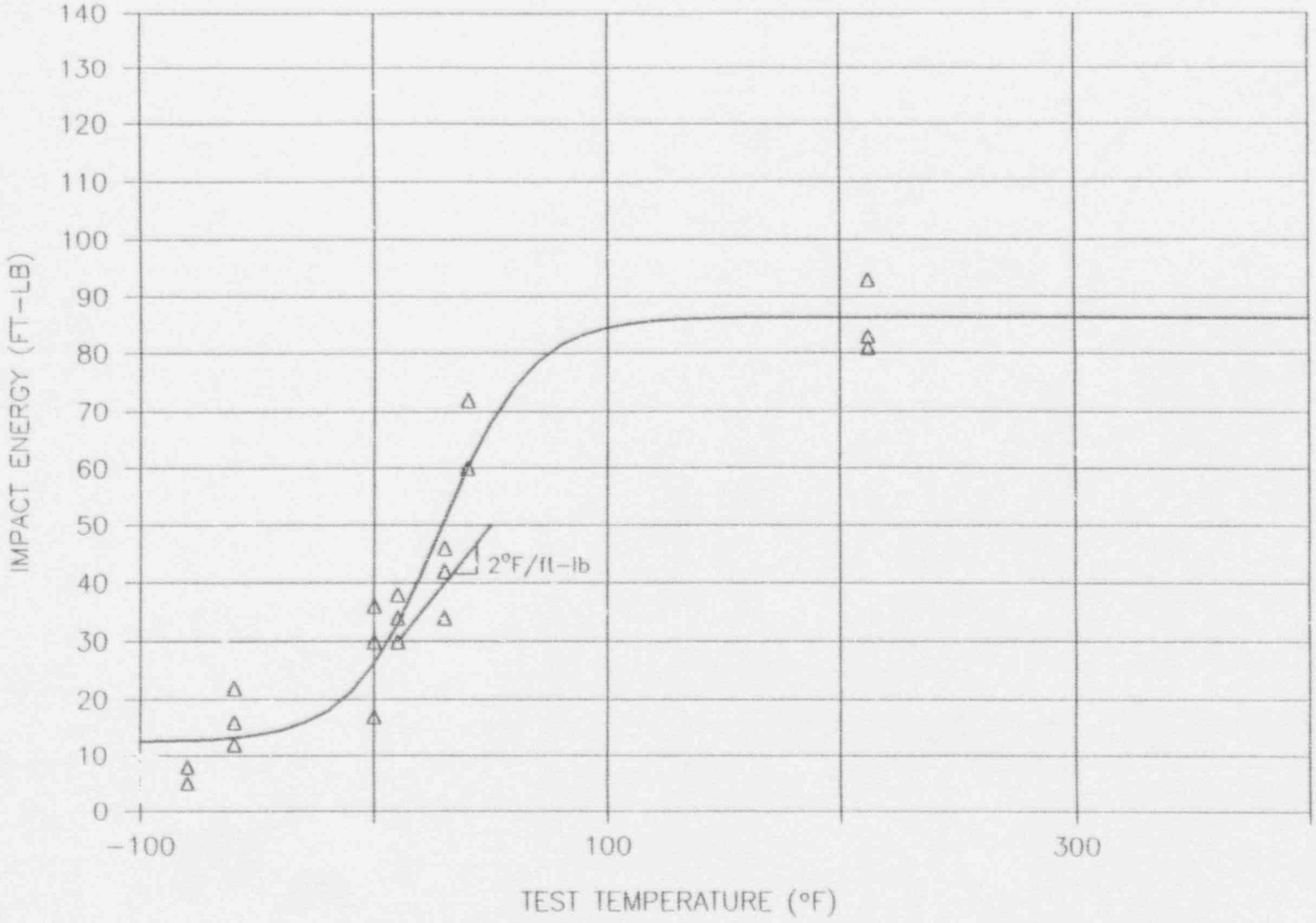

Figure 2. RT_{NDT} Method Applied to Typical Linde 124 Sub-Arc Weld

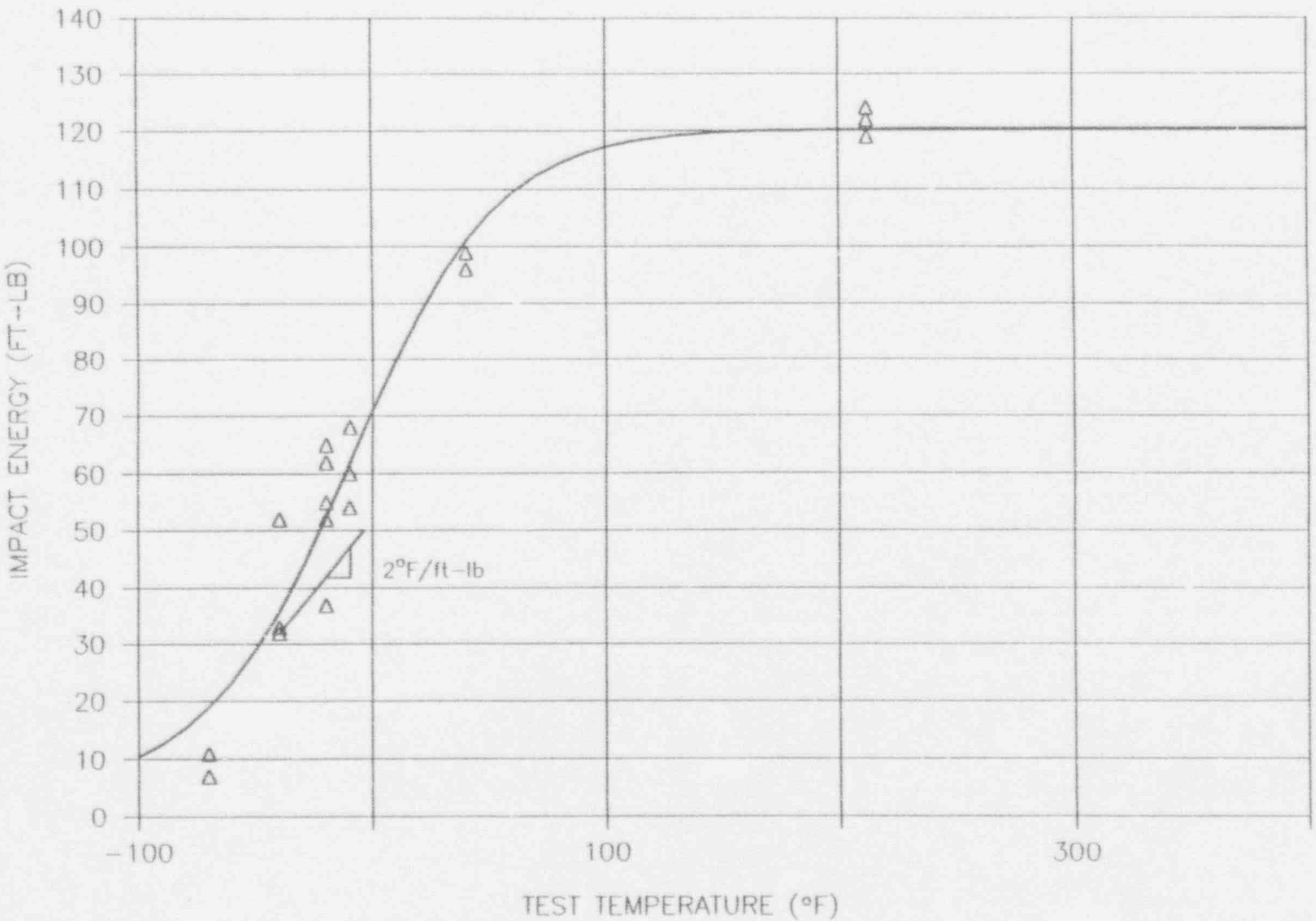

Figure 3. RT_{NDT} Method Applied to Typical Shielded Metal Arc Weld

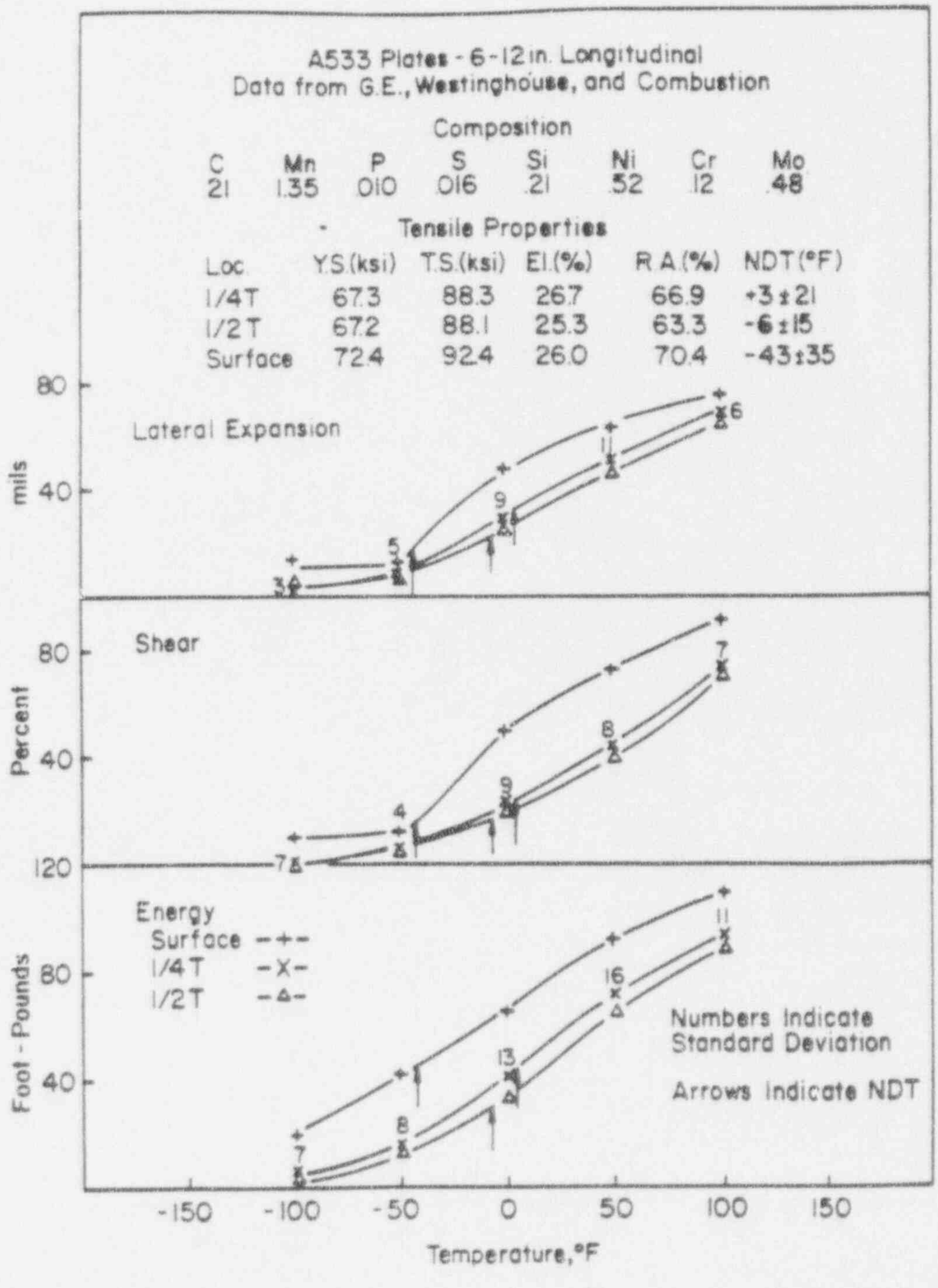

Figure 4. Longitudinal Data for A533 Plates

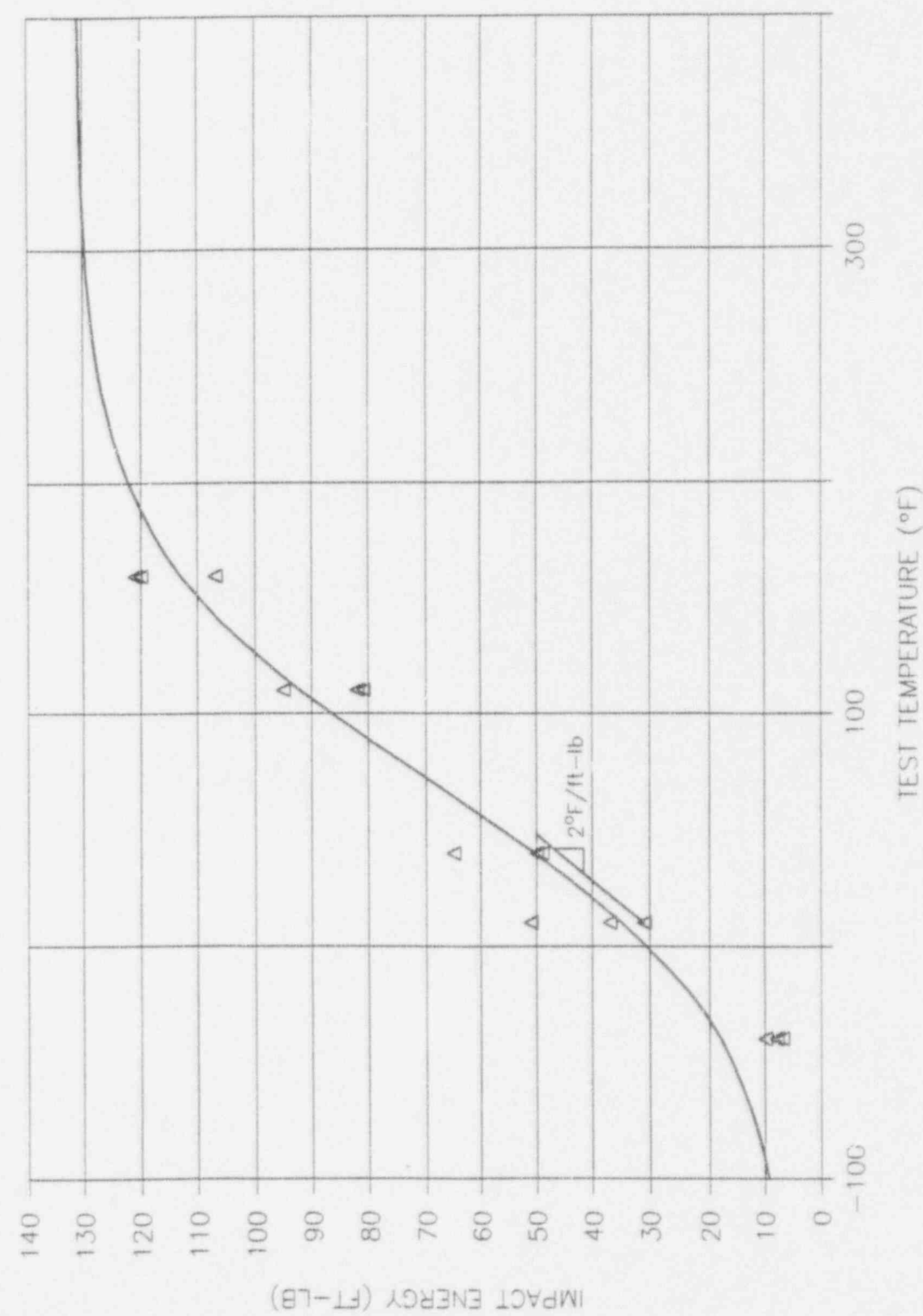

Figure 5. RT_{NDT} Method Applied to SA533 Heat C6003-2

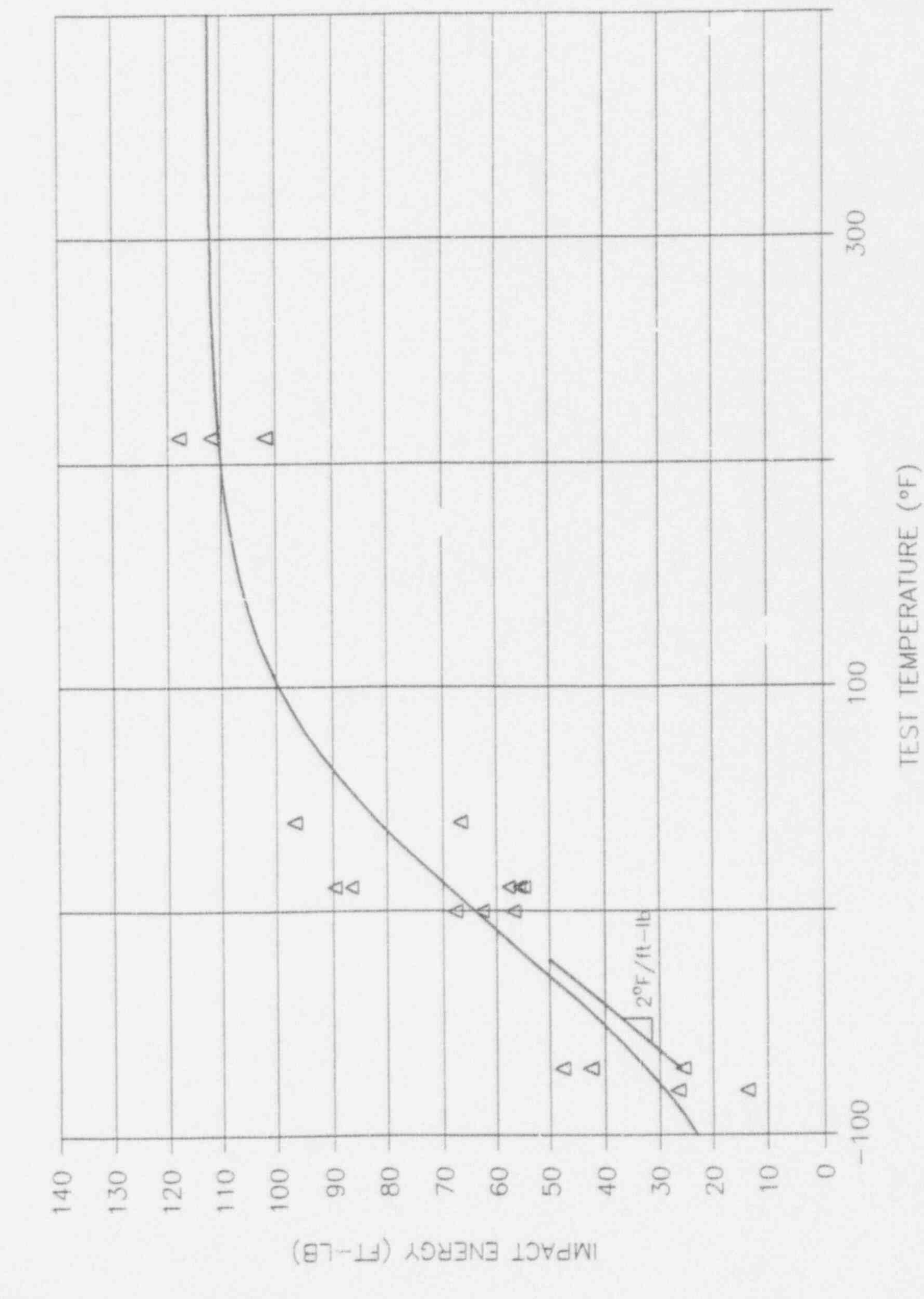

Figure 6. RT_{NDT} Method Applied to Linde 124 Sub-Arc Weld 4P7465