Foundation & Geotechnical Engineering, LLC
“Specializing in Deep Foundation Engineering”

March 18, 2008
FGE Project No.: G08-L-293

XXXXXX, Inc.
Street address
City, Florida Zip

Subject: **Shaft Integrity Testing Results**
XXXXXXXXXXXXXXXXXXXXXXXXX

Dear Sirs:

As requested, Foundation & Geotechnical Engineering (FGE), LLC in conjunction with the University of South Florida (USF) has performed drilled shaft Thermal Integrity (TI) evaluation at the above referenced project and herein discusses the results from these tests. As this is a new technology, FGE performed supplemental cross-hole (CSL) and sonic echo (PIT) testing for corroboration in cases where the various methods overlapped in capabilities. CSL and PIT results are submitted under separate cover.

A series of thermal scans were conducted between February 20, 2008 and February 29, 2008 at time frames range from 24 hrs after shaft concreting (ideal scenario) to several days after concreting. This report summarizes the results of the testing and incorporates our interpretation of the results. Testing conducted after this time frame will be reported in a supplemental document.

Instrumentation

Thermal Integrity Evaluation of drilled shafts relies on information from a *Thermal Probe* which contains four infrared temperature sensors that record the internal shaft temperature as it is lowered into standard 1.5” or 2” I.D. access tubes. A depth-encoded wheel mounted on a tripod at the shaft top records the position of the probe as it is lowered into the access tubes. Unlike CSL testing, the data is acquired as the probe descends rather than ascends; a data acquisition system records the field measurements for further processing. Shafts were equipped with four 1.5” I.D. steel access tubes in general accordance with standard practice for tube plurality.

Tube Numbering Convention. The tube identification / numbering used for this project assumed the northerly most tube to be No. 1 and increased in value in a clockwise fashion looking down on to the shaft top.

Analysis and Results

The intended principle on which the thermal evaluation derives usable information stems from heat generation of hydrating cement. The analysis of measured temperature profiles requires knowledge of the concrete mix used and soil profile for the purposes of determining heat generation and soil insulation parameters. For typical shaft concrete mixes, thermal testing should be carried out between one and two days after shaft concreting.

The concrete mix design for this project was supplied to FGE by XXXXXX on February 26, 2008 and is appended to this report for completeness. This information was used to create the input hydration energy parameters using the α, β, and τ method outlined by Schindler (2005). The model parameters assigned were 0.831, 0.786, and 18.3, respectively with an overall energy production of 70 kJ per kg of cementicious material; wherein, a type F flyash represented approximately 25% of the 785 lbs total cement /cu yd of concrete.

Prior to analysis of the field measurements a model was created based on the heat generation properties of the above concrete mix, insulation properties of the soil around the shaft and the time of the test relative to shaft construction. The expected normal temperature varies with time as the shaft either heats or cools depending on its stage in the hydration process. The following graph shows the anticipated temperatures for 30, 36, 42, 48, and 54 inch diameter shafts under the ambient and soil conditions at the XXXXXXXXXXXXXXXXXXXXXXXX.

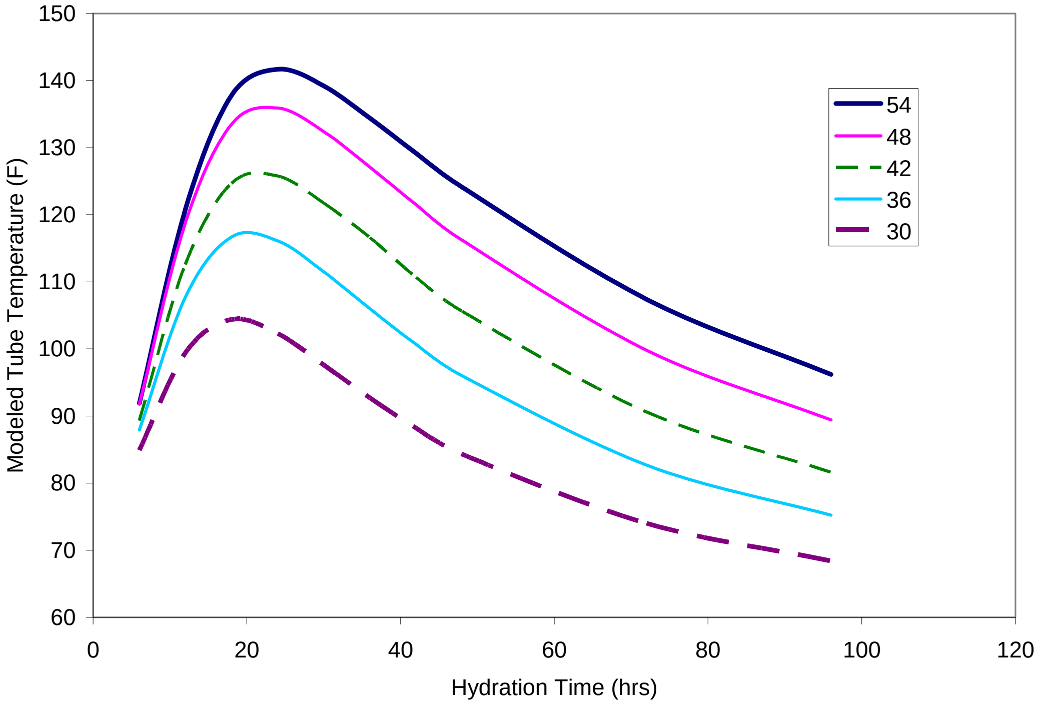

Figure 1 Normal access tube temperatures for shaft sizes tested.

Variations in the daily concrete placement temperature were used to tailor the predicted temperature graph above to exact field conditions. Deviations from the modeled norm were used to provide a quick assessment and indicate potential necking (decrease in shaft temperature) or bulging (increase in shaft temperature). Shafts 69 and 73 were fully modeled and signal matched to assess the severity of measured low temperature conditions. Figure 2 shows the effect of a 2 inch inward neck, 2 ft tall on the modeled output and its comparison to the measured temperature trace. Results for all shafts are included are appended to this report.

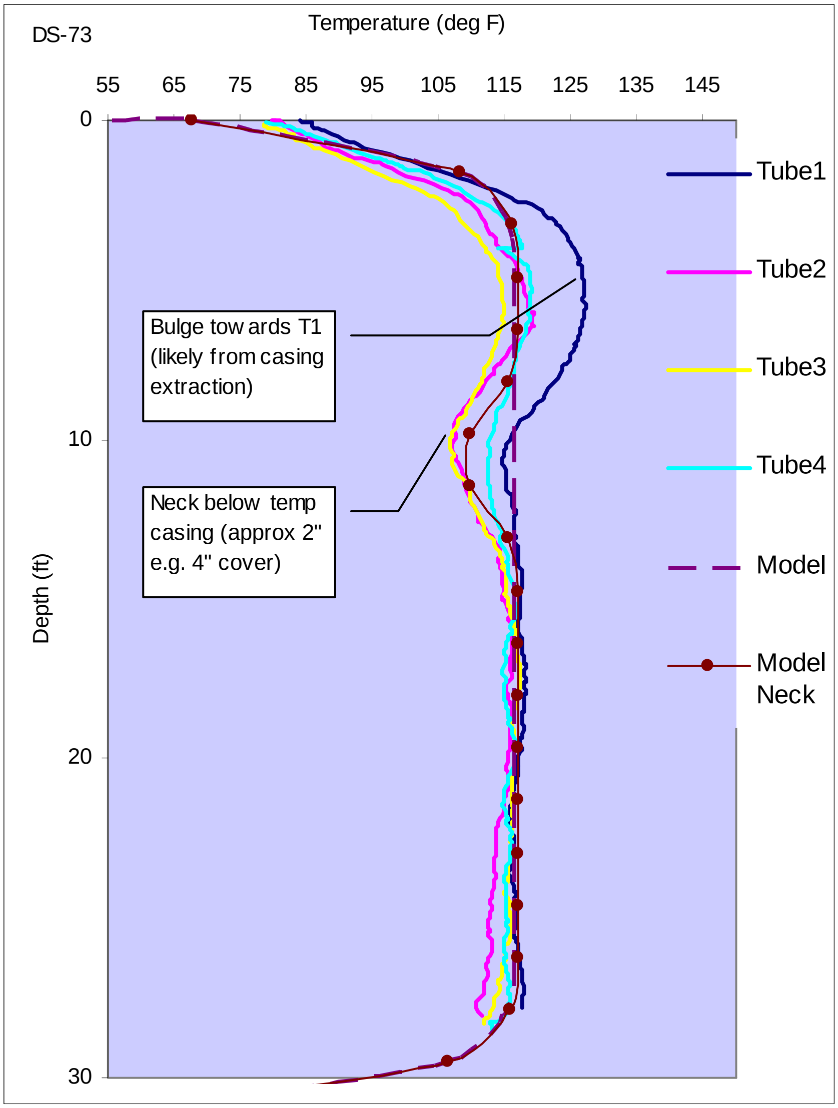

Figure 2 Signal match of Shaft DS-73 field results with modeled output, with and w/o neck.

In all, 14 shafts were scanned for defects. Table 1 shows a summary of the test findings. A detailed discussion of each shaft is provided as well.

Table 1 Shaft Testing Details

Shaft I.D.	Date Test Performed	Time Test Performed	Date Cast	Time of Casting	Casting Air Temp		Casting Conc Temp		Hydration Time (hrs)	Diam (in)	GWT (ft)	Length (ft)	Rock Socket Length (ft)	Vol. (cy)	General Comments
					C	F	C	F							
DS-5	2/22/2008	13:22	2/1/2008	16:00	21	70	22	72	501.4	36	N/A	90	25	N/A	Over 72 hr hydration / temp too low for proper evaluation
DS-10	2/22/2008	16:10	2/21/2008	16:30	19	66	20	68	23.7	36	N/A	83.25		32	Slight cage misalignment 45-55' bulge
DS-11	2/29/2008	16:45	2/28/2008	15:05	8	46	17	62	25.7	36	N/A	32.33	25	11	No concerns
DS-18	3/21/2008	10:16	3/18/2008	10:30	21	69	22	72	72.0	54 / 48	49	90	40		No concerns 54"casing to 74'; 48" rock socket
DS-20	3/27/2008	13:00	3/26/2008	2:57	23	73	26	78	24.4	54 / 48		90	31	67	Slight neck 11-14' 54"casing to 76'; 48" rock socket
DS-23	3/7/2008	13:05	3/4/2008	10:00	23	73	26	78	72.1	36		71	23		No concerns
DS-24	2/22/2008	14:48	2/21/2008	11:00	17	63	19	66	24.2	36	43	92	42	61	Bulge @ depth 30-65' all tubes
DS-29	3/7/2008	10:33	3/5/2008	2:45	22	72	26	79	48.3	36		77			No concerns
DS-30	2/29/2008	14:45	2/28/2008	10:05	8	46	17	62	28.7	30	N/A	65	20	33	Bulge @ depth 37 – 45' Slight bullet tip shape bottom 2'
DS-69	2/20/2008	16:10	2/19/2008	15:00	19	67	21	70	25.2	36	N/A	75	15	N/A	Partial pour / bullet end / low temp surface concrete
DS-70	2/26/2008	13:11	2/25/2008	13:38	22	72	22	72	23.6	36	N/A	65	41	33	Bulge 15-30' and 35-45'
DS-71	2/27/2008	12:57	2/25/2008	16:00	23	73	22	72	44.9	42	N/A	45	17	N/A	Bulge at toe near T1,T2, and T4
	2/28/2008	12:31	2/25/2008	16:00	23	73	22	72	68.5	42	N/A	45	17	N/A	
DS-72	2/28/2008	11:19	2/27/2008	10:03	14	58	18	64	25.3	42	N/A	30	19	25	Bulge @ depth 2-7' Slight neck @ depth 7-11'
DS-73	2/27/2008	14:45	2/26/2008	11:00	26	79	21	70	27.8	42	N/A	30	17	15	Slight neck near T1, T2, and T3 @ bottom of temp casing / depth 7-12' (approx 2 – 2.5" radius reduction)
	2/28/2008	9:18	2/26/2008	11:00	26	79	21	70	46.3	42	N/A	30	17	15	

DS-5. Although elevated temperatures were still present, this shaft was tested long after the recommended 24 to 48 hours and is thermally inconclusive. An outward thermal gradient is required to clearly delineate inclusions. Full modeling would not be productive. CSL testing and report produced separate to this document.

DS-10. No structural or durability concerns. Shaft shows over-pour bulging in all areas above the rock socket which is in keeping with field logs indicating 147% concrete usage when compared to theoretical. Full modeling is not necessary.

DS-11. No concerns. Shaft shows temperature signature of a normal shaft.

DS-18. No concerns. Shaft shows temperature signature consistent with over-pour bulging at all depths which is in agreement to the 54” temporary casing used to a depth of 74 ft. Figure DS-18 shows this region (near 74’) as a temperature transition zone to the rock socket.

DS-20. No major concerns. Slight neck from 11 – 14 ft; no more than 2 inches of cover loss. Higher than normal temperatures down to the depth of temporary casing (76’) is consistent with over-sized casing (54”) used to that depth.

DS-23. No concerns. Slightly higher than normal shaft temperature signature (typical of the site); testing performed at 72 hrs but produced usable data.

DS-24. No concerns. Shaft shows extensive over-pour and bulging between 30 and 65 ft in depth. Concreting logs indicate 250% of the theoretical concrete volume.

DS-29. No concerns. Typical over pour bulging above the rock socket.

DS-30. No major concerns. Mild cross-sectional reduction between 0 and 10 ft (no more than 2 inches). Over-pour bulging indicated at depths between 45 and 55 ft. Concrete usage is 280% of theoretical.

DS-69. Shaft construction experience difficulties removing tremie and only partially poured shaft from the bottom depth of 75’ to 28’. At approximate depths between 28 and 32 is a more dramatic change in temperature than expected. As it is shown in all tubes, it is likely a partially cemented material which under normal concreting processes would have been expelled as debris. As with many of the other shafts, a sizeable bulge in the shaft between 30 and 54 ft is present that caused the higher than normal temperature in that zone which is of no concern to the integrity. Also apparent is that the cage is out of alignment near the rock socket interface pushing tube No. 1 closer to the wall (cooler) and the opposite tube (No. 3) farther away from the wall (warmer); this 1.5 – 2” offset in the cage at depth 50’ decreases with depth. Finally, the bottom of the shaft shows a large reduction in temperature signal before reaching the bottom of the tube. Note the modeled response show a drastic decrease to be normal, but in this case it occurs prematurely. *This shaft was fully reported under separate cover February 27, 2008.*

DS-70. No concerns. Although not as drastic as some, this shaft shows common site characteristic of over-pour bulging in almost all regions above the rock socket. Inspector notes indicate 190% of theoretical concrete usage.

DS-71. No concerns. Concrete logs were unavailable at the time of reporting; however, no extensive over-pour is indicated by the thermal scans with the exception of the toe region of the shaft where a bell-shape is prominent on all sides except T3.

DS-72. No major concerns. Figure DS-72 shows slight necking between 8 and 11 ft in depth which is likely due to temporary casing extraction. Modeling of a similar condition in DS-73 revealed this is no greater than a 2" reduction in radius leaving 4" of concrete cover. A similar cross-section reduction is noted at the bottom 2 ft of the shaft. Finally, the cage appears to be slightly misaligned near the top on the order of 1 to 2 inches as indicated by opposite tubes T2 and T4 get cooler and warmer, respectively. The magnitude of the cage offset was determined by modeled normal response of the tube position relative to the excavation wall.

DS-73. No major concerns. Figure DS-73 shows the same slight necking between 8 and 12 ft in depth again just below the location of the temporary casing. The necking which was signal matched to be on the order of 2 inches is most prominent near tubes T2 and T3, reduces as it approaches T4, and is minimal at T1. The casing extraction process appears to have pushed against the excavation walls in the direction of T1 causing a bulge in that direction. This interpretation varies from DS-72 in that all other tubes return to a normal temperature (cover thickness) just above the neck whereas T1 experiences the higher than normal temperature.

Conclusions

Thermal Integrity testing and evaluation was performed on fourteen (14) of the XXXXXXXXXXXXXXXXXXXXXXXXX foundation shafts. Of the shafts thermally scanned and evaluated, only shaft DS-69 showed defects of concern the least of which (near the toe) can be mitigated by post grouting. The upper-most defect may not be so quick resolved. With the exception of shaft DS-5, the remaining shafts showed characteristics consistent with the strata and the construction methods used producing higher than normal temperature signatures due to over-pour bulging. In a few instances, slight necking was detected at a depth consistent with the base of the temporary casing, but reduced section showed no more than 2 inch reduction leaving 4 inches of cover. In the case of shaft DS-5, too much time had elapsed between time of concreting and thermal scanning to perform a satisfactory integrity evaluation. Thermal scans are ideally conducted between 24 and 48 hours after concreting.

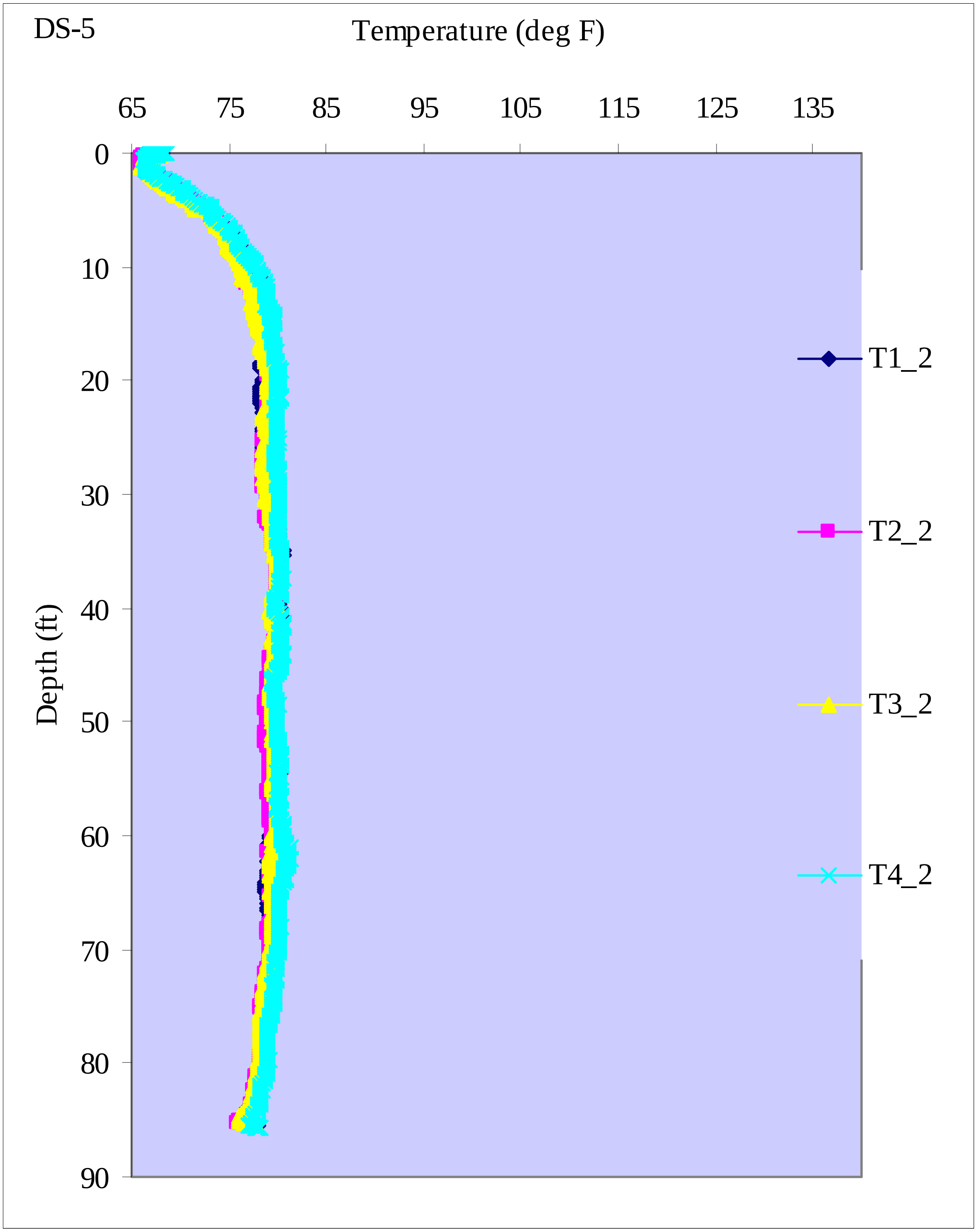

Figure DS-5 Measured temperature traces for Tubes 1 through 4.

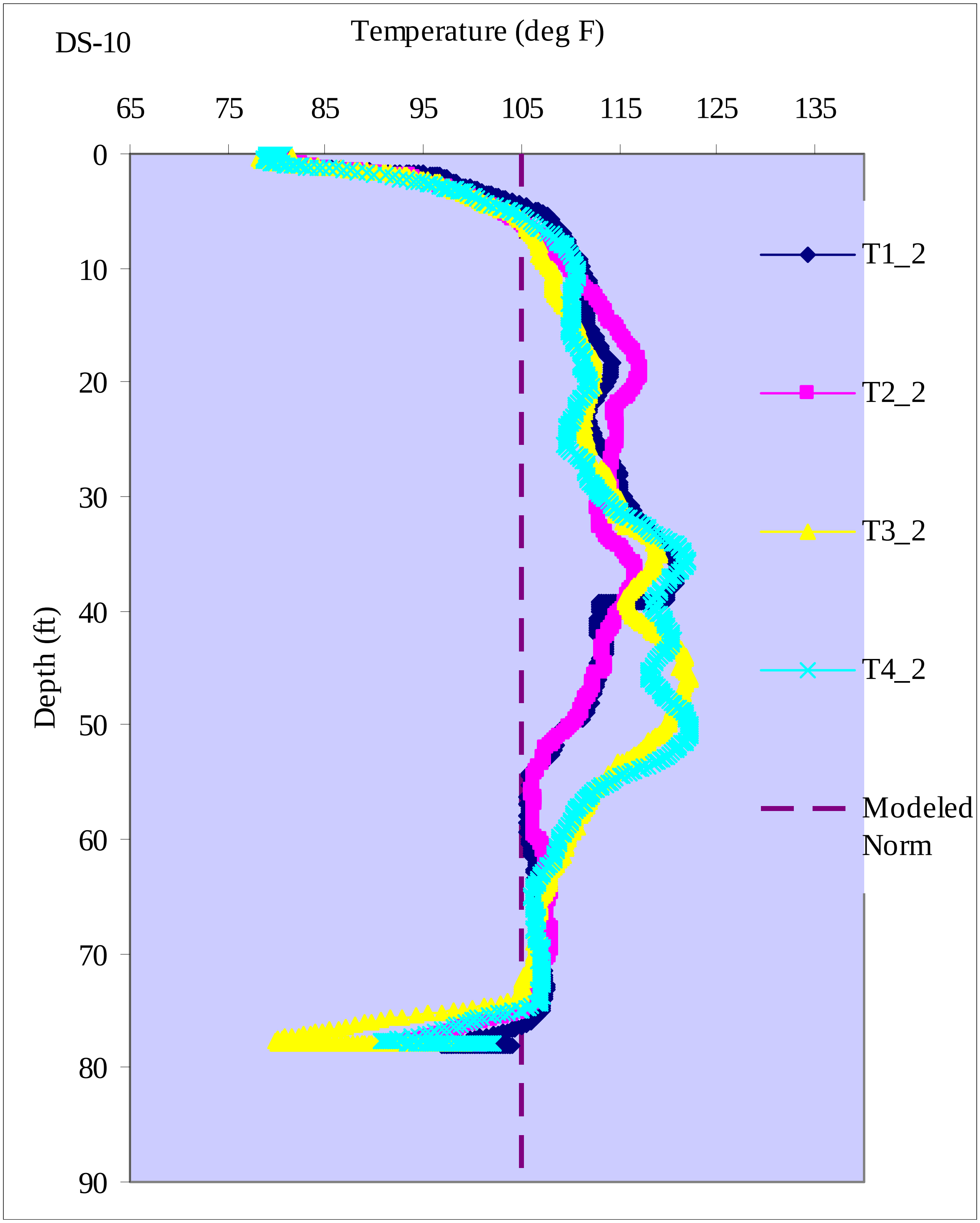

Figure DS-10 Measured temperature traces for Tubes 1 through 4 compared to the model norm.

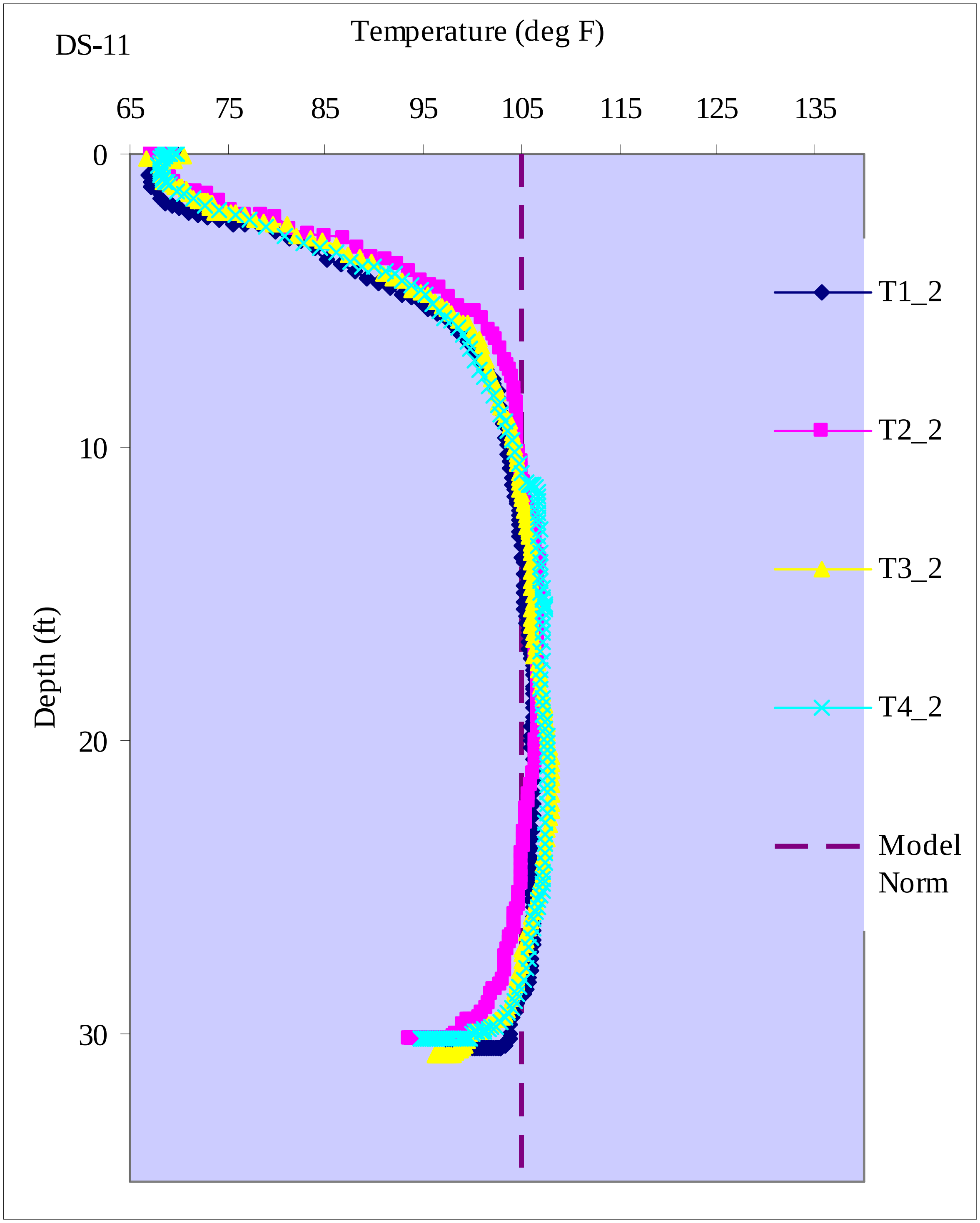

Figure DS-11 Measured temperature traces for Tubes 1 through 4 compared to the model norm.

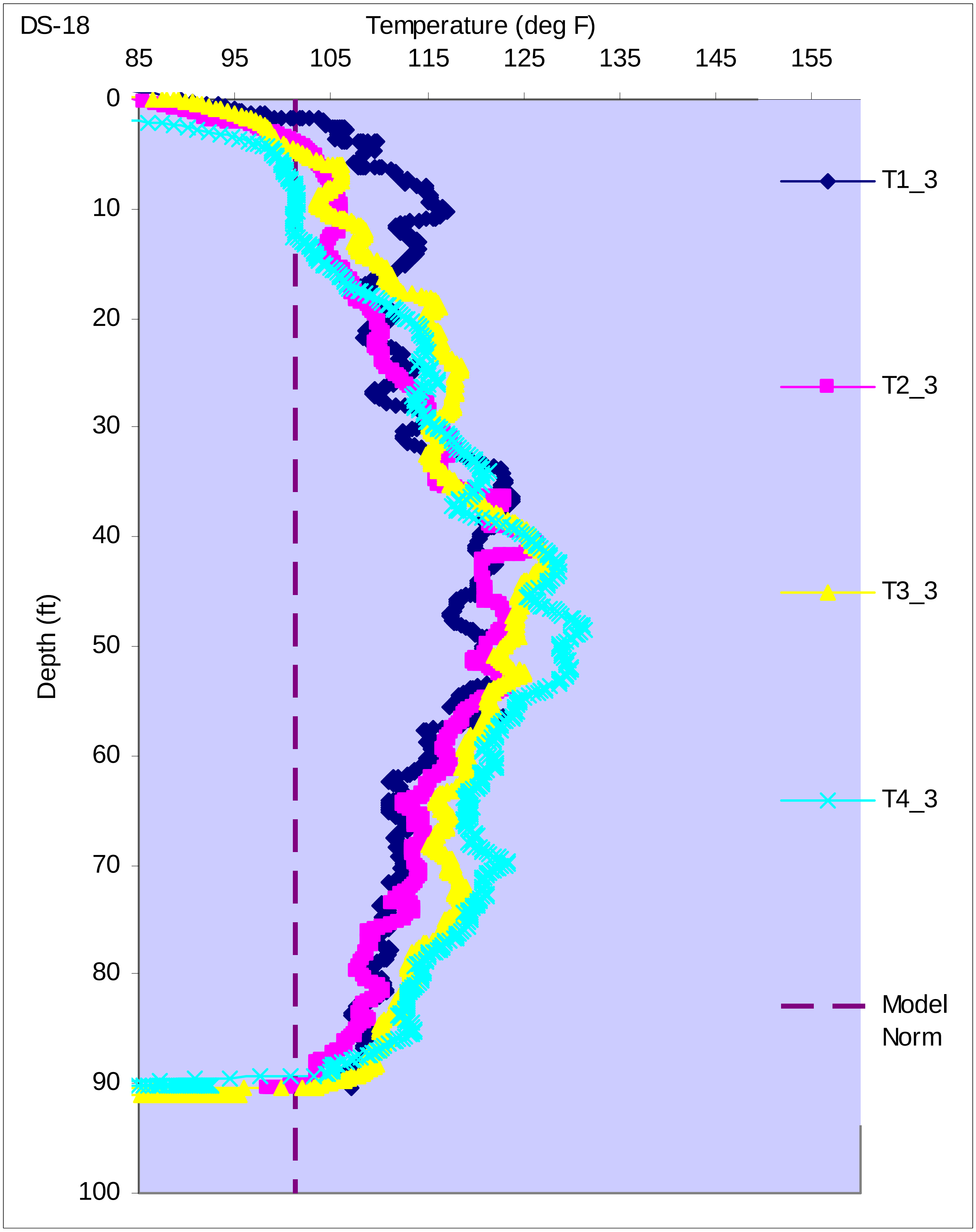

Figure DS-18 Measured temperature traces for Tubes 1 through 4 compared to the model norm.

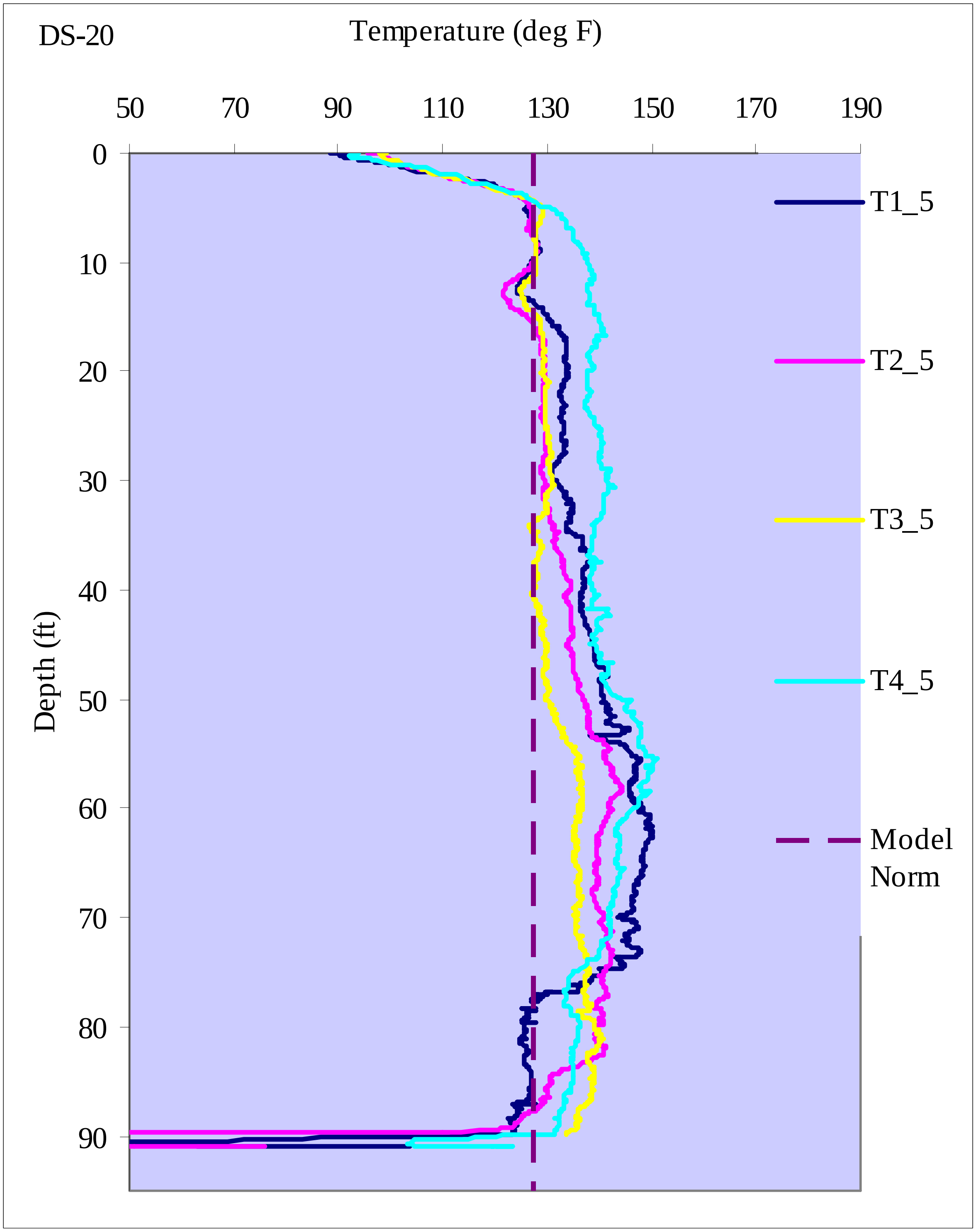

Figure DS-20 Measured temperature traces for Tubes 1 through 4 compared to the model norm.

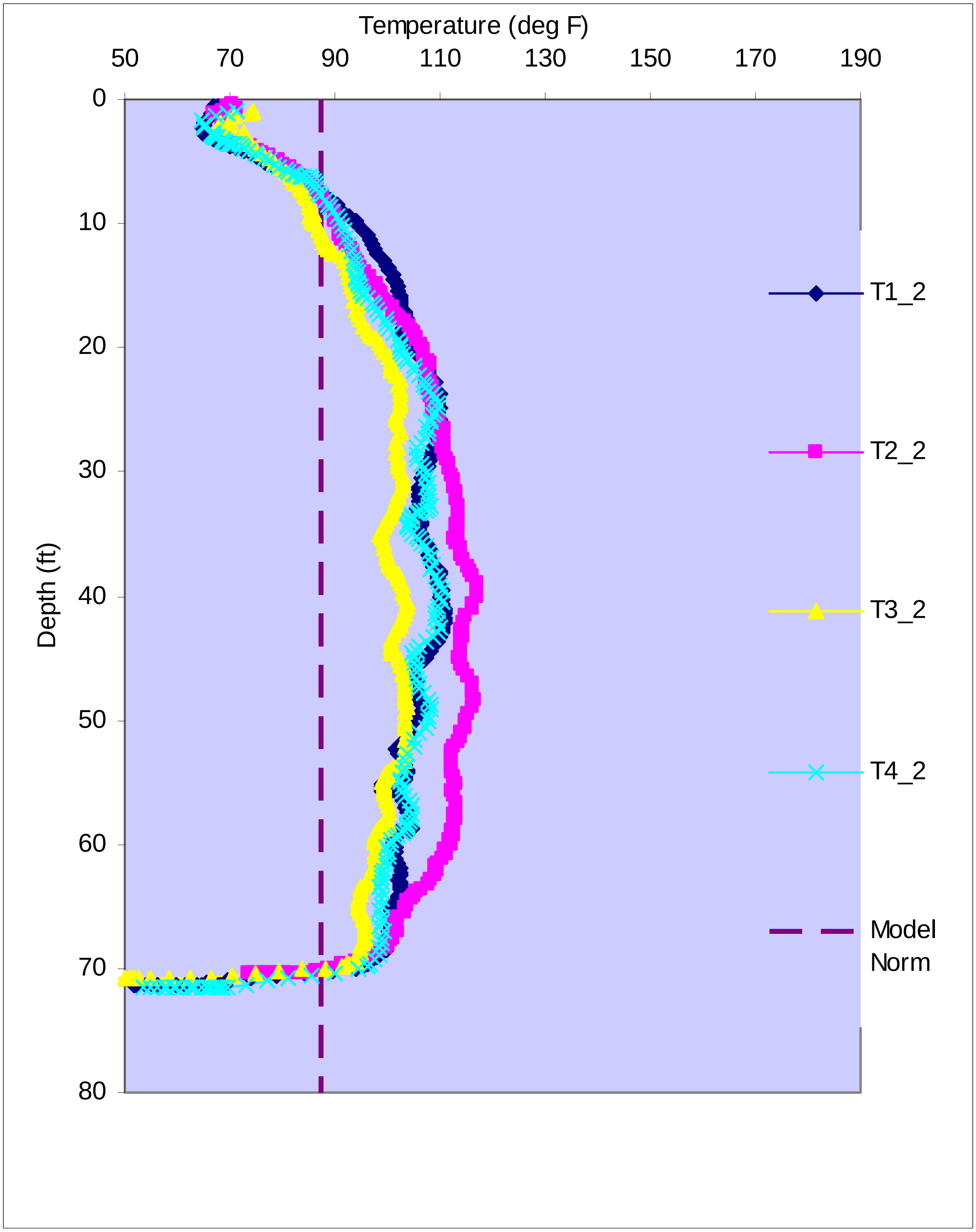

Figure DS-23 Measured temperature traces for Tubes 1 through 4 compared to the model norm.

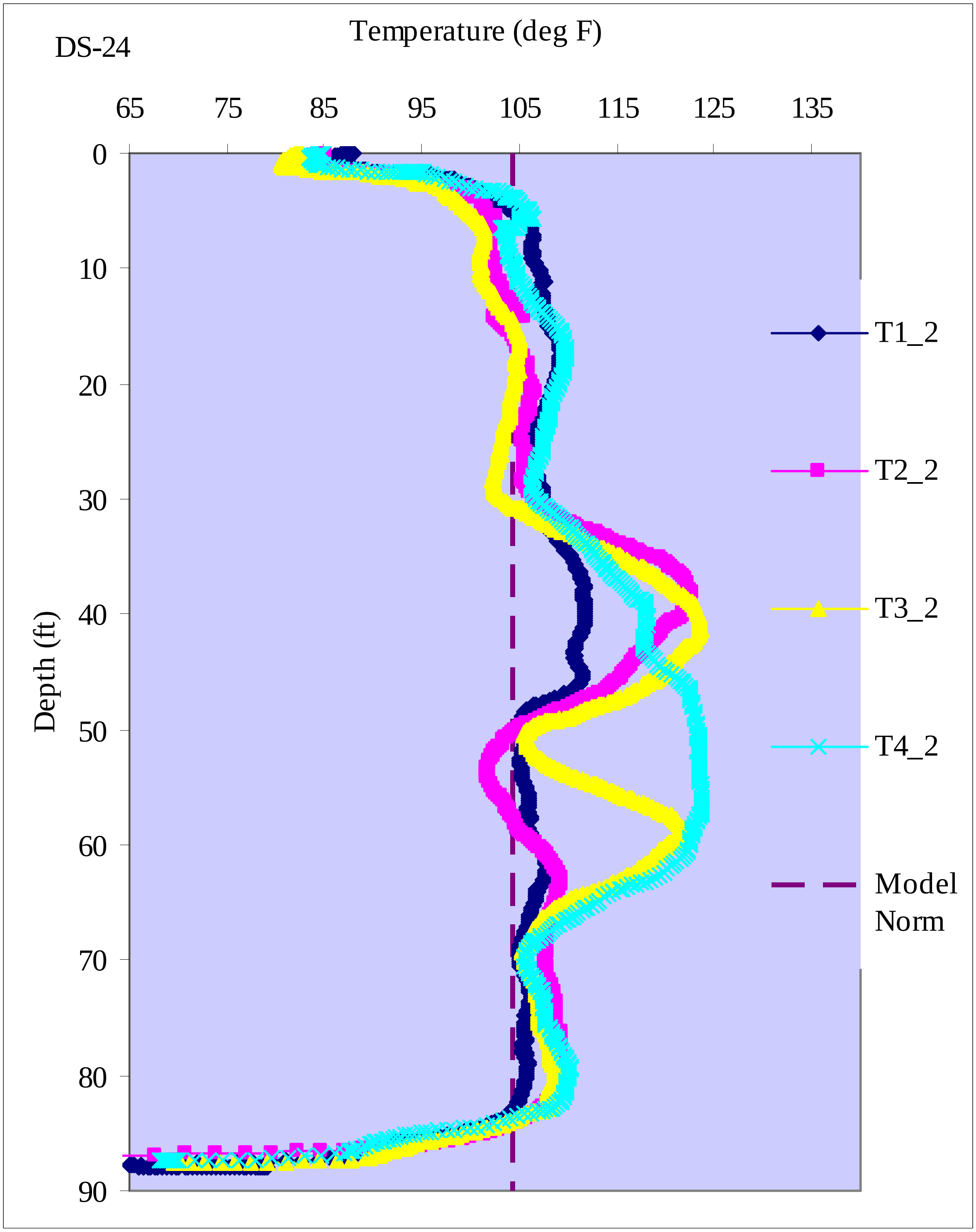

Figure DS-24 Measured temperature traces for Tubes 1 through 4 compared to the model norm.

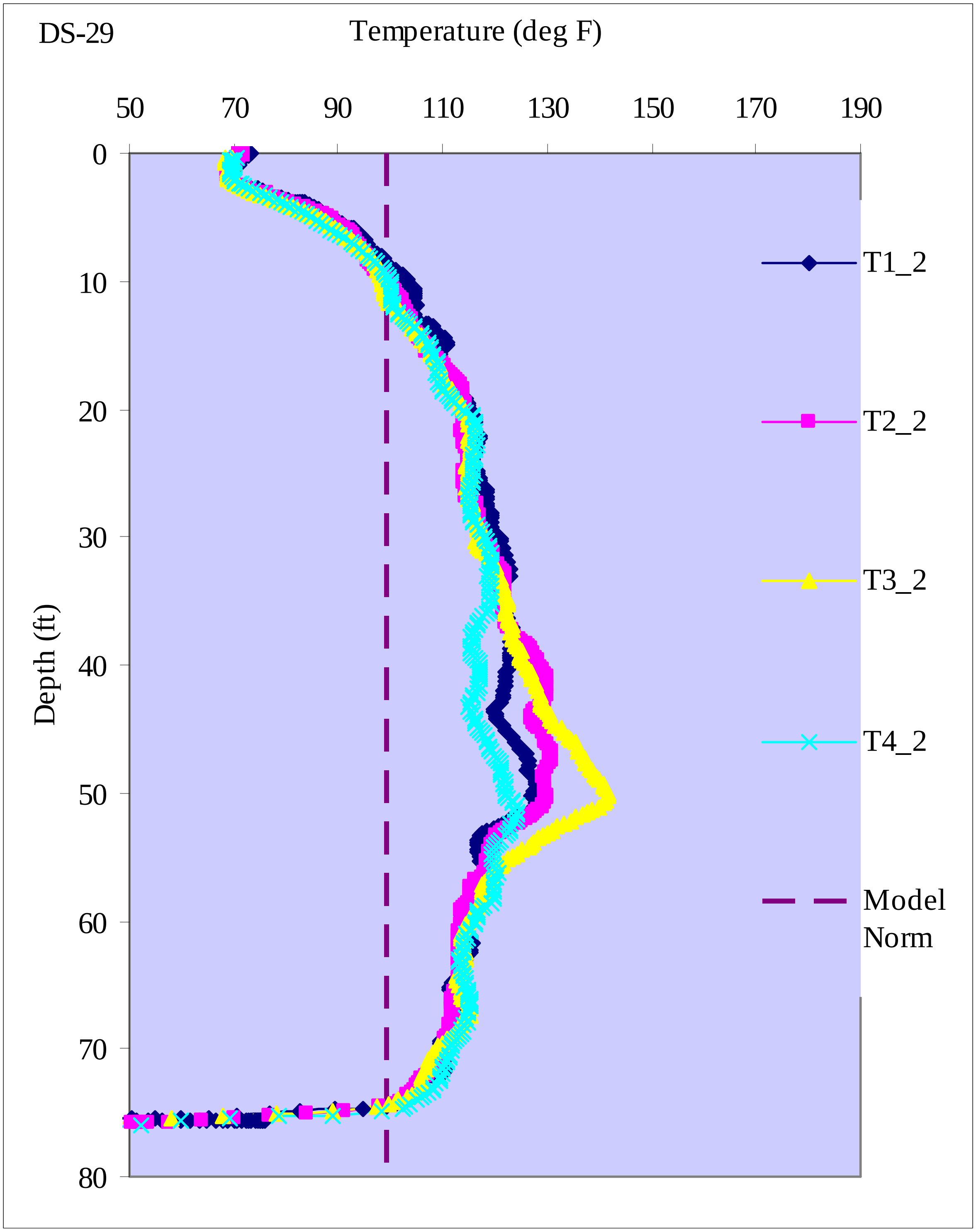

Figure DS-29 Measured temperature traces for Tubes 1 through 4 compared to the model norm.

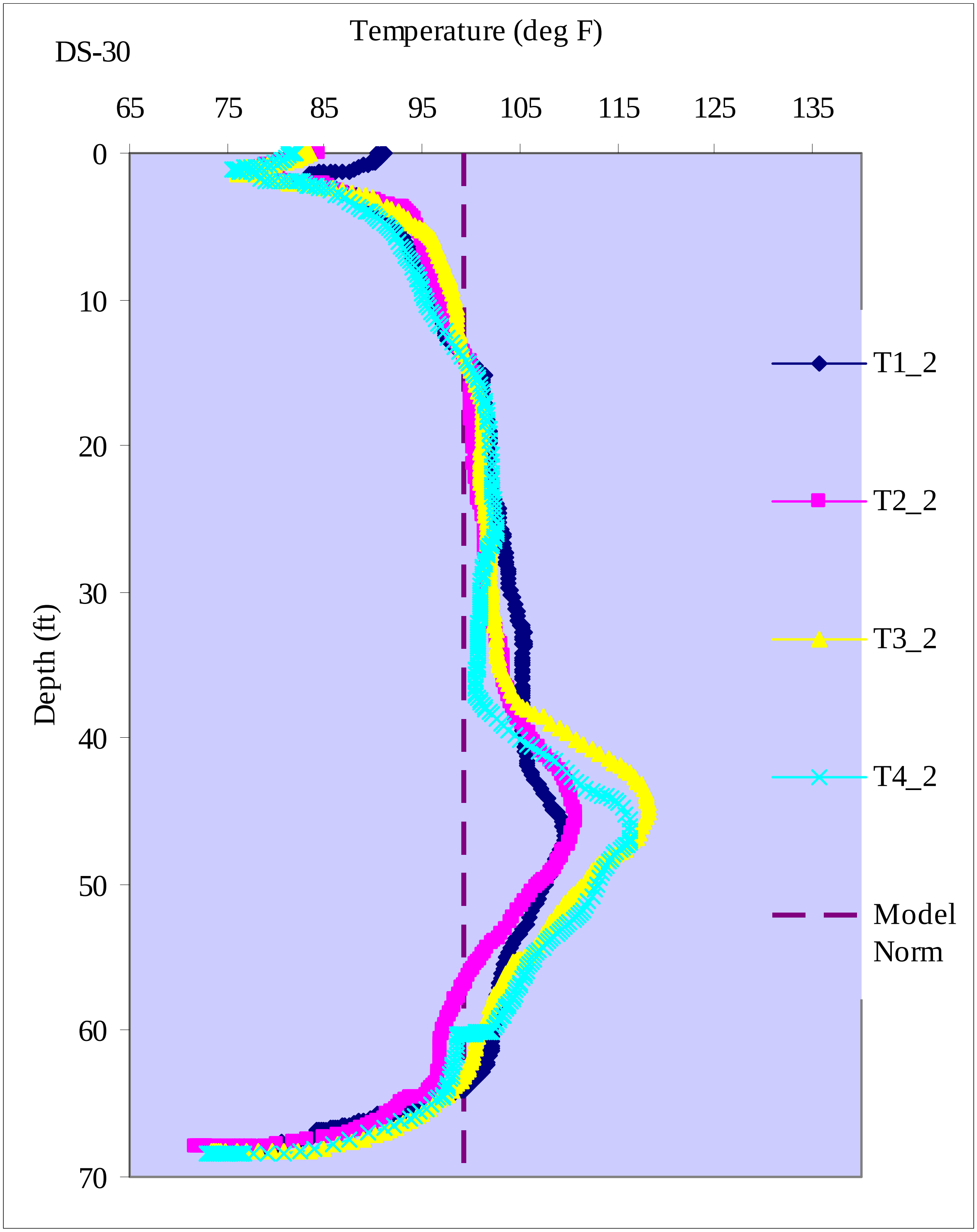

Figure DS-30 Measured temperature traces for Tubes 1 through 4 compared to the model norm.

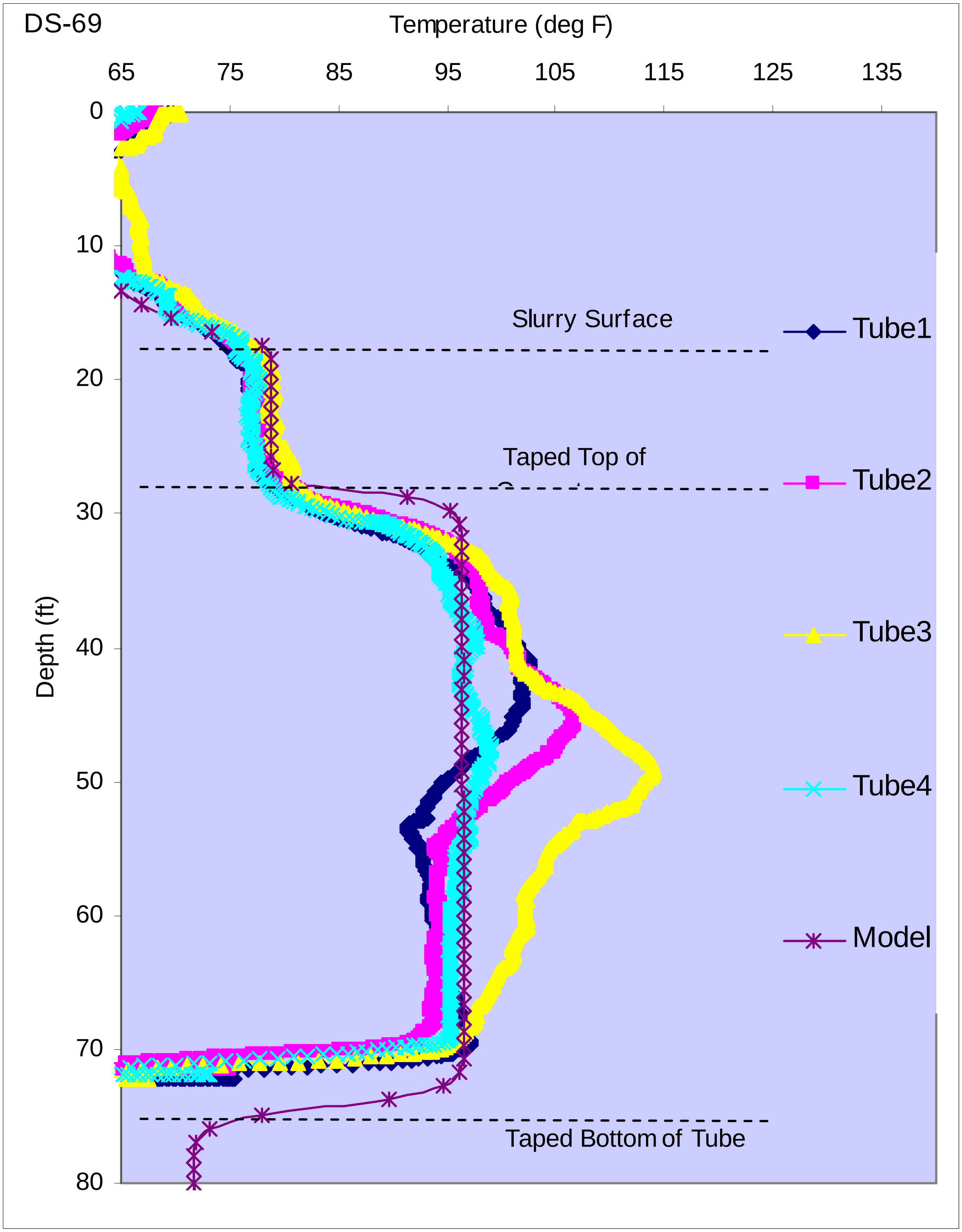

Figure DS-69 Measured temperature traces for Tubes 1 through 4 compared to full model norm.

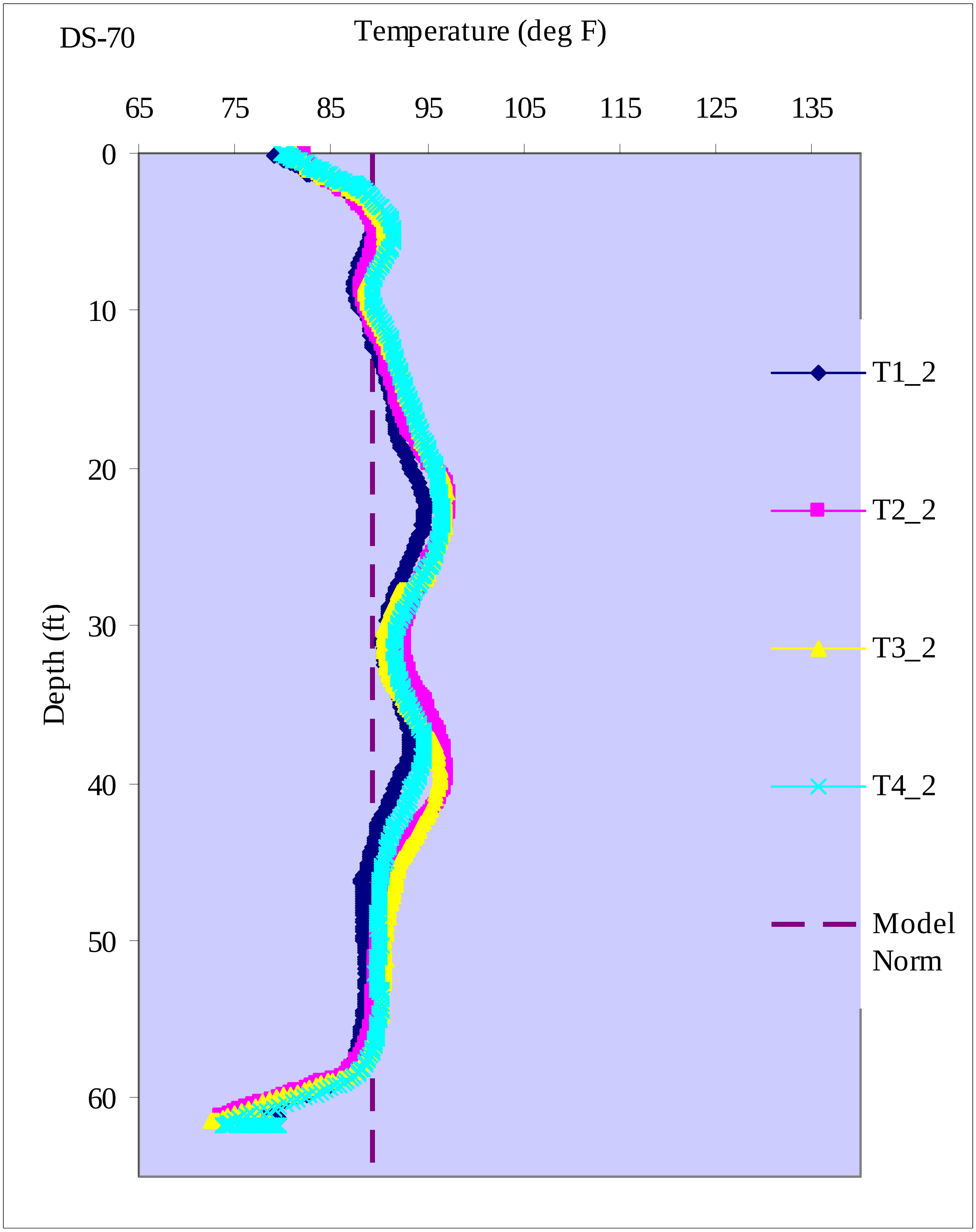

Figure DS-70 Measured temperature traces for Tubes 1 through 4 compared to the model norm.

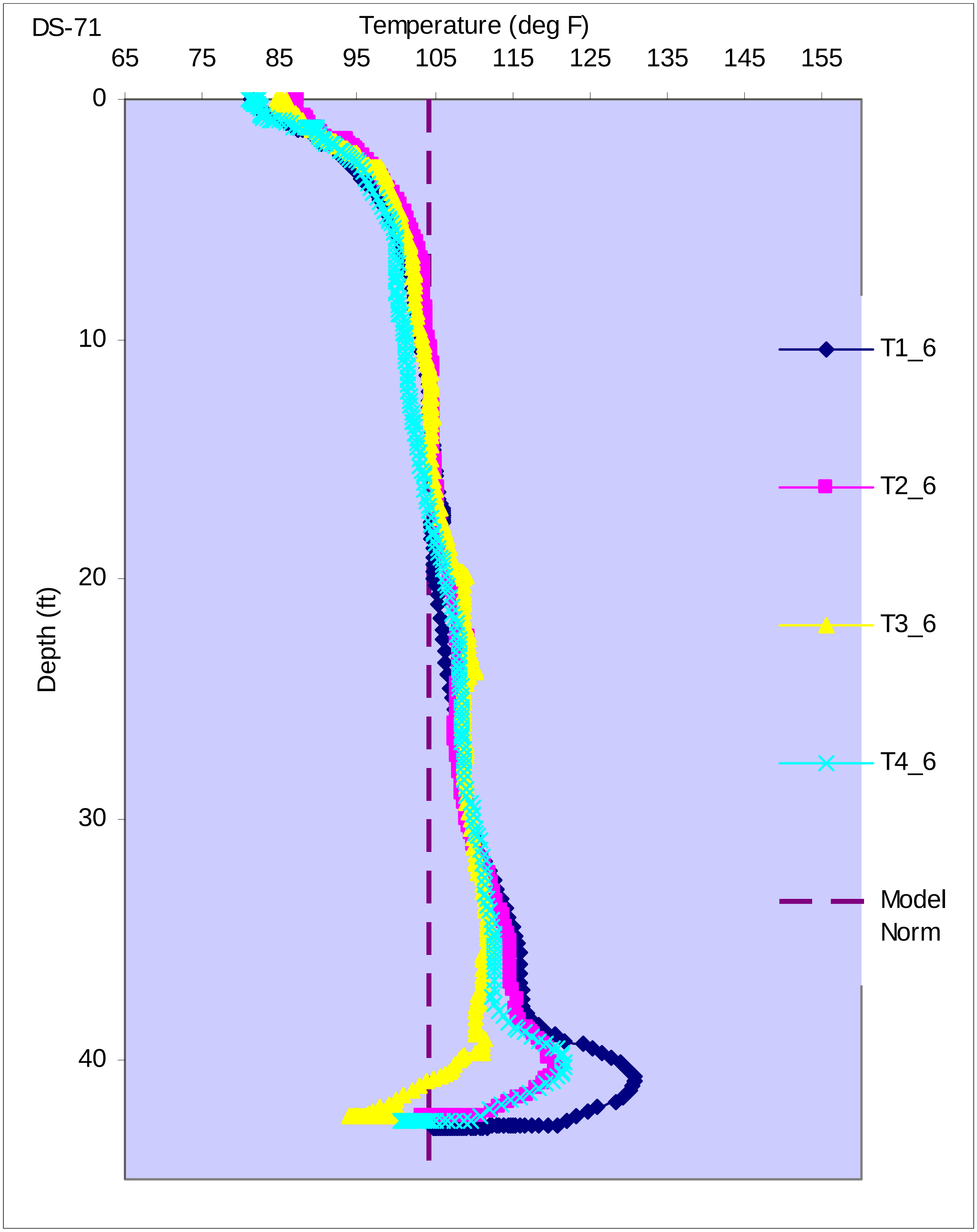

Figure DS-71 Measured temperature traces for Tubes 1 through 4 compared to the model norm.

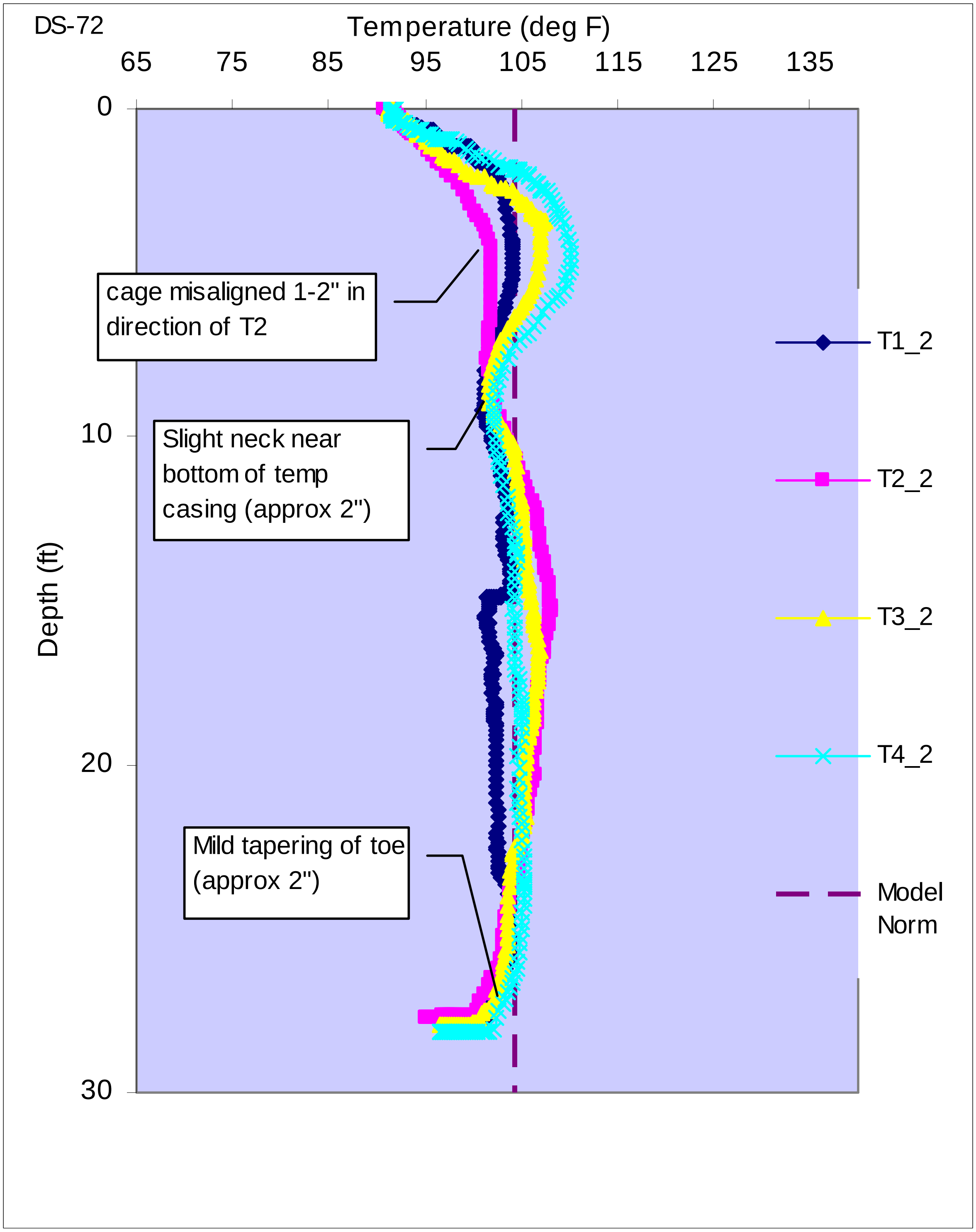

Figure DS-72 Measured temperature traces for Tubes 1 through 4 compared to the model norm.

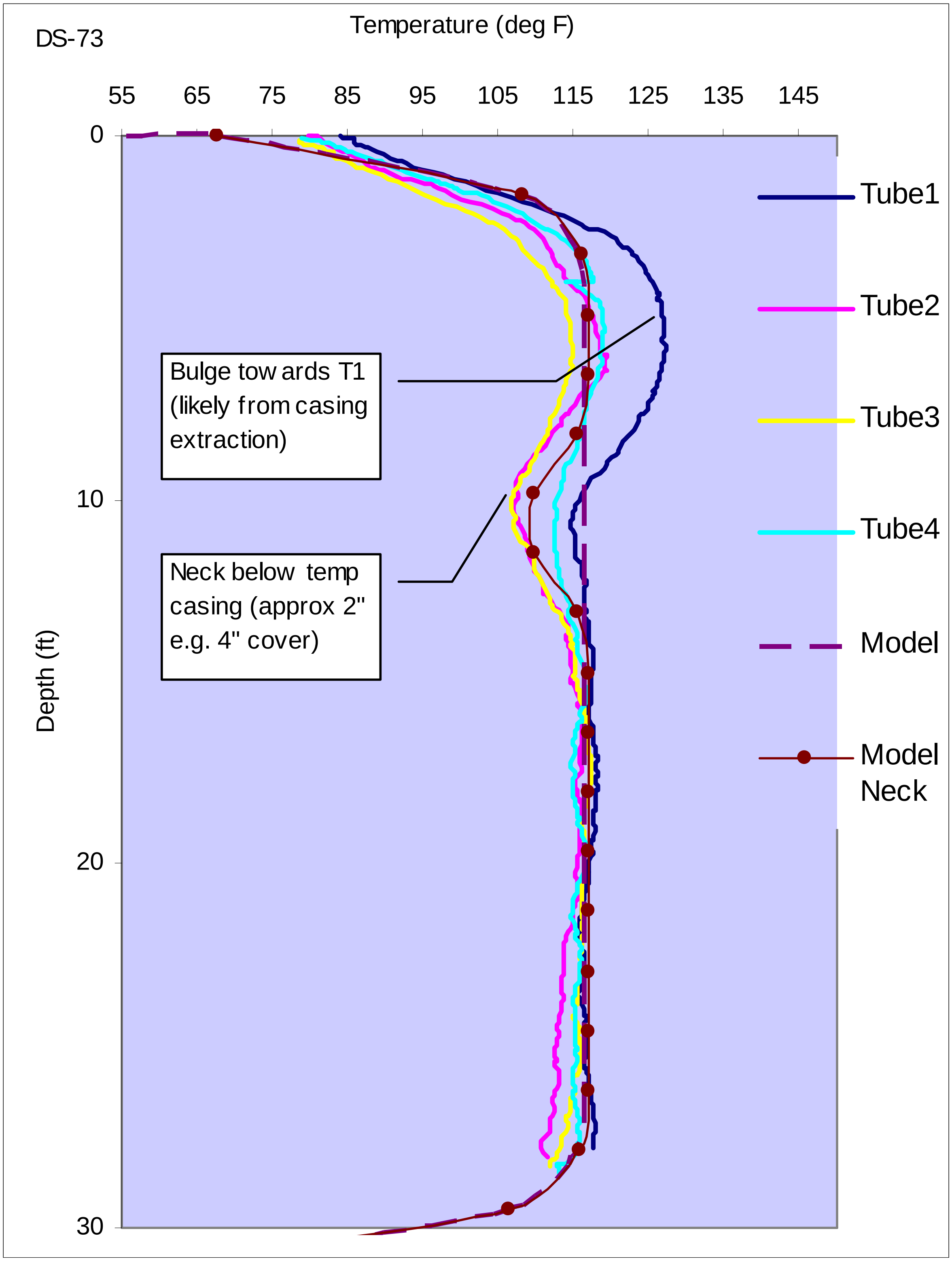

Figure DS-73 Measured temperature traces for Tubes 1 through 4 signal matched to model.