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Mackenzie Valley Environmental Impact Review Board (MVEIRB)
Box 938, 5102 – 50th Avenue
Yellowknife, NT X1A 2N7

Attention: Glenda Fratton, Environmental Assessment Coordinator

Dear: Glenda

SUBJECT: Snap Lake North Pile Thermal Model

Please accept the attached technical memorandum titled "Snap Lake North Pile Thermal Model" for submission to the Public Registry. This memo was compiled in response to issues raised during the MVEIRB Technical Sessions.

Additionally, information contained within this memo should address outstanding concerns identified by Indian and Northern Affairs Canada in their Request for Ruling to the Board dated 22 January 2003, and their technical report submitted 14 February 2003.

Should you have any questions, please feel free to contact the undersigned.

Sincerely,
SNAP LAKE DIAMOND PROJECT

Robin Johnstone
Senior Environmental Manager

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TECHNICAL MEMORANDUM

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TO:	Robin Johnstone De Beers Canada Mining	**DATE:**	February 14, 2003
FROM:	Dawn Kelly and Rick Schryer	**JOB NO:**	03-1322-017.5480
PREPARED BY:	Terry Eldridge		
RE:	**SNAP LAKE NORTH PILE THERMAL MODEL**		

The thermal modeling carried out for the proposed North Pile at the Snap Lake Diamond Project has been updated. The original modeling was done in 2001, with review comments provided during 2002. The thermal model was updated to address these review comments.

The purpose of this memorandum is to provide information to resolve outstanding technical issues raised by reviewers at the Snap Lake Technical Sessions on December 3-5/03 related to:

- PK Paste Material Properties,
- Geothermal Flux, and
- Ground Surface Temperature.

The information presented in this technical memorandum is in addition to the following issues raised by reviewers and responded to in the information requests (IR) process related to the North Pile Thermal Model:

- IRs 2.4.34 and 2.4.35,
- IR 2.6.18,
- IRs 3.4.16, 3.4.17, 3.4.18, and 3.4.20, and
- IR 3.8.2.

The thermal modeling has been carried out using Temp/W, version 5.13, produced by GeoSlope. This memorandum presents the overall model results and our conclusions.

1.0 PK PASTE MATERIAL PROPERTIES

The unfrozen water content curve of the processed kimberlite (PK) paste was determined in the laboratory by EBA in Edmonton in January 2003. Measurement of the thermal conductivity of the PK paste was carried out by EBA in 2001.

Figure 1 compares the unfrozen water content curve for the PK paste used in the 2001 thermal model and the curve based on laboratory measurements in 2003. A comparison of the grain size distribution of the tested sample and the design grain size distribution for the PK paste is presented on Figure 2. The unfrozen water content curve used in the 2001 model compares well with the laboratory determined curve. There is close agreement between the grain size distribution curves at the coarse end, with the laboratory tested material having less clay-sized material than the design curve.

The small difference in the temperature of the PK during deposition resulting from the change in the unfrozen water content curve is shown in Figure 3. The figure shows the calculated PK temperature at the end of the December following one and a half years of PK deposition. The laboratory determined unfrozen water content curve results in slightly lower PK temperatures.

2.0 GEOTHERMAL FLUX

The 2001 thermal model used a heat flux of 0.004 W/m^2 at the lower boundary of the model mesh.

The thermistor installed in Borehole BH-02-01 extends to a depth of 300 m below ground surface. The temperature gradient in the hole is in the range from 0.012 to 0.0.17 °C/m. For a granite thermal conductivity of 3 W/m°C, the heat flux is calculated to be 0.036 to 0.051 W/m^2.

The northern toe of the North Pile will be developed in close proximity to Snap Lake and there will be additional heat flux from the lake to this area. Borehole BH-30 has a temperature gradient of about 0.028 °C/m that, for a bedrock thermal conductivity in the range of 2 to 3 W/m°C, would give a heat flux in the range of 0.056 to 0.084 W/m^2. Model runs were carried out for boundary fluxes of 0.040 and 0.075 W/m^2 to assess the impact of this flux on the freezing behaviour of the paste PK. The geothermal flux was found to have a minor impact on the performance of the paste PK, because most of the heat in the pile is lost to the cold surface during winter.

3.0 GROUND SURFACE TEMPERATURE

The thermal modeling carried out in 2001 used a surface temperature boundary. The ground surface temperature was estimated using the average monthly air temperature estimated for the project site. The site weather station data collected during the period March 1998 through July 2001 and extrapolations from the Yellowknife and Lupin climate stations were used to estimate the average monthly air temperature. N factors were applied to the air temperatures to estimate the ground surface temperatures. An N factor of 0.5 was used for freezing conditions and 1.8 for thawing conditions.

The 2001 weather data from the site recording station was used in the recent round of thermal modeling. The air freezing and thawing index for this year was 3996 and 1118 °C days, respectively. For comparison, the Canadian Climate Normals for the period 1971 to 2000 for Fort Reliance has freezing and thawing indices of 3881 and 1526 °C days, respectively, and Yellowknife has 3476 and 1836 °C days, respectively.

The ground surface temperature depends on the type of ground cover, aspect and snow cover. During mine operation, PK will be deposited sequentially around the North Pile with each area receiving PK three or four times per year. Deposition of the warm PK will melt the snow cover in an area, and the full depth of snow cover will not be able to develop. Therefore, the surface temperature of the North Pile will be colder during the winter than the surface temperature where the snow cover is not removed. The effect of destroying the snow cover periodically during the winter is not included in the thermal model.

The effect of the snow cover was calculated by adding a layer of snow on the surface of the original ground surface in the thermal model. Snow layer thicknesses of 10, 25 and 50 cm were modeled. A uniform depth of snow was used for all freezing periods, the snow was not accumulated over the winter. The calculated surface temperatures for the three snow layer thicknesses are presented in Figure 4. These surface temperatures were applied to the original ground surface for a period of 10 or more years until the temperature regime was the same from year to year. The results were then compared to the thermistor results from the site.

The temperature distribution for the 10 cm snow layer provided the best fit with the site thermistors. The surface temperature distribution was then adjusted to produce a reasonable fit with the site measured temperatures by increasing the summer surface temperatures and also increasing the winter surface temperatures slightly. The surface temperature distribution that produced a reasonable fit with the site thermistors and was used in the PK deposition model is also shown on Figure 4. The calculated temperatures are compared to the site thermistors on Figure 5.

The computer program used for the analysis, TEMP/W, has recently (February 7, 2003) had a module added that allows the use of site weather data to calculate snow depth and ground surface temperature. This module was used with the 2001 site weather data to provide an estimate of the ground surface temperature. The 2001 site weather data includes hourly readings of temperature, relative humidity, wind speed and precipitation during the summer months. Snowfall and snow depth were not recorded at the site weather station.

For the thermal model, the mean monthly precipitation was used, with the precipitation applied in equal increments every 3 or 4 days. Calculations were done for a year starting on July 1, so that the full snow cover would be accumulated during the winter months. The daily average temperature for 2001 and the calculated ground surface temperatures are compared on Figure 6. The ground surface temperature calculated by the program is colder than the surface temperature calculated for a 10 cm snow layer during the early part of the winter, but similar to the 10 cm snow layer temperatures for the later parts of the winter.

The depth of snow calculated by the program is presented on Figure 7. The depth of snow at the end of the month calculated by the program is compared to the Canadian Climate Normals for Yellowknife and Fort Reliance climate stations in Table 1. The agreement between actual and calculated snow depths is good, except during the spring melt in April, at which time the program underestimates the rate of melting of the snow. Snow course surveys have also been carried out at Snap Lake in 1999, 2000 and 2001 at the end of March or the beginning of April. The open lake and upland areas had an average snow depth of 27 cm during these three years and the lowland areas had an average snow depth of 83 cm, showing the effect of drifting snow.

Table 1 Comparison of Calculated and Actual Month End Snow Depths (cm)

Station	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Fort Reliance	36	40	42	25	0	0	0	0	0	6	19	29
Yellowknife	33	38	37	6	0	0	0	0	0	7	21	27
Calculated for Snap Lake	32	37	42	45	0	0	0	0	0	5	16	26

4.0 THERMAL MODEL

A 1-D model was set up to evaluate the thermal performance of the PK paste deposited in the North Pile. The stratigraphy used in the model has a 2 m thick layer of sandy gravel mineral soil (till) overlying 4 m of fractured bedrock overlying intact granite bedrock.

The properties of the various materials used in the model are listed in Table 2.

Analyses were carried out with two sets of parameters for the paste PK: Set A with lower thermal conductivity values and Set B with higher thermal conductivity values. The unfrozen water content curve for the PK paste used in the model is the one used in the 2001 model because the laboratory testing was completed on February 6, 2003, which did not leave time for incorporating the curve in all of the model runs.

4.1 Surface Temperature

The surface temperature distribution used in the analyses is presented in Figure 4. In addition to using this temperature distribution, the effects of a single cold winter period (October through December) and a single warm winter period (October through March) were modeled using the PK paste Set A properties. In the cold and warm cases, the changed temperature was applied in the fifth year of deposition for a January start. The cold winter surface temperature was taken as the air temperature, the warm winter surface temperature was taken as the temperature distribution for 25 cm of snow.

After the completion of deposition, the model with each set of PK paste parameters was run for a period of 50 years using the surface temperature function. The PK paste parameters Set A was also run for a period of 50 years after the completion of deposition using a warmer surface temperature based on a 25 cm thick snow layer.

Table 2 Parameters used in the Thermal Model

Material	Dry Density (Mg/m^3)	Moisture Content by Weight (%)	Porosity (%)	Degree of Saturation (%)	Volumetric Water Content	Frozen Thermal Conductivity (W/m^oC)	Unfrozen Thermal Conductivity (W/m^oC)	Frozen Volumetric Heat Capacity ($MJ/m^{3o}C$)	Unfrozen Volumetric Heat Capacity ($MJ/m^{3o}C$)
Paste PK – Properties A	1.6	24	40	100	0.40	1.4**	1.15**	2.1	2.8
Paste PK – Properties B	1.6	33	48	100	0.48	2.6	1.4	2.0	3.0
Till	1.9	15	30	95	0.28	4.8	4.4	2.0	2.5
Fractured Granite Bedrock	2.1	10	20	100	0.2	4.8	4.4	2.4	2.9
Granite Bedrock	2.7	2	5	100	0.05	3.0	2.5	2.6	2.8

** Based on laboratory testing results by EBA.

4.2 PK Deposition

The PK paste deposition sequence was modeled as follows:

- 3 m of PK added each year for a 10 year period. This models either the East Cell or West Cell development.
- A 0.75 m layer of paste PK deposited during one month, followed by two months without deposition. Deposition in the model occurs in January, April, July and October.
- The PK paste was placed at a temperature of 10 °C during July deposition and at 5 °C for the other periods.
- Two deposition sequences were modeled: a January start to deposition and a July start to deposition for only the Set A parameters.
- The same surface temperature variation was used for each year, no allowance was made for climate warming. The destruction of the snow cover during deposition was not included in the model.
- After completion of deposition, the models were run for a period of 50 years using the same annual surface temperature function.

Sensitivity analyses were also run, looking at the effect of a single cold winter period (October through December) in the fifth year of deposition, and a single warm winter period (October through March) in the fifth year of deposition. Both sensitivity analyses used a July start of deposition.

5.0 RESULTS

The temperature profiles calculated at the end of the 10 year deposition period for both PK property sets are shown on Figure 8. For both property sets, only the portions of the PK deposited within the last two summers of operation are at or above 0 °C. The temperature change of recently deposited PK is shown on Figures 9 through 12 for PK with Set A properties and on Figures 13 through 16 for PK with Set B properties.

Figures 9 and 10 show the temperature change for PK deposited in January and July, and Figures 11 and 12 show the temperature change for PK deposited in April and October. The second figure in each set has an expanded temperature scale to more clearly show the freezing rate. For both property sets, the material deposited in January and October freezes completely in the first winter and the material deposited in April and July freezes completely in the second winter. Similar temperature changes happen for each layer of PK that is deposited.

The temperature profiles of the PK for periods up to 50 years following the end of deposition are shown on Figure 17. The figure shows that except for the active layer, the PK remains frozen, with the temperature gradually decreasing. After 50 years, the temperature has not reached an equilibrium state. Much of the PK remains at a temperature near -0.2 °C for decades.

The temperature profile calculated at the end of the 10 year deposition period for PK with Set A properties for the case with warm winter temperatures throughout the complete period of deposition is shown on Figure 18. Except for the PK deposition in the last year, most of the PK is at a temperature range of between –0.05 and –0.15 °C.

The effect of a single warm or cold winter does not persist past the next winter.

6.0 CONCLUSIONS

The results of the updated thermal model generally confirm the results of the 2001 thermal model. The unfrozen water content curve used for the paste PK in the 2001 model was confirmed by the laboratory testing carried out. The surface temperature distribution used in the 2001 model used slightly colder winter temperatures, but warmer summer temperatures. The geothermal flux at the site was estimated to be in the range of 0.04 to 0.08 W/m^2, an order of magnitude larger than that used in the 2001 model. The short term effect of the higher geothermal flux on freezing the PK is small because most of the heat in the PK is lost to the ground surface during winter. The paste PK freezes during the operating period, but remains at temperatures in the range of -0.15 to -0.3 °C for long periods.

The results of the thermal modelling of the North Pile that have been carried out indicate that for most conditions that can be expected over the operating period of each cell, most of the PK will be a temperatures just below 0 oC. There will be areas with PK at temperatures above 0 oC, but these cool and freeze during the following one or two winters. Some seepage is expected from the PK in the North Pile, but the rate of seepage will be controlled by the lower hydraulic conductivity of the material below 0 oC. EA predictions based on seepage estimates for unfrozen conditions will therefore be at the upper bound of conditions.

TLE/RS/cc
03-1322-017.5480

<u>Attachments</u>:

Figure 1 Unfrozen Water Content Characteristic Curves for Processed Kimberlite Paste
Figure 2 Grain Size Distribution Curves for Processed Kimberlite Paste
Figure 3 Temperature vs. Depth Curves for Processed Kimberlite Paste
Figure 4 Ground Surface Temperatures for 10, 25, and 50 cm Snow Layers
Figure 5 Thermal Model Calibration
Figure 6 Comparison of Daily 2001 Average Temperature and Calculated Ground Surface Temperature
Figure 7 Depth of Snow
Figure 8 PK Temperature After 10 Years of Deposition (January Start of Deposition)
Figure 9 PK Temperatures for January and July Deposition (PK with Set A Properties)
Figure 10 PK Temperatures for January and July Deposition (PK with Set A Properties) – Expanded Temperature Scale
Figure 11 PK Temperatures for April and October Deposition (PK with Set A Properties)
Figure 12 PK Temperatures for April and October Deposition (PK with Set A Properties) – Expanded Temperature Scale
Figure 13 PK Temperatures for January and July Deposition (PK with Set B Properties)
Figure 14 PK Temperatures for January and July Deposition (PK with Set B Properties) – Expanded Temperature Scale
Figure 15 PK Temperatures for April and October Deposition (PK with Set B Properties)
Figure 16 PK Temperatures for April and October Deposition (PK with Set B Properties) – Expanded Temperature Scale
Figure 17 PK Temperatures after Completion of Deposition (Temperature Profile for End of December)
Figure 18 PK Temperature at the End of Deposition Period (Warm Winter Temperature during Deposition Period)

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FIGURE ATTACHMENTS

Figure 1 **Unfrozen Water Content Characteristic Curves for Processed Kimberlite Paste**

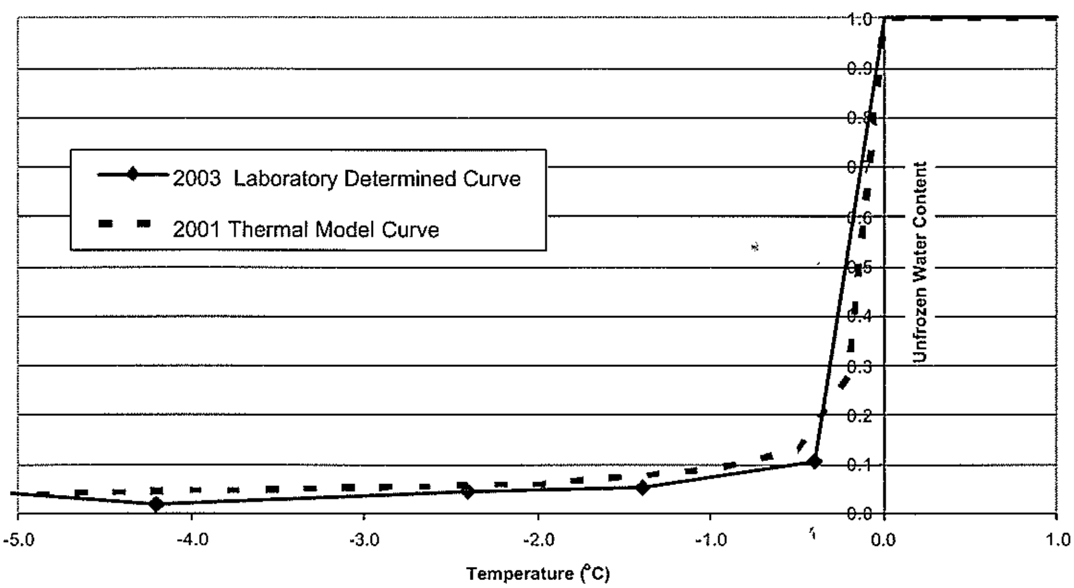

Figure 2 **Grain Size Distribution Curves for Processed Kimberlite Paste**

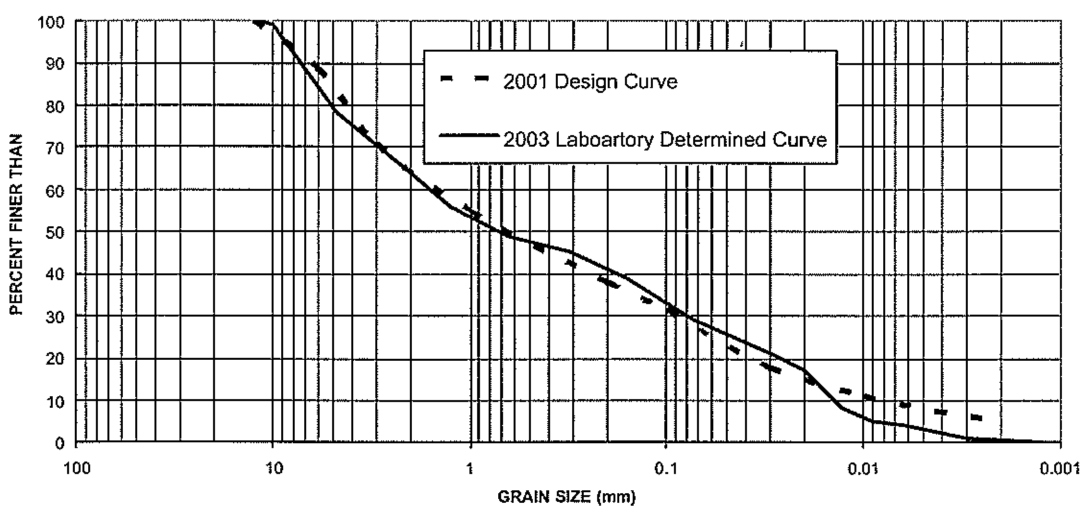

Figure 3 Temperature vs. Depth Curves for Processed Kimberlite Paste

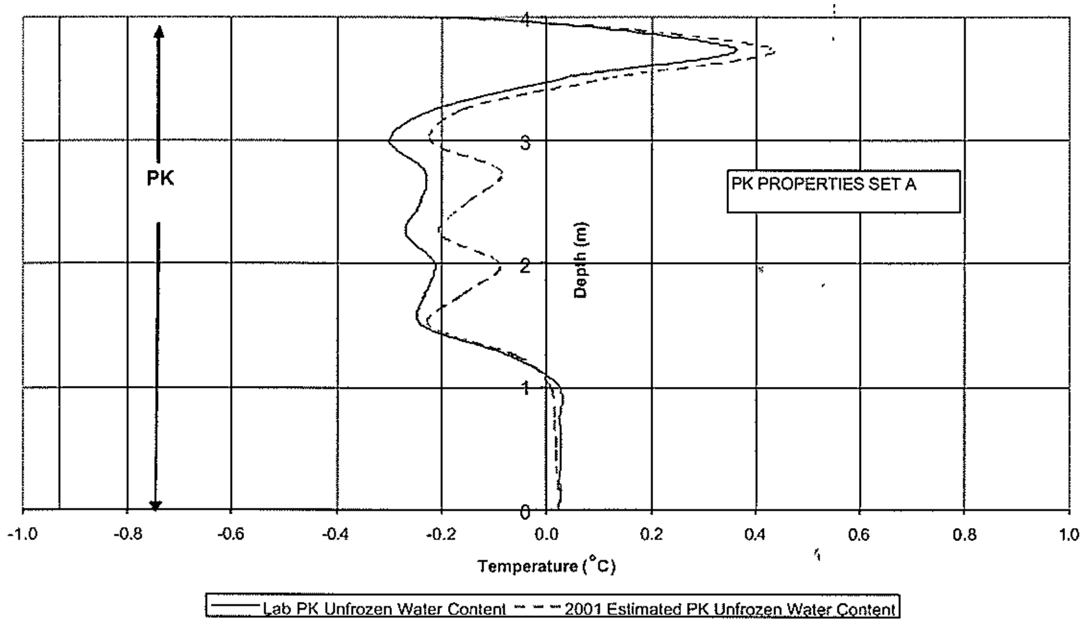

Figure 4 Ground Surface Temperatures for 10, 25, and 50 cm Snow Layers

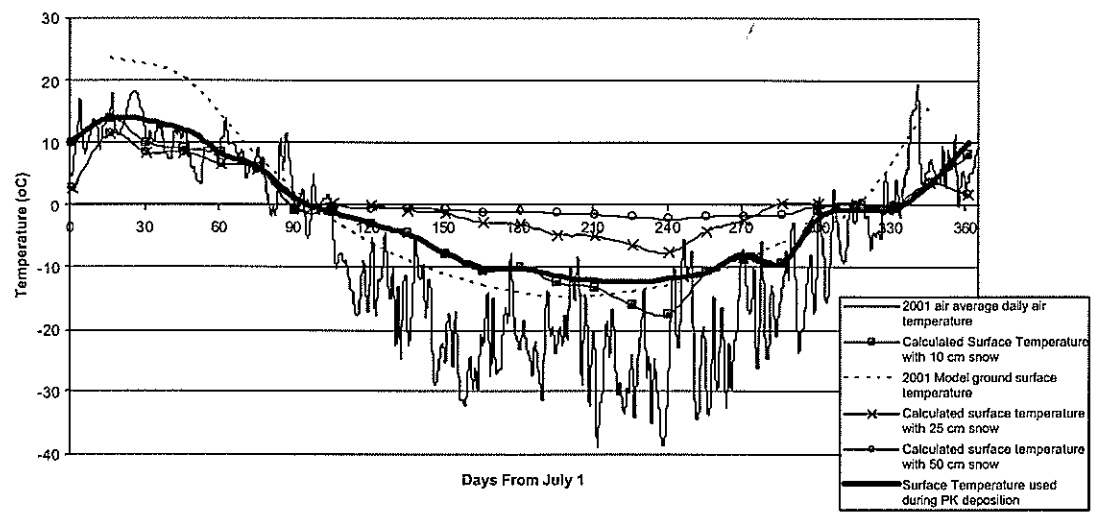

Figure 5 Thermal Model Calibration

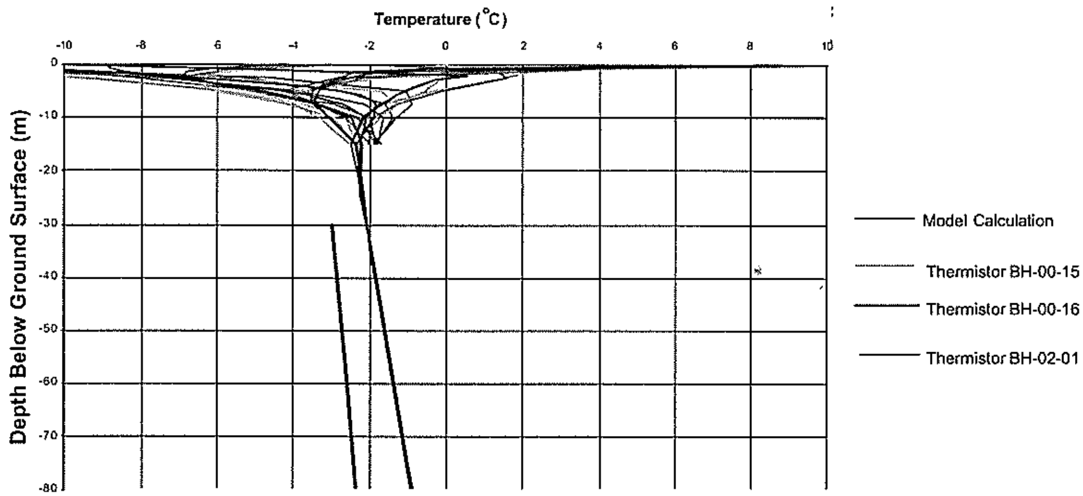

Figure 6 Comparison of Daily 2001 Average Temperature and Calculated Ground Surface Temperature

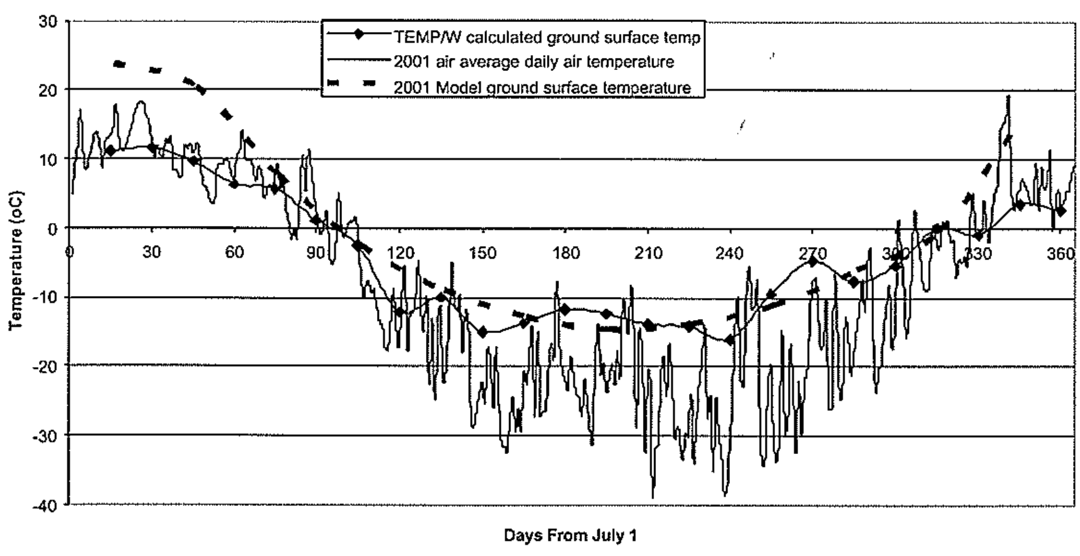

Figure 7 **Depth of Snow**

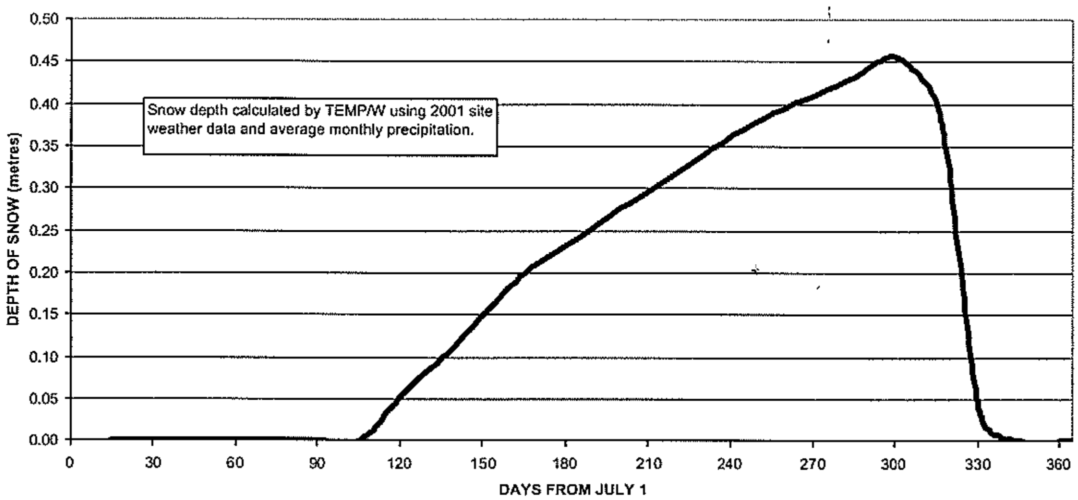

Figure 8 **PK Temperature After 10 Years of Deposition (January Start of Deposition)**

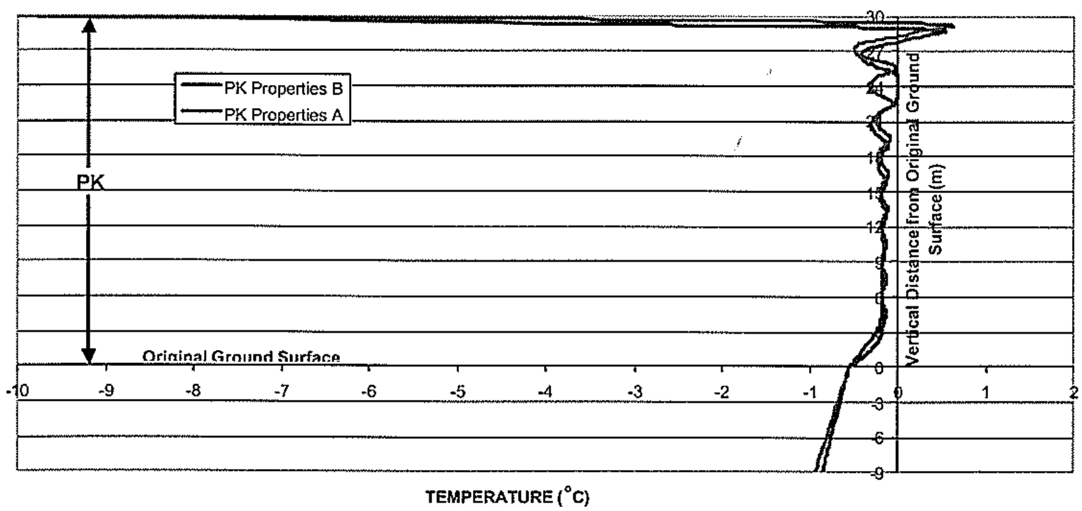

Figure 9 **PK Temperatures for January and July Deposition (PK with Set A Properties)**

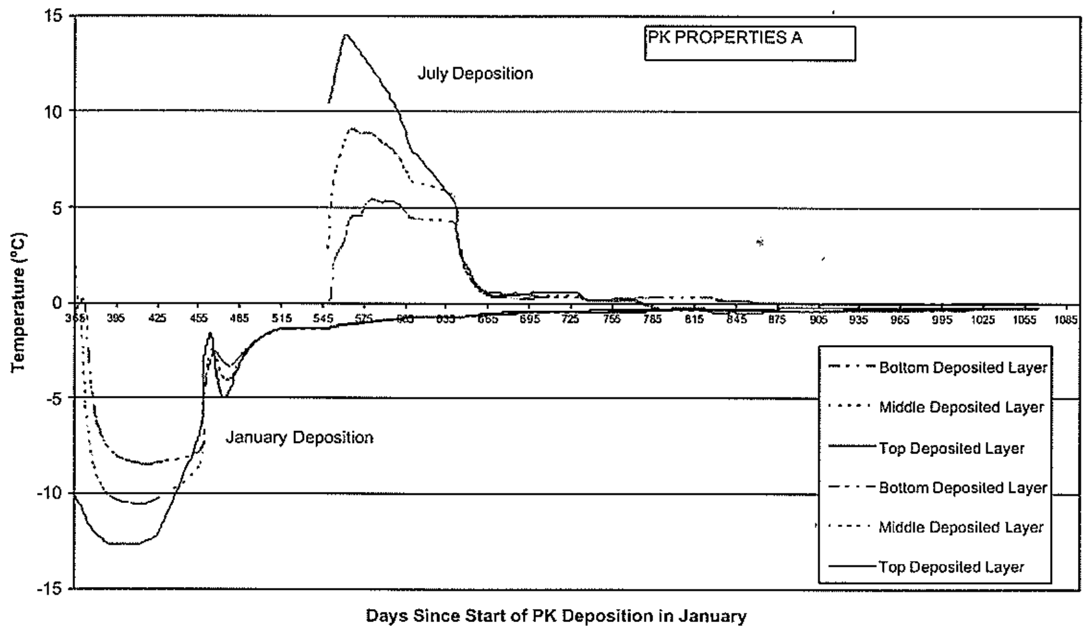

Figure 10 **PK Temperatures for January and July Deposition (PK with Set A Properties) – Expanded Temperature Scale**

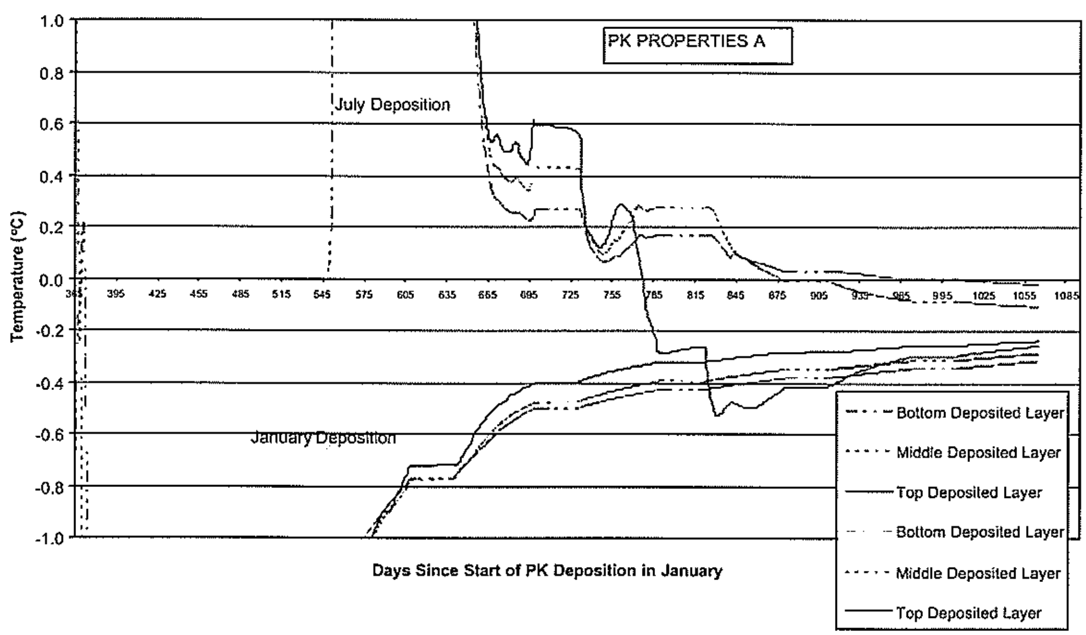

Figure 11 **PK Temperatures for April and October Deposition (PK with Set A Properties)**

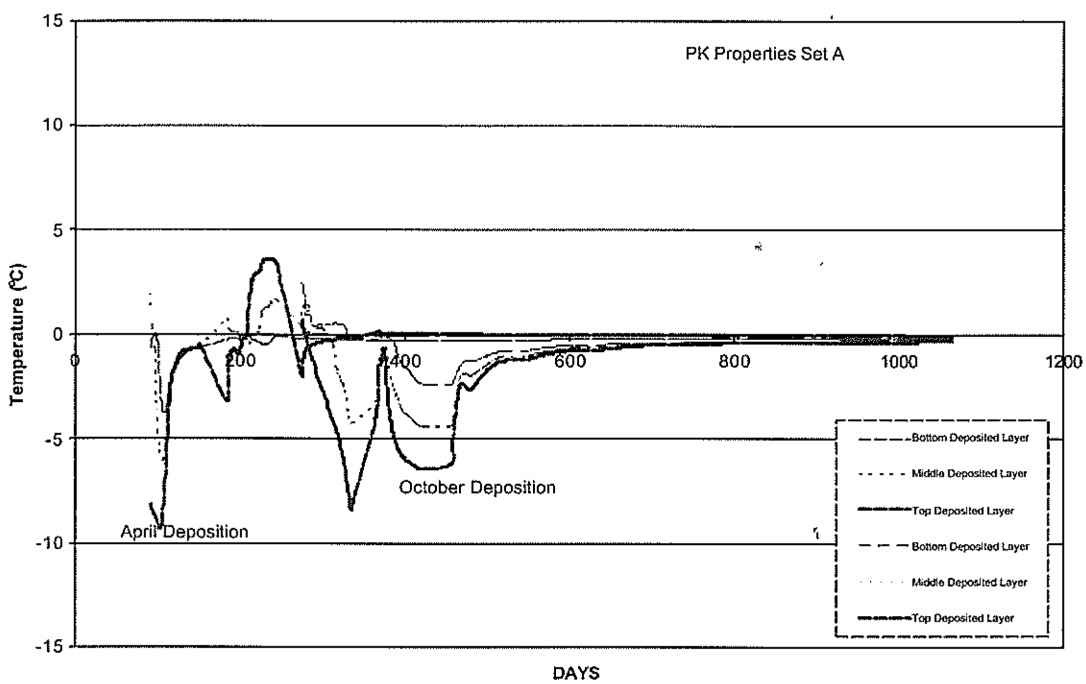

Figure 12 **PK Temperatures for April and October Deposition (PK with Set A Properties) – Expanded Temperature Scale**

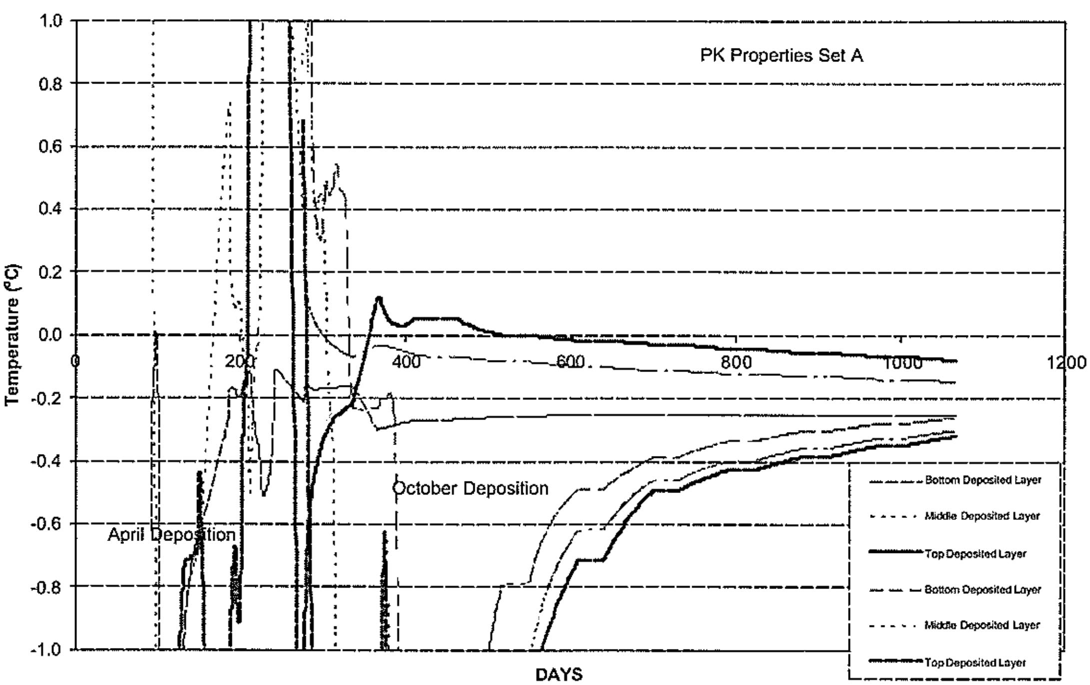

Figure 13 **PK Temperatures for January and July Deposition (PK with Set B Properties)**

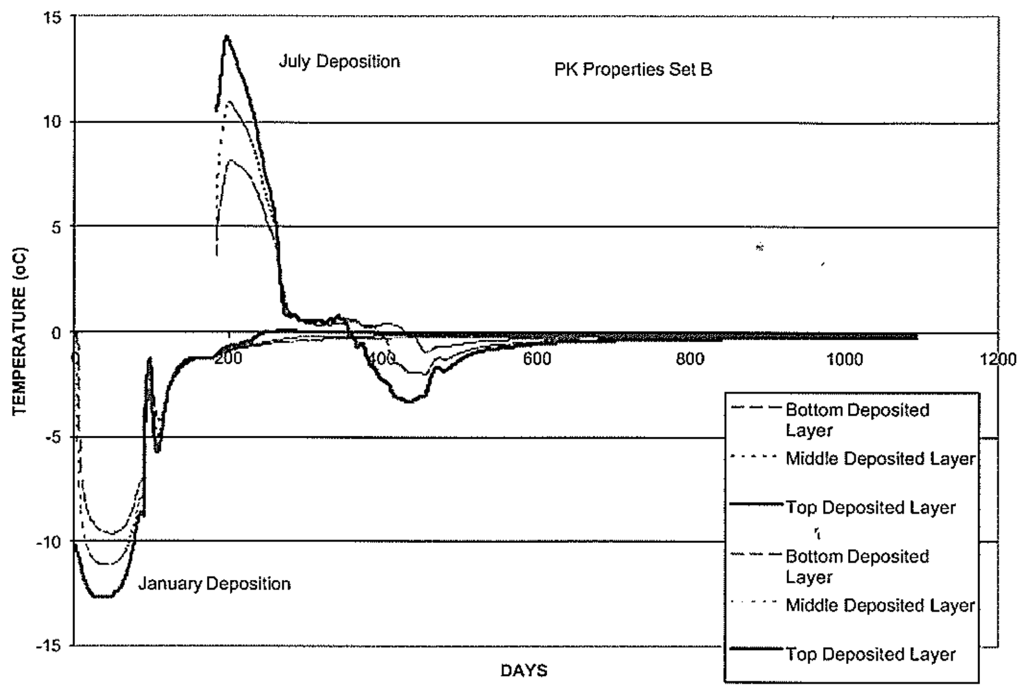

Figure 14 **PK Temperatures for January and July Deposition (PK with Set B Properties) – Expanded Temperature Scale**

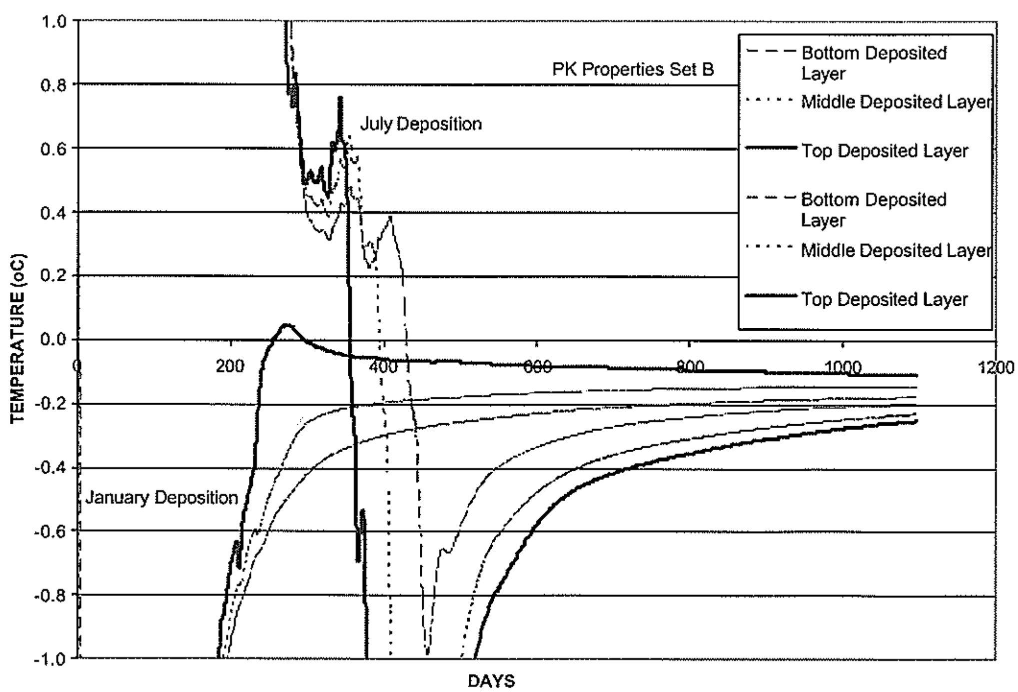

Figure 15 **PK Temperatures for April and October Deposition (PK with Set B Properties)**

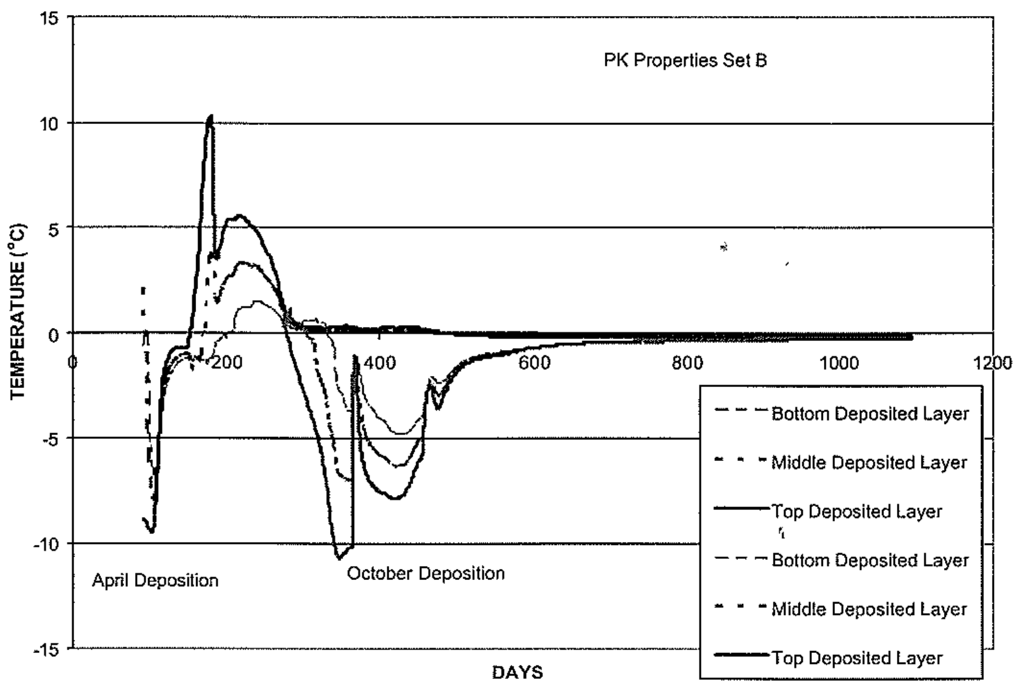

Figure 16 **PK Temperatures for April and October Deposition (PK with Set B Properties) – Expanded Temperature Scale**

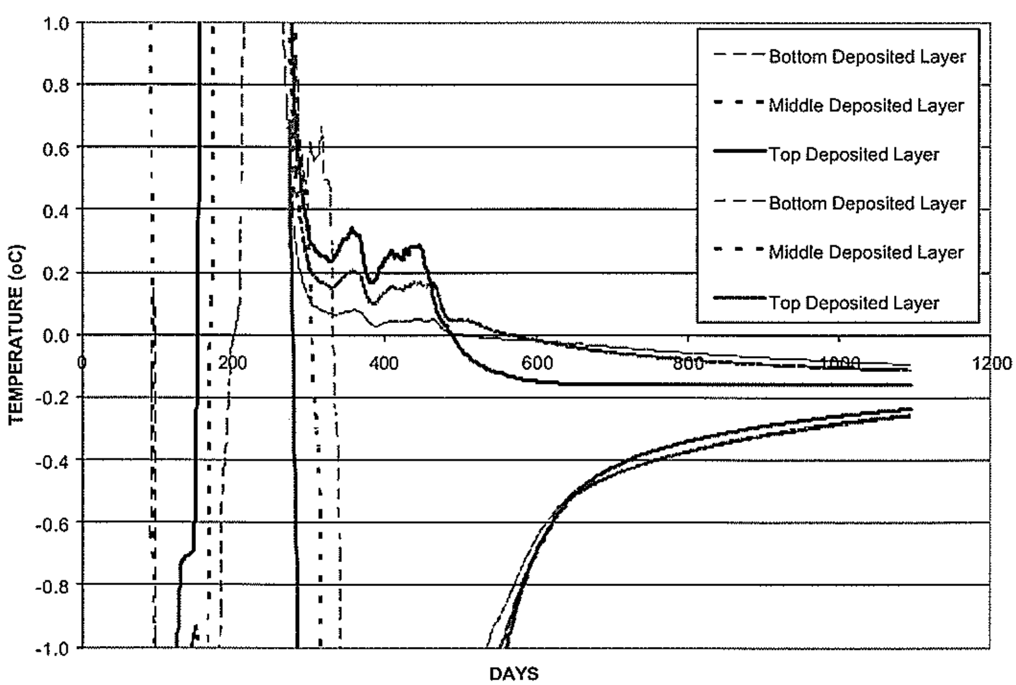

Figure 17 **PK Temperatures after Completion of Deposition (Temperature Profile for End of December)**

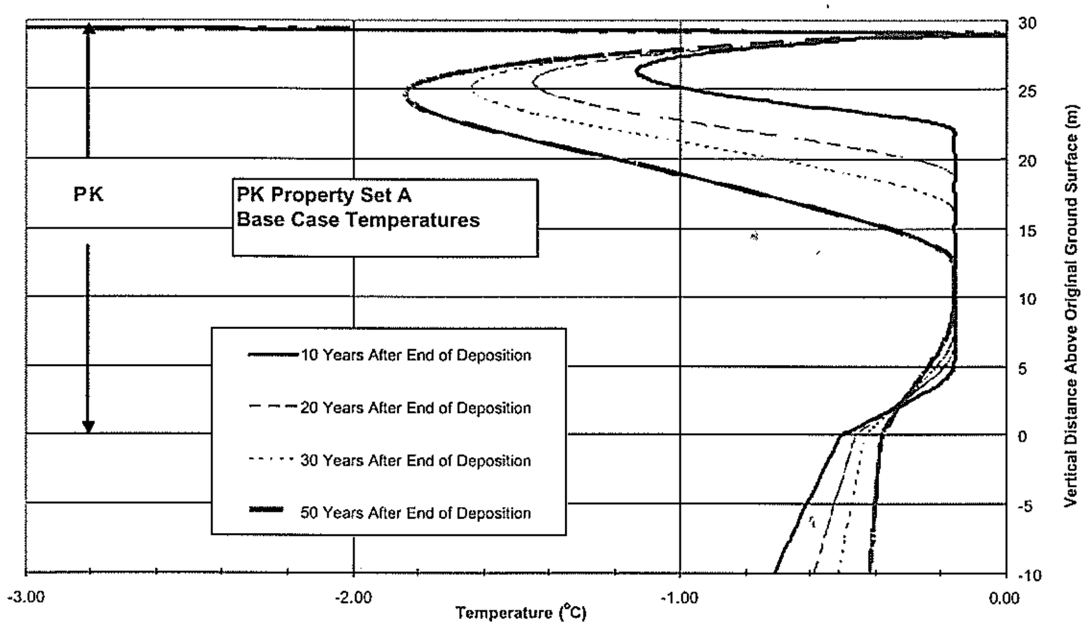

Figure 18 **PK Temperature at the End of Deposition Period (Warm Winter Temperature during Deposition Period)**