PMIC
MODEL MI-900
Data Analysis Guide

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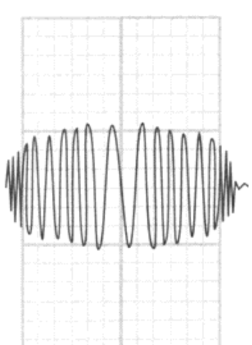

PMIC

MI-900 Documentation

The following documentation[1] is provided for this product:

- ❑ PMIC Model MI-900 Installation and Operator Guide (PMI-900-710)
- ❑ PMIC Model MI-900 Troubleshooting Guide (PMI-900-720)
- ❑ PMIC Model MI-900 CTE Analysis and Troubleshooting Guide (PMI-900-730)
- ❑ PMIC Model MI-900 Limited Warranty and System Components (PMI-900-740)

[1] The documentation for MI-900 is available on CD (PMI-900-700).

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Chapter 1. Introduction

As specialists in thermophysical and micromechanical measurements, PMIC is ready to meet your dimensional stability and thermo-mechanical measurement needs. We feature a variety of testing services ranging from thermal expansion (CTE), moisture expansion (CME), thermal conductivity (TK), mechanical properties, optical properties and non-destructive testing. PMIC offers custom development and design of instruments and applied research to a variety of industries.
Please visit our Web site at **http://www.pmiclab.com/**.

MI-900
The MI-900 employs Michelson laser interferometry to measure real time thermal expansion/contraction for maximum resolution and accuracy. Each shift in a fringe pattern corresponds to a change in specimen length of one-half the laser wavelength (12.456 micro-inches for a He-Ne laser in vacuum). Precision optics, photo detectors and interpolation techniques produce length resolution accuracy within less than three micro inches.

SPECIFICATIONS

Resolution	0.03 ppm/°F
Temperature Range	30K-420K
Specimen Size Maximum	2"X7"X0.5"
Lab Control Software	LABVIEW CTE Test Program: MI-900 executable

The MI-900 Data Analysis Application
This application provides a set of tools for:
- Data quality assessment
- Data selection
- CTE computation
- Error computation
- Preparing reports

Prerequisites
Environment:
The CTE Data Analysis program requires MS Windows® 98 or higher and MS Office® 2000 with MS Excel® 2000 spreadsheet program.

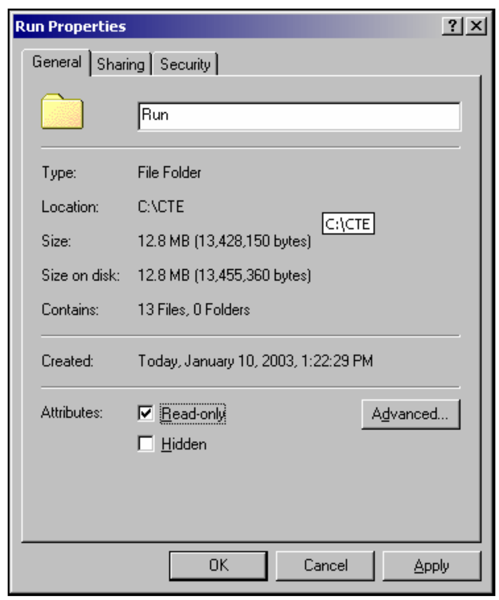
IMPORTANT: These programs require the location of the Excel program to have the following path:
C:\Program Files\Microsoft Office\office\excel.exe

Analyst Skill Level:
This manual assumes that the user has a general engineering or mathematical background and fundamental MS Windows and Excel spreadsheet skills.

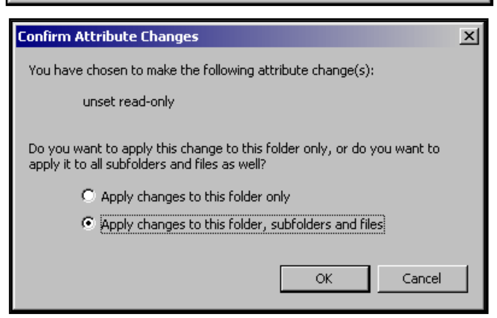
About this Guide
This Guide teaches the mechanics of analyzing MI-900 data using the CTE Data Analysis application. It provides guidelines and examples, but only practice can confer analytic expertise.
The documentation for MI-900 is available on CD (PMI-900-700).

Chapter 2. Installation

1. Create a CTE folder on your C[2] drive:
   C:\CTE\
2. Copy the application to the CTE folder:
   a. Place the Data Analysis installation disc in the CD drive.
   b. Copy or drag the Run directory from the CD to the CTE folder: C:\CTE\Run
3. Remove the *read-only* restriction from Run files, as follow:
   a. Open the **C:\CTE** folder.
   b. Select the **Run** folder.
   c. Use the menu **File: Properties** (or right click and choose **Properties**).
   d. Uncheck **Read-only** in the Attributes section of the Run Properties window.
   e. Click **OK**.



   f. In the Confirm Attribute Change window, click **Apply changes to this folder, subfolders and files.**
   g. Click **OK**.



[2] This is not optional. The analysis programs must be installed on the C drive, as described.
IMPORTANT: These programs require the Excel program to have the following path:
C:\Program Files\Microsoft Office\office\excel.exe

4. Create a data folder in CTE[3].
C:\CTE\data
This where your raw data files

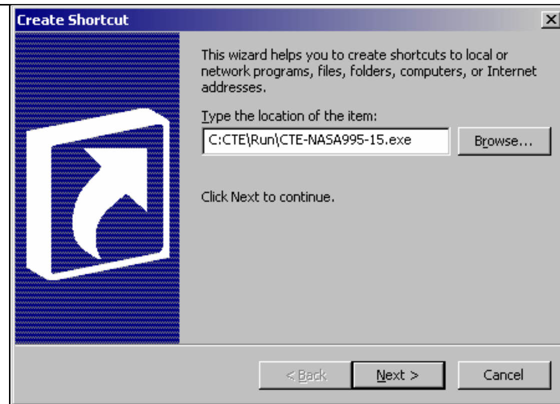
5. Create shortcuts for the CTE analysis program and/or the Review Data program on your Windows desktop. For example:

a. On the desktop, right click and choose **New: Shortcut**

b. In the **Create Shortcut** window, type the location of the item:
C:CTE\Run\CTE-NASA995-15.exe

(Or click **Browse** to locate this file.)

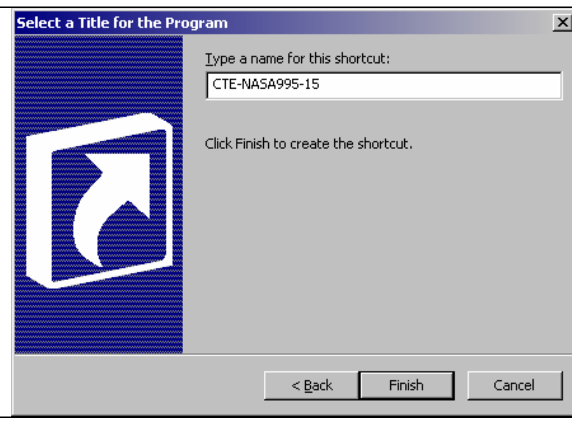
c. Click **Next**



d. In **Select a Title for the Program**, type a convenient name for the shortcut.

e. Click **Finish**

f. Repeat this step for the other program (**review data -NASA995-15.exe**), if you need it on this computer.



This completes installation.

[3] The data folder can be created in another location if you prefer.

Chapter 3. CTE Data Analysis

The CTE Analysis program computes the coefficient of thermal expansion in parts per million. The program takes as input a raw data file containing all the lab data generated during testing[4].
Output is in the form of Excel spreadsheets.
Use the CTE Analysis program and spreadsheets to:

- Assess data validity.
- Select which data to use.
- Generate graphs and reports.

<u>Preparation:</u>
Before you begin, ensure that:

- The CTE-NASA995-15.exe program has been properly installed (See page 5).
- The raw data test file is accessible from your computer.

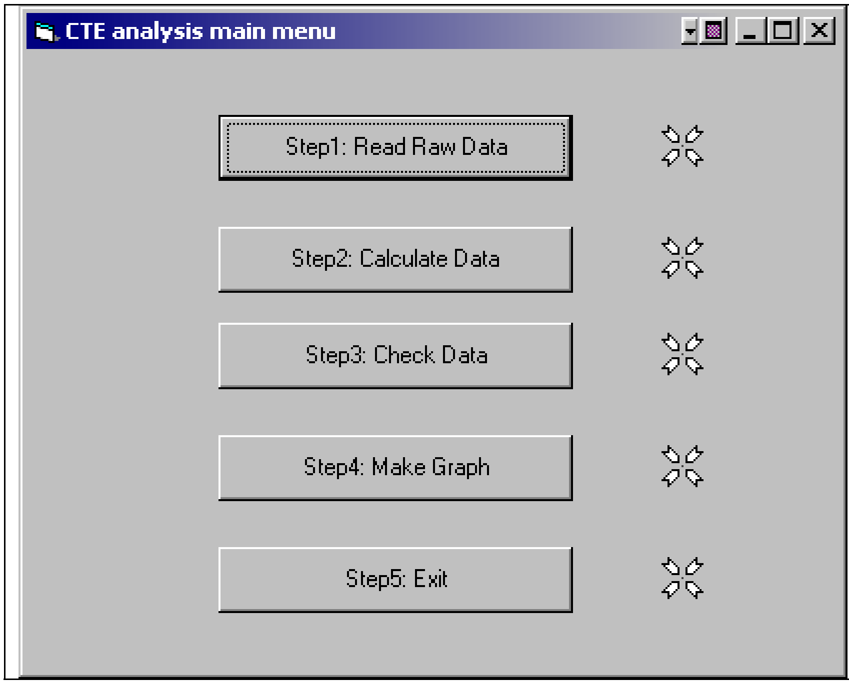
Running the Program
To use this program:

❑ Click the CTE-NASA995-15 program icon to start the program

NOTE: Analyzing the test data is an iterative process. The number of iterations depends upon the quality and quantity of data, and, most importantly, on the expertise of the analyst.

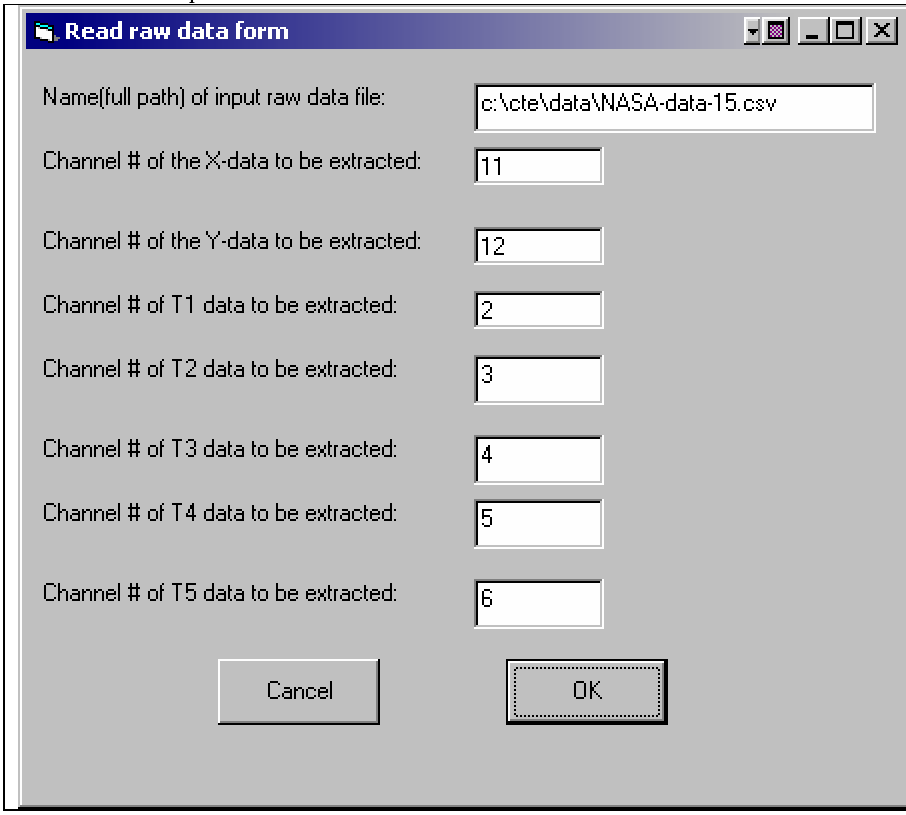
[4] Raw data is captured on 15 data channels, as follows:

Columns A-G contain date and time information.
Corresponding data logged for each data channel follows.
CH 1 is recorded room temperature.
Ch 2 - Ch 4 are Thermocouple data, specimen 1.
Ch 5 – Ch 6 are Thermocouple data, specimen 2.
CH 7 – Inner Heater Temperature
CH 8 – Outer Heater Temperature
Ch 9 – Si Diode data (voltage) data
CH10 is Set point.
CH 11 – CH 12 are Specimen 1 beam displacement data, X and Y respectively.
CH 13 – CH 14 are Specimen 2 beam displacement data, X and Y respectively.
Ch 15 is Pressure data.



This window remains open as you work. As you proceed through the steps, a star icon appears only after the most recent step completed. Later, if necessary, you can return to this window and click a selection to repeat the step.

❑ Click **Step 1**: **Read Raw Data**



- ❑ Enter the raw data-file name (complete path).
- ❑ Enter the channel numbers for the x and Y displacement data. Enter 11 and 12 for specimen 1. Or enter 13 and 14 for specimen 2.
- ❑ Enter five temperature channel numbers[5].
- ❑ Click **OK**.

The raw data file may be very large. The following steps judiciously select a subset that gives meaningful output without excessive processing.

Good data selection may require some iteration.

Note A. This program can handle up to 64,000 data lines.[6] If you specify more than that for any operation, an error occurs. See Appendix B.

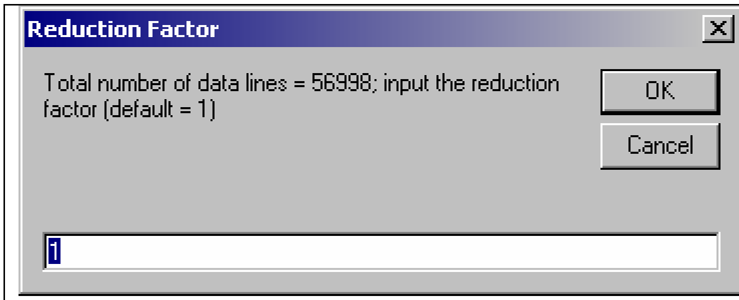
You can reduce the size of a very large file in these ways:

- o Enter a reduction factor, *n*, so that only every *n*th point is selected.
- o Analyze the data in segments, that is, specify a limited range of points. Repeat the analysis for each subsequent range.
  Example: Suppose the raw data file has 192000 data points. Do three separate analyses, with three ranges as follows:
  - 1 – 64000
  - 64001 – 128000
  - 128101 - 192000

[5] **Important:** If thermocouples are the only specimen sensors used, accept the default values shown (2,3,4,5 and 6) for T1-T5.

If the Silicon Diode (T9) is used: Enter T1=9. Enter any 4 of the other thermocouple data channels (2,3,4, or 5) for T2-T5, preferably, including the thermocouple closest to the Si Diode for calibration purposes. In general the Si Diode is more precise than the thermocouples at room temperature and below.

[6] A *data line* contains all the data collected at one data point. A *data point* represents a point in time at which data is recorded. There is one data line for every raw data point.

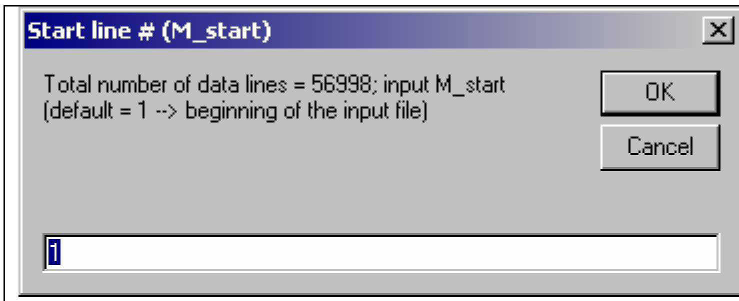


If number of data lines is < 64,000, accept the default, 1. This selects the entire data file.

If the number of data lines is more than 64,000, **see Note A.**

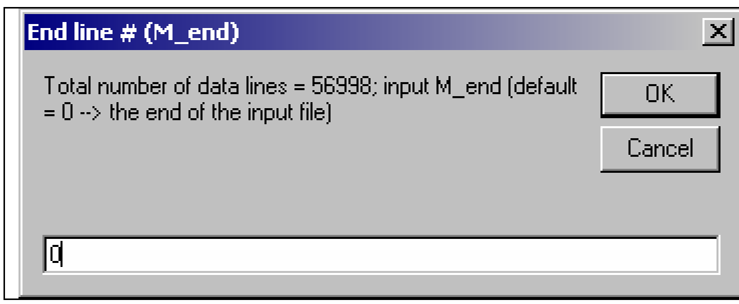
You can reduce the sample size by entering a reduction factor greater than 1. E.g., for a file of 120,000 data lines enter 2 to select 60,000 lines.

- ☐ Enter a reduction factor.
- ☐ Click **OK**.



Breaking data into segments is a troubleshooting technique. In most cases, you should accept the default here, M_start=1.
To specify a segment, set M_start to the number of the first data line in the segment you want to analyze.

- ☐ Enter the number of the segment start point.
- ☐ Click **OK**.

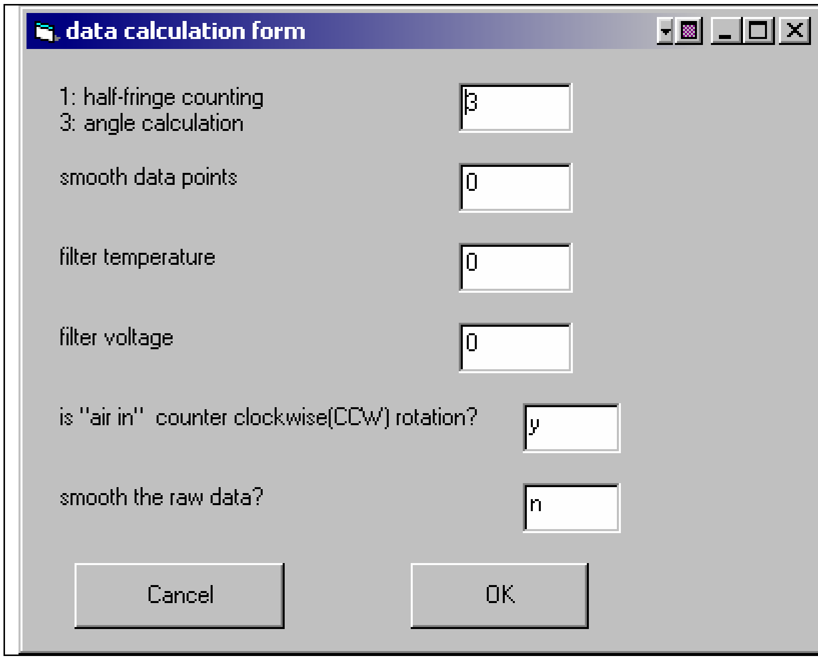


In most cases, you should accept the default M_end=zero, which takes in all data to the end of the file.
Specify the end of a segment by setting M_end to the number of the last data line in the segment.

- ☐ Enter the number of the segment end point.
- ☐ Click **OK**.

Allow time for processing. When complete, a star icon appears after **Step 1** on the main program menu.

- ☐ Click Step 2: Calculate data.

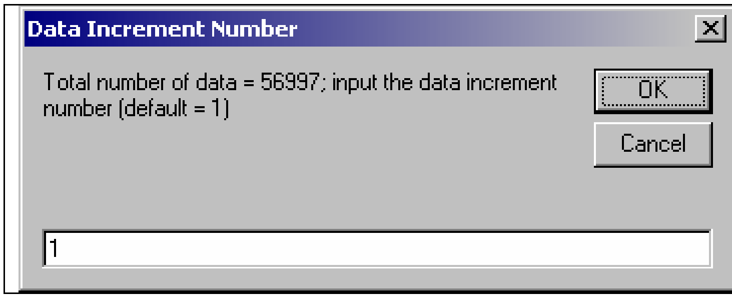


- ❑ Enter the data calculation parameters.

Note: In most cases, the default values shown give the best results. Options are used for troubleshooting.

- ❑ Check to see that “air in” was recorded with CCW rotation. If not, enter “n.”
- ❑ Click **OK**.

Allow time for processing.



First iteration, accept the default=1, to analyze every data line.
For subsequent iterations:

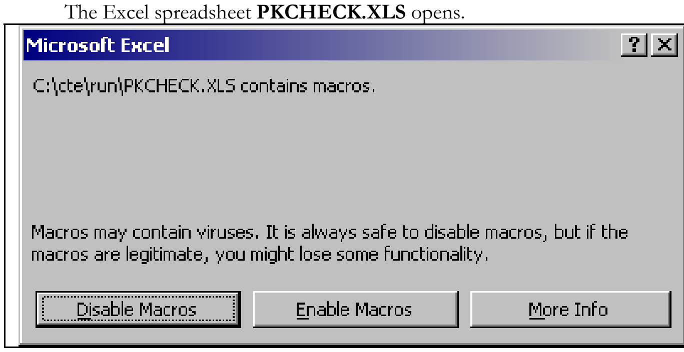
- To reduce the number of selected data points, enter a larger number.
- To increase the number, enter a smaller increment than on the previous iteration.

- ❑ Enter the data increment.
- ❑ Click **OK**.

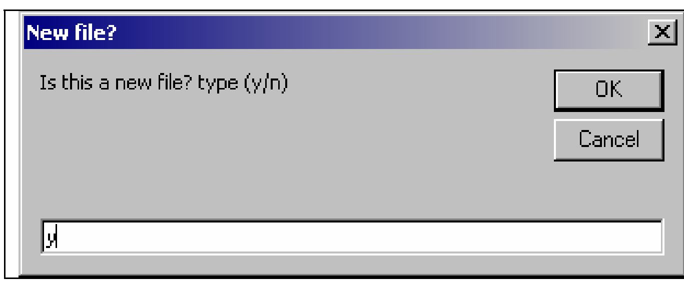
Allow time for processing. When complete, the star icon appears after step 2 on the main menu.

- ❑ Click **Step3: Check Data.**

The Excel spreadsheet **PKCHECK.XLS** opens.



- ❑ Click **Enable Macros**.



- ❑ On the first iteration, accept the default. **Y**. If you are repeating this step, enter **N**.
- ❑ Click **OK**.

Allow processing time. When processing is complete **Ready** appears in the lower left corner of the PKCHECK spreadsheet.
The PKCHECK spreadsheet file has these tabs (See Figure 1):

- **Sheet 1** (Figure 1) contains all the raw data.
- **Ellipse** (Figure 2) contains a plot of voltages from the photo detector, x and y components of the laser beam.
- **Chart 1** (Figure 3) graphs temperature and voltage vs. data points 1-16000.
- **Chart 2** graphs temperature and voltage vs. data points 16001-32000, if any.
- **Chart 3** graphs temperature and voltage vs. data points 32001-48000, if any.
- **Chart 4** graphs temperature and voltage vs. data points 48001-64000, if any.

	A	B	C	D	E	F	G	H
1		raw data			selected data			
2	data point	temperatur	x-data	y-data	data point	x-data	temperatur	fringe
3	56997	56997	56997	56997	11399	11399	11399	11399
4	1	72.81	0.723836	1.39274	6	0.979456	72.82	-0.48233
5	2	72.81	0.727711	1.41308	11	0.978091	72.91	-0.00263
6	3	72.81	0.979337	1.68793	16	0.973657	72.93	-6.05E-03
7	4	72.81	0.979151	1.67802	21	0.974429	73.04	-1.48E-03
8	5	74.14	0.977345	1.67066	26	0.975389	73.17	-3.24E-03
9	6	72.82	0.979456	1.67988	31	0.968863	73.53	-1.55E-02
10	7	72.82	0.982566	1.70108	36	0.97121	73.71	-5.75E-03
11	8	72.88	0.982086	1.69391	41	0.970562	73.96	-5.39E-03
12	9	72.81	0.979667	1.68784	46	0.95831	74.21	-2.40E-02
13	10	72.73	0.980381	1.68315	51	0.940412	74.39	-4.66E-02
14	11	72.91	0.978091	1.67117	56	0.930418	74.66	-2.46E-02
15	12	72.82	0.974456	1.65326	61	0.881697	74.8	-0.14562

Chart 2 (32000) / Chart 3 (48000) / Chart 4 (64000) / ellipse / **Sheet1**

Ready

Figure 1. **PKCHECK: Sheet 1. Raw and Selected Data.**
Row 3 (A-D) tells how many data points are in the raw data. These columns contain values for temperature plus x and y beam-component data.
Row 3 (E-H) tells how many points were used in calculations for the graph.

In the above example, the data increment was 5. Column E lists the selected data points. Columns F and G contain test data for selected points. Other columns contain computation values.

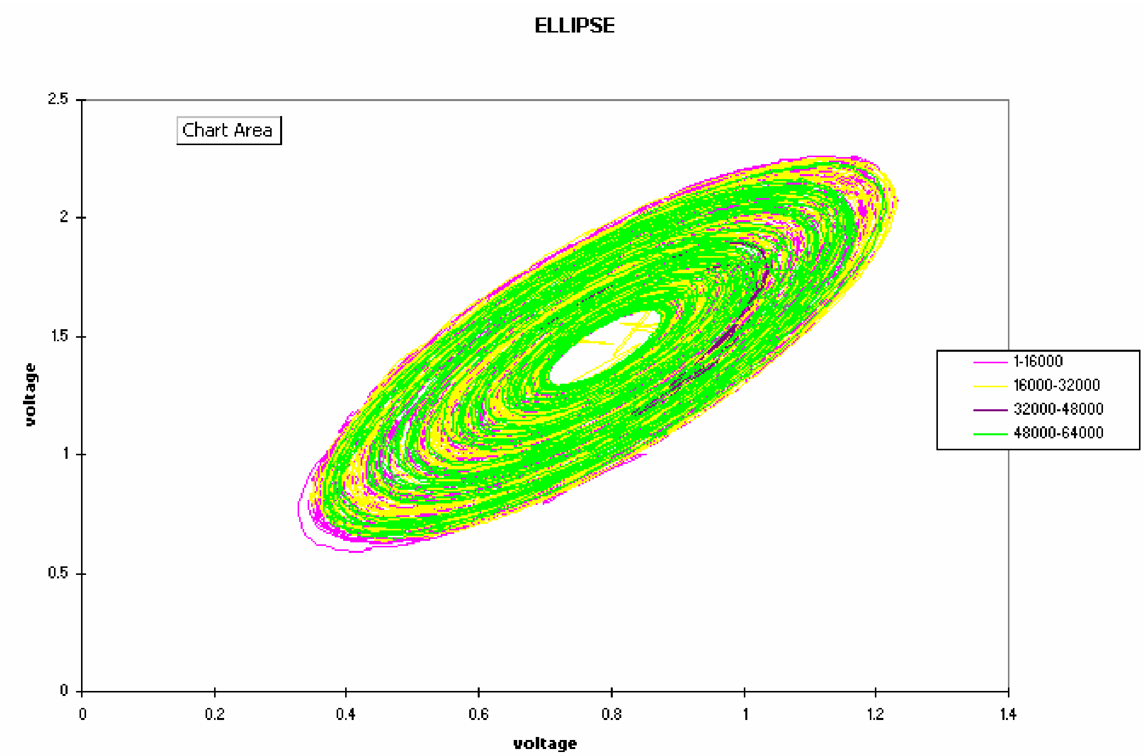


Figure 2. **PKCHECK: Ellipse.**
Look for a stable, concentric ellipse with a clear opening at the center. An ellipse like this one indicates valid data.

Any aberration, such as frequent bending, failure to paint around a consistent center, scattered circles or erratic lines suggest faulty data. If this occurs, refer to Troubleshooting.

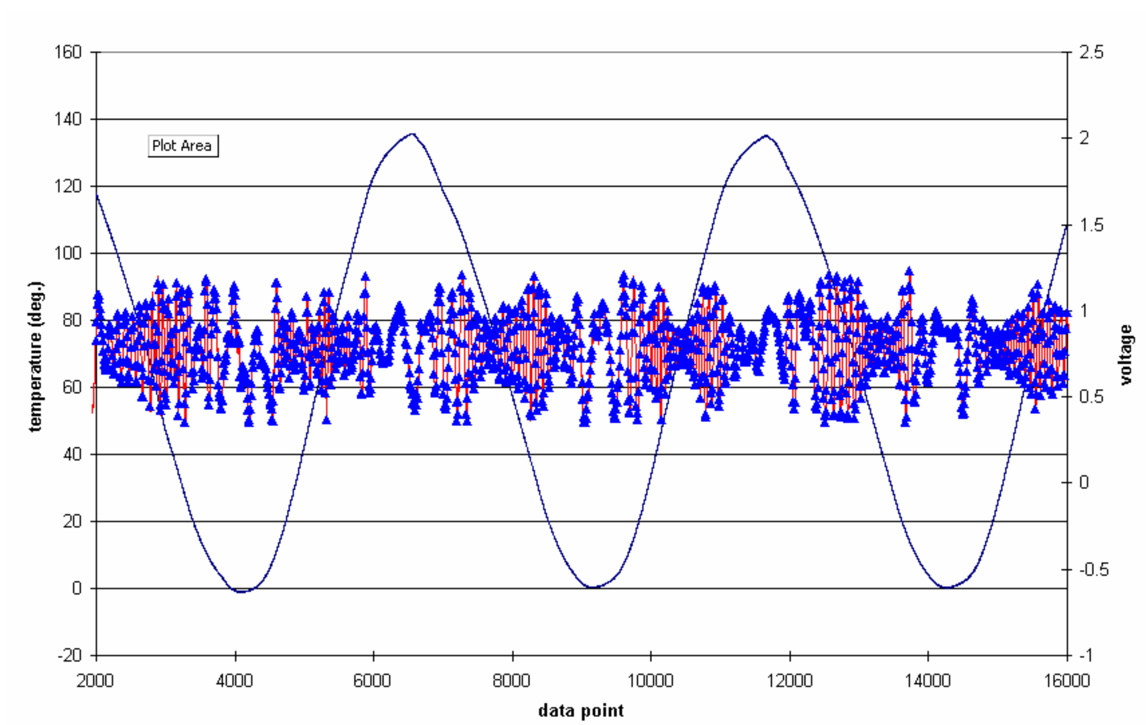
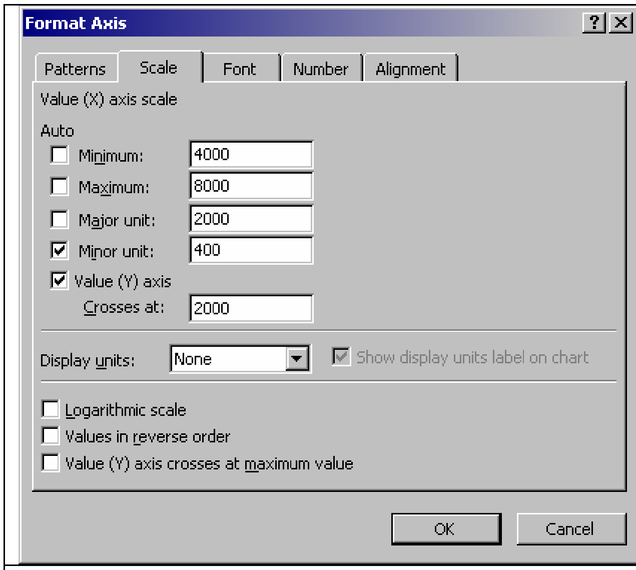


Figure 3. PKCHECK: Chart 1 (1-16000)

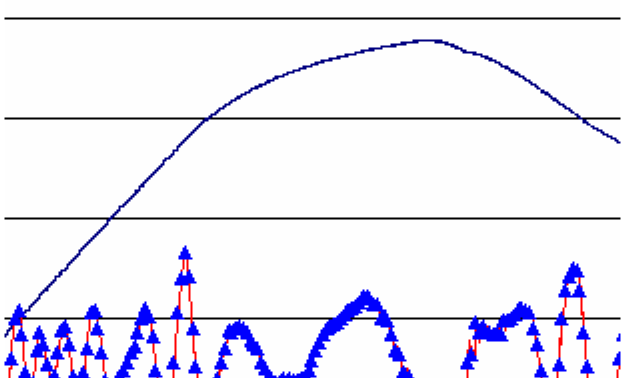
Temperature (°C) and displacement (voltage) are plotted against data points 2000-16000. Temperature is the blue sinusoidal line. Voltage is the red line representing raw data. The dots (▲) are the selected data points. (Charts 2, 3, 4 are similarly plotted for their respective data point ranges.)

This graph provides preliminary assessment of the data sample.
Examine Chart 1 to assess the data selection. Look for a plentiful, but not excessive, distribution of data points on each temperature cycle. See Note B. (Do the same for Charts 2, 3, and 4, if applicable)

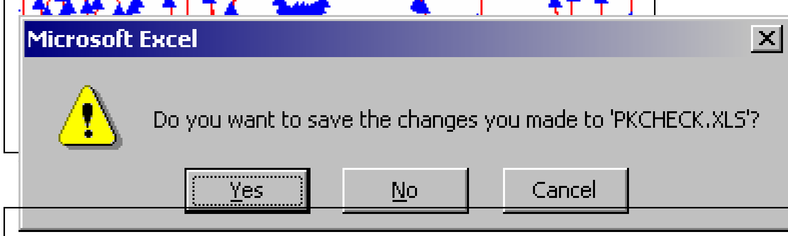
Note B. To examine a segment of the Chart 1 graph in detail, double click the X Axis and adjust the scale in the Format Axis window:



In this example the horizontal axis (initially 2-16000) is adjusted to examine data points 4000-8000, by changing the Minimum and Maximum X values.
Click **OK** to see the result.



In this example, the resulting detail of the graph shows a generous distribution of selected data points over the raw data.
Ideally from 5 to 20 selected data points lie between each pair of peaks in the raw data.
If you have too many or too few, change the increment and do another iteration. See Appendix B.
To adjust the Data Increment, go back to the **CTE Analysis Menu** and click **Step 2. Calculate Data**.

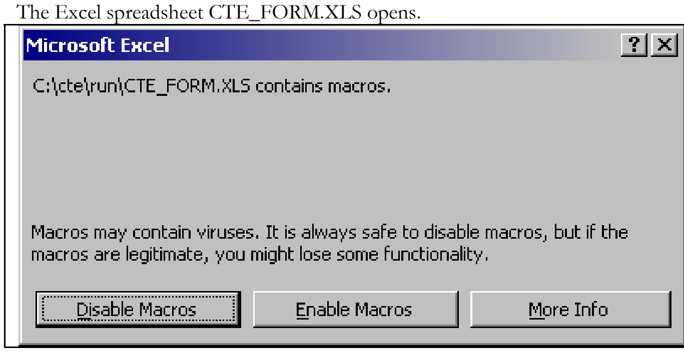


go to the next step.
Click **No**[7].

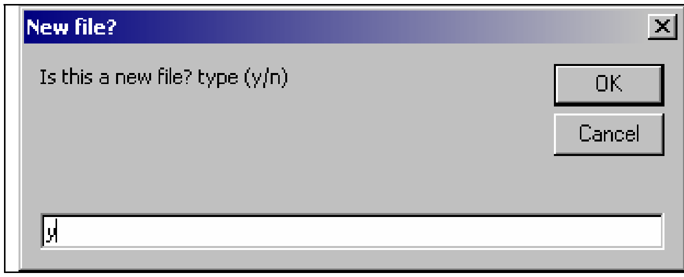
[7] **IMPORTANT.** PKCHECK.XLS is a calculation template with programmed formulas. **Never save it**. If you want to save this result, use the menu **File: Save as**.

- ☐ Click **Step 4. Make Graph**.

The Excel spreadsheet CTE_FORM.XLS opens.

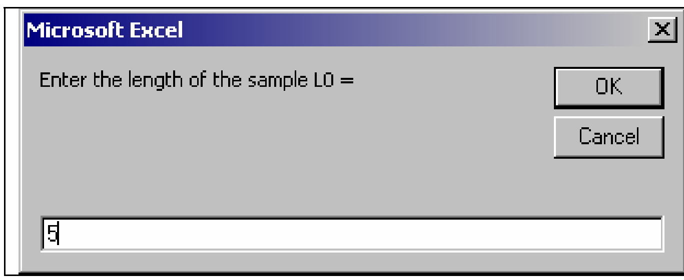


- ☐ Click **Enable Macros**.

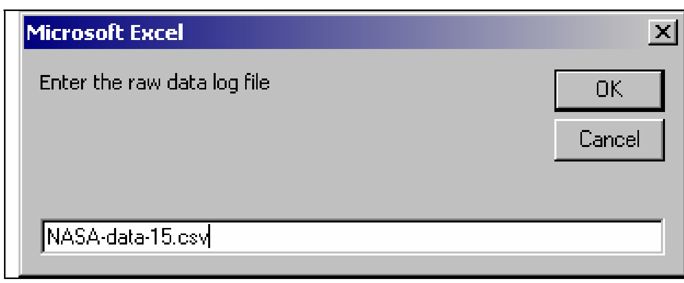


The default is Y.

- ☐ Click **OK**.

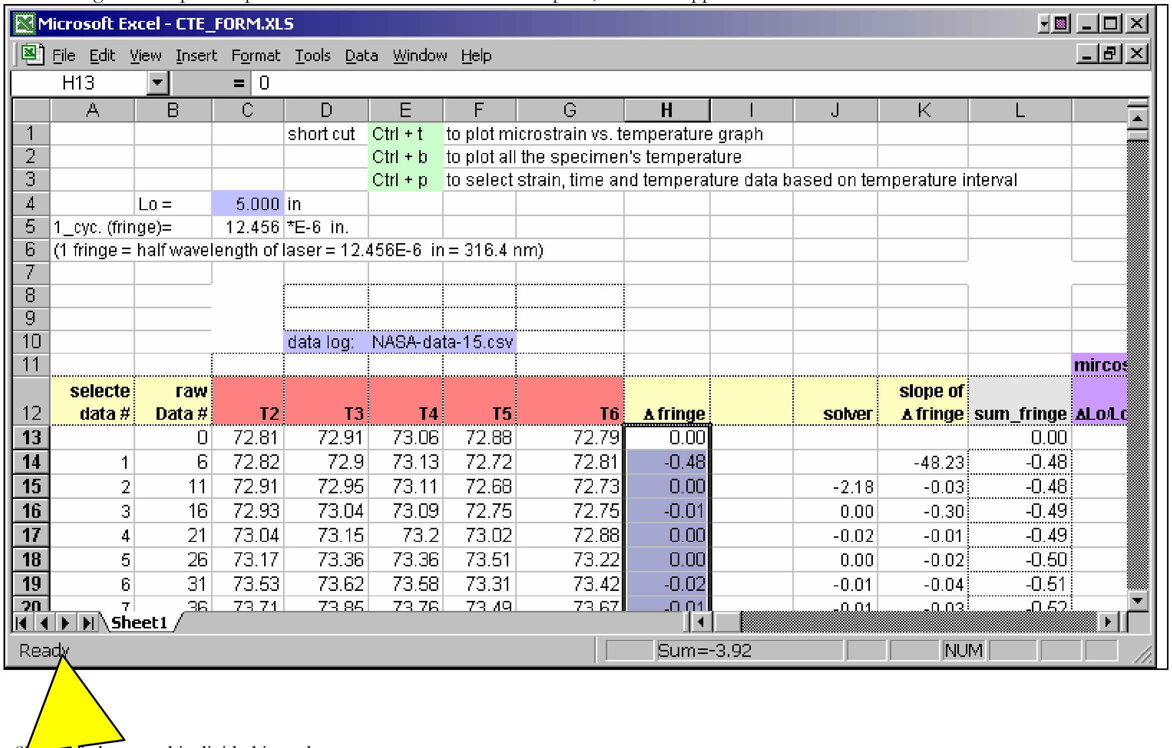


- ☐ Enter L_0 length of sample.
  Click **OK**.



- ☐ Enter the original data log file name.
  Click **OK**.

Processing time[8] depends upon selected data set size. When complete, **READY** appears in the lower left corner of the Excel window.



Sheet 1 is large and is divided into three parts.

- Part 1 (details in Figure 4) contains selected data. You can use this data to generate a temperature vs. microstrain graph (**<ctrl> T**) or a time vs. temperature graph (**<ctrl> P**).
- Part 2 (details in Figure 5) contains date and time information.
- Part 3 (details in Figure 6) contains a worksheet to assess and refine computations.

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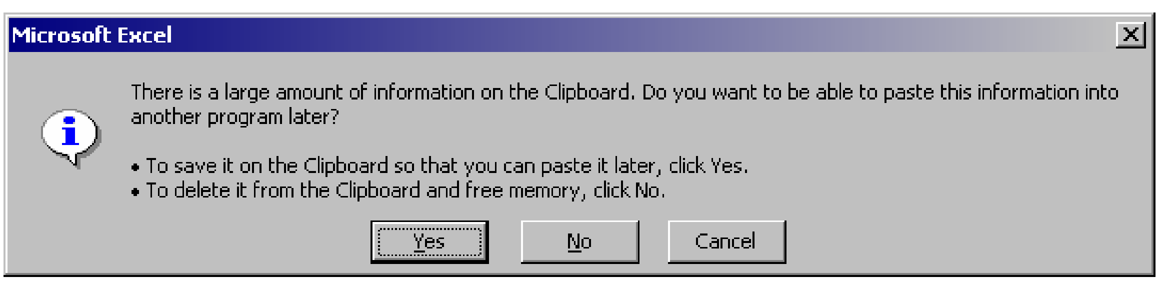
[8] You may see the following message:



If you see this message, click **No**.

CTE_FORM.XLS

	A	B	C	D	E	F	G	H	I	J	K	L	M
1				short cut	Ctrl + t	to plot microstrain vs. temperature graph							
2					Ctrl + b	to plot all the specimen's temperature							
3					Ctrl + p	to select strain, time and temperature data based on temperature interval							
4		Lo =	5.000	in									
5	1_cyc. (fringe)=		12.456	*E-6 in.									
6	(1 fringe = half wavelength of laser = 12.456E-6 in = 316.4 nm)												
7													
8													
9													
10				data log:	NASA-data-15.csv								
11													mircostrain
12	selecte data #	raw Data #	T2	T3	T4	T5	T6	Δ fringe		solver	slope of Δ fringe	sum_fringe	ΔLo/Lo (ppm)
13		0	72.81	72.91	73.06	72.88	72.79	0.00				0.00	**0.00**
14	1	6	72.82	72.9	73.13	72.72	72.81	-0.48			-48.23	-0.48	**-1.20**
15	2	11	72.91	72.95	73.11	72.68	72.73	0.00		-2.18	-0.03	-0.48	**-1.21**
16	3	16	72.93	73.04	73.09	72.75	72.75	-0.01		0.00	-0.30	-0.49	**-1.22**
17	4	21	73.04	73.15	73.2	73.02	72.88	0.00		-0.02	-0.01	-0.49	**-1.23**
18	5	26	73.17	73.36	73.36	73.51	73.22	0.00		0.00	-0.02	-0.50	**-1.23**
19	6	31	73.53	73.62	73.58	73.31	73.42	-0.02		-0.01	-0.04	-0.51	**-1.27**
20	7	36	73.71	73.85	73.76	73.49	73.67	-0.01		-0.01	-0.03	-0.52	**-1.29**
21	8	41	73.96	74.19	73.94	74.05	74.01	-0.01		-0.02	-0.02	-0.52	**-1.30**
22	9	46	74.21	74.43	74.1	74.25	74.23	-0.02		-0.04	-0.10	-0.55	**-1.36**
23	10	51	74.39	74.61	74.37	74.71	74.62	-0.05		-0.02	-0.26	-0.59	**-1.48**
24	11	56	74.66	74.95	74.55	74.97	74.8	-0.02		-0.18	-0.09	-0.62	**-1.54**
25	12	61	74.8	75.09	74.77	75.07	75.13	-0.15		-0.02	-1.04	-0.76	**-1.90**

Figure 4. **CTE Forms - Make Graphs – Part 1**

This page displays test parameters, computations, and results for the selected data points. See Figure 5 and Figure 6.
The raw data point number corresponding to each selected data point is found in column B.
Shortcuts for making graphs are provided on this page

V	W	X	Y	Z	AA	AB	AC	AD	AE	AF	AG
								time of the test			
							increment				
yr	mo	date	hr	min	sec	1/100 sec	(sec)	(sec)	min	hr	
2	11	14	15	9	53	0.29					
2	11	14	15	10	11	0.49	18.002	18.002	0.300033	0.005001	
2	11	14	15	10	21	0.59	10.001	28.003	0.466717	0.007779	
2	11	14	15	10	31	0.69	10.001	38.004	0.6334	0.010557	
2	11	14	15	10	41	0.79	10.001	48.005	0.800083	0.013335	
2	11	14	15	10	51	0.89	10.001	58.006	0.966767	0.016113	
2	11	14	15	11	1	0.99	10.001	68.007	1.13345	0.018891	
2	11	14	15	11	11	1.09	10.001	78.008	1.300133	0.021669	
2	11	14	15	11	21	1.19	10.001	88.009	1.466817	0.024447	
2	11	14	15	11	31	1.29	10.001	98.01	1.6335	0.027225	
2	11	14	15	11	41	1.39	10.001	108.011	1.800183	0.030003	
2	11	14	15	11	51	1.49	10.001	118.012	1.966867	0.032781	
2	11	14	15	12	1	1.59	10.001	128.013	2.13355	0.035559	
2	11	14	15	12	11	1.69	10.001	138.014	2.300233	0.038337	
2	11	14	15	12	21	1.79	10.001	148.015	2.466917	0.041115	
2	11	14	15	12	31	1.89	10.001	158.016	2.6336	0.043893	
2	11	14	15	12	41	1.99	10.001	168.017	2.800283	0.046671	
2	11	14	15	12	51	2.09	10.001	178.018	2.966967	0.049449	
2	11	14	15	13	1	2.19	10.001	188.019	3.13365	0.052228	
2	11	14	15	13	11	2.29	10.001	198.02	3.300333	0.055006	

Figure 5. **CTE Forms - Make Graphs – Part 2**

To view this part of the spreadsheet, move the bottom slider to the right.
This block contains time information for each selected data point.
Columns V-Z and AA-AB contain year, month, day, hour, minute, and second data for each selected data point.
Column AC displays the time increment between data points. Columns AD, AE, and AF show accumulated time in seconds, minutes, and hours, respectively.

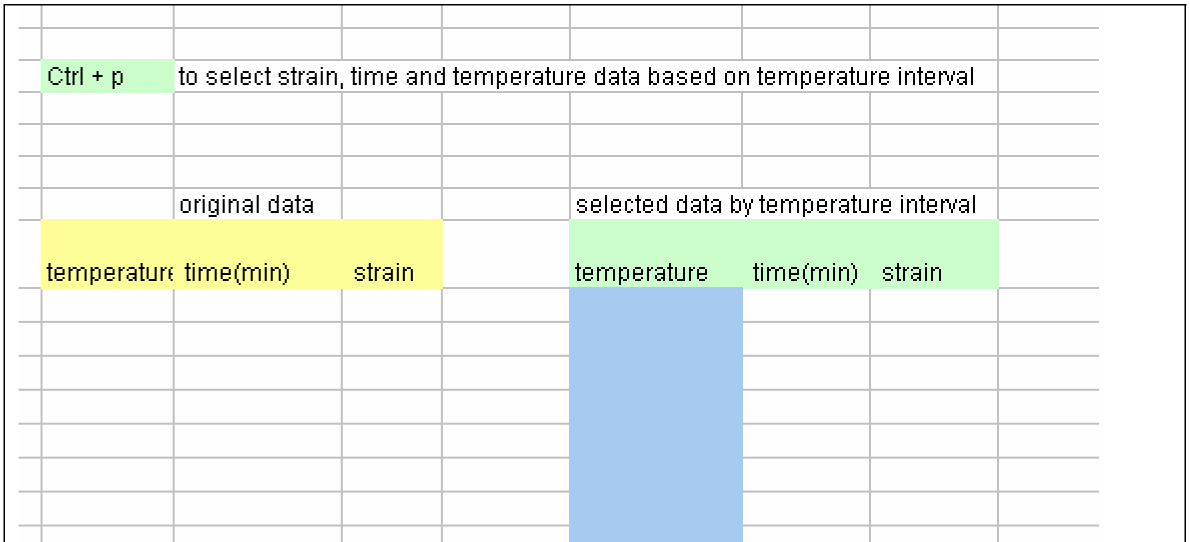


Figure 6. **CTE Forms - Make Graphs – Part 3**
To see this part of the spreadsheet, move the bottom slider to the right.
Use this table to generate microstrain data for a specified temperature interval. See Extracting Data for a Specified Temperature Interval.

- ❑ Key **<Ctrl> t** to generate a Microstrain vs. temperature graph.

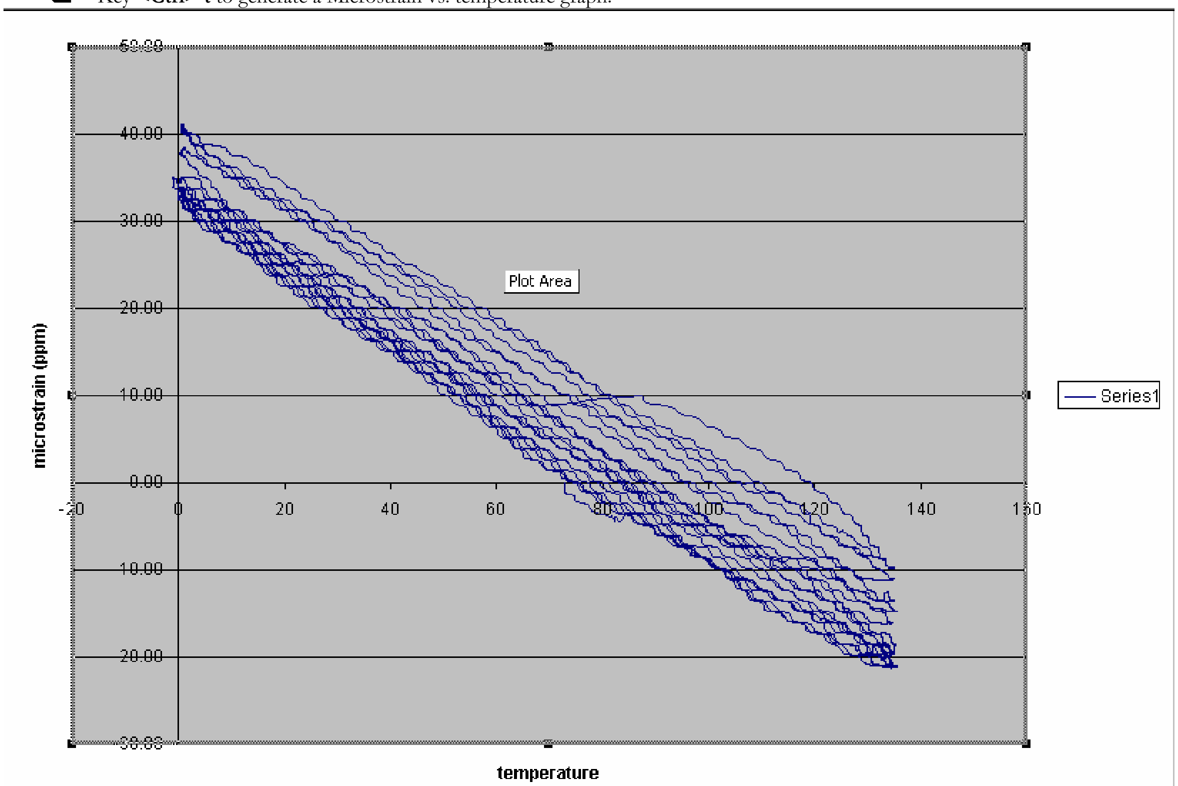


Figure 7. **CTE Forms - Make Graphs: Microstrain vs. Temperature**
Microstrain in parts per million plotted as a function of temperature.

- ❑ Key **<Ctrl > b** to plot all the specimen's temperatures.

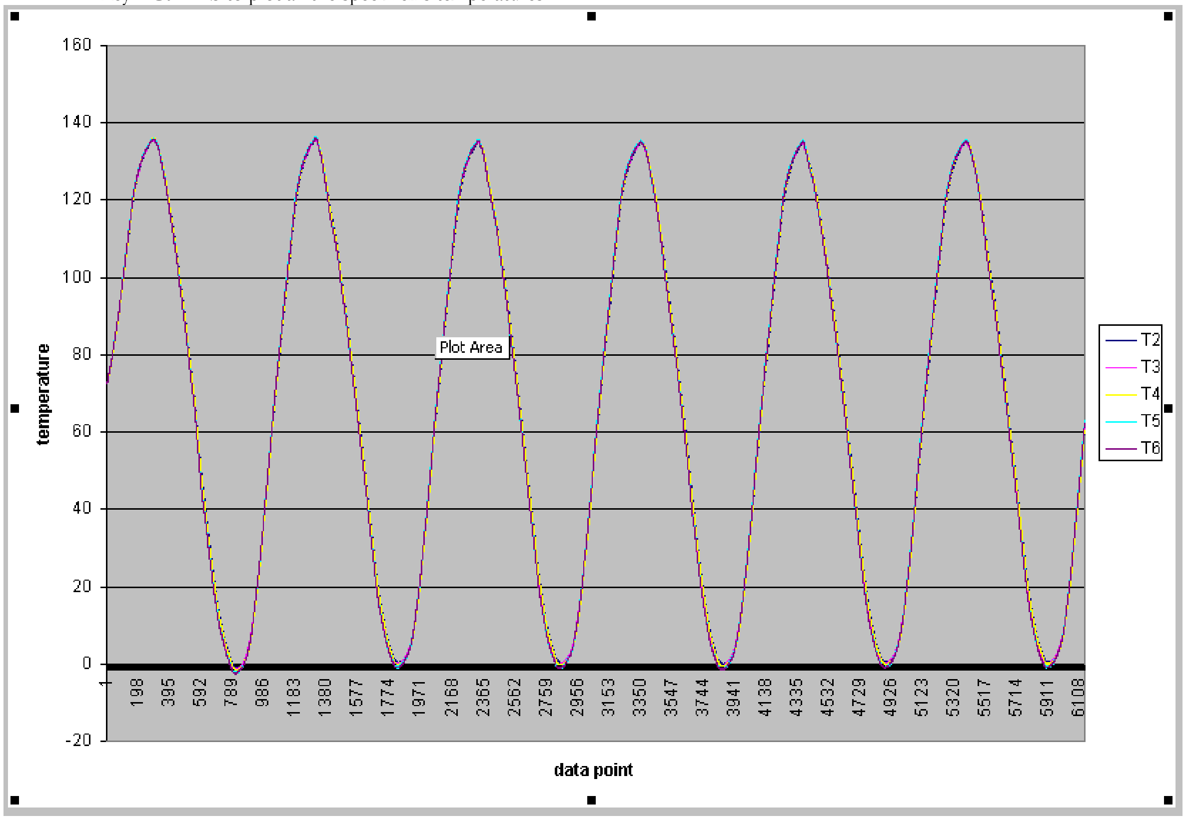
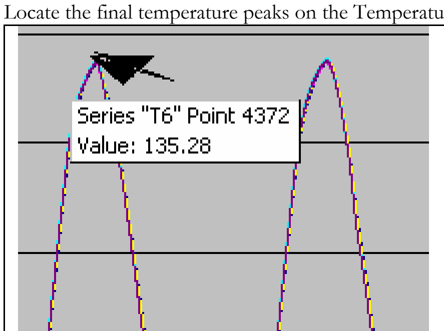


Figure 8. **CTE Forms - Make Graphs: Temperature vs. Data Points**
Temperature readings for the five data channels plotted as a function of data points (time).

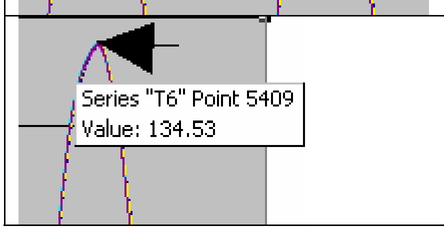
Many possibilities exist for displaying data and producing reports from the CTE_Forms spreadsheet. The following examples are useful and may be combined or modified to satisfy project requirements.

Extracting Data for a Particular Range
This example extracts microstrain data for only the final temperature cycle:

- ❑ Locate the final temperature peaks on the Temperature graph (Figure 8).



- ❑ Position your curser on the first peak and note the information: In this example the first peak occurs at data point 4372, start of desired range.



- ❑ Locate the second peak. In this case, data point 5409 ends the desired range.

- ❑ Locate each of these data points in the first column of the CTE_FORM spreadsheet (Figure 4). Copy the columns of interest within the range.

Note C. Many techniques can be used to copy columns from the desired range to the work area. The following example illustrates one technique:

1. For convenience, insert a row above the start point and a row below the end point to temporarily isolate the range of interest from the rest of the data:

selecte data #	raw Data #	T2	T3	T4	T5	T6	Δfringe		solver	slope of Δfringe	sum_fringe	ΔLo/Lo (ppm)
4368	21841	135.01	135.09	135.3	135.32	135.07	0.00		0.01	-0.03	-8.42	**-20.96**
4369	21846	134.91	135.03	135.41	135.36	135.21	-0.01		0.00	0.05	-8.42	**-20.98**
4370	21851	134.91	135.1	135.34	135.64	135.19	-0.01		0.00	0.00	-8.43	**-21.01**
4371	21856	134.76	135	135.37	135.66	**135.28**	0.00		0.00	-0.01	-8.43	**-21.01**
4372	21861	134.73	134.92	135.34	135.59	135.21	0.00		0.00	0.06	-8.43	**-21.01**
4373	21866	134.62	134.78	135.32	135.55	135.09	0.00		0.00	0.02	-8.44	**-21.02**
4374	21871	134.4	134.58	135.18	135.41	135.03	0.00		0.00	-0.02	-8.43	**-21.01**

12	selecte data #	raw Data #	T2	T3	T4	T5	T6	Δfringe		solver	slope of Δfringe	sum_fringe	ΔLo/Lo (ppm)
5417	5403	27016	134.55	134.67	135.21	135.32	134.91	0.01		0.00	-1.17	-8.51	**-21.21**
5418	5404	27021	134.55	134.6	135.14	135.05	134.82	0.00		0.00	0.00	-8.51	**-21.20**
5419	5405	27026	134.49	134.53	135.09	134.91	134.69	0.00		0.00	-0.01	-8.51	**-21.20**
5420	5406	27031	134.46	134.4	135.07	134.55	134.64	0.00		0.00	-0.06	-8.51	**-21.19**
5421	5407	27036	134.24	134.33	134.98	134.98	134.69	0.01		0.00	-0.02	-8.50	**-21.18**
5422	5408	27041	134.29	134.29	134.89	134.74	134.53	0.00		0.00	0.08	-8.50	**-21.17**
5423	5409	27046	134.15	134.22	134.83	134.83	134.44	0.01		0.00	-0.06	-8.49	**-21.15**
5424													
5425	5410	27051	134.1	134.04	134.8	134.29	134.28	0.00		0.00	-0.03	-8.49	**-21.15**
5426	5411	27056	133.86	133.95	134.64	134.62	134.29	0.00		-0.01	0.00	-8.49	**-21.15**

TIP: When you choose **Insert: Row**, Excel inserts a row *above* the curser.

2. Select a desired column in the range of interest.
For example, on this spreadsheet, the T5 column is selected for the desired range.

selecte data #	raw Data #	T2	T3	T4	T5	T6	Δfringe
4368	21841	135.01	135.09	135.3	135.32	135.07	0.00
4369	21846	134.91	135.03	135.41	135.36	135.21	-0.01
4370	21851	134.91	135.1	135.34	135.64	135.19	-0.01
4371	21856	134.76	135	135.37	135.66	**135.28**	0.00
4372	21861	134.73	134.92	135.34	135.59	135.21	0.00
4373	21866	134.62	134.78	135.32	135.55	135.09	0.00
4374	21871	134.4	134.58	135.18	135.41	135.03	0.00

TIP: With your cursor in the top cell of the range, key **<Ctrl><Shift><↓>** to select every cell in the column within the isolated range.

3. Copy the selected data.
TIP: To copy the selected, right click on the data and choose **Copy** from the hold-down menu.

4. Paste the data in the target column.
TIP: To paste the column, place the cursor on first cell of your target column. Right click and choose **Paste Special: Values**.

AJ	AK	AL	AM	AN	AO	AP
Ctrl + p	to select strain, time and temperature data based on temperature interval					
	original data			selected data by temperature interval		
temperatur	time(min)	strain		temperature	time(min)	strain
135.59						
135.55						
135.41						
135.21						

In this example the **T5** copied values in the range of interest are pasted into the work area, **original data Temperature** on CTE_FORM.XLS page.

NOTE: You can also paste selected data into a new spreadsheet or template.

5. Repeat steps 2 through 4 for each desired column in the selected range. That is, copy **microstrain**, column **M** to the computation area, Strain, column **AL**. Copy accumulated **minutes**, column **AE**, to the computation area, time (min), column **AN.**

Extracting Data for a Specified Temperature Interval

- Use the work area on CTE_FORM.XLS designed for this purpose (Figure 6).
- Copy Temperature, Time and Microstrain data for a range of interest as described above using the work area **original data** as target columns:

AJ	AK	AL	AM	AN	AO	AP
Ctrl + p	to select strain, time and temperature data based on temperature interval					
	original data			selected data by temperature interval		
temperatur	time(min)	strain		temperature	time(min)	strain
135.59	728.87	-21.01				
135.55	729.04	-21.02				
135.41	729.21	-21.01				
135.21	729.37	-21.00				
134.87	729.54	-21.01				
134.71	729.71	-21.00				
134.64	729.87	-21.00				
134.08	730.04	-20.99				
133.86	730.21	-20.99				
133.7	730.37	-20.98				
133.65	730.54	-20.97				
133.77	730.71	-20.98				
133.63	730.87	-20.98				
133.47	731.04	-20.97				

- To select strain, time and temperature data based for a specified interval, key **<Ctrl> P**.

- Enter 1.

Data selection is as follows:
Data points are selected at 1° intervals.
But, if a ΔTemperature is less than 1°C, then the next point is selected at a one-minute interval.
If ΔTemperature is less than 1° AND ΔTime is more than 1 minute, then data is extrapolated to one-minute intervals.

As before, when processing is complete, **Ready** appears in lower left corner of the spreadsheet.

AJ	AK	AL	AM	AN	AO	AP
Ctrl + p	to select strain, time and temperature data based on temperature interval					
	original data			selected data by temperature interval		
temperature	time(min)	strain		temperature	time(min)	strain
133.84	562.36	-19.93		133.84	562.36	-19.93
133.77	562.52	-20.00		133.77	562.52	-20.00
133.83	562.69	-20.04		133.38	563.52	-20.23
133.56	562.86	-20.10		132.24	564.52	-20.01
133.39	563.02	-20.07		131.23	565.52	-19.87
133.59	563.19	-20.20		130.41	566.52	-19.79
133.59	563.36	-20.35		129.36	567.36	-19.72
133.38	563.52	-20.23		129.16	567.52	-19.70
133.29	563.69	-20.30		127.71	568.52	-19.43
133.18	563.86	-20.14		126.70	569.36	-18.75
133	564.02	-20.06		126.45	569.52	-18.70
132.85	564.19	-20.04		125.42	570.19	-18.58
132.69	564.36	-19.98		125.13	570.52	-18.55
132.24	564.52	-20.01		124.02	571.19	-18.51
132.19	564.69	-19.93		123.55	571.52	-18.44
132.22	564.86	-19.94		122.47	572.19	-18.27
132.06	565.02	-19.91		122.25	572.52	-17.91
131.68	565.19	-19.90		121.17	573.36	-17.42
131.49	565.36	-19.88		120.92	573.52	-17.40
131.23	565.52	-19.87		119.39	574.19	-17.25
130.93	565.69	-19.85		119.10	574.52	-17.19
130.87	565.86	-19.83		117.99	575.19	-16.48
130.68	566.02	-19.83		117.43	575.52	-16.20

Figure 9. Microstrain vs. Temperature: Selected Data by Interval

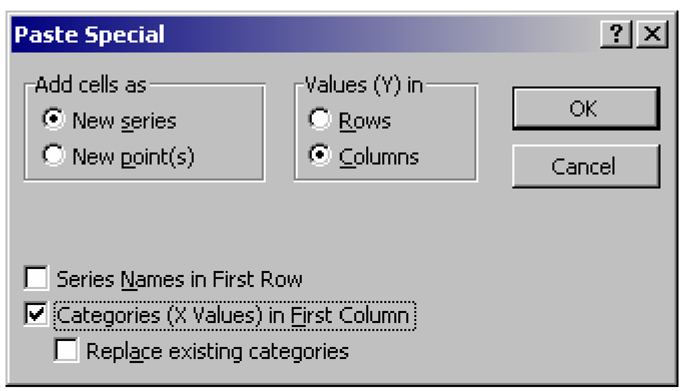
- ❑ When you finish, plot the selected points and compare with the raw-data graph:

1. Copy the **temperature** and **strain** data from **selected data by interval** generated in Figure 9. Paste them into adjacent columns:

selected data by temperature interval					
temperature	time(min)	strain		temperature	strain
133.84	562.36	-19.93		133.84	-19.93
133.77	562.52	-20.00		133.77	-20.00
133.38	563.52	-20.23		133.38	-20.23
132.24	564.52	-20.01		132.24	-20.01
131.23	565.52	-19.87		131.23	-19.87
130.41	566.52	-19.79		130.41	-19.79
129.36	567.36	-19.72		129.36	-19.72
129.16	567.52	-19.70		129.16	-19.70
127.71	568.52	-19.43		127.71	-19.43
126.70	569.36	-18.75		126.70	-18.75
126.45	569.52	-18.70		126.45	-18.70
125.42	570.19	-18.58		125.42	-18.58
125.13	570.52	-18.55		125.13	-18.55
124.02	571.19	-18.51		124.02	-18.51
123.55	571.52	-18.44		123.55	-18.44
122.47	572.19	-18.27		122.47	-18.27
122.25	572.52	-17.91		122.25	-17.91
121.17	573.36	-17.42		121.17	-17.42
120.92	573.52	-17.40		120.92	-17.40
119.39	574.19	-17.25		119.39	-17.25
119.10	574.52	-17.19		119.10	-17.19
117.99	575.19	-16.48		117.99	-16.48
117.43	575.52	-16.20		117.43	-16.20

2. Click the Chart 1 tab.
3. Select from the menu **Edit: Paste Special.**
4. Select **New Series** and **Categories (X Values) in First Column.**

   Click **OK.**



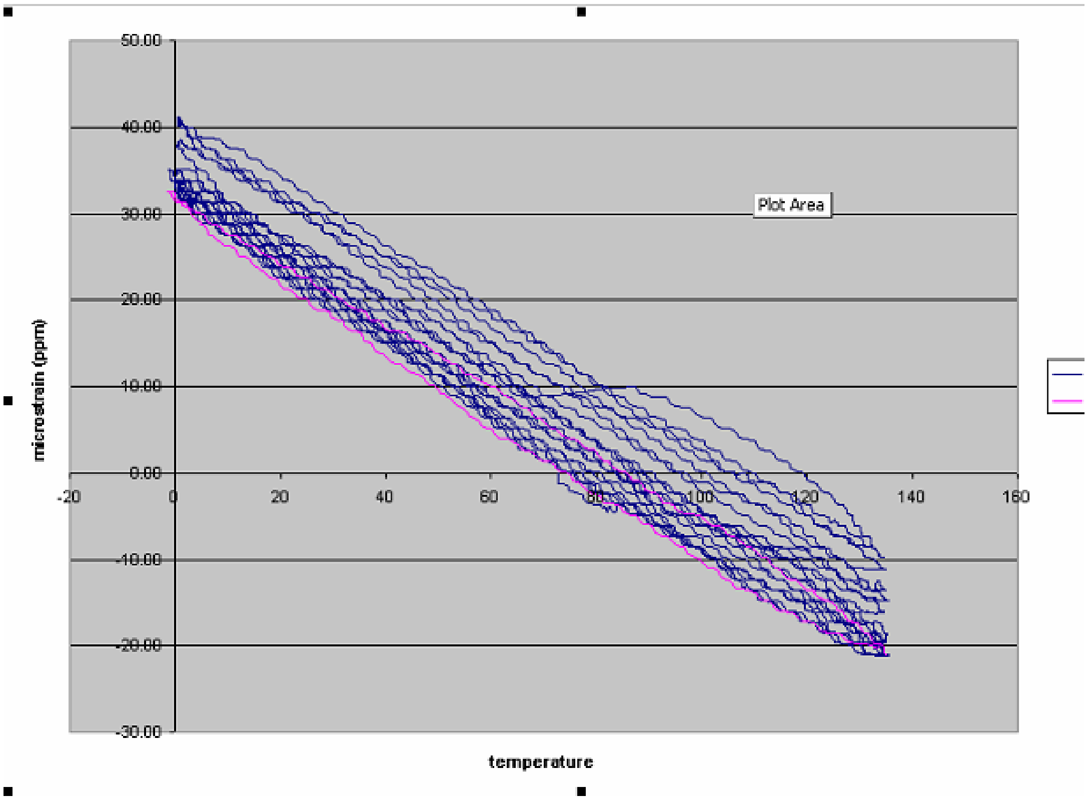


Figure 10. **Verify CTE by Comparing Graph with Raw Data**
In this example, satisfactory data selection produces a graph (Series 2) congruent to the raw data graph (Series 1).

Chapter 4. **Preparing Reports**

A PMIC standard **report template**[9] is provided. See Figure 11 and Figure 12. Copy and modify this template to as needed for project requirements.

Material:
Temperature: 200C to 24C
Tests conducted with a Michelson laser interferometer measurement system (ASTM Standard E 289 - 95), performed in vacuum.
Date:

SPECIMEN #1			SPECIMEN #2		
Temperature	time	Microstrain	Temperature	time	Microstrain
Deg. C	min	ΔL/Lo	Deg. C	min	ΔL/Lo
131.18	0.00	0.00			
131.36	0.60	-0.08			
131.56	1.60	-0.05			
131.86	2.60	-0.17			
131.99	3.60	-0.14			
131.83	4.60	-0.13			
131.86	5.60	-0.26			
131.61	6.60	-0.56			
131.05	7.60	-0.89			
130.51	8.60	-0.61			
129.90	9.61	-0.01			
129.16	10.60	0.17			
128.41	11.60	0.73			
127.42	12.60	1.21			
126.52	13.60	1.25			
125.28	14.60	1.33			
124.18	15.61	1.41			
123.03	16.60	1.73			
122.02	17.40	2.50			
121.71	17.60	2.56			

Figure 11. **CTE Data Page of Report Template.**
Copy extracted data from CTE forms into this template.

[9] When the analysis programs are loaded, the path of the template is:
C:\\CTE\Run\report **C:\\CTE\Run\report template.xls**.

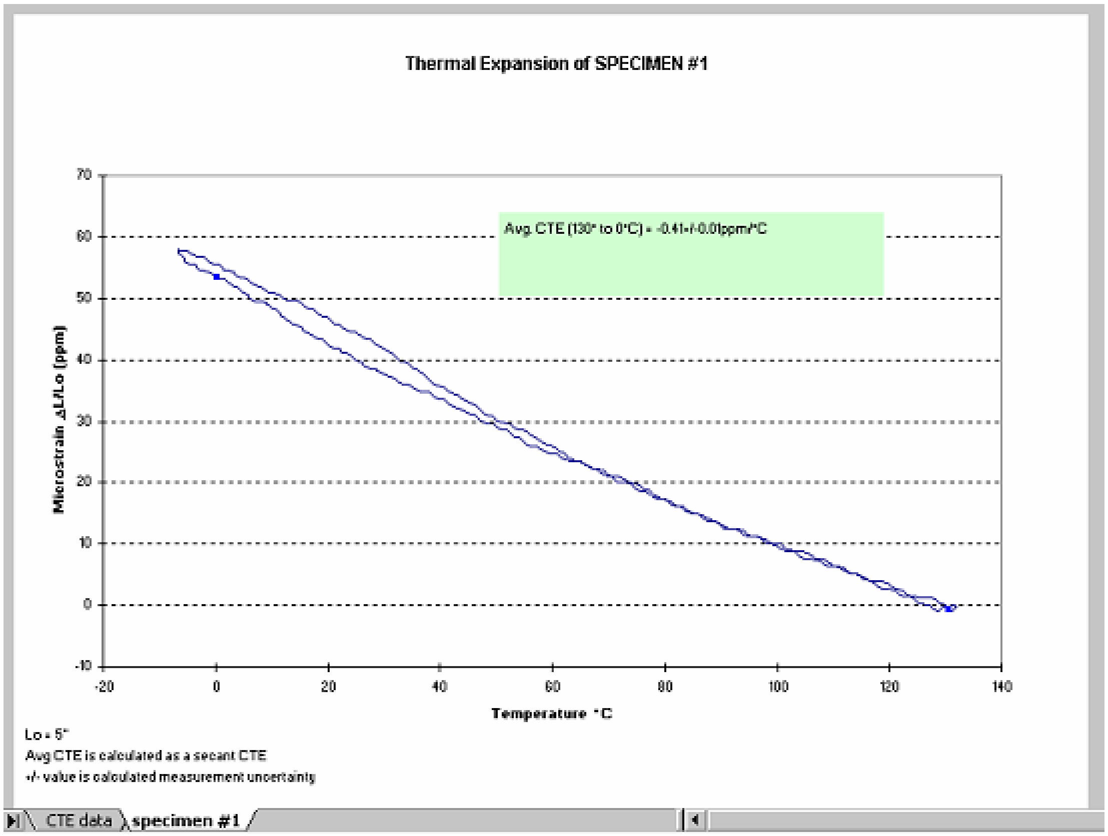


Figure 12. **Thermal Expansion Report Example**

The legend is an easily edited text box.

Change *Avg. CTE (130° to 0°C)* to reflect your range of interest, for example, **CTE (125 to -10°C).**

Calculate the average CTE as described in Calculating Average CTE and paste it here (replace -0.41).

Calculate the measurement uncertainty by the method described in Chapter 5. Paste result here (replace ±.01) to complete your report.

To use make a report using this template:

- ☐ Copy extracted data into the CTE Data page.
  In the following example, T_6 temperature data, time, and microstrain data for Specimen 1 is copied from CTE_Forms (Figure 9), into the template (Figure 13).
- ☐ Using <ctrl> + click, select the endpoints of your range of interest, that is two values in column A and their corresponding values in column C. Copy these points.

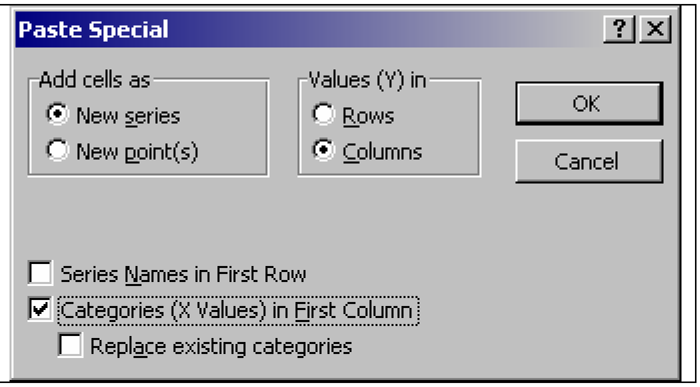
Material:
Temperature: 200C to 24C
Tests conducted with a Michelson laser interferometer measurement system (ASTM Standard E 289 - 95), performed in vacuum.
Date:

SPECIMEN #1			SPECIMEN #2		
Temperature Deg. C	time min	Microstrain ΔL/Lo	Temperature Deg. C	time min	Microstrain ΔL/Lo
134.15	561.86	-19.87			
133.77	562.52	-20.00			
133.18	563.52	-20.23			
132.10	564.52	-20.01			
131.18	565.52	-19.87			
130.10	566.52	-19.79			
128.93	567.52	-19.70			
127.60	568.52	-19.43			

Figure 13. Extracted Data Pasted to Template

- ❑ Click the **Specimen #1** tab.
- ❑ Click the menu **Edit: Paste special**.
- ☐ Select **New Series** and **Categories (X Values) in First Column**.

  Click **OK**.



The result is a linear graph (Figure 14).

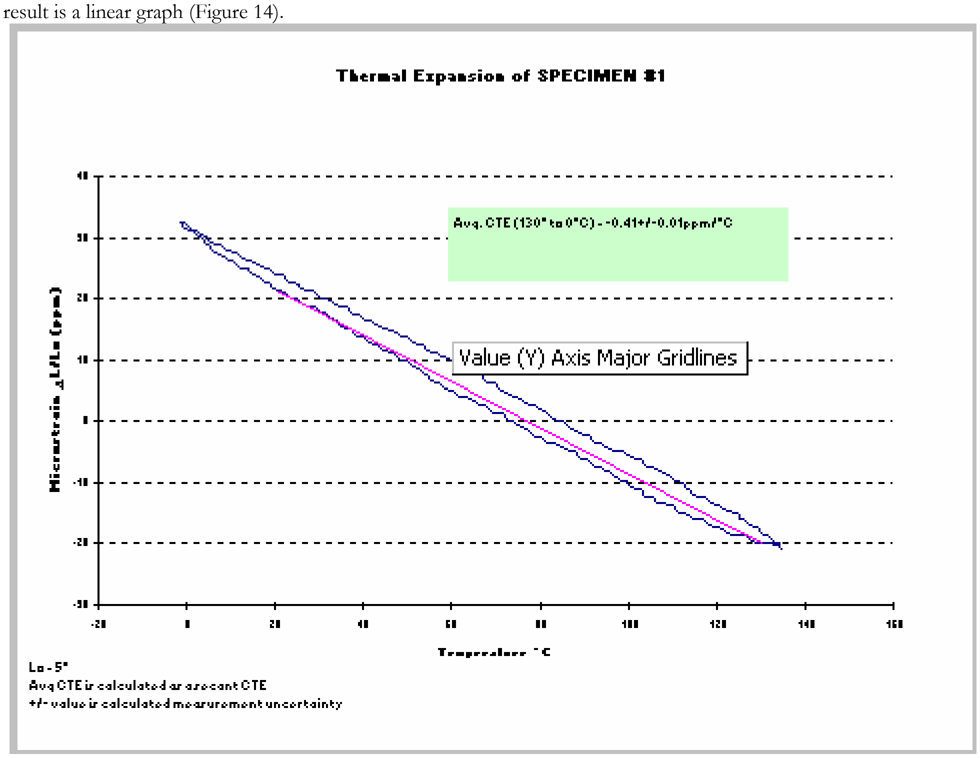
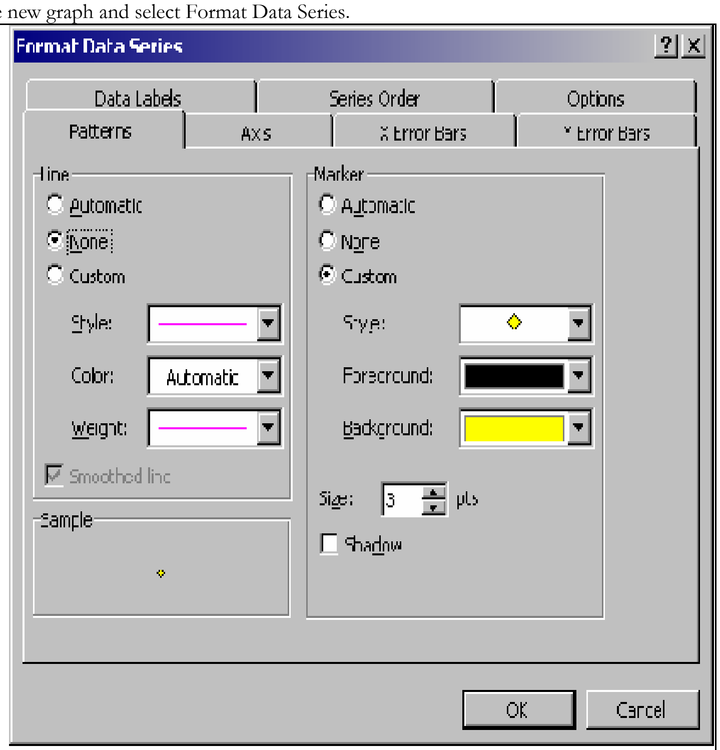


Figure 14. Graph of Pasted Endpoints

- [ ] To format the points right click on the new graph and select Format Data Series.

On the Patterns tab, select: **Line: None** **Marker:** style and color as desired. Click **OK**.	

The result shows the reformatted endpoints of interest (Figure 15):

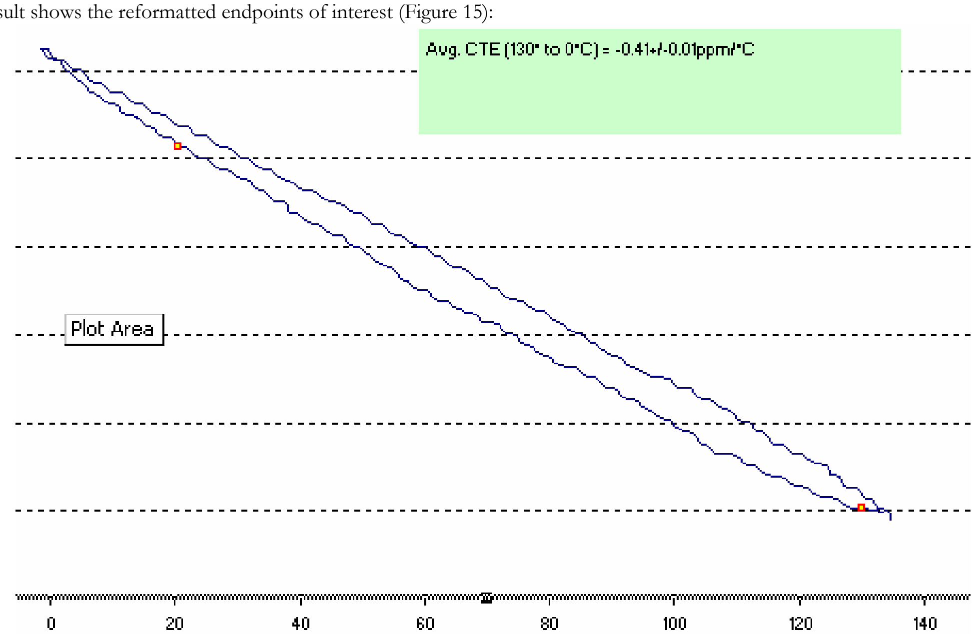
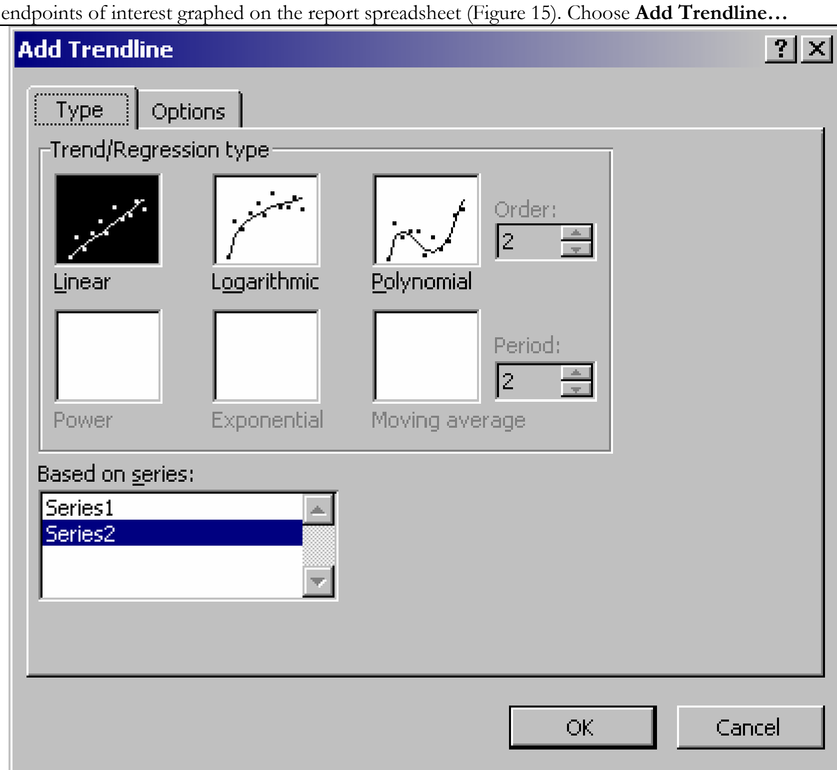


Figure 15. Endpoints of Interest

Calculating Average CTE
To calculate the Average CTE:

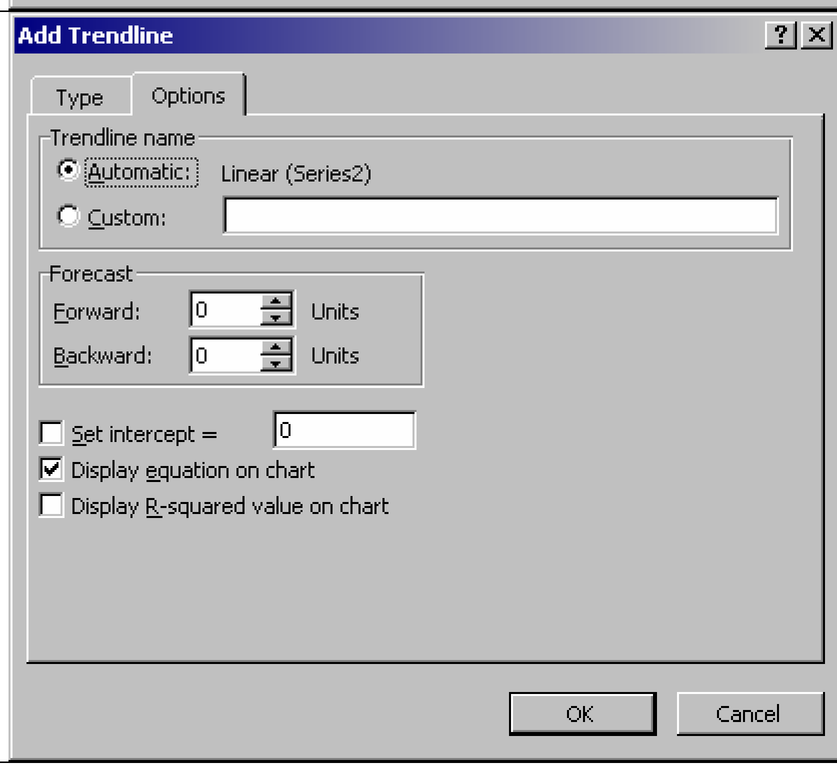
- ❑ Right click on one of the endpoints of interest graphed on the report spreadsheet (Figure 15). Choose **Add Trendline…**

On the **Type** tab, select **Linear** and **Series 2**

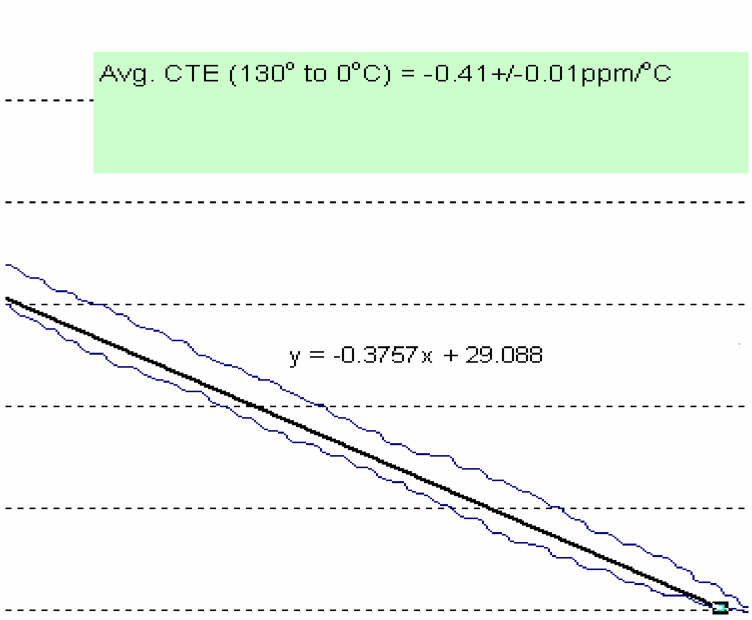


On the **Options** tab, select **Automatic** and **Display** equation on chart.

Click **OK**.



The result is shown in this enlargement of the Thermal Expansion graph:



The computed CTE value is **–0.3757**.

Note: to complete this report:

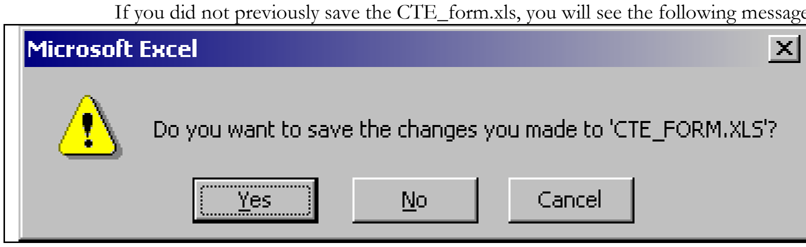
- ❑ Copy computed CTE value and paste it over **–0.41** in the original template.
- ❑ Remember to change the values 130°-0° C to the range of interest values.
- ❑ Remember to change **±.01** to the correct uncertainty as calculated in Chapter 5.

Closing the Program

- ❑ If the test results are acceptable, save the spreadsheet:
  On the menu, choose **File: Save as**.
  Give the spreadsheet a new name.

Caution: Do not save CTE_form.xls as it contains calculation formulas. If this file is accidentally saved, use the software CD to restore the original.

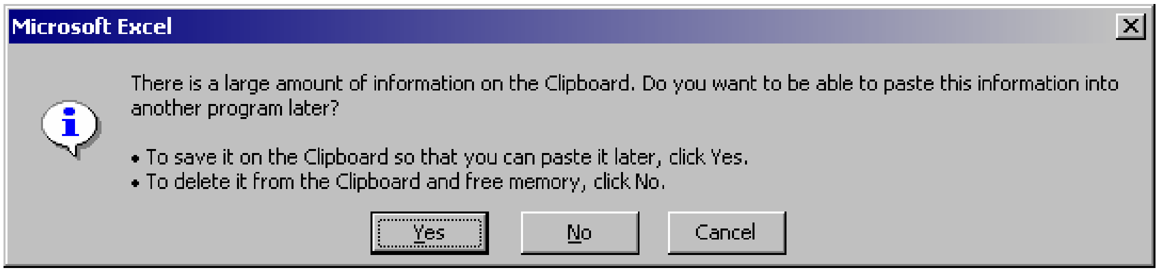
- ❑ Click Step5 Exit.
- ❑ Close Excel.
  If you did not previously save the CTE_form.xls, you will see the following message.



Click **No**.[10]

If you copied data to the clipboard, you may see the following prompt:

[10] **REMINDER.** CTE_FORM.XLS and PKCHECK.XLS are calculation templates with programmed formulas. **Never save them**. To save results, use the menu **File: Save as**.


Microsoft Excel
There is a large amount of information on the Clipboard. Do you want to be able to paste this information into another program later?
• To save it on the Clipboard so that you can paste it later, click Yes.
• To delete it from the Clipboard and free memory, click No.
Yes
No
Cancel

Click **No**.

Chapter 5. Error Calculation

Use the **Error Calculation Worksheet** to assess the reliability of test results.

INPUT FIELDS are yellow.

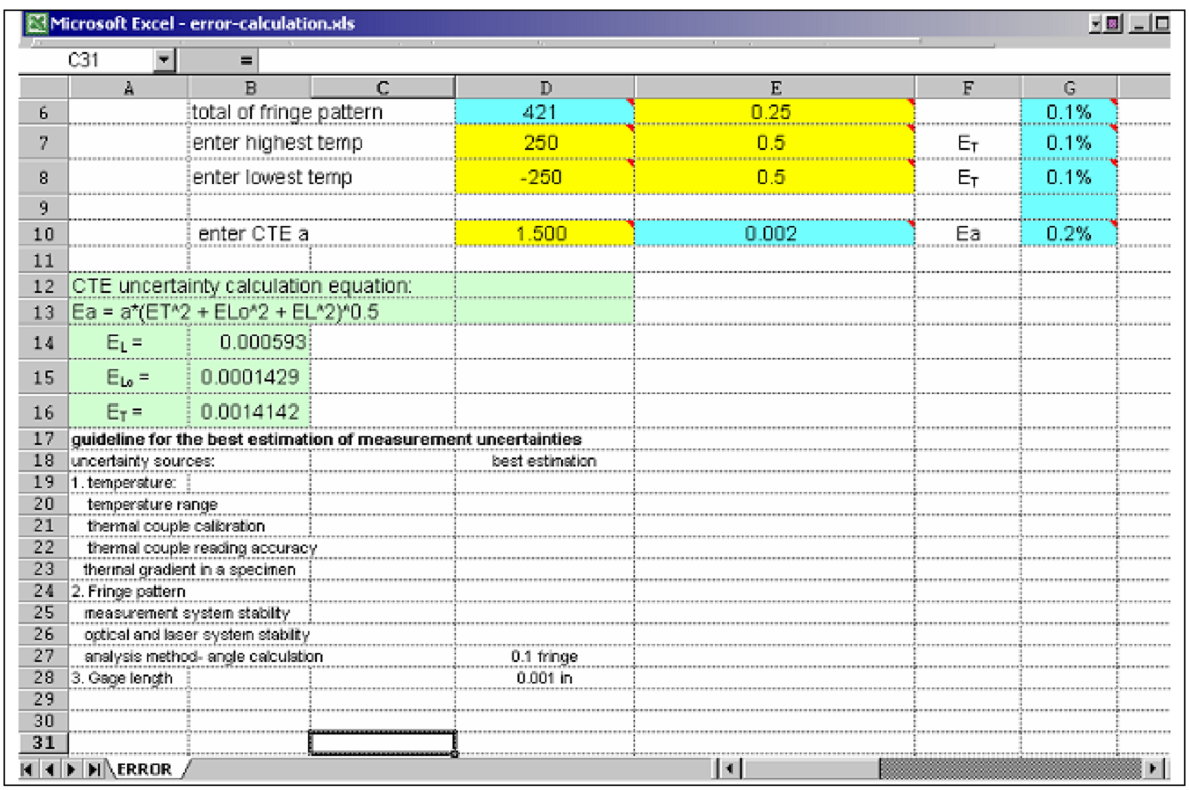
CALCULATED FIELDS are violet.

Input the following values:

gage length (Lo)	L_o
highest temp	Highest Temperature in range
lowest temp	Lowest Temperature in range
length (Lo) error	E_{Lo}
fringe error	$E_{\Delta L}$
highest temp error	E_T
lowest temp error	E_T

E_α is the uncertainty of the calculated CTE due to uncertainties of the measured values.

IMPORTANT: This manual and the Error Calculation spreadsheet template (Figure 16) will be updated with *best estimation* data in the near future.



	A	B	C	D	E	F	G
6		total of fringe pattern		421	0.25		0.1%
7		enter highest temp		250	0.5	E_T	0.1%
8		enter lowest temp		-250	0.5	E_T	0.1%
9							
10		enter CTE a		1.500	0.002	Ea	0.2%
11							
12	CTE uncertainty calculation equation:						
13	Ea = a*(ET^2 + ELo^2 + EL^2)^0.5						
14	E_L =	0.000593					
15	E_{Lo} =	0.0001429					
16	E_T =	0.0014142					
17	**guideline for the best estimation of measurement uncertainties**						
18	uncertainty sources:			best estimation			
19	1. temperature:						
20	temperature range						
21	thermal couple calibration						
22	thermal couple reading accuracy						
23	thermal gradient in a specimen						
24	2. Fringe pattern						
25	measurement system stability						
26	optical and laser system stability						
27	analysis method- angle calculation			0.1 fringe			
28	3. Gage length			0.001 in			
29							
30							
31							

Figure 16. **Error Calculation Worksheet**
Comments (visible on mouse-over at the red markers) provide important information.

The CTE uncertainty is calculated by the equation:

$E_\alpha = \alpha(E_T^2 + E_{Lo}^2 + E_{\Delta L}^2)^{0.5}$

where:

α is the CTE, calculated CTE = $\Delta L/(L_o * \Delta T)$

E_T is the calculated uncertainty of the CTE due to temperature change (ΔT) using best estimate of measured temperature error.[11]

$E_{\Delta L}$ is the calculated uncertainty of the CTE due to measured length change (ΔL) using best estimate of error in the measured fractional fringe.[12]

E_{Lo} is the calculated uncertainty of the CTE due to the estimated error in the measured length (L_o).

[11] Reference for this info to be added.

[12] Reference for this info to be added.

Appendix A. Troubleshooting

THIS SECTION TO BE ADDED SOON.

Appendix B. Some Data Selection Examples

A satisfactory data selection has from 5 to 20 data points between peaks of raw data. The following Examples illustrate how to use the CTE Data Analysis program to optimize your data selection:

1. Raw data file size ≤ 64,000 data lines.

Step 1: Read raw data:	Reduction Factor	Accept default =1.
	M_start	Accept default =1.
	M_end	Accept default =0.
Step 2: Calculate data:	Data Increment Number	First iteration: Accept default =1. Case 2. Second and subsequent iterations: Adjust increment to produce the desired data sample.
Step 3. Check Data:	**Case 1.**	If Chart 1, 2, and 3 data is well distributed, e.g., at least 5 data points on every cycle of raw data, and if are satisfied that your data is not too dense, go on to Step 4.
	Case 2.	If Chart 1, 2, and 3 data is very dense, e.g., more than 10 data points per cycle of raw data, and if your file has a large number of data points, go to Step 2. Repeat the Calculate data and check Data steps until you have a satisfactory sample. Go on to the next step.
	Case 3.	If Chart 1, 2, and 3 data points are scanty (e.g., if the raw data has cycles with fewer than 5 data points), then the test has not yielded sufficiently reliable data to continue. Go to step 5 and exit. Retesting is indicated.

2. Raw data file size › 64,000 data lines.

Step 1: Read raw data:	Reduction Factor	First Iteration: Choose a reduction factor to reduce the file size to 64,000 or fewer data lines. Example: 180,000 data lines. 180000/64000 = 2.8125=> a reduction factor of 3. 18000/3=60,000 data points Second iteration, Case 6: Adjust increment to produce the desired data sample.
	M_start	First Iteration: Accept default =1. Case 5: Accept default =1. Case 6: If more that 64,000 points in sample, define a segment, by entering the number of the first data line in the segment, which can be 1.
	M_end	First Iteration: Accept default =0. Case 5: Accept default =0. Case 6: If you are defining a segment, enter the number of the last data line in the segment.
Step 2: Calculate data:	Data Increment Number	First iteration: Accept default =1. Case 5. Second and subsequent iterations: Adjust increment to produce the desired data sample.
Step 3. Check Data:	**Case 4.**	If Chart 1, 2, and 3 data is well distributed, e.g., at least 5 data points on every cycle of raw data, and if are satisfied that your data is not too dense, go on to Step 4.
	Case 5.	If Chart 1, 2, and 3 data is very dense, e.g., more than 10 data points per cycle of raw data, and if your file has a large number of data points, go to Step 2. Repeat the Calculate data and Check data steps until you have a satisfactory sample. Go on to the next step.
	Case 6.	If Chart 1, 2, and 3 data points are scanty (e.g., if the raw data has cycles with fewer than 5 data points), go to step 1 choose a smaller Data Increment. If this condition persists when the data increment is 1, then the test has not yielded sufficiently reliable data to continue. Go to step 5 and exit. Retesting is indicated.

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To be added.