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"Effect of Elevated Ground Temperature (from Electric Cables) on the Pressure Rating of PE Pipe in Gas Piping Applications"

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Abstract

New underground high voltage electric cables can increase the average annual temperature of the soil at typical burial depths of about three feet. Older electric cable systems were designed with significant margin, therefore, they operated at a level significantly lower than their maximum capacity. Operating at such a lower level resulted in a significantly lower conductor temperature, and because of this lower conductor temperature, there was a lower heat flux to impact surrounding utilities. To reduce overall costs, while maximizing circuit ratings, today's electric cable systems are designed to operate much closer to their limit. Therefore, the actual conductor temperatures are closer to the maximum value, and this is what is causing the increased heat flux to the surrounding utilities. If these electric cables are near buried PE gas pipes, this increased ground temperature could decrease the pressure rating of the PE pipe. This paper will explain how these calculations can be made.

Summary

Palermo Plastics Pipe Consulting reviewed information supplied by Yankee Gas to determine the effect of an increased average annual ground temperature on the pressure rating of PE gas distribution pipe, due to a newly installed electric cable.

1. For PE materials used in some of the Yankee Gas distribution system where the new electric cable increased the average annual ground temperature to 65°F, there was no effect on pressure rating, because this increased temperature of 65°F was still lower than the PE pipe design temperature of 73°F.

2. For the PE 3408 or PE 3608 materials used in some of the Yankee Gas system where the new electric cable increased the average annual ground temperature to 87°F, there was an effect on pressure rating, because this increased temperature of 87°F was higher than the design temperature of 73°F. Based on temperature interpolation for these PE materials that have an HDB of 1600 psi at 73°F and 800 psi at 140°F, it was suggest that Yankee Gas lower the HDB to 1250 psi from 1600 psi for their pressure rating, or a reduction of 25%.

3. For the PE 100/PE 4710 materials used in the Yankee Gas system, there was no effect on pressure rating in the presence of the new electric cable, even though the average annual ground temperature of 87°F was higher than the design temperature of 73°F. Because these PE 100/PE 4710 materials have an HDB of 1000 psi at 140°F and also have an LTHS at 73°F well above 1600 psi, it was suggest that for these PE 100/PE 4710 materials, Yankee Gas continue to use an HDB of 1600 psi for their pressure rating, or NO reduction in pressure rating.

Background

Yankee Gas had PE pipe lines installed in their gas distribution system. A new 345KV electric cable was proposed near two of their PE distribution systems. Since these high-voltage electric cables would increase the average annual ground temperature of the earth near their PE distribution lines, Yankee Gas needed to know what effect, if any, this increase in ground temperature would have on the pressure rating of their PE distribution lines. They contacted Palermo Plastics Pipe (P^3) Consulting to obtain an answer.

Average Annual Ground Temperature

Palermo Plastics Pipe (P^3) Consulting reviewed all the documents that Yankee Gas had submitted. For one area in their distribution system, the maximum temperature two feet from the PE distribution line was 93°F, and the average annual ground temperature two feet from the PE pipe at a depth of 42 inches was 65°F. The details of the temperature profile for this first area are shown in Appendix A.

For the other area, the maximum temperature two feet from the PE distribution line was 117°F, and the average annual ground temperature two feet from the PE pipe at a depth of 42 inches was 87°F. The details of the temperature profile for this second area are shown in Appendix B.

The maximum temperature is only of interest if the ground temperature were at that temperature all year long. For the purposes of plastic pipe life forecasting or pressure rating determinations, it is more appropriate to use the average annual ground temperature. When a plastic pipe pressure rating is determined at 73°F, it is assumed that this is the average annual temperature. Many studies have been conducted to demonstrate that if plastic pipe is at one temperature for part of its life and another temperature for the rest of its life, the pressure rating is the same as if the pipe were at the average temperature for all of its life. Within the ISO system and some ASTM standards, Miner's Rule is used for plastic pipe. Miner's Rule assumes that when plastic pipe spends time at different temperatures, the effect is cumulative or additive, and is essentially the same as assuming an average annual temperature. Once we know the average annual ground temperature in the vicinity of plastic pipe, we can then determine the pressure rating for the pipe at that temperature.

Effect of Temperature on Pressure Rating

ASTM D 2513 specifies use of temperature interpolation to determine the pressure rating at a specified temperature between two temperatures where the pressure rating is known. Also, DOT Part 192 now recognizes this interpolation method for plastic pipe. The guidelines for plastic pipe temperature interpolation are provided in Plastics Pipe Institute (PPI) TR-3, which DOT Part 192 also references. The protocol for this temperature interpolation in TR-3 is shown in Appendix C.

By knowing the pressure rating for PE pipe at the standard temperature of 73°F, and also knowing the pressure rating at a higher temperature, typically 140°F, we can determine the pressure rating at a desired intermediate temperature by the interpolation method shown in Appendix C.

Based on information received from Yankee Gas, these are the PE materials, and corresponding HDB values, used in their distribution system:

PE Material	**73°F HDB (psi)**	**140°F HDB (psi)**
PE 100/PE 4710 A	1600	1000
PE 100/PE 4710 B	1600	1000
PE 100/PE 4710 C	1600	1000
PE 3608 A	1600	800
PE 3608 B	1600	800
PE 3408 A	1600	800
PE 3408 B	1600	800

These are all HDPE (high density polyethylene) materials, formerly all known as PE 3408, and have an HDB (hydrostatic design basis) of 1600 psi at 73°F. Some of these PE materials have an HDB at 140°F of 800 psi; these are the two PE 3608 and two PE 3408 materials. The other three materials are PE 100/PE 4710, and all have an HDB of 1000 psi at 140°F. The PE 3408 and PE 3608 materials with an HDB of 800 psi at 140°F will be more sensitive to temperature change, and will have a lower pressure rating at the interpolated temperature than the PE 100/PE 4710 materials.

Another nearby gas utility, Southern Connecticut Gas, also had MDPE (medium density polyethylene) materials installed next to this high voltage electric cable. These are PE 2406 or PE 2708 materials and have a 73°F HDB of 1250 psi and a 140°F HDB of 1000 psi or 800 psi.

Calculations

For the first area, the average annual ground temperature with the electric cable two feet away was 65°F. Since this is actually lower than the design temperature of 73°F, the new high voltage electric cable will have NO EFFECT on the pressure rating of any of the PE pipes in that area, the HDPE materials installed by Yankee Gas or the MDPE materials installed by Southern Connecticut Gas.

For the second area, the average annual ground temperature with the electric cable two feet away was 87°F. Since this is higher than the design temperature of 73°F, the new high voltage electric cable will have SOME EFFECT on the pressure rating of the PE pipes in that area. To determine the actual effect, we can use the temperature interpolation method as described in PPI TR-3 and shown in Appendix C of this paper. If we don’t know the actual LTHS (long-term hydrostatic strength) values for a given PE material, we would use the HDB values of 1600 psi at 73°F and either 800 psi or 1000 psi at 140°F. For PE 3408 or PE 3608 materials with an HDB of 800 psi at 140°F, the interpolated LTHS at 87°F is about 1435 psi, or a reduction of 165 psi. For PE 100/PE 4710 materials with an HDB of 1000 psi at 140°F, the interpolated LTHS at 87°F is 1475 psi, or a reduction of 125 psi. Obviously, the LTHS at the interpolated temperature is lower for the PE 3408 or PE 3608 materials than the PE 100/PE 4710 materials.

It would be more accurate to use the actual LTHS at 73°F, if it is known. For some PE 3408 or PE 3608 materials, the actual LTHS at 73°F is closer to 1550 psi (the minimum LTHS allowed by ASTM D 2837 for a 1600 psi HDB is 1530 psi). If we use this 1550 psi LTHS value at 73°F, then the interpolated LTHS at 87°F for the PE 3408 or PE 3608 materials is about 1395 psi. This is a significant decrease from the1600 psi value for the HDB. For an LTHS of 1395 psi, the corresponding HDB is 1250 psi. Therefore, for pressure rating purposes, Yankee Gas used an HDB of 1250 psi for these PE 3408 and PE 3608 materials when subjected to an average annual ground temperature of 87°F, or a DECREASE in pressure rating of 25%.

For the PE 100/PE 4710 materials, the actual LTHS is about 1700 psi at 73°F. If we use this 1700 psi LTHS value at 73°F, the interpolated LTHS value at 87°F for the PE 100/PE 4710 materials is about 1555 psi. This is still above the minimum LTHS of 1530 psi required for a 1600 psi HDB. Therefore, Yankee Gas could still use an HDB 1600 psi for pressure rating these PE 100/PE 4710 materials, which means there is NO REDUCTION in pressure rating for the PE 100/PE 4710 materials, even with the increased average annual ground temperature of 87°F.

Additional Gas Company LNG Plant Application

After receiving the report from Palermo Plastics Pipe Consulting, Yankee Gas was able to use this information for another application in their gas distribution system, i.e. in their new LNG plant. They reduced their capital and operating costs of the plant because they found they could tolerate higher tail gas temperatures in their distribution system. An explanation of this application is in Appendix D.

Conclusions

For all the PE materials (HDPE and MDPE) used in the first area, there is no effect on pressure rating in the presence of the new high-voltage electric cable, because the increased average annual ground temperature of 65°F is still lower than the design temperature of 73°F.

For the PE 3408 or PE 3608 materials used in the second area, there is an effect on pressure rating in the presence of the new high-voltage electric cable, because the increased average annual ground temperature of 87°F is now higher than the design temperature of 73°F. Because these PE 3408 and PE 3608 materials have an HDB of 800 psi at 140°F and the corresponding interpolated LTHS was 1395 psi at 87°F, it was suggested that for these PE 3408 and PE 3608 materials, Yankee Gas use an HDB of 1250 psi for their pressure rating, or a REDUCTION of 25%.

For the PE 100/PE 4710 materials, there is no effect on pressure rating in the presence of the new high-voltage electric cable, even though the increased average annual ground temperature of 87°F is higher than the design temperature of 73°F. Because these materials have an HDB of 1000 psi at 140°F and the corresponding interpolated LTHS was 1555 psi at 87°F, it was suggest that for these PE 100/PE 4710 materials, Yankee Gas use an HDB of 1600 psi for their pressure rating, or NO reduction.

For any additional questions, please contact Palermo Plastics Pipe Consulting at 865-995-1156 or gpalermo@plasticspipe.com.

Appendix A

AREA ONE
EARTH TEMPERATURE IN VICINITY OF DUCTBANK
FOR FOUR SEASONS

INTRODUCTION:

NU requested PDC to calculate the earth temperature in the vicinity of the 345-kV cable ductbank, for summer, fall, winter, and spring conditions.

The cable parameters, installation and operating conditions are the same as described in our earlier memorandum for summertime conditions. We assumed a constant year-round load of 1000 amperes on each line, and calculated temperatures at various depths and various distances from the ductbank centerline for each of the four seasons.

AMBIENT EARTH TEMPERATURE

The ambient earth temperature at a given depth varies with season. A well-defined equation, used by the University of Connecticut and others, defines temperatures as a function of depth and day of the year. We used 25^{O}C (77^{O}F) at 42 inches depth at the end of August as the fixed temperature; this is the value used by NU's distribution department and others for maximum summertime condition.

The calculated ambient temperatures are summarized below:

Table 1. Ambient Temperatures at Different Depths
Four Seasons

	Temperature, C			
Depth Inches	Summer Maximum	Fall Nov. 15	Winter Feb. 15	Spring 15-May
30	27.1	7.1	-7.0	12.8
36	25.9	8.4	-6.0	11.5
42	25.0	9.5	-5.0	10.4
48	24.0	10.5	-4.0	9.4
54	23.0	11.4	-3.0	8.5
69	21.0	13.0	-0.5	6.9
84	19.2	14.0	1.7	5.9

CALCULATED EARTH TEMPERATURES NEAR DUCTBANK

The earth temperatures were calculated by adding the temperature rise from the power cables to the ambient earth temperature for each of the depths and seasons shown in Table 1 above. Table 2 shows results for a 42-inch and an 84-inch depth. Curves showing the results for each depth, and for different distances, are given in Figures 1-4.

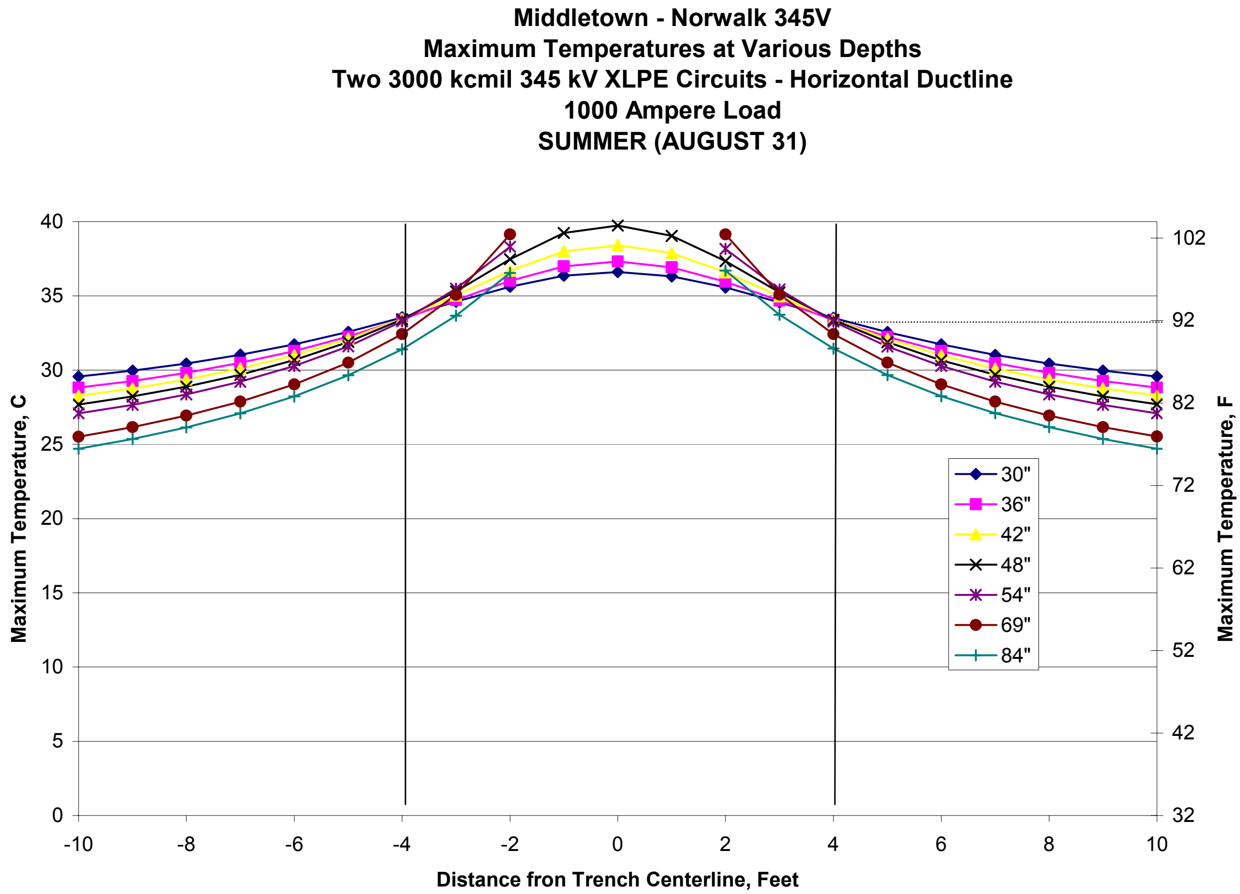
Table 2. Temperatures, Degrees Fahrenheit, Two Feet From Ductbank Edge For 42-inch and 84-inch Depths

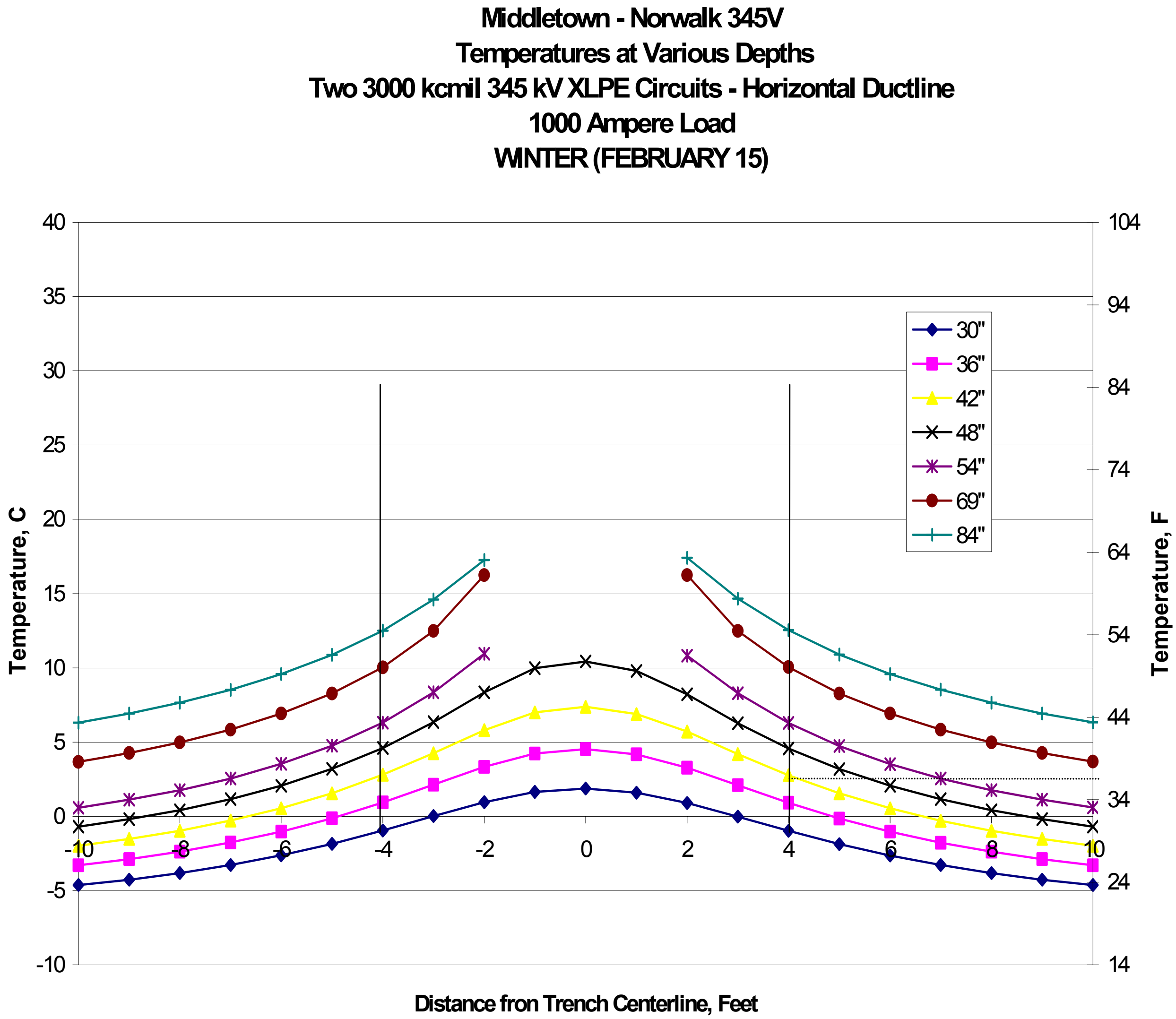
Season	42-inch Depth	84-inch Depth
Summer	92	87
Fall	64	75
Winter	37	54
Spring	65	63
Average	64.5 ^{O}F	70 ^{O}F

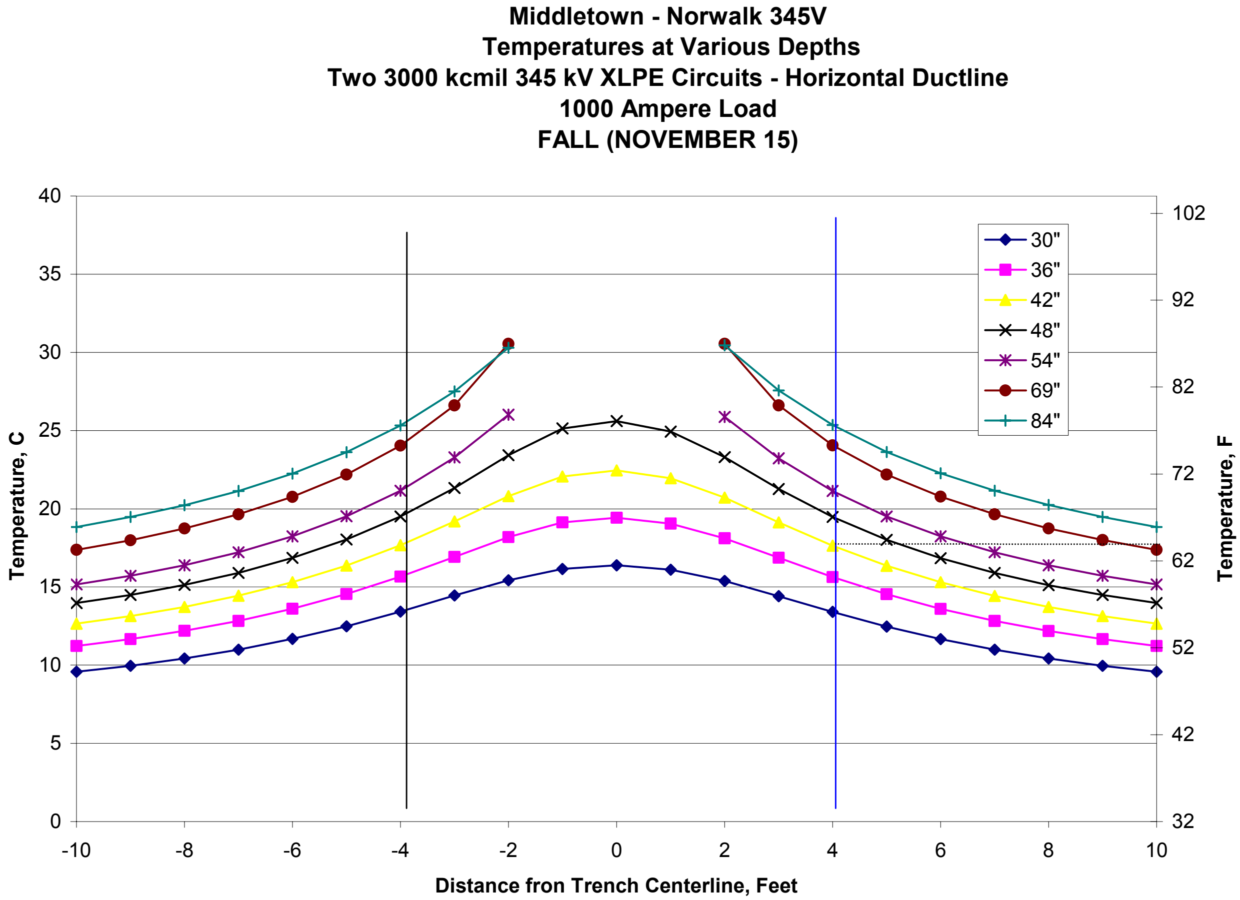
The Average simply takes the temperatures on the four dates and averages them; a day-by-day calculation may show a value very slightly different.

GRAPHS OF TEMPERATURES, FOUR SEASONS

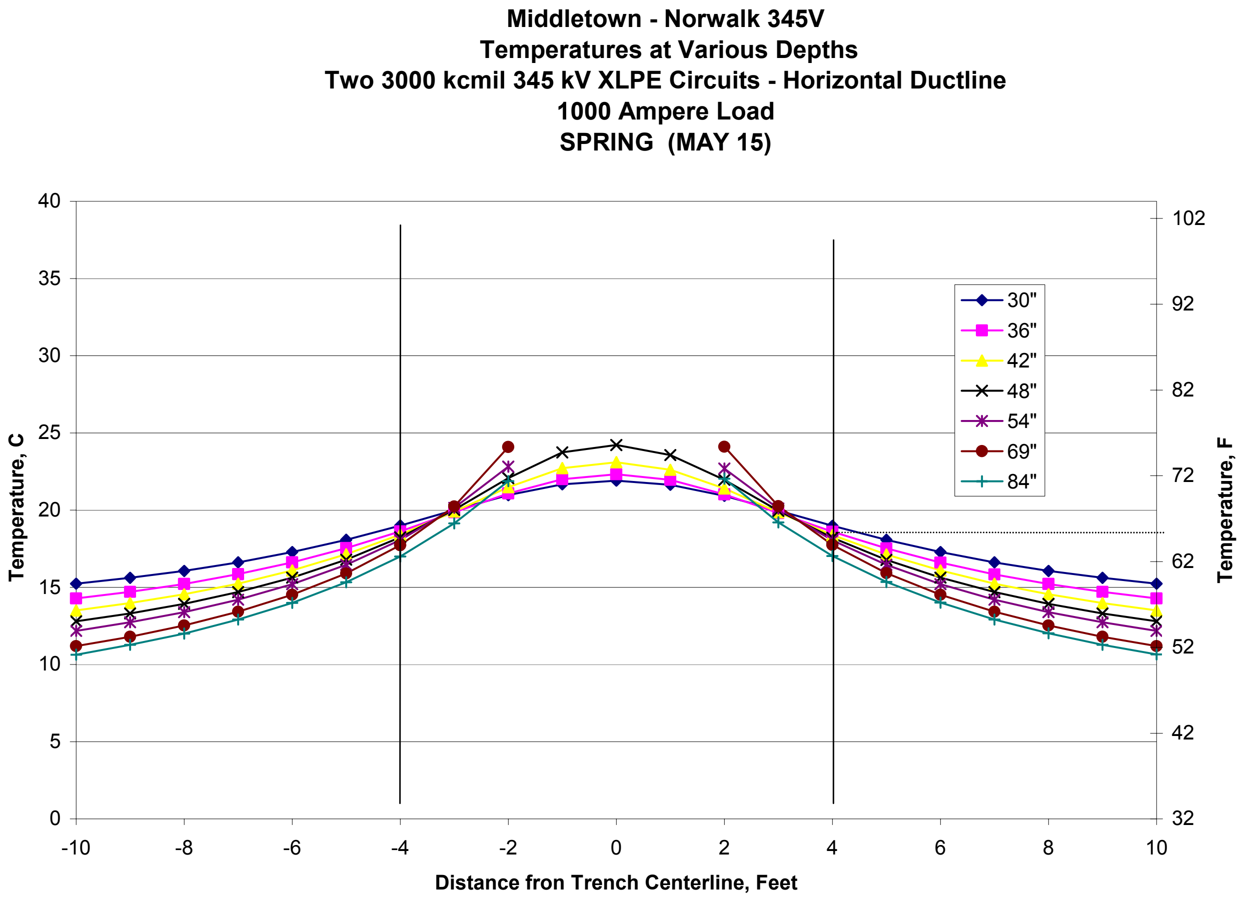
The following graphs show the calculated temperatures for different depths, for each of the four dates.




Middletown - Norwalk 345V
Temperatures at Various Depths
Two 3000 kcmil 345 kV XLPE Circuits - Horizontal Ductline
1000 Ampere Load
WINTER (FEBRUARY 15)
Temperature, C
Temperature, F
Distance fron Trench Centerline, Feet
30"
36"
42"
48"
54"
69"
84"
40
35
30
25
20
15
10
5
0
-5
-10
104
94
84
74
64
54
44
34
24
14
-10
-8
-6
-4
-2
0
2
4
6
8
10



Middletown - Norwalk 345V
Temperatures at Various Depths
Two 3000 kcmil 345 kV XLPE Circuits - Horizontal Ductline
1000 Ampere Load
FALL (NOVEMBER 15)
Temperature, C
Temperature, F
Distance fron Trench Centerline, Feet
30"
36"
42"
48"
54"
69"
84"
0
5
10
15
20
25
30
35
40
32
42
52
62
72
82
92
102
-10
-8
-6
-4
-2
0
2
4
6
8
10



SUMMARY

Based upon taking the average of the four seasonal temperatures, at a distance of two feet from the ductbank edge, the average annual temperature is 65 ^{O}F at a typical burial depth of 42 inches. It is 70 ^{O}F at a depth of 84 inches. Values at other depths and distances from the ductbank edge may be determined from the four figures.

Appendix B

EARTH TEMPERATURE IN VICINITY OF DUCTBANK FOR FOUR SEASONS

INTRODUCTION:

NU requested PDC to calculate the earth temperature in the vicinity of the 3 X 3 cable ductbank, for summer, fall, winter, and spring conditions.

The cable parameters, installation and operating conditions are the same as described in our earlier memorandum for summertime conditions. We assumed that both cable circuits were carrying rated current, and that a 115-kV Norwalk Harbor cable was in the center column, also carrying its rated current. We calculated temperatures at various depths and various distances from the ductbank centerline for each of the four seasons. Note that our model assumed that all three circuits carried their maximum rated current, at the assumed daily load factor, for long periods of time. The calculated temperatures are therefore conservatively high.

AMBIENT EARTH TEMPERATURE

The ambient earth temperature at a given depth varies with season. A well-defined equation, used by the University of Connecticut and others, defines temperatures as a function of depth and day of the year. We used 25^{O}C (77^{O}F) at 42 inches depth at the end of August as the fixed temperature; this is the value used by NU's distribution department and others for maximum summertime condition.

The calculated undisturbed ambient temperatures are summarized below:

Table 1. Ambient Temperatures at Different Depths
Four Seasons

	Temperature, C			
Depth Inches	Summer Maximum	Fall Nov. 15	Winter Feb. 15	Spring 15-May
30	27.1	7.1	-7.0	12.8
36	25.9	8.4	-6.0	11.5
42	25.0	9.5	-5.0	10.4
48	24.0	10.5	-4.0	9.4
54	23.0	11.4	-3.0	8.5
69	21.0	13.0	-0.5	6.9
84	19.2	14.0	1.7	5.9

CALCULATED EARTH TEMPERATURES NEAR DUCTBANK

The earth temperatures were calculated by adding the temperature rise from the power cables to the ambient earth temperature for each of the depths and seasons shown in Table 1 above. Table 2 shows results for a 42-inch depth. Curves showing the results for each depth, and for different distances, are given in Figures 1-4.

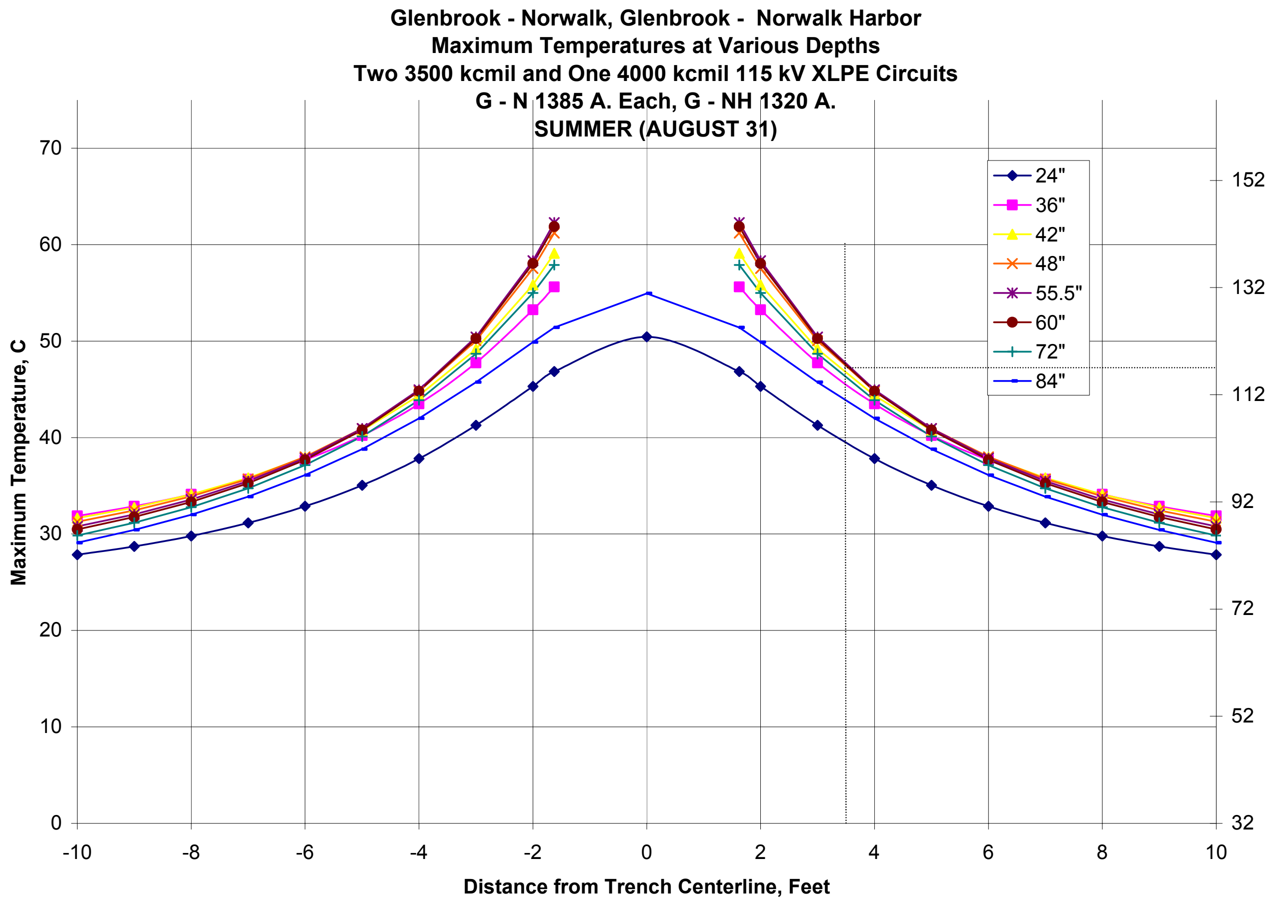
Table 2. Temperatures, Degrees Fahrenheit, Two Feet From Ductbank Edge For 42-inch Depth

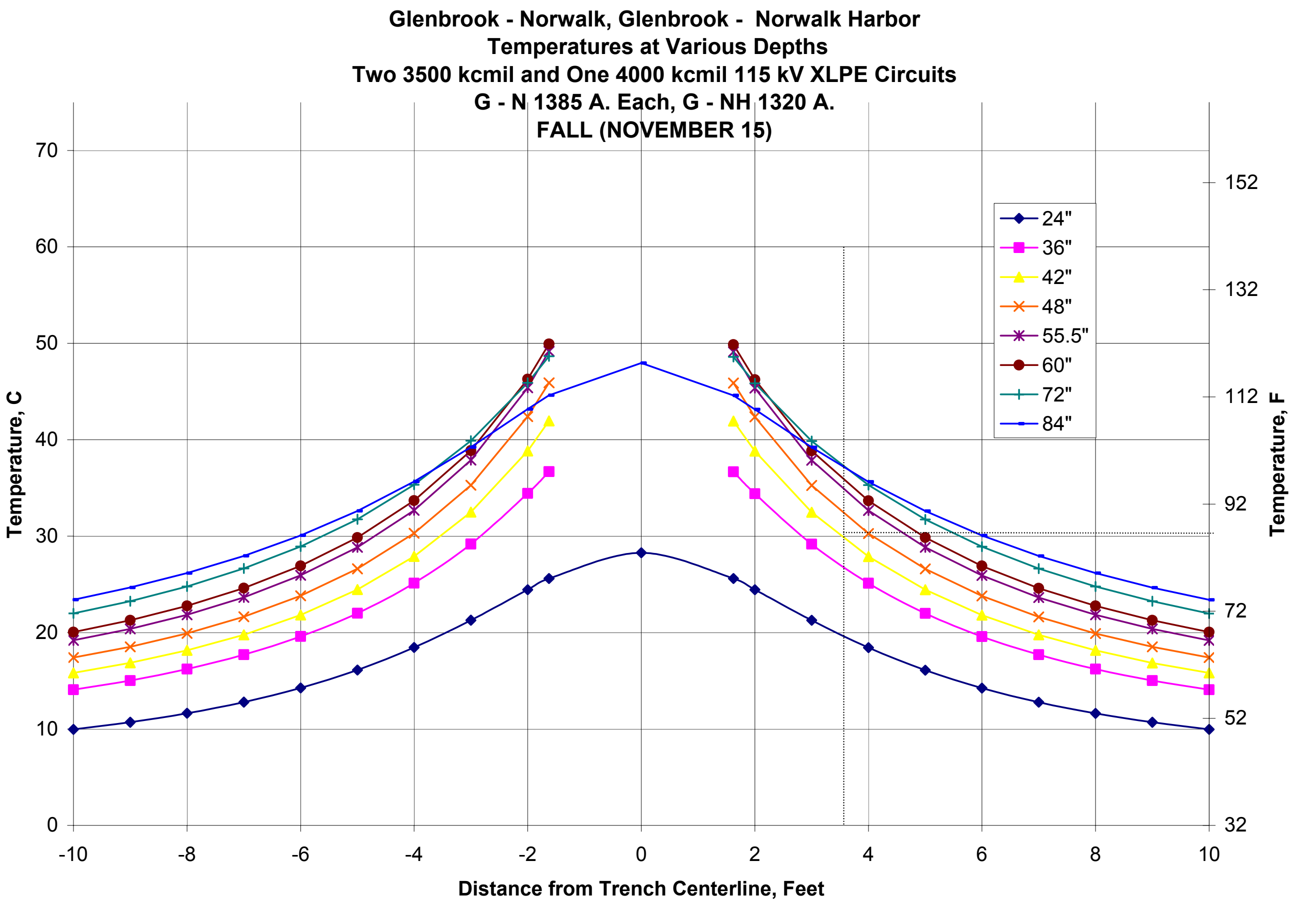
Season	42-inch Depth
Summer	116
Fall	86
Winter	54
Spring	87
Average	87 ^{O}F

The Average simply takes the temperatures on the four dates and averages them; a day-by-day calculation may show a value very slightly different.

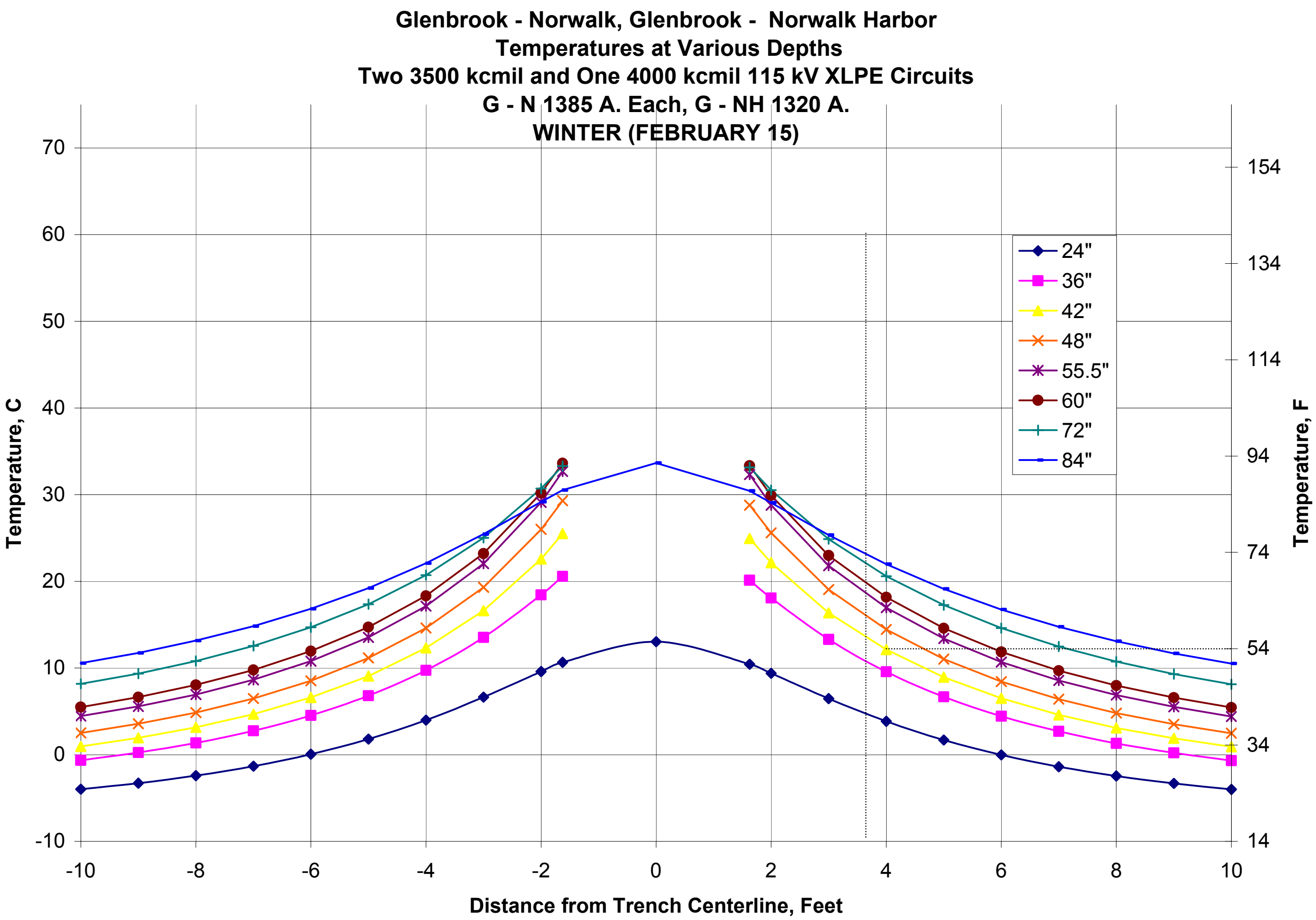
GRAPHS OF TEMPERATURES, FOUR SEASONS

The graphs on the following pages show the calculated temperatures for different depths, for each of the four dates.

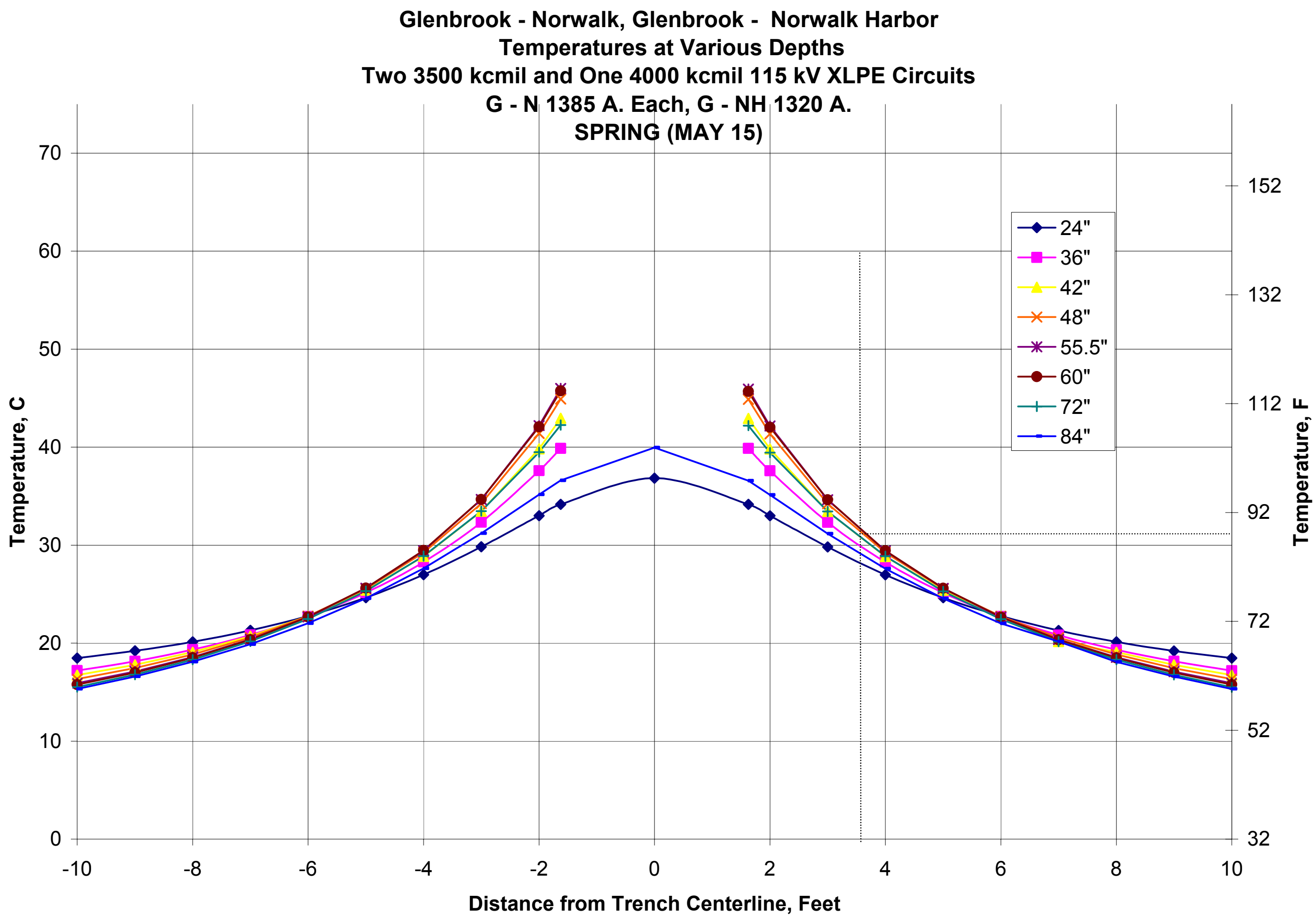

Glenbrook - Norwalk, Glenbrook - Norwalk Harbor
Maximum Temperatures at Various Depths
Two 3500 kcmil and One 4000 kcmil 115 kV XLPE Circuits
G - N 1385 A. Each, G - NH 1320 A.
SUMMER (AUGUST 31)
Maximum Temperature, C
Distance from Trench Centerline, Feet
24"
36"
42"
48"
55.5"
60"
72"
84"
0
10
20
30
40
50
60
70
32
52
72
92
112
132
152
-10
-8
-6
-4
-2
0
2
4
6
8
10



Glenbrook - Norwalk, Glenbrook - Norwalk Harbor
Temperatures at Various Depths
Two 3500 kcmil and One 4000 kcmil 115 kV XLPE Circuits
G - N 1385 A. Each, G - NH 1320 A.
FALL (NOVEMBER 15)
Temperature, C
Temperature, F
Distance from Trench Centerline, Feet
24"
36"
42"
48"
55.5"
60"
72"
84"



Glenbrook - Norwalk, Glenbrook - Norwalk Harbor
Temperatures at Various Depths
Two 3500 kcmil and One 4000 kcmil 115 kV XLPE Circuits
G - N 1385 A. Each, G - NH 1320 A.
WINTER (FEBRUARY 15)
Temperature, C
Temperature, F
Distance from Trench Centerline, Feet
24"
36"
42"
48"
55.5"
60"
72"
84"
70
60
50
40
30
20
10
0
-10
154
134
114
94
74
54
34
14
-10
-8
-6
-4
-2
0
2
4
6
8
10



SUMMARY

Based upon taking the average of the four seasonal temperatures, at a distance of two feet from the ductbank edge, the average annual temperature is 87 ^{O}F at a typical burial depth of 42 inches. Values at other depths and distances from the ductbank edge may be determined from the four figures.

D.2 POLICY FOR DETERMINING LONG-TERM STRENGTH (LTHS) BY TEMPERATURE INTERPOLATION

D.2.1. The HDB (Hydrostatic Design Basis) for a PPI standard listing temperature (73, 100, 120, 140, 160, 180, or 200°F) may be established on the basis of an LTHS that has been interpolated from LTHS values obtained for one higher and one lower temperature. The data used for this interpolation method must be in compliance with the applicable Parts of PPI TR-3. The following additional policies shall also apply in such cases:
D.2.1.1 The Grade of the HDB recommendation established from the interpolated LTHS shall be based on the minimum Grade for which the higher or lower temperature data would qualify.

D.2.1.2 The higher temperature data shall also be sufficient to qualify the subject material for at least the minimum Experimental Grade at that temperature. If this higher test temperature is not one of the PPI standard listing temperatures, then the minimum data requirements of the higher PPI standard listing temperature shall apply.

D.2.1.3 Data sets used in determining an interpolated LTHS do not need to be from the same lot. However, these lots used to determine an interpolated LTHS may not be used again for subsequent lots required by PPI TR-3.

Use the following equation to determine a temperature interpolated LTHS:

$$S_T = S_L - \frac{(S_L - S_H)\left(\frac{1}{T_L} - \frac{1}{T_T}\right)}{\left(\frac{1}{T_L} - \frac{1}{T_H}\right)}$$

Where: S_T = LTHS at interpolation temperature (psi)
S_L = LTHS at the lower temperature (psi)
S_H = LTHS at the higher temperature (psi)
T_T = interpolation temperature (K)
T_L = lower temperature (K)
T_H = higher temperature (K)

Appendix D

EFFECT OF THE OPERATION OF THE YANKEE GAS LNG PLANT ON POLYETHYLENE PIPE
9/18/06

A) Purpose and Summary

This analysis is to determine the effect of the temperature of the gas leaving the LNG plant on the polyethylene pipe in the Yankee Gas 60 psig distribution system.
The analysis concludes that there is no effect on the pressure rating of the PE pipe. The basis for this conclusion is shown in the recent study performed for Yankee Gas by Dr. Gene Palermo (Effect of Elevated Ground Temperature On Pressure Rating Of Polyethylene Pipe), which has been provided to the GPSU. Reference is made to the second paragraph of Section III of the study, which explains the use of the average annual temperature to determine the effect of pressure rating on PE pipe.

> "The maximum temperature is only of interest if the ground temperature were at that temperature all year long. For the purposes of plastic pipe life forecasting or pressure rating determinations, it is more appropriate to use the average annual ground temperature. When a plastic pipe pressure rating is determined at 73°F, it is assumed that this is the average annual temperature. Many studies have been conducted to demonstrate that if plastic pipe is at one temperature for part of its life and another temperature for the rest of its life, the pressure rating is the same as if the pipe were at the average temperature for all of its life. Within the ISO system and some ASTM standards, Miner's Rule is used for plastic pipe. Miner's Rule assumes that when plastic pipe spends time at different temperatures, the effect is cumulative or additive, and is essentially the same as assuming an average annual temperature. Once we know the average annual ground temperature in the vicinity of plastic pipe, we can then determine the pressure rating for that pipe at that temperature."

B) Assumptions

The following assumptions will be used in the calculation to determine the Maximum Average Annual Temperature of the plastic pipe in the Waterbury 60 psig distribution system.

1) The final temperature of the regeneration gas plus boiloff, leaving the LNG plant is assumed to be always at the maximum allowable design temperature of 90 deg F. This is the worst case design temperature. Refer to CB&I specification 11790 in Transmittal 223.

2) Assumed that liquefaction will take place for 200 days per year. This assumes filling an empty tank without utilizing trucking as a refill method.

3) Assume for a 60 day period in July and August, the sendout into the 60 psig distribution system will be 100% regeneration gas / boiloff. This is a conservative worst case scenario, since distribution system flows may only be low enough to use 100% regeneration / boiloff gas on a few summer nights each year.

4) Assume for a 60 day period in June and September, there will be an overall mixture of 50% regeneration gas / boiloff and 50% pipeline gas. (see paragraph 6 below for pipeline gas temperature)

5) For the remaining 80 days of liquefaction the overall mixture will be a higher percentage of pipeline gas than regeneration gas / boiloff. Assume a conservative 50/50 mix here also.

6) Assume pipeline distribution gas will be heated to obtain an outlet temperature of 45 deg F. The actual temperature will be approximately 40 deg F. Assume the addition of boiloff will cause the temperature to increase to 50 deg F.

7) Vaporized gas will be sent out at 60 deg F. This is also a very conservative assumption. Assume that vaporization will take place for 20 days per year. This assumes a complete, yearly cycling of the LNG tank. This is a worst case scenario, as at the very least, the "heel" of the LNG in the tank will never be removed unless the tank needs to be taken out of service.

C) Temperature Determination

Using the conservative assumptions above, the average annual temperature of the sendout gas, which is the temperature exposed to the PE pipe, can be determined.

Referenced Above	Gas Obtained From	When	# days	Temp - deg F	Temp Units
B3	Liquefaction	July & Aug	60	90	5400
B4	Liquefaction	June & Sept	60	70	4200
B5	Liquefaction	Remaining 80 days of Liquefaction	80	70	5600
B6	Pipeline	When not Liquefying or Vaporizing	145	50	7250
B7	Vaporization	When Vaporizing	20	60	1200
Totals			365		23650
Average Annual Temperature - deg F				64.8	

D) Conclusion

Assuming that the temperature of the long term hydro-static strength of all the PE pipe in the Yankee Gas distribution system was determined at the lowest temperature of 73 deg F (refer to 49 CFR 192.121 and 192.123), the effects of the operation of the LNG plant will not cause any de-rating of any of the PE pipe in the Yankee Gas distribution system. This is because the conservative calculated average annual temperature of 64.8 deg F is less than the 73 deg F temperature at which the long term hydro-static strength of the pipe was determined.